ECONOMIES OF SIZE IN MUNICIPAL WATER TREATMENT TECHNOLOGIES: TEXAS LOWER RIO GRANDE VALLEY

A Thesis

by

CHRISTOPHER NEIL BOYER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2008

Major Subject: Agricultural Economics

ECONOMIES OF SIZE IN MUNICIPAL WATER TREATMENT TECHNOLOGIES: TEXAS LOWER RIO GRANDE VALLEY

A Thesis

by

CHRISTOPHER NEIL BOYER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Approved by:

Chair of Committee,	M. Edward Rister
Committee Members,	Ronald D. Lacewell
	B.L. Harris
Head of Department,	John P. Nichols

August 2008

Major Subject: Agricultural Economics

ABSTRACT

Economies of Size in Municipal Water Treatment Technologies:
Texas Lower Rio Grande Valley.
(August 2008)

Christopher Neil Boyer, B.S., Texas A&M University
Chair of Advisory Committee: Dr. M. Edward Rister

As the U.S. population continues to increase, planning for future water quantity and quality needs is important. Historically, many municipalities have relied heavily on surface water as their major source of drinking water, but recently, technological advancements have improved the economic viability of reverse-osmosis (RO) desalination of brackish-groundwater as a potable water source. Brackish-groundwater may be an alternative water source that provides municipalities an opportunity to hedge against droughts, political shortfalls, and protection from potential surface-water contamination. This research specifically focuses on investigating *economies of size* for 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 results can have direct implications on future water planning.

Economic and financial life-cycle costs were estimated for a “small”-conventional-surface water facility (2.0 million gallons per day (mgd) Olmito facility) and a “small”-brackish-groundwater desalination facility (1.13 mgd La Sara facility). Prior analyses were modified to determine similar costs for a “medium”-sized conventional surface-water facility (8.25 mgd McAllen Northwest facility) and a “medium”-sized brackish-groundwater desalination facility (7.5 mgd Southmost facility). The life-cycle costs of the “small” Olmito facility are compared to the life-cycle costs of the “medium” Northwest facility and the life-cycle costs of the “small” La Sara facility are compared against the life-cycle costs of the “medium” Southmost facility to determine the existence of economies of size.

This research was facilitated by the use of the CITY H_20 ECONOMICS$^{\copyright}$ and the DESAL ECONOMICS$^{\copyright}$ Excel$_{®}$ spreadsheet models previously developed by Texas AgriLife Research and Texas AgriLife Extension Service agricultural economists. Although the results are applicable to the Texas LRGV, economies of size are apparent in conventional surface-water treatment and constant economies of size are evident in brackish-groundwater desalination. This research also concludes that RO desalination of brackish-groundwater is economically competitive with conventional surface-water treatment in this region.

ACKNOWLEDGMENTS

This thesis would not have been possible without the patient guidance and gracious support of several individuals. First, I would like to thank my committee chair Dr. Ed Rister for continuously challenging me to meet and extend my capabilities, Dr. Ron Lacewell for his invaluable insights, and Dr. Bill Harris and Dr. Allan Jones for their assistance from the Texas Water Resource Institute and Rio Grande Basin Initiative. In addition, I must thank Allen Sturdivant for providing the models as well as sharing his encouraging words which always seemed to make moments less stressful. Thank you for teaching me how to meticulously conduct research; without the above-mentioned, this research would not have been possible.

I would also like to thank my collaborators Chuck Browning, Orlando Cruz, James Elium III, and Jake White, for patiently allowing me to question them to gather the necessary data. Also, the administrative support of Mari-Michelle Musselman, Michele Zinn, Angela Catlin, Cindy Fazzino, and Tracy Davis in taking care of us on our trips to the Valley and the many other venues of their support is much appreciated.

Finally, I would like to thank my office mate Callie Rogers (a.k.a. “The Law”), whose WordPerfect wisdom saved me countless hours. Most important, I thank my amazing family for their loving support as well as God, who makes all things possible.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

Page

Page

INTRODUCTION[1]

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 2001 U.S. Census Bureau has identified the LRGV as the fourth-fastest-growing Metropolitan Statistical Area in the United States (U.S. Census Bureau 2000). Such rapid growth, combined with prolonged drought and shortfalls of water deliveries from Mexico,[2] 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 to their residents. In recent years, however, reverse-osmosis (RO) brackish-groundwater desalination has been implemented as another source. This thesis is a research report on these two water treatment technologies across two size categories each. The resulting four facilities and their associated results are used as a basis to investigate and report on any presence of economies of size for both of the technologies.

The thesis follows the style of the *American Journal of Agricultural Economics*.

[1] This thesis follows the format of the section method rather than the chapter method.

[2] The 1944 Treaty requires the United States and Mexico to share the downstream water release from Amistad and Falcon reservoirs (Sturdivant et al. 2008). 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 River (Spencer 2005).

In anticipation of an increase in municipal-water demand, the City of McAllen built a new conventional surface-water treatment facility in 2004, which expanded the city's water system capacity by 8.25 million gallons per day (mgd) (i.e., the facility's maximum-designed capacity) (Rogers 2008). Directly north of the City of Brownsville, Olmito Water Supply Corporation (OWSC) expects to refurbish and expand its current 1.0 mgd conventional surface-water treatment facility to 2.0 mgd in 2008-2009 (Elium 2008).

Recognizing the diversification benefits and estimated cost competitiveness of brackish-groundwater desalination, the City of Brownsville expanded its water treatment system by building the 7.5 mgd Southmost brackish-groundwater desalination facility in 2004. This adoption of an alternative technology is intended to reduce the City of Brownsville's reliance on the Rio Grande (Sturdivant et al. 2008). In November 2004, the North Alamo Water Supply Corporation (NAWSC) began operating its 1.13 mgd La Sara brackish-groundwater desalination facility. This facility is the first desalination facility in the NAWSC water treatment system, which contributes to the treatment and distribution of potable water to 16 rural communities in Willacy, Hidalgo, and northwestern Cameron counties (North Alamo Water Supply Corporation 2007).

Objective and Purpose

This research builds on two prior case studies that analyzed the economic and financial life-cycle costs of producing potable water in the LRGV of Texas with conventional surface-water treatment (Rogers 2008; Rogers et al. 2008) and brackish-groundwater desalination (Sturdivant et al. 2008). Specifically, this thesis focuses on identifying and interpreting the implications of life-cycle costs for four facilities (i.e., two from these prior studies and two additional, smaller facilities representing both technologies which are analyzed in this thesis). Based on the life-cycle costs derived for these four facilities, the presence and extent of *economies of size* are evaluated for both technologies.[3] The study matrix shown in Table 1 identifies the mix of facilities, technologies, and sizes evaluated.

Table 1. Matrix of the Lower Rio Grande Valley Potable Water Treatment Facilities by Size Category and Technology Type, 2008

Size Category	Facility Names & Maximum-Designed Capacities			
	Conventional Surface-Water		Reverse-Osmosis Desalination	
Small	Olmito WSC	2.00 mgd[a]	NAWSC - La Sara	1.13 mgd
Medium	McAllen Northwest	8.25 mgd	Brownsville - Southmost	7.50 mgd

[a] mgd: million gallons per day production capacity.

The purposes of the research encompassed by this thesis are to (a) calculate the life-cycle costs of producing potable water {$/acre-feet (ac-ft) and $/1,000 gallons

---

[3] *Economies of size* refers to a change in output brought about by a non-proportionate change in some or all of the production inputs (Beattie and Taylor 1985).

(gals)} for both the OWSCs 2.0 mgd Olmito conventional surface-water treatment facility[4] and NAWSCs 1.13 mgd La Sara desalination facility; and (b) compare the life-cycle costs of treating potable water {$/ac-ft and $/1,000 gals} for the OWSC facility to the Northwest conventional surface-water treatment facility (from Rogers 2008) to test for economies of size; and perform a similar comparison for desalination based on the La Sara facility and the Southmost facility (from Sturdivant et al. 2008) life-cycle costs. In essence, this research is testing for the presence of *economies of size* in conventional surface-water treatment and brackish-groundwater desalination in the LRGV. This premise is represented below in the null hypotheses (Ha_0 and Hb_0) and the alternative hypotheses (Ha_1 and Hb_1):

Ha_0 = Economies of size *are not present* in conventional surface-water treatment in the LRGV.

Ha_1 = Economies of size *are present* in conventional surface-water treatment in the LRGV.

Hb_0 = Economies of size *are not present* in RO desalination of brackish-groundwater in the LRGV.

Hb_1 = Economies of size *are present* in RO desalination of brackish-groundwater in the LRGV.

---

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

Answering these questions will provide state agencies, municipalities, agricultural producers, water planners, and engineers with vital information for future water planning.

As noted in Sturdivant et al. (2008) and Rogers et al. (2008), using the same capital-budgeting[5] methodology allows for an "apple-to-apples" comparison. In addition to this analytical approach, each facility is "modified/leveled"[6] across five common areas to assure a common basis for comparative results.

---

[5] As noted in Sturdivant et al. (2008), "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 "Summary of Economic and Financial Methodology" section in Sturdivant et al. (2008) and to the "Economic and Financial Methodology" section in Rogers (2008). Also refer to Rister et al. (2008).

[6] "Modified/Leveling" of a facility is discussed in more depth in the "Methodology" section of this thesis, but the general thought is to remove or modify any characteristic specific to an individual facility (e.g., construction design, location differences, operating efficiency levels, etc.) which can result in a misleading cost of production for comparing the technology/facility to other technologies/facilities.

LITERATURE REVIEW

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. 2008). Economies of scale is defined as the "expansion of output in response to an expansion of all factors [inputs] in fixed proportion" (Beattie and Taylor 1985). In increasing the output of potable water, however, not all inputs (e.g., land, labor, capital, energy) are necessarily increased proportionately. Therefore, the more correct concept to describe a change in the level of resources committed to production and the associated resulting change in costs is *economies of size*. This concept refers to a change in output brought about by a non-proportional change in inputs (Beattie and Taylor 1985). This thesis uses the term "economies of size" to discuss this concept.[7]

For the majority of studies that mention economies of size, researchers identify, analyze, and report on specific cost components/items (e.g., concentrate/sludge discharge, salinity/turbidity levels, energy cost, chemical cost, etc.). Few reports mention multiple cost components/items, and no reports were identified that completely analyzed every cost component/item in water treatment technologies. Due to the differences between conventional surface-water treatment and reserve-osmosis (RO) desalination, not all cost components/items are common across both water treatment

---

[7] Economies of size is discussed in more detailed in the "Methodology" section of this thesis.

technologies. The cost components/items found to be in the literature for both treatment technologies are:

- salinity levels/total dissolved solids (TDS);
- concentrate discharge/sludge disposal; and
- capital investments.[8]

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. In addition, the study highlighted raw water acquisition, conveyance (i.e., pipelines), storage, and residuals disposal (i.e., sludge and brine concentrate) as cost components which heavily impacts the cost of production. The facility sizes that Traviglia and Characklis (2006) analyzed include: 1.0 mgd, 10.0 mgd, and 30.0 mgd. The estimated costs for both technologies were calculated using cost relationships, which were derived in previous studies of operating and construction costs. The Traviglia and Characklis (2006) results presented in 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 cost components/items noted above, it is stated that economies of size were suggested for all of the individual cost components/items.

---

[8] Capital investment is defined as an original investment in construction cost of a long-term fixed capital item; that is, items having a useful life of greater than one year (e.g., water rights, storage tanks, pipeline capacity, etc.).

Table 2. Cost of Supply and Treatment ($/1,000 gallons) for Surface-Water Treatment Facilities and RO Desalination Facilities as per Traviglia and Characklis (2006)[a]

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

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

[b] Freshwater was assumed to have a salinity level below 500 mg/l of total dissolved solids (TDS), and brackish-water was assumed to have a salinity level of 2,000 mg/l TDS (Traviglia and Characklis 2006).

Source: Traviglia and Characklis (2006).

Salinity levels and/or total dissolved solids (TDS) are important factors that can affect the cost of producing water, as well as influence the decision makers' choice of which water treatment technology is the most economically viable. 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 a 2.0 mgd surface-water treatment facility and a 2.0 mgd RO desalination facility, as well as a 16.0 mgd surface-water treatment facility and a 16.0 mgd RO desalination facility. 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. However, 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, the smaller facility's cost of production is lower. Although this research was not directly focused on determining economies of size for surface water and desalination treatment technologies, the results are interesting and important for this thesis' analyses. The results imply that economies of size are present in surface-water treatment and desalination, as well as 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 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 a 1.0 mgd and a 10.0 mgd facility. The three 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" (Norris 2006a). The report also implies that a ground-storage tank, which is used for both conventional surface-water treatment and RO desalination, demonstrate economies of size. Norris (2006a) indicated a two (2) a million-gallon storage tank has a cost of $0.37/gallon whereas an eight (8) a 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 thesis 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 gals} 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.[9] The study concludes that, as research and technology improves, the cost of RO desalination may decrease and economies of size may increase. This conclusion apparently follows from his introspection of all costs, particularly with respect to the capital costs of source water, concentrated discharge, water storage, pumping and distribution, environmental/archeology, and land acquisition.

The general absence of studies and incomplete nature of the previous work on economies of size for both water treatment technologies provided the impetus for this thesis. 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 geographic area analyzed within the study.

---

[9] 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.

METHODOLOGY

To estimate costs associated with conventional and desalination water treatment, Capital Budgeting – Net Present Value (NPV) analysis, in combination with the calculation of annuity equivalents (AEs), is the methodology of choice for this thesis research.[10] This approach provides for integrating expected useful life with related annual costs and outputs, as well as consideration of other financial realities, into a comprehensive $/ac-ft {or $/1,000 gals} *life-cycle* cost. To facilitate application of this preferred methodology, Texas AgriLife Extension Service and Texas AgriLife Research agricultural economists developed two Microsoft® Excel® spreadsheet models, DESAL ECONOMICS© (Sturdivant et al. 2008) and CITY H_2O ECONOMICS© (Rogers 2008; Rogers et al. 2008). These models facilitate analysis of life-cycle costs (e.g., $/ac-ft) for producing and delivering potable water to its nearest possible tie-in point within the municipal water-delivery system. "Apples-to-apples" comparisons can be made among facilities, both within and across treatment technologies, so long as certain prescribed modifications are made.

The first aspect of the methodology (i.e., NPV analysis) adjusts potential uneven annual streams of dollars and water flows across a facility's total useful life into a uniform time-adjusted, or time and inflation-adjusted basis (i.e., current year). That is, to

---

[10] As noted in Sturdivant et al. (2008), "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." Refer to Rister et al. (2008) for additional information.

analyze life-cycle costs, the methodology first organizes each facility into a “project,” inclusive of dollars of initial investment to fund initial construction (and water rights purchase, if applicable), as well as costs for ongoing operations (operating costs, capital replacement, etc.). Each “project” is then expected to have a level of productivity some number of years into the future. With an expected life extending into future years, the financial realities of inflation, time-value of money, and other discounting considerations such as risk are incorporated. Specifically, the models/methodology incorporate a 6.125% discount rate for dollars (i.e., the multiplicative product of a 4.0% discount factor for social-time preference,[11] a 2.043% cost-compound factor to account for inflation,[12] and a 0.0% factor for risk as a government entity[13] is generally providing funding assistance/guarantee).[14] That is, the nominal values of dollars and water for each future year are discounted into real, current-year values by way of the NPV calculations, which, in effect, “normalize” values across “projects,” subject to additional consideration.

---

[11] The social-time preference of water is a highly-debated issue among economists. For further reading on the subject, refer to Rister et al. (2008), Rogers (2008), and Griffin and Chowdhury (1993).

[12] In March 2008, Orlando Cruz (2008), a professional engineer specializing in water resource projects in the LRGV, stated that the current actual inflation rate on large capital water projects are approximately 1.0% a month, or 10-12% annually. In recognition of the several forecasts of this thesis research already completed using the 2.043% inflation factor, comparison of the different types and sizes of water treatment facilities are calculated using this factor throughout. In general, a higher inflation rate would impact the calculated costs. However, once reliable base year investment are established, because of the relatively similar magnitudes of costs and projects lives, it is anticipated that relative results would be unchanged. The absolute impact of a higher inflation rate on these results is a topic for future research considerations.

[13] Even though Olmito WSC and NAWSC are not government entities (i.e., public), a 0.0% risk rate is applied for comparison purposes. Under the State of Texas Water Code chapter 67, a political subdivision may be contracted by the private entity to administrate the bonds, resulting in a virtually risk free bond (Texas Legislature Online 2008).

[14] For additional reading on discount rates and factors, refer to Rister et al. (2008) and Rogers (2008).

Facilities and their respective cash flows and water-production levels are expected to vary from facility to facility and the noted methodology, including calculation of annuity equivalents, neutralize such effects, thereby allowing derivation of comparable cost information. Analytically, the NPV equation for dollars (EC) is as follows:

$$EC_{NPV}^{P,Z} = \sum_{j=o}^{Y^P} \left\langle \left\{ \left[I_j^{P,Z} * (1+i)^j \right] \right\} \div \left\{ (1+r)^j \right\} \right\rangle$$

$$+ \sum_{t=Y^P+1}^{Y^P+N^P} \left\langle \left\{ \left[(OC_t^{P,Z} + CR_t^{P,Z}) * (1+i)^t \right] \right\} \div \left\{ (1+r)^t \right\} \right\rangle$$

$$- \left\langle \left\{ SV^{P,Z} \right\} \div \left\{ (1+r)^Z \right\} \right\rangle.$$

Similarly, the NPV equation for water flows (WP) is:

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

Refer to Table 3 for definitions of all of the elements in both equations.

The second aspect of the methodology transforms the summed NPV values (i.e., summed dollars and water over the course of the total facility's expected useful life) into annuity equivalents (AEs), or "annualized amounts." The purpose of this adjustment is to allow for facilities with different useful/productive lives to be compared. The two AE values (i.e., dollars and water) are calculated separately. The AE of dollars (AEEC) and the AE of water flows (AEWP) are calculated as follows:

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

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

Refer to Table 3 for definitions of all the elements in the equations.

As observed in the above equations, this thesis uses the discount rate (r) to calculate the NPV and AE of dollars and the discount rate (s) to calculate the NPV and AE of water flows. The purpose for implementing the two discount rates is to discount dollars, components for time preference, risk, and inflation are included in the discount rate (r), and to discount water, only the component for social-time preference is included in the discount rate (s).

Once the two AE values are determined, the AE for dollars (AEEC) is divided by the AE for water flows (AEWP). The resultant value is an annual dollar-per-unit value (i.e., \$/ ac-ft, or \$/1,000 gals), representing the life-cycle cost for a given facility and its associated technology. The dollars-per-unit value is represented mathematically as:

$$AEECWP_{AE}^{P,Z} = AEEC_{AE}^{P,Z} \div AEWP_{AE}^{P,Z} .$$

Refer to Table 3 for definitions of all of the elements in the equation.

Table 3. Definitions for the Elements of Economic and Financial Costs Calculations, CITY H_2O ECONOMICS© and DESAL ECONOMICS© Spreadsheet Models, 2008

Element	Definition
$EC_{NPV}^{P,Z}$	net present value of net economic and financial costs for water treatment plant P over the planning period Z
Z	time (in years) of planning period, consisting of construction period and expected useful life
j	the specific year in the construction period
Y^{P}	length of construction period (years) for water treatment plant P
$I_{j}^{P,Z}$	initial construction cost (which includes the purchase of water rights, if applicable) occurring during year j of the construction period for water treatment plant P in the planning period Z
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}	length of expected useful life (years following completion of construction period) for water treatment plant P
$OC_{t}^{P,Z}$	operation and maintenance costs during year t of useful life N^P for water treatment plant P over the single economic-planning period Z
$CR_{t}^{P,Z}$	capital replacement costs during year t of useful life N^P for water treatment plant P over the planning period Z
t	the specific year of the expected useful life
$SV^{P,Z}$	salvage value of water treatment plant P (including water rights, if applicable) at the end of year Z
$WP_{NPV}^{P,Z}$	net present value of annual water production for water treatment plant P over the planning period Z
$WP_{t}^{P,Z}$	annual water production (in ac-ft) in year t of water treatment plant P over the planning period Z
s	social time value discount rate (%) of water
$AEEC_{AE}^{P,Z}$	annuity equivalent of economic and financial costs for a series of water treatment plants P, each constructed and operating over a Z planning period, into perpetuity
$AEWP_{AE}^{P,Z}$	annuity equivalent of water production for a series of water treatment plants P, each constructed and operating over a Z time period, into perpetuity
$AEECWP_{AE}^{P,Z}$	annuity equivalent of costs per ac-ft for a series of water treatment plants P, each constructed and operating over a Z time period, into perpetuity

Source: Rister et al. (2008), Rogers (2008), Yow (2008), and own modifications.

Modifying/Leveling Baseline Analyses

The baseline results for each facility depict the facility in its current operating condition. While the results for each facility were determined using either the DESAL ECONOMICS© or CITY H_2O ECONOMICS© model (previously advocated as appropriate for making "apples-to-apples" comparisons of water-supply alternatives' life-cycle costs), some additional adjustments may be necessary to allow for correct comparisons of life-cycle costs across different facilities and technologies. That is, inherent variations in key data-input parameters under existing operating circumstances (at different facilities and/or for different technologies) can greatly distort subsequent comparisons. To compare as accurately as possible across facilities, the following data-input parameters are modified according to Sturdivant et al. (2008), Rogers (2008), and (Rogers et al. 2008):

- the *base period of analysis* assumes the construction period commences on January 1, 2006, thereby insuring financial calculations occur across a common time frame;[15, 16]
- the *annual production efficiency* is set at a constant 85% production efficiency (PE) rate. This stated achieved proportion of maximum-designed capacity is assumed reasonable, allowing for planned and unplanned downtime (e.g., maintenance, emergencies, demand interruptions, etc.), and complies with the

---

[15] This feature is already incorporated into baseline analysis of case study presented in this report.

[16] For facilities constructed in different time periods, either inflation or deflation of the cost values are necessary to accommodate specification of this stated benchmark period.

Texas Commission of Environmental Quality (TCEQ) mandate under the Texas Administrative Code (TAC) §291.93.[17] Leveling the PE to this stated rate for each facility avoids potential bias associated with operating circumstances at particular sites;[18]

- any potential *Overbuilds & Upgrades costs are ignored* in determining the modified total life-cycle cost.[19] Doing so ignores non-essential costs which allow a leveled comparison of: (a) different technologies based upon only the technology (i.e., indifferent as to the inclusion and level of non-essentials), and (b) different facilities whereby one can examine for the existence of economies of size within (or across) a technology;
- the *salvage, or residual value of capital assets, including water rights, are assumed to have an effective net salvage value of zero dollars* at the end of the facility's useful life. Doing so assumes facility decommissioning and site restoration costs equal the salvage (i.e., sale) value, and/or the investment (in

---

[17] TAC §291.93 states that when a retail public utility (possessing a certificate of public convenience and necessity) reaches 85% of its capacity as compare to the most restrictive criteria of the Commission's minimum capacity requirements in Chapter §290.45 of the TAC, it must submit to TCEQ a service-demand plan, including cost projections and installation dates for additional facilities (Texas Secretary of State 2008).

[18] In reality, individual facilities operate at different PE rates, for many different reasons. In addition to the constraint induced by TAC §291.93, items such as seasonal demand, source-water quality issues (e.g., abnormal arsenic, iron, etc.), mis-matched equipment and related flow capacity across facility processes, etc., attribute to less than 100% PE. Using such different PEs to calculate per-unit costs; however, can unrealistically portray one or more facilities relative to others being evaluated.

[19] "Overbuilds & Upgrades" are the 'elbow room' allowing for future growth and captures 'whistles & bells' beyond baseline necessities of the process technology itself (Sturdivant et al. 2008).

buildings, land, etc.) are intended to be long term, with no expectations of ever 'salvaging' the asset(s);[20]

- the *consolidation of the Administrative costs[21] into a separate cost segment*. General managers and engineers estimated these values for all of the facilities evaluated in this thesis, but for all four facilities, it was challenging for them to allocate these costs across the segments.[22] By consolidating the Administrative costs into a single cost segment, the anomalies in the results were reduced.[23]

This research does not adjust for any possible incoming and/or outgoing water quality disparities among different facilities beyond acknowledging that variability in water quality could lead to distortions in cost comparisons. For this analysis, final-product water quality at different facilities is considered or assumed comparable because all potable water suppliers are required to meet specified quality standards on final-product water (i.e., maximum contaminant levels and secondary levels set by Environmental Protection Agency (EPA) and TCEQ) such that extreme differences in

---

[20] 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.

[21] "Administrative" costs are annual expenses that are facility-related, but are not included on the water treatment facility's (e.g., Northwest, Southmost, La Sara, and Olmito) budget; rather, they are included on the owner-entity's (e.g., PUB and WSC) budget.

[22] To accurately determine the "Administrative" costs for publicly-owned facilities (i.e., Northwest and Southmost), a time-intensive and costly audit of the city's PUB accounting records would be required. For privately-owned facilities (i.e., Olmito and La Sara), determining an accurate value is difficult to obtain because of their accounting methods.

[23] This modification is not included in Sturdivant et al. (2008), Rogers (2008), and Rogers et al. (2008), but it is incorporated as part of this thesis.

quality attributes affecting human health are not expected to occur. However, it is suggested that incoming water be adjusted to a standard of quality among all facilities being compared, and further research to address this topic is encouraged.

These modified results for individual facilities are comparable and the basis for the investigation of economies of size. That is, after all four facilities' analyses are "leveled," the modified life-cycle costs of medium-sized facilities (i.e., the McAllen Northwest and the Southmost facilities) are comparable to the modified life-cycle costs of the smaller facilities (i.e., the Olmito and the La Sara facilities).

Economies of Size

As noted in the "Literature Review" section of this thesis, 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 output capacities of water treatment facilities, not all production inputs (e.g., land, labor, capital, management, etc.) are required to be increased proportionately to attain the increased output. Therefore, the correct term is economies of size referring to the concept that average total cost is decreased as output is increased from a non-proportional increase in the size (i.e., level) of some, but not necessarily, all inputs of production. That is, "scale" refers to a proportionate change in all production inputs, whereas "size" refers to a non-proportionate change in some, but not necessarily all, production inputs (Beattie and Taylor 1985).

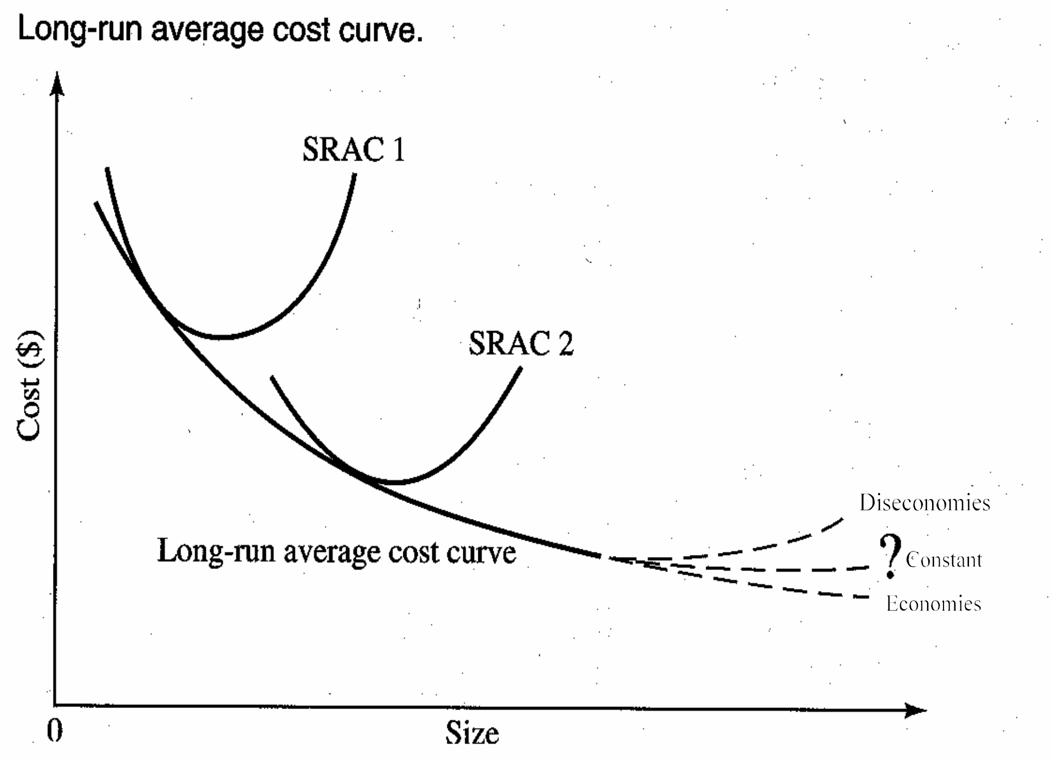
The economies of size concept is commonly discussed in economic textbooks in the context of one firm that is trying to find the production level where average total cost is minimized. This level of output can be identified for both short-run and long-run analyses (Maurice and Thomas 2002). In short-run analyses, production inputs are considered to be either fixed (e.g., land, building, concrete, pipes, etc.) and/or variable (e.g., chemical, energy, labor, etc.). The fixed production inputs cannot be either increased or decreased, while the variable production inputs can be either increased or decreased. In long-run analyses, all production inputs are considered variable and can be either increased or decreased to minimize a firm's average total cost of production. In this thesis, long-run analyses are the more appropriate for planning purposes in regards to evaluating the question of beginning or continuing production from one period to the next (Maurice and Thomas 2002).

