RECLAMATION

Managing Water in the West

Estimating the Cost of Brackish Groundwater Desalination in Texas

Final Report Submitted to the Texas Water Development Board

U.S. Department of the Interior
Bureau of Reclamation

July 2014

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Final Report Submitted to the Texas Water Development Board

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Executive Summary

Factors that affect the cost of desalination include: source water quality, pre-treatment needs, depth and distance to water source, power, production volume, and concentrate disposal method. Furthermore, the effort involved with estimating the cost of a project increases as the project progresses through the planning, design, and construction phases. As a project advances through the various phases, the degree of accuracy of the cost estimates increases as more site-specific data becomes available.

The goal of this study is to assess available methods for communities in Texas to develop a planning-level cost estimate (including capital and operation and maintenance costs) for brackish groundwater desalination facilities. The two cost estimating tools identified for this assessment are *The Desalting Handbook for Planners* (Handbook) as revised by the Bureau of Reclamation in 2003 and the *Unified Costing Model* developed by the Texas Water Development Board in 2013. Unlike the Handbook, the Unified Costing Model was developed for a variety of water management strategies with brackish groundwater desalination cost estimating as just one of the many standard functions.

In July 2012, Texas Water Development Board staff sent a data request to 13 brackish groundwater desalination facilities in Texas for capital costs and operations and maintenance costs. Seven facilities responded to the survey. In addition, publically available cost information was obtained for two additional facilities.

Based on the comparisons performed during this study, it appears that the cost curves presented in the Handbook can provide a planning-level estimate for the capital and operations and maintenance costs for brackish groundwater desalination facilities in Texas. Facility costs obtained from the nine plants (when indexed to the same year as the Handbook cost curves) typically fell within the -50% to +100% accuracy range of an Association for the Advancement of Cost Engineering Class 5 cost estimate. Although the limited number of reported brackish groundwater desalination facility costs included in this study typically fell within this accuracy range, there is no guarantee that a future cost estimate prepared by using the Handbook cost curves will produce a Class 5 cost estimate.

The Unified Costing Model was used to produce a cost curve for comparison during this study. This cost curve is approximately 18% lower than the indexed Handbook cost curve at the low end of the curve range, and approximately 26% higher than the indexed Handbook cost curve at the high end of the curve range. When comparing the time and effort required to generate a cost estimate using the Handbook cost curves and Unified Costing Model, the Handbook was quicker and easier than the Unified Costing Model because only the treatment plant capacity is

needed. However when more information is known about the proposed desalination facilities, it may be more appropriate to use the Unified Costing Model in order to take advantage of the wide range of user inputs that are available.

An opportunity may exist to further refine the Unified Costing Model specifically for brackish desalination plant costs. As new brackish groundwater desalination projects are constructed, estimates generated by the model can be refined with actual capital and operations and maintenance costs. These comparisons could help identify strengths and weaknesses within the current Unified Costing Model and guide future development of this tool for desalination costs.

Acronyms

AACE	Association for the Advancement of Cost Engineering
ac-ft/yr	acre-feet per year
BWRO	brackish water reverse osmosis
Handbook	Desalting Handbook for Planners
m^3/d	cubic meters per day
mgd	millions gallons per day
mg/l	milligrams per liter
NAWSC	North Alamo Water Supply Corporation
O&M	operation and maintanance
RO	reverse ssmosis
TDS	total dissolved solids
TWDB	Texas Water Development Board
UCM	Unified Costing Model

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1. Project Scope and Objectives

Currently, there are 46 municipal brackish water desalination facilities in Texas. Twelve of these facilities use brackish surface water as a source of raw water, which accounts for a design capacity of 50 million gallons per day (mgd) or 56,000 acre-feet per year (ac-ft/yr). Thirty-four facilities use brackish groundwater as a raw water source, which accounts for a design capacity of approximately 73 mgd (81,760 ac-ft/yr). Among the brackish groundwater desalination facilities, El Paso Water Utilities' Kay Bailey Hutchison Desalination facility has the highest design capacity in the state (27.5 mgd or 30,800 ac-ft/yr). In total, the state has a desalination design capacity of approximately 123 mgd (137,778 ac-ft/yr).

In the 2012 State Water Plan, five regional water planning groups recommended brackish groundwater desalination as a water management strategy to meet at least some of their projected water needs. In total, the regional water planning groups project that desalting brackish groundwater can create about 162 mgd (181,568 ac-ft/yr) of new water by 2060 accounting for 2 percent of all recommended water management strategies. Local water planners are now exploring brackish groundwater desalination to meet the recommendations of the water plan, but many are still questioning whether this will be achievable. One of the most common questions asked to the Texas Water Development Board (TWDB) has been what is the cost of brackish groundwater desalination in Texas, both in terms of construction cost and operations and maintenance (O&M) costs?

Factors that affect the cost of desalination include: source water quality, pre-treatment needs, depth and distance to water source, power, production volume, and concentrate disposal method. Furthermore, the effort involved with estimating the cost of a project increases as the project progresses through the planning, design, and construction phases. As a project advances through the various phases, the degree of accuracy of the cost estimates increases as more site-specific data becomes available.

The goal of this study is to assess available methods for communities in Texas to develop a planning-level cost estimate (including capital and operation and maintenance costs) for brackish groundwater desalination facilities. The two cost estimating tools identified for this assessment are *The Desalting Handbook for Planners* (Handbook) as revised by the Bureau of Reclamation in 2003 and the *Unified Costing Model* developed by the Texas Water Development Board in 2013. Unlike the Handbook, the Unified Costing Model was developed for a variety of water management strategies with brackish groundwater desalination cost estimating as just one of the many standard functions.

2. Data Collection

Reverse osmosis (RO) is the predominant desalination technology used in Texas; 44 of 46 brackish water desalination facilities use RO technology. To track the growth of desalination in Texas, the TWDB maintains a desalination plant database for Texas (TWDB desalination plant database for Texas). In July 2012, TWDB staff sent a request for data to 13 brackish groundwater desalination facilities in Texas for actual capital and O&M costs. The following seven RO facilities provided information:

- North Alamo Water Supply Corporation (NAWSC) Victoria Road RO Plant No. 5
- NAWSC Doolittle
- NAWSC Owassa
- Clarksville City
- Roscoe
- Kay Bailey Hutchison
- North Cameron

In addition to the survey responses, cost information was publically available for the following two facilities:

- Southmost: "Economic Costs of Desalination in South Texas: A Case Study" (Sturdivant, 2007) provides a detailed capital and O&M cost breakdown for the 7.5 mgd (8,407 ac-ft/yr) desalination facility.
- NAWSC La Sara: "Economies of Size in Municipal Water-Treatment Technologies: A Texas Lower Rio Grande Valley Case Study" (Boyer, 2010) provides a detailed capital and O&M cost breakdown for the 1.2 mgd (1,345 ac-ft/yr) desalination facility.

Table 1 summarizes the key information for each of the desalination plants used in this study. Information in this table was gathered from the TWDB desalination plant database, "Cost of Brackish Groundwater Desalination in Texas" (Arroyo, 2012), and survey responses. Please note that the facilities listed above provided cost information that varied in terms of level of detail and format. The project team used engineering judgment in determining how to compare these reported costs with currently available methods for developing planning-level cost estimates for brackish groundwater desalination facilities.

