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# An Analysis of the Economic and Financial Life-Cycle Costs of Reverse-Osmosis Desalination in South Texas:
## A Case Study of the Southmost Facility

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**Texas Water Resources Institute Technical Report**
**September 2009**

Texas Water Resources Institute
*make every drop count*

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## Editor's Note

This report is an update to an earlier article (Sturdivant et al. 2007) which also reported on the Southmost facility. The results presented herein are more comprehensive and reflect newer information which provides a more accurate analysis.

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# An Analysis of the Economic and Financial Life-Cycle Costs of Reverse-Osmosis Desalination in South Texas:

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## Abstract

Desalination provides a supply alternative for potable water for many communities, along with possible defenses against security threats potentially affecting clean water supplies. The economic and financial life-cycle costs associated with building and operating the Southmost desalination facility (near Brownsville, TX) in South Texas are investigated using the spreadsheet model DESAL ECONOMICS©. Primary data key to this analysis include actual initial construction costs, annual continued costs (i.e., for source-water acquisition and transport, pretreatment, purification, and delivery), capital replacement expenses, and desalination-process parameters. The input data used reflect the unique location and quality of source water, process-flow design, asset selection and configuration, management structure, local cost rates, and employed operational methods unique to the Southmost facility. Thus, the specific results are only applicable to the Southmost facility for a specific time, but do provide useful information and insight into life-cycle costs for public and commercial desalination facilities in a more general sense.

Annuity equivalent costs are reported (on both a \$/acre-foot (ac-ft) and \$/1,000 gallons of finished water basis, f.o.b. (free on board) municipal delivery point) for seven individual operational/expense areas, as well as for the entire desalination facility. Results are also presented across different cost types, categories, and items. The baseline results are deterministic, but are expanded to include sensitivity analyses of useful life, initial construction costs, annual energy costs, and production efficiency rate, amongst others.

The current estimated total annual life-cycle costs (in 2006 dollars) to produce and deliver desalinated water to a point in the municipal delivery-system infrastructure for the Southmost facility are \$769.62/ac-ft {\$2.3619/1,000 gal.}. These baseline estimates apply to the Southmost facility and are sensitive to changes in the production efficiency level, and costs incurred for energy, chemicals, initial construction, etc. Also, results indicate significant outlays, beyond those of Initial Construction, are involved with desalination. For the Southmost facility, when a commitment was made to build a facility for \$26.2 million, an implicit commitment for another \$39.1 million (basis 2006 dollars) was also made for Continued and Capital Replacement costs. Investigation into life-cycle costs during the design and planning stages of a desalination facility can assist with determining the least-cost asset configuration to adopt and operational methods to employ.

Also included are modifications to certain key data-input parameters that provide ‘modified results’ which facilitate a more fair basis of comparing facilities and/or technologies. The modified results, which are considered appropriate to use when comparing to similarly-calculated values (for other facilities or technologies), are \$615.01/ac-ft/yr {\$1.8874/1,000 gal./yr} (basis 2006 dollars).

# An Analysis of the Economic and Financial Life-Cycle Costs of Reverse-Osmosis Desalination in South Texas:

### A Case Study of the Southmost Facility

## Introduction

In the 1990s, water emerged as a critical issue for the Texas Lower Rio Grande Valley because of rapid population growth, a prolonged drought, and shortfalls in water deliveries from Mexico over many years.[1] Since that time, opportunities for, and investigations into, easing the stress from limited water (for municipal, industrial, and agricultural users) have taken many paths, with key identified alternatives including:

» water conservation in irrigation district water-conveyance systems,
» on-farm and municipal water-conservation measures, and
» desalination of brackish groundwater and/or seawater.

Alternatives, listed and otherwise, are capable of increasing the available local water supply, either by efficiency improvements in transport or usage, or by manufacturing.[2] Desalinated water is not considered a viable alternative for traditional agricultural irrigation purposes.

When prioritizing and/or selecting among alternatives, a plausible query is "Assuming equivalent quality (relatively speaking), which is the most cost efficient?" An appropriate approach for resolving this question is to identify and define each alternative as a capital investment (i.e., project) alternative, with each project likely differing in its initial and continued costs, quantity and quality of output, expected useful life, etc. Proper implementation of accounting, finance, and economic principles and techniques (i.e., capital budgeting), and consideration of appropriate quality-treatment cost adjustments can transform such data into comparable annual cost measures (e.g., $/acre-foot or $/1,000 gallons) for each alternative. Deriving and having comparable (i.e., 'apples-to-apples') costs can be useful in numerous situations, including regional water-resource planning, by highlighting the alternative(s) providing *the most bang-for-the-buck*.[3]

This analysis addresses the economic and financial life-cycle costs of one of the water-supply alternatives for South Texas (i.e., desalination of brackish groundwater), using actual construction and continued costs for an operating desalination facility. The method of analysis

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[1] Shortfalls in water deliveries from Mexico are in reference to The 1944 Treaty, a binational treaty in which the U.S. annually provides Mexico with 1.5 million ac-ft from the Colorado River, while Mexico in return annually provides the U.S. with 350,000 ac-ft from the Rio Grande. As of September 30, 2005, Mexico had paid its water debt which accumulated during 1992-2002 (Spencer 2005).

[2] Here, "manufacturing" refers to desalination as it "makes" potable water from previously unavailable or contaminated water. Another example is water reuse, which can provide potable or non-potable water.

[3] The phrase 'apples-to-apples' is useful lay terminology referring to the annuity-equivalent results being 'adjusted' for time and stated in current (i.e., 2006) dollars, thereby allowing comparisons across projects. Doing so is common among capital-project comparisons and, for example, allows a desalination facility (or component) having a 30-year useful life to be compared with one having a 50-year useful life. That is, the project alternative having the 'most-bang-for-the-buck' will be identified as the one having the lowest per-unit life-cycle cost (or, technically dubbed, the lowest per unit annuity-equivalent cost).

is Capital Budgeting – Net Present Value (NPV) analysis, with the calculation of annuity equivalent measures.[4] Resulting annuity equivalent costs (or 'annualized life-cycle costs') are provided on both a \$/ac-ft/year and a \$/1,000-gal/year basis.

A "life-cycle" is the length of time a facility "lives"; i.e., the time from whence construction commences until facility decommissioning. Therefore, "life-cycle costs" include all costs involved with the facility – initial construction, future operation and maintenance, and future capital replacement. These costs are expressed in current-year dollars and can be presented as (1) a life-cycle total, (2) an annual, monthly, or daily amount, or (3) a per-unit amount, such as dollars per acre-foot or dollars per 1,000 gallons.

The purpose of this report is to (a) provide a comprehensive economic and financial analysis of the costs of producing and delivering reverse osmosis (RO) desalinated water at an operating facility, and (b) document the template used in this, and subsequent, analyses. The estimates herein are applicable only to this facility for the stated operating circumstances, but provide insight into costs of desalination. By definition, any consideration of water sales revenue or other economic benefit which would act as a 'credit' to offset economic and financial costs would infer a cost/benefit study, and result in an analysis of the *net* costs. In this study, such non-cost items are irrelevant and not included.

## Alternatives to Desalination in South Texas

South Texas' dependency on the Rio Grande for its supply of municipal and industrial (M&I) water remains paramount as surface water from the River accounts for about 87% of M&I use (**Table 1**) (Rio Grande Regional Water Planning Group 2001). It is this heavy reliance, in combination with severely-reduced supplies in the mid-to-late 1990s, which sparked stakeholders' interest in desalination, particularly among the River's most downstream users. This interest was subsequently manifested into a recommended supply strategy by the Rio Grande Regional Planning Group (i.e., Region M in the State water-planning process) in 2003.[5]

The second largest supply source in South Texas is groundwater, which provides about 5.8%, while reuse and desalination currently provide about 3.7% and 3.3%, respectively of the region's water (**Table 1**) (Rio Grande Regional Water Planning Group 2001). Surface water from resacas is also listed as a Region M supply alternative, providing about 0.1% of the Region's supply. Other than some rainwater runoff into resacas, the originating supply source for resacas is the Rio Grande, thus diminishing the actual net contribution resacas provide.

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[4] "Capital Budgeting" is a generic phrase used to describe various financial methodologies of analyzing capital projects. Net Present Value (NPV) analysis is arguably the most entailed (and useful) of the techniques falling under Capital Budgeting. The use of annuity equivalents extends the standard NPV analysis method to accommodate comparisons of projects (or desalination facility segments) with different useful lives. The methodology used in the analysis are similar to methods documented in Rister et al. (2009). For more information, refer to the *Summary of Economic and Financial Methodology* section in this report, and Jones (1982); Levy and Sarnat (1982); Quirin (1967); Robison and Barry (1996); and Smith (1987).

[5] The recommendation to include desalination as a supply strategy was made via an amendment (in 2003) to the Water Plan which was originally completed/adopted in 2001 (Norris 2007).

Rainwater harvesting (RWH) is an idea/practice that is expanding in South Texas, although it contributes only a minuscule portion (approximately one-twentieth of 1%) toward M&I water supply in the Region. RWH is not a Region M denoted alternative, but it can serve as a location-specific source of landscape irrigation water, or, with treatment, serve as a source of potable water. Other alternatives (e.g., water transfers within or across basins) are technically possible, but have not been implemented. Thus, the Region is considered to currently have six supply alternatives (**Table 1**).

Table 1. Summary of Water-Supply Alternatives for Municipal and Industrial Users in South Texas, Ranked by Estimated Contribution to Regional Supply, 2006.

| Water-Supply Alternatives | Estimated % of Current Regional Supply |
|---|---|
| 1) surface water from the Rio Grande | 87.10 % |
| 2) groundwater | 5.80 % |
| 3) reuse | 3.70 % |
| 4) desalination | 3.25 % |
| 5) surface water from resacas | .10 % |
| 6) rainwater harvesting | .05 % |

Source: Rio Grande Regional Water Planning Group 2001.

## Importance of Economics and Finance

The water provided by each of the above-mentioned alternatives (**Table 1**) represents varying levels of quality (e.g., salinity). Consequently, treatment-cost adjustments may be required to place the final delivery cost of surface water, harvested water, and possibly groundwater on par with the quality of desalinated water. Nonetheless, each is a *supply* alternative. Further, other efficiency-improving capital-project alternatives identified in the introduction (e.g., on-farm and municipal water-conservation measures) can be termed *efficiency* alternatives (i.e., either in water's transport or usage). Though different in their "approaches," both *supply* and *efficiency* alternatives can add to the Region's water supply. Following through with the aforementioned concept of Capital Budgeting, each alternative can be evaluated, compared against each other, and ranked.

## Brackish Groundwater Desalination Facility in South Texas

Though multiple brackish groundwater desalination facilities exist (and more are planned) in South Texas, this study is limited to one existing facility near the Gulf of Mexico and the Texas-Mexico border just outside of Brownsville, TX (**Figure 1**).[6] This facility is termed the *Southmost Desalination Facility*, and is owned and operated by the Southmost Regional Water

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[6] Related research by the authors derive life-cycle costs of other brackish groundwater (and a planned seawater) desalination facilities (Boyer 2008), as well as traditional surface-water facilities (Rogers et al. 2009). These studies allow comparisons to be made across facilities and across technologies (Rogers et al. 2008).

Authority (SRWA) – a consortium of six partners which includes: Brownsville Public Utilities Board, City of Los Fresnos, Valley Municipal Utilities District No. 2, Town of Indian Lake, Brownsville Navigation District, and Laguna Madre Water District (Brownsville Public Utilities Board n.d.; Southmost Regional Water Authority n.d.).

Source: Google Earth (2007).

Figure 1. Approximate Location of the Southmost Desalination Facility Near Brownsville, TX and the Gulf of Mexico.

### Overview of the Southmost Desalination Facility

The Southmost facility was built to treat brackish groundwater and provide an alternative water supply for the majority of the Southmost Regional Water Authority (SRWA) partners in the southern Cameron County region (Brownsville Public Utilities Board n.d.).[7] With the completion of Phase I in the Summer of 2003, the designed 7.5 million gallons per day (mgd) total output can provide more than 40% of the annual municipal and industrial water needs for the participating entities. Since the facility's components were oversized, output can be expanded two or three times beyond the designed 7.5 mgd (Brownsville Public Utilities Board n.d.; Southmost Regional Water Authority n.d.).

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[7] At the time of the decision to build the Southmost desalination facility, the northern area of Brownsville, TX was experiencing rapid urban growth and faced with having to either build another conventional surface-water treatment facility or a desalination facility. Of the eventual $26.2 million invested in the desalination facility, about $12 to $15 million would have been required to build a surface-water treatment facility (Norris 2007).

The current maximum-designed capacity of the Southmost facility is 7.5 mgd, which is derived by combining 6.0 mgd of RO-processed water with 1.5 mgd of blend source water. Using a 100% production efficiency (PE) rate equates the 7.5 mgd production rate to 8,401 acre-feet (ac-ft) annually. As depicted in **Table 2**, the Southmost facility's actual PE rate has varied due to operational and product-demand interruptions.

Table 2. Annual Output and Production Efficiency (PE) Measures, as a Percentage of Maximum Designed Capacity, for the Southmost Desalination Facility.

| Capacity / Fiscal Year [a] | Average Daily Output (mgd) [b] | Total Annual Output (ac-ft) | Resulting Production Efficiency (PE) (% of max. design capacity) |
|---|---|---|---|
| Current Maximum-Designed Capacity | 7.500 | 8,401 | 100.0 % |
| Anticipated Capacity [c] | 7.050 | 7,897 | 94.0 % |
| Rule of 85 [d] | 6.375 | 7,141 | 85.0 % |
| Finance Dept. Forecast for 2007 [e] | 6.000 | 6,721 | 80.0 % |
| Modeled Capacity (baseline) [f] | 5.100 | 5,713 | **68.0 %** |
| Production for 2007 [g] | 5.047 | 5,654 | 67.3 % |
| Production for 2006 | 5.068 | 5,676 | 67.6 % |
| Production for 2005 | 3.665 | 4,105 | 48.9 % |
| Production for 2004 [g] | 0.976 | 1,093 | 13.0 % |

Source: Brownsville Public Utilities Board 2007a.

[a] Fiscal year is from October 1 to September 30.

[b] mgd: million gallons per day.

[c] The production rate anticipated by management and consulting engineers after operational and product-demand interruptions are completely overcome.

[d] Texas Commission on Environmental Quality (TCEQ) mandate 30 TAC §291.93(30) states that when a retail public utility (possessing a certificate of public convenience and necessity) reaches 85% of its capacity as compared to the most restrictive criteria of the commission's minimum capacity requirements in Chapter §290.45 of the TAC, it must submit to TCEQ a service-demand plan, including cost projections and installation dates for additional facilities (Texas Secretary of State 2008). Thus, although a facility may be operable at >85% capacity, it may necessarily be constrained (over the long term) to a lower PE rate as the public entity manages the operations of a portfolio of water supply/treatment facilities (Adams 2007)

[e] As of January 2007 (Brownsville Public Utilities Board 2007b).

[f] The production rate used in the baseline analysis discussed herein.

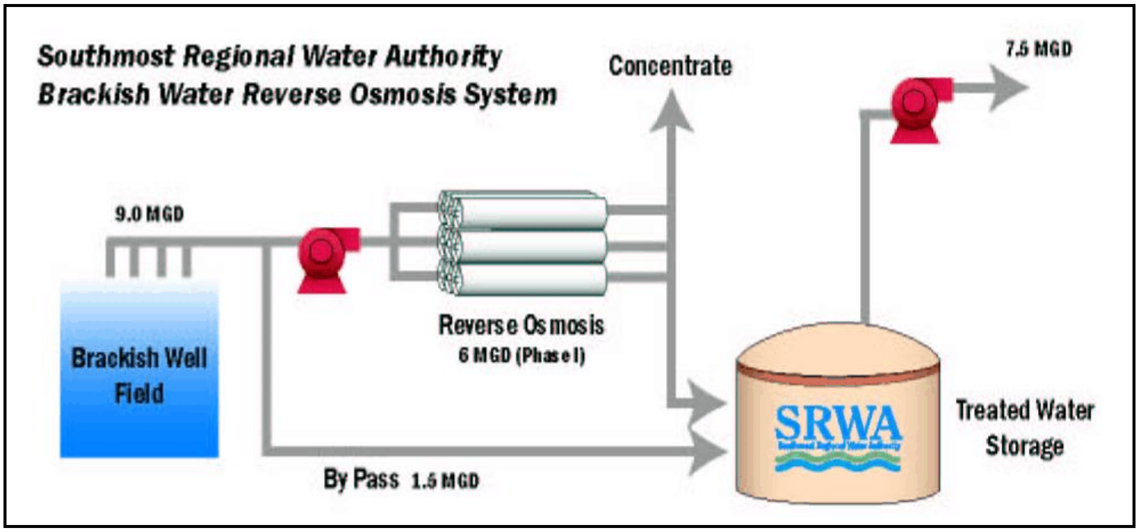
[g] The facility operated for less than twelve months; i.e., production/delivery began in April of 2004, while 2007 only includes 3 months (January - March) of operation. These partial-year data were annualized to provide comparable measures across all four years.

The Southmost facility utilizes brackish groundwater from the Gulf Coast aquifer as its source water (Norris 2007). This source water typically has incoming salinity levels of about 3,500 parts per million (ppm). Once processed, including blending with source water, the finished water from the Southmost facility typically has outgoing salinity levels of 300-475 ppm

(Norris 2007), which is below the 500 ppm maximum level set by the U.S. Environmental Protection Agency for drinking water (Arroyo 2005).[8]

### Desalination Process Description for the Southmost Facility

The source brackish groundwater from the Gulf Coast aquifer is obtained using 20 supply wells, in which 18 are primary and two serve as backup. The well field encompasses about 17 acres, with each individual well's depth ranging from 280-300 feet. Connecting the supply wells together and transporting the source water to the main facility requires approximately 15 miles of source-water collection lines (Southmost Regional Water Authority n.d.). Once the source groundwater is pumped and transported via a pipeline to the main facility, the process-flow depicted in **Figure 2** occurs in the Southmost facility (NRS Consulting Engineers n.d.).



Source: Southmost Regional Water Authority (n.d.); Norris (2007).

Figure 2. Graphical Depiction of the Process Flow for the Southmost Desalination Facility.

#### <u>Pretreatment Process</u>

Pretreatment occurs as the raw, untreated source water enters the main facility. This process consists of cartridge filtration to remove particulate matter and the addition of scale-inhibitor to control salts-scaling. The objective of pretreatment is to control the rate and type of possible fouling that can occur within the membrane elements performing the RO process (NRS Consulting Engineers n.d.). Suspended solids in the source water are removed, prior to the RO system, by a series of five (5) cartridge filters which improve the operation of the subsequent RO membranes. These filters are replaced approximately every four months.

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[8] An alternative source water for the Southmost facility would be seawater, which would have to be piped 30+ miles to the existing facility. Typical incoming seawater would have salinity levels of about 35,000 ppm (Arroyo 2005). There is a proposed seawater-dependant facility project (to be located along the ship-channel in Brownsville, TX, or at a nearby shore-side location) that received $1.34 million funding from the Texas Water Development Board for a pilot plant study (NRS Texas Water News 2006a).

