Brackish Groundwater Exploration Guidance Manual

Prepared for:

Upper Colorado River Authority and
Texas Water Development Board

April 2008

LBG-GUYTON ASSOCIATES
in association with
Freese and Nichols, Inc.

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(TWDB Contract No. 0604830580)

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Executive Summary

The desalination of brackish groundwater is one of a number of innovative technologies that is generating much interest in meeting the ever-increasing water demands in Texas. Desalination is the process of removing dissolved minerals from water, thus making the water more palatable for consumption. The term *brackish* refers to water that is slightly to moderately saltier than fresh water, typically containing total dissolved solids (TDS) in concentrations ranging from 1,000 to 10,000 milligrams per liter (mg/l).

For desalinated brackish groundwater to be a viable water supply option, two principal hydrologic components must be met. First, the subsurface water-bearing formation (aquifer) must be capable of yielding a sufficient volume of water over the desired lifetime of the desalination facility. And second, the water chemistry (concentration and constituent makeup of the dissolved mineral content) of the brackish groundwater must be within a range such that desalination can be economically achieved at a reasonable cost compared to other water supply alternatives. The intent of a brackish groundwater exploration project is to evaluate these two components. This manual describes activities that may be expected during the exploration phase of a desalination project. As part of the exploration project, certain activities such as drilling, testing, and waste fluid disposal may fall under regulatory guidelines governed by the Texas Commission on Environmental Quality (TCEQ), the Texas Department of Licensing and Regulation (TDLR), and local groundwater conservation districts.

Identifying a brackish groundwater source starts with a review of available information pertaining to local groundwater resources in the form of reports, maps, water well data, and geophysical logs. Based on depth, thickness and orientation of the geologic formation that hosts the aquifer, a preferential exploration corridor can be determined. The actual siting of test wells within the preferential exploration corridor now becomes a function of landowner cooperation, accessibility, and physical site conditions.

The next step is to drill a test well, or a series of test wells to provide more detailed hydrologic characterization of the water-bearing strata. Well yield and chemical quality test results from these wells will determine if the aquifer is capable of meeting the source supply requirements of the desalination project. The drilling and completion of a test well basically follows similar procedures and techniques used in drilling and completing a well that will be used for production purposes. However, because the aquifer to be explored is brackish, protection of freshwater supplies is paramount.

Data collection at the well site provides important information about the subsurface rock formations and the aquifers they contain. The subsurface geology is viewed in the crushed rock particles (drill cuttings) that are circulated to the surface. Borehole geophysical surveys are another important means of obtaining information from a test well. Following the completion of drilling, a pumping test is performed to measure the aquifer's capacity to produce water. Important measurements made during a pumping test are discharge rate and water-level decline versus time. Groundwater samples that accurately represent the chemistry of an aquifer should be collected according to proper procedures. Accurate water-sample analyses are necessary for the design phase of the desalination plant. Limited data on brackish aquifers may require

alternative methods of evaluating long-term supply availability, such as groundwater flow modeling. Assuming that a test well is not to be converted into a production well or retained as a water-level or water-quality monitoring well, the well will generally be plugged and the drilling site restored to an acceptable condition.

BRACKISH GROUNDWATER

EXPLORATION GUIDANCE MANUAL

Introduction

As the population of Texas continues to grow, an ever-increasing demand is being placed on the State's limited fresh-water resources. New innovative technologies are thus needed to meet these growing needs. The desalination of brackish water, including both surface water and groundwater, is one such technology that is generating much interest. Desalination is the process of removing dissolved minerals from water. Improvements in membrane technology in recent years have increased the efficiency and effectiveness of desalination, while significantly decreasing the cost of the process. In the most recent round of regional water planning (2007), eight of the 16 regional water planning groups recommended desalination as a water management strategy (http://www.twdb.state.tx.us/publications/reports/State_Water_Plan/2007/2007StateWaterPlan/2007StateWaterPlan.htm).

The Texas Water Development Board (TWDB) reports that there are currently 88 public water supply desalination plants in Texas, with a combined capacity of approximately 53 million gallons per day (MGD) of fresh water. In addition, more than 100 other desalination plants with a combined capacity between 60 to 100 MGD are used for industrial applications. This information, along with answers to frequently asked questions, is available from the TWDB website: (http://www.twdb.state.tx.us/iwt/desal/faqbrackish.html).

For desalinated brackish groundwater to be a viable water supply option, two principal hydrologic components must be met. First, the subsurface water-bearing formation (aquifer) must be capable of yielding a sufficient volume of water over the desired lifetime of the desalination facility. And second, the water chemistry (concentration and constituent makeup of the dissolved mineral content) of the brackish groundwater must be within a range such that desalination can be economically achieved at a reasonable cost compared to other water supply alternatives. The intent of an exploration project is to evaluate these two components. This guidance manual will assist interested parties in developing just such a project.

The development of this manual was coordinated with the Upper Colorado River Authority and funded by the TWDB. A companion brackish groundwater desalination guidance manual, currently being developed by NRS Consulting Engineers for the North Cameron Regional Water Supply Corporation and similarly funded by the TWDB, is expected to also be available in 2008.

What is Brackish Water?

The term *brackish* refers to water that is slightly to moderately saltier than fresh water, typically containing total dissolved solids (TDS) in concentrations ranging from 1,000 to 10,000 milligrams per liter (mg/l). By comparison, seawater has a TDS concentration of approximately 35,000 mg/l. In a reverse-osmosis desalination system, the greater the TDS concentration of the water, the higher the pressure needed to push water through the membranes, and consequently, the higher the energy cost. Desalinating seawater is, therefore, usually more costly than desalinating brackish groundwater. In a report prepared for the TWDB, LBG-Guyton Associates (2003) estimated that there is approximately 2.7 billion acre-feet of brackish groundwater "in place" in Texas aquifers (http://www.twdb.state.tx.us/RWPG/rpgm_rpts/2001483395.pdf). Figure 1 provides a statewide view of the general location of brackish groundwater sources.

Getting Started

Now that the decision has been made that brackish groundwater desalination might be a viable water-supply alternative and worthy of further evaluation, how do you get started? At the start of any project of this magnitude, there will be more questions than answers. However, these questions are important in that they set the framework for what is to be accomplished in the exploration project. Here are a few questions that might be generated:

- How do I determine if there is a potential brackish groundwater source within a reasonable distance from my community?
- How do I design a drilling and testing program to evaluate the groundwater source potential?
- How do I determine if the brackish groundwater source will be sustainable over time?
- What regulatory issues might I face?
- How much will the exploration project cost?

The first step in answering these questions is to get some free information and advice. The best starting point is with the TWDB. A wealth of information and resources are available from the following TWDB link: http://www.twdb.state.tx.us/iwt/desal.asp. Also visit directly with TWDB staff to learn more about desalination activities within the state.

Another source of information may lie within the Regional Water Plan for your area (http://www.twdb.state.tx.us/rwpg/main-docs/2006RWPindex.asp). These plans contain not only projections of future water needs, but also numerous strategies for meeting these needs; including, in some areas, potential brackish groundwater desalination alternatives. Figure 2 shows the location of the 16 water-planning regions in the state.

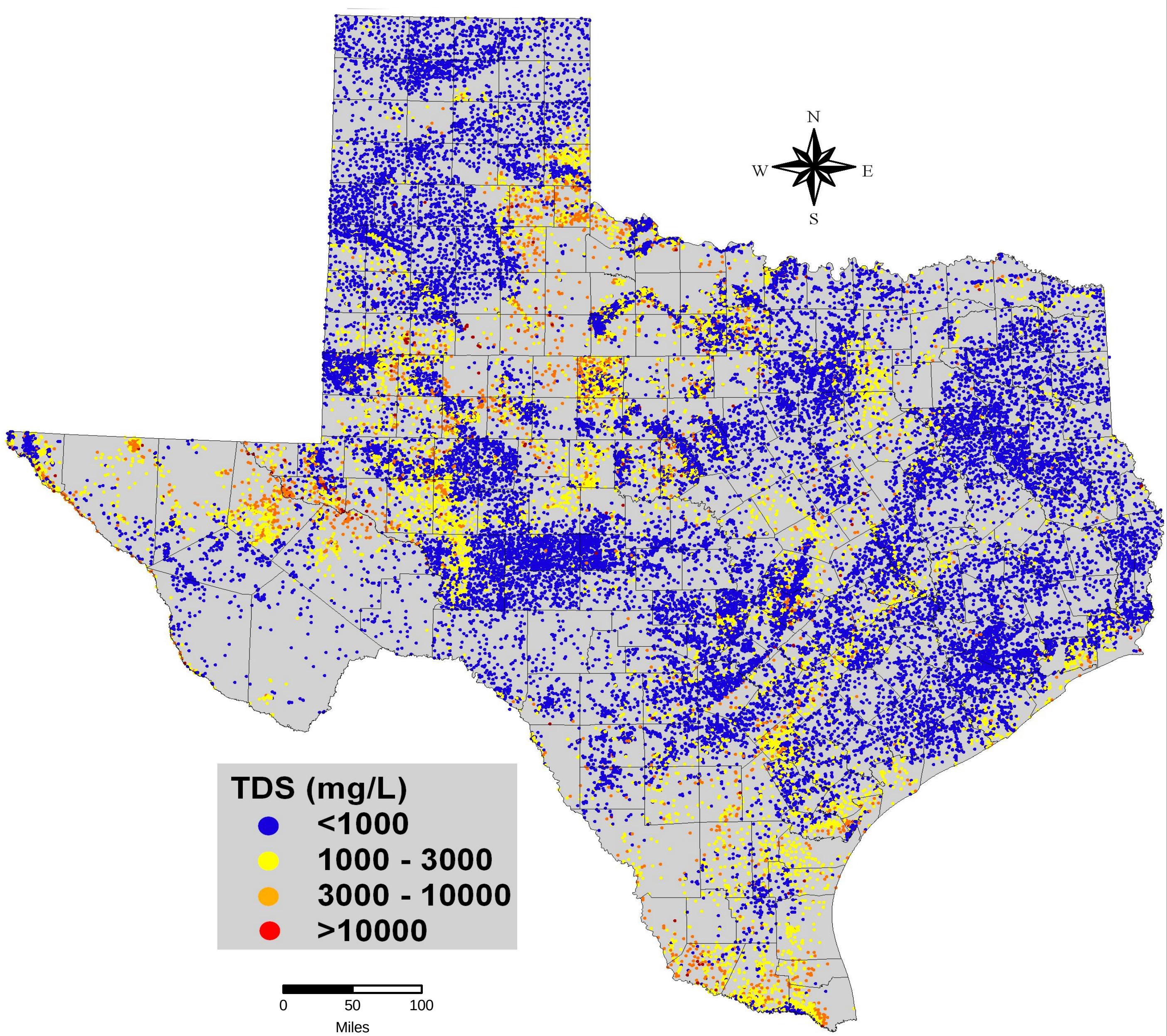
The next step is to inquire about existing groundwater desalination projects both in Texas and elsewhere. These communities are generally eager to discuss the pros and cons that they have experienced and may have project reports that they would be willing to share. Visit their facilities and ask specific questions pertaining to the route they took to get to where they are today.

