Step 1 Report

FEASIBILITY INVESTIGATION

Aquifer Storage and Recovery System

Submitted to
City of Laredo
Laredo, Texas

By
CH2M HILL

October 1996

DEN/PL/118069.H0.ZZ/6-96

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STATE OF TEXAS
J. MICHAEL ANGLEA
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DEN/PL/118069.H0.ZZ/6-96

Engineers
Planners
Economists
Scientists

October 1, 1996

118069.H0.ZZ

Mr. Jerry Pinzon, P.E.
Manager, Water Utility
4002 N. Bartlett Avenue
P.O. Box 2950
Laredo, TX 78044

Dear Mr. Pinzon:

Subject: Aquifer Storage and Recovery—Step 1 Report

CH2M HILL is pleased to transmit this Step 1 Report for the Aquifer Storage and Recovery (ASR) Feasibility Investigation. This phase of the project has consisted mostly of assembling and analyzing existing well information in the Laredo area and assessing the City's water supply and storage plans to determine how the ASR technology might fit into the City's future program.

It appears that the ASR technology does have potential applications in the City's future strategy and that the aquifer formations in the Laredo area may yield storage and recovery results that would support the development of a viable ASR program. Further field testing is necessary to confirm the Step 1 findings. Therefore, we are recommending that the City proceed with the second step of the investigation which will consist of developing and testing new wells in selected locations in and around the City.

It has been a pleasure working with you on this important project. We are prepared to review the conclusions and recommendations of this report at your convenience.

Sincerely,

CH2M HILL

Michael Anglea

J. Michael Anglea, P.E.
Project Manager

DEN/7638.DOC
c: Fernando Roman, P.E.
Rogelio Rivera, P.E.

Contents

Contents, Continued

Contents, Continued

Tables

Figures

SECTION 1

Introduction

Overview

The City of Laredo, Texas, operates a water supply system that serves residential, commercial, industrial, and wholesale customers in the city and surrounding areas. The Rio Grande River is the sole source of raw water. The City is located along a reach of the river between the Amistad and Falcon Reservoirs.

The City is experiencing growth in population and water demand, particularly in areas north and south of the City. The current and projected growth is resulting in increased water demands and the requirements for expanded water system facilities. Additionally, the population growth will result in the City exceeding its current municipal water rights in the near future. While there is an active market in water rights allocations, there is a finite limit to the amount of water available to meet continued growth in this area, especially during drought conditions. The Rio Grande Watermaster has already implemented restrictions on agricultural water rights and has the authority to prorate municipal water rights should this ever become necessary.

Due to continued growth, the City of Laredo applied for, and received, partial grant funding from the Texas Water Development Board (TWDB) to begin evaluating whether Aquifer Storage and Recovery (ASR) would be feasible and beneficial to the City. The City applied for the grant funding in July 1995.

The ASR concept works by storing large volumes of water through wells drilled into existing underground water bearing geologic formations known as aquifers. Water is typically produced for ASR recharge during times of the year when excess supply or treatment capacity is available. The stored water is later recovered to meet demands when supply is limited, or treatment capacity is exceeded. Experience with ASR systems for other utilities has also shown that ASR systems can typically be implemented for substantially less cost than the more conventional alternatives to meeting peak water demands.

This report on the preliminary feasibility of ASR for the City of Laredo represents the first step in a three-step investigative process. The work to prepare this report relied on existing information such as water use records, existing demand projections, geologic reports, verbal communications, and other associated information. The results of the investigation show that ASR may be a viable option for the City to help meet future demands and provide a backup supply of water for emergency or drought demands. However, this conclusion is based on several assumptions which must be verified through field testing.

Report Organization

A series of Technical Memorandums that each address the required topics to determine the preliminary feasibility of ASR were developed over the course of this study. The memorandums are included as appendices to this report. With the exception of Section 5, *Alternative Water System Improvements,* the sections of this report are summaries of the more detailed technical memorandums. Section 2 summarizes the general hydrogeologic resources and geochemical conditions. Section 3 summarizes current and future water supply and demand conditions. Section 4 describes conceptual ASR applications. Section 6 presents findings, recommendations, and the proposed implementation plan.

SECTION 2

Summary of Hydrogeologic Resources

Regional Setting

The Laredo area lies within the Rio Grande embayment of the Gulf Coastal Plain. The Gulf Coastal Plain is characterized by a relatively flat, low-lying topographic surface which slopes gradually to the Gulf of Mexico. The Gulf Coastal Plain sediments and alluvial sediments are composed of complexly interbedded sedimentary deposits of gravel, sand, silts, and clay of fluvial and deltaic origin.

The near surface geologic materials present in Laredo are Cenozoic in age (40 to 60 million years before present). From youngest to oldest, the materials include: recent terrace (alluvial) deposits associated with the Rio Grande River; the Laredo Formation; El Pico Clay; Bigford Formation; Reklaw Formation; and the Carrizo Formation; all of Eocene age. Of these units, the principal waterbearing units in Laredo include a relatively shallow aquifer in the Laredo Formation and deep aquifers in the Bigford, and Carrizo Formations. Historically, there have been several water wells installed in the shallow depths of the Laredo Formation for domestic and livestock water use. Because of the poor water quality and relatively low yields in the deep aquifers, very limited water well development has occurred in the Bigford and Carrizo Formations.

Shallow Aquifer

The Laredo Formation consists of sand, sandstone, glauconitic sandstone, clay, thin limestone, and marl. The formation is present at the surface in Laredo and outcrops in a north-south trending band that occurs between Sombreretillo Creek, located northwest of the City and Chacon Creek, located east of the City. The thickness of the Laredo Formation ranges from 620 feet at the outcrop to more than 875 feet in wells located east of the outcrop.

The Laredo Formation is an important source of water for domestic and irrigation purposes in the Laredo area. Water quality is generally poor in the upper beds and reportedly somewhat improves in the lower beds. Most of the wells in Laredo are screened in upper beds between 50 and 330 feet. The sand layers in this interval are typically 16 to 30 feet in thickness and yield approximately 20 gallons per minute (gpm). Using specific capacity data, the median transmissivity calculated in this zone is approximately 260-gallon per day per foot (gal/day-ft).

North, south, and east of Laredo, several wells have been drilled to depths between 400 and 800 feet. Productive zones were encountered between 400 and 600 feet and 700 to 825 feet below ground surface (bgs). The sand layer thickness at these depths range from 20 to 100 feet and are considered lower members of the Laredo Formation. Pumping rates in excess of 200 gpm have been recorded for several wells screened in this interval, however, the median pumping rate is approximately 50 gpm. The median transmissivity is 2,000-gal/day-ft.

Deep Aquifers

The deep aquifer zones consist of sand layers within the Bigford and Carrizo Formations and have similar characteristics. The Bigford and Carrizo Formations generally thicken from northwest to southeast. Side-wall core samples obtained during oil and gas well construction indicate that relatively low permeability conditions exist in both formations locally.

The Bigford Formation includes deposits of thin bedded to massive sandstone. The formation outcrops in a 10- to 12-mile band in northwestern Webb County. Based on geophysical logs, the top of the Bigford occurs between 1,250 and 2,222 feet in the Laredo area and is 500 to 900 feet in thickness. In the Laredo area, individual sandstone beds reach a maximum of 40 feet in thickness. The net sand thickness ranges from 427 feet in the northwestern part of the study area to 578 feet in the south central part. The thickest net sands occur in the lower portion of this formation. The Bigford Formation is not known to produce water suitable for domestic or irrigation purposes in the Laredo area but yields small to moderate quantities of fresh to slightly saline water (< 50 to 500 gpm) in areas to the north and west. There are no known wells screened in the Bigford Formation in the Laredo area.

The Carrizo Sand consists almost entirely of sandstone but may also contain minor amounts of clay or shale. Based on geophysical logs, the top of the Carrizo occurs between 2,200 and 3,200 feet in the Laredo area and is approximately 1,600 feet in thickness. In the massive member of the Carrizo, the net sand increases from 261 feet in the northwest to 509 feet in the east. The formation is an important groundwater resource for counties north and east of Webb County. However, in Webb County, most wells drilled into the Carrizo yield relatively low quantities of poor quality groundwater and none are known to produce water suitable for domestic or irrigation purposes. The City's Reverse Osmosis (RO) well is screened in the Carrizo Sand between 1,796 and 1,916 feet, however, the water yield is low and the quality is such that it will require treatment prior to distribution. The calculated transmissivity at this location is 340 gal/day-ft.

Groundwater Quality

Water quality data for the Laredo area was obtained from State and City records. Almost all of the available data pertains to wells screened in the upper portions of the Laredo Formation. Water quality in this aquifer is characterized as a sodium-bicarbonate type. Salty zones occur in the upper members, however, in general, the water quality improves with depth. The mean total dissolved solids (TDS) concentration in the shallow zone is 2,103 milligrams per liter (mg/L).

Only three data sets are available for the deep aquifer in the Carrizo Sand. The City's RO well is the only known water well screened in the Carrizo that still exists in the area. TDS concentrations range from 1,506 mg/L at the City's RO well to 3,050 mg/L in an abandoned oil and gas test hole located northeast of the City. These concentrations mimic a regional trend reported by Hamlin (1988) that shows TDS values increasing in the down-dip direction.

ASR Considerations

The information contained in this section represents a summary of existing information regarding hydrogeologic conditions in Laredo. As a result of the poor to low groundwater quality in the area, exploration has been limited. Most of the drilling in the area has been for water resource development in the Laredo Formation or oil and gas well construction through the Bigford and Carrizo Formations to deeper units. The Laredo Formation appears to have the potential to yield moderate quantities of groundwater. Historically, development has occurred only in the upper portions of the formation where water quality and yields are lower as compared with the lower member. The quality of data obtained during the explorations is generally very limited. Data obtained during oil and gas well exploration is generally limited to geophysical logs.

Based on this preliminary investigation of the three water bearing units that occur in the Laredo area, the Laredo Formation appears to have the greatest potential for ASR application. Not only is the formation shallower, as compared with the deeper aquifer zones, the Laredo Formation also appears to have a higher permeability. Due to the required depths of construction, ASR development in the Bigford and Carrizo may be cost prohibitive. Based on published regional data, oil and gas well sidewall core analyses, and pump test results from the City's RO well, there is an indication that the deeper aquifers may also have a high plugging potential during recharge. Due to the fine-grained nature of the sediments in those zones, plugging could severely limit the success of ASR. Also, deeper formations have more potential for interference from oil and gas wells and/or brine disposal wells.

The hydrogeologic data indicates that the lower units within the Laredo Formation could support wells with individual capacities of 200 to 400 gpm. Wells screened in the upper units would likely have lower capacities.

ASR facilities operate by storing fresh water in existing aquifers. When the native water in the aquifer is poor, the ASR wells must be designed to displace the native water during injection so as to result in a minimum of mixing between the native and injected waters. The Laredo Formation is semi-consolidated and appears to consist of sands and sandstones that are interbedded with silts and clays. Currently, two important data gaps exist: 1) the lateral continuity of the sands and sandstones and 2) the relative hydraulic connection between these layers and lower permeability silts and clays. Both pieces of information affect the degree of mixing as well as the amount of movement of the stored water.

The preliminary geochemical analysis (Technical Memorandum No. 3) identified several geochemical issues that need to be carefully evaluated during subsequent field testing. Given the chemistry of the Jefferson WTP finished water and the above geologic and water quality conditions, ASR testing and operations will need to consider the following issues:

- Iron and aluminum concentrations are critical to successful ASR operations and the existing data are too wide spread to be realistic, therefore the finished water needs to be reanalyzed for iron and aluminum.

- The amount of remaining alum floc in the finished water needs to be measured and minimized, otherwise there is a potential for irreversible particulate plugging during recharge using the fine-grained sandstone aquifers.
- If dissolved iron is as high as one of the reported values, there will be a strong potential for plugging due to precipitation of iron oxyhydroxide.
- Calcium carbonate will tend to precipitate in wells with groundwater above a pH of 8, producing a plugging problem.
- A small percentage of stored water needs to be left in the aquifer to form a buffer zone to minimize the tendency of the calcium-rich finished water to destabilize sodium smectite clays. This is expected to consist of 10 to 20 percent of the volume stored during the initial cycles. Subsequent full season cycles would be limited to 95 to 100 percent recovery.
- Mineralogical analysis of soil cores for clay mineralogy is recommended.

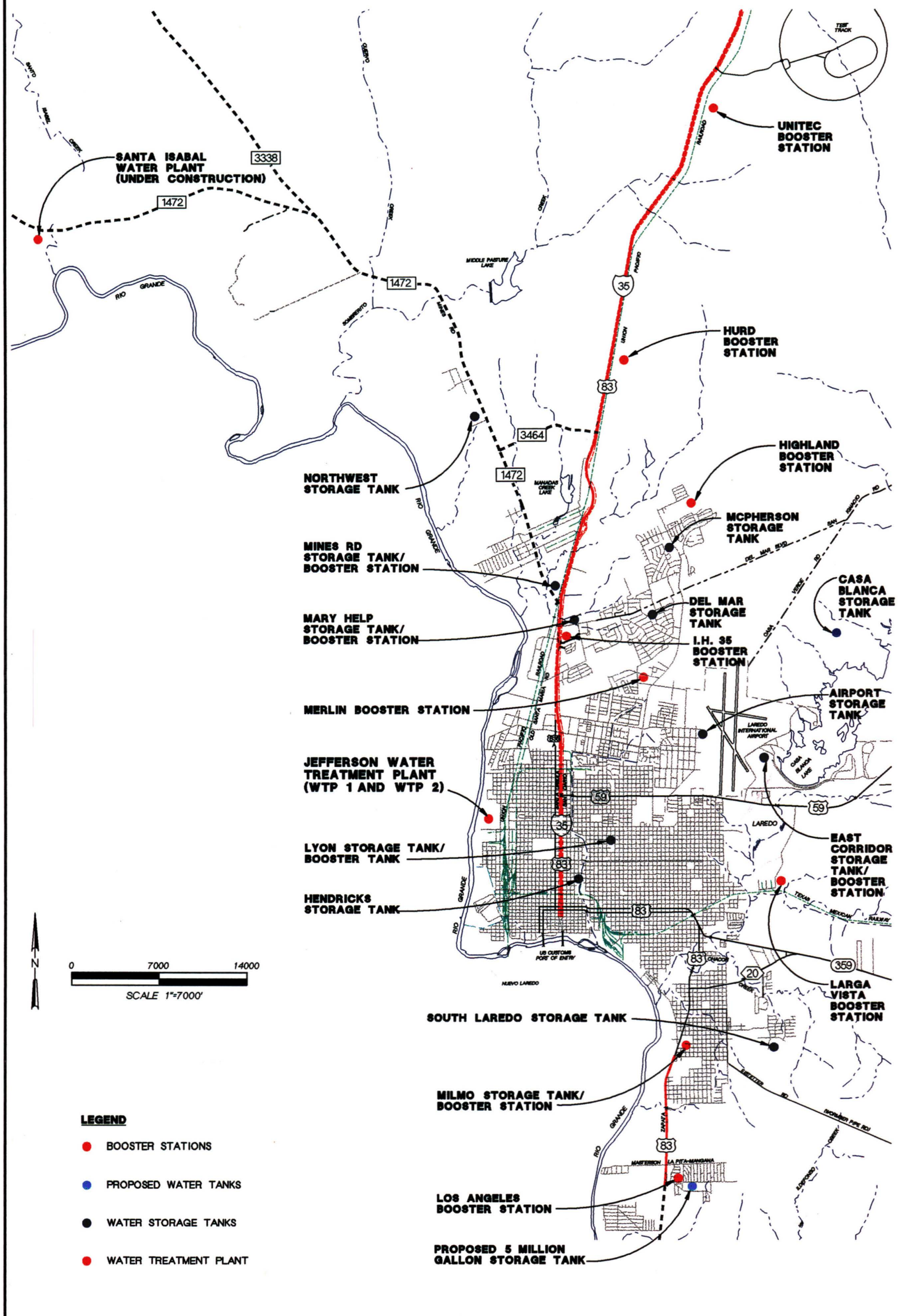


FIGURE 3-1
FACILITY LOCATIONS
AQUIFER STORAGE AND RECOVERY PROJECT
CITY OF LAREDO, TEXAS

8069MAP2.DGN

SECTION 3

Water Demand and Availability Overview

Existing Water System

The City of Laredo obtains raw water for treatment from the Rio Grande River which flows along the southwestern edge of the City. Water is pumped directly from the river to the Jefferson and Columbia Water Treatment Plants (WTPs). The Columbia WTP is a small WTP (0.5 mgd) which serves a border crossing guard station only and therefore was generally not included in the following analysis.

The combined total raw water pumping capacity of the Jefferson WTP pumping stations is 65.5 mgd. The firm capacity of the stations can be considered the pumping capacity with the largest unit at each station out of service. The firm raw water pumping capacity is then 43 mgd. A third intake/pumping station will soon be constructed at the Jefferson Street facility under an EPA funded grant. This station is expected to be online sometime during 1997 and is planned for a total pumping capacity of 60 mgd. This addition will increase the total raw water pumping capability to over 125 mgd. The firm capacity of the new intake/pumping station is not known at this time; however, the treatment capacity of the two WTPs located at the Jefferson Street site is limited by State permit to a combined rate of 84 mgd.

The Jefferson WTPs use conventional surface water treatment processes consisting of coagulation, flocculation, sedimentation, filtration, and disinfection. Alum is the primary coagulant. The water is disinfected using chloramines.

The distribution system has four primary service levels. The Jefferson treatment plant high service pumps feed the low service level. Booster pumping stations are used to pump water from the low service level to the other three service levels; high, Milmo, and Del Mar. The distribution system also includes the ground and elevated storage tanks shown in Figure 3-1.

