Identifying Economies of Size in Conventional Surface Water Treatment and Brackish-Groundwater Desalination: Case Study in the Rio Grande Valley of Texas

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ABSTRACT: Two primary potable water-treatment technologies used in South Texas include conventional surface-water and reverse-osmosis (RO) desalination of brackish-groundwater. As the region's population continues to grow, municipalities are searching for economical means to expand their water supplies. Economies of size for both technologies are an important consideration for future expansion decisions.

Introduction

The Texas Lower Rio Grande Valley's (LRGV) population is projected to more than double from 2010 to 2060 (Texas Water Development Board (TWDB 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,[1] have resulted in LRGV municipalities considering new construction of both traditional and alternative-technology capital projects to meet growing water demand.

Historically, the Rio Grande [River] has been the LRGV region's primary source of potable (drinkable) water. Municipalities typically use a technology referred to as conventional surface-water treatment to treat Rio Grande water for their residents. In anticipation of the increase in municipal-water demand, the City of McAllen built a new conventional surface-water treatment plant in 2004 which expanded its water system capacity by 8.25 million gallons per day (mgd) (i.e., maximum designed capacity). Directly North of Brownsville, Texas, Olmito Water Supply Corporation (OWSC) is expecting to refurbish and expand its current 1.0 mgd conventional-surface water treatment facility to 2.0 mgd in 2008-2009.

Recognizing the diversification benefits and estimated cost competitiveness of 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 alternative technology is intended to reduce the City of Brownsville's water-supply risks associated with

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[1] The 1944 Treaty requires the United States and Mexico to share the downstream water release from these two 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).

drought, shortfalls in water deliveries, and/or contamination. In November 2004, the North Alamo Water Supply Corporation (NAWSC) began operating its 1.1 mgd La Sara facility. This reverse-osmosis (RO) desalination facility treats brackish-groundwater and distributes potable water to 16 small rural communities in Willacy, Hidalgo, and northwestern Cameron counties (NAWSC 2007).

This study builds on two earlier case studies which analyzed the economic and financial life-cycle costs of producing potable water in the LRGV of Texas with conventional surface-water treatment (Rogers et al. 2008) and brackish-groundwater desalination (Sturdivant et al. 2008). Specifically, this study reports on life-cycle costs for four facilities (i.e., two from these prior studies and two additional, smaller facilities representing both technologies) and then discusses and reports on the *economies of size* for both technologies.[2] The study matrix indicated in Table 1 identifies the mix of facilities, technologies, and sizes evaluated.

Table 1. Matrix of Potable Water Treatment Facility Names, Size Category, Capacities (mgd), and Technology Types Used in this Study as a Basis of Discussing and Reporting on Economies of Size, 2008.

Size Category	Facility Names & Maximum Designed Capacities			
	Conventional Surface-Water		Reverse Osmosis Desalination	
Small	Olmito WSC	(2.0 mgd)	NAWSC - La Sara	(1.1 mgd)
Medium	McAllen Northwest	(8.25 mgd)	Brownsville - Southmost	(7.5 mgd)

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[2] *Economies of size* is a concept referring to a change in output brought about by a non-proportionate change in production inputs (Beattie and Taylor 1985).

Summary of Methodology and Models Used to Calculate Life-Cycle Costs

For each of the four facilities' analyses, Capital Budgeting - Net Present Value (NPV) analysis, in combination with the calculation of annuity equivalents (AEs), are the methodology of choice because of the capability of integrating expected useful life with related annual costs and outputs, as well as consideration of other financial realities into a comprehensive $/ac-ft/year {or $/1,000 gallons/year} *life-cycle* cost.[3] To facilitate this preferred methodology, agricultural economists from Texas AgriLife Extension Service and Texas AgriLife Research developed two Microsoft$_{®}$ Excel$_{®}$ spreadsheet models, DESAL ECONOMICS© and CITY H_2O ECONOMICS©. These models analyze and provide life-cycle costs (e.g., $/ac-ft/year) for producing and delivering potable water to a point within the municipal water-delivery system. "Apples to apples" comparisons can be made across facilities, both within and across the models (i.e., technologies), so long as certain prescribed modifications are made.