However, the specific answers to your initial set of questions are relatively detailed, are site specific to your community, and will generally require a level of expertise that is not readily available from existing city staff. Thus, it is often wise at this point to consider hiring an engineering consultant that can assist your community in developing the scope and carrying out the individual elements of the project. A competent consultant, or team of consultants, should be able to demonstrate the following:

- Successful experience with similar brackish groundwater desalination projects
- Geohydrologic and engineering knowledge pertaining to every aspect of the project
- Knowledge of federal, state, and local regulations
- Be a licensed engineer and/or geoscientist
- Ability to work with subcontractors to successfully complete the project
- Ability to communicate with the client (your city staff) as well as the general public

The consulting engineering company usually provides construction, observation and inspection services during the drilling, construction and testing of the wells. A greater field effort will be required while the wells are being drilled and constructed as decisions are occurring regarding the casing and screen settings, cementing operation, well development, and pumping test of the test well. Some of the components that an engineering company may be involved with include the following:

a. Provide construction management services during the contractor mobilization, well location staking and clearing of land for construction access.
b. Review and process contractor’s submittals including monthly pay estimate requests, requests for information and change requests during construction. Preparation of progress meeting minutes with contractor and checking of project completion items.
c. Provide construction management services including observation of significant phases of the drilling, water sampling and testing operations.
d. Obtain services and coordinate work of survey firm to stake test and monitoring well locations including establishment of temporary benchmarks and construction staking for roads and well sites for use by contractor.
e. Review manufacturer’s warranties or bonds on materials and equipment incorporated in the project.
f. Conduct project status meetings and keep the client and the other project participants informed as drilling and construction proceed.
g. Evaluate contractor change and cost proposals and substitutions and recommend to the client to either approve or disapprove the contractor’s proposal or substitution.



From TWDB's "Brackish Groundwater Manual for Texas Regional Water Planning Groups" prepared by LBG-Guyton Associates, 2003.

STATE MAP OF WATER WELLS WITH VARYING QUALITY RANGES

FIGURE 1

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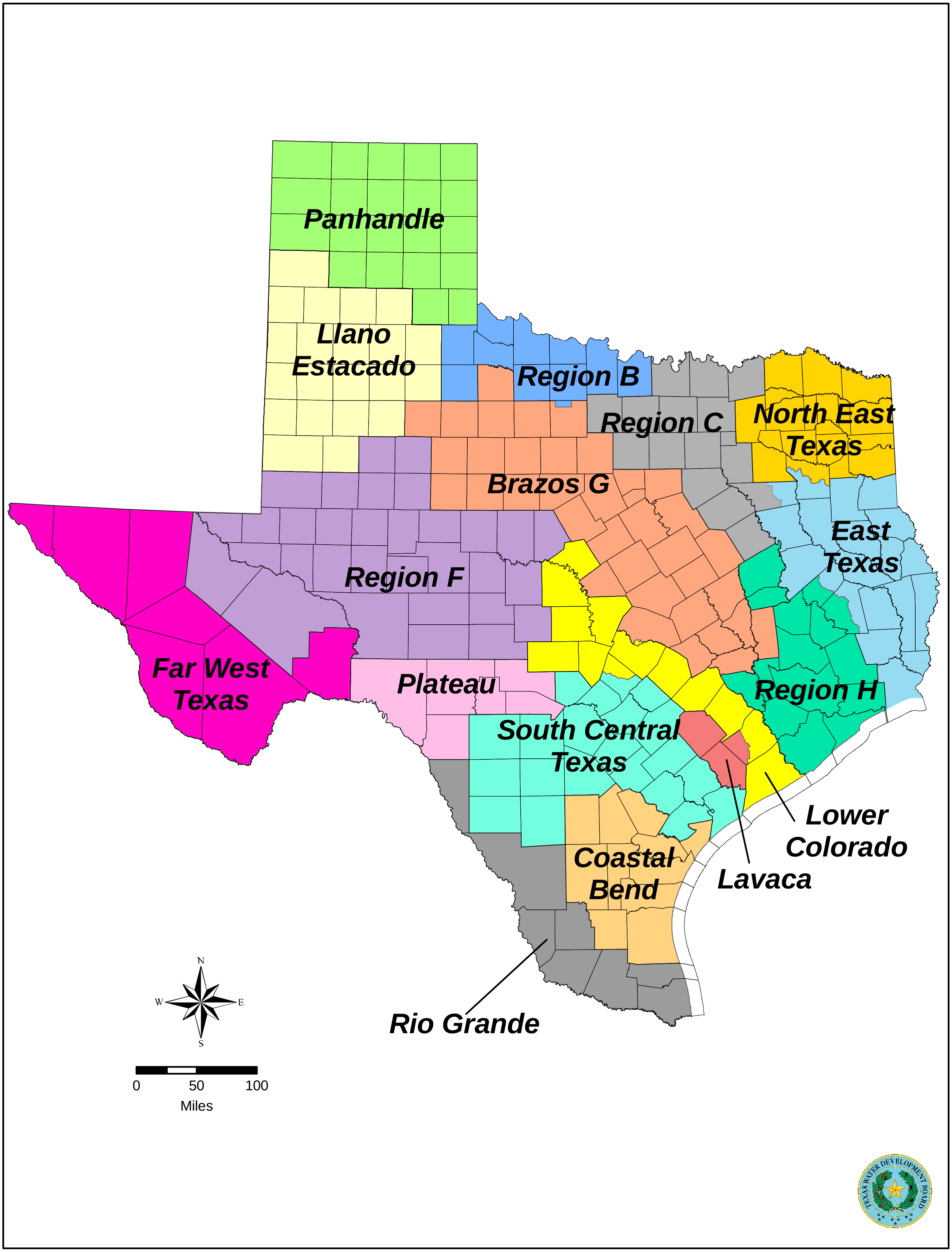

STATE MAP OF 16 REGIONAL PLANNING AREAS

FIGURE 2

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The following sections of this manual describe the activities that may be expected by your staff or by your chosen consultant during the exploration phase of a desalination project. Although most of these activities parallel those that occur when exploring for fresh groundwater, greater care must be taken when encountering brackish to saline groundwater so that fresh-water zones are not contaminated.

Regulatory Considerations

As a part of the exploration project, certain activities such as drilling, testing, and waste fluid disposal may fall under regulatory guidelines. State of Texas statute declares that groundwater, regardless whether it is fresh, brackish or saline, belongs to the landowner under which it lies. However, throughout much of the state, the legislature has given authority to local groundwater conservation districts (Figure 3) to manage the development, use and protection of groundwater within their respective boundaries. Of primary concern to the district and local landowners in the vicinity of your project is that the drilling and testing procedures will not contaminate fresh groundwater aquifers.

Each district has its own set of rules that were locally developed to best protect groundwater resources. Although most district rules are intended specifically to protect fresh groundwater, some districts are being confronted with the need to develop rules pertaining to brackish sources. You can expect that district rules may cover such exploration activities as well drilling permits, use of a state licensed drilling contractor, well location, spacing of wells, well construction, well plugging, disposal of water, and data requirements. If your exploration project occurs within a county that has a groundwater conservation district, it would be prudent to visit with the district manager as early in the planning phase of the project as possible and keep him/her informed throughout the project. Links to the various groundwater conservation districts around the state can be seen at http://www.texasgroundwater.org/Links.htm.

The State of Texas requires that water well drillers operating within the borders of Texas be licensed by the Texas Department of Licensing and Regulation (TDLR). The licensed driller is required to follow specified guidelines intended to "… ensure the quality of the State's ground water for the safety and welfare of the public …" (http://www.tsbbe.state.tx.us/wwd/wwdrules.pdf). At the conclusion of the drilling operations, the driller is required to file a "Driller's Report" within 60 days with the TDLR (and possibly with the local groundwater conservation district) that contains information pertaining to location, depth, well construction, estimated yield, and description of rock layers penetrated (http://www.tsbbe.state.tx.us/wwd/wwd001.pdf) (Figure 4). Likewise, if the test well is eventually abandoned, an additional report is to be filed with the TDLR (see *Test Well Abandonment and Site Remediation* section - page 28 in this manual). Local groundwater conservation districts may also require copies of these reports.

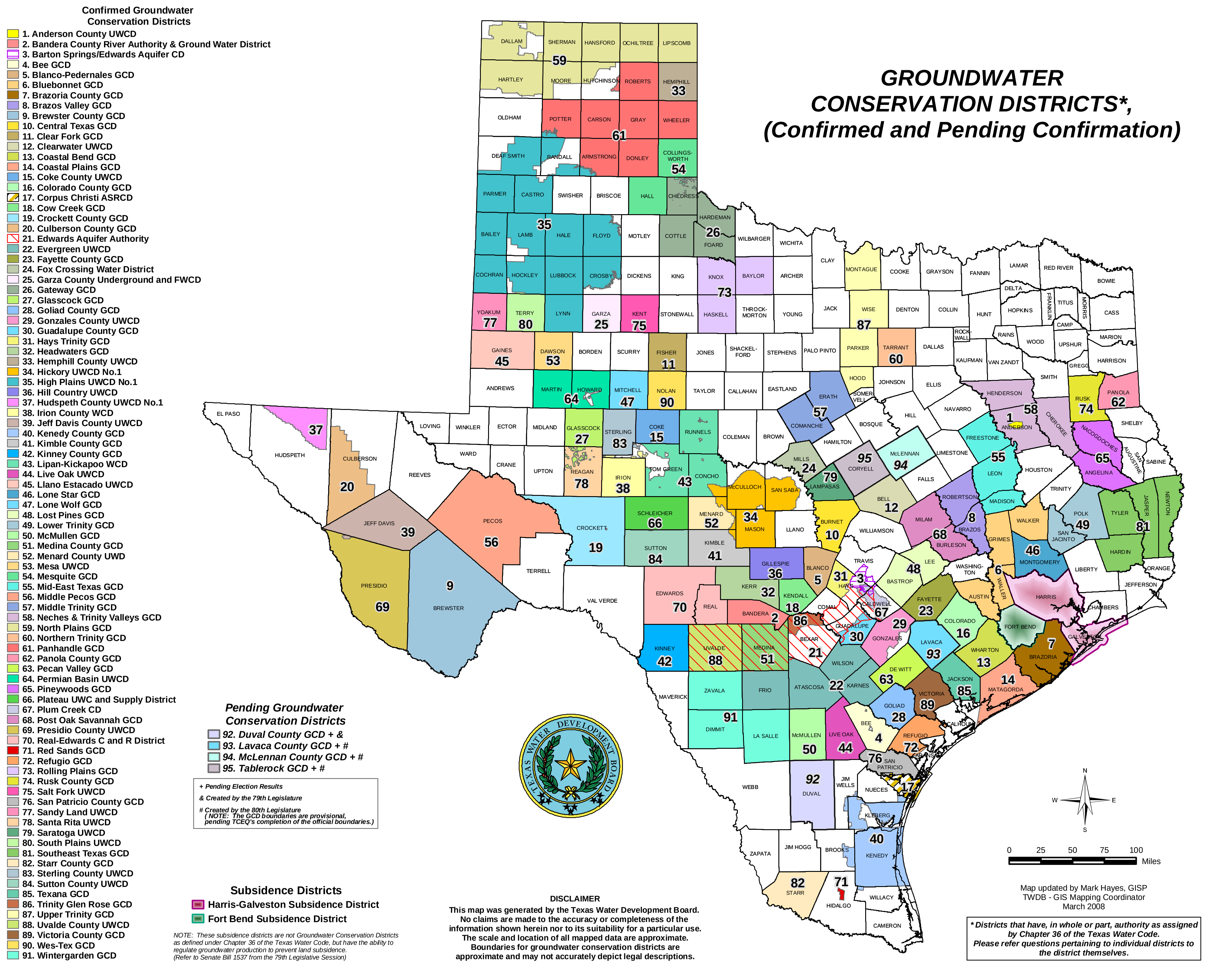


Figure 3 State Map of Groundwater Conservation Districts

Should your exploration project move forward toward the actual construction of a desalination facility, other regulatory requirements will come into play. Public water supply well design and operation, and disposal of the concentrate generated by the plant are just two components that will require regulatory permitting through the Texas Commission on Environmental Quality (TCEQ). A brackish groundwater desalination guidance manual currently being developed by NRS Consulting Engineers for the North Cameron Regional Water Supply Corporation and funded by the TWDB contains a wealth of information on regulatory requirements for permitting desalination plants in Texas.