Existing and Future Water Demand

Historic average and maximum treated water demands are presented in Figure 3-2 and illustrate steady increases over the last 35 years. A linear best fit trend line was plotted through the data and shows that average day demand has been increasing by 0.8-mgd per year and maximum day by 1.3-mgd per year. These projections indicate that the average raw water demand will exceed the City's current water rights allocation by the year 2007. The recently implemented water conservation effects will probably result in somewhat lower water demand than predicted with the linear trend. However, the linear projection results in projected water demands below those projected by TWDB using advanced water conservation practices. (See Technical Memorandum No. 4, Appendix 2). For this reason, the linear demand projection was not reduced further for future water conservation.

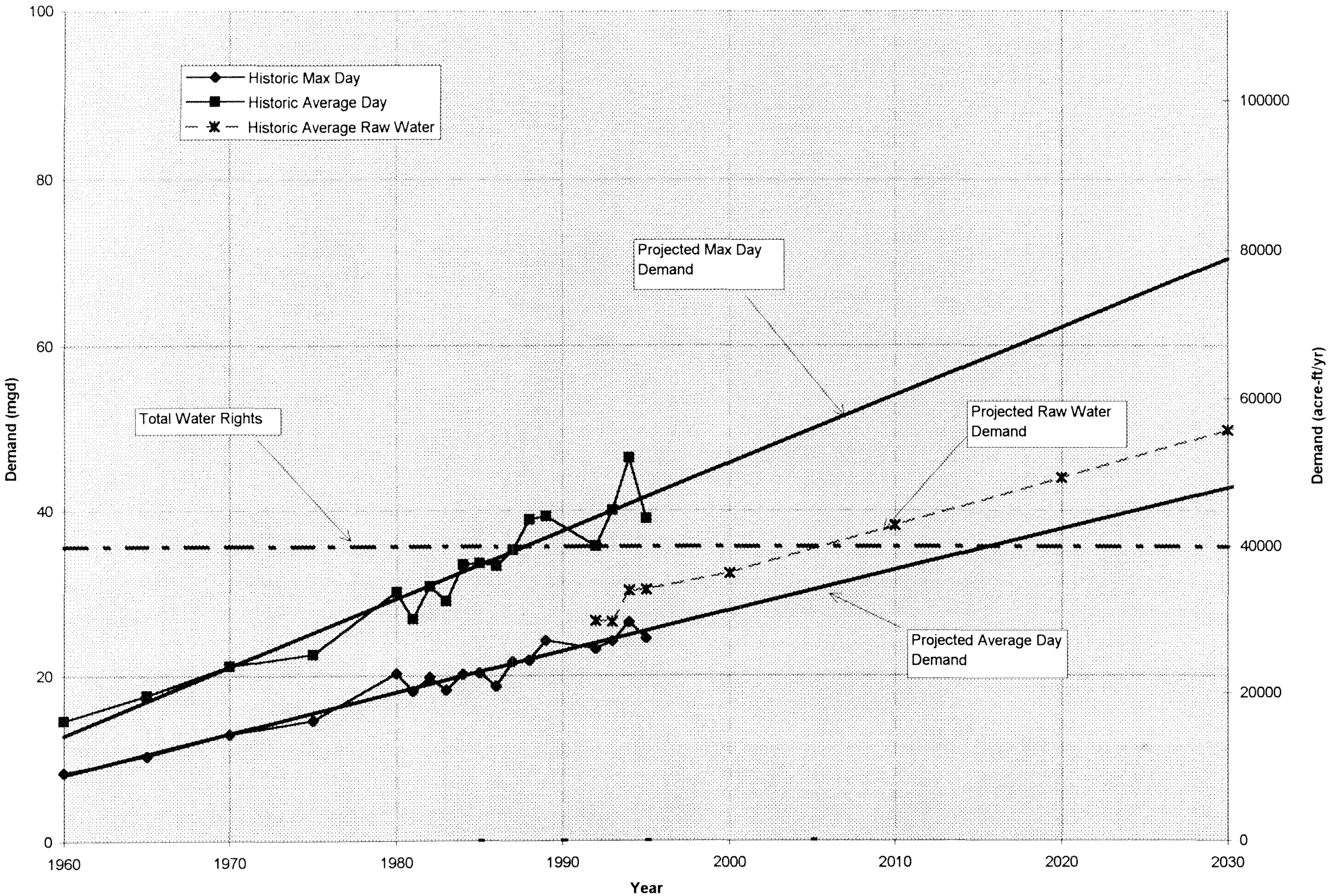


Figure 3-2 Historic Treated Water Demands and Linear Projections

Monthly average and maximum day treated water demands were used to calculate a demand factor, or ratio, of monthly demand to average annual raw water demand typical for a 4-year time period (1991 to 1995). The demand pattern shown in Figure 3-3 indicates water demands are highest during the period from May through September, peaking in July. Low demand season typically occurs during the period from mid-October through April. It is important to note that average raw water demands are less than the treated maximum day demands. This indicates the need to either increase the raw water pumpage appreciably during maximum day demand periods, or rely on storage. Because the City's system does not have raw water storage capacity, frequent changes in raw water pumping rates appear to be required. An ASR system or other large volume reservoir system could serve to significantly reduce the variability of these pumping rates over the course of a season.

The permitted treatment capacity of the Jefferson WTPs is a combined rate of 84 mgd. This capacity is seen to enable the City to treat water to meet demands well into the future. However, the treated water must be delivered to points in the City with water needs, and as seen in Figure 3-1, these points can be a substantial distance from the centralized WTPs.

Currently, the City is able to treat and distribute treated water throughout the distribution system under maximum day conditions. Growth in the City is occurring in the northern and southern areas and is resulting in increased water demands in those areas. Development is ongoing in areas east of the airport, and new water service to the Colonias through the outlying areas of the City is increasing the need to transport treated water further from the central WTPs. Within the next several years, additional booster pump stations, pipelines, and system storage will be required to adequately serve the areas experiencing growth. These capital improvements have not yet been specifically identified but will be required to provide an adequate level of treated water service throughout the distribution system.

Raw Water Availability

Surface water from the Rio Grande river is pumped by the City of Laredo under existing water rights. The City of Laredo currently holds rights to 39,837.133 acre-feet of municipal water rights from the Amistad/Falcon Reservoir system on the Rio Grande River. This water right is derived from the originally adjudicated water right and subsequent purchased water rights as shown in Table 3-1.

Laredo is located in Reach IV of the Middle Rio Grande or the portion of the river between Amistad and Falcon Reservoirs. The total amount of water in storage in this section of the Rio Grande is considered to be the total of the storage in both reservoirs, and water is continuously transferred from Amistad to Falcon Reservoir. The City of Laredo requests their diversion from the Rio Grande by placing a weekly call to the watermaster's office. The actual amount diverted is measured at the raw water intake pumping station in Laredo. This amount is cumulatively charged against the City's water rights.

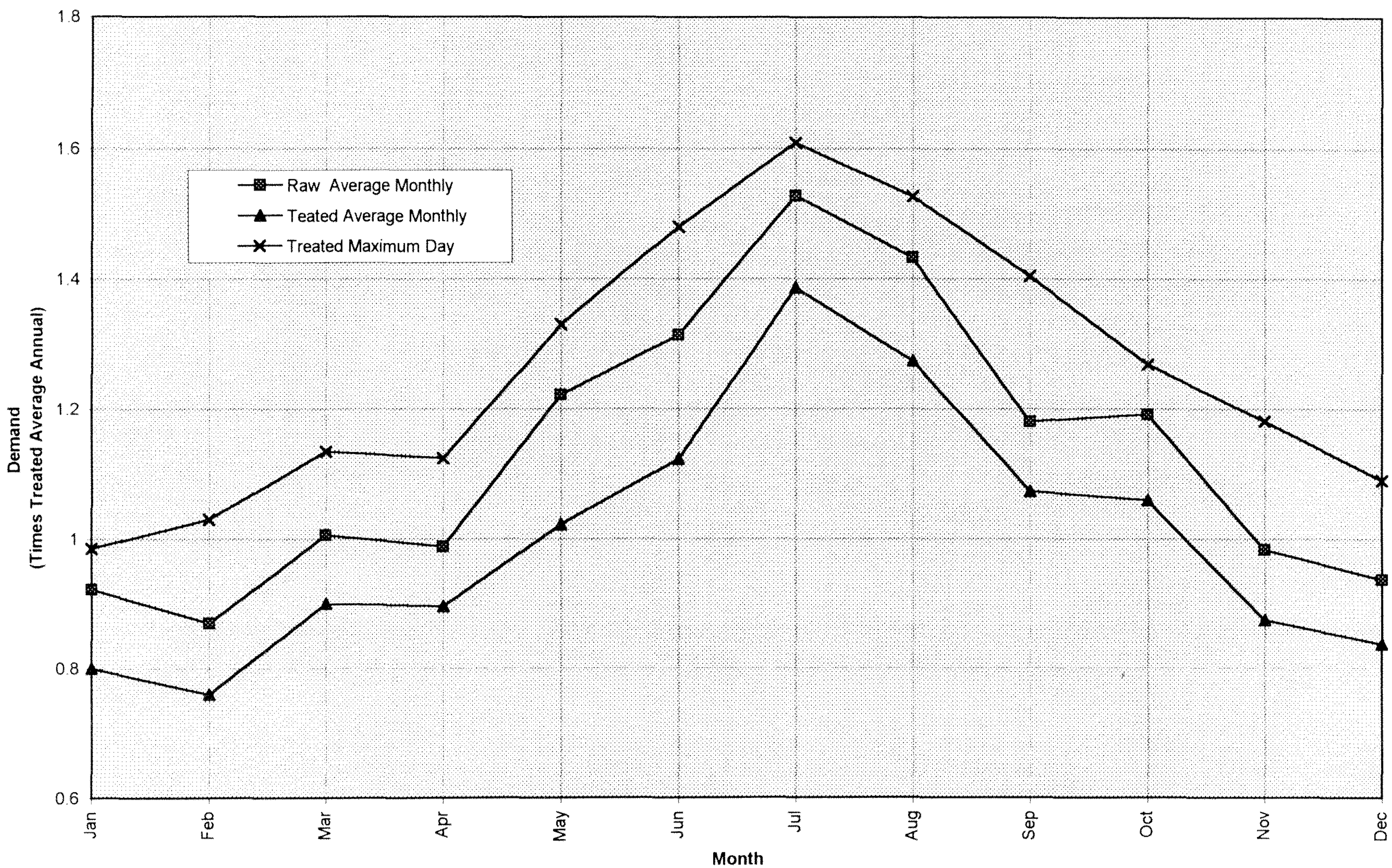


Figure 3-3 Seasonal Water Demand Variation: 1992 -1995

TABLE 3-1
Rio Grande Water Rights
City of Laredo
Certificate of Adjudication 23-3997

Date	Source of Right	Quantity (acre-feet)
8/14/85	Original Municipal Rights	28,420.000
1/11/93	Additional Municipal Rights	1,476.000
through	Converted Class A Irrigation Rights × 0.50	3,659.657
4/16/96	Converted Class B Irrigation Rights × 0.40	6,281.476
4/22/96	**Current Total Water Rights**	**39,837.133**

There is no maximum allowable diversion rate for the City's water rights, but they must balance current demands with expected future demands and attempt to end the year with at least a minimal balance in their water rights account. Therefore, timing diversions is not a critical issue, but total annual rights for diversion from the Rio Grande is potentially a significant issue. The municipal water right holders have never been prorated an amount of water in storage less than their full water right since the completion of the adjudication of the waters of the Rio Grande which began in 1983.

There are times when pumping may be designated as "no-charge" by the watermaster and diversion amounts are not charged against the permit holders' authorized amount of water rights. Because Amistad and Falcon are treated together in terms of total storage, this can only occur in the Middle Rio Grande when both Amistad and Falcon Reservoirs are full. This has occurred one time since adjudication, and lasted for about 18 months from about October 1991 until April 1993.

The Rio Grande watershed and those who rely on the Rio Grande for water supply are currently (July 1996) experiencing a drought and restrictions on allocations for the irrigation and mining accounts are in effect. This water right allocations system is designed to protect the municipal water rights holders, but does not ensure that municipal rights will be fully available in a severe drought. The watermaster has the authority to prorate water rights or take other actions (set maximum diversion rates) necessary to prevent the waste of water or alleviate emergencies. There may be times when the full authorization of municipal rights may not be available due to the volume of water in storage. It is during these times that water stored in an ASR system may be desirable to make up the difference in what is available from the river.

A free market in water rights operates along the Rio Grande in Texas. Water rights may be freely bought and sold under annual contracts or permanently between the Middle and Lower Rio Grande. Currently, municipal water rights cost $750 per acre-foot. The City has established a financing mechanism designed to build funds for the specific purpose of acquiring additional water rights.

Water Quality

Analysis of the raw and finished water turbidity results indicate that water quality varies seasonally with pulses of highly turbid (greater than 100 NTU) water over several day periods, these being more common in late spring and fall (Figure 3-4). The highly turbid water is often more difficult to treat to below a regulatory standard of 0.5 NTU. Raw water turbidity values over 300 NTU were strongly correlated with finished water samples that exceeded the 0.5 NTU standard.

General ASR Applications

The above information concerning present and future water demands, water system capacities, water rights, and water quality variations was used to identify conceptually how an ASR system may apply to the City's long-term water needs.

The existing water system could utilize ASR capacity in the northern portion of Laredo to help meet peak demands from continued growth. If ASR is shown to be feasible through testing, this application could postpone or eliminate the need to construct a WTP in the northern area of Laredo. An ASR application may also help alleviate flow or pressure constraints within the outlying portions of the distribution system and would allow the City to operate the WTP at a more even production rate.

Analysis of current and projected water demands indicates that approximately a 10-mgd ASR capacity could be utilized to help meet the City's seasonal peak demand. This rate represents the ASR storage and recovery capacity that could be utilized seasonally to maintain more constant rates of production at the WTP. Furthermore, if the storage zone is capable of storing large volumes of water, long-term ASR storage could be useful in possibly extending the effective life of the current water right, as well as providing a large volume of water to meet emergency or drought demands. ASR could also be used to store large volumes of excess treated water during future no-charge periods, should they occur.

The evaluation of raw and finished water turbidity data suggest that another ASR benefit could be recovering treated drinking water to meet a portion of system demand when raw water quality makes treatment more difficult. This application would allow lower filter loading rates and ultimately higher water quality leaving the WTP.

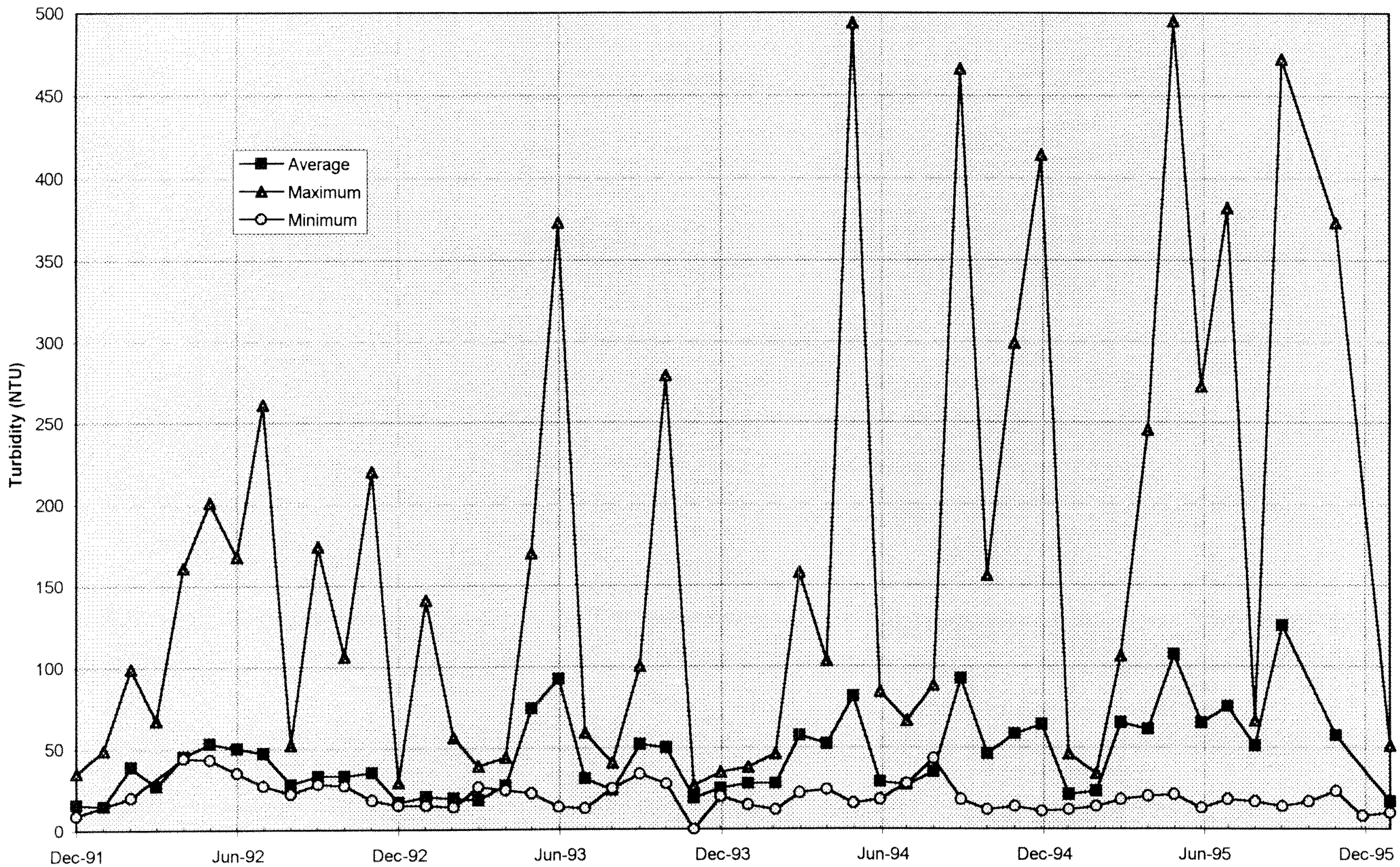


Figure 3-4 Monthly Raw Water Turbidity

SECTION 4

ASR Conceptual Applications

ASR systems can be used by water utilities in many different ways. Potential applications include the storage of raw, treated, and reclaimed water. Storage zones range from very brackish aquifers containing sea water to fresh aquifers that have been depleted by many years of over pumping. The concept can be applied to many situations requiring large volume water storage where (1) the existing water is suitable for storage, and (2) a suitable aquifer exists.

