FINAL REPORT

SPECIAL STUDY NO. 1: REFINEMENT OF GROUNDWATER SUPPLIES AND IDENTIFICATION OF POTENTIAL PROJECTS

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SPECIAL STUDY NO. 1: REFINEMENT OF GROUNDWATER SUPPLIES AND IDENTIFICATION OF POTENTIAL PROJECTS

1.0 EXECUTIVE SUMMARY

Future water supplies for Region F will likely be developed from groundwater or wastewater reuse. This study identified several new sites that have groundwater development potential and focused on refining the groundwater quantity and quality estimates for Region F. The objective of this study is to refine groundwater supply estimates in selected areas and identify potential projects that may use fresh and brackish groundwater. In addition, for each area, concentrate disposal and co-development options are evaluated. Data gaps are also identified and recommended steps to address data gaps are discussed.

Five Work Group meetings were held over the course of the study. On July 23, 2007 the Work Group identified four groundwater projects for further study. The four projects selected for further study were:

1. The Ogallala aquifer in the southeast portion of Andrews County,
2. Potential local groundwater sources for the City of Robert Lee in Coke County,
3. Region wide assessment using the TWDB database to assess areas containing multiple productive wells that might sustain long-term pumping, and
4. Any brackish or fresh groundwater in the San Angelo area.

Region F later canceled Project 4 to avoid duplication of effort because similar work was pursued by the City of San Angelo. Therefore, three projects remained. Existing data from public sources was used to refine the groundwater quantity and quality estimates for each project area.

<u>Groundwater Supply Evaluation</u>

The Andrews County project focused on the southeast corner of the county. Based on the data obtained for this study and the methods employed, there appears to be a few areas that may yield small volumes of fresh and brackish groundwater for municipal use in southeast Andrews County. However, the data indicate that there may be less groundwater available than previously estimated, depending on the assumptions used for the calculations. A willing seller would need to be located in these areas in order to complete more field investigations required to confirm the quantity and quality of groundwater for development.

The Coke County project focused on local groundwater sources for the City of Robert Lee and areas to the east, including western Runnels County. Based on available data, there are several potential areas/units that may merit further field investigation. These are (1) dual completion wells in San Angelo Formation/Choza Formation, (2) Choza Formation/Merkel Dolomite Member in southeast Coke County, (3) Choza Formation/Merkel Dolomite Member/Alluvium in Runnels County, and (4) River Alluvium.

The Regional Supply project evaluated the TWDB database to assess areas containing multiple productive wells that might sustain long-term pumping. The goal was to use the data to discern the long-term availability of groundwater from areas that have had high volume wells in the past. The assessment indicates that there are some areas with moderate to high production capacity. With the exception of the Pecos Valley Alluvium, the Groundwater Work Group indicated that most of the available groundwater in these areas is already being utilized. In most areas, groundwater would need to be transferred from an existing use to a new use. To move forward with that process, a willing seller and a willing project developer (buyer) would need to be identified. However, the regional water planning process is not an effective venue to facilitate these types of negotiations.

Co-Development

Co-development is a term that is used to describe developing multiple water supply sources as a single water management strategy. A co-development project may include joint development of fresh and brackish water sources or it may simply combine the infrastructure for multiple users to optimize transmission costs and efficiency. Based on the analyses of available groundwater, there is limited co-development potential in Region F, but the greatest potential for co-development exists in the Pecos Alluvium area due to the relative abundance of groundwater as compared to other areas in the region.

The study assessed the cost of co-developing groundwater from separate wellfields in the Pecos Valley Alluvium (Ward and Winkler County area) and transporting it to the Midland/Odessa area. The results indicate that unit costs of the joint project are slightly less than individual projects, but the initial capital costs are higher. This is because the joint project is developing and moving more water than the sum of the individual projects. However, pending the timing of increased demands, it may not be cost effective to develop the joint project. This would need to be evaluated by the entities developing the project(s).

Brackish Concentrate Disposal

Disposal of concentrate from the treatment of brackish groundwater was evaluated for each project area. Methods considered included sewer discharge, surface water discharge, deep well injection, land application, and evaporation ponds. Disposal to sewer, deep well injection, and evaporation ponds may be options for all of the areas considered. Discharge to surface water may or may not be viable for Coke County and Pecos Valley Alluvium. Land application may be an option in Coke County. Table 5-5 summarizes feasible disposal methods for each of the areas.

Data Gaps

The most significant data gaps in terms of estimating groundwater availability include the types of data that are publicly available, the lack of sufficient data, and uncertainty regarding the quality of the existing data. To develop a groundwater supply project, high quality localized data are required. Several types of data are required to fully assess groundwater resources. In some areas, some of these data are very sparse or non-existent, and in some cases, the quality of the existing data are uncertain. These factors make it difficult to refine water quantity and quality assessments with certainty. In addition, all aquifers exhibit some degree of natural variability, and this variability can affect project viability and cost and makes it difficult to conclusively determine groundwater quality and long-term availability.

The most significant data gap in terms of potential co-development and disposal options is the lack of specific facility locations and project design capacities. Some of the most critical factors in the selection of a suitable concentrate disposal option include:

- Distance between the facility and discharge point – Transport distance is a major factor in disposal cost.
- Volume of concentrate to be disposed – Concentrate volumes dictate which disposal options can be considered for each method of disposal and the available and/or allocated resources.

- Source water quality – Feedwater TDS is a major factor in pre-treatment and treatment options and cost, as well as volume of concentrate and the options considered for disposal.

It is difficult to recommend a disposal option without knowing specific locations, anticipated disposal volumes, and feedwater TDS concentrations. In addition, the most effective and efficient approach for developing brackish groundwater supplies is to evaluate groundwater supply, engineering and treatment, transport, and disposal issues simultaneously. Simultaneous assessment is important because of the many variables to consider in each component of the system.

Preliminary Cost Estimates

Preliminary cost estimates were developed for potential project areas. Section 6 presents the range of costs for each project site. The cost of projects is highly correlated to the transmission distance. Small quantities of water transmitted relatively long distances have very high unit costs, as demonstrated by the 50-mile delivery project for 500 acre-feet per year in Glasscock-Reagan Counties. Cost feasibility increases with greater quantities and relatively shorter distances.

Recommended Approach For Future Field Studies

Due to the existing data gaps and uncertainty, several more tasks need to be completed prior to developing a groundwater supply project. These steps include: (1) selection of a specific site for further characterization, (2) assessment of regulations, (3) establish a drilling program, (4) design and installation of test wells, (5) completion of pumping tests and water quality sampling, (6) assessment of wellfield viability and impacts, and (7) engineering studies and other project preparation. These are discussed further in Section 7.

2.0 INTRODUCTION

Region F has limited water sources for existing entities and future growth. Virtually all of the surface water is fully developed and allocated to existing uses. Future water supplies for the region will likely need to come from groundwater or wastewater reuse. During the last round of planning the region sponsored a study on available brackish groundwater, which provided a broad overview of the potential groundwater sources by aquifer and ranked the sources based on depth, productivity, and quality. The region also recommended the use of brackish groundwater with desalination for future supplies for the City of Andrews and CRMWD. As follow-on to the previous groundwater studies and refinement of the recommended water management strategies, this study identified up to five sites to be further defined as potential future water sources for Region F.

2.1 Authorization and Objectives

This study was authorized by the Region F Regional Water Planning Group and is funded through a Research and Planning Grant sponsored by the Texas Water Development Board.

This project will develop information on one of the few sources of new water available to meet needs in most of Region F: development of groundwater sources. This study will build on existing information on groundwater sources developed by TWDB, Region F and others and identify up to three specific projects for implementation. This study will generate more detailed site-specific information needed to refine these strategies.

The objective of this study is to refine groundwater supply estimates in selected areas and identify potential projects that may use fresh and brackish groundwater. In addition, for each area, concentrate disposal and co-development options are evaluated. Data gaps are also identified and recommended steps to address data gaps are discussed.

3.0 METHODOLOGY

The Region F Water Planning Group established a Groundwater Work Group to facilitate and guide the direction of this study. Work Group members included planning group members and interested public. A list of the members of the Groundwater Work Group is shown on Table 3-1.

Table 3-1 Groundwater Study Group

Work Group Member	Representing
Allan Lange	Lipan-Kickapoo GCD
Brent Wrinkle	Upton County
Buddy Sipes	Industry
Caroline Runge	Menard County UWD
David Sanders	City of Andrews
Dennis Clark	Emerald UWCD
Greta Ramsdell	Sutton Co. UWCD
John C. Shepard	Winkler County
John Grant	CRMWD
Ken Carver	Martin County
Kenneth Dierschke	Agriculture
Len Wilson	Public
Paul Weatherby	Middle Pecos GCD
Scott Holland	Irion County GCD
Sue Young	Mitchell County
Will Wilde	City of San Angelo
Woody Anderson	Irrigated Agriculture

Five Work Group meetings were held over the course of the study. On July 23, 2007 the Work Group identified four groundwater projects for further study. The four projects that were selected for further study were:

1. The Ogallala aquifer in the southeast portion of Andrews County. There is some debate as to the quality and quantity of water in the Ogallala in this area. This is referred to as the Andrews County project.

2. Potential local groundwater sources for the City of Robert Lee and areas to the east, including western Runnels County. This would include the evaluation of recently drilled wells. This is referred to as the Coke County project.

3. Region wide assessment using the TWDB database to assess areas containing multiple productive wells that could sustain long-term pumping. To the degree possible, the data was used to indicate the long-term availability of groundwater from highly productive areas. This is referred to as the Regional Supply project.

4. Any brackish or fresh groundwater in the San Angelo area. This is referred to as the San Angelo project.

In September 2007 the City of San Angelo and the Upper Colorado River Authority pursued tasks similar to that envisioned for the San Angelo project. To avoid duplication of effort, the Region F Groundwater Work Group cancelled the San Angelo project. Therefore, three projects remained. Each of the three remaining projects is discussed in Section 4.

4.0 QUANTITY AND QUALITY OF GROUNDWATER IN SELECTED PROJECT AREAS

4.1 Andrews County

A primary purpose of the Andrews County project was to bring some clarity to different interpretations of existing data regarding quality and quantity of Ogallala groundwater in the southeast portion of the Andrews County. Existing data were used for this study, and the effort was focused on how different interpretations could be obtained from that data and how they might affect groundwater availability estimates.

4.1.1 Evaluation of Existing Data

Figure 4-1 shows the study location area (lower left inset) and hydrographs for wells containing water level data from 1970-2006. Water level data was obtained from the TWDB Groundwater Database for specified wells. Wells are labeled according to state well number. This map gives a general idea of the depth to water in the wells in this area, which is generally from 20 to 90 feet below land surface. Most wells exhibit a steady trend of water level during their period of water level observation. The two wells that exhibit a slight water level decrease are SWN 2754701 and 2762201.