Identifying a Brackish Groundwater Source

The current depth of knowledge pertaining to brackish groundwater resources in the state is significantly less than our understanding of fresh groundwater resources. This is principally because there has historically been very little interest in developing anything other than fresh water supplies. The search for a desirable brackish groundwater source may be comparable to the oil field concept of "wildcatting"; however, searching for brackish groundwater should not be considered a "shot in the dark".

Although information may be relatively limited, there are beneficial resources available for use in developing rational exploration decisions. Reports, maps, water well data, remotely sensed imagery, aerial photos, and geophysical logs are accessible to the public from the following agencies:

Texas Water Development Board
- Groundwater availability reports
- Water well database

Texas Commission on Environmental Quality
- Water quality data
- Geophysical logs

Texas Railroad Commission
- Oil and gas well data

United States Geological Survey
- Groundwater availability reports
- Water well database
- Topographic maps
- Remotely sensed imagery

University of Texas at Austin, Bureau of Economic Geology
- Geologic and hydrologic reports
- Geophysical logs
- Surface geology maps

Other Sources
- Groundwater conservation districts
- Local water well drillers

Attention Owner:
Confidentiality Privilege Notice on reverse side of owner's copy.

Texas Department of Licensing and Regulation

Water Well Driller/Pump Installer Section
P.O. Box 12157 Austin, Texas 78711 (512)463-7880 FAX (512)463-8616
Toll free (800)803-9202
Email address: water.well@license.state.tx.us Web address: www.license.state.tx.us

This form must be completed and filed with the department and owner **within 60 days** upon completion of the well.

WELL REPORT

A. WELL IDENTIFICATION AND LOCATION DATA

1) OWNER

Name:	Address:	City:	State:	Zip:

2) WELL LOCATION

County:	Physical Address:	City:	State:	Zip:

3) Type of Work
❑ New Well ❑ Reconditioning
❑ Replacement ❑ Deepening

Lat. **Long.** **Grid #**

4) Proposed Use (check) ❑ Monitor ❑ Environmental Soil Boring ❑ Domestic
❑ Industrial ❑ Irrigation ❑ Injection ❑ Public Supply ❑ De-watering ❑ Testwell
❑ Rig Supply ❑ Stock or Livestock If Public Supply, were plans approved? ❑ Yes ❑ No

5) N↑

6) Drilling Date
Started ____/____/____
Completed ____/____/____

Diameter of Hole

Dia.(in)	From (ft)	To (ft)
	Surface	

7) Drilling Method (check)
❑ Driven ❑ Air Rotary ❑ Mud Rotary
❑ Bored ❑ Air Hammer ❑ Cable Tool
❑ Jetted ❑ Hollow Stem Auger
❑ Reverse Circulation
❑ Other

From (ft)	To (ft)	Description and color of formation material

(Use reverse side of Well Owner's copy, If necessary)

8) Borehole Completion ❑ Open Hole ❑ Straight Wall
❑ Under-reamed ❑ Gravel Packed ❑ Other ____
Gravel packed interval from : ft. to: ft. **Size:**

Casing, Blank Pipe, and Well Screen Data

Dia. (in.)	New Or Used	Steel, Plastic, etc. Perf., Slotted, etc Screen Mfg., if commercial	Setting (ft) From	Setting (ft) To	Gage Casing Screen

9) Annular Seal Data: i.e. *(from 0 ft to 100 ft #sacks & material 13 cement)*
from ________ft. to ________ft. #sacks & material ________
from ________ft. to ________ft. #sacks & material ________
from ________ft. to ________ft. #sacks & material ________
Method Used________ Performed By ________
Distance to septic field or other concentrated contamination ________ft.
Distance to Property Line ______ft Method
Verified:________

13) Plugged ❑ Well plugged within 48 hours
Casing left in well: Cement/Bentonite placed in well:

From (ft)	To (ft)	From (ft)	To (ft)	Material used & # Sacks

10) Surface Completion (If steel cased, leave blank)
❑ Surface Slab Installed ❑ Surface Sleeve Installed
❑ Pitless Adapter Used ❑ Alternative Procedure Used

14) Type Pump
❑ Turbine ❑ Jet ❑ Submersible ❑ Cylinder
❑ Other________
Depth to pump bowls, cylinder, jet etc., ________ft.

11) Water Level
Static level ________ft. Date: ____/____/____
Artesian Flow ________gpm

12) Packers:

Type	Depth	Type	Depth

15) Water Test
Type test ❑ Pump ❑ Bailer ❑ Jetted ❑ Estimated
Yield: ______ gpm with ______ft. drawdown after ________hrs.

16) Water Quality
Type of water ________ Depth of Strata:________ Was a chemical analysis made? ❑ Yes ❑ No
Did you knowingly penetrate a strata which contains undesirable constituents? ❑ Yes ❑ No If yes, Continue:
Check One: ❑ Naturally poor-quality groundwater – type________ ❑ Hydrocarbons (i.e. gas, oil, etc.)
❑ Hazardous material/waste contamination encountered ❑ Other (describe) ________

❑ *I certify that while drilling, deepening, or otherwise altering the above described well, undesirable water or constituents was encountered and the landowner was informed that such well must be completed or plugged in such a manner as to avoid injury or pollution.*

Company & Individual's Name: (type or print) Lic. No.:

Address : City: State: Zip

Signature: ____ / ____ / ____ **Signature:**

Licensed Driller/Pump Installer	Date	Apprentice	Apprentice Reg. Number

TDLR FORM 001WWD / 9-03 *TDLR (Original)* *Landowner (copy)* *Driller/Pump Installer (copy)*

WELL DRILLER'S WELL COMPLETION REPORT FORM **FIGURE 4**

A "Brackish Groundwater Manual ---" prepared for the TWDB provides a description of many brackish aquifers throughout the state and can be viewed at: (http://www.twdb.state.tx.us/RWPG/rpgm_rpts/2001483395.pdf). The water well database maintained by the TWDB (http://www.twdb.state.tx.us/GwRD/waterwell/well_info.asp) is particularly useful in that it contains information pertaining to location, aquifer, depth, well construction, water level, water chemistry, and yield for thousands of water wells throughout the state. The TWDB also has a very useful interactive site for rapidly viewing individual well data in desired locations (http://wiid.twdb.state.tx.us/).

Another important tool in evaluating brackish aquifers in areas with limited water well data are oil field geophysical logs. Geophysical surveys are almost always performed on oil and gas wells that often penetrate through the potential brackish target zones. With these logs as a starting point, a three-dimensional framework (thickness and angle of dip) of the brackish aquifer can be determined. The use of geophysical logs is also discussed in following sections pertaining to "Data Collection Procedures ---" (page 18) and "Water Quality Sampling ---" (page 26).

The process starts by using geologic and hydrologic data obtained from the above sources to determine which geologic formations offer the best potential for the production of brackish groundwater in terms of well yield, well depth, water level elevation, water chemistry, and transport distance.

> ***Well Yield*** - The potential well yield of an individual formation is a function of the rock's porosity, permeability, and thickness. Rock formations composed of sandstone or fractured limestone are generally more water bearing than formations consisting mostly of silt and clay. Note that when reviewing existing well data that small and shallow domestic and stock wells may not penetrate the full thickness of the water-bearing zone and thus their reported yield is often less than the optimal yield that might be obtained from a properly designed well. The average yield that can be obtained from the aquifer will determine the number of wells that will be required to provide the total supply of water that is desired from the project.
>
> ***Well Depth*** - Brackish groundwater is often (but not always) encountered at greater depths than fresher groundwater. Well depth is important in terms of both drilling and construction costs.
>
> ***Well Level Elevation*** - Although artesian water levels may rise significantly above the top of the water-producing formation, deeper pumping levels will require greater energy to lift the water to the land surface.
>
> ***Water Chemistry*** - As expressed earlier, the concentration of dissolved minerals in the brackish source-water supply plays a critical role in the economic viability of the desalination process. A more detailed discussion pertaining to this critical component is provided later in this manual.

Transport Distance – Because of the significant cost of pipelines, it is of fiscal importance to consider the distance from a brackish groundwater source to the potential location of the desalination facility, as well as to the desalinated water's final distribution destination.

After a thorough review of existing hydrogeologic data, more than one brackish aquifer may be identified. If this is the case, it may be helpful to organize the data for each source into a matrix (*such as the one shown below*) so that the range of data values can be compared, and the potential brackish sources thus prioritized.

Brackish Water Source	Well Yield (gpm)	Depth of Wells (feet)	Depth to Water (feet)	Water Quality (TDS)	Transport Distance (miles)	Source Priority Order
A	20- 60	1200 – 1500	600 –800	4000 - 5000	8 - 12	2
B	**100 – 250**	**600 – 800**	**200 – 300**	**1500 - 2000**	**4 - 5**	**1**
C	40 - 80	1800 - 2200	1200 - 1500	15000 - 18000	18 - 20	3

In this example scenario, brackish water source B is the obvious choice. However, in a real case scenario a single source may not be the best choice under every category. In such a case, it may be necessary to do a preliminary cost analysis to reassess the proper priority order.

Selecting an Exploration Site

Now that a brackish aquifer source has been identified, the next step is to drill a test well, or a series of test wells to provide more detailed hydrologic characterization of the water-bearing strata. Well yield and chemical quality test results from these wells will determine if the aquifer is capable of meeting the source supply requirements of the desalination project. The question now is where to position the test wells to best achieve this aquifer characterization evaluation.

Based on depth, thickness and orientation (dip direction) of the geologic formation that hosts the aquifer, along with any available well data, a preferential exploration corridor can be drawn on a surface map. The length, width, orientation and position of the preferential exploration corridor represents an area that an investigator feels has the best potential for wells to encounter desirable brackish groundwater supplies. In time, the results from the test wells will further refine this preferential corridor.

