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Economies of Size in Municipal Water-Treatment Technologies:
A Texas Lower Rio Grande Valley Case Study

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make every drop count

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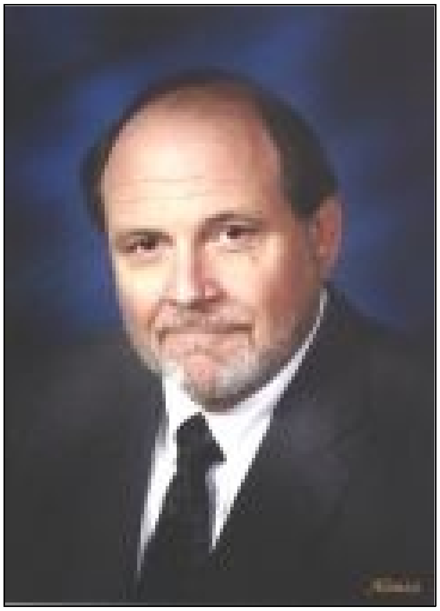
Dedication



Charles William Browning, Jr.
January 18, 1954 ~ May 6, 2010

As friend and colleague, Charles "Chuck" Browning, Jr. will be dearly missed. We value the time, kindness, and wisdom he shared with us. This work is dedicated to Chuck in celebration of his life here on earth!

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Authors' Note

This report is largely replicated from a Master's Thesis by Boyer (2008), with modifications which (a) alter certain assertions made about economies of size, and (b) make the result tables more comparable (directly) to other, related works by Sturdivant et al. (2009) and Rogers et al. (2010). That is, this work is associated with a series of other reports by the authors which are also reported as TWRI Technical Reports (e.g., TR-295, TR-311, etc.).

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Abstract

As the U.S. population continues to increase, the priority on planning for future water quantity and quality becomes more important. Historically, many municipalities have primarily relied upon surface water as their major source of drinking water. In recent years, however, technological advancements have improved the economic viability of reverse-osmosis (RO) desalination of brackish-groundwater as a potable water source. By including brackish-groundwater, there may be an alternative water source that provides municipalities an opportunity to hedge against droughts, political shortfalls, and protection from potential surface-water contamination. In addition to selecting a water-treatment technology, municipalities and their associated water planners must determine the appropriate facility size, location, etc.

To assist in these issues, this research investigates and reports on *economies of size* for both conventional surface-water treatment and brackish-groundwater desalination by using results from four water-treatment facilities in the Texas Lower Rio Grande Valley (LRGV). The methodology and associated results herein may have direct implications on future water planning as highlighting the most economically-efficient alternative(s) is a key objective.

In this study, economic and financial life-cycle costs are calculated for a “small” conventional surface-water facility (i.e., 2.0 million gallons per day (mgd) Olmito facility) and a “small” brackish-groundwater desalination facility (i.e., 1.13 mgd La Sara facility). Thereafter, these results are merged with other, prior life-cycle cost analyses’ results for a “medium” conventional surface-water facility (i.e., 8.25 mgd McAllen Northwest facility) and a “medium” brackish-groundwater desalination facility (i.e., 7.5 mgd Southmost facility). The combined data allow for examination of any apparent economies of size amongst the conventional surface-water facilities and the brackish-groundwater desalination facilities.

This research utilized the CITY H_20 ECONOMICS© and the DESAL ECONOMICS© Excel® spreadsheet models developed by agricultural economists with Texas AgriLife Research and Texas AgriLife Extension Service. The life-cycle costs calculated within these spreadsheet models provide input for work which subsequently provides the estimations of *economies of size*. Although the *economies of size* results are only based on four facilities and are only applicable to the Texas LRGV, the results are nonetheless useful. In short, it is determined that *economies of size* are apparent in conventional surface-water treatment and *constant economies of size* are apparent in brackish-groundwater desalination. Further, based on modified life-cycle costs (which seek to more-precisely compare across water-treatment technologies and/or facilities), this research also concludes that reverse-osmosis (RO) desalination of brackish-groundwater is economically competitive with conventional surface-water treatment in this region.

Economies of Size in Municipal Water-Treatment Technologies:
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Introduction

The Texas Lower Rio Grande Valley's (LRGVs) population is projected to more than double from 2010 to 2060 (Texas Water Development Board 2006). In addition, the U.S. Census Bureau has identified the LRGV as the fourth-fastest-growing Metropolitan Statistical Area in the United States (U.S. Census Bureau 2001). Such rapid growth, combined with prolonged drought and previous shortfalls of water deliveries from Mexico,[1] has resulted in LRGV municipalities considering new construction of both traditional and alternative-technology capital water projects to meet growing potable (drinkable) water demand in this region.

Historically, the Rio Grande [River] has been the LRGV region's primary source of municipal water. Municipalities typically use a conventional surface-water treatment process on Rio Grande water to provide potable water for their residents. In recent years, however, reverse-osmosis (RO) of brackish-groundwater desalination has been implemented as another source in the region. This report focuses on these two water-treatment technologies, across two size categories each. Life-cycle cost results derived from analyzing the four facilities are used as a basis to investigate and report on any presence of *economies of size* for both technologies. The four facilities analyzed herein include: (i) the McAllen Northwest facility, (ii) the Brownsville Southmost facility, (iii) the Olmito facility, and (iv) the La Sara facility.[2]

Facing an increase in potable-water demand, the City of McAllen, TX built a new 8.25 million gallon per day (mgd) conventional surface-water treatment facility in 2004 (Rogers 2008; Rogers et al. 2010). Similarly, recognizing the diversification benefits and estimated cost competitiveness of brackish-groundwater desalination, the City of Brownsville, TX built the 7.5 mgd Southmost brackish-groundwater desalination facility in 2004. This alternative-technology adoption is intended to reduce the City of Brownsville's reliance on the Rio Grande (Sturdivant et al. 2009). Further, the Olmito Water Supply Corporation (OWSC) in Olmito, TX (directly north of the City of Brownsville, TX) expects to refurbish and expand its current 1.0 mgd conventional surface-water treatment facility to 2.0 mgd in 2008-2009 (Elium 2008; Boyer 2008). Lastly, in November 2004, the North Alamo Water Supply Corporation (NAWSC) began operating its 1.13 mgd La Sara brackish-groundwater desalination facility, which is its first desalination facility contributing potable water to 16 rural communities in Willacy, Hidalgo, and northwestern Cameron counties (North Alamo Water Supply Corporation 2007; Boyer 2008).

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[1] The 1944 Treaty requires the United States and Mexico to share the downstream water release from Amistad and Falcon reservoirs (Sturdivant et al. 2009). In addition to sharing the water, the treaty requires the United States to provide Mexico with 1.5 million acre-feet per year from the Colorado River, while Mexico must provide the United States 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] Note the life-cycle costs for the first two mentioned facilities are presented in prior works (i.e., TWRI TR-311 (Rogers et al. 2010), and TWRI TR-295 (Sturdivant et al. 2009), respectively).

Purpose and Objectives

This research builds on and extends the work of two prior case studies which analyzed the economic and financial life-cycle costs of producing potable water in the LRGV of Texas with conventional surface-water treatment (Rogers 2008) and brackish-groundwater desalination (Sturdivant et al. 2009). The purpose of this work is to assist in water planning by providing comparable *life-cycle costs* of two different water-treatment technologies and reporting on any *economies of size* for those technologies.[3, 4] To attain its purpose, the following research objectives were identified:

(a) calculate life-cycle costs of producing potable water ($/acre-feet (ac-ft) and $/1,000 gallons (gals)) for two 'small' facilities (i.e., Olmito and La Sara);
(b) merge this calculated data with similarly calculated life-cycle cost data reported in Rogers (2008) and Sturdivant et al. (2009) for two 'medium' facilities (i.e., Southmost and McAllen Northwest); and
(c) subsequently investigate for existence of *economies of size* for conventional surface-water treatment and reverse-osmosis desalination of brackish-groundwater in the Texas LRGV using the four facilities' life-cycle cost data.

The first objective is facilitated by using the same capital-budgeting[5] methodology noted in Rogers (2008) and Sturdivant et al. (2009) in objective two as it allows for an "apple-to-apples" comparison of facilities' life-cycle costs of producing potable water. Specifically, the DESAL ECONOMICS© and CITY H_2O ECONOMICS© models are used. The last objective is facilitated by comparing economies of size ratios (ESRs) calculated using life-cycle costs ($/ac-ft and $/1,000 gallons) for conventional surface-water treatment based on the Olmito Water Supply Corporation (WSC) and McAllen Northwest (from Rogers 2008) facilities; and then by performing another comparison of ESRs calculated using life-cycle costs for desalination based on the La Sara and Southmost (from Sturdivant et al. 2009) facilities.

To more accurately compare the facilities/technologies requires, however, the use of "modified" (or "levelized") life-cycle cost values. Though more information is provided later in this report, the basic purpose of using "modified" values is to more-accurately compare facilities and/or technologies, thereby improving the accuracy of the *economies of size* (ES) work. **Table 1** and **Figure 1** identify the matrix of facilities, technologies, and size categories evaluated.

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[3] 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 (Sturdivant et al. 2009).

[4] *Economies of size* refers to the concept that economies (or decreasing marginal and average variable costs) are incurred as output is increased from a non-proportionate change in the 'size' (i.e., level) of some or all factors of production (i.e., inputs) (Beattie and Taylor 1985). The specificity of 'non-proportionate' is important because when you have increasing output capacities (of say, water-treatment facilities), not all production factors (e.g., land, labor, capital, management, etc.) are increased proportionately to attain the increased output.

[5] As noted in Sturdivant et al. (2009), "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." For additional information, refer to the various methodology sections found in this report, Rister et al. (2009), Sturdivant et al. (2009), or Rogers (2008).

Table 1. Matrix of Texas Lower Rio Grande Valley Water-Treatment Facilities Studied and Analyzed, by Size Category and Technology, 2008.

Size Category	~ ~ ~ Facility Names and Maximum-Designed Capacities (in mgd) [a] ~ ~ ~			
	Conventional Surface-Water		Reverse-Osmosis Desalination	
Small	OWSC - Olmito	2.00 mgd[b]	NAWSC - La Sara	1.13 mgd
Medium	McAllen - Northwest	8.25 mgd	Brownsville - Southmost	7.50 mgd

[a] mgd = million gallons per day.

[b] The Olmito facility (i.e., 2.0 mgd) is based on an actual expansion from a 1.0 mgd facility to a 2.0 mgd facility. Adjustments to initial construction costs and other continued costs for a 1.0 mgd facility were made (by Cruz (2008) and Elium (2008), respectively) to reflect a 2.0 mgd facility.

Source: Google Earth 5.2 (2010).

Figure 1. Approximate Location of the Four Facilities in the Texas Lower Rio Grande Valley Analyzed for Economies of Size (i.e., denoted with yellow stars).

Prior Economic Literature

Contemporary literature rarely contains articles focused directly on economies of size, and when it does, the literature typically (and mistakenly) refers to this economic concept as economies of *scale* (Sturdivant et al. 2009). *Economies of scale* is defined as "decreasing marginal and average variable costs incurred as output is increased from a proportionate change in the 'size' [level] of all factors of production [inputs]" (Beattie and Taylor 1985). In the real world, however, increasing the output of potable water at a facility does not require all inputs (e.g., land, labor, capital, energy, management, etc.) to be increased proportionately. Therefore, the correct term to describe the concept that economies (or decreasing marginal and average variable costs) are incurred as output is increased from a non-proportionate change in the 'size' [level] of some or all factors of production [inputs] is *economies of size* (Beattie and Taylor 1985). This report uses the term "economies of size."[6]

Most water-related studies which mention *economies of size* were typically found to identify, analyze, and/or report on a specific facility segment, issue, or cost item (e.g., concentrate/sludge discharge, salinity/turbidity levels, energy cost, chemical cost, etc.). That is, few reports mention multiple facility segments, issues, or cost items; and, no reports were found which identify, analyze, and report on multiple facility segments, issues, and cost items associated with water-treatment technologies. Further, due to the differences between conventional surface-water treatment and reserve-osmosis (RO) desalination, not all facility segments or cost items are common across both water treatment technologies.

Throughout the literature, it is rare to find a study that includes *economies of size* for both surface-water treatment and RO desalination technologies. An exception is Traviglia and Characklis (2006), who estimated the cost of producing water for three different-sized surface-water treatment and brackish-groundwater desalination facilities (i.e., 1 mgd, 10 mgd, and 30 mgd). In addition, the study identified raw water acquisition, conveyance (i.e., pipelines), storage, and residuals disposal (i.e., sludge and brine concentrate) as cost components which significantly impact the cost of production. The estimated costs for both technologies were calculated using cost relationships derived in previous studies of water treatment facility operating and construction costs. The Traviglia and Characklis (2006) results (**Table 2**) indicate that economies of size do exist for both water-treatment technologies. Although the report did not indicate the itemized cost for each of the facility segments or cost items noted above, it is stated that economies of size were suggested for all of the individual facility segments.

Table 2. Reported Cost of Supply and Treatment ($/1,000 gallons) for Surface-Water Treatment Facilities and RO Desalination Facilities.

	~ ~ ~ ~ ~ ~ ~ ~ Facility Size [a] ~ ~ ~ ~ ~ ~ ~ ~		
Technology	1.0 mgd	10.0 mgd	30.0 mgd
Surface-Water Treatment [b]	$1.14	$0.68	$0.49
Desalination [b]	$3.26	$2.10	$1.83

Source: Traviglia and Characklis (2006).

[a] All capital costs were annualized over 20 years with an assumed 8.0% interest rate.

[b] Incoming fresh water for the surface-water treatment was assumed to have a salinity level below 500 mg/L of total dissolved solids (TDS), while incoming brackish water for desalination was assumed to have a salinity level of 2,000 mg/L TDS (Traviglia and Characklis 2006).

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[6] See the "Economies of Size" section of this report for more discussion.

Salinity levels and/or total dissolved solids (TDS) can affect the cost of producing water and influence the decision makers' choice of water-treatment technologies to adopt. Another study by Characklis (2004) focused on the effects of high-salinity levels and/or TDS on the cost of conventional surface-water treatment and RO desalination facilities. The premise of the research was to determine the level of salinity and/or TDS when surface-water treatment is more economical than desalination and vice versa. Economic costs were estimated for both 2.0 mgd and 16.0 mgd surface-water treatment facilities, and for both 2.0 mgd and 16.0 mgd RO desalination facilities. Three salinity/TDS levels examined in this study were: 900 mg/L, 1,250 mg/L, and 1,600 mg/L. The results indicated that for RO desalination, when comparing two facilities with the same salinity/TDS level, the larger RO facility has the lowest cost of production. When the larger RO desalination facility had a salinity level of 1,600 mg/L and the smaller facility had a salinity level of 900 mg/L, however, the smaller facility's cost of production was lower. Although this research was not directly focused on economies of size for water-treatment technologies, the results are interesting and important. The results imply that economies of size are present in surface-water treatment and desalination, and emphasize the critical need in assuring a fair basis is used when comparing costs between types of technologies and/or sizes, i.e., factors other than size can account for observed differences in costs.

For desalination, the disposal of the brine water (i.e., concentrate discharge) can have a major impact on the cost of production. Economies of size research has been reported for this topic by Foldager (2003). He compared how different means of inland disposal of the brine discharge for a RO desalination facility affects the cost of producing potable water for both 1.0 mgd and 10.0 mgd facilities. The three disposal alternatives considered by Foldager (2003) for brine discharge included: deep-well injection, evaporation ponds, and solar ponds. Foldager (2003) assumed a construction cost range, as well as a certain recovery rate of water transported through the RO membranes. He then performed a regression analysis to identify how the three disposal methods influence the cost of production. He concluded that economies of size were identified for RO desalination facilities using deep-well injection, diseconomies were identified for evaporation ponds, and that little to no economies of size were associated with solar ponds.

Economies of size have also been observed in certain capital investment components that define a water-treatment facility's maximum-designed capacity. A report on the Southmost Regional Water Authority Regional Desalination Plant states, "Economies of scale of a 1.0 mgd plant component compared to a 6.0 mgd component yields a 38 percent savings [water per-unit] on RO equipment [for the larger facility]" (Norris 2006a). The report also implies that a ground-storage tank, which is used for both conventional surface-water treatment and RO desalination, demonstrates economies of size. Norris (2006a) indicated a 2.0 million gallon storage tank has a cost of $0.37/gallon, whereas an 8.0 million gallon storage tank has a cost of $0.20/gallon. Cost estimations were calculated by analyzing construction cost bids for water-treatment facilities from 2003-2004. In addition, focusing on the LRGV, Norris (2006b) states that economies of size can be attained in brackish-groundwater desalination if entities collaborate to build regional desalination facilities. The methodology used in this report facilitates further examination of Norris' (2006a; 2006b) recognition of economies of size in capital components.

Boisvert and Schmit (1996) analyzed the treatment and distribution of water for rural water systems, checking for the presence of any economies of size. The treatment process included the cost of building and operating a surface-water treatment facility. The distribution system consisted of the transmission pipelines and distribution mains. Boisvert and Schmit

(1996) estimated the costs by using the Engineering News-Record (ENR) construction cost index and wage history. They also assumed a 20-year useful life for the facility and distribution system, as well as an 8.0% discount rate. They concluded that economies of size do exist for the combined water-treatment facility and distribution system, but individually, the treatment facility showed economies of size while the distribution system had diseconomies of size.

Arroyo (2005) also determined bottom-line cost ($/1,000 gallons) for a number of multi-sized brackish-groundwater desalination facilities. The report estimated the cost of producing water from a high of $2.37/1,000 gals for a 0.1 mgd facility to a low of $0.71/1,000 gals for a 10.0 mgd facility. The methodology for estimating these values was not stated in his report; rather, the author only indicated the assumptions made in calculating "project" and "annual" costs.[7] The study concludes the cost of RO desalination may decrease and economies of size may increase as technology advances. This conclusion apparently follows from his introspection of all costs, particularly with respect to the capital costs of source water, concentrate discharge, water storage, pumping and distribution, environmental/archeology, and land acquisition.

The general absence of studies and incomplete nature of prior work on economies of size for water-treatment technologies provided the impetus for this research. The methodology used herein, combined with the collection and analysis of primary data, allows for a comprehensive and accurate assessment of economies of size for conventional surface-water treatment and RO desalination for the four specific facilities and the geographic area analyzed within the study.

Summary of Economic and Financial Methodology

> Authors' Note: To provide consistency across facility case studies (e.g., Rogers (2008)), the text in this section largely mimics that developed by the authors in Sturdivant et al. (2009). The abridged methodology description below applies to the CITY H_2O ECONOMICS© and DESAL ECONOMICS© models; i.e., the related models are developed on the same methodological platform and have the same design standards. Refer to **Appendix A** for more detail.

Capital water-treatment facility projects: (1) require an initial investment (i.e., dollars) to fund initial construction, (2) require dollars to fund ongoing operations, and (3) provide 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 gallons/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 herein are zero net salvage value (for land, buildings, equipment, etc.) and a continual replacement of such capital items into perpetuity.

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[7] Arroyo's (2005) assumptions include: (a) TDS ranging from 1,000 to 3,000 mg/L, (b) feed water pressure of 300 psi, and (c) power cost of $0.06 per kWh.

To facilitate a Capital Budgeting – NPV analysis (with annuity-equivalent calculations) of water-treatment facilities, agricultural economists from Texas AgriLife Extension Service and Texas AgriLife Research developed the Microsoft® Excel® spreadsheet models DESAL ECONOMICS© and CITY H_2O ECONOMICS©. These models analyze and provide life-cycle costs (e.g., $/ac-ft/year) for up to twelve individual functional expense areas (i.e., facility segments), 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 water-treatment facilities. The models are custom built and useful for analyzing and reporting on all water-treatment facilities, regardless of size, location, etc. Individual facility segments (i.e., expense) areas for a facility may resemble:

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[8]; and
8-12) *unused*.

Results derived using DESAL ECONOMICS© and/or CITY H_2O ECONOMICS© allow apples-to-apples comparisons to be made across different facilities, individual expense areas of like-type facilities, or across different treatment technologies. Noteworthy of mention is the ability of these models to analyze individual expense area results beyond the 'bottom line' of the entire facility. That is, with a standard aggregate analysis, one may observe drastic life-cycle cost differences across facilities, but have no (or minimal) explanation as to the functional cost area(s) causing the disparity. By also analyzing the individual functional cost areas, additional data are provided – such results may highlight the need for a review assessment to see if engineering or construction changes could be made toward reducing the composite life-cycle cost.

Though potentially 'different,' the qualities of potable waters from different treatment facilities are assumed inherently comparable and thus are not adjusted (for incoming/outgoing water quality) to facilitate across-facility/technology comparisons as (a) all potable-water suppliers are required to meet specified quality standards on potable 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 facility (e.g., chemical amount and costs, equipment, operations, etc.). That is, as long as costs (via the process-flow design, asset configuration, management structure, local cost rates, etc. unique to each facility) comparing potable water 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) level. Simply said, the assumption is

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[8] 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, some facilities may have equipment and amenities (e.g., training and meeting rooms) beyond the capabilities of a basic, no-frills facility.

‘potable water is potable water’. Thus, there are no quality adjustments made here to account for differences in incoming or outgoing water quality.[9]

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. 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.[10] 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 (Klinefelter 2002), i.e., only the time portion of the discount factor should be used. Discussions with Griffin and Klinefelter led 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).
>
> 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.[11] Thus, annual nominal dollar cost estimates for years beyond 2006 are inflated at 2.043269%.

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[9] Though adjustments (to account for incoming /outgoing quality differences) are not made here to facilitate comparing 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.

[10] One estimate of a discount rate from an owner's perspective is the cost at which money can be borrowed (Hamilton 2002). Griffin (2002) notes, however, because of the potential government/public funding of this project, the risk component could be ignored. After considering those views and interacting with Penson and Klinefelter (Penson 2002; Klinefelter 2002), a discount rate of 6.125%, consistent with and documented in Rister et al. (2009), was adopted for use in discounting all financial streams.

[11] As provided in Rister et al. (2009), represented mathematically: $\frac{1+6.125\%}{1+4.000\%}-1=2.043269\%$

Previous, Related Economic Case Studies

Recently, Texas AgriLife Research economists conducted economic and financial life-cycle cost case studies on conventional surface-water treatment and RO desalination facilities in the Texas LRGV. By developing and applying the CITY H_2O ECONOMICS© model, Rogers (2008) examined economic and financial life-cycle costs for the City of McAllen's 8.25 mgd Northwest conventional surface-water treatment facility. Sturdivant et al. (2009) performed a similar analysis for the City of Brownsville's 7.5 mgd Southmost RO desalination facility using the DESAL ECONOMICS© model. Since both models are designed on the same methodological platform and with the same design standards, their coordinated development allows for comparable analyses, both within and across water-treatment technologies.

The data input discussed in the following section are for the two 'small' facilities analyzed herein (i.e., Olmito and La Sara), as identified in this report's research objectives. Though original work (Boyer 2008), the following section follows the general format and layout style as that established in the earlier works by Sturdivant et al. (2009) and Rogers et al. (2010).

Overview and Key Data Input – Olmito Facility

This section provides a brief overview, and presents key data input for the Olmito Water Supply Corporation's (WSC) 2.0 mgd surface-water treatment facility; i.e., one of the 'small' facilities analyzed here for its economic and financial life-cycle cost of producing potable water. Determining the life-cycle cost (i.e., baseline) is the first step, with subsequent steps required to determine the "modified" life-cycle cost, which is then used to investigate any presence of economies of size in either, or both, water-treatment technologies. As such, presenting pertinent data used in calculating the baseline life-cycle cost is the next order of business. For organizational purposes, an overview and key input data for the Olmito facility is presented first, with that for the La Sara facility presented in the next section.

