Economic Siting Factors for Seawater Desalination Projects along the Texas Gulf-Coast

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Abstract

Technological advances in desalination, shifting market conditions, and increasingly stringent drinking water treatment regulations are making membrane desalination more attractive relative to conventional drinking water treatment to produce potable water for the growing Texas population. Rapid expansion in population has benefited the Texas economy but it is also straining the water resources of the state. Recognizing this condition, the Texas Legislature enacted legislation to support water supply and drought contingency planning within the state. As part of the planning process several Texas regions are evaluating options for reverse osmosis membrane desalination of seawater for potable water supply. This paper will highlight the siting factors for potential seawater desalination water supply options showing the factors that are shaping the desalination water supply landscape of the future. The Tampa Regional Water Supply project in Florida recently built a large capacity (approximately 25 million gallons per day (MGD)) seawater reverse osmosis (RO) system where the product water costs were lower by a factor of 2 to 3 times than those previously observed for other large-scale seawater desalination facilities. Results will be presented that capture the factors leading to this major advance in seawater desalination and their potential application along the Texas Coast. These factors were incorporated into a membrane plant cost-estimating model and a general framework was developed for making siting decisions for seawater desalination on the Texas Coast. Results indicate that many of the low cost factors for the Tampa Bay seawater desalination facility, with the possible exception of inexpensive concentrate disposal, may be applicable to the Texas coast thereby opening the door for large-scale seawater desalination to play a vital role in the future water supply of Texas. (Update 7/04: The Tampa desalination plant began production in March 2003 and has produced over 4 billion gallons of drinking water for the region. However, defects in the plant design and performance were discovered after start-up that greatly increased the long-term cost of running the desalination plant. The decreased performance is largely due to inadequate pre-treatment prior to the desalination reverse osmosis membranes. Tampa Bay Water is currently pursuing competitive proposals from two teams conducting pilot tests at the plant site to determine the best remedy[2]).

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[1] HDR Engineering, Inc.
[2] Updates to July 2004 primarily from Tampa Bay Water website at http://www.tampabaywater.org/WEB/Htm/News/news.htm.

Introduction

Water desalination is an increasingly attractive option to produce potable water for the growing Texas population. Technological advances in desalination, shifting market conditions, and increasingly stringent drinking water treatment regulations are making desalination more attractive relative to conventional drinking water treatment. Desalination of seawater in Texas has the potential to expand the resources available for producing potable water. It is increasingly difficult to develop freshwater storage projects, particularly in-channel reservoirs. Additionally, the value of interbasin water rights transfers has been diminished. Population growth continues even in areas vulnerable to drought where freshwater is limited. These factors are driving water utilities and industry to consider desalinating seawater in Texas.

The Tampa Regional Water Supply project for a 25 MGD seawater reverse osmosis (RO) system received proposals with water costs 2 to 3 times lower than those previously observed for other large-scale seawater desalination facilities. These low costs resulted from not only technological improvements, but also from siting and macroeconomic factors. Information from the Tampa project was gathered and reviewed for this report to determine the factors leading to this major advance in seawater desalination and their potential application along the Texas Coast. These factors were incorporated into a cost-estimating model and a general framework was developed for making siting decisions for seawater desalination on the Texas Coast. Potential environmental impacts and permitting issues for a desalination facility were evaluated and included for consideration of project feasibility.

Research was also conducted to review membrane technologies and costs in general for desalination of both brackish waters and seawater.[3] Reverse osmosis and electrodialysis reversal (EDR) are the primary membrane treatment processes currently implemented to remove dissolved salts from water. This paper focuses on desalination of high salinity waters either from the ocean or mixed bay systems. Therefore, findings and information for this paper are based on the use of reverse osmosis because EDR is generally not considered for desalination of waters with greater than 3,000 mg/L TDS.

Tampa Bay Seawater Desalination Project

Two recent contracts highlight the potential for low-cost seawater desalination. In July 1999, Tampa Bay Water entered into a water purchase agreement with the development team S&W Water, LLC to fund, design, build, operate, and, at some point, transfer a seawater desalination plant. The plant is to have an installed capacity of 29 million gallons per day (MGD), producing an average of 25 MGD of potable water at an average cost over 30 years in present day dollars of $2.08 per 1,000 gallons. This cost is two to three times lower than costs previously observed for large-scale seawater desalination facilities. Also, in late 1999, the Water and Sewerage Authority (WASA) of Trinidad and Tobago contracted with an Ionics, Inc. joint venture to design, build, and operate a seawater desalination plant. This plant is to produce 28.8 MGD of

[3]Black, Bryan, and Mark Graves, "Desalination for Texas Water Supply", Texas Water Development Board, August 2000.

potable water at an average cost over 23 years of $2.67 per 1,000 gallons.[4] (Update 7/04: Commercial operation of phase 1 of the desalination plant for the Republic of Trinidad and Tobago, an island nation located off the coast of Venezuela, began on April 11, 2002 and desalinated water is currently being purchased by WASA for $2.67 per 1,000 gallons)[11]. The low-cost factors for the Tampa Bay Water project are evaluated here to provide background for application of these factors in Texas.

Design-Build-Operate. The design-build-operate project delivery option offers many advantages for seawater desalination contracts. Seawater desalination facilities must be customized to treat source waters with variable water qualities to deliver product water that meets client/customer specifications. In most cases process parameters cannot be determined without extensive pilot testing and then process parameters may need to be modified once full-scale operation begins. These types of projects lend themselves to the performance based contract process where the water quality, quantity, delivery schedule, etc. are specified but the plant design is left to the developer. Performance based specifications allow the developer to propose the best and most cost-effective technology that they are familiar with. It also allows for the project to take advantage of innovations in desalination technology, which also generally lowers the cost. Design-build-operate also transfers more of the project risk to the developer in that the developer specifies the plant design and yet must meet the performance specifications.

Power Plant Co-Location. The Tampa Bay Water desalination plant will avoid substantial capital costs by sharing the intake and outfall canals with the Tampa Electric Company power station. The feed water for the desalination plant will flow through the trash grates and screens of the power plant. Underwater construction is avoided in that the intake and discharge pipeline from the desalination plant tie on land into the power plant cooling water discharge pipeline. The elevated temperature of the discharged cooling water (approximately 15º F above ambient Bay water temperature) will increase the amount of product water produced by the membranes in the desalination plant.