Table 1. Summary of brackish groundwater desalination plant cost information

Plant name	Year plant built	Plant capacity (mgd)[a]	Desal capacity (mgd)[b]	Feed water salinity (mg/l)	Pretreatment	Post treatment	Membrane recovery (%)	Concentrate disposal
NAWSC Victoria	2012	2.25	2.0	3,800	Not provided	Not provided	Not provided	Not provided
NAWSC Doolittle	2008	3.5	3.0	2,500 – 3,000	Cartridge filter, chemical addition	Blending, gas removal, pH adjustment, disinfection	Not provided	Not provided
NAWSC Owassa	2008	2.0	1.5	2,500 – 3,000	Cartridge filter	Blending, gas removal, pH adjustment	Not provided	Not provided
Clarksville City	2006	0.288	0.288	Not provided	Cartridge filter	Disinfection, scaling control	75	WWTP
Roscoe	2013	0.5	0.36	3,800	Not provided	Not provided	Not provided	Not provided
Kay Bailey Hutchison	2007	27.5	15	2,000 – 3,000	Cartridge filter, scaling control	pH adjustment, blending, corrosion control, disinfection	82.5	Well Injection

[a] Plant capacity as designed to include both RO capacity and raw water blending capacity.
[b] Desal capacity as designed to include only the RO capacity of the plant.

Table 1. Summary of brackish groundwater desalination plant cost information (continued)

Plant name	**Year plant built**	**Plant capacity (mgd)**[a]	**Desal capacity (mgd)**[b]	**Feed water salinity (mg/l)**	**Pretreatment**	**Post treatment**	**Membrane recovery (%)**	**Concentrate disposal**
North Cameron	2007	2.5	2.0	3,500	Cartridge filter, chemical addition	Blending, gas removal, pH adjustment, disinfection	75	Surface water discharge
Southmost	2004	7.5	6	3,500	Cartridge filter, pH adjustment, antiscalant	Blending, gas removal, pH adjustment, corrosion control, disinfection	75	Surface water discharge
NAWSC La Sara	2005	1.2	1.0	2,500 – 3,000	Cartridge filter, chemical addition	Blending, gas removal, pH adjustment, disinfection	Not provided	Not provided

[a] Plant capacity as designed to include both RO capacity and raw water blending capacity.
[b] Desal capacity as designed to include only the RO capacity of the plant.

3. Comparison of Texas Brackish Groundwater Desalination Plant Costs to Cost Estimating Methods

3.1 Desalting Handbook for Planners

Originally developed by the Office of Water Research and Technology and the Bureau of Reclamation in 1972 and later revised in 1977 and 2003, the Desalting Handbook for Planners (Handbook) was created to assist in the decision-making process for potential desalination users. This Handbook is designed for use by appointed and elected officials, planners, and consultants with a limited knowledge of the technologies involved, but who have enough familiarity with the general principles to recognize that desalting may have value as a viable alternative source of drinking water for their communities.

The Handbook contains a series of cost curve graphs for estimating the cost of numerous desalting processes and related infrastructure, along with annual operations and maintenance expenses. The Handbook states that these cost curves should be used only to compare alternative schemes for water supply at a planning level, with an implied level of accuracy of +/- 30%. All of the cost curves in the Handbook are presented in year 2000 dollars. These cost curves have not been updated since 2003, so any technological advances made in the last decade are not reflected in the curves.

There is little flexibility built into the Handbook cost curves, as they are all based on plant capacity. Plant capacities are listed along the x-axis of each curve, with the estimated cost on the y-axis. A number of assumptions are built into each curve, with no way of adjusting these assumptions. For example, the curve for brackish water reverse osmosis (BWRO) assumes 75% recovery with no blending, and a raw water total dissolved solids (TDS) of 2,000 – 3,000 milligrams per liter (mg/l). These inherent assumptions make it very difficult for a user to adjust the costs for local conditions.

Presented below is a series of graphs which compare various Handbook cost curves to the costs of nine brackish groundwater desalination facilities in Texas. All costs have been indexed to year 2000 dollars using the Engineering News Record Construction Cost Index to match the Handbook.

Also shown on each figure are dashed lines showing -50% of the cost curve and +100% of the cost curve. These values were chosen based on guidance provided by the Association for the Advancement of Cost Engineering (AACE) Recommended Practice No. 18R-97 (AACE, 2011), which describes a cost estimate classification system as applied in engineering, procurement, and construction for the process industries. This document describes a Class 5 cost estimate as follows:

> *"Class 5 estimates generally use stochastic estimating methods such as cost/capacity curves and factors."*
>
> *"Class 5 estimates are generally prepared based on very limited information, and subsequently have wide accuracy ranges. Class 5 estimates, due to the requirements of end use, may be prepared within a very limited amount of time and with little effort expended – sometimes required less than an hour to prepare. Often, little more than proposed plant type, location, and the capacity are known at the time of estimate preparation."*
>
> *"Class 5 estimates are prepared for any number of strategic business planning purposes, such as but not limited to market studies, assessment of initial viability, evaluation of alternative schemes, project screening, project location studies, evaluation of resource needs and budgeting, long-range capital planning, etc."*
>
> *"Typical accuracy ranges for Class 5 estimates are -20% to -50% on the low side, and +30% to +100% on the high side, depending on technological complexity of the project, appropriate reference information and other risks."*

Based on the guidance presented by AACE it appears that cost estimates generated using the Handbook can be classified as Class 5 estimates. The accuracy range of +/- 30% described in the Handbook falls within the Class 5 accuracy range defined by AACE.

Capital Costs

Figure 1 compares the Handbook cost curve for total capital cost of brackish groundwater reverse osmosis (BWRO) plants (Handbook Figure 9-8) to the costs of nine BWRO facilities in Texas (indexed to year 2000 dollars). The Handbook's capital cost curve includes: the desalting plant proper, in-plant piping, pumps, motors, controls, post treatment, building, membrane cleaning system, electrical distribution, and indirect costs. The Handbook does not provide any specific details for these included items, such as level of post treatment, building size or features, pumping requirements, etc. The capital cost curve excludes: land costs, product water delivery, and concentrate disposal. For this study the level of cost detail provided by BWRO facilities was sufficient to ensure that excluded items were not included in the capital costs shown in Figure 1.

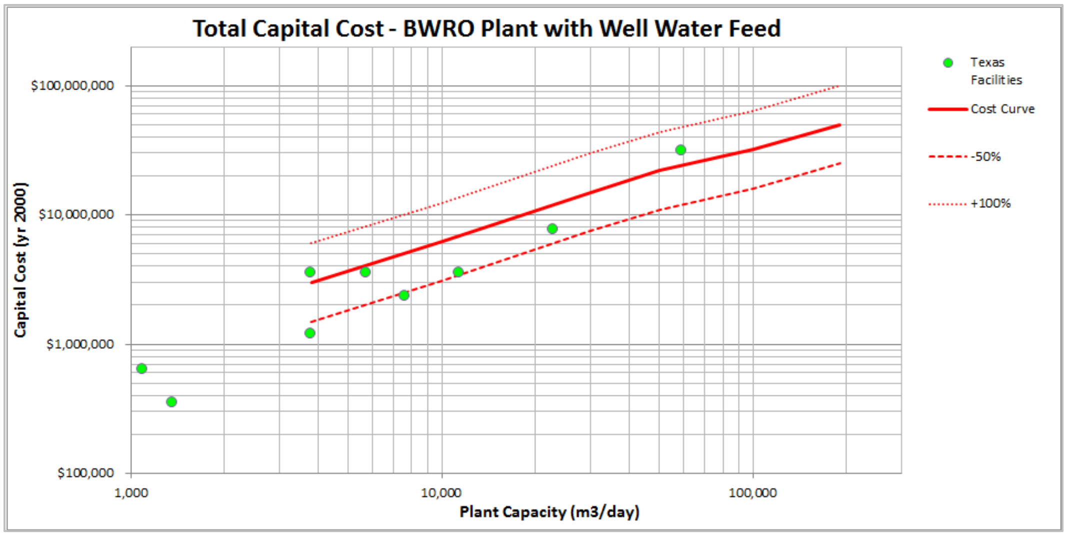

Figure 1: Total Capital Cost – BWRO Plant with Well Water Feed[1]. Larger versions of the figures are included in Section 6.

Generally the costs of the facilities fell within the AACE Class 5 estimate accuracy range of -50% to +100%. Four of the reported costs were near the -50% indicating that the Handbook cost curve estimates are higher than the actual costs for the Texas BWRO plants. Also note that the minimum capacity described by the Handbook cost curves is 3,800 cubic meters per day (m^3/day) (approximately 1 mgd); therefore, the Handbook cost curves cannot be used to prepare cost estimates of plants with capacity less than 1 mgd (1,120 ac-ft/yr).