Olmito Water Supply Corporation is a privately-owned and operated water utility located north of Brownsville, Texas in Cameron County.[12] Under their certificate of convenience and necessity, Olmito WSC is required to provide potable water and wastewater treatment to residents within a 16.5 square mile service area (Elium 2008). Currently, Olmito WSC manages a 1.0 mgd conventional surface-water treatment facility, which was built in 1964, as well as a 0.75 mgd wastewater treatment system. These facilities serve approximately 1,600 connections and a population of 5,870 (Elium 2008).

In 2007, Olmito WSC began the preliminary stages of designing and planning the expansion of their conventional water-treatment capacity. The goal was to refurbish and expand the existing 1.0 mgd conventional surface-water treatment facility to a 2.0 mgd facility (Elium 2008). The rationale for the expansion was based on Olmito WSC's anticipation of a new forthcoming residential development in their service area. Construction on the development's

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[12] In a privately-owned water utility, each connection (e.g., residential, business, etc.) in the designated serving area holds one share of stock in the water utility. This share of stock provides each connection the right to vote on all decisions the utility may face. In contrast, a publicly-owned water utility (e.g., McAllen Northwest facility) is managed by the respective city's Public Utility Board (PUB) (Browning 2007; Elium 2008).

infrastructure within Olmito's service area (i.e., roads, lot preparation, electric lines, and water line) had already commenced, and Olmito WSC anticipated the development to require upwards of 500 new potable water and wastewater connections (Elium 2008).

To facilitate financing of the expansion and refurbishing, Olmito WSC secured a United States Department of Agricultural (USDA) Rural Development grant for about $2,000,000, and a USDA Rural Development loan for approximately $2,000,000 (Elium 2008). The objectives of both the USDA Rural Development grant and loan programs are to promote growth in rural areas by providing resources for the development and construction of new and improved rural water and wastewater systems (U.S. General Service Administration 2008).[13] These funds allow Olmito WSC to subsidize the cost of expanding and refurbishing their potable water system capacity, along with repairing a water main and construction of a new elevated storage tank.[14]

Since the data input for the Olmito facility's initial construction costs and continued costs were extrapolated from the costs of expanding and refurbishing the current 1.0 mgd facility to a 2.0 mgd facility, the analysis is more accurately defined as an engineered case study of a 2.0 mgd conventional surface-water facility. That is, all data-input reflect accurate estimates of constructing a new 2.0 mgd facility "from scratch" and operating a new 2.0 mgd facility.

Construction Period and Expected Useful Life

Based on conversations with the consulting engineer (Cruz 2008), the construction period for the Olmito new 2.0 mgd facility is assumed to be 12-months. Though delays with construction are common, the one-year period provides ample time to achieve the construction goals.

Similar to the work by Rogers (2008) and Sturdivant et al. (2009), the various civil, electrical, and mechanical components of the Olmito facility are expected to have useful lives ranging from a low of five years for items such as high-speed pumps, to a high of 40 years for structural items such as buildings, storage tanks, concrete, etc.[15] For this analysis, a maximum useful life of 40 years is established for the entire 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 (Sturdivant et al. 2009). Combined, specified capital-replacement and annual-operational expenses provide for a facility that will maintain productive capacity for 40 years.

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[13] For more information such as uses, restrictions, interest rates, and loan terms, refer to the Catalog of Federal Domestic Assistance number 10.760 (U.S. General Service Administration 2008).

[14] A private water purveyor such as Olmito may ignore capital costs offset by federal/state grants when estimating their cost of production. Such an approach does not accurately portray the full societal costs, however. The benefit of the grant and loan attained by Olmito suggests the life-cycle cost of treating potable water are reduced by about $100/ac-ft ($0.50/1,000 gals); i.e., below that identified in the analysis reported herein.

[15] The facilities analyzed by Rogers (2008) and Sturdivant et al. (2009) had useful lives of 50-years. The employed methodology (see methodology sections in this report and the work by Rister et al. (2009), Sturdivant et al. (2009), and Rogers (2008)) is chosen for its ability to facilitate 'apples-to-apples' comparisons of facilities with differing useful lives.

Annual Water Production

At 2.0 mgd, the new Olmito facility would have a total annual output of 2,240 ac-ft, assuming a 100% production efficiency (PE) rate. For this analysis, however, allowances are made for real-world operations which necessarily allow for various demand/supply interruptions. Based on the current Olmito facility's (i.e., designed capacity of 1.0 mgd) annual output for FY 2007, the PE level observed is 52% of maximum designed capacity (Elium 2008). The modeled 52% rate (for the new 2.0 mgd facility) equates to an expected 1,165 ac-ft of annual output. This value is held constant during each year of the facility's productive life in the baseline analysis.

Purchase of Water Rights

Associated with an entity increasing its level of potable water production (using raw water from the Rio Grande) is the need to acquire additional water rights. Since one of this study's objectives is to derive a "total" life-cycle cost, the cost of purchasing water rights is included. This is consistent with prior, related work by Rogers (2008).

Stubbs et al. (2003) indicate municipal water suppliers in the Texas LRGV can purchase or lease municipal water rights from another municipality, a private individual, or from an irrigation district. The cost of the current market price is valued at a level equal to the opportunity cost of purchasing water rights in the Valley today. Recording the cost based on today's market price is consistent with the economic concept of opportunity cost.[16] That is, this analysis is premised on a current (i.e., 2006) basis, and reflects current costs, whether the entity purchased water rights in an earlier time period at a lower rate, or not (Rogers 2008).

Through communications with local irrigation district managers, the current (2006) price of a permanent municipal water right was estimated to be approximately $2,300/ac-ft for this region (Lambert 2007; Barrera 2007). This analysis assumes a purchase of 2,151 ac-ft of water rights, which is 96% of the annual maximum designed capacity of the new 2.0 mgd facility. This 96% level of required water rights was determined by assuming a municipality would purchase enough water rights for maximum annual capacity of a facility less a two-week shut-down time that is considered typical (Rogers 2008). Consequently, the total assumed cost of water rights purchased equals $4.95 million, which is calculated by multiplying the 2006 cost of a water right ($2,300/ac-ft) by the annual water production at 96% efficiency (2,151 ac-ft).

Initial Construction Costs

Olmito WSC's decision to expand its current conventional surface-water treatment facility allows it to continue to utilize some existing infrastructure (e.g., land, concrete, storage, etc.). As a result, the preliminary construction costs data identified did not include all of the input costs necessary to build a new self standing 2.0 mgd conventional surface-water treatment facility from the ground up. Working with Orlando Cruz (2008), Olmito WSC's consulting engineer, and James Elium III (2008), the manager of Olmito WSC, opportunity cost estimates were generated for the input items, however, that were not included in the new expansion construction cost data. The resulting comprehensive cost estimates approximate the initial

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[16] As provided by Rogers (2008), the concept of opportunity cost is defined as the value of the next best alternative of a resource (Perloff 2004). A more precise definition provided in Thomas and Maurice (2005) states, "opportunity cost of using an owner-supplied resource is the best return the owners of the firm could have received had they taken their own resource to market instead of using it themselves." Herein, the current market price is used as it represents the money Olmito WSC would receive if they sold water rights today.

construction costs for building a completely new 2.0 mgd conventional surface-water treatment facility.

Initial construction costs for a new 2.0 mgd facility for Olmito WSC totaled $4.74 million, in 2008 dollars (Cruz 2008). For this analysis, 2006 was chosen as the benchmark year in order to make the analysis more consistent with other, similar research analyses (e.g., Sturdivant et al. 2009, Rogers et al. 2010). Therefore, the construction costs were deflated two years at a 2.043% annual discount rate to account for inflation, resulting in an adjusted 2006 construction cost of $4.56 million. To facilitate analysis detail and water-treatment facility comparisons, the total cost is divided into 11 cost-item categories and dissected into six individual segments common to conventional surface-water treatment facilities (**Table 3**). As depicted, the most cost-intensive areas for initial construction of the Olmito facility are the *Delivery to Municipal Line/Storage* ($1,403,056), followed by the *Treatment Unit* ($1,175,454), and the *Raw Water Intake/Reservoir* ($976,978). When viewed from an individual cost item perspective, the *Metals* ($964,544) and *Equipment & Installation* ($951,649) items are the largest contributors to total initial construction costs.

Continued Costs

Continued costs represent the annual costs incurred during ongoing operations from the time of construction completion until the end of the facility's useful life (i.e., 40 years, in this case). Cruz (2008) and Elium (2008) estimated annual operation and maintenance (O&M) costs for a new 2.0 mgd facility, based upon actual FY2007 cost data prepared by Olmito WSC for its 1.0 mgd facility, with expansion factors used to attain estimated annual continued costs for a 2.0 mgd facility. These costs are further adjusted to a basis of 2006 dollars, and compounded at 2.043% every year thereafter. For the engineered 2.0 mgd Olmito facility, the continued costs totaled $681 thousand per year (in 2006 dollars) (Elium 2008), and are divided into two categories (**Table 4**): (1) administrative and (2) operations and maintenance (O&M).

Since there is no "umbrella," or other ownership/management entity overseeing the Olmito facility, the administrative category has $0 of related expenses. There are administrative expenses, however, at the plant level (i.e., depicted as "Operations and Maintenance" expenses).

Annual O&M expenses at the Olmito facility total $681 thousand. For analysis-detail and water treatment-facility-comparison reasons, this category is divided into 11 cost-item categories, as well as broken into six individual segments common to conventional water treatment facilities (**Table 4**). As depicted in **Table 4**, the most costly area to operate and maintain each year is the *Treatment Unit* ($264,317) followed by the *Delivery to Municipal Line/Storage* ($176,295). When viewed from an individual cost item perspective, the cost for *Labor* ($179,866) is the largest contributor to continued O&M costs.

Table 3. Initial Construction Costs for a 2.0 mgd Facility Based on the Olmito Conventional Surface-Water Treatment Facility, Across Individual Segments, in 2006 Dollars.

	Individual Segments of the Olmito Facility						
Initial Construction Cost Item	Raw Water Intake/ Reservoir	Treatment Unit	Sludge Disposal	Delivery to Municipal Line/ Storage	Operations' Supporting Facilities	Overbuilds & Upgrades [a]	Initial Total Costs
Pre-Project	$125,059	$109,319	$19,357		$89,492		$343,227
Building & Site Construction	67,258				205,132		272,390
Concrete Structures	24,585	115,947	33,612				174,145
Equipment & Installation	19,204	431,458		30,411	470,573		951,649
Excavation & Site Work	458,492	3,330	140,077				601,899
Land	28,267	24,709	4,375	12,236	20,228		89,815
Metals	9,604	33,000		921,940			964,544
Painting	14,405	14,865					29,270
Pipe	62,999	31,770	19,207	438,469			552,445
Pumping & Valve Control	167,102	54,524					221,626
Chemical Feed		356,531					356,531
TOTAL	$976,978	$1,175,454	$216,629	$1,403,056	$785,424	$0	$4,557,541

Source: Elium (2008); Cruz (2008).

[a] "Overbuilds" represent excess initial construction completed to allow for future facility expansion, while "upgrades" represent "over-the-top" construction beyond that necessary for basic water treatment (Sturdivant et al. 2009; Rogers et al. 2010). Though the Olmito facility has no "Overbuilds and Upgrades," the segment is included to be consistent with, and facilitate comparisons with, related analyses (e.g., Sturdivant et al. 2009, Rogers et al. 2010).

Table 4. Baseline Annual Continued Costs, Allocated Across Individual Segments, for a 2.0 mgd Facility Based on the Olmito Conventional Surface-Water Treatment Facility, in 2006 Dollars.[a]

			Allocation to Individual Segments (i.e., Cost Centers) of a 2.0 mgd Olmito Facility						
Continued Cost Item	Total Costs (for a 1.0 mgd facility)	Expansion Factor (to a 2.0 mgd facility)	Raw Water Intake/ Reservoir	Treatment Unit	Sludge Disposal	Delivery to Municipal Line/Storage	Operations' Supporting Facilities	Overbuilds & Upgrades [b]	Annual Total Costs (for a 2.0 mgd facility)
ADMINISTRATIVE									
- Administrative Overhead	$0	0%	$0	$0	$0	$0	$0	$0	$0
- Insurance									
- Labor									
- Maintenance									
- Other									
- Vehicles/Rolling Stock									
Sub-Total	$0		$0	$0	$0	$0	$0	$0	$0
OPERATIONS & MAINTENANCE									
- Administrative	$21,345	0%	$8,538	$5,336	$0	$5,336	$2,134	$0	$21,345
- Office Expense	31,113	20%	747	22,401	373	11,201	2,613		37,336
- Chemical	51,763	100%		103,526					103,526
- Electrical	48,167	100%	19,267	24,084	14,450	28,900	9,633		96,334
- Insurance	19,989	25%	4,997	12,493	4,997	1,249	1,249		24,986
- Labor	149,888	20%	26,980	44,966	8,993	71,946	26,980		179,866
- Repair & Maintenance	40,000	50%	6,000	27,000	6,000	18,000	3,000		60,000
- Licenses & Regulatory	36,855	10%	12,162	10,135	6,081	12,162			40,541
- Miscellaneous	25,000	50%	1,875	9,375		22,500	3,750		37,500
- Equipment Rental	20,000	0%	5,000	5,000	1,000	5,000	4,000		20,000
- Water Delivery	30,473	95%	59,422						59,422
Sub-Total	$474,593		$144,988	$264,317	$41,895	$176,295	$53,360	$0	$680,855
TOTAL	$474,593								$680,855

Source: Elium (2008); Cruz (2008).

[a] Costs are for the baseline analysis (i.e., operating at 52% PE); refer to **Appendix B** for modified analysis which omits certain costs for comparisons across facilities and/or technologies.

[b] Represents construction beyond the necessities and captures "elbow room" for future expansion; refer to footnote 8.

Capital Replacement Costs

Several capital replacement costs occur on an intermittent basis and facilitate perpetual water-treatment operations. That is, during the 40 years of the facility's maximum useful life, 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.[17] **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 for a 2.0 mgd Facility Based on the Olmito Facility, in 2006 Dollars.

Capital Item	Segment	Frequency of Replacement	Cost per Item (2006 dollars)	No. of Items Replaced Each Occurrence
High Speed Pump	Treatment Unit	5 years	$10,000	6
High Speed Pump	Delivery to Municipal Line/Storage	5 years	20,000	2
Filter Media	Treatment Unit	10 years	25,000	1
Disinfection System	Treatment Unit	10 years	60,000	1
Trucks	Operation's Facilities	7 years	16,000	2

Source: Elium (2008); Cruz (2008).

Overview and Key Data Input – La Sara Facility

This section provides a brief overview, and presents key data input for the North Alamo Water Supply Corporation's (NAWSC's) 1.13 mgd brackish-groundwater desalination facility; i.e., one of the 'small' facilities analyzed here for its economic and financial life-cycle cost of producing potable water. Determining the life-cycle cost (i.e., baseline) is the first step, with subsequent steps required to determine the "modified" life-cycle cost, which is then used to investigate any presence of economies of size in either, or both, water-treatment technologies. As such, presenting pertinent data used in calculating the baseline life-cycle cost is the next order of business. For organizational purposes, an overview and key input data for the Olmito facility was presented first, with that for the La Sara facility presented in this section.

The La Sara brackish-groundwater desalination facility is privately-owned and operated by North Alamo Water Supply Corporation.[18] The facility serves residents of eastern Hidalgo, Willacy, and northwest Cameron Counties with potable water and wastewater treatment services (Browning 2007). NAWSC's designated service area spreads across 973 square miles, covering

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[17] 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.

[18] In a privately-owned water utility, each connection (e.g., residential, business, etc.) in the designed serving area holds one share of stock in the water utility. This share of stock provides each connection the right to vote on all decisions the utility may face. In contrast, a publicly-owned water utility (e.g., McAllen Northwest facility) is managed by the respective city's Public Utility Board (PUB) (Browning 2007; Elium 2008).

16 rural communities, with approximately 140,000 customers. As of 2007, NAWSC managed six conventional surface-water treatment facilities and one brackish-groundwater desalination facility, with a second desalination facility in the final stages of being completed and two more desalination facilities in the planning stages (Browning 2007). In addition to the municipal water-treatment facilities, NAWSC also owns and operates four wastewater treatment facilities. Combined, all seven online potable water facilities produce a total of 22 mgd of potable water and the four wastewater facilities treat a combined total of 0.646 mgd of wastewater (North Alamo Water Supply Corporation 2007).

In 2003, NAWSC was faced with an increase in demand from their customers, which challenged its municipal water supply system and encouraged the expansion of its water-treatment capacity. NAWSC chose to diversify its municipal water system by building the 1.13 mgd La Sara brackish-groundwater desalination facility during 2003-2004.

The La Sara facility's raw water supply comes from one brackish-groundwater well, which taps the Gulf Coast aquifer at approximately 980 feet deep. The Gulf Coast aquifer follows along the Gulf of Mexico and stretches from Florida to Mexico. Historically, the aquifer has provided approximately 1.1 million ac-ft of water per year for agricultural and municipal purposes in Texas (Chowdhury and Turco 2006). The La Sara facility's source water has an incoming salinity level of approximately 2,700 parts per million (ppm) (Browning 2007).

Once the raw source water reaches the main facility, it is pumped through two 0.5 mgd reverse osmosis (RO) trains, which treat the water to a salinity level of about 100 ppm. The treated water is then blended with bypass water (i.e., partially treated by the cartridge filters),[19] resulting in final-product (potable) water that is approximately 87% treated water and 13% bypass water. The potable water has a salinity level of roughly 438 ppm (Browning 2007), which is comparable to the water quality achieved at the Southmost facility (Sturdivant et al. 2009).

Construction Period and Expected Useful Life

The construction period for the La Sara facility lasted 18-months, spanning from April 2003 to November 2004 (Browning 2007; White 2007). Consistent with Sturdivant et al. (2009), a construction period of 12-months was identified as appropriate and used in this analysis.[20]

Similar to the work by Rogers (2008) and Sturdivant et al. (2009), the various civil, electrical, and mechanical components of the La Sara facility are expected to have useful lives ranging from a low of three years for items such as vehicles, 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 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

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[19] RO desalination treats water to a purer salinity quality (i.e., 100 ppm) than is required by the EPA (i.e., 1,000 ppm (College Station Utilities 2006)). It is most cost effective to blend some minimally-treated water with treated water than to treat all of the water under less pressure (Sturdivant et al. 2009).

[20] The actual construction period was 18 months. Since the CITY H_2O ECONOMICS© model is based on complete years, a decision to be consistent with Sturdivant et al. (2009) was made. Extrapolating based on impromptu sensitivity tables suggests calculated results to be within 1.0%-1.1% of the reported baseline results.

replacement of such items (e.g., membranes, pumps, motors, etc.) to ensure the facility's full anticipated productive term. Other, non-capital expenses, such as electrical switches, valves, etc., are captured in annual operating expenses (Sturdivant et al. 2009). Combined, specified capital-replacement and annual-operational expenses provide for a facility that will maintain productive capacity for 50 years.

Annual Water Production

At 1.13 mgd, the La Sara facility would have a total annual output of 1,266 ac-ft, assuming a 100% production efficiency (PE) rate. For this analysis, however, allowances are made for real-world operations which necessarily allow for various demand/supply interruptions. Based on production data for the La Sara facility for FY 2006, the PE level of 65% of maximum designed capacity is used (Browning 2007). The modeled 65% rate equates to an expected 825 ac-ft of annual output. This value is held constant during each year of the facility's productive life in the baseline analysis.

Initial Construction Costs

Similar to the Olmito facility, some existing infrastructure (e.g., storage tank, pumps, etc.) at one of NAWSC's nearby conventional surface-water treatment facilities is in close proximity to the desired location for the La Sara facility such that it could be shared between the two. As a result, the preliminary construction costs data identified did not include all of the input costs necessary to build a new self-standing 1.13 mgd desalination facility from the ground up. By collaborating with Browning (2007) and White (2007), however, cost estimates (i.e., opportunity costs) for already existing infrastructure were determined. As a consequence, construction costs data for a separate and independent 1.13 mgd brackish-groundwater desalination facility were estimated.

Initial construction costs for a new 1.13 mgd facility for NAWSC totaled $2.44 million, in 2004 dollars (Browning 2007). For this analysis, 2006 was chosen as the benchmark year in order to make the analysis more consistent with other, similar, planned and work-in-progress research analyses. Therefore, the construction costs were inflated two years at a 2.043% annual discount rate to account for inflation, resulting in an adjusted 2006 construction cost of $2.54 million. To facilitate analysis detail and water-treatment facility comparisons, the total cost is divided into 11 cost-item categories and dissected into seven individual segments common to desalination facilities (**Table 6**). As depicted, the most cost-intensive areas for initial construction of the La Sara facility are the *Main Facility/Treatment Process* ($1,502,635), followed by the *Well Field* ($535,137). When viewed from an individual cost item perspective, the *RO Equipment & Installation* ($996,662) and *Well* ($392,629) items are the largest contributors to total initial construction costs.

Continued Costs

Continued costs represent the annual costs incurred during ongoing operations from the time of construction completion until the end of the facility's useful life (i.e., 50 years, in this case). Browning (2007) and White (2007) provided annual operation and maintenance (O&M) costs for the desalination facility based on actual FY 2006 financial data; i.e., such data was deemed accurate based on three years of facility operation. To account for inflation, the FY 2006 continued costs are compounded at 2.043% every year thereafter. For the 1.13 mgd La Sara facility, the continued costs totaled $301 thousand per year (in 2006 dollars) (Browning 2007) and are divided into two categories (**Table 7**): (1) administrative and (2) operations and maintenance (O&M).

The “umbrella”, or ownership/management entity overseeing the La Sara facility is NAWSC, which allocates proportional administrative-category expenses. The administrative expenses amount to $128 thousand annually.

Annual O&M expenses at the La Sara facility total $173 thousand. For analysis-detail and water treatment-facility-comparison reasons, this category is divided into six cost-item categories, as well as broken into seven individual segments common to conventional water treatment facilities (**Table 7**).[21] As depicted in **Table 7**, the most costly area to operate and maintain each year is the *Main Facility/Treatment Process* ($111,687), followed by the *Finished Water & Tank Storage* ($56,865). When viewed from an individual cost item perspective, the cost for energy, or *Electrical* ($119,875), is the largest contributor to continued O&M costs.

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[21] Recognition is made that the ‘Overbuilds & Upgrades’ segment has $0 allocated, as the facility is basic in design and construction.

Table 6. Initial Construction Costs for the 1.13 mgd La Sara Brackish Ground-Water Desalination Facility, Across Individual Segments, in 2006 Dollars.

	Individual Segments of the La Sara Facility							
Initial Construction Cost Item	Well Field	Transmission Line	Main Facility /Treatment Process	Concentrate Discharge	Finished Water & Tank Storage	High Service & Delivery Pipeline	Overbuilds & Upgrades [a]	Initial Total Costs
Pre-Project	$41,651		$5,206					$46,858
Land	820		2,461					3,281
Well	392,629							392,629
Pipeline	2,280			$6,482		$18,222		26,985
Building & Site Construction			176,386					176,386
RO Equipment & Installation			996,662					996,662
Storage Tank					$260,321			260,321
Electrical	44,833		268,997		44,833			358,663
SCADA	14,266		14,266		14,266			42,797
Engineering	34,232	$34,232	34,232	34,232	34,232	34,232		205,393
Miscellaneous	4,425	4,425	4,425	4,425	4,425	4,425		26,553
TOTAL	$535,137	$38,658	$1,502,635	$45,140	$358,077	$56,880	$0	$2,536,527

Source: Browning (2007); White (2007).

