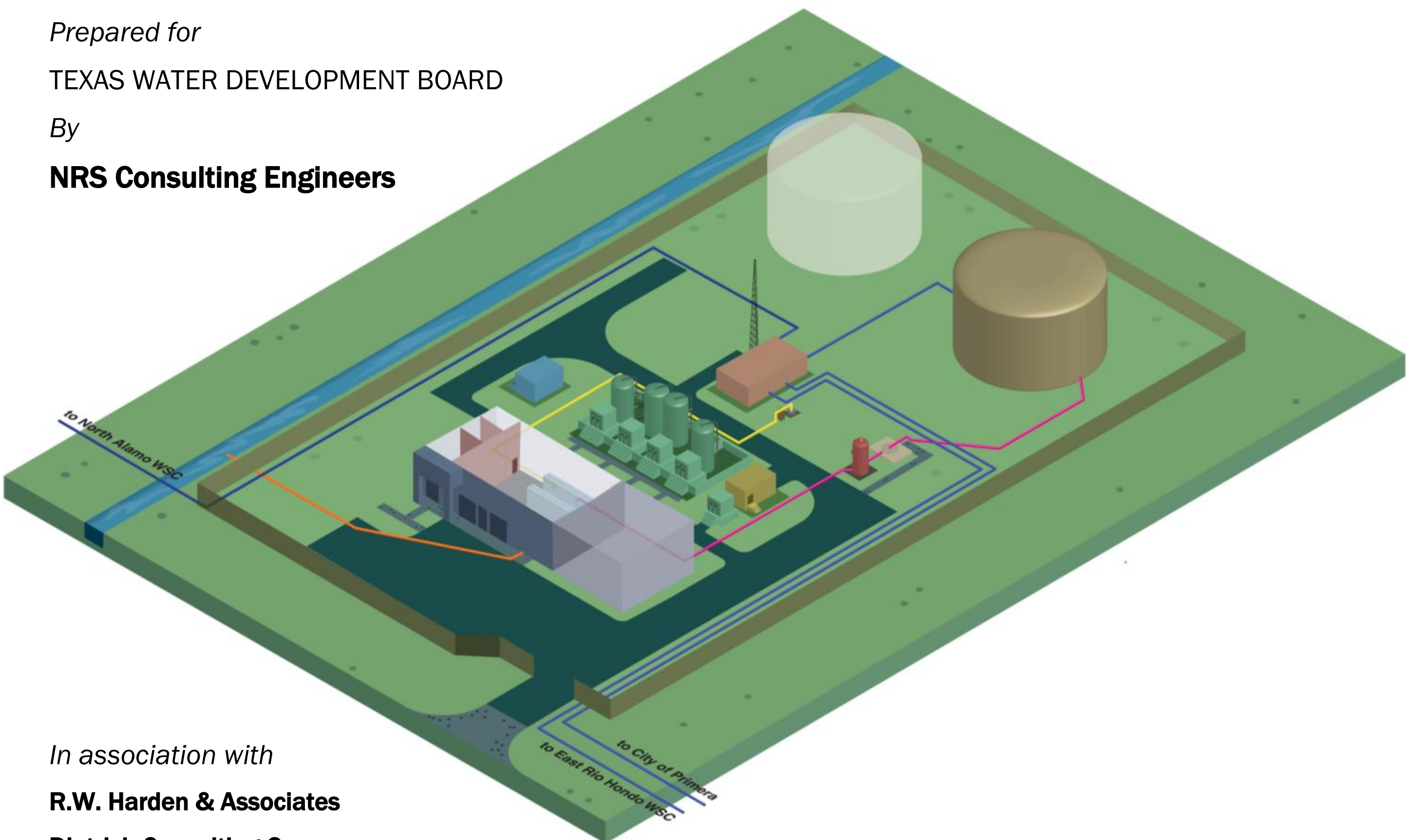
GUIDANCE MANUAL
For Brackish Groundwater Desalination in Texas

Prepared for

TEXAS WATER DEVELOPMENT BOARD

By

NRS Consulting Engineers



In association with

R.W. Harden & Associates

Dietrich Consulting Group

TRC

Electrical Expertise, Inc.

WaterPR

Texas Water Development Board
P.O. Box 13231, Capitol Station
Austin, Texas 78711-3231
April 2008

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Hydrologists – Geologists - Engineers

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We Talk Water

April 2008

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- Page 7, Brackish Groundwater Resources, Paragraph 1
- Pages 27-30, Facility Considerations, subheadings Groundwater Development, Preliminary Investigations, and Test Drilling.
- Page 52, Case Study B, subheading Groundwater Development
- Pages 58-59, Groundwater Development
- Page 64, Case Study C, Groundwater Considerations

______________________________ April 3, 2008

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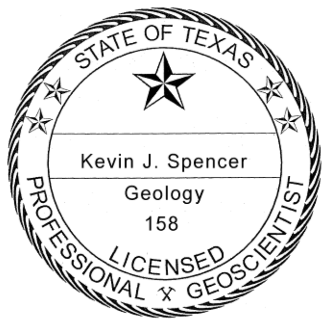

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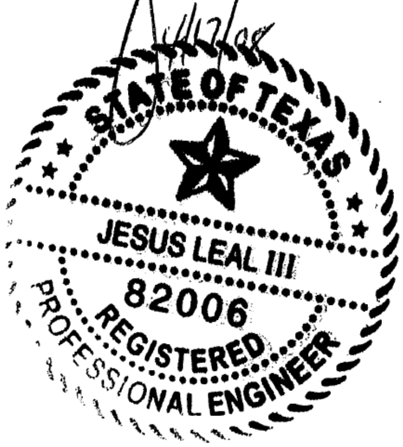

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Foreword

In 2004, three water supply entities came together to explore the possibility of developing brackish groundwater into a potable water supply. Our focus was on rural areas in northern Cameron and Willacy counties, Texas that were not being served by a conventional water treatment plant.

In 2007, our collaboration saw the completion of a state-of-the-art reverse osmosis desalination facility: the North Cameron Regional Water Project. This plant will produce 2.25 million gallons of drinking water a day from brackish groundwater at a wholesale cost of less than $1.40 per 1,000 gallons.

Desalination has become a welcome solution to our water supply needs, and it is less costly than purchasing, pumping, and treating surface water from the Rio Grande.

We firmly believe in brackish groundwater desalination. So much that we have partnered with the Texas Water Development Board and NRS Consulting Engineers in preparing this *Guidance Manual* to showcase our facility as how and why desalination works. We are proud to offer these lessons learned to other communities exploring desalination.

Charles Browning, General Manager
North Alamo Water Supply Corporation

Brian Macmanus, Director of Water and Wastewater
East Rio Hondo Water Supply Corporation

John Osborne, Mayor
City of Primera

Executive Summary

The goal of the Texas Water Development Board in publishing this *Guidance Manual* is to educate Texas communities about the emerging opportunities of brackish groundwater desalination. The abundance and distribution of brackish groundwater in Texas suggests this resource has significant potential. However, to meaningfully explore desalination opportunities, an understanding is required of basic water chemistry concepts, the differences among major desalination technologies, and the common project components.

This manual presents a systematic approach to developing a brackish groundwater desalination project in Texas in five phases: Planning, Permitting, Design, Construction, and Operations. Additionally, the Texas Water Development Board selected the recently completed North Cameron Regional Water Project as an educational example for developing additional water supplies from brackish groundwater sources in Texas. At strategic points throughout the *Guidance Manual*, examples from the North Cameron Regional Water Project are highlighted to provide real-life scenarios for other communities considering desalination.

North Cameron Regional Water Project.

Photograph courtesy of WaterPR

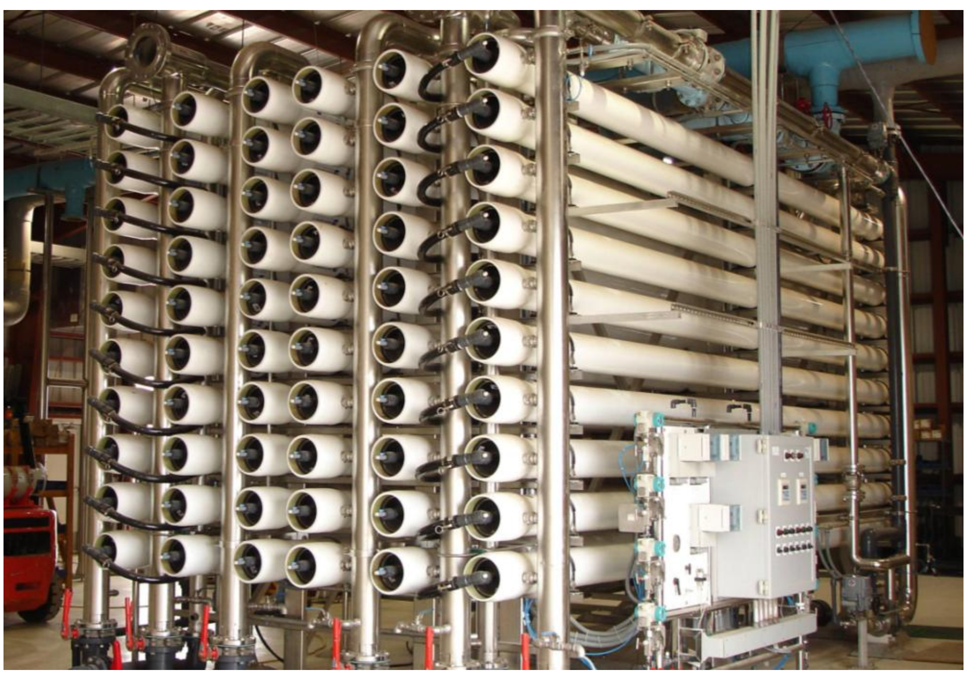
Initial activities in the Planning Phase focus on answering two fundamental questions: Are additional water supplies needed? And are there alternatives to meet this need that appear viable from engineering, environmental, and economic perspectives? As the process progresses, more specific information is developed to address critical engineering and financial questions, and also to help satisfy the informational demands of the regulatory (permitting) and design phases.

The Permitting Phase identifies all permits and authorizations necessary for construction and operation of a brackish groundwater desalination facility, including concentrate disposal.

The Design Phase involves effectively integrating the information, analysis, and decisions made during the previous phases into the material components of the project. Piloting studies provide the opportunity to evaluate actual performance of the proposed treatment system under site-specific conditions prior to final design and permitting. Of all the factors that influence the design process, the quality of the source water is the most significant.

The Construction Phase may be accomplished through a variety of project delivery methods, but success depends largely upon the level of experience held by the project engineers and contractors and the degree to which they partner with the owner.

The Operations Phase for a brackish groundwater desalination plant differs from, but is no more complex than, a conventional water treatment facility. Primary differences include care for the membrane elements during start up procedures, process instrumentation and controls, and training needs for operator staff.



Reverse osmosis membrane array, North Cameron Regional Water Project.
Photograph courtesy of WaterPR

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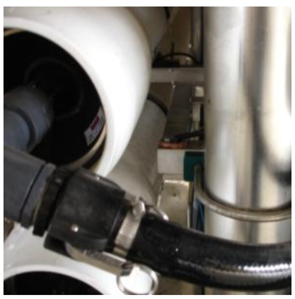
Why a Guidance Manual?



By 2060, Texas will need an additional 8.8 million acre-feet of water to meet the demands of a population that is expected to more than double. Since the beginning of the agency, the Texas Water Development Board has supported investigating the potential for using technologies for seawater and brackish groundwater desalination. The goal in publishing this *Guidance Manual* is to educate Texas communities about the emerging opportunities of brackish groundwater desalination to meet some of these projected water demands.

In January 2007, the Texas Water Development Board (TWDB) published the results of a multi-year, statewide water planning effort entitled *Water for Texas 2007*. The report found that the population of Texas is projected to increase from 21 million to about 46 million by the year 2060, fueling a 27 percent increase in water demand (Texas Water Development Board 2007a). During the same period, freshwater supplies are projected to decrease by about 18 percent, primarily because of accumulating sediments in reservoirs and depletion of aquifers.

The difference between projected demands and supplies is expected to result in a need for about 8.8 million additional acre-feet[1] of water per year. Of this amount, 3.8 million acre-feet is expected to be needed to meet projected municipal demands (Texas Water Development Board 2007a) (Figure 1). The report also recognized that, for a growing number of Texas communities, desalination offers a viable, drought-resistant solution to these water supply challenges.

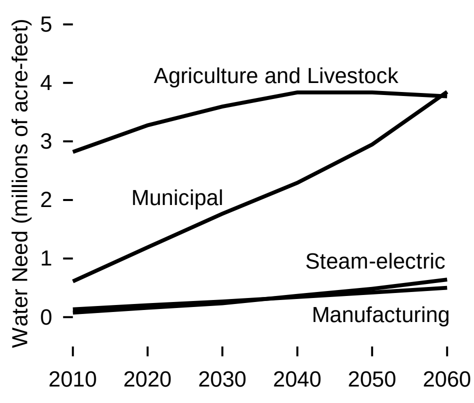


Figure 1

Projected need for water in Texas through 2060.

Not shown are modest amounts for mining (less than 80,000 acre-feet per year).

Graphic adapted from Texas Water Development Board (2007a)

[1] 1 acre-foot equals 325,851.4 gallons.

Texas Desalination Initiatives

The Texas Water Development Board has supported research and development of desalination technologies since the beginning of the agency. In recent years, this support has become focused on two primary approaches: seawater desalination and brackish groundwater desalination.

Seawater

In April 2002, Governor Rick Perry tasked TWDB with developing a proposal to build the first large-scale seawater desalination plant in Texas to produce drinking water. In 2003, the Texas Legislature passed House Bill 1370 directing TWDB to undertake research and studies to advance the development of cost effective water supplies from seawater desalination. In response, TWDB provided $1.5 million for three feasibility studies to assess the technical viability of proposed seawater desalination projects: Lower Rio Grande Valley (Brownsville), City of Corpus Christi, and Freeport.

The Brownsville project, sponsored by the Brownsville Public Utilities Board, was ultimately selected to proceed to a pilot phase. The pilot facility became operational in February 2007 with the goal of collecting data on source water quality and assessing the desalination processes. This information will shape the design of a full-scale facility on the southern Texas coast. The Brownsville project would be state's first large-scale seawater desalination plant for municipal use.

Brackish Groundwater

In 2005, TWDB expanded the scope of its desalination activities to include brackish groundwater. As discussed in the next chapter, groundwater in Texas is an abundant natural resource. While much of the state's groundwater water is relatively fresh and requires little treatment, estimates indicate 2.7 billion acre-feet of brackish groundwater are available statewide (Texas Water Development Board 2007a).

The goal of the TWDB Demonstration Brackish Groundwater Desalination Initiative is to facilitate the continued development of brackish groundwater supplies in Texas. One way this goal is being realized is by creating reproducible models of groundwater desalination projects that may be effectively transferred to other communities with similar profiles.

Brackish groundwater desalination is considered an attractive water supply option for several reasons. First, the water source is typically reliable, even during periods of drought, when surface water is limited. Second, the construction and operational costs of desalination facilities are becoming more competitive compared to other, more traditional water supply options. Also, brackish groundwater desalination facilities can be developed and implemented in relatively short time periods, and the modular design of the technology allows for easy, quick upgrades. Finally, desalination technology can remove contaminates like arsenic and radionuclides that traditional water treatment systems cannot.

The Brownsville Seawater Desalination Pilot Project.

Photograph courtesy of WaterPR

However, several challenges must be addressed before brackish groundwater desalination can be effectively implemented. First, desalination requires relatively high energy use that makes it vulnerable to rising energy costs. Second, disposal of concentrate (salty waste product) can be expensive and have adverse environmental consequences. In addition, the permitting process for desalination is relatively new and can be complex, time-consuming, and expensive. Finally, projecting long-term production quality and quantity from brackish groundwater aquifers poses additional challenges due to the limited amount of information on long-term production experience. This last challenge is most easily overcome with additional investigation and by implementing design criteria that limit risk.

Not withstanding these challenges, several Texas communities are implementing brackish groundwater desalination projects. The earliest use of this technology in the state was in 1981 with the start up of a 50,000 gallon per day brackish groundwater reverse osmosis unit by Haciendas Del Norte Water Improvement District in El Paso (Texas Water Development Board 2006). Since that time, the use of desalination for public water supplies in Texas has increased significantly.

In 2005, more than one hundred public water systems in Texas were using desalination technology. Thirty-eight of these systems had a design capacity of greater than 25,000 gallons per day[2] (Figure 2), 30 of which were treating brackish groundwater and eight were treating surface water (Texas Water Development Board 2006). Combined, these facilities represent a total of 52.3 million gallons per day of design desalination capacity[3]. Based upon the average desalination production of the 30 groundwater facilities (49.3 million gallons per day) (Texas Water Development Board 2006), Texas was then producing about 55,225 acre-feet of water per year from the desalination of groundwater.

And still the number and capacity of desalination facilities in Texas has continued to grow. For example, since the 2005 survey, the case study project highlighted in this *Guidance Manual*, the North Cameron Regional Water Project, became operational (2007) with 2.0 million gallons per day of desalination capacity. Additionally, also in August 2007, Texas inaugurated the nation's largest inland desalination plant. The El Paso-Fort Bliss Desalination Plant, a joint project between the El Paso Water Utilities and the U.S. Army, has a design desalination capacity of 15.5 million gallons per day, making it a critical component of the region's water portfolio. With blending, this facility is expected to produce 27.5 million gallons per day of potable water. Finally, in 2008, the North Alamo Water Supply Corporation will finish construction of two more brackish groundwater facilities in South Texas, each with 3.0 million gallons per day of desalination capacity.

The El Paso-Fort Bliss brackish groundwater desalination facility.

Photograph courtesy of El Paso Water Utilities

2 The remaining 67 facilities had individual desalination capacities below 25,000 gallons per day. The total desalination design capacity of these facilities was less than 500,000 gallons per day.

3 Texas Water Development Board (2006) also identified over 100 industrial facilities in Texas using desalination technology, mostly in the power and semiconductor industries, with an estimated cumulative desalination design capacity ranging from 60 to 100 million gallons per day.

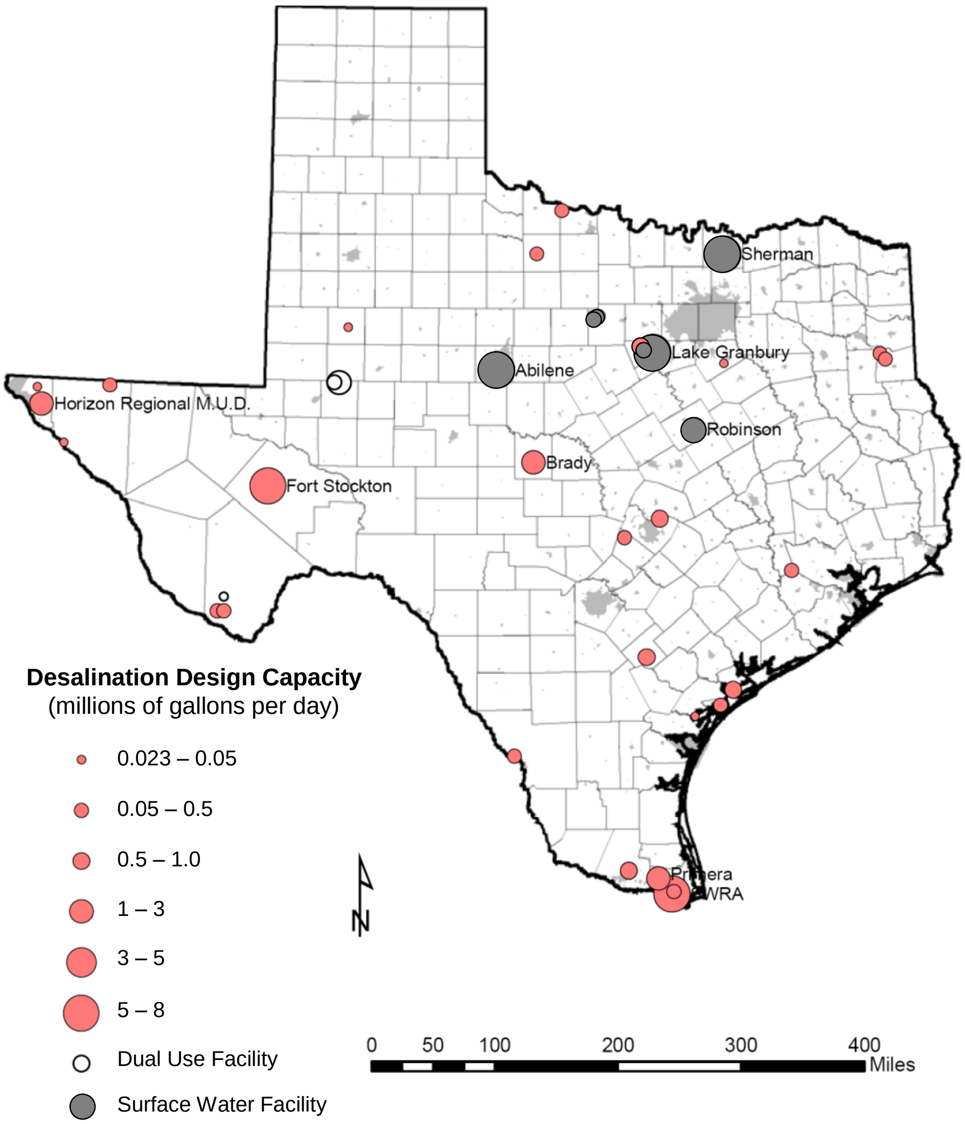


Figure 2

Desalination facilities in Texas, 2005.

Facilities with a design capacity greater than 1.5 million gallons per day are named. The location of some facilities is only approximate. Figure does not include projects completed after 2005, such as the North Cameron Regional Water Project (2.0 million gallons per day) and El Paso-Fort Bliss Desalination Plant (15.5 million gallons per day).

Graphic adapted from Texas Water Development Board (2006)

Many other water supply entities across the state are also looking to saline aquifers for future planning. By 2060, TWDB expects that brackish groundwater desalination will account for over 174,000 acre-feet per year of new water supplies (Texas Water Development Board 2007a). Although this amount is only a small portion (2 percent) of the total amount of new supplies needed, it does represent an increasing reliance upon brackish groundwater within the state. The actual development of brackish groundwater desalination capacity since 1995 indicates a more active trend that could meaningfully exceed these projections (Figure 3).

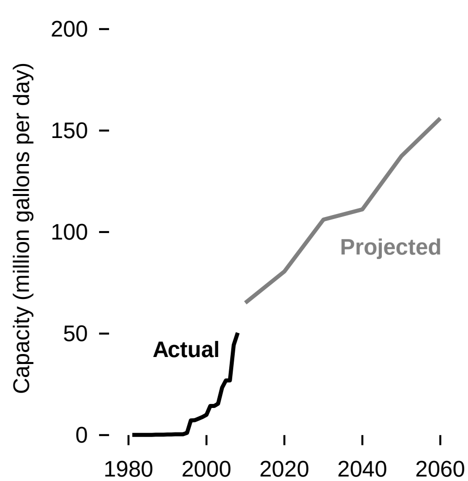


Figure 3

Design capacity for brackish groundwater desalination in Texas.

Data for actual capacity (1981 to 2005) from Texas Water Development Board (2006) plus projects recently completed (North Cameron and El Paso-Fort Bliss) and those under construction (North Alamo). Data for projected capacity was derived from approved regional water plans for Regions E, F, K, L, M, and O.

About This Guidance Manual

This *Guidance Manual* was developed to serve as a beginning point for Texas communities exploring the potential for desalination of brackish groundwater. It is intended to provide a general understanding of desalination technology as well as an overview of how to develop a brackish groundwater project. This manual presents a sequential approach to project development in five phases:

Phase I: Planning
Phase II: Permitting
Phase III: Design
Phase IV: Construction
Phase V: Operations

At strategic points throughout the *Guidance Manual*, examples from the North Cameron Regional Water Project are highlighted to provide real-life scenarios for other communities considering desalination.

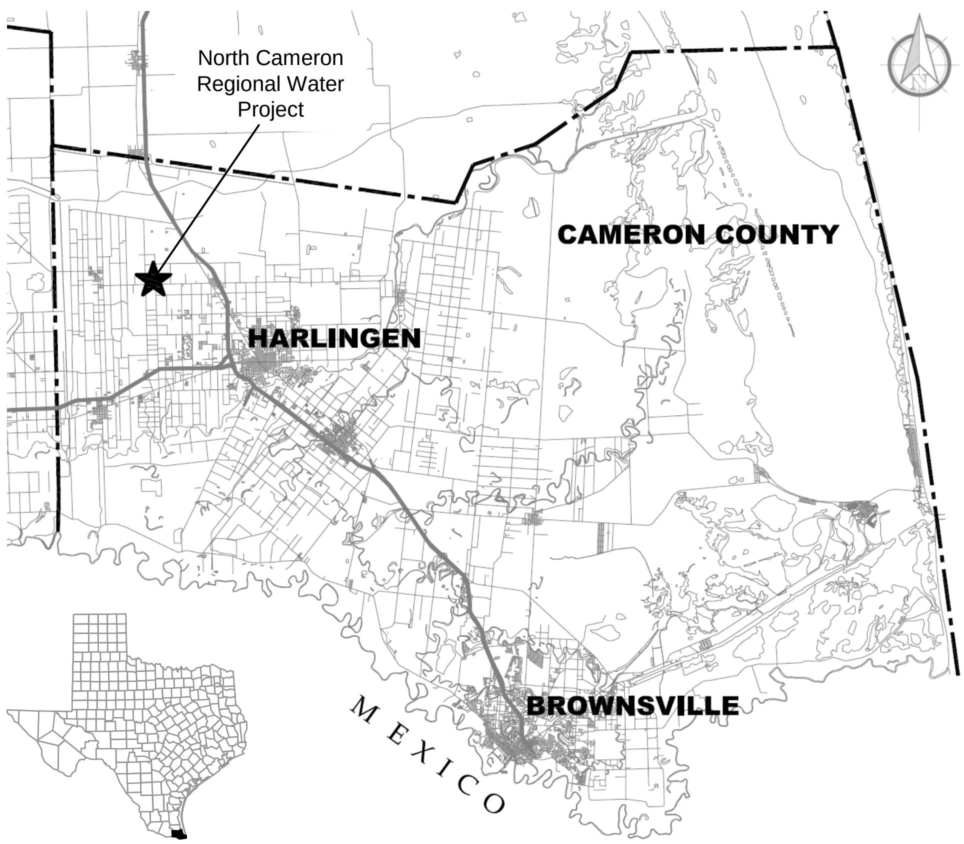
Case Study: *North Cameron Regional Water Project*

In 2007, the North Cameron Regional Water Supply Corporation finished construction of a reverse osmosis desalination facility that treats previously unusable brackish groundwater into high-quality drinking water. Located in northern Cameron County, Texas (Figure 4), the project is a cooperative venture between the North Alamo Water Supply Corporation, East Rio Hondo Water Supply Corporation, and the City of Primera.

Figure 4

Location of North Cameron Regional Water Project.

Graphic courtesy of NRS Consulting Engineers



The project has a desalination capacity of 2.0 million gallons per day and a total production capacity of 2.25 million gallons per day with blending. The desalination plant serves both municipal and industrial users, and has been designed to readily accommodate future expansion up to 4.5 million gallons per day (production). A schematic overview of the case study project is presented in Figure 5.

The Texas Water Development Board selected the North Cameron Regional Water Project as an educational example for developing additional water supplies from brackish groundwater sources in Texas. The project, including this *Guidance Manual* and accompanying on-line materials, were funded in part by TWDB to illustrate how desalination can work for small Texas communities.

On-line Companion Resources

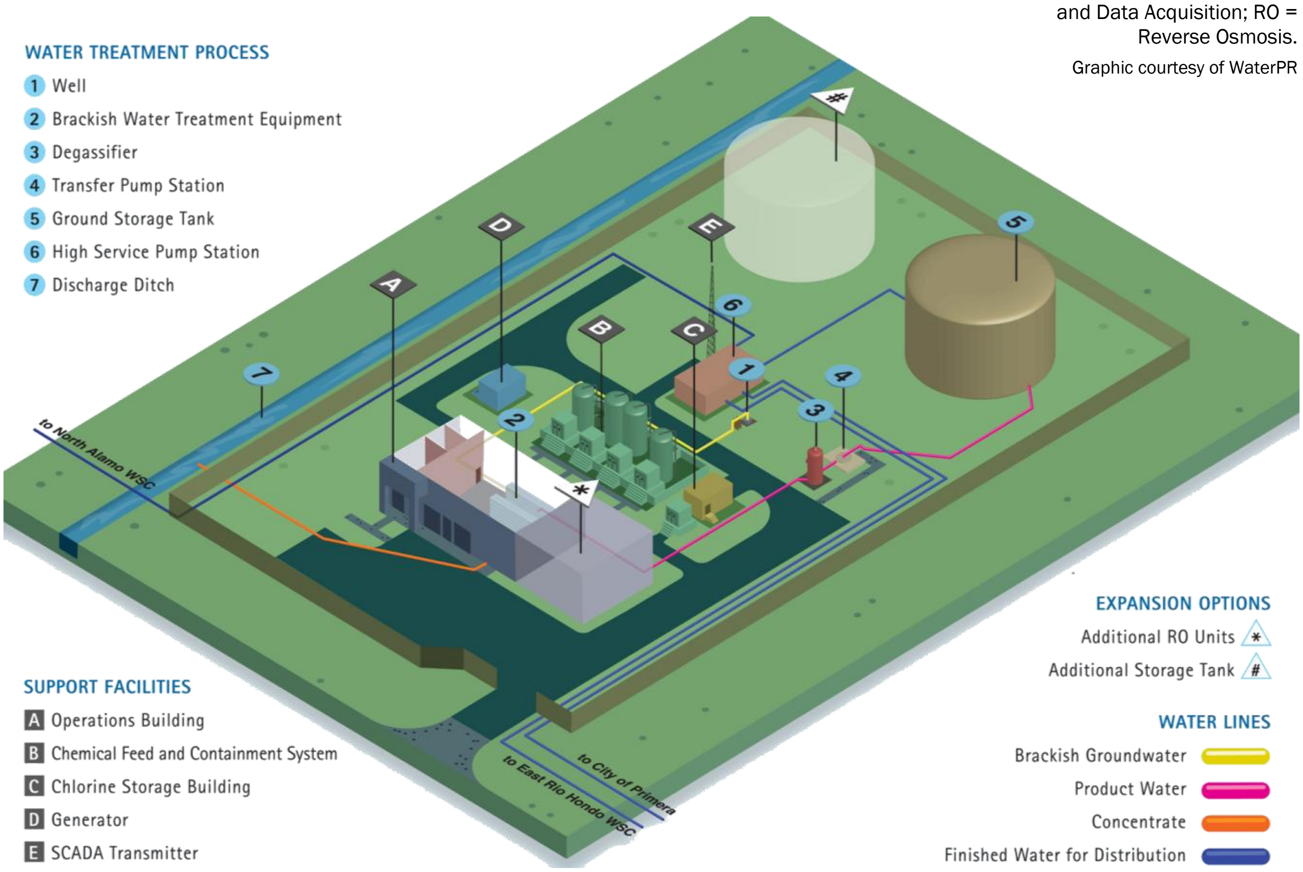
Additional materials about desalination and the North Cameron Regional Water Project have been developed as a companion resource to this *Guidance Manual*. An internet-based overview of the actual facilities and treatment processes, *Desal Demo: A Primer for Texas*, addresses some frequently asked questions, and provides links to other useful desalination resources. The Desal Demo website and this *Guidance Manual* are both accessible on-line at www.desal.org.

Figure 5

Schematic diagram of the major components of the North Cameron Regional Water Project.

SCADA = Supervisory Control and Data Acquisition; RO = Reverse Osmosis.

Graphic courtesy of WaterPR



Background

Texas Desalination 101

The abundance and distribution of brackish groundwater in Texas suggests this resource has significant potential to meet future water demands. To meaningfully explore opportunities for desalination, an understanding is required of some basic water chemistry concepts, the differences among major desalination technologies, and the common components of a groundwater desalination project.

The concentration of salts in water is usually measured as total dissolved solids and reported in milligrams per liter. Water with less than 3,000 milligrams per liter can be used without treatment, but with some limitations as to the type of use (Table 1).

Table 1: Use limitations for saline water.

Salt Concentration[a]	Use
<1,000	Considered fresh and usable for drinking.
<1,500	Usable for irrigation, depending on the crop type and level of specific salts.
<3,000	Usable for most livestock.
>3,000	Not considered usable without treatment.