Raw water ASR applications may serve a utility or agricultural practice where the supply of raw water varies seasonally in quantity or quality, such as seen in many rivers. During high river flows, water can be diverted and stored to be used later during low flow periods. For Laredo, raw water ASR would consist of storing water during "no charge" water periods to place as much water in storage as the system would allow. However, the water quality of the untreated Rio Grande water is typically high in turbidity (especially during high flows) and dissolved minerals which will most likely result in aquifer plugging. For this reason, raw water storage for Laredo is not recommended.

Most existing ASR facilities store treated potable water in brackish aquifers. In most cases the utilities operating ASR facilities are experiencing growth in demand and have seasonal variations in supply and demand. ASR is used to reduce the need to expand facilities to meet the projected seasonal peak demand since ASR systems can typically be developed for much less cost than a plant expansion to meet the same peak demand. Seasonal ASR applications work to even out water system operational peaks. System components are operated at higher rates during the low demand months to provide water for ASR storage. During peak demand months, the stored water is pumped from the ASR wells to off load other water system components.

The City of Laredo is not currently faced with limited central treatment capacity, but increasing water demands are resulting in additional stresses on outlying portions of the distribution system. The City's current treatment facilities are located centrally at the Jefferson Street WTPs, which provide raw water pumping, treatment, and high service pumping to the distribution system. Growth in the northern and southern portions of the City is resulting in the need for additional transmission piping, pumping, and storage facilities to transmit the treated water out to these areas. Additional treatment facilities, closer to the outlying areas, are also being considered as a way to meet these future water demands.

A large volume of treated water storage in the northern or southern growth area of the City's system could be used to help meet the peak demands. Storage of treated water in an ASR system could provide treated water pumping in the outlying areas to boost system pressures, reduce loading on the central WTPs, and improve overall system reliability. Additionally, water demands are projected to exceed current water rights by 2007. Storage of large volumes of water that could then be available for more than one season could potentially help the City to somewhat extend their current water right.

Many of the ASR applications involving long-term storage of water in aquifers are systems recharging freshwater aquifers. In these systems, aquifer water levels are monitored to demonstrate that the aquifer is being replenished. It is not critical that the water recovered be the same water that was put in storage because all the water is essentially fresh. Where the aquifers are brackish, like Laredo, additional criteria must be considered for long-term storage because of the undesirable nature of the native groundwater. It is important for these systems to recover the same water that was placed in storage with a minimum amount of mixing with the native water. Mixing of recharged water with native water results in the recovered water containing elevated levels of dissolved constituents that are present at higher levels in the native water. For example, in Laredo the preliminary geochemical evaluation suggests that certain ions such as chloride and sulfate are higher in the native groundwater and through mixing during recharge and storage may become elevated relative to the treated surface water. Through proper ASR well design and operation, mixing potential can be minimized.

Mixing during ASR storage can occur through several mechanisms. Three of significance are:

1. Through the injection process, where treated water is pushed through the aquifer matrix and rinses off the aquifer grains.

2. Through diffusion and/or density stratification while the stored water is idle in the aquifer and the edges of the stored water volume are in contact with the native waters.

3. Through movement of the stored water volume away from the ASR well due to regional groundwater movement.

The first mechanism contributing to mixing is aquifer specific and typically improves with several ASR cycles. The effect of several ASR cycles provides a flushing mechanism over the aquifer grains which reduces the mixing effect with system use. The second mechanism is a function of the aquifer, the time the injected water spends stored in the aquifer, and the difference in quality between the injected and native water. The third mechanism is a function of the hydrogeology of the area and can be an important controlling factor in the long-term storage of the recharged water.

At this point, it is not possible to determine a realistic length of time treated water could be stored in the Laredo Formation. The available information regarding the hydrogeologic conditions is limited and subject to interpretation. The fine-grained aquifer materials may increase the number of aquifer particles to be rinsed but should decrease the effects of diffusion or stratification and may help to minimize the amount of recharge water movement during storage. In order to determine a realistic storage time limit for the Laredo Formation, a test program will be needed to measure the actual effects of time on the stored water.

Conceptual ASR Application for Laredo

ASR could provide a method for the City to:

- Operate the water system at a more consistent rate and meet seasonal demand peaks with water treated and stored during low demand months
- Operate the WTP filters at a lower loading rate during poor raw water quality events by recovering previously treated water to meet a portion of the demand or to blend with finished water approaching or exceeding turbidity limits
- Treat and store excess current annual water rights enabling the City to purchase more water rights when market conditions are more favorable
- Store large volumes of treated water to supplement longer term or drought demand
- Capture and store excess water during future no-charge water periods
- Balance distribution system pressure and flow during high demand periods by substituting for, or augmenting, a booster pumping station and storage reservoir

In addition, ASR facilities may allow the City to store water to meet longer term objectives. To ensure a dependable water supply, the City must buy excess water rights to meet projected demands several years into the future. With ASR, the City could potentially divert its full annual water right and treat and store the excess thereby extending the effective life of the existing water right. In addition, if ASR facilities were operational during a no-charge water period the City could divert and store as much water as the ASR system could hold for use in the future or to supplement water supply during drought periods.

Water balance estimates indicate an ASR system with a maximum recharge and recovery capacity of about 10 mgd is optimum for Laredo. This is the projected peak demand quantity average and the maximum amount of water that may be available during low demand periods.

Based on the current understanding of hydrogeologic conditions, 28 total wells would be needed to supply 10 million gallons per day (mgd) of water for peak demand purposes. Hydrogeologic information indicates that the Laredo Formation varies in terms of both aquifer hydraulic properties and water quality laterally and vertically. It will be necessary to conduct substantial field testing to determine if ASR can be used, and the best depth and location for the ASR facilities. For the purposes of this conceptual ASR system configuration, the information currently known was used to evaluate where the most appropriate locations would be for the ultimate ASR facility. This conceptual configuration was developed to provide the City with an idea of how the system may operate, and also to estimate general cost levels for system development and construction.

The City's greatest need for ASR capacity is in the growth areas north and south of the City. For this reason, it is recommended to separate the total ASR capacity into several locations. Half of the capacity could be developed at several strategic locations in the North Laredo area such as the North West, McPherson, and Del Mar Storage Tank locations. Similarly, on the south end of Laredo, 5 mgd of ASR capacity could be developed at the

South Laredo Storage Tank and Los Angeles Booster stations. In addition, ASR capacity at Jefferson WTP could provide many benefits if the geology is suitable and well interference effects from Nuevo Laredo are not expected. Due to the relatively low yield of individual wells, it would be most cost effective to construct ASR wellfields consisting of several wells sharing a common disinfection facility and the piping and controls needed to transmit the appropriate recharge and recovery flows. This type of configuration would provide the City added flexibility in system operation as ASR flows would be distributed through the system and not just hydraulically concentrated at one point.

SECTION 5

Alternative Water System Improvements

Introduction

This project is partially funded by a TWDB Planning Grant under H.B. 1989. One of the provisions of grant funding is to identify other applicable water storage and supply options and evaluate their feasibility against or in conjunction with an ASR alternative. This chapter briefly discusses the feasibility and order-of-magnitude costs for other options capable of providing 10 mgd of potable water for at least 90 days per year. This chapter is organized into four sections. The first three sections describe alternatives by water source; surface water, groundwater, and reclaimed wastewater. The groundwater section contains several alternative variations presented as subsections. The final section compares the alternatives.

A thorough, comprehensive evaluation of the City's future water supply options is beyond the scope of this report. In this section, a general review of possible water supply alternatives is presented; however, this review is not intended to be a substitute for a comprehensive master planning effort.

Surface Water Alternatives

The surface water resources of the Rio Grande River watershed are treated as a whole under the water rights allocation system established and regulated by the TNRCC. All tributaries feeding the Rio Grande are considered part of the watershed. Therefore, developing Casa Blanca Lake or constructing other intermittent stream surface water impoundments for water supply would not provide the City any additional water resources.

Interbasin transfer of surface waters is allowed in Texas. However, in order to complete the transfer the receiving basin has to perform a study to demonstrate that it will not have sufficient resources to meet demands for the next 50 years and that the host basin has excess resources for the next 50 years. The neighboring Nueces River basin is not likely to have excess capacity therefore this alternative was not investigated further.

The most realistic surface water alternative option for the City of Laredo is to purchase 10 mgd (2,762 ac-ft) of excess permanent municipal surface water rights from the Amistad/Falcon reservoir system or other downstream water right holders. In the event of a severe drought the watermaster can prorate water rights. If Laredo purchases this volume of excess water rights, the City would still have enough raw water available to meet demands under most conditions. In the relatively brief history of the Amistad/Falcon reservoir system, the watermaster has not imposed municipal water right restrictions so it is difficult to estimate or predict the frequency or severity of a restriction.

There is an active market in Rio Grande water rights as described in Technical Memorandum No. 5. The estimated capital cost to purchase the excess capacity is

$2.3 million. Table 5-1 contains a more detailed breakdown of cost assumptions for this alternative.

TABLE 5-1
Purchase Excess Water Rights
City of Laredo, Texas

Item	Unit	No. Required	Estimated Unit Cost	Estimated Total Cost
Purchase Additional Water Rights	ac-ft	2,762	$750	$2,072,000
Engineering and Permitting	10%	1		$207,000
Contingency	20%	1		$21,000
Total Capital Cost				**$2,300,000**

Groundwater Alternatives

Groundwater is available to the City of Laredo under right of capture. In other words, there is no initial water right purchase or limitation on the amount of water which can be extracted from the aquifer. Interbasin issues are not applicable to groundwater resources. The only limitation is the amount of capital expended to locate, recover, and convey the resource to the customers.

Several groundwater supply scenarios were developed, including:

- Importing fresh groundwater supplies from the Winter Garden area in Northern Webb County
- Using local Laredo Formation groundwater without treatment to supply groundwater for blending with Jefferson WTP finished water
- Developing Laredo Formation wellfields supplying centralized reverse osmosis (RO) WTPs to provide water meeting drinking water standards
- Using Laredo Formation groundwater and RO WTPs to provide treated water for ASR storage to meet seasonal peak demands

Each alternative is described separately in the following subsections.

Import Fresh Groundwater Supplies

The Carrizo formation contains fresh water in the Winter Garden area as described in Technical Memorandum No. 1. Groundwater resources can be utilized in the State of Texas under the right of capture. If the City of Laredo were to purchase land overlying a freshwater aquifer, they could drill wells and produce water. There are no interbasin issues with groundwater resources so the City could pipe it back to their distribution system without creating water rights issues. However, the nearest point where the aquifer contains freshwater (TDS < 1,000 mg/L) is approximately 35 to 40 miles north in Northern Webb County.

- An order-of-magnitude cost estimate was developed for this alternative. The estimate included six wells in Northern Webb County. The water could be piped 40 miles back to Laredo using two pumping stations. As shown in Table 5-2, the capital cost estimate to utilize this alternative is approximately $35 million.

Blending Brackish Water

The City could increase the volume of water available to meet customer demands by blending groundwater with the treated surface water. The Laredo Formation contains brackish water (TDS = 3,150 mg/L) locally which limits the volume of water that can be added to the treated water (TDS = 800 mg/L) before exceeding water quality criteria (TDS = 1000 mg/L). Using these average TDS values, at most 2.5 mgd of groundwater could be used to meet a hypothetical demand of 30 mgd. Since this alternative cannot meet the 10 mgd criteria used to compare the other alternatives, no further evaluation was performed and order-of-magnitude costs were not developed.

Reverse Osmosis Treatment of Brackish Water

RO treatment processes could be used to treat the brackish groundwater from the Laredo or Carrizo Formations locally. The City is currently operating a pilot RO facility to treat water from the Santa Isabal well north of the City. The Santa Isabal well reportedly produces about 105 gpm of brackish water from the Carrizo Formation. The hydrogeologic analysis presented in Technical Memorandum No. 1 concluded that locally the Laredo Formation could be expected to produce similar yields and water quality. Therefore, the conceptual discussion and order-of-magnitude cost for this alternative is based on wells drilled into the Laredo Formation.

To clarify comparisons and simplify cost development, this alternative is similar to the ASR alternative presented in Chapter 4. The conceptual design is based on supplying 5 mgd at locations in north and south parts of the City. Due to the brine generated by RO (assumed to be 30 percent by volume), four additional wells are needed to produce 10 mgd of potable water, than were assumed for the ASR alternative. Two 5-mgd RO treatment plant facilities would be constructed. Brine generated could be disposed of through treatment and blending at the existing wastewater treatment plant (WWTP) or through an injection well. Since 3 mgd of concentrated brine would be generated, it was assumed that the existing WWTP would be unable to accept this volume. Determining the acceptable possibilities for this volume of brine disposal is beyond the scope of this project. For this reason, a cost allowance for brine disposal of $1 million for each 5 mgd facility was included in the order-of-magnitude cost. This cost is probably a mid-range cost as certain brine disposal alternatives will be higher and some could be lower.

The order-of-magnitude costs for this alternative are presented in Table 5-3. Based on this simplified analysis, it appears that the cost of reverse osmosis treatment and brine disposal make this alternative expensive on a large scale. Following the ongoing RO pilot test and development of actual quantities and unit costs this alternative could be reevaluated.

TABLE 5-2
Import Fresh Groundwater from Winter
Garden Area
City of Laredo, Texas

Item	Unit	No. Required	Estimated Unit Cost	Estimated Total Cost
Carrizo well, 16 inch, 1800 feet, 400 ft screen	each	6	$450,000	$2,700,000
300 hp well pump and piping	each	6	$100,000	$600,000
Collection and header piping	foot	15000	$32	$480,000
10 mgd disaffection facility	each	1	$300,000	$300,000
30 inch main	mi	40	$555,000	$22,200,000
Booster Pump Stations	each	2	$150,000	$300,000
I & C Allowance	each	1	$300,000	$300,000
Misc. other Construction	10%	1		$2,688,000
Engineering and Testing	15%	1		$2,687,000
Contingency	20%	1		$2,896,000
Total for 10 mgd Wellfield				**$35,151,000**

TABLE 5-3
Reverse Osmosis Treatment of
Brackish Water
City of Laredo, Texas

Item	Unit	No. Required	Estimated Unit Cost	Estimated Total Cost
Water Well 12-inch dia, 650 ft Total Depth, 100 ft screen	each	16	$65,000	$1,040,000
50 hp well pump and piping	each	16	$12,000	$192,000
Collection and header piping	foot	15000	$32	$480,000
5 mgd disinfection facility	each	1	$150,000	$150,000
5 mgd Reverse Osmosis WTP	each	1	$7,000,000	$7,000,000
Brine Disposal	each	1	$1,000,000	$1,000,000
I & C Allowance	each	1	$300,000	$300,000
Misc. other Construction	10%	1		$1,016,000
Engineering and Testing	15%	1		$1,014,000
Contingency	20%	1		$1,096,000
Total for Each 5 mgd RO System				**$13,288,000**
Total for 10 mgd RO Capacity				**$26,576,000**

Recharge of Treated Brackish Groundwater

Treatment of brackish groundwater could also be used in conjunction with ASR. For example, it is likely that the RO treated groundwater will have higher water quality and lower suspended solids or other constituents making it the preferred source of water for recharge. The surface water rights could be used to meet daily demands; a smaller RO facility could be used to treat brackish groundwater for storage in an ASR wellfield at other locations in the distribution system.

A possible scenario to develop 10 mgd of seasonal supply could entail a 5 mgd wellfield and RO plant feeding a 5 mgd ASR wellfield in the off peak season. During peak demand both the RO wellfield and the ASR wellfield could be pumped to provide 10 mgd of peak capacity. To be most comparable with the other alternatives and meet demands; in the growth areas north and south of the City, the RO wellfield could be constructed in the north area and used to feed the ASR system located in a southern area. Order-of-magnitude costs for this alternative are given in Table 5-4.

Reclaimed Wastewater Reuse

A *Water Reuse Study, Laredo Wastewater Treatment Plants, Final Report* was recently completed for the City by NRS Consulting Engineers (June, 1995). A summary of their analysis, recommendations, and cost estimates are presented below.

The study was performed to investigate whether the City's wastewater could be substituted for either potable water or freshwater. The study found that although some effluent is currently being used to irrigate two golf courses, the City still has approximately 17 mgd of wastewater effluent available for reuse. Six irrigation or industrial reuse options were evaluated. The study concluded that many of the options were expensive due to pumping and distribution piping improvements required. In general, the study concluded that substitution of the wastewater effluent for raw or well water was not cost effective due to their relatively low cost. Two options were recommended for further investigation: (1) providing a temporary truck filling station to test the market for industrial and construction use, and (2) diverting a portion of the flow to Zacate Creek to create an attraction similar to the San Antonio river walk. These nonpotable uses cannot be directly compared to the other alternatives presented in this chapter since they would not provide a 10-mgd source of potable water during a 90-day drought restriction.

Scenarios for direct and indirect reuse of the wastewater for potable purposes were also evaluated. The report concluded that direct reuse would not be cost effective at this time due to the additional treatment and extensive testing required. However, indirect reuse was recommended for further consideration.