Figure 4-2 illustrates the production estimates from wells in the TWDB database (shown as blue squares) and the database of drillers logs submitted since the year 2000 (shown as green triangles). Production rates vary from 15 to over 170 gallons per minute (gpm) throughout the study area. There is a relatively large area between US Hwy 385 and Ranch Road 1788 that contains wells producing over 100 gpm.

Figure 4-3 shows the concentration data for total dissolved solids (TDS) (mg/L) coupled with well depth. The data indicate that TDS is generally less than 3000 mg/L and less than 1000 mg/L in many areas. There are a few wells containing water greater than 5000 mg/L TDS. Data used in this analysis were obtained from the TWDB extending from years 1936-1998 as well as from the TWDB groundwater database extending from 2000-2004.

Two approaches were used to estimate saturated thickness and volume of water within this study area. Figure 4-4 shows the calculated saturated thickness using the base of Ogallala and water level information. The red squares indicate the locations where the base of Ogallala elevation was developed from a well or geophysical log. These data were taken from TWDB

Report LP-173 as well as from driller's logs reported to the TWDB. The yellow triangles indicate where TWDB water level elevations are available. To develop the saturated thickness map, both sets of data are used to develop a surface by interpolating between data points onto a regular grid. The first surface is for the water level and the second surface is for the base of Ogallala. Then, the base of Ogallala surface is subtracted from the water level surface, providing an interval indicating the saturated thickness. This was the first approach used to develop a saturated thickness map of the area.

With this approach, the saturated thickness is the greatest along Ranch Road 1788, with a thickness of over 100 feet, and indicates a reasonable volume of Ogallala water (of reasonable quality) southeast of the City of Andrews. The rest of the study area has saturated thickness estimates ranging from 25 to 75 feet.

Figure 4-5 shows the data used in an alternative approach for estimating saturated thickness. Instead of subtracting interpolated grids using data from different wells to determine saturated thickness, this method uses measurements within specific wells of both bottom and top of the saturated aquifer. With this method, the estimates of saturated thickness are only calculated at those locations where there is a base of Ogallala measurement and a water level measurement in the same well location reported by the TWDB. Figure 4-5 indicates the wells where this criterion is met, and the measurements made in the well. The blue number posted by the well is the depth to water and the brown number is the base of Ogallala depth. The difference between these two numbers indicates the saturated thickness in that particular well. These values are then used as point data to interpolate a saturated thickness map for the study area. The results of this method are shown in Figure 4-6.

Figure 4-6 illustrates the saturated thickness for the wells meeting the criterion and the values are posted as red numbers by the wells. The interpolated contours from these data are also shown on Figure 4-6. It is evident that the largest values of saturated thickness (posted in red) are not located along Ranch Road 1788 as was the case using the first methodology. Using this method, the largest saturated thickness estimates occur in the southwest portion of the study area, near US Hwy 385. In fact, the saturated thickness along Ranch Road 1788 is estimated to be only about 30 to 40 feet instead of 100 as in the first approach. The discrepancy between method results indicates a relatively large potential variation in groundwater availability in that area that should be evaluated further by more detailed field investigation if it is warranted. This saturated thickness information, in conjunction with the water quality data indicates that some areas of potential development do exist, but that further field investigation is required to confirm and refine existing data.

4.1.2 Conclusions

Based on the data obtained for this study and the methods employed, there appears to be a few areas that may yield small volumes of water for municipal use in southeast Andrews County. However, the data indicate that there may be less groundwater available than previously estimated, depending on the assumptions used for the calculations. If a willing seller were located in these areas, more field investigations would be needed to confirm the quantity and quality of groundwater for development.

4.2 Coke County

Available data from the Texas Water Development Board (TWDB) groundwater databases, Texas Commission on Environmental Quality (TCEQ), and Lipan-Kickapoo Water Conservation District (LKWCD) were assessed to determine potential areas that could support wells for the City of Robert Lee and areas to the east.

TWDB data include both the state well and driller's log (i.e., City of Bronte well reports) databases. The TCEQ database maintains information on public supply wells. The LKWCD data includes well records maintained by the district.

Production rates (gpm) and water quality data were compiled in order to achieve greater data density. All well locations with reported production rates or water quality data were included in this evaluation. Three geohydrologic units – River Alluvium, the Pease River Group/San Angelo Formation and the Clear Fork Group/Choza Formation are discussed below.

Production rates, water quality, and well completion formations are mapped on Figures 4-7, 4-8, and 4-9 respectively.

4.2.1 River Alluvium

Alluvial river deposits (Qal) as well as older fluvial terrace deposits (Qao, Qau) are associated primarily with the Colorado River channel and flood plain, however, significant alluvial deposits also occur along Oak Creek, Valley Creek and Elm Creek in Runnels County. Alluvial deposits are typically comprised of discontinuous beds, stringers, and lenses of gravel that are fining-upward to sand, silt and clay. The following data represent wells completed in alluvium:

Data Source	Well Count	Average Well Production (gpm)	Range of Production (gpm)	Average Well Depth (ft)	Range of Depth (ft)
TWDB	49	132	0.2 - 1,200	75	9 - 280
TCEQ	4	131	35 - 188	150.5	95 - 200

LKWCD data does not contain geologic unit designations; therefore, it was not included in the above table. The most productive alluvial wells reported by TWDB in Coke and Runnels counties are located just upstream of E.V. Spence Reservoir and were drilled in the 1960s. Reported well yields range from 20 to 325 gpm in this area, although the wells are no longer in use due to the inundation caused by the construction of Lake Spence, which was completed in 1969.

Average water quality parameters reported in the TWDB groundwater database for alluvium wells are as follows:

Data Source	Sample Count	Sulfate (mg/L)	Chloride (mg/L)	TDS (mg/L)
TWDB	102	481	160	1,239

Based on available TWDB data, water produced from alluvium wells has relatively high sulfate and low chloride content in terms of drinking water standards. The secondary standards for drinking water state that the maximum allowable concentration for both sulfate and chloride is 300 mg/L. The secondary s**ta**ndard for TDS is 1,000 mg/L. The average TDS concentration in river alluvium is above secondary standards. For consideration as a municipal source, water would need to be blended with other sources or treated by reverse osmosis or other methods.

4.2.2 Pease River Group/ San Angelo Formation

The closest relatively productive geohydrologic unit located east of Robert Lee is the San Angelo Sandstone (Psa). This formation is generally composed of alternating beds of conglomerate, sandstone and shale, and ranges from 100 to 200 feet in thickness. The formation dips to the west at about 40 feet per mile. Depth to the top of the San Angelo ranges from zero at the outcrop in the eastern third of the county and nearly 1,900 feet at the western edge of Coke County. This unit provides small to moderate quantities of fresh water to wells located in eastern

Coke County and brine (TDS > 10,000 mg/L) in the western part of the county. The following data represents wells completed in the Pease River Group:

Data Source	Well Count	Average Well Production (gpm)	Range of Production (gpm)	Average Well Depth (ft)	Range of Depth (ft)
TWDB	122	22	0.2 - 90	294	22 – 1,763
TCEQ	16	38	8 - 135	218	120 - 330

Production rates of up to 50 gpm have been reported near the Oak Creek Reservoir. The City of Bronte completed several public supply wells near the Oak Creek Reservoir in 2003. The driller's logs for these wells report 50 to 125 gpm, although sustained production rates from these wells is likely closer to 50 gpm. These wells may also be completed in the underlying Choza Formation, with production from both the San Angelo and the Choza. No water quality data are available for these wells.

Average water quality parameters reported in the TWDB groundwater database for Pease River/San Angelo wells are as follows:

Data Source	Sample Count	Sulfate (mg/L)	Chloride (mg/L)	TDS (mg/L)
TWDB – Pease River Group (Coke and Runnels Cos.)	107	3,022	37,946	65,975
TWDB – San Angelo Fm. (Tom Green Co.)	7	557	784	2,337

No wells designated as being completed in the San Angelo Formation were found in the databases in either Coke or Runnels Counties, therefore, wells meeting this criteria in Tom Green County were used to characterize water quality. Water produced from the San Angelo Formation is high in sulfate and chloride content relative to drinking water standards, whereas water from the Pease River Group (undifferentiated) is high in sulfate and very high in chloride and TDS (brine). Water from the San Angelo formation would require additional treatment for municipal use.

4.2.3 Clear Fork Group/ Choza Formation

The Choza Formation is a unit of the Clear Fork Group (Pcf), and consists of red shale with thin beds of fractured dolomite and gypsum stringers. The Merkel Dolomite Member, depending on its degree of fracturing and solution, tends to be the most productive zone of the Choza Formation. The Merkel Dolomite is about 25 feet thick in Coke County. The depth of this unit below the base of the San Angelo/ top of the Choza (an erosional surface) varies greatly but has been measured at 270 feet along the Colorado River in Coke County. The Vale and Arroyo Formations underlie the Choza and are part of the Clear Fork Group. The following data represents wells completed in the Clear Fork Group undivided:

Data Source	Well Count	Average Well Production (gpm)	Range of Production (gpm)	Average Well Depth (ft)	Range of Depth (ft)
TWDB	330	113	1.3 - 800	77	11 – 1,045
TCEQ	3	103	100 - 110	143	130 - 160

Wells completed in the Clear Fork Group are located in western Runnels and southeast Coke counties. The most productive wells identified within the Clear Fork Group are located in southeast Coke County (i.e. state well 43-14-607 yielded more than 800 gpm for a few days before dropping to 400 gpm) although most wells produce considerably less water. The higher production wells in southeast Coke County may have been completed in the Merkel Dolomite Member of the Choza Formation. A driller's log from a well completed in 2003 at a depth of 220 feet near the older high production wells reported an estimated well yield of 100 gpm, although a nearby well drilled to a depth of 180 feet in 2005 only reported a yield of 7 gpm. Because of this variability, developing new well fields with long-term sustainability is uncertain in many areas and requires more field investigation.

Data Source	Sample Count	Sulfate (mg/L)	Chloride (mg/L)	TDS (mg/L)
TWDB – Choza Fm.	38	193	363	1,379
TWDB – Merkel Dolomite	10	105	295	1,109
TWDB – Clear Fork Group	1,578	408	391	1,601

Water produced from the Clear Fork Group is moderately high in sulfate and chloride, but sulfate and chloride concentrations are relatively low in the Choza Formation and the Merkel Dolomite.

Hydrographs for 13 wells located in Coke and Runnels Counties were compiled from TWDB historic water level data. Wells locations are shown on Figure 4-10. Hydrographs for Coke and Runnels County wells are included as Figures 4-11 and 4-12, respectively.

Three of the hydrographs for Coke County are completed in the Pease River Group (San Angelo), and three are completed in the Clear Fork Group (Choza). Based on available data, water levels in some areas have risen about 20 to 30 ft or remained relatively stable since 1968.