Figure 2 compares the Handbook cost curve for total capital costs for wellfields with a 400 foot well depth (Handbook Figure 9-18) to the cost of wellfields for BWRO facilities in Texas (indexed to year 2000 dollars) excluding the cost of raw water delivery from the wellfield to the BWRO facility. The Handbook capital cost includes wells, pumping equipment, electrical, controls, wellhouse, lateral piping, and collector piping. The cost excludes land costs and well water delivery.

The costs for six desalinations plants are substantially higher than the Handbook cost curve. The Handbook cost curve assumes a water yield of 2 mgd (2,240 ac-ft/yr) per well, which may not be accurate for the Texas facilities surveyed. The well yield for each facility was not collected as part of this effort. The water yield per well determines the number of wells required to generate the desired capacity. Assuming an incorrect number of wells could escalate the cost of constructing the well field. The Handbook does not allow the user to adjust the well yield and could explain this cost difference.

[1] Note that the cost curves are shown on a log-log scale in order to show a wide range of plant capacities and costs on the same chart.

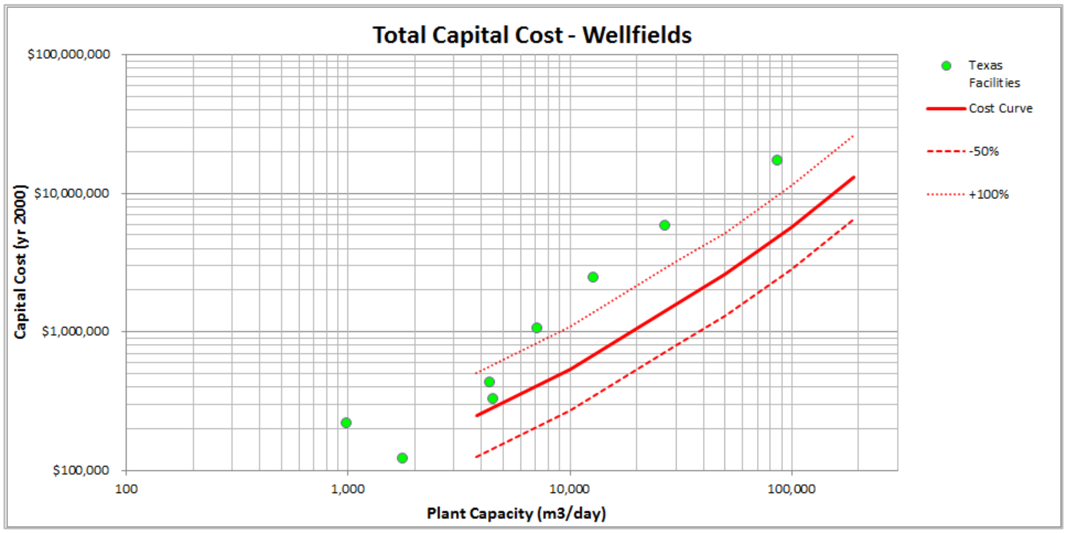

Figure 2: Total Capital Cost – Wellfields. Larger versions of the figures are included in Section 6.

Operation and Maintenance Cost

Figure 3 compares the Handbook cost curve for membrane process labor costs (Handbook Figure 9-37) to the labor costs of BWRO facilities in Texas (indexed to year 2000 dollars). The Handbook cost curve assumes a plant larger than 18,925 m^3/d (5 mgd) will be staffed 24 hours per day, 7 days per week. For a plant smaller than 5 mgd (5,600 ac-ft/yr), it assumes the plant will be staffed 16 hours per day, 5 days per week. A labor rate of $25,000 per year (in year 2000 dollars) is also assumed. Texas desalination plant labor costs are slightly higher than the Handbook cost curve for the two larger plants, while costs for the four smaller plants are significantly lower than the cost curve. The Handbook does not allow adjusting either the staffing level or labor cost to account for local conditions. This can result in discrepancies such as the fact that larger plants are usually in more developed, larger cities with a higher cost of living compared to small plants which are often in more rural areas with a lower cost of living.

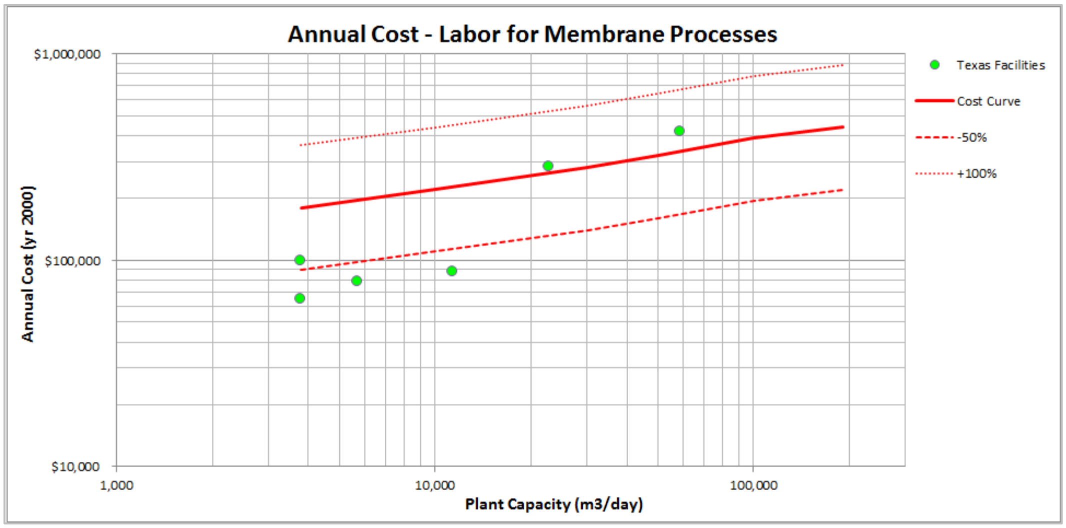

Figure 3: Annual Cost – Labor for Membrane Processes. Larger versions of the figures are included in Section 6.

Figure 4 compares the Handbook cost curve for membrane process chemical costs (Handbook Figure 9-42) to the costs of BWRO facilities in Texas (indexed to year 2000 dollars). The Handbook cost curve includes the chemical costs for pretreatment, post-treatment, and cleaning for membrane systems. The chemical costs for the two larger desalination plants are fairly close to the Handbook cost curve, while reported costs are more variable for smaller plants. The Handbook does not provide any method for adjusting the types, quantities, or unit costs of chemicals.

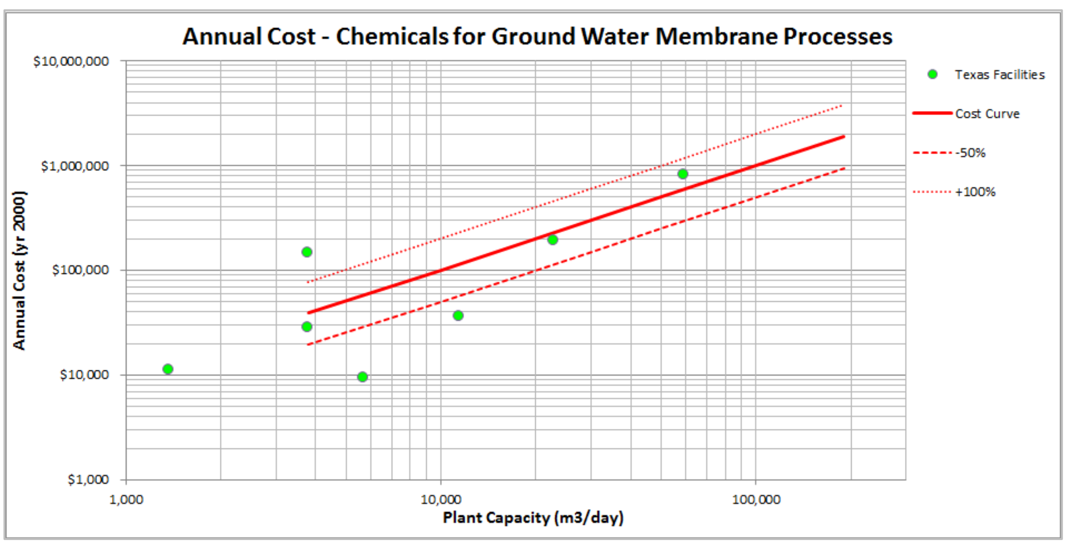

Figure 4: Annual Cost – Chemicals for Ground Water Membrane Processes. Larger versions of the figures are included in Section 6.