The treatment required to meet drinking water standards for six indirect potable reuse alternatives were evaluated in the report. Order-of-magnitude capital costs and cost per 1,000 gallons were also presented as follows:

1. Nitrogen removal, lime pretreatment, and membrane process ($32,986,500 or $1.54/1,000 gallons)

TABLE 5-4
Reverse Osmosis Treatment of Brackish Water with ASR
City of Laredo, Texas

Item	Unit	No. Required	Estimated Unit Cost	Estimated Total Cost
RO supply/ASR Well 12-inch dia, 650 ft Total Depth, 100 ft screen	each	32	$65,000	$2,080,000
50 hp well pump and piping	each	32	$12,000	$384,000
Collection and header piping	foot	15,000	$32	`$480,000
5 mgd disinfection facility	each	1	$150,000	$150,000
5 mgd Reverse Osmosis WTP	each	1	$7,000,000	$7,000,000
Brine Disposal	each	1	$1,000,000	$1,000,000
I & C Allowance	each	1	$300,000	$300,000
Misc. other Construction	10%	1		$1,139,000
Engineering and Testing	15%	1		$1,045,000
Contingency	20%	1		$1,111,400
Total for 10 mgd RO/ASR Capacity				**$14,689,400**

2. Nitrogen removal, conventional pretreatment, and membrane process ($28,713,750 or $1.33/1,000 gallons)

3. Nitrogen removal, direct filtration, and membrane process ($24,638,250 or $1.12/ 1,000 gallons)

4. Nitrogen removal and discharge into Casa Blanca Lake followed by treatment in Jefferson WTP ($16,339,050 or $0.40/1,000 gallons)

5. Nitrogen removal with discharge directly to Jefferson WTP ($14,573,000 or $0.28/ 1,000 gallons)

6. Nitrogen removal, discharge to Casa Blanca Lake with treatment by new WTP ($26,157,300 or $1.09/1,000 gallons)

Reuse in Conjunction with ASR

Following tertiary treatment, the reclaimed wastewater could potentially be used for ASR well recharge and recovery. As mentioned in the NRS report (June, 1995) El Paso is using reclaimed water to recharge an aquifer and recovering the water from different wells in the same aquifer and Orange County, California, is injecting reclaimed water into a potable water aquifer to form a saltwater intrusion barrier. Reclaimed water recharge and recovery using ASR wells has been discussed by other utilities and implementation is anticipated at some future date as water resources become more scarce. However, similar to the reuse scenarios described above, the expected tertiary treatment costs– and time required to obtain permits, makes this alternative unlikely at this time.

Comparison of Alternatives

Table 5-5 presents the capital costs for the various alternatives available to the City. It is important to note that only capital costs are presented and operations costs and many other factors associated with the alternatives are not presented. For this reason, it is not realistic to select the lowest capital cost alternative as the best alternative. However, the total capital cost for the alternatives is an important factor in selecting future water supply options.

Importing fresh groundwater supplies to provide the 10 mgd supply is seen to be the most expensive alternative from a capital cost standpoint. This alternative will also require obtaining land areas away from the City for well sites and pipeline easements. Additionally, operation of the system will require operation and maintenance of somewhat remote pumping facilities.

RO treatment of local groundwater supplies is the next costly alternative from a capital cost standpoint. On a smaller scale, this alternative is being tested by the City at the Santa Isabal site. Operation of the Santa Isabal site will provide the City with additional information regarding the use of RO facilities and if this alternative be revisited at that time.

RO combined with the ASR alternative could work to provide the City with additional water and large volume storage. These two alternatives together provide an additional source of water for the City, and a method to produce 10 mgd of peak supply at a cost much less than an RO alternative alone.

TABLE 5-5
Comparison of Alternatives
City of Laredo, Texas

Description	Quantity	Capital Cost ($)	Comments
Aquifer Storage and Recovery	10 mgd for 90 days (2,762 ac-ft)	$4,930,000	Feasibility must be confirmed, offers secondary benefits
Purchase Excess Surface Water Rights	10 mgd for 90 days (2,762 ac-ft)	$2,300,000	Dependent on market availability, right may be prorated during drought
Import Fresh Groundwater	10 mgd for 365 days (11,200 ac-ft)	$35,151,000	40 mile pipeline right-of-way and security may be difficult
Reverse Osmosis Treatment of Groundwater	10 mgd for 365 days (11,200 ac-ft)	$26,576,000	Brine disposal difficulties
Reverse Osmosis Treatment of Groundwater With ASR	10 mgd for 365 days (11,200 ac-ft)	$14,689,400	Brine disposal difficulties
Reclaimed Water Use at Jefferson WTP	10 mgd for 365 days (11,200 ac-ft)	$14,573,000	Public perception may be complicated
Assumptions:	Municipal Water Right = $750/acre-ft		

The purchase of additional water rights appears to be the lowest cost alternative from a capital cost standpoint. However, the availability of additional rights is not known.

ASR is seen to have a relatively low capital cost associated with a 10 mgd 3 month supply, however ASR is not a source of water. It may be possible to store existing excess water rights in an ASR system for later use but this concept requires testing and further evaluation.

SECTION 6

ASR Recommendations and Proposed Implementation Plan

Summary of Findings

The findings of this Step 1 Preliminary Feasibility Evaluation of ASR include:

- The City of Laredo operates a centrally located water treatment facility with adequate treated water capacity for current and future conditions, however, distribution of the treated water to future points distant in the distribution system may prove challenging.
- Growth is occurring in areas north, south, and east of the City with requirements for treated water service further away from the central water treatment facility.
- Due to future population growth and current drought conditions, the City of Laredo is projecting a shortfall in raw water supply to occur around year 2007.
- If found feasible, a 10-mgd ASR system could benefit the City by providing treated water supply in the areas of high demand and reduce the need for future booster pumping stations, system storage tanks, and additional treatment works near the areas of high demand.
- An ASR facility could potentially extend the life of the current water right by up to 10 years, providing a source of water to meet emergency or future drought demands, and providing other secondary operational benefits.
- Limited available data suggest that there are three potential aquifers beneath Laredo with similar characteristics: brackish water quality and moderate yield. Therefore, it would be the most cost effective to develop ASR wells in the shallowest aquifer, the Laredo Formation.

Recommendations

Several potential benefits were identified that an ASR system could provide the City. These include system operation benefits in helping to meet peak demands, possibly postponing or eliminating a future WTP in the northern portion of the City, and providing treated water storage and pumping in areas of growth within the City distribution system. Additionally, ASR could provide large volume storage of treated water for use during periods of poor quality in the Rio Grande, or during periods of low river supply or drought.

Other options to the City for providing a potable water supply were reviewed and compared to an ASR system. Some of these were seen to have cost benefits, however, they would not necessarily provide the other secondary benefits of ASR. In addition, the cost of developing and implementing ASR systems could be lower if a higher yield storage interval is identified during a test drilling program.

The ability to have a large volume of treated water stored for use during drought conditions is a highly desirable benefit ASR potentially offers the City. However, existing information on the area's aquifers is limited and not sufficient to truly evaluate potential capacities and the required details for an ASR application. More specific information is required on potential storage zones that can only be obtained from test drilling in the area.

For these reasons, it is recommended that the City of Laredo proceed with the ASR investigation and conduct a test drilling program. The drilling program should be limited to the Laredo Formation in several locations around the City. If adequate storage zones are identified, wells should be installed and hydraulic testing conducted to estimate if adequate storage properties exist.

Due to the potential benefits of ASR, the TWDB has offered the state-owned drilling rig services for the test drilling program.

Proposed Development Plan

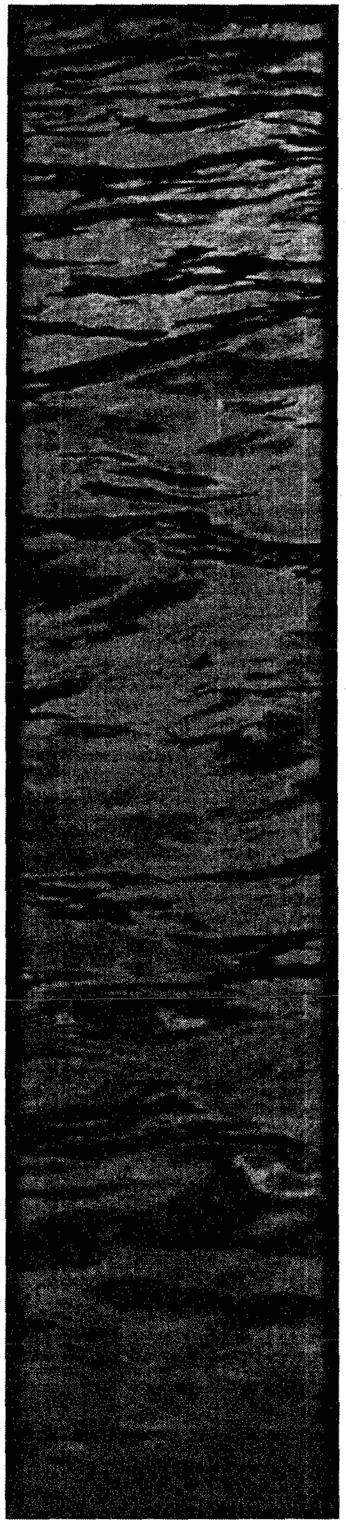
The recommended development plan includes the following elements:

- Conduct a secondary specific investigation on zones in the Laredo Formation suitable for ASR use. Review existing oil and gas logs, water well logs, and other Laredo specific information to identify specific areas for further field drilling and testing exploration.
- Finalize an agreement with TWDB for the use of the state-owned drilling rig, crew, geophysical logging devices, coring equipment, and other services to complete up to six deep borings at selected sites. Install and test up to six, 6-inch-diameter test borings/monitoring wells.
- Using the TWDB crew and equipment, perform pumping tests on selected existing wells in the Laredo area. Obtain geophysical logs of these wells during the pumping tests.
- The sites for the borings should be at locations within the City's distribution system and may include locations at or near the Jefferson WTP, former Del Mar WTP, McPherson Storage Tank, Del Mar Storage Tank, South Laredo Storage Tank , or Los Angeles Booster station.
- Drill mud rotary borings to the base of the Laredo formation at the selected sites. These borings could be up to 1000 feet in depth. Collect soil cuttings samples every 5 to 10 feet, wash the samples and record the relative percentages of fine, medium, and coarse sand. Upon reaching the total depth, perform geophysical logs on the open borehole. If the borings indicate the presence of aquifer zones potentially suitable for ASR, construct monitoring wells in the borings.
- Obtain core samples of the aquifer at locations that appear hydraulically suitable for ASR. This could be done using either the TWDB rig, or through a private coring contractor.

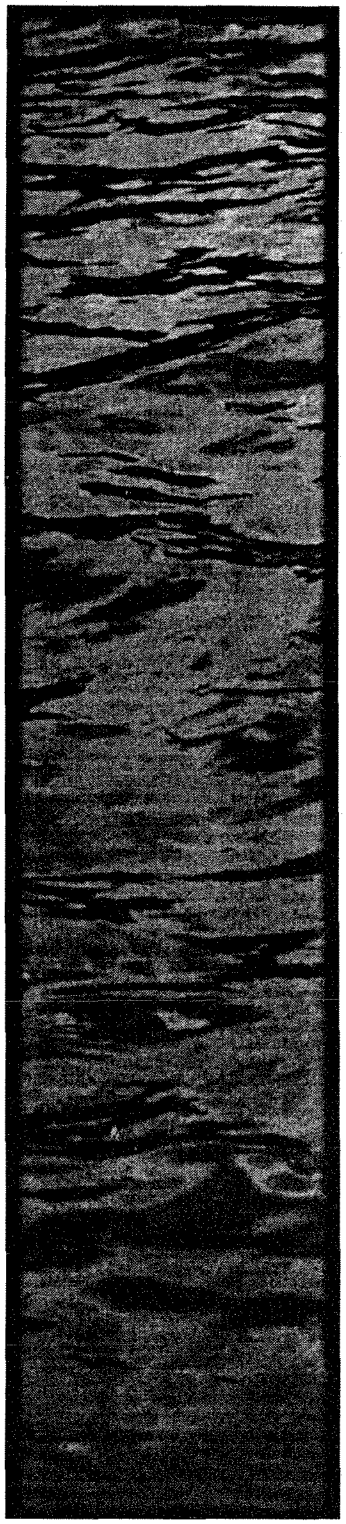
- Perform pumping tests on the monitoring wells to estimate aquifer hydraulic properties, and to collect and analyze native water quality samples.
- Reanalyze and reevaluate the average water quality of the Jefferson WTP finished water.

The completion of the above test program will provide the City with information regarding the presence and suitability of the aquifer zones for ASR and will allow better estimation of ASR system costs and performance. The interpretation of the native water, finished water, and geologic cores will enable more accurate projections of geochemical interactions during storage. Measurement of water levels in the new wells (particularly if in conjunction with concurrent water level measurements on other local Laredo Formation wells) will allow calculation of hydraulic gradients and groundwater velocities to be used in estimating the fate of recharged water.

Analysis of these results will further the understanding of potential ASR feasibility in Laredo and will be used to decide whether to proceed with Step 3 and construction of a prototype ASR test facility.



Appendix 1



Technical Memorandum No. 1
Phase 1 Geologic Assessment

DEN/7936.DOC

Phase I Geologic Assessment City of Laredo ASR Feasibility Study

PREPARED FOR: City of Laredo

PREPARED BY: CH2M HILL

DATE: March 25, 1996

Introduction

The purpose of this report is to characterize geologic and hydrogeologic conditions in the Laredo area as part of an Aquifer Storage and Recovery (ASR) feasibility assessment for the City of Laredo. Using existing information, waterbearing formations in the Laredo area were identified and their hydrogeologic properties evaluated for suitability in applying ASR technology.

Previous Investigation

Limited groundwater resource investigations have been performed in the Laredo area. The earliest groundwater resource investigation was performed by Lonsdale and Day (1937) who evaluated geologic and water resources in Webb County. No other Laredo-specific investigations have been published since then. Eargle (1968) provides information regarding stratigraphic nomenclature and correlations of middle Eocene strata for the Gulf Coastal Plain and the Rio Grande Embayment. Klemt et al. (1976) prepared a summary of groundwater resources for the Carrizo Aquifer in the Winter Garden area. The Winter Garden area includes those areas within the fresh water portion of the Carrizo Aquifer which exists north and west of Laredo. However, Laredo is not included in the Winter Garden area.

Hamlin (1988) provides a substantive report of depositional and groundwater flow systems within the Carrizo Formation, with particular emphasis on areas upgradient of the fresh water/saline water interface. Although the study included only a few water wells from Webb County, and none from the Laredo area, important information is provided about geologic and hydrogeologic trends in the Carrizo beneath Laredo. McCoy (1991) evaluated groundwater resources in the western portion of the Winter Garden area. While Laredo is not specifically included in this area, the report contains information on shallow aquifers that also occur beneath Laredo. The Texas Water Development Board (TWDB) regularly obtains waterlevels and water samples from observation wells across Texas including several in the Laredo area. Information from these wells is on file with the TWDB in Austin.

Methods

CH2M HILL conducted the following activities to support this investigation:

- A search for water well records from the TWDB and the Texas Natural Resource Conservation Commission (TNRCC).
- A search for oil and gas well records from the Texas Railroad Commission (RRC).
- A literature review of available geologic and hydrogeologic reports.
- A site visit to the City of Laredo.
- A geophysical analysis utilizing oil and gas well geophysical log records obtained from the Post Cambrian Association Log Library, a commercial electric log exchange, and various private sources in addition to the TWDB, the RRC and the TNRCC.

The geophysical investigation was performed by Alvin Schultz, a geophysical consultant under contract to CH2M HILL. The geophysical report is included as Attachment 1A to this report.

Water well records from the TNRCC and the TWDB were reviewed to identify waterbearing zones in the Laredo area. The records were reviewed for information regarding well construction, local geology, and, where available, aquifer test data. Water well records are organized according to a grid system generated by the TWDB utilizing USGS 7.5-minute quadrangle maps. The area investigated for this report is shown on Figure 1 and includes the following grid sections: 85-20 (7-9), 85-21 (7-9), 85-28 (1,2,3,6,9), 85-29 (1-9) and 85-37(1-9). Each of the section maps (i.e., 20, 21,28, 29, and 37) corresponds to a 7.5-minute quadrangle.

Regional Geologic Setting

The Laredo area lies within the Rio Grande embayment of the Gulf Coastal Plain. The Gulf Coastal Plain is characterized by a relatively flat, low-lying topographic surface which slopes gradually to the Gulf of Mexico. The most important geologic units in the Laredo area are Quaternary and Tertiary deposits of Eocene and Recent age. These deposits dip and thicken towards the Gulf of Mexico so that the older formations dip more steeply than younger ones. The materials of Eocene age extend updip for approximately 80 miles northwest of the City. Along the river, alluvial materials associated with the Rio Grande overlie the older deposits.

Locally, the occurrence of salt domes, faults and folds may cause reversals of the regional dip and thickening or thinning of the formations. Such features are likely responsible for oil and gas production from deeper units in the Laredo area.

The Gulf Coastal Plain sediments and alluvial sediments are composed of complexly interbedded sedimentary deposits of gravel, sand, silts and clay of fluvial and deltaic origin. The complexity of the deposits is the result of constant changes in sea level and upland precipitation.