The analyses in this thesis "modify" the necessary input data to represent the costs of production for four different facilities (two of each type for both conventional surface-water treatment and brackish-groundwater desalination facilities, with the two facilities for each type producing potable water at a "small"-level and "medium"-level, respectively). These modified life-cycle costs facilitate long-run (i.e., planning) economies of size analyses in conventional surface-water treatment and brackish-groundwater desalination. Based on Kay and Edwards (1994), long-run economies of size are expressed mathematically as:

$$Economies\,of\;\,Size\;Ratio = \frac{\%\,Change\,in\,Cost}{\%\,Change\,in\,Output}\,.$$

The “% Change in Cost” numerator in this equation is derived by comparing of the annuity equivalents of costs for the two different sized facilities of interest. The denominator “% Change in Output” is determined by comparing the annuity equivalents of water production for the facilities.

Economies of size (E) exist if the life-cycle costs decrease as the production of potable water is increased, i.e., the Economies of Size Ratio (ESR) is less than one. Constant (C) economies of size exist if the life-cycle costs remain constant as the production of potable water increases/decreases, i.e., the ESR is equal to one. Diseconomies of size (D) exist if the life-cycle costs increase as the production of potable water increases, i.e., the ESR is greater than one. Potential economies of size relationships between size of the facility and the cost of producing water are demonstrated graphically in Figure 1.



Source: Kay and Edwards (1994) and own modifications.

Figure 1. Illustration of economies and diseconomies of size

PREVIOUS CASE STUDY RESULTS

Recently, Texas AgriLife Research economists conducted economic 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. (2008) performed a similar analysis for the city of Brownsville's 7.5 mgd Southmost RO desalination facility using the DESAL ECONOMICS© model. These analyses focused on the facilities' current operating status, but also included modified results, or "leveled" analyses.[24]

McAllen Northwest Facility

In 2004, the McAllen Public Utilities Board (PUB) completed a new conventional surface-water treatment facility which expanded the city's water system capacity by 8.25 mgd. Further it includes the capacity of further expansion up to 32.0 mgd (Rogers 2008). The facility obtains water from the Rio Grande via a system of open surface canals and closed pipelines owned and operated by local irrigation districts (IDs).[25]

---

[24] The modified results presented in Sturdivant et al. (2008) and Roger (2008) do not included all of the modified areas discussed in this thesis (refer to pages 17-19 for a list of all the modifications). These previous studies did not consolidate the "Administrative" costs into a separate segment. This modification is specific to this thesis.

[25] The process of obtaining water from the irrigation districts stems from the Texas constitutional amendment Art. 3, Sect. 52 (Stubbs et al. 2003).

Currently, there are three IDs[26] that provide McAllen PUB with Rio Grande water. United Irrigation District of Hidalgo County is the specific ID that services water to the Northwest facility. Prior to the completion of the Northwest facility, McAllen's only source of potable of water came from the Southwest conventional surface-water treatment facility which was built in the 1950s (Rogers 2008).

Following Sturdivant et al. (2008), Rogers (2008) assumed a 50-year expected life for the Northwest facility and a zero net salvage value for capital assets. Based on historical water production at the Northwest facility, a baseline annual production efficiency of 78%[27] was applied. Rogers (2008) estimated that the Northwest facility will cost a nominal $207,706,012 (Table 4) to build and operate for 50-years. Adjusting for time and inflation, the real cost (i.e., versus nominal) of treating water over this time frame is $79,167,566 (Table 4) in 2006 dollars. Annualizing this value results in an annuity equivalent of $5,079,864.

Using the baseline production efficiency, the Northwest facility is estimated to produce a nominal 360,406 acre-feet (ac-ft) of potable water over the facility's 50-year useful life. Adjusting future water for time-value, results in a real volume of 143,164 ac-ft (Table 4). Annualizing this volume results in an annuity equivalent of 6,583 ac-ft. Dividing the annuity equivalent of costs ($5,079,864/yr) by the annuity equivalent of

---

[26] The irrigation districts that delivery water to McAllen Public Utilities are: Hidalgo County Irrigation District No. 2 (commonly referred to as San Juan #2), Hidalgo County Water Improvement District No. 3, and United Irrigation District of Hidalgo (a.k.a. United) (Rogers et al. 2008).

[27] This percentage represents the Northwest facility's average annual production level compared to its maximum-designed capacity (i.e., 8.25 mgd) for fiscal year 2005-2006.

water (6,583 ac-ft/yr) produces a cost of treating water of $771.67/ac-ft {$2.37/1,000 gals} for the Northwest facility (Table 4).

Table 4. Aggregate Baseline Results for Cost of Treating Water at the 8.25 mgd McAllen Northwest Facility, in 2006 Dollars[a]

Results	Units	Nominal Value	Real Value [b]
NPV of All Costs	2006 dollars	$207,706,012	$79,167,566
-Annuity Equivalent	$/yr	n/a	$5,079,864
NPV of Water Produced	ac-ft (lifetime)	360,406	143,164
-Annuity Equivalent	ac-ft/yr	n/a	6,583
NPV of Water Produced	1,000 gals (lifetime)	117,438,750	46,650,165
-Annuity Equivalent	1,000 gals/yr	n/a	2,145,074
Cost of Treating Water	$/ac-ft	n/a	$771.67
Cost of Treating Water	$/1,000 gals	n/a	$2.37

[a] The results of this table are considered the baseline analysis of the McAllen Northwest facility in its current operating state (i.e., 78% production efficiency, 2006 dollars, overbuilds and upgrades are included, and a zero net salvage value is recorded for all capital items and water rights).

[b] Values are reported on a real (vs. nominal) basis, determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.0% discount factor for water, and a 0.0% risk factor (Rister et al. 2008).

Source: Rogers (2008).

The Southmost Facility

Located northeast of the city of Brownsville, the Southmost facility is a RO desalination facility which treats brackish-groundwater. The facility was funded by the Southmost

Regional Water Authority (SWRA)[28] and began Phase I of operation in 2003 (Sturdivant et al. 2008). The facility was built with a maximum-designed capacity of 7.5 mgd, but has the capability to expand output two or three times beyond current designed capacity (Sturdivant et al. 2008). The Southmost facility pumps water from the Gulf Coast Aquifer, which has an approximate salinity level of 3,500 parts per million (ppm). The facility is designed to blend 6.0 mgd of the treated final-product water, which has a salinity level of 50 ppm, with an additional 1.5 mgd of bypass water[29] to reach its maximum-designed capacity of 7.5 mgd.[30] After the water is blended, the salinity level of the final-product potable water is 300-475 ppm (Sturdivant et al. 2008).[31,32]

The Southmost facility is assumed (by engineers) to have a 50-year useful life, as well as a zero net salvage value for all capital assets. Based on historical production, the Southmost facility is also estimated to have an annual baseline production efficiency of 68% (actual production efficiency in 2006) of its maximum-designed capacity (Sturdivant et al. 2008). Sturdivant et al. (2008) calculate that the Southmost facility will cost a nominal $195,914,480 (Table 5) to build and operate for 50-years. Adjusting

---

[28] SRWA is made up of six partners, including: Brownsville Public Utilities Board (PUB), City of Los Fresnos, Valley Municipal Utilities District No.2, town of Indian Lake, Brownsville Navigation District, and Laguna Madre Water District.

[29] Bypass water is source water that bypasses the RO membranes, but does go through the pretreatment process (i.e., cartilage filters), which reduces the salinity to 1,800 ppm (Sturdivant et al. 2008).

[30] The blending process described is how the facility is designed to operate; however, the Southmost facility is currently not blending because of high arsenic levels in the source water (Sturdivant et al. 2008). It is noted that both the baseline and modified results in this thesis assume that the Southmost is blending as designed.

[31] Bypass Water = 1,800 ppm * (1.5/7.5) = 360 ppm; Treated Water = 50 ppm * (6.0/7.5) = 40 ppm; Final Product Water = Bypass Water + Treat Water = 360 + 40 = 400 ppm.

[32] The U.S. Environmental Protection Agency (EPA) established a recommended maximum salinity level for drinking water at 1,000 ppm (College Station Utilities 2006).

for time and inflation, the real value cost of production is $65,281,089 (Table 5) in 2006 dollars. Annualizing this value produces an annuity equivalent of $4,201,075.

Using the baseline production efficiency, the Southmost facility is estimated to produce a nominal 285,637 ac-ft of water over the 50-year useful life. Adjusting for the time value of water production results in a real volume of 118,002 ac-ft. Annualizing this volume results in an annuity equivalent of 5,459 ac-ft. Dividing the annuity equivalent of costs ($4,201,075/yr) by the annuity equivalent of water (5,459 ac-ft/yr) produces an estimated baseline life-cycle cost of $769.62/ac-ft {$2.36/1,000 gals} (Table 5).

Table 5. Aggregate Baseline Results for Cost of Producing Water at the 7.5 mgd Southmost Facility, in 2006 Dollars[a]

Results	Units	Nominal Value	Real Value [b]
NPV of All Costs	2006 dollars	$195,914,480	$65,281,089
-Annuity Equivalent	$/yr	n/a	$4,201,075
NPV of Water Produced	ac-ft (lifetime)	285,637	118,002
-Annuity Equivalent	ac-ft/yr	n/a	5,459
NPV of Water Produced	1,000 gals (lifetime)	93,075,000	38,451,045
-Annuity Equivalent	1,000 gals/yr	n/a	1,778,701
Cost of Producing Water	$/ac-ft	n/a	$769.62
Cost of Producing Water	$/1,000 gals	n/a	$2.36

[a] The results of this table are considered the baseline analysis of the Southmost facility in its current operating state (i.e., 68% production efficiency, 2006 dollars, overbuilds and upgrades are included, and a zero net salvage value is recorded for all capital items).

[b] Values are reported on a real (vs. nominal) basis, determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.0% discount factor for water, and a 0.0% risk factor (Rister et al. 2008).

Source: Sturdivant et al. (2008).

CASE STUDY RESULTS

The discussion in this section focuses on the case study (i.e., baseline) analyses for the Olmito conventional surface-water facility and the La Sara brackish-groundwater desalination facility. These analyses reported here are the estimated life-cycle costs of producing potable water for the two facilities in their current operating efficiencies (i.e., current production efficiencies). The results presented in this section have not been modified or leveled, and are therefore not appropriate for use in making comparisons across facilities. 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 follow.

The Olmito Facility[33]

Olmito Water Supply Corporation (WSC) is a privately-owned and operated water utility which is located north of Brownsville, Texas in Cameron County.[34] Under their certificate of convenience and necessity (CCN), Olmito WSC is required to provide

---

[33] The input data 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. Therefore, it is not appropriate to refer to the analysis as an actual case study of the new Olmito facility. More accurately, the analysis is an engineered case study of a 2.0 mgd conventional surface-water facility which is based on projected costs of the Olmito expansion.

[34] In a privately-owned water utility, each connection (e.g., residential, business, etc.) in the utility's 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).

potable water and wastewater treatment to residents within a 16 ½ 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 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 WSCs anticipation of a new residential development in their service area. Construction on the development's infrastructure within Olmito's service area (i.e., roads, lot preparation, electric lines, and water line) had already commenced, and Olmito WSC anticipates the development to demand 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 approximately $2,000,000, as well as 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 to the development and construction of new and improved rural water and wastewater systems (U.S. General Service Administration 2008).[35] These funds allow

---

[35] 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).

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.[36]

Construction and Operation Cost

Olmito WSCs decision to expand its current conventional surface-water treatment facility, as opposed to building a new independent facility, allows it to continue to utilize some existing infrastructure (e.g., land, concrete, storage tank, 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. However, working with Orlando Cruz (2008), Olmito WSCs consulting engineer, and James Elium III (2008), the manager of Olmito WSC, opportunity cost estimates were generated for the input items that were not included in the new expansion construction cost data.

---

[36] A private water purveyor such as Olmito may elect to ignore the capital costs offset by federal and/or state grants when estimating the cost of production for a facility. Such an approach does not accurately portray the full societal costs (which are more properly reflected by the costs estimated in this thesis). An attempt to reflect the benefit of the grant and loan attained by Olmito suggests that life-cycle costs of treating potable water are reduced approximately $100/ac-ft {$0.50/1,000 gals} below these identified in the analysis reported subsequently in this thesis.

The resulting comprehensive cost estimates approximate the construction costs for building a completely new 2.0 mgd conventional surface-water facility. Also, the 2008 construction costs data were deflated two years at a 2.043% compound rate to equal 2006 dollars (i.e., the base year of analysis). A comprehensive identification of the extrapolated construction costs for the Olmito facility are presented in Table 6. A construction period of 12-months is assumed, as well as a 40-year useful life for the facility.[37]

Similarly, the continued costs and capital replacement costs data were already available for Olmito's 1.0 mgd conventional-surface water treatment facility. Again, by collaborating with Cruz (2008) and Elium (2008), estimates were obtained for the continued cost items and capital replacement cost items associated with a new 2.0 mgd facility. Each continued cost item and capital replacement cost item were individually identified to closely reflect the comprehensive costs for a 2.0 mgd facility with a 40-year useful life. The extrapolated input data associated with continued costs and capital replacement costs are available in Table 7 and Table 8.

---

[37] Annuity Equivalents converts the NPV of costs for a facility into an annual per-unit amount into perpetuity. This allows for comparisons across alternative water treatment facilities of different useful lives (Rister et al. 2008; Sturdivant et al. 2008; and Rogers et al. 2008).

Table 6. Initial Construction Costs for the 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]	Admini-strative[b]	Total Initial 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
Piping	62,999	31,770	19,207	438,469				552,445
Pumping & Valve Cost	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	$0	$4,557,541

[a] "Overbuilds" represent the excess construction completed to leave room for future expansion of the facility. "Upgrades" represent "over-the-top" construction beyond what is necessary for water treatment (Sturdivant et al. 2008, Rogers et al. 2008). There are no "Overbuilds and Upgrades" costs for the Olmito facility, but the cost segment is included to be consistent with the analyses of other facilities.

[b] "Administrative" costs are annual expenses that are facility-related, but are not included on the water treatment facility's (e.g., Northwest, Southmost, La Sara, and Olmito) budget; rather, they are included on the owner-entity's (e.g., PUB and WSC) budget. This segment was not included in Sturdivant et al. (2008) or Rogers (2008), but is a modification specific to this thesis.

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

Table 7. Baseline Continued Costs for the 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									
Continued Cost Item	Raw Water Intake/ Reservoir	Treatment Unit	Sludge Disposal	Delivery to Municipal Line/ Storage	Operations' Supporting Facilities	Overbuilds & Upgrades[a]	Admini-strative[b]	Total Costs for a 1.0 mgd facility	Expansion Factors to a 2.0 mgd facility[c]	Baseline Total Cost for a 2.0 mgd facility (i.e., 52% PE)
Administrative							$21,345	$21,345	0%	$21,345
Office Expense	747	22,401	373	11,201	2,614			31,113	20%	$37,336
Chemical		103,526						51,763	100%	$103,526
Electrical	19,267	24,084	14,450	28,900	9,633			48,167	100%	$96,334
Insurance	4,997	12,493	4,997	1,249	1,249			19,989	25%	$24,986
Labor	26,980	44,966	8,993	71,946	26,980			149,888	20%	$179,866
Repair & Maintenance	6,000	27,000	6,000	18,000	3,000			40,000	50%	$60,000
Licences & Regulatory	12,162	10,135	6,081	12,162				36,855	10%	$40,541
Miscellaneous	1,875	9,375		22,500	3,750			25,000	50%	$37,500
Equipment Rental	5,000	5,000	1,000	5,000	4,000			20,000	0%	$20,000
Water Delivery	59,422							30,473	95%	$59,422
Total	$136,450	$258,980	$41,894	$170,958	$51,226	$0	$21,345	$474,593		$680,856

[a] "Overbuilds" represent the excess construction completed to leave room for future expansion of the facility. "Upgrades" represent "over-the-top" construction beyond what is necessary for water treatment (Sturdivant et al. 2008, Rogers et al. 2008). There are no "Overbuilds and Upgrades" costs for the Olmito facility, but the cost segment is included to be consistent with the analyses of other facilities.

[b] "Administrative" costs are annual expenses that are facility-related, but are not included on the water treatment facility's (e.g., Northwest, Southmost, La Sara, and Olmito) budget; rather, they are included on the owner-entity's (e.g., PUB and WSC) budget. This segment was not included in Sturdivant et al. (2008) or Rogers (2008), but is a modification specific to this thesis.

[c] The listed expansion factors were estimated by Cruz (2008) and Elium (2008) to represent the increase for each cost item for a surface-water facility as it is expanded from a 1.0 mgd to 2.0 mgd facility.

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

Table 8. Capital Replacement Items, Occurrence, and Costs for the 2.0 mgd Facility Based on the Olmito Facility, in 2006 Dollars

Capital Replacement Item[a]	Segment	Frequency of Replacement	Cost per Item	No. of Items Replaced
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

[a] The capital replacement costs in this table are for the baseline analysis of the Olmito facility.

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

Annual Water Production

The raw source water for the Olmito facility originates in the Rio Grande and reaches the facility through a system of canals and pipelines which are owned and operated by the Cameron County Irrigation District No. 6 (Elium 2008). In remaining consistent with the approach followed by Rogers et al. (2008), this analysis establishes a municipal water-right value of $2,300/ac-ft and assumes the Olmito WSC purchases sufficient water rights for the facility to operate at 96% of the annual maximum-designed capacity. The 96% level assumes that the facility would purchase enough water (2,151 ac-ft) for the facility's maximum annual output less a two-week shut-down period, which is typical of municipal water operations (Rogers 2008; Rogers et al. 2008). The baseline production efficiency rate is established at 52% of the Olmito facility's operating capacity, as determined from the Olmito facility's total output for 2007.

Aggregate Baseline Results

The nominal value for total costs associated with the Olmito facility over a useful life of 40-years amounts to $54,897,294 (Table 9). This includes water-rights purchase, initial construction costs, continued costs, and capital-replacement costs (Elium 2008; Cruz 2008).

Adjusting this value for time and inflation using a 6.125% annual discount rate results in a real (i.e., versus nominal) value of $23,020,626. Annualizing this value into perpetuity results in an annuity equivalent of $1,545,037 (Table 9). This value represents the total annual costs associated with building and operating the facility (basis 2006 dollars) over the course of its expected 40-year useful life.

The total volume of water estimated to be treated over the Olmito facility's useful life is 46,598 ac-ft in nominal terms (Table 9). Adjusting for a 4.0% annual social-time preference (Griffin and Chowdhury 1993) results in a real volume of 22,171 ac-ft. Annualizing real volume into perpetuity indicates an annuity equivalent of 1,109 ac-ft.

Dividing the annuity equivalent of costs ($1,545,037/yr) by the annuity equivalent of water ($1,109/yr) produces a life-cycle cost of $1,393.28/ac-ft {$4.28/1,000 gals} for the baseline analysis (Table 9). Consistent with the methodology in Rister et al. (2008), this value represents the cost of treating (and delivering, to an initial point within the municipal water-delivery system) one ac-ft {1,000 gals} of potable water into perpetuity.

Table 9. Aggregate Baseline Results for Cost of Treating Water at the 2.0 mgd Olmito Conventional Surface-Water Treatment Facility, in 2006 Dollars[a]

Results	Units	Nominal Value	Real Value [b]
NPV of All Costs	2006 dollars	$54,897,294	$23,020,626
-Annuity Equivalent	$/yr	n/a	$1,545,037
NPV of Water Produced	ac-ft (lifetime)	46,598	22,171
-Annuity Equivalent	ac-ft/yr	n/a	1,109
NPV of Water Produced	1,000 gals (lifetime)	15,184,000	7,224,362
-Annuity Equivalent	1,000 gals/yr	n/a	361,344
Cost of Treating Water	$/ac-ft	n/a	$1,393.28
Cost of Treating Water	$/1,000 gals	n/a	$4.28

[a] The results of this table are considered the baseline analysis of the Olmito facility in its current operating state (i.e., 52% production efficiency, 2006 dollars, overbuilds and upgrades are included, and a zero net salvage value is recorded for all capital items and water rights).

[b] Values are reported on a real (vs. nominal) basis, determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.0% discount factor for water, and a 0.0% risk factor (Rister et al. 2008).

Baseline Results by Cost Type, Item, and Segment

The total cost of treating water for the Olmito facility, reported in Table 9, can be divided into three cost types: (1) initial construction/water rights purchase ($9,504,096), (2) continued costs ($12,957,707), and (3) capital replacement costs ($558,823). Initial construction/water rights purchase contribute 41.3% of the total cost, which includes the cost of building the facility and purchasing water rights for 96% of the facility's designed capacity. Of the 41.3%, the purchase of water rights account for 21.5% of the total cost.

The continued costs contribute 56.3% of the total cost, and capital replacement costs contribute the remaining 2.4% (Figure 2). In per-unit measurements, the initial construction/water rights purchase costs account for $575.22/ac-ft {$1.77/1,000 gals}, continued costs account for $784.24/ac-ft {$2.41/1,000 gals}, and capital replacement costs account for $33.82/ac-ft {$0.10/1,000 gals} (Table 10), which sum to $1,393.28/ac-ft {$4.28/1,000 gals}.

The total continued costs are allocated across six continued cost items: administrative ($406,228),[38] energy ($1,833,382), chemical ($1,970,256), labor ($3,423,115), water delivery ($1,130,897), and all other costs ($4,193,829).[39] In per-unit measurements, administrative costs are $24.59/ac-ft {$0.08/1,000 gals}, energy costs are $110.96/ac-ft {$0.34/1,000 gals}, chemicals are $119.25/ac-ft {$0.37/1,000 gals}, labor is $207.18/ac-ft {$0.64/1,000 gals}, water delivery costs are $68.45/ac-ft {$0.21/1,000 gals}, and all other costs are $253.81/ac-ft {$0.77/1,000 gals}. Refer to Table 10 and Figure 2 for the complete analysis of the Olmito facility's baseline (i.e., case study) cost of treating water across the different cost types and items.

---

[38] "Administrative" costs are annual expenses that are facility-related, but are not included on the water treatment facility's (e.g., Northwest, Southmost, La Sara, and Olmito) budget; rather, they are included on the owner-entity's (e.g., PUB and WSC) budget.

[39] "All Other" costs includes the remaining continued cost items (e.g., insurance, repairs, machinery rental, etc.) in the facility's income statement. Differing accounting methods between facilities results in a wide range of values for this comprehensive item.

Table 10. Baseline Life-Cycle Costs of Treating Water, by Cost Type and Item, for the 2.0 mgd Olmito Conventional Surface-Water Treatment Facility, in 2006 Dollars[a, b]

	Olmito (Conventional)				
Cost Type and Item	NPV of Cost Stream	Annuity Equivalent in $/yr	Annuity Equivalent in $/ac-ft	Annuity Equivalent in $/1,000 gals	% of Total Cost
Initial Construction/Investment	**$9,504,096**	**$637,871**	**$575.22**	**$1.77**	**41.3%**
- Water Right Purchase	*4,946,555*	*331,990*	*299.38*	*0.92*	*21.5%*
Continued	**12,957,707**	**869,661**	**784.24**	**2.41**	**56.3%**
- Administrative[c]	*406,228*	*27,264*	*24.59*	*0.08*	*1.8%*
- Energy	*1,833,382*	*123,048*	*110.96*	*0.34*	*8.0%*
- Chemical	*1,970,256*	*132,235*	*119.25*	*0.37*	*8.5%*
- Labor	*3,423,115*	*229,744*	*207.18*	*0.64*	*14.9%*
- Water Delivery	*1,130,897*	*75,501*	*68.45*	*0.21*	*4.9%*
- All Other[d]	*4,193,829*	*281,470*	*253.81*	*0.77*	*18.2%*
Capital Replacement	**558,823**	**37,505**	**33.82**	**0.10**	**2.4%**
Total	$23,020,626	$1,545,037	$1,393.28	$4.28	100.0%

[a] The results of this table are considered the baseline analysis of the Olmito facility in its current operating state (i.e., 52% production efficiency, 2006 dollars, overbuilds and upgrades are included, and a zero net salvage value is recorded for all capital items and water rights).

[b] Values are reported on a real (vs. nominal) basis, determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.0% discount factor for water, and a 0.0% risk factor (Rister et al. 2008).

[c] "Administrative" costs are annual expenses that are facility-related, but are not included on the water treatment facility's (e.g., Northwest, Southmost, La Sara, and Olmito) budget; rather, they are included on the owner-entity's (e.g., PUB and WSC) budget.

[d] "All Other" costs includes the remaining continued cost items (e.g., insurance, repairs, machinery rental, etc.) in the facility's income statement. Differing accounting methods between facilities results in a wide range of values for this comprehensive item.

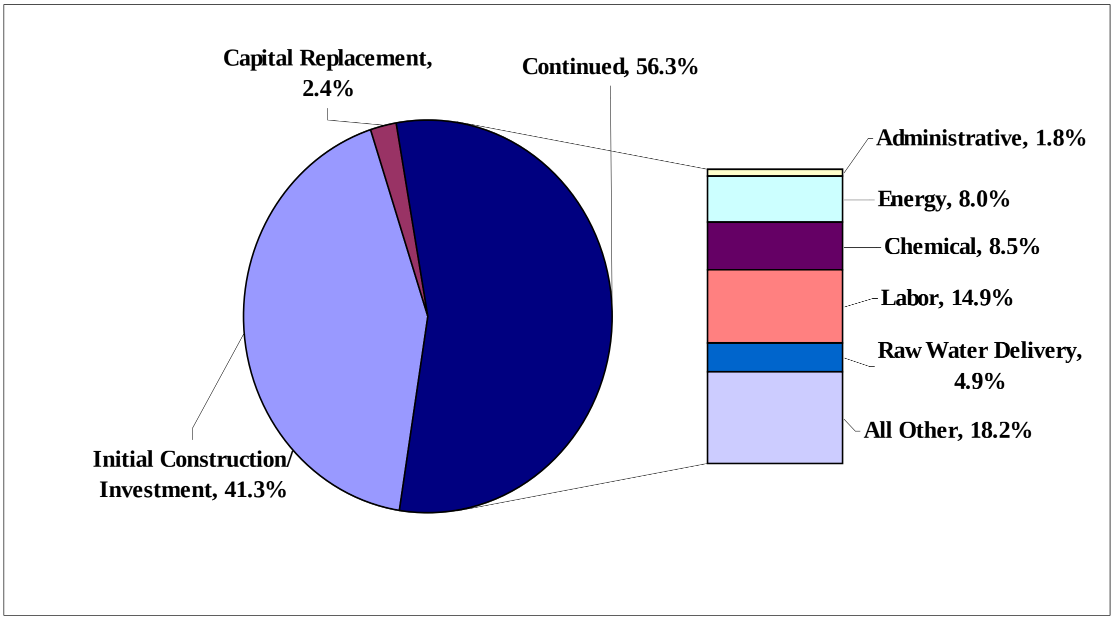


Figure 2. Proportion of total baseline cost, by cost type and item, for the 2.0 mgd Olmito conventional surface-water treatment facility

Shown in Table 11 and Figure 3 are the total baseline costs for the Olmito facility, divided into seven segments. Five of the segments represent the different stages source water travels to become potable in the conventional treatment process. The other two segments ("Overbuilds and Upgrades" and "Administrative") are included for "leveling" purposes. The three most cost-intensive segments are the water rights/raw water intake/reservoir ($8,520,385), the treatment unit ($6,449,807), and the delivery to municipal line/storage ($4,797,206). Combined, these three segments contribute 85.8% of the Olmito facility's total life-cycle cost. In per-unit measurements, the water rights/raw water intake/reservoir costs are $515.68/ac-ft {$1.58/1,000 gals}, the treatment unit costs are $390.36/ac-ft {$1.20/1,000 gals}, and delivery to municipal line/storage costs are $290.34/ac-ft {$0.89/1,000 gals}. For brevity purposes, not all of the segments are discussed, but refer to Table 11 and Figure 3 for the complete distribution of the Olmito facility's baseline cost of treating water across all of the segments.