## Reverse Osmosis (RO) Process

A series of six booster pumps move the water from the pretreatment cartridge filters to three 'banks' (or sometimes referred to as 'trains') of pressure vessels, with each configured in a 6:11 array (i.e., total of 198 vessels (3 x 6 x 11)), which remove total dissolved solids (TDS) (**Figure 3**).[9] The booster pumps pressure the pre-treated water against Thin Film Composite membranes housed in each pressure vessel with approximately 180 pounds per square inch (psi), allowing only fresh water to pass through the membrane. Each pressure vessel contains seven elements (i.e., canister filters) which require replacement approximately every six years.

From a water-flow view, each 'bank' (i.e., 6 columns and 11 rows) of vessels is 'split' into two halves containing 33 pressure vessels each. The pressure vessels are configured such that feed water from the pretreatment cartridge filters enters the initial 22 vessels of each half-bank (i.e., 2:11 array) for the 1st-stage RO process. The concentrate from the 1st-stage then feeds the 2nd-stage RO process which is performed by the next column of 11 pressure vessels (i.e., 1:11 array) in each half-bank (**Figure 3**). This process occurs in each of the three banks of pressure vessels.

Source: Sturdivant (2007).

Figure 3. Three Banks of Pressure Vessels (6:11 array each) at the Southmost Facility, 2007.

Each half-bank of 33 pressure vessels (1st and 2nd stages combined) is designed to produce 1.0 mgd of permeated water. Thus, current designed capacity of permeated water for the Southmost facility is 6.0 mgd (i.e., three banks, multiplied by two half-banks, multiplied by 1.0 mgd per half-bank). The entire RO system operates at a 75% recovery

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[9] The "*6:11*" notation is a way of describing a bank of pressure vessels which has six columns (width) and eleven rows (height). Different configurations of vessels are used in RO operations.

rate, meaning three-fourths of the water which enters the pressure vessels is captured as permeated (i.e., desalted) water (Norris 2007; Adams 2007).[10]

## Concentrate Waste Discharge

The 25% volume of water not recovered as permeated water in the RO pressure vessels is salt concentrate waste. Given its close proximity to the Texas Gulf Coast, the Southmost facility has the luxury of a relatively simple and inexpensive disposal issue. The concentrate waste is discharged (Texas Commission on Environmental Quality (TCEQ) permitted) through a 16" (dia.) pipeline into an earthen drainage ditch located adjacent to the Southmost facility and extending to the Laguna Madre.[11] For other, inland facilities, the discharge of concentrate waste is typically more complex and costly (e.g., at the El Paso Kay Bailey Hutchison Plant, the concentrate waste must be pumped into deep wells about 20 miles from the main facility site (Archuleta 2004).

## Blend Water

After cycling through the RO pressure membranes, the permeated water, now at 40-50 ppm salinity, is blended with non-permeated (i.e., brackish) blend water (from the pre-treatment process where suspended solids are removed), which is about 1,800 ppm. The blended water has a salinity level of about 300-475 ppm.[12]

The process of over desalting source water via the RO process (to 40-55 ppm) and then blending with 1,800 ppm nonpermeated water to attain product water with 300-475 ppm salinity (vs. permeating to the 300-475 ppm salinity level and not blending) happens for several, planned reasons. One is the booster pumps installed in the Southmost facility provide a constant level of pressure (i.e., not variable-pressure pumps) against the membranes, which require high pressure (i.e., 180 psi) to permeate water. In doing so, approximately 95-98% of the minerals are removed. Tweaking the permeate level is not permissible with the installed equipment/process. Benefits of this approach include (1) a reduced amount of water is pumped from the well field, (2) a smaller and less expensive intake pipeline from the well field to the main facility, (3) reduced chemical usage in the RO process, (4) reduced concentrate waste volume (which is State regulated by TCEQ), and (5) waste-energy recovery from the concentrate waste flow of the first stage to the source flow of the second stage.

## pH Adjustment and Disinfection

The blended product water is treated with caustic soda for pH adjustment and chloramines for disinfection of microorganisms (e.g., bacteria, viruses, protozoa) which can cause diseases such as typhoid fever and dysentery (Scranton Gillette Communications, Inc.

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[10] The 75% is obtained by a 50% recovery of the 1st-stage (i.e., in 22 vessels) and 50% recovery in the 2nd-stage (i.e., 11 vessels which use the concentrate from the 1st-stage) for each of the three banks.

[11] The Laguna Madre (translated: "mother lagoon") is a shallow, salty lagoon that is five miles across at its widest point and stretches for 200+ miles from southern Texas into northern Mexico (**Figure 1**). One of the five saltiest bodies of water on Earth, and considered an extraordinarily rich wetland area, it provides habitat for young finfish, shrimp, shellfish, etc., and is sheltered by a system of barrier islands and mainland beaches (The Nature Conservancy 2006).

[12] Such quality of blended water (i.e., 300-475 ppm) is comparable to conventional treatment of surface water from the Rio Grande (Norris 2007).

2007).[13] Calcium chloride (CaCl) is added to counter extreme product-water 'softness,' and to assist with the pH adjusting process (NRS Consulting Engineers n.d.).[14]

#### Degasification and Tank Storage

After the post-RO treatments, the product water is pumped into the transfer station clearwell for degasification (i.e., aeration) where "air bubbles" of carbon dioxide are removed. From here, the finished water is pumped into a 7.5 million gallon above ground storage tank.

#### Delivery of Product Water

From the above-ground storage tank, the product water is pumped via a pipeline to the municipal delivery point approximately two (2) miles away. Plans for a second delivery point to be installed in the near future exist. This will increase the acceptance capacity of the municipal system and thereby reduce demand interruptions of RO-desalinated water from the Southmost facility (i.e., not inhibit the maximum designed capacity).

### Construction Period and Expected Useful Life

The construction period for the Southmost desalination facility spanned 20 months between February 2003 and September 2004. Like other capital projects, various delays and challenges were incurred during the construction phase. These issues are discussed in further detail in Norris (2004). Without the unanticipated delays and needed phased-in start-up, Southmost facility management and consulting engineers advise construction could have been achieved in a 12-month period. For this analysis, a 1-year construction period is assumed.[15]

The various civil, electrical, and mechanical components of the Southmost facility are expected to have useful lives ranging from a low of three (3) years for items such as well-field pump motors, to a high of 50 years for structural items such as buildings, storage tanks, concrete, etc. For this analysis, a maximum useful life of 50 years is established for the entire desalination facility. Within that maximum-life limit, however, it is recognized that certain capital items have shorter lives. Thus, intermittent capital replacement expenses (inflation adjusted) are incorporated, as appropriate, to reflect the necessary replacement of such items (e.g., membranes, pumps, motors, etc.) to insure the facility's full anticipated productive term. Other, non-capital expenses, such as electrical switches, valves, etc. are captured in annual operating expenses. Combined, specified capital-replacement and annual-operational expenses provide for a facility that will maintain productive capacity for 50 years.

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[13] That is, when chlorine (Cl) (found in chloramines) is added to water, it forms hypochlorous acid (HOCl), an active disinfectant (Scranton Gillette Communications, Inc. 2007).

[14] Changes to U.S. Environmental Protection Agency (EPA) water-quality standards regarding arsenic, which took effect January 2006, have impacted the Southmost facility (and other municipal water suppliers relying on groundwater). The new requirements reduce the allowable arsenic limit from 50 parts per billion (ppb) to 10 ppb. Realizing a range from 14 to 35 ppb of arsenic, the Southmost facility collaborated with NRS Consulting Engineers to successfully deal with specific properties of the arsenic in the source water by adding 0.15 mg/L of chlorine to oxidize arsenic (III) to arsenic (V). This adjustment to the treatment process resulted in 2 ppb levels of arsenic (i.e., below the new 10 ppb level) in the permeated water (NRS Texas Water News 2006b). Chlorine levels are closely monitored as chlorine can damage the membranes inside the pressure vessels.

[15] The impact of this assumption upon results is very minimal. Results from a scenario with a 2-year (i.e, 24 months) construction period were within 1.9% of the baseline results reported herein. Extrapolating with a 20-month period, suggests results to be within 1.3% of the reported baseline results.

## Annual Water Production

The current maximum-designed capacity of the Southmost facility is 7.5 mgd (**Table 2**), which equates to a total annual output of 8,401 ac-ft (with blend water added), assuming a 100% production efficiency (PE) rate. For this analysis, however, allowances are made for typical operational and demand interruptions incurred by such a facility. Imposing the stated 68% PE rate in this analysis is considered appropriate and concurrent with PE levels observed in the most recent fiscal years (i.e., 2006 and 2007) (**Table 2**). The modeled 68% rate equates to 5.1 mgd average daily output, or 5,713 ac-ft annually. This value is held constant during each year of the facility's productive life in the baseline analysis. Other, successive notable rates are listed and discussed further in the table notes.

## Initial Construction Costs

Initial construction costs totaled \$26.2 million for the Southmost facility and are assumed to be spent before the initial 1-year (assumed) construction period (i.e., in time "zero"). For analysis-detail and desalination-facility-comparison reasons, the total cost is divided into 18 cost-item categories, and dissected into seven individual functional areas common to desalination facilities (**Table 3**). As depicted in **Table 3**, the most cost-intensive area of the Southmost facility is the *Main Facility* (\$9,554,574), followed by the *Well Field* (\$7,768,525) and *Overbuilds & Upgrades* (\$4,168,843) cost areas. When viewed from an individual cost-item perspective,[16] the *Pipeline* (\$5,682,754) and *Building & Site Construction* (\$5,630,904) items are the largest contributors to total initial construction costs.[17]

## Continued Costs

Continued costs facilitate perpetual operations from completion of construction to the end of useful life and are compounded at slightly more than 2.0% annually herein.[18] The continued costs used are based on actual expenses incurred for the Southmost desalination facility during the 2004-2005 fiscal year (FY), with adjustments made to reflect 2006 dollars and anticipated increases in energy and chemical costs for the current fiscal year.[19] That is, FY 2004-2005 expenses are used as a proxy (with increased adjustments to energy and chemical costs) in lieu of unavailable current FY expenses. The continued costs begin in the first year after completion of construction and are thereafter compounded at 2.0+% for each successive year of useful life. For this study, annual continued costs total \$1.7 million and are organized into two general categories (**Table 4**):[20]

> <u>Administrative</u>: These annual expenses total \$82,148 and account for facility-related expenses which are not included on the Southmost desalination facility's budget, but rather are included on other owner-entity budgets (e.g., Brownsville PUB).[21] For analysis-detail

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[16] Many detailed cost items have been "collapsed" into generalized categories.

[17] The amount and division of initial construction costs into cost-item categories and into facility segments were identified by NRS Consulting Engineers of Harlingen, Texas.

[18] More precisely, the compound rate is 2.043269% and is inferred, as is described later in this document, in the *Assumed Values for Discount Rates and Compound Factor* sub-section.

[19] Fiscal year is from October 1 to September 30.

[20] Operation and maintenance expenses and their allocation into facility segments were identified by Brownsville Public Utilities Board, the contracted operator and major stakeholder.

[21] Such administrative expenses are estimated as 5% of the O&M budget at the Southmost facility (Adams 2007).

and desalination-facility-comparison reasons, this category has been divided into six cost-item categories, as well as separated into seven individual functional areas common to desalination facilities (**Table 4**).[22] The most costly area is the *Main Facility* ($47,357) (**Table 4**).

<u>Operations & Maintenance (O&M)</u>: These annual expenses total $1,642,953 and account for facility expenses incurred at the Southmost facility. For analysis-detail and desalination-facility-comparison reasons, this category has been divided into ten cost-item categories, as well as separated into seven individual functional areas common to desalination facilities (**Table 4**). As depicted in **Table 4**, the most costly area is the *Main Facility* ($947,137). When viewed from individual cost items,[23] the *Electrical Power* ($816,347) item is the largest contributor to continued O&M costs.

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[22] Since the administrative costs are estimated, the amount is allocated into only one account (i.e., Administrative Overhead) in **Table 4**.

[23] Many detailed cost items have been "collapsed" into generalized categories.

Table 3. Initial Construction Costs for the Southmost Desalination Facility, Across Individual Functional Areas, in 2006 Dollars.

| | Individual Functional Areas (i.e., Cost Centers) of the Southmost Desalination Facility | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| INITIAL CONSTRUCTION COST ITEM | Well Field | Intake Pipeline (Well field to facility) | Main Facility | Concentrate Discharge | Finished Water Line & Tank Storage | Delivery Pipeline (to municipal line) | Overbuilds & Upgrades [a] | TOTAL COSTS |
| Administrative Overhead | $ 0 | $ 0 | $ 0 | $ 0 | $ 0 | $ 0 | $ 0 | $ 0 |
| Building & Site Construction | 1,429,009 | | 3,736,706 | 50,000 | | | 415,190 | 5,630,904 |
| Contingencies | | | | | | | | 0 |
| Contractor Fees | | | | | | | | 0 |
| Electrical Equipment | 891,192 | | 620,568 | | | | 167,973 | 1,679,733 |
| Electrical Service Installation | 360,000 | | | | | | | 360,000 |
| Engineering | 1,009,824 | 450,388 | 1,288,499 | 7,363 | 219,202 | 386,418 | | 3,361,694 |
| Labor | | | | | | | | 0 |
| Land | 500,944 | | | | | | | 500,944 |
| Miscellaneous | | | 266,325 | | | | | 266,325 |
| Other - non listed | | | | | | | | 0 |
| Pipeline | | 1,529,294 | | | | 1,312,083 | 2,841,377 | 5,682,754 |
| Pre-Project | 272,525 | | | | | | | $272,525 |
| Pumps | | | | | | | | 0 |
| RO Equipment & Installation | | | 3,478,265 | | | | | 3,478,265 |
| SCADA [b] | 300,000 | | 164,211 | | | | | 464,211 |
| Storage Tank | | | | | 744,303 | | 744,303 | 1,488,606 |
| Well Field | 3,005,031 | | | | | | | 3,005,031 |
| TOTAL | $ 7,768,525 | $ 1,979,682 | $ 9,554,574 | $ 57,363 | $ 963,505 | $ 1,698,501 | $ 4,168,843 | $ 26,190,993 |

[a] Captures the ‘whistles & bells' beyond baseline necessities, and some ‘elbow room' for future increased capacity – see footnote 28 in the text.

[b] Acronym for **S**upervisory **C**ontrol **A**nd **D**ata **A**cquisition – hardware and software technology which collects data from sensors at remote locations and in real time sends the data to a centralized computer where facility management can control equipment/conditions at those locations.

Table 4. Baseline Annual Continued Costs, Allocated Across Individual Functional Areas, for the Southmost Desalination Facility, Based on Fiscal Year 2004-2005 Expenses Inflated to 2006 Dollars.

| | Individual Functional Areas (i.e., Cost Centers) of the Southmost Desalination Facility | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| CONTINUED COST ITEM | Well Field | Intake Pipeline (Well field to facility) | Main Facility | Concentrate Discharge | Finished Water Line & Tank Storage | Delivery Pipeline (to municipal line) | Overbuilds & Upgrades [a] | TOTAL COSTS |
| ADMINISTRATIVE | | | | | | | | |
| - Administrative Overhead [b] | $ 18,283 | $ 204 | $ 47,357 | $ 184 | $ 3,354 | $ 8,924 | $ 3,842 | $ 82,148 |
| - Insurance (public officials) | | | | | | | | |
| - Labor | | | | | | | | |
| - Maintenance | | | | | | | | |
| - Other | | | | | | | | |
| - Vehicles / Rolling Stock | | | | | | | | |
| sub-total | $ 18,283 | $ 204 | $ 47,357 | $ 184 | $ 3,354 | $ 8,924 | $ 3,842 | $ 82,148 |
| OPERATIONS & MAINTENANCE | | | | | | | | |
| - Administrative Overhead | | | | | | | 62,933 | 62,933 |
| - Chemical [c] | | | 246,453 | | | | | 246,453 |
| - Concentrate Disposal | | | | | | | | 0 |
| - Electrical Power [c] | 293,885 | | 293,885 | | 57,144 | 171,433 | | 816,347 |
| - Insurance | 8,642 | | 32,409 | | 2,161 | | | 43,212 |
| - Labor | 36,868 | 3,687 | 313,380 | 3,687 | 7,374 | 3,687 | | 368,683 |
| - Maintenance | 15,842 | | 44,357 | | | 3,168 | | 63,367 |
| - Other | | | | | | | 13,911 | 13,911 |
| - Rental (land, equip., storage) | 8,456 | | | | | | | 8,456 |
| - Vehicles / Rolling Stock | 1,959 | 392 | 16,653 | | 392 | 196 | | 19,592 |
| sub-total | $ 365,652 | $ 4,079 | $ 947,137 | $ 3,687 | $ 67,071 | $ 178,484 | $ 76,844 | $ 1,642,953 |
| TOTAL | $ 383,935 | $ 4,283 | $ 999,494 | $ 3,871 | $ 70,425 | $ 187,408 | $ 80,686 | $ 1,725,101 |

[a] Captures the ‘whistles & bells' beyond baseline necessities, and some ‘elbow room' for future increased capacity – see footnote 28 in the text.

[b] Expenses incurred at the BPUB for and on behalf of the Southmost facility which are estimated as 5% of the O&M budget at the Southmost facility.

[c] Variable expenses associated with the baseline facility production rate of 68% (see **Table 2**). Production rates above/(below) the baseline necessarily raise/(lower) the total dollar amount of expense.

### Capital Replacement Costs

Similar to continued costs, capital replacement costs facilitate perpetual desalination operations, albeit on an intermittent (vs. annual) basis. That is, within the facility's maximum useful life of 50 years, certain capital items wear out and must be replaced intermittently (e.g., every 2, 5, or 10 years). Recognizing the financial reality of inflation, the costs for capital replacement items (which are based on current FY 2006 dollars) are compounded at slightly more than 2.0% annually in this study.[24] **Table 5** depicts the needed capital replacement items, as well as their replacement occurrence and costs, incorporated in this study:

Table 5. Capital Replacement Items, Occurrence, and Costs (basis 2006 dollars) for the Southmost Desalination Facility.

| Capital Item | Replacement Occurrence | Cost per Item | No. of Items Replaced Each Occurrence |
|---|---|---|---|
| Well / Pumps | 3 years | $10,000 | 20 |
| Membranes | 6 years | $700,000 | 1 |

## Prior Economic Estimates

A review of the desalination literature reveals many strategic-planning papers and much research focused on Texas, the U.S., and internationally. For brevity's sake, and a contemporary perspective, only select results and studies published or released within the past eight years are discussed here. Although little detail is provided on the methodology of these prior studies, the predominant methods of analysis used by their authors are regression[25] and capital budgeting. Without access to such methodological detail, however, commentary regarding the accuracy, comparability, and/or soundness of prior studies' results cannot be (and is not) made herein.

Many engineering-, economic-, regulatory-, institutional-, and environmental-related factors influence the final product costs of desalination facilities, with most or all factors being the focal point and/or the most-significant item in prior investigations. *Location* of a desalination facility dictates the source water type (i.e., brackish or seawater) and thus has a major impact on the facility's product cost. Illustrating the relevance of this factor, Zhou and Tol (2004) used regression techniques on data gathered from more than 2,500 RO desalination facilities (all over the world) and found that any given seawater RO desalination facility experienced higher per-unit costs than brackish-groundwater-dependant facilities. In Adams, Berg, and Harris' (2000) regression results from three South Texas brackish groundwater RO facilities indicate there is a positive linear relationship between treatment costs and total dissolved solids (TDS) concentration (i.e., impurities) of the source water. Both of these conclusions are arrived at because lower-salinity and higher-quality source water require less frequent filter replacement, lower power consumption, and lower chemical usage (Ettouney et al. 2002).