The first aspect of the methodology (i.e., NPV analysis) places potential uneven streams of dollars (i.e., costs) and water production (across a facility's total useful life) into a time-adjusted, or time- and inflation-adjusted basis (i.e., current year). That is, in short, to 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 ongoing operations. Each 'project' is then expected to have both a level of productivity and potable water quality for some number of years into the future. With an expected life lasting into future years, financial realities such as inflation, the time-value of money, and other

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[3] 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."

discounting considerations are incorporated. Specifically, the models/methodology incorporate a 6.125% discount rate for dollars (i.e., the multiplicative product of a 4.000% discount factor for social-time preference, a 2.043% cost-compound factor to account for inflation, and a 0.000% factor for risk as a government entity is generally providing funding assistance/guarantee).[4] 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' (i.e., facilities and their respective cash flows and water-production levels which will likely vary from facility to facility).

The second aspect of the methodology transforms the summed NPV values (i.e., summed dollars and water over the course of the entire expected useful life) into annuity equivalents, or "annualized amounts." The calculations necessarily calculate the two AE values (i.e., dollars and water) separately. With the two separate AE values, the methodology divides the AE for dollars by the AE for water. The resultant value is a dollar-per-unit value (i.e., $ per ac-ft/yr, or $ per 1,000 gallons/yr), or life-cycle cost for a given facility and its associated technology.[5] These *baseline* results are useful within a facility's analysis, but are inappropriate for use in comparing different facilities (within a technology) or comparing different technologies. Such analyses require *modified* results which are "leveled" across five common data-input parameters.[6]

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[4] For additional reading on discount rates and factors, refer to Rister et al. (2002).

[5] Assumed in the calculations and methodology are zero net salvage value (for land, buildings, equipment, water rights, etc.) and a continual replacement of such capital items into perpetuity.

[6] Modified results from a "leveled" analysis is discussed more in the next section, but the general thought refers to removing and/or modifying impacts from certain facility characteristics (e.g., construction design, managerial techniques, location differences, operating efficiency levels) which may result in misleading representations of the expected life-cycle costs of production for a particular facility and its associated technology.

Modifying Base Analyses to Compare Facilities and Technologies

The baseline results for each facility's analysis depicts the facility in its current operating state. While the results for each were determined using either the *DESAL ECONOMICS*© or *CITY H_2O ECONOMICS*© models (previously advocated as being appropriate for making *apples-to-apples* comparisons of water-supply alternatives' life-cycle costs), some adjustments are necessary to level the data as part of the analytical process to correctly make comparisons of life-cycle costs across different facilities and technologies. That is, inherent variations in key data-input parameters (at different facilities and/or for different technologies) can greatly distort subsequent comparisons. To correctly compare across facilities, the following data-input parameters are modified according to Sturdivant et al. (2008):

(1) the <u>base period of analysis</u> assumes the construction period commences on January 1, 2006, thereby insuring financial calculations occur across a common time frame. For facilities constructed in different time periods, either inflating or deflating the appropriate cost values (i.e., initial construction, water rights' purchase, continuing, and capital replacement) are necessary to accommodate this stated benchmark period;

(2) the <u>annual production efficiency</u> is set at a constant 85% production efficiency (PE) rate. This stated proportion of maximum-designed capacity is reasonable, allowing for planned and unplanned downtime (e.g., maintenance, emergencies, demand interruptions, etc.), and

complies with the *Rule of 85*.[7] Leveling the PE to this stated rate for each alternative avoids potential bias associated with operating circumstances at particular sites;[8]

(3) any potential <u>Overbuilds & Upgrades costs are ignored</u> in determining the total life-cycle cost.[9] Doing so ignores *non-essential* costs which allows a leveled comparison of:

(a) different technologies based upon only the technology itself (i.e., indifferent as to the inclusion and level of non-essentials), and (b) economies of size within (or across) a technology;

(4) the <u>salvage, or residual value of capital assets, including water rights are assumed to have an effective net salvage value of zero dollars</u> 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 buildings, land, etc.) are intended to be long term, with no expectations of ever 'salvaging' the asset(s);[10] and

(5) the <u>quality of water should be analyzed with similar quality standards</u> imposed on each of the analyses so that quality of water produced and chemical and other operating costs are not

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[7] The Rule of 85 refers to a Texas Commission on Environmental Quality (TCEQ)-mandated capacity requirement level (%) which <u>could</u> directly impact individual facilities. In simplified terms, when a public utility (possessing a certificate of public convenience and necessity) reaches 85% of its capacity, it must submit to TCEQ a service-demand plan, including cost projections and installation dates for additional facilities. Thus, although a facility may be operable at greater than 85% capacity, it may necessarily be constrained (over the long term) to a lower PE rate as the public entity manages the operations of a portfolio of water supply/treatment facilities (University of North Texas 2007).

[8] In reality, individual facilities operate at different PE rates, for many different reasons. In addition to the constraint induced by "The Rule of 85," 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.

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

[10] 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.

adversely compromised in any of the comparative projects. The comparable quality standard assumed for these analyses is the requirement that the product potable water pass both the maximum contaminant levels and secondary levels set by both TCEQ and Environmental Protection Agency (EPA).

These modified results for individual facilities are comparable and useful toward the investigation of economies of size. That is, after all facilities' analyses are "leveled," the modified life-cycle costs of differing facilities (either by size and/or technology) (e.g., the McAllen Northwest conventional surface-water treatment and the Southmost desalination facilities) are comparable to the modified life-cycle costs of the smaller facilities (i.e., Olmito conventional surface-water treatment and the La Sara desalination facilities).

Economies of Size

As noted in Sturdivant et al. (2008), 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 in fixed proportion* (Beattie and Taylor 1985). In the specific case of increasing output capacities of water treatment facilities, however, not all production factors (e.g., land, labor, capital, management, etc.) are increased proportionately to attain the increased output. Therefore, the correct term is 'economies of size' -- the concept that economies (or decreasing marginal and average variable costs) are incurred as output is increased from a non-proportional increase in the 'size' (i.e., level) of some or all factors of production (i.e., inputs). That is, 'scale' refers to a proportionate change in all production inputs, whereas 'size' refers to a non-proportionate change in some or all production inputs (Beattie and Taylor 1985). Based on Kay and Edwards (1994), the economic concept of economies of size is expressed mathematically as:

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

Economies of size 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 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 exist if the life-cycle costs increase as the production of potable water increases, i.e., the ESR is greater than one.

Modified Results: Life-Cycle Costs[11]

As indicated in Table 1, four individual potable water-treatment facilities are incorporated herein. Below, an abridged discussion of certain input data and the life-cycle cost results are provided for each. The conventional surface-water treatment facilities are discussed first, with the reverse-osmosis (RO) desalination of brackish groundwater facilities discussed next. For brevity's sake, the discussion focuses on real (vs. nominal) values for only the "modified" analyses as the baseline analyses are inadequate for making comparisons.

Conventional Surface-Water Treatment Facilities

(1) The Olmito Facility (2.0 mgd). The total amount of money estimated to be spent on this facility for water-rights purchase, initial construction, continued, and capital-replacement

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[11] The modified life-cycle cost results presented herein for the Olmito surface-water treatment facility and the ensuing comparisons and associated discussion should be cautiously interpreted as they are very preliminary and are subject to revision in early 2008. Nonetheless, the results are insightful and useful.

costs amount to a nominal value of \$148,293,242.[12] Adjusting this value for time and inflation results in a real value of \$42,969,519 per year (Table 2). Annualizing this real value results in an annuity equivalent of \$2,765,245 (Table 2). This value represents the total annual amount of money to be spent on constructing and operating the Olmito facility (basis 2006 dollars) over the course of its expected useful life. Refer to Table 3 for additional details.