[a] "Overbuilds" represent excess initial construction completed to allow for future facility expansion, while "upgrades" represent "over-the-top" construction beyond that necessary for basic water treatment (Sturdivant et al. 2009; Rogers et al. 2010). Though the La Sara facility has no "Overbuilds and Upgrades," the segment is included to be consistent with, and facilitate comparisons of, related analyses (e.g., Sturdivant et al. 2009, Rogers et al. 2010).

Table 7. Baseline Annual Continued Costs, Allocated Across Individual Segments, for the 1.13 mgd La Sara Brackish-Groundwater Desalination Facility, in 2006 Dollars.[a]

	Allocation to Individual Segments (i.e., Cost Centers) of the La Sara Facility							
Continued Cost Item	Well Field	Transmission Line	Main Facility/ Treatment Process	Concentrate Discharge	Finished Water & Tank Storage	High Service & Delivery Pipeline	Overbuilds & Upgrades [b]	Annual Total Costs (for a 1.13 mgd facility)
ADMINISTRATIVE								
- Administrative Overhead	$18,721	$18,721	$18,721	$18,721	$18,721	$18,721	$0	$112,327
- Insurance	2,598	2,598	2,598	2,598	2,598	2,598		15,586
- Labor								
- Maintenance								
- Other								
- Vehicles/Rolling Stock								
Sub-Total	$21,319	$21,319	$21,319	$21,319	$21,319	$21,319	$0	$127,913
OPERATIONS & MAINTENANCE								
- Administrative								
- Office Expense								
- Chemical			$26,877					$26,877
- Electrical	$29,969		59,938		$29,969			119,875
- Insurance								
- Labor	3,120	$3,120	3,120	$3,120	3,120	$3,120		18,720
- Repair & Maintenance	433	433	433	433	433	433		2,600
- Concentrate Disposal				3,000				3,000
- Miscellaneous								
- Water Testing	112			112	2,024			2,249
- Water Delivery								
Sub-Total	$33,635	$3,553	$90,368	$6,666	$35,546	$3,553	$0	$173,321
TOTAL	$54,953	$24,872	$111,687	$27,985	$56,865	$24,872	$0	$301,234

Source: Browning (2007); White (2007).

[a] Costs are for the baseline analysis (i.e., operating at 65% PE); refer to **Appendix B** for modified analysis which omits certain costs for comparisons across facilities and/or technologies.

[b] Represents construction beyond the necessities and captures "elbow room" for future expansion; refer to footnote 8.

Capital Replacement Costs

Several capital replacement costs occur on an intermittent basis and facilitate perpetual water-treatment operations. That is, during the 50 years of the facility's maximum useful life, 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.[22] **Table 8** depicts the needed capital replacement items, as well as their replacement occurrence and costs, incorporated in this study.

Table 8. Capital Replacement Items, Occurrence, and Costs for the 1.13 mgd La Sara Facility, in 2006 Dollars.

Capital Item	Segment	Frequency of Replacement	Cost per Item (2006 dollars) [a]	No. of Items Replaced Each Occurrence
Well Pump	Well Field	6 years	$36,000	1
RO Membrane	Main Facility/Treatment Process	6 years	79,166	1
Vehicle [b]	Main Facility/Treatment Process	3 years	2,200	1

Source: Browning (2007);White (2007).

[a] Based on three years of actual facility cost data. Thus, costs reflect actual values for items with ≤3 years useful life, and estimates for items with >3 years useful life.

[b] Proportional allocation of the NAWSC fleet.

Results of the Economic and Financial Analysis – Olmito and La Sara Facilities

> Authors' Note: To provide consistency across reports and facilitate comparisons across models, facility case studies, etc., the layout and text in this section largely mimics that developed by the authors in Sturdivant et al. (2009), with values reflecting the Olmito and La Sara facilities.

Composite results for the economic and financial analysis of the prior data, using the Excel® spreadsheet models CITY H_2O ECONOMICS© and DESAL ECONOMICS©, are presented. For the Olmito and La Sara facilities, a summary of aggregate estimated baseline results is presented first, with results presented across facility segments, and then by cost type, category, and item. Herein, the phrases '*cost-of-producing water*' and '*cost-of-producing-**and-delivering** water*' are often used interchangeably. Since the costs of the two facilities analyzed (i.e., Olmito and La Sara) 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. (i.e., free on board) municipal delivery point basis. This point of delivery destination should not be confused with household delivery, but rather is only to a point within the municipal delivery-system infrastructure.

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[22] 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.

The analyses reported here for the Olmito and La Sara facilities are the (baseline) estimated life-cycle costs of producing potable water for the two facilities with their current operating/production efficiencies. Though useful, the results presented in this section have not been "modified" or "leveled," and are therefore not the most appropriate measures for use in making comparisons (i.e., across the two facilities, or others). These results are useful, however, for understanding the economic and financial life-cycle costs for the Olmito and La Sara facilities, and for establishing the foundation for the modified analyses which are detailed in **Appendix B**.

Results – Aggregate Baseline – Olmito Facility

Initial Construction Costs: These costs for the Olmito facility (**Table 9**) amount to $4,946,555 in nominal 2006 dollars (**Table 9**). 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 9**).

Water Production: Over the 40-year expected useful life, the annual production of 1,165 ac-ft, using the modeled effective capacity of 52%, will total 46,598 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 22,171 ac-ft. The annuity equivalent of this real value, or 'annualized amount,' is 1,109 ac-ft per year (**Table 9**).[23]

Total Life-Cycle Costs: Summing all water rights, initial, continued, and capital replacement costs over the 40-year expected useful life result in $54,897,262 in nominal dollars. Adjusting this value for time and inflation at 6.125% results in a real value of $23,020,616 (**Table 9**). This value represents the net total life-cycle costs of constructing and operating the Olmito facility (in 2006 dollars). That is, at the time a commitment is made to fund the initial construction costs of $4,557,541, an additional $18,463,075 (i.e., $23,020,616 minus $4,946,555) is also implicitly committed (**Table 9**).

Annual Cost Annuity: Calculating the annuity equivalent of the $23,020,616 real value results in an 'annualized cost' of $1,545,037. This real value represents, in current 2006 dollars, the net annual costs of constructing and operating the Olmito facility.[24]

Cost of Producing (and Delivering) Water: To derive the annual *Cost-of-Producing (and Delivering) Water*[25] value on a per ac-ft basis, the total cost annuity of $1,545,037 per

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[23] 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.

[24] For the 'Water Production' and 'NPV of Total Cost Stream' results in **Table 9**, the real-value amounts are less than the nominal-value amounts. This occurs because continued and capital replacement costs, and water production, which occur in latter years of the facility's life are discounted (at 6.125% and 4.000%, respectively) and thus do not contribute to the summed real total as much as do costs incurred during earlier years. Also, the nominal water-production value makes no distinction of time and allows production in year 1 (after construction) to have the same impact as that produced in year 40. 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.

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

year is divided by the total water-production annuity of 1,109 ac-ft per year {361,344 1,000-gallon units per year}. This results in a baseline annual cost of producing and delivering treated water with the Olmito facility of $1,393.28 per ac-ft {$4.2758 per 1,000-gallons} (**Table 9**). 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 (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 facility, with all of the attributes previously described.

Table 9. Aggregate Baseline Results for Production and Costs for a 2.0 mgd Olmito Conventional Surface-Water Treatment Facility, in 2006 Dollars.[a]

Results	Units	Nominal Value	Real Value [b]
Initial Water Rights	2006 dollars	$4,946,555	$4,946,555
Initial Facility Costs	2006 dollars	$4,557,541	$4,557,541
Water Production	ac-ft (lifetime)	46,598	22,171
- annuity equivalent	ac-ft/year		1,109
Water Production	1,000-gal (lifetime)	15,184,000	7,224,362
- annuity equivalent	1,000-gal/year		361,344
NPV of Total Cost Stream [c]	2006 dollars	$54,897,262	$23,020,616
- annuity equivalent	$/year		$1,545,037
Cost-of-Producing & Delivering Water [d]	$/ac-ft/year		$1,393.28
Cost-of-Producing & Delivering Water [d]	$/1,000-gal/year		$4.2758

Source: Boyer (2008), with modifications.

[a] These baseline results reflect the Olmito facility in its current operating state (i.e., 52% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are not involved to be 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] These are the total net cost stream values (nominal and real) relevant to producing conventional surface-treated 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.

[d] Delivery is to a point within the municipal delivery-system infrastructure; i.e., not to individual households.

Results – Aggregate Baseline – La Sara Facility

Initial Construction Costs: These costs for the La Sara facility (**Table 10**) amount to $2,536,527 in nominal 2006 dollars (**Table 10**). 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 10**).

Water Production: Over the 50-year expected useful life, the annual production of 825 ac-ft, using the modeled effective capacity of 65%, will total 41,241 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 17,038 ac-ft. The annuity equivalent of this real value, or 'annualized amount,' is 788 ac-ft per year (**Table 10**).[26]

Total Life-Cycle Costs: Summing all initial, continued, and capital replacement costs over the 50-year expected useful life results in $31,139,496 in nominal dollars. Adjusting this value for time and inflation at 6.125% results in a real value of $9,127,005 (**Table 10**). This value represents the net total life-cycle costs of constructing and operating the La Sara facility (in 2006 dollars). That is, at the time a commitment is made to fund the initial construction costs of $2,536,527, an additional $6,590,478 (i.e., $9,127,005 minus $2,536,527) is also implicitly committed (**Table 10**).

Annual Cost Annuity: Calculating the annuity equivalent of the $9,127,005 real value results in an 'annualized cost' of $587,356. This real value represents, in current 2006 dollars, the net annual costs of constructing and operating the La Sara facility.[27]

Cost of Producing (and Delivering) Water: To derive the annual *Cost-of-Producing (and Delivering) Water*[28] value on a per ac-ft basis, the total cost annuity of $587,356 per year is divided by the total water-production annuity of 788 ac-ft per year {256,815 1,000-gallon units per year}. This results in a baseline annual cost of producing and delivering treated water with the La Sara facility of $745.25 per ac-ft {$2.2871 per 1,000-gallons} (**Table 10**). 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 (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 facility, with all of the attributes previously described.

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

[27] For the 'Water Production' and 'NPV of Total Cost Stream' results in **Table 10**, the real-value amounts are less than the nominal-value amounts. This occurs because the continued and capital replacement costs, and water production, occurring in latter years of the facility's life are discounted (at 6.125% and 4.000%, respectively) and thus do not contribute to the summed real total as much as do costs incurred during earlier years. Also, the nominal water-production value makes no distinction of time and allows production in year 50 (after construction) to have the same impact as that produced in year 1. 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.

[28] 'Delivery' is to a point within the municipal delivery-system infrastructure; i.e., not to individual households.

Table 10. Aggregate Baseline Results for Production and Costs for the 1.13 mgd La Sara Brackish-Groundwater Desalination Facility, in 2006 Dollars.[a]

Results	Units	Nominal Value	Real Value [b]
Initial Water Rights	2006 dollars	$0	$0
Initial Facility Costs	2006 dollars	$2,536,527	$2,536,527
Water Production	ac-ft (lifetime)	41,241	17,038
- annuity equivalent	ac-ft/year		788
Water Production	1,000-gal (lifetime)	13,438,500	5,551,699
- annuity equivalent	1,000-gal/year		256,815
NPV of Total Cost Stream [c]	2006 dollars	$31,139,496	$9,127,005
- annuity equivalent	$/year		$587,356
Cost-of-Producing & Delivering Water [d]	$/ac-ft/year		$745.25
Cost-of-Producing & Delivering Water [d]	$/1,000-gal/year		$2.2871

Source: Boyer (2008), with modifications.

[a] These baseline results reflect the La Sara facility in its current operating state (i.e., 65% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are not involved to be 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] These are the total net cost stream values (nominal and real) relevant to producing 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.

[d] Delivery is to a point within the municipal delivery-system infrastructure; i.e., not to individual households.

Results – by Facility Segment – Olmito Facility

CITY H_2O ECONOMICS© uniquely analyzes and provides comparable life-cycle costs for up to twelve individual functional expense areas and for the entire facility. Here, the above aggregate annual life-cycle cost-of-producing (and delivering) water of $1,393.28 per ac-ft (**Table 9**) is dissected into the six functional expense areas detailed earlier.[29]

Table 11 shows the NPV of the net cost stream to range from a low of $0 for *Overbuilds & Upgrades*, to a high of $6,551,361 for *Treatment Unit*. These values signify the relative impact individual components' initial construction and future O&M costs have on costs for the total facility. Also in **Table 11**, the annuity equivalent values are provided for individual components, which range from $0/year for *Overbuilds & Upgrades*, to a high of $439,697/year

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[29] CITY H_2O ECONOMICS© can analyze up to twelve individual expense areas. For this analysis, however, only six individual expense areas (not counting water rights) 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 Olmito facility).

for *Treatment Unit*. These values are interpreted as the annualized costs for each component, inclusive of all life-cycle costs and reported in 2006 dollars (Rister et al. 2009).

Further delineation of the annuity equivalents reveals the economic and financial life-cycle costs range from $0/day for the *Overbuilds & Upgrades* segment, to a high of $1,205/day for *Treatment Unit*. The total life-cycle cost for all six segments equates to $4,233/day (reported in 2006 dollars).

Key annualized cost results presented in **Table 11** are the segmented costs-of-producing water for the six individual facility components. This table reveals a range in the facility segments' cost-of-producing-water values from a low of $0/ac-ft/year {$0.0000/1,000-gallons/year} for *Overbuilds & Upgrades*, to a high of $396.51/ac-ft/year {$1.2168/1,000-gallons/year} for *Treatment Unit*. In both the aggregate and segmented form, the total annual cost-of-producing water at the Olmito facility and delivering it on a f.o.b. basis to the municipal delivery point is $1,393.28 per ac-ft {$4.2758 per 1,000 gallons} (**Tables 9** and **11**).

Table 11. Costs of Producing (and Delivering) Water for the Facility Segments of a 2.0 mgd Olmito 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-gal/year [e]	% of Total Cost
A) Initial Water Rights Purchase	$4,946,555	$331,990	$910	$299.38	$0.9188	21.5%
1) Raw Water Intake/Reservoir	3,736,317	250,764	687	226.13	0.6940	16.2%
2) Treatment Unit	6,551,361	439,697	1,205	396.51	1.2168	28.5%
3) Sludge Disposal	1,013,956	68,052	186	61.37	0.1883	4.4%
4) Delivery to Municipal Line/Storage	4,989,760	328,782	901	296.49	0.9099	21.3%
5) Operations' Supporting Facilities	1,873,667	125,752	345	113.40	0.3480	8.1%
6) Overbuilds & Upgrades	0	0	0	0.00	0.0000	0.0%
TOTAL	$23,020,616	$1,545,037	$4,233	$1,393.28	$4.2758	100.0%

Source: Boyer (2008), with modifications.

[a] These baseline results reflect a 2.0 mgd Olmito based on the current operating state of the existing 1.0 mgd facility (i.e., 52% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are not involved and thus not included, and a net salvage value of zero dollars is recorded for all capital assets and water rights).

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

[c] Total costs (in 2006 dollars) throughout the facility's life of treating and delivering 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-gal) for each segment.

Results – by Facility Segment – La Sara Facility

DESAL ECONOMICS© uniquely analyzes and provides comparable life-cycle costs 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 $745.25 (**Table 10**) is dissected into the seven functional expense areas detailed earlier.[30]

Table 12 shows the NPV of the net cost stream to range from a low of $0 for *Overbuilds & Upgrades*, to a high of $4,067,230 for the *Main Facility/Treatment Process*. These values signify the relative impact individual components' initial construction and future O&M costs have on costs for the total facility. Also in **Table 12**, the annuity equivalent values are provided for individual components, which range from $0/year for *Overbuilds & Upgrades*, to a high of $261,741/year for the *Main Facility/Treatment Process*. These values are interpreted as the annualized costs for each component, inclusive of all life-cycle costs and reported in 2006 dollars (Rister et al. 2009).

Further delineation of the annuity equivalents reveals the economic and financial life-cycle costs range from $0/day for the *Overbuilds & Upgrades* segment, to a high of $717/day for the *Main Facility/Treatment Process*. The total life-cycle cost for all seven segments equates to $1,609/day (reported in 2006 dollars).

Key annualized cost results presented in **Table 12** 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 $0/ac-ft/year {$0.0000/1,000-gallons/year} for *Overbuilds & Upgrades*, to a high of $332.10/ac-ft/year {$1.0192/1,000-gallons/year} for the *Main Facility/Treatment Process*. In both the aggregate and segmented form, the total annual cost-of-producing water at the La Sara facility and delivering it on a f.o.b. basis to the municipal delivery point is $745.25 per ac-ft {$2.2871 per 1,000 gallons} (**Tables 10** and **12**).

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[30] 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 La Sara facility).

Table 12. Costs of Producing (and Delivering) Water for the Facility Segments of the 1.13 mgd La Sara 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-gal/year [e]	% of Total Cost
1) Well Field	$1,780,861	$114,605	$314	$145.41	$0.4463	19.5%
2) Transmission Line	552,415	35,550	97	45.11	0.1384	6.1%
3) Main Facility / Treatment Process	4,067,230	261,741	717	332.10	1.0192	44.6%
4) Concentrate Discharge	623,188	40,104	110	50.89	0.1562	6.8%
5) Finished Water & Tank /Storage	1,532,674	98,633	270	125.15	0.3841	16.8%
6) High Service & Delivery Pipeline	570,638	36,723	101	46.59	0.1430	6.3%
7) Overbuilds & Upgrades	0	0	0	0.00	0.0000	0.0%
TOTAL	$9,127,005	$587,356	$1,609	$745.25	$2.2871	100.0%

Source: Boyer (2008), with modifications.

[a] These baseline results reflect a 1.13 mgd La Sara facility in its current operating state (i.e., 65% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are not involved and thus not included, and a net salvage value of zero dollars is recorded for all capital assets and water rights).

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

[c] Total costs (in 2006 dollars) throughout the facility's life of treating and delivering 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-gal) for each segment.

Results – by Cost Type, Category, and Item – Olmito Facility

Also unique regarding results provided by CITY H_2O ECONOMICS© is a presentation of life-cycle cost results differentiated by a breakdown of cost types, categories, and certain specific cost items. **Tables 13a-13c** provide a progression of interrelated results, whose successive presentation provides an increasing concentration of scope.

As revealed in **Table 9**, the total net costs (in 2006 dollars) of producing and delivering RO-desalinated water (by segment) amount to $23,020,616 over the facility's productive life. This total can be attained by summing the net costs for *Initial Water Rights* ($4,946,555), *Initial Construction* ($4,557,541), *Continued* ($12,957,697), and *Capital Replacement* ($558,823) (**Table 13a**). The summed total of $23,020,616 is the estimated total amount of money which will be invested and spent on the water-treatment facility over the course of its life-cycle, expressed in 2006 dollars.

Within **Table 13a**, the $12,957,697 of *Continued* costs are segmented into the two detailed *Administrative* ($0) and *O&M* ($12,957,697) cost categories.[31] Again, in successive detail of scope, the $12,957,697 in *O&M* costs are dissected into the five detailed *Energy*

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[31] "Administrative" category of costs are annual expenses that are facility-related, but are not included on the water treatment facility's budget; rather, they are handled by an "umbrella" organization which is allocating a portion of its owner- and/or managing-entity budget.

($1,833,382), *Chemicals* ($1,970,256), *Labor* ($3,423,115), *Raw Water Delivery* ($1,130,897) and *All Other* ($4,600,047) 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 13a. Total NPV and Annuity Equivalent Costs, by Cost Type, Category, and Item for a 2.0 mgd Olmito Facility, in 2006 Dollars.

Cost Type/Category/Item	- - - - NPV of Cost Streams - - - - "**Total** Life-Cycle Costs" [a]			- - - Annuity Equivalent Costs - - - "**Annual** Life-Cycle Costs" [a]		
	O&M	Continued	Total	O&M	Continued	Total
Initial Water Rights			$4,946,555			$331,990
Initial Construction			4,557,541			305,881
Continued [b]			12,957,697			869,661
» Administrative		$0			$0	
» O&M		12,957,697			869,661	
• Energy	$1,833,382			$123,048		
• Chemicals	1,970,256			132,235		
• Labor	3,423,115			229,744		
• Raw Water Deliv.	1,130,897			75,901		
• All Other	4,600,047			308,734		
Capital Replacement			558,823			37,506
TOTAL	$12,957,697	$12,957,697	$23,020,616	$869,661	$869,661	$1,545,037

Source: Boyer (2008), with modifications.

[a] These baseline results reflect a 2.0 Olmito facility in its current operating state (i.e., 52% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are not involved and thus not included, and a net salvage value of zero dollars is recorded for all capital assets).

[b] Since there is no "umbrella" organization overseeing the Olmito facility, there are no "Administrative"category costs (e.g., such as with the Southmost facility (see TR-295 by Sturdivant et al. 2009)) in association with the Olmito facility, while "Operation & Maintenance (O&M)" costs are incurred at the facility.

Table 13a 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 $4,557,541, an implicit commitment for an additional $18,463,075 (i.e., $23,020,616 - $4,557,541) (basis 2006 dollars) was also made for *Initial Water Rights, Continued*, and *Capital Replacement* costs.

Similarly, 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 side of **Table 13a**. Here, the "annualized" costs (calculated using annuity equivalent measures) are shown to total $1,545,037, with *Initial Water Rights Purchase* costs constituting $331,990, and *Initial Construction* costs comprising $305,881 of that total. The largest proportion is derived from *Continued* costs of $869,661, while *Capital Replacement* costs contribute $37,506 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 progressive continuation of results in **Table 13a** is further developed in **Table 13b** 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 9** and **11**, the total annual life-cycle costs are $1,393.28 per ac-ft and $4.2758 per 1,000-gallons. As per the left-portion of **Table 13b**, the per ac-ft life-cycle cost is dissected into *Initial Water Rights* ($299.38/ac-ft/year) *Initial Construction* ($275.84/ac-ft/year), *Continued* ($784.24/ac-ft/year), and *Capital Replacement* ($33.82/ac-ft/year) cost types, summing to an annual per ac-ft cost of $1,393.28. This value 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) potable water from the Olmito facility over the course of its life-cycle, expressed in 2006 dollars. Successive details for annual per ac-ft life-cycle costs, by cost category and cost item, are found on the left-side portion of **Table 13b**.

The right-side portion of **Table 13b** 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 13c** 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 13a** noted that "*... significant costs, beyond those of Initial Construction, are involved with desalination*," with supporting dollar values indicating the $4,557,541 in *Initial Construction* as being only a partial consideration of the total $23,020,616 in total life-cycle costs for the Olmito facility. As displayed in **Table 13c** below, *Initial Construction* costs constitute an estimated 20% of the total amount of money (basis 2006 dollars) which will be invested and spent on the facility over the course of its life-cycle. The proportion of *Initial Water Rights* amount to 21%; *Continued* costs which amount to 56% is derived by *Administrative* (0%) and *O&M* (56%) cost proportions. The *O&M* costs consist of 8% *Energy*, 9% *Chemical*, 15% *Labor*, 5% *Raw Water*, and 20% *All Other* (**Table 13c**). In total, *Non-Initial Construction Costs* constitute 80% of the Olmito facility's total life-cycle cost.