Once the general area or corridor of exploration has been determined and prior to actually designing the test wells, there is an important question to be considered; assuming a set budget for the drilling and testing program, how many and what size test wells are to be drilled. The geographical size of the area of interest and the variability of the aquifer will determine the number of wells needed to characterize the potential production area. If the aquifer characteristics are similar over the entire potential production area, then fewer test wells may be required. The options can be grouped into three basic scenarios: (1) multiple small-diameter wells; (2) fewer large-diameter wells; and (3) a combination of the first two.

Option one calls for the drilling of small-diameter test wells with minimal or no casing.
Pros: Because of lower cost, more wells can be drilled, thus exposing aquifer information over a larger area. Data derived from these wells are limited mostly to determining the depth and thickness of the brackish aquifer, a general yield estimate based on jetting of the wells, and a general estimate of water quality averaged over the entire exposed borehole.
Cons: The small diameter does not allow for the detailed examination of potential yield and water quality of individual water-bearing zones within the aquifer.

Option two provides for fewer test wells than option one but larger-diameter cased test wells.
Pros: Casing insures the integrity of the well and seals off undesirable water-bearing zones above and below the targeted brackish aquifer. The larger diameter also allows for the insertion of a pump for the withdrawal of water from the well, thus providing more accurate measurements of yield and water quality. If desired, these large-diameter cased test wells can potentially be converted into production wells.
Cons: The significantly greater cost of drilling and completing large-diameter test wells might be considered a gamble. There is always the possibility that the chosen drill site might be located in a less than desirable part of the aquifer and subsequently the well may be abandoned for more productive locations.

If the budget allows, the third and probably most prudent option is a combination of the previous two options. The multiple small-diameter test wells provide the spatial information needed to select the best locations for larger-diameter wells, thus taking much of the gamble out of their positioning.

The actual siting of test wells within the preferential exploration corridor now becomes a function of landowner cooperation, accessibility, and physical site conditions. Many obstacles might be avoided if the municipality or other entity conducting the project owns the land within the exploration corridor. However, in most cases, the land will probably be privately owned. In such case, landowner cooperation is essential. It would be prudent to work out considerations pertaining to leases, water rights acquisitions, or direct water sales in advance of the test wells.

Liability and access issues pertaining to working on private land should also be coordinated in advance. The landowner will likely have a say in where he will allow access on his property, and will be highly sensitive to any damages that might occur to roads, fences, creeks and ponds, livestock, and other personal property.

A desirable test well drilling site should be easily accessible from a public road (preferably in all weather conditions) by the drilling contractor's equipment, which will include the drilling rig and pipe trailer, a large water truck, and various other personal and service vehicles. The site itself should be large enough to allow for maneuvering of the drill rig and other vehicles, and if practical at a slightly higher elevation to avoid swampy conditions. It may be prudent to fence off the drilling site or at least the mud circulating pits to prevent livestock or wildlife from wandering into the site. An aerial photo of the general location may be useful in selecting specific well locations that meet the above specifications.

The drilling process requires a varying amount of water and, therefore, access to a water supply is mandatory. A local water supply source would be most desirable but is not generally available within close proximity to the site and, thus, water must often be delivered to the site. The landowner may allow water to be siphoned from a pond, tank, or creek, or possibly pumped from an existing water well on his property. If water is withdrawn from a creek or river, a temporary water right permit may be required from the TCEQ. To avoid delays, access to a water supply should be established prior to moving equipment to the site.

Selecting a Drilling Contractor - The Bid Process

Water well drilling and construction projects for public entities generally require an open bidding process. In order to retain a drilling contractor to perform the drilling and construction of water wells, a "bid package" should be compiled. A "bid package" for a public water supply entity is required to be prepared or at least supervised by a professional engineer licensed in the State of Texas. The package generally includes design specifications for the well(s), bidding requirements, summary of work to be performed, standards for completion of work, any special bond or insurance requirements, and a bid proposal with tabulated cost for completing work (Figure 5).

An advertisement for interested bidders is prepared and published. Specific contractors with known expertise also may individually be notified of the opportunity to bid on the work. Once potential contractors have responded, each contractor is supplied with a “bid package” with an invitation to bid, and a pre-bid meeting is scheduled to discuss and outline the work to be bid upon. A bid submittal date is given and the contractors are allowed to bid on the proposed work using the supplied tabulated bid sheet. For public entities, a public opening of the bids is often scheduled.

After the bid opening, an evaluation of the bid and qualifications of the contractors is performed. At this time, any bid modifications or requested variances from the specifications can be noted and evaluated. In evaluating the contractor, some of the important considerations are:

1) Is the drilling contractor licensed by the Texas Department of Licensing and Regulation?
2) Does the contractor have experience with similar drilling projects with similar subsurface characteristics such as depth and types of strata (sand or limestone)?
3) Does the contractor have adequate equipment (size and type of drill rig, mud pump or air compressor, and support vehicles) available to complete all phases of well construction and testing within the desired time-frame?

Item No.	Description	Est. Qty.	Unit	Unit Price	Extended Amount
	Part 1: Project Mobilization				
1.	Mobilization/Demobilization and setup (see note)	1	EA	$_________	$_________
	Unit Price in Words ______________________________				
	Part 2: Phase 1 - Option B Mud Rotary Test Hole				
1.	Furnish and install 16-inch nominal diameter surface casing in 20-inch hole at a base depth of 200 feet and pressure cement	600	LF	$_________	$_________
	Unit Price in Words______________________________				
2.	Drill one 8- to 10-inch diameter test hole from a base depth of 200 feet to a base depth of 650 feet with direct circulation mud rotary method, with driller's formation log, and formation samples all as specified in Phase I – Option B	1350	LF	$_________	$_________
	Unit Price in Words ______________________________				
3.	Standard geophysical logging suite for test hole	3	EA	$_________	$_________
	Unit Price in Words ______________________________				
4.	Ream test hole to 12 inches from a base depth of 200 feet to a base depth of 650 feet with direct circulation mud rotary method	1350	LF	$_________	$_________
	Unit Price in Words ______________________________				

Figure 5 Typical Bid Proposal

Design and Installation of Test Wells

The drilling and completion of a test well basically follows similar procedures and techniques used in drilling and completing a well that will be used for production purposes (Bloetscher and others, 2007). The principal difference is that a test well may be abandoned and plugged after testing has been completed. TAC 76.1000 provides the technical guidelines for drilling and completion of water wells (http://www.tsbbe.state.tx.us/wwd/wwdrules.pdf).

Cost considerations play a key role in the design process, with the costs incurred by the drilling contractor consuming the largest part of the test well project budget. The contractor's cost per well is dependent on the diameter and depth of the well, type of completion (open hole, gravel-packed screened casing, etc.), and other appurtenances. Many drilling contractors can estimate drilling and construction costs based on the number of feet to be drilled at a particular diameter, and then add on cost of materials (casing and screen) and cementing installation. Table 1 lists typical unit costs from recent bid tabulations for test wells of common size. Unit costs can vary widely depending on drilling contractor availability, and on current material cost, availability, and transport distance. Costs for engineering geotechnical services, geophysical logging services, and water quality analyses are dependent on the range of services desired, but represent a relatively small proportion of the overall budget.

Table 1 Major Test Well Bid Items with Estimated Unit Cost Ranges

Item	Unit	2008 Unit Price Estimated Range
Mobilization/Demobilization (per site)	each	$30,000 - $80,000
Pilot hole (10 inches or less)	linear feet	$30 - $60
Standard geophysical logging suite	each	$4,000 - $10,000
Reaming pilot hole (12- to 20-inch final diameter)	linear feet	$30 - $100
Conduct temporary well water sampling operation	each	$25,000 - $50,000
Plugging and abandonment (10- to 14-inch hole)	linear feet	$12 - $30
Well Casing (8-inch)	linear feet	$30 - $60
Well Casing (12-inch)	linear feet	$75 - $150
Well Screen (8-inch, stainless steel)	linear feet	$150 - $300
Filter pack installation	linear feet	$30 - $75
Cementing Casing	linear feet	$50 - $90
Install test pump, conduct pumping test	each	$40,000 - $60,000

Prior to mobilizing equipment to the project location, some site preparation may be required. A temporary or permanent all-weather road constructed of caliche or gravel may be necessary for equipment to move to and from the site (Figure 6a). A raised pad is often constructed such that the drilling site will be well drained (Figure 6b). And shallow pits may be dug adjacent to the drilling rig for circulating drilling fluids during drilling operations (Figure 6c).

The type of strata (consolidated or unconsolidated) to be encountered will dictate types of drilling, whether that is mud rotary, air, water or air-assisted reverse circulation. Each site should start with a slim, smaller diameter pilot hole drilled past the total desired depth to characterize the brackish aquifer. A geophysical log is then run in the slim hole to compare to the cuttings and samples retrieved during drilling. If the formation is principally composed of sand, then sieve analyses should be performed to measure grain size and sorting to help determine possible gravel pack and screen size for the well.

Upon assessment of the cuttings and geophysical log, the range in potential yields might be estimated. From this information, ranges in well size and diameter can be made depending on the potential yield of the well and the depth of the pumping water level. Smaller diameter wells can only accommodate smaller pumps, which result in a lower flow rate.

Additional monitoring wells located near the test well are optional on exploratory projects. These are usually smaller in diameter and less costly to complete. TAC 76.1000(b) 3-4 provides guidance on the required construction methods for monitoring wells. Water levels measured in monitoring wells during a pumping test provide the needed data to calculate the storage coefficient of the aquifer. Monitoring wells can also show nearby variability of the geology through its drill cuttings and geophysical logging.

Because the aquifer to be explored is brackish, protection of freshwater supplies is paramount. All precautions must be taken to protect the freshwater supply and prevent mixing between aquifers. Holding tanks are usually needed to control drilling fluids from entering surface water sources.

Surface casing may have to be installed and cemented prior to drilling the brackish aquifer to prevent contamination to freshwater aquifers. This is especially true in locations where a freshwater aquifer overlies the brackish aquifer. The casing is generally composed of steel and either the joints are welded or threaded and coupled. All installed casing should be centralized in the borehole to ensure that cement can be injected in a manner that completely surrounds the casing string.

After setting the well casing, the contractor will pressure cement the casing, which usually involves pumping cement from the interior base of the casing and circulating upward through the annulus to ground surface. Because of the expected water chemistry, special care should be taken in how the cement is prepared in terms of content and weight.

a. ROAD PREPARATION

b. DRILL-SITE PAD CONSTRUCTION

c. DRILLING MUD CIRCULATION PITS

PRE-DRILLING SITE PREPARATION **FIGURE 6**

Data Collection Procedures at the Well Site

Data collection begins immediately as the drill bit first pierces the land surface. As the drill bit penetrates deeper into the earth, crushed rock particles (drill cuttings) are brought to the surface. These rock particles provide the first opportunity to observe and describe the rock formation being penetrated. If requested, the drilling contractor will collect these cuttings at desired intervals (usually 5-foot or 10-foot) and place them where they can be examined in more detail (Figure 7a). A geoscientist (rig geologist) is often employed to examine and describe these cuttings on site (Figure 7b); and from this information, make critical drilling-procedure decisions. Examination of drill cuttings provides information pertaining to what type of rock is being encountered and when changes occur from one geologic formation to the next. This is important when targeting a specific formation as the primary water-bearing zone. The rig geologist may also be on hand later to conduct pumping tests and collect water quality samples.

