ECONOMIC COSTS OF CONVENTIONAL SURFACE-WATER TREATMENT: A CASE STUDY OF THE MCALLEN NORTHWEST FACILITY

A Thesis

by

CALLIE SUE ROGERS

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

May 2008

Major Subject: Agricultural Economics

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Approved by:

Chair of Committee,	M. Edward Rister
Committee Members,	B.L. Harris
	Ronald D. Lacewell
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ABSTRACT

Economic Costs of Conventional Surface-Water Treatment:

A Case Study of the McAllen Northwest Facility. (May 2008)

Callie Sue Rogers, B.S., Texas A&M University

Chair of Advisory Committee: Dr. M. Edward Rister

Conventional water treatment facilities are the norm for producing potable water for U.S. metropolitan areas. Rapidly-growing urban populations, competing demands for water, imperfect water markets, and uncertainty of future water supplies contribute to high interests in alternative sources of potable water for many U.S. municipalities. In situations where multiple supply alternatives exist, properly analyzing which alternative is the most-economically efficient over the course of its useful life requires a sound economic and financial analysis of each alternative using consistent methodology. This thesis discusses such methodology and provides an assessment of the life-cycle costs of conventional water treatment using actual data from an operating surface-water treatment facility located in McAllen, Texas: the McAllen Northwest facility. This facility has a maximum-designed operating capacity of 8.25 million gallons per day (mgd), but due to required shutdown time and other limitations, it is currently operating at 78% of the designed capacity (6.44 mgd).

The economic and financial life-cycle costs associated with constructing and operating the McAllen Northwest facility are analyzed using a newly-developed Excel® spreadsheet model, CITY H_2O ECONOMICS©. Although specific results are applicable only to the McAllen Northwest facility, the baseline results of $771.67/acre-foot (ac-ft)/yr {$2.37/1,000 gallons/yr} for this analysis provide insight regarding the life-cycle costs for conventional surface-water treatment.

The baseline results are deterministic (i.e., noninclusive of risk/uncertainty about data-input values), but are expanded to include sensitivity analyses with respect to several critical factors including the facility's useful life, water rights costs, initial construction costs, and annual operations and maintenance, chemical, and energy costs. For example, alternative costs for water rights associated with sourcing water for conventional treatment facilities are considered relative to the assumed baseline cost of $2,300/ac-ft, with results ranging from a low of $653.34/ac-ft/yr (when water rights are $2,000/ac-ft) to a high of $1,061.83/ac-ft/yr (when water rights are $2,600/ac-ft). Furthermore, modifications to key data-input parameters and results are included for a more consistent basis of comparison to enable comparisons across facilities and/or technologies. The modified results, which are considered appropriate to compare to other similarly calculated values, are $667.74/ac-ft/yr {2.05/1,000 gallons/yr}.

ACKNOWLEDGMENTS

I would like to first thank my committee chair, Dr. Ed Rister, and committee member Dr. Ron Lacewell, whose mentorship over my college career has been invaluable. I would also like to thank the other member of my committee, Dr. B.L. Harris, as well as Dr. Allan Jones, whose leadership and support from the Texas Water Resources Institute and the Rio Grande Basin Initiative made much of this research possible. I could not have an acknowledgments page without mentioning Allen Sturdivant, whose excellent advising and WordPerfect computer support enabled me to complete this thesis.

Without the outstanding help of my collaborator Javier Santiago and the rest of the employees at McAllen Public Utility Water Systems, this thesis would not be possible. In addition, the administrative support of Michele Zinn, Cindy Fazzino, Angela Catlin, and Tracy Davis, all of the Department of Agricultural Economics, made the many trips to the Valley possible.

I would like to thank my office mate, Chris Boyer, for not killing me through this process. Finally, I would like to express my deep gratitude to my parents, David and Shelly Rogers, for their continued support in everything I do.

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INTRODUCTION[1]

An issue receiving widespread attention is the availability of potable (drinkable) water. Growth in population and region-specific gains in affluence are resulting in an ever-increasing demand for water by all sectors of the economy. With the population of Texas expected to double by the year 2050 (Texas Water Development Board 2006), water quality and availability are of major concern. Water issues are especially acute in the Lower Rio Grande Valley of Texas (Valley). According to the 2000 U.S. Census Bureau, the Valley is the fourth-fastest-growing Metropolitan Statistical Area (MSA) in the United States, with the McAllen-Edinburg-Mission area realizing a 49% population growth from 1990 to 2000 (US Census Bureau 2000). Rapid regional growth is expected to continue into the future with an anticipated 2% annual growth rate for the next 50 years (Rio Grande Regional Water Planning Group 2001). This growth is expected to result in a compounded 20% population increase over the next ten years and a 143% increase over the projected 50 years. This continuing growth, as well as a prolonged drought, and difficulties in receiving full water deliveries from Mexico, has resulted in increased competition for water and a heightened uncertainty of future supplies.[2]

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

[1] The author of this thesis chose to employ a section method in which the paper is broken down into major sections rather than chapters.

[2] As stated in Sturdivant et al. (2008), "Shortfalls in water deliveries from Mexico are in reference to The 1944 Treaty, a binational treaty in which the U.S. annually provides Mexico with 1.5 million acre feet (ac-ft) from the Colorado River, while Mexico in return annually provides the U.S. with 350,000 ac-ft from the Rio Grande. As of September 30, 2005, Mexico had paid its water debt which accumulated from 1992-2002 (Spencer 2005)."

The predominant water supply for the Valley is the Rio Grande (River), which serves as a partial international boundary between the United States and Mexico, and supplies approximately 87% of the municipal and industrial water (Rio Grande Regional Water Planning Group 2001). Using the Rio Grande as the source water, the norm for producing potable water in the Valley is through conventional surface-water treatment (Texas Commission on Environmental Quality 2008).

To address the issue of meeting increasing water demand, water suppliers, water managers, consulting engineers, and other regional and state stakeholders are considering, evaluating, and implementing alternatives to conventional surface-water treatment. There are several strategies which can improve the available water supply in the Valley, either by supply enhancement or increasing use efficiency. Alternatives to the predominance of diverted Rio Grande water (i.e., supply) include: groundwater wells, wastewater reuse, desalination of seawater and/or brackish groundwater, and rainwater harvesting.[3] Efficiency-in-use improvements being applied in the Valley include on-farm and municipal water-conservation measures, as well as improved efficiency in irrigation district water-conveyance systems.

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[3] The majority of the groundwater in the Valley is brackish; therefore, the groundwater is not considered potable unless it is treated with a desalination process. In order to determine if water is brackish, the salinity of the water must be tested. Salinity is measured by the "total dissolved solids" (TDS) content which is reported in milligrams per liter (mg/l). Water with a salinity between 1,000 and 10,000 mg/l is considered brackish (Arroyo 2004). The Texas Commission on Environmental Quality (TCEQ) sets the maximum allowable TDS level at 1,000 mg/l. (TCEQ 2005).

When prioritizing among the available alternatives, it is important to compare the quality of water produced and to determine which option is the most cost efficient. Determining an objective, priority-ranked strategy of alternatives requires a sound and common methodology if economic and financial efficiency is to be used to guide expenditures for providing public water supplies. Such a methodology is expected to allow for an "apples-to-apples" comparison of alternatives, given each alternative will likely differ in initial and continued costs, quantity and quality of output, expected useful life, etc. This thesis utilizes a Capital Budgeting - Net Present Value (NPV) analysis, combined with the calculation of annuity equivalent (AE) measures, to achieve the above criteria. Using this combined approach allows for calculation of a single, comprehensive, annual $/acre feet (ac-ft)/yr {or $/1,000 gallons/yr} life-cycle cost, facilitating priority ranking among the available water supply alternatives.

OBJECTIVES

This research addresses the economic and financial costs of one water supply alternative available to the Valley: conventional surface-water treatment.[4] Conventional surface-water treatment was selected for analysis due to the large number of facilities currently operating in the Valley, accounting for almost 90% of the region's municipal water supply (Texas Commission on Environmental Quality 2008). Also, a review of current literature reveals a wide range of cost estimates and methodology employed, as well as a lack of original, recent (i.e., since the early 1980s) (Characklis 2007) economic studies on this subject; therefore, there is a need for sound, contemporary economic analysis of the life-cycle costs of producing potable water via conventional processes.

The scientific method calls for an identification of a null hypothesis when conducting research. One of the characteristics of a null hypothesis is that it cannot be proven. A researcher can only reject the null hypothesis or fail to reject the null hypothesis. One null hypothesis for this thesis is: "It is not possible to construct/develop a comprehensive explanatory model and conduct an economic and financial analysis of conventional surface-water treatment." A primary purpose of this study is to seek to reject this null hypothesis by achieving the following objectives: (a) develop and exhibit the capabilities of a spreadsheet model that could be used in analyses of conventional

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[4] Although similar, there are some differences between economic and financial costs. The primary differences are economic costs include the opportunity cost of the investment; financial costs account for the timing aspects of investments and related operating costs.

surface-water treatment facilities, (b) provide a comprehensive economic and financial analysis of the life-cycle costs of producing water at a conventional surface-water treatment facility (McAllen Northwest), and delivering such water to a point(s) within the municipal water delivery system, and (c) develop and document a template that could be used in subsequent analyses for other similar operating or planned facilities. Although the estimated results of this study are applicable only to the McAllen Northwest facility, this analysis provides insight into varied aspects of the costs of conventional surface-water treatment. The "comprehensive explanatory" nature of the model relates to its ability to achieve an analysis that goes beyond identifying only the bottom-line costs of production. When comparing multiple facilities, it is valuable to recognize not only which facility experiences the lowest (or highest) total or overall costs of production, but also to determine which cost item(s) is (are) causing the difference(s). Therefore, this thesis breaks down the aggregate costs into specific types, segments, and items to facilitate an in-depth analysis.[5]

A second null hypothesis of this report is: "Evaluations and comparisons of water treatment facilities can be accomplished using primary (operating/case study) data." Possible causes for rejecting this null hypothesis include identifying key data-input parameters which should be normalized to facilitate development of results appropriate

[5] "Type" refers to the large cost categories of (a) initial construction/investment, (b) continued costs, and (c) capital replacement expenses. "Segment" refers to the individual expense areas that represent the different functional segments of a water treatment facility (e.g., reservoir, filtration, storage, etc.). "Item" represents the expenses incurred annually in the operations and maintenance budget (e.g., electrical energy, chemicals, labor, etc.).

for comparison. These results are expected to prove useful in serving as a means of comparison between different conventional surface-water treatment facilities, as well as with other alternatives of obtaining potable water (e.g., desalination, wastewater reuse, etc.).

PRIOR LITERATURE AND ECONOMIC STUDIES

Today, essentially the same technology is being applied in conventional surface-water treatment facilities as has been used during the last several decades. This explains why there are few original economic studies that have been conducted since the late 1970s and early 1980s (Characklis 2007). Since the literature is generally outdated and a broad spectrum of analytical methods was used in the past, historical cost estimates are difficult to update to current day figures. A review of selected literature is provided in the following section.

Because of the varied nature of conventional surface-water treatment facilities' designs, (i.e., composed of many different components with varying designs for each), an idea that is often reflected in the literature is that comparison of facility construction costs is very difficult. As Clark and Dorsey (1982) point out, "No two treatment plants are alike"; therefore, costs for the construction of water treatment plants are very site-specific and must be developed for individual circumstances. The varying designs and the components that are required in the conventional water treatment process depend primarily on the quality and characteristics of the raw water (Jurenka, Martella, and Rodriguez 2001). In spite of these difficulties in generalizing the costs of construction, a study conducted by Gumerman, Culp, and Hansen (1979) attempts to do just that. Specifically, their report breaks the costs of constructing a conventional water treatment facility into the following eight cost categories: (1) excavation and site work, (2) manufactured equipment, (3) concrete, (4) steel, (5) labor, (6) pipe and valves, (7) electrical equipment and instrumentation, and (8) housing. Gumerman, Culp, and Hansen (1979) predicted the total construction cost for a five million gallon per day (mgd) conventional treatment facility to equal $2,364,000, which, when amortized over 20 years at 7% interest rate, equates to $223,140 per year (in 1978 dollars).[6] A similar report by Qasim et al. (1992) updates the numbers provided by Gumerman, Culp, and Hansen (1979) and establishes the annual "allocated" cost of construction to be $410,000 (in 1992 dollars) for a similar facility.

Beyond the initial construction costs, other, annual ongoing expenses are important. When examining annual ongoing expenses, one of the largest cost items for conventional surface-water treatment is chemicals, which typically include various coagulants, disinfectants, and pH adjusters (Dearmont, McCarl, and Tolman 1998). The quality of the source water, primarily the turbidity, determines the amount of chemicals required for water treatment.[7] In 1998, Dearmont, McCarl, and Tolman (1998) reported chemical costs to be a function of source water turbidity, pH, groundwater contamination, gallons produced, and average annual rainfall. The study used data

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[6] Although not clearly stated in the Gumerman, Culp, and Hansen (1979) report, it is inferred that the 20 years for the distribution of the construction costs is related to the financing for the retirement of the issued bonds, not for the actual life of the facility. In the research reported in this analysis of the McAllen Northwest facility, a 50-year life for the facility is assumed based on discussions with the facility manager (Santiago 2007).

[7] Turbidity is a measure of the amount of organic and inorganic particles in the water (Lloyd, Koenings, and Laperriere 1987). Turbidity is measured using an instrument called a nephelometer, which calculates a water's turbidity by determining the amount of light that is deflected or scattered by the suspended particles. The scattering of light increases with a greater amount of particles or turbidity.

collected from 12 surface-water treatment facilities in Texas (Table 1). Estimated results are provided in Table 2. Using a cross-sectional, time series model, Dearmont, McCarl, and Tolman (1998) derived selected elasticity measures, including determination that for every 1% increase in turbidity, chemical costs increase by 0.27%, and that for every 1% increase in gallons produced, chemical costs increase by 0.04%.

The literature shows the total production costs for a conventional water treatment facility to be a summation of construction capital costs and continuing operational costs. The Gumerman, Culp, and Hansen (1979) report also provides a breakdown of the total costs of production for a five (5) mgd, a 40 mgd, and a 130 mgd conventional water treatment facility (Figure 1 and Table 3). The per-unit cost for a facility assumed to be operating at 70% capacity was calculated as $0.32/1,000 gallons for the five (5) mgd facility, $0.18/1,000 gallons for the 40 mgd facility, and $0.13/1,000 gallons for the 130 mgd facility (in 1978 dollars) (Figure 1 and Table 3). A report by Jurenka, Martella, and Rodriguez (2001) provides similar predicted total costs of production for three facilities in 2001 dollars (Table 4). The results from both of these studies suggest the existence of economies of size in the conventional water treatment process, meaning that as the production output increases, the average total cost per unit of water produced decreases (Kay, Edwards, and Duffy 2008). This economic concept is seen in Figure 1, Table 3, and Table 4, when the cost per unit of water declines as the total production capacity of the facility expands.