The exception to this is well 43-05-502, located northeast of Robert Lee near Mountain Creek, which is completed in the San Angelo Fm. This well shows the greatest fluctuation in water level (58 ft) but overall has decreased about 12 ft since 1968.

The Runnels County hydrograph wells are all completed in the Clear Fork Group. In general, water levels remained relatively unchanged between 1969 and 1996. Only three of the selected wells have data through 2007. Of these three wells, one has decreased by only a few feet; however, the other two wells, 30-57-702 and 43-15-601, show water levels declining nearly 25 and 20 feet, respectively.

4.2.4 Discussion

There are three geologic units that provide small to moderate quantities of groundwater to Coke and Runnels Counties. These are the Alluvium, the San Angelo Formation and the Choza Formation, which includes the Merkel Dolomite.

In general, water quantity in these units in descending order is as follows:

- Merkel Dolomite Member of the Choza Formation,
- Alluvium,
- Choza Formation (without Merkel),
- San Angelo Formation.

Water quality in these units, in descending order is as follows:

- Merkel Dolomite Member of the Choza Formation,
- Choza Formation (without Merkel),
- Alluvium,
- San Angelo Formation.

Wells in some of these units appear to have a relatively rapid response to periods of higher/precipitation and runoff, whereas others do not. More precise correlation to geologic units is difficult given the limited nature of available data.

Significant runoff quantities occur in Runnels County, especially in Elm Creek. Flow in Elm Creek often equals flow in the Colorado River at Ballinger. Significant flow is gained by the Colorado River from these tributaries between Robert Lee and Ballinger. Flow loss studies along Elm Creek indicate some areas experience greater stream loss than others, whereas flow loss studies in the Colorado River channel do not, although channel conditions may have been changed by peak events since the flow loss studies were done in the Colorado River.

4.2.5 Conclusions and Recommendations

Based on available data, there are several potential areas/units that may merit further field investigation. These are:

1. San Angelo Formation/Choza Formation dual completion wells. The City of Bronte wells located near Oak Creek Reservoir appear to be dual completion wells. There is a possibility that reasonably productive wells could be completed further south, but due to limited data, field exploration would be required to know for sure. Water quality is variable east of Robert Lee, and thus test wells would also be required to confirm municipal water supplies.

2. Choza Formation/Merkel Dolomite Member in southeast Coke County. Historically, the highest production wells in Coke County have been located in this area, but the location of higher production wells does not seem to follow a predictable pattern based on the data available. Field assessment of structural features, geologic units, fracture orientations, etc. might provide more insight to where the higher production zones may be located.

3. Choza Formation/Merkel Dolomite Member/Alluvium in Runnels County. Since there is a reasonable amount of runoff in the streams in northern Runnels County, it may be worthwhile to map the more productive units of the Clear Fork Group in an effort to determine areas where greater recharge from surface runoff might occur to these units. Dual completion wells in these units and overlying alluvium located downdip of areas with greater recharge may potentially provide relatively high production wells.

4. River Alluvium. In general, alluvial wells are relatively shallow with good production and water quality; however, there is quite a bit of variability in the water quality. The impact of recharge zone proximity on water quality is not clear given the limited availability of data.

5. Recommended further investigations include test well drilling north and east of Bronte in the San Angelo and Choza formations, structural and well capacity assessment of Merkel

Dolomite in southeast Coke County, and water sampling of alluvial wells to determine water quality trends in alluvium.

4.3 Region-wide Assessment

As discussed during the July 23, 2007 Groundwater Work Group meeting, the objective of this task was to use available databases to identify areas containing productive wells that may have the potential to provide additional supplies for Region F. To the degree possible, the data were to be used to indicate the long-term availability of groundwater from productive areas.

4.3.1 Methodology

Sources include available data from the Texas Water Development Board (TWDB) groundwater databases, Texas Commission on Environmental Quality (TCEQ), Lipan – Kickapoo Water Conservation District (LKWCD), and Myers (1969). TWDB production data are derived from remarks within the groundwater database. These data report both estimated and measured production rates. TCEQ public supply well productions are actual measured values. WIID or driller's logs production values are typically estimates based on limited pumping. Production rates obtained from the Myers report are derived from pump tests.

Available TWDB data was assessed to determine potential areas that could sustain long-term pumping from multiple high-volume wells. Specifically, production rates (gallons per minute (gpm)) and specific capacity (gpm/foot of drawdown) data were compiled from various sources to achieve greater data density, since these data tend to be relatively limited.

The only well locations presented in this evaluation are those reporting production rates that are greater than 100 gpm. The data were divided into three subsets for presentation purposes: 1) major aquifers, 2) minor aquifers, and 3) wells located in aquifers designated as "other". Other aquifers were further divided into three general categories: Alluvium, Permian, and Cambrian.

Using these three aquifer categories, production rates, specific capacity, and water quality data were mapped in Region F. The regional presentation of this data was intended to provide an overview of the areas with the greatest potential production.

Limitations to this approach exist in terms of the quantity and quality of the data used. For example, in mapping high production areas only a small fraction of the data are utilized (Figure 4-13). The percentage of total wells in any given aquifer with reported production ranges between 7 percent (Ogallala) and 41 percent (Dockum). When considering only wells with greater than 100 gpm production, the data subset is reduced even further, and ranges from one percent (Trinity) to 21 percent (Dockum and Hickory) of the available well records for that aquifer. Additionally, some of the production values were measured during extended pump tests, whereas some were merely estimated based on initial flow volumes that occurred while drilling and completing the well. Another factor affecting the data quality concerns the age of the data, especially in terms of how accurately production data reported in the 1950s may actually characterize current conditions.

4.3.2 Discussion

Cumulative frequency distributions were calculated for 100 gpm ranges for each aquifer in an attempt to illustrate general well capacity trends. These graphs are included as Figures 4-14, 4-15 and 4-16. For example, as shown on Figure 4-14, 20 percent of Pecos Valley Alluvium wells have production exceeding 1000 gpm, whereas the other major aquifers have less than 5 percent of wells producing at this rate.

Figures 4-17 and 4-18 present well locations with greater than 100 gpm for the major and minor aquifers, respectively. Figures 4-19 and 4-20 show wells with greater than 100 gpm production mapped by aquifer and by reported production values for both major and minor aquifers. Figure 4-21 details production values for "other" aquifers.

Figures 4-22 and 4-23 map specific capacity data reported in the TWDB database and the Myers (1969) report. Data density for specific capacity is quite low.

Figures 4-24 and 4-25 map average TDS values for TWDB wells and for TCEQ public supply wells for both major and minor aquifers.

Historical primary use of TWDB high production wells (100 plus gpm) by aquifer is shown in Table 4-1.

Table 4-1 Historical primary use of TWDB high production wells

Aquifer	Number of Wells by Type						
	Domestic	Irrigation	Industrial	Public Supply	Aquaculture	Stock	Unused
Pecos Valley Alluvium	2	82	56	67		8	152
Ogallala		31		2		1	8
Edwards - Trinity Plateau	27	365	55	57		12	107
Trinity		3			2		1
Lipan	2	45		1		2	13
Igneous		1					
Dockum	4	185	42	15		1	89
Rustler		2				2	9
Capitan Reef Complex		1	7				7
Ellenburger - San Saba	1			2		3	2
Hickory	17	116	5	8		11	55
Other	7	46	10	20		6	31

Historically, most high-production wells have been utilized for irrigation, especially in the Edwards – Trinity Plateau, the Dockum and the Hickory. Public supply wells with greater than 100 gpm reported are predominantly located in the Pecos Valley Alluvium (67), the Edwards – Trinity Plateau (57) and other aquifers (20). A significant portion of wells in the Pecos Valley Alluvium, Edwards – Trinity Plateau and Dockum are designated as unused.

Of the 280 wells drilled between April 2001 and August 2007 reporting yields of 100 gpm or more, 119 wells are domestic, 85 are irrigation wells, 18 are for stock, 13 are industrial, and 7 are public supply

Based on the review of the regional data, areas containing the greatest density of high capacity wells include:

Major aquifers:

- Schleicher and surrounding counties (Edwards -Trinity Plateau)
- Glasscock, Reagan, and surrounding counties (Edwards - Trinity Plateau)
- Ward and surrounding counties (Pecos Valley Alluvium)

Minor aquifers:

- Mitchell and surrounding counties (Dockum)
- Tom Green and surrounding counties (Lipan)
- Mason and surrounding counties (Hickory, Ellenburger - San Saba)

Other aquifers:

- Coke and Runnels Counties (Permian and Alluvium)
- Menard County (Alluvium)
- Sterling and Glasscock Counties (Alluvium)

For illustration purposes, larger scale maps were created for the following areas:

- Area 1: Schleicher and surrounding counties (Edwards -Trinity Plateau)
- Area 2: Glasscock, Reagan, and surrounding counties (Edwards - Trinity Plateau)
- Area 3: Ward and surrounding counties (Pecos Valley Alluvium)
- Area 4: Mason and McCulloch counties (Hickory, Ellenburger - San Saba)
- Area 5: Mitchell County (Dockum)

Maps of these five areas with well production are included as Figures 4-26 through 4-30.

Additionally, for each of the selected areas, historic water levels were averaged by well location by decade. Decade water level averages were calculated for the 1960s, 1970s, 1980s, 1990s and 2000s. The change in water levels between previous decades to the current decade (1960s to 2000s, 1970s to 2000s, 1980s to 2000s, and 1990s to 2000s) were then calculated and mapped collectively for any well location that had water levels measured between 2000 and 2007. This was done in order to give an overview of water level fluctuations in the aquifers over the last 50 years. The water level changes in major aquifers are shown in Figures 4-31 through 4-33.

4.3.3 Conclusions and Recommendations

This evaluation indicates that there are some areas with moderate to high production capacity. With the exception of the Pecos Valley Alluvium, much of the groundwater in these areas is already being fully utilized. In most areas, groundwater would need to be transferred from an existing use to a new use. To move forward with that process, a willing seller and a willing buyer would need to be identified. The regional water planning process is not intended to facilitate these types of negotiations.

4.4 Data Gaps

The most significant data gaps in terms of groundwater availability include:

- Types of data – Several types of data are required to fully assess groundwater resources. Basic requirements include borehole data, geophysical logs, well completion information, historic and recent water levels, historic and current production data, aquifer test results, water quality and geochemical data, and regional hydrogeologic data. In some areas, some of these data are very sparse or non-existent, making it difficult to refine water quantity and quality assessments with certainty.
- Data availability – The density of borehole and well data varies significantly across regions and aquifers. In some cases, other data are available but requires significant resources to obtain and analyze. The lack of sufficient localized and site-specific information makes it difficult to conclusively determine groundwater quality and long-term availability. All aquifers exhibit some degree of natural variability, and this variability can create significant changes in project viability and cost depending on the location of the project.
- Quality of data – Available data has been collected, interpreted, and documented by many people over several decades. Therefore, these data are inherently variable in quality, because they have been obtained under various quality assurance and control procedures, and with various laboratory methodologies and protocols. In some cases, quality assurance documentation does not exist, and it is difficult to discern whether variability is caused by actual aquifer changes or data quality issues.