Figure 5 compares the Handbook cost curve for electricity costs (Handbook Figure 9-47) to the reported electricity costs of BWRO facilities in Texas (indexed to year 2000 dollars). The annual cost includes power for well pumps, process power, distribution pump power, and building services. A power cost of $0.06/kWh is assumed. The annual costs are within the accuracy range of the Handbook cost curve for all six of the plants that fall within the Handbook cost curve range.

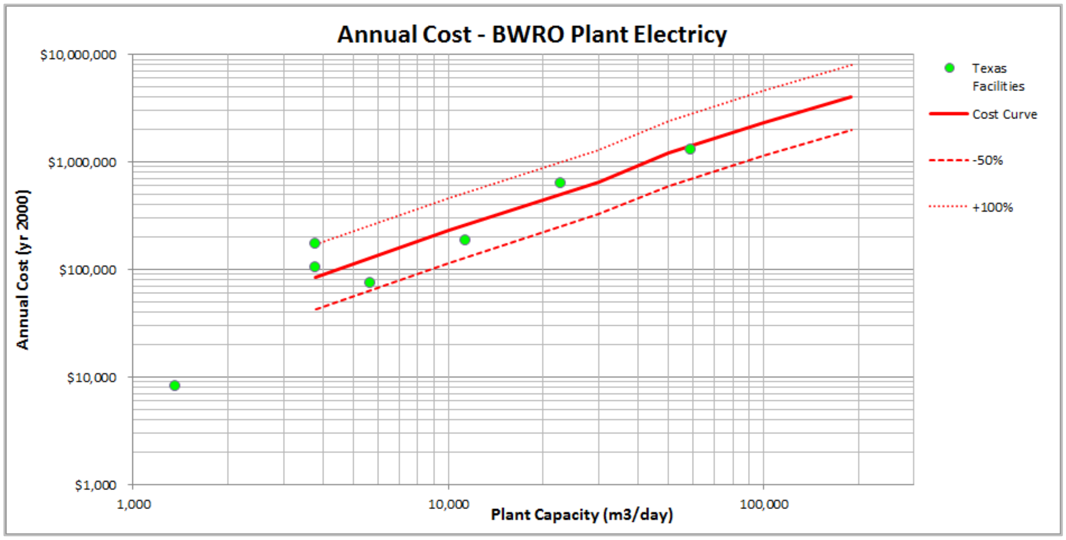

Figure 5: Annual Cost – BWRO Plant Electricity. Larger versions of the figures are included in Section 6.

3.2 Unified Costing Model

The Unified Costing Model (UCM) was developed by the TWDB in 2013. This tool helps the TWDB compile consistent cost estimates from all 16 State planning regions for use in developing the State Water Plan. The UCM contains a module for estimating the cost of brackish groundwater desalination facilities, which can also be compared to actual cost data. Unlike the Handbook, the UCM was developed for a variety of water management strategies with brackish groundwater desalination cost estimating as just one of the many standard functions.

The UCM is an Excel-based tool used to develop cost estimates for a wide range of infrastructure items, such as well fields, pipelines, treatment plants, pump stations, storage tanks, etc. In order to estimate the cost of a brackish groundwater desalination plant in the UCM, the required inputs are plant capacity and feed water salinity. For this study the UCM was used to generate a cost curve for comparison by inputting interval plant capacities. Figure 6 compares the curve generated by the UCM for a brackish groundwater desalination plant with a feed water TDS of 2,500 mg/l (indexed to year 2000 dollars) to the equivalent Handbook cost curve. The UCM cost curve is approximately 18% lower than the indexed Handbook cost curve at the low end of the curve range, and approximately 26% higher than the indexed Handbook cost curve at the high end of the curve range.

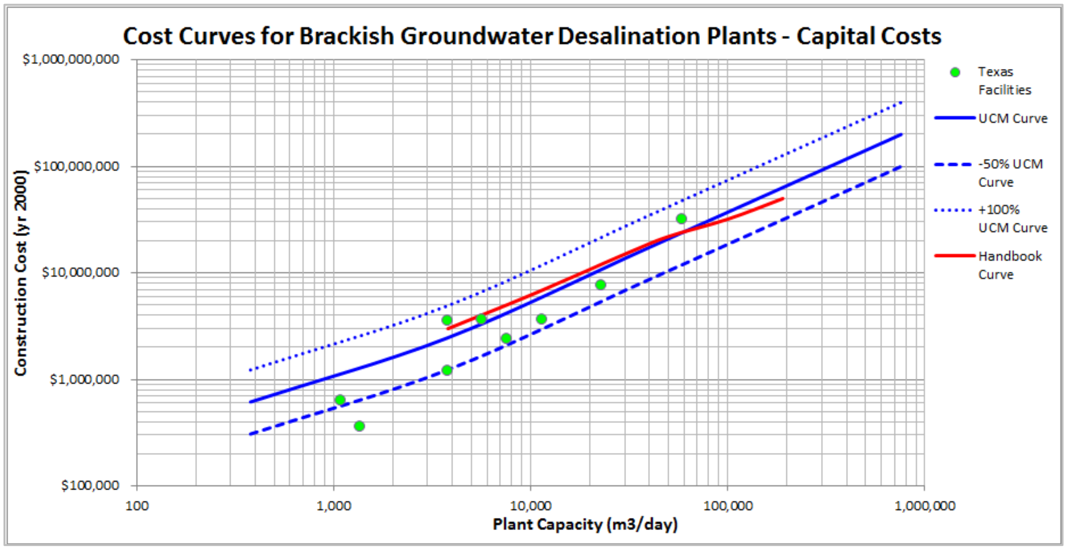

Figure 6: Cost Curves for BWRO – Capital Costs. Larger versions of the figures are included in Section 6.

The UCM estimates annual O&M costs as a lump sum, as opposed to the Handbook method of estimating certain individual O&M costs (such as electricity, chemicals, and labor). Figure 7 compares the O&M cost curve generated by the UCM for a brackish groundwater desalination plant with a feed water TDS of 2,500 mg/l (indexed to year 2000 dollars) to the sum of the Handbook cost curves for electricity, chemicals, and labor. The UCM curve is substantially higher than the Handbook curve, which is likely due to the UCM curve including all O&M costs, while the Handbook curve only includes the three components described above. O&M costs not accounted for in the Handbook curves could include items such as membrane replacement, equipment and instrumentation repair and replacement, environmental compliance monitoring, etc.

A benefit of the UCM model is that it is able to generate a cost estimate for a BWRO facility of any size (by interpolating between cost estimates of water treatment facilities ranging in capacity from 0.1 mgd to 200 mgd), while the Handbook curves can only provide a cost estimate over a fixed range of plant capacities (approximately 1 mgd to 50 mgd). However, both estimating methods, the Handbook for Planners and the UCM, have a tendency to over predict the capital and O&M costs for the majority of plants.