Table 1. Characteristics and Chemical Costs for Conventional Surface-Water Treatment Facilities

Location	Average Monthly Production (1,000 gal)	Raw Water Turbidity[a]	Raw Water pH[b]	Chemical Cost per Million Gallons	Chemical Cost per ac-ft
Archer City	8,684	89.2	7.9	$ 71.46	$ 23.29
Ballinger[c]	19,201	16.7	7.8	20.21	6.59
Big Spring	177,000	35.0	8.2	25.66	8.36
Brenham	63,925	6.2	7.8	133.53	43.51
Edinburg[c]	130,380	9.3	7.8	32.63	10.63
Harlingen 1[c]	190,460	36.2	8.2	197.51	64.36
Harlingen 2[c]	114,730	27.9	8.2	286.14	93.24
Henrietta	15,654	25.8	8.2	134.65	43.88
Lubbock[c]	881,930	7.3	8.4	32.32	10.53
Temple	416,630	5.9	7.7	58.30	19.00
Waco 1	343,870	11.2	7.8	34.88	11.37
Waco 26	305,730	9.8	7.8	32.23	10.50

Source: Dearmont, McCarl, and Tolman (1998) and own modifications.

[a]Turbidity is a measure of the amount of organic and inorganic particles in the water (Lloyd, Koenings, and Laperriere 1987).

[b]pH is a measurement of a substance's hydrogen ion concentration and can range from zero to 14. A low pH level (below 6.5) indicates the water is soft, acidic, and corrosive which could lead to leaching of materials from pipes. A high pH level (above 8.5) indicates the water is hard, and could cause build-ups of deposits in pipes (Water Systems Council 2004).

[c]Facility could potentially have groundwater contamination which requires extended chemical treatment.

Table 2. Estimation Results for Variables Determining Chemical Costs[a] of Conventional Surface-Water Treatment Facilities[b]

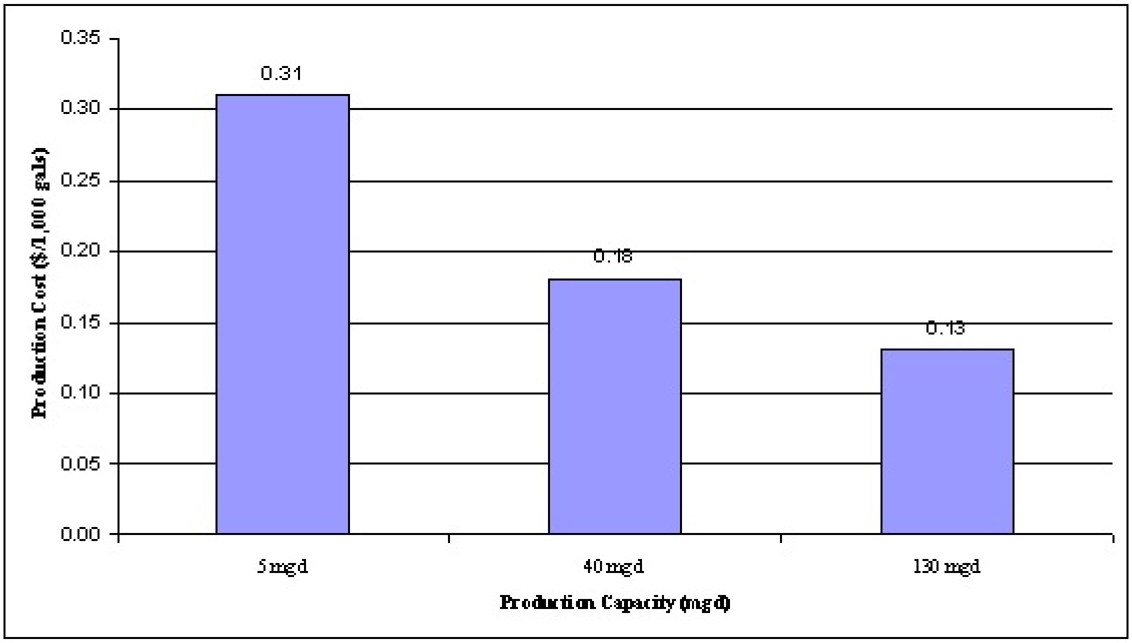
Variable	Estimated Coefficient	t-Ratio
Constant	-0.1314	-6.5053
Total Gallons Produced	$-1.6950*10^{-8}$	-4.1604
Turbidity * pH	$1.3496*10^{-4}$	4.3989
(Turbidity * pH)^2	$-1.5130*10^{-7}$	-2.6375
(Turbidity * pH)^3	$(5.5013*10^{-11})$	(1.9374)
Groundwater Contamination Dummy	0.0947	7.7713
Average Annual Rainfall	$5.6024*10^{-3}$	8.3164

Source: Dearmont, McCarl, and Tolman (1998) and own modifications.

[a]Chemical costs are presented in dollars per thousand gallons.

[b]The results for the model have a R^2 measure of 0.1865.

Note: All terms were determined to be statistically significant except for the (Turbidity * pH)^3 term.



Source: Gumerman, Culp, and Hansen (1979) and own modifications.

Figure 1. Estimation of production cost for conventional water treatment facilities of varying size

Table 3. Annual Cost for Conventional Water Treatment Facilities of Varying Facility Size[a]

Item	Annual Cost 5 mgd[b] Facility	Annual Cost 40 mgd[b] Facility	Annual Cost 130 mgd[b] Facility
Initial Construction[c]	$223,140	$975,460	$2,458,890
Annual Expenses			
-Labor	93,500	305,340	649,690
-Electricity	21,770	226,820	716,290
-Fuel	2,480	3,130	3,600
-Maintenance Material	13,930	55,900	122,070
-Chemicals	41,790	285,250	499,320
Total Annual Cost	$396,610	$1,851,900	$4,399,890
Dollars per 1,000 gallons	$0.31	$0.18	$0.13

Source: Gumerman, Culp, and Hansen (1979) and own modifications.

[a]Annual costs are in nominal, 1979 terms and do not account for inflation.

[b]mgd is an abbreviation for million gallons per day.

[c]The construction costs are amortized over 20 years at a 7% interest rate.

Table 4. Total Production Costs for Conventional Water Treatment Facilities of Varying Size

Product Flow of Facility (in million gallons per day (mgd))	Total Production Cost (in $/1,000 gallons)
0.25	$1.70
0.50	1.25
0.75	1.05
1.00	1.00

Source: Jurenka, Martella, and Rodriguez (2001) and own modifications.

Although the current literature concerning the *costs* of conventional water treatment lacks modern, consistent research, literature related to the *price charged* for treated water is on the rise. A cursory search of recent articles relating to water rates reveals a trend of increasing rates charged to consumers. From Hawaii (Yager 2007) to New York City (DePalma 2007), cities across the nation are increasing the rates charged for potable water. However, there is little reference to whether or not these increasing rates have any relation to the actual costs of producing the potable water. Traditionally, a large number of municipalities have placed the price of water at a level too low to cover the cost of service, thereby requiring subsidies from other city funds (Goldstein 1986). In contrast, there are municipalities that set water rates at levels which generate excess revenues which are diverted to meet other city expenses (Goldstein 1986). In talking with a current city financial officer, it is revealed that there are cities that have completely separate accounts for each of the departments (i.e., water, waste, energy) and therefore, the pricing of water is independent of other departments' financing decisions (Kersten 2007). Talks with a Valley city financial manager revealed that cities attempt to account for all water-related costs (i.e., initial construction, continued costs, water rights purchase) when pricing water for consumers (Carvajal 2007).

ECONOMIC AND FINANCIAL METHODOLOGY

Since different conventional water treatment facilities vary in so many aspects, including facility design, construction costs, and operating costs, an evaluation methodology is called for that allows for "apples to apples" comparisons. An appropriate way to allow for such comparisons and to determine the most cost-effective alternative is to identify and define each facility as a capital investment and then apply appropriate financial, accounting, and economic principles and techniques (Rister et al. 2002; Sturdivant et al. 2008).

The methodology used in this thesis combines standard Capital Budgeting - Net Present Value (NPV) analysis with the calculation of annuity equivalent measures, similar to the methods presented in Rister et al. (2002).[8] Standard NPV analysis allows for comparing uneven flows (of dollars and product water) among alternatives (i.e., projects), while the use of annuity equivalents extends the standard NPV analysis to accommodate comparisons of projects (and components thereof) with different useful lives. This combined approach is the methodology of choice because it integrates expected years of useful life with related annual costs and outputs, as well as other financial realities such as inflation and the time value of money, into a single, comprehensive annual $/acre-

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[8] Refer to the *Summary of Economic and Financial Methodology* section which also references Jones (1982); Levy and Sarnat (1982); Quirin (1967); Robison and Barry (1996); and Smith (1987).

foot/yr {or $/1,000 gallons/yr} life-cycle cost value. It is this life-cycle cost value which facilitates comparisons among alternatives and allows for priority rankings.[9]

NPV of Economic and Financial Costs

There are three primary cost types which are the foundation for the calculations in this financial analysis of the McAllen Northwest facility:

1) Initial Construction/Investment Costs;
2) Operation and Maintenance Costs (O&M); and
3) Capital Replacement (CR) Costs.

Also of importance is the salvage value of the capital investment at the end of the facility's expected useful life. Although this analysis assumes a zero net salvage value for land, buildings, equipment, etc., there could be a salvage, or resale value of the water rights at the conclusion of the useful life of the facility.[10]

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[9] Comparisons across facilities and across technologies are facilitated with certain, limited modifications to key data-input parameters. This topic is discussed in further detail in the "Modified Data Input and Results" section beginning on page 73.

[10] A zero net salvage value is recorded for the capital investment due to the assumption that any remaining value of the investment is offset by the cost of facility decommissioning and site restoration. In addition, the investment is intended to be long-term, with no expectations of salvaging the asset. The value of the water rights are retained and could potentially be used (i.e., have value) beyond the life of the facility; however, assuming this investment is intended to be long term, with no expectations of the municipality ever salvaging this asset, the resale value of the rights is not included in the baseline analysis.

Calculation of the net present value of the economic and financial costs of constructing, operating, and maintaining a conventional surface-water treatment facility over the course of its useful life can be achieved using the following equation:

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

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

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

where the elements are defined in Table 5.

The NPV calculations sum the costs for facility segment A, of the conventional water treatment plant P, over planning period Z, and discount the values to present-day terms.[11] The NPV calculations for each of the individual segments can then be aggregated over the G segments to achieve a comprehensive NPV of the economic and financial costs for the entire plant P, as seen below:

$$AEC_{AG}^{P,Z} = \sum_{A=1}^{A=G} EC_{NPV}^{P,A,Z},$$

where the elements are defined in Table 5.

[11] Calculating the NPV for each segment first and then summing across all segments for the entire plant allows for appropriate considerations/adjustments of different projected lives for individual segments.

Table 5. Definitions for the Elements of Economic and Financial Costs Calculations

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

Table 5. Continued

Element	Definition
$AEEC_{AE}^{P,A,Z}$	annuity equivalent of economic and financial costs for facility segment A for a series of conventional water treatment plants P, each constructed and operating over a Z planning period, into perpetuity
$AAEEC_{AG}^{P,Z}$	aggregate annuity equivalent of economic and financial costs for conventional water treatment plant P over a Z planning period into perpetuity
$AEWP_{AE}^{P,A,Z}$	annuity equivalent of water production for facility segment A for a series of conventional water treatment plants P, each constructed and operating over a Z time period, into perpetuity
$AEECAF_{AE}^{P,A,Z}$	annuity equivalent of costs per ac-ft for facility segment A for a series of conventional water treatment plants P, each constructed and operating over a Z time period, into perpetuity
AAE_{AG}^{P}	aggregate annuity equivalent of costs per ac-ft for a series of conventional water treatment plants P

Source: Rister et al. (2002) and own modifications.

NPV of Water Production

Similar to the steps performed previously, the sum of the water production for facility segment A, at water treatment plant P, over planning period Z, is discounted to present value terms using the following equation:[12]

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

where the elements are defined in **Table 5**.

Annuity Equivalent Values for Economic and Financial Costs

The NPV calculations identify the costs over the planning period of the plant and the associated potable water production in present-day terms. The next step, (i.e., calculation of annuity equivalents), extends the methodology to allow for comparisons across alternative water treatment plants of different economic lives. An annuity equivalent (or ‘annualized life-cycle cost’) converts the NPV of costs for one plant, over its useful life, into a per-unit amount which assumes an infinite series of purchasing and operating similar plants into perpetuity. Reference Barry, Hopkin, and Baker (1983, p. 187) and Penson and Lins (1980, p. 97) for clarification of this concept and examples.

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[12] The debates related to appropriateness of discounting a physical product are addressed later in this section starting on page 26.

This calculation can be used as the basis of comparison to similarly calculated costs for segments of other conventional water treatment plants and/or other water treatment technologies with varying useful lives:

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

where the elements are defined in Table 5.

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

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

where the elements are defined in Table 5.

Annuity Equivalent Values for Water Production

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

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

where the elements are defined in Table 5.

Annuity Equivalent of Costs per acre-foot of Water Production

This step in the methodology divides the "cost" annuity equivalent by the "water production" annuity equivalent. The result is a single, comprehensive annual \$/ac-ft/yr {or \$/1,000 gallons/yr} life-cycle cost. The purpose of this calculation is to provide a consistent, per-unit cost that provides a defined unit of water regardless of size, age, and type of plant, allowing comparisons among plants of varying projected lives and perhaps types.[13] This value for an individual segment is calculated as follows:

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

where the elements are defined in Table 5.

---

[13] Once the annuity equivalent calculations are complete, comparisons can easily be made; however, certain additional adjustments are necessary to level the playing field across different facilities to account for natural variations in key data-input parameters (Sturdivant et al. 2008). These variations include: base year period of analysis, level of annual production, quality of water, etc. (see the section entitled "Modified Data Input and Results" starting on page 73 for extended analysis of adjustments).

$AEECAF_{AE}^{P,A,Z}$ represents the cost per year for facility segment A in base-year dollars of producing one ac-ft {or 1,000 gallons} of water into perpetuity through a continual replacement of plant P.

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

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

where the elements are defined in Table 5.

McAllen Northwest Conventional Water Treatment Facility Study:

Values for Discount Rates and Compound Factor

Although much primary data are used in this thesis, two discount rates and a compound rate are assumed, based on prior work by Rister et al. (2002).

Discount Rate for Dollars

As described above, a NPV calculation must be used in order to “normalize” the cash flows over the life of the plant. A discount factor is required when calculating the NPV of costs. As outlined in Rister et al. (2002), the discount rate has three components: a time preference component, a risk premium, and an inflation premium. The relationship between these three components is multiplicative and can be seen in the following equation:

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

where the elements are defined in Table 6.

Using the multiplicative-form nature of the composite interest rate logic discussed in Rister et al. (2002), a 6.125% discount rate (r) is assumed, as well as a social preference rate of 4.000% (s), and a 0.000% risk premium (h) for federal/state/municipal projects.

Compounding Costs

When considering continued operational costs for future years, it is necessary to include inflation. This enables an estimate of nominal dollars for years beyond the benchmark year. This component represents the *i* parameter in the equation above. Using the assumed values for *r*, *s*, and *h*, the compounding factor (i) is determined to be 2.043269% annually.[14, 15]

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[14] Mathematically calculated as follows: $\frac{1+6.125\%}{1+4.000\%} - 1 = 2.043269\%$.

[15] The calculation of inflation rates are based on Rister et al. (2002). The author of this thesis does realize that inflation rates will change over time. Holding all other factors constant, as inflation rates increase, total costs increase, and as inflation rates decrease, total costs decrease.