The drilling contractor is also responsible for reporting specific information encountered at the drill site. At the conclusion of the drilling operations, the driller is required to file a "Driller's Report" with the Texas Department of Licensing and Regulation that contains information pertaining to location, depth, well construction details, estimated yield, and a description of rock layers penetrated.

Borehole geophysical surveys are another important means of obtaining information from a test well. Upon reaching total depth of a test well, a geophysical logging contractor is called in to perform this service. Sensing devices are lowered into the test well and then slowly retrieved back to the surface (Figure 8). On their way up the borehole, the various sensors record physical parameters that may be interpreted in terms of rock characteristics such as lithology, geometry, and fluid hydraulics (Keys and MacCary, 1971) (Figure 9). Some of the more useful logging sensors for groundwater exploration are:

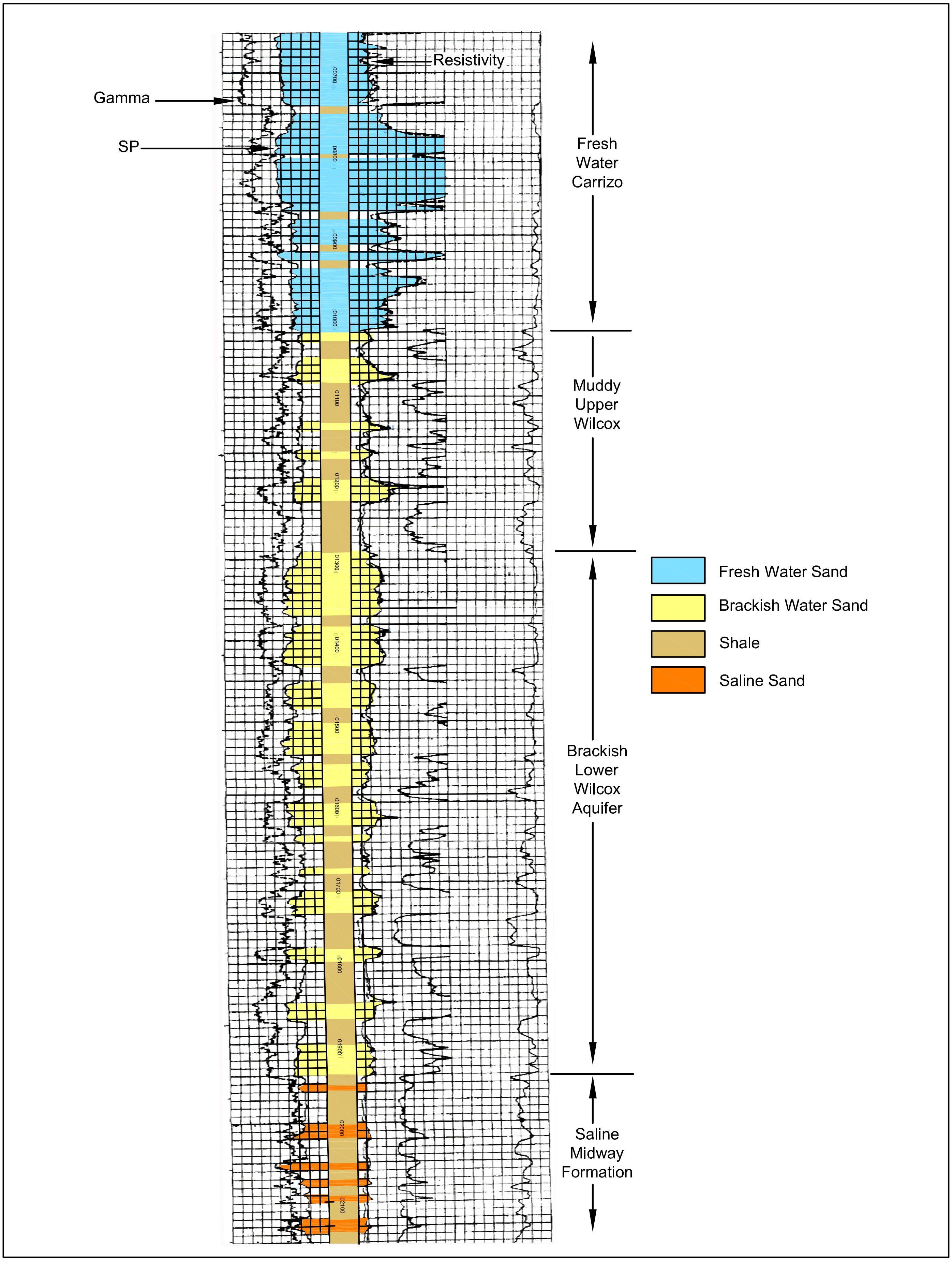
- *Spontaneous-potential (SP)* – Measures the natural potential developed between the borehole fluid and the surrounding rock materials. Used for geologic correlation, bed thickness, and distinguishing between porous and non-porous rocks in shale-sandstone and shale-carbonate sequences.
- *Resistivity* – Measures the electrical resistivity of the formation under the direct application of an induced electrical current. Used for estimating formation porosity, water saturation and salinity.
- *Gamma* – Measures the natural radiation that is emitted by the surrounding formation and usually reflects clay and shale content in sedimentary rocks.
- *Neutron* – Measures induced formation radiation. Used to measure moisture content above the water table and total porosity below the water table.
- *Acoustic* – Measures the transit time of an acoustic pulse between transmitters and receivers in the probe. Used to measure porosity and identify fractures in the rock.
- *Caliper* – Measures the diameter of the borehole and casing.
- *Temperature* – Measures the in-situ formation fluid temperature.
- *Fluid Conductivity* – Measures the conductivity of the inhole liquid between electrodes in the probe. Used to estimate the chemical quality of the borehole fluid.

a. DRILL CUTTING SAMPLE PILES

b. GEOLOGIC EVALUATION OF DRILL CUTTINGS

DRILL CUTTINGS **FIGURE 7**

GEOPHYSICAL WELL LOGGING SERVICE **FIGURE 8**



EXAMPLE OF EVALUATED GEOPHYSICAL LOG **FIGURE 9**

Geophysical logs run on the test well can also be compared to similar logs run on other wells in the area. Log correlation between wells allows the interpreter to estimate formation dip direction, change in thickness, and possible change in lithologic character (Figure 10). Using previously run geophysical logs with resistivity curves can be an important tool for determining the anticipated salinity and extent of the brackish groundwater.

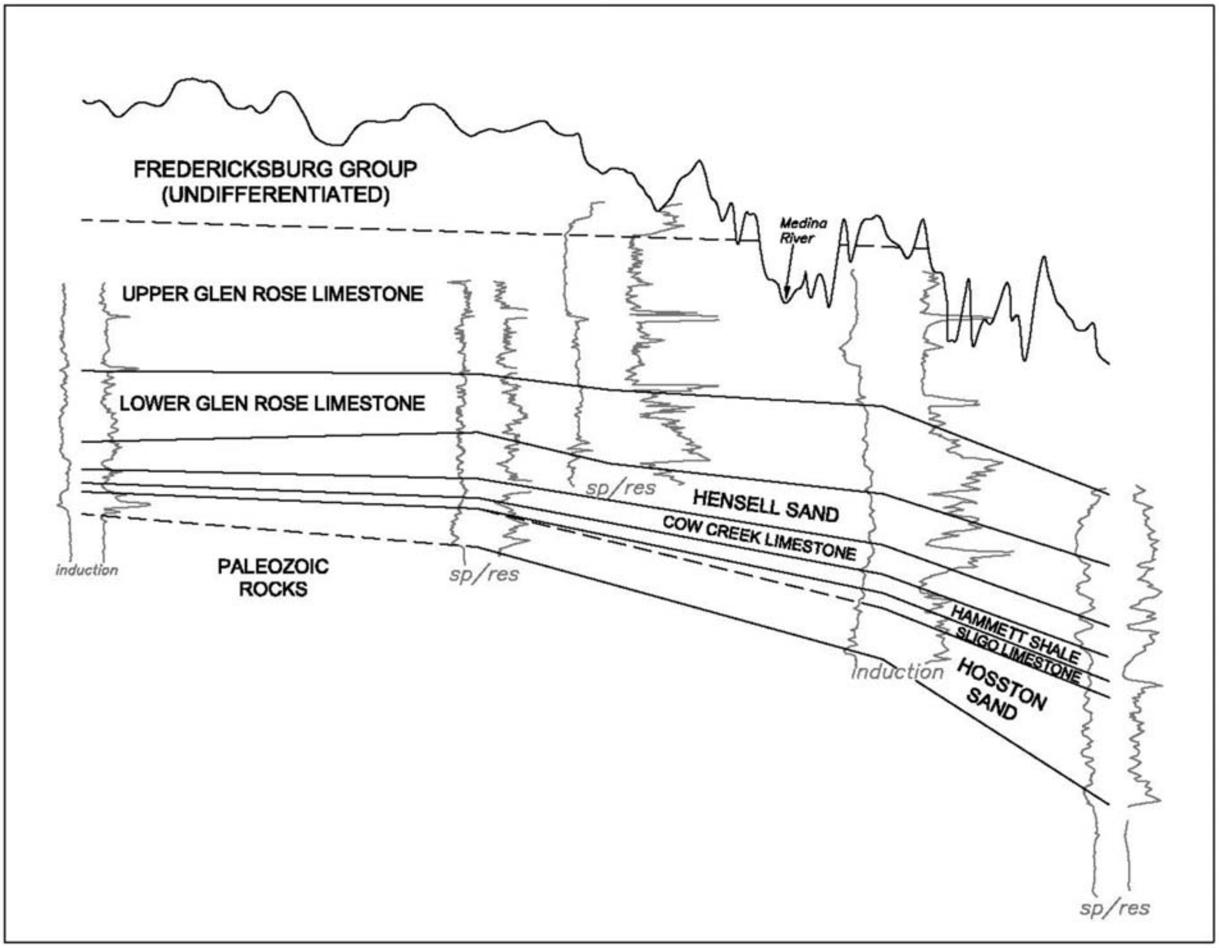


Figure 10 Example Geologic Cross Section Correlation with Geophysical Logs

Design, Performance and Evaluation of Pumping Tests

When a well is pumped and water is withdrawn from an aquifer, the water level surface in the vicinity is drawn down to form an inverted cone with its apex located at the pumping well. This is referred to as a "cone of depression". Groundwater flows from higher water levels to lower water levels and, therefore, in the case of a pumping well, toward the well or the center of the cone of depression. The shape and size of the cone is directly related to the aquifer's hydraulic parameters. Pumping tests are the accepted standard for evaluating this cone of depression, and thus determining an aquifer's capacity to produce water.

Prior to beginning a pumping test, the test well should be properly developed, meaning that the well is pumped sufficiently long to insure that all drilling fluid, well cuttings, and other debris are removed and the well is flowing water directly from the aquifer. The pump is then shut off and the water level in the well is allowed to recover to static condition. At this point, a simple specific capacity test can be conducted to establish the approximate range in flow and water-level drawdown that might be expected. For the test, the pump is restarted and allowed to run at a specified flow rate for generally less than an hour.