Source: Adapted from Winslow and Kister (1956)
[a] Reported in milligrams per liter total dissolved solids

Water with a total dissolved solid concentration from 3,000 to 10,000 milligrams per liter is considered "brackish" and represents a potential source of water for desalination.

Brackish Groundwater Resources in Texas

Brackish groundwater resources are abundant in Texas, and virtually every major and minor aquifer in the state contains some saline water. Because most municipal water suppliers have historically sought fresh groundwater, data on the quantity and extent of brackish groundwater have not been extensively documented. In fact, discoveries of brackish groundwater have historically been the result of unsuccessful attempts to locate fresh groundwater. Therefore, most groundwater resource evaluations have generally been devoted to establishing the extent and properties of freshwater aquifers, whereas evaluations of saline water-bearing units have been mostly devoted to determining the effects on freshwater movement (U.S. Geological Survey 2003).

Broad characterization of saline groundwater resources in the United States began in earnest during the 1950s with the publication of surveys in several states and of selected areas within states. A good example of this type of work shows the general depth to saline groundwater for the conterminous United States in 1965 (Figure 6). These types of surveys provide some perspective of the location of saline groundwater resources, but give limited information about critical factors required to understand the development potential of the resources, such as aquifer hydraulic conductivity and well yields (U.S. Geological Survey 2003).

In 1972, TWDB conducted a broad survey of saline water quality in Texas (Texas Water Development Board 1972). This study provided a summary of available data for major water quality parameters in Texas counties by average depth, including total solids, calcium, sodium, magnesium, chloride, sulfate, bicarbonate, iron, hydrogen, pH, specific gravity, and geologic formation.

More recently, LGB-Guyton Associates (2003) evaluated each major and minor aquifer in Texas and estimated the volume of groundwater containing between 1,000 and 10,000 milligrams per liter of total dissolved solids. Based on this evaluation, the general extent and quality of known groundwater resources in Texas were mapped (Figure 7).

To enhance the planning value of this groundwater evaluation, Kalaswad and others (2004) presented the LGB-Guyton Associates data by total dissolved solids concentration and regional water planning group as established by Senate Bill 1 (75th Session) (Table 2). About two-thirds of the total 2.7 billion acre-feet of brackish groundwater estimated to be in Texas is slightly brackish, or between 1,000 and 3,000 milligrams per liter total dissolved solids. This lower range is most favorable for desalination applications because of reduced energy requirements for treatment. Within the planning regions, approximately 56 percent of the total amount of estimated brackish groundwater is located within four areas: Region L (15 percent), Region M (15 percent), Region F (14 percent), and Region N (12 percent).

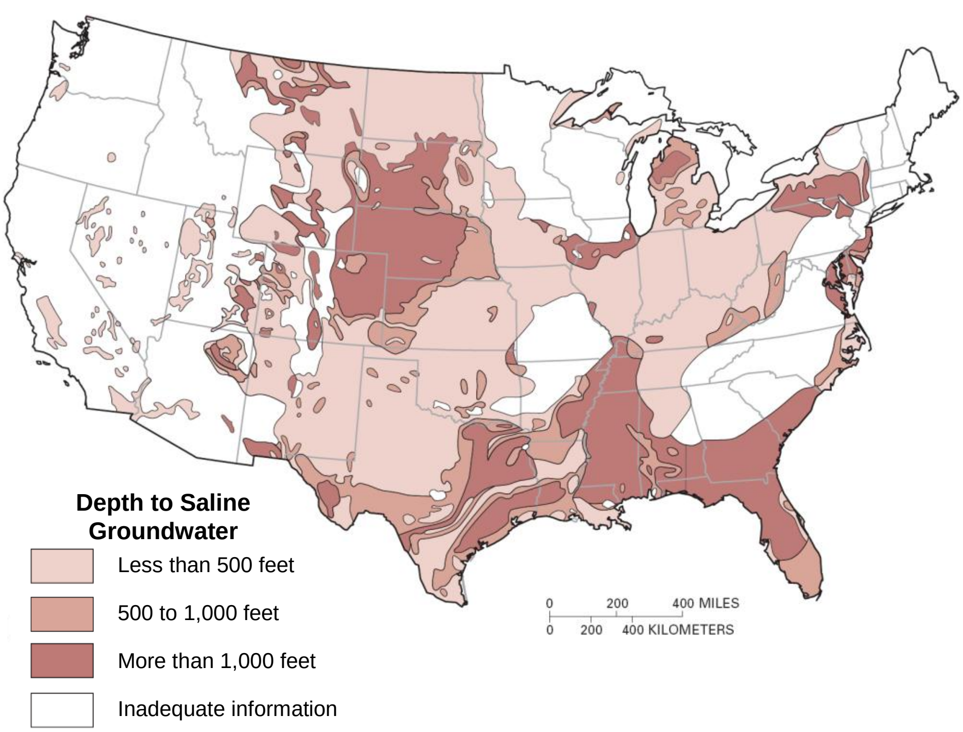


Figure 6

Depth to saline groundwater in the United States, 1965.

Figure reproduced from U.S. Geological Survey (2003)

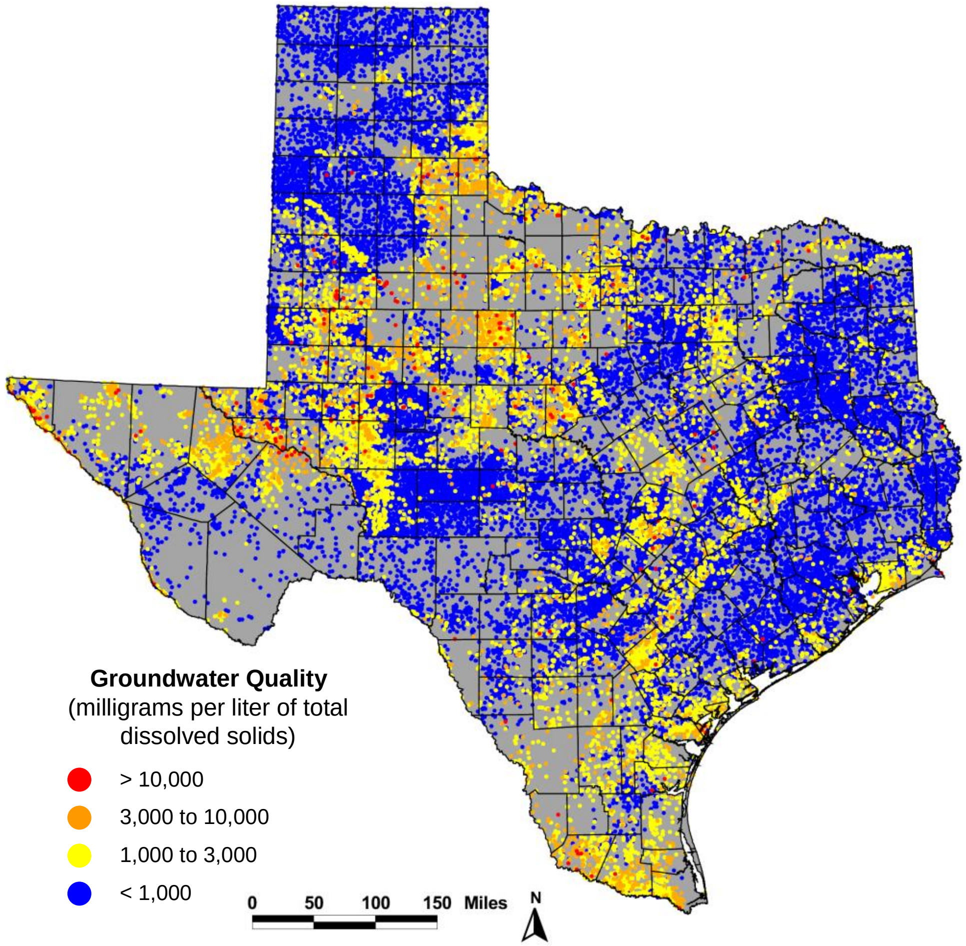


Figure 7

Groundwater quality in Texas, 2003.

The figure is heavily weighted toward fresh groundwater resources because the extent of knowledge of fresh groundwater resources is considerably more complete.

Figure reproduced from LBG-Guyton Associates (2003)

Table 2: Estimated brackish groundwater volume by regional water planning group.
All volumes reported in millions of acre-feet.

Planning Region	**1,000 to 3,000** milligrams per liter total dissolved solids	**3,000 to 10,000** milligrams per liter total dissolved solids	Total
A – Panhandle	7.9	11.2	19.1
B – Region B	6.0	8.6	14.6
C – Region C	43.4	41.6	85.0
D – Northeast Texas	28.9	26.9	55.8
E – Far West Texas	121.9	3.5	125.4
F – Region F	267.2	105.7	372.9
G – Brazos	122.0	73.6	195.6
H – Region H	122.6	73.3	195.9
I – East Texas	114.2	79.2	193.4
J – Plateau	3.2	5.4	8.6
K – Lower Colorado	101.8	100.1	201.9
L – South Central Texas	301.0	116.8	417.8
M – Rio Grande	270.8	125.3	396.1
N – Coastal Bend	200.3	132.1	332.4
O – Llano Estacado	46.7	45.1	91.8
P – Lavaca	1.4	6.5	7.9
Total	**1,759.0**	**954.8**	**2,713.8**

Source: Adapted from Kalaswad and others (2004).

Kalaswad and others (2004) also presented the LGB-Guyton Associate data by major and minor aquifers in Texas. Figures 8 and 9 show the locations of the 16 regional water planning groups with respect to major and minor aquifers in Texas, while Tables 3 and 4 present tabular data on the relative distribution of brackish water resources in each aquifer.

Table 3: Estimated brackish groundwater volume by major Texas aquifer.
All volumes reported in millions of acre-feet.

Major Aquifer	1,000 to 3,000 milligrams per liter total dissolved solids	3,000 to 10,000 milligrams per liter total dissolved solids	Total
Carrizo-Wilcox	270.0	160.2	430.2
Cenozoic-Pecos Alluvium	114.0	2.6	116.6
Edwards-Balcones Fault Zone	14.3	24.6	38.9
Edwards-Trinity (Plateau)	22.3	2.0	24.3
Gulf Coast	354.4	168.1	522.5
Hueco-Bolson[a]	24.5	0	24.5
Mesilla-Bolson[a]	0.5	0	0.5
Ogallala	32.7	3.5	36.2
Seymour	2.3	0	2.3
Trinity	97.5	80.7	178.2
Total	**932.5**	**441.6**	**1,374.1**

Source: Adapted from Kalaswad and others (2004).
[a] Designated as one aquifer by TWDB.

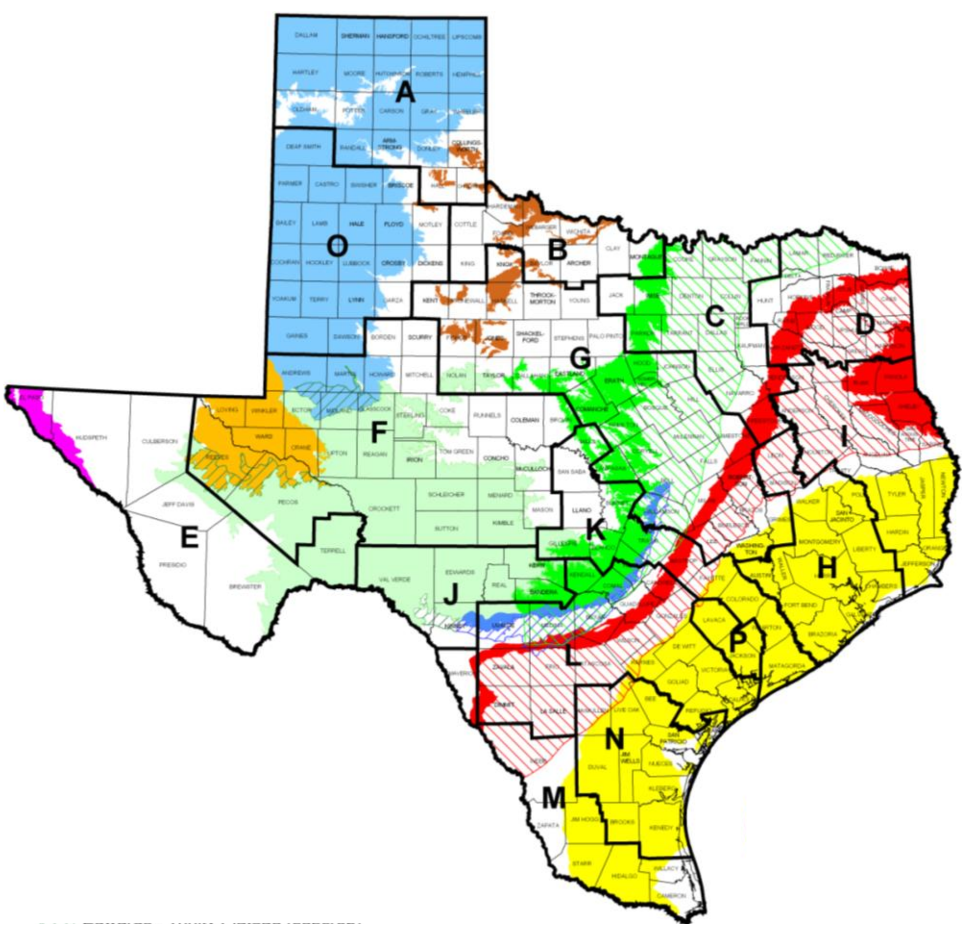


Figure 8

Major aquifers of Texas with regional water planning areas.

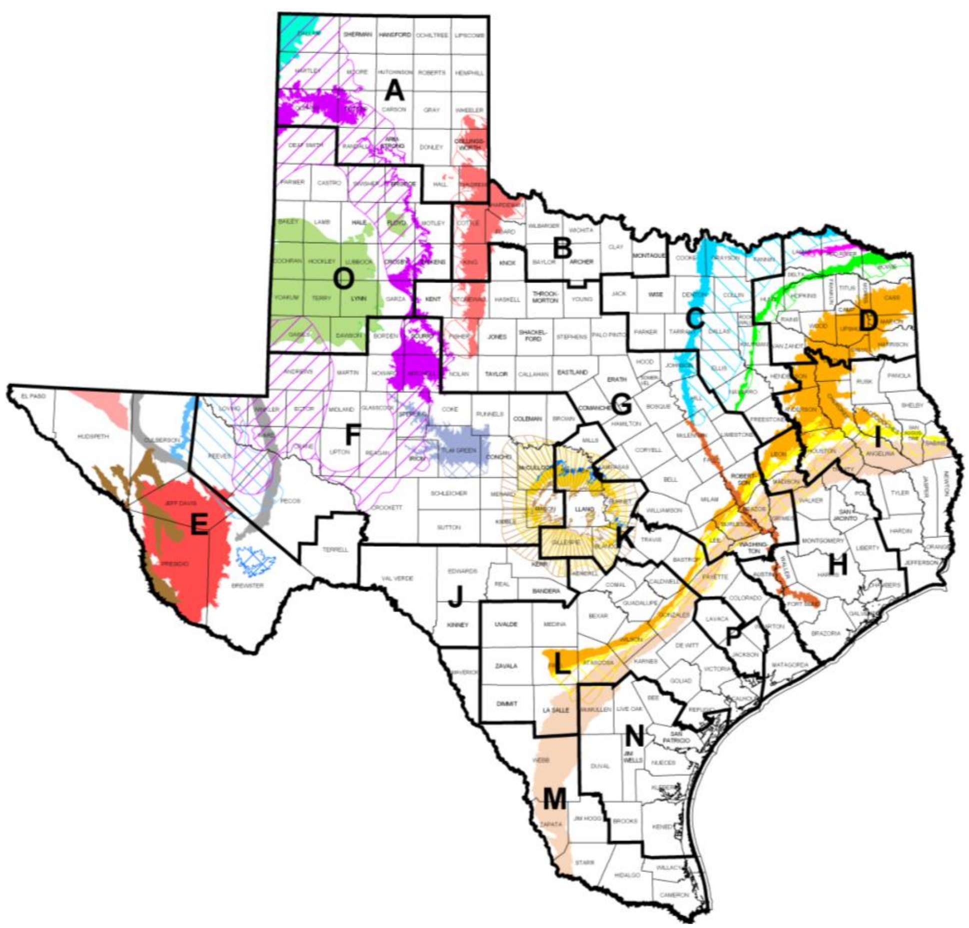
Graphic courtesy of the Texas Water Development Board

Table 4: Estimated brackish groundwater volume by minor Texas aquifer.
All volumes reported in millions of acre-feet.

Minor Aquifer	1,000 to 3,000 milligrams per liter total dissolved solids	3,000 to 10,000 milligrams per liter total dissolved solids	Total
Blaine	8.7	10.9	19.6
Blossom	1.1	0.3	1.4
Bone Spring-Victorio Peak	6.4	2.6	9.0
Captain Reef	54.3	20.4	74.7
Dockum	59.5	65.5	125.0
Edwards-Trinity (High Plains)	5.8	0.1	5.9
Ellenburger-San Saba	18.1	28.4	46.5
Hickory	68.9	49.2	118.1
Lipan	1.2	0.1	1.3
Nacatoch	10.9	3.4	14.3
Queen City and Sparta[a]	167.3	78.4	245.7
Rustler	18.4	18.4	36.8
West Texas Bolson	62.9	0	62.9
Whitehorse-Artesia	0.9	16.1	17.0
Woodbine	17.3	26.5	43.7
Yegua-Jackson	324.9	193.0	517.9
Total	**826.4**	**513.3**	**1,339.7**

Source: Adapted from Kalaswad and others (2004).
[a] Designated as two separate aquifers by TWDB.

Figure 9
Minor aquifers of Texas with regional water planning areas.
Graphic courtesy of the Texas Water Development Board



Basic Water Chemistry

Water has a wide range of physical and chemical characteristics that affect its quality and influence its response to treatment. With regard to brackish groundwater desalination, understanding basic water chemistry is critical for two primary reasons. First, potable water ultimately produced by the desalination facility is required by law to meet minimum drinking water quality standards. Second, water chemistry significantly affects the efficiency of the desalination process, the effectiveness of the equipment, and how water is conditioned prior to distribution.

Drinking Water Quality Standards

In 1974, Congress passed the Safe Drinking Water Act, which promotes cooperation among local, state, and federal entities to ensure safe drinking water, including bottled water, in the United States. Under the Act, the primary role of the federal government is to develop national drinking water standards for protection of public health. Individual states are responsible for implementing these standards and monitoring the performance of public water systems. The local public water systems are responsible for treating and testing drinking water to ensure consistent compliance with standards.

The Environmental Protection Agency is the lead federal agency for ensuring safe drinking water. The agency has developed primary and secondary drinking water standards, known as National Primary Drinking Water Regulations, for approximately 90 contaminants. Primary standards are legally enforceable standards that apply to public water systems. These required standards protect public health by limiting the levels of contaminants in drinking water. Secondary standards are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. The agency recommends secondary standards to water systems but does not require compliance. However, individual states may choose to adopt them as enforceable standards.

In Texas, the Texas Commission on Environmental Quality is the regulating agency and promulgates state Drinking Water Standards under 30 TAC Chapter 290 Subchapter F. Some local water providers may set contaminant goals more stringent than federal or state requirements. These are specific to each provider and the desired water quality needed for compatibility with the existing drinking water system.

Under Safe Drinking Water Act regulations, the Environmental Protection Agency addresses contaminants in six categories: microorganisms, disinfectants, disinfection byproducts, inorganic chemicals, organic chemicals (including both synthetic and volatile contaminants), and radionuclides. For each, either a Maximum Contaminant Level or required Treatment Technique is established by regulation. A Maximum Contaminant Level is the highest allowable concentration of a particular contaminant in drinking water, usually expressed in milligrams per liter. A Treatment Technique is a mandatory process intended to reduce the level of a specific contaminant in drinking water.

The ultimate success of any brackish groundwater desalination project depends upon its ability to consistently meet or exceed the drinking water quality standards established by the Environmental Protection Agency. A detailed discussion of all regulated drinking water contaminants and their enforceable standards may be found on-line at http://www.epa.gov/safewater/contaminants/.

Desalination Efficiency and Membrane Protection

The most critical factor in a membrane desalination facility is the quality of the source water. Therefore, water quality testing is essential during almost every phase of project development. During the early phases, water quality data help determine project feasibility and heavily influence design and permit considerations, such as treatment techniques and chemical dosing. During facility operation, regular testing of source water both prior to and during treatment ensures the desalination process is efficient and the sensitive membranes elements are protected. Water produced by desalination membranes (called product water, or permeate) is also regularly tested after treatment to ensure it is safe, meets all applicable drinking water standards, and acceptably blends with existing water chemistry.

Typical water quality tests are designed according to how solids and particulate matter react in water; namely, whether they tend to suspend or dissolve. Suspended solids can impair the ability of the membrane to work efficiently because the suspended material can physically block or plug the membrane pores. This condition inhibits the passage of water (production of permeate), potentially requiring more energy to create higher feed pressure to produce the same volume. Biological or organic material can cause or contribute to biological growth on the surface of the membrane elements with similar reductions in efficiency.

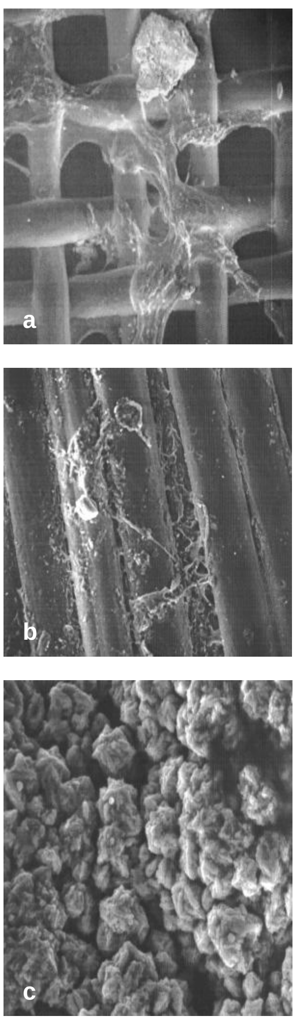
Dissolved solids, if they precipitate out of solution, can form a hard, scaling material on the membrane surface. Any of these occurrences will "foul" the membrane elements and reduce overall efficiency (Figure 10).

Figure 10

Examples of membrane fouling.

These electron microscope images show fouling due to (a) the deposition of silt and suspended solids, (b) microbiological growth, and (c) scaling of inorganic salts. Approximate scales are (a) 1 inch equals 400 microns, (b) 1 inch equals 300 microns, and (c) 1 inch equals 30 microns.

Photographs courtesy of Dietrich Consulting Group



SUSPENDED SOLIDS

Water can contain suspended solid matter consisting of particles of many sizes. These solids can include inorganic particles, such as silt or clay, or organic particles like plankton or detritus. While some suspended material will be large enough and heavy enough to settle rapidly, very small particles will settle very slowly or not at all if the sample is regularly agitated or the particles are colloidal (micro-granular). If such particles cannot pass through a sieve of two micrometers and yet are indefinitely suspended in solution, they are considered suspended solids. These solid particles cause the liquid to appear turbid, a term which describes the cloudiness or haziness of a fluid caused by individual particles that are generally invisible to the naked eye. Turbid water is also considered a risk to human health because contaminants like viruses and bacteria can become attached to the suspended solids, which then shields the organisms from chlorine disinfection or ultraviolet sterilization processes.

Two important water quality tests designed to measure suspended solids include turbidity and silt density index:

Turbidity
The cloudiness (or opacity) of water is measured by turbidity (Symons 2001). Because the particulate matter that causes cloudiness can also block or plug the pores of a reverse osmosis membrane, turbidity is used as an indicator of the rate of membrane fouling. Therefore, membrane manufactures generally limit the amount of turbidity that can be present in feedwater to 1.0 nephelometric turbidity units[4]. Nevertheless, turbidity is only an indicator, and even high values do not mean that suspended solids will necessarily foul a membrane.

Silt Density Index
Also known as the "fouling index", the silt density index is a measurement commonly used in the water treatment industry as another indicator of the potential for membrane fouling. It is

[4] Calculated by passing light through a water sample and measuring the amount of the light that is deflected.

popular because the test is easy to perform and does not require expensive instrumentation. In the test, water is diverted from the source through a 0.45-micrometer diameter filter under a constant pressure, usually 30 pounds per square inch. The time required for 500 milliliters of water to pass through the filter is measured initially and then again after the filter has been online for (typically) 15 minutes. The ratio between these two measurements is used to determine the extent of fouling.

Turbidity and silt density index are useful for characterizing groundwater sources during the planning and design phases of project development. They are also useful in measuring the ability of pre-treatment equipment to remove potential membrane fouling agents and should be performed regularly during project operations.

DISSOLVED SOLIDS

Naturally occurring minerals in the earth's crust that readily dissolve in water are generally called *salts*. In solution, they break down into cationic (positively charged) and anionic (negatively charged) components. Cations are primarily measured by the hardness of water, and anions are primarily measured by the alkalinity of water. Common ions present in brackish groundwater sources are presented in Table 5. Dissolved solids have the potential to cause membrane scaling if they precipitate out of solution during the treatment process.

Important water quality tests used to measure dissolved solids and their tendency to precipitate include hardness, pH, alkalinity, and total dissolved solids:

Hardness
Hardness is a measure of the concentration of calcium and magnesium salts in the water, usually present as bicarbonate salts. Total water hardness (including both Ca^{+2} and Mg^{+2} ions) is reported as a concentration of calcium carbonate ($CaCO_3$). Hardness is present in most natural water sources. Since these salts can precipitate out of solution, leaving behind scale formation on the membrane elements, controlling the precipitation of calcium or magnesium salts may be necessary to obtain satisfactory performance from a membrane desalination system.

pH
pH is a measure of the acidity or alkalinity of a solution. Aqueous solutions at 25 degrees Celsius with a pH less than 7.0 are considered acidic, while those with a pH greater than 7.0 are considered basic (alkaline). The pH of 7.0 is considered neutral because the concentration of H_3O^+ approximately equals the concentration of OH^- in pure water. pH is important to membrane desalination processes because it dramatically affects the solubility of a number of salts.

Acidity
Acidity is the measure of water's capacity to neutralize (or hydronate) a base (or alkalinity). Acidity of water is not normally a concern in brackish water membrane treatment because a slightly acidic feedwater will not usually precipitate salts in the concentrate stream. However, acidic water could have an excess of carbon dioxide, which passes through the membrane and may pose a chemical demand to stabilize (or buffer) the permeate with additional alkalinity.

Table 5: Major dissolved salts occurring in brackish groundwater.

CATIONS		ANIONS	
Name	**Chemical Formula**	**Name**	**Chemical Formula**
Calcium	Ca^{+2}	Bicarbonate	HCO_3^-
Magnesium	Mg^{+2}	Carbonate	CO_3^{-2}
Sodium	Na^+	Hydroxide	OH^-
Potassium	K^+	Sulfate	SO_4^{-2}
Iron (ferrous)	Fe^{+2}	Chloride	Cl^-
Iron (ferric)	Fe^{+3}	Fluoride	F^-
Manganese	Mn^{+2}	Nitrate	NO_3^-
Aluminum	Al^{+3}	Silica	SiO_2
Barium	Ba^{+2}	Sulfide	S^{-2}
Strontium	Sr^{+2}		

Alkalinity
Alkalinity is a measure of water's capacity to neutralize an acid. This capacity is based on the available amount of anions, such as bicarbonate, carbonate, and hydroxyl ions, and is usually measured in milliequivalents per liter. Most, if not all, of the alkalinity in naturally occurring water sources is in the form of bicarbonate alkalinity (HCO_3^-). However, for water sources with pH values greater than 8.3, more of the alkalinity will be in the carbonate form (CO_3^{2-}). As water is concentrated in a membrane treatment system, calcium carbonate salt tends to precipitate faster before other salts form. Therefore, successful operation of membrane desalination systems requires preventing or controlling calcium carbonate precipitation.

Total Dissolved Solids
Total dissolved solids refers to the combined content of all inorganic and organic substances contained in solution that are present in a molecular, ionized, or micro-granular (colloidal) suspended form. Generally these are solids that are small enough to survive filtration through a sieve size of two micrometers. In brackish groundwater, total dissolved solids consist primarily of inorganic minerals dissolved as salt cations and anions. Because total dissolved solids impair water aesthetics (particularly palatability), the Environmental Protection Agency has established a secondary water quality standard of 500 milligrams per liter[5].

Water quality considerations for specific salt ions relevant to membrane treatment processes are discussed in more detail as part of the Design Phase.

[5] Sulfates and chlorides are also regulated with secondary standards because of aesthetics considerations. Trace elements included in total dissolved solids that have primary Maximum Contaminant Levels due to their threat to human health include silver, mercury, arsenic, and selenium.

Overview of Desalination Technologies

The concept of desalination can be effectively summarized as a process by which some device separates saline water into two streams; one that is almost free of dissolved salts (the freshwater stream, or permeate) and the other containing most of the dissolved salts (the concentrated stream, or concentrate) (Buros 2000). The device, regardless of the technology used, requires energy to operate (Figure 11).

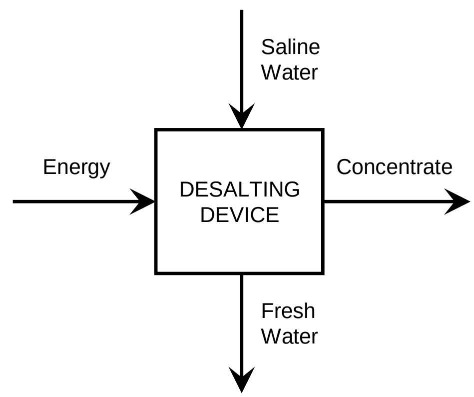


Figure 11
Summary of the desalination process.
Graphic adapted from Buros (2000)

Desalting devices generally use one of only two types of technology to remove salts from water: evaporation or membranes. Other desalination technologies that have not achieved the same commercial success as thermal or membrane applications include freezing (removing salts during the initial formation of ice crystals), membrane distillation (a combination of both processes), and solar humidification (using direct solar energy for distillation) (Buros 2000). A more detailed discussion of various desalination technologies is available from the U.S. Bureau of Reclamation (2003).

Evaporation Processes

Evaporation-based applications (also known as thermal processes) use distillation to produce freshwater. Distillation mimics the natural water cycle in that salt water is heated to the boiling point, producing water vapor that is condensed to form freshwater (Buros 2000). Evaporation processes generally require large amounts of energy and have relatively small recovery rates and large waste streams. Because of this, evaporation-based methods are most commonly used for large-scale, seawater desalination where the source water is very salty and energy is relatively abundant and inexpensive. Evaporation desalination processes are used in three primary applications: multi-stage flash (the most widely used distillation process), multiple-effect, and vapor compression.

Membrane Processes

Like evaporation, membrane filtration also occurs naturally, playing an important role in the separation of salts in the body (Buros 2000). Membrane desalination largely relies on two main types of processes: electro-potential (dialysis) and pressure (osmosis). Electro-potential-driven membranes use an electrical charge to move salts through a membrane, leaving freshwater behind. Pressure-driven membranes use osmotic pressure to force freshwater through the membrane, leaving the salts behind.

Pressure-driven membrane applications are further categorized in terms of the relative size of the membrane pores. The size of these openings determines which particles and molecules are separated from the water stream. Listed according to pore size (from smallest to largest), common membrane processes include reverse osmosis, nano-filtration, ultra-filtration and micro-filtration (Figure 12). In general, reverse osmosis and nano-filtration remove salts, metal ions, and organic molecules, while ultra-filtration and micro-filtration filter out larger suspended particles, such as bacteria, protozoa, and some viruses. To date, brackish groundwater desalination plants in Texas have almost exclusively used reverse osmosis (Texas Water Development Board 2006).

A comparison of major evaporation and membrane desalination technologies is summarized in Table 6.

Example of a multi-stage flash evaporator used for desalination.

Photograph courtesy of Caird & Rayner Clark

Figure 12

Comparison of membrane filtration processes.

Graphic adapted from Solvay Membranes (www.solvaymembranes.com)

Detection Method	Scanning Tunneling Electron Microscope	Scanning Electron Microscope		Optical Microscope	Naked Eye
Range	IONS	MOLECULES	MACRO MOLECULES	MICRO PARTICLES	MACRO PARTICLES

Size (microns)	0.001	0.01	0.1	1	10	100
Angstrom Units	10	100	1,000	10,000	100,000	1,000,000
Approx. Molecular Weight	200	20,000	200,000	>500,000		

Relative Size of Various Materials	Sugars; Viruses; Algae and Protozoans; Metal Ions; Albumin Protein; Bacteria; Sands; Pesticides; Red Blood Cells; Granular Activated Carbon; Herbicides; Paint Pigment; Dissolved Salts; Colloids; Human Acids; Human Hair
Process	Reverse Osmosis; Ultra-filtration; Particle Filtration; Nano-filtration; Micro-filtration

Table 6: Summary of characteristics of major desalination technologies.