Table 6. Values for Discount Rates and Compound Factor

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

Source: Rister et al. (2002).

Discount Rate for Water

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

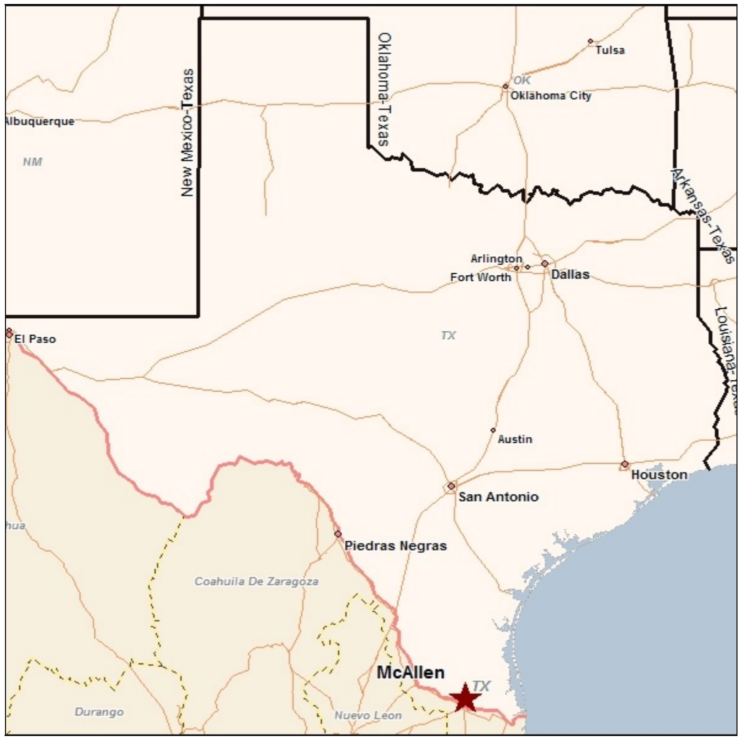
Conversely, other economists believe when values are not readily available, or are not easily ascertained, it is appropriate to discount the future physical amount (Griffin 2007). As Carlson, Zilberman, and Miranowski (1993) point out, such discounting includes the use of resources, stating specifically,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

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

OVERVIEW OF THE MCALLEN NORTHWEST CONVENTIONAL SURFACE-WATER TREATMENT FACILITY

The conventional surface-water treatment facility analyzed in this thesis is referred to as the McAllen Northwest facility, located just outside of McAllen, Texas near the Texas-Mexico Border (Figure 2). The city of McAllen is facing the challenges of rapid population growth and the need to expand its current potable water supply. With the fastest-growing metropolitan area in the state of Texas, according to the 2005 U.S. Census (McAllen Chamber of Commerce 2006), the McAllen Public Utilities Board (PUB) is continuously searching for a solution to the problem of meeting increasing water demand (Santiago 2007).

Among the different alternatives currently being considered by McAllen for expanding their potable water supply are: the desalination of brackish groundwater, wastewater reuse, the expansion/fine-tuning of existing conventional surface-water treatment facilities, and the building of a new conventional surface-water treatment facility (Santiago 2007). Prior to the construction of the McAllen Northwest facility, the only source of potable water for the McAllen municipal service area was the McAllen Southwest facility, which was built in the late 1950s. In 2002, faced with the need to expand the water system's capacity, the McAllen Public Utility Water Systems began construction on the McAllen Northwest facility (Figure 3). Completed in 2004, the facility currently has a maximum-designed capacity of 8.25 mgd, although some of the



Source: BusinessMap 3.0 (2003).

Figure 2. Location of McAllen, Texas

Source: MapQuest (2007).

Figure 3. Location of McAllen Northwest facility

facility's components are oversized to allow the operation to eventually expand to 32 mgd (Santiago 2007). With the completion of the McAllen Northwest facility's 8.25 mgd phase, the McAllen water system now has a capacity of 49 mgd and services approximately 50,000 homes in McAllen and the surrounding areas.

The source water for the Northwest facility is surface water originating from the Rio Grande. The water reaches the McAllen facility through a system of open-surface canals operated by various irrigation districts. This process of obtaining water from the irrigation districts (IDs) stems from a Texas constitutional amendment, Art. 3, Sect. 52, passed in 1904, which established that IDs provide water services including wholesale and untreated water supply (Stubbs et al. 2003). The specific irrigation districts that deliver water to the McAllen Public Utilities include: Hildalgo County Irrigation District No. 2 (commonly known as San Juan #2), Hildalgo County Water Improvement District No. 3, and the United Irrigation District of Hidalgo County (commonly known as United). The United Irrigation District is the specific ID which services the McAllen Northwest facility. Once diverted from the Rio Grande, the water travels approximately ten miles through the United Irrigation District's main canal before it reaches the reservoir at the Northwest facility (Santiago 2007).

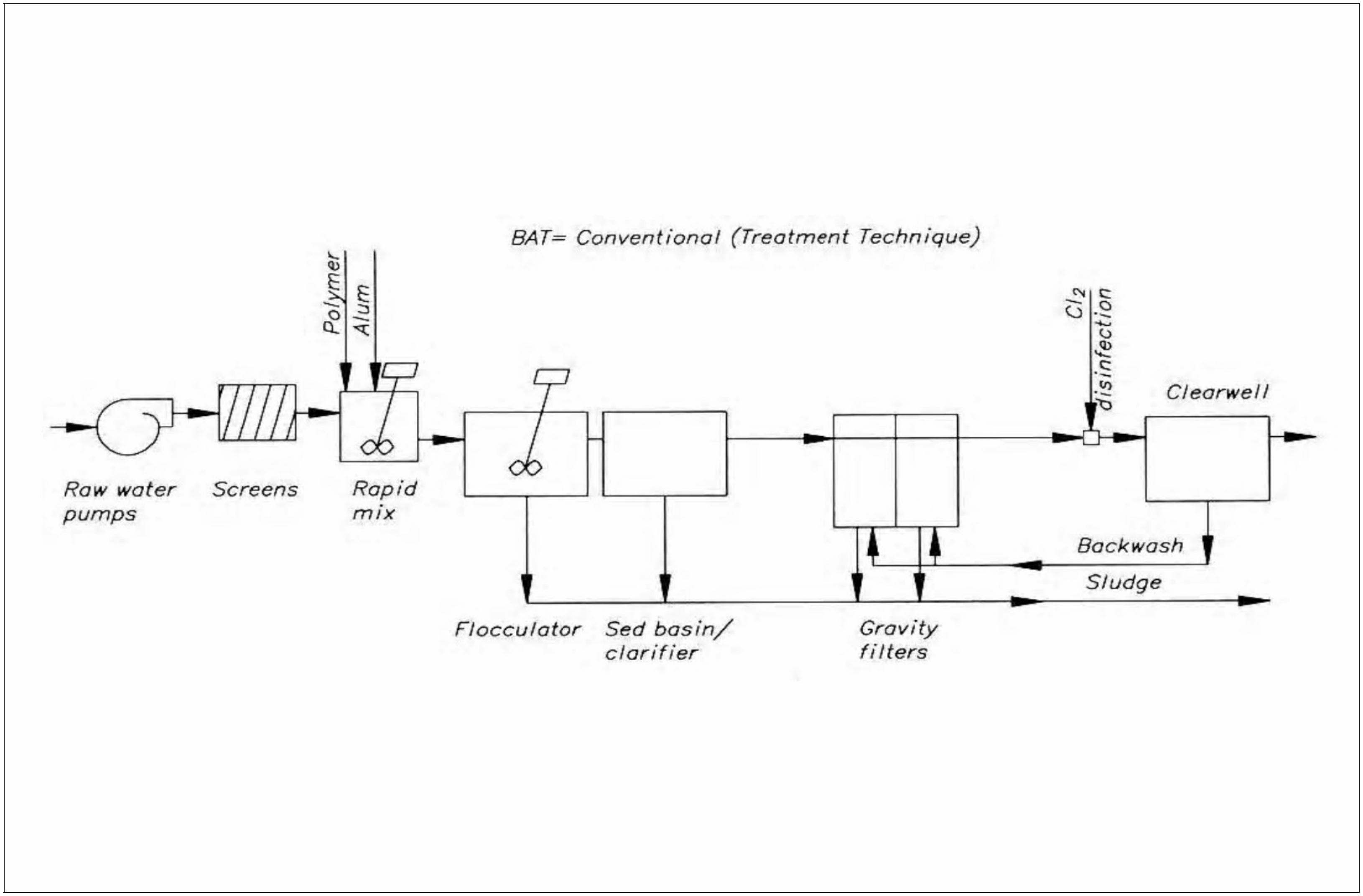
Description of Conventional Surface-Water Treatment Process

The McAllen Northwest facility utilizes a conventional surface-water treatment process. The objective of water treatment is to produce potable water from the untreated source or “raw” water. Raw water is treated to remove any disease-causing organisms, as well as silt, grit, and humus material. In addition, water treatment improves the taste, color, and odor of the raw water (Utah Division of Water Resources 2007). Figure 4 provides a schematic of this process and demonstrates the multiple stages that are required to convert raw, source water to potable drinking water through the conventional treatment process.

For the McAllen Northwest facility, before the water treatment process begins, the water is held in a reservoir adjacent to the treatment facility that is 30 ft deep, which covers approximately 30 acres of surface area, and has a capacity of 200 million gallons (Figure 5). This amount is enough to supply water to the facility for 23 days. The treatment process at the McAllen Northwest facility is as follows (Santiago 2007):

Pre-Disinfection

In this first step, the chemical compound chlorine dioxide (ClO_2), which is formed from the combination of sodium chlorite ($NaClO_2$) and chlorine (Cl), is added to the water to kill germs and improve the treatment process. Also, a coagulation chemical, aluminum



Source: Jurenka, Martella, and Rodriguez (2001).

Figure 4. Schematic of conventional water treatment process

Source: Sturdivant (2006).

Figure 5. McAllen Northwest facility reservoir

sulfate ($Al_2(SO_4)_3$), is added to encourage the aggregation of dissolved substances, thereby facilitating their subsequent removal (Buffalo Water Authority 2005).

Coagulation

The coagulation stage involves the water being moved to a rapid-mix tank which has fast-moving, rotating paddles that ensure the coagulation chemical is fully mixed with the water. The chemicals stick to the impurities (i.e., small, suspended particles) in the water and force the particles to bond together and form larger particles referred to as "floc."

Flocculation

The water then moves to the flocculation stage of treatment, which is composed of a series of six (6) consecutive chambers, each measuring approximately 14 ft long by 10 ft wide by 15 ft deep. These chambers have large, slow-moving paddles that are designed to further promote the formation of floc (or clusters of impurities). As the water moves from one chamber to the next, the speed of the paddles slow.

Sedimentation

From the flocculation chambers, the water flows to the two sedimentation basins (Figure 6). In the sedimentation basin, the floc that was formed in the previous two steps slowly settles to the bottom of the tank. Floc particles are removed continuously from the bottom of the tank by a rake system. The aggregated floc is then pumped to the sludge lagoons. Another chamber, located at the end of the sedimentation tanks, can be utilized as an alternate location for the injection of the primary disinfectant, chlorine dioxide (ClO_2).

Filtration/Backwash

The next step in the process is conventional filtration (Figure 7). The water flows through filters composed of anthracite (coal), sand, and garnet, thereby removing any remaining suspended particles.[16] The filters at the McAllen Northwest facility are capable of using granular activated carbon (GAC) to improve the quality and taste of the water; however, this method is currently not in use.[17] Every 100 hours, a backwash of the filters is performed. In this process, potable water is flushed backwards through the filter bed to clear trapped debris and floc from the filter media. The backwash water is then pumped to the sludge lagoons.

Sludge Disposal

The sludge from the sedimentation and filtration processes is pumped to three concrete-lined lagoons, each measuring 400 ft long by 80 ft wide by 10 ft deep where sludge is separated from the water naturally through gravity. The remaining water is then recycled

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[16] Garnet is a "high hardness, high density filter material used in multi-media filters. Recommended as a support bed for other materials such as filter sand, anthracite, corosex, etc." (Aqua Science 2007).

[17] The GAC process is not currently used because taste is not regulated and management's cost/benefit assessment favors forgoing the high operational and maintenance costs associated with GAC.

Source: Sturdivant (2006).

Figure 6. Sedimentation basins at McAllen Northwest facility

Source: Sturdivant (2006).

Figure 7. Filters at McAllen Northwest facility

through the water treatment process again. The leftover sludge is dried and removed by a third party and transferred to agricultural land.

Secondary Disinfection

In this final stage of water treatment, chloramines (NH_2Cl) are added to the water at a transfer station. The transfer station is the pump station located directly after the filtration which transfers the treated water to the storage tank. Chloramine is a chemical compound formed from the combining of Chlorine (Cl) and Liquid Ammonium Sulfate ($(NH_4)_2SO_4$). The Chloramine is used as a disinfectant to prevent the formation of bacteria and to improve the quality and taste of water. Chloramine is also the residual disinfectant required by the Texas Commission on Environmental Quality (TCEQ).[18]

Storage

The cleaned and purified water is sent to two aboveground storage tanks that have a total combined capacity of four million gallons (which is one-half of one day's production) before entering the distribution system. For the purposes of this thesis, the distinction is made that this is the final stage of the treatment process and the subsequent distribution system is not considered in the cost calculations.

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[18] TCEQ requires a residual disinfectant in all distribution systems to prevent the formation of bacteria (Santiago 2007).

Water Quality

An examination of the water quality prior to, and post treatment at the McAllen Northwest facility is provided in Table 7. As shown in the table, the treated water, for the period January to December 2006, meets all of the standards and guidelines set by the Environmental Protection Agency (EPA) and TCEQ. The Maximum Contaminant Level Goals (MCLG), set by the EPA, represent the level of a contaminant in drinking water below which there are no known health risks. Also set by the EPA are the Maximum Contaminant Levels (MCL), which represent the highest concentration of a contaminant allowed in drinking water, and are set as close to the MCLGs as feasible, using the best available treatment technology (Environmental Protection Agency 2008). Examples of the contaminants that are restricted by the MCLs because of potential health danger include arsenic, fluoride, and nitrate.