Table 13b. Life-Cycle (Annuity Equivalent) Costs – \$/ac-ft/year and \$/1,000-gal/year, by Cost Type, Category, and Item for the Olmito Facility, in 2006 Dollars.[a]

Cost Type/Category/Item	Annuity Equivalent Costs					
	$/ac-ft/year			$/1,000-gal/year		
	O&M	Continued	Total	O&M	Continued	Total
Initial Water Rights			$299.38			$0.9188
Initial Construction			275.84			0.8465
Continued [b]			784.24			2.4067
» Administrative		$0.00			$0.000	
» O&M		784.24			2.4067	
• Energy	$110.96			$0.3405		
• Chemicals	119.25			0.3660		
• Labor	207.18			0.6358		
• Raw Water Deliv.	68.45			0.2101		
• All Other	278.41			0.8544		
Capital Replacement			33.82			0.1038
TOTAL	$784.24	$784.24	$1,393.28	$2.4067	$2.4067	$4.2758

Source: Boyer (2008), with modifications.

[a] These baseline results reflect a 2.0 Olmito facility in its current operating state (i.e., 52% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are not involved and thus not included, and a net salvage value of zero dollars is recorded for all capital assets).

[b] "Administrative" costs are incurred at the facility level, and not by a managing entity.

Table 13c. Percentage of Life-Cycle Costs, by Cost Type, Category, and Item for the Olmito Facility, 2006.

Cost Type/Category/Item	% of Life-Cycle Costs		
	O&M	Continued	Total
Initial Water Rights			21%
Initial Construction			20%
Continued [b]			56%
» Administrative		0%	
» O&M		56%	
• Energy	8%		
• Chemicals	9%		
• Labor	15%		
• Raw Water Deliv.	5%		
• All Other	20%		
Capital Replacement			2%
TOTAL	56%	56%	100%

Results – by Cost Type, Category, and Item – La Sara Facility

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 14a-14c** provide a progression of interrelated results, whose successive presentation gives an increasing concentration of scope.

As revealed in **Table 10**, the total net costs (in 2006 dollars) of producing and delivering RO-desalinated water (by segment) amount to $9,127,005 over the facility's productive life. This total can be attained by summing the net costs for *Initial Construction* ($2,536,527), *Continued* ($6,222,267), and *Capital Replacement* ($368,212) (**Table 14a**). The summed total of $9,127,005 is the estimated total amount of money which will be invested and spent on the water-treatment facility over the course of its life-cycle, expressed in 2006 dollars.

Within **Table 14a**, the $6,222,267 of *Continued* costs are segmented into the two detailed *Administrative* ($2,642,160) and *O&M* ($3,580,107) cost categories.[32] Again, in successive detail of scope, the $3,580,107 in *O&M* costs are dissected into the four detailed *Energy* ($2,476,132), *Chemicals* ($555,170), *Labor* ($386,679), and *All Other* ($162,126) 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 14a. Total NPV and Annuity Equivalent Costs, by Cost Type, Category, and Item for the 1.13 mgd La Sara Facility, in 2006 Dollars.

Cost Type/Category/Item	- - - - NPV of Cost Streams - - - - "**Total** Life-Cycle Costs" [a]			- - - Annuity Equivalent Costs - - - "**Annual** Life-Cycle Costs" [a]		
	O&M	Continued	Total	O&M	Continued	Total
Initial Construction			$2,536,527			$162,235
Continued [b]			6,222,267			400,425
» Administrative		$2,642,160			$170,033	
» O&M		3,580,107			230,393	
• Energy	$2,476,132			$159,348		
• Chemicals	555,170			35,727		
• Labor	386,679			24,884		
• All Other	162,126			10,433		
Capital Replacement			368,212			
TOTAL	$3,580,107	$6,222,267	$9,127,005	$230,393	$400,425	$587,356

Source: Boyer (2008), with modifications.

[a] These baseline results reflect the 1.13 mgd La Sara facility in its current operating state (i.e., 65% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are not involved and thus not included, and a net salvage value of zero dollars is recorded for all capital assets).

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[32] "Administrative" category of costs are annual expenses that are facility-related, but are not included on the water treatment facility's budget; rather, they are handled by an "umbrella" organization which is allocating a portion of its owner- and/or managing-entity budget.

Table 14a 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 $2,536,527, an implicit commitment for an additional $6,590,479 (i.e., $6,222,267 + $368,212) (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 14a**. Here, the "annualized" costs (which are calculated using annuity equivalent measures) are shown to total $587,356, with *Initial Construction* costs comprising $163,235 of that total. The largest proportion is derived from *Continued* costs of $400,425, while *Capital Replacement* costs contribute $23,696 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 progressive continuation of results in **Table 14a** is further developed in **Table 14b** 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 10** and **12**, the total annual life-cycle costs are $745.25 per ac-ft and $2.2871 per 1,000-gallons. As per the left-portion of **Table 14b**, the per ac-ft life-cycle cost is dissected into *Initial Construction* ($207.11/ac-ft/year), *Continued* ($508.07/ac-ft/year), and *Capital Replacement* ($30.07/ac-ft/year) cost types, summing to an annual per ac-ft cost of $745.25. This value 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) potable water from the La Sara facility over the course of its life-cycle, expressed in 2006 dollars. Successive details for annual per ac-ft life-cycle costs, by cost category and cost item, are found on the left-side portion of **Table 14b**.

The right-side portion of **Table 14b** 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 14c** 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 14a** noted that "*... significant costs, beyond those of Initial Construction, are involved with desalination*," with supporting dollar values indicating the $2,536,527 in *Initial Construction* as being only a partial consideration of the total $9,127,005 in total life-cycle costs for the La Sara facility. As displayed in **Table 14c** below, *Initial Construction* costs constitute an estimated 28% of the total amount of money (basis 2006 dollars) which will be invested and spent on the facility over the course of its life-cycle. The proportion of *Continued* costs which amount to 68% is derived by *Administrative* (29%) and *O&M* (39%) cost proportions. The *O&M* costs consist of 27% *Energy*, 6% *Chemical*, 4% *Labor*, and 2% *All Other* (**Table 14c**). In total, *Non-Initial Construction Costs* constitute 72% of the La Sara facility's total life-cycle cost.

Table 14b. Life-Cycle (Annuity Equivalent) Costs – \$/ac-ft/year and \$/1,000-gal/year, by Cost Type, Category, and Item for the La Sara Facility, in 2006 Dollars.[a]

Cost Type/Category/Item	Annuity Equivalent Costs					
	\$/ac-ft/year			\$/1,000-gal/year		
	O&M	Continued	Total	O&M	Continued	Total
Initial Construction			\$207.11			\$0.6356
Continued [b]			508.07			1.5592
» Administrative		\$215.74			\$0.6621	
» O&M		292.33			0.8971	
• Energy	\$202.18			\$0.6205		
• Chemicals	45.33			0.1391		
• Labor	31.57			0.0969		
• All Other	13.24			0.0406		
Capital Replacement			30.07			0.0923
TOTAL	\$292.33	\$508.07	\$745.25	\$0.8971	\$1.5592	\$2.2871

Source: Boyer (2008), with modifications.

[a] These baseline results reflect the La Sara facility in its current operating state (i.e., 65% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are not involved and thus not included, and a net salvage value of zero dollars is recorded for all capital assets).

Table 14c. Percentage of Life-Cycle Costs, by Cost Type, Category, and Item for the La Sara Facility, 2006.

Cost Type/Category/Item	% of Life-Cycle Costs		
	O&M	Continued	Total
Initial Construction			28%
Continued [b]			68%
» Administrative		29%	
» O&M		39%	
• Energy	27%		
• Chemicals	6%		
• Labor	4%		
• All Other	2%		
Capital Replacement			4%
TOTAL	39%	68%	100%

Results – Key Sensitivity Analyses – Olmito Facility and La Sara Facility

The baseline economic and financial results presented above are deterministic (i.e., absent stochastic elements, or risk considerations in the data input) and are based on specific values for each of the data-input variables, such as actual construction costs, continued costs, level of potable water production, inflation, discount rates, etc.

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. 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 data-input parameters and leaving all others constant at the levels used in the baseline analysis. Such actions facilitate testing of the stability (or instability) that various data input have upon the economic and financial results, as well as the *economies of size* results presented later in this report.

Most data-input parameters in this analysis are technically suitable for sensitivity analyses. For practical and report-comparison 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. In the tables which follow, sensitivity results for the Olmito facility are provided in pairs of tables, where the initial table depicts annual results on a \$/ac-ft/year basis, and the accompanying table depicts equivalent results on a \$/1,000-gallon/year basis (**Tables 15a-15l**). Following these sensitivity tables are similar ones for the La Sara facility (**Tables 16a-16j**).

Here, interpretive guidance is provided for all sensitivity tables (**Tables 15a-16j**) with an explanation for **Tables 15a** and **15b**, which report on the sensitivities across plausible ranges for the **expected useful life** and the **production efficiency rate** for the Olmito facility – in terms of \$/ac-ft and \$/1,000 gallons. Note changes to the expected useful life of 40 years are tested with minus 5-year, 10-year, 15-year, and 20-year, variations, and plus 5-year and 10-year variations, while the baseline production efficiency rate of 52% is analyzed with variations ranging from a low of 40% to a high of 100%. Using these variation ranges, sensitivity results for these two data show the annual cost of producing potable water at the Olmito facility ranges from \$1,121.37 to \$1,672.58 per ac-ft in **Table 15a**, or from \$3.4414 to \$5.1330 per 1,000 gal in **Table 15b**. Note the least-cost values are for a facility with an expected useful life of 30 years. This is slightly counter-intuitive as intermittent capital-replacements costs are impacting the costs of longer-lived (e.g., 50-year) facilities. For brevity's sake, interpretation (of subsequent sensitivity tables) is left to the reader's inferential understanding.

Table 15a. Sensitivity Analysis of Annual Costs-of-Treating Water at the Olmito Facility ($/ac-ft), by Variations in Expected Useful Life and Production Efficiency Rate, in 2006 Dollars.

		Annual Production Efficiency Rate (% of current maximum design)								
		40%	45%	47%	50%	**52%**	55%	75%	90%	100%
		Annual Water Production (ac-ft) – ($/ac-ft, per year)								
		896	1,008	1,053	1,120	**1,165**	1,232	1,680	2,016	2,240
Expected Useful Life (years)	20	$1,672.58	$1,608.03	$1,569.58	$1,517.66	$1,486.38	$1,417.78	$1,360.24	$1,269.14	$1,146.36
	25	$1,601.15	$1,542.89	$1,508.18	$1,461.32	$1,433.08	$1,371.16	$1,319.22	$1,236.99	$1,126.16
	30	$1,565.75	$1,511.24	$1,478.77	$1,434.93	$1,408.51	$1,350.58	$1,301.99	$1,225.06	$1,121.37
	35	$1,546.40	$1,494.45	$1,463.50	$1,421.72	$1,396.54	$1,341.33	$1,295.02	$1,221.70	$1,122.88
	40	$1,538.29	$1,488.02	$1,458.07	$1,417.64	**$1,393.28**	$1,339.85	$1,295.05	$1,224.10	$1,128.48
	45	$1,535.50	$1,486.44	$1,457.21	$1,417.75	$1,393.97	$1,341.82	$1,298.09	$1,228.85	$1,135.51
	50	$1,537.07	$1,488.80	$1,460.05	$1,421.23	$1,397.84	$1,346.54	$1,303.52	$1,235.40	$1,143.59

Table 15b. Sensitivity Analysis of Annual Costs-of-Treating Water at the Olmito 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)								
		40%	45%	47%	50%	**52%**	55%	75%	90%	100%
		Annual Water Production (1,000 gal) – ($/1,000 gallons, per year)								
		292,000	328,500	343,100	365,000	**379,600**	401,500	547,500	657,000	730,000
Expected Useful Life (years)	20	$5.1330	$4.9349	$4.8169	$4.6575	$4.5615	$4.3510	$4.1744	$3.8949	$3.5180
	25	$4.9138	$4.7350	$4.6284	$4.4846	$4.3980	$4.2079	$4.0485	$3.7962	$3.4560
	30	$4.8051	$4.6378	$4.5382	$4.4036	$4.3226	$4.1448	$3.9957	$3.7596	$3.4414
	35	$4.7457	$4.5863	$4.4913	$4.3631	$4.2858	$4.1164	$3.9743	$3.7493	$3.4460
	40	$4.7208	$4.5666	$4.4746	$4.3506	**$4.2758**	$4.1119	$3.9743	$3.7566	$3.4632
	45	$4.7123	$4.5617	$4.4720	$4.3509	$4.2779	$4.1179	$3.9837	$3.7712	$3.4848
	50	$4.7171	$4.5690	$4.4807	$4.3616	$4.2898	$4.1324	$4.0003	$3.7913	$3.5095

Table 15c. Sensitivity Analysis of Annual Costs-of-Treating Water at the Olmito Facility ($/ac-ft), by Variations in Initial Water Right Purchase Price and Production Efficiency Rate, in 2006 Dollars.

		Annual Production Efficiency Rate (% of current maximum design)								
		40%	45%	47%	50%	**52%**	55%	75%	90%	100%
		Annual Water Production (ac-ft) – ($/ac-ft, per year)								
		896	1,008	1,053	1,120	**1,165**	1,232	1,680	2,016	2,240
Initial Water Right Purchase Price ($)	$2,000	$1,489.94	$1,442.89	$1,414.86	$1,377.03	$1,354.23	$1,304.23	$1,262.29	$1,195.90	$1,106.41
	$2,100	$1,506.06	$1,457.93	$1,429.27	$1,390.56	$1,367.24	$1,316.10	$1,273.21	$1,205.30	$1,113.76
	$2,200	$1,522.17	$1,472.98	$1,443.67	$1,404.10	$1,380.26	$1,327.98	$1,284.13	$1,214.70	$1,121.12
	$2,300	$1,538.29	$1,488.02	$1,458.07	$1,417.64	**$1,393.28**	$1,339.85	$1,295.05	$1,224.10	$1,128.48
	$2,400	$1,554.40	$1,503.06	$1,472.47	$1,431.18	$1,406.29	$1,351.73	$1,305.96	$1,233.50	$1,135.84
	$2,500	$1,570.52	$1,518.10	$1,486.87	$1,444.71	$1,419.31	$1,363.60	$1,316.88	$1,242.90	$1,143.19
	$2,600	$1,586.63	$1,533.14	$1,501.27	$1,458.25	$1,432.33	$1,375.48	$1,327.80	$1,252.30	$1,150.55

Table 15d. Sensitivity Analysis of Annual Costs-of-Treating Water at the Olmito Facility ($/1,000 gallons), by Variations in Initial Water Right Purchase Price and Production Efficiency Rate, in 2006 Dollars.

		Annual Production Efficiency Rate (% of current maximum design)								
		40%	45%	47%	50%	**52%**	55%	75%	90%	100%
		Annual Water Production (1,000 gal) – ($/1,000 gallons, per year)								
		292,000	328,500	343,100	365,000	**379,600**	401,500	547,500	657,000	730,000
Initial Water Right Purchase Price ($)	$2,000	$4.5725	$4.4281	$4.3421	$4.2259	$4.1560	$4.0025	$3.8738	$3.6701	$3.3954
	$2,100	$4.6219	$4.4742	$4.3863	$4.2675	$4.1959	$4.0390	$3.9073	$3.6989	$3.4180
	$2,200	$4.6714	$4.5204	$4.4305	$4.3090	$4.2359	$4.0754	$3.9408	$3.7278	$3.4406
	$2,300	$4.7208	$4.5666	$4.4746	$4.3506	**$4.2758**	$4.1119	$3.9743	$3.7566	$3.4632
	$2,400	$4.7703	$4.6127	$4.5188	$4.3921	$4.3158	$4.1483	$4.0079	$3.7855	$3.4858
	$2,500	$4.8197	$4.6589	$4.5630	$4.4337	$4.3557	$4.1847	$4.0414	$3.8143	$3.5083
	$2,600	$4.8692	$4.7050	$4.6072	$4.4752	$4.3957	$4.2212	$4.0749	$3.8432	$3.5309

Table 15e. Sensitivity Analysis of Annual Costs-of-Treating Water at the Olmito Facility ($/ac-ft), by Variations in Initial Construction Cost and Production Efficiency Rate, in 2006 Dollars.

		Annual Production Efficiency Rate (% of current maximum design)								
		40%	45%	47%	50%	**52%**	55%	75%	90%	100%
		Annual Water Production (ac-ft) – ($/ac-ft, per year)								
		896	1,008	1,053	1,120	**1,165**	1,232	1,680	2,016	2,240
Initial Construction Cost ($)	($1,500,000)	$1,425.89	$1,383.11	$1,357.63	$1,323.22	$1,302.49	$1,257.03	$1,218.90	$1,158.53	$1,077.17
	($1,000,000)	$1,463.35	$1,418.08	$1,391.11	$1,354.70	$1,332.75	$1,284.64	$1,244.28	$1,180.39	$1,094.27
	($500,000)	$1,500.82	$1,453.05	$1,424.59	$1,386.17	$1,363.02	$1,312.25	$1,269.66	$1,202.24	$1,111.37
	$4,557,541	$1,538.29	$1,488.02	$1,458.07	$1,417.64	**$1,393.28**	$1,339.85	$1,295.05	$1,224.10	$1,128.48
	$500,000	$1,575.75	$1,522.99	$1,491.55	$1,449.11	$1,423.54	$1,367.46	$1,320.43	$1,245.96	$1,145.58
	$1,00,000	$1,613.22	$1,557.95	$1,525.03	$1,480.58	$1,453.80	$1,395.07	$1,345.81	$1,267.81	$1,162.69
	$1,500,000	$1,650.69	$1,592.92	$1,558.51	$1,512.05	$1,484.06	$1,422.67	$1,371.19	$1,289.67	$1,179.79

Table 15f. Sensitivity Analysis of Annual Costs-of-Treating Water at the Olmito Facility ($/1,000 gallons), by Variations in Initial Construction Cost and Production Efficiency Rate, in 2006 Dollars.

		Annual Production Efficiency Rate (% of current maximum design)								
		40%	45%	47%	50%	**52%**	55%	75%	90%	100%
		Annual Water Production (1,000 gal) – ($/1,000 gallons, per year)								
		292,000	328,500	343,100	365,000	**379,600**	401,500	547,500	657,000	730,000
Initial Construction Costs ($)	($1,500,000)	$4.3759	$4.2446	$4.1664	$4.0608	$3.9972	$3.8577	$3.7407	$3.5554	$3.3057
	($1,000,000)	$4.4909	$4.3519	$4.2692	$4.1574	$4.0901	$3.9424	$3.8186	$3.6225	$3.3582
	($500,000)	$4.6058	$4.4592	$4.3719	$4.2540	$4.1829	$4.0271	$3.8965	$3.6896	$3.4107
	$4,557,541	$4.7208	$4.5666	$4.4746	$4.3506	**$4.2758**	$4.1119	$3.9743	$3.7566	$3.4632
	$500,000	$4.8358	$4.6739	$4.5774	$4.4472	$4.3687	$4.1966	$4.0522	$3.8237	$3.5157
	$1,00,000	$4.9508	$4.7812	$4.6801	$4.5437	$4.4616	$4.2813	$4.1301	$3.8908	$3.5682
	$1,500,000	$5.0658	$4.8885	$4.7829	$4.6403	$4.5544	$4.3660	$4.2080	$3.9578	$3.6206

Table 15g. Sensitivity Analysis of Annual Costs-of-Treating Water at the Olmito 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)								
		40%	45%	47%	50%	**52%**	55%	75%	90%	100%
		Annual Water Production (ac-ft) – ($/ac-ft, per year)								
		896	1,008	1,053	1,120	**1,165**	1,232	1,680	2,016	2,240
Annual O&M Costs (% change)	-30%	$1,303.01	$1,252.75	$1,222.80	$1,182.37	$1,158.01	$1,104.58	$1,059.77	$988.83	$893.21
	-20%	$1,381.44	$1,331.17	$1,301.22	$1,260.79	$1,236.43	$1,183.01	$1,138.20	$1,067.25	$971.63
	-10%	$1,459.86	$1,409.59	$1,379.64	$1,339.22	$1,314.85	$1,261.43	$1,216.62	$1,145.68	$1,050.05
	$680,855	$1,538.29	$1,488.02	$1,458.07	$1,417.64	**$1,393.28**	$1,339.85	$1,295.05	$1,224.10	$1,128.48
	+10%	$1,616.71	$1,566.44	$1,536.49	$1,496.06	$1,471.70	$1,418.28	$1,373.47	$1,302.52	$1,206.90
	+20%	$1,695.13	$1,644.86	$1,614.92	$1,574.49	$1,550.13	$1,496.70	$1,451.89	$1,380.95	$1,285.33
	+30%	$1,773.56	$1,723.29	$1,693.34	$1,652.91	$1,628.55	$1,575.12	$1,530.32	$1,459.37	$1,363.75

Table 15h. Sensitivity Analysis of Annual Costs-of-Treating Water at the Olmito 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)								
		40%	45%	47%	50%	**52%**	55%	75%	90%	100%
		Annual Water Production (1,000 gal) – ($/1,000 gallons, per year)								
		292,000	328,500	343,100	365,000	**379,600**	401,500	547,500	657,000	730,000
Annual O&M Costs (% change)	-30%	$3.9988	$3.8445	$3.7526	$3.6286	$3.5538	$3.3898	$3.2523	$3.0346	$2.7412
	-20%	$4.2395	$4.0852	$3.9933	$3.8692	$3.7945	$3.6305	$3.4930	$3.2753	$2.9818
	-10%	$4.4802	$4.3259	$4.2340	$4.1099	$4.0351	$3.8712	$3.7337	$3.5160	$3.2225
	$680,855	$4.7208	$4.5666	$4.4746	$4.3506	**$4.2758**	$4.1119	$3.9743	$3.7566	$3.4632
	+10%	$4.9615	$4.8072	$4.7153	$4.5912	$4.5165	$4.3525	$4.2150	$3.9973	$3.7038
	+20%	$5.2022	$5.0479	$4.9560	$4.8319	$4.7572	$4.5932	$4.4557	$4.2380	$3.9445
	+30%	$5.4429	$5.2886	$5.1967	$5.0726	$4.9978	$4.8339	$4.6964	$4.4786	$4.1852

Table 15i. Sensitivity Analysis of Annual Costs-of-Treating Water at the Olmito Facility ($/ac-ft), by Variations in Annual Energy Costs and Production Efficiency Rate, in 2006 Dollars.