Characteristics	EVAPORATION PROCESSES		MEMBRANE PROCESSES	
	Multiple-Effect Distillation	Multi-Stage Flash Distillation	Electro-Dialysis Reversal	Reverse Osmosis
Energy Cost	Very High	High	High	Moderate
Energy/Salinity	Independent of salinity	Independent of salinity	Increases fast with salinity	Increases with salinity
Applicable To	Seawater – brine	Seawater – brine	Brackish and Seawater	All types of water
Plant Size	Large	Large	Modular	Modular
Bacterial Contamination	Unlikely	Unlikely	Post-treatment always needed	Possible
Final Product Salinity	Can be <10 milligrams per liter of total dissolved solids	Can be <10 milligrams per liter of total dissolved solids	On demand	On demand
Complexity	Only large, complex plants	Only large, complex plants	Easy to operate; Small facility footprint	Easy to operate; Small facility footprint
Susceptibility to Scaling	Low	Low	Low	High
Recovery	Low, but better than multi-stage flash	Poor (10 to 25 percent)	High, but little to no silica removal	Moderate for seawater (30 to 50 percent); High for brackish water (up to 90 percent)

Source: Adapted from Texas Water Development Board (2006)

Project Components for Brackish Groundwater Desalination

Although many aspects of brackish groundwater desalination projects vary from site to site, four primary components are common to all projects: the pumping and delivery of brackish groundwater, the treatment facility where the water is desalted, the disposal of concentrate, and the delivery of the potable water to customers (Figure 13). Entities considering the use of desalination technology should understand the basic role of these major components and their influence on project cost and operations.

Groundwater Development

This component includes the well field and collection and conveyance system. The primary function of the well field is to draw brackish groundwater to the surface. The collection system collects pumped raw water into a single conveyance pipeline for transportation to the treatment facility. This pipeline system includes all associated pumping stations. If the well field is located at some distance from the treatment facility or if well spacing distances are great, the capital costs of the collection and conveyance system can be a significant portion of the overall project cost.

Brackish Water Treatment

PRE-TREATMENT

Raw brackish water arriving at the treatment plant from the conveyance system passes through facilities that prepare the water for the membranes. Although there can be site specific exceptions, pre-treating groundwater is often much simpler and less expensive than pre-treating surface water because disinfection, media filtration, and micro-filtration are not typically needed due to the natural filtering qualities of the aquifer formation itself. Pre-treatment processes typically required for brackish groundwater desalination include chemical additions, such as acidification and anti-scalant dosing, and cartridge filtration.

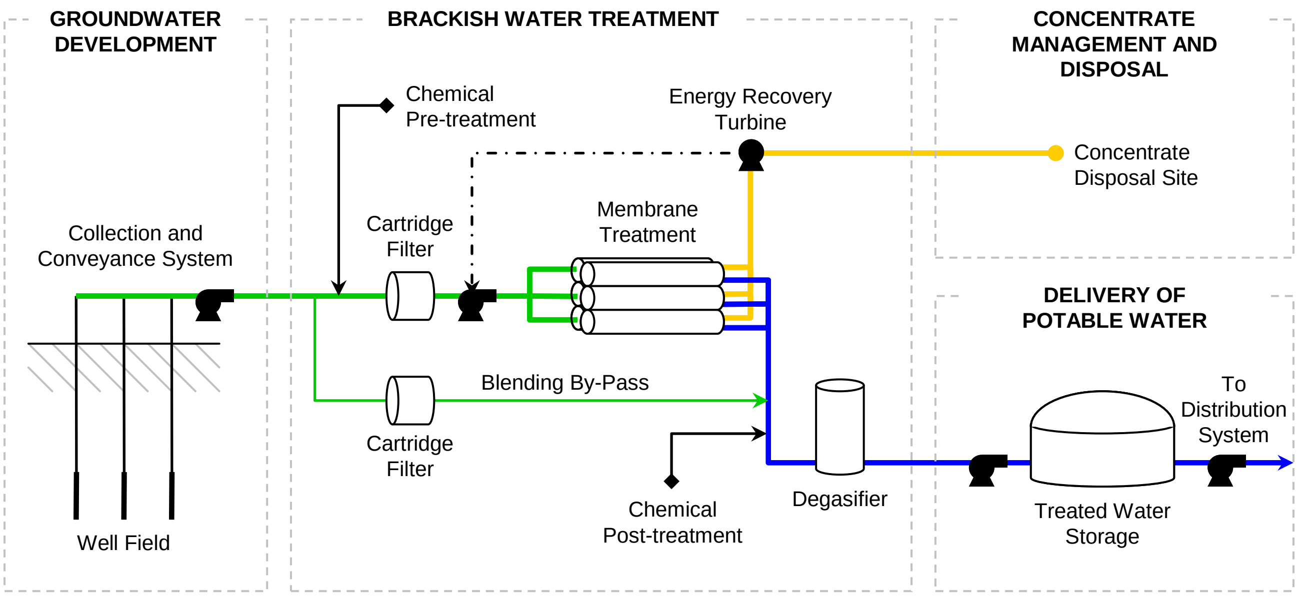


Figure 13

General flow process for a brackish groundwater desalination project.

Key process features are organized by major project component.

Graphic courtesy of NRS Consulting Engineers

DESALINATION

After suitable preparation, a high-pressure pump feeds clean saline water to the membranes for salt removal. The higher the salt concentration in the feed water, the higher the pressure required to force water passage through the membranes. The saline feed water is pumped into a closed vessel where it is pressurized against the membrane (Figure 14). As a portion of the water passes through the membrane, the remaining feed water increases in salt concentration. At the same time, a portion of this feed water is discharged without passing through the membrane. Without this controlled discharge, the pressurized feed water would continue to increase in salt concentration, creating such problems as precipitation of super-saturated salts and increased osmotic pressure across the membranes (Buros 2000). The amount of feed water discharged with the concentrate stream varies from 20 to 80 percent of the feed flow, depending upon the salt content of the feed water, pressure, and membrane type.

Recent technological advances in desalination have lowered the cost of water produced by the membrane treatment process. Although the process

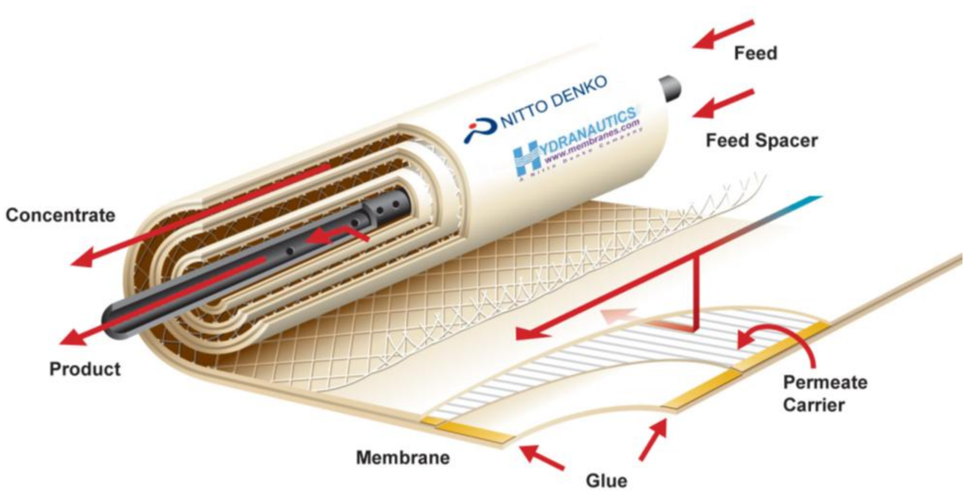


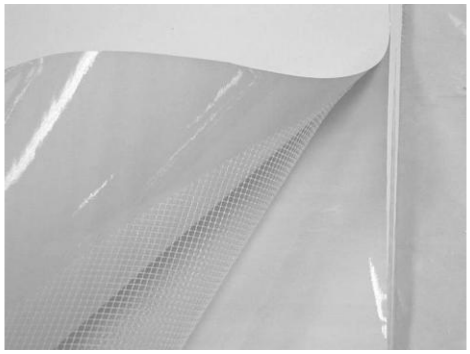
Figure 14

Diagram of the structure and function of a reverse osmosis membrane element.

Hydranautics supplied the membranes for the North Cameron Regional Water Project.

Graphic courtesy of Hydranautics

has not fundamentally changed in concept, significant improvements have been made in the efficiency of membranes, energy recovery, energy reduction, membrane life, control of operations, and operational methods.



Layer structure of a reverse osmosis membrane element.

Photograph courtesy of Dietrich Consulting Group

Another recent technology improvement relevant to the desalination process is that of energy recovery. The concentrate stream exits the membrane vessels with a high residual pressure. This energy is wasted if the concentrate is directly discharged to a drain. Energy recovery turbines can recapture a portion of this energy by extracting the hydraulic energy of the concentrate stream to produce a pressure boost in the membrane feed stream. Energy recovery systems reduce the power and cost necessary to operate the high pressure feed pump, and the liquid concentrate is finally discharged at atmospheric pressure.

POST-TREATMENT

As with surface water, several post-treatment processes are typically required for brackish groundwater desalination to stabilize the water and prepare it for distribution. Post-treatment processes include degasification to remove dissolved gasses, pH adjustment, stabilization, and disinfection.

The freshwater (permeate) derived from the membrane process can usually be mixed with some untreated raw water. This process is known as "blending," and it is used to restore some minerals to the water. Blending enhances taste, reduces the potential for treated water to damage metal elements within the customer distribution system, and increases the total production capacity of the plant.

After post-treatment and blending, water from the facility becomes "finished water" and is sent to storage. In many cases, finished water from the desalination plant is then mixed with finished water in the existing distribution system. The existing finished water might have been derived from a surface supply or well source, and may have been chlorinated or chloraminated with sequesterants and other additives. Potential water stability and corrosion potential may be characterized by parameters (corrosion indexes) indicating the potential of the desalinated water to precipitate calcium carbonate and by parameters that address corrosivity caused by specific compounds in permeate (World Health Organization 2007).

As discussed in subsequent chapters, it is critical to consider finished water compatibility during the planning and design phases to ensure existing and planned finished waters are compatible.

Concentrate Management and Disposal

Often the most challenging aspect of a desalination project is disposing of the waste products generated. Most of the waste produced is concentrate from the membrane process. However, there also are other wastes generated, including media filter cartridges, cleaning chemicals, filter backwash, and a variety of assorted facility drains. It is essential that the concentrate management and disposal system removes all waste products from the plant for disposal in accordance with state law and regulation and that this system be sustainable for the long-term operation of the plant. Individual methods for managing and disposing of desalination concentrate are discussed in more detail as part of the Planning Phase.

Delivery of Potable Water

As with a conventional water treatment plant, potable water produced from a brackish groundwater desalination facility must be stored and pumped to customers. Typical features include transfer pumps, storage facilities, high-service pumps, and distribution pipelines.

Transfer pumps force water from the treatment facility to storage. The transfer pump station is sized for current demand, but can be expanded with the addition of new pumping units. Ground storage tanks temporarily hold produced water until it is needed. High-service pumps deliver potable water from on-site storage to customers. The high-service pump station is usually sized to provide a variable demand pressure and capacity to each customer. As with the transfer pump station, expansion of the high-service pump station is readily accomplished with the addition of pumping units.

Water distribution lines provide for the delivery of potable water. For regional projects, this conveyance system can account for a significant part of the project cost, as the system must connect to the existing distribution system of each participating entity. The lines are usually sized to allow for future upgrades in the distribution system.

Phase I: Planning

Is Desalination Feasible?

Initial activities of the Planning Phase focus on two fundamental questions: Are additional water supplies needed? And are there alternatives to meet this need that appear viable from engineering, environmental, and economic perspectives? As the planning process progresses, more specific information is developed to address critical engineering and financial questions, and also helps satisfy the informational demands of the regulatory and design phases.

Exploring Needs and Opportunities for Desalination

The prospect of using desalination technology usually begins with perceived water needs or opportunities of a community or region. Therefore, the Planning Phase starts as potential solutions are contemplated for addressing specific needs or leveraging specific opportunities, or both. In this regard, potential brackish groundwater desalination projects are subject to the same fundamental water resources planning principles as are other traditional water supply projects.

Water supply needs and opportunities can be related to quantity, quality, or reliability and should be clearly and directly articulated early in the Planning Phase. Such statements aid in the formulation of alternative project plans and provide focus during the remaining phases of project development.

Many communities are facing future water demands that exceed existing supplies. In fact, the Texas Water Development Board (2007a) has estimated that by 2060, this challenge will confront approximately 1,200 water user groups in Texas, or 45 percent of the total water user groups in the state, including municipal, county, manufacturing, mining, power generation, livestock, and irrigation entities. Therefore, the need to develop additional water supply resources will be a major planning objective in future years for many communities.

Other communities have different water supply objectives or seek more than just additional supplies. For some, deteriorating water quality or changes in drinking water standards limit the usability of existing supplies. For others, existing water supply and treatment processes no longer sufficiently nor reliably meet the water quality goals of the community. Some cities are seeking to improve the reliability of water supply sources, especially in areas prone to drought or where the water supply is directly dependant upon the actions of others. Still others wish to reduce supply vulnerability by diversifying the type and location of their water sources. Whatever the challenge, it is important to identify and articulate each need and opportunity driving the evaluation of a brackish groundwater desalination facility.

Once the needs and opportunities for a project have been explored, clear project objectives should be stated in terms of alleviating problems and realizing those opportunities. Each statement of a problem or opportunity should be expressed as a desired output (objective) to result from the project. Alternative project plans, including brackish groundwater desalination, may then be compared in terms of how well they meet these stated objectives.

Considering a Regional Approach

In some cases, establishing a regional approach to addressing water supply problems and opportunities will result in the most cost effective project. Regionalization refers to developing one water project to serve multiple entities instead of each water provider developing their own supply system. Successful cooperative efforts yield better projects and allow for cost savings to be passed on to consumers.

ADVANTAGES

Potential advantages to a regional water supply project include:

Economies of Scale
The most obvious reason for working with other regional entities to implement a brackish groundwater desalination project is the ability to jointly construct a larger project than any one entity could otherwise afford. As with most capital projects, this approach generally results in lower per unit cost to each participant. However, economies of scale do eventually reach a level of diminishing return.

Smaller Entity Participation
A regional water supply approach also allows the participation of small water providers unable to develop supply projects on their own. Small water suppliers (requiring less than 1 million gallons per day) can partner with larger entities to supplement their water source while taking advantage of the economies of scale inherent in a regional project.

For example, the Southmost Regional Water Authority manages the second largest brackish groundwater desalination facility in Texas, providing 7.5 million gallons per day of potable water. The Brownsville Public Utilities Board uses 93 percent of this capacity and bears 93 percent of the cost. Five other entities have ownership of 2 percent each or less. These smaller entities would not have been able to develop this alternative water source without the benefit of the larger partner.

Southmost Regional Water Project. This regional brackish groundwater desalination project located in Cameron County, Texas, produces 7.5 million gallons of water per day for six area water providers.

Photograph courtesy of NRS Consulting Engineers

Efficiency of Operations
With a regional facility, the number of required operational staff is less than the total for multiple facilities. Because labor accounts for the second highest operational cost (behind power usage), this gained operational efficiency can result in significant project savings.

Leveraged Buying Power
Regional projects take advantage of cost savings derived from purchasing materials, equipment, services, and, at times, power in large quantities. Such savings are usually not available to small-scale individual projects.

Spirit of Cooperation and Ownership
A successful regional project results in each partner owning some responsibility for the positive accomplishment and builds a basis of trust for future collaborations. Thus, successful cooperation in implementing one project creates momentum for subsequent projects that are usually much easier, less costly, and timelier than the first.

Reduced Competition for Groundwater
Regional projects usually result in a single well field site to serve all participating project partners, which concentrates the demand on groundwater resources to a common point of extraction. These cooperative approaches reduce costly competition among individual water providers seeking to gain sufficient land ownership to ensure adequate groundwater supplies for their own customers.

DISADVANTAGES

Notwithstanding the potential advantages, a regional approach to brackish groundwater desalination is not always in the best interest of the project proponent. At a minimum, regional projects require a considerably larger commitment to involve stakeholders in the communication processes and constructive conflict resolution.

Potential disadvantages to a regional water supply approach include:

Political Boundaries
In many areas, political boundaries can limit the practicality of a regional approach, even if the technical merits of a potential project are promising. Often, this resistance is merely pride of ownership or an unwillingness to share credit for implementing a viable solution. All regional projects must address varying political boundaries at some level, and the limitations imposed by competing political interests will not always be surmountable. However, developing an effective public information and outreach program early during project formulation can prove to be a valuable investment toward building the necessary political support for a project.

Perceived Loss of Control
Another potential disadvantage of a regional approach is the perceived loss of control by one or several of the project partners. By nature, decision making for a regional project is a shared responsibility of the partners. In some instances, smaller entities considering partnerships with larger ones are concerned that major project decisions will be "taken over" by the larger entity to its exclusive benefit. Although the potential for this perception exists in any regional project where ownership is relatively unequal, this dynamic can be overcome by larger entities that are willing to work cooperatively and build the necessary trust.

Complication of Contractual Obligations
Due to the number of entities involved, the legal obligations and responsibilities of each participating entity in a regional project must be effectively reduced to specific contract terms. While this requirement does not usually result in serious complications, it does require a significantly more involved commitment than for a water supply project being developed by a single entity.

Working Within Regional Water Planning Groups

Entities investigating the feasibility of implementing a brackish groundwater desalination facility should verify whether the long-range regional water plan for their area includes this option as a water management strategy. Texas law[6] requires any project seeking state permitting or funding to be consistent with approved regional water plans. Regional water plans are updated every five years, but may also be amended to reflect new conditions at any time during the five-year planning cycle.

Brackish groundwater desalination is presently included as a recommended water management strategy for developing new supplies in six of the 16 regional water plans approved in 2006, including desalination are Regions E (Far West Texas), F, K (Lower Colorado), L (South Central Texas), M (Rio Grande), and O (Llano Estacado) (Figure 15). By 2060, these six regions plan to derive approximately 174,773 acre-feet per year from groundwater desalination (Table 7).

Figure 15

Texas regional water planning areas where groundwater desalination is a recommended water management strategy, 2007.

Graphic courtesy of the Texas Water Development Board

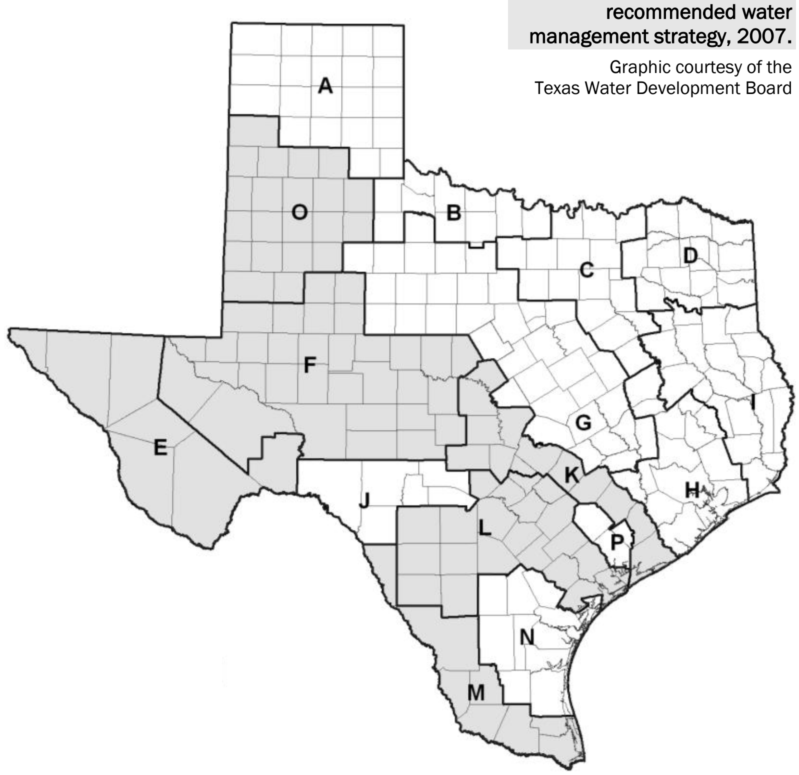


Table 7: Summary of water management strategies in Texas planning areas that depend on the use of brackish groundwater desalination.

Region	Strategy	Volume (acre-feet per year)	Implementation Schedule	Estimated Total Capital Cost
E	Importing desalinated brackish ground water from Dell City to El Paso	50,000	By 2030	$503 million
F	Desalinating brackish ground water for San Angelo Colorado River Municipal Water District	16,221	By 2020 By 2030	$131 million
K	Desalinating brackish groundwater by South Texas Project Electrical Generating Station	29,568	By 2010	$97 million
L	Desalinating brackish groundwater from Wilcox in Bexar County for San Antonio Water System	5,662	By 2010	$93 million
M	Various brackish groundwater projects for municipal uses	69,962	2010 - 2060	$342 million
O	Desalinating brackish groundwater for Lubbock	3,360	By 2020	$10 million
	TOTAL	**174,773**		**$1,176 million**

[6] Senate Bill 1, 75th Session.

Public Involvement

Effective public outreach is integral to the success of a brackish groundwater desalination project. Because desalination is likely to be new or unfamiliar to many customers, policymakers and other stakeholders, the public will have questions or concerns about the process, particularly if the cost of desalinated water will be higher than water produced by conventional methods. An open and public discussion of the perceived need, available alternatives, and results from alternative evaluations will minimize misunderstandings.

The goal of any outreach effort is to create two-way communication mechanisms that not only provide stakeholders with relevant, timely, and understandable information but also create avenues for dialogue and feedback. This will help ensure that messages are being received and understood and that any questions are directed to the proper expert for prompt, accurate replies.

Public outreach activities should be designed to involve stakeholders, establish readily accessible mechanisms for disseminating timely and pertinent information about the project, address concerns, and build on existing opportunities to share information.

Although public involvement begins in the Planning Phase, it should be considered an ongoing project activity through the start up and operation of the desalination plant.

Evaluating Alternatives

Usually, a number of alternative plans that could satisfy the stated project objectives are identified early in the planning process and become more refined through additional development and subsequent iterations. Additional alternative plans may be introduced at any time due to the emergence of new information or perspectives. It is important to understand that formulating a plan is a dynamic process with various steps that will likely be performed more than once. This process may sharpen or change the planning focus as new data are obtained, or as the specified problems and objectives are more clearly defined.

Preliminary alternatives that have been identified as potentially meeting the stated project objectives should be evaluated on the basis of engineering feasibility, potential environmental impacts, and potential cost effectiveness. The results of this evaluation will focus the remaining project development phases on the most viable alternative(s). Positive indications from these conceptual-level analyses will provide the necessary decision tools to continue with the Planning Phase.

Engineering Feasibility

The engineering assessment should include all facilities necessary for an operational desalination project, including well field and collection, conveyance, treatment, delivery of potable water, and concentrate disposal. Much of the engineering feasibility is dependant on the quality, quantity and reliability of groundwater available for project implementation. Thus the collection, review, and preliminary analysis of existing data[7] are critical. Computer

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[7] Recommended sources for preliminary groundwater information include reports and data by state, federal, and academic institutions, such as the Bureau of Economic Geology (access to geophysical logs), U.S. Geological Survey (airborne surveys and published hydrogeologic investigations), the Texas Commission on Environmental Quality.

simulations of groundwater flow and water quality may also be performed, depending on data availability and quality. Finally, although this step adds complexity to the analysis, the possibility of two separate aquifers (shallow and deep zones) should be evaluated when determining the potential to obtain the needed supply.

It is possible that no reliable hydrologic or geological information is available for a particular area. In this instance, a shift from a desktop evaluation to preliminary field test drilling should be considered. This field test drilling will provide the reliable information necessary for subsequent phases.

Potential Environmental Impacts

The Planning Phase should also assess potential impacts to the environment for each alternative. This information may then be incorporated into the ultimate project design with the goal of minimizing adverse environmental impacts during long-term operation of the facility.

The desalination process can have a number of environmental impacts that should be considered. Direct impacts include those associated with well field location, concentrate discharge, plant siting, and construction. Indirect impacts include those associated with energy use and downstream effects on other water users. On the other hand, membrane desalination can produce environmental benefits, such as supporting higher rates of water recycling and reducing the demands on natural water sources and the need for other large-scale infrastructure, such as dams and inter-basin water transfers. Also, membrane desalination processes can be used for environmental purposes such as treating contamination, augmenting stream flows, and recharging aquifers.

Input during the Planning Phase from state and federal agencies that regulate or manage natural resources is recommended but usually not required. The Texas Water Development Board (2007b), in cooperation with the Texas Parks and Wildlife Department and the Texas Commission on Environmental Quality, prepared a tool to assist potential project developers with environmental considerations for desalination facilities. Although this document focuses mainly on seawater desalination, it provides a useful overview of environmental concerns in Texas, as well as a discussion of the roles and permitting responsibilities of different state agencies.

Cost Effectiveness

Once the engineering systems have been conceptually defined, preliminary cost estimates for each system should be developed to compare alternatives. Such estimates should include both capital costs (design, permitting, and construction) and operational expenses (human capital, debt service, energy use, and materials replacement). Preparing cost ranges, instead of fixed values, is often more preferable during the Planning Phase due to the amount of uncertainty present early in the project development process. Cost-effective analyses are usually presented as annualized totals or per unit of produced water (for example, dollars per 1,000 gallons), or both. The results of this cost-effective analysis also begin to define the range of financing mechanisms that will be required to complete the project.

The overall objective of the initial activities in the Planning Phase is not to answer technical questions with certainty, but to accomplish enough work so that any fatal flaws are identified and the initial level of public support measured.

(drilling logs and groundwater chemical analysis), Texas Railroad Commission (oil and gas wells data with geophysical logs), local groundwater conservation districts (well information and pumping regulations), Texas Water Development Board (groundwater reports and groundwater availability models), and other nearby water utilities.

Facility Considerations

Refining conceptual ideas allows meaningful comparisons to be drawn between viable alternatives on the basis of engineering and financial considerations. This process should ultimately lead to the selection of a preferred alternative. Each of the major facility components can be first addressed somewhat independently and may have multiple alternatives. As each becomes more refined, an overall project plan of all project components can be developed and evaluated.

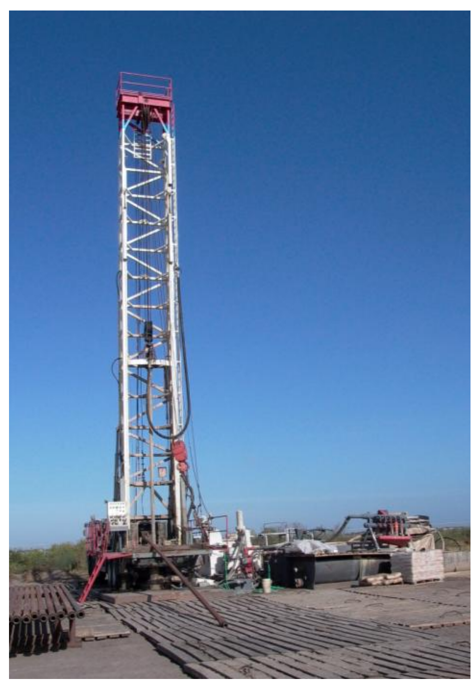
Groundwater Development

One of the most important aspects of planning a brackish groundwater desalination facility is that of accurately characterizing the groundwater source to be used. However, compared to fresh groundwater resources, data and information on brackish aquifers for planning purposes can be relatively sparse. Where available, existing information on brackish groundwater quality can greatly improve the success and reduce the cost of assessing groundwater availability. Examples of such data sources include the petroleum industry, which has been drilling in brackish water zones since its inception, and specific groundwater investigations[8]. Even so, the location, quantity, and quality of the brackish groundwater resources in Texas vary widely and must be evaluated individually.

Due to the limited availability of data on brackish groundwater resources in Texas, a phased approach to evaluating the feasibility of brackish groundwater development provides the greatest chance for ultimate success. This process allows the project to move forward incrementally so that potential risks and fatal flaws can be identified at the earliest possible time and with a minimal amount of capital investment. As new information is developed, the scope of additional work can be tailored to address project needs and minimize risk.

Conversely, a comprehensive scope of work developed at the start of the project to address all perceived data needs usually results in increased costs and unnecessary work. Such an all-encompassing approach to evaluating brackish groundwater resources is not sufficiently flexible to adapt to on-going project needs and findings.

Therefore, a phased approach for groundwater development activities is recommended by the present authors. This approach will typically include two parts: preliminary investigations and test drilling. Once these tasks have been completed, an accurate groundwater characterization may be made and a suitable treatment process planned.



Production well drilling rig onsite at the North Cameron Regional Water Project, July 2005.

Photograph courtesy of R.W. Harden & Associates

[8] For example, Chowdhury and Mace (2007), which developed a three-dimensional, numerical groundwater flow model of the Gulf Coast Aquifer in the Lower Rio Grande Valley, and LGB-Guyton (2004), an evaluation of brackish groundwater potential in Region F. An ongoing study is also being conducted on the potential use of the Whitehorse Aquifer for water supply (Texas Water Development Board (2008a).

PRELIMINARY INVESTIGATIONS

Preliminary investigations typically involve researching available aquifer data. Geophysical logs, a primary starting point for the investigation of brackish groundwater reserves, provide extremely useful information. The Texas Water Development Board and the Texas Commission on Environmental Quality maintain geophysical log libraries in Austin. In addition, private libraries also maintain geophysical logs not in the public domain.

Both public and private geophysical logs allow for subsurface mapping of brackish groundwater zones and allow preliminary analysis of production and quality. However, while geophysical logs provide reliable information about the depth and thickness of a proposed aquifer, production and water quality information are usually imprecise. Depending on the suite of logs that are included, general estimates of production and water quality can be made, but these should be verified through test drilling prior to implementation of the project.

Water well data are another important data source. A database of selected well data throughout the state is maintained by TWDB[9]. While this information only represents a small fraction of the total number of wells in Texas, it provides representative coverage of all aquifers and contains wells that are spaced at intervals where trends can be identified. The state database typically contains information on well depth, aquifer production intervals, water levels, and water quality.

Analysis of available geophysical log and well data, called a "preliminary desktop availability study," provides a basis for continuing to move the project forward with minimal risk, assuming that the results are favorable. Depending on the amount and quality of available information, preliminary computer groundwater modeling can also be performed using a reasonable range of aquifer parameters (bracketing analysis) that will allow conceptual well field designs, including well spacing and production amounts. The bracketing analysis assists in determining the feasibility of the project and the aquifer hydrologic conditions necessary to obtain the needed water.

Preliminary computer groundwater modeling is sometimes included as an optional item within the preliminary investigation if the desktop evaluation provides favorable results. The advantage of conducting preliminary modeling prior to collecting field data is that a general estimate of project feasibility can be obtained relatively inexpensively prior to implementing a field program. In addition, such analyses can assist in the design of test drilling programs and better direct field test drilling activities once the thickness and character of sands required for project success have been quantified.

In general, brackish groundwater assessments can be more difficult than those of freshwater aquifers. Water quality in most aquifers will vary by depth. Thus, the vertical water quality stratification must be fully understood so that assessments can be made of the individual impacts of well yield, well number, well depth, and well water quality. Therefore, any groundwater assessment must consider both the lateral and vertical extents of a supply.

In many aquifers in Texas, water quality typically becomes more mineralized (brackish) both laterally and with depth. This increased mineralization occurs laterally in a down dip direction within a single aquifer, and vertically within a single aquifer and other deeper aquifer zones. The significance of lateral and vertical variation in water quality within a single aquifer zone and vertical variation in different overlying aquifers should be carefully evaluated.

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[9] Available on-line at: http://wiid.twdb.state.tx.us/ims/wwm_drl/viewer.htm.

In the simplified example presented in Figure 16, there is a potential to develop a moderately deep brackish zone and a deep freshwater zone at location A. Comparative analyses should evaluate the additional construction cost (deeper wells) and operation cost (energy for higher vertical lift) of developing the freshwater zone against the costs of developing the brackish resource.

Furthermore, consideration should also be made for the potential for freshwater competition at location A to contribute to aquifer drawdown and thereby increase project cost and risk. Significant competition can encourage groundwater management districts to set tighter production limitations as a means of ensuring supply and protecting aquifer levels. Such competition factors may not be associated with the brackish groundwater due to lower demands for that resource.

At location B (Figure 16), potential development options include a shallow freshwater zone, and a moderate brackish zone, and a deep brackish zone. The freshwater zone, while having low construction and operation costs, may have limited availability due to shallow depth and probable heavy use. The two brackish water zones will likely offer reduced competition and lower project risk.