5.0 BRACKISH GROUNDWATER DISPOSAL OPTIONS AND CO-DEVELOPMENT OPTIONS

Potential disposal options include: land application, surface water discharge, sewer discharge, injection wells (commercial or oil field), evaporation ponds, and zero liquid discharge. The following table, adapted from NRS (2008), presents a summary of general planning guidelines and considerations for concentrate disposal methods:

Table 5-1 Summary of General Planning Guidelines for Concentrate Disposal Methods

Disposal Method	Planning Guidelines	Considerations
Sewer Discharge	Treated in System – Combination of quantity and quality does not disturb wastewater treatment plant operations. Mixed with Plant Outfall – Pipe size suitable for additional volume of concentrate; requires permit revision.	Must process in-system concentrate to comply with existing permit, upgrades to plant may be required. Concentrate can be diluted without treatment by plant.
Surface Water Discharge	Inland – Total dissolved solids (TDS), oxygen, and pH of concentrate compared to disposal point. Ocean – N/A	Most common and cost-effective method. Distance from treatment facility to discharge point and environmental impact cost considerations.
Deep Well Injection	Disposal zone does not have direct or indirect connection with an aquifer of lower TDS concentration or any aquifer designated as a drinking source.	Economically attractive if other methods involve long conveyance distances.
Land Application	Disposal zone does not have direct or indirect connection with an aquifer of lower TDS concentration or any aquifer designated as a drinking source.	Effective for small amounts of concentrate. Relies on uptake by plants and soils. Must meet groundwater quality standards.
Evaporation Ponds	Double lining with leachate collection system required; depth of pond suitable to hold all precipitated solids over the life of the plant.	Requires large surface area and may require periodic disposal of precipitated salts. Usually requires impervious lining material, a cost consideration.
Zero Liquid Discharge	Location of off-site location for disposal of solids adequate.	Considered most sustainable but current costs prohibitive.

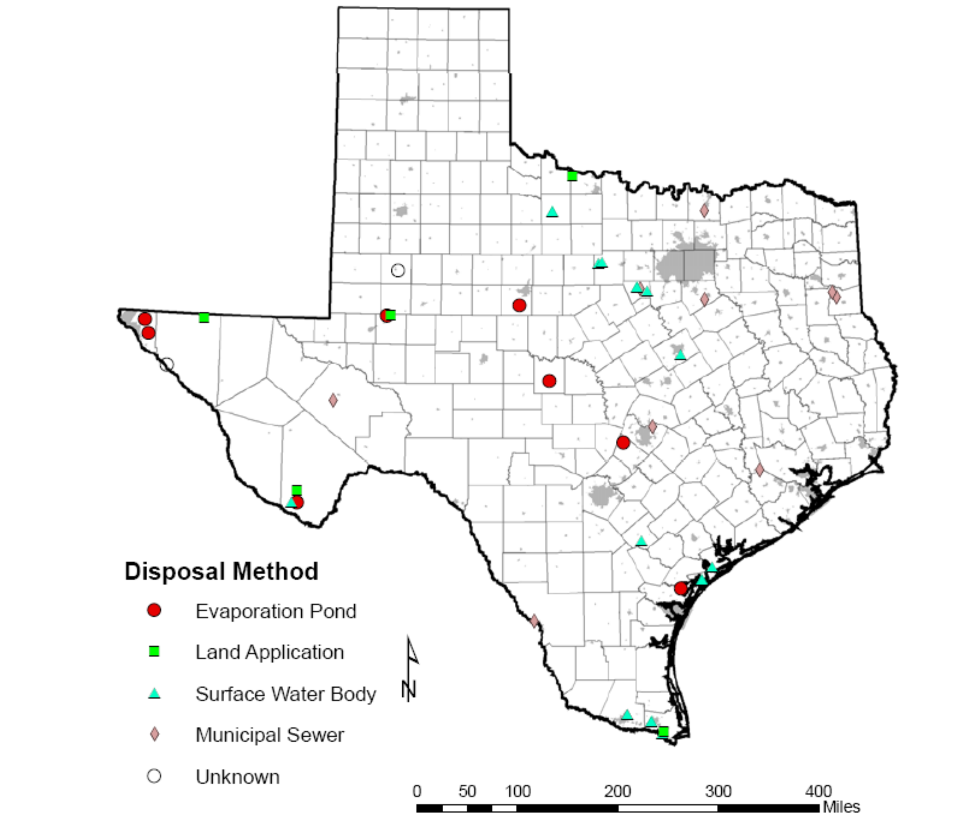
Nicot, et. al. (2005) compiled a database of Texas desalination facilities and mapped the various concentrate disposal methods. The report noted that there was no apparent trend in the spatial distribution of the disposal methods. The report also presented a table of concentrate disposal method statistics, which is reproduced here.

Table 5-2 Concentrate Disposal Method Statistics

Method	Number of Facilities	Cumulative Design Capacity (mgd)
Evaporation Pond	8	12.1
Land Application	5	3.3
Municipal Sewer	9	15.3
Surface Water Body	14	20.7
Unknown	2	0.02
TOTAL	38	52.3

In order to assess the feasibility of area-specific potential disposal methods with any degree of detail, it is necessary to consider them within the context of preliminary desalination facility design plan alternatives. This would include a consideration of engineering feasibility (source water, collection, conveyance, treatment, delivery, and disposal), potential environmental impacts (direct and indirect), and cost effectiveness (capital costs and operational) for each potential design configuration (NRS, 2008). This level of assessment is beyond the scope of work defined for this project; however, some of the disposal options will be generally more viable than others on an area-specific basis. These options are therefore only generally assessed to determine the most viable disposal options for: 1) Andrews County, 2) Coke County, and 3) Area 3 of the regional assessment, which is located in Ward and surrounding counties in the Pecos Valley Alluvium. The method of zero liquid discharge will not be considered for any of these areas in this evaluation since it is technologically not cost effective at the time of this report.

A map of desalination facilities less than or equal to 0.025 mgd design capacity (Nicot, et. al., 2005) is included as Figure 5-1.



NOTE: Location of some facilities is only approximate; Texas Statewide Mapping System projection

Figure 5-1 Map of desalination facilities showing concentrate disposal method (after Nicot, et. al., 2005)

5.1 Brackish Concentrate Disposal Options

5.1.1 Andrews County

Sewer Discharge

The only permitted wastewater treatment plant found in Andrews County in the TCEQ Chief Clerk's database is owned by the City of Andrews. The plant is located on County Road 1 just east of Andrews and receives up to 1,100,000 gallons per day of wastewater. After processing, water is stored until it is re-used by a local golf course. Desalination concentrate can either be treated by the existing facility, or discharged with the outfall without treatment. For this to be a viable option, the plant must either have existing treatment capacity to handle additional wastewater, the facility must be upgraded, or alternately, have enough available storage capacity in its outfall pond(s) to handle a *diluted* desalination concentrate. Compliance with the existing TPDES permit would need to also be addressed.

Surface Water Discharge

There are no active or inactive surface water right permits located within Andrews County. It is doubtful that discharge to surface waters could be considered a viable option for Andrews County, as surface water is not a significant enough resource to allow for allocation to potential users.

Deep Well Injection

Seventeen commercial disposal wells are currently permitted in Andrews County. There are also four cavern disposal wells that are currently permitted in Andrews County that are allowed to accept non-hazardous oil and gas wastes.

According to the RRC's disposal/injection well counts by district/field database (updated June 2008), there are currently 4,165 permitted injection wells in Andrews County. These wells are classified as either: 1) production zone wells, 2) non-production zone wells, or 3) secondary recovery wells. Of the 4,165 permitted injection wells in Andrews County, 103 inject into producing zones, 237 inject into non-producing zones, and 3,816 are used for secondary recovery operations. Permitted injection volumes range between 20 and 40,000 bpd, with an average injection rate of approximately 1,850 bpd (54 gpm). Permitted injection zones in Andrews County range between 1,000 and 14,200 ft bgl, however the majority of wells inject at depths between 4,000 and 5,000 ft bgl. A map illustrating Texas Class II injection wells (TWDB, 2006) with injection depth ranges is included as Figure 5-2. Note that none of the facilities surveyed by Nicot, et. al. (2005) utilized deep well injection as a disposal method; however, the Kay Bailey Hutchinson Desalination Plant, which utilizes injection wells as a disposal method, was not yet completed at the time the survey was published.

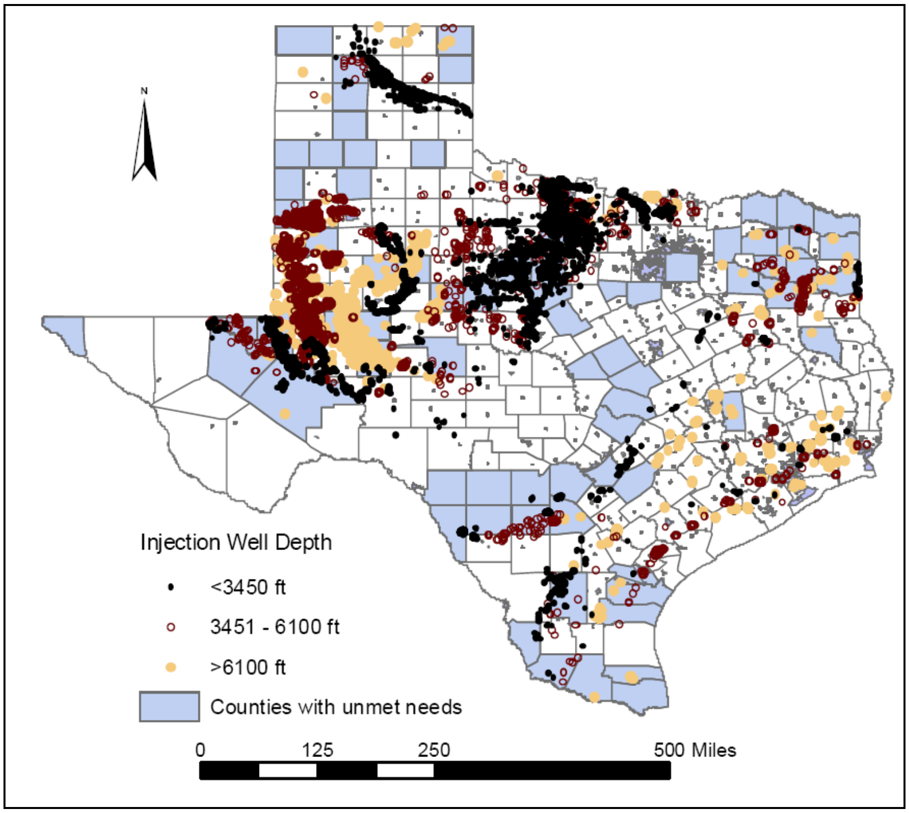


Figure 5-2 Locations of Class II injection wells in Texas with completion depths (after Nicot, et. al. 2005)

Non-hazardous desalination concentrate can be injected into a Class II well without any additional permitting if it is used for secondary recovery. Given that the RRC database indicates that 3,816 injection wells are being used for secondary recovery in Andrews County, this could be considered a feasible disposal scenario. Non-hazardous desalination concentrate can also be injected into a Class I well under a general permit; however, no existing Class I wells were found in Andrews County in the TCEQ database.