The power plant cooling water flow is approximately 1,350 MGD providing dilution for the 16.7 MGD concentrate discharge flow. Due to the high rate of dilution the salinity in the power plant effluent is expected to rise by less than 2 percent. Without this large cooling water flow it may not be possible to discharge the concentrate into the bay without additional mixing facilities. It is estimated that $15 to $130 million dollars in capital cost avoidance and considerable O&M cost saving was realized due to co-locating the desalination plant with the power plant. Table 1 summarizes approximate cost savings for co-location with the power plant.

[4]Membrane & Separation Technology News, October 1999.

Table 1 Tampa Bay Power Plant Co-location Cost Savings

	Low Estimate			***High Estimate***		
	Capital Cost	***O&M Cost***	***Cost per 1,000 gallons***	***Capital Cost***	***O&M Cost***	***Cost per 1,000 gallons***
Intake Canal	$5,000,000	$1,000,000	$0.15	$40,000,000	$2,000,000	$0.54
Outfall Canal	5,000,000	1,000,000	0.15	40,000,000	2,000,000	0.54
Trash Gates and Screens	300,000	30,000	0.01	500,000	300,000	0.04
Elevated Temperature[1]	4,000,000	250,000	0.06	7,563,492	334,106	0.10
Data and Modeling for Permits	1,000,000	100,000	0.02	2,000,000	100,000	0.03
Ongoing Monitoring	0	100,000	0.01	0	300,000	0.03
Total	15,300,000	2,480,000	$0.39	130,063,492	5,034,106	$1.59

[1] Water flux increases by 2 percent per degree Fahrenheit temperature increase. Cost savings for temperature increase based on 15 degree Fahrenheit increase resulting in flux rate increasing from 6.46 gal/sfd to 8.4 gal/sfd for 25 MGD product water flow rate with 168 x 8 element array (1,344 elements). The average Bay temperature is 77° F and the average boiler condenser discharge used for feedwater is 92° F.

Assumptions: Interest Rate = 6.0 percent; Financing Period = 30 years; Average Product Flow = 25 MGD.

Source: "Desalination for Texas Water Supply"[1].

Source Water Quality. Favorable water quality (lower Total Dissolved Solids [TDS]) of the raw water will contribute to decreased operating costs (principally, lower electric power requirements). Analysis indicated that TDS at the intake ranged from 10,000 to 33,000 mg/L, with an average annual salinity of about 26,000 mg/L. This is considerably lower than the typical open ocean TDS of approximately 35,000 mg/L. However, because of the fluctuating TDS concentration, variable frequency drives (VFDs) are required for the high-pressure pumps at an additional capital cost.

The surface water source for the desalination plant has a relatively high fouling potential due to biological activity in the bay and erosion runoff (sediment) into the bay. However, the Big Bend intake canal is approximately 3,460 feet long, 200 feet wide, and 20 feet deep, with a water flow velocity of about 0.5 feet per second. Therefore, even with high suspended solids loading in the bay, the intake channel will act as a settling basin to allow the majority of sand and silt to settle out. The algae and other biological matter have significant fouling potential requiring a high capacity pretreatment system to protect the reverse osmosis membranes. A budget of approximately $13,318,000 was set aside for the feedwater pretreatment system for the desalination plant. (Update 7/04: Operational reports from the Tampa plant indicate that the pretreatment system installed is not adequately removing this high fouling potential, therefore leading to decreased performance of the reverse osmosis membranes and increased requirements for cleaning the membranes)[10].

Environmental Conditions, Permits, and Mitigation Requirements. Extensive agency review is anticipated due to a lack of precedence in permitting in the United States a desalination facility of the size and configuration of the Tampa Bay project. However, the effort required by the developer to fully meet all environmental data acquisition and modeling requirements will be diminished at the selected site due to previous permits and studies required for the existing power plant. Additional savings for the developer will be realized due to studies conducted in the Bay for other purposes and studies conducted on behalf of Tampa Bay Water during the desalination proposal selection process. A budget of $1,300,000 has been established by the developer for obtaining the required permits for the desalination plant and pipeline.

Another advantage of the Tampa Bay location is the large amount of flushing that occurs in the Lower Hillsborough Bay where the Big Bend Power Station cooling water discharges. A study by the U.S. Geological Survey concluded that with each tide reversal, more than 25 times as much water enters or leaves Hillsborough Bay than is circulated through the power station.[5] The overall residence time for Tampa Bay is approximately 145 days.[6] However, the Big Bend Power Station discharges to the lower portion of Tampa Bay near the interface with the open Gulf, and therefore the overall residence time for all of Tampa Bay may not be representative of flushing that occurs near the Big Bend Power Station. Without adequate flushing it would not be possible to discharge the concentrate into the bay due to the risk of salinity buildup causing ecological damage. (Update 7/04: Discharge permits where obtained and ongoing monitoring required by the permits indicate that there has been no noticeable increase in the salinity of the Bay due to operation of the desalination plant)[10].

Desalination Cost Impacts Identified

The cost impacts of different siting parameters were estimated using developed cost models, engineering calculations, and example projects. Both initial capital expenditures and annual O&M costs are included in the cost impact analyses. Some siting parameters have a general impact on the entire desalination process and are quantified by estimating the impact on water production costs. Alternatively, other siting parameters only impact a particular portion of the desalination process and are quantified by their impact on those individual components of the water system. The term "water production costs" is used to refer to the core desalination process without the other ancillary components of a complete water supply system. Water production costs include standard water treatment components common to all seawater reverse osmosis (RO) systems. Water production costs include feedwater pumps with energy recovery turbines, standard pretreatment (acid and antiscalant addition and cartridge filters), RO membranes and process system, and membrane cleaning system. Since the cost models do not include energy recovery turbines, these were estimated using engineering calculations and historical costs. Water production costs do not include other costs that are more site-specific, such as costs for source water intake, additional pretreatment (e.g., chlorination/de-chlorination or media filtration), post treatment, concentrate disposal, or delivery to the point of distribution. These excluded items may have significant cost implications and are considered separately.