The decision to develop one or both of the brackish water zones depends on supply demands and costs. For example, if both brackish zones are developed, significant cost savings (for site acquisition, pipeline, pumping, and electrical transmission) could be realized by co-locating a shallow and deep well at the same site.

Without a three-dimensional analysis, the project planning process incurs additional risk for higher expenses related to land acquisition, treatment, and infrastructure. If multiple, vertically isolated aquifer zones exist at a single location (such as occurs in the Gulf Coast, Carrizo-Wilcox, Woodbine-Trinity, Ogallala-Dockum, and other aquifers), developing several zones with separate wells at a single well site could be advantageous. Careful evaluation of the quantity and quality from each zone should be performed so that the blended raw brackish groundwater is consistent in quality and meets the requirements of the treatment equipment.

Vertical water quality analysis is one of the most critical evaluations for a successful project, and test drilling programs for brackish groundwater development need to focus on this important aspect.

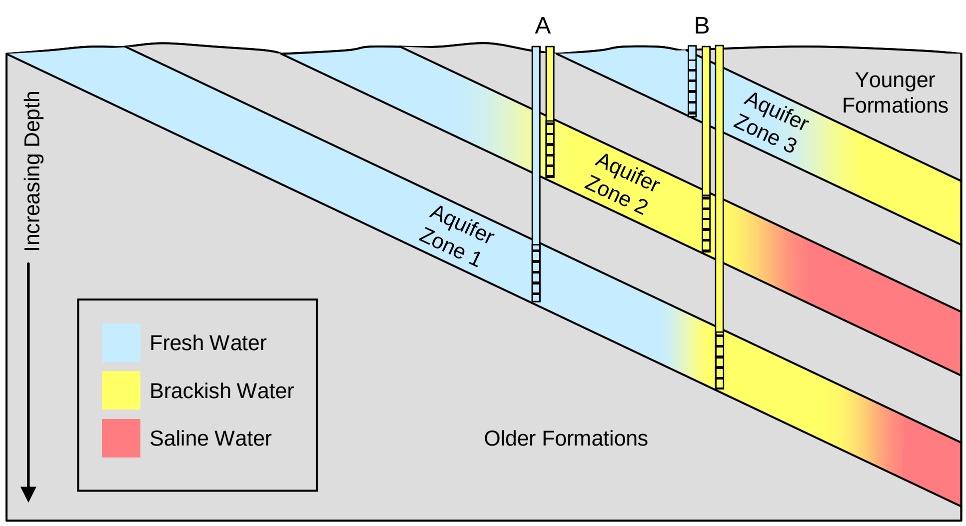

Figure 16

Conceptual aquifer cross section demonstrating vertical and horizontal water quality variation.

Simplified example only. Actual site conditions for a given project may be significantly more complex.

Graphic courtesy of R.W. Harden and Associates

TEST DRILLING PROGRAM

Test drilling is a prudent part of planning a brackish groundwater desalination project. The purpose of test drilling is to directly evaluate the quantity, quality, and reliability of the proposed supply. In most aquifers, significant savings in well construction and production costs can be realized by locating wells in the most productive portions of the aquifer. A well designed and executed test drilling program can pay for itself many times over by reducing the number and depth of production wells needed and minimizing the electrical costs of producing the water. However, where data available for an assessment are limited, the level of test drilling detail may involve more data collection to reduce project risk.

As with the preliminary investigations, it is not necessary to embark on large, costly studies and testing protocols at the onset of the field testing program. The amount of data collected and the level of detail needed largely depend on the results of the preliminary investigations and should be flexible to meet project needs. One of the most important test drilling protocols is "real time" analysis. The ability to accurately and timely transfer data and make decisions regarding ongoing drilling programs allows test drilling locations to be selected based on real-time findings, limits unnecessary work, reduces drilling costs, and provides the data required for the project.

In cases where very limited information is available on the proposed aquifer, a series of small diameter test holes can be drilled, geophysically logged, and sand samples collected. At some representative test holes, a few small diameter test wells (temporary or permanent) can be installed to evaluate aquifer productivity and water quality. The cost for such a field program can vary widely depending on the drilling protocols required, water quality stratification, depth of the test holes, drilling conditions, and regional drilling costs.

Assuming that the test drilling program provides favorable results, a second, more detailed phase is typically needed for developing larger supplies. This second test drilling phase typically includes the construction and long-term aquifer testing of one or more pilot production well(s). The pilot production well typically provides information on aquifer boundary conditions, longer term drawdown measurements, and an evaluation of the well design. Although drilling pilot production wells can be costly, these are typically incorporated into the final well field layout.

Preliminary investigation and field testing are dependent on the amount of available aquifer data, complexity of the hydrogeologic system and the supplier's risk tolerance. In all cases, a phased approach is recommended where project risks are identified as early as possible.

Brackish Water Treatment

Once the quality of the potential groundwater source(s) has been characterized, necessary treatment strategies can be identified.

PRE-TREATMENT

The main purpose of the pre-treatment step is to optimize the performance of subsequent membrane treatment processes. This is accomplished by reducing the potential for the source groundwater to foul the membrane elements by plugging or scaling.

An excellent brackish groundwater source is low in total dissolved solids (<4,000 parts per million), iron (<0.1 parts per million), arsenic (<10 parts per billion), and turbidity (<0.1 nephelometric turbidity units). These conditions would minimize the required pre-treatment processes (due to the low turbidity) and the potential for precipitate. This source would also impart no microbiological activity and contain little, if any, organics. In this scenario, a 5-micron cartridge

Key water treatment equipment, North Cameron Regional Water Project, August 2007. Photograph shows cartridge filters (left), stainless steel high pressure pumps (center) and reverse osmosis modules (right).

Photograph courtesy of WaterPR

filter[10] would be an adequate precaution to prevent particulate fouling and a scale inhibitor would prevent the precipitation of salts during treatment (scaling).

Under less ideal conditions, potential membrane foulants could include colloids, particulates, high iron content, high arsenic content, and dissolved organic compounds. Reducing or eliminating the feed water concentration of these types of materials to within certain limits is usually needed to satisfy warranty requirements of the membrane suppliers. Therefore, less optimal groundwater may require more advanced pre-treatment methods, potentially including ultra-filtration, micro-filtration, dual media filtration, or adsorption filtration[11]. Because of the capital and operational costs associated with these pre-treatment processes, their use should be carefully evaluated when selecting the groundwater source.

DESALINATION

Treatment methods suitable for brackish groundwater include electrodialysis and reverse osmosis, both of which are membrane-based processes.

Electrodialysis

Electrodialysis is a desalting process that uses electrical potential, rather than pressure, as the driving force. The process requires the use of two types of ion exchange membranes that allow passage of cations and anions, respectively. The membranes are placed into alternating stacks with electrodes at the end of each stack. Feed water is pumped through the spaces in between the membranes and an electrical potential (voltage) is placed on the electrodes. This charge causes ions dissolved in the water to move

[10] Cartridge filters are not intended to provide continuous removal of particulate matter from the feed stream. If continuous removal of suspended solids is required, more advanced pre-treatment is necessary.

[11] Ultra-filtration and micro-filtration are membrane filtration processes designed to remove small particulates without removing dissolved salts and therefore without requiring the higher operating pressures required by reverse osmosis. Ultra- and micro-filtration membranes typically operate at pressures between 20 and 60 pounds per square inch. Dual media filtration (sand and anthracite), adsorption filtration, and micro-filtration reduce iron, manganese, and arsenic. Dual media and adsorption filtration processes require an oxidation step using chlorine and a coagulation step using a coagulant, such as ferric chloride or ferric sulfate.

toward the electrodes, through the membrane, and into the adjacent flow space. A significant variation to the electrodialysis process is electrodialysis reversal[12]. In this process, the electrical potential applied by the electrodes is periodically reversed to prevent the buildup of scale and foulants on the membranes, thereby allowing higher water recovery.

There are several significant differences between electrodialysis and reverse osmosis. First, treated water does not pass through an elecrodialysis membrane as it does with reverse osmosis. This means that there is no barrier to microbial passage. Furthermore, electrodialysis is somewhat more tolerant of suspended solids in the feedwater. Also, because only electrically charged substances are affected, silica and most organics are not removed from the feed water by electrodialysis. Finally, because electrodialysis has the ability to produce a variable product water quality by varying the voltage applied to the system, blending is not practiced.

Electrodialysis is similar to reverse osmosis in that both processes require the use of acid and scale inhibitor to prevent precipitation of scaling materials on the membranes.

Reverse Osmosis
Reverse osmosis is a desalting process that uses pressure to force water through semi-permeable membranes while restricting the passage of dissolved solids. Water treatment by reverse osmosis generally falls within three broad categories: water softening[13], brackish water, and seawater. These different technology applications are summarized in Table 8.

Table 8: Summary of major reverse osmosis applications for salt removal.

Application	Range of Total Dissolved Solids in Feed Water (milligrams per liter)	Typical Operating Pressure (pounds per square inch)
Water Softening	< 2,000	125
Brackish Water	2,000 to 15,000	150 to 600
Seawater	> 15,000	600

Reverse osmosis membranes are more sensitive to feed water quality than electrodialysis membranes, so proper pre-treatment is critical. However, even with the highest quality feed water and appropriate membrane protection, reverse osmosis membranes lose some productivity over time. Therefore, it is necessary to chemically clean the membranes with various detergents, acids, or bases to restore membrane performance to a level close to initial. Cleaning is normally required about two to three times per year with a groundwater system. With proper care and correct plant operation, membrane life for a groundwater reverse osmosis plant can be expected to range from five to nine years.

Reverse osmosis membrane elements in standard (4- and 8-inch diameter) sizes.

Photograph courtesy of Hydranautics

POST-TREATMENT

Potable water intended for human consumption must meet certain basic requirements. Planning level considerations should include that finished water must contain no objectionable taste or odor, be non-corrosive for the distribution system, and be disinfected. Standard post-treatment processes used meet these requirements include removal of dissolved gases, pH adjustment, stabilization of the water chemistry, and disinfection. Finished water should also be compatible with the water in the existing distribution system expected to be used for delivery.

Degasification
Membrane desalination allows gases dissolved in the groundwater, such as hydrogen sulfide and carbon dioxide, to pass through the membrane elements.

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12 Electrodialysis reversal is a patented process of Ionics, Inc., which is the sole supplier.

13 Larger divalent ions, such as calcium and sulfate, can be effectively removed using nano-filtration membranes. Since these systems do not remove significant amounts of (smaller) monovalent ions, such as sodium, chloride, and nitrate, they are referred to as "water softening" systems.

Degasifier, North Cameron Regional Water Project, June 2007.

Photograph courtesy of WaterPR

In the finished water, hydrogen sulfide compromises taste and odor, and carbon dioxide lowers the pH and creates the potential for corrosion of the distribution system. The most common process used to reduce or control the amount of these gases is degasification.

Degasifiers are simple devices designed to facilitate the natural degassing of water containing supersaturated gases. This process is generally accomplished by passing the permeate through a vertical tower filled with randomly-dumped packing to break the water into small drops. Outside air is blown or sucked upward from the base of the tower and exists out the top, counter-current to the flow of the water. The packing is designed to provide optimum surface area contact between the water and the air. This process is known as 'wet-scrubbing'. If the scrubbing air stream that exists the tower contains hydrogen sulfide, then the air is usually treated to reduce the smelly 'rotten-egg' odor by passing upward through another packed-bed tower with a scrubbing liquid containing sodium hydroxide (caustic soda) and an oxidizing agent. Sometimes additional scrubbing or stages are required.

pH Adjustment and Water Stabilization
Membrane desalination produces permeate with low alkalinity, low total dissolved solids, and low pH. As with dissolved carbon dioxide, these factors make the product water potentially corrosive to the distribution system if not stabilized.

Common post-treatment stabilization strategies include blending, pH adjustment with caustic soda, and water stabilization with calcium chloride or sodium bicarbonate. Blending a portion of the feed groundwater with the permeate can create the desired product water quality and minimize post-treatment chemical use. Blending before the degasification process can be advantageous, especially if the raw groundwater contains hydrogen sulfide. However, selecting a blending strategy requires careful evaluation of the contaminants that might be present in the feed water and their impact on the quality of the final product water. The addition of caustic soda for pH adjustment and calcium chloride or sodium bicarbonate is generally conducted after degasification.

Disinfection
State and federal regulations require all potable water meet disinfection standards. The most commonly used disinfectants include chlorine and chloramines. Chlorine is most common because it is efficient and has a low potential for disinfection by-product precursors in the product water. Chloramines are a combination of ammonia and chlorine usually used when the product water from a desalination process blends with another product water (treated surface water) already using chloramines as the disinfection strategy. Either disinfectant is usually added after the degasification process.

Concentrate Management and Disposal

Every desalination process results in a waste stream of concentrate. During the Planning Phase, it is critical to identify viable management and disposal options for this waste product. Because of the potential for concentrate management and disposal issues to limit the applicability of desalination solutions in Texas, the subject has received more research attention in recent years[14]. At present, about half a dozen different methods exist for disposing of concentrate from desalination plants.

[14] For example, the Texas Water Development Board (2008b, 2008c, and 2008d) is funding several ongoing studies evaluating techniques to reduce the volume of concentrate generated by desalination operations.

SEWER DISCHARGE

There are two ways to discharge desalination concentrate in association with a conventional sewer system. First, concentrate can be discharged to a surface water body after passing through a wastewater treatment process. The treatment facility must be able to process the concentrate in addition to the existing wastewater effluent in compliance with discharge permit. If upgrades to the treatment plant are needed, any capital expense for such upgrades should be incorporated into the total project cost. Second, concentrate can be diluted and discharged with the outfall of the wastewater treatment plant, but not be treated by the plant.

SURFACE WATER DISCHARGE

The most common and cost-effective method for concentrate disposal is to discharge directly to a surface water body for dilution. This method can include direct discharge to a stream or sea, or variations of this, such as mixing with power plant cooling water or co-disposal with wastewater discharges prior to discharge to a water body. However, if the distance between the treatment facility and the point of discharge is great, surface water discharge can become prohibitively expensive. The primary concern with surface water discharge is environmental, namely the impact to the quality of water in the receiving stream, lake, bay, or canal.

DEEP WELL INJECTION

Under the right geologic conditions, desalination concentrate can be injected into a disposal well. The necessary conditions include the presence of a confining layer between the receiving aquifer and any other water-bearing formation that is, or could be, used as a source of drinking water. This disposal method becomes more economically attractive if other methods, such as surface water discharge, involve long conveyance distances.

LAND APPLICATION

Smaller amounts of desalination concentrate can be effectively managed and disposed of by land application, including the use of spray irrigation, percolation ponds or rapid infiltration basins. Because this method depends upon the uptake of concentrate by plants and soils, the ability of the land application method to consistently meet groundwater quality standards is critical. This is especially true in areas with shallow drinking water aquifers.

EVAPORATION PONDS

In areas with a suitably warm and dry climate, the disposal of concentrate by evaporation is viable. Potential drawbacks to this method are that it requires large surface areas and the periodic collection, transportation and disposal of remaining dry solids (precipitated salts). Also, groundwater protection regulations usually require that evaporation ponds use an impervious lining material, which can dramatically increase the capital cost of this disposal method.

ZERO LIQUID DISCHARGE

The primary objective of this concentrate disposal method is to achieve a zero liquid discharge. At present, this method is the least cost-effective disposal method because it requires specialized equipment and high energy usage[15]. Like evaporation ponds, zero liquid discharge involves collecting, transporting and disposing of precipitated salts and other solids. Notwithstanding these drawbacks, zero liquid discharge is considered to be the most sustainable desalination concentrate disposal method. However, current costs prevent its use for brackish groundwater desalination.

General planning guidelines for different concentrate disposal methods are summarized in Table 9.

Drainage channel used for discharge of desalination concentrate, North Cameron Regional Water Project, February 2006.

Photographs courtesy of NRS Consulting Engineers

View of the evaporation pond for the City of Brady desalination facility. Water from the Brady reservoir is desalted and blended with well water from the Hickory aquifer. Concentrate is diverted into this pond, constructed in 2005, for evaporation.

Photograph from Nicot and others (2007)

[15] At present, zero liquid discharge methods are only used primarily in industrial applications where fuel is inexpensive and liquid discharge is not feasible.

Table 9: Summary of general planning guidelines for concentrate disposal methods.

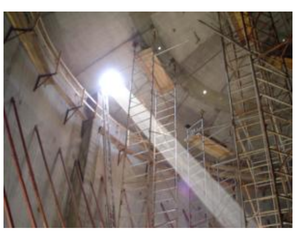
Disposal Method	Planning Guidelines
Sewer Discharge	Treated in System – Combination of quantity and quality of concentrate does not disturb wastewater treatment plant operations. Mixed with Plant Outfall – Pipe size suitable for additional volume of concentrate; requires permit revision.
Surface Water Discharge	Inland – Total dissolved solids, oxygen, and pH of concentrate compared to disposal point. Ocean – Concentrate discharge located to prevent recirculation intake; diffuser system is employed; oxygen and pH match disposal point.
Deep Well Injection	Disposal zone does not have direct or indirect connection with an aquifer of lower total dissolved solids concentration or any aquifer designated as a drinking water source.
Land Application	Disposal zone does not have direct or indirect connection with an aquifer of lower total dissolved solids concentration or any aquifer designated as a drinking water source.
Evaporation Ponds	Double lining with leachate collection system required; depth of pond suitable to hold all precipitated solids over the life of the plant.
Zero Liquid Discharge	Location of off-site location for disposal of solids adequate.

Source: Adapted from U.S. Bureau of Reclamation (2003)

Delivery of Potable Water

Potable water distribution systems serve consumers by satisfying volume demands and distribution pressures. Consumers can include residential, institutional, commercial, and industrial entities. Critical planning factors for treated water distribution systems include the volume of demand, location of the treatment plant, and location of delivery points. Information used to define these factors typically includes historical water usage, population trends, planned growth, topography, and existing system capacity.

Specific water distribution components include transfer pumps, on-site storage, high-service pumps, and distribution line connections. During planning, consideration should be given to co-locating elements of the desalination facility with existing water treatment and distribution infrastructure. Where delivery components (such as ground storage or high-service pumps) can be shared, total project costs can be reduced.



Construction of the ground storage tank, North Cameron Regional Water Project, March 2005.

Photographs courtesy of NRS Consulting Engineers and WaterPR

TRANSFER PUMPS

The transfer pump station conveys final treated water from the desalination plant to an on-site storage facility, usually a ground storage tank. Unlike the other components of the potable water delivery system, the capacity of the transfer pump station is not influenced by the volume of water delivered to consumers. These pumps are sized according to the total existing and potential future capacity of the desalination plant.

TREATED WATER STORAGE

The objective of having on-site storage for treated water is to provide a reserve water supply, buffering between average and peak flow demands. On-site storage minimizes service interruptions when treatment units are down for cleaning and repair or power outages. If the desalination facility serves as a supplemental source of potable water, it would not be expected to experience a constant flow demand. In this case, it is recommended that on-site storage capacity equal approximately 25 percent of the treatment plant capacity to account for limited peaking demands.

For regional desalination facilities, each project partner should provide peaking capacity from within its respective treatment systems. A desalination facility that serves as the single source of potable water to a community triggers more detailed requirements[16] to ensure reserve storage is available for operations, fire, and emergency needs.

[16] The Texas Commission on Environmental Quality requires the capacity and design of these storage facilities meet per Rules and Regulations for Public Water Systems 30, Texas Administrative Code Chapter 290 Subchapter D.

HIGH-SERVICE PUMP STATION

A high-service pump station should be sized to provide a variable demand pressure and capacity for the project partner(s). If the brackish groundwater desalination plant is intended to serve as a regional facility, the pump station would likely provide water to a main distribution pipeline. If an individual water supply project, the pump station would likely provide water to an existing elevated ground storage tank. The high-service pump station should be implemented with variable frequency drives and be easily expandable in subsequent phases with the addition of pumping units.

DISTRIBUTION SYSTEM ANALYSIS

Planning to deliver potable water into an existing distribution system requires careful evaluation of operational criteria and constraints, including base flow, peak hour demand, and maximum day demand. The pressures maintained in distribution systems of different communities can vary, but must meet state design requirements as discussed in later sections.

Financial Considerations

At some point during the Planning Phase, information about proposed project alternatives becomes sufficiently detailed to consider cost and financing issues. When comparing the costs of brackish groundwater desalination to other traditional methods, it is critical to ensure that factors are considered equally.

Cost

Considerations of project costs should include both capital and life-cycle expenses[17]. Key factors to address during cost evaluations include location of the treatment plant, the quality and treatment needs of the raw water, any acquisition costs for water rights, and energy use.

PLANT LOCATION

Plant location factors in overall cost of the facility from the standpoint of source water, location within the distribution system network, and concentrate disposal. The closer the desalination plant to the raw water source, the treated water distribution system, and the point of concentrate disposal, the lower the capital and operating costs of the project.

SOURCE WATER QUALITY

The quality of the source water, especially salinity (dissolved solids) and suspended solids, directly impacts project cost. Higher salt concentrations require higher pressures on the membranes. This translates into higher energy costs and lower recovery rate for the system. The reduced recovery, in turn, translates into higher capital costs to increase plant capacity. High suspended solids also negatively impact total project costs by requiring more frequent filter replacement.

However, properly developed groundwater will yield water that is mostly free of suspended materials, minimizing the pre-treatment needs prior to the reverse osmosis process. This is the primary advantage that brackish groundwater desalination has over surface water desalination. Conventional or membrane pre-treatment systems are necessary for most surface water sources and can add significant capital and operating costs.

SOURCE WATER COST

The cost of the source water should be calculated when comparing brackish groundwater desalination to other freshwater alternatives. One-time water expenses can include the acquisition of surface water rights or securing groundwater pumping permits. Ongoing water costs can include surface water leases and groundwater conservation district fees based on production amounts. Such factors should be

[17] For a sample economic analysis of one-time (capital) and continued (operation) costs of a brackish groundwater desalination facility in Texas, see Sturdivant and others (2007).

considered so that cost comparisons made among alternatives are truly accurate.

ENERGY CONSUMPTION

Power costs are the largest factor in operating a brackish groundwater desalination facility, accounting for approximately 40 to 60 percent of the operational cost (2007 estimate). Recent technological improvements that have reduced pressure requirements and increased salt rejection have somewhat offset rising power consumption costs. Projects can also include capital investments for newer energy recovery systems to take advantage of the by-product pressure, thereby reducing total energy consumption for the process.

Because energy costs are such a large portion of total operational costs and optimal energy use is limited to discrete times of day (generally off-peak use), expanding production beyond certain optimal bounds does not generate economies of scale. Size can be increased (thereby increasing capital costs) but the use of the additional capacity needs to be constrained or project costs will balloon.

CONCENTRATE DISPOSAL

The most appropriate concentrate disposal method for any given brackish groundwater desalination project depends largely on specific site conditions. In general, the larger the desalination capacity, the greater the disposal cost. However, some disposal methods can have greater economies of scale than others (Mickley 2004) (Figure 17).

Mickley (2004) also observed that the challenges of concentrate management and disposal are increasing due to the growing number and size of membrane plants, increasing regulatory pressure, and growing public awareness and concern over environmental issues. As a result, concentrate disposal costs are likely to continue to increase and represent a greater percentage of the total project cost[18]. Therefore, it is critical to develop a viable concentrate disposal strategy early in the planning process so that these can be included in the overall project cost.

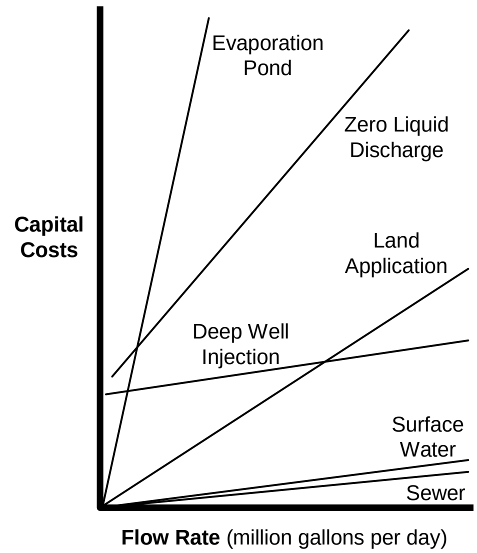


Figure 17
Relative capital cost of concentrate management and disposal options.
Graphic reproduced from Mickley (2004)

Financing

Local funding for water supply projects usually comes from the rates and charges water utilities assess their customers in support of the capital and operations portions of projects. The total cost to operate any water treatment project includes the capital cost of infrastructure and the operational costs of electricity, chemicals, and labor. Both operating and capital costs can be significant. If traditional capital 20-year debt financing assumptions were applied to a project, the local contribution through operation and maintenance revenues alone would amount to 40 to 50 percent of total project costs.

State participation in water resources development has a long history in Texas.

[18] For a more detailed discussion of design, cost, and regulatory considerations for concentrate disposal alternatives, see Mickley (2006).

Following the drought of the 1950s, a number of Texas communities embarked on developing major water supply projects. These projects were funded through a combination of federal, state, and local resources. The Texas Water Development Board actively participated in many of these projects, primarily through the Storage Acquisition Program, the forerunner of today's State Participation Program. Under these programs, TWDB became a partner in and part owner of numerous water supply projects. A similar opportunity now presents itself for the state to facilitate development of brackish groundwater desalination projects.

The State Participation Program is ideally suited to support a state interest in local projects that are not sustainable at the current customer base. Low interest loans through the Drinking Water State Revolving Fund also would appear to be a viable alternative, but funding is limited in total amount and competitive in an annual funding cycle.

Comparisons of several state and federal financial programs that may be used to develop water supply projects are presented in Table 10.

Overall Decision Process

Based on collective experiences, the present authors suggest a conceptual decision flow diagram for the planning, design, permitting, construction, and operation of brackish groundwater desalination projects in Texas (Figure 18).

This suggested process was developed with the understanding that all construction projects involve some degree of inherent risk, and the same is true for brackish groundwater desalination facilities. Primarily, these risks are associated with three different aspects of the project: performance, schedule, and budget. For each project, the owner sets the tolerable parameters for each of these factors, and they may not necessary be the same from project to project.

Therefore, to minimize the risks of compromising the owners need for project performance, project schedule and project budget, planning activities should be conducted in full consideration of the requirements and processes of other phases. A broad, disciplined implementation approach allows key decision points and critical paths to be identified and accommodated. Although deviations from the suggested approach are appropriate with varying circumstances, once a project has been determined to be technically and financially feasible at the conclusion of the Planning Phase, it is recommended that the minimum critical sequence of events include:

1. Obtain permits for concentrate disposal;
2. Prepare a preliminary design and cost estimate for the project;
3. Permit, design, and construct the production well(s);
4. Confirm water quality and quantity from the production well(s);
5. Develop pilot protocol and perform pilot study;
6. Finalize design and cost estimates for project;
7. Obtain permits for construction and operation of the water treatment facility; and
8. Construct the facility.

This conservative approach allows for incremental project development and increases owner confidence in the ultimate performance, schedule, and cost of the project being developed

Table 10: Comparison of state and federal financial programs suitable for water supply projects.

Program (Rules)	Eligible Applicants	Access and Eligibility	Type	Approximate Funds Available
Development Fund II (363) State	Political Subdivisions Districts Water Supply Corporations	•First come – first serve •Water and sewer projects •Pre-design funding option	LOAN Rate: State cost +0.35 percent Term: 20-25 years	Estimated $60 million available annually
Rural Water Assistance Fund (384) State	Political Subdivisions Districts Water Supply Corporations	•First come – first serve •Water and sewer projects •Pre-design funding option •Rural (≤10,000 population) •Provides rates close to tax exempt rates to WSCs	LOAN Rate: Slightly above state cost +0.12 percent Term: 40 years maximum	Approximately $25 million annually depending upon bond sales and availability of funds
State Participation (363) State	Political Subdivisions Districts Water Supply Corporations	•Priority rating system •No pre-design funding •Water and sewer projects •Fund excess capacity (up to 80 percent for new water supply projects; 50 percent for all others) •Targeted for State Water Plan projects	LOAN Rate: State cost +0.35 percent Term: 34 year model (scheduled deferred interest over first 12 years; level debt service of principal and interest in years 13-34)	$376 million authorized by House Bill 1 to be available February 2008
Water Infrastructure Fund (382) State	Political Subdivisions Districts Water Supply Corporations	•Water projects •Pre-design funding option •Targeted for State Water Plan projects	LOAN Rate: 2 percent below market Term: 20-30 years (options for deferred principal and interest payments for up to 10 years)	$437 million authorized by House Bill 1 to be available February 2008
Economically Distressed Areas Program (375) State	Political Subdivisions Districts Water Supply Corporations	•Water or wastewater services not meeting State minimum standards •Median household income less than 75 percent of state average •Established residential subdivision as of June 1, 2005 •Water and sewer projects •No pre-design funding •Model Subdivision Rules apply	LOAN / GRANT (ratio varies) Rate: varies Term: 20 years for loan portion	Approximately $25 million per year for 10 years
Drinking Water State Revolving Fund (371) State	Political Subdivisions Districts Water Supply Corporations Investor Owned Utilities State Agencies	•Annual Intended Use Plan •Priority rating system joint with Texas Commission on Environmental Quality •Water projects only •Pre-design funding option	LOAN Rate: 1.5 percent below market Term: 20 years	Approximately $50 million annually
Disadvantaged Drinking Water State Revolving Fund (371) Federal	Political Subdivisions Districts Water Supply Corporations State Agencies	•Annual Intended Use Plan •Water projects only •Pre-design funding option •Adjusted median household income ≤75 percent of state average	LOAN Rate: 0 to 1 percent (lower incomes can receive up to 35 percent of project funding as loan forgiveness) Term: 30 years	Approximately $20 million annually
Colonia Wastewater Treatment Program (355 and 363) Federal	Political Subdivisions Districts	•Within 100 kilometers of Texas-Mexico border •Water or wastewater services not adequate •Median household income less than 75 percent of State average •Established residential subdivision as of November 1, 1989 •Water and sewer projects •No pre-design funding •Model Subdivision Rules apply	LOAN / GRANT (ratio varies) Rate: varies Term: 20 years for loan portion	No new appropriations at this time

Source: Adapted from information provided by the Texas Water Development Board.

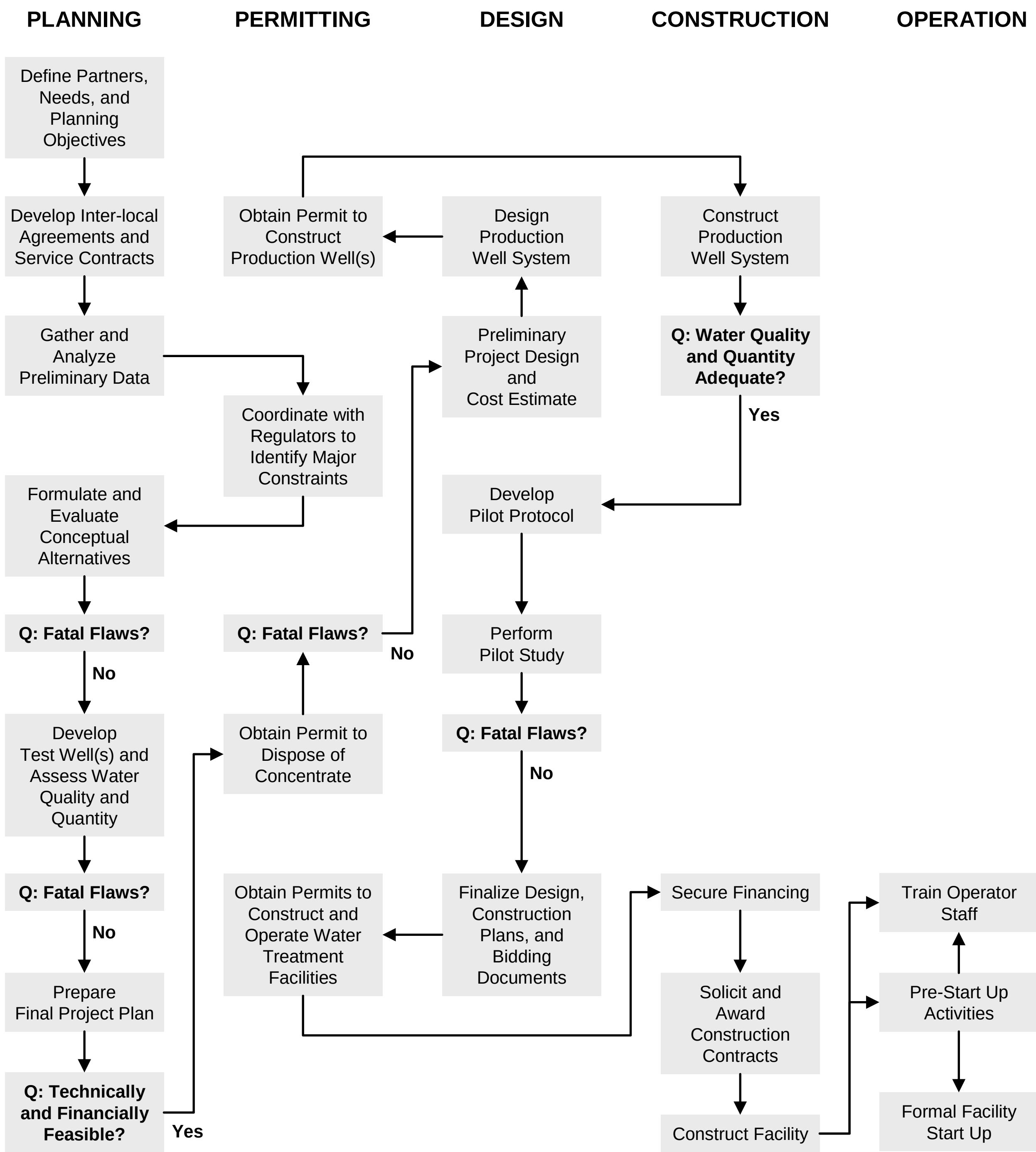


Figure 18

Conceptual decision flow diagram of major milestones associated with developing brackish groundwater desalination projects in Texas.