		Annual Production Efficiency Rate (% of current maximum design)								
		40%	45%	47%	50%	**52%**	55%	75%	90%	100%
		Annual Water Production (ac-ft) – ($/ac-ft, per year)								
		896	1,008	1,053	1,120	**1,165**	1,232	1,680	2,016	2,240
Annual Energy Costs (% change)	-20%	$1,516.09	$1,465.82	$1,435.88	$1,395.45	$1,371.09	$1,317.66	$1,272.85	$1,201.91	$1,106.29
	-10%	$1,527.19	$1,476.92	$1,446.97	$1,406.54	$1,382.18	$1,328.76	$1,283.95	$1,213.00	$1,117.38
	-5%	$1,532.74	$1,482.47	$1,452.52	$1,412.09	$1,387.73	$1,334.30	$1,289.50	$1,218.55	$1,122.93
	$96,334	$1,538.29	$1,488.02	$1,458.07	$1,417.64	**$1,393.28**	$1,339.85	$1,295.05	$1,224.10	$1,128.48
	+5%	$1,543.83	$1,493.56	$1,463.62	$1,423.19	$1,398.83	$1,345.40	$1,300.59	$1,229.65	$1,134.03
	+10%	$1,549.38	$1,499.11	$1,469.17	$1,428.74	$1,404.37	$1,350.95	$1,306.14	$1,235.20	$1,139.57
	+20%	$1,560.48	$1,510.21	$1,480.26	$1,439.83	$1,415.47	$1,362.05	$1,317.24	$1,246.29	$1,150.67

Table 15j. Sensitivity Analysis of Annual Costs-of-Treating Water at the Olmito 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)								
		40%	45%	47%	50%	**52%**	55%	75%	90%	100%
		Annual Water Production (1,000 gal) – ($/1,000 gallons, per year)								
		292,000	328,500	343,100	365,000	**379,600**	401,500	547,500	657,000	730,000
Annual Energy Costs (% change)	-20%	$4.6527	$4.4985	$4.4065	$4.2825	$4.2077	$4.0438	$3.9062	$3.6885	$3.3951
	-10%	$4.6868	$4.5325	$4.4406	$4.3165	$4.2418	$4.0778	$3.9403	$3.7226	$3.4291
	-5%	$4.7038	$4.5495	$4.4576	$4.3335	$4.2588	$4.0948	$3.9573	$3.7396	$3.4461
	$96,334	$4.7208	$4.5666	$4.4746	$4.3506	**$4.2758**	$4.1119	$3.9743	$3.7566	$3.4632
	+5%	$4.7379	$4.5836	$4.4917	$4.3676	$4.2928	$4.1289	$3.9914	$3.7737	$3.4802
	+10%	$4.7549	$4.6006	$4.5087	$4.3846	$4.3099	$4.1459	$4.0084	$3.7907	$3.4972
	+20%	$4.7889	$4.6347	$4.5428	$4.4187	$4.3439	$4.1800	$4.0425	$3.8247	$3.5313

Table 15k. Sensitivity Analysis of Annual Costs-of-Treating Water at the Olmito Facility ($/ac-ft), by Variations in Annual Chemical Costs and Production Efficiency Rate, in 2006 Dollars.

		Annual Production Efficiency Rate (% of current maximum design)								
		40%	45%	47%	50%	**52%**	55%	75%	90%	100%
		Annual Water Production (ac-ft) – ($/ac-ft, per year)								
		896	1,008	1,053	1,120	**1,165**	1,232	1,680	2,016	2,240
Annual Chemical Costs (% change)	-20%	$1,514.44	$1,464.17	$1,434.22	$1,393.79	$1,369.43	$1,316.00	$1,271.20	$1,200.25	$1,104.63
	-10%	$1,526.36	$1,476.09	$1,446.14	$1,405.71	$1,381.35	$1,327.93	$1,283.12	$1,212.18	$1,116.55
	-5%	$1,532.32	$1,482.05	$1,452.11	$1,411.68	$1,387.32	$1,333.89	$1,289.08	$1,218.14	$1,122.52
	$103,526	$1,538.29	$1,488.02	$1,458.07	$1,417.64	**$1,393.28**	$1,339.85	$1,295.05	$1,224.10	$1,128.48
	+5%	$1,544.25	$1,493.98	$1,464.03	$1,423.60	$1,399.24	$1,345.82	$1,301.01	$1,230.06	$1,134.44
	+10%	$1,550.21	$1,499.94	$1,469.99	$1,429.56	$1,405.20	$1,351.78	$1,306.97	$1,236.02	$1,140.40
	+20%	$1,562.14	$1,511.87	$1,481.92	$1,441.49	$1,417.13	$1,363.70	$1,318.89	$1,247.95	$1,152.33

Table 15l. Sensitivity Analysis of Annual Costs-of-Treating Water at the Olmito 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)								
		40%	45%	47%	50%	**52%**	55%	75%	90%	100%
		Annual Water Production (1,000 gal) – ($/1,000 gallons, per year)								
		292,000	328,500	343,100	365,000	**379,600**	401,500	547,500	657,000	730,000
Annual Chemical Costs (% change)	-20%	$4.6476	$4.4934	$4.4015	$4.2774	$4.2026	$4.0387	$3.9012	$3.6834	$3.3900
	-10%	$4.6842	$4.5300	$4.4381	$4.3140	$4.2392	$4.0753	$3.9378	$3.7200	$3.4266
	-5%	$4.7025	$4.5483	$4.4564	$4.3323	$4.2575	$4.0936	$3.9561	$3.7383	$3.4449
	$103,526	$4.7208	$4.5666	$4.4746	$4.3506	**$4.2758**	$4.1119	$3.9743	$3.7566	$3.4632
	+5%	$4.7391	$4.5849	$4.4929	$4.3689	$4.2941	$4.1302	$3.9926	$3.7749	$3.4815
	+10%	$4.7574	$4.6032	$4.5112	$4.3872	$4.3124	$4.1485	$4.0109	$3.7932	$3.4998
	+20%	$4.7940	$4.6397	$4.5478	$4.4238	$4.3490	$4.1850	$4.0475	$3.8298	$3.5364

Table 16a. Sensitivity Analysis of Annual Costs-of-Treating Water at the La Sara Facility ($/ac-ft), by Variations in Expected Useful Life and Production Efficiency Rate, in 2006 Dollars.

		Annual Production Efficiency Rate (% of current maximum design)								
		50%	55%	60%	63%	**65%**	75%	85%	90%	100%
		Annual Water Production (ac-ft) – ($/ac-ft, per year)								
		635	698	762	800	**825**	951	1,078	1,141	1,268
Expected Useful Life (years)	20	$899.77	$840.13	$790.40	$764.35	$748.31	$680.92	$629.35	$607.86	$571.31
	25	$881.05	$823.81	$776.09	$751.09	$735.70	$671.03	$621.54	$600.92	$565.84
	30	$874.42	$818.44	$771.76	$747.30	$732.25	$668.99	$620.59	$600.41	$566.11
	35	$870.78	$815.72	$769.81	$745.76	$730.95	$668.73	$621.13	$601.29	$567.55
	40	$874.28	$819.43	$773.70	$749.74	$734.99	$673.02	$625.61	$605.84	$572.23
	45	$879.19	$824.38	$778.67	$754.73	$739.98	$678.05	$630.66	$610.90	$577.31
	50	$884.64	$829.75	$783.99	$760.01	**$745.25**	$683.23	$635.77	$615.99	$582.36

Table 16b. Sensitivity Analysis of Annual Costs-of-Treating Water at the La Sara 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)								
		50%	55%	60%	63%	**65%**	75%	85%	90%	100%
		Annual Water Production (1,000 gal) – ($/1,000 gallons, per year)								
		206,903	227,525	248,148	260,521	**268,770**	310,015	351,260	371,883	413,128
Expected Useful Life (years)	20	$2.76	$2.5783	$2.4257	$2.3457	$2.2965	$2.0897	$1.9314	$1.8654	$1.7533
	25	$2.7038	$2.5282	$2.3817	$2.3050	$2.2578	$2.0593	$1.9074	$1.8441	$1.7365
	30	$2.6835	$2.5117	$2.3684	$2.2934	$2.2472	$2.0531	$1.9045	$1.8426	$1.7373
	35	$2.6723	$2.5034	$2.3625	$2.2886	$2.2432	$2.0523	$1.9062	$1.8453	$1.7417
	40	$2.6831	$2.5147	$2.3744	$2.3009	$2.2556	$2.0654	$1.9199	$1.8593	$1.7561
	45	$2.6981	$2.5299	$2.3897	$2.3162	$2.2709	$2.0809	$1.9354	$1.8748	$1.7717
	50	$2.7148	$2.5464	$2.4060	$2.3324	**$2.2871**	$2.0967	$1.9511	$1.8904	$1.7872

Table 16c. Sensitivity Analysis of Annual Costs-of-Treating Water at the La Sara Facility ($/ac-ft), by Variations in Initial Construction Cost and Production Efficiency Rate, in 2006 Dollars.

		Annual Production Efficiency Rate (% of current maximum design)								
		50%	55%	60%	63%	**65%**	75%	85%	90%	100%
		Annual Water Production (ac-ft) – ($/ac-ft, per year)								
		635	698	762	800	**825**	951	1,078	1,141	1,268
Initial Construction Cost ($)	($750,000)	$805.08	$757.41	$717.66	$696.83	$684.01	$630.14	$588.92	$571.73	$542.52
	($500,000)	$831.60	$781.52	$739.77	$717.89	$704.42	$647.83	$604.53	$586.49	$555.80
	($250,000)	$858.12	$805.64	$761.88	$738.95	$724.83	$665.53	$620.15	$601.24	$569.08
	$2,536,527	$884.64	$829.75	$783.99	$760.01	**$745.25**	$683.23	$635.77	$615.99	$582.36
	$250,000	$911.15	$853.86	$806.10	$781.07	$765.66	$700.92	$651.39	$630.75	$595.64
	$500,000	$937.67	$877.98	$828.21	$802.13	$786.07	$718.62	$667.01	$645.50	$608.92
	$750,000	$964.19	$902.09	$850.32	$823.18	$806.49	$736.32	$682.63	$660.25	$622.20

Table 16d. Sensitivity Analysis of Annual Costs-of-Treating Water at the La Sara Facility ($/1,000 gallons), by Variations in Initial Construction Cost and Production Efficiency Rate, in 2006 Dollars.

		Annual Production Efficiency Rate (% of current maximum design)								
		50%	55%	60%	63%	**65%**	75%	85%	90%	100%
		Annual Water Production (1,000 gal) – ($/1,000 gallons, per year)								
		206,903	227,525	248,148	260,521	**268,770**	310,015	351,260	371,883	413,128
Initial Construction Costs ($)	($750,000)	$2.4707	$2.3244	$2.2024	$2.1385	$2.0991	$1.9338	$1.8073	$1.7546	$1.6649
	($500,000)	$2.5521	$2.3984	$2.2703	$2.2031	$2.1618	$1.9881	$1.8552	$1.7999	$1.7057
	($250,000)	$2.6335	$2.4724	$2.3381	$2.2677	$2.2244	$2.0424	$1.9032	$1.8451	$1.7464
	$2,536,527	$2.7148	$2.5464	$2.4060	$2.3324	**$2.2871**	$2.0967	$1.9511	$1.8904	$1.7872
	$250,000	$2.7962	$2.6204	$2.4738	$2.3970	$2.3497	$2.1511	$1.9991	$1.9357	$1.8279
	$500,000	$2.8776	$2.6944	$2.5417	$2.4616	$2.4124	$2.2054	$2.0470	$1.9810	$1.8687
	$750,000	$2.9590	$2.7684	$2.6095	$2.5263	$2.4750	$2.2597	$2.0949	$2.0262	$1.9095

Table 16e. Sensitivity Analysis of Annual Costs-of-Treating Water at the La Sara 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)								
		50%	55%	60%	63%	**65%**	75%	85%	90%	100%
		Annual Water Production (ac-ft) – ($/ac-ft, per year)								
		635	698	762	800	**825**	951	1,078	1,141	1,268
Annual O&M Costs (% change)	-30%	$711.68	$664.88	$625.86	$605.41	$592.83	$539.95	$499.49	$482.62	$453.94
	-20%	$769.33	$719.83	$678.57	$656.94	$643.63	$587.71	$544.91	$527.08	$496.75
	-10%	$826.98	$774.79	$731.28	$708.47	$694.44	$635.47	$590.34	$571.54	$539.55
	$301,234	$884.64	$829.75	$783.99	$760.01	**$745.25**	$683.23	$635.77	$615.99	$582.36
	+10%	$942.29	$884.71	$836.70	$811.54	$796.05	$730.99	$681.20	$660.45	$625.16
	+20%	$999.94	$939.66	$889.41	$863.07	$846.86	$778.75	$726.63	$704.91	$667.97
	+30%	$1,057.60	$994.62	$942.12	$914.60	$897.67	$826.51	$772.06	$749.37	$710.77

Table 16f. Sensitivity Analysis of Annual Costs-of-Treating Water at the La Sara 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)								
		50%	55%	60%	63%	**65%**	75%	85%	90%	100%
		Annual Water Production (1,000 gal) – ($/1,000 gallons, per year)								
		206,903	227,525	248,148	260,521	**268,770**	310,015	351,260	371,883	413,128
Annual O&M Costs (% change)	-30%	$2.1841	$2.0404	$1.9207	$1.8579	$1.8193	$1.6570	$1.5329	$1.4811	$1.3931
	-20%	$2.3610	$2.2091	$2.0824	$2.0161	$1.9752	$1.8036	$1.6723	$1.6175	$1.5245
	-10%	$2.5379	$2.3778	$2.2442	$2.1742	$2.1312	$1.9502	$1.8117	$1.7540	$1.6558
	$301,234	$2.7148	$2.5464	$2.4060	$2.3324	**$2.2871**	$2.0967	$1.9511	$1.8904	$1.7872
	+10%	$2.8918	$2.7151	$2.5677	$2.4905	$2.4430	$2.2433	$2.0905	$2.0269	$1.9186
	+20%	$3.0687	$2.8837	$2.7295	$2.6487	$2.5989	$2.3899	$2.2300	$2.1633	$2.0499
	+30%	$3.2456	$3.0524	$2.8912	$2.8068	$2.7548	$2.5365	$2.3694	$2.2997	$2.1813

Table 16g. Sensitivity Analysis of Annual Costs-of-Treating Water at the La Sara Facility ($/ac-ft), by Variations in Annual Energy Costs and Production Efficiency Rate, in 2006 Dollars.

		Annual Production Efficiency Rate (% of current maximum design)								
		50%	55%	60%	63%	**65%**	75%	85%	90%	100%
		Annual Water Production (ac-ft) – ($/ac-ft, per year)								
		635	698	762	800	**825**	951	1,078	1,141	1,268
Annual Energy Costs (% change)	-20%	$844.20	$789.31	$743.55	$719.57	$704.81	$642.79	$595.34	$575.56	$541.92
	-10%	$864.42	$809.53	$763.77	$739.79	$725.03	$663.01	$615.56	$595.78	$562.14
	-5%	$874.53	$819.64	$773.88	$749.90	$735.14	$673.12	$625.66	$605.88	$572.25
	$119,875	$884.64	$829.75	$783.99	$760.01	**$745.25**	$683.23	$635.77	$615.99	$582.36
	+5%	$894.74	$839.86	$794.10	$770.12	$755.36	$693.34	$645.88	$626.10	$592.47
	+10%	$904.85	$849.97	$804.20	$780.22	$765.46	$703.45	$655.99	$636.21	$602.58
	+20%	$925.07	$870.19	$824.42	$800.44	$785.68	$723.66	$676.21	$656.43	$622.79

Table 16h. Sensitivity Analysis of Annual Costs-of-Treating Water at the La Sara 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)								
		50%	55%	60%	63%	**65%**	75%	85%	90%	100%
		Annual Water Production (1,000 gal) – ($/1,000 gallons, per year)								
		206,903	227,525	248,148	260,521	**268,770**	310,015	351,260	371,883	413,128
Annual Energy Costs (% change)	-20%	$2.5908	$2.4223	$2.2819	$2.2083	$2.1630	$1.9727	$1.8270	$1.7663	$1.6631
	-10%	$2.6528	$2.4844	$2.3439	$2.2703	$2.2250	$2.0347	$1.8891	$1.8284	$1.7251
	-5%	$2.6838	$2.5154	$2.3749	$2.3013	$2.2561	$2.0657	$1.9201	$1.8594	$1.7562
	$119,875	$2.7148	$2.5464	$2.4060	$2.3324	**$2.2871**	$2.0967	$1.9511	$1.8904	$1.7872
	+5%	$2.7459	$2.5774	$2.4370	$2.3634	$2.3181	$2.1278	$1.9821	$1.9214	$1.8182
	+10%	$2.7769	$2.6085	$2.4680	$2.3944	$2.3491	$2.1588	$2.0132	$1.9525	$1.8492
	+20%	$2.8389	$2.6705	$2.5301	$2.4565	$2.4112	$2.2208	$2.0752	$2.0145	$1.9113

Table 16i. Sensitivity Analysis of Annual Costs-of-Treating Water at the La Sara Facility ($/ac-ft), by Variations in Annual Chemical Costs and Production Efficiency Rate, in 2006 Dollars.

		Annual Production Efficiency Rate (% of current maximum design)								
		50%	55%	60%	63%	**65%**	75%	85%	90%	100%
		Annual Water Production (ac-ft) – ($/ac-ft, per year)								
		635	698	762	800	**825**	951	1,078	1,141	1,268
Annual Chemical Costs (% change)	-20%	$875.57	$820.68	$774.92	$750.94	$736.18	$674.16	$626.71	$606.93	$573.29
	-10%	$880.10	$825.22	$779.45	$755.47	$740.71	$678.69	$631.24	$611.46	$577.83
	-5%	$882.37	$827.48	$781.72	$757.74	$742.98	$680.96	$633.51	$613.73	$580.09
	$26,877	$884.64	$829.75	$783.99	$760.01	**$745.25**	$683.23	$635.77	$615.99	$582.36
	+5%	$886.90	$832.02	$786.25	$762.27	$747.51	$685.49	$638.04	$618.26	$584.62
	+10%	$889.17	$834.28	$788.52	$764.54	$749.78	$687.76	$640.31	$620.53	$586.89
	+20%	$893.70	$838.82	$793.05	$769.07	$754.31	$692.29	$644.84	$625.06	$591.42

Table 16j. Sensitivity Analysis of Annual Costs-of-Treating Water at the La Sara 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)								
		50%	55%	60%	63%	**65%**	75%	85%	90%	100%
		Annual Water Production (1,000 gal) – ($/1,000 gallons, per year)								
		896	1,008	1,053	1,120	**1,165**	1,232	1,680	2,016	2,240
Annual Chemical Costs (% change)	-20%	$2.6870	$2.5186	$2.3781	$2.3046	$2.2593	$2.0689	$1.9233	$1.8626	$1.7594
	-10%	$2.7009	$2.5325	$2.3921	$2.3185	$2.2732	$2.0828	$1.9372	$1.8765	$1.7733
	-5%	$2.7079	$2.5395	$2.3990	$2.3254	$2.2801	$2.0898	$1.9442	$1.8835	$1.7802
	$26,877	$2.7148	$2.5464	$2.4060	$2.3324	**$2.2871**	$2.0967	$1.9511	$1.8904	$1.7872
	+5%	$2.7218	$2.5534	$2.4129	$2.3393	$2.2940	$2.1037	$1.9581	$1.8974	$1.7941
	+10%	$2.7288	$2.5603	$2.4199	$2.3463	$2.3010	$2.1107	$1.9650	$1.9043	$1.8011
	+20%	$2.7427	$2.5742	$2.4338	$2.3602	$2.3149	$2.1246	$1.9789	$1.9182	$1.8150

Comparing Economic and Financial Results with Accounting-Based Results

> Authors' Note: To provide consistency across reports, model comparisons, facility case studies, etc., the text in this section largely mimics that developed by the authors in Sturdivant et al. (2009), with values reflecting the NAWSC's 1.13 mgd La Sara (desalination) facility. This text also pertains to other facilities due to differences in accounting and economic perspectives.

The life-cycle cost results presented above are financial and economic in nature, and will differ with accounting-based, nominal cash-flow results.[33] Remember, both the baseline and modified results (see **Appendix B**) are put on 'annuity equivalent' (AE) measures; i.e., adjusted for time and inflation, and are presented on a 2006 calendar-year basis. Typical accounting approaches to calculating the annual production costs involve the periodic escalation, albeit implicit, of nominal-based dollars for inputs. This incremental increase in costs-of-production happens slowly over time and accounts for inflation non-explicitly. That is, input costs tend to increase over time, thereby causing a ratcheting-up of the final per-unit production costs (**Figure 2**).[34]

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 La Sara facility baseline results (i.e., life-cycle of $745.25/ac-ft/yr, or $2.2871/1,000 gallons/yr) (**Table 10**), 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 2**). Thus, an assessment of $745.25 (basis 2006) for each ac-ft produced, for every year of the facility's useful life, is intended to 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 $31,139,496 in nominal dollars (**Table 10**) will be spent constructing and operating the La Sara facility (i.e., from time of commencement of construction to completion of facility decommissioning). A graphical representation of such annual accounting (i.e., nominal) costs are depicted by the blue vertical bars in **Figure 2**. Arriving at an average annual dollar per ac-ft cost (from an accounting perspective) can thus be obtained by (a) amortizing the initial construction costs (over 30 years at 5% interest) for an annual amount of 'fixed' costs, and (b) adding that cost to annual O&M costs (which are based on actual 2006 costs and inflated at slightly more than 2% (see the *Assumed Values for Discount Rates and Compound Factor* section for more information). Summing the amortized fixed costs with the annual O&M costs, and dividing by the number of ac-ft produced by the La Sara facility results in the *Likely Accounting Costs ($/ac-ft)* depicted by the green dashed line in **Figure 2**.

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[33] The *baseline* results are applicable to the 1.13 mgd La Sara 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 (see **Appendix B**), 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 as they (i.e., modified results) do not include all costs.

[34] The *Likely Accounting Costs* represented by the green-dashed line in **Figure 1** are based on the La Sara facility's Initial Construction Costs (amortized over 30 years at 5% interest) and its annual Continued Costs (inflated at slightly more than 2%).