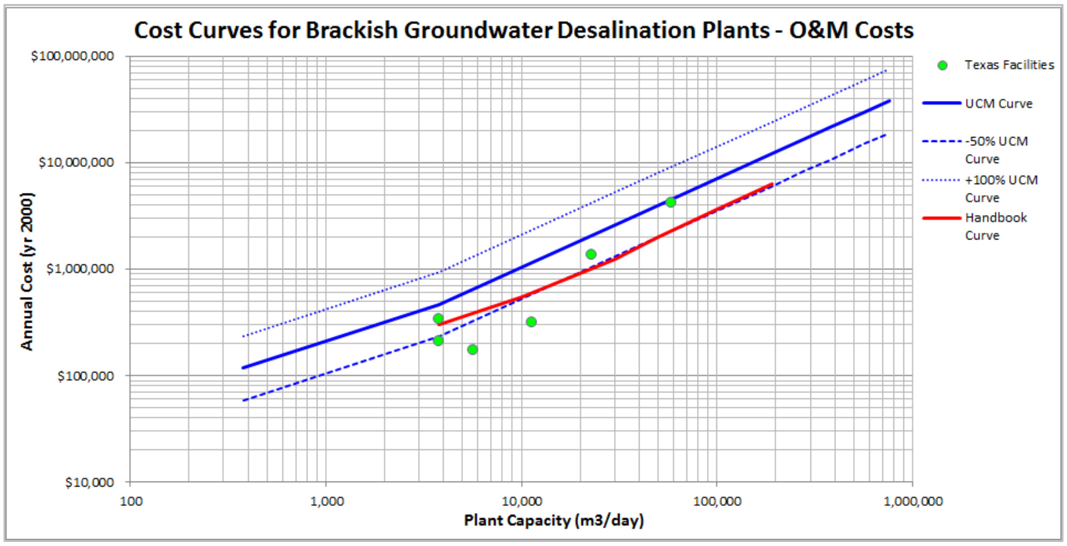

Figure 7: Cost Curves for BWRO - O&M Costs. Larger versions of the figures are included in Section 6.

4. Conclusions / Recommendations

Based on the comparisons performed during this study, it appears that the cost curve presented in the Handbook can provide a planning-level capital cost estimate for BWRO facilities in Texas. Facility costs obtained from the seven plants within the Handbook capacity curve (when indexed to the same year as the Handbook cost curves) fell within or very close to the -50% to +100% accuracy range of an American Association of Cost Engineering Class 5 cost estimate. The cost curve presented in the Handbook for electricity costs at BWRO facilities also fell within the -50% to +100% accuracy range for all six plants. Please note that this range is significantly higher than the +/- 30% accuracy range described in the Handbook. Although the limited number of reported BWRO facility capital costs and electricity costs included in this study fell within the -50% to +100% accuracy range, there is no guarantee that a future cost estimate prepared by using the Handbook cost curves will produce a Class 5 cost estimate.

The costs curves presented in the Handbook were not as successful at generating cost estimates within the -50% to +100% accuracy range for wellfields and individual O&M items. The Handbook curves fell outside of this accuracy range for four out of six wellfield estimates, three out of six labor estimates, and three out of six chemical estimates.

While a cost estimate can be generated very quickly using the Handbook cost curves, the primary drawback of these cost curves is the inflexibility of the cost estimating methodology. Many assumptions are incorporated within each cost curve, and it is very difficult (or impossible) to adjust these assumptions based on local conditions, such as electricity cost, labor rate, well depth, raw water conveyance, and source water quality. The UCM provides users much more flexibility in generating a cost estimate, as many inputs can be adjusted to account for local conditions such as those listed above. If more information is known about the proposed desalination facilities, it may be more appropriate to use the UCM in order to take advantage of the wider range of user inputs that are available.

As seen above, the number of data points used in this study was relatively modest, ranging from six to nine points per curve. It would be useful to include cost data for additional brackish groundwater desalination facilities in Texas if such information becomes available in the future.

An opportunity may exist to further refine the Unified Cost Model specifically for desalination plant costs. As new brackish groundwater desalination projects are constructed, estimates generated by the model can be refined with actual capital and O&M costs. These comparisons could help identify strengths and weaknesses within the current Unified Cost Model and guide future development of this tool for desalination costs.

5. References

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6. Larger versions of Figure 1-7

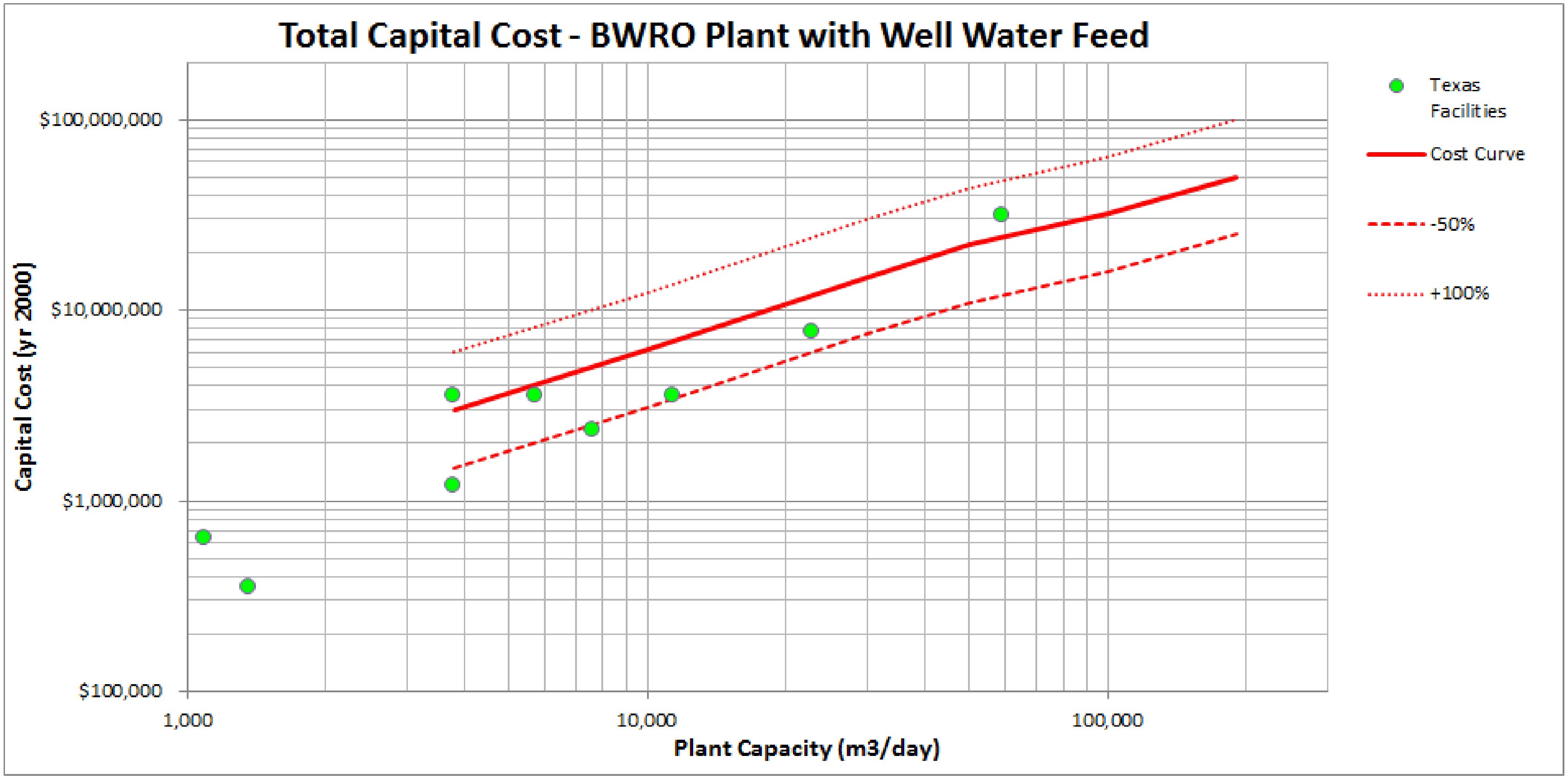

Figure 1: Total Capital Cost – BWRO Plant with Well Water Feed[2]

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[2] Note that the cost curves are shown on a log-log scale in order to show a wide range of plant capacities and costs on the same chart.