The total amount of water estimated to be produced over the Olmito facility's useful life totals 95,212 ac-ft in nominal terms. Adjusting for a 4.0% social-time preference (Griffin and Chowdhury 1993) results in a real volume of 39,334 ac-ft (Table 2). Annualizing this real volume results in an annuity equivalent of 1,820 ac-ft (Table 2). Dividing the two annuity equivalents results in a life-cycle cost of \$1,519.75/ac-ft/yr {\$4.6639/1,000 gallons/yr} (Table 2) for the modified analysis. Consistent with the methodology in Rister et al. (2002), this value represents the annual cost of producing (and delivering, to a point within the municipal water-delivery system) one ac-ft {1,000 gallons} of potable water, in 2006 dollars.

(2) The McAllen Northwest Facility (8.25 mgd). The total amount of money estimated to be spent on this facility for water-rights purchase, initial construction, continued, and capital-replacement costs amount to a nominal value of \$199,159,431 (Rogers et al. 2008). Adjusting this value for time and inflation results in a real value of \$72,633,777 per year (Table 2). Annualizing this real value results in an annuity equivalent of \$4,660,618 (Table 2). This value represents the total annual amount of money to be spent on constructing and operating the McAllen Northwest facility (basis 2006 dollars) over the course of its expected useful life.

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[12] The data input for the 'Olmito Facility' is based on information provided by Elium (2007) and Cruz (2008) for a 1-mgd expansion of an existing 1-mgd facility at Olmito. Adjustments to the initial 1-mdg cost data (i.e., initial, continuing, and capital replacement) were made to reflect cost estimates required of a 2-mgd facility. Thus, data for the 2-mgd facility analyzed herein were extrapolated from costs representative of a 1-mgd facility.

Table 2. Modified Aggregate Results for the Life-Cycle Costs of Producing Water at the Olmito (2.0 mgd) and the McAllen Northwest (8.25 mgd) Conventional Surface-Treatment Facilities, and the La Sara (1.1 mgd) and Southmost (7.5) Desalination Facilities, 2006.[a, b, c]

		Conventional Surface-Treatment		Desalination	
Results	Units	Olmito	McAllen Northwest	La Sara	Southmost
NPV of Total Cost Stream	2006 dollars	$42,969,519	$72,633,777	$10,049,721	$65,208,300
- annuity equivalent	$/year	$2,765,245	$4,660,618	$646,736	$4,196,391
NPV of Water Produced	ac-ft (lifetime)	39,334	156,012	22,224	147,502
- annuity Equivalent	ac-ft/year	1,820	7,174	1,028	6,823
NPV of Water Produced	1,000 gal (lifetime)	12,817,015	50,836,718	7,241,613	48,063,806
- annuity Equivalent	1,000 gal/year	592,900	2,337,580	334,989	2,223,376
Cost of Producing Water	$/ac-ft/yr	$1,519.75	$649.67	$629.09	$615.01
Cost of Producing Water	$/1,000 gal/yr	$4.6639	$1.9938	$1.9306	$1.8874

[a] These results are the adjusted (or modified) analyses of the individual facilities (i.e., all 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 4.00% discount factor for water, and a 0% risk factor (Rister et al.).

[c] Results for the Olmito and La Sara facilities are considered very preliminary and subject to confirmation by facility operators.