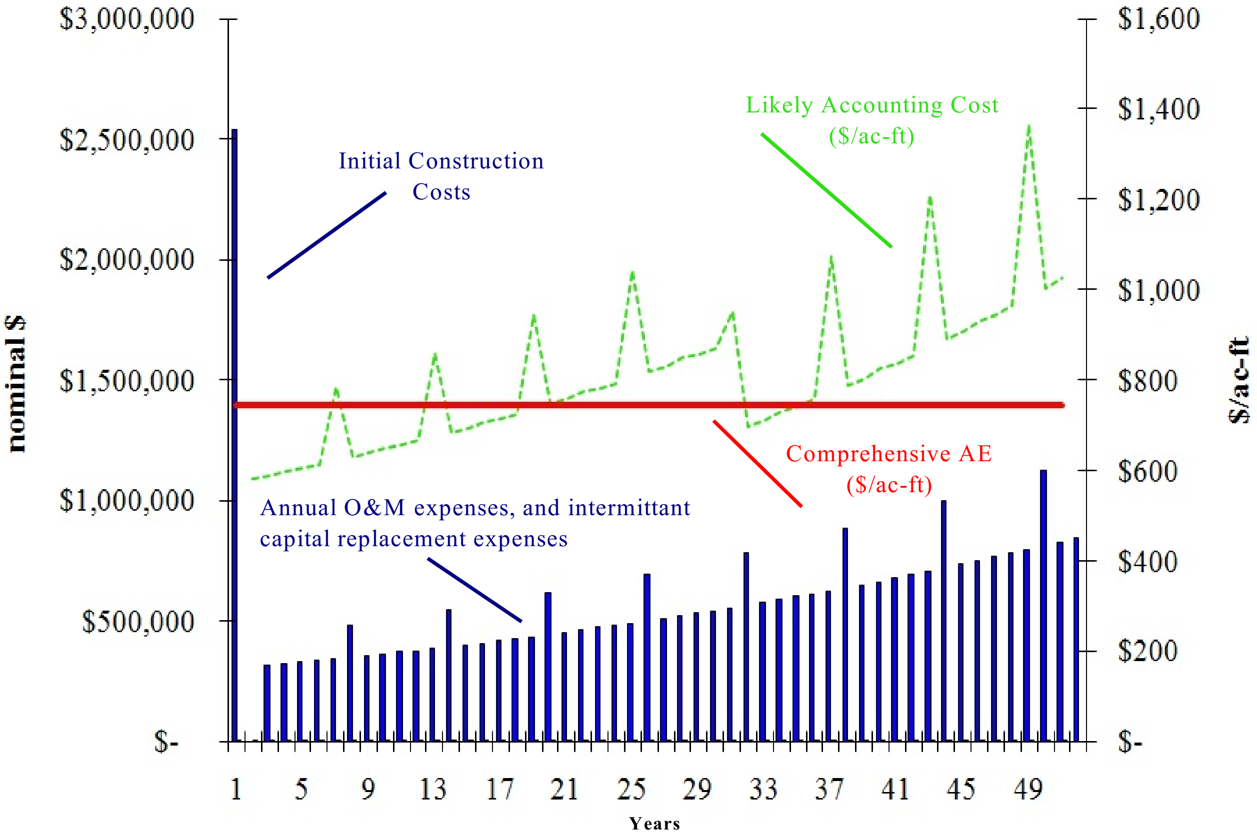
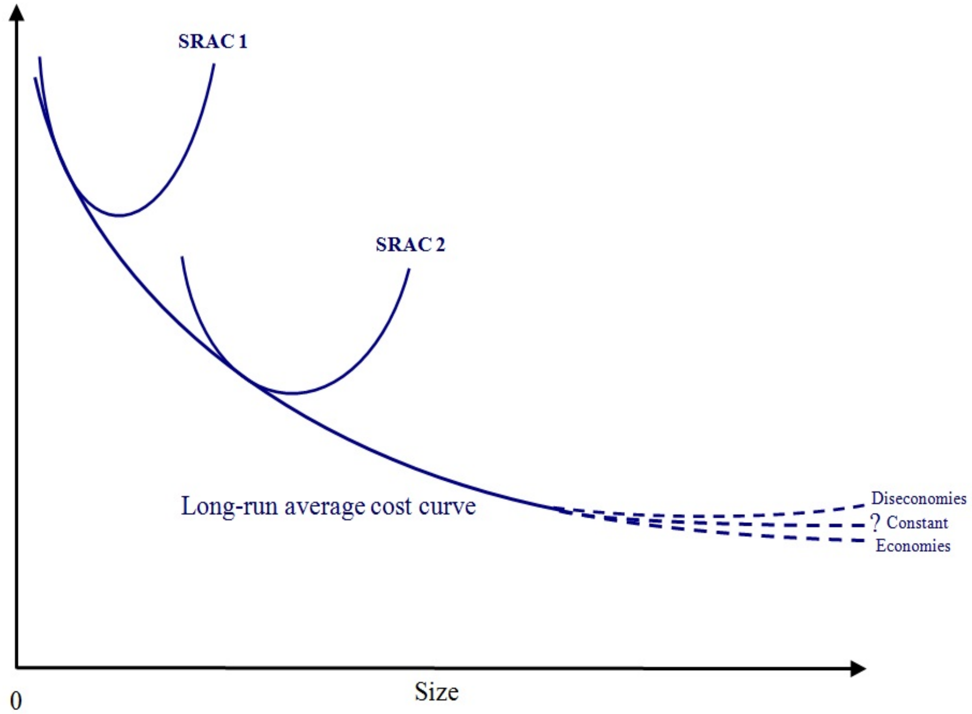


Figure 2. Depiction of Annual Cash Flow Requirements (Nominal Dollars), Likely Accounting Costs per acre-foot, and Comprehensive Annuity Equivalent (AE) Cost for the La Sara Facility Over its Useful Life.

The associated economic and financial value (of the $31,139,496) is $9,127,005, in real terms (**Table 10**). That is, a beginning cash balance of $9,127,005 in a banking account earning 6.125% interest annually will provide the cash flow requirements for 'withdrawals' for construction costs, annual O&M costs, and capital replacement costs (inflated 2.043% annually; see **Appendix A**), with a $0 balance left over at the end of the 50-year useful life.

Economies of Size

As noted in the *Prior Economic Literature* section, 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 all factors [inputs] in fixed proportion" (Beattie and Taylor 1985). In the specific case of increasing capacities of water treatment facilities, not all production inputs (e.g., land, labor, capital, management, etc.) are required to be increased proportionately to attain increased output. Therefore, the correct term is economies of *size* (ES) -- referring to the concept that marginal and average total costs decrease as output is increased from a non-proportional increase in the size (i.e., level) of some, but not necessarily all, inputs of production (**Figure 3**). That is, *scale* refers to a proportionate change in all inputs, whereas *size* refers to a non-proportionate change in some, but not necessarily all, inputs (Beattie and Taylor 1985).



Source: Kay and Edwards (1994), with modifications.

Figure 3. Illustration of Economies and Diseconomies of Size.

Long-Run Cost Curves

A common context in which *economies of size* (ES) is discussed often involves a situation where a firm is seeking the production level which minimizes its average total costs. This level of output can be identified for both short-run and long-run analyses (Maurice and Thomas 2002). In the short-run, production inputs are considered as being "fixed" (e.g., land, building, concrete, pipes, etc.) or "variable" (e.g., chemical, energy, labor, etc.). That is, in the short-run, fixed inputs cannot be increased or decreased, while variable inputs always vary with the level of output. In the long-run, however, all inputs are considered variable as the usage level of any resource can eventually be increased or decreased to minimize a firm's average total production costs. In this report, a long-run viewpoint is used.

Modified Life-Cycle Cost Results and Economies-of-Size

While the baseline results presented above were determined using DESAL ECONOMICS© and *CITY H_2O ECONOMICS*© (models previously advocated as being appropriate for making *apples-to-apples* comparisons of water treatment facilities life-cycle costs), some adjustments are necessary to *level the playing field* if comparisons are to be more precisely made across the potable water facilities' life-cycle costs. That is, natural variations in key data-input parameters of different facilities can distort any subsequent comparison of results. To more precisely compare across individual facilities producing potable water, certain data-input parameters (in both models) were modified.[35] In short, the modified results aim to 'equalize' facilities and technologies by establishing both a common base year (i.e., beginning) and production efficiency level, and by 'removing' the impacts caused by expenses associated with overbuilds

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[35] The models are built using the same methodological platform and design standards, but focused on different types of treatment facilities. Refer to Rogers (2008) and Sturdivant et al. (2009) for additional information.

and/or upgrades. The modified results facilitate a more precise means of comparison. For more details on the modified data-input variables and results, refer to **Appendix B**.

The following discussion and presentation of results on *economies of size* (ES) use "modified" economic and financial results for four water treatment facilities as data input; i.e., two conventional surface-water treatment and two brackish-groundwater desalination facilities. To perform the ES analysis for each water-treatment technology, both a 'small-' and a 'medium-sized' facility are used.

As displayed in **Table 17**, modified results can differ substantially from baseline results. Even so, they do facilitate, however, a more precise comparison of facilities' life-cycle costs and provide more accurate data input for analyzing ES. Further, as mentioned in the *Purpose and Objectives* section, the economic and financial work (and results) by Rogers (2008) and Sturdivant et al. (2009) provide input for this ES work. For brevity purposes, only abridged summary results (i.e., pertinent input into this report's work on economies of size) are presented and discussed below. Additional modified life-cycle cost results are provided in **Appendix B**.

Table 17. Baseline and Modified Life-Cycle Costs per Unit of Water, by Facility Type and Size, in 2006 Dollars.

		Life-Cycle Costs of Producing (and Delivering) Water [a]				
		Baseline			Modified [b]	
Facility	Facility Size Category	PE (%) [c]	$/ac-ft	$/1,000 gals	$/ac-ft	$/1,000 gals
				Conventional Surface-Treatment		
Olmito	small	52%	$1,393	$4.28	$968	$2.97
Northwest	medium	78%	$772	$2.37	$668	$2.05
				RO Desalination Treatment		
La Sara	small	65%	$745	$2.29	$629	$1.93
Southmost	medium	68%	$770	$2.36	$615	$1.89

Sources: Boyer (2008), Rogers (2008), and Sturdivant et al. (2009).

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

[b] For all modified analyses, the production efficiency is set at 85% of maximum-designed capacity. Also, certain costs (e.g., overbuilds and upgrades) are ignored (refer to **Appendix B** for additional information).

[c] PE = production efficiency; i.e., % of maximum-designed capacity.

Note all facilities' *baseline* life-cycle costs are higher than their *modified* life-cycle costs. This occurs due to the (a) removal of certain expenses (e.g., for overbuilds and upgrades) and (b) increasing of production efficiencies (PE's) to a consistent 85% (i.e., an assumed increase in the amount of potable water output for all facilities).[36] With the increased water output, total expenses for energy, chemicals, and water delivery (if applicable) are increased. Initial capital investment costs are allocated over more water output; thereby lowering per-unit life-cycle costs.

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[36] Refer to **Appendix B** for additional information.

Across Water-Treatment Technologies: As discussed in **Appendix B**, the modified life-cycle costs presented in **Table 17** for each facility are suitable for comparison. From the viewpoint of absolute difference, **Table 17** indicates that both the small- and medium-sized brackish-groundwater RO desalination facilities produce the lowest-cost potable water in the Texas LRGV. This indicates that, for both facility sizes, brackish-groundwater reverse-osmosis desalination is economically competitive (in the Texas LRGV) with the more common-place conventional surface-water treatment.

Within Water-Treatment Technologies: Again, from the viewpoint of absolute difference, **Table 17** indicates a decreased life-cycle cost (modified), for both technologies, as the size of the facility increases – albeit just slightly for RO desalination.

Economies of Size Ratio (ESR)

Though absolute differences can be useful, the defined economies of size assessment requires a more thorough analysis. That is, it is appropriate to calculate and evaluate the economies of size ratio (ESR) to ascertain the existence and degree of any ES. The long-run ES analysis is made using this mathematical equation from Kay and Edwards (1994),

$$\mathit{Economies\ of\ Size\ Ratio} = \frac{\%\ \mathit{Change\ in\ Cost}}{\%\ \mathit{Change\ in\ Output}}$$

where the numerator is derived by comparing the annuity equivalent of annual costs for the two different-sized facilities of interest, and the denominator is determined by comparing the annuity equivalents of annual water production. The possibility exists for this ratio to be <1, 1, or >1. Obviously, the ratio’s value affects its interpretation. Consistent with **Figure 3** (depicting various cost and facility size relationships), the three potential outcomes are:

Dis-Economies of Size (*DES*) ... ESR>1

The life-cycle costs increase as water production is increased, i.e., the ESR is greater than one.

Constant Economies of Size (*CES*) ... ESR=1

The life-cycle costs remain constant as water production is increased/decreased, i.e., the ESR equals one.

Economies of Size (*ES*) ... ESR<1

The life-cycle costs decrease as water production is increased, i.e., the ESR is less than one.

The ESR approach is a mathematical technique to determine the existence and degree of ES. Although only a single pair-wise comparison of life-cycle costs (per-unit of potable water production) by two facilities (for each technology) is used, insight into any ES is provided.

Adjusted Interpretation of Economies of Size Ratio (ESR)

As discussed in *Results – Key Sensitivity Analyses*, the baseline results are deterministic (i.e., absent stochastic elements, or risk considerations in the data input), meaning they are point estimates and, given inexactness in data input, baseline results are not expected to be exactly precise. To account for such imprecise data, and to ‘err on the side of conservativeness’ with respect to assertions about economies of size, the authors ran alternative scenarios by increasing and decreasing input costs by ±10% for facilities analyzed using the CITY H_2O ECONOMICS© and DESAL ECONOMICS© models. The observed range of results varied by as much as 36% from the original, baseline results. Thus, a ±0.36 'confidence interval' was arbitrarily established in this report for interpreting all ESRs. With this approach, the authors have *adjusted* the original ESR interpretations provided by Kay and Edwards (1994) to be:

Dis-Economies of Size (DES_{adj}) ... ESR>1.36

The ESR must be greater than 1.36 to conclude that dis-economies of size exist; i.e., life-cycle costs increase as water production is increased.

Constant Economies of Size (CES_{adj}) ... $0.64 \leq \text{ESR} \leq 1.36$

The ESR must be equal to or greater than 0.64, and equal to or less than 1.36 to conclude constant economies of size exist; i.e., life-cycle costs remain constant as water production is increased/decreased.

Economies of Size (ES_{adj}) ... ESR<0.64

The ESR must be less than 0.64 to conclude that economies of size exist; i.e., life-cycle costs decrease as water production is increased.

Results – Economies of Size

Using the aforementioned modified life-cycle costs and the adjusted ES interpretations, the implications for economies of size for conventional surface-water treatment and brackish-groundwater reverse-osmosis desalination in the Texas LRGV are estimated. Economies of size ratios (ESRs) and interpretations are made for each technology and facility segment, and for all cost types, categories, and items. Results for conventional surface-water treatment are provided first, with those for brackish-groundwater reverse-osmosis desalination following.[37]

Conventional Surface-Water Treatment

From an aggregate viewpoint, when comparing the Olmito facility (2.0 mgd) and the Northwest facility (8.25 mgd), economies of size (ES) are observed for conventional surface-water treatment in the Texas LRGV (**Table 18**). That is, refer to the ESR of 0.58 towards the bottom of **Table 18**. This value is obtained by determining the values to the Kay and Edwards (1994) ratio equation (on page 51). Specifically, the ESR is calculated by dividing the 1.73% percent change in modified annual life-cycle costs (i.e., [\$4,790,190 - \$1,755,211] ÷ \$1,755,211 = 1.73%) by the 2.96% change in modified annual water production (i.e., [7,174 - 1,813] ÷ 1,813 = 2.96%). The resulting ESR of 0.58 is then interpreted as indicating economies of size, as this value is less than the defined 0.64. [38, 39]

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[37] ES is examined by comparing two facility's life-cycle costs. Refer to the *Limitations* for additional information.

[38] See the *Adjusted Interpretation of Economies of Size Ratio (ESR)* section in the preceding pages for more.

[39] This value is interpreted as a 1.00% increase in output (i.e., potable water delivered to a point in the municipal water-delivery system) results in a 0.58% increase in the cost of treating surface-water in the Texas LRGV, i.e., costs increase less (proportionally) than the increase in the facility size (i.e., output).

Table 18. Economies of Size Ratios (ESRs) and ES Inference Classifications, by Cost Type, Category, and Item, for Conventional Surface-Water Treatment in the Texas Lower Rio Grande Valley, basis 2006.

	Facility				
Water Output / Cost Category, Type, and Item	Olmito (2.0 mgd)	Northwest (8.25 mgd)	% change	ESR [a]	ES Inference Classification [b]
Annual Water Output (ac-ft)	**1,813**	**7,174**	**2.96 %**	**n/a**	**n/a**
	“Modified” Life-Cycle Cost ($/yr)				
Initial Water Rights Purch. [c]	**$331,990**	**$1,309,277**	**2.94 %**	**1.00**	**CES**
Initial Construction Costs	**305,881**	**1,090,343**	**2.56 %**	**0.87**	**CES**
Continued Costs	**1,079,835**	**2,345,320**	**1.17 %**	**0.40**	**ES**
» Administrative	0	104,880	n/a	n/a	n/a
» O&M	1,079,835	2,240,440	1.07 %	0.36	ES
• Energy	201,136	506,198	1.52 %	0.51	ES
• Chemical	216,153	404,839	0.87 %	0.30	ES
• Labor	229,744	457,173	0.99 %	0.33	ES
• Raw Water Delivery	124,068	662,343	4.34 %	1.47	DES
• All Other	308,734	209,887	-0.32 %	-0.11	ES
Capital Replacement	**37,506**	**45,249**	**0.21 %**	**0.07**	**ES**
Facility Aggregate	**$1,755,211**	**$4,790,190**	**1.73 %**	**0.58**	**ES**

Sources: Rogers (2008) and Boyer (2008), with modifications.

[a] Economies of Size Ratio (ESR) calculated by dividing the *% change for costs*, by the *% change for water production* (Kay and Edwards (1994)); e.g., for initial water rights purchases, 2.94%÷2.96%=1.00.

[b] Inferences made based on adjusted classifications of: if ESR>1.36, then Dis-Economies of Size (DES) observed {shaded red}; if 0.64≤ESR≤1.36, then Constant Economies of Size (CES) observed {shaded yellow}; and if ESR<0.64, then Economies of Size (ES) observed {shaded green}. Adjusting the original interpretation classifications (provided in Kay and Edwards (1994)) is done to recognize the impreciseness of data input values and thus provide conservative assertions regarding ES.

[c] *Initial Water Rights Purchase* is maintained as a separate cost category because of its significance and distinction from monies spent on *Initial Construction Costs*.

ES Classification by Cost Category, Type, and Item: A review of **Table 18** also shows various values and provides a classification for the different cost categories, types, and items. Note with an ESR of 1.00, the *Initial Water Rights Purchase* cost category is identified as having constant economies of size (CES); this result is no surprise as water rights for both facilities were assigned the current market price of $2,300 per ac-ft (Rogers 2008). Somewhat counter to conventional wisdom (i.e., expectations), however, *Initial Construction Costs* also display CES. That is, fixed costs which can be spread out across higher-output firms typically exemplify lower per-unit costs (i.e., economies of size would be expected) (Kay and Edwards 1994). The authors’ adoption of an adjusted range of interpretation classification for the ratio for ES (i.e., if ESR<0.64, then ES observed) may have impacted this assertion.[40]

When evaluating the four different cost categories, the ratios can be interpreted as a 1.00% increase in conventional surface-water output infers a 1.0% increase in *Initial Water Rights Purchase* costs, a 0.87% increase in *Initial Construction Costs*, a 0.40% increase in *Continued Costs*, and a 0.07% increase in *Capital Replacement Costs*. A further review of **Table 18** shows both the *Continued Cost* and *Capital Replacement* categories to have ES. The apparent ES for the *Continued* and *Capital Replacement* cost categories can be attributable to price discounts for large volume purchases of inputs (e.g., chemicals, pumps, vehicles, etc.), and larger firms typically utilize labor (and other inputs) more efficiently than smaller firms (Kay and Edwards 1994).

When viewing *O&M* cost type, all cost items have ES, except for the *Water Delivery* item (i.e., raw water delivered by irrigation districts) which exhibits Dis-Economies of Size (DES).[41] These ESRs can be interpreted as a 1.00% increase in conventional surface-water output infers a 0.51% increase in *Energy* costs, a 0.30% increase in *Chemical* costs, a 0.33% increase in *Labor* costs, a 1.47% increase in *Water Delivery* costs, and a 0.11% decrease in *All Other* costs (**Table 18**).

ES Classification by Facility Segment:[42] The modified annuity equivalent of costs can also be allocated across the different facility segments, with each having its own ESR (**Table 19**). Note, with an ESR of 1.00, the *Initial Water Rights Purchase* facility segment is identified as having constant economies of size (CES); this is no surprise as water rights for both facilities were assigned the current market price of $2,300 per ac-ft (Rogers 2008). Also, the *Raw Water Intake/Reservoir* displays CES with an ESR of 0.90. The authors' adoption of an adjusted range of interpretation classification for the ratio for ES (i.e.,if ESR<0.64, then ES observed) may have impacted this assertion.[43]

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[40] That is, under the original assessment criteria by Kay and Edwards (1994), the initial construction costs would have been classified as having economies of size (i.e., 0.87 < 1.00). But with the adjusted criteria, 0.87 is not less than 0.64, and is thus asserted herein as representing CES. Refer to the *Adjusted Interpretation of Economies of Size Ratio (ESR)* section for more. Another item supporting the CES assertion for *Initial Construction Costs* is construction cost data for the Olmito facility were received in 2008 dollars and deflated by two years using a 2.043% annual inflation rate. Cruz (2008) indicates local construction costs increasing at 10-12% annually; i.e., perhaps the 2006 construction costs for the Olmito facility were under discounted from 2008. A sensitivity analysis indicates an annual inflation rate of about 4.8% would result in a reclassification to ES (i.e., ESR < 0.64) for *Initial Construction Costs*.

[41] Note the two municipalities receive their raw water from different irrigation districts diverting water from the Rio Grande. The DES observation may be due to contractual differences between them, and may speak to ES of irrigation districts more than DES of surface-water treatment facilities.

[42] Note the ES results and related interpretations herein are largely the same as those presented in Boyer (2008), but differ some in the reported values (e.g., ESRs) and inference classifications due to this report not separating *Administrative* costs into a separate and independent facility segment. Such administrative costs are apportioned based on each facility segment's proportion of all other costs, except *Administrative*.

[43] That is, under the original assessment criteria by Kay and Edwards (1994), the initial construction costs would have been classified as having economies of size (i.e., 0.90 is less than 1.00). But with the adjusted criteria, 0.90 is not less than 0.64, and is thus asserted herein as representing constant economies of size (CES). Refer to the *Adjusted Interpretation of Economies of Size Ratio (ESR)* section for more information.

Table 19. Economies of Size Ratios (ESRs) and ES Inference Classifications, by Facility Segment, for Conventional Surface-Water Treatment in the Texas Lower Rio Grande Valley, basis 2006.

Water Output / Facility Segment	Facility Olmito (2.0 mgd)	 Northwest (8.25 mgd)	% change	ESR [a]	ES Inference Classification [b]
Annual Water Output (ac-ft)	1,813	7,174	2.96 %	n/a	n/a
	"Modified" Life-Cycle Cost ($/yr)				
A) Initial Water Rights Purchase [c]	$331,990	$1,309,277	2.94 %	1.00	CES
1) Raw Water Intake/Reservoir	314,550	1,155,678	2.67 %	0.90	CES
2) Treatment Unit [d]	543,137	1,327,763	1.44 %	0.49	ES
» pre-disinfection	n/a	567,308	n/a	n/a	n/a
» coagulation/flocculation	n/a	187,746	n/a	n/a	n/a
» sedimentation	n/a	104,026	n/a	n/a	n/a
» filtration/backwash	n/a	232,376	n/a	n/a	n/a
» secondary disinfection	n/a	236,307	n/a	n/a	n/a
3) Sludge Disposal	79,765	190,665	1.39 %	0.47	ES
4) Del. to Municipal Line / Storage	352,209	590,080	0.68 %	0.23	ES
5) Operations' Support Facilities	133,561	216,727	0.62 %	0.21	ES
6) Overbuilds & Upgrades	0	0	n/a	n/a	n/a
Facility Aggregate	$1,755,211	$4,790,190	1.73 %	0.58	ES

Sources: Rogers (2008) and Boyer (2008), with modifications.

[a] Economies of Size Ratio (ESR) calculated by dividing the *% change for costs*, by the *% change for water production* (Kay and Edwards (1994)); e.g., for initial water rights purchases, 2.94%÷2.96%=1.00.

[b] Inferences made based on adjusted classifications of: if ESR>1.36, then Dis-Economies of Size (DES) observed {shaded red}; if 0.64≤ESR≤1.36, then Constant Economies of Size (CES) observed {shaded yellow}; and if ESR<0.64, then Economies of Size (ES) observed {shaded green}. Adjusting the original interpretation classifications (provided in Kay and Edwards (1994)) is done to recognize the impreciseness of data input values and thus provide conservative assertions regarding ES.

[c] *Initial Water Rights Purchase* is maintained as a separate facility segment because of its significance and distinction from monies spent on facility segments.

[d] The Olmito facility's comprehensive-systems design prevents cost and ESR values for individual facility segments observed in the Northwest facility. Thus, the Northwest facility's detailed cost segments listed are combined (i.e., summed) into the Treatment Unit segment.

When evaluating the different facility segments, the ratios can be interpreted as a 1.00% increase in conventional surface-water output infers a 1.0% increase in *Initial Water Rights Purchase* costs, a 0.90% increase in *Raw Water Intake/Reservoir* costs, a 0.49% increase in *Treatment Unit* costs, etc. A further review of **Table 19** shows all facility segments, except for the *Initial Water Rights Purchase* and *Raw Water Intake/Reservoir* segments, to exhibit ES.

These results (**Tables 18** and **19**) suggest ES are present for conventional surface-water treatment. This conclusion aligns with the literature (i.e., Traviglia and Characklis (2006), Characklis (2004), and Boisvert and Schmit (1996)). The CES found in the *Initial Construction Costs* are perplexing, given the literature commonly reports per-unit costs decrease as output increases. This indicates that construction costs in the Texas LRGV may not follow national trends, or are an anomaly to the facilities examined. Alternatively, the authors' use of *adjusted* ESR interpretations impacts the assertion.