In addition, sensitivity analyses were performed for the Olmito facility. Sensitivity tables for the cost per-unit of various continued cost ranges and production efficiency ranges as well as various energy cost ranges and production efficiency ranges are displayed and discussed in Appendix A.

Table 11. Baseline Life-Cycle Costs of Treating Water, by Cost Segment, for the 2.0 mgd Olmito Conventional Surface-Water Treatment Facility, in 2006 Dollars[a,b]

Cost Segment	NPV of Cost Stream	Annuity Equivalent in $/yr	Annuity Equivalent in $/ac-ft	Annuity Equivalent in $/1,000 gals	% of Total Costs
1) Water Rights/Raw Water Intake/Reservoir	$8,520,385	$571,849	$515.68	$1.58	37.0%
2) Treatment Unit	6,449,807	432,881	390.36	1.20	28.0%
3) Sludge Disposal	1,013,956	68,052	61.37	0.19	4.4%
4) Delivery to Municipal Line/Storage	4,797,206	321,966	290.34	0.89	20.8%
5) Operations' Supporting Facilities	1,833,045	123,026	110.94	0.34	8.0%
6) Overbuilds and Upgrades[c]	0	0	0.00	0.00	0.0%
7) Administrative[d]	406,227	27,263	24.59	0.08	1.8%
Total	$23,020,616	$1,545,037	$1,393.28	$4.28	100.0%

[a] The results of this table are considered the baseline analysis of the Olmito facility in its current operating state (i.e., 52% production efficiency, 2006 dollars, overbuilds and upgrades are included, and a zero net salvage value is recorded for all capital items and water rights).

[b] Values are reported on a real (vs. nominal) basis, determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.0% discount factor for water, and a 0.0% risk factor (Rister et al. 2008).

[c] "Overbuilds" represent the excess construction completed to leave room for future expansion of the facility. "Upgrades" represent "over-the-top" construction beyond what is necessary for conventional water treatment technology (Sturdivant et al. 2008; Rogers et al. 2008). There are no "Overbuilds and Upgrades" costs for the Olmito facility, but the cost segment is included to be consistent with the analyses of other facilities.

[d] Due to the difficulty in estimating this value as well as in allocating it across the segments, all of the "Administrative" costs are combined into a single segment. This segment was not included in Sturdivant et al. (2008) or Rogers (2008), but is a modification specific to this thesis.

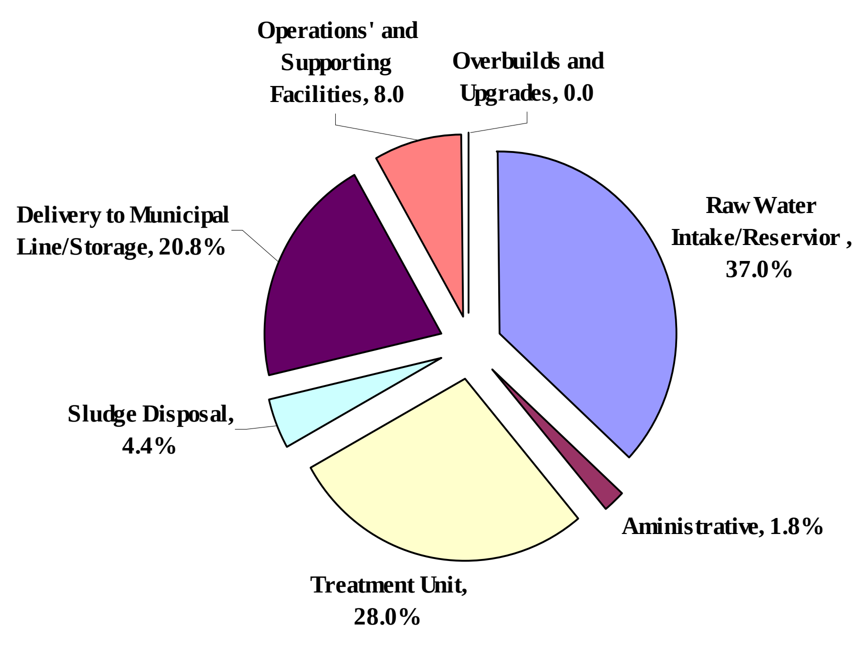


Figure 3. Proportion of total baseline cost, by cost segment, for the 2.0 mgd Olmito conventional surface-water treatment facility

The La Sara Facility

The La Sara brackish-groundwater facility is privately-owned and operated by North Alamo Water Supply Corporation (NAWSC). The facility serves residents of eastern Hidalgo, Willacy, and northwest Cameron Counties with potable water and wastewater treatment services (Browning 2007). NAWSCs designated serving area spreads across 973 square miles that include 16 rural communities, which total 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 twenty-two (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 2008).

In 2003, NAWSC was faced with an increase in their customers' potable water demand, which challenged its municipal water supply system, encouraging an 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.

Construction and Operation Cost

The construction period for the La Sara facility was 18-months, spanning from April 2003 to November 2004. The actual construction costs were provided by Charles "Chuck" Browning (2007), the general manager of NAWSC, and Jake White (2007), engineer-in-training with NRS Consulting Engineers in Harlingen, Texas. Similar to the Olmito facility, some existing infrastructure (e.g., storage tank, pumps, etc.) at one of NAWSCs nearby conventional surface-water treatment facility was in close enough proximity to the La Sara facility that it could be shared between the two facilities. By collaborating with Browning (2007) and White (2007), cost estimates 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. Also, since the construction costs were basis 2004, they were inflated by two years using a 2.043% annual interest rate to equal 2006 dollars. The input data associated with construction costs for the La Sara facility are shown in Table 12. A construction period of 12-months was identified as appropriate, as well as a 50-year useful life for the facility.[40]

Continued costs and capital replacement costs were also provided by Browning (2007) and White (2007). Continued costs were identified directly from the La Sara facility's fiscal year 2006 financial statements. Since the facility has been in operation for three years, actual capital replacement costs were obtained for items with three-year useful lives. For items with greater than three-year useful lives (i.e., well pumps and vehicles), estimates were obtained. The continued and capital replacement costs for the La Sara facility are presented in Tables 13 and 14.

---

[40] It is recognized that the actual construction period was 18-months, but to allow relative comparisons of the life-cycle costs for the La Sara facility with the Southmost facility costs, a 12-month construction period was established.

Table 12. Initial Construction Costs for the 1.13 mgd La Sara Brackish-Groundwater Desalination Treatment 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]	Admin-istrative[b]	Total Initial Costs
Pre-Project	$41,651		$5,206						$46,857
Land Cost	820		2,461						3,281
Well Cost	392,629								392,629
Pipeline Cost	2,280			6,482		18,222			26,984
Building & Site Construction			176,386						176,386
RO Equipment & Installation			996,662						996,662
Storage Tank Cost					260,321				260,321
Electrical Cost	44,833		268,997		44,833				358,663
SCADA Cost	14,266		14,266		14,266				42,798
Engineering Cost	34,232	34,232	34,232	34,232	34,232	34,232			205,392
Miscellaneous Cost	4,425	4,425	4,425	4,425	4,425	4,425			26,550
Total	$535,137	$38,657	$1,502,635	$45,139	$358,077	$56,880	$0	$0	$2,536,524

[a] "Overbuilds" represent the excess construction completed to leave room for future expansion of the facility. "Upgrades" represent "over-the-top" construction beyond what is necessary for desalination water treatment technology (Sturdivant et al. 2008; Rogers et al. 2008). There are no "Overbuilds and Upgrades" costs for the La Sara facility, but the cost segment is included to be consistent with the analyses of other facilities.

[b] "Administrative" costs are annual expenses that are facility-related, but are not included on the water treatment facility's (e.g., Northwest, Southmost, La Sara, and Olmito) budget; rather, they are included on the owner-entity's (e.g., PUB and WSC) budget. This segment was not included in Sturdivant et al. (2008) or Rogers (2008), but is a modification specific to this thesis.

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

Table 13. Baseline Continued Costs for the 1.13 mgd La Sara Brackish-Groundwater Desalination Treatment Facility, Across Individual Segments, in 2006 Dollars

	Individual Segments of the La Sara Facility								
Continued Cost Item	Well Field	Trans-mission Line	Main Facility/ Treatment Process	Concentrate Discharge	Finished Water & Tank Storage	High Service & Delivery Pipeline	Overbuilds & Upgrades[a]	Admin-istrative[b]	Total Initial Costs
Administrative								$127,913	$127,913
Chemical			26,877						26,877
Concentrated Discharge				3,000					3,000
Electrical	29,969		59,938		29,969				119,875
Labor	3,120	3,120	3,120	3,120	3,120	3,120			18,720
Maintenance	433	433	433	433	433	433			2,600
Water Testing	112			112	2,024				2,249
Total	$33,624	$3,553	$90,368	$6,665	$35,546	$3,553	$0	$127,913	$301,234

[a] "Overbuilds" represent the excess construction completed to leave room for future expansion of the facility. "Upgrades" represent "over-the-top" construction beyond what is necessary for desalination water treatment technology (Sturdivant et al. 2008; Rogers et al. 2008). There are no "Overbuilds and Upgrades" costs for the La Sara facility, but the cost segment is included to be consistent with the analyses of other facilities.

[b] "Administrative" costs are annual expenses that are facility-related, but are not included on the water treatment facility's (e.g., Northwest, Southmost, La Sara, and Olmito) budget; rather, they are included on the owner-entity's (e.g., PUB and WSC) budget. This segment was not included in Sturdivant et al. (2008) or Rogers (2008), but is modification specific to this thesis.

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

Table 14. Capital Replacement Items, Occurrence, and Costs for the 1.13 mgd La Sara Facility, in 2006 Dollars

Capital Replacement Item[a]	Segment	Frequency of Replacement	Cost per Item	No. of Items Replaced Each Time
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

[a] The capital replacement costs in this table are for the baseline analysis of the La Sara facility.

[b] NAWSC shares vehicles among all of their water treatment facilities, therefore, the capital replacement expense is not for one vehicle, but for a proportion of one vehicle.

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

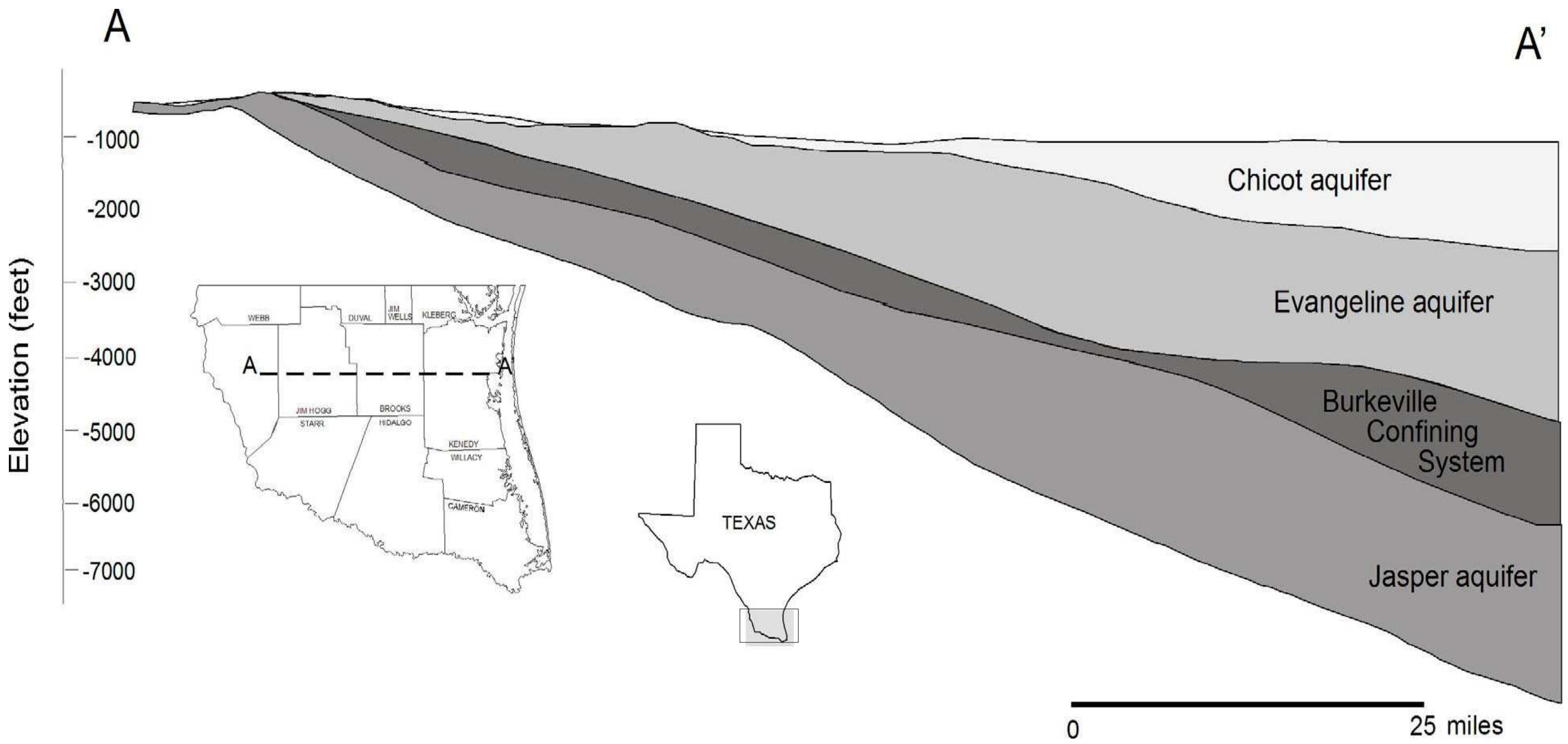
Annual Water Production

The La Sara facility's raw water supply comes from one brackish-groundwater well, which taps the Gulf Coast Aquifer at an approximate depth of 980 feet. 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). According to Chowdhury and Mace (2007), the Gulf Coast Aquifer is classified into four hydrostratigraphic units. Figure 4 is a display of the four units by depth, spanning from west to east. The La Sara facility's source water has an incoming salinity level of approximately 2,700 parts per million (ppm) (Browning 2007) compared to 3,500 ppm for the Southmost facility.

Once the raw source water reaches the main facility, it is pumped through two 0.5 mgd RO trains, which treat the water to a salinity level of approximately 100 ppm. The treated water is then blended with bypass water (i.e., partially treated by the cartridge filters only),[41] resulting in final-product water that is approximately 87% treated water and 13% bypass water.

---

[41] 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. 2008).



Source: Chowdhury and Mace (2007).

Figure 4. Illustration of the Gulf Coast Aquifer in the Lower Rio Grande Valley of Texas

The final-product water has a final salinity level of roughly 438 ppm (Browning 2007), which is comparable to the water quality achieved at the Southmost facility (Sturdivant et al. 2008).

Similar to the Olmito and other water treatment facilities, a number of operating parameters such as seasonal demands, unexpected breakdowns, repairs and maintenance, and State regulations restrict the La Sara facility from operating at 100% of its maximum-designed capacity. Therefore, a baseline (i.e., case study) production efficiency level is established at 65% of the facility's annual operating capacity, as determined based on the La Sara facility's production level in 2006.

Aggregate Baseline Results

The total nominal value of dollars associated with the La Sara facility over a useful life of 50-years amounts to $31,139,496. This includes initial construction costs, continued costs, and capital-replacement costs (Browning 2007; White 2007). Adjusting this value for time and inflation using a 6.125% annual discount rate results in a real value of $9,127,005 (Table 15). Annualizing this real value into perpetuity indicates an estimated annuity equivalent of $587,356 (Table 15).

This value represents the total annual cost of producing water at the La Sara facility (basis 2006 dollars) over the course of its expected useful life.

The total volume of water estimated to be produced over the La Sara facility's useful life of 50-year amounts to 41,241 ac-ft in nominal terms (Table 15). Adjusting for a 4.0% annual social-time preference (Griffin and Chowdhury 1993) results in a real volume of 17,038 ac-ft. Annualizing this real volume into perpetuity produces an estimated annuity equivalent of 788 ac-ft.

Dividing the annuity equivalent of costs ($587,356/yr) by the annuity equivalent of water (788 ac-ft/yr) produces a baseline life-cycle cost of $745.25/ac-ft {$2.29/1,000 gals} (Table 15). Consistent with the methodology in Rister et al. (2008), this value represents the annual cost of producing (and delivering, to an initial point within the municipal water-delivery system) one ac-ft {1,000 gals} of potable water into perpetuity.

Table 15. Aggregate Baseline Results for Cost of Producing Water at the 1.13 mgd La Sara Brackish-Groundwater Desalination Facility, in 2006 Dollars[a]

Results	Units	Nominal Value	Real Value [b]
NPV of All Costs	2006 dollars	$31,139,496	$9,127,005
-Annuity Equivalent	$/yr	n/a	$587,356
NPV of Water Produced	ac-ft (lifetime)	41,241	17,038
-Annuity Equivalent	ac-ft/yr	n/a	788
NPV of Water Produced	1,000 gals (lifetime)	13,438,500	5,551,669
-Annuity Equivalent	1,000 gals/yr	n/a	256,815
Cost of Producing Water	$/ac-ft	n/a	$745.25
Cost of Producing Water	$/1,000 gals	n/a	$2.29

[a] The results of this table are considered the baseline analysis of the La Sara facility in its current operating state (i.e., 65% production efficiency, 2006 dollars, overbuilds and upgrades are included, and a zero net salvage value is recorded for all capital items).

[b] Values are reported on a real (vs. nominal) basis, determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.0% discount factor for water, and a 0.0% risk factor (Rister et al. 2008).

Baseline Results by Cost Type, Item, and Segment

The total cost of producing water for the La Sara facility ($9,127,005), reported in Table 15, can be divided into three cost types: (1) initial construction ($2,536,527), (2) continued costs ($6,222,266), and (3) capital replacement costs ($368,212) (Table 16). The initial construction costs contribute 27.8% of the total costs, while continued costs contribute 68.1%, and capital replacement costs contribute the remaining 4.1% (Figure 5). In per-unit measurements, the initial construction costs are $207.11/ac-ft {$0.64/1,000 gals}, continued costs are $508.07/ac-ft {$1.56/1,000 gals}, and capital replacement costs are $30.07/ac-ft {$0.09/1,000 gals} (Table 16), which sum to $745.25/ac-ft {$2.29/1,000 gals}.

The total continued costs of potable water production are allocated across five continued cost items: administrative ($2,642,160),[42] energy ($2,476,132), chemical ($555,170), labor ($386,679), and all other costs ($162,125)[43] (Table 16). In per-unit measurements, administrative costs are $215.74/ac-ft {$0.66/1,000 gals}, energy costs are $202.18/ac-ft {$0.62/1,000 gals}, chemicals are $45.33/ac-ft {$0.14/1,000 gals}, labor is $31.57/ac-ft {$0.10/1,000 gals}, and all other costs are $13.25/ac-ft {$0.04/1,000 gals}. Refer to Table 16 and Figure 5 for the detailed set of La Sara's baseline (i.e., case study) cost of producing water across different cost types and items.

---

[42] "Administrative" costs are annual expenses that are facility-related, but are not included on the water treatment facility's (e.g., Northwest, Southmost, La Sara, and Olmito) budget; rather, they are included on the owner-entity's (e.g., PUB and WSC) budget.

[43] "All Other" costs includes the remaining continued cost items (e.g., insurance, repairs, machinery rental, etc.) in the facility's income statement. Differing accounting methods between facilities results in a wide range of values for this comprehensive item .

Table 16. Baseline Life-Cycle Costs of Producing Water, by Cost Type and Item, for the 1.13 mgd La Sara Brackish-Groundwater Desalination Facility, in 2006 Dollars[a, b]

	La Sara (Desalination)				
Cost Type and Item	NPV of Cost Stream	Annuity Equivalent in $/yr	Annuity Equivalent in $/ac-ft	Annuity Equivalent in $/1,000 gals	% of Total Cost
Initial Construction/Investment	**$2,536,527**	**$163,235**	**$207.11**	**$0.64**	**27.8%**
Continued	**6,222,266**	**400,425**	**508.07**	**1.56**	**68.1%**
- Administrative[c]	*2,642,160*	*170,033*	*215.74*	*0.66*	*28.9%*
- Energy	*2,476,132*	*159,727*	*202.18*	*0.62*	*27.1%*
- Chemical	*555,170*	*35,727*	*45.33*	*0.14*	*6.1%*
- Labor	*386,679*	*24,884*	*31.57*	*0.10*	*4.2%*
- All Other[d]	*162,125*	*10,432*	*13.25*	*0.04*	*1.8%*
Capital Replacement	**368,212**	**23,696**	**30.07**	**0.09**	**4.1%**
Total	$9,127,005	$587,356	$745.25	$2.29	100.0%

[a] The results of this table are considered the baseline analysis of the La Sara facility in its current operating state (i.e., 65% production efficiency, 2006 dollars, overbuilds and upgrades are included, and a zero net salvage value is recorded for all capital items).

[b] Values are reported on a real (vs. nominal) basis, determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.0% discount factor for water, and a 0.0% risk factor (Rister et al. 2008).

[c] "Administrative" costs are annual expenses that are facility-related, but are not included on the water treatment facility's (e.g., Northwest, Southmost, La Sara, and Olmito) budget; rather, they are included on the owner-entity's (e.g., PUB and WSC) budget.

[d] "All Other" costs includes the remaining continued cost items (e.g., insurance, repairs, machinery rental, etc.) in the facility's income statement. Differing accounting methods between facilities results in a wide range of values for this comprehensive item.

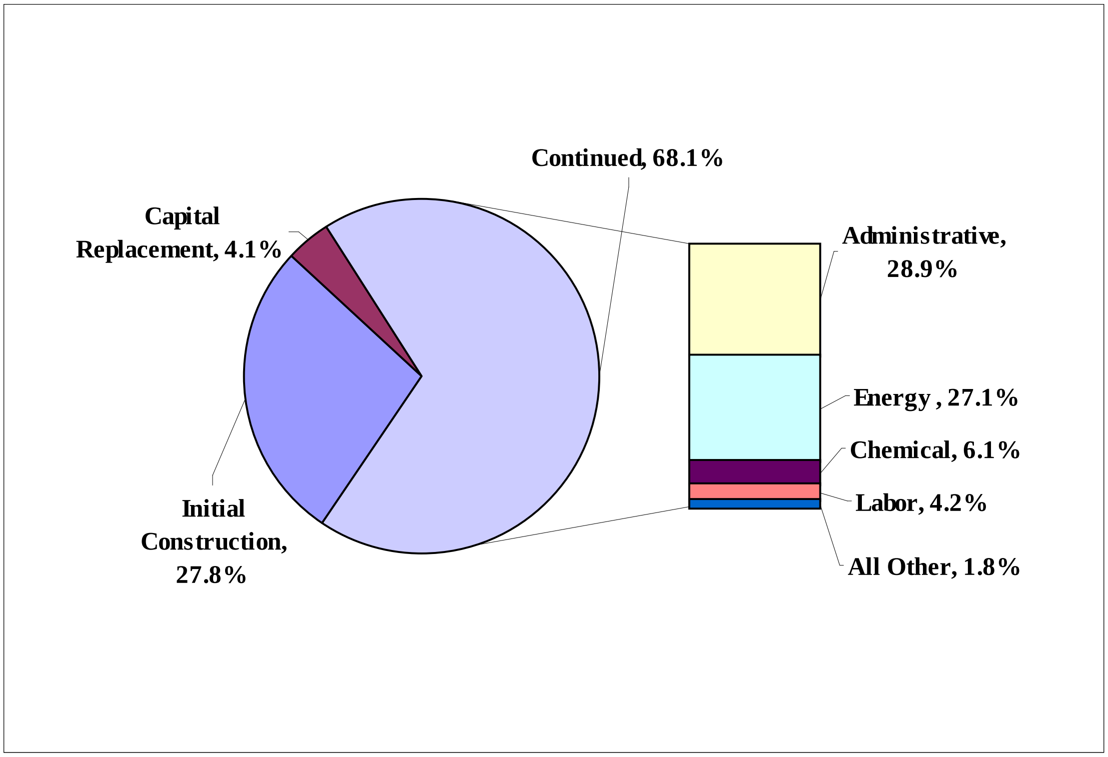


Figure 5. Proportion of total baseline cost, by cost type and item, for the 1.13 mgd La Sara brackish-groundwater desalination facility

Demonstrated in Table 17 and Figure 6 are the costs of producing water at the La Sara facility, divided into eight segments. Six of the segments represent the different stages of the RO desalination process. The other two segments ("Overbuilds and Upgrades" and "Administrative") are included for "leveling" purposes. The three most cost-intensive segments are the well field ($1,340,500), the main facility/treatment process ($3,626,870), and the administrative costs ($2,642,160). Combined, these three segments contribute 83.4% of the La Sara facility's baseline life-cycle costs. In per-unit measurements, the well field costs are $109.46/ac-ft {$0.34/1,000 gals}, the main facility/treatment process costs are $296.14/ac-ft {$0.91/1,000 gals}, and administrative costs are $215.74/ac-ft {$0.66/1,000 gals}. For brevity purposes, not all of the segments are discussed, but refer to Table 17 and Figure 6 for a detailed listing of La Sara's baseline costs of producing water across the different cost segments.

In addition, sensitivity analyses were performed for the La Sara facility. Sensitivity tables for the cost per-unit of various continued cost ranges and production efficiency ranges, as well as various energy cost ranges and production efficiency ranges are displayed and discussed in Appendix B.

Table 17. Baseline Life-Cycle Costs of Producing Water, by Cost Segment, for the 1.13 mgd La Sara Brackish-Groundwater Desalination Facility, in 2006 Dollars[a,b]

Cost Segment	NPV of Cost Stream	Annuity Equivalent in $/yr	Annuity Equivalent in $/ac-ft	Annuity Equivalent in $/1,000 gals	% of Total Costs
1) Well Field	$1,340,500	$86,266	$109.46	$0.34	14.7%
2) Transmission Line	112,055	7,211	9.15	0.03	1.2%
3) Main Facility/Treatment Process	3,626,870	233,402	296.14	0.91	39.8%
4) Concentrated Discharge	182,828	11,766	14.93	0.05	2.0%
5) Finished Water/Storage Tanks	1,092,314	70,294	89.19	0.27	12.0%
6) High Service and Delivery Pipeline	130,278	8,384	10.64	0.03	1.4%
7) Overbuilds and Upgrades[c]	0	0	0.00	0.00	0.0%
8) Administrative[d]	2,642,160	170,033	215.74	0.66	28.9%
Total	$9,127,005	$587,356	$745.25	$2.29	100.0%

[a] The results of this table are considered the baseline analysis of the La Sara facility in its current operating state (i.e., 65% production efficiency, 2006 dollars, overbuilds and upgrades are included, and a zero net salvage value is recorded for all capital items).

[b] Values are reported on a real (vs. nominal) basis, determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.0% discount factor for water, and a 0.0% risk factor (Rister et al. 2008).

[c] "Overbuilds" represent the excess construction completed to leave room for future expansion of the facility. "Upgrades" represent "over-the-top" construction beyond what is necessary for desalination water treatment technology (Sturdivant et al. 2008; Rogers et al. 2008). There are no "Overbuilds and Upgrades" costs for the La Sara facility, but the cost segment is included to be consistent with the analyses of other facilities.

[d] Due to the difficulty in estimating this value as well as allocating it across the segments, all of the "Administrative" costs are combined into a single segment. This segment was not included in Sturdivant et al. (2008) or Rogers (2008), but is a modification specific to this thesis.