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[24] More precisely, the compound rate is 2.043269% and is inferred, as is described later in this document in the *Assumed Values for Discount Rates and Compound Factor* sub-section.

[25] Regression analysis is a statistical (i.e., mathematical) technique which seeks to predict the value of a variable, based upon the value or characteristics of other (i.e., generally at least two) variables (Wooldridge 2006).

*Energy* accounts for a large portion of final product costs. Younos (2005) credits energy as the primary cost difference between desalination of seawater and brackish water. The data show electric power accounts for 11% of total costs for brackish-water dependant facilities and 44% for seawater-dependant facilities. Graves and Choffel (2004) report electricity costs account for about 30% of the total costs for seawater-dependant facilities. Energy is a factor that is highly dependent on the location, as power rates can vary greatly from state to state and country to country. Ettouney et al. (2002) note the cost of electricity ranges from $0.04 - $0.09/kWh, with the lower ranges experienced in the Gulf States and the U.S., while European countries experience the higher end of the range.

Seaside desalination facilities typically experience lower *brine-concentrate disposal* costs as they elude costly deep-injection wells. To minimize environmental impacts, however, seaside facilities may be required to pump the concentrate some distance offshore. A detailed look at such costs for a seaside facility is given in Graves and Choffel (2004). They report, for a 25 mgd seawater facility (generating 16.7 mgd of concentrate), disposal costs associated with piping concentrate 1-mile offshore are $32.59 per ac-ft {$0.10 per 1,000 gallons} and $309.59 per ac-ft {$0.95 per 1,000 gallons} for a 20-mile discharge pipe. For facilities which are unable to utilize the ocean for concentrate disposal, the remaining options include deep-well injections or evaporation ponds. Archuleta (2004), in a study for a potential facility in El Paso, Texas, indicates that deep-well injection would be the most economical choice.[26] Further, Archuleta notes that a conventional evaporation pond covering 772 acres would cost an initial $41 million, plus an additional $1 million in annual operation and maintenance costs. Nicot and Chowdhury (2005) discuss the reduction of concentrate-disposal costs associated with using depleted oil and gas fields since the substantial initial costs to dig the deep well can be avoided.

A predominant theme in much of the current literature on desalination is the idea of *economies of scale*.[27] Several reports indicate that increasing the total capacity of the facility decreases the per-unit costs for both seawater- and brackish-water-dependant facilities. Arroyo (2005) estimates that production costs for brackish groundwater facilities range from $772.27 per ac-ft {$2.3700 per 1,000 gallons} for a 0.10 mgd RO facility down to $231.35 per ac-ft {$0.7100 per 1,000 gallons} for a 10 mgd RO facility. This theme of utilizing economies of "size" to reduce per-unit costs is also noted by Norris (2004) and Archuleta (2004) in which more than one entity collaborated to build one larger facility, rather than multiple, smaller facilities in South Texas and El Paso, Texas, respectively.

Pittman et al. (2004) reported seawater desalination in South Texas was not economically competitive with conventional-treated municipal water. This conclusion was based on a comparison of charges for conventional-treated water in Brownsville, Corpus Christi, and

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[26] The Kay Bailey Hutchison Desalination Plant located in El Paso, Texas began operating in 2007.

[27] Much, if not all, of the current literature refers to 'economies of *scale,*' which is defined as the "expansion of output in response to an expansion of <u>all</u> factors in <u>fixed</u> proportion" (Beattie and Taylor 1985). In the specific case of increasing output capacities of desalination facilities, however, not all production factors (e.g., land, labor, capital, management, etc.) are increased proportionately to attain the increased output. Therefore, the correct term is 'economies of *size*' -- the concept that *economies* (or decreasing marginal and average variable costs) are incurred as output is increased from a non-proportional increase in the 'size' (i.e., level) of some or all factors of production (i.e., inputs). That is, *scale* refers to a proportionate change in all production inputs, whereas *size* refers to a non-proportionate change in some or all production inputs (Beattie and Taylor 1985). A study by Boyer (2008) reports on 'economies of size' in municipal water treatment technologies.

Freeport, Texas which ranged from $527.88/ac-ft to $661.48/ac-ft, with proposed seawater desalination costs ranging from a low of $1,166.55/ac-ft to a high of $1,306.66/ac-ft (**Table 6**). The cost to desalinate brackish groundwater could be considered economically competitive, however, as Norris (2004) states desalinating brackish groundwater at the Southmost facility (located near Brownsville, Texas) costs between $521.36 and $586.53 per ac-ft {$1.6000 and $1.8000 per 1,000 gallons} to treat and deliver (**Table 6**).

Table 6. Select Charges for Conventional-Treated Water and Costs of Desalinated Seawater, and Costs of Brackish-Groundwater Desalination.

| | Pittman et al. (2004) [a] | | | | Norris (2004) | |
|---|---|---|---|---|---|---|
| | Conventional-Treated Water Charges | | Proposed *Seawate*r Desalination Water Costs | | Proposed *Brackish Groundwater* Desalination Water Costs | |
| Texas City | $/ac-ft | $/1,000 gals | $/ac-ft | $/1,000 gals | $/ac-ft | $/1,000 gals |
| Brownsville | $661.48 | $2.03 | $1,306.66 | $4.01 | $521.36 - $586.53 | $1.60 - $1.80 |
| Corpus Christi | $580.01 | $1.78 | $1,378.35 | $4.23 | n/a | n/a |
| Freeport | $527.88 | $1.62 | $1,166.55 | $3.58 | n/a | n/a |

Source: Pittman et al. (2004), Norris (2004).

[a] Note the conventional-treated values are <u>charges</u>, which may not equate with <u>costs</u> of such water, thus making for a possible imbalanced comparison with seawater desalination costs.

## Summary of Economic and Financial Methodology

Like other capital projects, the Southmost desalination facility: (1) required an initial investment (i.e., dollars) to fund initial construction, (2) requires dollars to fund ongoing operations, and (3) provides both a level of productivity and water quality for some number of years into the future. With an expected life lasting into future years and financial realities such as inflation, the time-value of money, etc., the *life-cycle cost* of providing an acre-foot of desalinated water is the appropriate cost measure to be determined. Capital Budgeting – Net Present Value (NPV) analysis, in combination with the calculation of annuity equivalents, is the methodology of choice because of the capability of integrating expected life with related annual costs and outputs, and other financial realities into a comprehensive $/ac-ft/year {or $/1,000 gals/year} *life-cycle* cost. In short, calculating NPV values for dollars and water allows for comparing alternatives with differing cash flows and water production output, while the use of annuity equivalents (of the NPV values) facilitates comparisons of projects with different useful lives. Assumed in the calculations and methodology are zero net salvage value (for land, buildings, equipment, etc.) and a continual replacement of such capital items into perpetuity.

To facilitate a NPV – Capital Budgeting analysis (with annuity-equivalent calculations) of the Southmost facility, agricultural economists from Texas AgriLife Extension Service and Texas AgriLife Research developed the Microsoft® Excel® spreadsheet model DESAL ECONOMICS©. This model analyzes and provides life-cycle costs (e.g., $/ac-ft/year) for <u>up to</u> twelve individual functional expense areas, as well as for the entire facility. To the authors' knowledge, and from a literature search, this capability appears unique among economic and financial cost models directed at desalination facilities. DESAL ECONOMICS© is custom built and useful for analyzing and reporting on all desalination facilities, regardless of size, location, etc. Individual expense areas for the Southmost facility are:

1) Well Field;
2) Intake Pipeline (from the well field to the main facility);
3) Main Facility;
4) Concentrate Discharge;
5) Finished Water Line & Tank Storage;
6) Delivery Pipeline (to the municipal delivery point);
7) Overbuilds & Upgrades[28]; and
8-12) *unused*.[29]

Results derived using DESAL ECONOMICS© allow an "apples to apples" comparison to be made across different desalination facilities and/or across individual expense areas of different desalination facilities. Noteworthy of special mention of this model is having the ability to analyze individual expense area results (i.e., detail beyond the 'bottom line' of the entire facility). That is, with a standard 'aggregate' analysis of a desalination facility, one may experience dramatic life-cycle cost differences across facilities, but have no explanation as to the functional cost area(s) which are causing the disparity. By also analyzing the individual functional cost areas, additional useful data is provided – this may highlight the need for a review assessment to see if engineering/construction changes could be made in one or more specific areas toward reducing the composite life-cycle cost.

Also, if the same methodology and factors are used, comparisons can be made with other capital projects which 'add' to the region's available water supply (e.g., on-farm and municipal water-conservation measures, seawater desalination, rainwater harvesting, ponding and retainment, rehabilitation of water-conveyance systems (e.g., Rister, Lacewell, and Sturdivant (2006)), etc.).[30] Ultimately, having comparable costs for all alternatives which add water to a region's supply will provide information useful for prioritizing projects in the event of limited funding, and other varied circumstances.

Though potentially 'different,' the qualities of final-product waters from different municipal treatment facilities are assumed inherently comparable and are not adjusted (for incoming source-water quality, nor outgoing final-product water quality) to facilitate across-facility or across-technology comparisons as (a) all potable-water suppliers are required to meet

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[28] This expense area captures the 'whistles & bells' included in the initial construction costs beyond baseline necessities, and some 'elbow room' for future increased capacity. That is, the Southmost facility is considered a Type A 'cornerstone' building as its equipment and amenities facilitate desalination-related training and meetings beyond the capabilities of a basic, no-frills facility. The associated notoriety has helped to bring the Southmost facility to the forefront of desalination in Texas (Southmost Regional Water Authority n.d.).

[29] The nature of the Southmost facility is such that only seven of the permissible twelve facility segments (i.e., functional areas, or expense areas) within DESAL ECONOMICS© were required for the analysis. Thus, there are unused facility segments in DESAL ECONOMICS© for this particular analysis and report.

[30] Note, the cost-of-saving water via rehabilitation of water-conveyance systems needs to be adjusted for municipal treatment costs to par the quality of Rio Grande surface water with that of desalinated water. Also, ongoing efforts by the authors are focused on analyzing the listed capital project alternatives.

specified quality standards on final-product water such that extreme differences in qualities affecting human health cannot occur, and (b) the comparative costs of attaining the relatively-narrow standards is reflected in the input data for each (e.g., chemical amount and costs, equipment used, and costs for specific operating regimes). That is, as long as costs (via the process-flow design, asset selection/configuration, management structure, local cost rates, and employed operational methods unique to each facility) comparing final-product water (i.e., potable) are used, the unique location **and quality** of the source water are reflected in the life-cycle cost of getting the source water's unacceptable quality level to an acceptable (per State and Federal regulations) quality level for each facility's final-product water. Simply said, the assumption is 'potable water is potable water'. Thus, herein, there are no quality adjustments made to account for differences in incoming or outgoing water quality to facilitate across-facility or across-technology comparisons of potable-water producing facilities.[31]

## Assumed Values for Discount Rates and Compound Factor

Much primary data are used in this analysis. Two important discount rates and a compound rate are assumed, however. The discount rate used for calculating the net present values of cost streams represents a firm's required rate of return on capital (i.e., interest). The discount rate is generally considered to contain three components: a risk-free component for time preference, a risk premium, and an inflation premium (Rister et al. 1999).

> Discounting Dollars: Having different annual operating costs and expected lives across facilities (and possibly functional areas) encourages 'normalizing' such flows by calculating the NPV of costs, which requires a discount factor. Since successive-years' costs are increased by an inflationary factor, there is an inflationary influence to consider in the discounting of costs (Klinefelter 2002), i.e., the *inflation premium (I)* and *time (t)* portions of the discount factor should be used.[32] The discount rate used in this analysis is 6.125%, which is consistent with and documented in Rister et al. (2009).
>
> Discounting Water: Having different annual water output and expected useful lives across facilities encourages 'normalizing' such flows by calculating the NPV of production, which requires a discount factor. Since it is incorrect to inflate successive-years' water production, there is no inflationary influence to consider in the discounting of water (Klinefelter 2002), i.e., only the *time (t)* portion of the discount factor should be used. Consultations with Griffin and Klinefelter contributed to adoption of the 4% rate used by Griffin and Chowdhury for the social time value in this analysis (Griffin 2002; Klinefelter 2002; Griffin and Chowdhury 1993).

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[31] Though adjustments (to account for incoming or outgoing water quality differences) are not made herein to facilitate comparing potable-water-producing facilities (or technologies), certain adjustments are needed to properly compare life-cycle costs for raw water from infrastructure rehabilitation (e.g., Rister, Lacewell, and Sturdivant 2006), or invasive weed removal (Seawright 2009), with life-cycle costs for potable water obtained from desalination.

[32] One estimate of a discount rate from a desalination-facility owner's perspective is the cost at which it can borrow money (Hamilton 2002). Griffin (2002) notes, however, that because of the potential government/public funding component of this project, it could be appropriate to ignore the risk component of the standard discount rate as that is the usual approach for federal projects. After considering those views and interacting with Penson and Klinefelter (Penson 2002; Klinefelter 2002), both Texas A&M University agricultural economists specializing in finance, a discount rate of 6.125%, consistent with and documented in Rister et al. (2009), was adopted for use in discounting all financial streams.

Compounding Costs: Inflation is a financial reality with future years' ongoing operational costs. As presented in Rister et al. (2009), use of an overall discount rate of 6.125%, with a 4.000% social time value and a 0% risk premium, infers a 2.043269% annual inflation rate.[33] Thus, nominal dollar cost estimates for years beyond 2006 are inflated at 2.043269% annually.

## Results of the Economic and Financial Analysis

Composite results for the economic and financial analysis of the prior data, using the Excel® spreadsheet model DESAL ECONOMICS©, are presented. A summary of aggregate estimated baseline results is presented first, with more results presented across facility segments and then by cost type. Thereafter, brief presentations of key sensitivity analyses for select parameters are provided. Herein, the phrases '*cost-of-producing water*' and '*cost-of-producing-**and-delivering** water*' are often used interchangeably. Since the costs of the Southmost facility analyzed include delivery to a point in the municipal delivery-system infrastructure, the phrase '*cost-of-producing-**and-delivering** water*' is sometimes used to denote the delivery of finished water on an f.o.b. municipal delivery point basis. This should not be confused with household delivery, but only to a point within the municipal delivery-system infrastructure.

### Results – Aggregate Baseline

Initial Construction Costs: The total initial construction costs for the Southmost facility (**Table 3**) amount to $26,190,993 in nominal 2006 dollars (**Table 7**). Since these costs are assumed to be incurred immediately prior to commencement of construction, the real value does not require adjustment for time and inflation, and hence equals the nominal value (**Table 7**).

Water Production: Over the 50-year expected useful life, the annual production of 5,713 ac-ft, using the modeled effective capacity of 68% (**Table 2**), will total 285,637 ac-ft on a nominal basis. This value, when adjusted for time at the 4.000% social-preference rate, results in a present-day amount of 118,002 ac-ft. The annuity equivalent of this real value, or 'annualized amount,' is 5,459 ac-ft per year (**Table 7**).[34]

Total Life-Cycle Costs: Summing all facility costs (i.e., initial, continued, and capital replacement) over the 50-year expected useful life result in $195,914,480 in nominal dollars. Adjusting this value for time and inflation at 6.125% results in a real value of $65,281,089 (**Table 7**). This value represents the net total life-cycle costs of constructing and operating the Southmost facility (in 2006 dollars). That is, at the time a commitment is made to fund the initial construction costs of $26,190,993, an additional $39,090,096 (i.e., $65,281,089 minus $26,190,993) in current 2006 dollars is also implicitly committed (**Table 7**).

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[33] Represented mathematically: $\frac{1+6.125\%}{1+4000\%} - 1 = 2.043269$.

[34] Here, *nominal value* (or nominal basis) refers to non-inflation adjusted values, while *real value* (or real basis) refers to values expressed in time- and inflation-adjusted terms, with the benchmark year for both time and inflation being 2006 in this analysis.

Annual Cost Annuity: Calculating the annuity equivalent of the $65,281,089 real value results in an 'annualized cost' of $4,201,075. This real value represents, in current 2006 dollars, the net annual costs of constructing and operating the Southmost facility.[35]

Cost of Producing (and Delivering) Water: To derive the annual *Cost-of-Producing (and Delivering) Water*[36] value on a per ac-ft basis, divide the total cost annuity of $4,201,075 per year by the total water-production annuity of 5,459 ac-ft per year {1,778,701 1,000-gallon units per year}. This results in a baseline annual cost of producing and delivering desalinated water at the Southmost facility of $769.62 per ac-ft {$2.3619 per 1,000-gallons} (**Table 7**). This value can be interpreted as the cost of leasing one ac-ft {1,000 gallons} of water in year 2006. It is not the cost of purchasing the water right for one ac-ft {1,000 gallons} (Rister et al. 2009). Consistent with the methodology presented in Rister et al. (2009), this value represents the costs per year in present-day dollars of producing and delivering one ac-ft {1,000 gallons} of water each year into perpetuity through a continual replacement of the new desalination facility, with all of the attributes previously described.

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[35] For the 'Water Production' and 'NPV of Total Cost Stream' results in **Table 7**, the real-value amounts are less than the nominal-value amounts. This occurs because the continued and capital replacement costs, and water production which occur in the latter years of the facility's life are significantly discounted (at 6.125% and 4.000%, respectively) and thus do not contribute to the summed real total as much as do costs during earlier years. Also, the nominal water-production value makes no distinction of time and allows year 1 (after construction) to have the same impact as year 50. Also, note the 'NPV of Total Cost Stream' values are positive. This infers net costs will be incurred and no off-setting revenues, 'credits,' or positive externalities exist which could exceed the costs; i.e., a negative NPV of total costs would infer a net profit.

[36] 'Delivery' is to a point within the municipal delivery-system infrastructure, not household delivery.

Table 7. Aggregate Baseline Results for Production and Costs for the Seven Facility Segments of the Southmost Desalination Facility, in 2006 Dollars. [a]

| Results | Units | Nominal Value | Real Value [b] |
|---|---|---|---|
| **Initial Facility Costs** | 2006 dollars | $26,190,993 | $26,190,993 |
| **Water Production** | ac-ft (lifetime) | 285,637 | 118,002 |
| - annuity equivalent [c] | ac-ft/year | | 5,459 |
| **Water Production** | 1,000-gal (lifetime) | 93,075,000 | 38,451,045 |
| - annuity equivalent [c] | 1,000-gal/year | | 1,778,701 |
| **NPV of Total Cost Stream** [d] | 2006 dollars | $195,914,480 | $65,281,089 |
| - annuity equivalent [c] | $/year | | $4,201,075 |
| *Cost-of-Producing & Delivering Water* [e] | $/ac-ft/year | | $769.62 |
| *Cost-of-Producing & Delivering Water* [e] | $/1,000-gal/year | | $2.3619 |

[a] These baseline results reflect the Southmost facility in its current operating state (i.e., 68% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are included, and a net salvage value of zero dollars is recorded for all capital assets).