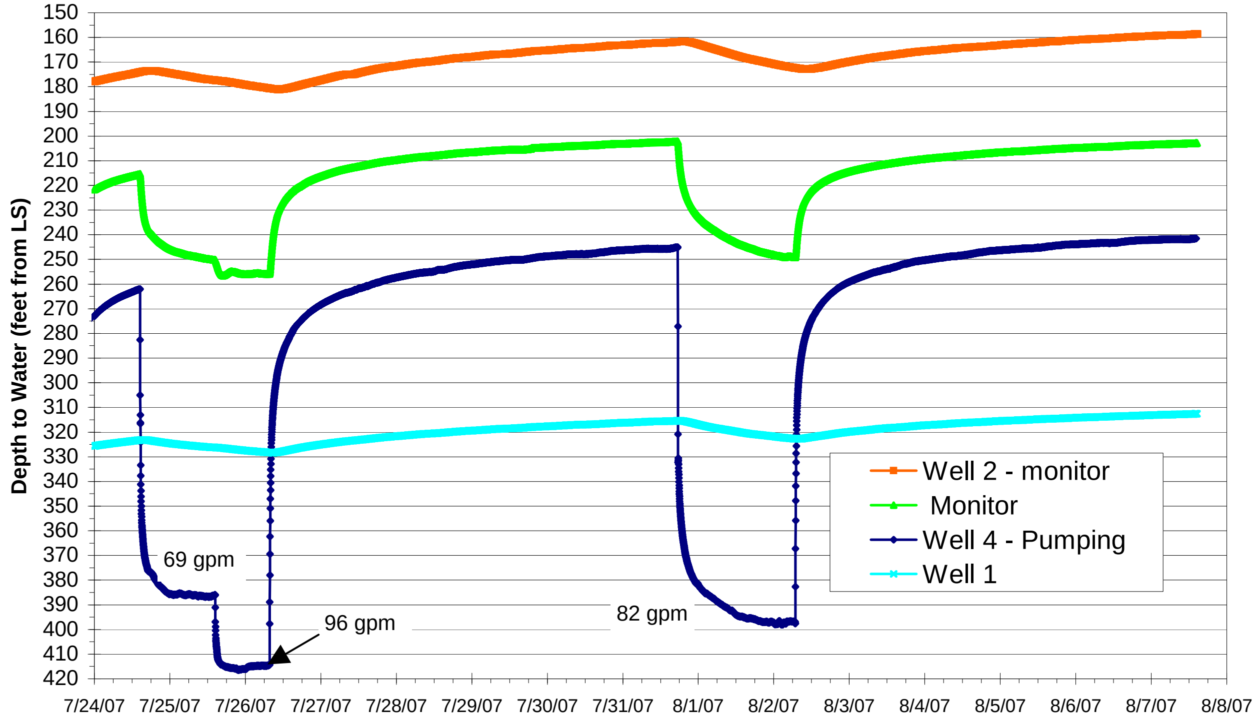
Just before turning the pump off a final water-level measurement is made. The specific capacity of the well is then calculated in terms of gallons per minute of flow per foot of water level drawdown.

Similar to a specific capacity test, a slug test can be performed on the well to provide preliminary estimates of well capacities. In a slug test a given quantity of water is introduced into the well and the change in water level is recorded. Generally, the water level rises as the water is placed in the well and then declines back to a static level over a measured period of time.

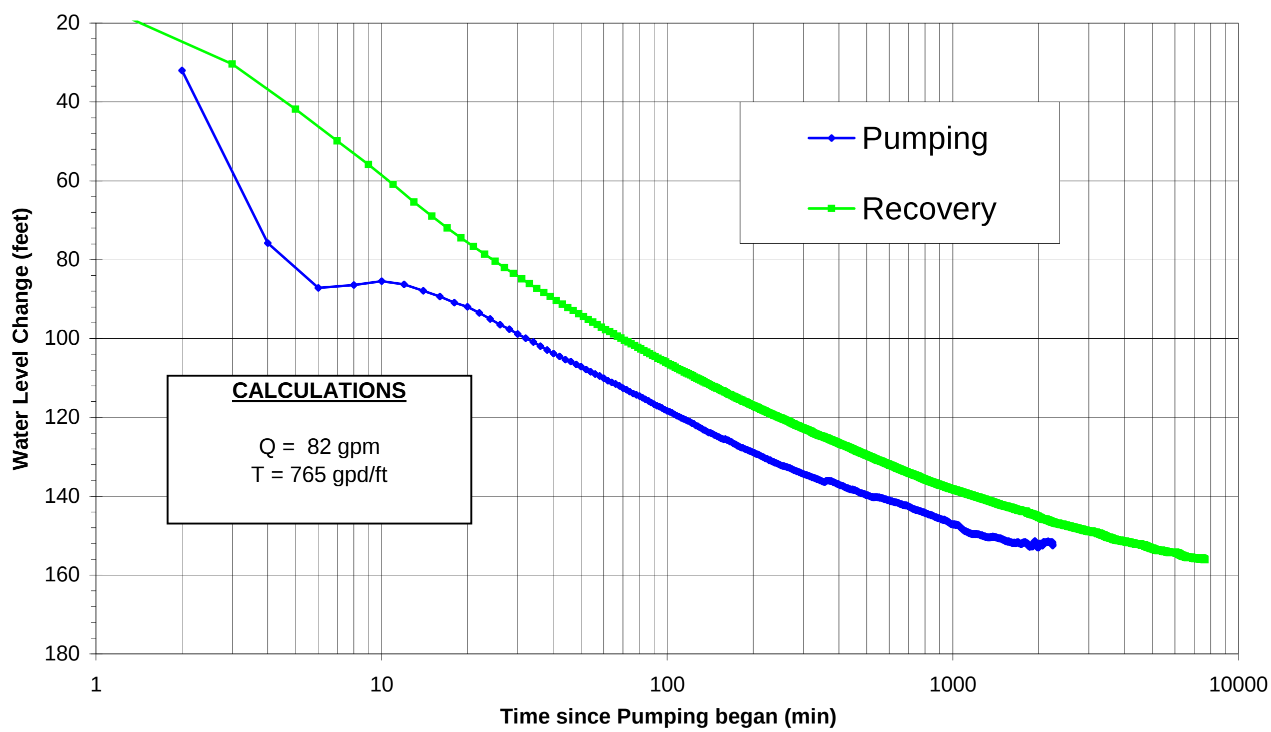
The actual pumping test is similar to the specific capacity test but is conducted for a longer period of time and possibly at varying pumping rates. The duration of testing can range from a few hours to many days of pumping. Generally, longer duration of testing allows for a larger area of the aquifer to be evaluated. However, when discharging brackish water, limitations on total volume of saline water being discharged may shorten the length of the pumping test. If the level of total dissolved solids is too high for surface discharge of the produced water, then other capture and disposal options will need to be sought.

Important measurements made during a pumping test are well discharge rate and water-level decline versus time. The water level is measured prior to pumping for a short duration to determine the non-pumping (static) level. Then after the pump is started, the water level is measured at specific intervals.

During pumping tests, transducers and data loggers can be used to electronically measure and record water level changes. The transducer is installed in the well below the water surface, no deeper than the maximum rating for the transducer, but deeper than the drawdown level in the pumping well. The data logger records water pressure on the transducer that is converted to feet of water above the probe. These data are then converted to depth of water from the surface or measuring point by comparing to measurements made with a calibrated electrical tape (Figure 11a). These tapes are lowered into the well and register when the probe comes in contact with the water surface.



a. HYDROGRAPH SHOWING WATER-LEVEL RESPONSE TO PUMPING



b. PUMPING TEST SOLUTION CURVE

PUMPING TEST DATA

FIGURE 11

LBG-GUYTON ASSOCIATES

The discharge rate or yield from a well can be measured using a number of techniques. Often, a well discharge rate is measured with a flow meter. A totalizing water meter installed in the discharge line to observe flow rate and total number of gallons discharged during testing is usually best. When using a flow meter, the meter should have been recently calibrated to verify its accuracy. Another method that is used for measuring flow from a well is an orifice weir, which is attached in the discharge line causing a slight pressure build-up that is measured in a sight tube (Figure 12). Depending on the size of the discharge pipe and weir, conversion tables are available that list different flow rates with height of water in the sight tube. If the volume being discharged from the test well is small, the discharge rate can be measured by timing the rate that a bucket or barrel of known value is filled.

Figure 12 Pumping Test in Operation

Various hydrologic parameters ascertained from data obtained during the pumping test are required to make a quantitative evaluation of an aquifer. The primary aquifer characteristics of concern are *transmissivity* (T), which is an index of the aquifer's ability to transmit water, and its *storage coefficient*, which is an index of the amount of water released from or taken into storage as water levels change. *Hydraulic conductivity* can be estimated by dividing the calculated T by the aquifer thickness. Data from the pumping test can be analyzed using several methods, mostly derived from the Theis equation. In general, these methods graphically portray the water level response to pumping of the well (Figure 12b).

Often, the best hydrologic data is derived from measurements taken in a non-pumping observation well that is located a known distance from the pumping well. Using an observation well, the shape of the cone at some distance can be measured. In fact, the accepted method for deriving the *storage coefficient* for an aquifer is only made through data obtained in an observation well.

One of the basic assumptions in determining aquifer parameters from pumping-test data is that flow takes place through a homogeneous medium having the same properties in all directions. In properly applying the results, however, one must be mindful of their limitations and take into consideration the physical characteristics of the aquifer, which are usually not the same in all directions.

Water Quality Sampling, Analysis and Evaluation

Brackish water was previously defined as having a TDS ranging from 1,000 mg/l to 10,000 mg/l. TDS refers to the sum of all the chemicals that are dissolved in the water. This includes the major dissolved anions and cations that are typically found in a groundwater; but in brackish groundwater, they may occur at higher concentrations. As water flows through an aquifer it dissolves some of the minerals in the rock. How much is dissolved depends on the solubility of different minerals. The more soluble the mineral (e.g. salt, which is called halite, is very soluble), the easier it is to dissolve and the higher the concentration will be in the water. Typically, brackish water is composed primarily of sodium and chloride, because salt is very soluble. There may also be high concentrations of some of the other dissolved chemicals in brackish groundwater. Brackish groundwater in sandstone may have high concentrations of silica because minerals such as quartz will partly dissolve as groundwater flows through the aquifer. Brackish groundwater in limestone will have high concentrations of calcium and bicarbonate from the dissolution of the mineral calcite. And groundwater in aquifers with beds of gypsum will have high concentrations of calcium and sulfate.

Desalination (e.g. reverse osmosis) causes the concentration of the dissolved chemicals in the “rejected” water to increase as the water is “filtered” through a membrane. The increase in concentrations of these dissolved chemicals may be great enough to cause the same minerals as mentioned above (calcite, amorphous silica, and gypsum), to re-precipitate and “plug” the membrane. To prevent this precipitation (scaling) on the membranes, chemicals, called inhibitors or anti-scalents, are added to prevent or slow down the precipitation of these plugging minerals.