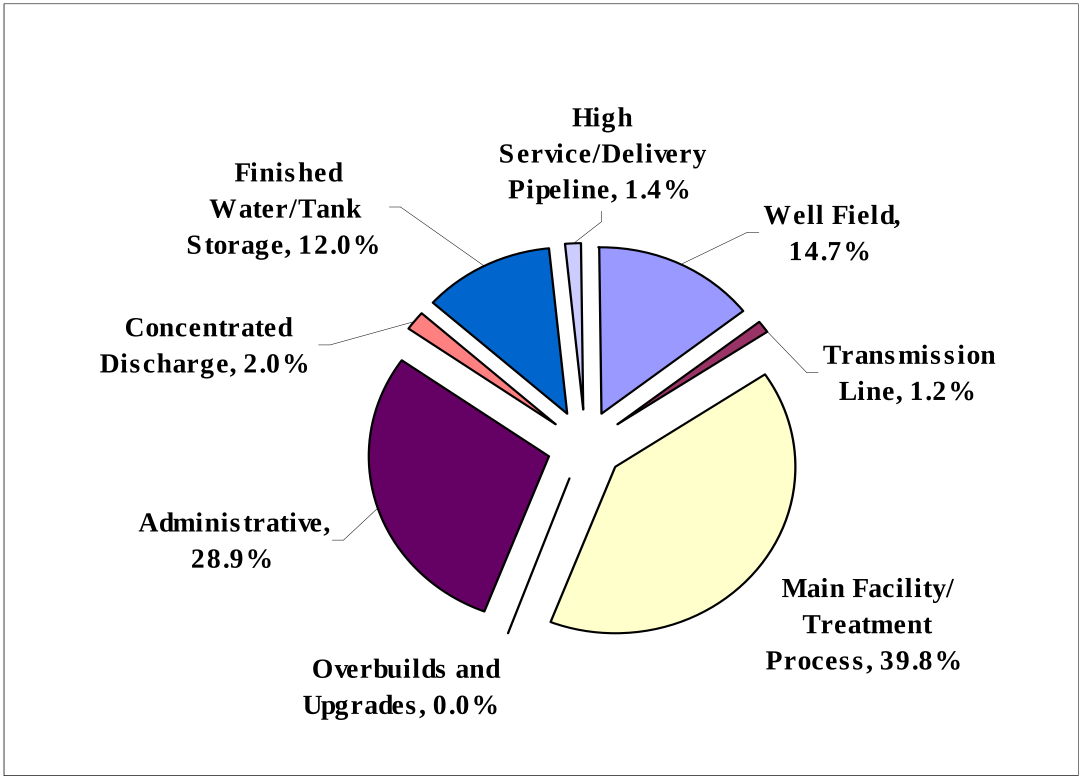


Figure 6. Proportion of total baseline cost, by cost segment, for the 1.13 mgd La Sara brackish-groundwater desalination facility

Baseline Summary of the Olmito and the La Sara Facilities

Using the actual level of production efficiency, as well as including any overbuilds and upgrades, a review of life-cycle costs for the Olmito and the La Sara facilities provide insight on the current situation. For example, the 2006 real value of all costs associated with the Olmito facility is $23,020,626 compared to $9,127,005 for the La Sara facility. After accounting for the potable water produced, the life-cycle costs for the Olmito facility are $1,393.28/ac-ft {$4.28/1,000 gals} compared to $745.25/ac-ft {$2.29/1,000 gals} for the La Sara facility. However, as stated previously, these values are not appropriate for comparison because no modifications have been made to key input data to remove facility-specific discrepancies between the facilities and technologies.

MODIFIED RESULTS

A detailed evaluation of the modified or leveled life-cycle costs result is provided in this section for all four water treatment facilities evaluated in this thesis. The two conventional surface-water treatment facilities (i.e., Olmito and Northwest) are discussed first, with the review of the two reverse-osmosis (RO) brackish-groundwater desalination facilities (i.e., La Sara and Southmost) following. As previously discussed on pages 17-20, modifying key input data allows for "apple-to-apple" comparisons between facilities, as well as for definitive conclusions to be determined for economies of size.

The Olmito Facility

The Olmito facility is considered, within this thesis, as a "small"-sized conventional surface-water treatment facility. As previously stated in the "Case Study Results" section of this thesis, the Olmito facility has a maximum-designed production capacity of 2.0 mgd.

Aggregate Modified Results

The modified total cost estimated for the Olmito facility over its 40-year useful life amounts to $65,344,046 in nominal terms (Table 18). Adjusting for time and inflation using a 6.125% annual discount rate results in a real value of $26,152,158 compared to $23,020,626 for the baseline scenario.[44] Annualizing this real value into perpetuity indicates an estimated annuity equivalent of $1,755,211 (Table 18). This value represents the modified total annual cost of constructing and operating the Olmito facility (basis 2006 dollars) over the course of its 40-year useful life extended into perpetuity.

The modified total volume of water estimated to be produced over the Olmito facility's useful life is 76,170 ac-ft in nominal terms (Table 18). Adjusting for a 4.0% annual social-time preference (Griffin and Chowdhury 1993) results in a real volume of 36,241 ac-ft compared to 22,171 ac-ft for the baseline scenario. Annualizing this real volume into perpetuity results in an estimated annuity equivalent of 1,813 ac-ft (Table 18).

Dividing the annuity equivalent of costs ($1,755,211/yr) by the annuity equivalent of water (1,813/yr) produces a life-cycle cost of $968.31/ac-ft {$2.97/1,000 gals} for the modified analysis (Table 18) compared to $1,393.28/ac-ft {$4.28/1,000 gals} for the baseline analysis. Consistent with the methodology in Rister

---

[44] The apparent increase in the NPV of costs is because of the additional chemicals and energy required to increase production efficiency to 85% of the facility's maximum-designed capacity. The NPV of water also appears to increase because of the production efficiency being increased to 85%.

et al. (2008), this value represents the annual cost of treating one ac-ft {1,000 gals} of potable water into perpetuity.

Table 18. Aggregate Modified Results for Cost of Treating Water at the 2.0 mgd Olmito Conventional Surface-Water Treatment Facility, in 2006 Dollars[a]

Results	Units	Nominal Value	Real Value [b]
NPV of All Costs	2006 dollars	$65,344,046	$26,152,158
-Annuity Equivalent	$/yr	n/a	$1,755,211
NPV of Water Produced	ac-ft (lifetime)	76,170	36,241
-Annuity Equivalent	ac-ft/yr	n/a	1,813
NPV of Water Produced	1,000 gals (lifetime)	24,820,000	11,809,054
-Annuity Equivalent	1,000 gals/yr	n/a	590,658
Cost of Treating Water	$/ac-ft	n/a	$968.31
Cost of Treating Water	$/1,000 gals	n/a	$2.97

[a] These results are the adjusted (or modified) analyses of the Olmito facility (i.e., operating at 85% production efficiency, ignoring costs for “Overbuilds and Upgrades,” and assuming a zero net salvage value for all capital items and water rights, and basis 2006 dollars).

[b] Values are reported on a real (vs. nominal) basis, determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.0% discount factor for water, and a 0.0% risk factor (Rister et al. 2008).

Modified Results by Cost Type, Item, and Segment

The modified total cost of treating water for the Olmito facility, reported in Table 18, can be divided into three cost types: (1) initial construction/water rights purchase costs ($9,504,096), which are equivalent to the baseline value, (2) continued costs ($16,089,239), which increased from the baseline scenario ($12,957,707), and (3) capital replacement costs ($558,823), which are also equal to the baseline analysis (Table 19). The initial construction/water rights purchase accounts for 36.4% of the total modified costs. Of the 36.4%, the purchase of the water rights contribute 18.9%. Continued costs contribute 61.5%, and capital replacement costs contribute the remaining 2.1% of the total modified costs (Figure 7). In per-unit measurements, the initial construction/water rights purchase costs are $351.90/ac-ft {$1.08/1,000 gals}, continued costs are $595.72/ac-ft {$1.83/1,000 gals}, and capital replacement costs are $20.69/ac-ft {$0.06/1,000 gals} (Table 19), which sum to $928.31/ac-ft {$2.97/1,000 gals}.

The modified total continued costs are allocated across six continuing cost items: administrative ($406,228),[45] energy ($2,996,874), chemical ($3,220,612), labor ($3,423,115), water delivery ($1,848,582), and all other costs ($4,193,828).[46] In per-unit measurements, administrative costs are $15.04/ac-ft {$0.05/1,000 gals}, energy costs are $110.96/ac-ft {$0.34/1,000 gals}, chemicals are $119.25/ac-ft {$0.37/1,000 gals}, labor is $126.74/ac-ft {$0.39/1,000 gals}, water delivery costs are $68.45/ac-ft {$0.21/1,000 gals}, and all other costs are $155.28/ac-ft {$0.47/1,000 gals} (Table 19). Refer to Table 19 and Figure 7 for the complete analysis of the Olmito facility's modified cost of treating water across the different cost types and items. Primarily, the modified or leveled scenario involves a higher production efficiency; therefore, the

---

[45] "Administrative" costs are annual expenses that are facility-related, but are not included on the water treatment facility's (e.g., Northwest, Southmost, La Sara, and Olmito) budget; rather, they are included on the owner-entity's (e.g., PUB and WSC) budget.

[46] "All Other" costs includes the remaining continued cost items (e.g., insurance, repairs, machinery rental, etc.) in the facility's income statement. Differing accounting methods between facilities results in a wide range of values for this comprehensive item.

investment in construction and purchasing of water rights are spread over a greater quantity of output (i.e., potable water). As a result, the per-unit costs are lower in comparison to the baseline cost estimates.

Table 19. Modified Life-Cycle Costs of Treating Water, by Cost Type and Item, for the 2.0 mgd Olmito Conventional Surface-Water Treatment Facility, in 2006 Dollars[a,b]

	Olmito (Conventional)				
Cost Type and Item	NPV of Cost Stream	Annuity Equivalent in $/yr	Annuity Equivalent in $/ac-ft	Annuity Equivalent in $/1,000 gals	% of Total Cost
Initial Construction/Investment	**$9,504,096**	**$637,871**	**$351.90**	**$1.08**	**36.4%**
- *Water Right Purchase*	*4,946,555*	*331,990*	*183.15*	*0.56*	*18.9%*
Continued	**16,089,239**	**1,079,834**	**595.72**	**1.83**	**61.5%**
- *Administrative*[c]	*406,228*	*27,263*	*15.04*	*0.05*	*1.6%*
- *Energy*	*2,996,874*	*201,136*	*110.96*	*0.34*	*11.5%*
- *Chemical*	*3,220,612*	*216,153*	*119.25*	*0.37*	*12.3%*
- *Labor*	*3,423,115*	*229,744*	*126.74*	*0.39*	*13.1%*
- *Water Delivery*	*1,848,582*	*124,068*	*68.45*	*0.21*	*7.1%*
- *All Other*[d]	*4,193,828*	*281,470*	*155.28*	*0.47*	*15.9%*
Capital Replacement	**558,823**	**37,506**	**20.69**	**0.06**	**2.1%**
Total	$26,152,158	$1,755,211	$968.31	$2.97	100.0%

[a] These results are the adjusted (or modified) analyses of the Olmito facility (i.e., operating at 85% production efficiency, ignoring costs for “Overbuilds and Upgrades,” and assuming a zero net salvage value for all capital items and water rights, and basis 2006 dollars).

[b] Values are reported on a real (vs. nominal) basis, determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.0% discount factor for water, and a 0.0% risk factor (Rister et al. 2008).

[c] “Administrative” costs are annual expenses that are facility-related, but are not included on the water treatment facility’s (e.g., Northwest, Southmost, La Sara, and Olmito) budget; rather, they are included on the owner-entity’s (e.g., PUB and WSC) budget.

[d] “All Other” costs includes the remaining continued cost items (e.g., insurance, repair, machinery rental, etc.) in the facility’s income statement. Differing accounting methods between facilities results in a wide range of values for the comprehensive item.

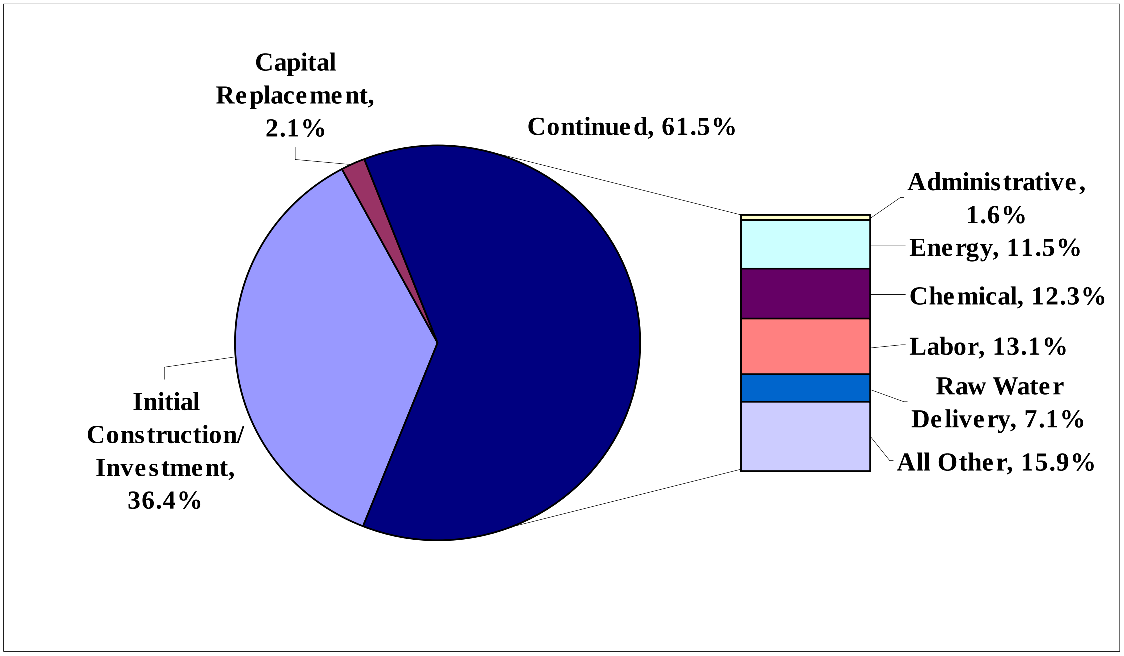


Figure 7. Proportion of modified total cost, by cost type and item, for the 2.0 mgd Olmito conventional surface-water treatment facility

Presented in Table 20 and Figure 8 are the total modified costs for the Olmito facility, divided into six cost segments. The three most cost-intensive segments are the raw water intake/reservoir ($9,470,768), the treatment unit ($7,991,035), and the delivery to municipal line/storage ($5,146,254). In per-unit measurements, the water rights/raw water intake/reservoir costs are $350.66/ac-ft {$1.07/1,000 gals}, the treatment unit costs are $295.87/ac-ft {$0.91/1,000 gals}, and the delivery to municipal line/storage costs are $190.54/ac-ft {$0.58/1,000 gals}. For brevity purposes, not all of the segments are discussed, but refer to Table 20 and Figure 8 for the complete analysis of the Olmito facility's modified cost of treating water across the segments. Similar to the cost types and items, the per-unit costs for each of these segments decreased compared to the baseline analysis because of the increase in the annual output of water from 1,109 ac-ft/yr at 52% production efficiency to 1,813 ac-ft/yr at 85% production efficiency.

Table 20. Modified Life-Cycle Costs of Treating Water, by Cost Segment, for the 2.0 mgd Olmito Conventional Surface-Water Treatment Facility, in 2006 Dollars[a, b]

Cost Segment	NPV of Cost Stream	Annuity Equivalent in $/yr	Annuity Equivalent in $/ac-ft	Annuity Equivalent in $/1,000 gals	% of Total Costs
1) Raw Water Intake/Reservoir/ Water Rights Purchase	$9,470,768	$635,634	$350.66	$1.07	36.2%
2) Treatment Unit	7,991,035	536,321	295.87	0.91	30.5%
3) Sludge Disposal	1,188,480	79,765	44.01	0.14	4.5%
4) Delivery to Municipal Line/Storage	5,146,254	345,393	190.54	0.58	19.7%
5) Operations' Supporting Facilities	1,949,394	130,834	72.18	0.22	7.5%
6) Administrative[c]	406,227	27,264	15.05	0.05	1.6%
Total	$26,152,158	$1,755,211	$968.31	$2.97	100.0%

[a] These results are the adjusted (or modified) analyses of the Olmito facility (i.e., operating at 85% production efficiency, ignoring costs for "Overbuilds and Upgrades," assuming a zero net salvage value for all capital items and water rights, and basis 2006 dollars).

[b] Values are reported on a real (vs. nominal) basis, determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.0% discount factor for water, and a 0.0% risk factor (Rister et al. 2008).

[c] Due to the difficulty in estimating this value as well as allocating it across the segments, all of the "Administrative" costs are combined into a single segment. This modification is specific to this thesis.

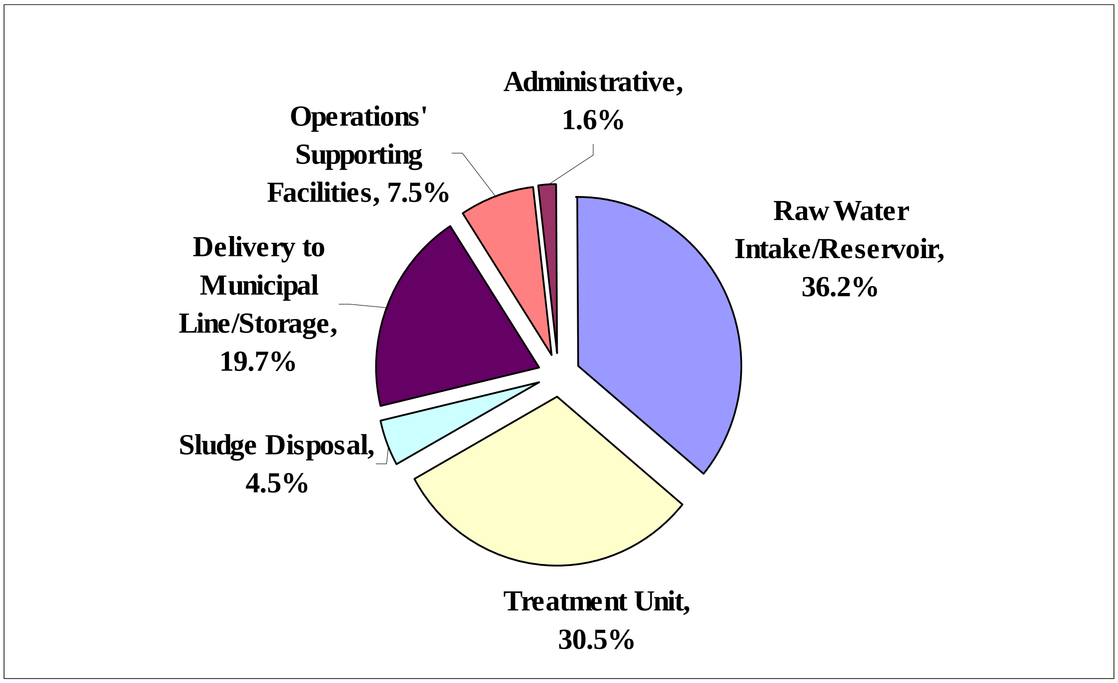


Figure 8. Proportion of modified total cost, by cost segment, for the 2.0 mgd Olmito conventional surface-water treatment facility

The Northwest Facility

The McAllen Northwest facility is considered, within this thesis, as a "medium"-sized conventional surface-water treatment facility. As previously stated in Rogers (2008), the Northwest facility has a maximum-designed production capacity of 8.25 mgd.[47]

---

[47] The modified results presented in Rogers (2008) do not include all the modifications made in this thesis. Rogers (2008) did not consolidate the "Administrative" costs into a separate cost segment. This modification is specific to this thesis, but does not change the bottom-line modified cost reported in Rogers (2008).

Aggregate Modified Results

The modified total cost estimated for the Northwest facility over its 50-year useful life amounts to $208,408,155 in nominal terms (Table 21) (Rogers 2008). Adjusting this value for time and inflation using a 6.125% annual discount rate results in a real value of $74,653,110 compared to $79,167,565 for the baseline value.[48] Annualizing this real value into perpetuity indicates an estimated annuity equivalent of $4,790,190 (Table 21). This value represents the modified annual cost of constructing and operating the Northwest facility (basis 2006 dollars) over the course of its 50-year useful life extended into perpetuity.

The modified total volume of water estimated to be produced over the Northwest facility's useful life totals 392,750 ac-ft in nominal terms (Table 21) (Rogers 2008). Adjusting for a 4.0% annual social-time preference (Griffin and Chowdhury 1993) results in a real volume of 156,012 ac-ft compared to 143,164 ac-ft for the baseline scenario. Annualizing this real volume into perpetuity determines an estimated annuity equivalent of 7,174 ac-ft.

Dividing the annuity equivalent of costs ($4,790,190/yr) by the annuity equivalent of water ($7,174/yr) produces a life-cycle cost of $667.74/ac-ft {$2.05/1,000 gals} for the modified analysis (Table 21) compared to $771.67/ac-ft {$2.37/1,000 gals} for the baseline analysis (Rogers 2008). Consistent with the

---

[48] Although, the Northwest facility will require more chemicals, energy, and raw water with its production efficiency increased to 85%, the NPV of total costs decreases in the modified calculations because "Overbuilds and Upgrades" costs ($6,533,789) were removed to modify the facility (Rogers et al. 2008).

methodology in Rister et al. (2008), this value represents the annual cost of treating one ac-ft {1,000 gals} of potable water into perpetuity.

Table 21. Aggregate Modified Results for Cost of Treating Water at the 8.25 mgd Northwest Conventional Surface-Water Treatment Facility, in 2006 Dollars[a]

Results	Units	Nominal Value	Real Value [b]
NPV of All Costs	2006 dollars	$208,408,155	$74,653,110
-Annuity Equivalent	$/yr	n/a	$4,790,190
NPV of Water Produced	ac-ft (lifetime)	392,750	156,012
-Annuity Equivalent	ac-ft/yr	n/a	7,174
NPV of Water Produced	1,000 gals (lifetime)	127,978,125	50,836,718
-Annuity Equivalent	1,000 gals/yr	n/a	2,337,580
Cost of Treating Water	$/ac-ft	n/a	$667.74
Cost of Treating Water	$/1,000 gals	n/a	$2.05

[a] These results are the adjusted (or modified) analyses of the Northwest facility (i.e., operating at 85% production efficiency, ignoring costs for "Overbuilds and Upgrades," assuming a zero net salvage value for all capital items and water rights, and basis 2006 dollars).

[b] Values are reported on a real (vs. nominal) basis, determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.0% discount factor for water, and a 0.0% risk factor (Rister et al. 2008).

Source: Rogers (2008) and own modifications.

Modified Results by Cost Type, Item, and Segment

The modified total cost of treating water for the Northwest facility, reported in Table 21, can be divided into three cost types: (1) initial construction/water rights purchase ($37,397,088), (2) continued costs ($36,550,837), and (3) capital replacement costs ($705,185) (Rogers 2008). The initial construction/water rights purchase accounts for

50.1% of the modified total costs. Of the 50.1%, the water rights purchase contribute 27.3%. The continued costs contribute 49.0% and capital replacement costs contribute the remaining 0.9% of the total modified costs (Figure 9). In per-unit measurements, the initial construction/water rights purchase costs are $334.50/ac-ft {$1.03/1,000 gals}, continued costs are $326.93/ac-ft {$1.00/1,000 gals}, and capital replacement costs are the remaining $6.31/ac-ft {$0.02/1,000 gals} (Table 22), which sum to $667.74/ac-ft {$2.05/1,000 gals}.

The total modified continued costs are allocated across six continued cost items: administrative ($1,634,518),[49] energy ($7,888,890), chemical ($6,309,248), labor ($7,124,847), water delivery ($10,322,366), and all other costs ($3,270,998)[50] (Rogers 2008). In per-unit measurements, administrative costs are $14.62/ac-ft {$0.05/1,000 gals}, energy costs are $70.56/ac-ft {$0.22/1,000 gals}, chemicals are $56.43/ac-ft {$0.17/1,000 gals}, labor is $63.73/ac-ft {$0.20/1,000 gals}, water delivery costs are $92.33/ac-ft {$0.28/1,000 gals}, and all other costs are $29.26/ac-ft {$0.08/1,000 gals}. Refer to Table 22 and Figure 9 and Rogers (2008) for the complete analysis of the Northwest facility's modified cost of treating water across the different cost types and items. The per-unit cost types and items decreased from the baseline analysis because of the overbuilds and upgrade expenses were removed, as well as the

---

[49] "Administrative" costs are annual expenses that are facility-related, but are not included on the water treatment facility's (e.g., Northwest, Southmost, La Sara, and Olmito) budget; rather, they are included on the owner-entity's (e.g., PUB and WSC) budget.

[50] "All Other" costs includes the remaining continued cost items (e.g., insurance, repairs, machinery rental, etc.) in the facility's income statement. Differing accounting methods between facilities result in a wide range of values for this comprehensive item.

increased production efficiency spreads the construction costs and cost of water rights purchased across a greater quantity of water.

Table 22. Modified Life-Cycle Costs of Treating Water, by Cost Type and Item, for the 8.25 mgd Northwest Conventional Surface-Water Treatment Facility, in 2006 Dollars[a, b]

	Northwest (Conventional)				
Cost Type and Item	NPV of Cost Stream	Annuity Equivalent in \$/yr	Annuity Equivalent in \$/ac-ft	Annuity Equivalent in \$/1,000 gals	% of Total Cost
Initial Construction/Investment	**\$37,397,088**	**\$2,399,621**	**\$334.50**	**\$1.03**	**50.1%**
- Water Right Purchase	*20,404,541*	*1,309,277*	*182.51*	*0.56*	*27.3%*
Continued	**36,550,837**	**2,345,320**	**326.93**	**1.00**	**49.0%**
-Administrative[c, d]	*1,634,518*	*104,880*	*14.62*	*0.05*	*2.2%*
- Energy	*7,888,890*	*506,198*	*70.56*	*0.22*	*10.6%*
- Chemical	*6,309,248*	*404,839*	*56.43*	*0.17*	*8.5%*
- Labor	*7,124,847*	*457,173*	*63.73*	*0.20*	*9.5%*
- Water Delivery	*10,322,336*	*662,343*	*92.33*	*0.28*	*13.8%*
- All Other[e]	*3,270,998*	*209,887*	*29.26*	*0.08*	*4.4%*
Capital Replacement	**705,185**	**45,249**	**6.31**	**0.02**	**0.9%**
Total	\$74,653,110	\$4,790,190	\$667.74	\$2.05	100.0%

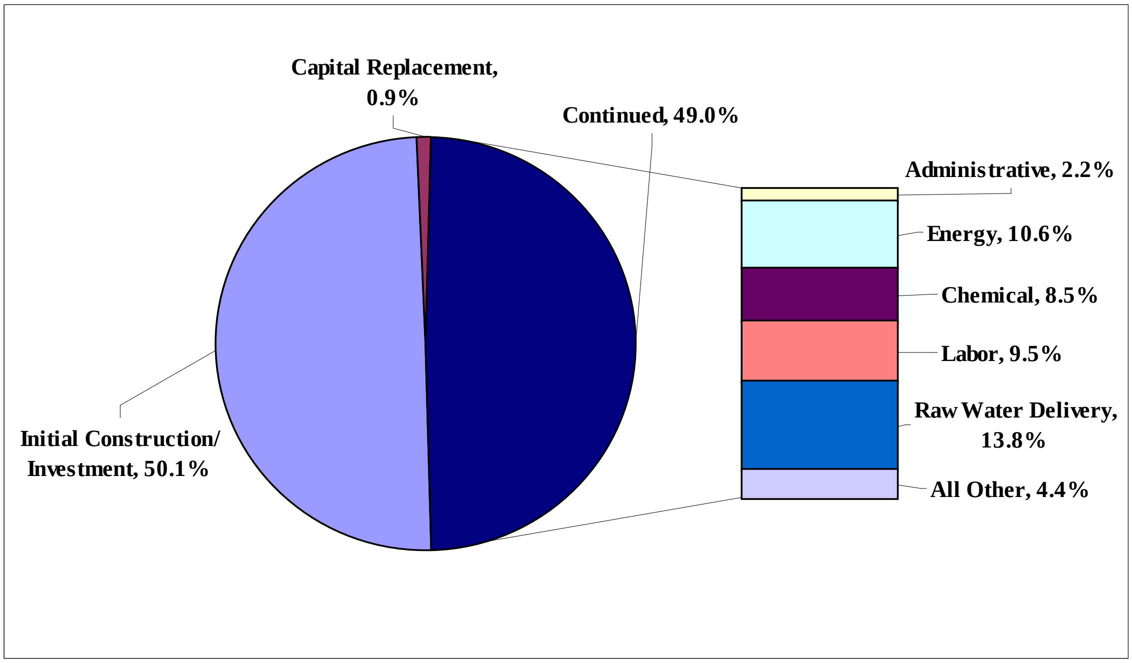
[a] These results are the adjusted (or modified) analyses of the Northwest facility (i.e., operating at 85% production efficiency, ignoring costs for "Overbuilds and Upgrades," assuming a zero net salvage value for all capital items and water rights, and basis 2006 dollars).