Local Geology

The near surface geologic materials present in Laredo are Cenozoic in age (40–60 million years before present). From youngest to oldest, the materials include Recent fluviatile terrace (alluvial) deposits associated with the Rio Grande River and the Laredo

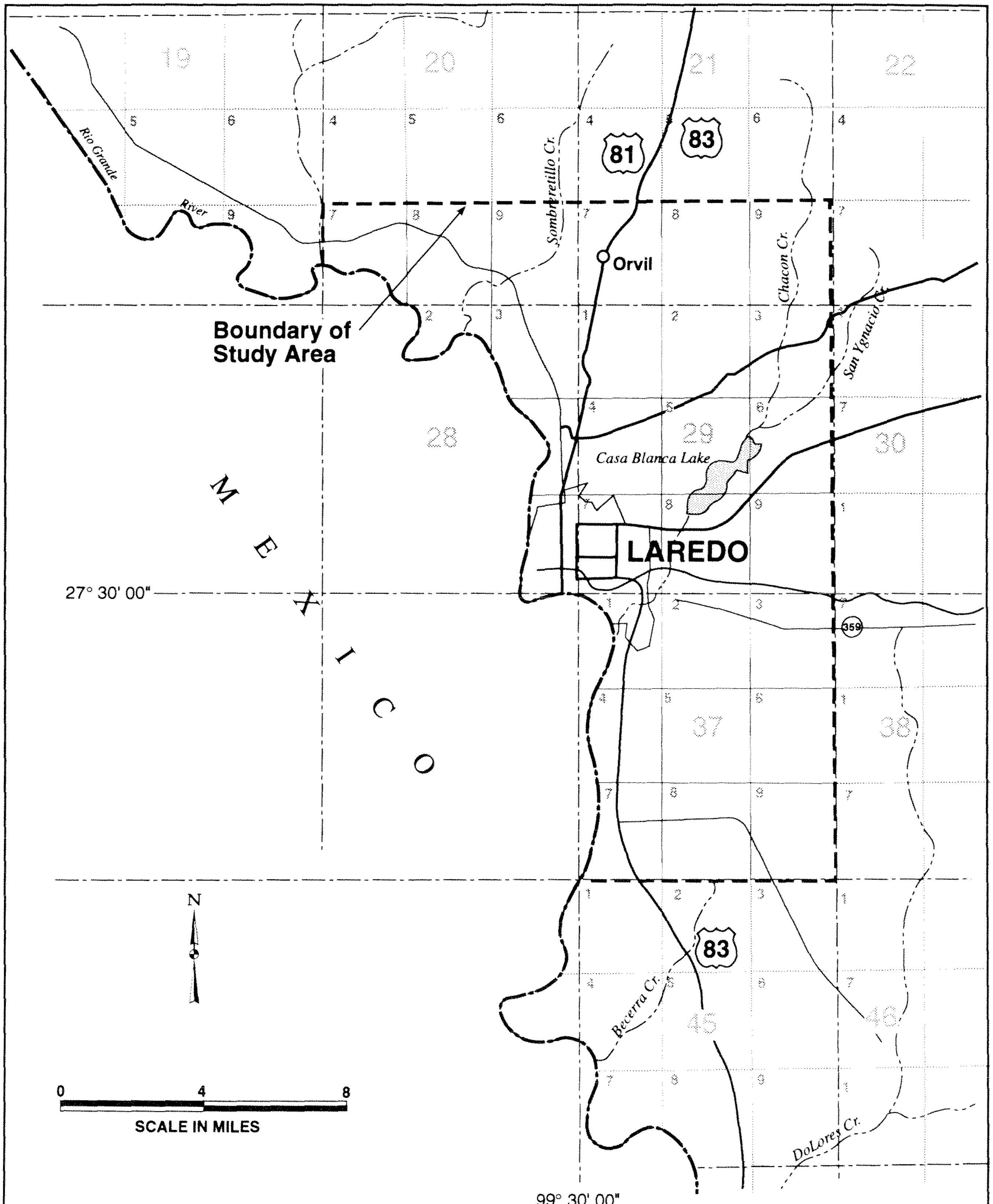


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Figure 1
Site Location Map
Laredo Aquifer Storage & Recovery Project

CH2M HILL

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Formation of Eocene age. Beneath the Laredo Formation lie older formations that include the El Pico Clay, Bigford Formation, Reklaw Formation, and the Carrizo Formation, all of Eocene age. Table 1 provides a stratigraphic section of the geologic materials. A generalized lithologic summary of these units is provided below.

Fluviatile Terrace Deposits

The alluvial deposits of recent age consist of unconsolidated gravel, sand, silt and clay associated with floodplain and delta deposits of the Rio Grande. Wells located within one mile of the Rio Grande near Laredo penetrate approximately 40 feet of alluvium. Shallow exposures of the alluvium contain gravel which are mined locally. The alluvial deposits become thinner away from the river. No alluvial deposits are mapped further than 1 or 2 miles from the river. According to Lonsdale and Day (1937), wells in the alluvium yield only small quantities of water (< 50 gallons per minute [gpm]). The depth to groundwater in the alluvium in most areas around Laredo exceeds 50 feet and, for this reason, the unit contains little or no saturated thickness.

Laredo Formation

The Laredo Formation consists of sand, sandstone, glauconitic sandstone, clay, thin limestone, and marl. The sand and sandstone are generally medium to fine grained and comprise more than 50% of the formation. In general, the upper beds are dominated by clay whereas, the lower beds are sandy. The formation is present at the surface in the study area. The formation outcrops in a north-south trending band that occurs between Sombreretillo Creek, located northwest of the City and Chacon Creek, located east of the City (Figure 1). The thickness of the Laredo Formation ranges from 620 feet at the outcrop to more than 875 feet in wells located east of the outcrop.

The Laredo Formation is an important source of water for domestic and irrigation purposes in the Laredo area. Water quality is generally poor in the upper beds but improves in the lower beds. According to McCoy (1991), the Laredo Formation yields from less than 50 gpm to 500 gpm in the western part of the Winter Garden Area.

El Pico Clay

The El Pico Clay is dominated by clay but also contains minor beds of sandstone. Coal beds are also common. The formation typically yields only limited quantities (< 50 gpm) of highly mineralized water. The sandstone beds are typically quite thin and contain soluble minerals. The outcrop of the El Pico Clay is exposed along the Rio Grande northwest of Laredo. In the Laredo area, the top of the El Pico probably occurs between 600 and 900 feet below ground surface. The maximum thickness of the El Pico Clay is approximately 900–1,150 feet.

Bigford Formation

The Bigford Formation consists of gypsiferous clay, thin bedded to massive sandstone, concretionary limestone, lignite, and coal. The formation outcrops in a 10 to 12-mile band in northwestern Webb County. The top of the Bigford occurs between 1250 and 2222 feet in the Laredo area and is 500 to 900 feet in thickness (Schultz, 1996). In the Laredo area, individual sandstone beds reach a maximum of 40 feet in thickness.

The formation yields small to moderate quantities of fresh to slightly saline water (< 50 to 500 gpm). The Bigford Formation is not known to produce water suitable for domestic or irrigation purposes in the Laredo area.

Reklaw Formation

The Reklaw formation occurs between 2000 and 3200 feet below ground surface in the Laredo area and consists of marine shales and mudstone (Eargle, 1965). North and west of Laredo, the Reklaw is replaced by the Bigford Formation (Hamlin, 1988). According to Schultz (1996), the Reklaw is considered to be an important marker bed in the Laredo area and is used in geophysical log interpretation to separate the base of the Bigford from the top of the Carrizo Formation.

Carrizo Sand

The Carrizo Sand consists almost entirely of sandstone but may also contain minor amounts of clay or shale. The formation outcrops in the northwestern corner of Webb County and in this area, the unit is mapped as a friable, massive sandstone, highly porous and lacking cement. Based on geophysical logs, the top of the Carrizo occurs between 2200 and 3200 feet in the Laredo area and is estimated to be approximately 1600 feet thick (Schultz, 1996).

The Carrizo Sand is an important groundwater resource for counties north and east of Webb County. In Webb County, the Carrizo is considerably finer grained than deposits to the northeast (Hamlin, 1988). Most wells drilled into the Carrizo in Webb Country yield relatively low quantities of poor quality groundwater. The Carrizo is not known to produce water suitable for domestic or irrigation purposes in the Laredo area.

Groundwater Conditions in Study Area

The primary water bearing zones in the Laredo area include a shallow zone and two deep zones. Based on water well records shown in Table 2, the shallow aquifer zone encompasses sandy layers within the Laredo Formation that occur between 50 and 850 feet below ground surface (bgs). Although the City provides potable water from surface supplies, historically, there have been numerous water wells installed in the shallow depths of the Laredo Formation for domestic and livestock water use. The deeper zones consist of the Bigford and Carrizo formations. In general, poor water quality in these deeper zones have limited development of water wells in these formations in the Laredo area. Uses of groundwater in Laredo are included in Table 2.

Shallow Aquifer

The shallow aquifer consists of alternating sand beds within the Laredo Formation. The median water well depth in the Laredo area is approximately 310 feet. Most wells draw their water from thin sand zones between 180 and 330 feet bgs and are considered upper members of the Laredo Formation. The layers are typically 16 to 30 feet in thickness and yield approximately 20 gpm (Table 2). Upper portions of El Pico Clay may also supply limited water in some areas.

North, south, and east of Laredo, several wells have been drilled to depths between 400 and 800 feet. Productive zones were encountered between 400 and 600 feet and 700-825 feet bgs. The sand layer thickness at these depths range from 20 to 100 feet and are considered lower members of the Laredo Formation. Records from 18 wells screened between 500 and 850 are highlighted in Table 2. Pumping rates in excess of 200 gpm have been recorded for several wells screened in this interval (85-21-7(1)) however, the median pumping rate is approximately 50 gpm.

The water levels (i.e., depth to top of water) in wells shown in Table 2 which are completed in the Laredo Formation, indicate depths ranging from 12 to 225 feet bgs. The depth to water is highly variable as result of nonequilibrium waterlevel conditions, irregular topography, and the proximity of some wells to surface water bodies. Based on hydrographs from two wells screened in the Laredo Formation in northern Webb County and northern La Salle County, there appears to be very little change in water level since 1970 (McCoy, 1991).

Aquifer Characteristics. There have been no documented pumping tests performed in the Laredo area. However, specific capacity tests were run on 34 of the 72 wells evaluated for this study. All of the tests, with one exception, were performed in wells screened in the shallow zone. With this information, transmissivities were estimated using the following relationship:

$$T = 2000\, Q/s$$

Where:
T = Transmissivity (gal/day-ft)
Q = discharge (gpm)
s = drawdown (feet) (Driscoll, 1986)

It should be noted that the data used in the calculations was obtained from available records and could not be verified for accuracy. Test results are presented in Table 2. For comparison, the wells listed in Table 2 were sorted according to transmissivity values from highest to lowest.

Specific capacity tests were performed on 28 of the 54 wells screened in the shallow portions of the Laredo Formation between 40 and 500 feet. The median transmissivity for these wells is 260 gallons per day per foot (gal/day-ft). The highest transmissivity in this interval occurred in well 85-29-8 (4,200 gal/day-ft) which is located within the City. The next highest transmissivities occurred in two wells, 85-37-8(1) and 85-37-8(3), both located southeast of the City. The transmissivity values for these wells are between 1800 and 1667 gal/day-ft with pumping rates of 50 and 30 gpm respectively. The next highest transmissivity is from well 85-20-8-3 (750 gal/day-ft), located northwest of the City, within 1 mile of the City's Santa Isabel Creek well (i.e., the reverse osmosis, or RO well) which is shown on Figure 2. This well is screened in the shallow portions of the Laredo Formation between 40 and 120 feet below ground and yields 30 gpm.

Specific capacity test data is available for 6 wells screened in the deeper portions of the Laredo Formation between 500 and 850 feet. The median transmissivity calculated is approximately 2000 gal/day-ft. The highest producing wells occur north of the City in sections 85-21-7, 85-29-1, and 85-29-2. The highest producing well, 85-29-1(3) yields 280 gpm and is operated by the Laredo Country Club.

Deep Aquifer Zones

The deep aquifer zones consist of sand layers within the Bigford and Carrizo formations and have similar characteristics. Based on available well records, there are two existing wells that appear to be screened in the Carrizo. There are no known wells screened in the Bigford Formation. The City's RO well is screened in the Carrizo Sand between 1796 and 1916 feet. Based on data obtained from the City, the calculated transmissivity in this well is 340 gal/day-ft. Another well in the vicinity, 85-20-7-1, is screened across discrete sand layers that occur between 1881 and 1946 feet. This well was pumped at 15 gpm and no drawdown was recorded. No analytical data was available for this well; however, well records indicate that "good" quality water was obtained.

Records are on file for two other wells drilled to approximately 3200 feet near the City (85-29-301, 85-29-703) however, no aquifer data was available for either location.

Geophysical Investigation

Alvin Schultz (1996) conducted a geophysical evaluation of the Bigford and Carrizo formations that is summarized below. A complete investigation report is provided in Attachment 1A. The investigation utilized geophysical logs from twenty oil and gas wells and sidewall core data from two oil and gas wells, all in the Laredo area. The location of the geophysical investigation study area is shown in Attachment 1A, Plate 1. The purpose of the evaluation was to determine the distribution, thickness, porosity, and permeability of the Bigford Formation and the massive member of the Carrizo Sand in the Laredo area. The massive member of the Carrizo was selected for investigation because, in general, it encompasses higher permeability sands than lower members of the Carrizo.

Schultz identified stratigraphic contacts and sand layer thicknesses within the Bigford and Carrizo formations for twenty wells in the area. Sand layers in each formation having net porosity's greater than, or equal to, 20% were identified and the net thickness calculated. Units having a porosity of less than 20% were not included in the net sand thickness calculation. Porosities were determined via laboratory measurements of sidewall cores and porosity logs obtained from two well locations. The porosity data was correlated to other wells having similar geophysical signatures.

The Bigford and Carrizo formations generally thicken from northwest to southeast. In the Bigford, the net sand thickness ranges from 427 feet in the northwestern part of the study area to 578 feet in the south central part. The thickest net sands occur in the lower portion of this formation. In the massive member of the Carrizo, the net sand increases from 261 feet in the northwest to 509 feet in the east. Both the Bigford and Carrizo formations thicken along channels that are oriented from northeast to southwest (Attachment 1A: Plates 2 & 3).

Three sidewall cores were obtained in the Bigford from a single boring. The average porosity calculated for these cores is 27.3%. All of the cores were obtained from the lower parts of the Bigford and may not be representative of the entire formation. An average porosity of 24.6 % was estimated from 24 sidewall cores obtained from the massive member of the Carrizo Formation. The cores were obtained from two separate boreholes in the Laredo area. The average permeability determined from the sidewall cores is 75.8 millidarcies for the Bigford Formation and 63.5 millidarcies for the massive member of the Carrizo Formation. All of the cores obtained from the two locations are composed of very fine-grained sands and silty sands.

The information obtained during this investigation is consistent with observations recorded for the two existing wells screened in the Carrizo Formation as well as abandoned test holes

85-29-901 and 85-29-703. The findings are also consistent with Hamlin's work (1988) that was discussed earlier.

Groundwater Quality

Water quality data for the Laredo area was obtained from TWDB water well records and the City of Laredo. Data is available for 11 of the 74 well records presented in Table 2. Water quality data is summarized in Table 3. The location of the wells listed in Table 3 is shown on Figure 2. Where more than one sample set is available, only the most recent data is presented.

Shallow Aquifer

Analytical data was available for eight of the shallow aquifer locations listed in Table 2. Groundwater in the shallow aquifer has a mean TDS of 2103 milligrams per liter (mg/L). The range of TDS is 1350 mg/L to 3090 mg/L. The dominant cation is sodium and the dominant anions are bicarbonate and sulfate. These analytes occur at mean concentrations of 768 mg/L, 323 mg/L, and 888 mg/L, respectively. The mean chloride value is 362 mg/L.

All the data appears to have been obtained from wells screened in the upper parts of the Laredo Formation and is not necessarily representative of the lower member. Based on driller's logs, lower water quality groundwater is often encountered during drilling and probably reflects the presence of connate water in less continuous sand layers found in the upper Laredo Formation. Because of the uncertain construction of many wells and overlying poorer quality groundwater, the reliability of individual analyses may be questionable.

Deep Aquifer

Three data sets are available for the deep aquifer zone in the Carrizo Sand. The City's RO well is the only known water well screened in the Carrizo that still exists in the area. The other two samples were obtained from open boreholes during drilling and for this reason, the reliability of individual analyses is questionable.

Total dissolved solids concentrations range from 1506 mg/L at the City's RO well to 3050 mg/L in well 85-29-202, an abandoned oil and gas test hole located northeast of the City. These concentrations mimic a regional trend reported by (Hamlin, 1988) that shows TDS values increasing in the down-dip direction. The dominant cations and anions in the samples analyzed are sodium and bicarbonate at mean concentrations of 887 mg/L and 1562 mg/L, respectively. Hamlin (1988) reports that with increasing depth and downdip distance, the composition of Carrizo groundwater becomes more enriched with sodium and bicarbonate and that below 2500 feet, the formation of sodium-bicarbonate water is complete.

Summary and Conclusions

The findings and conclusions of this investigation are listed below:

- Three aquifers were identified in this investigation: a shallow aquifer consisting of the Laredo Formation and two deep aquifer zones within the Bigford and Carrizo formations. The Laredo Formation is the primary aquifer in the Laredo area. Poorer water quality in the deeper formations has limited water well development there.

- The Laredo Formation is dominated by sand and sandstone that is interlayered with thin beds of limestone, marl and clay. The upper member of the formation contains significantly more fines than the lower member. The majority of wells in the Laredo area are screened in the upper member and produce between 10 and 30 gpm. The median estimated transmissivity in the upper member is 260 gal/day-ft. Salty zones occur in the shallow intervals, however, in general, water quality in the formation improves with depth. The water quality in the upper member of the Laredo Formation is characterized by sodium-bicarbonate type water. In the lower member, coarser and thicker deposits of sand occur, and yields as high as 280 gpm have been reported north of the City. The median transmissivity in the lower member is approximately 2,000 gal/day-ft. No water quality data was available for the lower member.
- The City's Santa Isabel Creek well is the only known well in the study area that is screened in a deep aquifer zone. The well is located north and west of Laredo and yields approximately 105 gpm from the Carrizo Formation. Water quality at this location is fair to poor. There are no known wells screened in either the Bigford or Carrizo formations within the study area. Information from the geophysical investigation indicates that both formations contain layers of sand and sandstone that can be correlated between boreholes. Boring logs, geophysical logs, and sidewall cores indicate that the formations consist of very fine-grained sands and sandstone.