The engineering design to prevent membrane scaling depends on the detailed chemistry of the source water. Therefore, during the exploration phase for a brackish groundwater desalination project, it is important to measure the specific chemistry of the brackish water as well as the total dissolved concentrations (TDS). The chemicals that should be analyzed for include: sodium (Na), calcium (Ca), magnesium (Mg) and potassium (K), chloride (Cl), bicarbonate (HCO_3), sulfate (SO_4), dissolved silica (SiO2), some minor constituents, such as barium (Ba) and arsenic (As) and radioactive constituents such as uranium, radium, gross alpha, beta and gamma. Some of the chemicals, such as arsenic and radium, may not cause problems with plant design, but their presence could become potential issues associated with disposal of the reject concentrate.

Obtaining groundwater samples that accurately represent the water chemistry of an aquifer can be a complex task. The simple acts of separating the groundwater from the rock matrix, changing the pressure under which it has existed, allowing the water to come in contact with the casing, and agitating the water as it is pumped to the surface can result in chemical changes. A contractor trained in the proper procedure for collecting water samples can greatly enhance the accuracy of the resulting water-quality analysis. Regardless of who collects the samples, certain procedures should always be followed.

Prior to the collection of a water sample, water should to be removed (pumped) from the newly drilled well until it is visibly clear and devoid of drill-cuttings and mud. This process may take several hours (and sometimes days). Monitoring the specific conductivity of the water as the well is being pumped is one way of determining when the water chemistry has stabilized.

After stabilization, water samples should be collected in such a way that no potential contamination to the sample occurs. The sampling point should be as close to the wellhead as possible to avoid unnecessary contact with foreign objects, including the atmosphere. Temperature, specific conductance, and pH are measured directly at the well since these values will likely change by the time samples reach a laboratory. Water samples are collected in clean sample bottles of appropriate size for the type of analysis to be performed. These bottles are often available from the water-quality laboratory that will be analyzing the samples.

Preparation of the samples for shipment to the lab is the next critical step. Sample bottles should be labeled with an identification number, date, and any other important information necessary to insure that the samples are matched to the appropriate analysis. Samples should be properly preserved and chilled, then delivered to a certified laboratory as soon as possible.

Water-quality analysis fees will vary between laboratories and with the type of analyses being performed. However, general chemical analyses can be expected to range between $300 and $500. More complicated full suites of inorganic and organic analyses could range up to $3,000.

Test Well Abandonment and Site Remediation

Assuming that a test well is not to be converted into a production well or retained as a water-level or water-quality monitoring well, the well will generally be plugged and the drilling site restored to an acceptable condition. By TDLR rule, a well not used for six consecutive months may be declared "abandoned" and must be properly plugged. TAC 76.1004 provides the technical requirements for capping and plugging wells (http://www.tsbbe.state.tx.us/wwd/wwdrules.pdf). The recommended procedure for plugging a well is to remove all casing and pressure fill the entire well via a tremie pipe with cement from bottom up to the land surface (TAC 76.1004.a.1-3). In lieu of this procedure, alternative plugging procedures are available (TAC 76.1004.a.4-5).

If the test well is to be retained as a water-level or water-quality monitoring well, then the surface completion should follow well construction guidelines and a locking cap should be placed over the well (TAC 76.1000b3-4) (Figure 13). Within 30 days following the plugging of a well a "Plugging Report" (http://www.tsbbe.state.tx.us/wwd/wwd004.pdf) (Figure 14) must be filed with the TDLR (and possibly with the local groundwater conservation district).

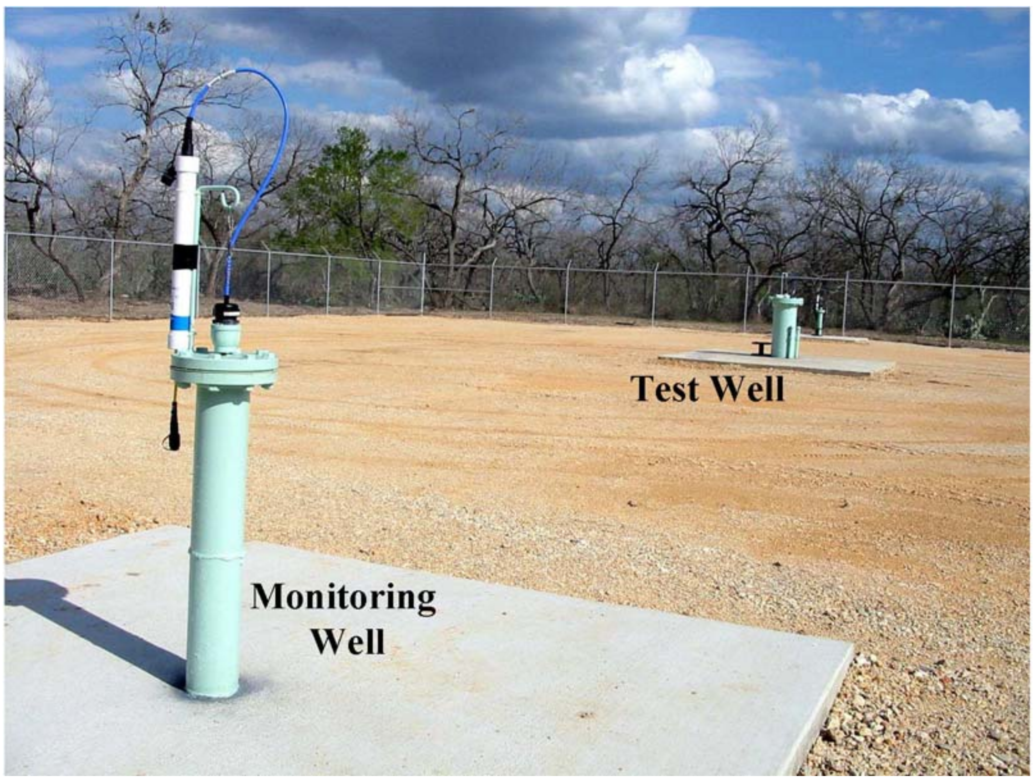


Figure 13 Monitoring Well Adjacent to Test Well

Texas Department of License and Regulation

Water Well Driller/Pump Installer Program
P.O. Box 12157 Austin, Texas 78711 (512)463-7880 FAX (512)463-8616
Email address: water.well@license.state.tx.us

This form must be completed and filed with the department within 30 days following the plugging of the well.

PLUGGING REPORT

A. WELL IDENTIFICATION AND LOCATION DATA

1) OWNER

Name	Address	City	State	Zip

2) WELL LOCATION

County	Physical Address	City	State	Zip

3) Owner's Well No. **Long.** | | **Lat.** | | **Grid #**

4) Type of Well ❑ Water ❑ Monitor ❑ Injection ❑ De-Watering

5) N↑

Drill, Pump Installer, or Landowner performing the plugging operations **must** locate and identify the location of the well within a specific grid on a full scale gridded map available from Texas Natural Resource Information Service. The location of the well should be denoted within the grid by placing a corresponding dot in the square to the right. The legal description is optional.

B) HISTORICAL DATA ON WELL TO BE PLUGGED (if available)

6) Driller License No.

7) Drilled / / **8)** Diameter of hole____________Inches **9)** Total depth of well________ feet.

C. CURRENT PLUGGING DATA

10) Date well plugged / /

12) Name of Driller/Pump Installer or Well Owner performing the plugging

License No.

11) REMOVE ALL REMOVEABLE CASING
Please check box beside the method of plugging used

❑ Tremmie pipe cement from bottom to top.

❑ Tremmie pipe bentonite from bottom to 2 feet from From surface, cement top 2 feet.

❑ Pour in 3/8 bentonite chips when standing water in well is less than 100 feet depth, cement top 2 feet.

❑ Large diameter well filled with clay material from top to bottom.

13) CASING AND CEMENTING DATA RELATIVE TO THE PLUGGING OPERATIONS.

CASING LEFT IN WELL

DIAMETER (inches)	FROM(feet)	TO (feet)

CEMENT/BENTONITE PLUG(S) PLACES IN WELL

FROM (feet)	TO (feet)	SACKS

COMMENTS

D. VALIDATION OF INFORMATION INCLUDED IN FORM

I certify that I plugged this well (or the well was plugged under my supervision) and that all of the statements herein are true and correct.
I understand that failure to complete items 1 through 13 will result in the report(s) being returned for completion and resubmitted.

Company or individual's Name (type or print)

Address	City	State	Zip

Signature	/ /	Signature	/ /
Licensed Driller/Pump Installer	Date	Apprentice	Date

TDLR FORM a004WWD *White - TDLR* *Yellow - Owner* *Pink - Driller/Pump Installer*

WELL DRILLER'S PLUGGING REPORT FORM **FIGURE 14**

Restoration of the drill site is accomplished after the drilling rig and all other support equipment has been removed. The project manager and the landowner should agree upon the extent to which the site is to be restored in advance and the necessary instructions included in the drilling contractor's contract.

Drilling mud circulating pits are the most common surface alteration that requires restoration. These pits are often several feet in depth and measure several feet in length and width, and may have retained drilling fluid. After the fluid has been vacuumed from the pit and the accumulated drill cuttings removed by a backhoe, the pit can be backfilled with dried drill cuttings and capped with the earth material that was originally excavated from the pit. The fill material should be mounded over the pit to accommodate for compaction and surface depression that will occur over time. Other restoration activities may include debris removal, fence and road repairs, and surface drainage modifications.

Use of Limited Data to Predict Long-term Supply Availability

In some areas, aquifers containing brackish groundwater are well understood and in other cases they are not. In areas where a brackish aquifer has been used for irrigation or other uses, there may be a good understanding of groundwater availability and aquifer characteristics so that the production capacity and long-term availability from the aquifer can be estimated with relative certainty. However, in other areas, information on the aquifer characteristics may need to be determined through test well drilling and testing before long-term availability can be estimated. In some areas, information and geophysical logs from oil and gas exploration are available to help characterize the brackish aquifer prior to test well drilling and well completion. While these data may be helpful in characterizing the aquifer, they do not provide complete information for long-term groundwater availability assessment.

Ideally, to make a good estimate of long-term availability, the hydrogeologic system should be understood relatively well and there should be a cohesive conceptual model for the entire system. The conceptual model should include a description of aquifer properties such as transmissivity and storativity, recharge from lateral inflow and precipitation, hydrogeologic boundaries such as fractures and faults, discharge from wells and natural springs, spatial variations in water quality, and hydrologic connection to other units. All of these factors provide insight into the long-term availability of brackish groundwater. To better understand these factors, a thorough hydrogeologic assessment should be performed in order to develop the confidence required to invest in a desalination facility.

Having limited data does not preclude evaluating the long-term availability of brackish groundwater from an aquifer. Regardless of the amount of hydrogeologic information available, a conceptual model should be developed and aquifer parameters from similar aquifers should be used to estimate availability and production capacity. If the initial evaluation indicates sufficient groundwater reserves with a relatively high factor of safety, it may be appropriate to move forward with the project. If the evaluation does not indicate sufficient groundwater reserves, then it is advisable to perform more site-specific hydrogeologic investigation prior to moving forward.