[b] Values are reported on a real (vs. nominal) basis, determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.0% discount factor for water, and a 0.0% risk factor (Rister et al. 2008).

[c] "Administrative" costs are annual expenses that are facility-related, but are not included on the water treatment facility's (e.g., Northwest, Southmost, La Sara, and Olmito) budget; rather, they are included on the owner-entity's (e.g., PUB and WSC) budget.

[e] "All Other" costs includes the remaining continued cost items (e.g., insurance, repairs, machinery rental, etc.) in the facility's income statement. Differing accounting methods facilities results in a wide range of values for this comprehensive item.

Source: Rogers (2008) and own modifications.



Source: Rogers (2008) and own modifications.

Figure 9. Proportion of modified total cost, by cost type and item, for the 8.25 mgd Northwest conventional surface-water treatment facility

Demonstrated in Table 23 and Figure 10 are the total modified costs for the Northwest facility, divided into ten cost segments. The three most cost-intensive segments are the raw water intake/reservoir ($38,231,943), the pre-disinfection ($8,326,125), and the delivery to municipal line/storage ($8,921,500) (Table 23) (Rogers 2008). In per-unit measurements, the raw water intake/reservoir costs are $341.97/ac-ft {$1.05/1,000 gals}, the pre-disinfection costs are $74.47/ac-ft {$0.23/1,000 gals}, and the delivery to municipal line/storage costs are $79.80/ac-ft {$0.25/1,000 gals}. For brevity purposes, not all of the segments are discussed, but refer to Table 23 and Figure 10 and to Rogers (2008) for the complete analysis of the Northwest facility's modified cost of treating water across the segments. The per-unit costs for each of these segments decreased compared to the baseline analysis because of the increase in the annual output of water from 6,583 ac-ft/yr at 78% production efficiency to 7,174 ac-ft/yr at 85% production efficiency, as well as due to the removal of overbuilds and upgrades.

Table 23. Modified Life-Cycle Costs of Treating Water, by Cost Segment, for the 8.25 mgd Northwest Conventional Surface-Water Treatment Facility, in 2006 Dollars[a,b]

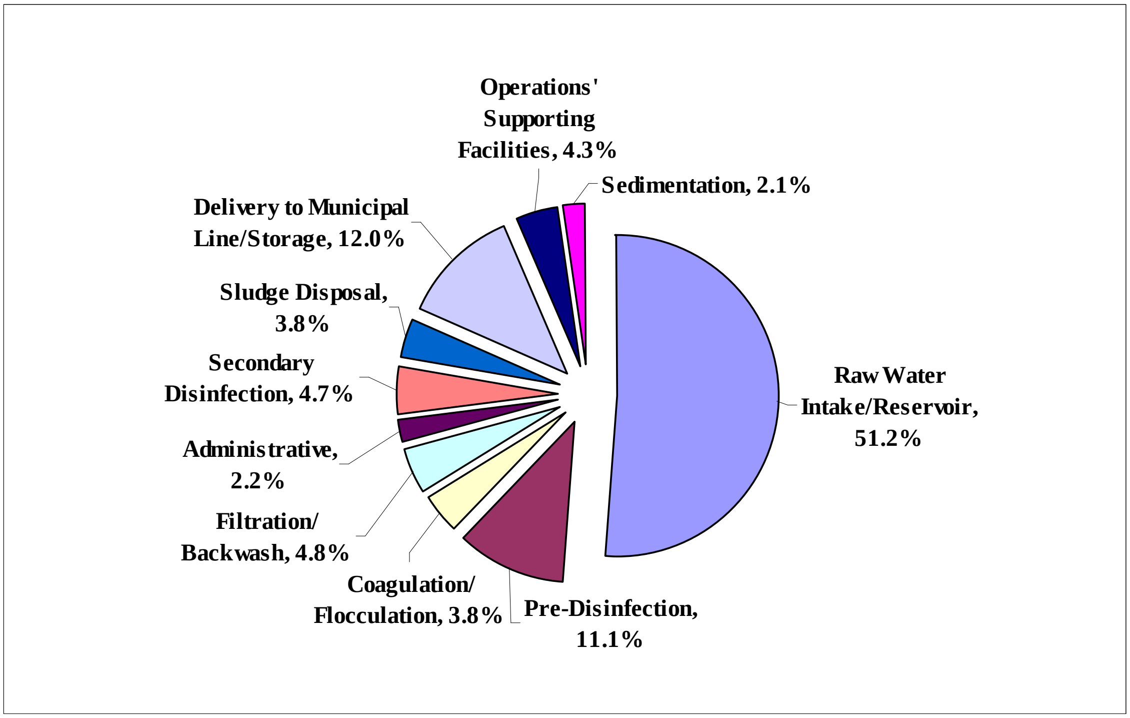
Cost Segment	NPV of Cost Stream	Annuity Equivalent in $/yr	Annuity Equivalent in $/ac-ft	Annuity Equivalent in $/1,000 gals	% of Total Costs
1) Raw Water Intake/Reservoir/ Water Rights Purchase	$38,231,943	$2,453,190	$341.97	$1.05	51.2%
2) Pre-Disinfection	8,326,125	534,254	74.47	0.23	11.1%
3) Coagulation/Flocculation	2,834,006	181,847	25.35	0.08	3.8%
4) Sedimentation	1,575,323	101,082	14.09	0.04	2.1%
5) Filtration/Backwash	3,575,081	229,399	31.98	0.10	4.8%
6) Secondary Disinfection	3,485,520	223,652	31.18	0.10	4.7%
7) Sludge Disposal	2,834,082	181,852	25.35	0.08	3.8%
8) Delivery to Municipal Line/Storage	8,921,500	572,457	79.80	0.25	12.0%
9) Operations' Supporting Facilities	3,235,012	207,577	28.93	0.08	4.3%
10) Administrative[c]	1,634,518	104,880	14.62	0.04	2.2%
Total	$74,653,110	$4,790,190	$667.74	$2.05	100.0%

[a] These results are the adjusted (or modified) analyses of the Northwest facility (i.e., operating at 85% production efficiency, ignoring costs for "Overbuilds and Upgrades," assuming a zero net salvage value for all capital items and water rights, and basis 2006 dollars).

[b] Values are reported on a real (vs. nominal) basis, determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.0% discount factor for water, and a 0.0% risk factor (Rister et al. 2008).

[c] Due to the difficulty in estimating this value as well as allocating it across the segments, all of the "Administrative" costs are combined into a single segment. This modification is specific to this thesis.

Source: Rogers (2008) and own modifications.



Source: Rogers (2008) and own modifications.

Figure 10. Proportion of modified total cost, by cost segment, for the 8.25 mgd Northwest conventional surface-water treatment facility

The La Sara Facility

The La Sara facility is considered, within this thesis, as a "small"-sized brackish-groundwater desalination facility. As previously stated in the "Case Study Results" section of this thesis, the La Sara facility has a maximum-designed production capacity of 1.13 mgd.

Aggregate Modified Results

The modified total costs estimated for the La Sara facility over its 50-year useful life amounts to $35,121,706 in nominal terms (Table 24). Adjusting this value for time and inflation using a 6.125% annual discount rate results in a real value of $10,049,721 compared to $9,127,005 for the baseline value.[51] Annualizing this real value into perpetuity determines an estimated annuity equivalent of $646,736 (Table 24). This value represents the modified annual cost of building and operating the La Sara facility (basis 2006 dollars) over the course of its expected useful life.

The modified total volume of water estimated to be produced over the La Sara facility's useful life amounts to 53,795 ac-ft in nominal terms (Table 24). Adjusting for a 4.0% annual social-time preference (Griffin and Chowdhury 1993) results in a real volume of 22,224 ac-ft compared to 17,038 ac-ft for the baseline scenario. Annualizing this real volume into perpetuity indicates an estimated annuity equivalent of 1,028 ac-ft.

Dividing the annuity equivalent of costs ($646,736/yr) by the annuity equivalent of water ($1,028/yr) produces a life-cycle cost of $629.09/ac-ft {$1.93/1,000 gals} for the modified analysis (Table 24) compared to $745.25/ac-ft {$2.29/1,000 gals} for the baseline analysis. Consistent with the methodology in Rister et al. (2008), this value represents the annual cost of producing one ac-ft {1,000 gals} of potable water into perpetuity.

---

[51] The apparent increase in the NPV of costs is because of the additional chemicals and energy La Sara will require to operate at 85% of its designed-maximum capacity compared to 65% in the baseline analysis. The increase in production efficiency from 65% to 85% also increases the NPV of water.

Table 24. Aggregate Modified Results for Cost of Producing Water at the 1.13 mgd La Sara Brackish-Groundwater Treatment Facility, in 2006 Dollars[a]

Results	Units	Nominal Value	Real Value [b]
NPV of All Costs	2006 dollars	$35,121,706	$10,049,721
-Annuity Equivalent	$/yr	n/a	$646,736
NPV of Water Produced	ac-ft (lifetime)	53,795	22,224
-Annuity Equivalent	ac-ft/yr	n/a	1,028
NPV of Water Produced	1,000 gals (lifetime)	17,529,125	7,241,613
-Annuity Equivalent	1,000 gals/yr	n/a	334,989
Cost of Producing Water	$/ac-ft	n/a	$629.09
Cost of Producing Water	$/1,000 gals	n/a	$1.93

[a] These results are the adjusted (or modified) analyses of the La Sara facility (i.e., operating at 85% production efficiency, ignoring costs for “Overbuilds and Upgrades,” assuming a zero net salvage value for all capital items, and basis 2006 dollars).

[b] Values are reported on a real (vs. nominal) basis, determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.0% discount factor for water, and a 0.0% risk factor (Rister et al. 2008).

Modified Results by Cost Type, Item, and Segment

The modified total cost of production for the La Sara facility, reported in Table 24, can be divided into three cost types: (1) initial construction costs ($2,536,527), which are equivalent to the baseline value, (2) continued costs ($7,144,982), which increased from the baseline scenario ($6,222,266), and (3) capital replacement costs ($368,212), which are also equal to the baseline analysis (Table 25). The initial construction costs contribute 25.2% of the total modified costs, continued costs contribute 71.1%, and capital replacement costs contribute the remaining 3.7% (Figure 11). In per-unit measurements, initial construction costs are $158.78/ac-ft {$0.49/1,000 gals}, continued costs are $447.26/ac-ft {$1.37/1,000 gals}, and capital replacement costs are $23.05/ac-ft {$0.07/1,000 gals} (Table 25), which sum to $629.09/ac-ft {$1.93/1,000 gals}.

Table 25. Modified Life-Cycle Costs of Producing Water, by Cost Type and Item, for the 1.13 mgd La Sara Brackish-Groundwater Desalination Facility, in 2006 Dollars[a, b]

	La Sara (Desalination)				
Cost Type and Item	NPV of Cost Stream	Annuity Equivalent in $/yr	Annuity Equivalent in $/ac-ft	Annuity Equivalent in $/1,000 gals	% of Total Cost
Initial Construction/Investment	**$2,536,527**	**$163,235**	**$158.78**	**$0.49**	**25.2%**
Continued	**7,144,982**	**459,805**	**447.26**	**1.37**	**71.1%**
- Administrative[c]	*2,642,160*	*170,033*	*165.39*	*0.51*	*26.3%*
- Energy	*3,229,856*	*207,853*	*202.18*	*0.62*	*32.1%*
- Chemicals	*724,162*	*46,602*	*45.33*	*0.14*	*7.2%*
- Labor	*386,679*	*24,884*	*24.21*	*0.07*	*3.8%*
- All Other[d]	*162,126*	*10,433*	*10.15*	*0.03*	*1.7%*
Capital Replacement	**368,212**	**23,696**	**23.05**	**0.07**	**3.7%**
Total	$10,049,721	$646,736	$629.09	$1.93	100.0%

[a] These results are the adjusted (or modified) analyses of the La Sara facility (i.e., operating at 85% production efficiency, ignoring costs for “Overbuilds and Upgrades,” assuming a zero net salvage value for all capital items, and basis 2006 dollars).

[b] Values are reported on a real (vs. nominal) basis, determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.0% discount factor for water, and a 0.0% risk factor (Rister et al. 2008).

[c] “Administrative” costs are annual expenses that are facility-related, but are not included on the water treatment facility’s (e.g., Northwest, Southmost, La Sara, and Olmito) budget; rather, they are included on the owner-entity’s (e.g., PUB and WSC) budget.

[d] “All Other” costs includes the remaining continued cost items (e.g., insurance, repairs, machinery rental, etc.) in the facility’s income statement. Differing accounting methods between facilities results in a wide range of values for this comprehensive item.

The modified total continued costs are allocated across five continued cost items: administrative ($2,642,160),[52] energy ($3,229,856), chemical ($724,162), labor ($386,679), and all other costs ($162,126).[53] In per-unit measurements, administrative costs are $165.39/ac-ft {$0.51/1,000 gals}, energy costs are $202.18/ac-ft {$0.62/1,000 gals}, chemicals are $45.33/ac-ft {$0.14/1,000 gals}, labor is $24.21/ac-ft {$0.07/1,000 gals}, and all other costs are $10.15/ac-ft {$0.03/1,000 gals} (Table 25). Refer to Table 25 and Figure 11 for the complete analysis of the La Sara facility's modified cost of producing water across the different cost types and items. Similar to the Olmito facility, the modifications increase production efficiency (PE) at the La Sara facility, which spreads the initial investment in construction across a greater quantity of output, producing lower per-unit costs as compared to the baseline analysis.

Presented in Table 26 and Figure 12 are the modified total costs for the La Sara facility, divided into seven cost segments. The three most cost-intensive segments for the La Sara facility are the well field ($1,528,932), the main facility/treatment process ($4,172,724), and the administrative costs ($2,642,160). In per-unit measurements, the well field costs are $95.71/ac-ft {$0.29/1,000 gals}, the main facility/treatment process costs are $261.21/ac-ft {$0.80/1,000 gals}, and the administrative costs are $165.39/ac-ft {$0.51/1,000 gals}.

---

[52] "Administrative" costs are annual expenses that are facility-related, but are not included on the water treatment facility's (e.g., Northwest, Southmost, La Sara, and Olmito) budget; rather, they are included on the owner-entity's (e.g., PUB and WSC) budget.

[53] "All Other" costs includes the remaining continued cost items (e.g., insurance, repairs, machinery rental, etc.) in the facility's income statement. Differing accounting methods between facilities results in a wide range of values for this comprehensive item.

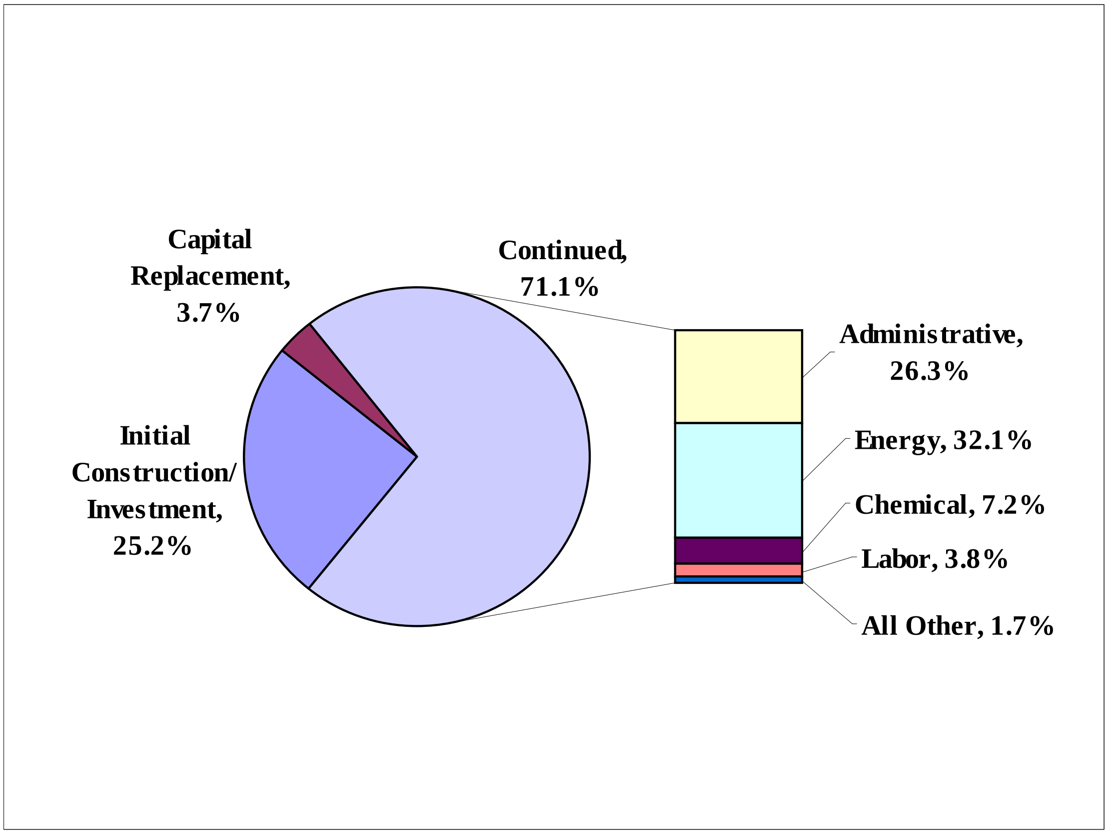


Figure 11. Proportion of modified total cost, by cost type and item, for the 1.13 mgd La Sara brackish-groundwater desalination facility

For brevity purposes, not all of the segments are discussed, but refer to Table 26 and Figure 12 for the complete analysis of the La Sara facility's modified cost of producing water across the segments. The per-unit costs for each of these segments decreased compared to the baseline analysis because of the increase in the annual output of water from 788 ac-ft/yr at 65% production efficiency to 1,028 ac-ft/yr at 85% production efficiency.

Table 26. Modified Life-Cycle Costs of Producing Water, by Cost Segment, for the 1.13 mgd La Sara Brackish-Groundwater Desalination Facility, in 2006 Dollars[a, b]

Cost Segment	NPV of Cost Stream	Annuity Equivalent in $/yr	Annuity Equivalent in $/ac-ft	Annuity Equivalent in $/1,000 gals	% of Total Costs
1) Well Field	$1,528,932	$98,391	$95.71	$0.29	15.2%
2) Transmission Line	112,055	7,211	7.01	0.02	1.2%
3) Main Facility/Treatment Process	4,172,724	268,530	261.21	0.80	41.5%
4) Concentrated Discharge	182,827	11,766	11.44	0.04	1.8%
5) Finished Water/Storage Tanks	1,280,746	82,421	80.17	0.25	12.7%
6) High Service and Delivery Pipeline	130,277	8,384	8.16	0.02	1.3%
7) Administrative[c]	2,642,160	170,033	165.39	0.51	26.3%
Total	$10,049,721	$646,736	$629.09	$1.93	100.0%

[a] These results are the adjusted (or modified) analyses of the La Sara facility (i.e., operating at 85% production efficiency, ignoring costs for Overbuilds and Upgrades, assuming a zero net salvage value for all capital items, and basis 2006 dollars).

[b] Values are reported on a real (vs. nominal) basis, determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.0% discount factor for water, and a 0.0% risk factor (Rister et al. 2008).

[c] Due to the difficulty in estimating this value as well as allocating it across the segments, all of the "Administrative" costs are combined into a single segment. This modification is specific to this thesis.

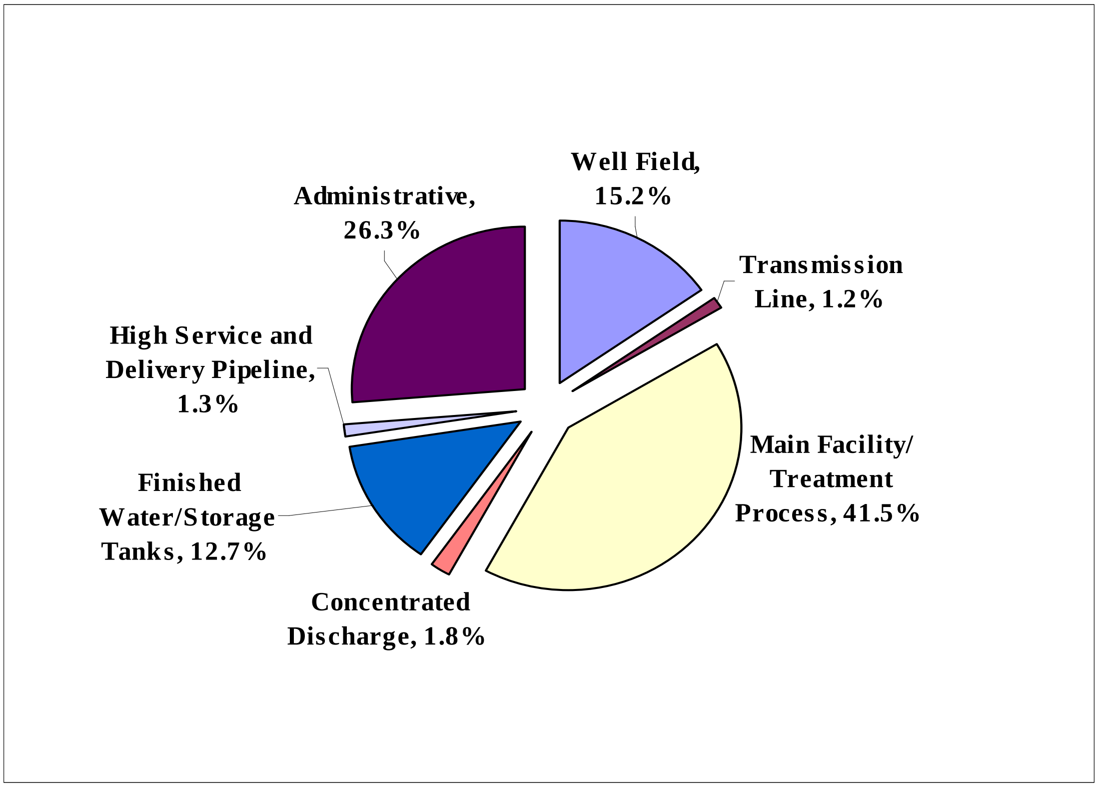


Figure 12. Proportion of modified total cost, by cost segment, for the 1.13 mgd La Sara brackish-groundwater desalination facility

The Southmost Facility

The Southmost facility is considered, within this thesis, as a "medium"-sized facility in the economies of size calculation for RO desalination of brackish-groundwater. As previously stated in Sturdivant et al. (2008), the Southmost facility has a maximum-designed production capacity of 7.5 mgd.[54]

---

[54] The modified results presented in Sturdivant et al. (2008) do not include all of the modifications made in this thesis. Sturdivant et al. (2008) did not consolidate the "Administrative" costs into a separate cost segment. This modification is specific to this thesis, but does not change the bottom-line modified cost reported in Sturdivant et al. (2008).

Aggregate Modified Results

The modified total costs estimated for the Southmost facility over its 50-year useful life amounts to $209,423,179 in nominal terms (Table 27) (Sturdivant et al. 2008). Adjusting this value for time and inflation using a 6.125% annual discount rate results in a real value of $65,208,300 compared to $65,281,088 for the baseline value.[55] Annualizing this real value into perpetuity determines an estimated annuity equivalent of $4,196,391 (Table 27). This value represents the total annual cost of constructing and operating the Southmost facility (basis 2006 dollars) over the course of its expected useful life extended into perpetuity.

The modified total volume of water estimated to be produced over the Southmost facility's useful life amounts to 357,046 ac-ft in nominal terms (Table 27) (Sturdivant et al. 2008). Adjusting for a 4.0% annual social-time preference (Griffin and Chowdhury 1993) results in a real volume of 147,502 ac-ft compared to 118,002 for the baseline scenario. Annualizing this real volume into perpetuity indicates an estimated annuity equivalent of 6,823 ac-ft.

Dividing the annuity equivalent of costs ($4,196,391/yr) by the annuity equivalent of water (6,823 ac-ft/yr) produces a life-cycle cost of $615.01/ac-ft {$1.89/1,000 gals} for the modified analysis (Table 27) compared to $769.62/ac-ft {$2.36/1,000 gals} for the baseline analysis (Sturdivant et al. 2008). Consistent with the

---

[55] Even though "Overbuilds and Upgrades" costs ($5,756,122) are removed for the modified analysis, it appears that the increase in the NPV of costs are a result of more energy and chemicals being required as production efficiency increases from 68% to 85%. The increase in production efficiency from 68% to 85% also increases the NPV of water.

methodology in Rister et al. (2008), this value represents the modified annual cost of producing one ac-ft {1,000 gals} of potable water into perpetuity.

Table 27. Aggregate Modified Results for Cost of Producing Water at the 7.5 mgd Southmost Brackish-Groundwater Treatment Facility, in 2006 Dollars[a]

Results	Units	Nominal Value	Real Value [b]
NPV of All Costs	2006 dollars	$209,423,179	$65,208,300
-Annuity Equivalent	$/yr	n/a	$4,196,391
NPV of Water Produced	ac-ft (lifetime)	357,046	147,502
-Annuity Equivalent	ac-ft/yr	n/a	6,823
NPV of Water Produced	1,000 gals (lifetime)	116,343,750	48,063,806
-Annuity Equivalent	1,000 gals/yr	n/a	2,223,376
Cost of Producing Water	$/ac-ft	n/a	$615.01
Cost of Producing Water	$/1,000 gals	n/a	$1.89

[a] These results are the adjusted (or modified) analyses of the Southmost facility (i.e., operating at 85% production efficiency, ignoring costs for "Overbuilds and Upgrades," assuming a zero net salvage value for all capital items, and basis 2006 dollars).

[b] Values are reported on a real (vs. nominal) basis, determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.0% discount factor for water, and a 0.0% risk factor (Rister et al. 2008).

Source: Sturdivant et al. (2008) and own modifications.

Modified Results by Cost Type, Line, and Segment

The modified total costs for the Southmost facility, reported in Table 27, can be divided into the three cost types: (1) initial construction costs ($22,022,150), (2) continued costs ($39,729,651), and (3) capital replacement costs ($3,456,499) (Sturdivant et al. 2008).

The initial construction costs contribute 33.8% of the total modified costs, continued costs contribute 60.9%, and capital replacement costs contribute the remaining 5.3% (Figure 13). In per-unit measurements, initial construction costs are $207.70/ac-ft {$0.64/1,000 gals}, continued costs are $374.71/ac- ft {$1.15/1,000 gals}, and capital replacement costs are $32.60/ac-ft {$0.10/1,000 gals} (Table 28), which sum to $615.01/ac-ft {$1.89/1,000 gals}.

The modified total continued costs are allocated across five continued cost items: administrative ($1,891,888),[56] energy ($21,078,014), chemical ($6,363,404), labor ($7,615,484), and all other costs ($2,780,861)[57] (Sturdivant et al. 2008). In per-unit measurements, administrative costs are $17.84/ac-ft {$0.06/1,000 gals}, energy costs are $198.80/ac-ft {$0.61/1,000 gals}, chemicals are $60.02/ac-ft {$0.18/1,000 gals}, labor is $71.83/ac-ft {$0.22/1,000 gals}, and all other costs are $26.22/ac-ft {$0.08/1,000 gals}. Refer to Table 28 and Figure 13 and Sturdivant et al. (2008) for the complete analysis of the Southmost facility's modified cost of producing water across the different cost types and items.

---

[56] "Administrative" costs are annual expenses that are facility-related, but are not included on the water treatment facility's (e.g., Northwest, Southmost, La Sara, and Olmito) budget; rather, they are included on the owner-entity's (e.g., PUB and WSC) budget.

[57] "All Other" costs includes the remaining continued cost items (e.g., insurance, repairs, machinery rental, etc.) in the facility's income statement. Differing accounting methods between facilities results in a wide range of values for this comprehensive item.