Secondary levels are set by both EPA and TCEQ and represent the reasonable goals for drinking water quality. These levels deal with contaminants that are not a risk to human health, but rather concern the aesthetic qualities of drinking water (i.e., taste, color, and odor) (College Station Utilities 2006). EPA and TCEQ do not enforce the secondary levels, but rather use them as guidelines. Examples of these unregulated substances include aluminum, calcium, pH, hardness, and sodium. Another item listed in Table 7 is the residual level of chloramine in water leaving the facility. As mentioned previously,

Table 7. Quality of Outgoing Treated Product Water (for January to December 2006) and Incoming Raw Water (for June 2007) of McAllen Northwest Conventional Surface-Water Treatment Facility

Substance	Units[a]	Incoming Level	Outgoing Levels			Maximum Contaminant Level (MCL)[b]
			Min.	Max.	Avg.	
Regulated Contaminants						
-Arsenic	ppb		3	3	3	10
-Barium	ppm		.097	.109	.103	2
-Fluoride	ppm		.42	.43	.43	4
-Gross Beta Emitters	pCi/L		4.5	5.8	5.15	50
-Nitrate	ppm		.12	.24	.18	10
-Selenium	ppb		0	3.1	1.6	50
-Total Organic Carbon	ppm	5.49	3.18	4.37	3.71	25% Removal[c]
Unregulated Substances						Secondary Limit[d]
-Aluminum	ppm		.094	.124	.109	50
-Bicarbonate	ppm		91	100	96	NA
-Calcium	ppm		74.7	79	76.9	NA
-Chloride	ppm		147	148	148	300
-Magnesium	ppm		21.1	24	22.6	NA
-pH	Units	8.25	7.7	7.9	7.8	7
-Sodium	ppm		109	121	115	NA
-Total Alkalinity-CaCO3	ppm	132	91	100	96	NA
-Total Dissolved Solids	ppm		690	739	715	1,000
-Total Hardness-CaCO3	ppm	280	273	273	273	NA
Residual						Maximum
-Chloramine	ppm		1.2	3.9	3.5	4

Source: McAllen Public Utilities Water Systems (2006) and City of McAllen Water Laboratory (2007) and own modifications.

[a]'ppb' is an abbreviation for 'parts per billion.' 'ppm' is an abbreviation for 'parts per million.' 'pCi/L' is an abbreviation for 'pico curies per liter' which is a measurement of radioactivity in the water (NSF International 2008).

[b]MCL represents the highest level of the contaminant allowed in drinking water (Environmental Protection Agency 2008).

[c]Percentage removal depends on raw water total organic carbon and alkalinity levels (Environmental Protection Agency 2008).

[d]Secondary limit represents a level of the contaminant that is acceptable/preferred for drinking water quality; these levels deal with contaminants that mostly affect the aesthetic qualities of drinking water (College Station Utilities 2006).

the McAllen Northwest facility utilizes chloramines as their disinfectant residual. The limit for this residual in treated water is four (4) parts per million (ppm).

Construction and Performance

The construction period for the McAllen Northwest facility spanned 24 months, from January of 2002 to January of 2004, during which time there were no notable delays or problems (Santiago 2007). A two-year construction period is assumed for this analysis and represents $Y^{P,A}$ in the methodology equations discussed beginning on page 15. The different capital components of the facility have varying expected lives, ranging from two years for the anthracite component of the filters, to at least 50 years for structural items such as buildings, concrete, etc. This analysis assumes the maximum useful life of the facility (following construction) to be 50 years. During this life span, however, there are selected capital items that must be replaced intermittently (i.e., pumps, turbidity meters, etc.). These capital replacement expenses are incorporated into the analysis, as well as other non-capital expenses which are captured in annual operating expenses.

The original maximum-designed capacity of the McAllen Northwest facility is 8.25 mgd. This capacity equates to an output of 9,241 ac-ft annually if the facility is operating at 100%, 365 days per year. Operating at 100% of the maximum-designed capacity for 365 days per year is not realistic for any water treatment facility, however. As with other facilities, the McAllen Northwest facility encounters equipment maintenance and failure issues which require a certain amount of shut-down time in the course of a year, typically two to three weeks. There is another limiting factor in the operating capabilities of this facility: the pumps can only handle a maximum of eight (8) mgd (Santiago 2007). Therefore, due to required shut-down maintenance time, and the limiting factor of the pumps' capacities, the McAllen Northwest facility is operating at less than the designed 8.25 mgd. A review of real flow data for fiscal year (FY) 2005-2006 (Santiago 2007) indicates the facility is producing roughly 2,349 million gallons for the year (or 7,208 ac-ft), averaging 6.435 mgd.[19] This level of production equates to 78% of the maximum-designed capacity and is used as the benchmark level of production in this case-study analysis.[20]

Costs

When McAllen PUB decided to build an additional conventional water treatment facility, two major expenses were incurred: (1) acquiring the water rights, and (2) constructing the facility. Since the commencement of operations in 2004, additional expense categories have occurred: (1) continued annual operation & maintenance expenses, and (2) intermittent capital replacement expenses.

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[19] The fiscal year for the McAllen PUB is October-September.

[20] Throughout this thesis when the production efficiency is referred to, it is important to note that this value is an annual average of daily water production.

Purchase of Water Rights

A municipality considering increasing their level of water production using conventional municipal water treatment faces two options to enhance their available source water supply: drill a groundwater well or obtain additional surface water. In the Texas Lower Rio Grande Valley, this situation is more complicated. Since the majority of the Valley's groundwater is brackish, desalination treatment is required to use the groundwater for drinking-water purposes, which is a distinctly different treatment process.[21] Therefore, in order to obtain additional raw water for subsequent treatment in conventional treatment facilities, municipalities can purchase or lease Rio Grande municipal water rights from another municipality, a private individual, or from an irrigation district (Stubbs et al. 2003).

The McAllen Northwest facility utilizes raw water obtained by McAllen PUB through a purchase of permanent municipal water rights in the 1990s and early 2000s. In this analysis, the current purchase price of permanent water rights is included and valued at a level equal to the opportunity cost of purchasing water rights in the Valley today. The reasoning for recording the cost in today's price, rather than the price at which the rights were purchased (i.e., at lower levels), is consistent with the economic concept of

[21] Refer to Sturdivant et al. (2008) for an in-depth analysis of desalination technology and its application in the Lower Rio Grande Valley.

opportunity cost.[22] That is, this analysis is premised on a current (i.e., 2006) basis, and thus needs to reflect current costs.

Through communications with local irrigation district managers, the current (2006) price of a permanent municipal water right was estimated to be approximately $2,300/ac-ft for this region (Kaniger 2007; Barrera 2007). This analysis assumes a purchase of 8,872 ac-ft of water rights, which is 96% of the annual maximum designed capacity of the facility. This 96% level of required water rights was determined by assuming a municipality would purchase enough water rights for maximum annual capacity of a facility less a two-week shut-down time that is considered typical. Consequently, the total assumed cost of water rights purchased equals $20.4 million, which is calculated by multiplying the 2006 cost of a water right ($2,300/ac-ft) by the annual water production at 96% efficiency (8,872 ac-ft).

Initial Construction Costs

"Initial Construction Costs" for the McAllen Northwest facility totaled $21.30 million, in 2002 dollars (McAllen Public Utilities Water Systems 2002). For this analysis, 2006 was chosen as the benchmark year in order to make the analysis more current and consistent with other, similar, planned and work-in-progress research analyses.

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[22] The concept of opportunity cost, in its most basic definition, is the value of the next best alternative of a resource (Perloff 2004). A more precise definition provided in Thomas and Maurice (2005) states, "opportunity cost of using an owner-supplied resource is the best return the owners of the firm could have received had they taken their own resource to market instead of using it themselves." In this thesis, the current price of the water rights is included, for it represents the financial capital McAllen would receive if they sold the rights on the market today.

Therefore, the construction costs were compounded four years (using the 2.043 annual compounding rate) to account for inflation, resulting in an adjusted 2006 construction cost of $22.96 million. To facilitate an analysis-detail and conventional treatment facility-comparison, the total cost is divided into 16 cost-item categories and dissected into ten individual segments common to conventional surface-water treatment facilities (Table 8). As depicted in Table 8 and Figure 8, the most cost-intensive areas for initial construction of the McAllen Northwest facility are the *Overbuilds & Upgrades* ($5,971,571), followed by the *Raw Water Intake/Reservoir* ($4,737,742), and the *Delivery to Municipal Line/Storage* ($4,683,612). When viewed from an individual cost item perspective, the *Storage Tanks* ($5,638,204) and *Building & Site Construction* ($4,889,076) items are the largest contributors to total initial construction costs.

Continued Costs

"Continued Costs" represent the annual costs incurred during ongoing operations from the time of construction completion until the end of the facility's useful life. The annual continued costs recorded are based on the actual FY 2005-2006 budget prepared by McAllen Public Utility Water Systems (McAllen Public Water Utilities 2007) and are compounded at 2.043% annually. The referenced budget reports the expenses incurred for the entire McAllen water system, which also includes the larger, older McAllen Southwest facility. To isolate the continued costs for the Northwest Facility, which is the facility of interest in this report, the overall budget for continued expenses was multiplied by a ratio of 8/25. This rate represents McAllen PUB's management

Table 8. Initial Construction Costs for the McAllen Northwest Conventional Surface-Water Treatment Facility, Across Individual Functional Areas in 2006 Dollars

	Individual Functional Areas (i.e., Cost Centers) of the McAllen North Facility										
INITIAL CONSTRUCTION COST ITEM	Raw Water Intake/ Reservoir	Pre-Disinfection	Coagulation/ Flocculation	Sedimentation	Filtration & Backwash	Secondary Disinfection	Sludge Disposal	Delivery to Municipal Line/ Storage	Operations' Supporting Facilities	Overbuilds & Upgrades[a]	Initial Total Costs
Administrative Overhead[b]											
Building & Site Construction	$716,293	$144,503	$507,635	$240,894	$893,682	$96,414	$316,902	$105,420	$694,926	$1,172,407	$4,889,076
Concrete Structures	3,713	101	301	182	33,302	88	156	976	191	1,244	40,254
Engineering[b]											
Equipment & Installation	2,990	235,913	619,422	453,767	927,663	235,913	27,848	2,990		172,024	2,678,530
Excavation & Site Work	2,041,917	13,444	47,069	21,081	91,296	10,341	227,760	69,671	12,465	108,389	2,643,433
Labor[b]											
Land	1,025,354	12,563	37,677	22,801	69,737	11,017	19,471	121,969	23,901	155,510	1,500,000
Metals	59,581	5,971	17,908	10,837	33,145	5,236	9,254	57,972	11,360	73,914	285,178
Miscellaneous	634	64	191	115	352	55	99	617	121	787	3,035
Mobilization/Insurance	138,299	13,860	41,568	25,156	76,938	12,155	21,482	134,564	26,368	171,568	661,958
Painting	39,305	3,939	11,814	7,150	65,237	3,454	6,106	38,243	58,374	48,761	282,383
Piping	256,450	6,634	26,993	11,154	234,401	8,543	48,224	23,703	3,667	1,553,04	2,172,817
Pre-Project[b]											
SCADA	453,206	45,420	136,218	82,437	252,126	39,831	70,397	440,969	86,411	562,233	2,169,248
Storage Tanks								3,686,518		1,951,68	5,638,204
TOTAL	$4,737,742	$482,412	$1,446,796	$875,574	$2,677,879	$423,047	$747,699	$4,683,612	$917,784	$5,971,571	$22,964,116

Source: McAllen Public Utilities Water Systems (2002) and own modifications.

[a]Represents construction beyond the necessities and captures "elbow room" for future expansion, refer to footnote 26 on page 52 in text.

[b]Costs for this category were not identifiable in the data available, but rather are included elsewhere in other cost item categories.

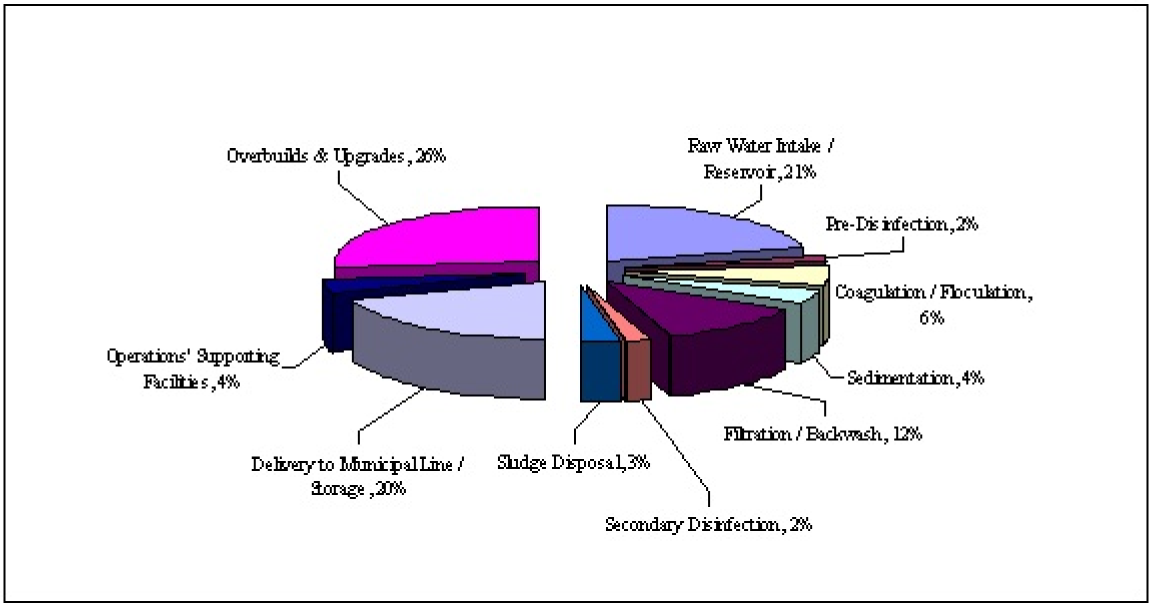

Figure 8. Proportion of construction costs, by segment, for the McAllen Northwest facility

allocation of fixed costs to the McAllen Northwest facility (Santiago 2007). For the McAllen Northwest facility, the continued costs totaled $1.77 million per year (in 2006 dollars) (McAllen Public Utilities Water Systems 2007), and are divided into two categories (Table 9): (1) administrative and (2) operations and maintenance (O&M).

Totaling $84,138, annual administrative expenses account for facility-related expenses which are not included on the McAllen Water Systems budget, but rather are included on other owner-entity budgets (e.g., McAllen PUB's budget). For analysis-detail and water treatment-facility-comparison reasons, this category is divided into six cost-item categories, as well as broken into ten individual segments common to conventional water treatment facilities (Table 9).[23]

Totaling $1.68 million, annual O&M expenses account for facility expenses incurred at the McAllen Northwest facility. This category is divided into 12 cost-item categories, as well as broken into ten individual segments common to conventional water treatment facilities (Table 9). As depicted in Table 9, the most costly area to operate and maintain each year is the *Raw Water Intake/Reservoir* ($618,664) followed by *Pre-Disinfection* ($398,911). When viewed from an individual cost item perspective, the cost of obtaining *Water* ($476,916) is the largest contributor to continued O&M costs.[24]

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[23] Although the CITY H2O ECONOMICS© model (introduced in full in section starting on page 51) is capable of dividing the administrative costs into six cost-item categories, McAllen PUB, which provided the data for this specific analysis, did not provide a break-down of these costs; therefore, only one cost-item category for administration is used in this analysis.

[24] Although the purchase of the permanent water rights is a one-time payment, irrigation districts charge annual fees for the delivery of the water from the Rio Grande to the McAllen water system. These delivery costs are included in this category.