[b] Determined using a 2.043% compound rate and a 6.125% discount factor for dollars, and a 4.000% discount factor for water.

[c] Basis 2006.

[d] These are the total net cost stream values (nominal and real) relevant to producing RO-desalinated water for the life of the facility as they include initial capital-investment costs, increased O&M and capital replacement expenses, and ignore any value (or sales revenue) of the final water product.

[e] Delivery is to a point within the municipal delivery-system infrastructure, not household delivery.

## Results – by Facility Segment

DESAL ECONOMICS© uniquely analyzes and provides comparable life-cycle costs (e.g., $/ac-ft/year) for up to twelve individual functional expense areas and for the entire facility. Here, the above aggregate cost-of-producing (and delivering to a point in the municipal delivery-system infrastructure) water of $769.62 (**Table 7**) is dissected into the seven functional expense areas detailed earlier.[37]

**Table 8** shows the NPV of the net cost stream to range from a low of $137,325 for *Concentrate Discharge*, to a high of $32,247,556 for the *Main Facility*. These values signify the relative impact individual components' initial construction and future O&M costs have on costs for the total desalination facility. Also in **Table 8**, the annuity equivalent values are provided for individual components, which range from $8,837/year for *Concentrate Discharge*, to a high of $2,075,247/year for the *Main Facility*. These values are interpreted as the

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[37] DESAL ECONOMICS© can analyze up to twelve individual expense areas. For this analysis, however, only seven individual expense areas were present (and modeled). Other expense areas could be included (e.g., an integrated and dedicated power source such as wind turbine or solar-panel structure, or some other distinguishable functional area not present at the Southmost facility).

annualized costs for each component, inclusive of all life-cycle costs and reported in 2006 dollars (Rister et al. 2009).

A further delineation of the annuity equivalents reveals the economic and financial life-cycle costs range from $24/day for the *Concentrate Discharge* segment, to a high of $5,686/day for the *Main Facility*. The total life-cycle cost for all seven segments equates to $11,510/day. Again, these are the total daily life-cycle costs, reported in 2006 dollars (Rister et al. 2009).

Key annualized cost results presented in **Table 8** are the segmented costs-of-producing water for the seven individual facility components. This table reveals a range in facility segments' cost-of-producing-water values from a low of $1.62/ac-ft/year {$0.0050/1,000-gallons/year} for *Concentrate Discharge*, to a high of $380.18/ac-ft/year {$1.1667/1,000-gallons/year} for the *Main Facility*. In both the aggregate and segmented form, the total annual cost-of-producing water at the Southmost facility and delivering it on a f.o.b. basis to the municipal delivery point is $769.62 per ac-ft {$2.3619 per 1,000 gallons} (**Tables 7** and **8**).

Table 8. Costs of Producing (and Delivering) Water for the Seven Facility Segments of the Southmost Desalination Facility, in 2006 Dollars. [a, b]

| | | ---------- Annuity Equivalents ---------- | | | | |
|---|---|---|---|---|---|---|
| Facility Segment | NPV of Cost Stream [c] | ($/yr) [d] | ($/day) [d] | $/ac-ft/year [e] | $/1,000-gals/year [e] | % of Total Cost |
| 1) Well Field | $17,004,809 | $1,094,321 | $2,998 | $200.48 | $0.6152 | 26.0% |
| 2) Intake Pipeline | $2,068,143 | $133,092 | $365 | $24.38 | $0.0748 | 3.2% |
| 3) Main Facility | $32,247,556 | $2,075,247 | $5,686 | $380.18 | $1.1667 | 49.4% |
| 4) Concentrate Discharge | $137,325 | $8,837 | $24 | $1.62 | $0.0050 | 0.2% |
| 5) Finished Water Line & Tank Storage | $2,418,178 | $155,619 | $426 | $28.51 | $0.0875 | 3.7% |
| 6) Delivery Pipeline | $5,569,592 | $358,423 | $982 | $65.66 | $0.2015 | 8.5% |
| 7) Overbuilds & Upgrades | $5,835,486 | $375,535 | $1,029 | $68.80 | $0.2111 | 8.9% |
| TOTAL | $65,281,089 | $4,201,075 | $11,510 | $769.62 | $2.3619 | 100.0% |

[a] These baseline results reflect the Southmost facility in its current operating state (i.e., 68% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are included, and a net salvage value of zero dollars is recorded for all capital assets).

[b] Delivery is to a point in the municipal delivery-system infrastructure, not individual household delivery.

[c] Total costs (in 2006 dollars) throughout the facility's life of producing and delivering RO-desalinated water to a point in the municipal delivery-system infrastructure.

[d] Total costs for ownership and operations, stated in 2006 dollars, and the annuity values for the first column entitled 'NPV of Cost Stream.'

[e] Total 'annualized costs' on a per ac-ft basis (or $/1,000-gals) for each segment.

The proportions of annual cost-of-producing desalinated water at the Southmost facility are depicted for the seven functional areas in **Figure 4**. The respective percentages are those reported in **Table 8**. The most significant segment of the Southmost facility is the *Main Facility*, which contributes 49.4% of the total life-cycle cost. The *Concentrate Discharge* segment constitutes the lowest portion, representing only 0.2% of all life-cycle costs.

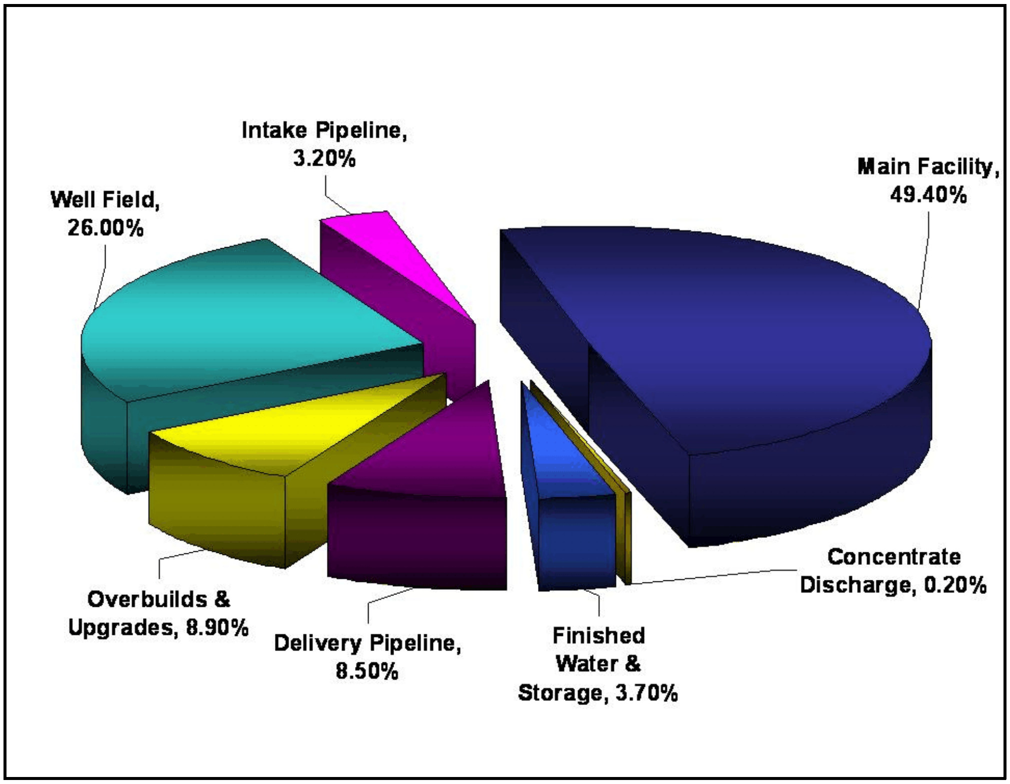

Figure 4. Proportion of Total Life-Cycle Cost, by Segment, for the Southmost Desalination Facility, 2006.

This analysis and presentation of segmented cost-of-producing-water results is believed to be unique among economic and financial analyses, as it goes beyond analyzing the 'bottom line' cost of an entire desalination facility. The segmenting of costs into functional areas (as is done in DESAL ECONOMICS©) allows for both single- and multi-facility analyses:

> Single-Facility Analysis: Within a single-facility analysis, the additional segmented-cost data identify the relative life-cycle costs, which can (a) highlight the need for a review assessment to see if engineering and/or construction changes could be made in a specific area to reduce the composite life-cycle cost (i.e., least-cost engineered design and/or asset configuration), and/or (b) analyze at what annual cost would a desalination-facility owner prefer to out-source a functional segment.[38]
>
> Multi-Facility Analysis: Within a multi-facility analysis, significant cost differences could occur across facilities. With a standard 'bottom line' analysis, there is no explanation as to which of the functional cost area(s) may be causing the disparity. By analyzing the individual functional cost areas, the additional detail provided can highlight the need for a review assessment to see if engineering/construction changes could be made in a specific area to reduce the composite life-cycle cost to a level observed at another similar facility.

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[38] For example, as indicated in Table 8, the *Well Field* costs $200.48 per ac-ft (2006 dollars) to buy, develop, and operate over the course of its life. If a third party were to offer to provide that same task (e.g., supply the source water at a rate based on 2006 dollars), the owner could make a comparison and evaluate the offer's soundness.

### Results – by Cost Type, Category, and Item

Also unique regarding results provided by DESAL ECONOMICS© is a presentation of life-cycle cost results differentiated by a breakdown of cost types, categories, and certain specific cost items. **Tables 9a-9c** provide a progression of interrelated results, whose successive presentation gives an increasing concentration of scope.

As revealed in **Table 8**, the total net costs (in 2006 dollars) of producing and delivering RO-desalinated water (by segment) amount to $65,281,089 over the facility's productive life. This total can be attained by summing the net costs for *Initial Construction* ($26,190,993), *Continued* ($35,633,597), and *Capital Replacement* ($3,456,499) (**Table 9a**). The summed total of $65,281,089 is the estimated total amount of money which will be invested and spent on the desalination facility over the course of its life-cycle, expressed in 2006 dollars.

Within **Table 9a**, the $35,633,597 of *Continued* costs are segmented into the two detailed *Administrative* ($1,696,838) and *O&M* ($33,936,759) cost categories. Again, in successive detail of scope, the $33,936,759 in *O&M* costs are dissected into the four detailed *Energy* ($16,862,411), *Chemicals* ($5,090,723), *Labor* ($7,615,483), and *All Other* ($4,368,142) cost items. For each category and item, these values are the estimated total amount of money which will be invested and spent on the facility over the course of its life-cycle, in 2006 dollars.

Table 9a. Total NPV and Annuity Equivalent Costs, by Cost Type, Category, and Item for the Southmost Desalination Facility, in 2006 Dollars. [a]

| Cost Type/Category/Item | - - - - NPV of Cost Streams - - - - | | | - - - Annuity Equivalent Costs - - - | | |
|---|---|---|---|---|---|---|
| | “**Total** Life-Cycle Costs” [b] | | | “**Annual** Life-Cycle Costs” [b] | | |
| | O&M | Continued | Total | O&M | Continued | Total |
| Initial Construction | | | $26,190,993 | | | $1,685,486 |
| Continued [c] | | | $35,633,597 | | | $2,293,151 |
| » Administrative | | $1,696,838 | | | $109,198 | |
| » O&M | | $33,936,759 | | | $2,183,954 | |
| • Energy | $16,862,411 | | | $1,085,157 | | |
| • Chemicals | $5,090,723 | | | $327,607 | | |
| • Labor | $7,615,483 | | | $490,084 | | |
| • All Other | $4,368,142 | | | $281,106 | | |
| Capital Replacement | | | $3,456,499 | | | $222,438 |
| TOTAL | $33,936,759 | $35,633,597 | $65,281,089 | $2,183,954 | $2,293,151 | $4,201,075 |

[a] These baseline results reflect the Southmost facility in its current operating state (i.e., 68% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are included, and a net salvage value of zero dollars is recorded for all capital assets).

[b] Basis 2006 dollars.

[c] “Administrative” costs are incurred by the Brownsville Public Utilities Board in association with the Southmost facility, while “Operation & Maintenance (O&M)” costs are incurred at the facility.

**Table 9a** indicates that significant costs, beyond those of *Initial Construction*, are associated with desalination. For this facility, when a commitment was made to build a facility for $26,190,993, an implicit commitment for an additional $39,090,096 (i.e., $65,281,089 - $26,190,993) (basis 2006 dollars) was also made for *Continued* and *Capital Replacement* costs.

In similar fashion, the associated annuity equivalent costs (or annual life-cycle costs, or “annualized” costs) for the NPV of Cost Stream are presented for each cost type, category, and item on the right-hand portion of **Table 9a**. Here, the “annualized” costs (which are calculated using annuity equivalent measures) are shown to total $4,201,075, with *Initial Construction* costs constituting $1,685,486 of that total. The largest proportion is derived from *Continued* costs of $2,293,151, while *Capital Replacement* costs contribute $222,438 to the annual economic and financial costs. Again, successive cost detail, as explained for NPV of Cost Streams in the preceding two paragraphs, applies.

The successive continuation of results in **Table 9a** is further developed in **Table 9b** where annuity equivalent (“annualized”) costs are presented on a per unit basis for both *$/ac-ft/year* and *$/1,000-gal/year* measures. As per **Tables 7** and **8**, the total annual life-cycle costs are $769.62 per ac-ft and $2.3619 per 1,000-gallons. As per the left-portion of **Table 9b**, the per ac-ft life-cycle cost is dissected into *Initial Construction* ($308.77/ac-ft/year), *Continued* ($420.10/ac-ft/year), and *Capital Replacement* ($40.75/ac-ft/year) cost types, summing to an annual per ac-ft cost of $769.62. This is the estimated total amount of money which will be invested and spent annually (per ac-ft) to produce and deliver (to a point within the municipal delivery-system infrastructure) desalinated water from the Southmost facility over the course of its life-cycle, expressed in 2006 dollars. Successive detail for annual per ac-ft life-cycle costs, by cost category and cost item, is found on the left-side portion of **Table 9b**.

The right-side portion of **Table 9b** provides the same type of detailed cost information as discussed in the previous paragraph, but on a dollars per 1,000-gallon basis. The successive and progressive presentation of more detailed results concludes in **Table 9c** where the proportions of per-unit annual life-cycle costs (i.e., $/ac-ft/year and $/1,000-gal/year) are provided for the various cost types, categories, and items.

An earlier comment regarding results in **Table 9a** noted that “*... significant costs, beyond those of Initial Construction, are involved with desalination*,” with supporting dollar values indicating the $26,190,993 in *Initial Construction* as being only a partial consideration of the total $65,281,089 in total life-cycle costs for the Southmost facility. As displayed in **Table 9c** below, *Initial Construction* costs constitute an estimated 40% of the total amount of money (basis 2006 dollars) which will be invested and spent on the desalination facility over the course of its life-cycle. Again, the proportion of *Continued* costs which amount to 55% is derived by *Administrative* (3%) and *O&M* (52%) cost proportions. The *O&M* costs consist of 26% *Energy*, 8% *Chemical*, 12% *Labor*, and 18% *All Other* (**Table 9c**). In total, *non-Initial Construction Costs* constitute 60% of the Southmost desalination facility’s total life-cycle cost.

Table 9b. Life-Cycle (Annuity Equivalent) Costs – $/ac-ft/year and $/1,000-gal/year, by Cost Type, Category, and Item for the Southmost Desalination Facility, in 2006 Dollars. [a]

| Cost Type/Category/Item | Annuity Equivalent Costs [b]<br>$/ac-ft/year<br>O&M | <br><br>Continued | <br><br>Total | <br>$/1,000-gal/year<br>O&M | <br><br>Continued | <br><br>Total |
|---|---|---|---|---|---|---|
| Initial Construction | | | $308.77 | | | $0.9476 |
| Continued [c] | | | $420.10 | | | $1.2892 |
| » Administrative | | $20.00 | | | $0.0614 | |
| » O&M | | $400.10 | | | $1.2278 | |
| • Energy | $198.80 | | | $0.6101 | | |
| • Chemicals | $60.02 | | | $0.1842 | | |
| • Labor | $89.78 | | | $0.2755 | | |
| • All Other | $51.50 | | | $0.1580 | | |
| Capital Replacement | | | $40.75 | | | $0.1251 |
| TOTAL | $400.10 | $420.10 | $769.62 | $1.2278 | $1.2892 | $2.3619 |

[a] These baseline results reflect the Southmost facility in its current operating state (i.e., 68% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are included, and a net salvage value of zero dollars is recorded for all capital assets).

[b] Basis 2006 dollars.

[c] "Administrative" costs are incurred by the Brownsville Public Utilities Board in association with the Southmost facility, while "Operations & Maintenance (O&M)" costs are incurred at the facility.

Table 9c. Percentage of Life-Cycle Costs, by Cost Type, Category, and Item for the Southmost Desalination Facility, 2006.

| Cost Type/Category/Item | % of Life-Cycle Costs<br>O&M | <br>Continued | <br>Total |
|---|---|---|---|
| Initial Construction | | | 40 % |
| Continued | | | 55 % |
| » Administrative | | 3 % | |
| » O&M | | 52 % | |
| • Energy | 26 % | | |
| • Chemicals | 8 % | | |
| • Labor | 12 % | | |
| • All Other | 7 % | | |
| Capital Replacement | | | 5 % |
| TOTAL | 52 % | 55 % | 100 % |

## Results – Key Sensitivity Analyses

The baseline results presented above are deterministic (i.e., absent stochastic elements, or risk considerations in the data input) and are based on specific values for:

(1) actual construction costs,
(2) estimated future years' continued costs (based on FY 2004-2005 as a proxy adjusted to FY 2006, with increases for higher energy and chemical expenses, and assumed 2.0+% inflation),
(3) estimated future years' capital replacement costs (based on 2006 dollars and 2.0+% inflation, and estimated replacement-period occurrences), and
(4) assumed discount rates of 6.125% for dollars and 4.000% for water.

Having data input which are absent stochastic elements does not negate the usefulness of the baseline results. It only means the baseline results are point estimates and, given inexactness in data input, baseline results are not expected to be exactly precise. Further, given the likely range in values for input parameters, a range in results also probably exists. To further the deterministic results presented above, the two-way Data Table feature of Excel® (Walkenbach, pp. 570-7 1996) is used to provide sensitivity analyses on the cost-of-producing (and delivering) water by varying two parameters and leaving all others constant at the levels used in the baseline analysis. Such actions facilitate testing of the stability (or instability) various data input have upon the results.

Most data-input parameters in this analysis are technically suitable for sensitivity analyses. For practical reasons, however, an abridged analysis of sensitivities is investigated and presented. Those input parameters presented are chosen for their likelihood of displaying significantly different results with slight-to-modest changes. Sensitivity results are provided in pairs of tables, where the "a" table depicts annual results on a \$/ac-ft/year basis, while the "b" table depicts equivalent results on a \$/1,000-gallon/year basis (**Tables 10a-16b**).