Land Application

Land application is only a viable alternative in locations where the disposal area does not have direct or indirect contact with either an aquifer of lower TDS concentration or any aquifer designated as a drinking water source. Since the Ogallala aquifer underlies most of the county, land application should not be considered a viable alternative for concentrate disposal in Andrews County unless the criteria for industrial wastewater overlying a recharge zone are met. The criteria for industrial wastewater overlying the recharge zone of a major or minor aquifer requires that the soil liner (in-situ or constructed) must be at least 3 feet thick, with a hydraulic conductivity less than 10^{-7} cm/s. The minimum thickness required for a geomembrane liner is 30 mils, as specified by 30 TAC 309.13(d).

Evaporation Ponds

Evaporation ponds are only feasible in areas with relatively inexpensive land since they require a large land footprint and storage capacity. Smaller desalination facilities located in arid climates use them because they are easy to construct and are not expensive to maintain; however, the required impermeable liner is typically the most costly component of an evaporation pond. Presently, approved liners include a 3-foot thick clay layer with a maximum hydraulic conductivity of 10^{-7} centimeters/second (cm/s), or a minimum 30-mil geomembrane liner *with* a leak-detention monitoring system. Self-sealing pond liners, composed of the precipitated clay mineral sepiolite, have the potential to become an approved liner technology; however, currently they are not pre-approved by the TCEQ. Otherwise, an evaporation pond would only require a Texas Land Application Permit (TLAP) from the TCEQ.

Since the Ogallala aquifer underlies most of Andrews County, the geomembrane component of an evaporation pond would be especially critical to ensure protection of the aquifer. This may be a viable disposal option assuming sufficient integrity of the liner.

5.1.2 Coke County

Sewer Discharge

There are two permitted wastewater treatment plants found in Coke County in the TCEQ Chief Clerk's database operated by the Cities of Robert Lee, and Bronte. Desalination concentrate can either be treated by an existing facility, or discharged with the outfall without treatment.

Surface Water Discharge

The cities of Robert Lee and Bronte have eight and four, respectively, active surface water right permits located downstream from them on the Colorado River within Coke County. It is doubtful that discharge to the Colorado River would be considered a viable option, unless the receiving waters could be shown to provide enough dilution that water quality stream standards would not be exceeded and downstream users would not experience material impacts.

Deep Well Injection

Dedicated Disposal Wells

No commercial disposal wells or cavern disposal wells are currently permitted in Coke County.

Co-Disposal with Oil Field Brines

According to the RRC's disposal/injection well counts by district/field database (updated June 2008), there are currently 242 permitted injection wells in Coke County. These wells are classified as either: 1) production zone wells, 2) non-production zone wells, or 3) a secondary recovery wells. Of the 242 permitted injection wells in Coke County, 43 inject into producing zones, 13 inject into non-producing zones, and 186 are used for secondary recovery operations. Permitted injection volumes range between 20 and 7,000 bpd, with an average injection volume of approximately 1,500 to 2,500 bpd (44-73 gpm). Permitted injection zones in Coke County range between 3,000 and 7,000 ft bgl, however the majority of wells inject at depths between 5,000 and 7,000 ft bgl. Most of these wells are located in the Jameson field, which is in the northwest section of the county. Note that none of the facilities surveyed by Nicot, et. al. (2005) utilized deep well injection as a disposal method; however, the Kay Bailey Hutchinson Desalination Plant, which utilizes injection wells as a disposal method, was not yet completed at the time the survey was published. The El Paso project is discussed in further detail in Section 6.3 of this report.

Non-hazardous desalination concentrate can be injected into a Class II well without any additional permitting if it is used for secondary recovery. Given that the RRC database indicates that 186 injection wells are being used for secondary recovery in Coke County, this could be considered a feasible disposal scenario. Non-hazardous desalination concentrate can also be injected into a Class I well under a general permit; however, no existing Class I wells were found in Coke County in the TCEQ database.

Land Application

Nicot (2005) documented that seven of the 105 public water system facilities that were surveyed operated a desalination facility with a capacity greater than or equal to 0.025 mgd and utilized land application as a disposal method. These facilities are as follows:

Table 5-3 Desalination Facilities using Land Application as a Disposal Method

Plant Name	County	Design Capacity (mgd)	Average Desalination Production (mgd)	Use	Source	Startup Year	Process	Blending?	Disposal Method
Horizon Regional MUD	El Paso	2.2	1.13	DW	GW	2001	RO	Yes	LA/IRR/EP
Valley MUD #2	Cameron	0.5	0.26	DW	GW	2000	RO	Yes	SW/LA
City of Electra	Wichita	0.5	0.347	DW	GW	1999	RO	No	LA/IRR
Dell City	Hudspeth	0.1	0.05	DW	GW	1996	EDR	No	LA/IRR
Hacienda del Norte WID	El Paso	0.05	0.04	DW	GW	1981	RO	Yes	LA/IRR/EP
Water Runner, Inc.*	Midland	0.028/2.16	1.5	DW/IND	GW	2001	RO	No	LA/IRR
Longhorn Ranch Motel*	Brewster	0.023	0.023	DW/IRR	GW	1990	RO	Yes	LA/IRR

NOTES: DW – drinking water; IND – industrial; GW – groundwater; RO – reverse osmosis; EDR – electrodialysis reversal; EP – evaporation pond; IRR – irrigation; LA – land application; SW – discharge to surface water; * - dual use facility.

Note that average desalination production at these facilities ranges between 0.023 and 1.5 mgd; however, none of them use land application exclusively for a disposal method.

Land application is only a viable alternative in locations where the disposal area does not have direct or indirect contact with either an aquifer of lower TDS concentration or any aquifer designated as a drinking water source. Land application may be a suitable disposal option for Coke County in the event that groundwater quality is inferior to the wastewater stream, an alternative liner may be adequate for permit approval via 30 TAC 317(a)(4)(B) as an innovative or nonconforming technology.

Evaporation Ponds

See discussion of evaporation ponds in Section 5.1.5. Desalination concentrate disposal via an evaporation pond is an option for this area. In areas where it can be shown that fresh water aquifers don't exist, permitting of evaporation ponds may be simplified.

5.1.3 Pecos Valley Region

Sewer Discharge

There are six permitted wastewater treatment plants found in Ward and Winkler Counties in the TCEQ Chief Clerk's database operated by the Cities of Grandfalls, Monahans, Pyote, Wickett, Kermit, and Wink. Desalination concentrate can either be treated by an existing facility, or discharged with the outfall without treatment. If concentrate is treated by an existing WWTP, the NPDES (TPDES) wastewater permit will require modification. Upgrades to the facility may also be required to enable treatment of concentrate disposal in addition to existing wastewater effluent. In order for concentrate to be discharged at the existing outfall without treatment, the concentrate might require dilution to maintain compliance with existing TPDES wastewater permit, and may potentially require permit modification.

Surface Water Discharge

There are no active or inactive surface water right permits located within Andrews County. It is doubtful that discharge to surface waters could be considered a viable option for Loving, Ward, or Winkler Counties, as surface water is not a significant enough resource to allow for allocation to potential users. In the event that it does prove to be a feasible option, the receiving waters need to provide enough dilution that water quality stream standards would not be exceeded and downstream users would not experience material impacts.

Deep Well Injection

According to the RRC's disposal/injection well counts by district/field database (updated June 2008), there are currently 4,277 permitted non-commercial injection wells in Loving, Ward, and Winkler Counties as shown in Table 5-4.

Table 5-4 Oil and Gas Injection Wells Currently Operating in Loving, Ward and Winkler Counties

County	Commercial Disposal	Cavern Disposal	Non-Producing Zone	Producing Zone	Secondary Recovery
Loving	3	0	24	50	136
Ward	9	0	57	280	1,636
Winkler	12	0	50	271	1,773
TOTAL	24	0	131	601	3,545

Non-hazardous desalination concentrate can be injected into a Class II well without any additional permitting if it is used for secondary recovery. Given that the RRC database indicates that 3,545 injection wells are being used for secondary recovery in Loving, Ward, and Winkler Counties, this could be considered a feasible disposal scenario. Non-hazardous desalination concentrate can also be injected into a Class I well under a general permit; however, no existing Class I wells were found in Loving, Ward, or Winkler Counties in the TCEQ database.

Land Application

Land application is only a viable alternative in locations where the disposal area does not have direct or indirect contact with either an aquifer of lower TDS concentration or any aquifer designated as a drinking water source. Land application may be a suitable disposal option in only limited portions of Loving, Ward, or Winkler Counties since the Pecos Valley Alluvium underlies large portions of these counties.

Evaporation Ponds

Since the Pecos Valley Alluvium aquifer underlies most of Loving, Ward, or Winkler Counties, the liner of an evaporation pond would be necessary to ensure protection of the aquifer. This may be a viable disposal option assuming sufficient integrity of the liner.

5.1.4 Summary of Brackish Water Disposal

Disposal to sewer, deep well injection, and evaporation ponds may be options for all of the areas considered. Discharge to surface water may or may not be viable for Coke County and Area 3 (Pecos Valley Alluvium). Land application may be an option in Coke County. Zero liquid discharge was not evaluated. Table 5-5 summarizes feasible disposal methods for each of the areas.

Table 5-5 Summary of Disposal Options

Area	Sewer	Surface Water	Deep Well Injection	Land Application	Evaporation Ponds	Zero Liquid Discharge
Andrews County	√		√		√	N/A
Coke County	√	?	√	√	√	N/A
Area 3 (Pecos Valley Alluvium)	√	?	√		√	N/A

5.2 Co-Development

Co-development is a term that is used to describe developing multiple water supply sources as a single water management strategy. A co-development project may include joint development of fresh and brackish water sources or it may simply combine the infrastructure for multiple users to optimize transmission costs and efficiency.