Table 9. Baseline Annual Continued Costs, Across Individual Functional Areas, for the McAllen Northwest Facility in 2006 Dollars

	Individual Functional Areas (i.e., Cost Centers) of the McAllen North Facility										
CONTINUED COST ITEM	Raw Water Intake/ Reservoir	Pre-Disinfection	Coagulation/ Flocculation	Sedimentation	Filtration & Backwash	Secondary Disinfection	Sludge Disposal	Delivery to Municipal Line/Storage	Operations' Supporting Facilities	Overbuilds & Upgrades[a]	Annual Total Costs
Administrative Item											
-Administrative verhead	$9,231	$25,936	$4,629	$2,310	$2,336	$9,930	$6,916	$13,828	$7,179	$1,843	$84,138
-Insurance[b]											
-Labor[b]											
-Maintenance[b]											
-Other[b]											
-Vehicles/Rolling Stock[b]											
Sub-Total	9,231	25,936	4,629	2,310	2,336	9,930	6,916	13,828	7,179	1,843	84,138
Operations & Maintenance Item											
-Administrative Overhead											
-Capital Outlay	121		169	48	265	193	24	24	1,568		2,412
-Chemicals		209,881				81,621					291,502
-Electrical Power	75,934	3,797	37,967	18,984	18,984	3,797	53,154	113,902	37,967	15,187	379,673
-Insurance[b]											
-Labor	40,240	113,055	20,177	10,070	10,184	43,287	30,145	60,277	31,293	8,035	366,763
-Maintenance	8,845	24,849	4,435	2,213	2,239	9,514	6,626	13,249	6,878	1,766	80,614
-Supplies									9,700		9,700
-Rental[b]											
-Other Services & Charges	7,377	21,393	3,688	2,213	2,213	8,115	10,328	11,065	5,902	1,475	73,769
-Vehicles/Rolling Stock									1,436		1,436
-Water Delivery	476,916										476,916
Sub-Total	609,433	372,975	66,436	33,528	33,885	146,527	100,277	198,517	94,744	26,463	1,682,785
TOTAL	$618,664	$398,911	$71,065	$35,838	$36,221	$156,457	$107,193	$212,345	$101,923	$28,306	$1,766,923

Source: McAllen Public Utilities Water Systems (2007) and own modifications.

[a] Represents construction beyond the necessities and captures "elbow room" for future expansion, refer to footnote 26 on page 52 in text.

[b] Costs for this category were not identifiable in the data available, but rather are included elsewhere in another cost item category.

Capital Replacement Items

"Capital Replacement Costs" are an essential part of the continual operations of a treatment facility. Within the useful life of a facility, certain capital items must be replaced during that time period due to wear and tear. The costs for capital replacement items are compounded at 2.043% to account for inflation, as discussed previously. Table 10 depicts the capital replacement items for the McAllen Northwest facility, as well as the frequency and cost of the replacement. The seven capital replacement items have frequencies varying from two years for the anthracite (i.e., the anthracite coal component of the filters) to 18 years for the high-speed pumps. The cost per item for these capital replacements ranges greatly, varying from $2,500 for a turbidity meter up to $75,000 for a SCADA upgrade. SCADA is an acronym for 'Supervisory Control and Data Acquisition' "which is the hardware and software technology which collects data from sensors at remote locations, and in real time sends the data to a centralized computer where facility management can control equipment/conditions at those locations" (Sturdivant et al. 2008).

Table 10. Capital Replacement Items, Occurrence, and Costs for the McAllen Northwest Facility

Capital Item	Frequency of Replacement	Cost per Item[a]	No. of Items Replaced Each Occurrence
SCADA Upgrades	5 years	$75,000	1
Anthracite	2 years	15,000	1
High Speed Pump	18 years	45,000	3
Trucks	7 years	16,000	2
Chemical Feed Pumps	5 years	3,750	4
Lawnmower	5 years	3,500	1
Turbidity Meters	6 years	2,500	6

Source: Santiago (2007).

[a]In 2006 dollars.

CITY H_2O ECONOMICS© - AN ECONOMIC AND FINANCIAL MODEL

To facilitate a Capital Budgeting - NPV analysis using the methodology previously presented for the McAllen Northwest facility, Texas AgriLife Extension Service and Texas AgriLife Research agricultural economists developed a Microsoft® Excel® spreadsheet model, CITY H_2O ECONOMICS©. This model provides life-cycle costs for both the entire surface-water treatment facility as well as detailed cost information for up to 12 individual functional expense areas (i.e., segments).[25] Using the cost data reported above, the individual expense areas for the McAllen Northwest facility are:

1) Water Rights/Raw Water Intake/Reservoir;
2) Pre-Disinfection;
3) Coagulation/Flocculation;
4) Sedimentation;
5) Filtration/Backwash;
6) Secondary Disinfection;
7) Sludge Disposal;
8) Delivery to Municipal Line/Storage;

[25] In this initial application of CITY H_2O ECONOMICS©, the 11th and 12th functional expense areas are unused.

9) Operations' Supporting Facilities; and

10) Overbuilds and Upgrades.[26]

Zero net salvage values (for buildings, equipment, land, etc.) are assumed for all capital assets in the calculations as well as a continual replacement of such capital items into perpetuity. In the model, there is an option to include a resale value for the selling of the water rights at the conclusion of the life of the facility (50 years plus construction period); however, for this baseline analysis, this resale value is set at zero.

The model CITY H_2O ECONOMICS© facilitates comparisons both within and across different treatment technologies. Beyond having the ability to compare the "bottom line" cost results for a water treatment facility, this model can be applied to analyze individual expense areas. That is, results provided by the model allow for a breakdown of costs into facility segment, cost type, and item. Such details are useful when comparing two facilities with substantially different life-cycle costs. The ability to recognize individual segment costs, beyond the standard aggregate, bottom line, overall analysis facilitates identification of which functional cost area(s) is (are) causing the disparity.

[26] 'Overbuilds' represent the excess construction completed to leave room for future expansions of the facility. An example of an overbuild at the McAllen Northwest facility is the piping system, which, although the facility's current maximum capacity is 8.25 mgd, is large enough to handle 32 mgd (Santiago 2007). 'Upgrades' represent "over-the-top" construction beyond what is necessary for conventional water treatment technology. An example of an upgrade is the main office building, which, although the basic requirements for an office building are quite minimal for a conventional facility of this size, is a considerably large building at the McAllen Northwest facility, with two stories and an elevator.

RESULTS

These economic and financial estimates are based on the methodology introduced previously, the aforementioned CITY H_2O ECONOMICS© model, and the primary data provided by the McAllen Public Utility Water Systems. The results are insightful for both identifying the costs of potable water produced at the McAllen Northwest facility and for facilitating multi-facility evaluations aimed at determining the most economic water supply alternative (i.e., for meeting future potable-water demands). The results reported herein cover the costs of producing and delivering the water to an initial point in the distribution system, but not the costs of delivering to individual households. Therefore, these cost estimates are not to be considered the appropriate price to charge consumers.

Aggregate Results

Presented below are the baseline estimates of the McAllen Northwest facility.[27] The goal is to begin with the generalized overview which will be followed by a presentation of costs by categories.

[27] The baseline results for this analysis are characterized by a 78% production efficiency (PE) rate, a 2006 base year, the inclusion of the 'overbuilds and upgrades' segment, and the exclusion of the resale of water rights. That is, in effect, these results reflect a case study of the McAllen Northwest facility operating in its current mode. Note that the section entitled "Modified Data Input and Results" contains results that remove the 'overbuilds and upgrades', as well as an 85% PE rate, with the intention of achieving a more accurate comparison between water treatment technologies.

NPV of Costs and Water Production

The NPV of all costs for the McAllen Northwest facility over the assumed 50-year life of the facility totals $79.17 million in real, 2006 dollars. The NPV of water production for the McAllen Northwest facility over the 50-year life equates to a real value of 143,164 ac-ft (Table 11).

Annuity Equivalent of Costs and Water Production

Extending the NPV of the costs for the McAllen Northwest facility into perpetuity, using the annuity equivalent calculations, results in an estimated $5.08 million/year annuity equivalent. The same calculations are conducted on the NPV of water production, resulting in an annuity equivalent for water production of 6,583 ac-ft/year (Table 11).

Annuity Equivalent of Costs per Acre-foot of Water Production

Dividing the annuity equivalent for costs by the annuity equivalent for water production provides an estimate of the annualized life-cycle cost, or the annuity equivalent of costs

Table 11. Aggregate Results for Costs of Production at the McAllen Northwest Facility in 2006 Dollars[a, b]

Results	Units	Nominal Value	Real Value[c]
Initial Construction & Water Rights Investment	2006 dollars	$43,368,658	$43,368,658
NPV of Total Cost Stream	2006 dollars	$207,706,012	$79,167,566
- annuity equivalent	$/yr		$5,079,864
Water Production	ac-ft (lifetime)	360,406	143,164
- annuity equivalent	ac-ft/yr		6,583
Water Production	1,000-gal (lifetime)	117,438,750	46,650,165
- annuity equivalent	1,000-gal/yr		2,145,074
Cost-of-Treating Water	$/ac-ft/yr		$771.67
Cost-of-Treating Water	$/1,000-gal/yr		$2.37

[a]The results of this table are considered the baseline or "case study" 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]Refer to Tables 12-13 for a more detailed analysis of the baseline results.

[c]Determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.000% discount factor for water, and a 0.000% risk factor (Rister et al. 2002).

per ac-ft. For the McAllen Northwest facility, this equates to a per unit life-cycle cost of $771.67/ac-ft/yr or $2.37/1,000 gallons/yr (Table 11).[28, 29]

Results by Cost Type

In this section, the aggregate results reported in Table 11 are separated into specific cost types. As shown in Table 12, the largest cost type for the entire facility is the initial construction/investment, which contributes 55% of the total costs, totaling $43.37 million over the life of the facility. Of this 55%, 26% of the costs are attributed to the purchase of water rights, with the remaining 29% associated with actual construction of the plant. The results by cost type are further illustrated in Figure 9, which shows that continued costs represent less than half of the total costs. The least significant cost type is the capital replacement expense, accounting for only 1% of total costs. When examined on a per-unit cost basis, again it is clear the initial construction/investment category represents the greatest proportion of costs, with $422.72/ac-ft/yr {$1.30/1,000 gallons/yr}, followed by the continued cost category, contributing $342.07/ac-ft/yr

[28] If the resale of water rights were included (assuming the rights are sold in year 53 and the price of the water rights increased with the inflation rate, meaning the initial $2,300/ac-ft price for water rights is compounded forward 53 years using the 2.043% compounding rate resulting in a price sold of $6,450/ac-ft), the life-cycle cost of producing water would be $746.79/ac-ft/yr {$2.29/1,000 gallons/yr}.

[29] Section 49.507 of Senate Bill 3 passed by the Texas Legislature in 2007 states that municipalities are now (i.e., after January 1, 2008) only required to pay 68% of the market value for permanent water rights converted from agricultural to municipal use in the Rio Grande Valley (Texas Legislature Online 2007). In this analysis, if the opportunity cost of water rights were valued at 68% of the original price ($2,300/ac-ft), the adjusted price of water rights would be $1,564/ac-ft. Such an adjustment would bring the total life-cycle cost of production down from $771.67 to $708.02/ac-ft/yr {$2.17/1,000 gallons/yr}.

Table 12. Costs of Producing Water by Cost Type for the McAllen Northwest Facility in 2006 Dollars[a]

Cost Type	NPV of Cost Stream	Annuity Equivalent in $/yr	Annuity Equivalent in $/ac-ft/yr	Annuity Equivalent in $/1000-gal/yr	% of Total Cost
Initial Construction/ Investment	$43,368,658	$2,782,792	$422.72	$1.30	55%
-Water Rights Purchase	*20,404,541*	*1,309,277*	*198.89*	*0.61*	*26%*
Continued Costs[b]	35,093,723	2,251,823	342.07	1.05	44%
Capital Replacement	705,185	45,249	6.88	0.02	1%
Total	$79,167,566	5,079,864	$771.67	$2.37	100%

[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]Refer to Table 14 for more details on “Continued Costs.”

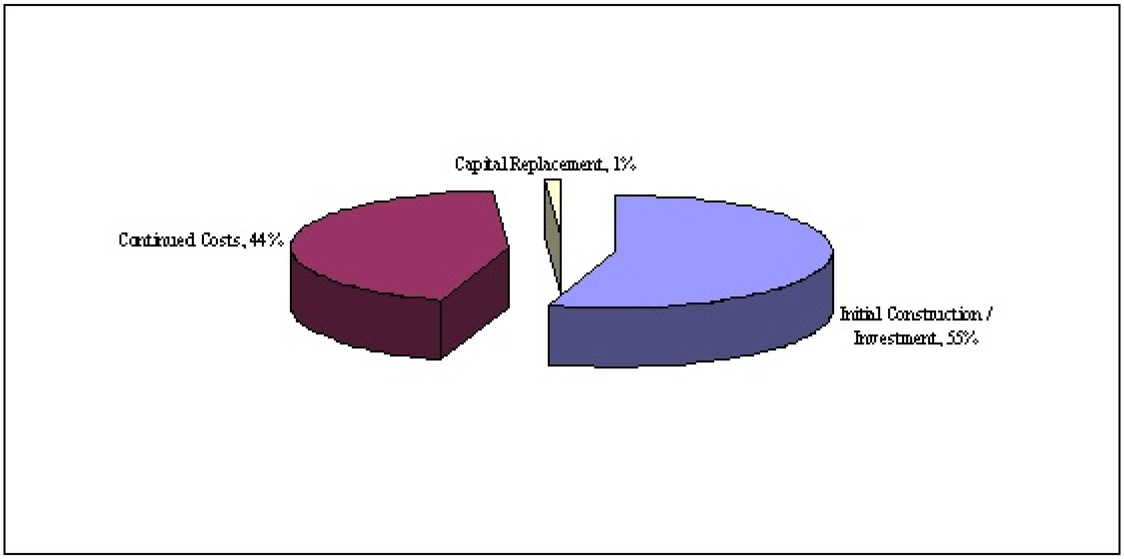

Figure 9. Proportion of total life-cycle costs, by cost type, for the McAllen Northwest facility

{$1.05/1,000 gallons/yr}, and lastly the capital replacement expense, representing only $6.88/ac-ft/yr {$.02/1,000 gallons/yr}.

Results by Segment

The following section takes the aggregate results for the initial construction/investment, continued, and capital replacement costs, and separates these cost items into ten individual expense areas. This ability to dissect the total life-cycle costs of the facility into the individual facility segments is a distinct feature of CITY H_2O ECONOMICS©. The values for the NPV, the annuity equivalent, the cost of production per unit (i.e., annuity equivalent values), and the percentage of the total costs for each of the individual segments are shown in Table 13. The largest cost segment is the *Raw Water Intake/Water Rights/Reservoir* component, which has a NPV value of $37.43 million and accounts for 47% of the total costs. The least costly segment is *Sedimentation*, which has a NPV value of $1.59 million and accounts for 2% of total costs. Figure 10 further illustrates the cost breakdown by segment, clearly indicating that the *Raw Water Intake/Water Rights/Reservoir* segment contributes the greatest amount to total costs.