Case Study A

Planning

Exploring Needs and Opportunities for Desalination
In recent years, residents of South Texas have experienced difficulty in acquiring sufficient water from the Rio Grande. Recurring drought conditions and dramatic population growth continue to increase the risk of relying on the river as the sole source of water. In the Rio Grande Regional Water Plan published in 2001, none of the water user groups had listed desalination as an alternative source of water to meet their 50-year demands. The ensuing drought compelled many entities to reassess their options and plan for less dependence upon the Rio Grande. As a result, 30 out of 63 municipalities in the region revised their water supply strategies and worked to amend the planning report in 2003 to include desalination.

LESSON LEARNED:

The planning process can be dynamic, resulting in project partners and alternatives not originally envisioned.

In 2003, the City of Primera, East Rio Hondo Water Supply Corporation, and North Alamo Water Supply Corporation agreed to develop a regional approach to the water problems facing their customers in north Cameron County. The primary planning objectives of the North Cameron Regional Water Project were to diversify their water supply sources, improve the reliability of water delivery, and improve water quality. The initial discussions, however, included only two of these entities and were focused on addressing short-term supply issues by interconnecting their systems and adding some additional storage capacity. As the conversation expanded to include long-term supply strategies, desalination was identified as a potential option. A total of five other entities also eventually participated in these formative discussions and considered project partnership. In the end, only the three partners committed to the project.

Evaluating Alternatives
Each of the three project owners confronted unique circumstances that affected their planning outlook. As an example, the City of Primera identified a need for an additional 400,000 gallons per day of water supply and evaluated two basic alternatives: 1) purchasing additional treated (surface) water from the City of Harlingen; or 2) developing brackish groundwater desalination capability, either individually or as part of a regional project. After an initial planning review of these alternatives (Table 11), both appeared feasible from an engineering perspective, neither was likely to have serious adverse environmental effects, and both were considered potentially cost effective.

Table 11: Comparison of water supply alternatives, City of Primera.

Criterion	**Alternative A:** Treated Surface Water	**Alternative B:** Brackish Groundwater Desalination
Engineering Feasibility	The City of Harlingen could provide potable water from the Rio Grande through an existing treatment and distribution system.	Although fresh groundwater is limited, success of recently completed facilities in the region proved that brackish groundwater desalination was practical.
Potential Environmental Impacts	Additional surface water for municipal use is commonly derived from converting irrigation water rights.	Other groundwater desalination facilities in the region had undergone regulatory review and successfully permitting.
Cost Effectiveness	Harlingen proposed a total delivery and treatment cost of $1.87 per 1,000 gallons, including carriage rate, fuel, and debt service, but not including water rights which, if available, could be as much as $2,000 per acre-foot.	Experiences from existing plants in the area indicated a total development and operational cost less than $2.00 per 1,000 gallons of potable water from brackish groundwater desalination.

Facility Considerations
A preliminary investigation of brackish groundwater resources in the area showed the planning area to be within the extent of the Gulf Coast Aquifer, a brackish formation already being used as a water supply. The well location was proposed at the treatment plant site, allowing project costs to be contained by eliminating the need for an extensive collection and conveyance pipeline from the well field. In order to quantify the volume and quality of water that could be produced, two test wells and two monitoring wells were installed. During well testing, water level measurements were made in the monitoring wells to calculate the drawdown effects of well production.

These preliminary evaluations revealed an excellent source of project water. The water contained practically no iron, arsenic levels were below the drinking water standard, and turbidity was well below the requirements of membrane suppliers. Furthermore, the source would impart no microbiological activity and contained very little organics. A Silt Density Index performed at the wellhead for the water source indicated a value (<1.0) well below the requirements of membrane suppliers and would require minimum pre-treatment. A summary of the chemical analyses for major constituents in the water for the North Cameron Regional Water Project is presented in Table 12.

Table 12: Summary of major test well water quality constituents, North Cameron Regional Water Project.

Alternative	Concentration	Units
Total dissolved solids	3,800	milligrams per liter
pH	7.5	-
Turbidity	0.1	nephelometric turbidity units
Iron	<0.1	milligrams per liter
Arsenic	<10	milligrams per liter
Total organic content	<1.0	milligrams per liter
Hydrogen sulfide	Not detected	-
Microbiological activity	Not detected	-

Based on these results, it was calculated that a reverse osmosis membrane process could produce water with 80 milligrams per liter of total dissolved solids. To increase production and stabilize the treated water, some raw water would be blended with the permeate to a concentration of 500 milligrams per liter.

An irrigation drainage ditch located adjacent to the proposed project was identified as a potential site for surface disposal of the concentrate. Discussions with the Texas Commission on Environmental Quality and previous work experience determined that a viable and cost effective concentrate disposal method was surface water discharge.

The high-service pump station for North Cameron would be designed to serve three separate distribution systems (one for each project partner), each with its own high-service pump and controls. Water provided to the City of Primera would fill the City's elevated storage tank. The other two partners specified a target pressure and flow rate. A fourth pump would serve as a backup for all three entities.

Financial Considerations
Early during project planning, each partner evaluated the relative economic advantage of developing their own water supply solution versus partnering together. For example, the City of Primera narrowed its focus to evaluating four specific water

supply alternatives. As a part of this process, the estimated construction and operational costs for each were evaluated and compared (Table 13).

LESSON LEARNED:

Regional projects can provide benefits of economy of scale where these are not offset by extensive distribution systems.

Table 13: Preliminary cost analysis of water supply alternatives for the City of Primera, 2002.

		COST (per 1,000 gallons)			
Alternative	**Volume** (gallons)	**Rates and Fees**	**Debt Service**	**Operations and Maintenance**	**Total**
1. Treated surface water (Rio Grande)	400,000	$ 2.20[a]	0	0	**$ 2.20**
2. Individual desalination	400,000	0	$ 0.85	$ 0.65	**$ 1.50**
3. Regional desalination	2,000,000	0	$ 0.49	$ 0.60	**$ 1.09**
4. Regional oversized desalination	4,000,000	0	$ 0.65	$ 0.30[b]	**$ 0.95**

[a] Included $0.33 per 1,000 gallons for water rights acquisition (assumes $1,500 per acre-foot).
[b] Assumed off-peak operation resulting in reduced power costs.

LESSON LEARNED:

There is considerable risk associated with pursuing elements of the permitting, design, and construction phases concurrently.

Overall Decision Process

Specific circumstances and needs of the North Cameron Regional Water Project partners created an accelerated project schedule, overlapping the implementation sequence of some project components, including permitting, design, and construction. For example, the concentrate discharge application was being processed while the production well was under construction and the reverse osmosis treatment system was being designed. This does not represent an ideal sequence of project development activities. The project was ultimately completed without complications from this arrangement, but the potential did exist for major setbacks. For example, had the Texas Commission on Environmental Quality denied the concentrate disposal permit, or had significant opposition arisen during the review period, the project schedule would have been seriously compromised. Also, had the production well water quality differed greatly from the test well water quality, major changes in the treatment process design could have been required and pre-purchased reverse osmosis equipment potentially rendered unusable.

Planning Scope of Work

The following scope of work identifies the major tasks conducted during planning for the North Cameron Regional Water Project:

Task 1: Data Gathering

A. Maps to determine water source(s) and designated jurisdictional boundaries.
B. Existing water quantity and quality studies and data prepared by State, Federal, and academic institutions.
C. Population within the study area.
D. Water supply and treatment capacity within the study area.
E. Water distribution infrastructure within the study area (as detailed as possible).
F. Cost(s) to treat drinking water on a per 1,000 gallons basis within the study area.

Task 2: Engineering Feasibility Assessment

A. Assess possible mixing of untreated groundwater and surface water as to projected water quality and quantity to be blended. In addition, identify any potential problems associated with mixing different water sources.
B. Assess the groundwater availability in the area to include: quantities, qualities, pumping tests of existing wells, maximum pumping rates, and total capacities available for treatment.

C. Evaluate the groundwater production potential and water quality from the proposed well field location.
D. Estimate capital and operational costs of the proposed well field.
E. Determine the most appropriate means of disposal of concentrate.
F. Determine the engineering-related benefits to be gained, including but not limited to:
    a. Improved level of service
    b. Establishment of previously unavailable water source
    c. Greater efficiency of service operations
    d. Compliance with local, state, and federal requirements
G. Determine current service and water sources needs and required levels of demand.
H. Determine staffing level required, the number of employees, supervisors, clerical, support staff, etc., for the planned facility.
I. Present recommendations for the size, design, cost, structure, and location of the proposed facility for each alternative site considered.
J. Identify potential problem areas.

<u>Task 3: Financial Feasibility Assessment</u>

A. Identify the total cost of the proposed brackish groundwater treatment facility.
B. Identify the total cost of providing treated water, including all direct and indirect costs.
C. Determine the cost of treated water.
D. Forecast the expected annual cost of providing treated water from the brackish groundwater treatment facility over a 10-year period.

<u>Task 4: Reporting</u>

A. Prepare and present a detailed draft report summarizing all findings and conclusions.
B. Prepare and present a detailed final report incorporating all comments received on the draft report.
C. Provide ten copies and digital version of the final report.

Phase II: Permitting

Navigating the Regulatory Process

The primary objective of the Permitting Phase is to identify and secure all permits and authorizations that may be necessary to construct and operate a brackish groundwater desalination facility. With the exception of concentrate disposal, many of these requirements are the same as for conventional water treatment plants.

Regulatory approval must be obtained for the construction and operation of a brackish groundwater desalination plant. In many respects, the requirements are similar or identical as those for conventional water treatment plants. However, others are necessary due to the use of membrane technology. Because regulatory activities can adversely affect project timelines and budgets, the permitting strategies for each project component should be closely coordinated throughout planning and design activities.

In recognition of the importance and complexity of the permitting process for brackish groundwater desalination projects, TWDB sponsored the development of a guidance manual addressing this specific issue. Prepared by R.W. Beck (2004), the *Guidance Manual for Permitting Requirements in Texas for Desalination Facilities Using Reverse Osmosis Processe*s recognizes that the selection of project components directly affects the types of permits needed; the types, scope, and cost of environmental investigations; and the amount of time required to complete permitting activities.

Three project components of a brackish groundwater desalination project have significant permitting activities: developing the groundwater well field, constructing the treatment facility, and disposing of the concentrate. For these components, several useful permitting models[19] were developed that address the major regulatory requirements (R.W. Beck 2004). Regulatory requirements for the fourth component, delivery of potable water, are primarily addressed through compliance with federal and state drinking water standards, as previously discussed. This chapter, then, should be considered as a supplement to the work already performed addressing desalination permitting requirements.

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[19] Including models for groundwater, surface water, new construction, project development, other operating, other environmental, injection well, evaporation pond, surface water discharge, and concentrate and membrane cleaning disposal.

Groundwater Development

Permitting requirements for developing groundwater in Texas depend largely on whether the potential well field is located within the jurisdictional boundary of a groundwater conservation district (Figure 19). Many of the state's groundwater conservation districts belong to the Texas Alliance of Groundwater Districts. Information on member districts and links to their websites are provided at www.texasgroundwater.org. The TWDB Groundwater Resources Division also maintains information on and provides assistance to these districts.

Groundwater conservation districts in Texas are required to develop and implement plans for the effective management of groundwater (Table14). Therefore, where a groundwater conservation district is present, well registration and production permits will likely be required. Another important factor in determining permitting requirements is whether the well(s) are new or existing. If new, permits from the local groundwater district and regulatory approval from the Texas Commission on Environmental Quality will be required.

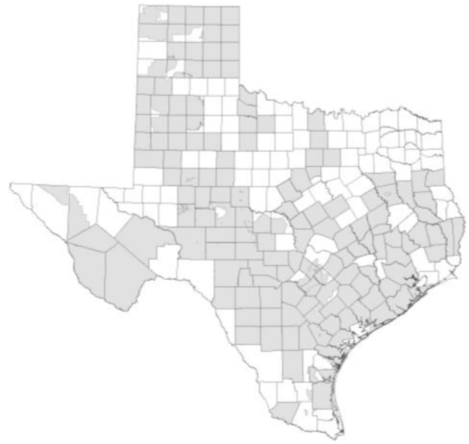


Figure 19

Jurisdiction of groundwater conservation districts in Texas, 2007.

Includes both confirmed and unconfirmed districts.

Graphic courtesy of the Texas Water Development Board

Permitting requirements for the collection and conveyance system are similar to those for any linear pipeline project. These requirements can include federal and state approval of the pipeline alignment with regard to protected habitats or cultural resources, federal permits for crossing jurisdictional or navigable waters of the United States, and right-of-way approvals from affected land owners or other easement-holding utilities. The conveyance of raw brackish groundwater should not invoke permitting or approval requirements other than those typically required for the construction of traditional water lines.

Table 14: Summary of potential permits required to develop groundwater wells.

Purpose of Permit	Process	Permit	Issuing Agency
Test Wells	Approval for well and test hole installation	Well and Test Hole Permits	Local groundwater districts (where these exist)
		Plan Approval Prior to Conversion to Public Drinking Water Well	Texas Commission on Environmental Quality
Production Wells (existing)	Approval for existing wells	Water Well Registration	Local groundwater districts (where these exist)
	Approval to produce water from existing wells	Permit to Produce Water	
	Approval to blend raw water with permeate	Plan Approval Prior to Construction	Texas Commission on Environmental Quality
Production Wells (new)	Approval for new wells or well modifications	Water Well Construction and Alteration Permit	Local groundwater districts (where these exist)
		Plan Approval Prior to Construction	Texas Commission on Environmental Quality
	Approval to blend raw water with permeate	Plan Approval Prior to Construction	Texas Commission on Environmental Quality
High Production Wells	Approval to own and operate wells that cross a high production threshold	Application for High-Impact Production Permit	Local groundwater districts (where these exist)
Conveyance	Approval to transport produced water	Transport Permit	Local groundwater districts (where these exist)

Source: Adapted from R.W. Beck (2004)

Brackish Water Treatment

Most of the permitting and regulatory requirements for constructing a brackish groundwater desalination plant are similar, if not identical, to those required for a conventional water treatment plant (Table 15). General permitting requirements include those to satisfy local building codes, construction and erosion control regulations, and site clearance restrictions.

Texas Commission on Environmental Quality permit requirements for treatment of water for public use include regulatory approval to construct a new or modified public water system, authorization to discharge hydrostatic testing water, construction of a degasifier, and construction of any above- or below-ground storage fuel tanks. Finally, other state and local permitting requirements could be invoked if on-site sewage facilities or wastewater treatment capabilities are associated with the plant.

Table 15: Summary of potential permits required for facility construction.

Purpose of Permit	Process	Permit	Issuing Agency
Need Assessment for Desalination Facility	Approval to construct new or modified public water system	Public Water System Plan Review	Texas Commission on Environmental Quality
Wastewater Treatment	Approval for new or modified wastewater treatment facilities	Summary Transmittal Letter for Wastewater Treatment Facilities	Texas Commission on Environmental Quality
Wetlands and Water Quality Certification	Approval to dredge or place dredge or fill material into state and federal waters and/or wetlands	Section 401 and 404 Permits Environmental Impact Statement (as needed)	U.S. Army Corps of Engineers and Texas Commission on Environmental Quality
Navigable Waters	Approval for construction within navigable waters	Section 10 Permit Environmental Impact Statement (as needed)	U.S. Army Corps of Engineers
Edwards Aquifer	Approval for construction in the recharge, transition and contributing zones of the Edwards Aquifer	Edwards Aquifer Protection Program Application	Texas Commission on Environmental Quality
Air Emissions	Degasification and other ancillary equipment that emit air pollution	Air Permit – Construction of a New Source	Texas Commission on Environmental Quality
Petroleum Storage Tanks	Approval to construct above- and below-ground petroleum storage tanks (if applicable)	Petroleum Storage Tanks Registration and Construction Notification	Texas Commission on Environmental Quality
Buildings	Approval to construct new buildings	Building Permit	City and/or county
Tree Removal	Approval for tree removal and replacement	Tree Removal Permit	City and/or county
Erosion Prevention	Approval for erosion prevention plans for construction	Erosion Permit	City and/or county
Road Crossings and Easements	Approval for easements for coastal, miscellaneous, upland surface and commercial leases, and submerged lands	Easement	Texas General Land Office
	Approval for work in a Texas department of transportation roadway or right-of-way	Utility Permit	Texas Department of Transportation
	Approval for roadway and public way crossings or use	Right-of-Way/Easement Use	City and/or county
	Approval for pipeline crossing over or under railroad property and tracks	Authorization for Crossing	Railroad companies
Cultural Resources	Review to determine if cultural resources are impacted and necessary mitigation (simultaneously conducted with federally mandated permits)	Section 106 Review	Texas Historical Commission
Historical Properties and Landmarks	Review to determine if historical properties or landmarks are impacted and necessary mitigation	Antiquities Permit	Texas Historical Commission

Source: Adapted from R.W. Beck (2004)

The operation of a brackish groundwater desalination facility also requires similar permitting approvals as conventional water treatment plants. For example, Texas Commission on Environmental Quality approval is required to use on-site fuel storage tanks, store and treat commercial non-hazardous wastes, operate sand/multimedia filtration equipment, and operate any on-site sewage facilities.

Concentrate Management and Disposal

The management and disposal of concentrate and other wastes resulting from brackish groundwater desalination involve significantly different permitting requirements than those associated with other conventional water supply projects. At present, the Texas Commission on Environmental Quality considers membrane concentrate an "industrial" waste. This label creates some misunderstanding in the public eye if concentrate is misconstrued as toxic or hazardous. The desalination process does not produce pollutant material or mass, but rather concentrates impurities already present in the groundwater source.

Specific permitting and regulatory requirements depend greatly on the type of disposal method proposed. Because surface discharge and deep well injection are more commonly used, these strategies are discussed in relatively more detail.

SEWER DISCHARGE

Disposing of desalination concentrate to an existing wastewater treatment facility will typically require modification of that facility's Texas Pollutant Discharge Elimination System Waste Discharge Permit – Wastewater (Domestic) permit. If the wastewater treatment plant must be modified or a new one constructed, additional state permitting for construction of the treatment facility will be required. In addition to these state requirements, local authorizations for such a discharge may also be needed.

SURFACE DISCHARGE

Discharging the concentrate to surface waters requires a Texas Pollutant Discharge Elimination System Waste Discharge Permit – Wastewater (Industrial) from the Texas Commission on Environmental Quality. The time-frame goal for issuing an individual wastewater permit is 330 days, but protests could lengthen that by an indeterminate amount.

Permit applications require preparing an Industrial Administrative Report and an Industrial Technical Report. The Administrative Report, requires applicant information, facility information, identification of receiving waters and discharge route, identification of adjacent and downstream landowners, and site photographs. The technical report requires facility information and wastewater generating process; materials and products to be handled; identification of flood plains and flood protection measures; detailed information on treatment processes, including schematics and flows; information on any impoundments, including evaporation ponds (liners are required for all ponds); outfall(s) information; four separate detailed analyses of effluent (concentrate), including standard parameters, metals, organic priority pollutants, and any hazardous substances reasonably expected to be present; and detailed information on character of receiving waters, including physical characteristics of the stream.

The primary pollutant of concern with respect to the discharge of concentrate from a brackish groundwater desalination plant is generally total dissolved solids. Concentrate from brackish groundwater desalination processes contain varying levels of total dissolved solids, but typically fall between 10,000 to 15,000 milligrams per liter. Other pollutants of concern include metals, such as arsenic. These elements are often present in the raw water and may be concentrated by up

Table 16: Types of injection wells in Texas.

Well Class	Disposal Use	Regulatory Agency
Class I	Deep injection – inject hazardous and radioactive waste, or nonhazardous industrial and municipal waste, below all underground sources of drinking water.	Texas Commission on Environmental Quality (with review and comment by Railroad Commission of Texas)
Class II	Energy byproducts – inject nonhazardous fluids for enhanced oil recovery, oil and gas exploration and production wastes, or liquid hydrocarbons for underground storage.	Railroad Commission of Texas
Class III	Extracted minerals other than oil and gas – inject fluids for insitu production of minerals ("solution-mining wells").	Texas Commission on Environmental Quality or Railroad Commission of Texas, depending on well type
Class IV	Certain environmental cleanup operations – inject hazardous and/or radioactive wastes into or above underground sources of drinking water.	Texas Commission on Environmental Quality or U.S. Environmental Protection Agency
Class V	Various activities not related to oil, gas, or industrial waste – miscellaneous injection not fitting other well classes.	Texas Commission on Environmental Quality or Railroad Commission of Texas, depending on well type

to a factor of four in the waste stream of the desalination process. Dissolved anions that have their own specific water quality standards, such as sulfate and chloride, can also be of concern.

The Texas Commission on Environmental Quality first evaluates applications to determine if they are administratively complete. Once complete, the agency conducts a technical evaluation. The initial and most important aspect of this technical evaluation is performed by the Water Quality Standards Team to determine whether the proposed discharge will meet instream standards. The governing laws for this evaluation (Texas Surface Water Quality Standards) may be found in 30 Texas Administrative Code sections 307.1-10. The Water Quality Standards Team conducts its evaluation based upon these statutes according to an accompanying guidance document (Texas Commission on Environmental Quality 2003). Further evaluations could include modeling for toxics.

DEEP WELL INJECTION

Injection wells in Texas are classified into five different categories, depending on the type of waste to be disposed of in the well. An injection well is defined as "an artificial excavation or opening in the ground made by digging, boring, drilling, jetting, driving, or some other method, and used to inject, transmit, or dispose of industrial and municipal waste or oil and gas waste into a subsurface stratum; or a well initially drilled to produce oil and gas which is used to transmit, inject, or dispose of industrial and municipal waste or oil and gas waste into a subsurface stratum; or a well used for the injection of any other fluid" [20]. Some types are regulated by the Texas Commission on Environmental Quality and others by the Texas Railroad Commission (Table 16).

An injection well for a full-scale brackish desalination plant would likely be permitted as a Class I non-hazardous well[21], which is required for most industrial wastewaters. If the concentrate is determined to be hazardous, then a Class I hazardous injection well would be required. The application process for a

[20] Chapter 27 of the Texas Water Code.

[21] In limited situations, a brackish desalination plant might also be permitted as a Class V well. This classification is used for "other" wells not related to oil, gas, or industrial waste. Factors affecting the use of Class V wells include the quality of the aquifer which is being targeted for disposal and the constituent levels in the concentrate Disposal of domestic wastewater effluent, treated groundwater from a remediation project, or a temporary disposal (as from a pilot plant) are typical uses for Class V wells. A Class V authorization has fewer requirements than Class I. Operational monitoring requirements are also usually less, being typically once per year as opposed to continuous.

non-hazardous injection well typically takes longer than a year and requires extensive information. Also, operating requirements for Class I wells are fairly strict, including continuous monitoring of various parameters.

The permit application process for a Class I non-hazardous injection well in Texas involves submitting a complete Texas Commission on Environmental Quality No. 0623 permit application form and attached technical report to the Underground Injection Control permits section. The first four parts of the application involve administrative information. The fifth through fourteenth parts comprise the technical report. The Texas Commission on Environmental Quality goal for application processing time for a Class I injection well is 390 days from receipt of application to final determination (issuance, denial, return), including:

- Submittal of an application
- Administrative review
- Administrative notice of deficiency (if necessary)
- Technical review
- First technical notice of deficiency (if necessary)
- Submission by applicant of response to notice of deficiency
- Review of notice of deficiency
- Second technical notice of deficiency (if necessary)
- Submission by applicant of response to notice of deficiency
- Review of notice of deficiency
- Development of draft permit
- Public notice
- Final determination

The technical report involves detailed discussions of the geology, well construction, reservoir mechanics, area of review, wastes and waste management, waste compatibility, and pre-injection units. The permit application[22] typically takes several months to complete and includes various sections are required to be sealed by a Texas licensed professional geoscientist and a Texas licensed professional engineer. Detailed geologic mapping, predictive reservoir modeling, and detailed well design are the main technical aspects of the report.

As this *Guidance Manual* went to press, the Texas Commission on Environmental Quality was working on new rules to allow entities to obtain general statewide permits to inject into Class I wells certain nonhazardous byproducts of drinking water production, including brine from water desalination plants. The rulemaking will implement House Bill 2654, enacted by the Texas Legislature in 2007, which authorized the Texas Commission on Environmental Quality to issue general permits lasting up to 10 years instead of separate permits for each injection. Final rules are expected to be adopted in 2008.

LAND APPLICATION

Disposal of desalination concentrate by land application also requires a Texas Pollutant Discharge Elimination System Waste Discharge – Wastewater (Texas Land Application) permit from the Texas Commission on Environmental Quality.

EVAPORATION PONDS

Nicot and others (2007) conducted a recent review of the potential to use self-sealed evaporation ponds for desalination facilities in Texas. This would include disposal of concentrate from a brackish groundwater desalination process. The following observations were made to characterize the regulatory issues relating to self-sealing pond liners. First, no significant regulatory barriers currently exist that would prevent the permitting of self-sealing evaporation pond-liner technologies at desalination facilities in Texas. Next, no Federal authorizations are required, but a Texas Land Application Permit must be obtained from the Texas Commission on

[22] Complete details and forms for submitting an application to the Texas Commission on Environmental Quality for an injection well permit are available on-line at www.tceq.state.tx.us/nav/permits/uic.html.

Environmental Quality Water Quality Division. And finally, the Texas Commission on Environmental Quality has considerable latitude for approving alternative permit requirements for industrial permits[23] (Nicot and others 2007).

An overview of the potential permitting requirements for concentrate disposal is presented Table 17.

Table 17: Summary of potential permits required to manage and dispose of concentrate.

Purpose of Permit	Process	Permit	Issuing Agency
Concentrate and/or Wastewater Disposal	Wastewater disposal via discharge to surface water	National/Texas Pollutant Discharge Elimination System (NPDES/TPDES[a]) – Wastewater	Texas Commission on Environmental Quality
Concentrate and/or Wastewater Disposal	Wastewater disposal via Class I disposal well(s)	Class I Injection Well Permit Oil and Gas Non-Endangerment Letter	Texas Commission on Environmental Quality Texas Railroad Commission
Concentrate and/or Wastewater Disposal	Disposal via Class V disposal well(s)	Class V Injection Well Authorization to Permit Class V Injection Well Authorization Letter Class V Injection Well Permit Oil and Gas Non-Endangerment Letter	Texas Commission on Environmental Quality Texas Railroad Commission
Concentrate and/or Wastewater Disposal	Disposal via publicly owned treatment works or other wastewater treatment facility	NPDES/TPDES – Wastewater	Local regulatory agency authorized by the Texas Commission on Environmental Quality to approve a disposal permit
Concentrate and/or Wastewater Beneficial Reuse	Beneficial reuse via Class II well(s)	Groundwater Protection Recommendation Letter Class II Underground Injection Control Permit	Texas Commission on Environmental Quality Texas Railroad Commission
Concentrate Disposal	Disposal via evaporation pond	Permit for Land Application of Water Treatment Sludge	Texas Commission on Environmental Quality
Stormwater	Industrial site stormwater disposal via discharge to surface water	NPDES/TPDES – Stormwater	Texas Commission on Environmental Quality
Stormwater	Stormwater disposal via discharge to surface water during construction activities	NPDES/TPDES – General Permit TXR040000	Texas Commission on Environmental Quality
Stormwater	Stormwater disposal via discharge to separate municipal storm sewer system	NPDES/TPDES – General Permit TXR050000 Submit Notice of Intent or No Exposure Certification to Appropriate Municipal Sewer System Operator	Texas Commission on Environmental Quality
Wastewater	Hydrostatic testing wastewater disposal via discharge to surface water	NPDES/TPDES – General Permit TXG670000	Texas Commission on Environmental Quality
Onsite Sewage Facilities	Construct and operate onsite sewage treatment facilities	Local Permit	Local regulatory agency authorized by Texas Commission on Environmental Quality to approve such facilities
Waste Disposal	Storage and/or treatment of commercial/industrial non-hazardous waste	Commercial Industrial Non-Hazardous Waste Permit	Texas Commission on Environmental Quality
Residual Solids	Sand/multi-media filtration sludge disposal	Registration	Texas Commission on Environmental Quality
Air Emissions	Degasification and other ancillary equipment that emit air pollutants	Air Permit – Title V Operating Permit	Texas Commission on Environmental Quality

Source: Adapted from R.W. Beck (2004).
[a] NPDES = National Pollutant Discharge Elimination System; TPDES = Texas Pollutant Discharge Elimination System.

Case Study B

Permitting

Multiple permits were required for the construction and operation of the North Cameron Regional Water Project. Many of these permits required application and processing fees, but these costs (which ranged from a few hundred dollars to a few thousand dollars each) were not consequential relative to the total project cost.

Groundwater Development
Prior to design and construction of the production well for the project, four test wells were installed to identify production zone, water quality, and aquifer productivity information. Based on test well data, it was expected that two wells would be required (one shallow and one deep) to supply the desalination plant at full capacity. Approval from the Texas Commission on Environmental Quality to construct both wells was sought and obtained. After the first (shallow) well was constructed, the yield surpassed expectations so the second well was not immediately developed. A permit to produce water from the well was then sought from the commission. The total time from the start of well design to approval to produce water was about 16 months.

Brackish Water Treatment
As with conventional public water supply systems, the Texas Commission on Environmental Quality required plans and specifications, an engineering report, and a submittal form sealed by a professional engineer for approval prior to construction of the North Cameron Regional Water Project. At the outset of project planning, it was considered imperative that a dialogue with the agency be opened in respect of their critical permitting role. Close and careful communication with agency review staff ensured that plans and specifications were received and a log number assigned. At the time the project was being considered, the agency reported limited review staff and a backlog in the review process. Examples of efforts made to ensure adequate communication during the facility permitting phase include hand-delivery of specifications to the plans review section of the agency, regular phone conversations with review staff about required information or discrepancies to avoid the need for formal agency correspondence, and mutual education about technical and regulatory issues of the project. This level of coordination helped ensure accurate routing and completion of the application package, avoiding costly time delays.

LESSON LEARNED:

Communication during the permitting process is critical for building trust and avoiding time delays.

Concentrate Management and Disposal
Numerous concentrate disposal methods were initially considered for the project, including sewer discharge, evaporation pond, deep well injection, and surface discharge. After careful evaluation, project engineers determined that surface discharge to an agricultural drainage ditch adjacent to the site would be the most cost effective option. The drainage ditch flows into the North Floodway, which is a large drain that flows to Laguna Madre. Other alternatives were dismissed because there was no municipal sanitary sewer in the vicinity to allow discharge to a wastewater treatment plant, the projected costs for deep well injection were determined prohibitive, and there was insufficient land for land application or evaporation ponds.