Table 3. “Modified” Life-Cycle Costs of Producing Water by Cost Type and Item, for the Olmito (2.0 mgd) and the McAllen Northwest (8.25 mgd) Conventional Water-Treatment Facilities, 2006.[a, b]

	Olmito (Conventional)					McAllen Northwest (Conventional)				
Cost Type and Item	NPV of Cost Stream	Annuity Equivalent in $/yr	Annuity Equivalent in $/ac-ft/yr	Annuity Equivalent in $/1,000 gallons/yr	% of Total Cost	NPV of Cost Stream	Annuity Equivalent in $/yr	Annuity Equivalent in $/ac-ft/yr	Annuity Equivalent in $/1,000 gallons/yr	% of Total Cost
Initial Construction/Investment	**$11,222,998**	**$722,241**	**$396.94**	**$1.2181**	**15%**	**$37,397,088**	**$2,399,621**	**$334.50**	**$1.0265**	**52 %**
- Water Right Purchase	*4,946,555*	*318,329*	*174.95*	*0.5369*	*12%*	*20,404,541*	*1,309,277*	*182.51*	*0.5601*	*28 %*
Continued	**31,663,382**	**2,037,654**	**1,119.87**	**3.4368**	**74%**	**34,531,504**	**2,215,748**	**308.87**	**0.9479**	**47 %**
- Energy	*1,940,123*	*124,854*	*68.62*	*0.2106*	*5%*	*7,239,217*	*464,511*	*64.75*	*0.1987*	*10 %*
- Chemicals	*1,978,045*	*127,294*	*69.96*	*0.2147*	*5%*	*5,789,663*	*371,499*	*51.79*	*0.1589*	*8 %*
- Labor	*12,146,154*	*781,649*	*429.59*	*1.3183*	*28%*	*7,124,847*	*457,173*	*63.73*	*0.1956*	*10 %*
- Raw Water Delivery	*1,227,425*	*78,989*	*43.41*	*0.1332*	*3%*	*9,472,261*	*607,797*	*84.72*	*0.2600*	*13 %*
- All Other	*14,371,634*	*924,869*	*508.30*	*1.5599*	*33%*	*3,270,998*	*209,887*	*29.26*	*0.0898*	*5 %*
Capital Replacement	**83,140**	**5,350**	**2.94**	**0.0090**	**1%**	**705,185**	**45,249**	**6.30**	**0.0194**	**1 %**
Total	$42,969,519	$2,765,425	$1,519.75	$4.6639	100%	$72,633,777	$4,660,617	$649.67	$1.9938	100.0 %

[a] These results are the adjusted (or modified) analyses of the individual facilities (i.e., all 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] Results for the Olmito and La Sara facilities are considered very preliminary and subject to confirmation by facility operators.

The total amount of water estimated to be produced over the McAllen Northwest facility's useful life totals 392,750 ac-ft in nominal terms. Adjusting for a 4.0% social-time preference (Griffin and Chowdhury 1993) results in a real volume of 156,012 ac-ft (Table 2). Annualizing this real volume results in an annuity equivalent of 7,174 ac-ft (Table 2). Dividing the two annuity equivalents results in a life-cycle cost of $649.67/ac-ft/yr {$1.9938/1,000 gallons/yr} (Table 2) for the modified analysis. Consistent with the methodology in Rister et al. (2002), this value represents the annual cost of producing (and delivering, to a point within the municipal water-delivery system) one ac-ft {1,000 gallons} of potable water, in 2006 dollars. Refer to Table 3 for additional details.

Desalination (Reverse-Osmosis) of Brackish Groundwater Treatment Facilities

(3) The La Sara Facility (1.1 mgd). The total amount of money estimated to be spent on this facility for initial construction, continued, and capital-replacement costs amount to a nominal value of $35,121,721.[13] Adjusting this value for time and inflation results in a real value of $10,049,721 per year (Table 2). Annualizing this real value results in an annuity equivalent of $646,736 (Table 2). This value represents the total annual amount of money to be spent on constructing and operating the La Sara facility (basis 2006 dollars) over the course of its expected useful life. Refer to Table 4 for additional details.