**Tables 10a-b** test the sensitivities across plausible ranges for the **facility's expected useful life** and the **production efficiency rate**. Changes to the expected useful life of 50 years are tested with minus (-) 5-year, 10-year, 15-year, 20-year, 25-year and 30-year variations, while the production efficiency rate is analyzed with variations ranging from a low of 60% to a high of 100% (inclusive of the baseline 68%). Using these variation ranges, sensitivity results for these two data show the annual cost of producing (and delivering) desalinated water ranges from \$610.30 to \$897.99 per ac-ft in **Table 10a**, and from \$1.8730 to \$2.7558 per 1,000 gallons in **Table 10b**. As expected, higher production efficiency rates contribute to lower cost-of-producing-water estimates. The impact that length of useful life has depends upon the number of expected useful years; i.e., for useful lives lasting 35 to 50 years, the costs are essentially the same, while useful lives shorter than 35 years tend to increase the costs of producing and delivering desalinated water. The key factor affecting this is the timing of capital replacement costs within the specified useful lives.

**Tables 11a-b** test the sensitivities across plausible ranges for **initial construction costs** and the **production efficiency rate**. Changes about the baseline initial construction costs of \$26,190,993 are tested with +/- \$1.0-million, \$2.5-million, and \$5.0-million variations, while the production efficiency rate is analyzed with variations ranging from a low of 60% to a high of 100% (inclusive of the baseline 68%). Using these variation ranges, sensitivity results for these two data show the annual cost of producing (and delivering) desalinated water ranges from $570.22 to $902.81 per ac-ft in **Table 11a**, and from $1.7499 to $2.7706 per 1,000 gallons in **Table 11b**. As expected, higher production efficiency rates and lower initial construction costs contribute to lower cost-of-producing-water estimates, and vice versa.

**Tables 12a-b** test the sensitivities across plausible ranges for **annual O&M costs** and the **production efficiency rate**. Changes about the baseline annual O&M costs of $1,725,101 are tested with +/- 10%, 20%, and 30% variations, while the production efficiency rate is analyzed with variations ranging from a low of 60% to a high of 100% (inclusive of the baseline 68%). Using these variation ranges, sensitivity results for these two data show the annual cost of producing (and delivering) desalinated water range from $494.79 to $976.13 per ac-ft in **Table 12a**, and from $1.5185 to $2.9956 per 1,000 gallons in **Table 12b**. As expected, higher production efficiency rates and lower annual O&M costs contribute to lower cost-of-producing-water estimates, and vice versa.

**Tables 13a-b** test the sensitivities across plausible ranges for **annual energy costs** and the **production efficiency rate**. Changes about the baseline annual energy costs of $816,347 are tested with +/- 5%, 10%, and 20% variations, while the production efficiency rate is analyzed with variations ranging from a low of 60% to a high of 100% (inclusive of the baseline 68%). Using these variation ranges, sensitivity results for these two data show the annual cost of producing (and delivering) desalinated water range from $568.56 to $877.75 per ac-ft in **Table 13a**, and from $1.7448 to $2.6937 per 1,000 gallons in **Table 13b**. As expected, higher production efficiency rates and lower energy costs contribute to lower cost-of-producing-water estimates, and vice versa.

**Tables 14a-b** test the sensitivities across plausible ranges for **annual chemical costs** and the **production efficiency rate**. Changes about the baseline annual chemical costs of $246,453 are tested with +/- 5%, 10%, and 20% variations, while the production efficiency rate is analyzed with variations ranging from a low of 60% to a high of 100% (inclusive of the baseline 68%). Using these variation ranges, sensitivity results for these two data show the annual cost of producing (and delivering) desalinated water range from $597.70 to $848.61 per ac-ft in **Table 14a**, and from $1.8343 to $2.6043 per 1,000 gallons in **Table 14b**. As expected, higher production efficiency rates and lower chemical costs contribute to lower cost-of-producing-water estimates, and vice versa.

**Tables 15a-b** test the sensitivities across plausible ranges for **capital replacement costs for RO membranes** and the **production efficiency rate**. Changes about the baseline capital replacement cost for RO membranes of $700,000 are tested with +/- $50,000, $75,000, and $100,000 variations, while the production efficiency rate is analyzed with variations ranging from a low of 60% to a high of 100% (inclusive of the baseline 68%). Using these variation ranges, sensitivity results for these two data show the annual cost of producing (and delivering) desalinated water range from $607.84 to $840.11 per ac-ft in **Table 15a**, and from $1.8654 to $2.5782 per 1,000 gallons in **Table 15b**. As expected, higher production efficiency rates and lower capital replacement costs contribute to lower cost-of-producing-water estimates, and vice versa.

**Tables 16a-b** test the sensitivities across plausible ranges for **capital replacement periods for RO membranes** and the **production efficiency rate**. Changes about the baseline capital replacement period for RO membranes of once every six (6) years is tested with +/- 1-year, 2-year, and 3-year variations, while the production efficiency rate is analyzed with variations ranging from a low of 60% to a high of 100% (inclusive of the baseline 68%). Using these variation ranges, sensitivity results for these two data show the annual cost of producing (and delivering) desalinated water range from \$603.63 to \$868.33 per ac-ft in **Table 16a**, and from \$1.8525 to \$2.6648 per 1,000 gallons in **Table 16b**. As expected, higher production efficiency rates and less-frequent capital replacement periods contribute to lower cost-of-producing-water estimates, and vice versa.

Table 10a. Sensitivity Analysis of Annual Costs-of-Producing Water at the Southmost Desalination Facility ($/ac-ft), by Variations in Expected Useful Life and Production Efficiency Rate, in 2006 Dollars.

| | | Annual Production Efficiency Rate (% of current maximum design) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 60% | 65% | **68%** | 70% | 80% | 85% | 90% | 95% | 100% |
| | | Annual Water Production (ac-ft) – ($ per acre-foot, per year) | | | | | | | | |
| | | 5,041 | 5,461 | **5,713** | 5,881 | 6,721 | 7,141 | 7,561 | 7,981 | 8,401 |
| Expected Useful Life (years) | 20 | $897.99 | $847.03 | $820.04 | $803.34 | $732.35 | $703.12 | $677.13 | $653.88 | $632.96 |
| | 25 | $864.62 | $816.81 | $791.50 | $775.83 | $709.23 | $681.81 | $657.43 | $635.62 | $615.99 |
| | 30 | $847.80 | $801.81 | $777.47 | $762.40 | $698.36 | $671.98 | $648.54 | $627.57 | $608.69 |
| | 35 | $836.70 | $792.07 | $768.43 | $753.80 | $691.63 | $666.03 | $643.27 | $622.91 | $604.58 |
| | 40 | $834.34 | $790.32 | $767.02 | $752.60 | $691.29 | $666.04 | $643.60 | $623.52 | $605.45 |
| | 45 | $834.61 | $790.97 | $767.86 | $753.56 | $692.77 | $667.74 | $645.49 | $625.58 | $607.66 |
| | **50** | $836.00 | $792.60 | **$769.62** | $755.40 | $694.94 | $670.05 | $647.92 | $628.12 | $610.30 |

Table 10b. Sensitivity Analysis of Annual Costs-of-Producing Water at the Southmost Desalination Facility ($/1,000 gallons), by Variations in Expected Useful Life and Production Efficiency Rate, in 2006 Dollars.

| | | Annual Production Efficiency Rate (% of current maximum design) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 60% | 65% | **68%** | 70% | 80% | 85% | 90% | 95% | 100% |
| | | Annual Water Production (1,000 gal) – ($ per 1,000-gallons, per year) | | | | | | | | |
| | | 1,642,500 | 1,779,375 | **1,861,500** | 1,916,250 | 2,190,000 | 2,326,875 | 2,463,750 | 2,600,625 | 2,737,500 |
| Expected Useful Life (years) | 20 | $2.7558 | $2.5994 | $2.5166 | $2.4654 | $2.2475 | $2.1578 | $2.0780 | $2.0067 | $1.9425 |
| | 25 | $2.6534 | $2.5067 | $2.4290 | $2.3809 | $2.1765 | $2.0924 | $2.0176 | $1.9506 | $1.8904 |
| | 30 | $2.6018 | $2.4607 | $2.3860 | $2.3397 | $2.1432 | $2.0622 | $1.9903 | $1.9259 | $1.8680 |
| | 35 | $2.5678 | $2.4308 | $2.3582 | $2.3133 | $2.1225 | $2.0440 | $1.9741 | $1.9116 | $1.8554 |
| | 40 | $2.5605 | $2.4254 | $2.3539 | $2.3096 | $2.1215 | $2.0440 | $1.9751 | $1.9135 | $1.8581 |
| | 45 | $2.5613 | $2.4274 | $2.3565 | $2.3126 | $2.1260 | $2.0492 | $1.9809 | $1.9198 | $1.8648 |
| | **50** | $2.5656 | $2.4324 | **$2.3619** | $2.3182 | $2.1327 | $2.0563 | $1.9884 | $1.9276 | $1.8730 |

Table 11a. Sensitivity Analysis of Annual Costs-of-Producing Water at the Southmost Desalination Facility ($/ac-ft), by Variations in Initial Construction Costs and Production Efficiency Rate, in 2006 Dollars.

| | | Annual Production Efficiency Rate (% of current maximum design) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 60% | 65% | **68%** | 70% | 80% | 85% | 90% | 95% | 100% |
| | | Annual Water Production (ac-ft) – ($ per acre-foot, per year) | | | | | | | | |
| | | 5,041 | 5,461 | **5,713** | 5,881 | 6,721 | 7,141 | 7,561 | 7,981 | 8,401 |
| Initial Construction Costs ($'s) | ($5,000,000) | $769.20 | $730.93 | $710.67 | $698.13 | $644.84 | $622.89 | $603.38 | $585.93 | $570.22 |
| | ($2,500,000) | $802.60 | $761.77 | $740.15 | $726.76 | $669.89 | $646.47 | $625.65 | $607.02 | $590.26 |
| | ($1,000,000) | $822.64 | $780.27 | $757.83 | $743.94 | $684.92 | $660.62 | $639.01 | $619.68 | $602.29 |
| | **$26,190,993** | $836.00 | $792.60 | **$769.62** | $755.40 | $694.94 | $670.05 | $647.92 | $628.12 | $610.30 |
| | $1,000,000 | $849.36 | $804.93 | $781.41 | $766.85 | $704.96 | $679.48 | $656.83 | $636.56 | $618.32 |
| | $2,500,000 | $869.41 | $823.43 | $799.09 | $784.03 | $719.99 | $693.63 | $670.19 | $649.22 | $630.34 |
| | $5,000,000 | $902.81 | $854.27 | $828.57 | $812.66 | $745.04 | $717.20 | $692.46 | $670.31 | $650.39 |

Table 11b. Sensitivity Analysis of Annual Costs-of-Producing Water at the Southmost Desalination Facility ($/1,000 gallons), by Variations in Initial Construction Costs and Production Efficiency Rate, in 2006 Dollars.

| | | Annual Production Efficiency Rate (% of current maximum design) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 60% | 65% | **68%** | 70% | 80% | 85% | 90% | 95% | 100% |
| | | Annual Water Production (1,000 gal) – ($ per 1,000-gallons, per year) | | | | | | | | |
| | | 1,642,500 | 1,779,375 | **1,861,500** | 1,916,250 | 2,190,000 | 2,326,875 | 2,463,750 | 2,600,625 | 2,737,500 |
| Initial Construction Costs ($'s) | ($5,000,000) | $2.3606 | $2.2431 | $2.1810 | $2.1425 | $1.9789 | $1.9116 | $1.8517 | $1.7981 | $1.7499 |
| | ($2,500,000) | $2.4631 | $2.3378 | $2.2714 | $2.2304 | $2.0558 | $1.9839 | $1.9201 | $1.8629 | $1.8114 |
| | ($1,000,000) | $2.5246 | $2.3945 | $2.3257 | $2.2831 | $2.1019 | $2.0274 | $1.9611 | $1.9017 | $1.8483 |
| | **$26,190,993** | $2.5656 | $2.4324 | **$2.3619** | $2.3182 | $2.1327 | $2.0563 | $1.9884 | $1.9276 | $1.8730 |
| | $1,000,000 | $2.6066 | $2.4702 | $2.3981 | $2.3534 | $2.1634 | $2.0852 | $2.0157 | $1.9535 | $1.8976 |
| | $2,500,000 | $2.6681 | $2.5270 | $2.4523 | $2.4061 | $2.2096 | $2.1287 | $2.0567 | $1.9924 | $1.9345 |
| | $5,000,000 | $2.7706 | $2.6216 | $2.5428 | $2.4940 | $2.2865 | $2.2010 | $2.1251 | $2.0571 | $1.9960 |

Table 12a. Sensitivity Analysis of Annual Costs-of-Producing Water at the Southmost Desalination Facility ($/ac-ft), by Variations in Annual O&M Costs and Production Efficiency Rate, in 2006 Dollars.

| | | Annual Production Efficiency Rate (% of current maximum design) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 60% | 65% | **68%** | 70% | 80% | 85% | 90% | 95% | 100% |
| | | Annual Water Production (ac-ft) – ($ per acre-foot, per year) | | | | | | | | |
| | | 5,041 | 5,461 | **5,713** | 5,881 | 6,721 | 7,141 | 7,561 | 7,981 | 8,401 |
| Annual O&M Costs ($'s) | -30% | $699.64 | $660.25 | $639.39 | $626.48 | $571.61 | $549.01 | $528.93 | $510.96 | $494.79 |
| | -20% | $744.68 | $703.96 | $682.40 | $669.06 | $612.34 | $588.99 | $568.23 | $549.65 | $532.94 |
| | -10% | $790.13 | $748.07 | $725.81 | $712.03 | $653.45 | $629.33 | $607.89 | $588.71 | $571.44 |
| | **$1,725,101** | $836.00 | $792.60 | **$769.62** | $755.40 | $694.94 | $670.05 | $647.92 | $628.12 | $610.30 |
| | +10% | $882.29 | $837.53 | $813.83 | $799.16 | $736.81 | $711.13 | $688.31 | $667.89 | $649.52 |
| | +20% | $929.00 | $882.87 | $858.44 | $843.32 | $779.06 | $752.59 | $729.07 | $708.03 | $689.09 |
| | +30% | $976.13 | $928.61 | $903.45 | $887.88 | $821.68 | $794.43 | $770.20 | $748.52 | $729.01 |

Table 12b. Sensitivity Analysis of Annual Costs-of-Producing Water at the Southmost Desalination Facility ($/1,000 gallons), by Variations in Annual O&M Costs and Production Efficiency Rate, in 2006 Dollars.

| | | Annual Production Efficiency Rate (% of current maximum design) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 60% | 65% | **68%** | 70% | 80% | 85% | 90% | 95% | 100% |
| | | Annual Water Production (1,000 gal) – ($ per 1,000-gallons, per year) | | | | | | | | |
| | | 1,642,500 | 1,779,375 | **1,861,500** | 1,916,250 | 2,190,000 | 2,326,875 | 2,463,750 | 2,600,625 | 2,737,500 |
| Annual O&M Costs ($'s) | -30% | $2.1471 | $2.0262 | $1.9622 | $1.9226 | $1.7542 | $1.6849 | $1.6232 | $1.5681 | $1.5185 |
| | -20% | $2.2853 | $2.1604 | $2.0942 | $2.0533 | $1.8792 | $1.8075 | $1.7438 | $1.6868 | $1.6355 |
| | -10% | $2.4248 | $2.2958 | $2.2274 | $2.1851 | $2.0054 | $1.9313 | $1.8655 | $1.8067 | $1.7537 |
| | **$1,725,101** | $2.5656 | $2.4324 | **$2.3619** | $2.3182 | $2.1327 | $2.0563 | $1.9884 | $1.9276 | $1.8730 |
| | +10% | $2.7077 | $2.5703 | $2.4976 | $2.4525 | $2.2612 | $2.1824 | $2.1124 | $2.0497 | $1.9933 |
| | +20% | $2.8510 | $2.7094 | $2.6345 | $2.5881 | $2.3908 | $2.3096 | $2.2374 | $2.1729 | $2.1147 |
| | +30% | $2.9956 | $2.8498 | $2.7726 | $2.7248 | $2.5217 | $2.4380 | $2.3637 | $2.2971 | $2.2373 |

Table 13a. Sensitivity Analysis of Annual Costs-of-Producing Water at the Southmost Desalination Facility ($/ac-ft), by Variations in Annual Energy Costs and Production Efficiency Rate, in 2006 Dollars.

| | | Annual Production Efficiency Rate (% of current maximum design) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 60% | 65% | **68%** | 70% | 80% | 85% | 90% | 95% | 100% |
| | | Annual Water Production (ac-ft) – ($ per acre-foot, per year) | | | | | | | | |
| | | 5,041 | 5,461 | **5,713** | 5,881 | 6,721 | 7,141 | 7,561 | 7,981 | 8,401 |
| Annual Energy Costs ($/year) | -20% | $794.26 | $750.85 | $727.87 | $713.65 | $653.19 | $628.30 | $606.17 | $586.37 | $568.56 |
| | -10% | $815.13 | $771.73 | $748.75 | $734.52 | $674.07 | $649.17 | $627.05 | $607.25 | $589.43 |
| | -5% | $825.57 | $782.16 | $759.18 | $744.96 | $684.50 | $659.61 | $637.48 | $617.68 | $599.87 |
| | **$816,347** | $836.00 | $792.60 | **$769.62** | $755.40 | $694.94 | $670.05 | $647.92 | $628.12 | $610.30 |
| | +5% | $846.44 | $803.04 | $780.06 | $765.83 | $705.38 | $680.48 | $658.36 | $638.56 | $620.74 |
| | +10% | $856.88 | $813.47 | $790.49 | $776.27 | $715.81 | $690.92 | $668.79 | $648.99 | $631.18 |
| | +20% | $877.75 | $834.35 | $811.37 | $797.14 | $736.69 | $711.79 | $689.67 | $669.87 | $652.05 |

Table 13b. Sensitivity Analysis of Annual Costs-of-Producing Water at the Southmost Desalination Facility ($/1,000 gallons), by Variations in Annual Energy Costs and Production Efficiency Rate, in 2006 Dollars.

| | | Annual Production Efficiency Rate (% of current maximum design) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 60% | 65% | **68%** | 70% | 80% | 85% | 90% | 95% | 100% |
| | | Annual Water Production (1,000 gal) – ($ per 1,000-gallons, per year) | | | | | | | | |
| | | 1,642,500 | 1,779,375 | **1,861,500** | 1,916,250 | 2,190,000 | 2,326,875 | 2,463,750 | 2,600,625 | 2,737,500 |
| Annual Energy Costs ($/year) | -20% | $2.4375 | $2.3043 | $2.2338 | $2.1901 | $2.0046 | $1.9282 | $1.8603 | $1.7995 | $1.7448 |
| | -10% | $2.5015 | $2.3683 | $2.2978 | $2.2542 | $2.0686 | $1.9922 | $1.9243 | $1.8636 | $1.8089 |
| | -5% | $2.5336 | $2.4004 | $2.3298 | $2.2862 | $2.1007 | $2.0243 | $1.9564 | $1.8956 | $1.8409 |
| | **$816,347** | $2.5656 | $2.4324 | **$2.3619** | $2.3182 | $2.1327 | $2.0563 | $1.9884 | $1.9276 | $1.8730 |
| | +5% | $2.5976 | $2.4644 | $2.3939 | $2.3503 | $2.1647 | $2.0883 | $2.0204 | $1.9597 | $1.9050 |
| | +10% | $2.6297 | $2.4965 | $2.4259 | $2.3823 | $2.1968 | $2.1204 | $2.0525 | $1.9917 | $1.9370 |
| | +20% | $2.6937 | $2.5605 | $2.4900 | $2.4463 | $2.2608 | $2.1844 | $2.1165 | $2.0558 | $2.0011 |