Results by Operations and Maintenance Cost Item

Another feature of the spreadsheet model CITY H_2O ECONOMICS© is separation of the operations and maintenance costs into detailed, itemized specifics. Table 14 is a

Table 13. Costs of Producing Water for the Ten Facility Segments of the McAllen Northwest Facility in 2006 Dollars[a]

Facility Segment	NPV of Cost Stream	Annuity Equivalent in $/yr	Annuity Equivalent in $/ac-ft/yr	Annuity Equivalent in $/1,000-gals/yr	% of Total Costs
1) Water Rights/Raw Water Intake/Reservoir	$37,429,870	$2,401,724	$364.84	$1.12	47%
2) Pre-Disinfection	8,460,382	542,869	82.47	0.25	11%
3) Coagulation/Flocculation	2,858,269	183,404	27.86	0.09	4%
4) Sedimentation	1,587,368	101,855	15.47	0.04	2%
5) Filtration/Backwash	3,587,649	230,205	34.97	0.11	5%
6) Secondary Disinfection	3,530,502	226,538	34.41	0.10	4%
7) Sludge Disposal	2,876,691	184,586	28.04	0.09	4%
8) Delivery to Municipal Line/Storage	8,993,125	577,053	87.66	0.27	11%
9) Operations' Supporting Facilities	3,309,921	212,384	32.26	0.10	4%
10) Overbuilds & Upgrades[b]	6,533,789	419,247	63.69	0.20	8%
Total	$79,167,566	$5,079,865	$771.67	$2.37	100%

[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]Represents construction beyond the necessities and captures "elbow room" for future expansion, refer to footnote 26 on page 52 in text.

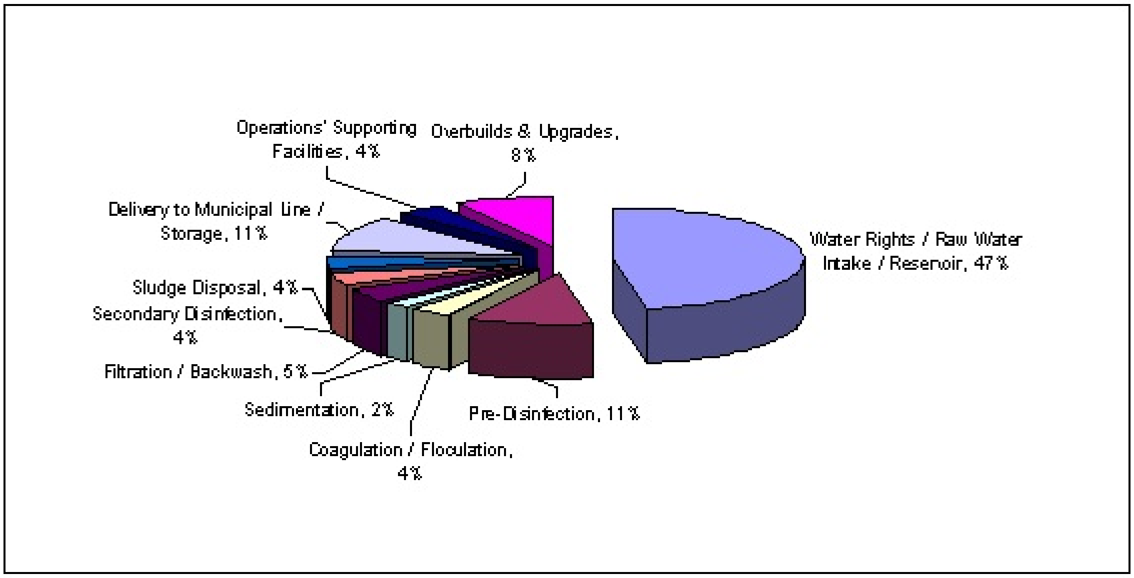

Figure 10. Proportion of life-cycle costs, by segment, for the McAllen Northwest facility

Table 14. Costs of Producing Water by Continued Cost Item for the McAllen Northwest Facility in 2006 Dollars[a]

Continued Cost Item	NPV of Cost Stream	Annuity Equivalent in $/yr	Annuity Equivalent in $/ac-ft/yr	Annuity Equivalent in $/1,000 gal/yr	% of O&M Cost	% of Total Cost
Administrative[b]	$1,671,130	$107,230	$16.29	$.05	--	2%
Operations & Maintenance (O&M)[b]						
-Energy	7,540,851	483,866	73.50	0.23	23%	10%
-Chemicals	5,789,663	371,499	56.43	0.17	17%	7%
-Labor	7,284,439	467,413	71.01	0.22	22%	9%
-Raw Water Delivery	9,472,261	607,797	92.33	0.28	28%	12%
-All Other	3,335,379	214,018	32.51	0.10	10%	4%
Sub-Total	33,422,593	2,144,593	325.78	1.00	100%	42%
Total	$35,093,723	$2,251,823	$342.07	$1.05		44%

[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]"Administrative" costs are incurred at the McAllen Public Utilities Board in association with the McAllen Northwest facility, while O&M costs are incurred at the facility.

specification of the breakout of the specific operations and maintenance cost items and their contribution to the total costs. For the McAllen Northwest facility, the largest operations and maintenance cost item is the cost of moving raw water from the Rio Grande to the facility by the irrigation districts. Over the life of the facility, McAllen Utilities will spend $9.47 million (2006 dollars) for the expense of delivering the water, which accounts for 12% of total costs for the facility and $92.33/ac-ft/yr {$0.28/1,000 gallons/yr}. Closely behind this cost item are energy, labor, and chemical costs, contributing 10%, 9%, and 7%, respectively.

Results for Key Sensitivity Analyses

The results presented in this thesis are deterministic (i.e., no stochastic or risk element about data-input values), and are based on specific values for each of the input variables, such as actual construction costs, continued costs, level of potable water production, etc. An estimate lacking a stochastic element is a point estimate; therefore, depending on the accuracy of the input data, the results are not expected to be exactly precise (e.g., Popp et al. 2004). To further the deterministic results, the two-way data table feature of Excel (Walkenbach 1996, pp. 570-77) is used to provide sensitivity analyses of the cost of producing potable water (and delivering to a point within the distribution system) by varying two of the input parameters. Most data-input parameters in this analysis are suitable for sensitivity analysis; however, for practical reasons, only the six parameters thought most significant in influencing total costs were selected.

Tables 15 and 16 report the sensitivities across plausible ranges for the expected useful life and the facility-use efficiency rate. Changes to the expected useful life of 50 years are minus 5, 10, 15, 20, 25, and 30, bringing the tested low to 20 years for the expected life, while changes to the baseline facility-use efficiency rate of 78% are analyzed with variations ranging from a low of 50% to a high of 100%. Using the given ranges of variation, the annual cost of producing potable water for the McAllen Northwest facility ranges from $673.57 to $1,220.68 per ac-ft in Table 15, and from $2.07 to $3.75 per 1,000 gallons in Table 16. As expected, the lower the expected useful life, the higher the costs of production. Likewise, as expected, the higher the facility use-efficiency rate, the lower the costs of production.

Tables 17 and 18 report the sensitivities across plausible ranges for the initial water right purchase price and the facility-use efficiency rate. Changes to the initial water right purchase price of $2,300 per ac-ft range from a low of $2,000 per ac-ft to a high of $2,600 per ac-ft, while changes to the baseline facility-use efficiency rate of 78% are analyzed with variations ranging from a low of 50% to a high of 100%. Using the given ranges of variation, the annual life-cycle cost of producing water for the McAllen Northwest facility ranges from $653.34 to $1,061.83 per ac-ft in Table 17, and from $2.01 to $3.26 per 1,000 gallons in Table 18. As expected, the higher the initial water right purchase price, the higher the costs of production. Likewise, as expected, the higher the facility use-efficiency rate, the lower the costs of production.

Table 15. Sensitivity Analysis of Cost of Treating Water ($/acre-foot) by Variations in Production and Expected Useful Life at McAllen Northwest Facility in 2006 Dollars

Expected Useful Life (Years)	Annual Water Production in acre-feet								
	4,621	6,007	6,469	6,931	**7,208**	7,393	7,855	8,317	9,241
	50%	65%	70%	75%	**78%**	80%	85%	90%	100%
20	$1,220.68	$1,004.34	$952.83	$908.19	$884.16	$869.13	$834.67	$804.03	$751.95
25	1,137.68	942.57	896.11	855.85	834.17	820.62	789.54	761.91	714.94
30	1,088.92	906.96	863.63	826.08	805.86	793.23	764.24	738.47	694.66
35	1,058.86	885.55	844.29	808.52	789.27	777.23	749.62	725.08	683.36
40	1,040.51	872.98	833.09	798.52	779.91	768.27	741.58	717.86	677.53
45	1,028.69	865.26	826.35	792.63	774.47	763.12	737.09	713.94	674.60
50	1,021.36	860.84	822.62	789.50	**771.67**	760.52	734.95	712.21	673.57

Note: Numbers in bold represent the baseline results for the McAllen Northwest facility in its current operating state.

Table 16. Sensitivity Analysis of Cost of Treating Water ($/1,000 gallons) by Variations in Production and Expected Useful Life at McAllen Northwest Facility in 2006 Dollars

Expected Useful Life (Years)	Annual Water Production in 1,000 gallons								
	1,505,625	1,957,313	2,107,875	2,258,438	**2,348,775**	2,409,000	2,559,563	2,710,125	3,011,250
	50%	65%	70%	75%	**78%**	80%	85%	90%	100%
20	$3.75	$3.08	$2.92	$2.79	$2.71	$2.67	$2.56	$2.47	$2.31
25	3.49	2.89	2.75	2.63	2.56	2.52	2.42	2.34	2.19
30	3.34	2.78	2.65	2.54	2.47	2.43	2.35	2.27	2.13
35	3.25	2.72	2.59	2.48	2.42	2.39	2.30	2.23	2.10
40	3.19	2.68	2.56	2.45	2.39	2.36	2.28	2.20	2.08
45	3.16	2.66	2.54	2.43	2.38	2.34	2.26	2.19	2.07
50	3.13	2.64	2.52	2.42	**2.37**	2.33	2.26	2.19	2.07

Note: Numbers in bold represent the baseline results for the McAllen Northwest facility in its current operating state.

Table 17. Sensitivity Analysis of Cost of Treating Water ($/acre-foot) by Variations in Production and Initial Water-Right Purchase Price at McAllen Northwest Facility in 2006 Dollars

Initial Water Right Purchase Price	Annual Water Production in acre-feet								
	4,621	6,007	6,469	6,931	**7,208**	7,393	7,855	8,317	9,241
	50%	65%	70%	75%	**78%**	80%	85%	90%	100%
$2,000	$ 980.89	$829.71	$793.72	$762.52	$745.72	$735.22	$711.14	$689.73	$653.34
$2,100	994.38	840.09	803.35	771.51	754.37	743.66	719.07	697.23	660.08
$2,200	1,007.87	850.47	812.99	780.51	763.02	752.09	727.01	704.72	666.83
$2,300	1,021.36	860.84	822.62	789.50	771.67	760.52	734.95	712.21	673.57
$2,400	1,034.85	871.22	832.26	798.49	780.31	768.95	742.88	719.71	680.32
$2,500	1,048.34	881.60	841.90	807.49	788.96	777.38	750.82	727.20	687.06
$2,600	1,061.83	891.97	851.53	816.48	797.61	785.81	758.75	734.70	693.80

Note: Numbers in bold represent the baseline results for the McAllen Northwest facility in its current operating state.

Table 18. Sensitivity Analysis of Cost of Treating Water ($/1,000 gallons) by Variations in Production and Initial Water-Right Purchase Price at McAllen Northwest Facility in 2006 Dollars

Initial Water Right Purchase Price	Annual Water Production in 1,000 gallons								
	1,505,625	1,957,313	2,107,875	2,258,438	**2,348,775**	2,409,000	2,559,563	2,710,125	3,011,250
	50%	65%	70%	75%	**78%**	80%	85%	90%	100%
$2,000	$3.01	$2.55	$2.44	$2.34	$2.29	$2.26	$2.18	$2.12	$2.01
$2,100	3.05	2.58	2.47	2.37	2.32	2.28	2.21	2.14	2.03
$2,200	3.09	2.61	2.50	2.40	2.34	2.31	2.23	2.16	2.05
$2,300	3.13	2.64	2.52	2.42	2.37	2.33	2.26	2.19	2.07
$2,400	3.18	2.67	2.55	2.45	2.39	2.36	2.28	2.21	2.09
$2,500	3.22	2.71	2.58	2.48	2.42	2.39	2.30	2.23	2.11
$2,600	3.26	2.74	2.61	2.51	2.45	2.41	2.33	2.25	2.13

Note: Numbers in bold represent the baseline results for the McAllen Northwest facility in its current operating state.

Tables 19 and 20 report the sensitivities across plausible ranges for the initial construction cost and the facility-use efficiency rate. Changes to the initial construction cost range +/- $5,000 to the original $22,964,120, from a low of $17,964,120 to a high of $27,964,120, while changes to the baseline facility-use efficiency rate of 78% are analyzed with variations ranging from a low of 50% to a high of 100%. Using the given ranges of variation, the annual life-cycle cost of producing water for the McAllen Northwest facility ranges from $635.56 to $1,097.39 per ac-ft in Table 19, and from $1.95 to $3.37 per 1,000 gallons in Table 20. As expected, the higher the initial construction costs, the higher the costs of production. Likewise, as expected, the higher the facility use-efficiency rate, the lower the costs of production.

Tables 21 and 22 report the sensitivities across plausible ranges for annual O&M cost and the facility-use efficiency rate. Changes about the annual O&M baseline cost of $1,766,923 vary +/- 5%, 10%, and 20%, while changes to the baseline facility-use efficiency rate of 78% are analyzed with variations ranging from a low of 50% to a high of 100%. Using the given ranges of variation, the annual life-cycle cost of producing water for the McAllen Northwest facility ranges from $572.03 to $1,126.72 per ac-ft in Table 21, and from $1.76 to $3.46 per 1,000 gallons in Table 22. As expected, the higher the annual O&M costs, the higher the costs of production. Likewise, as expected, the higher the facility use-efficiency rate, the lower the costs of production.

Table 19. Sensitivity Analysis of Cost of Treating Water ($/acre-foot) by Variations in Production and Initial Construction Cost at McAllen Northwest Facility in 2006 Dollars

Initial Construction Cost ($)	Annual Water Production in acre-feet								
	4,621	6,007	6,469	6,931	**7,208**	7,393	7,855	8,317	9,241
	50%	65%	70%	75%	**78%**	80%	85%	90%	100%
-5,000,000	$ 945.33	$802.36	$768.32	$738.82	$722.93	$713.00	$690.22	$669.98	$635.56
-2,500,000	983.35	831.60	795.47	764.16	747.30	736.76	712.58	691.09	654.56
-1,000,000	1,006.16	849.15	811.76	779.36	761.92	751.01	726.00	703.77	665.97
-	1,021.36	860.84	822.62	789.50	**771.67**	760.52	734.95	712.21	673.57
+1,000,000	1,036.57	872.54	833.49	799.64	781.41	770.02	743.89	720.66	681.17
+2,500,000	1,059.38	890.08	849.78	814.84	796.03	784.28	757.31	733.33	692.58
+5,000,000	1,097.39	919.33	876.93	840.19	820.40	808.04	779.67	754.45	711.58

Note: Numbers in bold represent the baseline results for the McAllen Northwest facility in its current operating state.