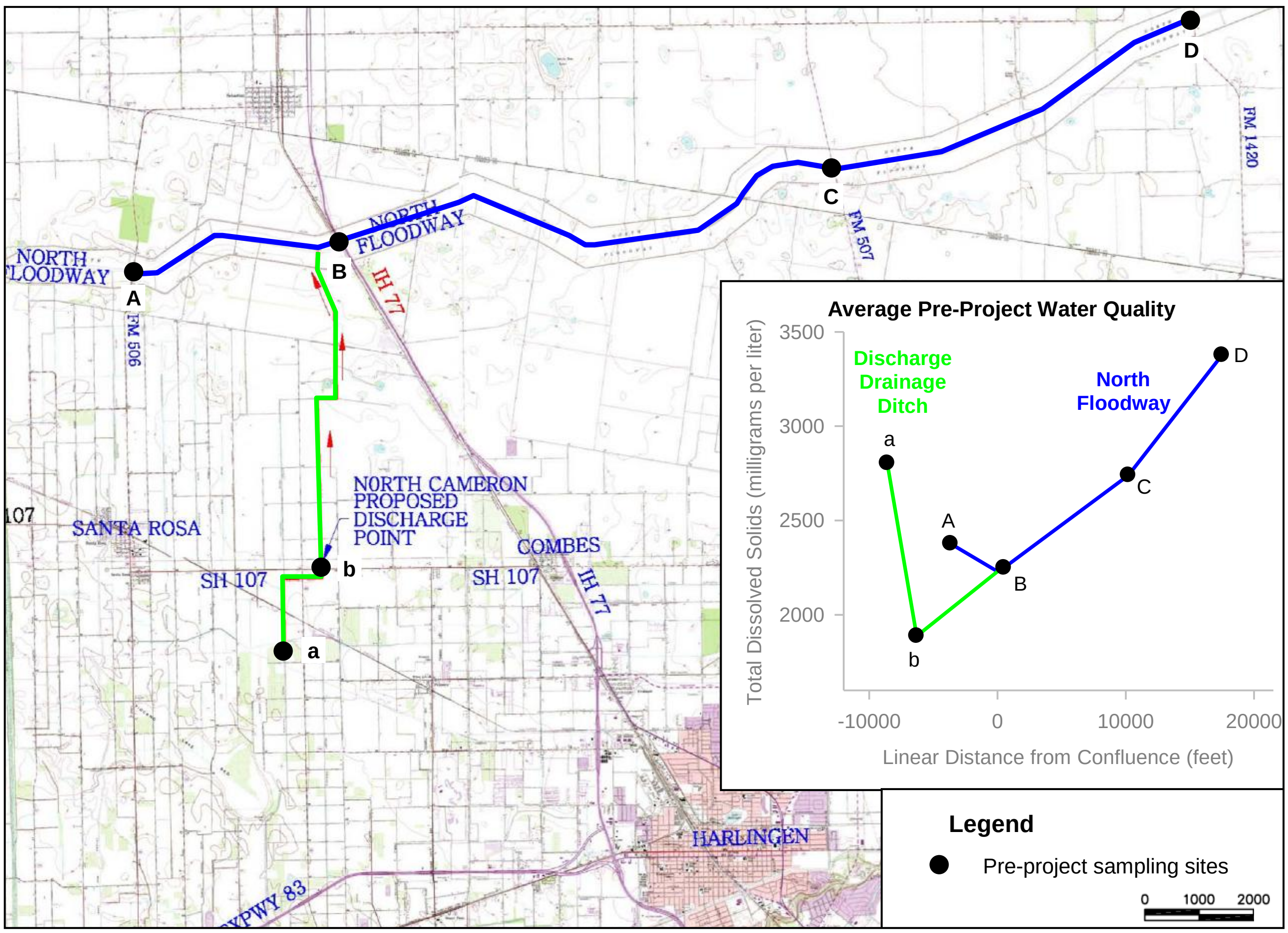
In Texas, instream uses must be established for waters proposed to receive discharges. Texas Commission on Environmental Quality bases effluent limitations on the instream water quality standards and protection of those uses. Drainage ditches are not classified stream segments, but are still generally considered waters of the State and have general standards and uses. Therefore, the proposed concentrate disposal was required to meet specified standards and uses for waters of the State.

During the concentrate disposal permitting phase, measurements of total dissolved solids were required by the Texas Commission on Environmental Quality of the surface stream proposed to receive the concentrate discharge. Background water quality in the drainage ditch was documented with a sampling program to determine the likely impact of the proposed discharge on existing total dissolved solids concentrations. A total four locations along the North Floodway were sampled monthly for three consecutive months in 2003, as well as two locations in the discharge ditch itself (Figure 20). The sampling program allowed the agency to establish background conditions and ultimately determine that the proposed discharge would not violate water quality standards or impair existing uses.

Figure 20

Pre-project water quality sampling for concentrate discharge permit application, North Cameron Regional Water Project.

Water quality values represent average monthly samples taken from August to October, 2003.



LESSON LEARNED:

A proactive commitment to mutual education was very constructive when working with regulatory staff on unfamiliar permit issues.

Because of the lack of classified stream segments, it was not initially clear what was required to obtain a permit with total effluent limitations that could be met by the facility. During the process of administrative and technical review of the application by the Texas Commission on Environmental Quality, it became clear that the permit would fall into the industrial permits section of the agency. Staff in this section worked frequently with treated effluent from wastewater facilities, but were not very familiar with concentrate disposal. On the other hand, project engineers were familiar with the permitting requirements of wastewater facilities, but not in the specific context of concentrate disposal. Therefore, project engineers engaged agency staff in a process of mutual education; engineers learning a different application of permitting requirements and agency staff learning physical processes of membrane desalination. This process was assisted by previous concentrate discharge permits issued for other facilities which successfully utilized the same disposal strategy. The engineer and owner were very proactive in this process, providing supplemental information not necessarily requested on the permit application.

The agency eventually determined that a higher “daily maximum” concentration could be permitted only with no “daily average” limitation. Discharges into classified segments other than drainage ditches would likely result in more stringent effluent limitations. The final permit issued for the project included a requirement to monitor instream total dissolved solids concentrations upstream and downstream of the outfall.

Permitting Scope of Work

Permitting tasks for the North Cameron Regional Water Project were conducted with design tasks (see next chapter).

Phase III: Design

Plans, Profiles and Specifications

The goal of the Design Phase is to create the most cost effective and reliable brackish groundwater desalination system that satisfies the primary planning objectives. Piloting studies provide the opportunity to evaluate actual performance of proposed treatment system under site-specific conditions prior to final design and permitting. Of all the factors that influence the design process, the quality of the raw water is the most significant.

Numerous factors influence the design of a brackish groundwater desalination facility: the quality of the raw groundwater source; requirements to comply with laws or permit conditions; financial limitations, such as available capital, bonding authority, or the willingness of customers to absorb rate increases; system reliability; and how the liability is shared among project partners for the long-term operation of the project. As each of these factors is addressed, the project design becomes a unique work. This means that effective or efficient design considerations for one project may not necessarily be appropriate for others.

The primary factor affecting the design process is raw water quality, which influences virtually every component of a brackish water desalination facility. Water quality largely determines the type of membrane element necessary to meet finished water quality requirements; the pre-treatment system required to protect the reverse osmosis membranes; the post-treatment system required to ensure finished water from the desalination facility is compatible with the existing infrastructure, distribution system water quality, and customer requirements; and the concentrate discharge permitting approaches and testing requirements that are implemented.

When designing a brackish water desalination facility, it is critical to document each conceptual idea as it is brought forth. The process of arriving at a final design is lengthy and involves multiple iterations to determine the best method with which to accomplish each design goal. Accurate engineering documentation of these critical decisions will allow for the accurate recitation of the design mentality during project development and operation. This is of particular importance should an aspect of the design require reevaluation during construction or start up operation.

Piloting

During the design of a brackish groundwater desalination plant, it should be recognized that planning decisions and cost estimates derived solely from desk-top assessments are limited in the level of accuracy and degree of performance guarantee they can provide (Reiss 2004). These limitations are addressed through a short-term field demonstration of the proposed desalination technology, known as a 'pilot study'. Pilot studies provide the opportunity to evaluate actual performance of proposed treatment system(s) under site-specific conditions. Results from pilot studies enable more precise planning and design adjustments, thereby resulting in a more complete design, more refined cost estimate, and a more accurate understanding of the viability of the proposed project[24].

Under current Texas Commission on Environmental Quality rules, membrane filtration applications (including micro-filtration, ultra-filtration, nano-filtration, and reverse osmosis) are considered 'non-conventional, innovative, or alternative' water treatment technologies. When such treatment technologies are proposed, current rules[25] require a licensed professional engineer to provide pilot test data or data collected from similar full-scale operations that demonstrate the proposed treatment technique will produce finished water that meets drinking water standards[26]. Engineers can demonstrate this capability through the use of pilot study data submitted in a pilot study report for review and acceptance, which must occur prior to submitting site-specific engineering plans and specifications for a treatment facility. To ensure that a pilot study report contains the information required by the agency, a pilot study protocol should be submitted for the agency's review and acceptance prior to initiation of the pilot test. These two documents, the pilot study protocol and the pilot study report, are discussed in more detail in the following sections.

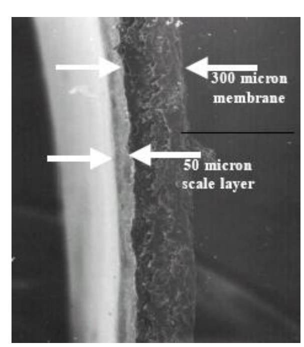
Pilot Study Protocol

To ensure a pilot study report contains the required information, a pilot study protocol should be submitted for Texas Commission on Environmental Quality review and acceptance. The pilot protocol is a written plan defining the scope and duration of the proposed pilot study and must be prepared under the direction of and sealed by a professional engineer. The protocol for operation of the pilot study should address the parameters to be analyzed; equipment to be tested; frequency of water quality sampling; operational procedures; the start up, shut down, and cleaning procedures; and testing matrix. A well prepared and executed pilot protocol will produce all of the necessary data and information to design a site-specific, full-scale membrane filtration installation and verify that water produced from the facility will meet minimum federal and state requirements for quality and quantity.

It is important to consider broader objectives of the pilot study when developing the protocol. Reiss (2004) recognizes that, while a pilot protocol will define equipment and testing procedures, a pilot study represents a significant investment and can be leveraged to meet multiple project objectives. For example, at this stage in pilot study implementation, the role of the pilot relative to public outreach should be determined. Some communities obtain a drinking water permit for their pilot system, bottle the water, and distribute it to the community during public workshops on the project. These and other objectives of the pilot should be clearly defined and understood, above and beyond the operational and logistical details that are identified in a pilot study protocol (Reiss 2004).

Example cross sectional view of membrane scaling due to silica precipitation. Piloting studies are critical because they allow these types of potential issues to be identified prior to final design of a full-scale desalination facility.

Photograph from Semiat and Hasson (No Date)



[24] Reiss (2004) recently developed a useful overview of the importance of pilot studies in the development of desalination project.

[25] 30 TAC §290.42(g).

[26] Specifically, 30 TAC Chapter 290, Subchapter F (Drinking Water Standards Governing Water Quality and Reporting Requirements for Public Water Systems).

Pilot scale reverse osmosis skid, Brownsville Seawater Desalination Project, Texas.

Photograph courtesy of NRS Consulting Engineers

The Texas Commission on Environmental Quality (2004a) has prepared staff guidance on the review of pilot study protocols for membrane filtration. This guidance is intended to facilitate consistent and timely reviews of pilot study protocols submitted for membrane filtration pilot studies and assist staff develop a written response for each submittal stating whether the pilot study was acceptable. The guidance includes detailed requirements for the protocol and should be referenced during the planning and early design phases of project development.

Pilot Study Report

The pilot study report and the agency's written response are to be used by the design engineers to develop the required engineering plans and specifications for the proposed membrane installation. A pilot study report contains the results of the pilot study and recommendations for the full-scale design criteria. The purpose of a pilot study report is to provide the Texas Commission on Environmental Quality staff with the results and conclusions of the pilot study, as well as to facilitate acceptance of the recommendations for the full-scale water treatment plant design. Although agency guidance for review of pilot study reports of membrane technology addresses only raw water sources (such as surface water and groundwater under the influence of surface waters), current rules require the use of membrane technology for treatment of brackish groundwater to follow the same guidance pilot protocols.

Again, to facilitate a common understanding of the objectives and criteria of acceptable pilot study reports, agency staff has been provided guidance (Texas Commission on Environmental Quality 2004b) to aid their review process. In addition to identifying specific content requirements, the guidance encourages staff to be aware of the following ideas when reviewing pilot study reports:

- Acceptance of pilot study data or the proposed full-scale design criteria is not approval for construction of any membrane units for treatment of water for a public water system.
- Unless a site-specific request for an exception was received and granted by agency staff, a pilot study must be conducted and data collected for a period of at least 90 days, usually in three stages.
- The pilot study report must be prepared by the systems' professional engineer, licensed by the Texas Board of Professional Engineers, and accompanied by a cover letter that is signed, sealed and dated.
- Each membrane unit tested must be of the same design and contain elements of the same length and type as will be specified in the full-scale water treatment plant.

It is recommended that this staff guidance also be referenced during the planning and early design phases.

Groundwater Development

Once the preliminary investigations and test-drilling programs have been completed, the well field itself can be designed. Two primary considerations associated with well field design include: layout (the number of wells, well spacing, and production volume) and equipment (individual production wells and pumps).

Well Field Layout

The well field layout is typically based on the results of the field testing program and groundwater modeling. Well field layout considerations for brackish water are similar to those for freshwater. Design activities for both types of projects should address the variability of hydrogeologic conditions found; evaluation of well spacing that compares electrical costs resulting from interference drawdown with the capital cost for longer pipeline and electrical transmission; the possible desire for future expansion; the potential for competitive pumping; land availability limitations; and vertical and horizontal salt water intrusion issues. The depth, number of wells, and projected reliability of the well field also factor into the design of a treatment facility. Finally, additional wells for back-up capacity may be necessary if well maintenance is expected to occur regularly and very high facility utilization is desired (>95 percent).

At any point during project development, new information can generate changes to design considerations. For example, a Source Water Assessment and Protection[27] evaluation, which helps determine the "level of risk" a facility might be exposed to from existing point or non-point pollution sources, could identify a hazardous waste or other groundwater contamination in the vicinity of a projected well field location. This discovery could require that alternative well field locations be investigated. If the well field were to be relocated, the new raw water quality could be substantially different from that originally anticipated. This could significantly affect the design and cost of the treatment components.

Brackish water wells for municipal use must be approved by the Texas Commission on Environmental Quality if the plants blend a portion of the raw water with the permeate (treated water). Blending of permeate with brackish groundwater is typically conducted so that a non-corrosive water is produced and delivered water costs are minimized.

Well and Pumping Equipment

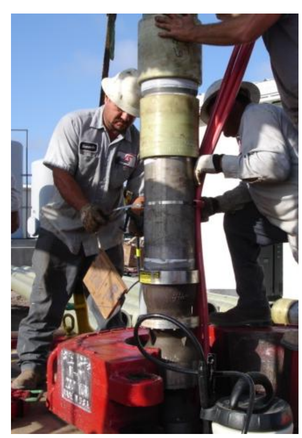
Construction materials for the production wells and pumping equipment should be selected after careful consideration of several factors: the water quality, corrosiveness of the water, depth of the wells, tensile strength of the pipe, and the casing's resistance to hydraulic collapse. Several options for material selection are available and inattention to these considerations poses significant risk with respect to well field life and cost.

The design of production wells and pumping equipment for brackish water projects also presents additional challenges as compared to freshwater wells. The added principal consideration is corrosion resistance of the materials used. Adequately protecting well construction materials from corrosion can have significant implications to well field cost, operation and maintenance costs, and life duration.

The current, most frequently considered options for well casing materials include carbon steel, coated carbon steel, stainless steel and, in shallower applications, polyvinyl chloride (PVC) and fiberglass.

Stainless steel submersible motor and pump with fiberglass column pipe, North Cameron Regional Water Project, August 2006.

Photographs courtesy of NRS Consulting Engineers



[27] In November 1999, the State of Texas received U.S. Environmental Protection Agency approval of its Source Water Assessment and Protection Program. The program is intended to be a state and federal partnership to develop and implement a scientifically-defensible methodology for assessing susceptibility of Texas' public water supplies (PWS) to contamination (U.S. Geological Survey 2000).

Fiberglass column pipe originally used for the production well, North Cameron Regional Water Project, August 2006.

Photographs courtesy of R.W. Harden & Associates and NRS Consulting Engineers

Stainless steel is currently the most expensive option and the cost variations can be large depending on the grade of stainless steel used. Coated steel pipe has significant disadvantages due to the rigors of transport and setting (avoiding scrapes and scratches) and the difficulty with field coating the inside and outside of casing joints. Polyvinyl chloride has excellent corrosion resistance, but has limited use in deeper settings due to low collapse pressures. This limitation is further exacerbated by the higher temperature generated by curing casing cement, which further weakens the material.

The use of fiberglass casing has been researched and shows excellent potential in terms of its cost, corrosion resistance and available diameters. However, there are depth limitations relating to its resistance to hydraulic collapse. Additionally, fiberglass well casing is not currently approved for use in public supply wells[28]. At this time, the Texas Commission on Environmental Quality does not permit alternate grouting materials (such as bentonite) to be used in completing municipal wells.

Consideration must also be given to the corrosion resistance of the pumping equipment. The use of submersible or line-shaft pumping equipment has been dependent on cost, water quality considerations, pumping water levels, operator preference, and noise or security considerations. In general, stainless steel line-shaft pumping equipment has a higher initial capital cost[29] but has a reduced operation and maintenance cost due to longer life and better reliability. In some instances, the electrical costs may also be reduced due to the generally greater pump efficiency of line-shaft pumping equipment.

Pump column materials used in brackish well fields include polyvinyl chloride, carbon steel, stainless steel, and fiberglass. Selection of an appropriate material for each application is largely dependent on water quality, setting depth of the pumping equipment, horsepower requirements (for submersible applications), type of pumping equipment (line-shaft or submersible), and availability. Stainless steel columns currently have the highest cost, but are the most versatile in terms of water quality, depth setting, size availability, and type of pumping equipment. To date, fiberglass columns have only been recommended for submersible applications and are currently available in sizes up to eight inches. Polyvinyl chloride has the lowest cost of any pipe column material, but is generally limited to submersible applications with moderate horsepower and low to moderate pumping rates. Typically, the limiting factor in using polyvinyl chloride for a pump column is the impact of motor torque on the column pipe joints[30].

[28] The Texas Commission on Environmental Quality will not approve any public supply wells constructed with casings lacking an American Water Works Association standard. R.W. Harden & Associates is currently working with the American Water Works Association and the Texas Commission on Environmental Quality to obtain approval for alternate grouting materials and fiberglass well casing.

[29] To date, only stainless steel pump motors (for submersible applications) and pump bowls and impellers have been recommended because the difference in cost between stainless steel and cast iron or bronze relative to overall project costs has been insignificant.

[30] R.W. Harden & Associates has worked with polyvinyl chloride manufacturers to increase the torque resistance of polyvinyl chloride column pipe joints. With special modifications to the joints, polyvinyl chloride column pipe has been successfully used with submersible motors up to 125 horsepower, pump settings as deep as 700 feet, and pumping rates of up to 1,200 gallons per minute.

Raw Water Conveyance System

A suitable well field, along with a successfully sited water treatment facility, has little value without a means to move raw water to the facility. The design of the conveyance system must consider several issues not directly related to the primary goal of producing a sustainable supply of potable water.

RIGHT-OF-WAY

Securing the legal right to construct, operate, and maintain a conveyance system can be a costly aspect if the well field is located far from the treatment plant. Private landowners may be unwilling to sell right-of-way for an affordable price. Also, a lengthy pipeline often crosses rivers, railroads, highways, and bridge crossings. These actions require careful and occasionally time-intensive coordination with transportation and resource protection authorities. To the degree that the preferred conveyance system route is not possible, project costs are likely to increase.

PIPE PROTECTION AND MONITORING

Protection of the pipeline conveyance system, especially for the metal components, is critical to ensure long-term performance. Design considerations need to determine the need for such protection and develop adequate measures. Typically these involve using an impressed current or sacrificial metal to protect the pipeline from the galvanic effect due to using dissimilar materials in the pipeline or adverse soil conditions.

TRANSIENTS ANALYSIS

Pumps and valves in the collection and distribution system can cause transients (a change from a steady-state condition) because they influence the flow and pressure of water in a pipeline. If flow or pressure is altered too quickly, pipelines or equipment may be damaged[31]. Proper transient analyses reveal potential for damage under different operational scenarios and prescribe protective measures in the design process.

NATURAL RESOURCES

To avoid adverse impacts to natural resources protected by law or regulation, the alignment of the conveyance pipeline may need to be changed or the project may incur mitigation expenses to offset unavoidable impacts. Such resource areas can include ecological habitats of unique value (such as wetlands), species of concern and their habitats, areas with a high or valuable concentration of archaeological artifacts, and historical properties. The regulatory processes for identifying these resources and determining the level of potential impacts can be time-intensive and require documentation and permits. However, such delays can be minimized through early involvement of the resource and regulatory agencies with jurisdiction over the project's impacts and close coordination with the same agencies during project design.

PIPELINE SECURITY AND SAFETY

The security of the conveyance system and safety of the water it carries directly affect project design activities. Vulnerability issues have become more important in recent years, particularly with regard to the finished water distribution system. Security and safety considerations will usually generate costs and operational implications above those necessary for the simple transportation of water, but are necessary to minimize the risk to consumers in the service area from unauthorized access and outside contamination. Typical accommodations include gated areas around vents and air release valves, proximity sensors, video cameras, and subsurface installation in especially vulnerable areas.

[31] For example, during the start up and commissioning process of one brackish groundwater desalination facility, the well field was shut down while the treatment processes continued to run. As a result, several hundred feet of transmission pipeline collapsed under vacuum.

PIPELINE COMMISSIONING

One of the most overlooked components of the design process for brackish groundwater desalination facilities is related to pipeline commissioning. Prior to full operation, facility pipes are pressure tested to verify the absence of leaks. Typically, the groundwater source for the facility provides this test water, which must be discharged after testing. Therefore, proper diversion or temporary impoundment accommodations that are consistent with facility permits should be anticipated for the commissioning process and, where necessary, integrated into the design of the facility.

Brackish Water Treatment

The treatment components of a desalination facility include pre-treatment and chemical conditioning, the reverse osmosis membrane treatment process, and post-treatment conditioning of product water. Treatment of the concentrate (if required), management of residuals and solids wastes, and any issues with air emissions (if lime is used in the post-treatment process) are addressed as part of the concentrate disposal system.

Installation of cartridge filters, North Cameron Regional Water Project, November 2006.

Photographs courtesy of NRS Consulting Engineers

Pre-Treatment

The importance of designing an effective pre-treatment system cannot be overemphasized. The most sensitive components of a brackish groundwater desalination projects are the membrane elements that actually reject salts at the molecular level. Therefore, these membranes must be adequately protected from contaminants in the raw water source. Damaged or fouled membranes will have reduced performance and efficiency, and may ultimately need replacement.

Most raw water requires some form of pre-treatment before it enters the membrane vessels for salt removal. Small quantities of sand and other larger particles are easily removed with standard cartridge or bag filtration. Other contaminants require a detailed understanding of the feed water quality characteristics to determine what pre-treatment adjustments are necessary. For example, an oxidizing agent, such as oxygen in the air, can cause some dissolved metals like iron to precipitate out of solution and lodge on the membrane surface. Also, under the right chemical conditions, salts rejected and concentrated during membrane treatment can precipitate and foul the membrane.

Therefore, the potential for feed water contaminants to negatively affect the membrane elements is usually addressed by chemical or physical means during the pre-treatment process. Common examples of these chemical additions include the use of iron or manganese reduction systems or pH control using acid. Table 18 summarizes important considerations with regard to pre-treating salts common in brackish groundwater.

A successfully designed pre-treatment system will balance the cost and benefits of chemical conditioning versus the recovery rate of the membrane process to produce the greatest amount of water at the lowest qualified risk.

Desalination

Once feed water quality has been sufficiently reviewed and pre-treatment requirements determined, the remaining considerations pertain to the actual removal of salt. These decisions include selecting a membrane and assessing the power requirements to produce the requisite flow. Most brackish reverse osmosis systems have the capability to reject up to 99 percent or more of the salt from the feed water, though specific, nominal salt rejection qualities vary. The quantity of permeate extruded through the reverse osmosis membrane (expressed as a percentage recovered from the feed water) will usually exceed 70 percent.

Table 18: Considerations for dissolved salt ions in reverse osmosis treatment processes.

Ion		Consideration
Aluminum	Al^{+3}	Aluminum is a dissolved element usually not appreciably present in groundwater sources. However, with a valence of +3, aluminum has high charge characteristics. Therefore, aluminum is similar to iron in many of the ways it tends to react, such as combining with an oxidizing agent to form an oxide precipitate that can scale membrane elements.
Barium and Strontium	Ba^{+2} Sr^{+2}	Barium and strontium, if present in relatively small concentrations (generally >0.01 milligrams per liter) along with sulfates, can easily fall out of solution as scale on membrane surfaces. The scales of these salts are extremely difficult to re-dissolve; therefore prevention of this precipitate is critical.
Iron and Manganese	Fe^{+2} Mn^{+2}	Iron and manganese are found in water either in a reduced state, which tends to be soluble, or in an oxidized state, which tends to be insoluble. If these metals remain in reduced (soluble) states, they should not cause any fouling problems. However, if any air gets into the system or if another oxidizing agent is introduced, reduced iron or manganese will oxidize into an insoluble state and can foul the membrane elements.
Sodium	Na^{+}	Sodium salts are very soluble in water but are not as well rejected by reverse osmosis as other ions. This is because sodium is mono-valent (that is, containing a single positive valence charge).
Chloride	Cl^{-}	Chlorides pose little threat to membrane treatment systems from the standpoint of scale formation because nearly all chloride salts are quite soluble in water. However, high concentrations of chloride can attack 304-grade stainless steel. Therefore, if the chloride in the reverse osmosis concentrate exceeds several thousand parts per million, a 316L-grade stainless steel may be required for high-pressure piping to prevent corrosion.
Fluoride	F^{-}	Fluoride concentrations are usually low in most water sources. At lower concentrations (0.8 to 1.2 milligrams per liter), Fluoride is recommended for dental health benefits, but higher concentrations (4.0 milligrams per liter) are avoided due to adverse health risks (skeletal fluorosis). In combination with calcium (calcium fluoride), this salt can be fairly insoluble if fluoride is present in an appreciable concentration, which presents a scaling risk to the membrane from the concentrate.
Nitrate	NO_3^{-}	Nitrates also pose little threat to membrane treatment system from the standpoint of scale formation. The presence of nitrates in a source groundwater is more of a concern with respect to the ability of the water treatment system to remove them. Because of poor charge characteristics, nitrates are not well removed by reverse osmosis. Depending on membrane type and system recovery, nitrate removal by reverse osmosis usually falls within the range of 50 to 90 percent.
Silica	SiO_2	Silica is a major ion of concern for membrane desalination systems because it easily falls out of solution, depending upon the pH. Below a pH of 9.0, silica is present mostly in the silicic acid form (H_4SiO_4). At lower pH values, silicic acid can polymerize to form a colloid (known as *colloidal silica*). At higher pH values, silica can precipitate as a salt with calcium, magnesium, iron, or aluminum. Because silica and silicates can be difficult to re-dissolve, the potential for silica precipitation should be addressed in groundwater with concentrations greater than 20 milligrams per liter.
Sulfate	SO_4^{-2}	Sulfates are present in relatively large concentrations in most groundwater and have limited solubility in water, depending on the concentrations of divalent cations also present. Such cations include calcium, magnesium, barium, and strontium. The prevention of sulfate scale formation in a reverse osmosis system is usually performed by reducing or controlling the divalent cations in the groundwater source.
Sulfide	S^{-2}	Sulfides are generally present in groundwater as a dissolved gas (hydrogen sulfide, or H_2S). If oxidized by oxygen from the atmosphere or by chlorine injected into the water for biological control, sulfides will fall out of solution as elemental sulfur and potentially foul the membrane elements. Hydrogen sulfide gas can be removed by running the water through a degasifier, which will give off the odor or rotten eggs and therefore may be prohibited in some areas. Another means of removing sulfides is to intentionally oxidize them by chlorine injection or some other means, then remove the precipitated sulfur using a media filtration.

Post-Treatment

Membrane technology very efficiently removes most of the dissolved salts and minerals from the feed water. In most cases, the freshwater permeate will meet or exceed primary drinking water quality standards, as well as many secondary standards. However, the permeate often contains so little total dissolved solids and can be aggressively corrosive to the distribution pipeline and pumping equipment. Therefore, in most facilities, post-treatment chemical conditioning is necessary to stabilize the water by restoring the stability and buffering capability of the water. The degree of required post-treatment depends on the chemistry and scaling tendencies of the existing distribution system. Options to stabilize, condition, or otherwise reduce the corrosive nature of permeate most commonly include direct blending with some feed water, hydrogen sulfide (gas) stripping, pH adjustment using acid or a base, lime for buffering, fluoride addition, chlorine addition for disinfection purposes, and a corrosion inhibitor to protect the distribution line.

Chlorine storage building, North Cameron Regional Water Project, June 2007.

Photograph courtesy of WaterPR

Concentrate Management and Disposal

The rejected feed water (concentrate) contains a higher concentration of dissolved solids by several times than that present in the feed water. The degree of concentration depends on the initial concentration of constituents in the feed water and percent of permeate recovered by the membranes. The characteristics of the concentrate will likely require some assessment prior to disposal to satisfy regulatory requirements. A close approximation of the projected range of concentrate contents can be calculated or modeled for permitting purposes.

Because of the broad variety of available means to manage and dispose of the concentrate, design considerations for this project component will vary dramatically from project to project. Applicable regulations for concentrate disposal, as well as the costs they invoke, will like be a major factor in the design consideration.

Delivery of Potable Water

The distribution of finished water from a brackish groundwater desalination plant is not significantly different from other conventional water treatment facilities. After the membrane permeate is conditioned, treated water is stored and then distributed to the public.

Determining adequate onsite storage volume is influenced requirements like fire flow storage, disinfection contact time, and diurnal consumer demand. It is also possible to build larger finished water storage capacity to allow facility turn-down during high power demand periods (called peak-shaving). This approach incurs a higher capital cost for the increased storage capacity which can be offset by a reduction in the power costs if off-peak or interruptible rates negotiated with the power provider.

Membrane desalination facilities are most efficient when operated at full capacity. This allows maximum utilization of the purchased equipment (capital expense), which is the primary means of cost recovery. However, many plants will supplement other water supply sources treated by different treatment plants. In this case, the desalination facility should be planned to run continuously and provide a base flow. This operation allows other available facilities to supply the peak day and hour demands. If the desalination facility is the only source of potable water, the production capacity and distribution system should be capable of meeting the maximum day demand. Membrane plants can also be modularized, allowing incremental adjustments of capacity.

Standby capabilities and state requirements[32] should be considered during the design process. If the entire production capacity must meet the maximum demand, any portion of the treatment or delivery systems placed out of service for maintenance or malfunction will result in a deficiency of potable water supply. Therefore, redundancy should be included in the implementation of wells, pumping, and process equipment.

[32] For example, the Texas Commission on Environmental Quality requires that potable water distribution systems be designed to maintain a minimum pressure of 35 pounds per square inch at all points within the distribution network at flow rates of at least 1.5 gallons per minute per connection. It must be designed to maintain a minimum pressure of 20 pounds per square inch if the system is intended to provide fire fighting capabilities and drinking water flow conditions.

Design

Piloting

When the North Cameron Regional Water Project was being permitted and designed, the Texas Commission on Environmental Quality did not require facility piloting for brackish groundwater projects using membrane technology[33].

Groundwater Considerations

Based on the results of the test drilling program, the design team determined that two wells (shallow and deep, each producing about 1,100 gallons per minute) could supply the feed water needed to run two reverse osmosis modules at the same time. The maximum production from the first (shallow) production well could supply up to 2.92 million gallons per day (2,025 gallons per minute), more than that required to satisfy the full demand of the plant[34]. Based on these results and consideration for the project budget, the owners decided that the second (deep) well would be constructed at a later date. The completed shallow well included a submersible well pump, operated and controlled through a variable frequency drive.

Fiberglass pipe is corrosion resistant and very cost effective compared to stainless steel. The original design for the column pipe of the submersible pump included fiberglass with integrated external upset couplings. The submersible pump was set to a depth of about 250 feet with 240 feet of threaded fiberglass column pipe. The original well motor was a water-cooled, 250 horsepower submersible motor and a vertical turbine pump designed to produce 2,025 gallons per minute with 360 feet of total dynamic head. The submersible motor specifications met all standards for this application. Nevertheless, there were three separate failures of the motor. Although the column pipe sections were assembled using a few hundred foot-pounds of torque, almost 5,000 pounds were required to separate them. It is unclear if the rotational torque of the motor, the change in above ground assembly temperatures to down hole temperatures or binding of the Teflon® thread sealing tape resulted in the increased torque needed to unthread the column pipe joints. Whether by contractor inexperience with fiberglass pipe or actual material limitations (or both), the repeated process of re-installation caused unacceptable wear on the pipe threads, and the entire column pipe was ultimately replaced with 304-grade stainless steel. Drilling contractors are more experienced with stainless steel well components and the physical limitations of these materials are better known.