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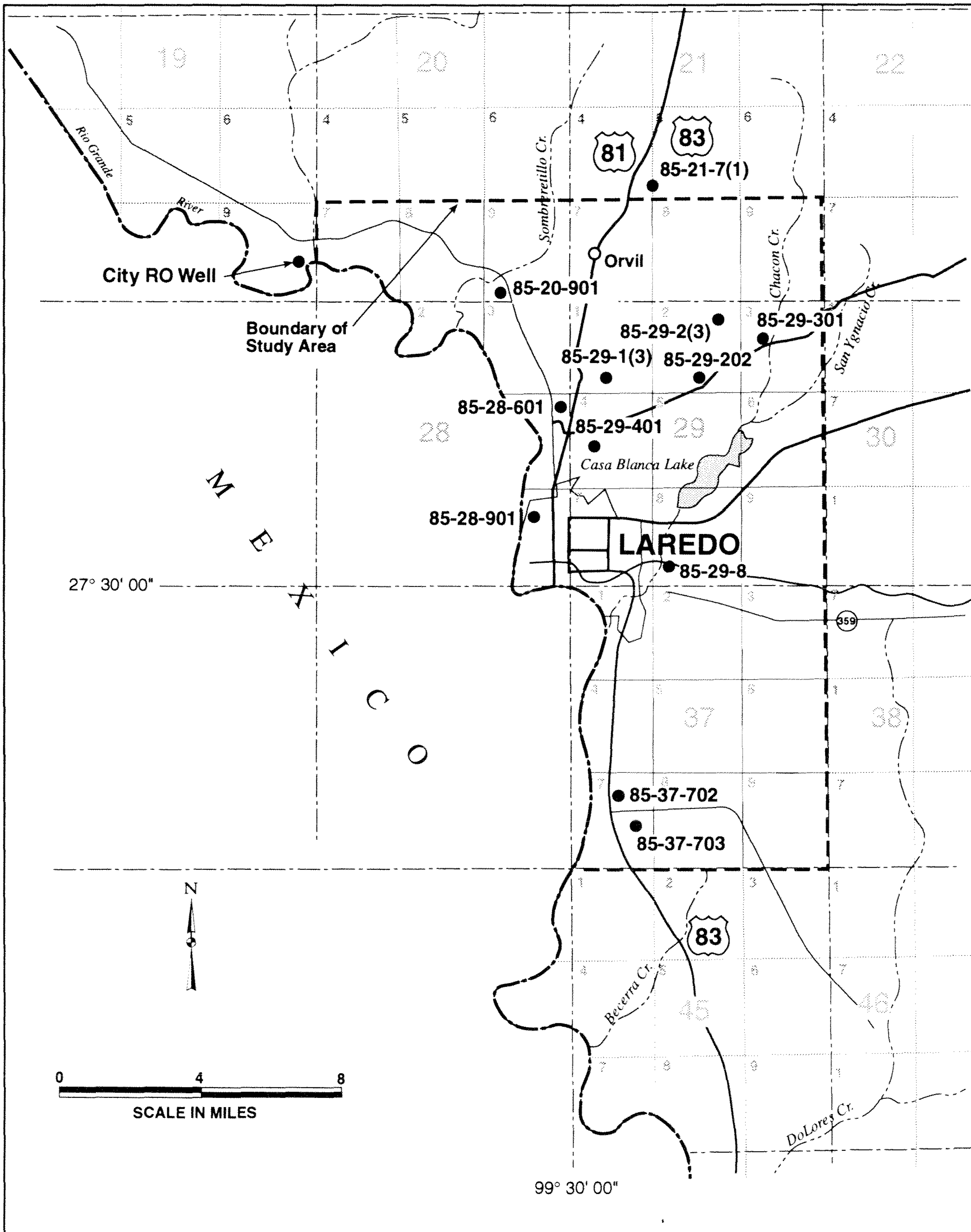

Figure 2
Location of Selected Water Wells
Laredo Aquifer Storage & Recovery Project

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Table 1
Paleocene to Lower Eocene Stratigraphic Relationships in South Texas
Laredo Aquifer Storage and Recovery Project

Chronostratigraphy		Lithostratigraphy			
Series	Stage	Outcrop/Shallow Subsurface		Deeper Subsurface (>4000 ft)	
		Southwest	Northeast		
Eocene	Lutetian	El Pico Clay	Weches Formation	Queen City Formation	Mount Selman Formation lower Claiborne Group
			Queen City Formation		
		Bigford Formation	Reklaw Formation	Reklaw Formation	
	Ypresian	Carrizo Formation		upper Wilcox	Wilcox Group
Paleocene	Thanetian	Indio Formation	Wilcox Group	middle Wilcox	
	Danian	Midway Group		lower Wilcox	
				Midway Group	

Reference: (Hamlin, 1988)

Table 2
Summary of Water Well Records:
Laredo and Surrounding Areas
Laredo Aquifer Storage Recovery Project

Location Coordinates	Type of well	Total boring depth	Maximum screen depth	Screen Interval	Estimated thickness of water bearing unit (ft)	Static Waterlevel & Date (ft)	Water Quality	Aquifer Parameters					Comments
								Pumping Rate (GPM)	Draw-down (FT)	Specific Capacity (Gallons/ Ft-min)	Transmissivity Gal-Ft-Day	Hydraulic Conductivity (Ft per day)	
85-29-1-(3)	Irr	800	660	440-660	165	65/1993	good	280	100	2.80	5600	4.54	Laredo Country Club
85-21-7-(1)	Ind	895	820	541-583;668-712;780-820	126	130/1989	fresh	210	80	2.63	5250	5.57	12-hr drawdown test
85-29-8	Dom	720	450	380-450	70	12/?	Fresh	105	50	2.10	4200	8.02	
85-29-2-(4)	Dom	710	710	630-710	80	131/1991	fresh	50	50	1.00	2000	3.34	
85-37-8-(1)	Dom	400	400	180-400	50	105/1993	good	45	50	0.90	1800	4.81	streaks of sand
85-29-2-(3)	Dom	710	710	645-710	65	140/1992	good	50	60	0.83	1667	3.43	
85-37-8-(3)	Dom	280	280	245-280	35	85/1992	med salt	25	30	0.83	1667	6.37	
85-20-8-(3)	Dom	120	120	40-120	70	25/1991	fresh	30	80	0.38	750	1.43	streaks of sand
85-28-3D	Dom	150	130	90-130	40	90/1983	fresh	5	20	0.25	500	1.67	
85-29-401	Dom	1000	300	240-300	50	95/1988	Table 3	30	140	0.21	429	1.15	
85-37-7-(2)	Dom	380	380	160-380	70	80/1993	good	60	300	0.20	400	0.76	streaks of sand
85-29-6D	Other	281	275	254-275	21	43/?	Comment	25	132	0.19	379	2.41	Salt water @ 25-30, 62-74, 125--136
85-20-9-(1)	Dom	210	210	175-210	35	85/1988	fresh	15	80	0.19	375	1.43	
85-37-8-(2)	Dom	410	410	374-410	35	175/1993	good	20	110	0.18	364	1.39	
85-37-8-(4)	Dom	280	280	250-280	30	110/1993	good	12	70	0.17	343	1.53	
City RO Well	Pub	1930	1916	1796-1916	104	54/?	Table 3	105	618	0.17	340	0.44	Laredo RO well
85-20-8-(4)	Dom	300	120	90-120	30	39/1991	fresh	10	60	0.17	333	1.49	
85-20-8-(3/4)	Dom	300	120	90-120	30	39/1991	fresh	10	60	0.17	333	1.49	
85-37-8C	Dom	580	580	540-580	40	150/?	fresh	15	100	0.15	300	1.00	
85-37-406	N/A	330	325	116-130;140-205;305-325	79	80/1975	n/a	25	176	0.14	284	0.48	
85-37-405	N/A	300	260	110-148;192-227;232-260	101	94/1962	n/a	24	170	0.14	282	0.37	
85-29-7D	Dom	260	260	200-260	20	62	Salt Wate	20	150	0.13	267	1.78	
85-21-7G	Lvstk	300	260	178-190;237-260	35	113/1963	n/a	20	160	0.13	250	0.95	
85-28-3A	Dom	205	194	172-194	22	50/1966	fresh	24	192	0.13	250	1.52	
85-20-8A	Dom	210	200	90-120;128-156;182-200	76	72/1970	n/a	23	200	0.12	230	0.40	
85-29-1A	Dom	322	322	276-322	37	90/1963	fresh	20	200	0.10	200	0.72	
85-29-2-(2)	Dom	782	755	746-755	50	160/1985	slightly sal	15	170	0.09	176	0.47	
85-29-1B	Dom	240	240	210-240	25	43/1967	fresh	20	235	0.09	170	0.91	
85-29-3A	Dom	315	310	130-142;300-310	22	40/1967	n/a	20	250	0.08	160	0.97	
85-21-7A	Lvstk	267	267	227-261	34	140/1963	fresh	20	250	0.08	160	0.63	
85-20-8B	Dom	235	235	173-200;213-227	44	83/1972	n/a	15	227	0.07	132	0.40	

Table 2
Summary of Water Well Records:
Laredo and Surrounding Areas
Laredo Aquifer Storage Recovery Project

Location Coordinates	Type of well	Total boring depth	Maximum screen depth	Screen Interval	Estimated thickness of water bearing unit (ft)	Static Waterlevel & Date (ft)	Water Quality	Aquifer Parameters					Comments
								Pumping Rate (GPM)	Draw-down (FT)	Specific Capacity (Gallons/ Ft-min)	Transmissivity Gal-Ft-Day	Hydraulic Conductivity (Ft per day)	
85-29-5B	?	305	300	146-160,220-232,290-300	36	72	n/a	17	300	0.06	113	0.42	
85-20-8-5	Dom	230	230	160-230	?	66/1992	fresh	4	94	0.04	85		
85-20-8D	Dom	225	60	40-60	20	30/1977	n/a	2	60	0.03	67		
85-20-8E	Dom	240	240	220-240	21	132/1984	fresh	6	220	0.03	55		
85-20-8F	Dom	400	110	80-110	20	54/1984	fresh	1.5	260	0.01	12		
85-37-5E	Dom	675	675	397-418;595-675	145	n/a	little salty	80-100	n/a				
85-37-8A	Dom	516	501	388-501	?	n/a	slightly sa	60-80					
85-21-7-(2)	Dom	1100	821	534-560;660-718;779-821	126	130/1989	fresh	210		0.00	0		
85-29-2-(1)	Dom	710	710	645-710	streaks	180/1991	fresh	50	0				no drawdown reported
85-29-202	Oil	545	545	465-545	105	140/1981	slightly sa	30					
85-37-6C	Dom	463	463	421-463;273-315	88	165/1979	n/a	30	n/a				
85-29-1D	Dom	626	550	530-550	87	189/1984	Table 3	30					Didn't screen all sand layers
85-37-7D	Dom	363	363	323-363	53	103/1980	fresh	30	n/a				
85-37-7-(1)	Dom	360	360	230-360	125/streaks	85/1994	n/a	30	0				no drawdown reported
85-28-601	Ind	231	231	214-231				25					
85-20-901	Ind	475	475	?	?		y	20					1994 TWBD
85-29-301	Lvstk/Ob	200	200	167-200	16	71.54/1970	Table 3	18					
85-29-1-(2)	Dom	300	300	270-300	30	85/1993	fresh	15	0				no drawdown reported
85-20-7-(1)		2010	1946	1881-1887;1897-1905;1910-1946	50	130/1993	good	15					no drawdown - across from RO well
85-37-9B	Dom	680	680	620-680	40	225/1994	good	12	0				no drawdown reported
85-29-803	Observ.	200	200	167-200	20	84.18/1970	n/a	5					
85-20-7A	Lvstk	400	400	dry	n/a	n/a	n/a	n/a	n/a				
85-20-8C	Dom	300	300	n/a	n/a	n/a	n/a	n/a	n/a				
85-29-703	Dom	3074	3074	n/a	n/a	n/a	poor	n/a	n/a				Abandoned (Central Power and Light well)
85-37-3D	Publ.	1245	1245	1190-1245	30	180	n/a	n/a	n/a				
85-37-2L	Dom	568	568	448-568	108	120	n/a	n/a	n/a				
85-37-701	Dom	550	550	n/a	n/a	90/1960	n/a	n/a	n/a				

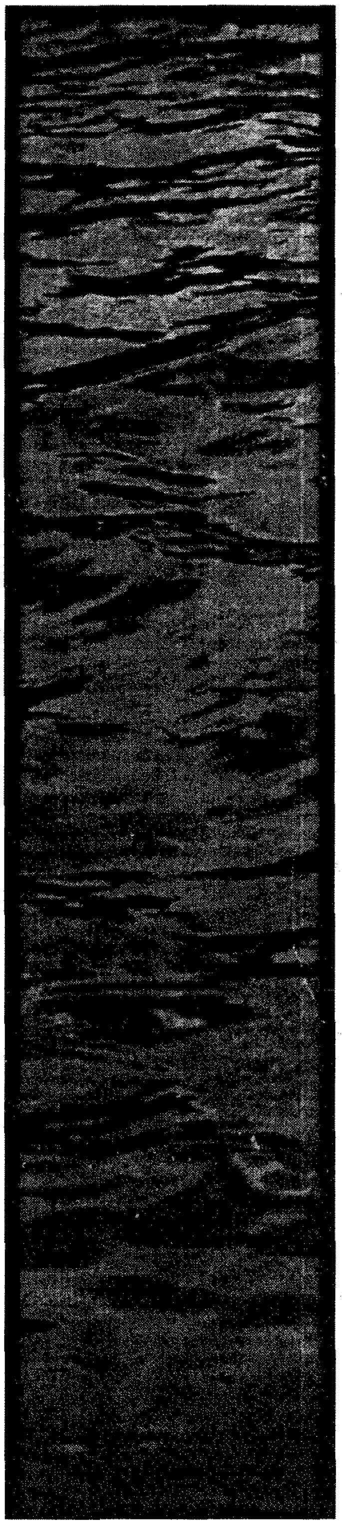
Table 2
Summary of Water Well Records:
Laredo and Surrounding Areas
Laredo Aquifer Storage Recovery Project

Location Coordinates	Type of well	Total boring depth	Maximum screen depth	Screen Interval	Estimated thickness of water bearing unit (ft)	Static Waterlevel & Date (ft)	Water Quality	Aquifer Parameters					Comments
								Pumping Rate (GPM)	Draw-down (FT)	Specific Capacity (Gallons/ Ft-min)	Transmissivity Gal-Ft-Day	Hydraulic Conductivity (Ft per day)	
85-37-4F	Dom	568	512	403-512	n/a	n/a	n/a	n/a	n/a				
85-37-2E	Lvstk	500	490	472-490	18	?	?	n/a	n/a				
85-29-2E	Dom	484	483	189-231;420-483	70	90	n/a	n/a	n/a				
85-29-801	Dom	310	310	268-310	n/a	n/a	n/a	n/a	n/a				
85-29-2P	Dom	300	300	260-300	45	180/1982	n/a	n/a	n/a				
85-29-4E	Other	300	300	n/a	20	76	n/a	n/a	n/a				
85-29-802	Dom	300	300	n/a	n/a	n/a	n/a	n/a	n/a				
85-37-202	Dom	275	275	233-275	n/a	147.37/1961	n/a	n/a	n/a				
85-29-701	Dom/lvst	250	250	208-250	138.76/1961	n/a	n/a	n/a	n/a				
85-37-403	Dom	250	250	208-250	n/a	n/a	n/a	n/a	n/a				
85-37-702	Dom	250	250	200-250	15	104/1960	Table 3	n/a	n/a				
85-29-4A	Lvstk	102	98	85-98	17	n/a	n/a	n/a	n/a				
85-37-301	Lvstk	230	230	170-230	4	n/a	n/a	n/a	n/a				
85-28-901	Oil	3245	3245	n/a	n/a	n/a	Table 3						Abandoned oil test hole
85-20-7B	Lvstk	300	300	open	18		salty						
85-37-703	Dom	177	177	97-177?	15		Table 3						

Notes:
Dom = Domestic use
Lvstk = Stock well
Ind = Industrial well
Obs = observation well
Oil = Oil/gas Test well
Transmissivity calculated using following relationship: T = Q*2000/s
Hydraulic Conductivity calculated as follows: K = T/B where B equals thickness of waterbearing unit
n/a = Information not available

Table 3
Summary of Inorganic Water Quality Analyses - Water Wells, Laredo, TX
Laredo Aquifer Storage and Recovery Project

Zone:	Shallow Aquifer								Deep Aquifer		
Well Designation:	85-37-703	85-29-301	85-37-702	85-20-901	85-29-401	85-29-1D	85-28-601	85-37-402	RO Well	85-28-901	85-29-202
Date Sampled:	5/10/61	2/17/86	4/12/94	4/20/94	4/14/94	3/19/84	4/19/94	5/10/61	9/15/93	8/2/53	1/31/76
Screen Interval (ft):	97-177	167-200	200-250	475?	240-300	530-550	214-231	207	1796-1916	2442	3215-3245
Constituents:											
Laboratory pH, units	7.5	8.7	7.86	7.45	8.92		8.72	7.4	9.24	8.1	8.8
Total Dissolved Solids, mg/L	2890	3090	2080	1975	1350		1590	2314	1506		3050
Total Alkalinity, mg/L ($CaCO_3$)		208	333.4	283	270.6		196		2275		1590
Total Hardness, mg/L ($CaCO_3$)	1170	29	175	175	8		12	633	18	37	20
Specific Conductance, µmhos	3660	3250	3160	2480	1960		2420	3330	2800	6940	4720
Cations: (mg/L)											
Boron				1.96			1.96				
Calcium	205	9	34	36			3.6	92			5
Magnesium	159	1	21	3.4			0.71	103	.15		2
Potassium		2	7.5	5.8			2.8	7.4			
Silica		12	14	19			14				11
Sodium	1513	1103	677	601			566	536	639		1230
Anions: (mg/L)											
Bicarbonate	430	234	406.9	345.4	291.2		222.1	402	1388		1760
Bromine/Bromide			1.4	1.3			1.83				
Carbonate		9	0	0	19.2		252		244	1600	1.89
Chloride	200	763	322	264		500	415	305	450	1650	790
Flouride	0.4	1	1.78	.3			.34	1.6	2.4		3.5
Nitrate	.0	.09	.02	.11			<0.01				<0.4
Sulfate	1580	1110	758	846			415	1050	220	3.9	54
Metals: (µg/L)											
Aluminum			<20	<20			<20				
Arsenic			<16	<8			<4				
Barium			17.7	12.4			14.8				
Cadmium			<2	2.2			<2				
Chromium			<10	<10			<10				
Copper			<10	10.6			<10		<0.1		
Iron			42.8	<10			160		1.3		
Lead			<5	<5			<5				
Manganese			39.3	3.4			6.2		<0.05		
Strontium			2860	1320			237				
Zinc			71.6	22.6			<10		<0.5		



Attachment 1A
Geophysical Report

AN INVESTIGATION TO DETERMINE

the

NET SAND THICKNESS, POROSITY, AND PERMEABILITY

of the

BIGFORD FORMATION AND THE MASSIVE CARRIZO MEMBER

of the

CARRIZO FORMATION

LAREDO AREA
WEBB COUNTY, TEXAS

CONTENTS

ILLUSTRATIONS

TABLES

PLATES

(at end of volume in side pocket)

Appendices
(at end of volume)

Appendix A.	Individual well work sheets for determining net sand in the Bigford Formation in all study area wells.
Appendix B.	Individual well work sheets for determining net sand in the Massive Carrizo Member of the Carrizo Formation in all study area wells.