The total amount of water estimated to be produced over the La Sara facility's useful life totals 53,795 ac-ft in nominal terms. Adjusting for a 4.0% social-time preference (Griffin and

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[13] The data input for the 'La Sara Facility' is based on information provided by Browning (2007) and White (2007) for a 1.1-mgd facility in La Sara, Texas.

Table 4. “Modified” Life-Cycle Costs of Producing Water by Cost Type and Item, for the La Sara (1.1 mgd) and the Southmost Northwest (7.5 mgd) Brackish-Groundwater Desalination Facilities, 2006.[a, b]

	La Sara (Desalination)					Southmost (Desalination)				
Cost Type and Item	NPV of Cost Stream	Annuity Equivalent in $/yr	Annuity Equivalent in $/ac-ft/yr	Annuity Equivalent in $/1,000 gallons/yr	% of Total Cost	NPV of Cost Stream	Annuity Equivalent in $/yr	Annuity Equivalent in $/ac-ft/yr	Annuity Equivalent in $/1,000 gallons/yr	% of Total Cost
Initial Construction/Investment	**$2,536,527**	**$163,235**	**$158.78**	**$0.4873**	**25%**	**$22,022,150**	**$1.417,205**	**$207.70**	**$0.6374**	**34%**
Continued	**7,144,982**	**459,806**	**447.26**	**1.3726**	**71%**	**39,729,651**	**2,556,747**	**374.71**	**1.1499**	**61%**
- Energy	*3,229,856*	*207,853*	*202.18*	*0.6205*	*32%*	*21,078,014*	*1,356,447*	*198.80*	*0.6101*	*32%*
- Chemicals	*724,162*	*46,602*	*45.33*	*0.1391*	*7%*	*6,363,404*	*409,508*	*60.02*	*0.1842*	*10%*
- Labor	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*7,615,483*	*490,084*	*71.83*	*0.2204*	*12%*
- All Other	*548,805*	*35,318*	*34.35*	*0.1054*	*6%*	*2,780,863*	*178,959*	*26.23*	*0.0805*	*4%*
Capital Replacement	**368,212**	**23,696**	**23.05**	**0.0707**	**4%**	**3,456,499**	**222,438**	**32.60**	**0.1000**	**5%**
Total	$10,049,721	$646,736	$629.09	$1.9306	100%	$65,208,300	$4,196,391	$615.01	$1.8874	100%

[a] These results are the adjusted (or modified) analyses of the individual facilities (i.e., all 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] Results for the Olmito and La Sara facilities are considered very preliminary and subject to confirmation by facility operators.

Chowdhury 1993) results in a real volume of 22,224 ac-ft (Table 2). Annualizing this real volume results in an annuity equivalent of 1,028 ac-ft (Table 2). Dividing the two annuity equivalents results in a life-cycle cost of \$629.09/ac-ft/yr {\$1.9306/1,000 gallons/yr} (Table 2) for the modified analysis. Consistent with the methodology in Rister et al. (2002), this value represents the annual cost of producing (and delivering, to a point within the municipal water-delivery system) one ac-ft {1,000 gallons} of potable water, in 2006 dollars.

(4) The Southmost Facility (7.5 mgd). The total amount of money estimated to be spent on this facility for initial construction, continued, and capital-replacement costs amount to a nominal value of \$209,423,179 (Sturdivant et al. 2008). Adjusting this value for time and inflation results in a real value of \$65,208,300 per year (Table 2). Annualizing this real value results in an annuity equivalent of \$4,196,391 (Table 2). This value represents the total annual amount of money to be spent on constructing and operating the Southmost facility (basis 2006 dollars) over the course of its expected useful life. Refer to Table 4 for additional details.

The total amount of water estimated to be produced over the Southmost facility's useful life totals 357,046 ac-ft in nominal terms. Adjusting for a 4.0% social-time preference (Griffin and Chowdhury 1993) results in a real volume of 147,502 ac-ft (Table 2). Annualizing this real volume results in an annuity equivalent of 6,823 ac-ft (Table 2). Dividing the two annuity equivalents results in a life-cycle cost of \$615.01/ac-ft/yr {\$1.8874/1,000 gallons/yr} (Table 2) for the modified analysis. Consistent with the methodology in Rister et al. (2002), this value represents the annual cost of producing (and delivering, to a point within the municipal water-delivery system) one ac-ft {1,000 gallons} of potable water, in 2006 dollars.