LESSON LEARNED:

Contractor inexperience with and physical limitations of specialized materials required for brackish groundwater desalination wells can limit project performance.

The 250 horsepower well motor originally installed for the project is not presently in place, despite being rebuilt and reinstalled several times. The well is currently being produced by a 100 horsepower submersible motor, allowing operation of each reverse osmosis module every other day. As the facility grows into full demand, an alternative pump arrangement will be required. The implementation of submersible motors can be a cost effective option up to 200 horsepower using standard duty equipment. For applications where more than 200 horsepower is required, vertical line-shaft turbine pumps or heavy-duty submersible motors are a considerably more expensive option, but may provide greater reliability. The motor for the vertical line-

LESSON LEARNED:

Above 200 horsepower, a vertical line-shaft turbine pump should be considered in lieu of standard duty submersible motors due to the dramatic increase in capital cost of heavy-duty submersible motors and wire.

33 Subsequent to approval of the North Cameron Regional Water Project, agency staff met in late 2007 to re-evaluate program requirements and determined that membrane filtration applications, which are considered to be ‘non-conventional, innovative, or alternative water treatment technologies, will require pilot test data or equivalent to demonstrate drinking water standards will be met.

34 At a recovery rate of 75 percent, a flow of 2.67 million gallons per day of feed water to the treatment plant would provide a permeate flow of 2.0 million gallons per day.

shaft turbine would be located above ground, eliminating the need to pull the pump column, shaft, and pump out of the well if the motor becomes inoperative.

Brackish Water Treatment
Because of the excellent quality of the groundwater at the North Cameron Regional Water Project, pre-treatment requirements are limited to the injection of a scale inhibitor to prevent precipitation of (calcium carbonate) salts and membrane scaling and a 5-micron cartridge filter to prevent particulate fouling. Once the feed water is pretreated, it is pressurized and passed through reverse osmosis membranes for desalination. A high pressure pump utilizes the residual pressure from the well field and provides the additional feed pressure to the membrane system. The use of energy recovery systems into the design also lowers the feed pressures to about 160 pounds per square inch into the reverse osmosis process.

The reverse osmosis system at the plant consists of two modules, each with a permeate capacity of 1.0 million gallons per day. The reverse osmosis process for each module consists of a 20:10 array (Figure 21). Feed water enters the first stage reverse osmosis process, consisting of 20 banks. Each bank consists of one pressure vessel containing seven membrane elements. The concentrate from the first stage feeds the second stage reverse osmosis process consisting of 10 banks. Each bank in the second stage also consists of one pressure vessel containing seven elements. This process results in a recovery of 75 percent of the feed water stream and a concentrate flow of 25 percent. After membrane treatment, an additional 0.125 million gallons per day of filtered feed water is blended with the reverse osmosis permeate to provide a total of 1.125 million gallons per day of product water from each of the two modules.

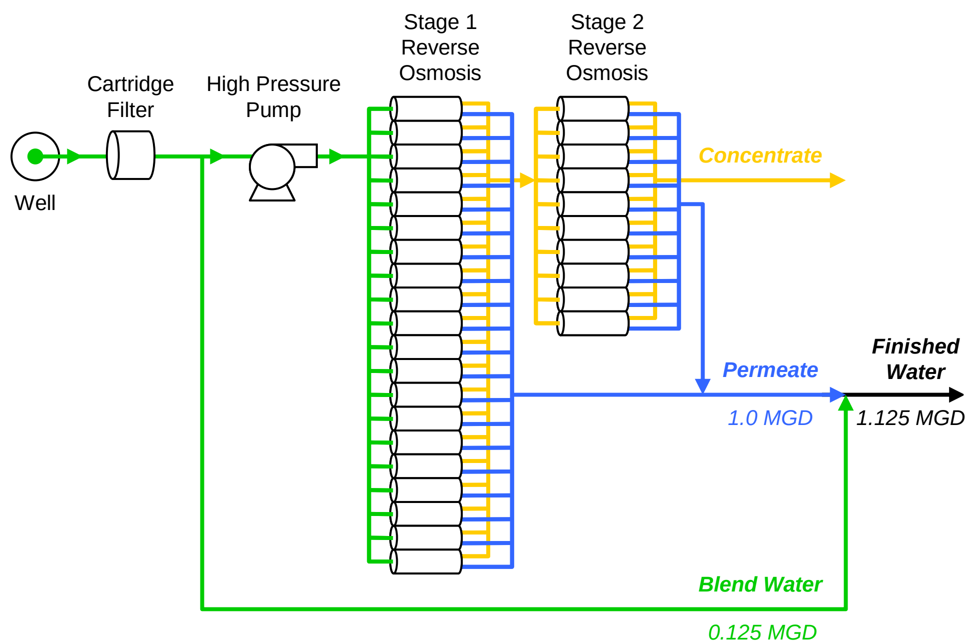


Figure 21
Schematic of the 20:10 reverse osmosis membrane module array, North Cameron Regional Water Project.
The project consists of two of these membrane modules, each with a permeate capacity of 1.0 million gallons per day.

Post-treatment processes include adding caustic soda for pH adjustment, calcium chloride for water stabilization, and chloramines (chlorine with ammonium sulfate) for disinfection. In anticipation of supplying future water demands, the pre-treatment and post-treatment facilities were designed to accommodate expansion up to 4.0

million gallons per day of desalination capacity (4.5 million gallons per day with blending).

The design team made careful consideration of day to day operation and maintenance activities, incorporating feedback from other operators of similar plants. For example, the intentional spaces between modules and around equipment and instrumentation provide easy access by personnel and vehicles to equipment and instruments for repair and maintenance in place. Also, all major manifold lines (for raw water, permeate, and concentrate) into and out of the building were placed overhead in lieu of using trenches. Trenching constitute a major construction expense and was only used for the cleaning system piping around the entire perimeter enclosing the proposed and future reverse osmosis modules. The trench also serves as the collection trench for drain water from all instruments. The drain water from the instruments into this trench then discharges into a manhole outside the building collecting the reverse osmosis concentrate before the drainage ditch outfall. This design consideration avoids the potential for drain water to create overflow conditions in the septic system. Visitors to the North Cameron Regional Water Project continue to positively remark about the overall simplicity and efficiency of the plant layout.

LESSON LEARNED:

An efficient facility design anticipates the needs of day-to-day operations and maintenance activities.

Based on the consideration of several factors, including test well water quality characteristics, membrane performance specifications, and capital and operational costs, the design team selected Hydranautics as the membrane supplier and the Hydranautics ESPA2[35] as the membrane elements for treatment. The owners negotiated and purchased the membranes from the vendor well in advance of project completion to take advantage of favorable pricing terms. The quality of the groundwater from the production well proved to be slightly different than that of the test well. To confirm raw water quality, the design team requested a minimum of three additional full spectrum (anions and cations) chemical analyses. The differences in water quality were not drastic enough to require a design change, but such a change could have jeopardized the investment already made in membrane equipment. Also, delaying circumstances postponed the construction of the project and the membrane elements had to be stored longer than the period recommended by supplier (generally greater than one year). This would not have occurred had the membranes been purchased after completion of the production well and facility design. Once the membranes were installed, additional cleaning precautions were taken before start up to prevent bio-fouling during initial operations.

LESSON LEARNED:

Final design of the reverse osmosis treatment process should be completed based on production well water quality data, not just test well water quality data.

Concentrate Management and Disposal

Concentrate from the plant is discharged into an agricultural drainage ditch adjacent to the project site. These ditches are common in the Lower Rio Grande Valley and drain irrigation return flows and storm water runoff into the Laguna Madre and Gulf of Mexico. The owners of the North Cameron Regional Water Project pay attention to the aesthetics of the plant. The concentrate line goes out of the main building in front of the parking lot where visitors and employees park as they arrive to the plant. The owner has indicated that it would have been more aesthetically pleasing if the concentrate pipe would have been routed to the other side of the building.

Delivery of Potable Water

Product water is discharged into a degasifier tower for stripping of carbon dioxide. From the degasifier, water flows to the transfer pump station clearwell where it is pumped to a 2.0 million gallon ground storage tank. Ground storage is used to buffer average flows to peak flows and is not intended to provide peak day flow for each

[35] The ESPA2 membranes are spiral wound composite polyamide with 400 square feet of membrane surface per element. These membranes have a minimum salt rejection of 99.5 percent and allow a permeate flow of 9,000 gallons per day per membrane element.

project partner. Storage is used for times when units may be down for cleaning and repair or power outages, so each partner provides peaking capacity from its respective water treatment plants.

LESSON LEARNED:

Well placed bypass lines for finished water improve the operational flexibility of the plant.

From the ground storage tank, a high-service pump station is sized to provide a variable demand pressure and capacity to each entity. The pump station consists of variable frequency drives and is easily expandable in subsequent phases with the addition of pumping units. One beneficial design consideration included in the facility was a bypass line for the transfer pumps station clearwell directly to the high service pump station. This feature will be useful if the ground storage tank needs to be removed for service. A beneficial design consideration not included in the facility would have been a bypass line around the degassifiers and directly into the ground storage tank. This feature would have benefited plant operations by preventing a complete shutdown of the reverse osmosis operations if a problem was to occur with both transfer pumps. If utilized, the product water would require more chemicals for water stabilization but would not stop the provision of water into the distribution system.

Design and Permitting Scope of Work

The following scope of work identifies the major tasks conducted during permitting and design of the North Cameron Regional Water Project:

Task 1: Preliminary Design

A. Prepare feasibility level study and use the information presented in this report as a basis for the design. Components shall include:
    a. Well field design
    b. Well field delivery system
    c. Plant works, including chemical feed system, operations building, reverse osmosis system, electrical, Supervisory Control and Data Acquisition, and related facilities.
B. Conduct soil investigations, borings, laboratory testing, and topographical survey as required to complete design for treatment system.
C. Prepare engineering data as required by necessary permit applications to determine discharge parameters.
D. Apply for new permit to discharge reverse osmosis concentrate effluent from the plant (including maps, reports, and forms) and coordinate testing requirements and other items required to complete the application process (the cost of any testing or application processing fee not included).
E. Design the treatment system and prepare a design analysis report, construction plans, and technical specifications.
F. Prepare multiple contract documents and plans according to construction discipline to achieve cost savings through construction management.

Task 2: 60 Percent Complete Design

A. Furnish three copies of the 60 percent construction plans for review and comment, including:
    a. An Executive Summary
    b. Design assumptions and analysis
    c. Reverse osmosis size, materials, pumping units, etc.
    d. Well pumping and materials
    e. Pipe size, materials, etc.
    f. Rationale for why materials were selected
    g. Advantages of selections
    h. List of specifications to be included in final design
    i. Unique requirements, if any

Task 3: 90 Percent Complete and Final Design

A. Incorporate comments into the 60 percent construction plans and develop a Construction Bid and Contract Documents package for the treatment system, including all necessary construction plans, technical specifications, contract clauses, agreement forms, general and supplemental conditions, invitation to bid, instructions to bidders, insurance and bonding requirements, safety and health requirements, and all other items necessary to satisfy the owner's contracting requirements.
B. Furnish three copies of the 90 percent Construction Bid and Contract Documents package for review and comment.
C. Prepare final quantities and estimate construction costs schedule for the treatment system.
D. Provide one set (hard copy and electronic) of the final Construction Bid and Contract Documents package suitable for reproduction. These documents will henceforth become sole property and ownership of the owner.

Phase IV: Construction

From Drawings to Reality

In Texas, a brackish groundwater desalination project may be constructed through a variety of project delivery methods. Regardless of the procurement method used, successful construction depends largely upon the level of experience held by the project engineers and contractors and the degree to which they partner with the owner.

Bidding and Procurement

For the purposes of this *Guidance Manual*, the design and construction phases of a brackish groundwater desalination facility have been discussed separately. However, the two should be considered together when determining which method will be used for actual project delivery. In most cases, the project owner will decide which method will be used based upon the relative importance of project cost, schedule, and risk.

Recently, more bidding and procurement options have become available with the enactment of House Bill 1886 in 2007. Governmental entities in Texas now have some liberty to use Design-Build contracts. Because this represents a major departure from long-standing restrictions on contracting for engineering services, the Texas Legislature elected to take a phased approach to full implementation, with tiers based on the size of the entity and the number of projects.

Initially, only large local governmental entities (those with populations over 500,000) are authorized to use Design-Build contracts. In September 2009, the option also becomes available to mid-sized entities (populations of 100,000 plus). By September 2013, all municipalities may adopt Design-Build procurement for civil works projects (NRS Consulting Engineers 2007).

Large entities are restricted initially to using Design-Build for three projects per year until 2011, when the limit becomes six projects per year. Mid-sized entities are permitted two projects per year initially, increasing to four in 2013. Certain municipally owned water utilities in large municipalities are allowed additional Design-Build contracts.

Traditional Design-Bid-Build Approach

The Design-Bid-Build project delivery method offers fewer challenges because it is a tried-and-true approach, but this approach can also be more costly. Basically, the owner contracts with an engineer to design and bid the project. A separate entity is awarded the contract for actual construction (general contractor).

This method has some drawbacks relevant to brackish groundwater desalination projects, primarily because desalination technology is still relatively new to Texas and few general contractors are familiar with it. As a result, general contractors will often mark up equipment costs, passing this increase on to the owner. The owner and engineer also have less control over the process unless they specify special contracting methods to separate equipment costs from the bid. Finally, extensive coordination during construction is often required on the part of the engineer to ensure the general contractor is sufficiently familiar with desalination technology and processes to successfully construct the project. The potential drawbacks to the Design-Bid-Build process should diminish somewhat over time as the experience and expertise of general contractors with desalination technology increases.

Variations of the Design-Build Approach

The Design-Build approach allows the owner to contract with a single entity for the design and construction of the project. This approach usually exposes the owner to less risk (whether actual or perceived). The Design-Build approach is most effective with lower risk projects where the owner has an expedited delivery schedule as well as a comfort level sufficient to take over the project upon completion. A Design-Build contracting approach can have several variations.

DESIGN-BUILD

A straightforward Design-Build approach is much like the traditional Design-Bid-Build method except it eliminates separate design approach and approval steps. The Design-Build contractor can design during construction, potentially shortening the design time. This approach can limit participation by traditional, qualified engineering firms not willing to participate in a Design-Build process.

Design-Build contracts can potentially result in cost savings because they offer lower mark-ups than by general contractors under a Design-Bid-Build scenario. However, offsetting these savings is the cost of risk allocations by the Design-Build contractor. For relatively small projects (for example, those less than $50 million), larger firms are generally less likely to bid due to overhead considerations associated with implementation.

DESIGN-BUILD-OPERATE

The Design-Build-Operate approach is a variation of Design-Build in which the contractor also serves as operator of the project upon completion of construction. The owner retains some risk and has less control over the methods of construction and operation. Because of their operation and maintenance responsibilities for the project, Design-Build-Operate contractors have a greater incentive to deliver an effective and efficient project. The contractor will typically recover operational costs through fees and includes profits according to terms specified in the contract.

Contract negotiations for this approach can be lengthy and complicated because the owner and contractor will attempt to forecast all potential issues during facility construction and operation. This project delivery approach works best when the owner lacks the resources to operate the facility or when an outside entity may perform operations in a more cost effective manner.

DESIGN-BUILD-OWN-OPERATE-TRANSFER

The Design-Build-Own-Operate-Transfer varies from the Design-Build-Operate approach in that a provision is included in the contract for the project sponsor to buy out ownership of the project at some point in the future, usually during facility operation. This approach eliminates risk to the potential owner by allowing a commitment to ownership only after the project is operational and an evaluation of the efficiency and cost-effectiveness of the plant can be made. The terms of the buy out provision will compensate the contractor for assuming all project risks until the transfer is made, increasing the overall project cost from other project delivery methods.

DESIGN-BUILD-FINANCE-OWN-OPERATE-TRANSFER

The Design-Build-Finance-Own-Operate-Transfer is yet another Design-Build variation where the contractor actually finances construction of the project. The terms of the contract will usually provide for the contractor to recover from the owner the initial project financing costs, including any associated debt service expenses, when ownership of the facility is ultimately transferred.

Overview of construction site, North Cameron Regional Water Project, May 2006. NRS Consulting Engineers served as the construction management/ engineering firm using a Hybrid Design-Build project delivery method for the project.

Photograph courtesy of
NRS Consulting Engineers

Hybrid Design-Build Approach

Under the Hybrid Design-Build approach, the owner contracts with a qualified construction management/engineering firm to design and manage construction, which includes serving in the role of a general contractor. Once the test drilling and necessary piloting work are complete, project delivery is straightforward, with no greater risk than that posed by a standard water treatment project. The construction management/ engineering firm develops bid packages for individual disciplines of the project, such as membrane process, electrical, supervisory control and data acquisition, concrete structures, buildings, equipment (except membrane equipment), equipment installation (except membrane equipment), paving, and site work.

The most significant risk factors associated with the Hybrid Design-Build approach are responsibility and implementation during construction. These factors are primarily minimized by selecting a qualified construction management/engineering firm and extensive communication between the multiple contractors and subcontractors.

This approach will usually result in a modest increase to the project cost to cover the additional contract management and coordination expenses incurred by the construction management/engineering firm. However, such increases are significantly off-set because equipment mark-ups usually charged to the owner by a general contractor are eliminated. Control of the project remains with the owner and construction management/ engineering firm, while the owner realizing most of the savings. Based on recent actual project delivery experiences, a Hybrid Design-Build approach can provide the best value for delivery of a brackish groundwater desalination project[36].

[36] Based upon the authors' experience with five brackish groundwater desalination facilities constructed since 2004, this approach can net a 20 to 30 percent savings over a traditional Design-Bid-Build approach.

Membrane Contractors

The bidding and procurement period is the last opportunity to ensure a cost effective project. Most of the bid items are straightforward except for the membrane process item, which is the most specialized area of a brackish groundwater desalination project and deserves special attention. This item includes pressure vessels, membrane elements, and other specialized ancillary equipment.

Often, membrane contractors have different perspectives on project design and may recommend changes during construction to equipment and piping arrangements, materials to be used, or operational processes. It is important to maintain flexibility in certain instances to ensure cost efficiency, especially for the membrane process bid items[37]. However, such flexibility should not extend to the point of accommodating changes that could potentially jeopardize the process (flux design changes) or materials of construction (for example, painted steel in lieu of stainless steel).

Qualified membrane contractors generally fall into two major categories: industrial and municipal. Experiences in Texas indicate that both are fully qualified to implement brackish groundwater desalination projects. Industrial membrane contractors tend to be larger companies with experience primarily in the industrial sector. This group is generally not very familiar with drinking water regulations. Industrial membrane contractors gear the construction of membrane projects in a skid modular form. Skid-mounted membrane units are constructed in the factory and shipped in an almost complete stage. Each skid is pre-tested in the factory and most of the instrumentation and wiring is completed before the unit arrives on site.

[37] This flexibility will also encourage continued involvement with and support for the project by the membrane contractor.

Municipal membrane contractors tend to be smaller companies with experience primarily in the municipal sector and thus are usually very familiar with drinking water regulations. These membrane contractors gear the construction of membrane projects to custom designs on an individual basis, adjusting the membrane units to local site conditions. The membrane process equipment parts (such as pumps, pressure vessels, frames, filters, and piping) are delivered to the construction site and assembled on-site. The membrane units are electrically and hydraulically connected then tested once assembly and installation are complete.

Construction Considerations

With any construction project, construction activities should proceed under strict legal terms as defined by the construction documentation and personnel management directives.

Documentation

Having the contract documents in place before the agreement is executed and work begins is of primary importance. The contract documents consist of the notice to contractors (advertisement), general conditions, special conditions, proposal, signed agreement, payment and performance bonds, special bonds (when required), technical specifications, plans, and all modifications (addenda). These documents serve to define the project as planned and designed.

On-site documentation at the construction site must include contract drawings (as-built drawings), specifications, addenda, reviewed shop drawings, change orders and field directives, contract modifications, field test records, manufacturer certifications, requests for information, and correspondence. In addition, it is critical to maintain detailed construction records, including daily construction reports,

Assembly of the pressure vessel racks, North Cameron Regional Water Project, December 2005.

Photographs courtesy of NRS Consulting Engineers reports of any and all observations, and meeting agendas and summaries with the different contractors. These documents serve to define the project as actually constructed.

Construction Management

Effective communication is the best approach to implementing a brackish groundwater desalination facility. Most disputes between the owner, engineer, and contractor can be avoided as long as open and frequent communication allows questions and concerns to be resolved in a timely manner. Often, the last 10 percent of project construction can be the most critical and most difficult to complete. Therefore, it is very important that the flow of communication continues among all parties until final project completion.

Because the construction of a brackish groundwater desalination facility requires sustained coordination among many individuals over a long period of time, a team concept for managing and performing required activities must be implemented. The team approach offers continuity and awareness of the status of the project and forms a mechanism for exchanging information among team members. Critical positions necessary for a successful project include project manager, project engineer, and project representative(s).

Inspection and project review by construction team, North Cameron Regional Water Project, August 2007.

Photograph courtesy of NRS Consulting Engineers

PROJECT MANAGER

A project manager is responsible to the owner and the engineer for successful execution of the project. They have complete authority and responsibility for the project throughout the duration of the contract(s). The project manager participates in establishing time requirements for project completion, negotiating contracts, establishing project goals and objectives, selecting project team members, scheduling milestones, accounting for project costs, and monitoring accomplishments.

PROJECT ENGINEER

The project engineer reports to the project manager and assists in establishing and maintaining necessary records, processing submittals, administering activities, updating project schedules and progress, monitoring contractor progress and performance, maintaining project accounting records, coordinating payment requests, and overseeing project close out activities.

PROJECT REPRESENTATIVE

The project representative, who also reports to the project manager, serves as the eyes of the owner so as to protect their interests. Through daily reports, the representative communicates with all parties, indicating the progress of work and identifying any items of concern. The representative produces and maintains written and photo documentation of all construction events, providing the owner with historical information should any dispute arise. Representatives are not supervisors and do not exercise control over the project. Effective project representatives possess good verbal and written communication skills.

Construction

Bidding and Procurement

The Hybrid Design-Build method of project delivery was successfully utilized for the North Cameron Regional Water Project. This method was selected by the project partners based upon other project experiences in the region using the same method. By serving as the intermediary between the owner and multiple specialized contactors, the construction management/engineering firm was able to mitigate the lack of awareness and familiarity with desalination technology and processes by local general contractors.

During the bidding phase, the project was divided into 11 major bid packages and several smaller ones (Table 19). Each bid package focused on a specific discipline to increase competition while allowing for contractors to bid on portions of the project in which they were most familiar. Local contractors bid on and were awarded contracts for every aspect of the plant with the exception of reverse osmosis treatment, the ground storage tank, and the well layout.

Table 19: Summary of major bid packages and contractors used to construct the North Cameron Regional Water Project.

Bid Item
1. Reverse osmosis building and flatwork
2. Reverse osmosis system
3. Well drilling and pump installation
4. Ground storage tank (2 million gallons)
5. Site fencing
6. High service pump station and chlorination building
7. Secondary containment system and installation of pipe, valves, and pumps
8. PVC piping, valves, accessories, pumps, and fiberglass wet well
9. Electrical and Supervisory Control and Data Acquisition systems
10. Chlorination system
11. Site paving, grading, sidewalks, and driveways

There were challenges, however, to the Hybrid Design-Build approach. The first involves managing the administrative and scheduling details of such a large number of contracts. Under a traditional Design-Bid-Build approach, a single contract would be executed with a general contractor to cover all work items. Without a strong commitment of adequate personnel by the construction management/engineering firm, contract management and performance details can easily slip, resulting in sequential delays. Therefore, a minimum recommended staff dedication for a Hybrid Design-Build project delivery approach includes a Project Manager, Project Engineer, and Project Representative.

LESSON LEARNED:

The dedication of a Project Manager, Project Engineer, and Project Representative are minimum requirements using the Hybrid Design-Build project delivery method.

LESSON LEARNED:

A contingency fund should be established to address gaps between individual contracts under the Hybrid Design-Build approach.

Another challenge was that the multiple bid packages will have gaps between contractors, and it is important for the owner and construction management/engineering firm to anticipate these during construction. These gaps can best be addressed through use of a contingency fund assigned at the beginning of the project. This fund can be pre-approved by the owner and utilized by the Project Manager as necessary with coordination and approval of the owner. The allowance of a contingency fund can be very beneficial for the Project Manager in ensuring continuance during the construction phase. The North Cameron Regional Water Project did not have a contingency fund and gaps in the project did occur during the construction phase. Without the use of such a fund, these gaps were closed in coordination with the owner through change orders with existing contractors, the owners' own manpower, or other outside contractors. This was possible because the owner is a non-profit corporation with only three board members, so the Project Manager did not have to go through a long approval process. Another factor contributing to the success of the approach was a very high level of communication and trust between owner and construction management/engineering firm.

Membrane Contractors

LESSON LEARNED:

Screening of potential reverse osmosis contractors through the use of a pre-qualification proposal can improve the quality of the pool of bidding contractors.

Because reverse osmosis technology is still fairly specialized, flexibility during the bidding process is essential to maintain the overall integrity of the project. In the case of the North Cameron Regional Water Project, a membrane contractor with experience in brackish desalination projects in the Lower Rio Grande Valley was pre-selected to provide and install the reverse osmosis portion of the project. This arrangement was part of a negotiated package between the owner and the reverse osmosis contractor to provide services and equipment not only for the North Cameron Regional Water Project, but for two additional desalination facilities as well. Although a previous working relationship with the owner, engineer, and contractor proved to be invaluable in terms of project coordination and added to the overall success of the project, it is generally recommended that membrane contractors be pre-screened through the use of pre-qualification proposals to improve the quality of bidders. Competitive bidding among at least three reverse osmosis contractors should provide the most cost effective procurement results.

Construction Considerations

LESSON LEARNED:

Participants with experience in developing similar projects can minimize critical learning curves, improve comfort levels, and reduce overall risks.

During construction of the North Cameron facility, weekly construction meetings were held with the owner and contractors. This allowed the construction management/ engineering firm to successfully schedule and coordinate multiple, concurrent contracts. The approach and structure of these meeting were based on previous experiences of the construction management/engineering firm from similar projects in the area. Such meetings were vital in holding all parties accountable to the original project plans and subsequently reducing conflict and confusion. Daily inspection reports were prepared by the on-site project coordinator and reviewed by the project manager and project engineer. This level of documentation ensured that all portions of the construction phase were being monitored on a daily basis.

LESSON LEARNED:

The Hybrid Design-Build project delivery method places the responsibility of timely completion full upon the construction management/ engineering firm.

Completion of the North Cameron Regional Water Project was completed much later than originally planned. This delay was attributable to several factors. First, project design was delayed to re-collect and re-interpret test well data. This was necessary because of turnover in contractor staff and missing or misplaced data. This event also lead to an increase in the project cost. Next, the membrane contractor, using a different approach than on previous projects, used much more time to calibrate the automated control and measurement equipment. Finally, and most significantly, multiple failures and replacements of the well motor caused a seven-month delay in facility start-up and plant commissioning. The lack of a general contractor precluded the owner from seeking liquidated damages as under a traditional Design-Bid-Build approach. In addition to delaying facility completion, these delays combined to also increase the total project cost.

Project Costs

The final total project cost of the North Cameron Regional Water Project was just under $7.3 million. This cost includes test well investigations, land acquisition, construction, engineering, and construction management (Table 20).

Table 20: Summary of total project costs for the North Cameron Regional Water Project.

Item	Cost
CONSTRUCTION COSTS	
Reverse osmosis building, concentrate lines, off-site	$662,605
Reverse osmosis system	$1,783,651
Production well	$410,824
Ground storage tank (2 million gallons)	$1,007,740
Site fencing	$34,381
High service pump system and chlorination building	$289,985
Secondary containment (pipes, valves, pumps, and installation)	$318,173
PVC piping (valves, accessories, pumps and wet well)	$407,435
Electrical and Supervisory Control and Data Acquisition	$1,107,972
Chlorination	$64,770
Paving, grading, and flatwork (sidewalks and driveway)	$81,189
Ductile iron header	$8,000
Culvert	$4,000
Irrigation line	$3,689
Transformer pad and conduit from service to pad	$8,730
Temporary power hookup	$1,850
Subtotal Construction	**$6,194,895**
NON-CONSTRUCTION COSTS	
Land purchase	$100,00
Test wells	$40,000
Test well evaluation	$30,000
Total engineering and construction management	$834,883
Laboratory testing	$64,133
Subtotal Non-Construction	**$1,069,016**
TOTAL PROJECT COST	**$7,263,911**

Construction Scope of Work

The following scope of work identifies the major tasks conducted during construction of the North Cameron Regional Water Project:

Task 1: Bidding

A. Participate in the pre-bid conference.
B. Assist the owner in solicitation of bids/quotes by identification of prospective qualified bidders and review of bids solicited interests.
C. Review all pre-bid questions and submissions concerning the bid documents.
D. Prepare addenda or other revisions necessary to inform contractors of approved changes prior to bidding.
E. Attend bid opening, analyze, bids, evaluate, prepare bid tabulations, and make recommendation concerning award of the contract.
F. Prepare the contract for execution between the owner and the contractor(s).

G. Arrange and pay for printing of all documents and addenda to be distributed to prospective bidders.
H. Advertise the project for bidding, maintain the list of prospective bidders, receive and process plan purchases for all bid documents, issue (with the assistance of the owner) any addenda, and conduct the bid opening.

<u>Task 2: Construction</u>

A. Participate in the pre-construction meetings.
B. Review shop and working drawings, materials, construction schedules, and other submittals for conformance to the contract documents.
C. Review field and laboratory tests. Ensure all quality control testing is conducted in accordance with the contract documents.
D. Provide interpretations and clarifications of the contract documents for the contractor and authorized minor changes, which do not affect the contractor's price and are not contrary to the general interest of the owner under the contract.
E. Prepare change orders in coordination with the owner.
F. Provide on-site inspector to continuously monitor the contractor's construction progress and quality of work, and to ensure that the work is being performed in accordance with the contract documents.
G. Prepare progress estimates for payments to contractor(s).
H. Conduct monthly construction meetings with the contractor an owner staff to discuss construction issues and progress. Issue meeting minutes documenting these meetings and prepare monthly progress reports.
I. Conduct final construction inspections with the owner. Prepare a punchlist and provide the owner with final acceptance documents for the project.
J. Review contractor's construction "red-line" drawings to determine if drawings are prepared in accordance with the contract documents, prepare record drawings of the project as constructed (from the "red-line" drawings, inspections, and the contractor-provided plans), and deliver to the owner a reproducible set and electronic file (AutoCAD 2000 or later) of the record drawings.

Phase V: Operations

The End Goal

The operation of a brackish groundwater desalination plant differs from, but is no more complex than, a conventional water treatment facility. Primary differences include care for the membrane elements during start up procedures, process instrumentation and controls, and training needs for operator staff. Similarities include state-required inspections and reporting requirements.

Facility Start Up

The Operations Phase strives to optimize system performance over the life of the membrane system, maximize the useful life of the membrane elements, and minimize operating and maintenance costs. The successful long-term performance of a desalination process is largely dependent on proper operation and maintenance of the system. Therefore, a well planned pre-treatment scheme and initial plant start up can prevent membrane fouling, thereby preserving permeate flow rate and salt rejection.

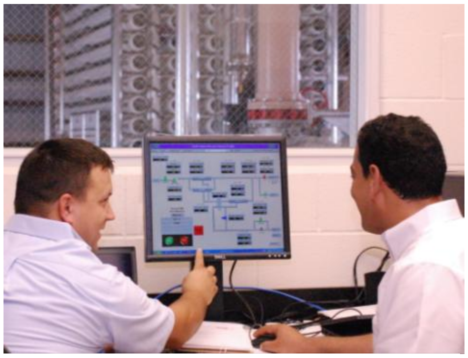
Critical activities must be performed before and after facility start up to ensure the facility meets the performance goals established by the owner and engineer.

Start Up Responsibilities of Team Members

Because the start up operation is the responsibility of all entities involved in the project, the availability of all major contractors is absolutely necessary for successful facility activation. Key individuals involved in pre-start up operations include the staff operators, engineer, original membrane equipment manufacturer, electrical contractor, well contractor, and supervisory control and data acquisition contractor. Communication is the key for a well orchestrated pre-start up operation, and a well delineated plan of action is essential.