Parameters of the Tampa Bay Water desalination project were used as the base assumptions in most of the estimated example costs. The base assumptions used in the cost estimates are given in Table 2. These are the base assumptions used for all the variables in the estimates except

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[5]Levesque, Victor A., and K.M. Hammett, "Water Transport in Lower Hillsborough Bay, Florida, 1995-96," U.S. Geological Survey Open-File Report 97-416, Tallahassee, Florida, 1997.
[6]Bianchi, Pennock, and Twilley, "Biogeochemistry of Gulf of Mexico Estuaries, John Wiley & Sons Inc., 1999.

where noted in the individual cost impact estimates. The cost impacts of a few of the major siting parameters are included in the following portions of this section.

Source Water Salinity. Source water salinity affects almost every aspect of the RO process. Required driving pressure across the membrane is dictated by the osmotic pressure caused by the difference in salinity concentrations between the feed and product waters. Increased feedwater salinity increases the osmotic pressure, requiring higher driving pressure. Higher operating pressures necessitate the use of stronger membrane pressure vessels and RO elements designed to handle higher operating pressures.

Recovery rate and process configurations are also affected by source water salinity. Higher salinity generally decreases the recovery rate of a single stage process configuration. Depending on the source water salinity and required product water TDS concentration, different levels of reject staging, product staging, or bypassing/blending staging may be necessary. High TDS source water will produce higher TDS reverse osmosis concentrate that may be more difficult to dispose of due to permitting issues.

Table 2. Base Assumptions for Estimates

Parameter	***Assumption***	***Description***
Labor, including Benefits	$25 per hour	
Energy Cost	$0.04 per kWh	Interruptible Power
Interest Rate	6 percent	
Financing Period	30 years	
Recovery Rate	60 percent	Percent of feedwater recovered as product
Flux	8.4 gfd	Rate product water passes through membrane
Pumping Head	900 psi	Pressure for seawater
Cleaning Frequency	6 months	Membranes cleaned once every 6 months
Membrane Life	5 years	Membrane elements replaced every 5 years

Water production costs versus feedwater TDS are shown in Figure 3. These costs are based on increasing feedwater pressure with increasing TDS concentration. Feedwater pressures vary from 400 to 900 psi as the TDS concentrations increase from 10,000 to 35,000 mg/L, with the pressure increasing by 100 psi for each 5,000 mg/L increase in TDS. The costs are based on constant flux rate of 8.4 gfd and recovery rate at 60 percent regardless of TDS concentration. Curves could be significantly steeper if process configuration and/or product water quality requirements cause a decrease in flux rate and/or recovery rate in response to higher TDS concentrations.

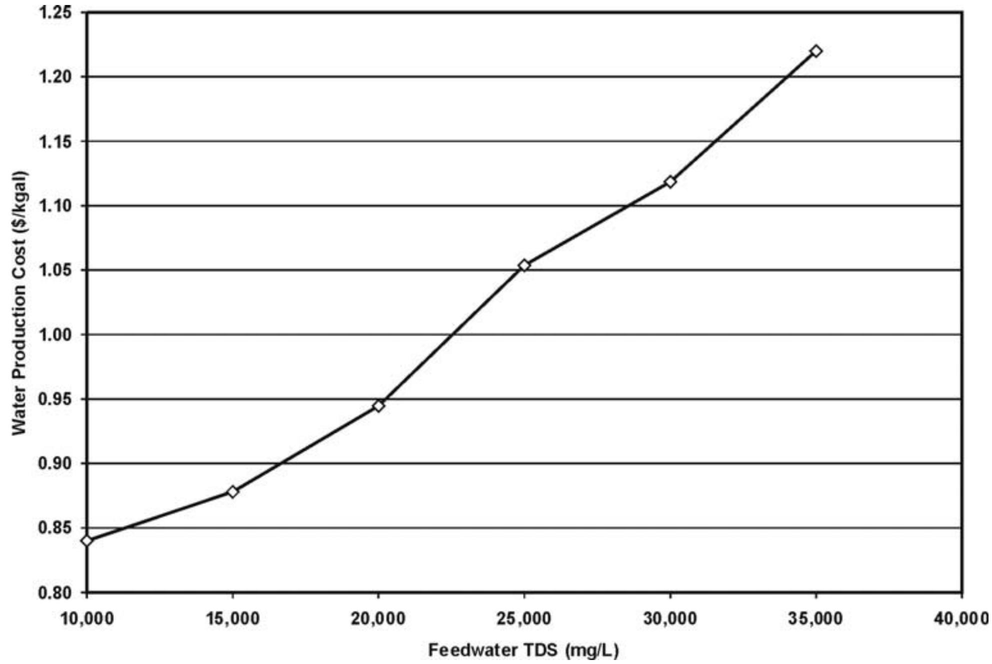

Figure 3. Reverse Osmosis Water Production Cost Versus Feedwater TDS

Source Water Fouling Potential. Reverse osmosis membrane elements are susceptible to fouling that can decrease the flux rate through the membrane thereby decreasing the treatment capacity per element or requiring higher operating pressures to maintain production. Sources of fouling include suspended solids, organic matter, microbial growth, and inorganic scale deposits.

Source waters with a higher fouling potential can also increase desalination costs by requiring higher levels of pretreatment and/or membrane cleaning. Pretreatment may include chlorination/de-chlorination, acid addition, antiscalant, and cartridge filters. Poor source water quality can also require additional pretreatment, such as chemical coagulation, media filtration, and/or ultrafiltration (low-pressure membrane filtration). The required frequency of membrane cleanings may increase with higher fouling potential. Also, some fouling agents are difficult, if not impossible, to remove by current cleaning methods, thereby shortening the effective life of the membranes requiring more frequent membrane replacement.