Table 20. Sensitivity Analysis of Cost of Treating Water ($/1,000 gallons) by Variations in Production and Initial Construction Cost at McAllen Northwest Facility in 2006 Dollars

Initial Construction Cost ($)	Annual Water Production in 1,000 gallons								
	1,505,625	1,957,313	2,107,875	2,258,438	**2,348,775**	2,409,000	2,559,563	2,710,125	3,011,250
	50%	65%	70%	75%	**78%**	80%	85%	90%	100%
-5,000,000	$2.90	$2.46	$2.36	$2.27	$2.22	$2.19	$2.12	$2.06	$1.95
-2,500,000	3.02	2.55	2.44	2.35	2.29	2.26	2.19	2.12	2.01
-1,000,000	3.09	2.61	2.49	2.39	2.34	2.30	2.23	2.16	2.04
-	3.13	2.64	2.52	2.42	**2.37**	2.33	2.26	2.19	2.07
+1,000,000	3.18	2.68	2.56	2.45	2.40	2.36	2.28	2.21	2.09
+2,500,000	3.25	2.73	2.61	2.50	2.44	2.41	2.32	2.25	2.13
+5,000,000	3.37	2.82	2.69	2.58	2.52	2.48	2.39	2.32	2.18

Note: Numbers in bold represent the baseline results for the McAllen Northwest facility in its current operating state.

Table 21. Sensitivity Analysis of Cost of Treating Water ($/acre-foot) by Variations in Production and Annual Operations and Maintenance (O&M)Cost at McAllen Northwest Facility in 2006 Dollars

Changes in Annual O&M Cost (%)	Annual Water Production in acre-feet								
	4,621	6,007	6,469	6,931	**7,208**	7,393	7,855	8,317	9,241
	50%	65%	70%	75%	**78%**	80%	85%	90%	100%
-30%	$ 916.01	$757.25	$719.45	$686.69	$669.05	$658.02	$632.73	$610.25	$572.03
-20%	951.12	791.78	753.84	720.96	703.25	692.19	666.80	644.23	605.87
-10%	986.24	826.31	788.23	755.23	737.46	726.35	700.87	678.22	639.72
-	1,021.36	860.84	822.62	789.50	**771.67**	760.52	734.95	712.21	673.57
+10%	1,056.48	895.38	857.02	823.77	805.87	794.68	769.02	746.20	707.42
+20%	1,091.60	929.91	891.41	858.04	840.08	828.85	803.09	780.19	741.27
+30%	1,126.72	964.44	925.80	892.32	874.29	863.02	837.16	814.18	775.12

Note: Numbers in bold represent the baseline results for the McAllen Northwest facility in its current operating state.

Table 22. Sensitivity Analysis of Cost of Treating Water ($/1,000 gallons) by Variations in Production and Annual Operations and Maintenance (O&M) Cost at McAllen Northwest Facility in 2006 Dollars

Changes in Annual O&M Cost (%)	Annual Water Production in 1,000 gallons								
	1,505,625	1,957,313	2,107,875	2,258,438	**2,348,775**	2,409,000	2,559,563	2,710,125	3,011,250
	50%	65%	70%	75%	**78%**	80%	85%	90%	100%
-30%	$2.81	$2.32	$2.21	$2.11	$2.05	$2.02	$1.94	$1.87	$1.76
-20%	2.92	2.43	2.31	2.21	2.16	2.12	2.05	1.98	1.86
-10%	3.03	2.54	2.42	2.32	2.26	2.23	2.15	2.08	1.96
-	3.13	2.64	2.52	2.42	**2.37**	2.33	2.26	2.19	2.07
+10%	3.24	2.75	2.63	2.53	2.47	2.44	2.36	2.29	2.17
+20%	3.35	2.85	2.74	2.63	2.58	2.54	2.46	2.39	2.27
+30%	3.46	2.96	2.84	2.74	2.68	2.65	2.57	2.50	2.38

Note: Numbers in bold represent the baseline results for the McAllen Northwest facility in its current operating state.

Tables 23 and 24 report the sensitivities across plausible ranges for annual energy cost and the facility-use efficiency rate. Changes about the annual energy baseline cost of $379,672 vary +/- 5%, 10%, and 20%, while changes to the baseline facility-use efficiency rate of 78% are analyzed with variations ranging from a low of 50% to a high of 100%. Using the given ranges of variation, the annual life-cycle cost of producing water for the McAllen Northwest facility ranges from $658.87 to $1,036.06 per ac-ft in Table 23, and from $2.02 to $3.18 per 1,000 gallons in Table 24. As expected, the higher the annual energy costs, the higher the costs of production. Likewise, as expected, the higher the facility use-efficiency rate, the lower the costs of production.

Tables 25 and 26 report the sensitivities across plausible ranges for annual chemical cost and the facility-use efficiency rate. Changes about the annual chemical baseline cost of $291,502 vary +/- 5%, 10%, and 20%, while changes to the baseline facility-use efficiency rate of 78% are analyzed with variations ranging from a low of 50% to a high of 100%. Using the given ranges of variation, the annual life-cycle cost of producing water for the McAllen Northwest facility ranges from $662.28 to $1,032.65 per ac-ft in Table 25, and from $2.03 to $3.17 per 1,000 gallons in Table 26. As expected, the higher the annual chemical costs, the higher the costs of production. Likewise, as expected, the higher the facility use-efficiency rate, the lower the costs of production.

Table 23. Sensitivity Analysis of Cost of Treating Water ($/acre-foot) by Variations in Production and Annual Energy Costs at McAllen Northwest Facility in 2006 Dollars

Changes in Annual Energy Cost (%)	Annual Water Production in acre-feet								
	4,621	6,007	6,469	6,931	**7,208**	7,393	7,855	8,317	9,241
	50%	65%	70%	75%	**78%**	80%	85%	90%	100%
-20%	$1,006.66	$846.14	$807.92	$774.80	$756.96	$745.82	$720.24	$697.51	$658.87
-10%	1,014.01	853.49	815.27	782.15	764.32	753.17	727.59	704.86	666.22
-5%	1,017.69	857.17	818.95	785.83	767.99	756.84	731.27	708.54	669.90
-	1,021.36	860.84	822.62	789.50	**771.67**	760.52	734.95	712.21	673.57
+5%	1,025.04	864.52	826.30	793.18	775.34	764.19	738.62	715.89	677.25
+10%	1,028.71	868.19	829.97	796.85	779.02	767.87	742.30	719.56	680.92
+20%	1,036.06	875.54	837.32	804.20	786.37	775.22	749.65	726.91	688.27

Note: Numbers in bold represent the baseline results for the McAllen Northwest facility in its current operating state.

Table 24. Sensitivity Analysis of Cost of Treating Water ($/1,000 gallons) by Variations in Production and Annual Energy Costs at McAllen Northwest Facility in 2006 Dollars

Changes in Annual Energy Cost (%)	Annual Water Production in 1,000 gallons								
	1,505,625	1,957,313	2,107,875	2,258,438	**2,348,775**	2,409,000	2,559,563	2,710,125	3,011,250
	50%	65%	70%	75%	**78%**	80%	85%	90%	100%
-20%	$3.09	$2.60	$2.48	$2.38	$2.32	$2.29	$2.21	$2.14	$2.02
-10%	3.11	2.62	2.50	2.40	2.35	2.31	2.23	2.16	2.04
-5%	3.12	2.63	2.51	2.41	2.36	2.32	2.24	2.17	2.06
-	3.13	2.64	2.52	2.42	**2.37**	2.33	2.26	2.19	2.07
+5%	3.15	2.65	2.54	2.43	2.38	2.35	2.27	2.20	2.08
+10%	3.16	2.66	2.55	2.45	2.39	2.36	2.28	2.21	2.09
+20%	3.18	2.69	2.57	2.47	2.41	2.38	2.30	2.23	2.11

Note: Numbers in bold represent the baseline results for the McAllen Northwest facility in its current operating state.

Table 25. Sensitivity Analysis of Cost of Treating Water ($/acre-foot) by Variations in Production and Annual Chemical Costs at McAllen Northwest Facility in 2006 Dollars

Changes in Annual Chemical Cost (%)	Annual Water Production in acre-feet								
	4,621	6,007	6,469	6,931	**7,208**	7,393	7,855	8,317	9,241
	50%	65%	70%	75%	**78%**	80%	85%	90%	100%
-20%	$1,010.08	$849.56	$811.34	$778.21	$760.38	$749.23	$723.66	$700.93	$662.28
-10%	1,015.72	855.20	816.98	783.86	766.02	754.87	729.30	706.57	667.93
-5%	1,018.54	858.02	819.80	786.68	768.84	757.70	732.12	709.39	670.75
-	1,021.36	860.84	822.62	789.50	**771.67**	760.52	734.95	712.21	673.57
+5%	1,024.18	863.66	825.45	792.32	774.49	763.34	737.77	715.04	676.39
+10%	1,027.01	866.49	828.27	795.14	777.31	766.16	740.59	717.86	679.21
+20%	1,032.65	872.13	833.91	800.79	782.95	771.80	746.23	723.50	684.86

Note: Numbers in bold represent the baseline results for the McAllen Northwest facility in its current operating state.

Table 26. Sensitivity Analysis of Cost of Treating Water ($/1,000 gallons) by Variations in Production and Annual Chemical Costs at McAllen Northwest Facility in 2006 Dollars

Changes in Annual Chemical Cost (%)	Annual Water Production in 1,000 gallons								
	1,505,625	1,957,313	2,107,875	2,258,438	**2,348,775**	2,409,000	2,559,563	2,710,125	3,011,250
	50%	65%	70%	75%	**78%**	80%	85%	90%	100%
-20%	$3.10	$2.61	$2.49	$2.39	$2.33	$2.30	$2.22	$2.15	$2.03
-10%	3.12	2.62	2.51	2.41	2.35	2.32	2.24	2.17	2.05
-5%	3.13	2.63	2.52	2.41	2.36	2.33	2.25	2.18	2.06
-	3.13	2.64	2.52	2.42	**2.37**	2.33	2.26	2.19	2.07
+5%	3.14	2.65	2.53	2.43	2.38	2.34	2.26	2.19	2.08
+10%	3.15	2.66	2.54	2.44	2.39	2.35	2.27	2.20	2.08
+20%	3.17	2.68	2.56	2.46	2.40	2.37	2.29	2.22	2.10

Note: Numbers in bold represent the baseline results for the McAllen Northwest facility in its current operating state.

MODIFIED DATA INPUT AND RESULTS

The previous results presented in this thesis represent a case analysis of the McAllen Northwest facility in its current operating state. While the results were determined using the Net Present Value (NPV) and Annuity Equivalent approach in the CITY H_2O ECONOMICS© model previously advocated as appropriate for "apples-to-apples" comparisons, certain modifications to key data-input parameters are required to the baseline analysis in order to allow for a valid comparison across facilities and/or technologies. These adjustments allow for a more consistent basis of comparisons and alter the base assumptions in the following ways:

- base period of analysis – assume the construction period commenced on January 1, 2006, thereby assuring all financial calculations are determined in a common time frame;[30, 31]

- level of annual production – assume a constant 85% rate of production relative to actual maximum-designed daily capacity, thereby accommodating routine maintenance, reasonable unexpected shutdown, and compliance with the TCEQ

[30] Already incorporated into baseline analysis of case study presented in this thesis.
[31] For facilities constructed in different time periods, either inflation or deflation of the cost values is necessary to accommodate this stated benchmark period.

mandate 30 TAC 291.93(30) (Texas Secretary of State 2008), but avoiding the potential bias associated with operating circumstances at this particular site;[32, 33]

- overbuilds and upgrades – assume the construction design and other initial capital investments are sufficient to maintain the reasonable operation of the facility, but ignore those costs associated with "over-the-top" features intended to facilitate other functions and/or future expansions;[34]

- salvage of capital assets – assume that all capital assets have a net salvage value of zero, reflecting either (1) circumstances whereby costs of disposing of the assets and returning the footprint of the property to its original state are virtually equivalent to the assets' salvage value and/or (2) the municipality's investments are intended to be long term, with no expectations of ever salvaging the assets;[35, 36]

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[32] TCEQ mandate 30 TAC 291.93(30) states that "A retail public utility that possesses a certificate of public convenience and necessity that has reached 85% of its capacity as compared to the most restrictive criteria of the commission's minimum capacity requirements in Chapter 290 of this title shall submit to the executive director a planning report that clearly explains how the retail public utility will provide the expected service demands to the remaining areas within the boundaries of its certificated area" (Texas Secretary of State 2008).

[33] Some individual facilities may not be able to fully attain the expected designed operating performance, e.g., abnormal arsenic, iron, and/or other objectionable water quality attributes for which original project design was incomplete and subsequent operating conditions were adversely affected. To facilitate correct comparisons, such circumstances should be removed from the analysis calculations, thus assuming the facility operates as originally designed/intended.

[34] 'Overbuilds' represent the excess construction completed to leave room for potential future expansions of the facility. 'Upgrades' represent construction beyond a level deemed necessary for conventional water treatment technology.

[35] Already incorporated into baseline analysis of case study presented in this thesis.

[36] Admittedly, the opportunity cost value aspects of land well fields, water rights, and perhaps the capital assets associated with potable water production facilities can be argued to be net positive. Projection of such values 50+ years into the future are subject to a broad range of subjective assumptions, however. Furthermore, the financial discounting of such values 50+ years virtually eliminates the positive influence of such calculations.

- quality of raw water – the quality of the incoming source water will vary depending on the location of the facility affecting the total treatment costs. To establish a consistent basis of comparison between facilities, the cost-input data should be modified to account for variations in raw water quality. Determination of appropriate adjustments can be quite difficult, and currently there is no established solution. Although a solution for this modification has not been defined, it is important to recognize the potential artifacts associated with comparing results for water treatment facilities processing different qualities of raw water; and

- quality of outgoing, product water – it is important that similar quality standards be imposed on each of the analyses so that quality of water produced and associated chemical and other operating costs are not adversely compromised in any of the comparative projects. The comparable quality standard assumed for this analysis is the requirement that the product potable water pass both the maximum contaminant levels and secondary levels set by both TCEQ and EPA.[37]

Incorporating considerations of the above-noted issues with the methodology embedded in CITY H_2O ECONOMICS© for the McAllen Northwest facility results in the "modified" life-cycle cost of producing potable water of $667.74/ac-ft/yr {$2.05/1,000

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[37] The contributors of this thesis do realize there are some quality comparisons that are impossible to make equal between facilities (i.e., desalination treatment can achieve a higher-quality water than conventional treatment); however, it is felt that this standardization is the most feasible and appropriate.

gallons/yr} (Table 27).[38, 39] These results are appropriately adjusted and suitable for comparison to life-cycle costs of other alternatives for producing potable water calculated using similar assumptions.

The following tables provide further demonstration of the changes to the original, baseline life-cycle cost of production when the data is modified to include the benchmark comparison assumptions. Tables 28-30 show the life-cycle costs broken down by cost type, segment, and item as presented in the preceding text.

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[38] If the resale of water rights were included (assuming the rights are sold in year 53 and the price of the water rights increased with the inflation rate, meaning the initial $2,300/ac-ft price for water rights is compounded forward 53 years using the 2.043% compounding rate resulting in a price sold of $6,450/ac-ft), the life-cycle cost of producing water would be $644.91/ac-ft/yr {$1.98/1,000 gallons/yr}.