Brackish Groundwater Reverse-Osmosis Desalination

From an aggregate viewpoint, when comparing the La Sara facility (1.13 mgd) and the Southmost facility (7.50 mgd), constant economies of size (CES) are observed for brackish groundwater reverse-osmosis desalination in the Texas LRGV (**Table 20**). Refer to the ESR of 0.97 towards the bottom of **Table 20**. This value is obtained by determining the values to the Kay and Edwards (1994) ratio equation (on page 51). Specifically, the ESR is calculated by dividing the 5.49% percent change in modified annual life-cycle costs (i.e., [\$4,196,391 - \$646,736] ÷ \$646,736 = 5.49%) by the 5.64% change in modified annual water production (i.e., [6,823 - 1,028] ÷ 1,028 = 5.64%). The resulting ESR of 0.97 is then interpreted as indicating constant economies of size, as this value is greater than 0.64, and less than the defined 1.36. [44, 45]

ES Classification by Cost Category, Type, and Item: A review of **Table 20** also shows various values and provides a classification for the different cost categories, types, and items. Note with an ESR of 1.36, the *Initial Construction Costs* are identified as having constant economies of size (CES). This may seem counter to conventional wisdom (i.e., expectations) which holds that fixed costs that can be spread out across higher-output firms typically exemplify lower per-unit costs (i.e., economies of size would be expected) (Kay and Edwards 1994). The authors' adoption of an adjusted range of interpretation criteria for the ratio for ES (i.e., if ESR≤1.36, then CES observed) may have impacted this assertion.[46]

When evaluating the three different cost categories (i.e., a fourth category, *Initial Water Rights Purchase*, is not applicable to desalination, as it is with surface-water treatment), the ratios can be interpreted as a 1.00% increase in reverse-osmosis desalination output infers a 1.36% increase in *Initial Construction Costs*, a 0.81% increase in *Continued*

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[44] See the *Adjusted Interpretation of Economies of Size Ratio (ESR)* section in the preceding pages for additional information.

[45] This value can be interpreted as a 1.00% increase in output (i.e., potable water delivered to an initial point within the municipal water-delivery system) results in a 1.36% increase in the cost of producing water with brackish groundwater reverse-osmosis desalination in the Texas LRGV, i.e., costs increase in proportion to facility size (i.e., output), thereby representing constant economies of size.

[46] That is, under the original assessment criteria by Kay and Edwards (1994), the initial construction costs would have been classified as having dis-economies of size (i.e.,1.00 < 1.36). But with the adjusted criteria, 1.36 is not greater than 1.36, and is thus asserted herein as representing CES. Refer to the *Adjusted Interpretation of Economies of Size Ratio (ESR)* section for additional information.

Costs, and a 1.49% increase in *Capital Replacement Costs*.[47] A further review of **Table 20** shows both the *Initial Construction Costs* and *Continued Costs* to have CES, which may be attributed to the modular (i.e., stackable) nature of the assets employed (e.g., pumps, filters, etc.) in the reverse-osmosis desalination process.

Table 20. Economies of Size Ratios (ESRs) and ES Inference Classifications, by Cost Type, Category, and Item, for Brackish Groundwater Reverse-Osmosis Desalination in the Texas Lower Rio Grande Valley, basis 2006.

Water Output / Cost Category, Type, and Item	Facility La Sara (1.13 mgd)	 Southmost (7.50 mgd)	% change	ESR [a]	ES Inference Classification [b]
Annual Water Output (ac-ft)	**1,028**	**6,823**	**5.64 %**	**n/a**	**n/a**
	"Modified" Life-Cycle Cost ($/yr)				
Initial Construction Costs	**163,235**	**1,417,205**	**7.68 %**	**1.36**	**CES**
Continued Costs	**459,806**	**2,556,747**	**4.56 %**	**0.81**	**CES**
» Administrative	170,033	121,750	-0.28 %	-0.05	ES
» O&M	289,773	2,434,997	7.40 %	1.31	CES
• Energy	207,853	1,356,447	5.53 %	0.98	CES
• Chemical	46,602	409,508	7.79 %	1.38	DES
• Labor	24,884	490,084	18.69 %	3.32	DES
• All Other	10,433	178,959	16.15 %	2.87	DES
Capital Replacement	**23,696**	**222,438**	**8.39 %**	**1.49**	**DES**
Facility Aggregate	**$646,736**	**$4,196,391**	**5.49 %**	**0.97**	**CES**

Sources: Rogers (2008) and Boyer (2008), with modifications.

[a] Economies of Size Ratio (ESR) calculated by dividing the *% change for costs*, by the *% change for water production* (Kay and Edwards (1994)); e.g., for initial construction costs, 7.68%÷5.64%=1.36.

[b] Inferences made based on adjusted classifications of: if $ESR>1.36$, then Dis-Economies of Size (DES) observed {shaded red}; if $0.64 \leq ESR \leq 1.36$, then Constant Economies of Size (CES) observed {shaded yellow}; and if $ESR<0.64$, then Economies of Size (ES) observed {shaded green}. Adjusting the original interpretation classifications (provided in Kay and Edwards (1994)) is done to recognize the impreciseness of data input values and thus provide conservative assertions regarding ES.

When viewing *O&M* cost types, *Energy* has CES, while the remaining items demonstrate DES. These ESRs can be interpreted as a 1.00% increase in brackish groundwater reverse-osmosis desalination output infers an increase in costs for *Energy* of 0.98%, *Chemical* of 1.38%, *Labor* of 3.32%, and *All Other* of 2.87% (**Table 20**).[48]

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[47] The La Sara facility treats lower-salinity water than the Southmost facility. Since high salinity reduces the life of certain components (e.g., RO membranes) in the main facility, more frequent replacement and higher capital replacement costs can be expected (i.e., diseconomies of size) (Browning 2007; White 2007). As discussed in the "Limitations" section, failing to adjust for different incoming source water can be a limitation of this report.

[48] The La Sara facility's SCADA system, operational designs, etc. do not require a trained professional to be continuously on location. Typically, only hourly workers are on location to monitor the system (Browning 2007). This can partially explain why La Sara has a lower per-unit labor cost, relative to the Southmost facility.

ES Classification by Facility Segment:[49] The modified annuity equivalent of costs can also be allocated across the different facility segments, with each having its own ESR (**Table 21**). Note, with ESRs of 1.50 and 1.84, respectively, the *Well Field* and *High Service and Delivery Pipeline* facility segments show DES.[50] Not surprisingly, the *Main Facility/Treatment Process* facility segment displays CES with an ESR of 1.18 -- that is, the 'modular'(i.e., stackable) nature of the assets employed (e.g., pumps, filters, etc.) in the reverse-osmosis desalination process may prevent any ES with the *Main Facility/Treatment Process* of a reverse-osmosis desalination facility. The authors' adoption of an adjusted range of interpretation classification for the ratio for ES (i.e., if ESR$\leq$1.36, then CES observed) may have impacted this assertion.[51]

The remaining three facility segments, *Transmission Line (to facility)*, *Concentrate Discharge*, and *Finished Water Line/Delivery Pipeline* are shown to display ES with ESRs of 0.49, -0.14, and 0.10, respectively -- well within the bounds of any interpretation classification (**Table 21**) signaling ES.[52] When evaluating the different facility segments, the ratios can be interpreted as a 1.00% increase in brackish groundwater reverse-osmosis desalination output infers a 1.50% increase in *Well Field* costs, a 0.49% increase in *Transmission Line (to facility)* costs, etc. Overall, facility costs increase 0.97% with a 1.00% increase in water output (**Table 21**).

These ESR results (**Tables 20** and **21**), based on the two facilities in the Texas LRGV, show CES for brackish groundwater reverse-osmosis desalination in the Texas LRGV. This conclusion does not concur with the literature (Traviglia and Characklis (2006), Characklis (2004), Arroyo (2005), and Norris (2006a; 2006b)). That is, these results suggest an increase of output does not decrease the per-unit cost of producing potable water via reverse-osmosis desalination of brackish-groundwater in the Texas LRGV. As discussed in the *Limitations* section, additional life-cycle costs for additional facilities of different sizes are needed to extend this research.

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[49] Note the ES results and related interpretations herein are largely the same as those presented in Boyer (2008), but differ some in the reported values (e.g., ESRs) and inference classifications due to this report not separating *Administrative* costs into a separate and independent facility segment. Such administrative costs are apportioned based on each facility segment's proportion of all other costs, except *Administrative*.

[50] The La Sara facility's source water is supplied from one well (Browning 2007), compared to the Southmost facility which receives its source water from 18 wells (Sturdivant et al. 2009).

[51] That is, under the original assessment criteria by Kay and Edwards (1994), the *main facility/treatment process* would have been classified as having dis-economies of size (i.e., 1.18 is greater than 1.00). But with the adjusted criteria, 1.18 is less than 1.36, and is thus asserted herein as representing CES. Refer to the *Adjusted Interpretation of Economies of Size Ratio (ESR)* section for additional information.

[52] The La Sara facility is located approximately 50 feet from its source water (Browning 2007), whereas the Southmost facility is located approximately 18 miles away from its raw source water (Sturdivant et al. 2009).

Table 21. Economies of Size Ratios (ESRs) and ES Inference Classifications, by Facility Segment, for Brackish Groundwater Reverse-Osmosis Desalination in the Texas Lower Rio Grande Valley, basis 2006.

	Facility				
Water Output / Facility Segment	La Sara (1.13 mgd)	Southmost (7.5 mgd)	% change	ESR [a]	ES Inference Classification [b]
Annual Water Output (ac-ft)	1,028	6,823	5.64 %	n/a	n/a
	"Modified" Life-Cycle Cost ($/yr)				
1) Well Field	$126,731	$1,196,869	8.44 %	1.50	DES
2) Transmission Line (to facility)	35,550	133,092	2.74 %	0.49	ES
3) Main Facility / Treat. Process	296,869	2,263,791	6.63 %	1.18	CES
4) Concentrate Discharge	40,104	8,837	-0.78 %	-0.14	ES
5) Finished Water Line / Tank Storage	110,759	175,558	0.59 %	0.10	ES
6) High Service and Delivery Pipeline	36,723	418,243	10.39 %	1.84	DES
7) Overbuilds and Upgrades	0	0	n/a	n/a	n/a
Facility Aggregate	$646,736	$4,196,391	5.49 %	0.97	CES

Sources: Rogers (2008) and Boyer (2008), with modifications.

[a] Economies of Size Ratio (ESR) calculated by dividing the *% change for costs*, by the *% change for water production* (Kay and Edwards (1994)); e.g., for the well field, 8.44%÷5.64%=1.50.

[b] Inferences made based on adjusted classifications of: if ESR>1.36, then Dis-Economies of Size (DES) observed {shaded red}; if 0.64≤ESR≤1.36, then Constant Economies of Size (CES) observed {shaded yellow}; and if ESR<0.64, then Economies of Size (ES) observed {shaded green}. Adjusting the original interpretation classifications (provided in Kay and Edwards (1994)) is done to recognize the impreciseness of data input values and thus provide conservative assertions about ES.

Discussion

As stated earlier, the purpose of this work is to assist in water planning by (a) providing comparable *life-cycle costs* of two different water-treatment technologies, (b) merging this data with similarly-calculated life-cycle cost data (by the authors) for two other facilities, and (c) reporting on any *economies of size* for those technologies in the Texas LRGV using the four facilities' life-cycle cost data.[53] As such, this study encompasses collaborative efforts of a team of agricultural economists to assimilate multiple localized studies providing relevant implications for water planners and decision makers (e.g., municipalities, engineers, etc.).

In this work, comparison of key results of the two technologies (in their aggregate) provides for the following assertions:

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[53] The total of four facilities (i.e., two 'small' and two 'medium-sized' facilities), representing two water-treatment technologies (i.e., two conventional and two desalination), is recognized as a study limitation.

- » Economies of Size (ES) are present in conventional surface-water treatment in the Texas LRGV, and
- » Constant Economies of Size (CES) are present in brackish groundwater reverse-osmosis desalination in the Texas LRGV.

Remember, however, this research incorporates modified life-cycle costs with adjusted interpretation criteria (i.e., a ±0.36 'confidence interval') of the ESRs to ascertain the presence of ES for both technologies. The standards for determining ES in other studies by other authors (mentioned in the *Prior Economic Literature* section) are unclear, however, and thus only allow for relative comparisons to be made across the different studies' results.

> *Conventional Surface-Water Treatment* – The results presented herein seem to agree with the literature. Specifically, Characklis (2004) reported similar ES as Traviglia and Characklis (2006) for conventional surface-water treatment. Characklis (2004) relied on data from the literature, but did make attempts to adjust the data to a study region. In addition, his study was more focused on the effects of salinity level on the two water-treatment technologies than on economies of size.
>
> *Reverse-Osmosis Desalination* – The conclusions drawn herein seem to be inconsistent with the literature. Using cost relationships from the literature (i.e., secondary data) to calculate construction and operating costs, Traviglia and Characklis (2006) report ES were identified for RO desalination. Also, Arroyo (2005) reported ES with brackish-groundwater desalination as he stated the costs decrease from $1.09/1,000 gals for a 1.0 mgd facility to $0.71/1,000 gals for a 10.0 mgd facility. Note that Arroyo (2005) did not include, however, many cost items included in this research/report (e.g., source water development, concentrate disposal, finished water storage, land, etc.).

Additional observations from this report's results are worthy of mention as they have the capacity to impact Texas LRGV water-planning strategies:

- First, results herein suggest a "small" RO desalination facility, serving residents on the outer edges of a larger municipality, can provide an economically-competitive source of potable water. By building multiple small desalination facilities, communities can avoid extending existing distribution networks; which Boisvert and Schmit (1996) report as having dis-economies of size.

- RO desalination is economically competitive with conventional surface-water treatment and provides Texas LRGV municipalities a viable alternative for potable water. With anticipated population growth, any significant increase in the use of RO water would reduce municipalities' reliance upon converted water rights (i.e., from irrigation-to-municipal).

Caveats and Limitations

When one considers (a) the development of the models DESAL ECONOMICS© and CITY H_2O ECONOMICS©, (b) the data gathering, analysis, and reporting of the earlier, related case studies, (c) the data gathering, analysis, and reporting of economic and financial life-cycle cost results in this report, and (d) the synthesizing of intermediate results and interpretation of ESRs in this report, it is obvious that considerable work was required to get to this point. Regardless, the authors would be amiss if a discussion of this study's limitations were not provided.

- As with any case study, the results are location specific and represent *a point in time* whereas costs continually change over time. That is, the life-cycle costs and the associated economies of size ratios (ESRs) are point estimates as the dynamics of costs and other factors prevent the mass application of the specific results (i.e., life-cycle costs, and ESRs) to all time periods or other locations.

- Making assertions about ES based on adjusted interpretation criteria (i.e., a ± 0.36 'confidence interval') with only four facilities, representing two technologies, and two facility-size categories (i.e., small and medium) is obviously limiting. Even though the collected primary data is reliable (i.e., originated from collaborating municipal water managers and their consulting engineers), additional study of more facilities, including some from larger facilities (e.g., 25 mgd range), would improve and strengthen the study's assertions regarding ES.

- The philosophy applied to baseline life-cycle cost analyses 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 B**, this philosophy is maintained, even though certain other adjustments facilitating a more precise comparison of dissimilar facilities and/or technologies, are discussed. Again, however, adjustments to account for different incoming/outgoing water qualities are not made with the modified analyses. Determining the protocol of such a process could be the subject of future research.[54]

- Prior to calculating the ESRs (economies of size ratios), the authors take certain liberties in adjusting certain data-input variables which go into calculating the comprehensive economic and financial life-cycle costs (see **Appendix B**). The adjustments 'level' such costs and facilitate a more-precise comparison of facilities/technologies. Of the adjustments, the most potentially contentious is the setting all facilities production efficiencies (PEs) to 85% of maximum design capacity. Selecting this level was based upon TCEQ's Rule of 85 (see **Appendix B**) and offers a necessary threshold level which is obtained in a manner better than 'just pulling a number from thin air.' Obviously, the established 85% PE affects the modified life-cycle cost results, the ESRs, and ultimately the assertions made about ES in water-treatment facilities in the Texas LRGV.

Conclusions

This report extends work by Sturdivant et al. (2009) and Rogers et al. (2010) on the analyses of life-cycle costs of water-treatment facilities by (a) providing similar case studies on two

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[54] This limitation text is liberally borrowed from Sturdivant et al. 2009. Since the authors have developed similar models on the same methodological platform (e.g., CITY H_2O ECONOMICS© and DESAL ECONOMICS©), similar limitations exist.

additional 'small-sized' facilities, and aggregating the four facilities' results to calculate ESRs for making assertions about ES of Texas LRGV water-treatment technologies (i.e., conventional surface-water treatment and reverse-osmosis desalination of brackish groundwater). Thus, insights into which technology and which size of facility provides 'the most bang for the buck' in the Texas LRGV is provided to water planners and managers. This report also aids evaluating technology and facility-size alternatives with:

(a) its comprehensive two-part methodology (i.e., net present value analysis and annuity equivalent calculations) calculating life-cycle costs which consider all costs over the life of the facility (i.e., not just initial construction costs), and

(b) its calculation of ESRs and adoption of adjusted interpretation criteria (i.e., a ± 0.36 'confidence interval') for making ES assessments which provide an effective evaluation of the long-run returns to size for capital water projects.

That is, this sound economic and financial research contributes not only to the literature, but also toward enhancing decisionmakers' abilities to evaluate and determine cost-effective decisions.

Selected specific results of this report lead to the conclusion that brackish-groundwater desalination is an economically-viable alternative to surface-water treatment in the Texas Lower Rio Grande Valley. Further, the results reveal ES are present for conventional surface-water treatment, but that CES are present in reverse-osmosis desalination of brackish groundwater. Thus, as the region seeks to expand its potable water supplies to meet future demands, calculating accurate costs for both water-treatment technologies and across different facility sizes are important considerations.

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Appendix A:
Economic and Financial Methodology

Economic and Financial Methodology

> Authors' Note: To provide consistency across reports and facilitate comparisons across two models (i.e., DESAL ECONOMICS© as discussed in Sturdivant et al. 2009, and CITY H_2O ECONOMICS© as discussed in Rogers et al. 2010), facility case studies, etc., the text in this section largely mimics that developed by the authors in Rogers et al. (2010).

Since conventional water treatment facilities vary in many aspects (e.g., design, construction and O&M costs, etc.), an evaluation methodology is called for that facilitates "apples to apples" comparisons. An appropriate way to allow for such comparisons and to determine the most cost-effective alternative is to identify and define each facility as a capital investment and then apply appropriate financial, accounting, and economic principles and techniques (Rister et al. 2009; Sturdivant et al. 2009).

The methodology used in this report combines standard Capital Budgeting – Net Present Value (NPV) analysis with the calculation of annuity equivalent measures, similar to the methods presented in Rister et al. (2009).[55] Standard NPV analysis allows for comparing uneven flows (of dollars and product water) among alternatives (i.e., projects), while the use of annuity equivalents extends the standard NPV analysis to accommodate comparisons of projects (and components thereof) with different useful lives. This combined approach is the methodology of choice because it integrates expected years of useful life with related annual costs and outputs, as well as other financial realities such as inflation and the time value of money, into a single, comprehensive annual $/acre-foot {or $/1,000 gallons} life-cycle cost value. It is this life-cycle cost value which facilitates comparisons among alternatives and allows for priority rankings.[56]

NPV of Economic and Financial Costs

There are three primary cost types which are the foundation for the calculations in this economic and financial analysis of the Olmito and La Sara facilities:

1) Initial construction/investment costs;[57]
2) Annual operation and maintenance costs (O&M); and
3) Intermittent capital replacement costs.

Also of importance is the salvage value of the capital investment at the end of each facility's expected useful life. Although this analysis assumes a zero net salvage value for land, buildings,

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[55] Refer also to Jones (1982); Levy and Sarnat (1982); Quirin (1967); Robison and Barry (1996); and Smith (1987).

[56] More precise comparisons across facilities and across technologies are facilitated with certain, limited modifications to key data-input parameters. This topic is discussed in further detail in **Appendix B**: *Modified Data Input and Results*.

[57] For the Olmito facility (i.e., conventional surface-water treatment), the costs of purchasing water rights is an initial investment cost, in addition to the initial construction costs.

equipment, etc., for both facilities, there could be a salvage or resale value of the water rights at the conclusion of the useful life of the Olmito facility.[58]

Calculation of the net present value of the economic and financial costs of constructing, operating, and maintaining each facility segment (A) of a water treatment plant (P) over the course of its useful life can be achieved using the following equation:

$$\begin{aligned} EC_{NPV}^{P,A,Z} &= \sum_{j=o}^{Y^{P,A}} \left\langle \left\{ \left[I_j^{P,A,Z} * (1+i)^j \right] \right\} \div \left\{ (1+r)^j \right\} \right\rangle \\ &+ \sum_{t=Y^{P,A}+1}^{Y^{P,A}+N^{P,A}} \left\langle \left\{ \left[(OC_t^{P,A,Z_A} + CR_t^{P,A,Z_A}) * (1+i)^t \right] \right\} \div \left\{ (1+r)^t \right\} \right\rangle \\ &- \left\langle \left\{ SV^{P,A,Z_A} \right\} \div \left\{ (1+r)^{Z_A} \right\} \right\rangle, \end{aligned}$$

where the elements are defined in **Table A1**.

NPV of Water Production

Similar to the step performed previously, the NPV of water production can also be calculated for a water treatment plant.[59] This calculation differs from the NPV of costs because water production is the same for all segments at a water treatment facility; therefore, the NPV of water production is calculated for the entire plant (not individual segments), as follows:

$$WP_{NPV}^{P,Z} = \sum_{t=Y^P+1}^{Y^P+N^P} \left\langle \left\{ WP_t^{P,Z} \right\} \div \left\{ (1+s) \right\}^t \right\rangle,$$

where the elements are defined in **Table A1**.

Annuity Equivalent Values for Economic and Financial Costs

The NPV calculations identify the costs over the planning period of a water treatment plant and the associated potable water production in present-day terms. The next step, (i.e., calculation of annuity equivalents), extends the methodology to allow for comparisons across alternative water treatment plants of different economic lives.[60] An annuity equivalent (or 'annualized life-cycle cost') converts the NPV of costs for one plant over its useful life into a per-unit amount. By nature, the annuity equivalent assumes an infinite series of purchasing and operating to maintain a facility into perpetuity. Reference Barry, Hopkin, and Baker (1983, p. 187) and Penson and Lins (1980, p. 97) for clarification of this concept and examples. This calculation can be used as the basis of comparison to similarly calculated costs for segments of other water treatment plants and/or other water treatment technologies with varying useful lives:

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[58] A zero net salvage value is recorded for the capital investment; it is assumed any remaining value of the investment is offset by the cost of facility decommissioning and site restoration. Also, the investment (including water rights) is intended to be long-term, with no expectations of salvaging the asset. The value of the water rights are retained and could have value beyond the life of the Olmito facility, but also have a $0 salvage value for the reasons noted.

[59] The debates related to appropriateness of discounting a physical product are addressed later in this section.

[60] Annuity equivalent calculations also allow for individual segments at a water treatment facility to have different expected lives, which is the reason for calculating the annuity equivalents on a per segment basis. It is not expected, however, that varying segment lives will occur frequently.

$$AEEC_{AE}^{P,A,Z_A} = EC_{NPV}^{P,A,Z_A} \div \left\langle \left\{1 - (1+r)^{-Z_A}\right\} \div \{r\} \right\rangle,$$

where the elements are defined in **Table A1**.