Feedwater characteristics used to predict fouling potential include pH, alkalinity, temperature, and concentrations of several constituents. The pH affects alkaline scale formation, membrane stability, and salt rejection optimization. Lowering pH by acid addition to about 5.5 to 6.0 so the Langlier index is negative can reduce the scaling potential due to calcium carbonate. Temperature affects flux rates, membrane life, and scaling. Elevated levels of water constituents, such as strontium, barium, iron, hydrogen sulfide, and silica, can impair performance of RO membranes. The fouling potential of source water can also affect the flux rate achieved across the RO membrane elements. Lower flux rates require more membrane elements or operating at a higher pressure to produce the same quantity of product water. (Update 7/04: The decreased performance of the Tampa desalination plant is considered to largely be the result of inadequate pre-treatment prior to the desalination reverse osmosis membranes. Tampa Bay Water is currently pursuing competitive proposals from two teams conducting pilot tests at the plant site to determine the best remedy) [10].

Concentrate Disposal. One of the most contentious siting factors for a large-scale desalination facility is determining an acceptable location to discharge the concentrate. Potential concentrate disposal methods include discharge to a bay or open ocean, deep well injection, solar ponds, thermal evaporation, and discharge to sewer system. With seawater desalination recovery rates ranging from 40 to 60 percent there can be a high volume of concentrate generated. Example concentrate production quantities and qualities with varying recovery rates are shown in Table 3. For large seawater desalination facilities the only practical option for concentrate disposal may be discharge to a bay or open ocean. Other options may be feasible for smaller plants (less than 5 MGD) where the volume of concentrate is less prohibitive for other disposal options.

Table 3. Concentrate Production

Recovery Rate	***40 percent***	***50 percent***	***60 percent***	***70 percent***
Feedwater Flow (MGD)	62.50	50.00	41.67	35.71
Concentrate Flow (MGD)	37.50	25.00	16.67	10.71
TDS of Concentrate (mg/L)	50,000	60,000	75,000	100,000
Source Water TDS = 30,000 mg/L		Product Water Flow = 25 MGD		

A study[7] for the Tampa Bay Water desalination plant indicated that an increase in salinity of less than 6 percent above baseline in the receiving surface water is most likely not detrimental to native biota. Current EPA regulations allow for an increase of no greater than 10 percent in background salinity concentration. Additional studies by the Florida Department of Environmental Protection (FDEP) and others have also shown that, with sufficient dilution, desalination concentrate can be discharged to marine waters with negligible impact to the surrounding environs.[8] However, site-specific studies are necessary to characterize existing conditions and to quantify potential impacts to water quality and living resources resulting from a desalination facility at sites along the Texas coast.

Typical concentrate production values are shown in Table 3. The volume of concentrate decreases as the recovery rate increases. However, when concentrate volume is reduced, dissolved solids in the concentrate are more highly concentrated. Depending on disposal method and regulatory considerations it may be more or less advantageous to have a greater volume with lower concentration. For highly concentrated discharge, allowance for a mixing zone may allow surface discharge of the concentrate. However, disposal of highly concentrated discharge may be limited by bioassay test requirements. Where there are allowances for a mixing zone, the

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[7]PBS&J, Inc., "Impact Analysis of the Anclote Desalination Water Supply Project," prepared for Tampa Bay Water, November 1998.
[8]Response to Best & Final Offer Seawater Desalination Water Supply Project for Tamp Bay Water, Stone & Webster, 1999.

maximum concentration within the mixing zone is dependent on the acute toxicity concentration. The concentrate at higher recoveries may exceed the allowable toxicity concentration.[9]

Concentrate disposal costs can vary widely depending on regulatory requirements and disposal method utilized. Disposing of concentrate through a co-sited outfall, such as the power plant outfall proposed in Tampa Bay, can dramatically decrease concentrate disposal costs. However, concentrate disposal costs can be a large portion of the total desalination cost if more costly options such as offshore discharge are required.

Estimated offshore concentrate disposal costs are shown in Figure 6. Costs are based on disposing of 16.7 MGD of concentrate, which is the concentrate from a seawater desalination plant producing 25 MGD of product water with a recovery rate of 60 percent. The offshore disposal system consists of concentrate pumps, 42-inch pipeline laid on the ocean floor in a 6-foot deep trench and covered, and a diffuser array at the end of the pipeline. Pumps are sized to provide a residual pressure of 100 psi at the end of the pipeline to allow sufficient concentrate exit velocity from the diffuser nozzles for mixing. Sea grass mitigation costs are included assuming that 50 percent of the disposal line will be laid in sea grass areas. Mitigation is assumed to consist of replacing five times the sea grass area disturbed. From previous project experience, mitigation cost is estimated to be $200,000 per acre of sea grass area disturbed. An additional 10 percent of the construction cost is added to account for potential environmental studies and reports. Costs are shown as dollars per 1,000 gallons of product water (25 MGD or 28,000 acft/yr).