Comparison of Conventional and RO Desalination

Comparison of the comprehensive potable-water treatment costs presented in Table 2 for two conventional surface-water treatment facilities and in Table 3 for two RO-desalination facilities is suggestive that this type of desalination technology has reached economic feasibility. Focusing on the larger-size facilities of each technology type investigated in this research, the \$615.01 per ac-ft/yr {\$1.8874/1,000 gallons/yr} for the 7.5 mgd Southmost RO-desalination facility (Table 2) is marginally less expensive than the \$649.67 per ac-ft/yr {\$1.9938/1,000 gallons/yr} for the 8.25 mgd Northwest conventional surface-water treatment facility (Table 2). Greater magnitude of advantages to desalination are evident in the analyses for two smaller-size facilities of each technology investigated in this research, the 1.1 mgd La Sara RO-desalination facility (\$629.09 per ac-ft/yr {\$1.9306/1,000 gallons/yr}) and the 2.0 mgd Olmito conventional surface-water treatment facility (\$1,519.75 ac-ft/yr {\$4.6639/1,000 gallons/yr}) (Table 2).

Previous discussion associated with Tables 3 and 4 provided considerable insight as to the details associated with the results suggestive of the apparent competitiveness of brackish groundwater desalination. As stipulated in footnote 12 of this paper, admittedly, these results are conditional on the limited evaluation of two treatment plants of each type in the Texas Rio Grande Valley. Nonetheless, the methodological approach and the case study results are revealing and useful for stakeholders and others interested in identifying most economical alternatives of expanded future supplies of potable water. Further insights can also be obtained by considering the economies of size issue with respect to the brackish groundwater desalination and surface water conventional treatment plants, respectively.

Modified Results: Economies of Size

Conventional Treatment. Table 5 is a presentation of selected economies-of-size analysis results for the two conventional surface-water treatment facilities considered in this study. As previously identified in Table 2, the Olmito facility's real costs of producing potable water equal $1,519.75/ac-ft/yr and the Northwest facility's real costs of producing potable water are $649.67/ac-ft/yr. As evidenced by the lower cost of producing potable water for the medium-sized Northwest facility compared to the smaller-sized Olmito facility, some aggregate economies of size are evident between the two RO desalination facilities (Table 2). The calculated 0.23 ESR reported in Table 5 further documents the substantial nature of the decrease in relative per-unit costs, as the size of a conventional surface-water treatment facility increases.

Desalination. Table 6 is a presentation of selected economies-of-size analyses results for the two RO-desalination facilities considered in this study. As previously identified in Table 2, the La Sara facility's real costs of producing potable water equal $629.09/ac-ft/yr and the Southmost facility's real costs of producing potable water are $615.01/ac-ft/yr. As evidenced by the lower cost of producing potable water for the medium-sized Southmost facility compared to the smaller-sized La Sara facility, some aggregate economies of size are witnessed between the two RO-desalination facilities (Table 2). The calculated 0.97 ESR reported in Table 5 further documents the slight nature of the decrease in relative per-unit costs as the size of a RO-desalination facility increases.