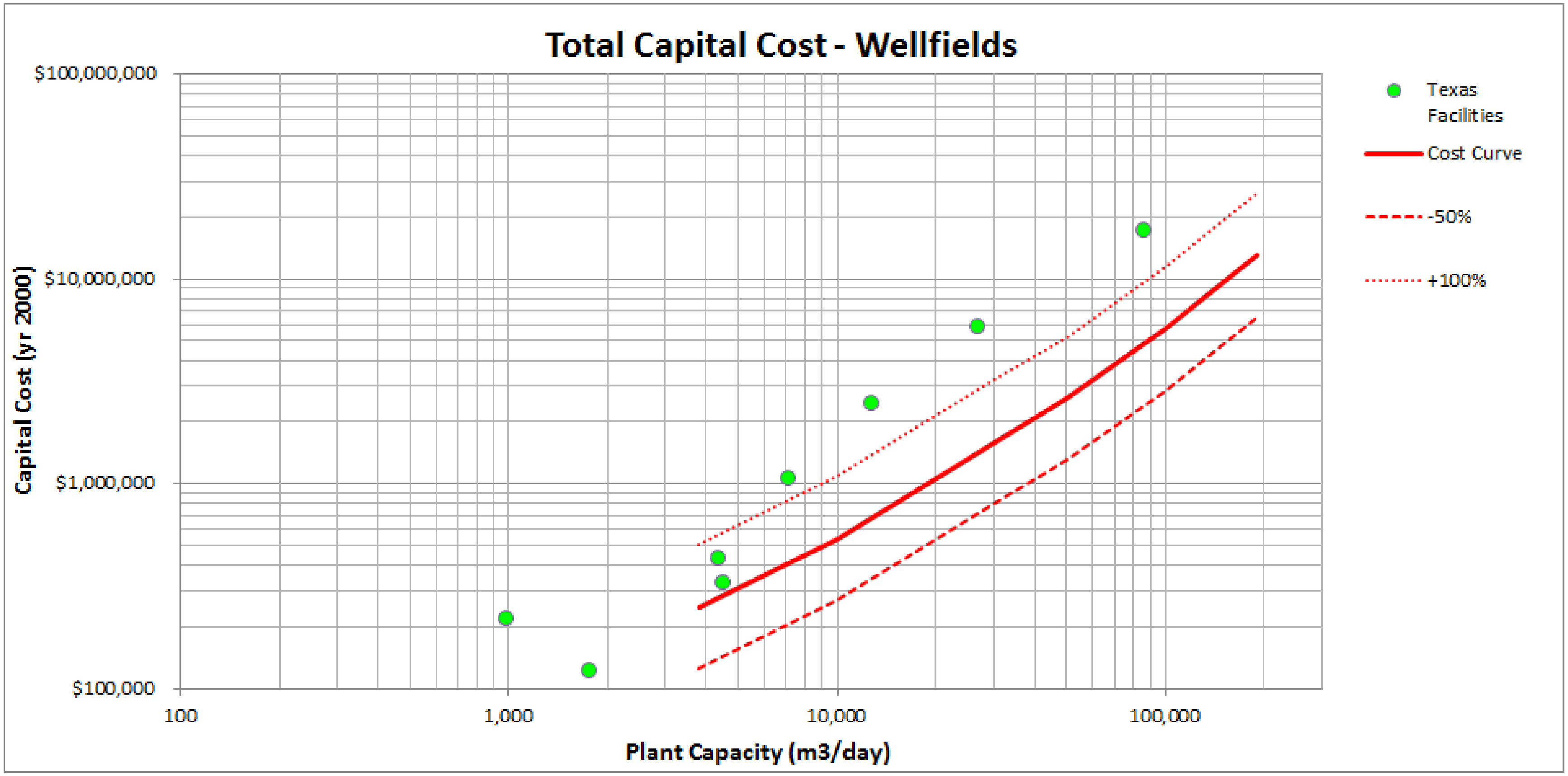


Figure 2: Total Capital Cost – Wellfields

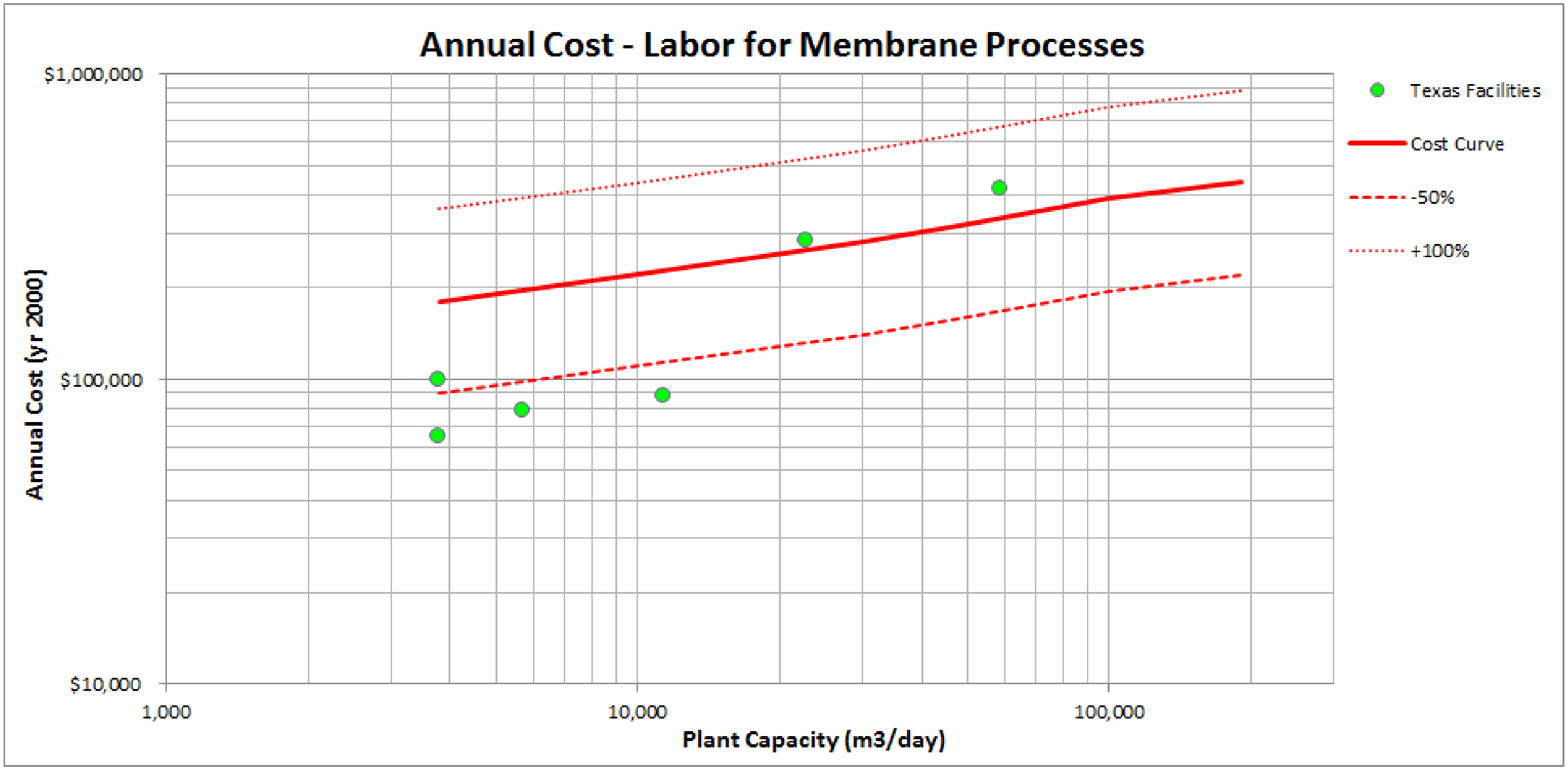