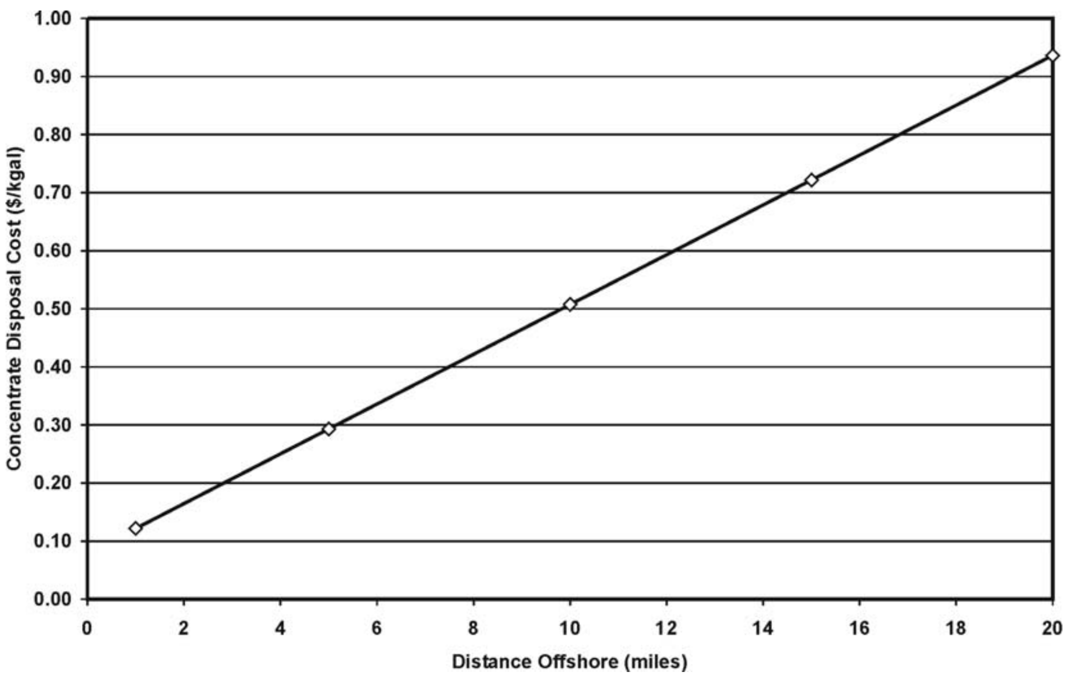

Figure 6. Offshore Concentrate Disposal Cost Impact

[9]Mickley, M., et al., "Membrane Concentrate Disposal," AWWA Research Foundation and American Water Works Association, 1993.

Some of the offshore concentrate disposal cost information was derived from an offshore brine disposal project associated with the storage facility at the Bryan Mound Salt Dome that was part of the Strategic Petroleum Reserve (SPR) Program that started in 1975 and was implemented by the Department of Energy (DOE). The Bryan Mound SPR site is located in Brazoria County near Freeport, Texas. The Bryan Mound project consisted of storing petroleum reserves in underground caverns previously filled primarily with salt. The salt from the caverns was leached out with water diverted from the Brazos River. A pipeline and diffuser was built to dispose of the concentrated brine in the open Gulf of Mexico.[10] Construction costs for the 36-inch pipeline and diffuser only with costs updated to March 2000 were approximately $2,500,000 per mile[11][12] for a construction cost of $31,250,000 for the 12.5-mile pipeline. This cost does not include construction costs for pumping and other miscellaneous costs for the project, such as design and permitting.

Power Cost. Seawater desalination is a power-intensive treatment process, so desalination costs are highly sensitive to the price of power. Power costs are generally about 30 percent of total seawater desalination costs. Electrical consumption for state-of-the-art RO seawater desalination with energy recovery can range from about 11 to 19 kWh per 1,000 gallons of product water. Use of energy recovery turbines can significantly reduce power requirements by recovering a large portion of the energy remaining in the concentrate. Stone & Webster's Tampa Bay proposal indicates that for their desalination facility the energy recovery turbines will recover about 26 percent of the total power used by the feedwater high pressure pumps (HPRO pumps = 13.3 kWh/kgal, ERT = - 3.5 kWh/kgal). Because the RO process can be easily started and stopped, interruptible power can typically be used provided adequate on-site water storage facilities are provided. The relative impact of power cost on the RO water production cost is shown in Figure 7.

All the base assumptions shown in Table 2 are used to determine the relative impact of power cost. The feedwater pumps consume the majority of power. Energy required is dependant on several factors including the salinity and related feedwater pressure and also the recovery rate that affects the amount of feedwater that must be pumped. The impact of recovery rate on the quantity of power required is somewhat mitigated with the use of efficient energy recovery turbines. The costs assume that energy recovery turbines that recover 65 percent of the energy in the rejected concentrate are used.

Product Water Flow. The quantity of water to be treated has an impact on total water costs. Significant savings can be realized from efficiencies present in facilities producing larger quantities. Figure 8 shows the relative impact of product water flow versus water production cost for flows from 1 to 50 MGD. Energy recovery turbines are included for product water flows of 5 MGD and greater. They are not included for the 1 MGD flow because the capital cost of the turbines evaluated outweighs the power savings for flows less than 5 MGD.

[10] Department of Energy, 1981.
[11] Ramen, Raghu. PB-KBB Houston, TX. Personal Communication. March 2000.
[12] Update to July 2004 on the Republic of Trinidad and Tobago desalination project from website at http://www.guardian.co.tt/bussguardian3.html.