Based on the analyses of available groundwater, there is limited co-development potential in Region F. There are few recommended projects in the 2006 Region F Water Plan that would be conducive to co-development. The new projects identified in Special Study No. 3, *Study of the Economics of Rural Water Distribution and Integrated Water Supply Study*, are very costly and likely will not be developed. Co-development of groundwater with these projects may slightly reduce the unit costs of the projects, but it will likely not reduce it sufficiently to make the projects cost effective. There may be some small projects in Coke-Runnels, Andrews and Schleicher counties, but these would need to be identified on an individual basis.

The greatest potential for co-development exists in the Pecos Alluvium area. Groundwater quantity is relatively plentiful. The quality can vary from site to site, so the potential for co-development of differing water qualities may be high. Region F also has identified two water management strategies that would use water from the Pecos Alluvium: 1) development of the CRMWD Winkler well field, and 2) development of Midland's T-Bar ranch groundwater.

CRMWD owns water rights in southern Winkler County with an estimated reliable supply of 6,000 acre-feet per year. The recommended water management strategy in the 2006 Region F Water Plan assumes that CRMWD will develop this source and transport the water to a point near the City of Odessa for blending with other water sources. The blended water could then be used to supply Odessa and other CRMWD customers.

The City of Midland owns approximately 20,230 acres in northwestern Winkler County and northeastern Loving County. The City has estimated the available groundwater in storage at 650,000 acre-feet with an annual recharge rate of 6,600 acre-feet per year. The City intends to use this source during drought and times of high demand. For purposes of regional planning, it was assumed that an annual supply of 13,600 acre-feet per year is available.

Based on the assessment of available water in the Pecos Alluvium, it is reasonable to assume that an additional 10,000 acre-feet per year of water could be co-developed with the CRMWD Winkler well field and the Midland T-Bar ranch well field. Collectively, this would provide 29,600 acre-feet per year of groundwater to Region F water users.

A joint project to develop this water was evaluated. This project assumed that the CRMWD well field, Midland's well field and a new well field will be developed, totaling 29,600 acre-feet per year. Since the location of the new well field has not been identified, it was assumed that the well field would be located within 30 miles of the proposed intersection of the pipelines from the T-Bar Ranch and the CRMWD Winkler well field. The water would then be transported to Odessa and Midland for use and/or distribution to other users. A schematic of the proposed transmission system is shown on Figure 5-3. The location of the new well field would likely fall within the western half of the shaded area. The area to the east of Winkler and Ward Counties has limited groundwater supplies and is outside of the project study area.

To assess the feasibility of co-development of Pecos Alluvium groundwater, costs were developed and compared to the individual projects. Infrastructure costs were updated to 2007 dollars, and the cost assumptions are included in Appendix A. Due to the lack of data on water quality, treatment costs beyond chlorination are not included. Also, water purchase costs for water from a new well field are not included.

A summary of the costs for the projects is presented in Table 5-6 and shown on Figure 5-4. The unit costs of the joint project are slightly less than each of the individual projects, but the initial capital costs are higher. This is because the joint project is developing and moving more water than the sum of the individual projects. However, pending the timing for when this water is needed, it may not be cost effective to develop the joint project. This would need to be evaluated by the entities developing the project(s).

Table 5-6 Cost Comparison of Co-Development Project to Individual Projects

Project	Amount	Unit Cost ($/1,000 Gal)		Capital Costs (million $)
		During Debt	After Debt	
T-Bar	13,600	$ 3.86	$ 0.94	$148.40
Winkler	6,000	$ 4.19	$ 1.04	$70.80
Co-Development	29,600	$ 3.49	$ 0.86	$291.80

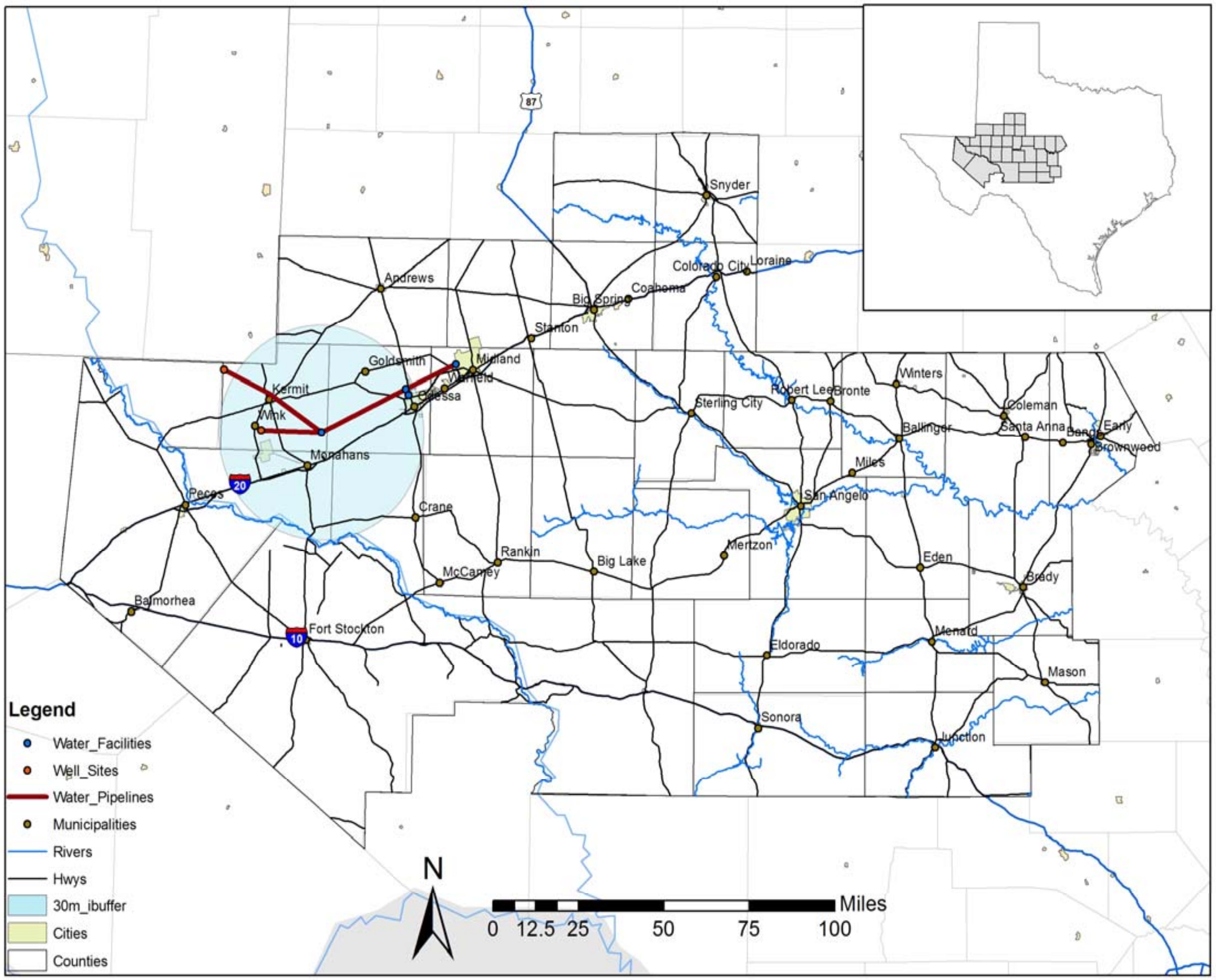


Figure 5-3 Schematic of Pecos Alluvium Co-Development Project

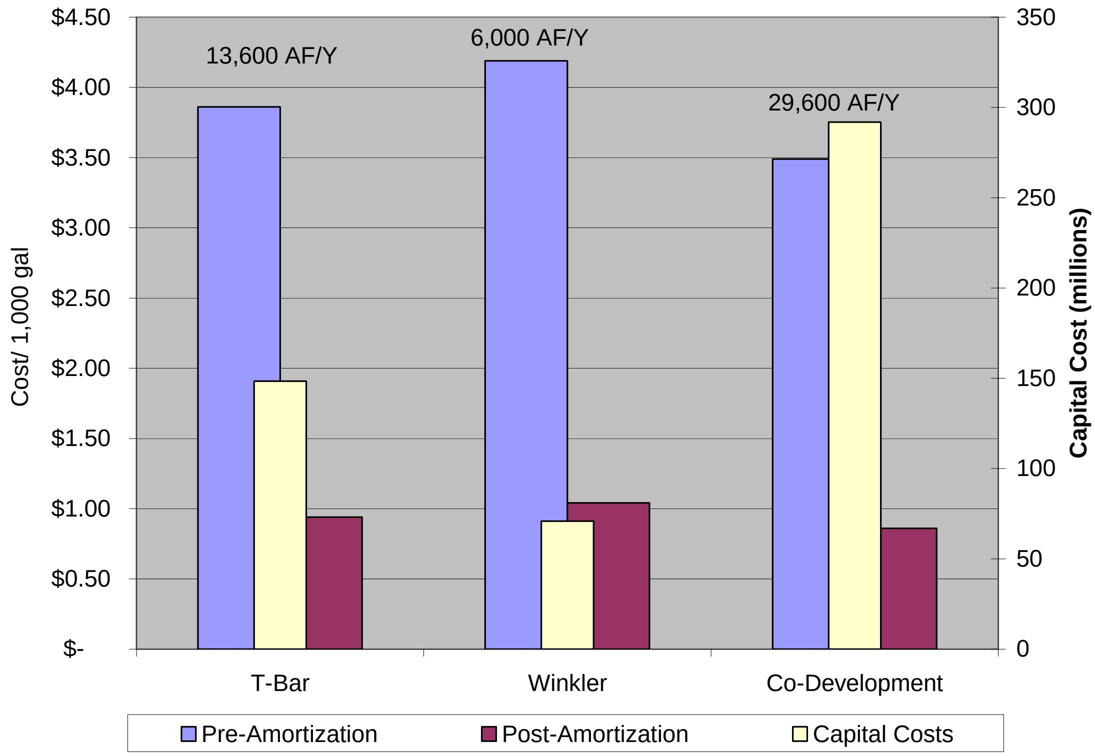


Figure 5-4 Cost Summary of Co-Development Project

5.3 Data Gaps

The most significant data gap in terms of potential disposal options and co-development is the lack of specific facility locations and facility design capacities. Some of the most critical factors in the selection of a suitable concentrate disposal option include:

- Distance between the facility and discharge point – Transport distance is a major factor in disposal cost.
- Volume of concentrate to be disposed – Concentrate volumes dictate which disposal options can be considered for each method of disposal and the available and/or allocated resources.
- Source water quality – Feedwater TDS is a major factor in pre-treatment and treatment options and cost, as well as volume of concentrate and the options considered for disposal.

It is difficult to recommend a disposal option without knowing specific locations, anticipated disposal volumes, and feedwater TDS concentrations. In addition, the most effective and efficient approach for developing brackish groundwater supplies is to evaluate groundwater supply, engineering and treatment, transport, and disposal issues simultaneously. Simultaneous assessment is important because of the many variables to consider in each component of the system.