Table 14a. Sensitivity Analysis of Annual Costs-of-Producing Water at the Southmost Desalination Facility ($/ac-ft), by Variations in Annual Chemical Costs and Production Efficiency Rate, in 2006 Dollars.

| | | Annual Production Efficiency Rate (% of current maximum design) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 60% | 65% | **68%** | 70% | 80% | 85% | 90% | 95% | 100% |
| | | Annual Water Production (ac-ft) – ($ per acre-foot, per year) | | | | | | | | |
| | | 5,041 | 5,461 | **5,713** | 5,881 | 6,721 | 7,141 | 7,561 | 7,981 | 8,401 |
| Annual Chemical Costs ($/year) | -20% | $823.40 | $780.00 | $757.02 | $742.79 | $682.34 | $657.44 | $635.32 | $615.52 | $597.70 |
| | -10% | $829.70 | $786.30 | $763.32 | $749.09 | $688.64 | $663.75 | $641.62 | $621.82 | $604.00 |
| | -5% | $832.85 | $789.45 | $766.47 | $752.24 | $691.79 | $666.90 | $644.77 | $624.97 | $607.15 |
| | **$246,453** | $836.00 | $792.60 | **$769.62** | $755.40 | $694.94 | $670.05 | $647.92 | $628.12 | $610.30 |
| | +5% | $839.15 | $795.75 | $772.77 | $758.55 | $698.09 | $673.20 | $651.07 | $631.27 | $613.45 |
| | +10% | $842.30 | $798.90 | $775.92 | $761.70 | $701.24 | $676.35 | $654.22 | $634.42 | $616.60 |
| | +20% | $848.61 | $805.20 | $782.22 | $768.00 | $707.54 | $682.65 | $660.52 | $640.72 | $622.91 |

Table 14b. Sensitivity Analysis of Annual Costs-of-Producing Water at the Southmost Desalination Facility ($/1,000 gallons), by Variations in Annual Chemical Costs and Production Efficiency Rate, in 2006 Dollars.

| | | Annual Production Efficiency Rate (% of current maximum design) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 60% | 65% | **68%** | 70% | 80% | 85% | 90% | 95% | 100% |
| | | Annual Water Production (1,000 gal) – ($ per 1,000-gallons, per year) | | | | | | | | |
| | | 1,642,500 | 1,779,375 | **1,861,500** | 1,916,250 | 2,190,000 | 2,326,875 | 2,463,750 | 2,600,625 | 2,737,500 |
| Annual Chemical Costs ($/year) | -20% | $2.5269 | $2.3937 | $2.3232 | $2.2795 | $2.0940 | $2.0176 | $1.9497 | $1.8890 | $1.8343 |
| | -10% | $2.5463 | $2.4131 | $2.3425 | $2.2989 | $2.1134 | $2.0370 | $1.9691 | $1.9083 | $1.8536 |
| | -5% | $2.5559 | $2.4227 | $2.3522 | $2.3086 | $2.1230 | $2.0466 | $1.9787 | $1.9180 | $1.8633 |
| | **$246,453** | $2.5656 | $2.4324 | **$2.3619** | $2.3182 | $2.1327 | $2.0563 | $1.9884 | $1.9276 | $1.8730 |
| | +5% | $2.5753 | $2.4421 | $2.3715 | $2.3279 | $2.1424 | $2.0660 | $1.9981 | $1.9373 | $1.8826 |
| | +10% | $2.5849 | $2.4517 | $2.3812 | $2.3376 | $2.1520 | $2.0756 | $2.0077 | $1.9470 | $1.8923 |
| | +20% | $2.6043 | $2.4711 | $2.4006 | $2.3569 | $2.1714 | $2.0950 | $2.0271 | $1.9663 | $1.9116 |

Table 15a. Sensitivity Analysis of Annual Costs-of-Producing Water at the Southmost Desalination Facility ($/ac-ft), by Variations in Capital Replacement Costs for RO Membranes and Production Efficiency Rate, in 2006 Dollars.

| | | Annual Production Efficiency Rate (% of current maximum design) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 60% | 65% | **68%** | 70% | 80% | 85% | 90% | 95% | 100% |
| | | Annual Water Production (ac-ft) – ($ per acre-foot, per year) | | | | | | | | |
| | | 5,041 | 5,461 | **5,713** | 5,881 | 6,721 | 7,141 | 7,561 | 7,981 | 8,401 |
| Capital Replacement Costs for RO Membranes ($/occurrence) | ($100,000) | $831.90 | $788.81 | $766.00 | $751.88 | $691.86 | $667.15 | $645.18 | $625.53 | $607.84 |
| | ($75,000) | $832.92 | $789.76 | $766.90 | $752.76 | $692.63 | $667.87 | $645.87 | $626.18 | $608.46 |
| | ($50,000) | $833.95 | $790.70 | $767.81 | $753.64 | $693.40 | $668.60 | $646.55 | $626.82 | $609.07 |
| | **$700,000** | $836.00 | $792.60 | **$769.62** | $755.40 | $694.94 | $670.05 | $647.92 | $628.12 | $610.30 |
| | $50,000 | $838.06 | $794.49 | $771.43 | $757.16 | $696.48 | $671.50 | $649.29 | $629.42 | $611.53 |
| | $75,000 | $839.08 | $795.44 | $772.34 | $758.03 | $697.25 | $672.22 | $649.97 | $630.07 | $612.15 |
| | $100,000 | $840.11 | $796.39 | $773.24 | $758.91 | $698.02 | $672.94 | $650.66 | $630.71 | $612.77 |

Table 15b. Sensitivity Analysis of Annual Costs-of-Producing Water at the Southmost Desalination Facility ($/1,000 gallons), by Variations in Capital Replacement Costs for RO Membranes and Production Efficiency Rate, in 2006 Dollars.

| | | Annual Production Efficiency Rate (% of current maximum design) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 60% | 65% | **68%** | 70% | 80% | 85% | 90% | 95% | 100% |
| | | Annual Water Production (1,000 gal) – ($ per 1,000-gallons, per year) | | | | | | | | |
| | | 1,642,500 | 1,779,375 | **1,861,500** | 1,916,250 | 2,190,000 | 2,326,875 | 2,463,750 | 2,600,625 | 2,737,500 |
| Capital Replacement Costs for RO Membranes ($/occurrence) | ($100,000) | $2.5530 | $2.4208 | $2.3508 | $2.3074 | $2.1232 | $2.0474 | $1.9800 | $1.9197 | $1.8654 |
| | ($75,000) | $2.5561 | $2.4237 | $2.3535 | $2.3101 | $2.1256 | $2.0496 | $1.9821 | $1.9217 | $1.8673 |
| | ($50,000) | $2.5593 | $2.4266 | $2.3563 | $2.3128 | $2.1280 | $2.0519 | $1.9842 | $1.9237 | $1.8692 |
| | **$700,000** | $2.5656 | $2.4324 | **$2.3619** | $2.3182 | $2.1327 | $2.0563 | $1.9884 | $1.9276 | $1.8730 |
| | $50,000 | $2.5719 | $2.4382 | $2.3674 | $2.3236 | $2.1374 | $2.0607 | $1.9926 | $1.9316 | $1.8767 |
| | $75,000 | $2.5750 | $2.4411 | $2.3702 | $2.3263 | $2.1398 | $2.0630 | $1.9947 | $1.9336 | $1.8786 |
| | $100,000 | $2.5782 | $2.4440 | $2.3730 | $2.3290 | $2.1421 | $2.0652 | $1.9968 | $1.9356 | $1.8805 |

Table 16a. Sensitivity Analysis of Annual Costs-of-Producing Water at the Southmost Desalination Facility ($/ac-ft), by Variations in Replacement Period for RO Membranes and Production Efficiency Rate, in 2006 Dollars.

| | | Annual Production Efficiency Rate (% of current maximum design) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 60% | 65% | **68%** | 70% | 80% | 85% | 90% | 95% | 100% |
| | | Annual Water Production (ac-ft) – ($ per acre-foot, per year) | | | | | | | | |
| | | 5,041 | 5,461 | **5,713** | 5,881 | 6,721 | 7,141 | 7,561 | 7,981 | 8,401 |
| Replacement Period for RO Membranes (No. of years) | -3 | $868.33 | $822.44 | $798.14 | $783.10 | $719.18 | $692.86 | $669.47 | $648.54 | $629.70 |
| | -2 | $852.15 | $807.51 | $783.87 | $769.24 | $707.05 | $681.45 | $658.69 | $638.32 | $619.99 |
| | -1 | $842.93 | $799.00 | $775.74 | $761.34 | $700.14 | $674.94 | $652.54 | $632.50 | $614.46 |
| | **6** | $836.00 | $792.60 | **$769.62** | $755.40 | $694.94 | $670.05 | $647.92 | $628.12 | $610.30 |
| | +1 | $831.57 | $788.50 | $765.71 | $751.59 | $691.61 | $666.91 | $644.96 | $625.32 | $607.64 |
| | +2 | $827.95 | $785.17 | $762.52 | $748.50 | $688.90 | $664.36 | $642.55 | $623.04 | $605.47 |
| | +3 | $824.87 | $782.33 | $759.80 | $745.86 | $686.59 | $662.19 | $640.50 | $621.09 | $603.63 |

Table 16b. Sensitivity Analysis of Annual Costs-of-Producing Water at the Southmost Desalination Facility ($/1,000 gallons), by Variations in Replacement Period for RO Membranes and Production Efficiency Rate, in 2006 Dollars.

| | | Annual Production Efficiency Rate (% of current maximum design) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 60% | 65% | **68%** | 70% | 80% | 85% | 90% | 95% | 100% |
| | | Annual Water Production (1,000 gal) – ($ per 1,000-gallons, per year) | | | | | | | | |
| | | 1,642,500 | 1,779,375 | **1,861,500** | 1,916,250 | 2,190,000 | 2,326,875 | 2,463,750 | 2,600,625 | 2,737,500 |
| Replacement Period for RO Membranes (No. of years) | -3 | $2.6648 | $2.5240 | $2.4494 | $2.4033 | $2.2071 | $2.1263 | $2.0545 | $1.9903 | $1.9325 |
| | -2 | $2.6152 | $2.4781 | $2.4056 | $2.3607 | $2.1699 | $2.0913 | $2.0214 | $1.9589 | $1.9027 |
| | -1 | $2.5869 | $2.4520 | $2.3806 | $2.3365 | $2.1486 | $2.0713 | $2.0026 | $1.9411 | $1.8857 |
| | **6** | $2.5656 | $2.4324 | **$2.3619** | $2.3182 | $2.1327 | $2.0563 | $1.9884 | $1.9276 | $1.8730 |
| | +1 | $2.5520 | $2.4198 | $2.3499 | $2.3066 | $2.1225 | $2.0467 | $1.9793 | $1.9190 | $1.8648 |
| | +2 | $2.5409 | $2.4096 | $2.3401 | $2.2970 | $2.1142 | $2.0389 | $1.9719 | $1.9120 | $1.8581 |
| | +3 | $2.5314 | $2.4009 | $2.3317 | $2.2889 | $2.1071 | $2.0322 | $1.9656 | $1.9061 | $1.8525 |

## Discussion

Desalination of seawater and brackish groundwater has historically been considered an expensive source for municipal and industrial (M&I) users, and prohibitively expensive for traditional agricultural users. Though beyond the scope of this report, such costs are purportedly decreasing (Graves and Choffel 2004). As analyzed with DESAL ECONOMICS© and reported herein, the 'costs' of a desalination facility can be segregated into several facility segments (or 'cost centers'), as well as dissected into different types, categories, and items. This capability offers additional information which can provide further insight and added value in post-construction case studies, and during the planning and design stage of future facilities.

Research and development efforts to reduce costs with improved RO membranes are key industry topics/goals. As exemplified herein, however, several cost items (e.g., concrete, energy, chemicals, membranes, administrative overhead, labor, etc.), over many years, are involved in comprising the final total life-cycle costs (i.e., NPV of cost stream) of groundwater desalination. As energy accounts for the single largest cost item (26% as per **Table 9c**), it is likely the most significant impact associated with new RO membranes may be their ability to permeate with reduced energy and less maintenance. That is, direct initial and replacement costs of RO membranes amount to a limited portion of the life-cycle NPV cost stream and should be recognized as such with regards to their relative impact upon total life-cycle costs.

Other cost-reduction activities, such as the design and 'fast track' procurement and construction management philosophy as implemented by NRS Consulting Engineers for the Southmost facility (Norris n.d.; Norris 2004) are very effective at reducing *Initial Construction* costs and the associated life-cycle NPV cost stream. As displayed in **Table 9c**, the Southmost facility has 40% of its life-cycle cost deriving from *Initial Construction* costs, and a combined 60% from *Continued* and *Capital Replacement* costs. Thus, *ceteris paribus,*[39] efforts to significantly reduce initial and/or future costs can be expected to lower life-cycle cost.

Putting it all into context, brackish groundwater desalination <u>might</u> be a more expensive alternative for communities in the Texas Lower Rio Grande Valley, but if so, it does offer a regional supply alternative which is dependable <u>and</u> provides a measure of defense against potential security-related threats.[40] There is anticipation that desalination costs will decline in future years as a result of technology development. Any future cost reductions provided by marginal membrane-technology advancements and/or engineering-related procurement and construction-management techniques may be countered, however, with higher prices for inputs such as cement, chemicals, and energy (which is observed in today's current global economic environment). That is, in absolute nominal terms, the life-cycle cost ($/ac-ft/year) of RO-desalinated water in South Texas may not decrease much, or any, in the future. What is important to measure, however, is the <u>costs</u> of RO-desalinated water <u>relative to</u> the <u>costs</u> of conventionally-treated surface water from the Rio Grande.[41]

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[39] An economic term (Latin) meaning "other (relevant) factors being equal" (Wooldridge 2006, p. 13).

[40] The modal verb "might" is used because analyses of conventional surface-water treatment costs have not yet been finalized with comparable methodology by the authors.

[41] Note the 'costs' of conventionally-treated surface water from the Rio Grande may not necessarily equal (and could be less than) the 'charges' for such water.

Finally, at the time of the decision to build the Southmost desalination facility, the northern area of Brownsville, TX (a) was experiencing rapid urban growth and drought conditions, (b) realized its geographical position as last among diverters along the Rio Grande, and (c) was faced with having to increase M&I water supplies. The principal options identified included building another surface-water treatment facility or constructing a desalination facility. The latter option was selected. The point being, if a community's water supply is limited or considered in jeopardy because of its geographic location and/or proximity to other sources, drought, etc., having potentially expensive RO-desalinated water may be better than having no water at all. If such conditions exist, the 'premium' (above that for conventionally-treated surface water) for desalinated water could be considered a 'societal insurance premium.'[42]

## Comparing Economic and Financial Results with Accounting-Based Results

These life-cycle cost results are financial and economic in nature, and will likely differ with accounting-based results.[43] Remember, both the baseline and modified results (discussed in the appendix) are put on 'annuity equivalent' (AE) measures. That is, they are adjusted for both time and inflation, and are presented on a 2006 calendar-year basis. Typical accounting approaches to calculating the annual costs of producing water involve the periodic escalation, albeit implicit, of nominal-based dollars for the various inputs. This incremental increasing of costs-of-producing happens slowly over time and can account for inflation in a non-explicit sense. That is, input costs tend to increase over time, thereby causing a ratcheting-up of the final per-unit production costs (**Figure 5**).[44]

With these AE-based results, however, inflation and other time effects are incorporated into a single value (i.e., cost), which does not need to be periodically inflated on an incremental basis to account for increasing input costs. In the case of the baseline results (i.e., life-cycle of \$769.62/ac-ft/yr, or \$2.3619/1,000 gallons/yr) (**Table 7**), the AE value can be thought of as being a constant, average amount (basis 2006 dollars) which will allow for all costs (i.e., construction, continuing, and capital replacement) to be covered (denoted by the solid, horizontal, red line in **Figure 5**). Thus, an assessment of \$769.62 (basis 2006) for each ac-ft produced, for every year of the facility's useful life, will cover the specified treatment costs, and result in a net zero-dollar profit, or a "break-even" situation.

Also differing from accounting-based results are the total dollars spent on the facility over the course of its productive life. From an accounting perspective, a total of \$195,914,480,

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[42] In this context, a societal insurance premium is the amount local stakeholders are willing to pay to insure local water supply.

[43] The *baseline* results are applicable to the 7.5 mgd Southmost facility, with the described characteristics, costs, etc., and are useful in understanding the true long-term economic and financial costs of the facility. The *modified* results (discussed in the appendix), however, have had specific input data adjusted to allow this facility's results to be compared to others'; i.e., the *modified* results are not appropriate for use in analyzing a single facility. For example, facilities operate at different production efficiency rates, thus leveling specific input data allows for fair and useful side-by-side comparisons.

[44] The *Likely Accounting Costs* depicted in **Figure 5** in the green-dashed line are based on Southmost's initial construction costs (amortized over 30 years at 5% interest) and Southmost's annual Continued Costs (inflated at a level slightly over 2%).

in nominal dollars (**Table 7**), will be spent constructing and operating the Southmost facility (i.e., from time of commencement of construction to completion of facility decommissioning). A graph representing such accounting (i.e., nominal) costs are represented by the blue vertical bars in **Figure 5**. The associated economic and financial value is $65,281,089, in real terms (**Table 7**). That is, a beginning cash balance of $65,281,089 in a banking account drawing 6.125% interest (see page 18) will provide the cash flow requirements for 'withdrawals' for construction costs and annual O&M costs and capital replacement costs (inflated 2.04% annually; see page 18), with a $0 balance left over at the end of the 50 years of useful life.