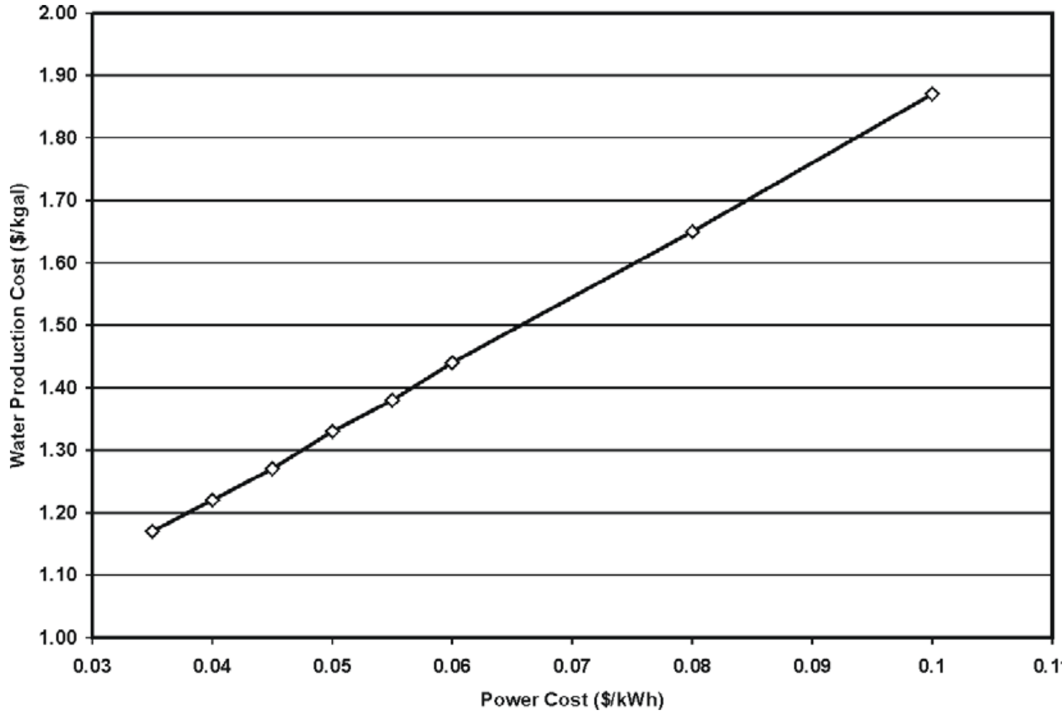

Figure 7. Reverse Osmosis Power Cost Impact

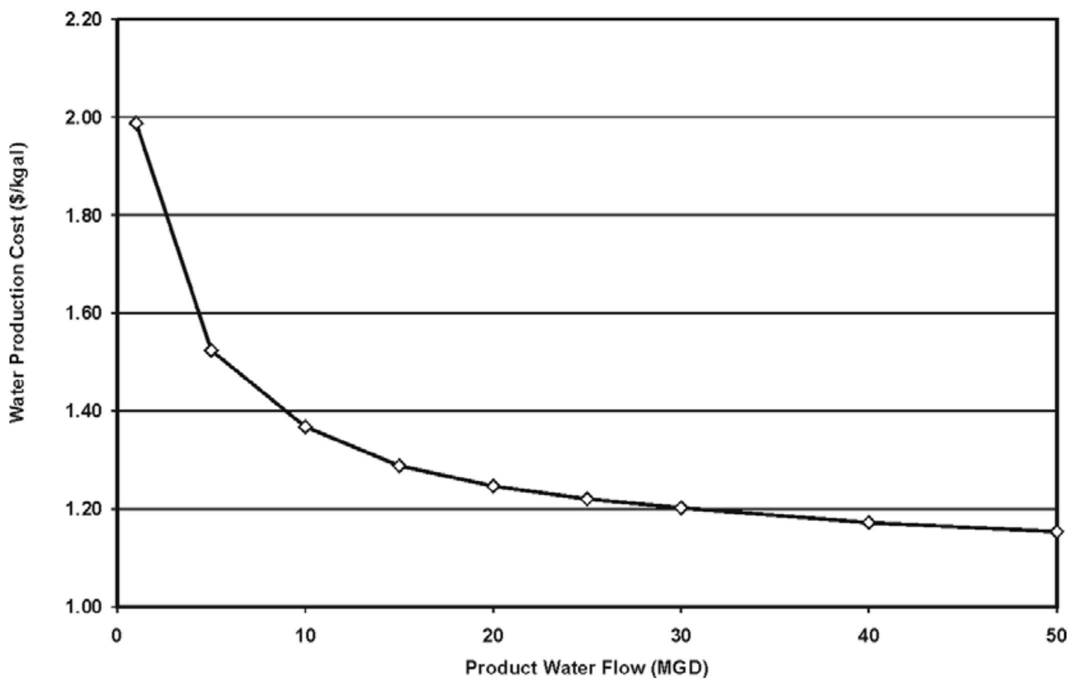

Figure 8. Product Water Flow Cost Impact

Total Reverse Osmosis Seawater Desalination Costs. To compare the cumulative impact of some of the desalination process parameters and siting factors, a range of total costs for RO seawater desalination facilities are shown in Table 4. These costs are for an example facility treating seawater with an average salinity of 30,000 mg/L TDS that produces an average of 25 MGD of desalinated water. Most of the typical assumptions shown in Table 2 are used. Some of the parameters are modified to account for varying source water quality. The parameters from Table 2 that fluctuate are the recovery rate that ranges from 40 to 60 percent, flux rate that ranges from 6 to 10 gfd, and cleaning frequency that ranges from once every 2 weeks to once every year. Other modifications are specific to individual portions of the desalination process and are explained below. The financial assumptions in Table 2 are used for all portions of the estimates.

Table 4.
Total Reverse Osmosis Seawater Desalination Cost Range

	Low Estimate			***High Estimate***		
	Capital Cost	***O&M Cost***	***$/kgal***	***Capital Cost***	***O&M Cost***	***$/kgal***
Raw Water Supply	$1,100,000	$200,000	0.03	$40,000,000	$2,000,000	0.54
Desalination Process	51,000,000	6,200,000	1.09	105,000,000	15,000,000	2.48
Concentrate Disposal	6,900,000	370,000	0.10	112,583,000	977,000	1.00
Delivery to Demand Center	17,382,000	300,000	0.17	205,336,000	2,840,000	1.95
Total	$76,382,000	$7,070,000	1.38[1]	$445,919,000	$17,817,000	5.97

Notes:
Cost is expressed in dollars per 1,000 gallons of product water.
Costs are for plants producing an average of 25 MGD of desalinated water.
Costs are for reverse osmosis desalination of seawater with average salinity of 30,000 mg/L TDS.
Each case is site-specific and costs can vary beyond these ranges.
[1] The total low estimate represents an idealized condition that could not actually occur on any single site.

Raw water supply includes the necessary intake structure, pumps, and piping to deliver seawater to the RO treatment plant. Raw water supply facilities on the low end include only minimal pumps and piping for a desalination plant that is co-sited with a power plant that has an adequate intake structure for use by the desalination plant. Raw water supply facilities on the high end include a large intake structure with precautions to prevent impingement, an intake canal several thousand feet long, pumps, and piping.

Desalination process includes all necessary pretreatment, feedwater pumping, RO membrane process system, and cleaning system. The desalination process on the low end is for the treatment of an ideal source water that requires minimal pretreatment, allows the membranes to operate at around the maximum design flux rate and recovery rate, and does not require frequent cleaning of the membranes. The desalination process on the high end is for poor source water that requires extensive pretreatment including coagulation and filtration, prevents the membranes from operating at a high design flux rate and recovery rate, and requires frequent cleaning of the membranes.

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Concentrate disposal includes the necessary outfall, pumps, and piping to dispose of the RO concentrate to surface water. Concentrate disposal facilities on the low end include only minimal pumps and piping for a desalination plant that is co-sited with a power plant that has an adequate outfall for use by the desalination plant. Concentrate disposal facilities on the high end include pumps, piping, and diffuser for an open ocean discharge into waters a minimum of 30 feet deep.