Table 28. Modified Life-Cycle Costs of Producing Water, by Cost Type and Item, for the 7.5 mgd Southmost Brackish-Groundwater Desalination Facility, in 2006 Dollars[a, b]

	Southmost (Desalination)				
Cost Type and Item	NPV of Cost Stream	Annuity Equivalent in $/yr	Annuity Equivalent in $/ac-ft	Annuity Equivalent in $/1,000 gals	% of Total Cost
Initial Construction/Investment	**$22,022,150**	**$1,417,205**	**$207.70**	**$0.64**	**33.8%**
Continued	**39,729,651**	**2,556,747**	**374.71**	**1.15**	**60.9%**
- Administrative[c]	*1,891,888*	*121,750*	*17.84*	*0.06*	*2.9%*
- Energy	*21,078,014*	*1,356,447*	*198.80*	*0.61*	*32.3%*
- Chemicals	*6,363,404*	*409,508*	*60.02*	*0.18*	*9.7%*
- Labor	*7,615,484*	*490,084*	*71.83*	*0.22*	*11.7%*
- All Other[e]	*2,780,861*	*178,958*	*26.22*	*0.08*	*4.3%*
Capital Replacement	**3,456,499**	**222,438**	**32.60**	**0.10**	**5.3%**
Total	$65,208,300	$4,196,391	$615.01	$1.89	100.0%

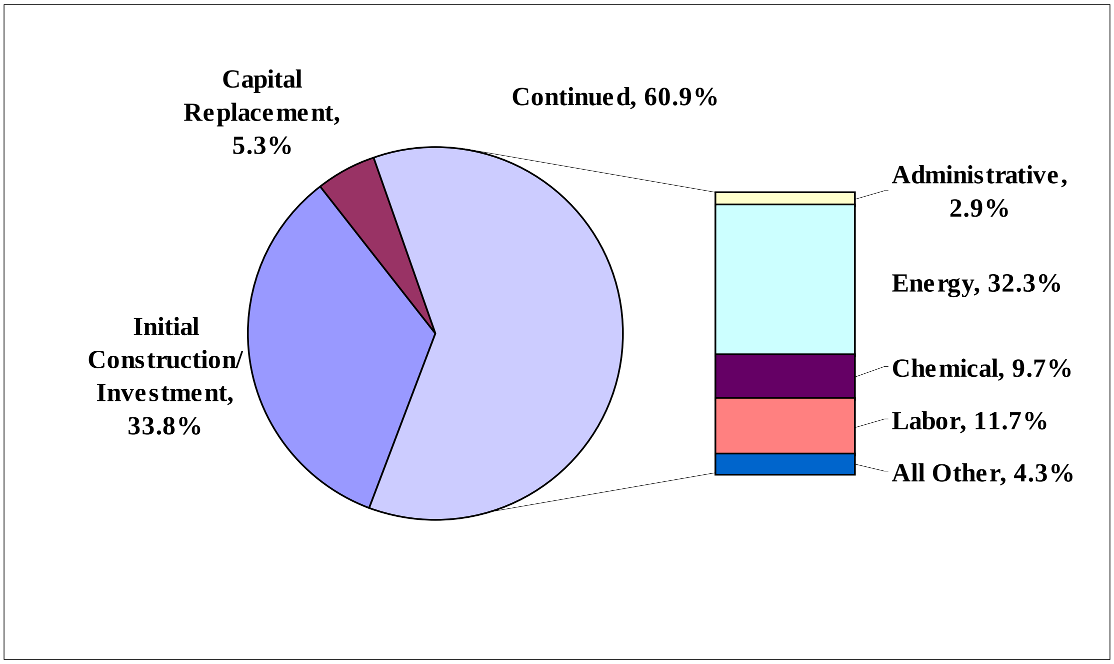
[a] These results are the adjusted (or modified) analyses of the Southmost facility (i.e., operating at 85% production efficiency, ignoring costs for "Overbuilds and Upgrades," assuming a zero net salvage value for all capital items, and basis 2006 dollars).

[b] Values are reported on a real (vs. nominal) basis, determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.0% discount factor for water, and a 0.0% risk factor (Rister et al. 2008).

[c] "Administrative" costs are annual expenses that are facility-related, but are not included on the water treatment facility's (e.g., Northwest, Southmost, La Sara, and Olmito) budget; rather, they are included on the owner-entity's (e.g., PUB and WSC) budget.

[e] "All Other" costs includes the remaining continued cost items (e.g., insurance, repairs, machinery rental, etc.) in the facility's income statement. Differing accounting methods between facilities results in a wide range of values for this comprehensive item.

Source: Sturdivant et al. (2008) and own modifications.



Source: Sturdivant et al. (2008) and own modifications.

Figure 13. Proportion of modified total cost, by cost type and item, for the 7.5 mgd Southmost brackish-groundwater desalination facility

Presented in Table 29 and Figure 14 are the modified total costs for the Southmost facility, divided into seven cost segments. The three most cost-intensive segments for the Southmost facility are the well field ($18,144,781), the main facility/treatment process ($34,059,653), and the high service and delivery pipeline ($6,270,530). In per-unit measurements, the well field costs are $171.13/ac-ft {$0.53/1,000 gals}, the main facility/treatment process costs are $321.23/ac-ft {$0.99/1,000 gals}, and high service and delivery pipeline costs are $59.14/ac-ft {$0.18/1,000 gals}. For brevity purposes, not all the segments are discussed, but refer to Table 29 and Figure 14 and Sturdivant et al. (2008) for the complete analysis of the Southmost facility's modified cost of producing water across the segments. The per-unit costs for each of these segments decreased compared to the baseline analysis because of the increase in the annual output of water from 5,459 ac-ft/yr at 68% production efficiency to 6,823 ac-ft/yr at 85% production efficiency, as well as the removal of overbuilds and upgrades.

Table 29. Modified Life-Cycle Costs of Producing Water, by Cost Segment, for the 7.5 mgd Southmost Brackish-Groundwater Desalination Facility, in 2006 Dollars[a, b]

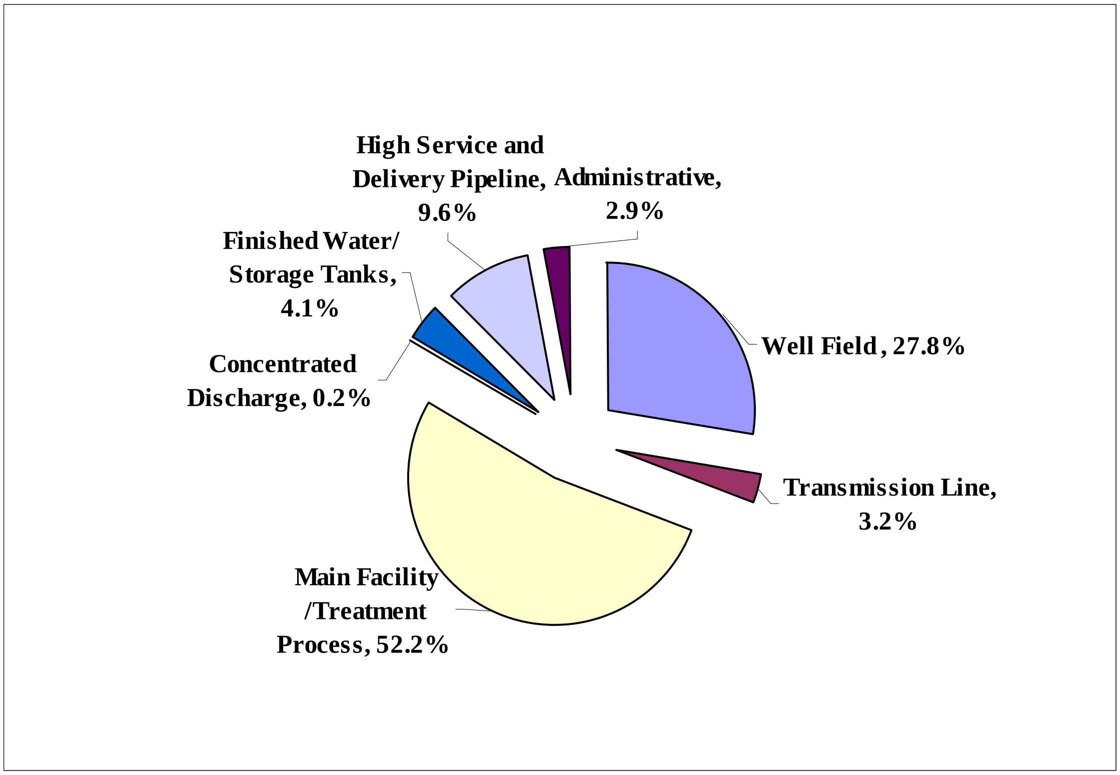
Cost Segment	NPV of Cost Stream	Annuity Equivalent in $/yr	Annuity Equivalent in $/ac-ft	Annuity Equivalent in $/1,000 gals	% of Total Costs
1) Well Field	$18,144,781	$1,167,683	$171.13	$0.53	27.8%
2) Transmission Line	2,063,930	132,822	19.47	0.06	3.2%
3) Main Facility/Treatment Process	34,059,653	2,191,862	321.23	0.99	52.2%
4) Concentrated Discharge	133,518	8,592	1.26	0.01	0.2%
5) Finished Water/Storage Tanks	2,644,000	170,151	24.94	0.07	4.1%
6) High Service and Delivery Pipeline	6,270,530	403,531	59.14	0.18	9.6%
7) Administrative[c]	1,891,888	121,750	17.84	0.05	2.9%
Total	$65,208,300	$4,196,391	$615.01	$1.89	100.0%

[a] These results are the adjusted (or modified) analyses of the Southmost facility (i.e., operating at 85% production efficiency, ignoring costs for "Overbuilds and Upgrades," assuming a zero net salvage value for all capital items, and basis 2006 dollars).

[b] Values are reported on a real (vs. nominal) basis, determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.0% discount factor for water, and a 0.0% risk factor (Rister et al. 2008).

[c] Due to the difficultly in estimating this value as well as allocating it across the segments, all of the "Administrative" costs are combined into a single segment. This modification is specific to this thesis.

Source: Sturdivant et al. (2008) and own modifications.



Source: Sturdivant et al. (2008) and own modifications.

Figure 14. Proportion of modified total cost, by cost segment, for the 7.5 mgd Southmost brackish-groundwater desalination facility

Evaluation of Baseline and Modified Life-Cycle Costs

A review of Table 30 indicates that all of the facilities have higher baseline life-cycle costs than modified costs. This is explained by the increase of potable water output for all of the facilities as their production efficiencies are increased to 85% from their baseline PE in the modified analyses. Although more energy, chemicals, and water delivery (if applicable) are required for greater output, the capital investment costs are spread across a greater amount of output, resulting in a decrease in the per-unit life-cycle costs. In addition, "Overbuild and Upgrades" expenses are removed from the Northwest facility and the Southmost facility,[58] decreasing their life-cycle costs as well.

Table 30. Baseline and Modified Life-Cycle Costs per Unit of Water, by Facility Type and Size, in 2006 Dollars

		Conventional Surface-Water		RO Desalination	
Size	Units	Baseline	Modified[a]	Baseline	Modified[a]
Small	$/1,000 gals	$4.28[b]	$2.97[b]	$2.29[c]	$1.93[c]
Medium	$/1,000 gals	$2.37[d]	$2.05[d]	$2.36[e]	$1.89[e]

[a] Modified production efficiency was 85% and overbuilds and upgrades costs are removed.

[b] The Olmito Facility; baseline (i.e., case study) production efficiency was 52%.

[c] The La Sara Facility; baseline (i.e., case study) production efficiency was 65%.

[d] The Northwest Facility; baseline (i.e., case study) production efficiency was 78%.

[e] The Southmost Facility; baseline (i.e., case study) production efficiency was 68%.

---

[58] The "Overbuild and Upgrade" costs for the Northwest facility are $0.19/1,000 gals (Rogers et al. 2008) and are $0.21/1,000 gals for the Southmost facility (Sturdivant et al. 2008). For a complete report on the "Overbuilds and Upgrades" costs for the Northwest and Southmost facilities, refer to Rogers et al. (2008) and Sturdivant et al. (2008), respectively.

Summary of Modified Life-Cycle Costs for All Facilities

After the modifications are applied to costs and potable water production for all of the facilities, the life-cycle costs for each facility are suitable for comparisons. Presented in Table 31 are the per-unit modified costs for all the analyzed facilities. Examining this table indicates that both the “small”-and “medium”-sized brackish-groundwater desalination facilities produce the lowest cost potable water in the LRGV. This indicates that brackish-groundwater desalination is economically competitive with conventional surface-water treatment for both “small”- and “medium”-sized facilities. In addition, it is evident that life-cycle costs for conventional surface-water treatment decreases as output increases, as well as life-cycle costs slightly decrease for brackish-groundwater desalination as output increases. However, it is appropriate to calculate and evaluate the economies of size ratio (Kay and Edwards 1994) to ascertain the existence and degree of economies of size.

Table 31. Modified Life-Cycle Costs per Unit of Water, by Facility Type and Size, in 2006 Dollars

Size	Units	Conventional Surface-Water	RO Desalination
Small	$/ac-ft	$968.31[a, b]	$629.09[a, c]
	$/1,000 gals	$2.97[a, b]	$1.93[a, c]
Medium	$/ac-ft	$667.74[a, d]	$615.01[a, e]
	$/1,000 gals	$2.05[a, d]	$1.89[a, e]

[a] Modified production efficiency was 85% and overbuilds and upgrades costs are removed.

[b] The Olmito facility.

[c] The La Sara facility.

[d] The Northwest facility.

[e] The Southmost facility.

ECONOMIES OF SIZE RESULTS

Using the modified set of life-cycle costs presented in the previous section, implications related to economies of size for conventional surface-water treatment and brackish-groundwater desalination in the LRGV are estimated. Economies of size ratios (ESRs) and interpretations are determined for each technology, as well as for all of the cost types, items, and segments. Since the analyses of these facilities are deterministic (i.e., no stochastic factors are included), a plus or minus 0.36 confidence interval is established in this thesis for the economies of size calculations.[59] Therefore, in this thesis, the ESR must be less than 0.64 to conclude that economies of size exist, and greater than 1.36 to conclude diseconomies of size exist. For any ESR that is between this range (i.e., 0.64 to 1.36), constant economies of size are considered to be present.

Following the pattern of the previously-presented results, conventional surface-water treatment is discussed first and the evaluation of brackish-groundwater desalination follows. The ESR approach is a mathematical technique to determine the

---

[59] The "confidence interval" calculation (a.k.a. "confidence interval") referred to is intended to reflect and account for the possibility of slight errors in the raw data collected from the respective water treatment facility managers. Subjectively, based on the author's perception of the accuracy of the information provided him and the various interpolations that were necessary to determine the baseline cost information used in the CITY H_2O ECONOMICS© and DESAL ECONOMICS© models, the respective sets of raw data were increased and decreased by 10% to reflect possible ranges of "more correct" cost data. Subsequently, the overall Economic Size Ratios (ESRs) for both conventional water treatment and brackish groundwater desalination treatment were examined for the alternate combinations of 10% lower (higher) input costs for the small-sized facility and 10% higher (lower) input costs for the medium-sized facility. The corresponding changes in overall ESRs were then compared to the respective baseline overall ESRs and a maximum variation of 36% change was observed. Consequently, it was determined that a range of ± 36% about an ESR of 1.00 represents constant economies of size, with greater than 1.36 signaling diseconomies of size and less than 0.64 indicating economies of size.

existence and the degree of economies of size. However, it is acknowledged within this thesis that a single pair-wise comparison of cost per-unit of potable water production by two facilities provides insight into possible existence of economies of size between two facilities.

Conventional Surface-Water Treatment

By applying a consistent methodology (i.e., application of the CITY H_2O ECONOMICS$^©$ model and modified data) to calculate the life-cycle costs for both “small”-and “medium”-sized conventional surface-water treatment facilities, a valid basis for use in determining the existence and degree of economies of size is established. This approach extends the literature to provide a detailed exploration of economies of size for conventional surface-water treatment; however, only two facilities are available for this analysis.[60]

Aggregate Economies of Size Implications

Presented in Table 32 are the modified annuity equivalent of costs ($1,755,211/yr) and of water (1,813 ac-ft/yr) for the Olmito facility, as well as the modified annuity equivalent of costs ($4,790,190/yr) and of water (7,174 ac-ft/yr) for the Northwest facility. Using the Olmito facility (i.e., small facility) as the initial value in the percent change

---

[60] That is, in this thesis, economies of size can only be examined by comparing one facility’s life-cycle costs against the other facility’s costs. As discussed in the “Limitations” section of this thesis, costs for more facilities of different sizes are needed to better evaluate and understand the implications of economies of size in this technology.

calculation indicates an ESR of 0.58, indicating economies of size (E) (Table 32). This value can be interpreted as a 1.00% increase in conventional surface-water treatment output (i.e., potable water delivered to an initial point within the municipal water-delivery system) results in a 0.58% increase in the cost of treating surface-water in the LRGV, i.e., costs increase less proportionally than the increase in the facility size, representing economies of size.

Table 32. Modified Aggregate Annuity Equivalent of Costs and of Water and the Aggregate Economies of Size Ratio, for Conventional Surface-Water Treatment in the Lower Rio Grande Valley of Texas, in 2006 Dollars

Results	Units	Olmito (2.0 mgd)	Northwest (8.25 mgd)[a]	% change[b]
Annuity Equivalent of Costs	$/yr	$1,755,211	$4,790,190	1.73
Annuity Equivalent of Water	ac-ft/yr	1,813	7,174	2.96
Aggregate Economies of Size Ratio (ESR)[c]				**0.58**

[a] Source: Rogers (2008).

[b] The small-sized Olmito Facility is the initial value from which the % change calculation is determined.

[c] Economies of size is calculated based on Kay and Edwards (1994); i.e., economies of size ratio equals the percent (%) change in cost divided by the percent (%) change in output.

Economies of Size Implications by Cost Type, Item, and Segment

Dividing the modified annuity equivalent of costs for each facility across the three cost types, an ESR can be estimated for each.[61] The ESR for initial construction costs is 0.93, and the purchase of water rights has an ESR of 1.00,[62] indicating constant economies of size (C) under the assumption in this thesis of plus or minus 0.36 confidence interval. The continued costs ESR is 0.40, and the capital replacement costs ESR is 0.07 (Table 33; Figure 15), indicating economies of size (E) exist for both cost types. The ratios can be interpreted as a 1.00% increase in conventional surface-water output infers a 0.93% increase in the initial construction costs, a 1.00% increase in the purchasing water rights, a 0.40% increase in the continued costs, and a 0.07% increase in the capital replacement costs.

The apparent economies of size for the continued and capital replacement costs 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). The constant economies of size for the initial construction costs did not follow conventional wisdom, since it is typical for fixed costs to be spread out more across larger output firms, which produces lower per-unit costs (i.e., economies of size) (Kay and Edwards 1994).

---

[61] The annuity equivalents of cost (i.e., numerator) are allocated across the cost types, items, and segments, but the annuity equivalent of water (i.e., denominator) is held constant at its aggregate level. That is, each type, item, and segment is gauged using the aggregate annuity equivalent of water, but each type, item, and segment comprise a different proportion of the annuity equivalent of costs.

[62] A cost of $2,300/ac-ft for water rights (Rogers 2008) was assumed for both facilities; therefore, constant economies of size for purchasing water rights are given.

Table 33. Economies of Size Ratios, by Cost Type and Item, for Conventional Surface-Water Treatment in the Lower Rio Grande Valley of Texas, in 2006 Dollars

		Surface-Water Treatment			
Cost Type and Item	Unit	Olmito (2.0 mgd)	Northwest (8.25 mgd)[a]	Economies of Size Ratio (ESR)[b]	Economies of Size Inference[c]
Initial Construction/Investment	$/yr	**$637,871**	**$2,399,621**	0.93	C
- Water Rights Purchase	"	*331,990*	*1,309,277*	*1.00*	*C*
Continued	"	**1,079,834**	**2,345,310**	0.40	E
- Administrative	"	*27,263*	*104,880*	*0.96*	*C*
- Energy	"	*201,163*	*506,198*	*0.51*	*E*
- Chemical	"	*216,153*	*404,839*	*0.30*	*E*
- Labor	"	*229,744*	*457,173*	*0.33*	*E*
- Water Delivery	"	*124,068*	*662,343*	*1.47*	*D*
- All Other[d]	"	*281,470*	*209,887*	*-0.09*	*E*
Capital Replacement	"	**37,506**	**45,249**	0.07	E
Modified Annuity Equivalent[e]	$/yr	$1,755,211	$4,790,190	0.58	E

[a] Source: Rogers (2008) and own modifications.

[b] Economies of size ratios are calculated based on Kay and Edwards (1994); i.e., economies of size ratio equals the percent (%) change in cost divided by the percent (%) change in output, the latter remains constant at 2.96 for all ratio calculations for this table (refer to Table 32).

[c] Interpretation (i.e., inference) of the calculated economies of size ratio results are:
- Economies of Size (E) exist ... ESR < 0.64;
- Constant Economies of Size (C) exist ... 0.64 ≤ ESR ≤ 1.36; and
- Diseconomies of Size (D) exist ... ESR > 1.36.

[d] Such extreme economies of size results can be associated with the different accounting methods used by the facilities (i.e., public vs. private). For example, different accounting approaches resulted in costs being recorded in the "All Other" costs item for the Olmito facility when they might be more accurately included in another item (e.g., the "Administrative" costs item).

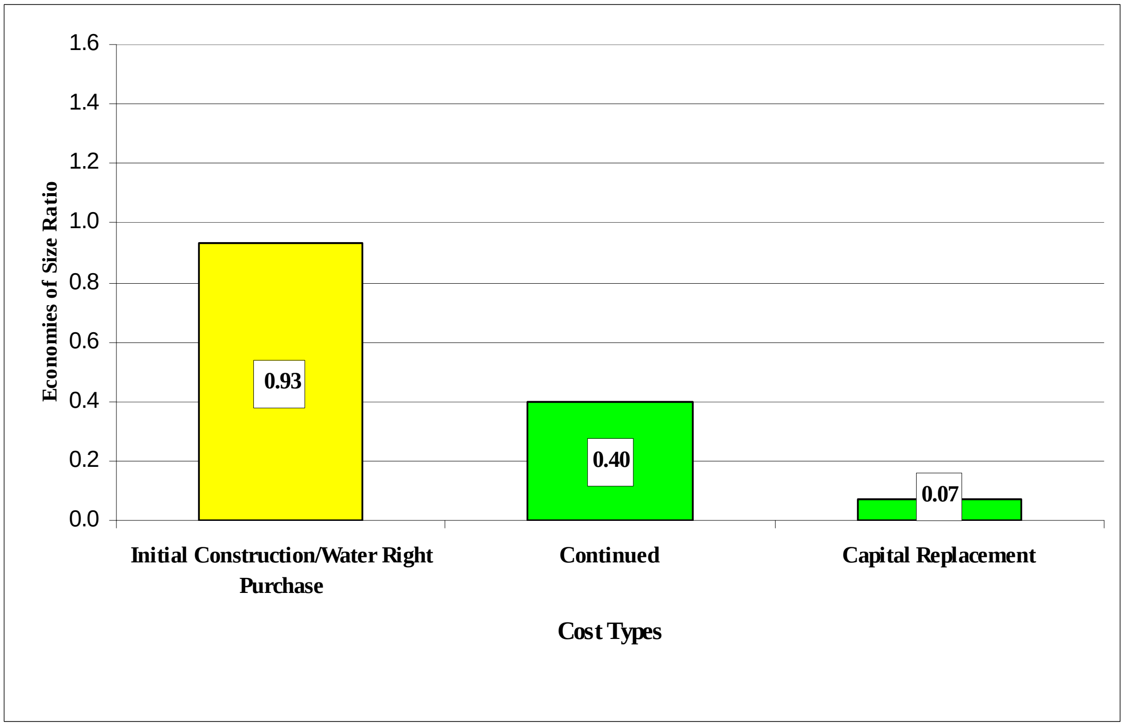
[e] These are the modified total annuity equivalents (real values, basis 2006 dollars) relevant to producing potable surface-water for a given year.

The modified annuity equivalent of continued costs can be further allocated across six cost items to determine an ESR for each item. The ESR results in Table 33 demonstrate that there are economies of size (E) for energy costs (0.51), chemical costs (0.30), labor (0.33), and all other costs (-0.09),[63] constant economies of size (C) for administrative costs (0.96), and diseconomies of size (D) for water delivery (1.47)[64] (Table 33; Figure 16). The ESRs can be interpreted as a 1.00% increase in conventional surface-water treatment output results in a 0.96% increase in the administrative costs, a 0.51% increase in the energy costs, a 0.30% increase in the chemical costs, a 0.33% increase in the labor costs, a 1.47% increase in the water delivery costs, and a 0.09% decrease in the all other costs. Figure 16 is a graphical presentation of ESRs by cost items for conventional surface-water treatment.

---

[63] Such extreme economies of size (i.e., a negative ESR ratio) results can be associated with the different accounting methods used by the facilities (i.e., public vs. private). For example, different accounting approaches resulted in costs being recorded in the “All Other” costs item for the Olmito facility when they might be more accurately included in another item (e.g., the “Administrative” costs item).

[64] Since the Olmito facility and the McAllen Northwest facility receive their source water from different IDs, possible differences in the rates the IDs charge to deliver the source water could be a explanation of the diseconomies of size present in water delivery costs.

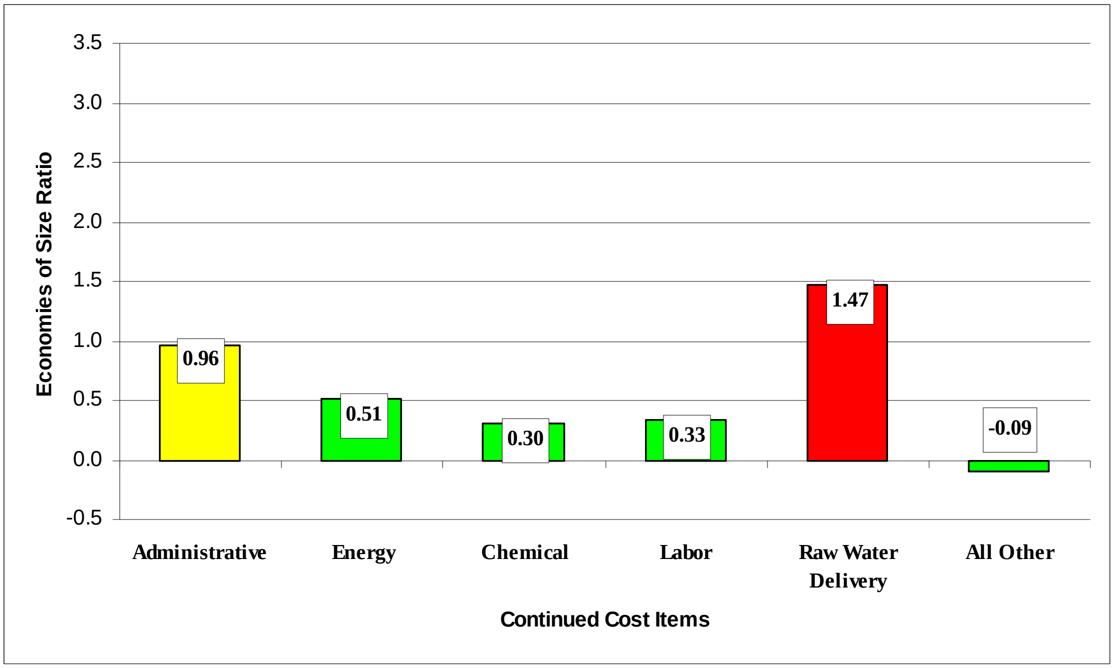


Note: Interpretation (i.e., inference) of the calculated economies of size ratio results are:

- Economies of Size (E) exist ... ESR < 0.64;
- Constant Economies of Size (C) exist ... 0.64 ≤ ESR ≤ 1.36; and
- Diseconomies of Size (D) exist ... ESR > 1.36.

Yellow denotes Constant Economies of Size; Green denotes Economies of Size; and Red denotes Diseconomies of Size.

Figure 15. Economies of size ratios, by cost type, for the Olmito and Northwest conventional surface-water treatment facilities in the Lower Rio Grande Valley of Texas



Note: Interpretation (i.e., inference) of the calculated economies of size ratio results are:

- Economies of Size (E) exist ... ESR < 0.64;
- Constant Economies of Size (C) exist 0.64 ≤ ESR ≤ 1.36; and
- Diseconomies of Size (D) exist ... ESR > 1.36.