The annuity equivalent calculations for each of the facility segments have a common denominator, which allows for a summation of the different annuity equivalents for each segment into one aggregated (AG) annuity equivalent of economic and financial costs for the entire water treatment plant P, as demonstrated below:

$$AAEEC_{AG}^{P,Z} = \sum {}_{A=1}^{A=G} AAEC_{AE}^{P,A,Z_A},$$

where the elements are defined in **Table A1**.

Table A1. Definitions for the Elements of the Economic and Financial Cost Calculations in the DESAL ECONOMICS© and CITY H_2O ECONOMICS© Models Used to Analyze the La Sara and Olmito Water-Treatment Facilities.

Element	Definition
EC_{NPV}^{P,A,Z_A}	net present value of net economic and financial costs for facility segment A of conventional water treatment plant P over the planning period Z_A
A	individual facility segment (functional area) of conventional treatment plant P
Z_A	time (in years) of planning period for facility segment A, consisting of construction period and expected useful life, $Z_A \leq Z$
Z	time (in years) of planning period for water treatment plant P, consisting of construction period and expected useful life, $Z \geq Z_A$
j	the specific year in the construction period
$Y^{P,A}$	length of construction period (years) for facility segment A of conventional water treatment plant P
I_j^{P,A,Z_A}	initial construction cost (which includes the purchase of water rights) for facility segment A occurring during year j of the construction period for conventional water treatment plant P in the planning period Z_A
i	compounding inflation rate applicable to construction, operation, and maintenance inputs
r	the discount rate (%) used to transform nominal cash flows into a current (i.e., benchmark) dollar standard
$N^{P,A}$	length of expected useful life (years following completion of construction period) for facility segment A of conventional water treatment plant P
OC_t^{P,A,Z_A}	operation and maintenance costs for facility segment A during year t of useful life $N^{P,A}$ for conventional water treatment plant P over the single economic-planning period Z_A
CR_t^{P,A,Z_A}	capital replacement costs for facility segment A during year t of useful life $N^{P,A}$ for conventional water treatment plant P over the planning period Z_A
t	the specific year of the expected useful life

(continued)

Table A1. Continued

Element	Definition
G	number of individual facility segments
SV^{P,A,Z_A}	salvage value for facility segment A of conventional water treatment plant P (including water rights) at the end of year Z_A
$WP_{NPV}^{P,Z}$	net present value of annual water production of conventional water treatment plant P over the planning period Z
$WP_t^{P,Z}$	annual water production (in ac-ft) in year t of conventional water treatment plant P over the planning period Z
s	social time value discount rate (%)
$AEEC_{AE}^{P,A,Z_A}$	annuity equivalent of economic and financial costs for facility segment A for a series of conventional water treatment plants P, each constructed and operating over a Z_A planning period, into perpetuity
$AAEEC_{AG}^{P,Z}$	aggregate annuity equivalent of economic and financial costs for conventional water treatment plant P over a Z planning period into perpetuity
$AEWP_{AE}^{P,Z}$	annuity equivalent of water production for a series of conventional water treatment plants P, each constructed and operating over a Z time period, into perpetuity
$AEECAF_{AE}^{P,A,Z_A}$	annuity equivalent of costs per ac-ft for a series of conventional water treatment plants P, each constructed and operating over a Z time period, into perpetuity
$AAE_{AG}^{P,Z}$	aggregate annuity equivalent of costs per ac-ft for a series of conventional water treatment plants P, each constructed and operating over a Z time period, into perpetuity

Source: Rister et al. (2009).

Annuity Equivalent Values for Water Production

Similarly, the NPV of water production over the planning period Z needs to be transformed into a comparable annuity equivalent value. To convert the NPV of potable water production over the useful life of a plant into an infinite stream of production, the annuity equivalent is calculated as follows:

$$AEWP_{AE}^{P,Z} = WP_{NPV}^{P,Z} \div \left\langle \left\{1-(1+s)^{-Z}\right\} \div \left\{s\right\} \right\rangle,$$

where the elements are defined in **Table A1**.

Annuity Equivalent of Costs per unit of Water Production

This step in the methodology divides the "cost" annuity equivalent by the "water production" annuity equivalent. The result is a single, comprehensive annual \$/ac-ft {or \$/1,000 gallons} life-cycle cost. The purpose of this calculation is to provide a consistent, per-unit cost for a defined unit of water regardless of size, age, and type of plant, allowing comparisons among plants of varying projected lives and perhaps types.[61] This value for an individual segment is calculated as follows:

$$AEECAF_{AE}^{P,A,Z_A} = AEEC_{AE}^{P,A,Z_A} \div AEWP_{AE}^{P,A,Z},$$

where the elements are defined in **Table A1**.

The annuity equivalent of costs per unit of water production represents the cost per year for facility segment A in base-year dollars of producing one ac-ft {or 1,000 gal} of water into perpetuity through a continual replacement of plant P.

To get the total per-unit cost annuity equivalent for the entire plant, the per-unit cost annuity equivalents for each of the individual plant segments must be aggregated (AG). This measure represents the key critical value attained in this report and is accomplished through the following calculation:

$$AAE_{AG}^{P,Z} = \sum_{A=1}^{A=G} AEECAF_{AE}^{P,A,Z_A},$$

where the elements are defined in **Table A1**.

Values for Discount Rates and Compound Factor

Although much primary data are used in this report, two discount rates and a compound rate are assumed, based on prior work by Rister et al. (2009).

Discount Rate for Dollars

As described above, NPV and annuity equivalent calculations must be used to "normalize" the cash flows over the life of the plant. A discount factor is required when calculating the NPV and annuity equivalents of costs. As outlined in Rister et al. (2009), the discount rate has three components: a time preference component, a risk premium, and an inflation premium. The relationship between these three components is multiplicative and can be seen in the following equation:

$$r = [(1+s)*(1+h)*(1+i)]-1.00,$$

where the elements are defined in **Table A2**.

Using the multiplicative-form nature of the composite interest rate logic discussed in Rister et al. (2009), a 6.125% discount rate (r) is assumed, as well as a social preference rate of 4.000% (s), and a 0.000% risk premium (h) for federal/state/municipal projects.

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[61] Once the annuity equivalent calculations are complete, comparisons can easily be made; however, certain additional adjustments are necessary to level the playing field across different facilities to account for natural variations in key data-input parameters (Sturdivant et al. 2009). These variations include: base year period of analysis, level of annual production, salvage of capital assets, etc. (see **Appendix B**) for more discussion.

Compounding Costs

When considering continued operational costs for future years, it is necessary to include inflation. This enables an estimate of nominal dollars for years beyond the benchmark year. This component represents the *i* parameter in the equation above. Using the assumed values for r, s, and h, the compounding factor (i) is determined to be 2.043% annually.[62]

Table A2. Values for Discount Rates and Compound Factor.

Rate	Definition	Assumed Value
r	comprehensive discount rate	6.125%
s	social time value	4.000%
h	risk premium	0.000%
i	rate representing inflation	2.043%

Source: Rister et al. (2009); Rogers (2008).

Discount Rate for Water

Included in this analysis is a discount rate for the annual water output. This reflects the argument that (most) people place a lower value on future items or events in relation to the value associated with the current availability of items or events. This is a contentious issue as some economists believe the actual physical amount of future resources should not be discounted, but rather only the dollar value of those resources (Michelsen 2007). Some claim that a high discount rate on resources will lead to a disproportionate amount of resources being allocated to earlier periods (Committee on Valuing Ground Water 1997). This disproportionate allotment brings up the concept of intergenerational fairness, which argues for neutrality between the welfare of current and future generations (Portney and Weyant 1999). This viewpoint suggests it would be unfair to place a discount rate on water because the present generation might receive a greater allocation of water than future generations.

Conversely, other economists, including the authors of this report, believe when values are not readily available, or are not easily ascertained, it is appropriate to discount the future physical amount (Griffin 2007). As Carlson, Zilberman, and Miranowski (1993) point out, such discounting includes the use of resources, stating specifically, people "discount the value associated with future resource use." Portney and Weyant (1999) also state, "it is appropriate-indeed essential-to discount future benefits and costs at some positive rate." The latter stance (i.e., discounting) is the approach the authors of this report have chosen to take.

To account for the social preference of present-day resource use, a 4.000% discount factor is utilized to convert future water flows into present-day terms. This discount factor is achieved by assuming a social preference rate of 4.000%, combined with a 0.000% risk premium, as well as a 0.000% inflation rate assumed for water. For further discussion of this topic, refer to Rister et al. (2009), which includes references to Griffin (2002), and Griffin and Chowdhury (1993).

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[62] As provided in Rister et al. (2009), represented mathematically as: $\frac{1 + 6.125\%}{1 + 4.000\%} - 1 = 2.043269\%$

Appendix B:
Modified Data Input and Results

Modified Data Input and Results

Authors' Note: To provide consistency across reports and facilitate comparisons across models (i.e., DESAL ECONOMICS© as discussed in Sturdivant et al. 2009 and CITY H_20 ECONOMICS© as discussed in Rogers et al. 2010), facility case studies, etc., the text in this section largely mimics that developed by the authors in Sturdivant et al. (2009), with values reflecting the Olmito and La Sara facilities.

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 Olmito and La Sara facilities baseline scenarios – enabling a comparison across other facilities and/or technologies with the *CITY H_2O ECONOMICS©* model, and its companion model *DESAL ECONOMICS©* (e.g., Rogers 2008, Sturdivant et al. 2009). That is, the baseline results presented in the main text depict the Olmito and La Sara facilities in their current operating state. While the baseline results were determined using *CITY H_2O ECONOMICS©* and *DESAL ECONOMICS©* (previously advocated as being appropriate for making *apples-to-apples* comparisons of facilities life-cycle costs), some adjustments are necessary to *level the playing field* if comparisons are to be more precisely made across other potable water facilities' life-cycle costs. That is, natural variations in key data-input parameters of different facilities can distort any subsequent comparison of results. To more precisely compare across individual facilities producing potable water, the following data-input parameters in either the *DESAL ECONOMICS©* model, or the *CITY H_2O ECONOMICS©* model[63] must be made so that they are the same for all facilities being analyzed:[64]

[Authors' note: text for each of the following four data-input variables discusses actions required to more precisely compare other facilities to the McAllen Northwest and the Brownsville Southmost facilities. If other facilities are to be compared to one another (and not the McAllen Northwest or Brownsville Southmost), 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.)]

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[63] The *DESAL ECONOMICS©* model is built on the same methodological platform and with the same design standards as *CITY H_2O ECONOMICS©*, but targeted toward analyzing desalination facilities. Documentation and implementation results using these models can be found in Rogers (2008), Boyer (2008), and Sturdivant et al. (2009).

[64] As discussed in the *Limitations* section, the assumption applied to baseline analyses is 'potable water is potable water.' That is, there are no adjustments made 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 B** with the modified results, even though other adjustments are made which improve the preciseness of comparing dissimilar facilities and/or technologies.

» 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) is 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 planned and unplanned downtime (e.g., maintenance, emergencies, demand interruptions, etc.), and complies with the *Rule of 85*.[65] Leveling the PE to this stated rate for each avoids potential bias associated with operating circumstances at particular facilities/sites.[66]

» overbuilds and upgrades – Ignore the *Overbuilds & Upgrades* facility segment and its impact upon the total life-cycle cost.[67] Doing so ignores the *non-essential* costs which allows leveled comparison of: (1) different technologies (e.g., desalination 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, water rights, etc.) have an effective net salvage value of zero dollars. Doing so assumes facility decommissioning and site restoration costs equal the salvage (i.e., net 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).[68]

It is the *modified results* for individual facilities which are comparable to other facilities and/or technologies (calculated with like methodology). Making the above data-input changes to the analysis file for the Olmito and La Sara facilities (in *CITY H_2O ECONOMICS*©, and *DESAL ECONOMICS*©) results in modified life-cycle costs of $968.31/ac-ft/year {$2.9716/1,000

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[65] 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).

[66] 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.

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

[68] 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.

gals/year}(**Table B1**) and $629.09/ac-ft/year {$1.9306/1,000 gals/year}(**Table B6**), respectively. Additional results after making the above parameter changes to the analysis file for the Olmito and La Sara facilities are provided below. For brevity's sake, a textual discussion is not included with modified-results' **Tables B1 through B10** below. Refer to the results discussion provided for baseline-results **Tables 9 through 14c** for related interpretation. Though the values are different, the baseline-results discussion provides direction for inferential understanding.

Table B1. "Modified" Aggregate Results for Production and Costs for the 2.0 mgd Olmito Conventional Surface-Water Treatment Facility, in 2006 Dollars.[a]

Results	Units	Nominal Value	Real Value [b]
Initial Water Rights	2006 dollars	$4,946,555	$4,946,555
Initial Facility Costs	2006 dollars	$4,557,541	$4,557,541
Water Production	ac-ft (lifetime)	76,170	36,241
- annuity equivalent	ac-ft/year		1,813
Water Production	1,000-gal (lifetime)	24,820,000	11,809,054
- annuity equivalent	1,000-gal/year		590,658
NPV of Total Cost Stream [c]	2006 dollars	$65,344,014	$26,152,148
- annuity equivalent	$/year		$1,755,211
Cost-of-Producing & Delivering Water [d]	$/ac-ft/year		$968.31
Cost-of-Producing & Delivering Water [d]	$/1,000-gal/year		$2.9716

Source: Boyer (2008), with modifications.

[a] These results reflect the Olmito facility in its modified operating state (i.e., 85% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are not involved to be 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] These are the total net cost stream values (nominal and real) relevant to treating 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.

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

Table B2. "Modified" Costs of Producing (and Delivering) Water for the Facility Segments of the 2.0 mgd Olmito 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-gal/year [e]	% of Total Cost
A)	Initial Water Rights Purchase	$4,946,555	$331,990	$910	$183.15	$0.5621	18.9%
1)	Raw Water Intake / Reservoir	4,686,700	314,550	862	173.53	0.5325	17.9%
2)	Treatment Unit	8,092,589	543,137	1,488	299.64	0.9195	30.9%
3)	Sludge Disposal	1,188,480	79,765	219	44.00	0.1350	4.5%
4)	Delivery to Municipal Line/Storage	5,247,808	352,209	965	194.30	0.5963	20.1%
5)	Operations' Supporting Facilities	1,990,016	133,561	366	73.68	0.2261	7.6%
6)	Overbuilds & Upgrades	0	0	0	0.00	0.0000	0.0%
	TOTAL	$26,152,148	$1,755,211	$4,809	$968.31	$2.9716	100.0%

Source: Boyer (2008), with modifications.

[a] These results reflect the 2.0 mgd Olmito facility in its modified operating state (i.e., 85% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are not involved and thus not included, and a net salvage value of zero dollars is recorded for all capital assets and water rights).

[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 treating and delivering 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-gal) for each segment.

Table B3. “Modified” Total NPV and Annuity Equivalent Costs, by Cost Type, Category, and Item for the 2.0 mgd Olmito Facility, in 2006 Dollars.

Cost Type/Category/Item	- - - - NPV of Cost Streams - - - -			- - - Annuity Equivalent Costs - - -		
	“**Total** Life-Cycle Costs” [a]			“**Annual** Life-Cycle Costs” [a]		
	O&M	Continued	Total	O&M	Continued	Total
Initial Water Rights			$4,946,555			$331,990
Initial Construction			4,557,541			305,881
Continued [b]			16,089,229			1,079,835
» Administrative		$0			$0	
» O&M		16,089,229			$1,079,835	
• Energy	$2,996,874			$201,136		
• Chemicals	3,220,612			216,153		
• Labor	3,423,115			229,744		
• Raw Water Deliv.	1,848,582			124,068		
• All Other	4,600,047			308,734		
Capital Replacement			558,823			37,506
TOTAL	$16,089,229	$16,089,229	$26,152,148	$1,079,835	$1,079,835	$1,755,211

Source: Boyer (2008), with modifications.

[a] These results reflect the 2.0 Olmito facility in its modified operating state (i.e., 85% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are not involved and thus not included, and a net salvage value of zero dollars is recorded for all capital assets).

[b] Since there is no “umbrella” organization overseeing the Olmito facility, there are no “Administrative”category costs (i.e., such as with the Southmost facility (see TR-295 by Sturdivant et al. 2009) in association with the Olmito facility, while “Operation & Maintenance (O&M)” costs are incurred at the facility.

Table B4. “Modified” Life-Cycle (Annuity Equivalent) Costs – \$/ac-ft/year and \$/1,000-gal/year, by Cost Type, Category, and Item for the Olmito Facility, in 2006 Dollars.[a]

Cost Type/Category/Item	Annuity Equivalent Costs					
	\$/ac-ft/year			\$/1,000-gal/year		
	O&M	Continued	Total	O&M	Continued	Total
Initial Water Rights			\$183.15			\$0.5621
Initial Construction			168.75			0.5179
Continued [b]			595.72			1.8282
» Administrative		\$0.00			\$0.000	
» O&M		595.72			\$1.8282	
• Energy	\$110.96			\$0.3405		
• Chemicals	119.25			0.3660		
• Labor	126.74			0.3890		
• Raw Water Deliv.	68.45			0.2101		
• All Other	170.32			0.5227		
Capital Replacement			20.69			0.0635
TOTAL	\$595.72	\$595.72	\$968.31	\$1.8282	\$1.8282	\$2.9716

Source: Boyer (2008), with modifications.

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

[b] “Administrative” costs are incurred at the facility level and not by a managing entity.

Table B5. "Modified" Percentage of Life-Cycle Costs, by Cost Type, Category, and Item for the Olmito Facility, 2006.

Cost Type/Category/Item	---- % of Life-Cycle Costs ----		
	O&M	Continued	Total
Initial Water Rights			19 %
Initial Construction			17 %
Continued			62 %
» Administrative		0 %	
» O&M		62 %	
• Energy	11 %		
• Chemicals	12 %		
• Labor	13 %		
• Raw Water Deliv.	7 %		
• All Other	18 %		
Capital Replacement			2 %
TOTAL	62 %	62 %	100 %

Table B6. "Modified" Aggregate Results for Production and Costs for the 1.13 mgd La Sara Brackish-Groundwater Desalination Facility, in 2006 Dollars.[a]

Results	Units	Nominal Value	Real Value [b]
Initial Facility Costs	2006 dollars	$2,536,527	$2,536,527
Water Production	ac-ft (lifetime)	53,795	22,224
- annuity equivalent	ac-ft/year		1,028
Water Production	1,000-gal (lifetime)	17,529,125	7,241,613
- annuity equivalent	1,000-gal/year		334,989
NPV of Total Cost Stream [c]	2006 dollars	$35,121,706	$10,049,721
- annuity equivalent	$/year		$646,736
Cost-of-Producing & Delivering Water [d]	$/ac-ft/year		$629.09
Cost-of-Producing & Delivering Water [d]	$/1,000-gal/year		$1.9306

Source: Boyer (2008), with modifications.

[a] These baseline results reflect the La Sara facility in its modified operating state (i.e., 85% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are not involved to be 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] These are the total net cost stream values (nominal and real) relevant to treating 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.

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

Table B7. “Modified” Costs of Producing (and Delivering) Water for the Facility Segments of the 1.13 mgd La Sara 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-gal/year [e]	% of Total Cost
1) Well Field	$1,969,292	$126,731	$347	$123.27	$0.3783	19.6%
2) Transmission Line (to facility)	552,415	35,550	97	34.58	0.1061	5.5%
3) Main Facility / Treatment Process	4,613,084	296,869	813	288.77	0.8862	45.9%
4) Concentrate Discharge	623,188	40,104	110	39.01	0.1197	6.2%
5) Finished Water & Tank /Storage	1,721,106	110,759	303	107.74	0.3306	17.1%
6) High Service & Delivery Pipeline	570,638	36,723	101	35.72	0.1096	5.7%
7) Overbuilds & Upgrades	0	0	0	0.00	0.0000	0.0%
TOTAL	$10,049,721	$646,736	$1,772	$629.09	$1.9306	100.0%

Source: Boyer (2008), with modifications.

[a] These baseline results reflect the 1.13 mgd La Sara facility in its modified operating state (i.e., 85% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are not involved and thus 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] Total costs (in 2006 dollars) throughout the facility’s life of treating and delivering 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-gal) for each segment.

Table B8. “Modified” Total NPV and Annuity Equivalent Costs, by Cost Type, Category, and Item for the 1.13 mgd La Sara Facility, in 2006 Dollars.

Cost Type/Category/Item	---- NPV of Cost Streams ---- “**Total** Life-Cycle Costs” [a]			--- Annuity Equivalent Costs --- “**Annual** Life-Cycle Costs” [a]		
	O&M	Continued	Total	O&M	Continued	Total
Initial Construction			$2,536,527			$162,235
Continued [b]			7,144,983			459,806
» Administrative		$2,642,160			$170,033	
» O&M		4,502,823			289,773	
• Energy	$3,229,856			$207,853		
• Chemicals	724,161			46,602		
• Labor	386,679			224,884		
• Raw Water Deliv.	0			0		
• All Other	162,126			10,433		
Capital Replacement			368,212			23,696
TOTAL	$4,502,823	$7,144,983	$10,049,721	$289,773	$459,806	$646,736

Source: Boyer (2008), with modifications.

[a] These baseline results reflect the 1.13 La Sara facility in its modified operating state (i.e., 85% production efficiency level, basis 2006 dollars, costs for overbuilds and upgrades are not involved and thus not included, and a net salvage value of zero dollars is recorded for all capital assets).

[b] The “Administrative” costs are incurred at NAWSC, the “umbrella” organization overseeing the Olmito facility. Other, localized administrative and other “Operation & Maintenance (O&M)” costs are incurred at the facility.

Table B9. "Modified" Life-Cycle (Annuity Equivalent) Costs – \$/ac-ft/year and \$/1,000-gal/year, by Cost Type, Category, and Item for the La Sara Facility, in 2006 Dollars.[a]

Cost Type/Category/Item	- - - - - - - - - - - - - - - - Annuity Equivalent Costs - - - - - - - - - - - - - - - -					
	- - - - - - - \$/ac-ft/year - - - - - - -			- - - - - - \$/1,000-gal/year - - - - - -		
	O&M	Continued	Total	O&M	Continued	Total
Initial Construction			\$158.78			\$0.4873
Continued [b]			447.26			1.3726
» Administrative		\$165.39			\$0.5076	
» O&M		281.87			\$0.8650	
• Energy	\$202.18			\$0.6205		
• Chemicals	45.33			0.1391		
• Labor	24.21			0.0743		
• Raw Water Deliv.	0.00			0.0000		
• All Other	10.15			0.0311		
Capital Replacement			23.05			0.0707
TOTAL	\$281.87	\$447.26	\$629.09	\$0.8650	\$1.3726	\$1.9306

Source: Boyer (2008), with modifications.

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

[b] The "Administrative" costs are incurred at NAWSC, the "umbrella" organization overseeing the Olmito facility. Other, localized administrative and other "Operation & Maintenance (O&M)" costs are incurred at the facility.

Table B10. “Modified” Percentage of Life-Cycle Costs, by Cost Type, Category, and Item for the La Sara Facility, 2006.

Cost Type/Category/Item	---- % of Life-Cycle Costs ----		
	O&M	Continued	Total
Initial Construction			25 %
Continued			71 %
» Administrative		26 %	
» O&M		45 %	
• Energy	32 %		
• Chemicals	7 %		
• Labor	4 %		
• Raw Water Deliv.	0 %		
• All Other	2 %		
Capital Replacement			4 %
TOTAL	45 %	71 %	100 %

Notes