STAFF OPERATORS

The individual staff operators will be responsible for long-term operation of the desalination project. For this reason, it is imperative that these key individuals be involved from the very beginning of the project, including shadowing contractors during the construction of the project and assisting in start up operations. This level of involvement by the staff operators will accelerate the process of learning membrane treatment systems.



Training for the master control system, North Cameron Regional Water Project, June 2007.
Photograph courtesy of WaterPR

ENGINEER

The engineer is the central coordinator of all other project participants. The engineer is responsible for ensuring the flow of effective communications, and should develop a pre-start up operations checklist for all others to follow. Recommended items for such a checklist include:

- Adjust regulators, valve positions, relief valves, flow rates, alarms, and set points.
- Tune modulating loops for design response to input signals. Adjust travel stops to 'open/close' valves. Confirm set points and sequences on discrete functions.
- Acquire certificate from software vendor that simulation testing is complete and appropriate corrections have been loaded for all applications affecting treatment processes.
- Confirm control system operation, including loop checks, independent/dependant loop operation, and intended operation.
- Calibrate all on-line instruments, including analytical, switches, gauges, chemical feed pumps (if applicable), and alarms.
- Confirm circuits are energized in normal/automatic position.
- Confirm availability of concentrate discharge lines for backwash and filtered water disposal (if utilized).
- Acquire Certificate of Proper Installation (CIP) form for the owner for each component of the treatment process.
- Demonstrate functional, performance, and reliability acceptance testing requirements for owner approval.

ORIGINAL MEMBRANE EQUIPMENT MANUFACTURER

The original equipment manufacturer for the membrane units serves as the desalination process contractor. They evaluate the most recent water quality data and conduct a thorough review of the membrane protection system. Once they confirm the initial design conditions, start up of the membrane system may proceed.

ELECTRICAL CONTRACTOR

The electrical contractor is responsible for all internal and external coordination necessary to supply power to all facility systems. During pre-start up operations, the electrical contractor should be responsible for coordinating with the following entities:

Local serving power company to verify the service classification is correct and that all metering requirements have been met.

Local building officials for all inspections necessary for temporary or permanent electrical service.

General contractor, other sub-contractors, engineer, and owner, advising that the electrical switchgear has been energized.

Equipment suppliers concerning electrical machinery protective functions, such as setting minimum speed and ramp-up and ramp-down times for variable frequency drives; connecting over-temperature switches and motor condensation heaters; and setting and verifying analytical/analog

device interlock settings (temperature, pressure, level, flow and analytical.).
- Other trade representatives to troubleshoot problems with equipment and machinery.
- Staff operators for instructions in starting, stopping, and controlling electrical equipment.

WELL CONTRACTOR

The well contractor must ensure that the well is fully developed and meets state standards and specifications. Prior to pre-start up operations, the engineer and well contractor must obtain interim approval to use the wells from the Texas Commission on Environmental Quality.

SUPERVISORY CONTROL AND DATA ACQUISITION CONTRACTOR

The supervisory control and data acquisition contractor is charged with providing automatic control of the desalination system. This includes verifying radio communications with remote locations. During pre-start up operations, the supervisory control and data acquisition contractor coordinates with the following entities:

- Local communications company to verify service is correct for telemetry to remote locations, as required.
- General contractor, other sub-contractors, engineer, and owner, advising that the electrical switchgear may be controlled remotely.
- Electrical contractor to interface the supervisory control and data acquisition system with the electrical control and instrumentation systems.
- Other representatives to troubleshoot remote control and monitoring of equipment and machinery.
- Staff operators for instruction in remote starting, stopping, and controlling electrical equipment.

Communications tower for the supervisory control and data acquisition system, North Cameron Regional Water Project, August 2007.

Photograph courtesy of WaterPR

Once the pre-start up check lists have been verified and all parties are satisfied with their completion, the membranes should be loaded into the pressure vessels. This is an excellent opportunity for thorough involvement by staff operators as part of their training development, a subject discussed in subsequent sections.

Pre-Start Up

Pre-start up activities include all work prior to loading of the membrane elements into the pressure vessels. Typical pre-start up work incorporates testing individual pieces of process equipment to ensure they operate as designed and intended before the commissioning process. These tests vary in complexity and are usually referred to as reliability acceptance tests and functional acceptance tests. Most system "bugs" can be worked out of the treatment process using this approach before the system is operated as a whole.

Before starting up the facility, it is important to make sure that the whole process is working according to specifications. If the chemical characteristics of the raw water are changed, then a full analysis of the water entering the reverse osmosis unit should be done so that proper measurements can be made to put the variables under control. Table 21 presents a pre-start up check off list to be completed before actual start-up operations begin.

Post-Start Up

The post-start up operation focuses on data collection and proper documentation of all relevant data on the membrane system. This information is necessary for following the performance of the system, troubleshooting operational problems, and supporting any warranty claims.

NORMALIZATION DATA

The performance of the membrane system depends primarily on the proper operation of the pre-treatment process. Real system performance is influenced by changes in feed water total dissolved solids, feed pressure, temperature, and recovery ratio. Data normalization is a technique to covert the real performance of the reverse osmosis system into a form

Table 21: Recommended pre-start up checklist for various brackish groundwater desalination equipment.

Control Panel	Instrumentation Feature
Groundwater	1. Confirm electrical wiring configuration through visual inspection. 2. Measure static water level. 3. Inspect lubrication drip system for oil lubricated line-shaft pumps (if applicable). 4. Confirm electrical operations including, voltage, motor revolutions per minute, proper megging of three-phase motors, and current draw at start up and normal operation. 5. Conduct a pump performance test to ensure that the pump, flow meter and well head pressure gauge are functioning, including running the pump at various flow rates (controlled with the gate or butterfly valve) on the pump operating curve to ensure that the well flow rate is correct at the rated total dynamic. 6. Verify that the produced water is free of turbidity and sand in accordance with specifications. 7. Inspect discharge piping for leaks. 8. Check operation and maintenance manuals for completeness. 9. Proper training for operators.
Reverse Osmosis Process	1. Confirmation of groundwater quantity and quality (latest analyses with such parameters as turbidity, temperature, pH, total dissolved solids, anions, cations, residual chlorine, and bacteria counts). 2. Coordinate the start up with all Contractors and Manufacturers for them to provide a check list of everything that should be present for the start up (cartridge filters, chemicals, etc.). 3. Obtain copies of all leak testing reports for all piping to ensure compliance with specifications. 4. Disinfection of all piping in accordance with American Water Works Association. Purge and flush of feed line before pressure vessels are connected. 5. Inspect the operational conditions of cartridge filters (including rinse housing and bleed pressure). 6. Check chemical injection lines and valves. 7. Ensure proper mixing of chemicals is in place into the feed stream. Confirm dilution ratios of chemicals and purified water, if utilized. 8. Confirm proper operation of safety shut off of the system when the chemical dosage pumps are shut-down. 9. Ensure complete chlorine removal prior installation of new membranes. 10. Proper operation of pressure relief protection system. 11. Inspect piping and securing of pressure vessels for operation and cleaning mode. 12. Lubrication and proper rotation of pumps. 13. Valves for permeate line, feed flow, and reject flow control are in open position. 14. Adjust regulators, valve positions, relief valves, flow rates, alarms, set points. 15. Tune modulating loops for design response to input signals. Adjust travel stops to “Open/Close” valves. Confirm set points and sequences on discrete functions. 16. A certificate from the software vendor that simulation testing is complete and appropriate corrections have been loaded for all software affecting treatment processes. 17. Confirmation of control system operation, including loop checks independent/dependent loop operation and intended operation. 18. Calibrate all on-line instruments, includes analytical, switches, gauges, chemical feed pumps (if applicable), alarms. 19. Confirm circuits are energized in normal/automatic position. 20. Availability of concentrate discharge line and permeate water disposal (if utilized). 21. Certificate of Proper Installation (CPI) form to the owner for each component of the treatment process. 22. Functional, performance, and reliability acceptance testing requirements for owner approval. 23. Check operation and maintenance manuals for completeness. 24. Proper training for operators.
Electrical	1. Communication with local serving power company to verify the service classification is correct and that all metering requirements have been met. 2. Communication with local building official for all inspections necessary for temporary or permanent electrical service to the facility. 3. General contractor, other sub contractors, engineer, and owner advising that the electrical switchgear has been energized. 4. Equipment suppliers concerning electrical machinery protective functions, such as setting minimum speed and ramp-up and ramp-down times for variable frequency drives; connecting over-temperature switches and motor condensation heaters; and setting and verifying analytical/analog device interlock settings (temperature, pressure, level, flow, and analytical.). 5. Other trade representatives to troubleshoot problems with equipment and machinery. 6. Staff operators for instructions in starting, stopping, and controlling electrical equipment. 7. Check operation and maintenance manuals for completeness. 8. Proper training for operators.
Supervisor Control and Data Acquisition	1. Coordinate with local communication company to verify service is correct for telemetry to remote locations as required. 2. General contractor, other subcontractors, engineer, and owner, advising that the electrical switchgear may be controlled remotely. 3. Electrical contractor to interface the supervisory control and data acquisition system with the electrical control and instrumentation systems. 4. Other trade representative to troubleshoot remote control and monitoring of equipment and machinery. 5. Staff operators for instruction in remote starting, stopping, and controlling electrical equipment. 6. Check operation and maintenance manuals for completeness. 7. Proper training for operators.

which can be compared to a given referenced performance (either designed performance or measured initial performance). Each membrane supplier has their own data normalization program that can usually be downloaded from an internet website.

Data normalization should be performed and recorded daily. The data normalization technique allows early warnings of a potential problem, such as membrane fouling, chemical damage, or mechanical failure. The effects can be directly monitored through three main representative variables provided by the data normalization technique. Such normalized variables include salt passage, differential pressure, and permeate flow.

Proper system monitoring and maintenance will maximize membrane life and minimize system downtime. The most common problems with membrane treatment systems are fouling or scaling[38]. System monitoring is essential to prevent problems and to detect them early enough while they may be easily reversed. By measuring the source water conductivity, operators can track potential changes that vary from measurements at start up, specifically fluctuations in the dissolved solids level of the feed water. The saturation levels of specific compounds must be determined because a value in excess of a compound's saturation point can lead to scaling. This information is important for the selection of a scale inhibitor and its optimum dosage.

If membrane elements become fouled or scaled, the material has to be removed by chemical cleaning. Chemical cleaning of the system can dissolve and remove inorganic scales, flush out particulate material, break down microbial growth, and eliminate bacteria.

[38] As previously discussed, the fouling potential of suspended particles is indicated by measurements of turbidity and a silt density index test. The scaling potential of dissolved solids is indicated by measurements of conductivity and the saturation levels of specific scaling compounds.

Instrumentation and Control

The instrumentation and control package provides an integrated control and reporting system for operating the project. The primary purpose of the system is to monitor, control, report, and safeguard the membrane system. A proper system allows automatic sequence and control of start up, operation, and shutdown activities through a master control panel. The instrumentation and control system is based on a programmable logic controller, linked to a process computer and peripherals, with selected monitoring and alarm functions displayed in the control room.

Instrumentation

Instrumentation on the master control panel should include different variables associated with the feed water, membrane unit, product water, and concentrate. Two basic types of instruments should be included: indicator instruments and transmitter instruments. The specific recommended features to be mounted in the master control panel of a brackish groundwater desalination project are provided in Table 22.

Table 22: Recommended features for master control panel instrumentation.

Control Panel	Instrumentation Feature
Feed Water	• Flow • Temperature • Conductivity • Total Dissolved Solids • Turbidity
Membrane Train	• Pressure, Inlet • Flow, First Stage Permeate • Flow, Total Permeate • Conductivity, Permeate
Product Water	• pH • Turbidity • Residual Chloramine • Flow • Conductivity • Total Dissolved Solids • Flow, Blend Water
Concentrate Water	• Conductivity • Flow, Total Concentrate

Control

Well operation is initiated manually by the operator at the control console. The operator should start the membrane unit through the membrane computer, which allows selection of individual membranes. This selection should initiate the start up pre-treatment cycle, starting the scale-inhibitor pump, degasifier blower, and automatically opening the bypass waste valve. Alarm and control points for the concentrate and permeate flows, permeate and concentrate conductivity values, and the set point value for permeate flow should be disabled during this phase of the start up.

After an elapsed time (set by the membrane supplier) the unit control system should be enabled, automatically opening the membrane feed pump valve, starting the membrane feed pump, and closing the bypass waste valve. The membrane feed pump should accelerate to a preset speed, and then transfer to cascade control based on permeate flow. All alarm functions should be enabled at this point. The operator must then manually adjust the blend flow control valve to provide the pre-determined product water conductivity.

Post-treatment additions of calcium chloride, caustic soda, ammonium sulfate, and chlorine systems should be started simultaneously with the membrane feed pump. The sequence should also include pre- and post-flushing periods.

When the first unit started is in full, controlled operation, additional units may be started, one by one, either manually or automatically. Unit start up should trigger the following:

- Additional well pumps as needed for start up of additional membrane units.
- Additional scale inhibitor metering pump.
- Additional membrane feed pump.
- Additional calcium chlorine, caustic soda and ammonium sulfate metering pumps and chlorine feed.
- Manual adjustment of the blend control valve, as necessary.

Shutdown controls for the system should be triggered by the following:

- Loss of feed water.
- High feed water turbidity.
- Loss of scale inhibitor flow.
- High product water pH.
- High product water conductivity.
- High concentrate water conductivity.

A set of emergency shutdown controls should shut down individual units to protect the equipment if conditions occur that could damage the equipment. Shut down of an individual membrane unit should be triggered by:

- Low concentrate flow.
- High permeate flow.
- High permeate conductivity.
- Low suction pressure.
- High discharge pressure.
- High water level in the transfer pump station clear well.

The process computer should be maintained by an uninterruptible power supply that provides sufficient time to transfer operating data storage with the loss of power and system shutdown.

Membrane train control panel, North Cameron Regional Water Project, June 2007.

Photograph courtesy of WaterPR

Human Resources

Human resources management for the operation of a brackish groundwater desalination facility is similar to that for conventional water treatment plants. Key areas are the management structure of the staff, licensing and other requirements, and training and education needs. One aspect of operations that may differ from conventional systems is the number of personnel. For brackish groundwater desalination projects, the total number of required staff operators generally depends upon the type of desalination technology being used (Table 23).

Table 23: Estimated total number of operational staff required for various desalination facilities.

Desalination Process	Desalination Capacity (million gallons per day)				
	1	5	10	25	50
Evaporation (Distillation)	14	14	18	20	35
Seawater Reverse Osmosis	6	12	15	18	20
Brackish Water Reverse Osmosis	6	10	12	15	17
Electrodialysis Reversal	6	10	12	15	17

Source: Adapted from U.S. Bureau of Reclamation (2003).
Note: These estimates should be considered conservative. The total number of full-time operational staff dedicated to the North Cameron Regional Water Project, a 2.25 million gallon per day brackish groundwater desalination plant with a Supervisory Control and Data Acquisition system, is no more than two.

Management Structure

The management structure of any brackish groundwater desalination facility should reflect the size of the facility, number of customers served, operating parameters, familiarity with the process, reporting requirements, and staff availability. It is important to develop an operational organization chart early in the design phase. This will identify key personnel among the owners and staff operators and facilitate their full involvement during project development. Such participation will increase familiarity with the technical aspects of the project and create a strong sense of ownership. Full involvement should continue throughout the construction and start up phases of the project.

Operator Requirements

The Texas Administrative Code[39] requires that the production, treatment, and distribution facilities of a public water system be operated at all times under the direct supervision of a water works operator who holds an applicable, valid license issued by the Texas Commission on Environmental Quality. This requirement applies to the operators of both surface water and groundwater treatment facilities.

It should be noted that two types of groundwater treatment facilities exist: those that treat groundwater that is not under the direct influence of surface water and those that treat groundwater that is directly influenced by surface water. In some areas of Texas, groundwater is considered "under the influence" of surface water because of geological conditions (such as karst, fractured granite, and volcanic layers) that allow interaction. Because of this interaction, "groundwater under the influence" is susceptible to microbiological or chemical contaminants often found in surface water. Public water systems that use such water are required to treat water to surface water standards.

Most brackish groundwater resources in Texas are not under the influence of surface water, and requirements for facilities treating this type of groundwater are based on the number of connections served by the distribution system. A Class D or higher license is required for an operator of a system serving no more than 250 connections. A Class C license is required for an operator of a system serving more than 250 but less than 1,000 connections. Finally, at least two operators with a Class C license are required for systems serving more than 1,000 connections, and these operators must work at least 16 hours per month each at the public water system's production, treatment, or distribution facilities.

[39] Rule §290.46: Minimum Acceptable Operating Practices for Public Drinking Water Systems.

During the development of a brackish groundwater desalination project, it is recommended that specific operator requirements be discussed with the Texas Commission on Environmental Quality.

Training and Education

Training and education allow staff operators the opportunity to gain understanding about the equipment and processes for which they are responsible and increase their level of comfort in performing their duties.

TRAINING

A strict and thorough training regimen for staff operators of a brackish desalination facility is critical, especially for operators with little experience with membrane treatment technology. Training requirements typical for any new water plant include air conditioning, security, and electrical systems. Training requirements specific to a brackish groundwater desalination facility include: safety, principles of operation, system start up and shutdown, control philosophy, plant operation, maintenance, troubleshooting, and water sampling and testing.

Prior to plant start up, the equipment suppliers and contractors should provide comprehensive training on their products. The owner, staff operators, engineer, suppliers, and contractors should participate in the preparation and review of this training agenda. This will ensure that each session addresses any outstanding questions or confusion regarding the equipment or treatment process.

During plant start up, questions will likely arise from the plant operators regarding the in-depth working of the plant during operation. Even minor questions should be brought up and addressed during this period. The goal of having aware operators who understand the intricacies of the process should be the driving force behind the training.

EDUCATION

Numerous agencies and firms offer educational materials and seminars specifically related to the operation of a brackish desalination facility. A partial list of these entities includes:

South Central Membrane Association
American Water Works Association
American Membrane Technology Association
International Desalination Association
North American Membrane Society

SOUTH CENTRAL MEMBRANE ASSOCIATION

In Texas, the South Central Membrane Association offers training and educational opportunities on membrane treatment operations. This organization is an affiliate of the American Membrane Technology Association, and membership is open to operators, utility managers, engineering consultants, government officials, vendors and suppliers, and other interested parties.

The association's Training and Certification Committee is presently working to develop a standardized progression of courses on membrane treatment that could lead to a specialized membrane endorsement for operator licenses. Also, the association offers conferences twice each year on topics of interest, all with a special operators' track that provide hands-on training at an actual membrane treatment facility. All South Central Membrane Association workshops and conferences have been approved by the Texas Commission on Environmental Quality for continuing education for operators. No other association in Texas is focused solely on membrane treatment, including reverse osmosis, nano-, ultra-, and micro-filtration, in water and wastewater operations. Detailed information on the South Central Membrane Association and its training opportunities is provided on-line at www.scmembrane.org.

Operator training for membrane desalination sponsored by the South Central Membrane Association at the Southmost Regional Water Authority, February 2007.

Photograph courtesy of WaterPR

Inspections and Reporting

As a public water supply source, a brackish groundwater desalination facility will receive two types of inspections by the Texas Commission on Environmental Quality: a sanitary survey for providing potable water and a wastewater survey for producing a sub-product labeled as concentrate.

SANITARY SURVEY REQUIREMENTS

A sanitary survey is required for all facilities that provide potable water. The survey is a comprehensive state inspection designed to help water systems protect public health. Sanitary surveys evaluate the capability of the plant to consistently and reliably deliver an adequate quality and quantity of safe drinking water to the consumer and to comply with drinking water standards. The most essential elements of a sanitary survey include:

- Source water (protection, physical components and condition)
- Treatment
- Distribution system
- Finished water storage
- Pump facilities and controls
- Monitoring, reporting, and data verification
- Water system management and operations
- Operator compliance with state requirements

A summary of the objectives, areas of inspection, and on-site documentation requirements for each of these survey elements is provided in Table 24.

A survey report will be provided after each inspection by the state inspector. The sanitary survey will describe any problems or deficiencies that may be considered significant public health issues, and the facility will be required to implement a correction program. When a deficiency is identified, the water system must provide within 45 days a response that includes the following:

- A statement of the deficiency.
- The approach to correcting the deficiency.
- The time required to correct the deficiency.
- The source of funding, if capital construction is required.
- Measures put in place to prevent the situation from recurring.
- Additional follow up actions planned.

A copy of the Texas Commission on Environmental Quality Sanitary Survey check list with detailed explanations can be obtained on-line at www.tceq.com. While the available sanitary survey check-off lists are geared toward the inspection of surface water plants and groundwater plants under the influence of surface water, the available information is very useful for brackish groundwater desalination plants.

WASTEWATER REQUIREMENTS

The concentrate from desalination operations is considered a wastewater discharge and must be permitted. This permit will set limitations in terms of flow and total dissolved solids. Wastewater site inspections are much simpler than sanitary surveys. The plant is required to continuously monitor concentrate flow and total dissolved solids. Recent discharge permits require monitoring for total dissolved solids upstream and downstream of the discharge point. Some discharge permits also stipulate annual bio-monitoring.

Table 24: Summary of sanitary survey requirements for potable water supply systems in Texas.

Survey Element	Primary Objective	Inspection Areas	On-site Documentation Requirements
Source Water	To ensure the prevention of source water contamination.	• Groundwater quality and quantity • Groundwater quantity • Location, capacity, design, and condition of well(s) • Transmission of groundwater to the membrane plant	• Information prepared for state approval concerning well construction and water quality • Plans and specifications for the construction of the well(s)
Treatment	To evaluate process control and operation, data documentation of process parameters, and finished water quality so as to ensure compliance with safe drinking water standards.	• Location of desalination plant • Desalination process units • Plant capacity • Flow metering systems • Chemicals and chemical feed systems • Disinfection process • Concentrate disposal • In-plant cross-connection control	• State approval letter for construction of the facility • Plans and specifications for the desalination process
Distribution System	To address the potential for finished water degradation in the distribution system, reliability and vulnerability of the system, and evaluation of the sampling and monitoring programs to ensure compliance with regulations.	• Distribution maps and records, • Field sampling and results • System design and maintenance, • Disinfection of repaired and new water lines • Cross-connection control • Elimination of water loss.	• Documentation for sampling and monitoring of the system • Distribution plans
Finished Water Storage	To review of the design and major components of storage to determine reliability, adequacy, quantity, and vulnerability, operation and maintenance, and identification of potential sanitary risks attributable to storage facilities.	• Type, location and capacity of storage tanks • Design of storage tanks • Painting of storage tanks • Cleaning and maintenance • Site security	• Plans and specifications • Documentation on the operation and maintenance
Pump Facilities and Control	To review the design, components, operation and maintenance, reliability, and safety practices of the pump facilities.	• Type, capacity, and condition of pumps • Pumping station housing, structure, and appurtenances	• Plans and specifications for each of the pump facilities • Operation and maintenance information
Monitoring, Reporting, and Data Verification	To verify water quality data, process control parameters, and procedures followed for identification of process problems and protocols to correct the problem.	• Regulatory records review and water quality monitoring plans (including regulatory and non-regulatory)	• Process control monitoring plan (non-regulatory) • Monthly operating reports • Any monitoring plans implemented for process control and any state approved monitoring plans for regulatory compliance with drinking water regulations
Water System Management and Operations	To review water quality goals, administrative and operational procedures, and financial standing of the facility.	• Administrative records review • Water quality goals • Water system management and staffing • Operation and maintenance manuals and procedures • Water system funding	• Administrative records (such as personnel, budgets, compliance monitoring plans, and related issues), • Organizational charts • Standard operating procedures • Risk management plan • Standard maintenance procedures
Operator Compliance with State Requirements	To evaluate the level of competency of desalination plant operators.	• Certification of operators and competency of operators	• Training records for all personnel involved in the operation and maintenance (recommended only; there is currently no certification requirement for desalination plants operators)

Case Study E

Operations

Facility Start Up

Prior to start up of the North Cameron Regional Water Plant, the owner, construction management/engineering firm, and all contractors coordinated extensively to ensure proper operation. During start up, special emphasis continued to be placed on training the intended plant operators, including well operation, reverse osmosis equipment operation, data acquisition, transfer pump operation, and high-service pump operation. Data acquisition and documentation was an integral part of the start up process, and reporting requirements for the Texas Commission on Environmental Quality were given special consideration.

LESSON LEARNED:

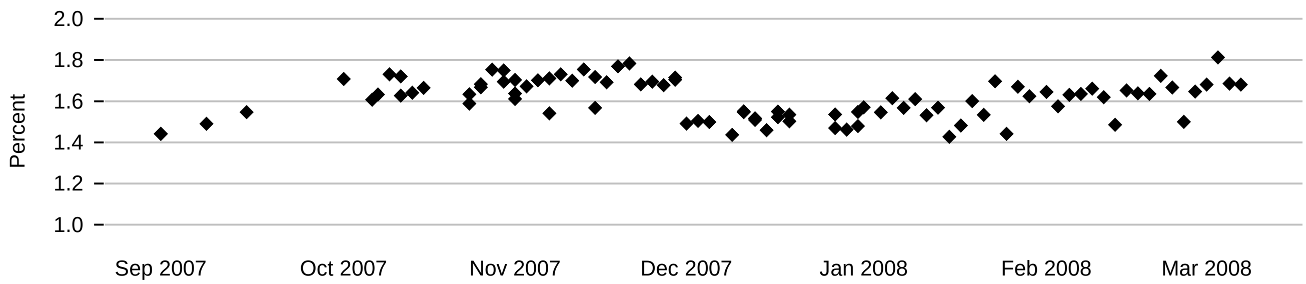
A backup well pump and motor should be available during plant start up until sustained plant operation has been achieved.

The project had a very smooth pre-start up period. After loading the membranes and confirming pre-start up checklist items, the facility began producing drinking water and supplying the distribution system. All major contractors (well, electrical, supervisory control and data acquisition, reverse osmosis, and pumps) were conducting start up operations and check ups of their respective systems when a major fault in the well pump occurred bringing the entire plant down. The well pump had to be pulled by the well contractor for inspection and repair. Inspection and repair of the 250 horsepower submersible pump took several months, during which time project operations came to a stand still. This event significantly disrupted the schedules of the other major contractors. The availability of only one well and one pump created this situation of not able to continue with plant operations. Ultimately, the owners purchased a back-up pump through the well contractor. This 100 horsepower pump was installed to continue system checks and the plant successfully became operational. This issue was primarily overcome through cooperation of the owners, construction management/consulting engineering firm, staff operators, and project contractors working together to accomplish the primary objective, which was ‘plant operation’. The plant now has a back-up pump for contingency operations.

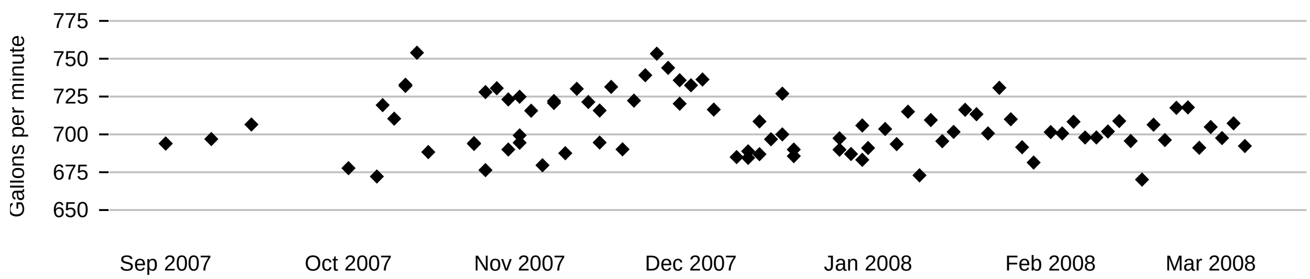
Data normalization is a technique to convert the real performance of the RO system into a form which can be compared to a given referenced performance which may be the designed performance or the measured initial performance. In the case of the North Cameron Regional Water Project, the initial performance served as the referenced performance. Figure 22 displays key normalization information for actual data performance of one of the reverse osmosis modules (Train A) using software from the membrane supplier (Hydranautics) (including normalized salt passage, normalized permeate flow, and normalized differential pressure).

Differences between the normalized data and the initial performance may indicate problems in the system, such as membrane fouling or scaling, membrane chemical damage, mechanical failure (such as a broken O-ring or element glue line), or hydraulic plugging with the presence of large colloids or scale stuck to the flow channel spacing between the membrane leaves of spiral-wound elements. The normalized program requires the input of data for temperature, feed and permeate conductivities or total dissolved solids, permeate and concentrate flows, and the pressures for all streams (feed, concentrate, and permeate). The program automatically calculates all normalized data in a tabular form and provides a graphical representation to track the performance of the system. The membrane elements for this project should be cleaned when a loss of 15 percent in normalized permeate flow, a decrease of 0.5 percent in salt rejection, or the normalized differential pressure increases by 15 percent from initial performance. Following the guidelines above, the normalized data information to date indicate a steady performance of the system without indication of fouling.

System Salt Passage



System Permeate Flow



Differential Pressure

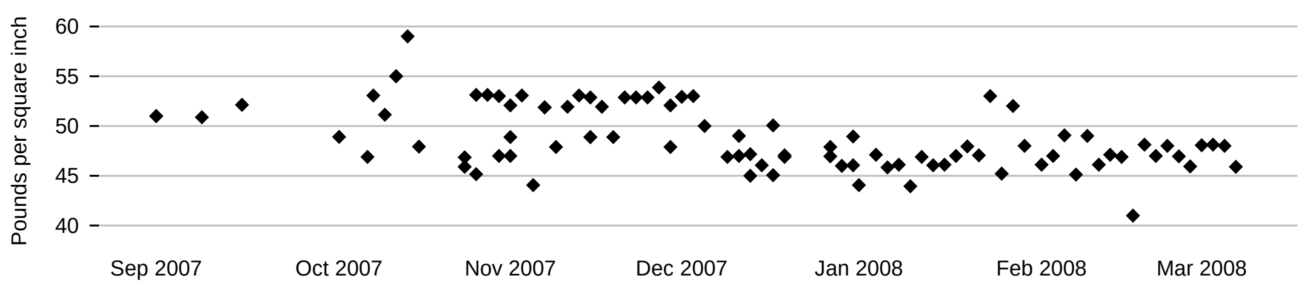


Figure 22

Sample normalized performance data for the North Cameron Regional Water Project, September 2007 through March 2008.

Instrumentation and Control

The instrumentation and control equipment associated with the facility differs significantly from the typical instrumentation at surface water treatment plants. Feed water flow, turbidity, conductivity, temperature, and pH are monitored using in-line equipment. Membrane performance is monitored on the first stage and the second stage utilizing using equipment comparable to that found on the feed water stream. Finally, reverse osmosis product water and concentrate are monitored continuously utilizing in-line instrumentation.

Operation of the North Cameron Regional Water Plant is performed manually or automatically. Automatic operation of the facility is done through the electrical interface governed by the program developed and installed by the membrane equipment manufacturer. The program at the plant went through a number of iterations to determine the proper operating parameters necessary to develop and maintain consistent and user friendly operation of the facility. Delivery of potable water to the three project partners is performed through the Supervisory Control and Data Acquisition system. Two different contractors were involved in this project: one for the East Rio Hondo Water Supply Corporation and another for the North Alamo Water Supply Corporation and the City of Primera.

Human Resources

LESSON LEARNED:

Intentional, intensive involvement of the planned operators during the design, construction, and start up phases minimize intimidation by new technology and enhance ownership.

East Rio Hondo Water Supply Corporation operates the facility for the partnership. Due to the remote monitoring and operations capability of the facility, which is monitored 24 hours a day, it is only necessary for one operator to be on site daily. It has been the experience of the present authors that the involvement of the operators during the construction phase of these facilities plays a major role in the success of the project start up. The operators already have momentum during project start up and tend to become more proactive and involved. This allows for a smoother transition of the plant to the owner. This project benefitted from the experience of the engineer on similar projects where minimum or no involvement of operators during the construction phase created a more difficult environment for the team (owner-operator, engineer, and contractors) during start up, normal operations, and ultimately final transition out of the project. Based on interviews, the current operators reported that the intensity of training necessary to overcome the learning curve associated with reverse osmosis technology lasted for about two or three months. After that point, especially after start up checks had been completed, the operators believe operating the facility to be simpler than a conventional surface water treatment plant.

Inspections and Reporting

As is typical with any water treatment plant, the Texas Commission on Environmental Quality will be performing a sanitary survey for providing potable water and a wastewater survey for producing a sub-product labeled as concentrate. These surveys are performed on a yearly basis, and the operators of the North Cameron Regional Water Project are properly documenting critical operational information in preparation for these surveys.

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