Table 5. ***Economies of Size*** **Comparisons for Two Conventional Surface-Water Treatment Facilities in the Texas Rio Grande Valley - - Olmito (2.0 mgd) and McAllen Northwest (8.25 mgd) - - Using the "Modified" Analyses for Each, 2008.**

		Surface-Water Treatment Facility and Capacity			
Cost Type and Item	Unit	Olmito (2.0 mgd)	McAllen Northwest (8.25 mgd)[a]	Economies of Size Ratio (ESR)[b]	Economies of Size Inference[c]
Initial Construction/Investment	2006 dollars	$ 722,241	$ 2,399,621	0.79	E
- Water Rights Purchase	"	*$ 318,329*	*$ 1,309,277*	*1.06*	*slight D*
Continued	2006 dollars	$ 2,037,654	$ 2,215,748	0.03	E
- Energy	"	*$ 124,854*	*$ 464,511*	*0.92*	*E*
- Chemical	"	*$ 127,294*	*$ 371,499*	*0.65*	*E*
- Labor	"	*$ 781,649*	*$ 457,173*	*-0.14*	*high E*
- Raw Water Delivery	"	*$ 78,989*	*$ 607,797*	*2.28*	*high D*
- All Others	"	*$ 924,869*	*$ 209,887*	*-0.26*	*high E*
Capital Replacement	2006 dollars	$ 5,350	$ 45,249	2.54	high D
NPV of Total Cost Stream[d]	$/year	$ 2,265,425	$ 4,660,617	0.23	E

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

[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.

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

- Economies of Size ratio < 1 ... Economies of size exist (E)
- Economies of Size ratio = 1 ... Constant economies of size (C)
- Economies of Size ratio > 1 ... Diseconomies of size exist (D).

[d] These are the total net costs (real values; basis 2006 dollars) relevant to producing potable surface water for the life of each facility as they include initial capital-investment costs, increased O&M and capital replacement expenses, and ignore any value (or sales revenue) of the final water product.

Table 6. ***Economies of Size*** **Comparisons for Two Reverse-Osmosis (RO) Desalination Facilities in the Texas Rio Grande Valley Treating Brackish Groundwater - - La Sara (1.1 mgd) and Southmost (7.5 mgd) - - Using the "Modified" Analyses for Each, 2008.**

		Desalination Facility and Capacity			
Cost Type and Item	Unit	La Sara (1.1 mgd)	Southmost (7.5 mgd)[a]	Economies of Size Ratio (ESR)[b]	Economies of Size Inference[c]
Initial Construction/Investment	2006 dollars	$ 163,235	$ 1,417,205	1.36	D
Continued	2006 dollars	$ 459,809	$ 2,556,747	0.81	E
- Energy	"	*$ 207,853*	*$ 1,356,447*	*0.98*	*slight E*
- Chemical	"	*$ 46,602*	*$ 409,508*	*1.38*	*D*
- All Others	"	*$ 35,318*	*$ 669,043*	*3.18*	*D*
Capital Replacement	2006 dollars	$ 23,696	$ 222,438	1.49	D
NPV of Total Cost Stream[d]	$/year	$ 646,736	$ 4,196,391	0.97	slight E

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

[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.

[c] Interpretation (i.e., inference) of the calculated economies of size ratio results are:
- Economies of Size ratio < 1 ... Economies of size exist (E)
- Economies of Size ratio = 1 ... Constant economies of size (C)
- Economies of Size ratio > 1 ... Diseconomies of size exist (D).

[d] These are the total net costs (real values; basis 2006 dollars) relevant to producing RO-desalinated water for the life of each facility as they include initial capital-investment costs, increased O&M and capital replacement expenses, and ignore any value (or sales revenue) of the final water product.

Discussion

For future water planning in the LRGV, municipalities must search and choose among traditional and alternative capital water projects. Economics is an important component in that choice, and more particularly is the existence and degree to which economies of size are found in the different treatment technologies. The capital budgeting-NPV analyses combined with the annuity equivalent methodology are an effective evaluation of the life-cycle costs of producing potable water for the capital water projects. Sound economic and financial analyses should contribute useful information toward making effective decisions among traditional and alternative capital water projects. The results presented in this research are suggestive that RO desalination of brackish groundwater is a valid alternative to be considered. Further, economies of size are apparent for both technologies, indicating selection of facility size is an important consideration as the region seeks to expand its potable water supplies to meet expanding demand.

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