Delivery to demand center includes the necessary pumps, piping, and water storage tanks for supply of the desalinated water to the distribution system. Delivery to demand center on the low end includes a 13-MGD storage tank with pumps and pipes for delivery 1 mile to the distribution system. Delivery to demand center on the high end includes a 13-MGD storage tank with pumps and pipes for delivery 140 miles to San Antonio.

Example Seawater Desalination Sites on the Texas Coast

Sites were chosen to present example costs for a complete seawater desalination water supply on the Texas coast. Facilities were assumed to supply 25 MGD of desalted water. The example presented below is a facility co-sited with a power plant in Corpus Christi. Financial and other assumptions given in Table 2 were used except where stated in the example. Site-specific water quality and physical conditions for the location were used to the extent possible.

Example: Corpus Christi. The seawater desalination facility for Corpus Christi was assumed to be located next to the Barney M. Davis Power station between Laguna Madre Bay and Oso Bay in south Corpus Christi. Figure 9 shows the location for this example. Davis is a once-through cooling water power plant with an existing reported cooling water flow of 467 MGD. Cooling water is diverted from Laguna Madre Bay and returned to Oso Bay. Engineering assumptions for the Davis seawater desalination example are shown in Table 5.

The estimate assumes that the power plant seawater intake is utilized to obtain the RO treatment plant feedwater. Drawing the source water from the power plant discharge eliminates the need to draw additional flow from the bay for cooling water and supplies feedwater with an increased temperature that is beneficial for the RO process.

Preliminary data indicates that there may be insufficient flushing in Oso Bay and the other surrounding bays for discharge of the RO concentrate. Therefore, for this estimate a separate RO concentrate disposal outfall is included to pipe the RO concentrate to the open Gulf. The outfall crosses Laguna Madre Bay and Padre Island and extends into the Gulf to be diffused in water over 30 feet deep. The concentrate disposal assumptions used in Figure 6 were applied including the assumption that half of the concentrate pipeline will be located through sea grass beds and appropriate mitigation will be required.

Water treatment parameters are estimated based on available water quality data for Laguna Madre Bay near the power plant intake. Coagulation and media filtration is included along with the other standard pretreatment components (cartridge filtration, antiscalant and acid addition). Included sludge handling consists of mechanical sludge dewatering and disposal to a nonhazardous waste landfill. A product water recovery rate of 50 percent was used for this example. This is a lower recovery rate than the 60 percent reported for the Tampa Bay Water project. The lower recovery rate is anticipated due to the higher average salinity of the Laguna Madre Bay at 33,000 mg/L TDS as compared to the water source for the Tampa Bay Water project at 26,000 mg/L TDS.

Land acquisition includes 20 acres for the desalination plant and 97 acres for the desalted water storage tank and transmission pipeline. No land acquisition is included for the concentrate disposal pipeline but surveying costs are included. A 13 million gallon water storage tank and water transmission pumps and pipeline are included to transport the product water 20 miles to either the Stevens plant to blend into the city system or to distribution lines supplying industries along the ship channel. Post treatment stabilization and disinfection are included.

Table 5.
Seawater Desalination at Barney M Davis Power Station
Engineering Assumptions

Parameter	Assumption	Description
Raw Water Salinity	33,000 mg/L	Intake from power plant at Laguna Madre Bay
Raw Water Total Suspended Solids	40 mg/L	
Finished Water Chlorides	100 mg/L	Existing median at Stevens Plant is about 120 mg/L
Product Water Flow	25 MGD	
Concentrate Pipeline Length	10 miles	Diffused in open gulf in over 30 feet of water
Treated Water Pipeline Length	20 miles	Distance to Stevens Plant or port industries
Feedwater Pumping Head	900 psi	
Pretreatment	High	Coagulation, media filtration, and chemical addition
Post-treatment	Stabilization & disinfection	Lime and chlorination
Recovery Rate	50 percent	
Flux	8 gfd	Rate product water passes through membrane
Cleaning Frequency	6 months	Membranes cleaned once every 6 months
Membrane Life	5 years	Membrane elements replaced every 5 years

Table 6 shows the cost estimate summary for seawater desalination at Barney M Davis Power Station. The estimated total cost at 100 percent utilization of $3.08 per 1,000 gallons of product water is about 45 percent higher than the lowest proposal received for the Tampa Bay Water desalination project. The estimated increased costs for this project are primarily the result of higher source water salinity and additional costs for the concentrate disposal pipeline and diffuser system. The total product water cost at 85 percent utilization is estimated at $3.40 per 1,000 gallons.

Permitting of this facility will require extensive coordination with all applicable regulatory entities. Use of the existing power plant intake should facilitate permitting for the source water because no additional water is to be drawn from the bay. However, permitting the construction of the concentrate pipeline across Laguna Madre and Padre Island and construction of the ocean outfall will be major project issues.