[39] Section 49.507 of Senate Bill 3 passed by the Texas Legislature in 2007 states that municipalities are now only required to pay 68% of the market value for permanent water rights converted from agricultural to municipal use after January 1, 2008 in the Rio Grande Valley (Texas Legislature Online 2007). In this analysis, if the opportunity cost of water rights were valued at 68% of the original price ($2,300/ac-ft), the adjusted price of water rights would be $1,564/ac-ft. Such an adjustment would bring the adjusted, total life-cycle cost of production in its modified operating state down from $667.74 to $609.33/ac-ft/yr {$1.87/1,000 gallons/yr}.

Table 27. "Modified" Aggregate Results for Costs of Production at the McAllen Northwest Facility in 2006 Dollars[a, b]

Results	Units	Nominal Value	Real Value[c]
Initial Construction and Water Rights Investment	2006 dollars	$37,397,088	$37,397,088
NPV of Total Cost Stream	2006 dollars	$208,408,155	$74,653,110
- annuity equivalent	$/yr		$4,790,190
Water Production	ac-ft (lifetime)	392,750	156,012
- annuity equivalent	ac-ft/yr		7,174
Water Production	1,000-gal (lifetime)	127,978,125	50,836,718
- annuity equivalent	1,000-gal/yr		2,337,580
Cost-of-Treating Water	$/ac-ft/yr		$667.74
Cost-of-Treating Water	$/1,000-gal/yr		$2.05

[a]The results of this table are considered the adjusted analysis of the McAllen Northwest facility in its modified operating state (i.e., 85% production efficiency, 2006 dollars, overbuilds and upgrades are not included, and a zero net salvage value is recorded for all capital items and water rights).

[b]Refer to Tables 28-30 for a more detailed analysis of the modified results.

[c]Determined using a 2.043% compound rate on costs, a 6.125% discount factor for dollars, a 4.000% discount factor for water, and a 0.000% risk factor (Rister et al. 2002).

Table 28. "Modified" Costs of Producing Water by Cost Type for the McAllen Northwest Facility in 2006 Dollars[a]

Cost Type	NPV of Cost Stream	Annuity Equivalent in $/yr	Annuity Equivalent in $/ac-ft/yr	Annuity Equivalent in $/1000-gal/yr	% of Total
Initial Construction/ Investment	$37,397,088	$2,399,621	$334.50	$1.03	50%
-Water Rights Purchase	*20,404,541*	*1,309,277*	*182.51*	*0.56*	*27%*
Continued Costs[b]	36,550,837	2,345,320	326.93	1.00	49%
Capital Replacement	705,185	45,249	6.31	0.02	1%
Total	$74,653,110	$4,790,190	$667.74	$2.05	100%

[a]The results of this table are considered the adjusted analysis of the McAllen Northwest facility in its modified operating state (i.e., 85% production efficiency, 2006 dollars, overbuilds and upgrades are not included, and a zero net salvage value is recorded for all capital items and water rights).

[b]Refer to Table 30 for more details on "Continued Costs."

Table 29. "Modified" Costs of Producing Water for the Nine Facility Segments of the McAllen Northwest Facility in 2006 Dollars[a]

Facility Segment	NPV of Cost Stream	Annuity Equivalent in $/yr	Annuity Equivalent in $/ac-ft/yr	Annuity Equivalent in $/1,000-gals/yr	% of Total Costs
1) Water Rights/Raw Water Intake/Reservoir	$38,415,293	$2,464,955	$343.61	$1.06	52%
2) Pre-Disinfection	8,841,251	567,308	79.08	0.24	12%
3) Coagulation/Flocculation	2,925,943	187,746	26.17	0.08	4%
4) Sedimentation	1,621,205	104,026	14.50	0.05	2%
5) Filtration/Backwash	3,621,486	232,376	32.39	0.10	5%
6) Secondary Disinfection	3,682,753	236,307	32.94	0.10	5%
7) Sludge Disposal	2,971,435	190,665	26.58	0.08	4%
8) Delivery to Municipal Line/Storage	9,196,149	590,080	82.26	0.25	12%
9) Operations' Supporting Facilities	3,377,595	216,727	30.21	0.09	4%
TOTAL	$74,653,110	$4,790,190	$667.74	$2.05	100%

[a]The results of this table are considered the adjusted analysis of the McAllen Northwest facility in its modified operating state (i.e., 85% production efficiency, 2006 dollars, overbuilds and upgrades are not included, and a zero net salvage value is recorded for all capital items and water rights).

Table 30. "Modified" Costs of Producing Water by Continued Cost Item for the McAllen Northwest Facility in 2006 Dollars[a]

Continued Cost Item	NPV of Cost Stream	Annuity Equivalent in $/yr	Annuity Equivalent in $/ac-ft/year	Annuity Equivalent in $/1,000 gal/year	% of O&M Cost	% of Total Cost
Administrative[b]	$ 1,634,519	$104,880	$14.62	$0.05	--	2%
Operations &Maintenance (O&M)						
-Energy	7,888,890	506,198	70.56	0.22	23%	11%
-Chemicals	6,309,248	404,839	56.43	0.17	18%	9%
-Labor	7,124,847	457,173	63.73	0.19	20%	9%
-Raw Water Delivery	10,322,336	662,343	92.33	0.28	30%	14%
-All Other	3,270,999	209,887	29.26	0.09	9%	4%
Sub-Total	34,916,320	2,240,440	312.31	0.95	100%	47%
Total	$36,550,837	$2,345,320	$326.93	$1.00		49%

[a]The results of this table are considered the adjusted analysis of the McAllen Northwest facility in its modified operating state (i.e., 85% production efficiency, 2006 dollars, overbuilds and upgrades are not included, and a zero net salvage value is recorded for all capital items and water rights).

[b]"Administrative" costs are incurred at the McAllen Public Utilities Board in association with the McAllen Northwest facility, while O&M costs are incurred at the facility.

DISCUSSION

Historically, conventional surface-water treatment has been the preferred method of producing potable (i.e., drinkable) water in the Valley, due to the seemingly-abundant supply of Rio Grande surface water and the technology's supposed lower cost of production, relative to other available, feasible treatment methods. The natural process in potable water supply management decision making is to use the least expensive source first. Since untreated groundwater is not an option in this region (without first undergoing desalination treatment), surface-water treatment is perceived as the most logical choice as the least-cost available source for potable water, which is demonstrated by the fact that an overwhelming majority (i.e., almost 90%) of water-treatment facilities in the Valley use conventional surface-water treatment (Texas Commission on Environmental Quality 2008).

The 'total' cost of conventional surface-water treatment involves a large number of cost factors and items as facilities can be very complex with many different components. Estimated results can therefore vary substantially, depending on what cost factors and items are included/excluded in the analysis. This case study for the McAllen Northwest conventional surface-water treatment facility resulted in higher cost estimates ($2.37/1,000 gallons) than other recent literature (e.g., Jurenka, Martella, and Rodriguez (2001) indicated potable water costs were between $1.00 and $1.70 per 1,000 gallons). The apparent substantial difference identified between the results in this thesis and previous studies could be due to a number of reasons. First, the data utilized in this thesis are primary data which provide a more in-depth and complete analysis than reports built on secondary data, with the latter appearing to be the case for much of the literature. Most likely, additional principal reasons for differences in cost estimates are related to the varying methods of analysis employed and the time-period of analysis. In general, when developing cost estimates, it is easy to realize a wide range of estimates depending on the assumptions employed by the analyst(s) (e.g., including/excluding present value of water rights, including/excluding overbuilds and excessive costs, base year of analysis, etc.). Since a primary objective of this thesis is to provide a protocol for developing a complete 'economic' analysis of a surface-water treatment facility, opportunity costs were included in the case study (e.g., present value of owned water rights, present value of owned land, etc.); such costs might not be included if the analyst(s) is (are) considering only accounting or purely financial costs. The fact that differing assumptions and methodology produce a wide range of cost estimates points to the need for standardized measures of comparison and common methodology for use in planning future potable water supply development.

The total cost estimates for conventional surface-water treatment are also dynamic (i.e., change over time) as input costs and other items change. This thesis provides a snapshot of the current operating costs of the McAllen Northwest facility for the year 2006, but in reality, the costs of production are constantly changing. Given the current environment of rising concrete, steel, and energy prices, there is a trend of increasing input costs, which is not likely to reverse.[40] Also, following the events of September 11, 2001, there has been an increased awareness of the country's security. As a result, water security and quality issues are on the rise, which may have an impact on future operating costs if water treatment facility design and operations must be altered to accommodate increased security concerns. Over time, total costs of production for the McAllen Northwest facility will change from their current level due to fluctuations in input prices and facility-design requirements.

Some municipalities, in the Valley and elsewhere, only have the option of conventional surface-water treatment. Where alternatives do exist, an economic comparison of the alternative technologies cannot be based on the prices charged for the treated, potable water. Since prices charged by utilities reflect the cost of distribution to the individual households, as well as the varying fiscal management decisions by utility managers (e.g., whether the water utilities division is a profit or cost center within the total municipal operations mentioned in the Goldstein (1986) study referred to in the "Prior Literature and Economic Studies" section), prices charged are not accurate predictors of the costs of producing potable water. To determine which alternative is the most economical source of potable water, a sound and common methodology must be applied to all technologies being considered. This study, its considerations and methodology,

[40] In talks with a Valley water treatment engineer, it is discovered that currently (i.e., 2008) total construction costs (i.e., cement, land, labor, etc.) for large capital projects are incurring an approximately one percent increase per month, which amounts to a 10-12 percent annual escalation in the region (Cruz 2008). If this substantial rate of increase continues, it will have an effect on total costs for water treatment facilities constructed in the future (i.e., holding all other factors constant, if construction costs increase, total costs will increase, and if construction costs decrease, total costs will also decrease).

are useful and can be used (with appropriate modifications) in multi-technology comparisons.

As mentioned in the "Introduction" section, potable water treatment alternatives to conventional surface-water treatment for the Valley include groundwater/seawater desalination, wastewater reuse, rainwater harvesting, etc. Given recent advancements in technology, the desalination of brackish groundwater is increasingly becoming an economically and financially-feasible alternative. The costs of desalinating groundwater have decreased in recent years to the apparent extent that many water managers and planners are asking themselves, "Which is the more economic source of potable water?" This dilemma is especially significant in the Texas Rio Grande Valley, where the price of surface-water rights is steadily on the rise, in effect increasing the relative cost of conventional surface-water treatment. With a current price of $2,300/ac-ft (as opposed to a price at $1,400/ac-ft in 2000 (Elium 2008)), which is expected to rise in the future at a rate higher than inflation (Hinojosa 2007), municipal water rights expense will continue to account for a greater proportion of the anticipated increasing total conventional surface-water treatment costs. For this case study, the water rights accounted for 26% of total costs and delivery of such water from the Rio Grande to the treatment facility contributed another 12% of total costs, i.e., obtaining source water contributes to 38% of the total costs of potable water produced at the McAllen Northwest surface-water treatment facility.

Beyond analyzing the economic and financial competitiveness of conventional surface-water treatment against alternative technologies, there are other logistical issues that must be considered as population increases and the demand for water rises. A conventional surface-water treatment facility is a very land/resource intensive project (e.g., the McAllen Northwest facility covers approximately 50 acres) which requires a large ecological footprint.[41] The large land requirement is an issue where population centers become more dense and large, open land areas become more scarce. Thus, limitations from a physical constraint could become a higher priority in water supply management decisions than economic efficiency in certain situations.

The decisions behind whether or not to expand potable water supply and which water treatment technology to employ are not easy for water planners and managers. As mentioned in the preceding paragraphs, there are many factors that must be considered when deciding which water technology to use (i.e., economic costs, ecological footprint, etc.). In addition, water supply expansion projects take significant amounts of time to plan, design, and construct. This lengthy time period makes it especially difficult on water planners and managers when population is increasing at a rapid rate. In a region that is experiencing rapid population growth such as the Rio Grande Valley, water managers and planners are often forced to make hasty decisions about potable water supply expansions. Conventional surface-water treatment is just one of the options

[41] An ecological footprint is defined as "resource management tool that measures how much land and water area a human population requires to produce the resources it consumes and to absorb its wastes under prevailing technology" (Global Footprint Network 2008).

available, and while it has historically been the method of choice in the Valley region, the optimal alternative could change in the future as other treatment technologies develop and ecological and security requirements change.

LIMITATIONS

This thesis would not be complete without an acknowledgment of the limitations of the research presented. Despite the advantages of having primary data from an operating facility, this case study of the conventional water treatment technology is limited in the fact that there is only one facility and one set of numbers presented. If more facilities and results were presented, one could be more confident of the accuracy of the results. The results presented are also generated using a newly-developed model, CITY H_20 ECONOMICS©, and represent the first application of this model. The model has been verified, validated, and used, however, in another related research study (Boyer 2008; Boyer et al. 2008), without identification of any major shortcomings.

The section titled "Modified Data Input and Results" provides a list of suggested adjustments to the data to encourage "leveling the playing field." There is one admitted weakness in these modifications related to the absence of a solution for leveling the quality of incoming, raw water in primary data analyses. Although it is not essential to this thesis, as only one facility is examined, when comparing multiple facilities the quality of incoming water must be leveled to obtain a true comparison of facility operating costs. This missing solution is one unfinished topic that could be the subject of future research. There are other undeveloped areas of this thesis that have the potential for future research. For example, the methodology and 'leveling' modifications developed provide a standard of comparison that could be used to compare alternative potable water technologies to determine the most economically-efficient option for the Lower Rio Grande Valley or elsewhere. In addition, as mentioned in the "Prior Literature and Economic Studies" section, there is some suggestion in the literature of economies of size in water treatment technologies. The extent to which economies of size contribute to the costs of production could further be examined for facilities of differing size.

CONCLUSIONS

This thesis provides an economic and financial analysis of the conventional surface-water treatment technology using primary data from an operating 8.25 mgd facility, McAllen Northwest. A two-part methodology (NPV and annuity equivalent calculations) is established which considers all costs over the life of the facility and provides an accurate portrayal of future costs. Current life-cycle costs of production estimates for the McAllen Northwest facility are $771.67/ac-ft/yr {2.37/1,000 gallons/yr}, and are generated using a newly-developed model, CITY H_20 ECONOMICS©. Beyond providing the 'bottom-line' costs of production, the model also enables a breakout of costs into cost type, section, and item. This application of the model provides the water managers and planners with detailed insight regarding the most significant factors of cost to produce potable water. Given the above conclusions, the first null hypothesis stated in the "Objectives" section (i.e., "It is not possible to construct/develop a comprehensive explanatory model and conduct an economic and financial analysis of conventional surface-water treatment) is thereby rejected.

This thesis also establishes a standard protocol of comparison for analyzing water treatment facilities. This protocol is a contribution to the current literature which represents a wide range of methodology and associated variance in results. The factors to be accounted for in the comparison across different facilities include modifications to the following key data-input parameters: base period of analysis, level of annual production, exclusion of overbuilds and upgrades, salvage of capital assets, and quality of incoming and outgoing, product water. The "modified" results developed in this thesis for McAllen Northwest, which are $667.74/ac-ft/yr {$2.05/1,000 gallons/yr}, are reported on a current 2006 basis and are considered appropriate to compare to other similarly-calculated values (e.g., Sturdivant et al. 2008). The recognized necessity and accomplishment of providing modified results which are appropriate for comparisons of water treatment facilities thereby rejects the second null hypothesis stated in the "Objectives" section (i.e., "Evaluations and comparisons of water treatment facilities can be accomplished using primary (operating/case study) data").

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