One way to quantify long-term groundwater availability is to build a groundwater model that incorporates the relevant components of the conceptual model. The degree of sophistication required for this model depends on many things including the amount of data available and the complexity of the hydrologic system. In some cases, a simple analytical groundwater model might be sufficient to determine the impact of proposed production. However, if the conceptual model or the hydrogeology is more complex, it may be appropriate to develop a numerical model using a groundwater flow model such as MODFLOW. Numerical models are capable of incorporating aquifer heterogeneity, variable recharge, complex hydrogeology, evapotranspiration, stream-aquifer interaction, and many other hydrologic components. In some cases, it may be appropriate or necessary to model water quality or water quality changes over time, and numerical models are appropriate for this task as well.

The type of scenarios that should be assessed with a numerical model includes quantification of production of brackish water for the life of the project, and well-field configuration similar to that envisioned for the project. The model should be used to assess impact of production on nearby wells, other aquifers, and potentially to look at impact to water quality and surface water resources. The model can be used to estimate the water level decline in the well field, the lift required for pumps, the spread of the cone of depression over time, and other site-specific factors.

What's Next

Hopefully at this point you have completed the exploration phase and have concluded that an adequate (volume and quality) brackish groundwater supply exists. The process forward is beyond the scope of this guidance manual; however, you can expect to encounter the following basic elements.

Pilot plant operations

A small desalination pilot plant is often located adjacent to a test well and allowed to operate for several weeks or months. The pilot plant provides the opportunity to test the effectiveness of various filtration systems with the native water chemistry in the brackish aquifer.

Engineering feasibility studies

An engineering feasibility analysis will provide a preliminary assessment of the infrastructural and financial requirements that will likely be encountered during the project, including source water development, desalination plant construction, and concentrate disposal.

Financial funding opportunities

The construction and operation of a desalination facility represents a significant outlay of dollars. Opportunities for funding assistance may be available for all aspects of the project from the preliminary source-water exploration and construction feasibility assessment phases to the final ribbon-cutting ceremony. Consider beginning your search for funding by discussing options with the TWDB.

Brackish source-water supply construction
This phase of the project includes the siting, drilling, construction and permitting of the source-water production wells. The location and design of these wells are based on the hydrologic data gained from the exploration project. These wells will be drilled and completed to TCEQ – Public Drinking Water standards.

Design and construction of desalination facility
The desalination plant houses the membrane filtration system and is the most visible building in the project. Consider incorporating meeting and educational facilities as part of the overall design.

Concentrate disposal options
The disposal of the concentrate fluid generated after the fresh water has been separated from the brackish source water can be relatively expensive; and therefore may be a critical factor in whether or not the desalination option is financially feasible. Disposal of this fluid may be accomplished in a number of ways including evaporation, discharge to a waste treatment plant, or deep-well injection. It is often good planning to research the various disposal options at the same time that the brackish groundwater exploration is being conducted. Expect regulatory permitting issues to be a significant component of the disposal operation. Securing the proper permits may be a lengthy process, in some cases taking several years.

Distribution system integration
Moving the fresh water generated from the desalination process into the drinking water distribution system is the final step. A common option is to blend the desalinated fresh water with existing water sources of less quality to produce a greater volume of available supply.

Further guidance on these elements is provided in a brackish desalination guidance manual currently being developed by NRS Consulting Engineers for the North Cameron Regional Water Supply Corporation and funded by the TWDB. This manual is expected to be available in 2008.

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Texas Water Development Board Comments on Final Draft Report

Attachment I
Draft Final Report Review
TWDB Contract No. 0604830580
Upper Colorado River Authority

Comments on Reports for the San Angelo Brackish Groundwater Exploration Project

Brackish Groundwater Exploration Guidance Manual

General Comments:

Please verify by means of a sign/seal that the geoscientific work performed for this project was done by or under the supervision of a Texas-licensed geoscientist.

Article V, Item 2 of the Contract requires that TWDB be acknowledged in any publication relating to work performed under the contract. Please include this acknowledgement.

Article III, Item 3 of the Contract requires an Executive Summary in the report. Please include an Executive Summary.

Please consider including a reference list in the manual.

TWDB would appreciate receiving a copy of high-resolution images taken during the course of the project. We will, of course, acknowledge UCRA and LBG-Guyton Associates when we use these images.

Specific Comments:

Introduction: Page 1, paragraph 1, lines 7 to 9. Please check the accuracy of the statement "In the most recent round of regional water planning (2007), 10 of the 16 regional water planning groups recommended desalination as a water management strategy". Table 10.6, SWP 2007, shows eight regional water planning groups recommending desalination as a water management strategy.

What is Brackish Water?: Page 2, paragraph 1, line 3. Please verify the volume of "in-place" brackish groundwater in Texas. Table 6, LBG-Guyton Associates, 2003, lists the volume as 2.707 billion acre-feet. This is the number that is being used by the TWDB.

Getting Started: Page 2, paragraph 4. Please consider mentioning the brackish groundwater desalination guidance manual currently being developed by NRS Engineers for the North Cameron Regional Water Supply Corporation. The manual is being prepared as part of a TWDB-funded project and is expected to be available in March/April 2008.

Getting Started: Page 6, paragraph 2, lines 3 to 5. The word "encountering" as used in the sentence is misleading. Please rewrite the sentence.

Regulatory Considerations: Page 7, Figure 3. The GCD map is dated. Currently, there are 95 GCDs in Texas. Please update the map.

Regulatory Considerations: Page 8, paragraph 1, line 10. Please change the spelling of "filled" to "filed".

Regulatory Considerations: Page 8, paragraph 1, line 11. Please consider adding a page number after the reference to the Test Well Abandonment and Site Remediation section. It will be useful to the reader.

Regulatory Considerations: Page 8, paragraph 2. Please consider adding a short paragraph on the brackish groundwater desalination guidance manual currently being developed by NRS Engineers for the North Cameron Regional Water Supply Corporation. The manual is being prepared as part of a TWDB-funded project and is expected to be available in March/April 2008. It will contain a wealth of information on regulatory requirements for permitting desalination plants in Texas.

Identifying a Brackish Groundwater Source: Please consider adding a discussion on other exploration tools such as aerial photos and remotely sensed imagery to this section.

Identifying a Brackish Groundwater Source: Page 10. Please consider adding an additional list of sources for information on brackish groundwater resources. This list could be entitled "Other Sources" and could include sources such as local water well drillers, groundwater conservation districts, etc.

Identifying a Brackish Groundwater Source: Page 10, paragraph 2, line 6. Please consider adding page numbers after the reference to the Data Collection Procedures and Water Quality Sampling sections. They will be useful to the reader.

Identifying a Brackish Groundwater Source: Page 11, paragraph 3, line 2. Typically, a desalination plant will be built after a brackish groundwater source is established. Please consider rewriting the sentence to reflect this.

Selecting a Drilling Contractor – The Bid Process: Page 13, paragraph 1, lines 3 to 4. Please clarify if a bid package is required to be prepared or supervised by a professional engineer licensed in Texas.

Selecting a Drilling Contractor – The Bid Process: Page 13, paragraph 1, line 6. Please correct the spelling of "preformed". It should be "performed".

Selecting a Drilling Contractor – The Bid Process: Page 13, paragraph 2, line 3. Please correct the spelling of "schedules". It should be "scheduled".

Selecting a Drilling Contractor – The Bid Process: Page 13, paragraph 2. Please consider including a sample bid sheet for the benefit of the user of this manual.

Selecting a Drilling Contractor – The Bid Process: Page 14, paragraph 1. Please add a question mark (?) after each bulleted item in the list.

Design and Installation of Test Wells: Please consider including unit cost estimates for drilling and installing wells. A real life example of costs from a drilling project such as the San Angelo project would be helpful. Also, it would be useful for the user to have a schematic of a test well, monitoring well, and a production well included in the manual.

Design and Installation of Test Wells: Page 16, paragraph 2, line 2. What is the TAC reference for? Please clarify.

Design and Installation of Test Wells: Page 16, paragraph 4, line 5. Please correct the spelling of "manor". It should be "manner".

Data Collection Procedures at the Well Site: Page 17, paragraph 3, line 6. The Keys and MacCary reference is not listed in the Reference section. In fact, there is no Reference section in the manual. Please consider including one.

Design Performance and Evaluation of Pumping Tests: Please consider including a discussion on other types of hydraulic tests available such as slug tests.

Design Performance and Evaluation of Pumping Tests: page 23, paragraph 3, line 7. Please change the spelling of "contacted" to "contact".

Water Quality Sampling, Analysis and Evaluation: Page 25. This section discusses the characteristics of brackish water, its causes, and its effect on desalination membranes. It does not, however, address groundwater sample collection methods, typical field and laboratory analytical tests, and cost estimates for conducting these tests. Please consider including this information in the section.

Test Well Abandonment and Site Remediation: Page 27, figure 13. Please match the caption with the label in the figure: test well or production well?

What's Next?: Page 30. Please consider adding a short paragraph on the brackish groundwater desalination guidance manual currently being developed by NRS Engineers for the North Cameron Regional Water Supply Corporation. The manual is being prepared as part of a TWDB-funded project and is expected to be available in March/April 2008. It would be an appropriate transition from this manual to the desalination manual.

Brackish Source Water Exploration in the San Angelo Area

General Comments:

Please verify by means of a sign/seal that the geoscientific work performed for this project was done by or under the supervision of a Texas-licensed geoscientist.

Article V, Item 2 of the Contract requires that TWDB be acknowledged in any publication relating to work performed under the contract. Please include this acknowledgement.

Article III, Item 3 of the Contract requires an Executive Summary in the report. Please include an Executive Summary.

Please include (as an appendix) the specifications for the test holes and test wells that were prepared prior to drilling. This is Task 2 of the Scope-of-Work.

For the three test sites, please provide start and end dates of drilling, name of the drilling company, dates of water sampling, and well-plugging dates, where applicable.

For the three test sites, please consider including a lithologic interpretation of the geophysical logs included in the appendices.

Specific Comments:

Introduction: Page 1. Please provide some background information for the project in terms of the regional water planning process (water supply needs in San Angelo, recommended water management strategy, etc.).

Introduction: Page 1. Please consider including a geologic map of the San Angelo area showing the locations of the test holes.

Schmidt-1 Test Hole: Page 6, paragraph 3. How was the pumped water managed? Was a TCEQ discharge permit necessary? Please provide this information.

Figure 5: Please identify the rock or sediment shown in the photograph. Also, please include the magnification of the image.

Figure 10: Please identify the rock particle shown in the photograph. Also, please include the magnification of the image.

Table 1: Please identify the nature of the sample that was analyzed and explain what the Sample ID numbers denote (different depths?). Please spell out (in a Notes section below the table) the short forms of the units used in the measurements.

Table 2: Please identify the nature of the sample that was analyzed. Also, please spell out (in a Notes section below the table) the short forms of the units used in the measurements.

Schmidt-1 Interval Sampling Analytical Results: Please explain why the results from these samples were not included in the discussion in the main body of the text nor listed in Table 2.