Figure 3: Annual Cost – Labor for Membrane Processes

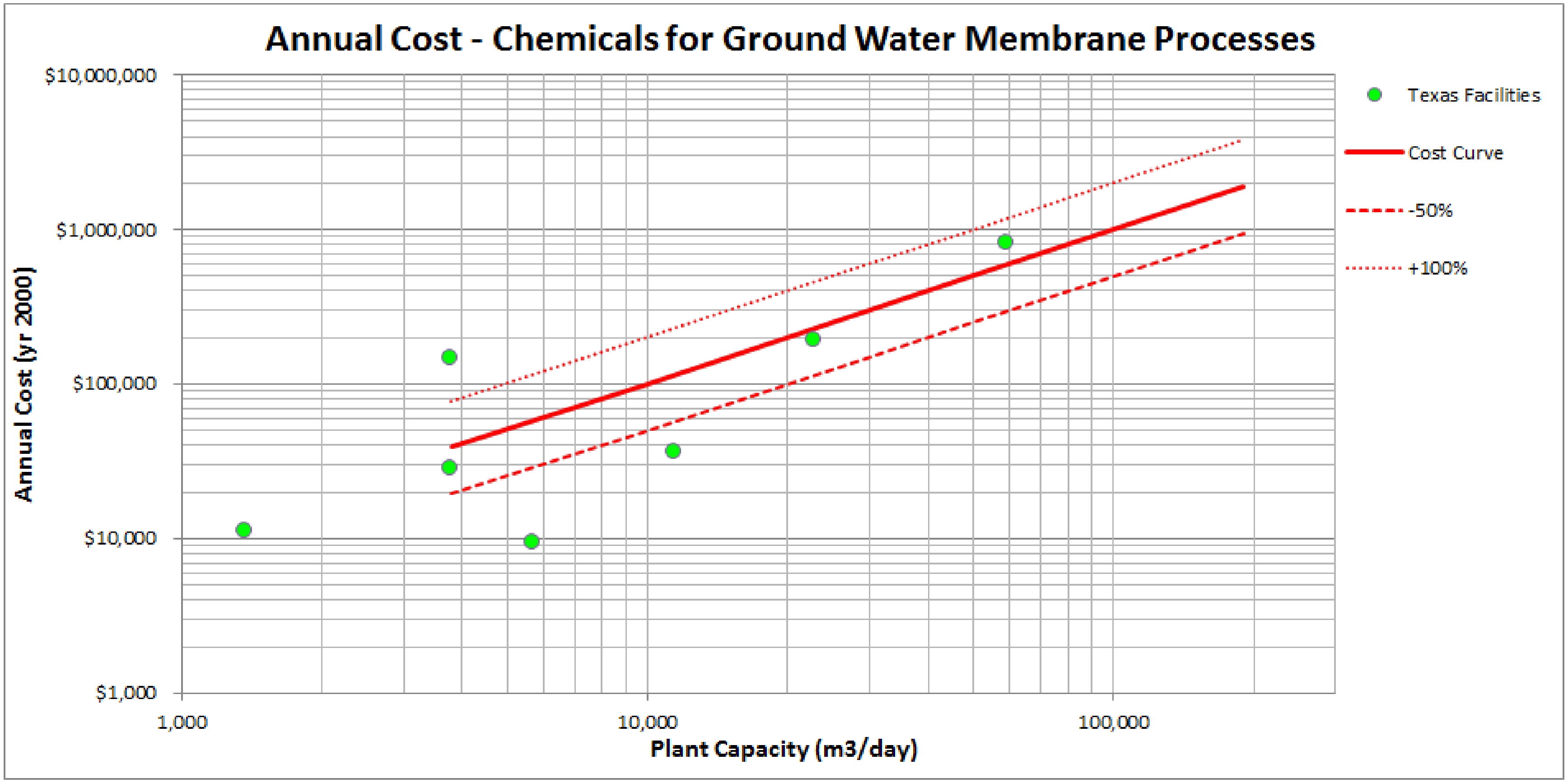
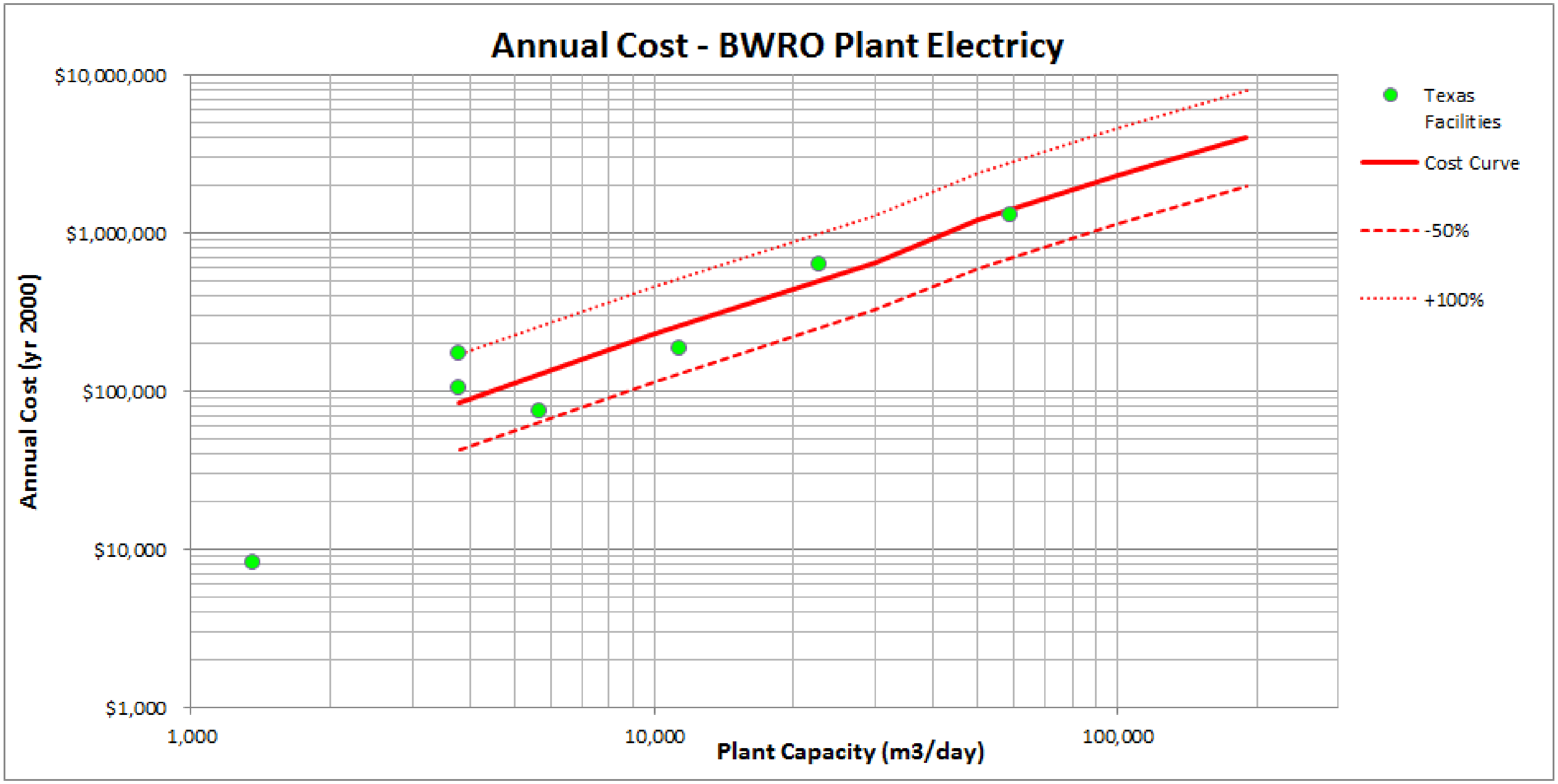