6.0 CONCEPTUAL DESIGN AND COST ESTIMATES

Conceptual groundwater projects were defined for each of the two specific project sites and the three potential regional sites identified in Section 4. These conceptual projects are based on available supply from each site and an assumed distance to transport the water to the end user.

There were three primary considerations in developing costs:

1. Quantity
2. Delivery range
3. Topography

The quantity of water that could reasonably be developed from a project site was based on the assessment in Section 4. Generally, a single-sized project was identified for each groundwater site with quantities ranging from 200 acre-feet per year in Coke-Runnels County to 2,000 acre-feet per year in Schleicher County. For the Pecos Alluvium area, which may have the largest untapped groundwater reserves in the region, two sized projects were identified: a small scale project at 3,000 acre-feet per year and a large project at 10,000 acre-feet per year. A summary of the potential well field development by site is presented in Table 6-1.

Table 6-1 Potential Groundwater Projects

Site	Well field Capacity (af/yr)	Number of wells in Well field	Potential Number of Well fields	Minimum Distance between Well fields (miles)
Andrews	300	5	4	1
Coke-Runnels	200	5	3	1
Pecos Valley (large)	10,000	10	3	3
Pecos Valley (small)	3,000	3	10	1
Schleicher	2,000	6	2	2
Glasscock, Reagan	500	9	3	2

The delivery range was based on the size of the project and potential end users. For the Andrews County project, it was assumed that the end user is the City of Andrews and a single delivery range of 20 miles was assumed. For the other project sites, the end user was not defined, so delivery ranges were assumed generally assumed at 10-mile and 50-mile radii from the center of the project site. For very small projects, such as Coke-Runnels County, only the smaller distance was assumed. For the large Pecos Alluvium project, it was assumed that an end user might be farther. Delivery ranges of 50 miles and 100 miles were used for the large Pecos Alluvium project. Figure 6-1 shows the assumed transmission distances for each project area.

West Texas has a wide range of topography and depending on the location of the well field and the delivery point, the transmission system may have to pump up hill or it could flow down hill. To assess the potential impacts of static head on the costs of moving the groundwater, two scenarios were included: 1) no static head for the transmission system and 2) assumed static head relative to the transmission distance (higher static head for longer pipelines).

While it is recognized that the individual projects may differ from the assumptions used for the conceptual design, these costs estimates present a planning level feasibility assessment of costs for potential future projects. The quantities of available water are based on available data and theoretical estimates. Actual quantities and quality of groundwater within any of these project sites would need to be assessed through field studies.

6.1 Costs

Capital costs were developed following the Texas Water Development Board's guidance for the special studies. These costs are based on second quarter 2007 dollars. Capital cost estimates are based on standard unit costs for groundwater well fields, installed pipe, pump stations and other facilities developed from experience with similar projects throughout Texas. All unit costs include the contractor's mobilization, overhead and profit. The costs for engineering, contingencies, financial and legal services, and right-of-ways are estimated separately from the unit costs. Costs for water purchase and treatment are not included. These costs present a very rough assessment of the feasibility to develop new groundwater in each of the identified project sites. The assumptions used in the cost development are included in Appendix A. Cost tables for the conceptual projects are also included in Appendix A. A summary of the project descriptions and associated costs are shown in Table 6.2.

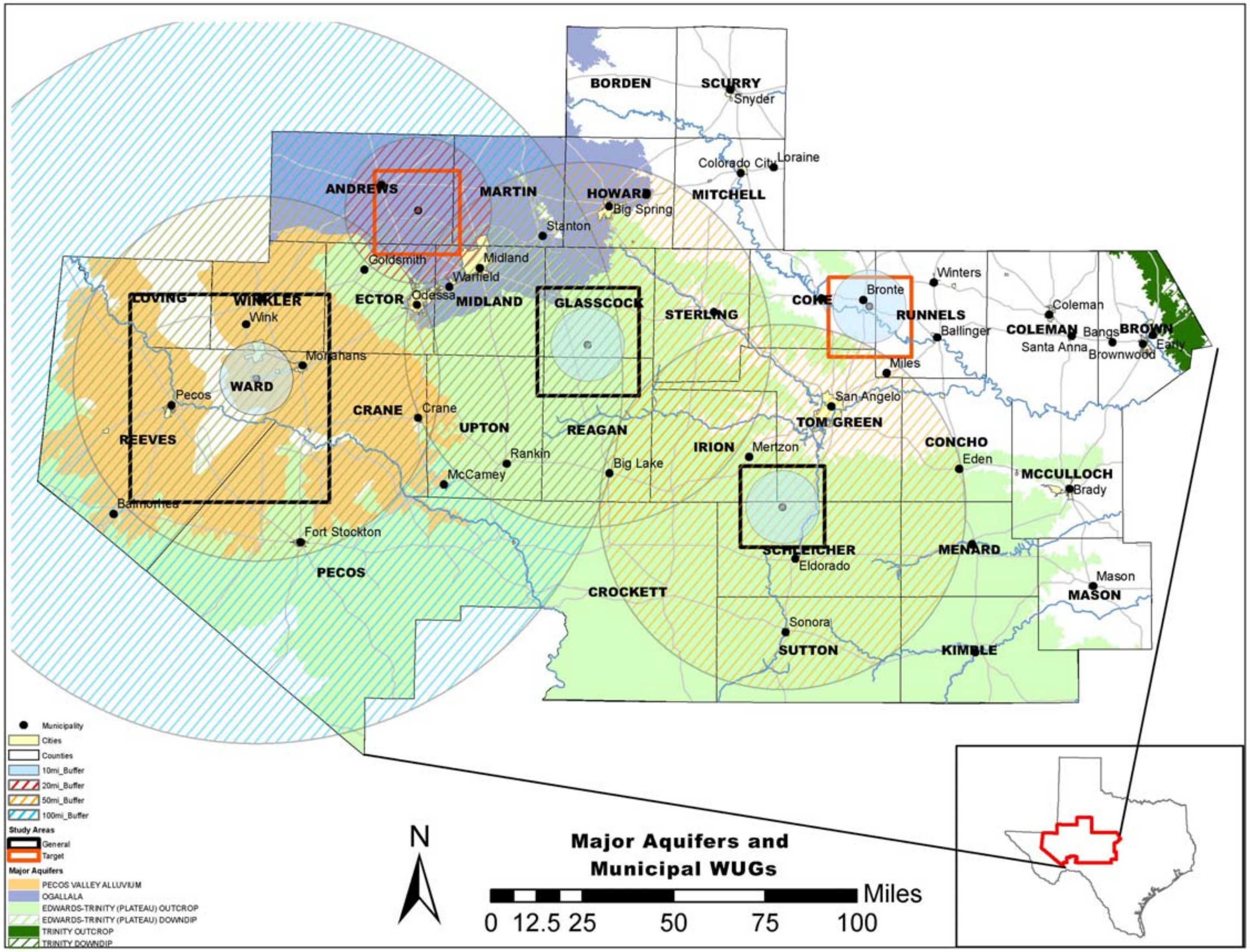


Figure 6-1 Conceptual Project Locations

Table 6-2 Summary of Cost Analyses for Conceptual Projects

Site	Quantity (af/yr)	Distance (miles)	Static Head (ft)	Capital Cost	Annual Cost	Unit Costs ($/ ac-ft)		Unit Costs ($/ 1,000 gal)	
					During Debt	During Debt	After Debt	During Debt	After Debt
Andrews	300	20	0	$8,029,000	$807,000	$2,690	$357	$8.30	$1.10
		20	100	$8,064,000	$814,000	$2,713	$370	$8.35	$1.15
Coke-Runnels	200	10	0	$4,363,000	$449,000	$2,245	$345	$6.90	$1.10
		10	50	$4,391,000	$454,000	$2,270	$355	$7.00	$1.10
Pecos Valley Counties (Large Project)	10,000	50	0	$76,874,000	$9,206,000	$921	$250	$2.85	$0.80
		50	200	$78,196,000	$9,594,000	$959	$278	$2.95	$0.90
		100	0	$143,440,000	$15,838,000	$1,584	$333	$4.90	$1.05
		100	200	$145,039,000	$16,257,000	$1,626	$361	$5.00	$1.15
Pecos Valley Counties (Small Project)	3,000	10	0	$10,873,000	$1,539,000	$513	$197	$1.60	$0.65
		10	50	$11,061,000	$1,578,000	$526	$205	$1.65	$0.65
		50	0	$36,908,000	$4,135,000	$1,378	$306	$4.25	$0.95
		50	200	$37,340,000	$4,256,000	$1,419	$334	$4.40	$1.05
Schleicher	2,000	10	0	$8,763,000	$983,000	$492	$110	$1.55	$0.35
		10	50	$8,840,000	$1,004,000	$502	$117	$1.55	$0.40
		50	0	$30,610,000	$3,130,000	$1,565	$231	$4.85	$0.75
		50	200	$31,050,000	$3,226,000	$1,613	$260	$5.00	$0.80
Glasscock, Reagan	500	10	0	$6,920,000	$726,000	$1,452	$246	$4.50	$0.80
		10	50	$6,938,000	$732,000	$1,464	$254	$4.50	$0.80
		50	0	$21,163,000	$2,099,000	$4,198	$508	$12.90	$1.60
		50	200	$21,245,000	$2,120,000	$4,240	$536	$13.05	$1.65

Notes: Cost during debt includes repayment of capital costs, which were amortized over 20 years. Cost after debt repayment includes operation and maintenance costs.

Figure 6-2 presents the range of costs for each project site. As shown on Table 6.2, the cost feasibility of a project tends to be related to the transmission distance. Small quantities of water transmitted relatively long distances have very high unit costs, as demonstrated by the 50-mile delivery project for 500 acre-feet per year in Glasscock-Reagan Counties. Cost feasibility increases with greater quantities and relatively shorter distances.