PURPOSE

The purpose of this study is to investigate the net sand thickness, porosity, and permeability of the Bigford Formation and the Massive Carrizo Member of the Carrizo Formation in the Laredo, Texas area. Geophysical logs and other information gathered from previously drilled oil and gas tests are the primary data sources. The following items are used to fulfill the requirements of the study:

1. Determine the net sand count of the Bigford Formation and the Massive Carrizo Member of the Carrizo Formation.
2. Construct a net sand isopach map of the Bigford Formation and a net sand isopach map of the Massive Carrizo Member of the Carrizo Formation.
3. Fabricate two structural cross sections through the City of Laredo,
4. Acquire porosity and permeability data from sidewall cores taken in the Bigford Formation and Massive Carrizo Member.
5. Present a brief summary of the results of the study.

A DILIGENT AND CONCENTRATED EFFORT HAS GONE INTO THE PREPARATION OF THIS REPORT. HOWEVER, ALL INTERPRETATIONS ARE BASED UPON INFERENCES FROM ELECTRICAL AND OTHER MEASUREMENTS AND OTHER DATA. THE AUTHOR CANNOT, AND DOES NOT GUARANTEE THE ACCURACY OR CORRECTNESS OF ANY INTERPRETATIONS OR THE RELIABILITY OF THE DATA SUPPLIED FROM OTHER SOURCES, AND SHALL NOT BE LIABLE OR RESPONSIBLE FOR ANY LOSS, COSTS, DAMAGES OR EXPENSES INCURRED OR SUSTAINED BY ANYONE RESULTING FROM ANY RELIANCE UPON ANY INTERPRETATION MADE IN THIS REPORT.

INTRODUCTION

Geophysical logs on twenty pre-selected wells in the Laredo, Texas area were gathered and analyzed in order to gain a better understanding of the net sand thickness of the Bigford Formation and the Massive Carrizo Member of the Carrizo Formation. Porosity estimates were calculated from available porosity sensitive logs. Additionally, limited sidewall core data was obtained from two wells, one northeast of Laredo and the other southeast of Laredo.

Interpretation of net sand thicknesses as shown on the isopach maps indicates that the Bigford Formation (B.F.) has a net sand thickness that ranges from 385 feet to 578 feet in the study area (Plate 1), with a net thickness of 469 feet in the Laredo Water Works well in the northern part of the City of Laredo. The net sand thickness of the Massive Carrizo Member (M.CZ.M.) varies from 202 feet to 578 feet where the interval has been penetrated. Only 122 feet of net sand is penetrated in the Laredo Water Works water well in the northern part of the City of Laredo. Interpretation of the net sand isopach map indicates that approximately 320 to 340 feet of net sand should be present at the Laredo Water Works well location.

Porosity data from sidewall cores and geophysical log interpretation agree very favorably. The average porosity for the B.F. was determined to be 27.3% from sidewall core analysis, while the M.CZ.M. porosity averaged 24.6% from sidewall core analyses. Porosity measurements from sidewall core analysis are usually higher than those from whole core analysis (Webster, 1958). A case study in a Lower Wilcox sand in McMullen County indicates that sidewall core analysis results are about one porosity unit higher than that obtained from whole core analysis. Results from this study indicate that porosity determined from sidewall core analysis is about one porosity unit higher than porosity obtained from an accurate set of geophysical logs in clean sands.

A minimum of permeability data was gathered from oil and gas tests in the study area. Sidewall core analyses were available on only three cores from the B.F. and twenty three sidewall cores were extracted from the M.CZ.M. Permeability averaged 75.8 millidarcies in the B.F. and 63.5 millidarcies in the M.CZ.M. based upon the limited data. Additionally, sidewall or whole core information at depths less than 2489 feet was not located.

The two cross sections indicate that good hydraulic continuity should be present throughout the area in both the B.F. and the M.CZ.M.

ACQUISITION OF DATA

Geophysical logs and other data from twenty study area wells (Table 1) were gathered. Well selection was based upon proximity to the City of Laredo, availability, log quality, and apparent near vertical borehole conditions. Geophysical logs, scout tickets, and sidewall core analyses were obtained from the Post Cambrian Association (log library), a commercial electric log exchange, the Texas Railroad Commission, the Texas Water Development Board, and various private sources.

Acquisition of data did not require any confidentiality agreements.

BASE MAP AND WELL LOCATIONS

The base map used in this report was procured by CH2M Hill from the Texas Railroad Commission and modified for this study. Numerous oil and gas tests have been drilled in the study area. However, for clarity, only the pre-selected twenty wells are posted (Plate 1). Wells not shown on the original map from the Texas Railroad Commission were spotted utilizing scout tickets. The Pe Mex #101 Laredo well in Mexico was positioned using data from Claughton (1977).

Locations are approximate. If well drilling is to be done and any study well is critical, the area of interest and all critical wells should be re-surveyed by one competent registered surveyor.

STRATIGRAPHIC NOMENCLATURE

The lithostratigraphic relationships employed in this study are those proposed by Hargis (Hargis, 1962, 1985) and endorsed by the Texas Bureau of Economic Geology (Hamlin, 1988). Several other classifications have been presented in the past by other workers (Claughton, 1977). However, the nomenclature and identification of formation tops by Hargis takes advantage of more subsurface control. In addition, unpublished work by Hargis (personal communication) was used to select formation tops in the Laredo area.

Table 1. Study area wells and summary of gross and net sand thicknesses of the Bigford Formation (B.F.) and the Massive Carrizo Member (M.CZ.M.) of the Carrizo Formation. All thicknesses shown are obtained from geophysical log interpretations.

Operator and Well Name:	Stratigraphic Unit	Net sand thickness (ft.)	Gross sand thickness (ft.)	Net sand/ Gross interval
Amoco Production Company	B.F.	480	881	0.54
#8 Bruni Mineral Trust	M.CZ.M.	358	846	0.42
Amoco Production Company	B.F.	465	805	0.58
#1 Killam-Hurd-Amoco "F"	M.CZ.M.	372	690	0.54
Amoco Production Company	B.F.	503	798	0.63
#1 J.C. Trevino, Jr.	M.CZ.M.	315	744	0.42
C.F. Braun & Co.	B.F.	543	867	0.63
#1 Hilltop	M.CZ.M.	383	768	0.5
Columbus Energy Corp.	B.F.	385	782	0.49
#1 Richter Unit	M.CZ.M.	355	788	0.45
Good Hope Refineries Inc.	B.F.	564	908	0.62
#1 Killam & Hurd	M.CZ.M.	345	791	0.44
Gulf Oil Corp.	B.F.	503	815	0.62
#1 D.D. Ramos	M.CZ.M.	423	772	0.55
Killam & Hurd, Ltd.	B.F.	559	800	0.7
#1-P25 Oralia Cantu	M.CZ.M.	509	770	0.66
Killam & Hurd	B.F.	560	802	0.7
#1-P24 Fee	M.CZ.M.	494	765	0.65
Laredo Water Works	B.F.	469	806	0.58
#1 Laredo Water Works (WW)	M.CZ.M.	122	(Net & Gross not penetrated)	
Lobo Resources, Ltd.	B.F.	474	820	0.58
#2 Laredo Air Force Base	M.CZ.M.	356	768	0.46
Louisiana Land & Exploration Co.	B.F.	427	818	0.52
#1 A.F. Muller	M.CZ.M.	261	721	0.36
Michael Petroleum Corp.	B.F.	441	824	0.54
#1 Hurd-Peko-Garcia Unit	M.CZ.M.	202	811	0.25
Pe Mex (Frontura)	B.F.	468	771	0.61
#101 Laredo	M.CZ.M.	340	742	0.46
Sanchez-O'Brien & W.O.C.,Inc.	B.F.	513	822	0.62
#1 Jacaman	M.CZ.M.	412	780	0.53
Sanchez-O'Brien	B.F.	496	821	0.6
#3 Jacaman	M.CZ.M.	351	779	0.42
Sanchez-O'Brien & W.O.C., Inc.	B.F.	477	810	0.59
#1 A.F. Muller Gas Unit	M.CZ.M.	345	770	0.45
Sanchez-O'Brien	B.F.	578	862	0.67
#1 Alfredo Villarreal Gas Unit	M.CZ.M.	379	768	0.49
Sanchez-O'Brien	B.F.	499	839	0.59
#1 Webb County	M.CZ.M.	429	760	0.56
Transamerica Natural Gas Corp.	B.F.	427	818	0.52
#12 Schwartz	M.CZ.M.	317	812	0.39

POROSITY AND PERMEABILITY FROM SIDEWALL CORE ANALYSIS

Porosity and permeability measurements from two wells (Table 2) were collected. Sidewall or whole core analysis is very limited in the study area because formation evaluation has been concentrated in the Lower Wilcox gas producing horizons.

Porosity observed in the B.F. is consistent and averages 27.3% using the three cores taken in the C.F.Braun & Company #1 Hilltop Farms well. These cores were taken in the lower part of the formation. The permeability averages 75.8 millidarcies from the same three cores. A plot of porosity vs. permeability does not provide sufficient data to yield a sound relationship (Figure 1). No direct measurements of porosity or permeability were located for the middle and upper portions of the B.F.

Sidewall core analysis results exhibit a wider range of porosity and permeability for the M.CZ.M. This is probably due to more cores being taken over a wider depth span, more zones analyzed, and other mechanical factors. Porosity is observed to range from 19.2% to 28.6%.

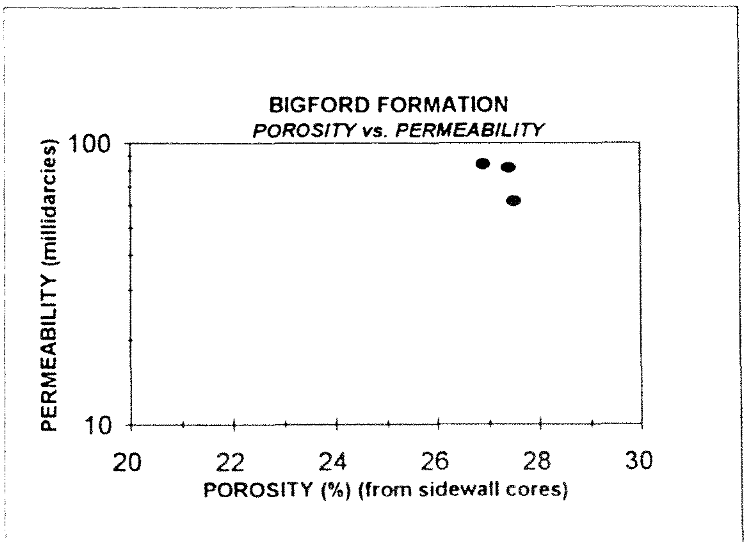


Figure 1. Comparison of porosity and permeability from sidewall core analysis for the Bigford Formation in the Laredo area of Webb County, Texas.

There appears to be a better correlation between porosity and permeability for the M.CZ.M. (Figure 2). In this case, there seems to be a good trend in the 21% to 27% porosity range. Since, by design, the net sand isopach maps are constructed assuming an estimated porosity exceeding 20%, a log-linear plot is presented to compare porosity and permeability where porosity exceeds 20% (Figure 3).

Table 2. Porosity and permeability determined from sidewall core analysis on sidewall cores taken from the Bigford Formation (Bigford Fm.) and the Massive Carrizo (Cz.) Member (Mbr.) of the Carrizo Formation. Sidewall cores are taken from the Killam & Hurd, LTD. #1-P25 Oralia Cantu and the C.F. Braun and Company #1 Hilltop Farms.

Operator & Well Name:	*Stratigraphic Unit*	*Depth in feet*	*Permeability in Millidarcies*	*Porosity as %*
C.F. Braun & Co.	Bigford Fm.	2489	81.6	27.4
#1Hilltop Farms	Bigford Fm.	2499	61.9	27.5
"	Bigford Fm.	2509	84	26.9
"	Massive Cz. Mbr. of Cz. Fm.	2760	59.9	24.8
"	Massive Cz. Mbr. of Cz. Fm.	2762	72.3	25.7
"	Massive Cz. Mbr. of Cz. Fm.	2766	89.4	26.6
	Massive Cz. Mbr. of Cz. Fm.	2922	N.T.	27.1
"	Massive Cz. Mbr. of Cz. Fm.	3156	74.9	26.4
"	Massive Cz. Mbr. of Cz. Fm.	3326	54.6	27.7
"	Massive Cz. Mbr. of Cz. Fm.	3382	116	28.6
"	Massive Cz. Mbr. of Cz. Fm.	3509	10.8	23.8
"	Massive Cz. Mbr. of Cz. Fm.	3511	49.3	25.7
Killam & Hurd, LTD.	Massive Cz. Mbr. of Cz. Fm.	3630	120	25.7
#1-P25 Oralia Cantu	Massive Cz. Mbr. of Cz. Fm.	3677	77	24.5
"	Massive Cz. Mbr. of Cz. Fm.	3687	7.2	19.6
"	Massive Cz. Mbr. of Cz. Fm.	3694	63	23.9
"	Massive Cz. Mbr. of Cz. Fm.	3698	85	26.2
"	Massive Cz. Mbr. of Cz. Fm.	3718	212	27.9
"	Massive Cz. Mbr. of Cz. Fm.	3730	104	27.0
"	Massive Cz. Mbr. of Cz. Fm.	3735	90	26.2
"	Massive Cz. Mbr. of Cz. Fm.	3757	4.1	19.2
"	Massive Cz. Mbr. of Cz. Fm.	3774	44	24.9
"	Massive Cz. Mbr. of Cz. Fm.	3776	35	23.5
"	Massive Cz. Mbr. of Cz. Fm.	3805	22	21.9
"	Massive Cz. Mbr. of Cz. Fm.	3820	27	21.3
"	Massive Cz. Mbr. of Cz. Fm.	3852	5.7	19.2
"	Massive Cz. Mbr. of Cz. Fm.	3928	38	24.0

Averages:

Bigford Fm.	**75.8**	**27.3**
Massive Cz. Mbr. of Cz. Fm.	**63.5**	**24.6**

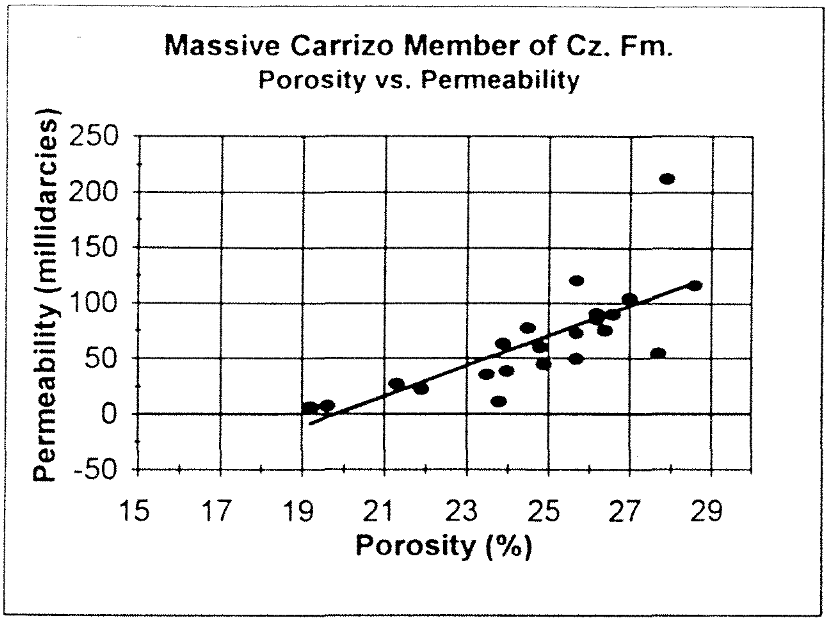


Figure 2. Comparison of porosity and permeability from sidewall core analysis for the Massive Carrizo Member of the Carrizo Formation in the Laredo area of Webb County, Texas. Correlation coefficient (r), r = .77. Relationship is: Estimated permeability = -269 + 13.56(Sidewall core analysis porosity).