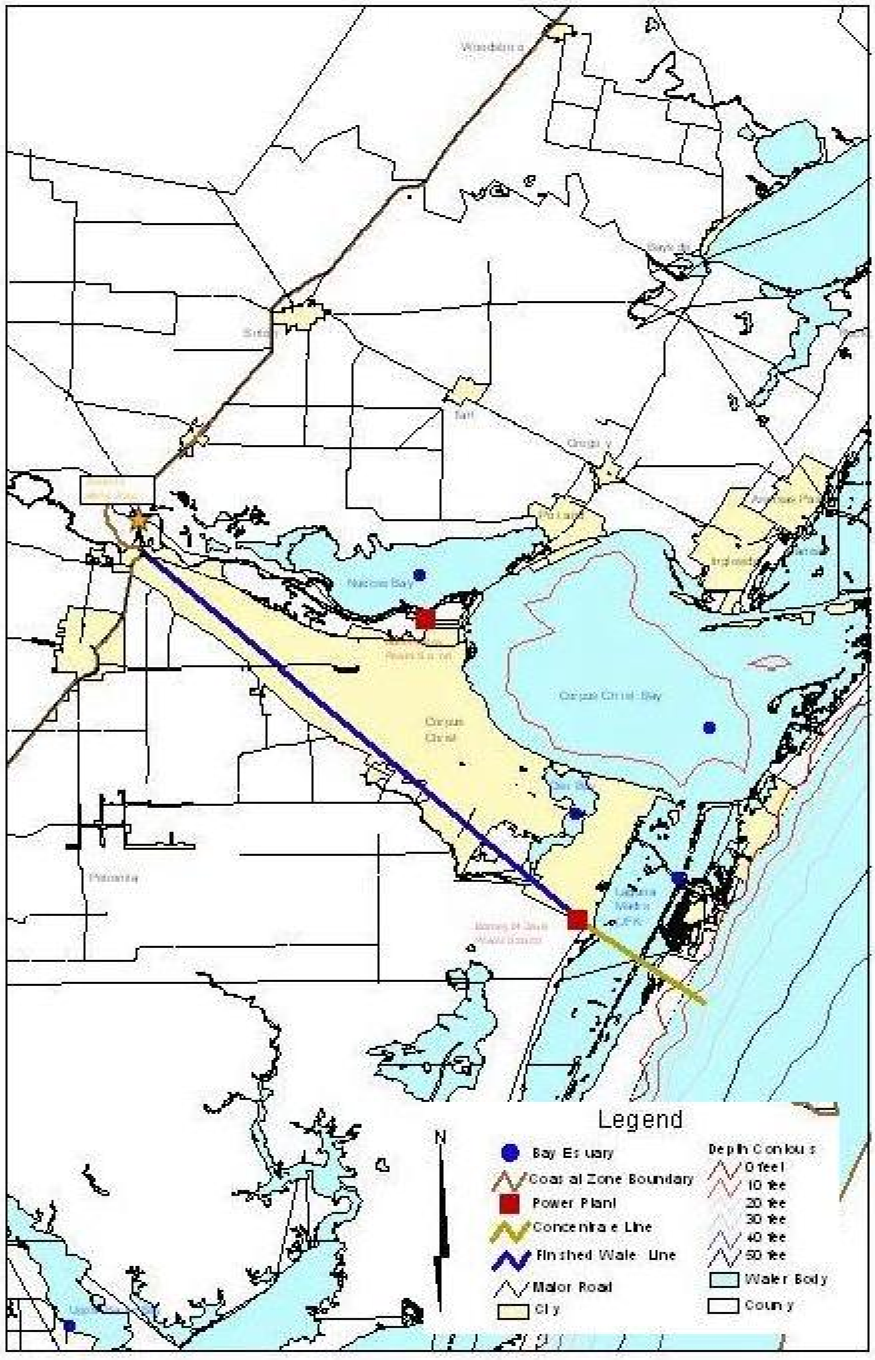

Figure 9. Example: Corpus Christi

Table 6.
Seawater Desalination at Barney M Davis Power Station
Cost Estimate Summary

Item	***Estimated Costs (100% Utilization)***	***Estimated Costs (85% Utilization)***
Capital Costs		
Source Water Supply	$800,000	$800,000
Water Treatment Plant	72,000,000	72,000,000
Concentrate Disposal	32,000,000	32,000,000
Finished Water Transmission	20,000,000	20,000,000
Total Capital Cost	**$124,800,000**	**$124,800,000**
Engineering, Legal Costs and Contingencies (35%)	$43,680,000	$43,680,000
Land Acquisition and Surveying	2,100,000	2,100,000
Environmental & Archaeology Studies and Mitigation	6,900,000	6,900,000
Interest During Construction (6 percent for 2.5 years)	18,720,000	18,720,000
Total Project Cost	**$196,200,000**	**$196,200,000**
Annual Costs		
Debt Service (6 percent for 30 years)	$14,254,000	$14,254,000
Operation and Maintenance:		
Source Water Supply	200,000	200,000
Water Treatment Plant (Except Energy)	8,000,000	6,900,000
Water Treatment Plant Energy Cost	4,300,000	3,700,000
Concentrate Disposal	700,000	650,000
Distribution	700,000	650,000
Total Annual Cost	**$28,154,000**	**$26,354,000**
Available Project Yield (acft/yr)	**28,004**	**23,803**
Annual Cost of Water ($ per acft)	**$1,005**	**$1,107**
Annual Cost of Water ($ per 1,000 gallons)	**$3.08**	**$3.40**

Conclusions

Analysis of the Tampa Bay Water desalination project and siting conditions on the Texas coast indicate that a seawater desalination project on the Texas coast may be economically feasible. At just over $3.00 per 1,000 gallons of product water, the cost developed for the example site at Corpus Christi is about 50% higher than the lowest proposal received for the Tampa Bay Water desalination project. However, the example cost is not far above the current range for other water supply projects to provide large quantities of potable water to these portions of the Texas coast. Also, desalination costs have decreased by a factor of 2 or 3 in the last ten years and may continue to decrease in the future, although further cost decreases will most likely proceed at a much slower pace.

Additional information will be needed once a site has been identified as a potential seawater desalination location. The Tampa Bay Water desalination project provides an example of the kind of information required to reduce uncertainty about the suitability of a particular location for a desalination facility. Tampa Bay Water obtained several environmental reports and studies that helped establish the feasibility of a desalination plant disposing of concentrate to a Florida bay or the Gulf of Mexico. Reports included an analysis from the U.S. Geologic Survey on the water transport in Lower Hillsborough Bay, Florida. This USGS report helped establish that there is most likely sufficient flushing in the bay to allow discharge of the desalination concentrate without salinity buildup. If concentrate discharge to a Texas bay is pursued, a similar analysis is needed to determine the water transport characteristics of the Texas bay that is being considered as receiving water for concentrate. Tampa Bay Water also commissioned a report titled "Impact Analysis of the Anclote Desalination Water Supply Project." This report focused on the potential environmental impacts associated with 1) the discharge of desalination plant concentrate to the coastal estuary of the Anclote Sound and 2) the intake of ambient surface waters for potable water production. These are the two primary environmental concerns that will need to be addressed for a Texas coastal desalination facility.

The above mentioned Tampa Bay Water siting evaluations are only the ones performed prior to receiving best and final offers from the developers. Additional detailed studies will be required once a site has been settled upon to ensure that all regulatory requirements are met. The selected Developer for the Tampa Bay Water project was required to perform all additional studies required to obtain permits for the seawater desalination facility.

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