Yellow denotes Constant Economies of Size; Green denotes Economies of Size; and Red denotes Diseconomies of size

Figure 16. Economies of size ratios, by cost item, for the Olmito and Northwest conventional surface-water treatment facilities in the Lower Rio Grande Valley of Texas

The modified annuity equivalent of costs can also be allocated across six common cost segments to determine an ESR for each (Table 34). The estimated ESRs for the cost segments are: 0.97 for the raw water intake/reservoir/water rights purchase, 0.46 for the treatment unit costs, 0.43 for the sludge disposal costs, 0.22 for the delivery-to-municipal-line costs, 0.20 for the operations' supporting facilities costs, and 0.96 for the administrative costs (Table 34; Figure 17). The ESRs determine economies of size (E) exist for all of the stated cost segments with the exception of the raw water intake/reservoir/water rights purchase and the administrative costs, which demonstrate constant economies of size (C).[65] The ESRs can be interpreted as a 1.00% increase in conventional surface-water treatment output results in a 0.97% increase in the cost of raw water intake/reservoir/water rights purchase, a 0.46% increase in the treatment unit costs, a 0.43% increase in the sludge disposal costs, a 0.22% increase in the delivery-to-municipal-line costs, a 0.20% increase in the operations' supporting facilities costs, and a 0.96% increase in the administrative costs.

A word of caution is related to the analysis of economies of size for individual segments. The level of certainty is surely limited because methods used for identifying the segment costs for all of the facilities. These results are presented to provide insight on details with the caveat of care in making literal interpretations.

---

[65] Refer to footnotes 62 and 63 for an explanation on constant economies of size for these two cost segments.

Table 34. Economies of Size Ratios, by Cost Segment, for Conventional Surface-Water Treatment in the Lower Rio Grande Valley of Texas, in 2006 Dollars

		Surface-Water Treatment			
Cost Segment	Unit	Olmito (2.0 mgd)	Northwest (8.25 mgd)[a]	Economies of Size Ratio (ESR)[b]	Economies of Size Inference[c]
Raw Water Intake/ Reservoir/Water Purchase	$/yr	$635,634	$2,453,190	0.97	C
Treatment Unit[d]	"	536,321	1,270,534	0.46	E
- *Pre-disinfection*	"	*n/a*	*534,234*	*n/a*	*n/a*
- *Coagulation/Flocculation*	"	*n/a*	*181,847*	*n/a*	*n/a*
- *Sedimentation*	"	*n/a*	*101,082*	*n/a*	*n/a*
- *Filtration/Backwash*	"	*n/a*	*229,399*	*n/a*	*n/a*
- *Secondary Disinfection*	"	*n/a*	*223,652*	*n/a*	*n/a*
Sludge Disposal	"	79,765	181,852	0.43	E
Delivery to Municipal Line	"	345,393	572,457	0.22	E
Operations' Supporting Facilities	"	130,834	207,577	0.20	E
Administrative	"	27,264	104,880	0.96	C
Modified Annuity Equivalent[e]	$/yr	$1,755,211	$4,790,190	0.58	E

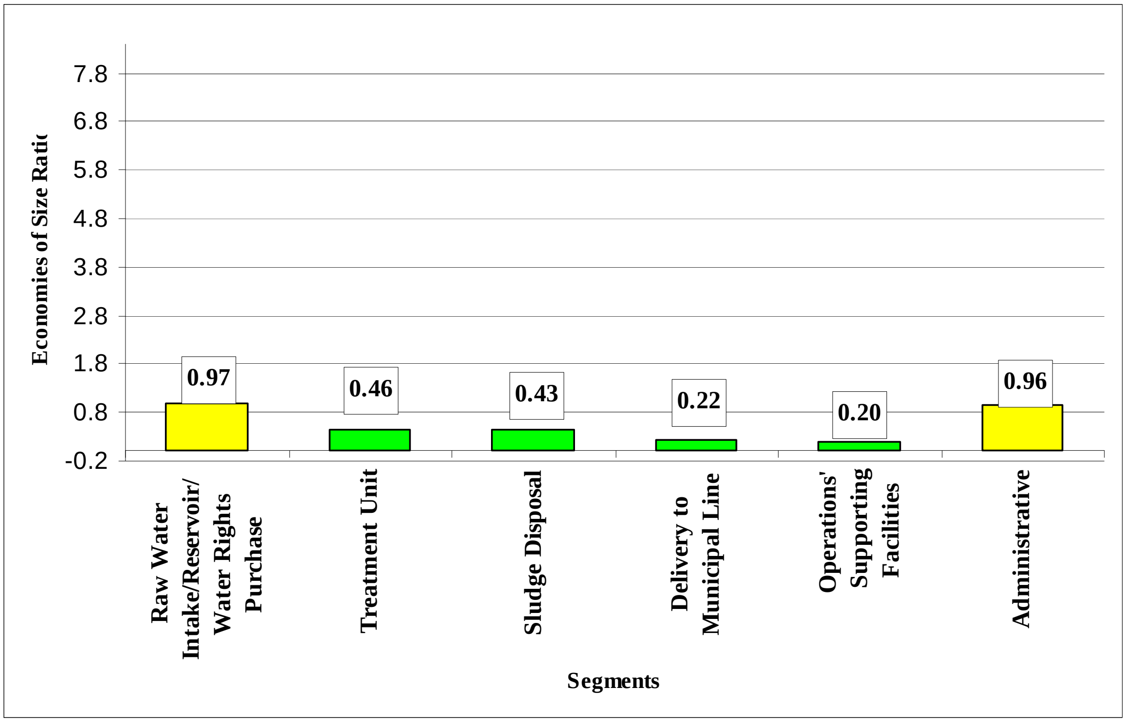
[a] Source: Rogers (2008) and own modifications.

[b] Economies of size ratios are calculated based on Kay and Edwards (1994); i.e., economies of size ratio equals the percent (%) change in cost divided by the percent (%) change in output, the latter remains constant at 2.96 for all ratio calculations for this table (refer to Table 32).

[c] Interpretation (i.e., inference) of the calculated economies of size ratio results are:
- Economies of Size (E) exist ... ESR < 0.64;
- Constant Economies of Size (C) exist ... 0.64 ≤ ESR ≤ 1.36; and
- Diseconomies of Size (D) exist ... ESR > 1.36.

[d] The Olmito facility was not designed in a way that cost estimates could be allocated for the italicized cost segments. Therefore, the Northwest facility's detailed cost segments listed in italics are combined into the treatment unit segment to determine an ESR.

[e] These are the modified total annuity equivalents (real values, basis 2006 dollars) relevant to producing potable surface-water for a given year.



Note: Interpretation (i.e., inference) of the calculated economies of size ratio results are:

- Economies of Size (E) exist ... ESR < 0.64;
- Constant Economies of Size (C) exist ... 0.64 ≤ ESR ≤ 1.36; and
- Diseconomies of Size (D) exist ... ESR > 1.36.

Yellow denotes Constant Economies of Size; Green denotes Economies of Size; and Red denotes Diseconomies of Size.

Figure 17. Economies of size ratios, by cost segment, for the Olmito and Northwest conventional surface-water treatment facilities in the Lower Rio Grande Valley of Texas

The results derived within this thesis give cause to reject the null hypothesis (Ha_0) and suggest that economies of size 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 constant economies of size found in the initial construction costs are perplexing given the literature commonly reports that per-unit costs decrease as water treatment facilities output increases. This indicates that construction costs for the LRGV do not follow national trends or are an anomaly to the facilities examined for the LRGV within this thesis.

Possible explanations for constant economies of size found for the construction costs could be that the construction costs 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 that construction costs in the LRGV are actually increasing at a rate of 10-12% annually. Therefore, it is possible that the 2006 construction costs for the Olmito facility were under discounted from 2008, causing a slightly distorted basis for the analysis. In addition, given the explosive grow occurring in the LRGV, the demand for new infrastructure (e.g., water systems, housing developments, etc.) may not be sufficiently met by the current engineering and construction firms in the LRGV. This surplus of potential projects can give engineering and construction firms little incentive to bid projects with the lowest costs in mind. Instead, LRGV firms may have such a large volume of projects to select from that they commit only to projects that will bring the highest rate of return. This phenomena results in construction costs being higher than if there was a shortage of construction projects in the LRGV. Other artifacts (i.e., administrative costs, all other costs, and water delivery costs) are somewhat explained in the footnotes, but would be expected to become clearer with availability of life-cycle costs for additional facilities.

Brackish-Groundwater Desalination

By applying a consistent methodology (i.e., application of the DESAL ECONOMICS© model and modified data) to calculate the life-cycle costs for two brackish-groundwater desalination facilities, a valid basis for use in examining the existence and degree of economies of size. This approach extends the literature to provide a detailed exploration of economies of size for brackish-groundwater desalination; however, only two facilities are available for this analysis.[66]

Aggregate Economies of Size Implications

Presented in Table 35 are the modified annuity equivalent of costs ($646,736/yr) and water (1,028 ac-ft/yr) for the La Sara facility, and the modified annuity equivalent of costs ($4,196,391/yr) and of water (6,823 ac-ft/yr) for the Southmost facility. Using the La Sara facility (i.e., small facility) as the initial value in the percent change calculation indicates an ESR of 0.97, which falls within the specified confidence interval for this thesis, indicating constant economies of size (C) for brackish-groundwater desalination

---

[66] That is, in this thesis, economies of size can only be examined by comparing one facility's life-cycle costs against the other facility's costs. As discussed in the "Limitations" section of this thesis, more life-cycle costs for more facilities of different sizes are needed to better evaluate and understand the implications of economies of size in this technology.

in the LRGV (Table 35). This value can be interpreted as a 1.00% increase in brackish-groundwater desalination output (i.e., potable water delivered to an initial point within the municipal water-delivery system) results in approximately the same percentage increase in the cost of producing water in the LRGV.

Table 35. Modified Aggregate Annuity Equivalent of Costs and of Water and the Aggregate Economies of Size Ratio, for Brackish-Groundwater Desalination in the Lower Rio Grande Valley of Texas, in 2006 Dollars

Results	Units	La Sara (1.13 mgd)	Southmost (7.50 mgd)[a]	% change[b]
Annuity Equivalent of Costs	$/yr	$646,736	$4,196,391	5.49
Annuity Equivalent of Water	ac-ft/yr	1,028	6,823	5.64
Aggregate Economies of Size Ratio (ESR)[c]				**0.97**

[a] Source: Sturdivant et al. (2008).

[b] The small-sized La Sara Facility is the initial value from which the % change calculation is determined.

[c] Economies of size is calculated based on Kay and Edwards (1994); i.e., economies of size ratio equals the percent (%) change in cost divided by the percent (%) change in output.

Economies of Size Implications by Cost Type, Item, and Segment

Dividing the modified annuity equivalent of costs for each facility across the three cost types, an ESR was estimated for each. Presented in Table 36, the ESR for the initial construction/investment costs is 1.36, indicating constant economies of size (C). The ESR for continued costs is 0.81, representing constant economies of size (C), and the ESR for capital replacement costs is 1.49,[67] indicating diseconomies of size (D) (Table 36; Figure 18). The ESRs can be interpreted as a 1.00% increase in brackish-groundwater desalination output results in a 1.36% increase in the initial construction costs, a 0.81% increase in the continued costs, and a 1.49% increase in the capital replacement costs.

The constant economies of size identified for the initial construction costs and continued costs were not expected, suggesting that these costs could be an anomaly to the LRGV. Similar to conventional surface-water treatment, the current supply of engineering and construction firms in the LRGV could not be sufficient to meet the demand for new infrastructure. As discussed on page 104, this could be an explanation for constant economies of size found for initial construction costs. It appears that price discounts for large volume purchases of RO desalination production inputs do not occur in the LRGV.

---

[67] Referring back to the La Sara case study in this thesis and Sturdivant et al. (2008), the La Sara facility treats source water that has a lower salinity level than the Southmost facility. High salinity levels can reduce the life of certain components (e.g., RO membranes) in the facility, resulting in more frequent replacement and higher capital replacement costs (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 thesis.

Table 36. Economies of Size Ratios, by Cost Type and Item, for Brackish-Groundwater Desalination in the Lower Rio Grande Valley of Texas, in 2006 Dollars

Cost Type and Item	Unit	Brackish-Groundwater Desalination		Economies of Size Ratio (ESR)[b]	Economies of Size Inference[c]
		La Sara (1.13 mgd)	Southmost (7.5 mgd)[a]		
Initial Construction/Investment	$/yr	**$163,235**	**$1,417,205**	1.36	C
Continued	“	**459,809**	**2,556,747**	0.81	C
- Adminstrative[d]	“	*170,033*	*121,750*	*-0.05*	*E*
- Energy	“	*207,853*	*1,356,447*	*0.98*	*C*
- Chemical	“	*46,602*	*409,508*	*1.38*	*D*
- Labor	“	*24,884*	*490,084*	*3.32*	*D*
- All Others	“	*10,433*	*178,959*	*2.87*	*D*
Capital Replacement	“	**23,696**	**222,438**	1.49	D
Modified Annuity Equivalent[e]	$/yr	$646,736	$4,196,391	0.97	C

[a] Source: Sturdivant et al. (2008) and own modifications.

[b] Economies of size ratios are calculated based on Kay and Edwards (1994); i.e., economies of size ratio equals the percent (%) change in cost divided by the percent (%) change in output, the latter remains constant at 5.64 for all ratio calculations for this table (refer to Table 35).

[c] Interpretation (i.e., inference) of the calculated economies of size ratio results are:
- Economies of Size (E) exist ... ESR < 0.64;
- Constant Economies of Size (C) exist ... 0.64 ≤ ESR ≤ 1.36; and
- Diseconomies of Size (D) exist ... ESR > 1.36.

[d] Such extreme economies of size results can be associated with the different accounting methods used by the facilities (i.e., public vs. private). For example, different accounting approaches resulted in costs being recorded in the “Administrative” costs item for the La Sara facility when they might be more accurately included in another item (e.g., the “All Other” costs item).

[e] These are the modified total annuity equivalents (real values, basis 2006 dollars) relevant to producing potable surface water for a given year.

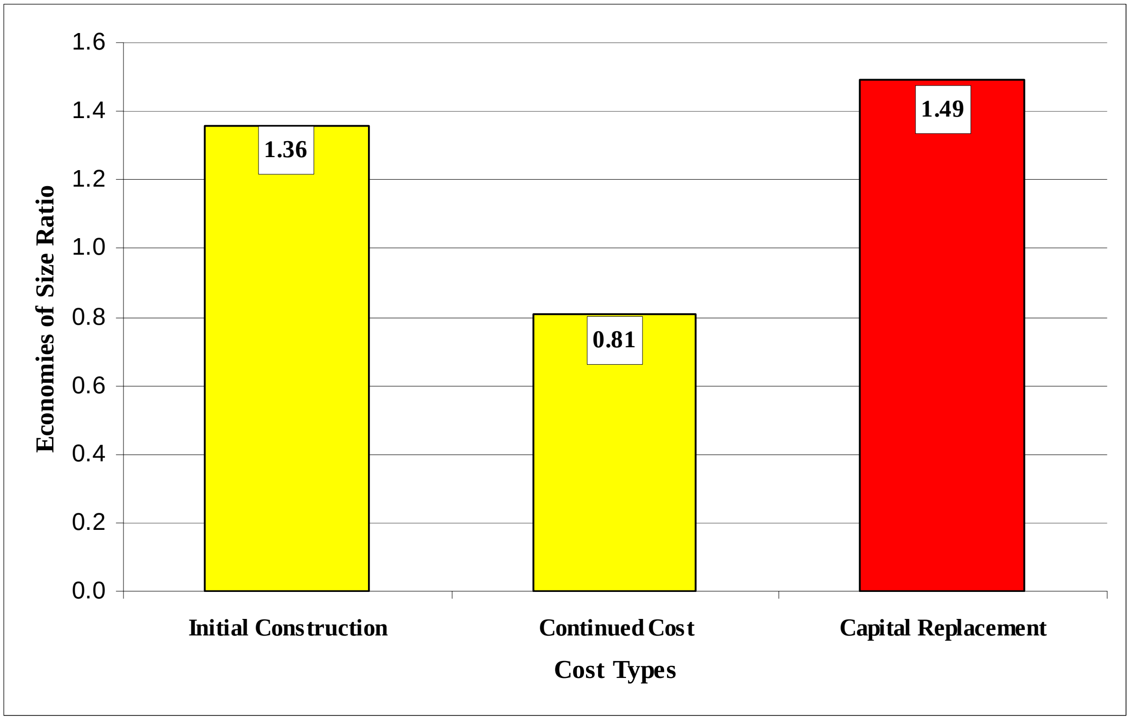
As mentioned in footnote 67, the source water at the Southmost facility has higher levels of salinity than the La Sara facility. This may require the Southmost facility to use more energy and chemicals to treat the source water to a potable level, resulting in constant economies in size.

The modified annuity equivalent of continued costs can be further allocated across five cost items to determine an ESR for each (Table 36). The ESR results presented in Table 36, demonstrate economies of size (E) for administrative costs (-0.05),[68] constant economies of size (C) for energy (0.98), and diseconomies of size (D) for chemicals (1.38), labor (3.32),[69] and all other costs (2.87) (Table 36; Figure 19). The ESRs can be interpreted as a 1.00% increase in brackish-groundwater desalination output results in a 0.05% decrease in administrative costs, a 0.98% increase in the energy costs, a 1.38% increase in the chemical costs, a 3.32% increase in the labor cost, and a 2.87% increase in all other costs.

---

[68] Such extreme economies of size can be associated with the different accounting methods used by the facilities (i.e., public vs. private). For example, different accounting approaches resulted in costs being recorded in the "Administrative" costs item for the La Sara facility when they might be more accurately included in another item (e.g., the "All Other" costs item).

[69] NAWSCs (i.e., the La Sara facility) SCADA system and other operational designs 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 explain why La Sara has a lower per-unit labor cost relative to the Southmost facility.

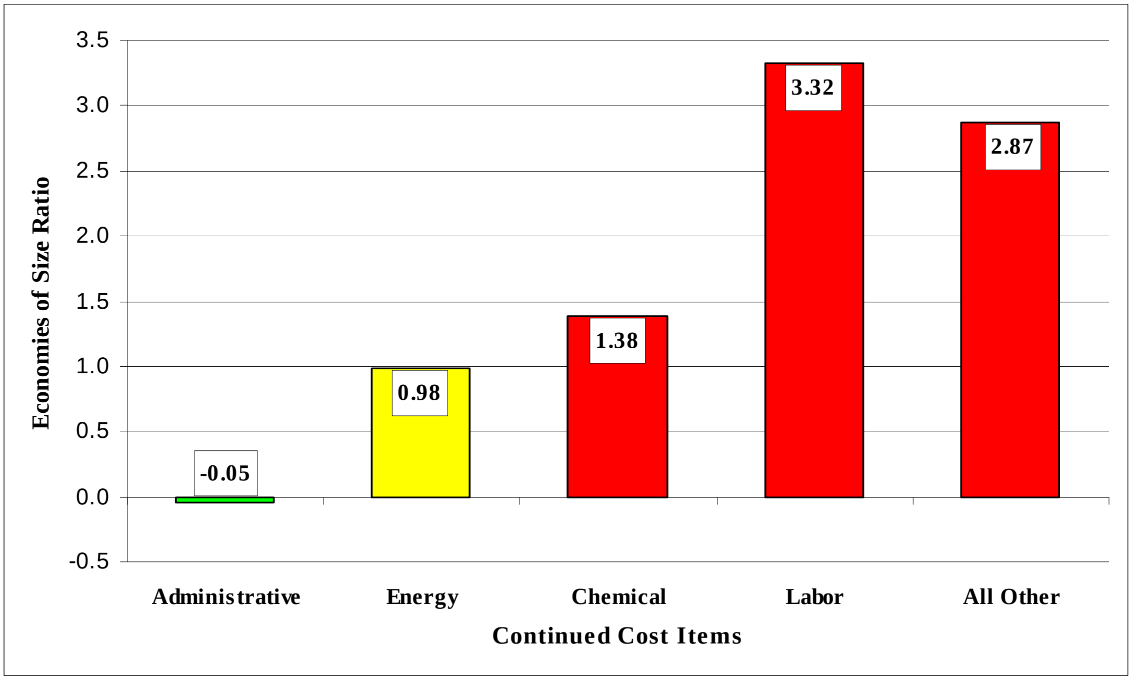


Note: Interpretation (i.e., inference) of calculated economies of size ratio results are:

- Economies of Size (E) exist ... ESR < 0.64;
- Constant Economies of Size (C) exist ... 0.64 ≤ ESR ≤ 1.36; and
- Diseconomies of Size (D) exist ... ESR > 1.36.

Yellow denotes Constant Economies of Size; Green denotes Economies of Size; and Red denotes Diseconomies of Size.

Figure 18. Economies of size ratios, by cost type, for the La Sara and Southmost brackish-groundwater desalination facilities in the Lower Rio Grande Valley of Texas



Note: Interpretation (i.e., inference) of the calculated economies of size ratio results are:

- Economies of Size (E) exist ... ESR < 0.64;
- Constant Economies of Size (C) exist ... 0.64 ≤ ESR ≤ 1.36; and
- Diseconomies of Size (D) exist ... ESR > 1.36.

Yellow denotes Constant Economies of Size; Green denotes Economies of Size; and Red denotes Diseconomies of Size.

Figure 19. Economies of size ratios, by cost item, for the La Sara and Southmost brackish-groundwater desalination facilities in the Lower Rio Grande Valley of Texas

The modified annuity equivalent of costs can also be allocated across seven common cost segments to determine an ESR for each.[70] The estimated ESRs for the cost segments are 1.27 for the main facility/treatment process, -0.05 for the concentrated discharge, 0.19 for the finished water/tank storage, 8.39 for the high service and delivery

---

[70] Engineers and facility managers for both brackish-groundwater desalination facilities had difficultly allocating costs across the segments. These difficulties contributed to several issues in calculating precisely-accurate cost segments' ESRs.

line, 1.92 for the well field,[71] 3.09 for the transmission line,[72] and -0.05 for the administrative costs (Table 37; Figure 20). The ESRs for each cost segment indicate diseconomies of size (D) for the well field, the transmission line, and the high service and delivery pipeline; economies of size (E) were identified for the concentrated discharge, the finished water/tank storage, and the administrative costs; and constant economies of size (C) for the main facility/treatment process. The ESRs can be interpreted as a 1.00% increase in brackish-groundwater desalination output results in a 1.92% increase in the well field costs, a 3.09% increase in the transmission line costs, a 1.27% increase in the main facility/treatment process costs, a 0.05% decrease in the concentrated discharge costs, a 0.19% increase in the finished water/tank storage costs, a 8.36% increase in the high service and delivery pipeline costs, and a 0.05% decrease in the administrative costs.

The estimated economies of size implications for brackish-groundwater desalination based on the two facilities in the LRGV do not concur with the literature (Traviglia and Characklis (2006), Characklis (2004), Arroyo (2005), and Norris (2006a; 2006b)). Based on the estimates derived within this thesis, a fail to reject conclusion is drawn on the null hypothesis (Hb_0). The evidence produced in this thesis research is suggestive that an increase of output does not decrease the per-unit cost of

---

[71] The La Sara facility's source water is supplied from its one well (Browning 2007), compared to the Southmost facility which receives its source water from 18 wells (Sturdivant et al. 2008).

[72] 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. 2008).

producing potable water via RO desalination of brackish-groundwater in the LRGV. As mentioned throughout this section and further discussed in the “Limitations” section of this thesis, additional life-cycle costs for facilities of different sizes are needed to extend this test of the null hypothesis.

Table 37. Economies of Size Ratios, by Cost Segment, for Brackish-Groundwater Desalination in the Lower Rio Grande Valley of Texas, in 2006 Dollars

		Brackish-Groundwater Desalination			
Cost Segment	Unit	La Sara (1.13 mgd)	Southmost (8.25 mgd)[a]	Economies of Size Ratio (ESR)[b]	Economies of Size Inference[c,d]
Well Field	$/yr	$98,391	$1,167,683	1.92	D
Transmission Line	“	7,211	132,821	3.09	D
Main Facility/Treatment Process	“	268,530	2,191,862	1.27	C
Concentrated Discharge	“	11,766	8,592	-0.05	E
Finished Water/Tank Storage	“	82,421	170,151	0.19	E
High Service and Delivery Pipeline	“	8,384	403,531	8.36	D
Administrative	“	170,033	121,750	-0.05	E
Modified Annuity Equivalent[e]	$/yr	$646,736	$4,196,391	0.97	C

[a] Source: Sturdivant et al. (2008) and own modifications.

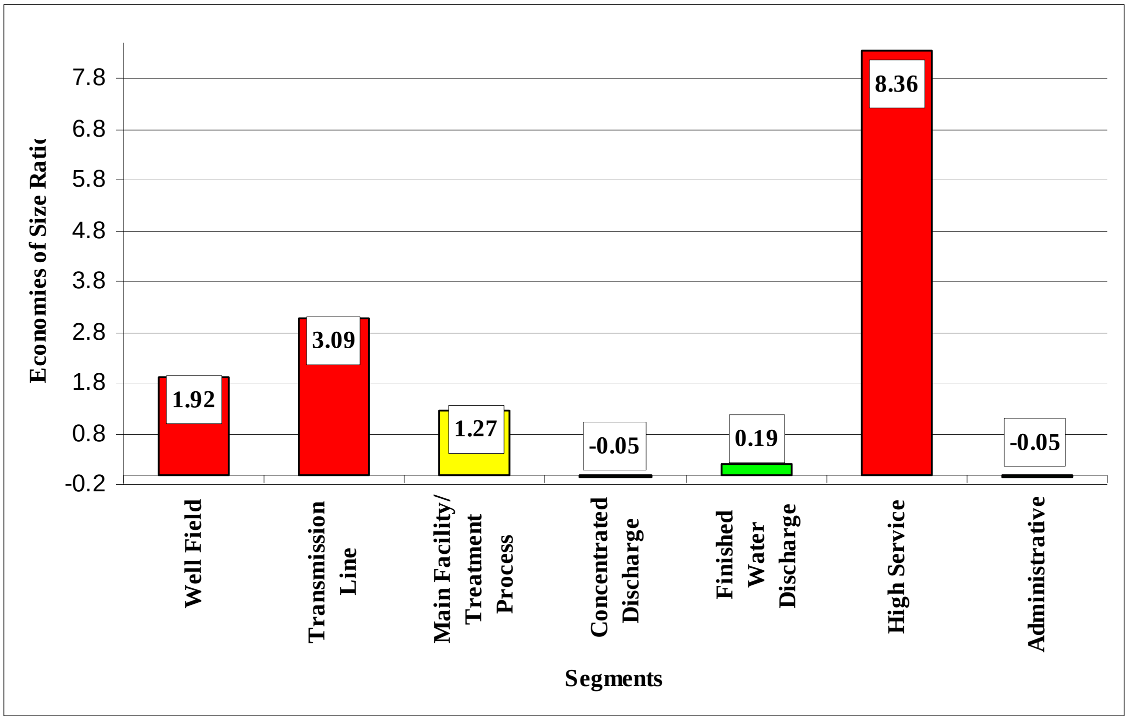
[b] Economies of size is calculated based on Kay and Edwards (1994); i.e., economies of size ratio equals the percent (%) change in cost divided by the percent (%) change in output, which is held constantly at 5.64 (refer to table 35).

[c] Economies of size ratios are calculated based on Kay and Edwards (1994); i.e., economies of size ratio equals the percent (%) change in cost divided by the percent (%) change in output, the latter remains constant at 5.64 for all ratio calculations for this table (refer to Table 35).

[d] Interpretation (i.e., inference) of the calculated economies of size ratio results are:

- Economies of Size (E) exist ... ESR < 0.64;
- Constant Economies of Size (C) exist ... 0.64 ≤ ESR ≤ 1.36; and
- Diseconomies of Size (D) exist ... ESR > 1.36.

[e] These are modified annuity equivalent (real values, basis 2006 dollars) relevant to producing potable surface-water for a given year.



Note: Interpretation (i.e., inference) of the calculated economies of size ratio results are:

- Economies of Size (E) exist ... ESR < 0.64;
- Constant Economies of Size (C) exist ... 0.64 ≤ ESR ≤ 1.36; and
- Diseconomies of Size (D) exist ... ESR > 1.36

Yellow denotes Constant Economies of Size; Green denotes Economies of Size; and Red denotes Diseconomies of Size.

Figure 20. Economies of size ratios, by cost segment, for the La Sara and Southmost brackish-groundwater desalination facilities in the Lower Rio Grande Valley of Texas

DISCUSSION

The purposes of this research included estimating life-cycle costs for “small” water treatment facilities using conventional surface-water treatment and RO desalination. Further, combining those estimates with results of other related LRGV studies of water treatment facilities, an additional objective was to test for evidence of economies of size. Thus, this thesis represents the collaboration of the efforts of a team of agricultural economists to bring together several studies and draw broad implications for use by decision makers (i.e., engineers, water planners, municipalities, IDs, etc.) in the LRGV.