Figure 4: Annual Cost – Chemicals for Ground Water Membrane Processes



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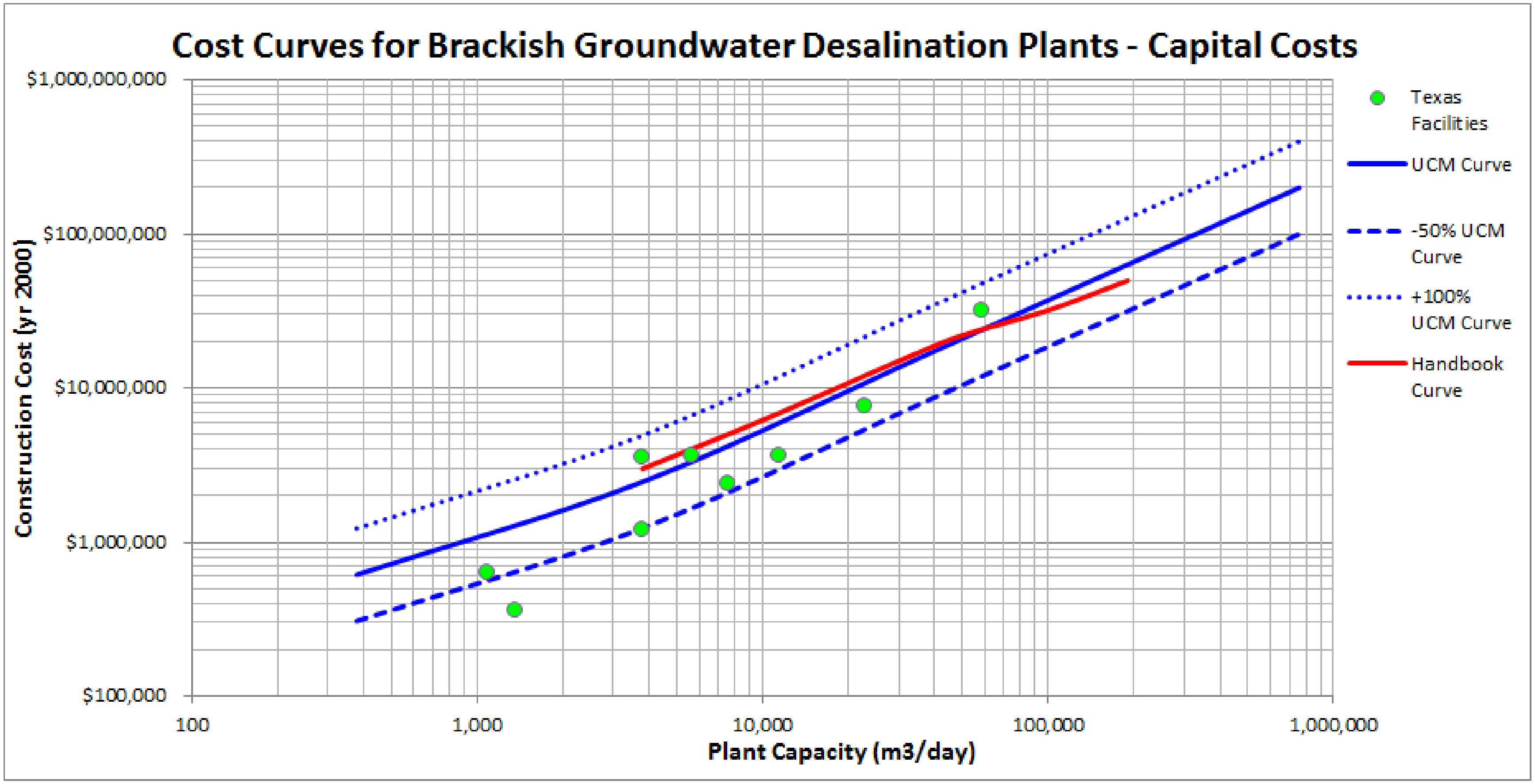

Figure 6: Cost Curves for BWRO – Capital Costs

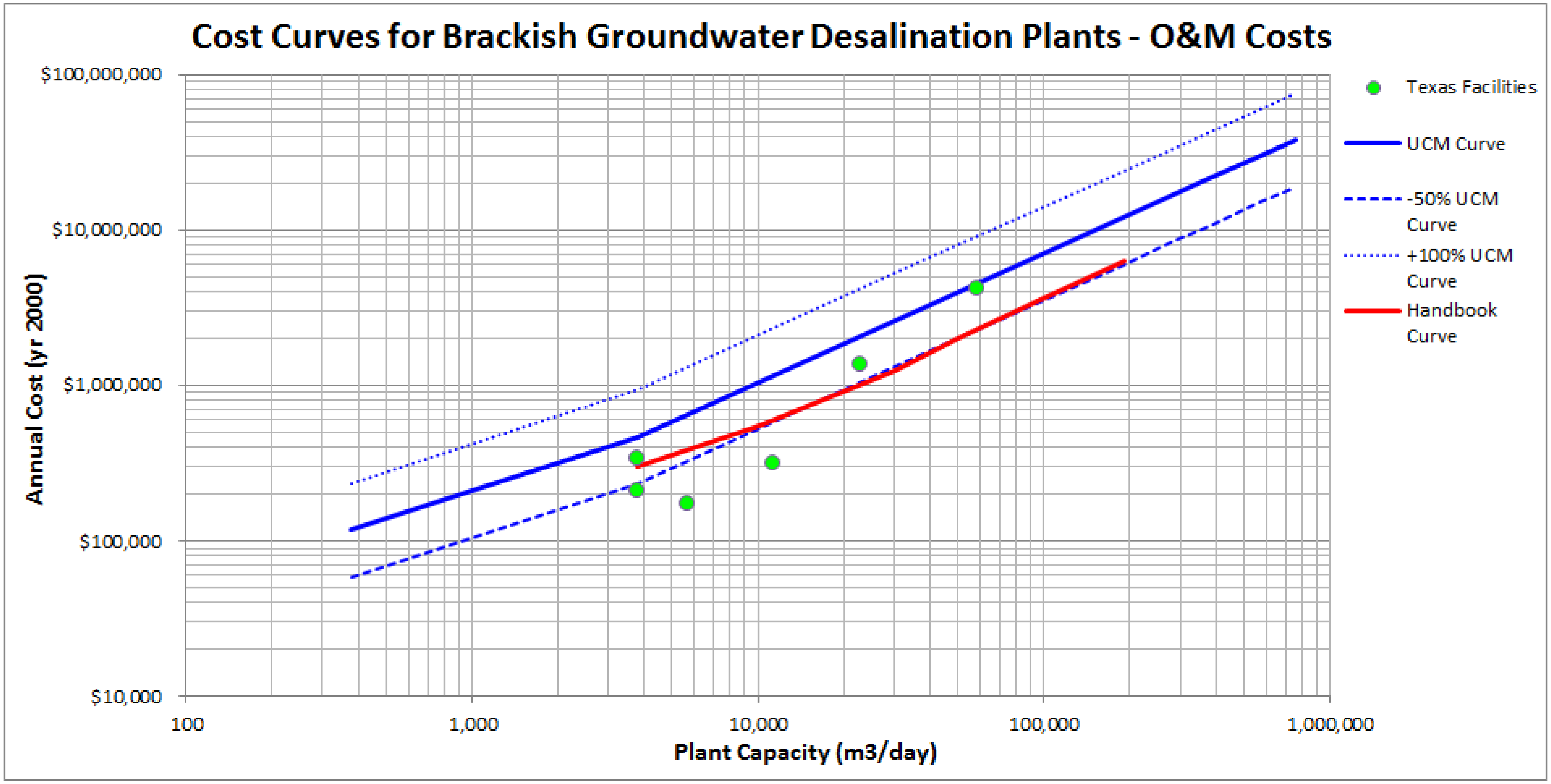

Figure 7: Cost Curves for BWRO - O&M Costs