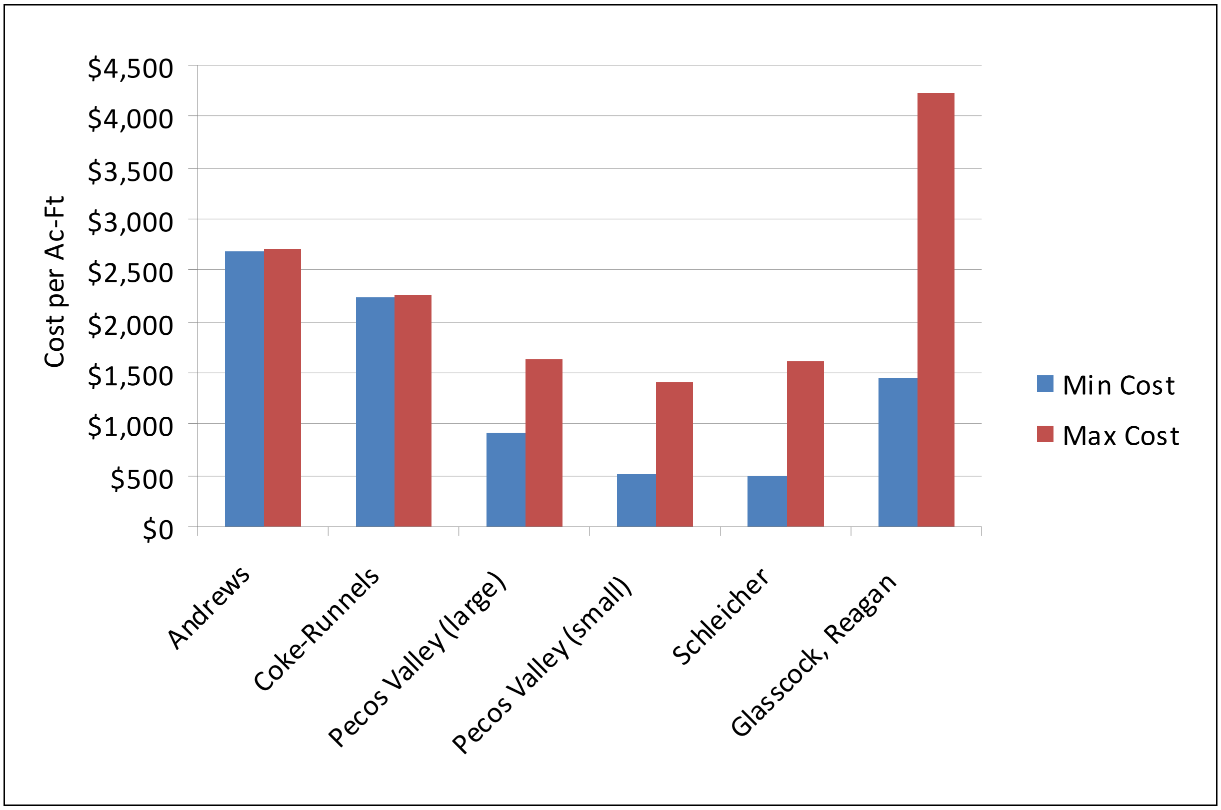


Figure 6-2 Unit Cost Range for Conceptual Groundwater Projects

6.2 Potential Issues with Development of Groundwater

Andrews County

There is limited available groundwater is southwestern Andrews County. As discussed in Section 4, the amount of water is uncertain. Pending further field investigations, there may be sufficient supplies to provide additional water to the City of Andrews, but there is not sufficient supply to fully meet the City's projected need.

As with most of the study areas, there is competition for groundwater in Andrews County. There are projected unmet agricultural needs in the county. Due to the competition for groundwater the development of a new well field may have some impacts on agriculture and rural areas. These impacts are considered low to moderate pending the amount of supply proposed for this project.

There is little surface water in this project area, and development of the groundwater would likely have little potential of impacting springflow, baseflow in rivers, or habitats.

Coke-Runnels Counties

The project area in Coke-Runnels Counties overlies three potential formations for future groundwater development. As discussed in Section 4, the formation with the highest reliability and water quality is the Choza Formation (with Merkel Dolomite). However, production rates are low and the available supply is limited. It is estimated that a typical well field (with 5 wells) could produce 200 acre-feet per year.

The 2006 Region F Water Plan shows some unmet agricultural needs in both Coke and Runnels Counties. While these needs are relatively small, there is competition for the water supplies in the project area.

While it is not anticipated that there will be significant environmental impacts with the development of a groundwater project in this area, several of the formations are fairly shallow and groundwater withdrawals may impact nearby surface water streams.

Pecos Valley

The Pecos Valley has the greatest potential for future groundwater development. Based on the desktop analysis conducted for this study, there is about 30,000 acre-feet per year of available groundwater in this project area. Some of this water has been identified as management strategies for CRMWD and the City of Midland, but there is the potential for additional development. One of the drawbacks with this source is the distance to areas with needs. The greater needs in the region are located more than 50 miles from this project area and some needs are located even farther. Economic development of this water may be through joint projects or as a regional project, but this will require more study by entities with needs.

In the proposed development areas there is little flowing surface water in the northern part of the project area in Winkler and Loving Counties. The Pecos River runs along the county lines of Ward, Reeves and Pecos Counties. Pending the location of a new well field, the development of this source is expected to have minimal impacts to the Pecos River watershed. The project area is located north of the documented springs in Pecos and Reeves Counties. The area that is closer to projected needs is in Loving and Winkler Counties, which would probably have no impacts to springflow or surface water habitats.

Schleicher

The Schleicher County project area also covers small parts of southeast Irion County and southwest Tom Green County. Available supply in this area is estimated at 4,000 acre-feet per year. However, there is concern about the reliability of this source under high and consistent pumping conditions. Most of the groundwater in this area has been used for agricultural purposes using low to moderate production wells.

There are several significant springs in southeastern Irion and southwestern Tom Green Counties. Depending on the location of a new well field, development of groundwater could have impacts to these springs and associated surface water streams.

The Region F water supply analysis shows sufficient water supply to meet local agricultural and municipal needs in Schleicher County. However, if water currently used for irrigation was shifted to another use, the impact on irrigated agriculture and rural areas is currently unknown.

Glasscock-Reagan Counties

The available quantity of water from the Glasscock-Reagan Counties project area is relatively small. Total production in the project area was estimated at 1,500 acre-feet per year, of which almost all is currently used for agricultural purposes. Well production tends to be low such that many wells are required to deliver moderate amounts of water supply.

There is little surface water in this project area, and development of the groundwater would likely have little potential of impacting springflow, baseflow in rivers, or habitats.

The Glasscock-Reagan area is currently heavily irrigated resulting in competition with other uses for groundwater. The 2006 Region F Water Plan shows unmet agricultural needs in these counties. Even if a significant number of willing sellers could be identified, transfer of water could potentially impact agricultural lands and agricultural production in the area.

7.0 RECOMMENDED APPROACH FOR FUTURE FIELD STUDIES

As part of developing a groundwater supply, several more tasks need to be completed. Although the list is not exhaustive, it can be considered as general guidance in assessing a site for potential development. For a more complete discussion of this topic, please refer to the Brackish Groundwater Exploration Guidance Manual (LBG-Guyton, 2008).

7.1 Selection of Specific Sites

Identify potential site(s) for further characterization and study. This may include negotiation with landowners and/or water rights holders for available water rights and to obtain access. Technically, the process starts by using existing geologic and hydrologic data to determine which geologic formations offer the best potential for the production of groundwater in terms of well yield, well depth, water level elevation, water chemistry, and transport distance.

In some areas, aquifers containing groundwater are well understood, and in other cases they are not. In areas where an 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.

For fresh or brackish groundwater to be a viable water supply option, two principal hydrologic components must be considered. First, the subsurface water-bearing formation (aquifer) must be capable of yielding a sufficient volume of water over the desired lifetime of the wellfield. And second, the water chemistry (concentration and constituent makeup of the dissolved mineral content) of the groundwater should be of reasonable quality or such quality 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.

7.2 Assess Regulations

In areas managed by a groundwater conservation district, obtain the district rules and management plan. Consult with attorneys and other specialists that understand water law and project development. A preliminary assessment of all regulatory issues should be completed to obtain a good understanding of the scope and time frame required to meet regulatory requirements, as well as the risk of not attaining regulatory approval.

7.3 Establish Drilling Program

Develop a drilling and testing program that will better establish groundwater quantity and quality, as well as long-term availability. This will include developing drilling specifications and testing protocols, advertising a bid package, assessing bids, and selection of contractors.

A geoscientist (rig geologist) is often employed to examine and describe these cuttings on site, 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.

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. 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). 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. Using previously run geophysical logs with resistivity curves can be an important tool for determining the anticipated salinity and extent of the brackish groundwater.

7.4 Design and Install Test Wells

Generally, test wells are designed and installed to confirm the preliminary hydrogeologic assessment. 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. 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.

Some site preparation may be required prior to mobilizing equipment to the project location. Because the aquifer to be explored is brackish, protection of freshwater supplies is important. All precautions must be taken to protect the freshwater supply and prevent mixing between aquifers. The type of strata (consolidated or unconsolidated) to be encountered will dictate types of drilling, whether 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 should be 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.

7.5 Pumping Tests and Water Quality Sampling

Aquifer tests are performed to determine aquifer transmissivity and storage properties. 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 to determine the non-pumping (static) level. Then after the pump is started, the water level is measured at specific intervals.

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. If possible, measurements should also be 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.

The duration of a pumping test 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.

Groundwater samples are collected from test wells to confirm water quality and to assess and plan for water treatment requirements. This step may include evaluation of water treatment required for desalination. Brackish water was previously defined as having a TDS ranging from 1,000 mg/l to 10,000 mg/l. 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.

At a minimum, 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.

7.6 Assessment of Wellfield Viability and Impacts

Quantitative modeling should be performed to assess the long-term availability from the wellfield as well as local and regional impacts with regard to water level declines and impact on other water resources. This may require development of a groundwater model that accounts for local hydrogeology and hydrology as well as the regional setting. This type of tool can be used to evaluate wellfield design issues such as well spacing, long-term availability, land requirements, etc.

7.7 Engineering Studies and Other Project Preparation

There are several other project components that are more related to project design, implementation and construction which should be considered. They are listed below.

- Pilot plant operations
- Engineering feasibility studies
- Financial funding opportunities
- Brackish source-water supply construction
- Design and construction of desalination facility
- Concentrate disposal options
- Distribution system integration

8.0 REFERENCES

LBG-Guyton Associates, *Brackish Groundwater Manual for Texas Regional Water Planning Groups,* February 2003. TWDB Contract Report.

LBG-Guyton Associates, *Brackish Groundwater Exploration Guidance Manual*, April, 2008. TWDB Contract Report.

NRS Consulting Engineers, *Guidance Manual for Brackish Groundwater Desalination in Texas,* April, 2008. TWDB Contract Report.

Nicot, J., Walden, S., Greenlee, L., and Els, J., *A Desalination Database for Texas,* October 2005. TWDB Contract Report.

Nicot, J., Gross, B., Walden, S., and Baier, R., *Self-Sealing Evaporation Ponds for Desalination Facilities in Texas*, March 2007. TWDB Contract Report.

Texas Railroad Commission, 2008. Injection/Disposal Well Database.

Texas Commission on Environmental Quality, 2008. Chief Clerk's Database.

TWDB Report 366*, Please Pass the Salt: Using Oil Fields for the Disposal of Concentrate from Desalination*, April 2006.

U.S. Bureau of Reclamation, *Desalting Handbook for Planners, 3rd edition,* July, 2003.

Chapter 4 Figures

Appendix A

Assumptions and Details used in Cost Analyses