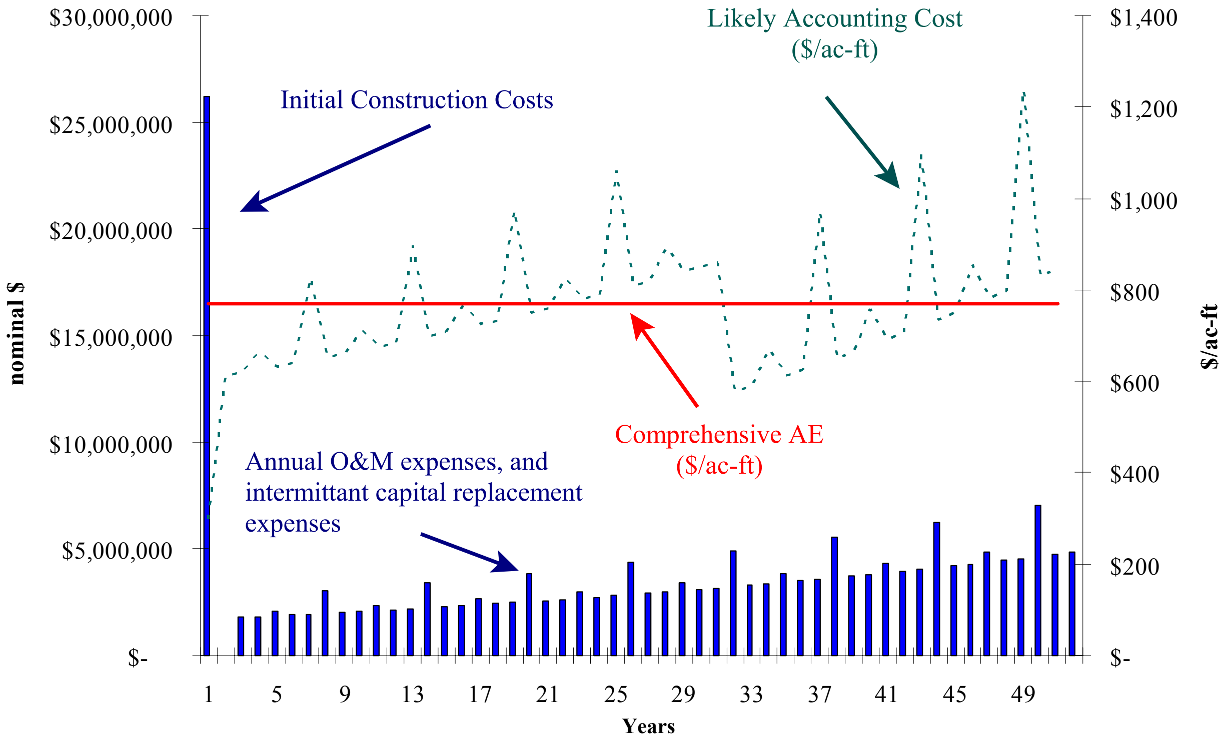

Figure 5. Depiction of Annual Cash Flow Requirements (Nominal Dollars), Likely Accounting Costs per acre-foot, and Comprehensive Annuity Equivalent (AE) Cost for the Southmost Facility Over its Useful Life.

## Caveats and Limitations

Much thought and effort were put into developing the DESAL ECONOMICS$^{©}$ model, its comprehensive methodology, and attaining the necessary data-input for this case study. Nonetheless, a review of the usefulness of this work reveals certain caveats and limitations one should be aware of to limit any misuse and misunderstanding as to what the results represent.

- The baseline analysis/results represent a *snapshot in time* for one facility. That is to say, the results are estimates as the dynamics of costs and numerous other factors prevent the mass application of these specific life-cycle cost results of $769.62/ac-ft/yr {$2.3619/1,000 gals/yr} to other facilities. Life-cycle costs, even for the Southmost facility, change yearly, monthly, and even daily. Do not be dissuaded, however, as the results are very useful.

- The impact of location on a facility's life-cycle cost can be significant. The Southmost facility is a brackish groundwater RO facility physically close to the Gulf of Mexico. Thus, life-cycle costs incurred with disposing of the concentrate waste are very minimum for the Southmost facility (i.e., $1.62/ac-ft/yr {$0.0100/1,000 gal/yr}) and may not be representative of other facilities.

- The Southmost facility has a current maximum designed capacity of 7.5 mgd and at the data-gathering phase of the case-study had an operating production efficiency (PE) of 68%. As such, the baseline life-cycle cost results of $769.62/ac-ft/yr {$2.3619/1,000 gal/yr} may not accurately represent larger/smaller facilities, or facilities operating at higher/lower PEs. That is, this report does not report on the *economies of size* issue regarding RO desalination facilities. However, discussion and a series of sensitivity tables incorporating PEs (and other factors) differing from the baseline are provided for the Southmost facility, beginning on page 27.

- Since this study's analysis period (i.e., basis 2006) construction costs have risen about 1% per month, or about 10-12% per year (Cruz 2008). The life-cycle cost of the Southmost facility (built in 2003) has 40% of its total life-cycle cost from initial construction expenses. Thus, the 1% increase has significant implications for the life-cycle costs for any facility built after the Southmost facility.

- For the *Continued Cost*, the *Administrative* category (**Table 4**) accounts for expenses incurred at the Brownsville Public Utilities Board (BPUB) for and on behalf of the Southmost facility which are estimated as 5% of the O&M budget at the Southmost facility. This allocation amount is an approximation by management and is used in lieu of an extensive and costly accounting review/study which may, or may not, improve upon the accuracy of the *Administrative* costs used in this analysis/report.

- Oftentimes, the economic competitiveness of desalinated water is measured against conventionally-treated surface water. A caveat is warranted, however, in comparing the <u>costs</u> of desalination with that of <u>charges</u> assessed by municipalities for conventionally-treated potable water. That is, conventional-treated charges may not equate with the costs of such water. Making such an inadvertent comparison will make for an imbalanced comparison. A more appropriate comparison would involve evaluating life-cycle-derived costs for each alternative.

- The data input, and subsequently the baseline results, are deterministic. That is, they are absent stochastic elements, or risk considerations in the data input, and are based on singular, specific values for data (e.g., costs, water production, inflation, discounting, etc.). To compensate for this uncertainty about the precise exactness in the data input, several sets of sensitivity tables are included, beginning on page 27.

- The established methodology and subsequent economic and financial results significantly rely on the use of real values, which, over time, do not correlate well with accounting of nominal values. For additional discussion on this issue, please refer to the prior section entitled *Comparing Economic and Financial Results with Accounting-Based Results*.

- Nominal cost increases, specific inflation rates over relatively short periods of time, and numerous other factors can have a drastic effect on the NPV of costs. Therefore, caution is warranted in taking the baseline results of \$769.62/ac-ft/yr {\$2.3619/1,000 gals/yr}and making an inferential adjustment to future year values. That is, hypothetically speaking, in year 2015, it is incorrect to take these values and transform them to basis 2015 results by multiplying the baseline life-cycle cost results of \$769.62/ac-ft/yr {\$2.3619/1,000 gals/yr} by the then inter-temporal contemporary inflation rate.

- As discussed in the *Summary of Economic and Financial Methodology* section, the philosophy applied to baseline life-cycle cost analyses (i.e., 68% PE) is 'potable water is potable water.' That is, there are no adjustments made to a baseline analysis which accounts for differences in the quality of incoming or outgoing water at different potable-water-producing facilities. In Appendix A, this philosophy is maintained; even though certain other adjustments facilitating a more balanced comparison of dissimilar facilities and/or technologies, are discussed/made. Again, however, adjustments to account for different incoming/outgoing water qualities are not made with the modified analysis. Determining the protocol of such a process could be the subject of future research.

## Implications

Though limitations exist, one should not be dissuaded from believing in the usefulness of this case study and its documentation of the initial application of the DESAL ECONOMICS© model. Though the case study provides a *look-in-time* for the Southmost facility, the DESAL ECONOMICS© model is quite capable, and really has its strength in providing information in the planning and design stages of future facilities. This holds true particularly when there are multiple alternatives amongst key facility characteristics affecting costs (e.g., location and distance from the well field and delivery point(s), process-flow designs and specific equipment used in individual segments, etc.) being considered.

As is revealed, the abridged listing of questions below points to the need for economic considerations to be an extension of engineering work in the pre-planning and design stages of a project as there are many items affecting the long-term economic/financial efficiencies. With regards to desalination facilities, answers to these questions/issues can be aided with the use of DESAL ECONOMICS©. With that said, there are several important items to be inferred and deduced from this work. Of key noteworthiness:

- Contemporary, robust data on life-cycle costs for RO desalination of brackish groundwater for South Texas is provided. Though this is a fast-growing part of the state and country, others who find themselves studying desalination for their own area or interests can benefit from the report's content, both in terms of pure information, as well as items one needs to consider (e.g., methodology, inflation, useful life, future costs beyond construction, etc.) if sound decisions are to be made regarding economically- and financially-efficient ways to increase local and/or regional water supplies;

- Awareness of the DESAL ECONOMICS© model, focused on a technology making significant inroads in today's world, provides much for water planners, investors (private or public), consulting engineers involved with project pre-planning and design, and those involved with operations management to consider. Specific insights addressed by the model's 'what-if' capabilities include:[45]

- The unique break-down of results by facility segment (see page 21) and the ability to analyze a facility (or across facilities) beyond a single, bottom-line cost value provides management the unique ability to evaluate the outsourcing of particular functions by other third parties (see footnote 38 on page 23).

- The break-down of results by cost type, category, and item (see page 24) and the implicit commitment of future years' expenses, enables stakeholders to gauge the effectiveness of different philosophies; e.g., buy lower-cost equipment up front, but spend more in chemicals, energy, repairs or replacements in subsequent years, versus spending more up front and less on future years' costs.

- Given the current escalation in construction costs of 1% per month (Cruz 2008) and the model's ability to analyze facilities by segment (see page 21), life-cycle costs of alternative facility designs and asset configurations can vary greatly. This leads to several questions, including:

    - » What are the 'overbuilds & upgrades' costing, and do we need them?
    - » Is the designed water-producing capacity right? or too low, or too high?
    - » Will the operations plan optimize use of the facility's target capacity?
    - » Within a given facility segment, is there a better, more cost-effective way?

- Given rapidly-increasing energy costs (anticipated to continue) and energy's dominance amongst cost items (see page 26), certain questions arise:

    - » Will enough energy be available at affordable rates?
    - » Is energy 'from the grid' the best? What about wind or other sources?
    - » Should the facility operate 24-7, or at off periods for the best energy rates?

- Given the potential for tougher water-quality standards, certain questions arise:

    - » Does the water-producing zone of the well field have potential problems with excess salts, arsenic, etc.?

        - redo the well-field design/depth, or compensate with more chemicals?
        - purchase land and include a back-up well-field location?
        - drill one deep well, or several shallow wells?

    - » Does the facility design and capacity take this into consideration?

○ Having a flexible design and a solid methodology in DESAL ECONOMICS© permits the analysis of any sized facility, regardless of location. As such, comparisons of different sized facilities are possible and are investigated and discussed by the authors in work by Boyer (2008) which exams the economies of size issue. Further, though beyond the scope of this report, the authors have built a related economic and financial model, CITY $H_2O$ ECONOMICS©, on the same methodological platform and design standards as the

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[45] Note that much of the information in a DESAL ECONOMICS© model analysis is engineering related and thus necessarily requires the close collaboration with engineers and economists.

original DESAL ECONOMICS©, but designed to analyze conventional surface-water treatment facilities. Work by Rogers et al. (2009) investigates and reports on the 'Conventional' vs. 'Desalination' issue facing water planners.

## Conclusions

This research has announced the development of the DESAL ECONOMICS© model and its abilities via case-study assessment of the economic and financial life-cycle cost of producing potable water, through reverse-osmosis desalination, using brackish groundwater from the Gulf Coast aquifer, at the Southmost facility in South Texas. Inferential understandings from this work can be drawn from the many engineering-, economic-, regulatory-, institutional-, and environmental-related factors encountered in this investigation. Key lessons learned include:

- Though the issue of economics and desalination are not new, this work and the related DESAL ECONOMICS© model do introduce some innovative and original approaches.

- The aggregate annual baseline life-cycle cost results herein of $769.62/ac-ft are higher than the $521.36 to $586.53 per ac-ft range estimated by Norris in 2004 (i.e., prior to construction), largely due to Norris' estimate of 94% production efficiency (PE) (Norris 2007) and the DESAL ECONOMICS© analysis' use of actual data supporting a 68% PE.

- The modeled 68% PE, hampered by various operational and product-demand issues, is below the 85% level provided for the TCEQs *Rule-of-85*.[46] The difference in the life-cycle cost between the two is about $100 per ac-ft (i.e., $769.62/ac-ft, vs $670.05/ac-ft).

- Consistent with other literature-review sources, energy costs are a major contributing factor in producing potable water via RO desalination. Here, energy represents 26% of total costs, or $198.80 of the total aggregate annual life-cycle cost $769.62/ac-ft. Given the current high-cost environment for energy, efforts to reduce the amount of energy required in desalination, and/or efforts to incorporate potentially more cost-effective alternative energy supplies (e.g., wind-powered desalination, zero-emission technology using organic wastes, etc.) will increase desalination's effectiveness and use/adoption.

- Potable water from desalination is limited in the Valley, representing only about 3% of the region's supplies. Within its immediate service area, however, the Southmost facility can provide upwards of 40% of potable water needs.

- The Southmost facility is a medium-sized reverse-osmosis (RO) desalination facility with a current maximum-designed capacity of 7.5 mgd. It is strategically located to provide

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[46] TCEQ mandate 30 TAC §291.93(30) states "A retail public utility that possesses a certificate of public convenience and necessity that has reached 85% of its capacity as compared to the most restrictive criteria of the commission's minimum capacity requirements in Chapter 290 of this title shall submit to the executive director a planning report that clearly explains how the retail public utility will provide the expected service demands to the remaining areas within the boundaries of its certificated area" (Texas Secretary of State 2008). Thus, although a facility may be operable at >85% capacity, it may necessarily be constrained (over the long term) to a lower PE rate as the public entity manages the operations of a portfolio of water supply/treatment facilities (Adams 2007).

water-supply assurances for the most downstream uses of surface water from the Rio Grande [River]. Also, its proximity to the Laguna Madre facilitates inexpensive disposal costs of the concentrate-waste discharge.

- Preferences for risk adverseness against supply shortages of downstream users of water from the Rio Grande [River] provided the impetus for building the Southmost facility. It is unlikely desalination (3% of supply) will ever overtake the dominance of Rio Grande surface water (87% of supply) in the Valley.

- Built in 2003, before a very significant escalation in costs for construction materials (about 1% per month according to Cruz 2008), the Southmost facility may have life-cycle cost advantages over similar-sized facilities built in latter, more expensive time periods (i.e., assuming future operating costs (potentially impacted by new, forthcoming technologies) are un-impacting).

## Final Comments

Complete and thorough *life-cycle* cost analyses of *supply-* and/or *efficiency-oriented* capital projects which can add water to a region, including desalination, provide much useful information if they are based on methodology using NPV and annuity equivalent measures. This two-part methodology considers time and all cost types (i.e., initial construction, continuing, and capital replacement) and promotes an accurate portrayal of future years' costs ($/ac-ft/year) and productive capacity. Having the ability to objectively compare different water-supply projects and make capital investment decisions will become more important over time as populations increase, input costs rise, and water supplies become relatively scarcer. As such, sound analyses of finance and economics should be considered an extension of engineering-related tasks for capital-project alternatives involved in a region's water-resource planning.

## Cited References

Adams, J. 2007. Water Treatment Manager. Brownsville Public Utilities Board. Brownsville, TX. Personal communications.

Adams, R., M. Berg, and H. Harris. 2000. *Rio Grande RWPG Evaluation of Desalination & Development of Water Supply Alternatives*. Available at: http://www.twdb.state.tx.us/rwp/m/Submitted_Files/02-Volume%20II/05%20-%20Tech%20Memos/05%20-%20Desal/00%20-%20Desal-reuse-TM-final1.doc. Accessed May 22, 2006.

Archuleta, E.G. 2004. *Desalination of Brackish Groundwater in El Paso Texas*. Available at: http://www.twdb.state.tx.us/iwt/desal/docs/The%20Future%20of%20Desalination%20in%20Texas%20-%20Volume%202/documents/D8.pdf. Accessed May 26, 2006.

Arroyo, J.A. 2005. *Chapter 15, Water Desalination*. Available at: http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWReports/R360AEPC/Ch15.pdf. Accessed May 2006.

Beattie, B., and R. Taylor. 1985. *The Economics of Production*. John Wiley & Sons. New York, NY.

Boyer, C.N. 2008. "Economies of Size in Municipal Water Treatment Technologies: Texas Lower Rio Grande Valley." Master's thesis. Texas A&M University.

Brownsville Public Utilities Board. 2007a. Unpublished, internal annual production reports for years 2004-2007 for the Southmost Regional Water Authority desalination facility. Brownsville, TX. Obtained April 23, 2007.

Brownsville Public Utilities Board. 2007b. Unpublished, internal accounting document of budget vs. actual costs, dated 1/18/2007. Finance Department. Brownsville, TX. Obtained April 26, 2007.

Brownsville Public Utilities Board. n.d. Website text. Available at: http://www.brownsville-pub.com/water/desalination.html. Accessed May 17, 2006.

Cruz, O. 2008. President, Cruz-Hogan Consultants, Inc. Harlingen, TX. Personal communications.

Ettouney, H.M., H.T. El-Dessouky, R.S. Faibish, and P.J. Gowin. 2002. *Evaluating the Economics of Desalination*. Chemical Engineering Progress. Available at:http://proquest.umi.com/pqdweb?index=0&did=267246051&SrchMode=1&sid=1&Fmt=6&VInst=PROD&VType=PQD&RQT. Accessed May 18, 2006.

Gleick, P.H., H. Cooley, D. Katz, E. Lee, J. Morrison, M. Palaniappan, A. Samulon, and G.H. Wolff. 2006. *The World's Water, 2006-2007, The Biennial Report on Freshwater Resources*. Pacific Institute for Studies in Development, Environment, and Security. Oakland, CA.

Graves, M., and K. Choffel. 2004. *Economic Siting Factors For Seawater Desalination Projects along the Texas Gulf-Coast*. Available at: http://www.twdb.state.tx.us/Desalination/The%20Future%20of%20Desalination%20in%20Texas%20%20Volume%202/documents/C11.pdf. Assessed May 22, 2006.

Griffin, R.C. 2002. Professor of Natural Resource Economics, Department of Agricultural Economics, Texas AgriLife Research. College Station, TX. Personal communications.

Griffin, R.C., and M.E. Chowdhury. 1993. Evaluating a Locally Financed Reservoir: The Case of Applewhite. *Journal of Water Resources Planning and Management*. 119,6:628-44.

Hamilton, B. 2002. Economist, U.S. Bureau of Reclamation. Denver, CO. Personal communications.

Jones, B.W. 1982. *Inflation in Engineering Economic Analysis*. John Wiley & Sons. New York, NY.

Klinefelter, D. 2002. Professor and Extension Economist, Agricultural Finance and Management Development, Texas AgriLife Research. College Station, TX. Personal communications.

Levy, H. and M. Sarnat. 1982. *Capital Investment and Financial Decisions*. 2nd Edition. Prentice-Hall International. Englewood Cliffs, NJ.

Nicot, J. and A. Chowdhury. 2005. *Disposal of Brackish Water Concentrate Into Depleted Oil and Gas Fields: a Texas Study*. Available at: http://www.beg.utexas.edu/environqlty/desalination/RevDesalinationPaper.pdf. Accessed May 22, 2006.

Norris, J.W. 2007. Principal, NRS Consulting Engineers. Harlingen, TX. Personal communications.

Norris, J.W. n.d. *Chapter 14, Brackish Groundwater Desalination in South Texas: An Alternative to the Rio Grande*. Available at: http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWReports/R365/ch14-Desalination%20in%20South%20TexasR1.pdf. Accessed November 2005.

Norris, J.W. 2004. *Southmost Regional Water Authority Regional Desalination Plant*. Available at: http://www.twdb.state.tx.us/Desalination/The%20Future%20of%20Desalination%20in%20Texas%20-%20Volume%202/documents/D7.pdf. Assessed May 26, 2006.

NRS Consulting Engineers. n.d. Engineering Report Regional Brackish Groundwater Treatment and Supply Project, Southmost Regional Water Authority. Selected pages (10-16) provided July 2006.

NRS Texas Water News. 2006a. Website news pamphlet; Volume 5, Issue 4. Available at: http://www.nrsengineers.com/newsletters/twn-v5i4-apr06.pdf. Assessed June 2006.