The null hypothesis (Ha_0: “Economies of size are not present in conventional surface-water treatment in the LRGV.”) is rejected. Therefore, the alternative hypothesis (Ha_1: “Economies of size are present in conventional surface-water treatment in the LRGV.”) is accepted, indicating economies of size do exist in the LRGV. The null hypothesis (Hb_0: “Economies of size are not present in RO desalination of brackish-groundwater in the LRGV.”) fails to be rejected, indicating constant economies of size are present in brackish-groundwater desalination in the LRGV.

The conclusions drawn on the economic viability and the constant economies of size for RO desalination of brackish-groundwater do not agree with work by Traviglia and Characklis (2006). They report that surface-water treatment was cheaper than RO desalination for facilities sized 1.0 mgd, 10.0 mgd, and 30.0 mgd, as well as that economies of size were identified for RO desalination. Traviglia and Characklis (2006) used cost relationships, which were derived from the literature (i.e., secondary data), to calculate construction and operating costs for both water-treatment technologies. The research in this thesis analyzed primary construction and operating costs data to calculate life-cycle costs for all four facilities. The dated literature could reflect costs no longer being experienced. Other deviations between this thesis and Traviglia and Characklis (2006) include: a different discount rate, different useful life for the facilities, different production efficiencies, and different levels of surface-water and brackish-groundwater quality.

Characklis (2004) reported similar economies of size as Traviglia and Characklis (2006) for conventional surface-water treatment and brackish-water desalination. The primary reasons for the contrasting results between this thesis and Characklis (2004) can be explained by data and methodology which were applied. 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.

In 2005, Arroyo (2005) reported that economies of size were present in brackish-groundwater desalination. In his analysis, Arroyo states that the cost of producing brackish-groundwater decreases from \$1.09/1,000 gals for a 1.0 mgd facility to \$0.71/1,000 gals for a 10.0 mgd facility. However, Arroyo (2005) did not include the cost of source water development, concentrated disposal, finished water storage, pumping and distribution, environmental/archeology, land acquisition, and surveying in his analysis; that is, the costs estimates in this thesis are more comprehensive than that of Arroyo (2005). As presented in this thesis, not all cost types, items, and segments capture similar degrees of economies of size, if any. Some of the excluded costs in Arroyo's (2005) report might experience diseconomies of size, which would reduce or even reverse the degree of economies of size being reported. In addition to Arroyo (2005), Norris (2006b) also states that economies of size are present in brackish-groundwater desalination. Norris' (2006b) assessment is not demonstrated with cost estimates, but based on his experience in constructing and operating desalination facilities.

The standards for determining economies of size in the studies mentioned above are unclear. This thesis uses a mathematical approach (i.e., ESR) with a fairly conservative confidence interval (plus or minus 0.36) to ascertain the existence of economies of size for both water treatment technologies. Therefore, only relative comparisons of the results presented in this thesis can be made to the conclusions in the previous studies.

Extending the results achieved in this thesis beyond the literature, two important implications can be made about future water expansion in the LRGV. First, results presented in this research suggest that a "small" RO desalination facility, which is within close proximity of its residents, provides a competitive economic source of potable water in the LRGV. By building multiple small desalination facilities close to new developments that require potable water connections, communities can avoid extending their existing distributions networks, which Boisvert and Schmit (1996) report as having diseconomies of size. For example, a new residential development on the outer edges of a city in the LRGV might receive lowest-cost potable water by building a "small" RO desalination facility adjacent to the development, as opposed to extending the city's distribution system from one large facility to reach the new development.

Second, an additional null hypothesis (Hc_0) stating "RO desalination of brackish-groundwater *is not* economically competitive with conventional surface-water treatment in the LRGV" and the alternative to the null (Hc_1) stating "RO desalination of brackish-groundwater *is* economically competitive with conventional surface-water treatment in the LRGV" could have been included in the objectives of this thesis. The null would have been rejected and the alternative would have been accepted, indicating that RO desalination provides LRGV cities a viable alternative to conventional surface-water for potable water. This conclusion is important to stakeholders in the LRGV because it could alleviate municipalities' need to purchase of water rights from IDs. Agriculture is a major contributor to the LRGV economy (Stubbs et al. 2003; Yow 2008), and producers rely on Rio Grande water for irrigation purposes. Unfortunately, most LRGV agricultural producers do not have an alternative source of irrigation water at this time, and by reducing the purchase and conversion of agricultural water rights to municipal water rights, they are "protected" from losing their only source of irrigation water.

To reiterate, there is only one facility each with cost estimates for the small-sized conventional and desalination treatment alternatives and one each for the medium-sized conventional and desalination technologies. Each facility is unique and subject to different constraints. Therefore, the results have limitations related to extrapolation of the data. On the positive side, the work is based on primary data and reflects actual investment and operation costs, albeit modified to reflect basis year 2006 results.

LIMITATIONS

This research uses primary data collected from municipal water managers and their consulting engineers, as well as a consistent methodology to calculate life-cycle costs. Even so, this thesis does have shortcomings and limitations. The modifications to the data for the economies of size calculations are intended to remove many of the limitations, but are lacking in completeness. The first limitation in this research is that only two facilities' life-cycle costs are calculated for each water treatment technology. More life-cycle costs for facilities of different sizes would provide a broader understanding of costs estimates for both water treatment technologies, as well as more robust calculations and associated economies of size inferences. Future research is encouraged to apply this same methodology to calculate life-cycle costs for large-sized (e.g., 25 mgd) conventional surface-water and brackish-ground desalination facilities.

In addition, each facility analyzed has a different owner-entity and general manager, which implies possibilities of differing managerial philosophies along with different accounting methods. No attempt to adjust for a manager's decision-making ability was accounted for in this thesis, but it is acknowledged that differences in such abilities could affect a facility's life-cycle costs estimates. Also, as noted in footnotes throughout the results sections, several discrepancies were present among cost items when making economies of size calculations. These inconsistencies are perceived to be a product of different accounting methods between publicly-owned and privately-owned firms. For instance, it is believed that some costs included in the "Administrative" costs item at the La Sara facility would be more accurately included under the “All Other” costs item if consistency with the categorization of costs for the other facilities is desired. As a result, artifacts are present for both the “All Other” costs item and “Administrative” costs item when calculating the economies of size ratios. The aggregate estimate does not suffer from this limitation, however.

Another limitation of this thesis is that the effects of different incoming water quality are not considered, but it is recognized that incoming water quality needs to be normalized across all of the facilities, if one wishes to precisely compare technologies. As such, the calculated life-cycle costs include the expenses necessary for an individual facility to take its raw source water to potable water. Incoming water that contains higher levels of TDS and/or salinity reduces the life expectancy of components and/or can require more chemicals and energy to treat the water to a potable level, causing higher chemical, energy, and/or capital replacement costs (White 2007). That is, incoming water quality affects life-cycle costs for a facility. If the objective is for a direct comparison of different facilities, such abnormalities need to be neutralized before proceeding with the analyses.

Finally, the results for this thesis are limited to the facilities studied, but provide insight for the LRGV region. Certain factors that are unique to the LRGV (e.g., $2,300/ac-ft municipal water rights) make brackish-groundwater desalination more economically competitive than the literature generalizes for the entire U.S. However, the methodology and models used in this thesis are thought to be applicable to other regions.

CONCLUSION

For future water planning in the LRGV, municipalities, IDs, planning groups, state agencies, and engineers will search and choose among both traditional and alternative water treatment technologies. Economics (e.g., life-cycle costs) are an important component in evaluating that choice, and more particularly are the existence and degree to which economies of size are found in the different treatment technologies. Capital budgeting – NPV analyses combined with the annuity-equivalent methodology offer an effective evaluation technique as it provides life-cycle costs of treating/producing potable water for the different capital water projects. The economies of size ratio provides an equally effective evaluation of the long-run returns to size for the capital water projects. That is, sound economic and financial analyses contribute useful information toward making cost-effective decisions. The results of this thesis lead to the conclusion that brackish-groundwater desalination is an economically-viable alternative to surface-water treatment in the Lower Rio Grande Valley. Further, the results determine that economies of size are present for conventional surface-water treatment and constant economies of size are present in brackish-groundwater desalination. These results indicate that determining accurate costs for both water treatment technologies, as well as for alternative facility sizes, are important considerations as the region seeks to expand its potable water supplies to meet future demand.

REFERENCES

Arroyo, J.A. 2005. "Water Desalination." Texas Water Development Board Report 360, Austin, Texas.

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

Boisvert, R.N., and T.M. Schmit. 1996. "Tradeoff between Economies of Size in Treatment and Diseconomies of Distribution for Rural Water System." *Agricultural and Resource Economics Review* 26(2):237-46.

Browning, C. 2007, June. Personal Communication. General Manager of North Alamo Water Supply Corporation, Edinburg, Texas.

Characklis, G.W. 2004. "Economic Decision Making in the Use of Membrane Desalination for Brackish Supplies." *Journal of American Water Resource Association* 40(3):615-630.

Chowdhury, A., and M.J. Turco. 2006. "Geology of the Gulf Coast Aquifer, Texas." Texas Water Development Board Report 365, Austin, Texas.

Chowdhury, A., and R.E. Mace. 2007. "Groundwater Resource Evaluation and Availability of the Gulf Coast Aquifer in the Lower Rio Grande Valley of Texas." Texas Water Development Board Report 368, Austin, Texas.

College Station Utilities. 2006. "Water Illustrated-2006 Water Quality Report." Available at: http://www.cstx.gov/docs/1628521962007water_quality_report_06_web.pdf. Accessed June 5, 2008.

Cruz, O. 2008, January. Personal Communication. President of Cruz-Hogan Consultants, Harlingen, Texas.

Elium, J., III. 2008, January. Personal Communication. Manager of Olmito Water Supply Corporation, Olmito, Texas.

Foldager, R. 2003. "Economics of Desalination Concentrate Disposal Methods in Inland Regions: Deep-Well Injection, Evaporation Ponds, and Salinity Gradient Solar Ponds." Available at http://wrri.nmsu.edu/research/rfp/studentgrants03/reports/foldager.pdf. Accessed June 15, 2007.

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

Kay, R.D., and W.M. Edwards. 1994. *Farm Management*. 3rd Edition. New York: McGraw-Hill.

Maurice, C.S., and C.R. Thomas. 2002. *Managerial Economics*. 7th Edition. New York: McGraw-Hill.

Norris, J.W. 2006a. “Southmost Regional Water Authority Regional Desalination Plant.” Available at http://www.twdb.state.tx.us/Desalination/The%20Future%20of%20Desalination%20in%20Texas%20-%20Volume%202/documents/D7.pdf. Accessed July 15, 2007.

Norris, J.W. 2006b. “Development of Brackish GroundWater Resources in South Texas: An Alternative to the Rio Grande.” Texas Water Development Board Report 365, Austin, Texas.

North Alamo Water Supply Corporation (NAWSC). 2007. Available at www.nawsc.com. Accessed July 2007.

Rister, M.E., R.D. Lacewell, J.R. Robinson, J.R. Ellis, and A.W. Sturdivant. 2008. “Economic Methodology for South Texas Irrigation Projects - RGIDECON©.” Texas Water Resources Institute TR-203 revised, College Station, Texas.

Rogers, C.S. 2008. “Economic Costs of Conventional Surface-Water Treatment: A Case Study of the McAllen Northwest Facility.” Master of Science thesis, Department of Agricultural Economics Texas A&M University, College Station, Texas.

Rogers, C.S., A.W. Sturdivant, M.E. Rister, R.D. Lacewell, and J.G. Santiago. 2008. “Economic Costs of Conventional Surface-Water Treatment: A Case Study of the McAllen Northwest Plant.” Texas Water Resource Institute TR-311, College Station, Texas.

Spencer, S. 2005. “Mexico Pays Rio Grande Water Deficit.” News Release of the Office of the Commissioner, International Boundary and Water Commission, U.S. Section. El Paso, Texas.

Stubbs, M.J., M.E. Rister, R.D. Lacewell, J.R. Ellis, A.W. Sturdivant, J.R.C. Robinson, and L. Fernandez. 2003. “Evaluation of Irrigation Districts and Operating Institution: Texas, Lower Rio Grande Valley.” Texas Water Resources Institute TR-228, College Station, Texas.

Sturdivant, A.W., M.E. Rister, R.D. Lacewell, J.W. Norris, J. Leal, C.S. Rogers, J. Garza, and J. Adams. 2008. “Economic Costs of Desalination in South Texas: A Case Study of the Southmost Facility.” Texas Water Resources Institute TR-295, College Station, Texas.

Texas Legislature Online. 2008. *Texas Water Code: Chapter 67. Nonprofit Water Supply or Sewage Service Corporations.* Available at: http://tlo2.tlc.state.tx.us/statutes/wa.toc.htm. Accessed March 1, 2008.

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

Texas Water Development Board (TWDB). 2006. “Population and Water Demand Projections.” *2007 State Water Plan.* 4:122.

Traviglia, A.M., and G.W. Characklis. 2006. “Considering Location, Compliance, and Storage in Decision on Brackish Water Resource Development.” *Journal of Water Resource Planning and Management* 132(6):513-9.

U.S. Census Bureau. 2000. *Census 2000 PHC-T-3. Ranking Tables for Metropolitan Atrea: 1990 and 2000*. Available at http://www.census.gov/population/cen2000/phc-t3/tab.pdf. Accessed September 2007.

U.S. General Service Administration. 2008. *The Catalog of Federal Domestic Assistance: 10.760 USDA Water and Waste Disposal Systems for Rural Communities.* Available at http://12.46.245.173/pls/portal30/CATALOG.PROGRAM_TEXT_RPT.SHOW?p_arg_names=prog_nbr&p_arg_values=10.760. Accessed March 8, 2008.

White, J. 2007, June. Personal Communication. Engineer-in-Training at NRS Consultant Engineers, Harlingen, Texas.

Yow, S.R. 2008. "An Investigation of Unintended Consequences of Legislation." Undergraduate thesis, Department of Agricultural Economics Texas A&M University, College Station, Texas.

APPENDIX A

Tables A1 and A2 are summaries of the sensitivity of the cost-per-unit (i.e., $/ac-ft and $/1,000 gals) for the Olmito facility across various continued costs and the production efficiency levels. The continued costs range from a plus or minus 10%, 20%, and 30% about the expected level, while production efficiency levels range from 42% to 92%, including the expected level. Across the given ranges of variation, the life-cycle costs for the Olmito facility range from a high of $1,914.73/ac-ft {$5.88/1,000 gals} to a low of $749.59/ac-ft {$2.30/1,000 gals} about the expected $1,393.28/ac-ft {$4.28/1,000 gals}. As expected, higher life-cycle costs are found when the continued costs increase and, likewise, higher life-cycle costs are found when production efficiency is reduced.

Tables A3 and A4 demonstrate the sensitivity of the cost-per-unit (i.e., $/ac-ft and $/1,000 gals) for the Olmito facility across various energy costs and the production efficiency levels. The energy costs range from a plus or minus 5%, 10%, and 20% about the expected level, while production efficiency levels range from 42% to 92%, including the expected level. Across the given ranges of variation, the life-cycle costs for the Olmito facility range from a high of $1,676.10/ac-ft {$5.14/1,000 gals} to a low of $895.10/ac-ft {$2.75/1,000 gals}, about the expected $1,393.28/ac-ft {$4.28/1,000 gals}. As expected, higher life-cycle costs are found when the energy costs increase and, likewise, higher life-cycle costs are found when production efficiency is lower than expected.

Table A1. Sensitivity Analysis of Cost of Treating Water ($/Acre-Foot), by Variations in Production and Annual Continued Costs at the Olmito Facility, in 2006 Dollars

Annual Continued Cost	Annual Water Production in $/acre-foot								
	941	1,008	1,053	1,120	**1,165**	1,277	1,389	1,613	2,061
	42%	45%	47%	50%	**52%**[a]	57%	62%	82%	92%
-30.0%	$1,393.08	$1,314.14	$1,267.12	$1,203.64	$1,165.38	$1,081.49	$1,011.14	$815.51	$749.59
-20.0%	$1,480.02	$1,397.28	$1,347.99	$1,281.44	$1,241.35	$1,153.42	$1,079.67	$874.61	$805.51
-10.0%	$1,566.96	$1,480.42	$1,428.86	$1,359.25	$1,317.31	$1,225.34	$1,148.20	$933.71	$861.43
0.0%[a]	$1,653.90	$1,563.55	$1,509.73	$1,437.06	**$1,393.28**	$1,297.26	$1,216.73	$992.81	$917.35
+10.0%	$1,740.84	$1,646.69	$1,590.60	$1,514.87	$1,469.24	$1,369.18	$1,285.26	$1,051.90	$973.28
+20.0%	$1,827.79	$1,729.85	$1,671.43	$1,592.68	$1,545.21	$1,441.10	$1,353.79	$1,111.00	$1,029.29
+30.0%	$1,914.73	$1,812.96	$1,752.34	$1,670.49	$1,621.17	$1,513.02	$1,422.32	$1,170.10	$1,085.12

[a] Numbers in bold represent the baseline results for the Olmito facility in its current operating status.

Table A2. Sensitivity Analysis of Cost of Treating Water ($/1,000 Gallons), by Variations in Production and Annual Continued Costs at the Olmito Facility, in 2006 Dollars

Annual Continued Cost	Annual Water Production in 1,000 gallons								
	306,600	328,500	343,100	365,000	**379,600**	416,100	452,600	525,600	671,600
	42%	45%	47%	50%	**52%**[a]	57%	62%	82%	92%
-30.0%	$4.28	$4.03	$3.89	$3.69	$3.58	$3.32	$3.10	$2.50	$2.30
-20.0%	$4.54	$4.29	$4.14	$3.93	$3.81	$3.54	$3.31	$2.68	$2.47
-10.0%	$4.81	$4.54	$4.39	$4.17	$4.04	$3.76	$3.52	$2.87	$2.64
0.0%[a]	$5.08	$4.80	$4.63	$4.41	**$4.28**	$3.98	$3.73	$3.05	$2.82
+10.0%	$5.34	$5.05	$4.88	$4.65	$4.51	$4.20	$3.94	$3.23	$2.99
+20.0%	$5.61	$5.31	$5.13	$4.89	$4.74	$4.42	$4.15	$3.41	$3.16
+30.0%	$5.88	$5.56	$5.38	$5.12	$4.98	$4.64	$4.36	$3.60	$3.33

[a] Numbers in bold represent the baseline results for the Olmito facility in its current operating status.

Table A3. Sensitivity Analysis of Cost of Treating Water ($/Acre-Foot), by Variations in Production and Annual Energy Cost at the Olmito Facility, in 2006 Dollars

Annual Energy Cost	Annual Water Production in acre-foot								
	941	1,008	1,053	1,120	**1,165**	1,277	1,389	1,613	2,061
	42%	45%	47%	50%	**52%**[a]	57%	62%	82%	92%
-20.0%	$1,631.71	$1,541.36	$1,487.54	$1,414.87	$1,371.04	$1,275.07	$1,194.53	$970.61	$895.10
-10.0%	$1,642.81	$1,552.46	$1,498.63	$1,425.97	$1,382.18	$1,286.16	$1,205.63	$981.71	$906.26
-5.0%	$1,648.36	$1,558.00	$1,504.18	$1,431.51	$1,387.73	$1,291.71	$1,211.18	$987.26	$911.81
0.0%[a]	$1,653.90	$1,563.55	$1,509.73	$1,437.06	**$1,393.28**	$1,297.20	$1,216.73	$992.81	$917.35
+5.0%	$1,659.45	$1,569.10	$1,515.28	$1,442.61	$1,398.83	$1,302.81	$1,222.27	$998.35	$922.90
+10.0%	$1,665.00	$1,574.65	$1,520.82	$1,448.16	$1,404.37	$1,308.35	$1,227.82	$1,003.90	$928.45
+20.0%	$1,676.10	$1,585.75	$1,531.92	$1,459.26	$1,415.47	$1,319.45	$1,238.92	$1,015.00	$939.55

[a] Numbers in bold represent the baseline results for the Olmito facility in its current operating status.

Table A4. Sensitivity Analysis of Cost of Treating Water ($/1,000 Gallons), by Variations in Production and Annual Energy Cost at the Olmito Facility, in 2006 Dollars

Annual Energy Cost	Annual Water Production in 1,000 gallons								
	306,600	328,500	343,100	365,000	**379,600**	416,100	452,600	525,600	671,600
	42%	45%	47%	50%	**52%**[a]	57%	62%	82%	92%
-20.0%	$5.01	$4.73	$4.57	$4.34	$4.21	$3.91	$3.67	$2.98	$2.75
-10.0%	$5.04	$4.76	$4.60	$4.38	$4.24	$3.95	$3.70	$3.01	$2.78
-5.0%	$5.06	$4.78	$4.62	$4.39	$4.26	$3.96	$3.72	$3.03	$2.80
0.0%[a]	$5.08	$4.80	$4.63	$4.41	**$4.28**	$3.98	$3.73	$3.05	$2.82
+5.0%	$5.09	$4.82	$4.65	$4.43	$4.29	$4.00	$3.75	$3.06	$2.83
+10.0%	$5.11	$4.83	$4.67	$4.44	$4.31	$4.02	$3.77	$3.08	$2.85
+20.0%	$5.14	$4.87	$4.70	$4.48	$4.34	$4.05	$3.80	$3.12	$2.88

[a] Numbers in bold represent the baseline results for the Olmito facility in its current operating status.

APPENDIX B

Tables B1 and B2 demonstrate the sensitivity of the cost-per-unit (i.e., $/ac-ft and $/1,000 gals) for the La Sara facility across various continued costs and the production efficiency levels. The continued costs range from a plus or minus 10%, 20%, and 30% about the expected level, while production efficiency levels range from 50% to 100%, including the expected level. Across the given ranges of variation, the life-cycle costs for the La Sara facility range from a high of $1,069.87/ac-ft {$3.28/1,000 gals} to a low of $446.22/ac-ft {$1.37/1,000 gals}, about the expected $745.25/ac-ft {$2.29/1,000 gals}. As expected, higher life-cycle costs are found when the continued costs increase and, likewise, higher life-cycle costs are found when production efficiency is reduced.

Tables B3 and B4 demonstrate the sensitivity of the cost-per-unit (i.e., $/ac-ft and $/1,000 gals) for the La Sara facility across various energy costs and the production efficiency levels. The energy costs range from a plus or minus 5%, 10%, and 20% about the expected level, while production efficiency levels range from 50% to 100%, including the expected level. Across the given ranges of variation, the life-cycle costs for the La Sara facility range from a high of $934.51/ac-ft {$2.87/1,000 gals} to a low of $530.89/ac-ft {$1.63/1,000 gals} about the expected $745.25/ac-ft {$2.29/1,000 gals}. As expected, higher life-cycle costs are found when the energy costs increase and, likewise, higher life-cycle costs are found when production efficiency is decreased.

Table B1. Sensitivity Analysis of Cost of Producing Water ($/Acre-Foot), by Variations in Production and Annual Continued Costs at the La Sara Facility, in 2006 Dollars

Annual Continued Cost	Annual Water Production in acre-foot								
	635	698	762	800	**825**	951	1,078	1,141	1,268
	50%	55%	60%	63%	**65%**[a]	75%	85%	90%	100%
-30.0%	$718.28	$668.88	$627.69	$606.11	$592.83	$537.01	$494.30	$476.49	$446.22
-20.0%	$776.88	$724.41	$680.67	$657.74	$643.63	$584.35	$538.98	$520.07	$487.92
-10.0%	$835.48	$779.94	$733.64	$709.37	$694.44	$631.69	$583.67	$563.66	$529.62
0.0%[a]	$894.08	$835.47	$786.61	$761.01	**$745.25**	$679.03	$628.36	$607.24	$571.33
+10.0%	$952.67	$891.00	$839.58	$812.64	$796.05	$726.37	$673.05	$650.82	$613.03
+20.0%	$1,011.27	$946.53	$892.55	$864.27	$846.86	$773.71	$717.73	$694.40	$654.73
+30.0%	$1,069.87	$1,002.06	$945.53	$915.90	$897.67	$821.05	$762.42	$737.99	$696.43

[a] Numbers in bold represent the baseline results for the La Sara facility in its current operating status.

Table B2. Sensitivity Analysis of Cost of Producing Water ($/1,000 Gallons), by Variations in Production and Annual Continued Costs at the La Sara Facility, in 2006 Dollars

Annual Continued Cost	Annual Water Production in 1,000 gallons								
	206,903	227,525	248,148	260,521	**268,770**	310,015	351,260	371,883	413,128
	50%	55%	60%	63%	**65%**[a]	75%	85%	90%	100%
-30.0%	$2.20	$2.05	$1.93	$1.86	$1.82	$1.65	$1.52	$1.46	$1.37
-20.0%	$2.38	$2.22	$2.09	$2.02	$1.98	$1.79	$1.65	$1.60	$1.50
-10.0%	$2.56	$2.39	$2.25	$2.18	$2.13	$1.94	$1.79	$1.73	$1.63
0.0%[a]	$2.74	$2.56	$2.41	$2.34	**$2.29**	$2.08	$1.93	$1.86	$1.75
+10.0%	$2.92	$2.73	$2.58	$2.49	$2.44	$2.23	$2.07	$2.00	$1.88
+20.0%	$3.10	$2.90	$2.74	$2.65	$2.60	$2.37	$2.20	$2.13	$2.01
+30.0%	$3.28	$3.08	$2.90	$2.81	$2.75	$2.52	$2.34	$2.26	$2.14

[a] Numbers in bold represent the baseline results for the La Sara facility in its current operating status.

Table B3. Sensitivity Analysis of Cost of Producing Water ($/Acre-Foot), by Variations in Production and Annual Energy Costs at the La Sara Facility, in 2006 Dollars

Annual Energy Cost	Annual Water Production in acre-foot								
	635	698	762	800	**825**	951	1,078	1,141	1,268
	50%	55%	60%	63%	**65%**[a]	75%	85%	90%	100%
-20.0%	$853.64	$795.04	$746.17	$720.57	$704.81	$638.59	$587.92	$566.80	$530.89
-10.0%	$873.86	$815.25	$766.39	$740.79	$725.03	$658.81	$608.14	$587.02	$551.11
-5.0%	$883.97	$825.36	$776.50	$750.90	$735.14	$668.92	$618.25	$597.13	$561.22
0.0%[a]	$894.08	$835.47	$786.61	$761.01	**$745.25**	$679.03	$628.36	$607.24	$571.33
+5.0%	$904.19	$845.58	$796.72	$771.12	$755.36	$689.14	$638.47	$617.35	$581.43
+10.0%	$914.29	$855.69	$806.83	$781.22	$765.46	$699.25	$648.58	$627.46	$591.54
+20.0%	$934.51	$875.91	$827.05	$801.44	$785.68	$719.46	$668.80	$647.68	$611.76

[a] Numbers in bold represent the baseline results for the La Sara facility in its current operating status.

Table B4. Sensitivity Analysis of Cost of Producing Water ($/1,000 Gallons), by Variations in Production and Annual Energy Costs at the La Sara Facility, in 2006 Dollars

Annual Energy Cost	Annual Water Production in 1,000 gallons								
	206,903	227,525	248,148	260,521	**268,770**	310,015	351,260	371,883	413,128
	50%	55%	60%	63%	**65%**[a]	75%	85%	90%	100%
-20.0%	$2.62	$2.44	$2.29	$2.21	$2.16	$1.96	$1.80	$1.74	$1.63
-10.0%	$2.68	$2.50	$2.35	$2.27	$2.23	$2.02	$1.87	$1.80	$1.69
-5.0%	$2.71	$2.53	$2.38	$2.30	$2.26	$2.05	$1.90	$1.83	$1.72
0.0%[a]	$2.74	$2.56	$2.41	$2.34	**$2.29**	$2.08	$1.93	$1.86	$1.75
+5.0%	$2.77	$2.60	$2.45	$2.37	$2.32	$2.11	$1.96	$1.89	$1.78
+10.0%	$2.81	$2.63	$2.48	$2.40	$2.35	$2.15	$1.99	$1.93	$1.82
+20.0%	$2.87	$2.69	$2.54	$2.46	$2.41	$2.21	$2.05	$1.99	$1.88

[a] Numbers in bold represent the baseline results for the La Sara facility in its current operating status.

VITA

Name: Christopher Neil Boyer

Address: 318 F John R. Blocker Building
2124 TAMU
College Station, Texas 77843-2124

Email Address: chris.n.boyer@gmail.com

Education: B.S., Agricultural Business, Texas A&M University, May 2006
M.S., Agricultural Economics, Texas A&M University, August 2008