NRS Texas Water News. 2006b. Website news pamphlet; Volume 5, Issue 6. Available at: http://www.nrsengineers.com/newsletters/twn-v5i6-jun06.pdf. Assessed October 2006.

Penson, Jr., J.B. 2002. Regents Professor and Stiles Professor of Agriculture, Department of Agricultural Economics, Texas AgriLife Research. College Station, TX. Personal communications.

Pittman, R., J. Hunt, D. Guerra Jr., T.W. Labatt III, J. Herring, W. Meadows, and K. Ward. 2004. *The Future of Desalination in Texas Volume 1*. Available at: http://www.twdb.state.tx.us/Desalination/Report_to_legislatureVol1/VOL%201-v7_final.pdf. Assessed May 30, 2006.

Quirin, G.D. 1967. *The Capital Expenditure*. Richard D. Irwin, Inc. Homewood, IL.

Rio Grande Regional Water Planning Group (Region M). 2001. *Regional Water Supply Plan for the Rio Grande Regional Water Planning Area (Region M), Vols. I and II*. Lower Rio Grande Valley Development Council and Texas Water Development Board.

Rister, M.E., E.G. Smith, V.M. Aguilar, D.P. Anderson, and R.D. Lacewell. 1999. “An Economic Evaluation of Sugarcane Production and Processing in Southeast Texas.” Environmental Issues/Sustainability DET 99-01, Texas Agricultural Experiment Station and Texas Agricultural Extension Service, Texas A&M University System. College Station, TX.

Rister, M.E., R.D. Lacewell, and A.W. Sturdivant. 2006. "Economic and Conservation Evaluation of Capital Renovation Projects: United Irrigation District of Hidalgo County (United) – Rehabilitation of Main Canal, Laterals, and Diversion Pump Station – Final." Texas Water Resources Institute. TR-288. College Station, TX.

Rister, M.E., C.S. Rogers, R.D. Lacewell, J.R.C. Robinson, J.R. Ellis, and A.W. Sturdivant. 2009. "Economic and Financial Methodology for South Texas Irrigation Projects – RGIDECON©." Texas Water Resources Institute. TR-203 (Revised). College Station, TX.

Robison, L.J. and P.J. Barry. 1996. *Present Value Methods and Investment Analysis*. The Academic Page. Northport, AL.

Rogers, C.S., A.W. Sturdivant, M.E. Rister, R.D. Lacewell, and B.L. Harris. 2008. "Economic Implications of Conventional Water Treatment Versus Desalination: A Dual Case Study." Paper presented at the 2008 Southern Agricultural Economics Association Annual Meeting. Adams Mark Hotel. Dallas, TX. Abstract published in Journal of Agricultural and Applied Economics 40,2:724.

Rogers, C.S., A.W. Sturdivant, M.E. Rister, R.D. Lacewell, and J.G. Santiago. 2009. "Economic and Financial Costs of Conventional Surface-Water Treatment: A Case Study of the McAllen Northwest Facility." Texas Water Resources Institute. TR-311. College Station, TX.

Scranton Gillette Communications, Inc. (owner/licensor). 2007. Choosing the Right Disinfection Technology for a Municipal Drinking Water Plant - Part 2, by Dr. H. Fleming and W. Huebner. Available at: http://www.wwdmag.com/Choosing-the-Right-Disinfection-Technology-for-a-Municipal-Drinking-Water-Plant-Part-2-article1973. Accessed February 8, 2007.

Seawright, E.K. 2009. "Select Economic Implications for the Biological Control of Arundo donax along the Rio Grande." Master's thesis. Texas A&M University.

Smith, G.W. 1987. *Engineering Economy – Analysis of Capital Expenditures, 4th ed.* Iowa State University Press. Ames, IA.

Southmost Regional Water Authority. n.d. Regional Solutions to Regional Water Issues. Available at: http://www.fernandezgroupinc.com/portfolio/srwa-brochure.pdf. Accessed May 30, 2006.

Spencer, S. 2005. *Mexico Pays Rio Grande Water Deficit*. News release of the Office of the Commissioner, International Boundary and Water Commission, U.S. Section. El Paso, TX.

Sturdivant, A.W. 2007. Extension Associate (Economist), Texas AgriLife Extension Service. Weslaco, TX. Photographs.

Sturdivant, A.W., C.S. Rogers, M.E. Rister, R.D. Lacewell, J.W. Norris, J. Leal, J.A. Garza, and J. Adams. 2007. "Economic Costs of Desalination in South Texas: A Case Study." Journal of Contemporary Water Research and Education, Issue 137, Pages 21-39.

Texas Secretary of State. 2008. *Texas Administrative Code. Adequacy of Water Utility Service.* Available at: http://info.sos.state.tx.us/pls/pub/readtac$ext.TacPage?sl=R &app=9&p_dir=&p_rloc=&p_tloc=&p_ploc=&pg=1&p_tac=&ti=30&pt=1&ch=291&rl=93. Accessed on 22 February 2008.

The Nature Conservancy. 2006. Website text. Available at: http://www.nature.org/wherewework/fieldguide/projectprofiles/lmt.html. Accessed May 17, 2006.

Walkenbach, J. *1996. Excel 97 Bible*. IDG Books Worldwide. Southlake, TX.

Wooldridge, J.M. 2006. *Introductory Econometrics: A Modern Approach*. Thompson Southwestern. USA.

Younos, T. 2005. *The Economics of Desalination.* Available at: http://www.ucowr.siu.edu/updates/132/6.pdf. Accessed June 5, 2006.

Zhou, Y. and R.S.J. Tol. 2004. *Evaluating the Costs of Desalination and Water Transport*. Available at: http://www.uni-hamburg.de/Wiss/FB/15/Sustainability/DesalinationFNU41_revised.pdf=309&VName=PQD&TS=1147975157&clientId=2945. Accessed May 17, 2006.

## **Appendix A**: Modified Data Input and Results

## Modified Data Input and Results

As advised on page 72 in Gleick et al. (2006), *"Extreme caution, even skepticism, should be used in evaluating different estimates and claims of future desalination costs. Predictions of facilities costs tend to conflict with actual costs once plants are built, and many cost estimates are based on so many fundamental differences that direct comparisons are invalid or meaningless. ... Comparison years are rarely normalized*."

To address these valid points and provide meaning to facility comparisons, in a pro-active manner, the authors provide alternative life-cycle cost results (below) which incorporate limited modifications to the Southmost facility's baseline scenario – in anticipation of their comparing its results to other facilities and/or technologies with the *DESAL ECONOMICS*© model, and its companion model *CITY $H_2O$ ECONOMICS*© (e.g., Boyer 2008, Rogers et al. 2009). That is, the baseline results presented in the main text depict the Southmost facility in its current operating state. While the baseline results were determined using *DESAL ECONOMICS*© (previously advocated as being appropriate for making *apples-to-apples* comparisons of desalination facilities life-cycle costs), some adjustments are necessary to *level the playing field* if future comparisons are to be precisely made across other potable water facilities' (e.g., desalination, surface treatment, etc.) life-cycle costs. That is, natural variations in key data-input parameters of different facilities can distort any subsequent comparison of results. To precisely compare across individual facilities producing potable water, adjust the following data-input parameters in either the *DESAL ECONOMICS*© model, or the *CITY $H_2O$ ECONOMICS*© model[47] (for individual facility-analysis files) so that they are the same for all facilities being analyzed:[48]

[Author's note: text for each of the following four data-input variables discusses actions required to precisely compare other facilities to the Southmost facility (using either the *DESAL ECONOMICS*© model, or the *CITY $H_2O$ ECONOMICS*© model). If other facilities are to be compared to one another (and not the Southmost facility), however, a common standard for each of the four variables should still be used in the analysis of each facility. That is, the specifics of those standards may need to be different than that discussed here (e.g., a commencement date different than January 1, 2006.)]

» base period of analysis – Assume the construction period commences on January 1, 2006. This insures financial calculations occur across a common time frame. For facilities constructed in different time periods, either inflating or deflating the appropriate cost values (i.e., initial construction, continuing, and capital replacement) will be necessary to accommodate this stated benchmark period.

» annual production efficiency – Assume a constant 85% production efficiency (PE) rate. This stated proportion of maximum-designed capacity is reasonable, allows for

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[47] The *CITY $H_2O$ ECONOMICS*© model is built upon the same methodological platform and with the same design standards as *DESAL ECONOMICS*©, but targeted toward analyzing conventional surface-water treatment facilities. Documentation and implementation results using *CITY $H_2O$ ECONOMICS*© by the authors can be found in Boyer (2008) and Rogers et al. (2009).

[48] As discussed in the *Summary of Economic and Financial Methodology* and the *Caveats and Limitations* sections, the assumption applied to baseline analyses is 'potable water is potable water.' That is, there are no adjustments made to an analysis which accounts for differences in the quality of incoming or outgoing water at different potable-water-producing facilities. That same philosophy is maintained here in Appendix A with the modified results ... even though other adjustments are made which improve the preciseness of comparing dissimilar facilities and/or technologies.

planned and unplanned downtime (e.g., maintenance, emergencies, demand interruptions, etc.), and complies with the *Rule of 85*.[49] Leveling the PE to this stated rate for each avoids potential bias associated with operating circumstances at particular facilities/sites.[50]

» overbuilds and upgrades – Ignore the *Overbuilds & Upgrades* facility segment and its impact upon the total life-cycle cost.[51] Doing so ignores the *non-essential* costs which allows levelised comparison of: (1) different technologies (e.g., desal vs. surface-water treatment) based upon only the technology itself (i.e., indifferent as to the inclusion and level of non-essentials), and (2) economies of size within (or across) a technology.

» salvage value of capital assets – Assume all capital assets (e.g., buildings, land) have an effective net salvage value of zero dollars. Doing so assumes facility decommissioning and site restoration costs equal the salvage (i.e., sale) value, and/or the investment (in buildings, land, etc.) are intended to be long term, with no expectations of ever 'salvaging' the asset(s).[52]

It is the *modified results* for individual facilities which are comparable. Making the above data-input changes to the analysis file for the Southmost facility in *DESAL ECONOMICS*© results in a modified life-cycle cost of $615.01/ac-ft/year {$1.8874/1,000 gals/year}(**Table A1**). Additional results after making the above parameter changes to the analysis file for the Southmost facility in *DESAL ECONOMICS*© are provided below. For brevity's sake, a textual discussion is not included with modified-results' tables A1, A2, A3, A4, and A5, below. Refer to the results discussion provided for baseline-results tables 7, 8, 9a, 9b, and 9c, respectively. Though the values are different, the baseline-results discussion provides direction for inferential understanding.

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[49] TCEQ mandate 30 TAC §291.93(30) states "A retail public utility that possesses a certificate of public convenience and necessity that has reached 85% of its capacity as compared to the most restrictive criteria of the commission's minimum capacity requirements in Chapter 290 of this title shall submit to the executive director a planning report that clearly explains how the retail public utility will provide the expected service demands to the remaining areas within the boundaries of its certificated area" (Texas Secretary of State 2008). Thus, although a facility may be operable at >85% capacity, it may necessarily be constrained (over the long term) to a lower PE rate as the public entity manages the operations of a portfolio of water supply/treatment facilities (Adams 2007).

[50] In reality, individual facilities operate at different PE rates, for many different reasons. In addition to the constraint induced by The Rule of 85 (see above footnote), items such as seasonal demand, source-water quality issues (e.g., abnormal arsenic, iron, etc.), and mis-matched equipment and related flow capacity across facility processes, etc. attribute to less than 100% PE.

[51] *Overbuilds & Upgrades* are the 'elbow room' allowing for future growth and 'whistles & bells' beyond baseline necessities of the process technology itself.

[52] The opportunity cost values for land, well fields, water rights, etc. associated with potable water production facilities can be argued to be net positive. Projections of such values 50+ years into the future are subject, however, to a broad range of subjective assumptions. Also, the financial discounting of such values 50+ years virtually eliminates the positive influence of such calculations in current (i.e., 2006) dollars.

Table A1. "Modified" Aggregate Results for Production and Costs for the Six Facility Segments of the Southmost Desalination Facility, in 2006 Dollars. [a]

| Results | Units | Nominal Value | Real Value [b] |
|---|---|---|---|
| **Initial Facility Costs** | 2006 dollars | $22,022,150 | $22,022,150 |
| **Water Production** | ac-ft (lifetime) | 357,046 | 147,502 |
| - annuity equivalent [c] | ac-ft/year | | 6,823 |
| **Water Production** | 1,000-gal (lifetime) | 116,343,750 | 48,063,806 |
| - annuity equivalent [c] | 1,000-gal/year | | 2,223,376 |
| **NPV of Total Cost Stream** [d] | 2006 dollars | $209,423,179 | $65,208,300 |
| - annuity equivalent [c] | $/year | | $4,196,391 |
| *Cost-of-Producing & Delivering Water* [e] | $/ac-ft/year | | $615.01 |
| *Cost-of-Producing & Delivering Water* [e] | $/1,000-gal/year | | $1.8874 |

[a] These modified results reflect the Southmost facility in a modified operating state (i.e., 85% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are not included, and a net salvage value of zero dollars is recorded for all capital assets).

[b] Determined using a 2.043% compound rate and a 6.125% discount factor for dollars, and a 4.000% discount factor for water.

[c] Basis 2006.

[d] These are the adjusted total net cost stream values (nominal and real) relevant to producing RO-desalinated water for the life of the facility as they include initial capital-investment costs, increased O&M and capital replacement expenses, and ignore any value (or sales revenue) of the final water product.

[e] Delivery is to a point within the municipal delivery-system infrastructure, not household delivery.

Table A2. "Modified" Costs of Producing (and Delivering) Water for the Six Facility Segments of the Southmost Desalination Facility, in 2006 Dollars. [a, b]

| | Facility Segment | NPV of Cost Stream [c] | Annuity Equivalents ($/yr) [d] | ($/day) [d] | $/ac-ft/year [e] | $/1,000-gals/year [e] | % of Total Cost |
|---|---|---|---|---|---|---|---|
| 1) | Well Field | $18,598,307 | $1,196,869 | $3,279 | $175.41 | $0.5383 | 28.5% |
| 2) | Intake Pipeline | $2,068,143 | $133,092 | $365 | $19.51 | $0.0599 | 3.2% |
| 3) | Main Facility | $35,177,368 | $2,263,791 | $6,202 | $331.77 | $1.0182 | 53.9% |
| 4) | Concentrate Discharge | $137,325 | $8,837 | $24 | $1.30 | $0.0040 | 0.2% |
| 5) | Finished Water Line & Tank Storage | $2,728,024 | $175,558 | $481 | $25.73 | $0.0790 | 4.2% |
| 6) | Delivery Pipeline | $6,499,132 | $418,243 | $1,146 | $61.30 | $0.1881 | 10.0% |
| | TOTAL | $65,208,300 | $4,196,391 | $11,497 | $615.01 | $1.8874 | 100.0% |

[a] These modified results reflect the Southmost facility in a modified operating state (i.e., 85% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are not included, and a net salvage value of zero dollars is recorded for all capital assets).

[b] Delivery is to a point in the municipal delivery-system infrastructure, not individual household delivery.

[c] Adjusted (i.e., modified) total costs (in 2006 dollars) throughout the facility's life of producing and delivering RO-desalinated water to a point in the municipal delivery-system infrastructure.

[d] Adjusted (i.e., modified) total costs for ownership and operations, stated in 2006 dollars, and the annuity values for the first column entitled 'NPV of Cost Stream.'

[e] Adjusted (i.e., modified) total 'annualized costs' on a per ac-ft basis (or $/1,000-gals) for each segment.

Table A3. “Modified” Total NPV and Annuity Equivalent Costs, by Cost Type, Category, and Item for the Southmost Desalination Facility, in 2006 Dollars. [a]

| Cost Type/Category/Item | ---- NPV of Cost Streams ---- “**Total** Life-Cycle Costs” [b] | | | --- Annuity Equivalent Costs --- “**Annual** Life-Cycle Costs” [b] | | |
|---|---|---|---|---|---|---|
| | O&M | Continued | Total | O&M | Continued | Total |
| Initial Construction | | | $22,022,150 | | | $1,417,205 |
| Continued [c] | | | $39,729,651 | | | $2,556,747 |
| » Administrative | | $1,891,888 | | | $121,750 | |
| » O&M | | $37,837,763 | | | $2,434,997 | |
| • Energy | $21,078,014 | | | $1,356,447 | | |
| • Chemicals | $6,363,404 | | | $409,508 | | |
| • Labor | $7,615,483 | | | $490,084 | | |
| • All Other | $2,780,863 | | | $178,959 | | |
| Capital Replacement | | | $3,456,499 | | | $222,438 |
| TOTAL | $37,837,763 | $39,729,651 | $65,208,300 | $2,434,997 | $2,556,747 | $4,196,391 |

[a] These modified results reflect the Southmost facility in a modified operating state (i.e., 85% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are not included, and a net salvage value of zero dollars is recorded for all capital assets).

[b] Basis 2006 dollars.

[c] “Administrative” costs are incurred by the Brownsville Public Utilities Board in association with the Southmost facility, while “Operations & Maintenance (O&M)” costs are incurred at the facility.

Table A4. “Modified” Life-Cycle (Annuity Equivalent) Costs – $/ac-ft/year and $/1,000-gal/year, by Cost Type, Category, and Item for the Southmost Desalination Facility, in 2006 Dollars. [a]

| Cost Type/Category/Item | Annuity Equivalent Costs [b] | | | | | |
|---|---|---|---|---|---|---|
| | $/ac-ft/year | | | $/1,000-gal/year | | |
| | O&M | Continued | Total | O&M | Continued | Total |
| Initial Construction | | | $207.70 | | | $0.6374 |
| Continued [c] | | | $374.71 | | | $1.1499 |
| » Administrative | | $17.84 | | | $0.0548 | |
| » O&M | | $356.87 | | | $1.0952 | |
| • Energy | $198.80 | | | $0.6101 | | |
| • Chemicals | $60.02 | | | $0.1842 | | |
| • Labor | $71.83 | | | $0.1842 | | |
| • All Other | $26.23 | | | $0.2204 | | |
| Capital Replacement | | | $32.60 | | | $0.1000 |
| TOTAL | $356.87 | $374.71 | $615.01 | $1.0952 | $1.1499 | $1.8874 |

[a] These modified results reflect the Southmost facility in a modified operating state (i.e., 85% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are <u>not</u> included, and a net salvage value of zero dollars is recorded for all capital assets).

[b] Basis 2006 dollars.

[c] “Administrative” costs are incurred by the Brownsville Public Utilities Board in association with the Southmost facility, while “Operational & Maintenance (O&M)” costs are incurred at the facility.

Table A5. “Modified” Percentage of Life-Cycle Costs, by Cost Type, Category, and Item for the Southmost Desalination Facility, based on 2006 Dollars.

| Cost Type/Category/Item | % of Life-Cycle Costs | | |
|---|---|---|---|
| | O&M | Continued | Total |
| Initial Construction | | | 34 % |
| Continued | | | 61 % |
| » Administrative | | 3 % | |
| » O&M | | 58 % | |
| • Energy | 32 % | | |
| • Chemicals | 10 % | | |
| • Labor | 12 % | | |
| • All Other | 4 % | | |
| Capital Replacement | | | 5 % |
| TOTAL | 58 % | 61 % | 100 % |

# Notes