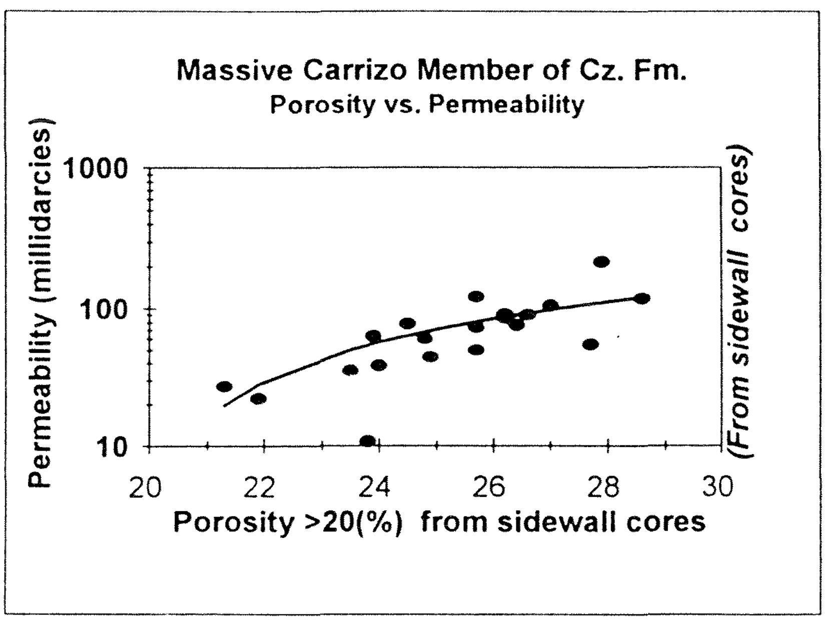


Figure 3. Comparison of porosity and permeability from sidewall core data for the Massive Carrizo Member of the Carrizo Formation where porosity exceeds 20%. Well data is from two wells in the Laredo area of Webb County, Texas.

Sidewall core analysis and whole core analysis will frequently yield different values of porosity and permeability. Porosity from sidewall core analysis is generally higher than that measured by whole core analysis (Webster,1959). Permeability is usually lower from sidewall core data compared to whole core analysis, except where permeabilities are lower than 10 to 20 millidarcies (Webster, 1959). A Lower Wilcox well utilizing both techniques of core analysis is shown in Table 3. The porosity and permeability values are similar to some of those shown in Table 2.

SIDEWALL CORE AND GEOPHYSICAL LOG POROSITY

Accurate porosity values can be calculated from geophysical logs. In many instances, responses from a compensated density log and a borehole compensated neutron log yield very accurate values of porosity in water bearing sandstones. The combination of the two apparent porosity values yields a computed porosity (CP). The general equation is: CP = (Density log porosity + Neutron log porosity)/2. Since the intervals selected for net sand count are those believed to be fairly clean sandstones, the results shown as CP (Table 4) should be the best estimate of porosity. However, a minor increase in shale will cause the computed porosity to be slightly optimistic. A porosity comparison between sidewall core analysis and geophysical log calculations which have been performed with several porosity devices yields results that are very reasonable (Table 4).

NET SAND COUNT

The first step taken to find net sand thickness was to analyze log characteristics where sidewall core analysis and porosity sensitive geophysical logs demonstrated that porous and permeable sand zones could be identified. This was accomplished by using the sidewall core and porosity data (Table 2, Table 4) along with the resistivity logs on the wells from which the porosity and permeability values were obtained. The following definition and technique was utilized to determine net sand thickness for all study area wells:

Net sand is the estimated net porous sand which is interpreted to have porosity equal to or greater than 20%. This is based upon sonic log derived porosity, sidewall core analysis, Spontaneous Potential (SP) development, and resistivity curve responses over zones where sidewall core analysis and/or geophysical log analysis has revealed 20% porosity or greater. 20% porosity was selected as a cut off for net sand count since

Table 3. Comparison of sidewall core analysis and whole core analysis from the same interval in the same well. The well is the Hawn Brothers #2-20 S.T.S. in McMullen County, Texas. The zone cored is a Lower Wilcox oil producing sand.

	SIDEWALL CORE POROSITY	WHOLE CORE POROSITY	SIDEWALL CORE PERM.	WHOLE CORE PERM.
	18.7	14.0	5.4	0.5
	18.4	21.6	3.6	59.0
	18.9	22.1	6.2	62.0
	26.4	23.8	132.0	108.0
	26.0	24.2	182.0	90.0
	25.8	24.7	87.0	110.0
	24.2	23.6	75.0	107.0
	25.3	21.9	96.0	34.0
	26.5	23.2	106.0	143.0
	23.6	17.8	57.0	8.3
	27.4	21.5	210.0	53.0
	19.4	24.0	7.4	195.0
	19.0	16.2	4.1	1.0
	21.0	16.7	19.0	0.7
	16.4	17.8	0.0	5.9
	24.5	19.3	96.0	18.0
	26.5	23.4	110.0	103.0
	18.7	19.2	5.2	7.0
	18.3	17.4	3.6	2.9
	18.9	19.0	4.4	9.4
	18.0	20.4	2.6	43.0
	24.1	23.0	110.0	99.0
	26.3	22.8	132.0	59.0
	19.1	22.1	5.4	95.0
		23.6		80.0
		23.5		95.0
		22.8		53.0
		21.0		26.0
AVERAGES	**22.1**	**21.1**	**60.8**	**59.6**

Porosity is in percent (%)
Permeability is in millidarcies

Table 4. Comparison of porosity values determined from sidewall core analysis and geophysical logs. Well is the Killam and Hurd, Ltd. #1-P25 Oralia Cantu in Webb County, Texas.

DEPTH	SIDEWALL CORE POROSITY (%)	SONIC DT	SONIC POROSITY	NEUTRON POROSITY	DENSITY POROSITY	CP POROSITY
3630	25.7	82	22.3	26	18	22.0
3677	24.5	82	22.3	29	21	25.0
3687	19.6	84	23.4	32	14	23.0
3694	23.9	82	22.3	27	19	23.0
3698	26.2	85	23.9	27	20	23.5
3718	27.9	82	22.3	28	19	23.5
3730	27.0	83	22.9	26	23	24.5
3735	26.2	90	26.5	26	24	25.0
3757	19.2	83	22.9	25	20	22.5
3774	24.9	80	21.1	24	15	19.5
3776	23.5	81	21.7	25	18	21.5
3805	21.9	84	23.4	28	21	24.5
3820	21.3	85	23.9	24	19	21.5
3852	19.2	85	23.9	25	15	20.0
AVERAGES	**23.6**	**83.4**	**23.1**			**22.8**

LEGEND

DEPTH IN FEET
POROSITY IS IN PERCENT (%)

SONIC DT = TRANSIT TIME IN MICROSECONDS PER FOOT RECORDED BY THE SONIC LOG

DENSITY POROSITY = POROSITY FROM DENSITY LOG

NEUTRON POROSITY = POROSITY FROM NEUTRON LOG

CP POROSITY = POROSITY USING BOTH DENSITY POROSITY AND NEUTRON POROSITY

CP = .5(DENSITY POROSITY + NEUTRON POROSITY) (GENERAL EQUATION)

SONIC POROSITY = POROSITY FROM SONIC LOG

SONIC POROSITY = .69[(SONIC DT - 55.5)/SONIC DT] (HUNT - RAYMER TRANSFORM) (RAYMER, et al, 1980) sidewall core analysis indicates effective permeability is lacking where porosity is less than 20% (Figure 2). Wells possessing only resistivity logs are compared to wells with porosity logs and sidewall core analysis and zones exhibiting similar curve shapes, values, and signatures. Zones possessing a good correlation are interpreted to be net sand. Net sand values for wells lacking porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

Table 5 is an example of net sand count utilizing porosity logs and Table 6 is an example of a net sand tabulation employing only resistivity and SP logs. A summary of net sand thicknesses for the B.G. and the M.CZ.M. for each well is shown in Table 1. Detailed sand thickness tabulations for each well are included in Appendices A and B.

ISOPACH MAPS AND CROSS SECTIONS

Net sand thicknesses posted on the isopach maps of the B.F. and M.CZ.M. are compatible with previous Bigford Formation and Carrizo Formation studies (Hamlin, 1988; and Guevara and Garza, 1972). Both the B.F. and the M.CZ.M. exhibit a pattern of general wedging from northwest to southeast (Plates 2 and 3). Also, in the eastern half of the study area both units mapped reveal a channel like pattern trending north-northeast and south-southwest. This type of sand-dispersal pattern is common for both the B.F. and the M.CZ.M.

Net sand thicknesses in the B.F. vary from 427 feet in the northwestern to 578 feet in the south central part of the study area. The net sand thickness of the B.F. gradually increases from 468 feet in the Pe Mex #101 Laredo well to 469 feet in the Laredo Water Works #l Water Works well and is 474 feet in the Lobo Resources #2 Laredo Air Force well (Plate 2). From the northwestern corner of the study area to the southeastern corner of Laredo the net sand thickness varies from 427 feet to 578 feet. An irregular channel-like dispersal pattern is present in the eastern half of the study area (Plate 2). The cross sections (Plates 4 and 5) indicate that the thickest net sand units are developed in the lower part of the formation.

261 feet of net M.CZ.M. sand is developed in the Louisiana Land and Exploration Company well northwest of Laredo (Plate 3). Thickening occurs gradually to an elongated north-northeast/south-southwest trending channel-like pattern with a maximum net sand thickness of 509 feet in the Killam and Hurd #1-P25 Cantu well (Plate 3). The Laredo Water Works #1 Water Works well did not penetrate the entire thickness of the M.CZ.M. Based upon the net sand isopach (Plate 3) and observing the

Table 5. Example of net sand count utilizing porosity sensitive geophysical logs, resistivity logs, and Spontaneous Potential (SP) logs.

OPERATOR: AMOCO PRODUCTION COMPANY
#1 J.C. TREVINO,JR. Elevation: GL: 422', K.B. 440', Log measured from KB
Approximate location: North side of the city of Laredo: Also 2672' FSWL & 608' FNL of T. Rodriguez, A-268, Porc 24, Webb County, Texas

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	1506	1066	798	
Reklaw Formation	2304	1864	90	
Massive Carrizo Member	2462	2022	744	0.42
Wilcox-Carrizo Member	3206	2766	806	
Carrizo Formation	2394	1954	1618	

Net Sand and Sonic Derived Porosity

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand	Dt sonic	Porosity (sonic)	Porosity feet (sonic)	Porosity (N)	Porosity (D)	(Porosity (CP)
Massive Carrizo Member	2488	2542	54	83.0	0.23	12.3	0.27	0.18	0.225
of the Carrizo Formation	2566	2580	14	83.0	0.23	3.2	0.27	0.19	0.23
	2610	2628	18	87.0	0.25	4.5	0.3	0.21	0.255
	2634	2655	21	88.0	0.25	5.4	0.27	0.22	0.245
	2687	2728	41	86.0	0.24	10.0	0.27	0.21	0.24
	2742	2746	4	85.0	0.24	1.0	0.27	0.18	0.225
	2776	2782	6	86.0	0.24	1.5	0.27	0.21	0.24
	2790	2798	8	85.0	0.24	1.9	0.27	0.2	0.235
	2828	2834	6	83.0	0.23	1.4	0.25	0.22	0.235
	2849	2852	3	83.0	0.23	0.7	0.23	0.2	0.215
	2863	2894	31	83.5	0.23	7.2	0.24	0.2	0.22
	2917	2928	11	85.0	0.24	2.6	0.245	0.17	0.2075
	2952	2978	26	85.0	0.24	6.2	0.27	0.16	0.215
	3013	3026	13	82.0	0.22	2.9	0.25	0.17	0.21
	3030	3049	19	84.0	0.23	4.4	0.25	0.17	0.21
	3068	3086	18	82.5	0.23	4.1	0.24	0.19	0.215
	3156	3168	12	81.0	0.22	2.6	0.23	0.2	0.215
	3173	3178	5	83.0	0.23	1.1	0.23	0.2	0.215
	3183	3188	5	83.0	0.23	1.1	0.24	0.18	0.21
Total net sand (feet) & porosity feet			**315**			**74.2**			
Average porosity values calculated from both sonic log and crossplot (CP) from neutron and density log data					**0.235**				**0.226**

Legend

Dt = sonic transit time in microseconds/ft

Porosity (sonic) = porosity sonic log = 69[(Dt sonic - 55.5)/Dt sonic]

Porosity (N) = Porosity from neutron log

Porosity (D) = Porosity from density log

Porosity (CP) = porosity computed = (Porosity (N) + Porosity (D))/2

Table 6. Example of net sand count determined by utilizing resistivity and Spontaneous Potential (SP) logs.

OPERATOR: LOBO RESOURCES, LTD.
WELL: #2 LAREDO AIR FORCE BASE   Elevation: GL: 497', K.B. 515', Log measured from KB
Approximate location: 1 mile NE of Laredo: also 1435' FNEL & 3751 FNWL of Vidaurri Rafael Survey #1020; A-780, Webb County, Texas

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	1878	1363	820	
Reklaw Formation	2698	2183	97	
Massive Carrizo Member	2858	2343	768	0.46
Wilcox-Carrizo Member	3626	3111	840	
Carrizo Formation	2795	2280	1671	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Massive Carrizo Member of the	2890	2915	25
Carrizo Formation	2920	2923	3
	2930	2940	10
	2950	2988	38
	3016	3034	18
	3040	3080	40
	3090	3120	30
	3130	3152	22
	3201	3225	24
	3270	3311	41
	3330	3340	10
	3350	3368	18
	3420	3450	30
	3472	3497	25
	3570	3580	10
	3598	3610	12
Total net sand (ft.)			356

cross sections (Plates 4 and 5), an estimated net thickness of 200 to 220 net feet of sand should be present in the undrilled M.CZ.M. footage. The more uniform net sand zones in the M.CZ.M. are generally thinner than those found in the bottom 300 feet of the B.F. Typically some of the net sand zones in the M.CZ.M. are in the 30 foot range (Plates 4 and 5). Net sand thicknesses for the B.F. and the M.CZ.M. are shown on a net sand worksheet for each well in Appendices A and B.

The potential for encountering oil or gas and faulting exists within the study area. There are unconfirmed reports of gas production (Hargis, personal communication) in the Pe Mex #101 Laredo well from a sand zone in the El Pico Clay (above the B.F.) and from an interval in the B.F. Additionally, gas is produced at present in Webb and Zapata counties from the stratigraphic equivalent of the B.F.

Missing sections in the Columbus Energy #1 Richter and the Amoco #1 Killam-Hurd-Amoco "F" wells are interpreted to be caused by faulting. With only 20 wells studied, and faulting detected in two, faulting is a potential cause for a decrease in net sand thickness in any well drilled near Laredo.

SUMMARY

Geophysical logs in conjunction with sidewall core analyses were used to determine the net sand thicknesses of the B.F. and M.CZ.M. in the Laredo area of Webb County, Texas. The net sand thicknesses of both stratigraphic units gradually increases to the east-southeast in the City of Laredo. Approximately 450 to 500 feet of net sand should be encountered in the B.F. in wells drilled in the northern part of the City of Laredo, while nearly 320 to 380 feet of net M.CZ.M. sand should be penetrated in the same area.

Average permeability as determined from limited sidewall core analysis is 75.8 millidarcies for the B.F. and 63.5 millidarcies for the M.CZ.M. Porosity determined from sidewall core analysis yielded 27.3 % for the B.F. and 24.6% in the M.CZ.M. Permeability measurements at depths less than 2489 feet were not available. Porosity values from sidewall core analysis appear to be about one porosity unit higher than those obtained by utilizing a combination of density and neutron logs.

The cross sections reveal that the B.F. and M.CZ.M. are relatively easy to correlate on geophysical logs and that no major lateral stratigraphic barriers are present.

Specific values of net feet of sand for each of the two stratigraphic units studied can be found in Appendices A and B.

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Also, the assistance provided by Richard Hargis in determining the proper correlations for the formations in the study area is greatly appreciated.

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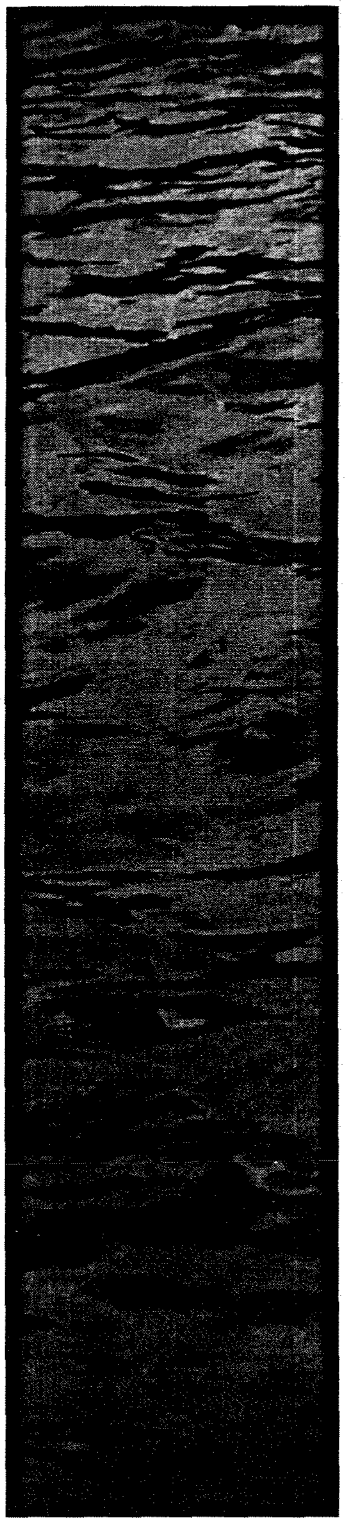


Attachment 1A
Geophysical Report Plates

Geophysical Report Plates

will be bound separately

APPENDIX A

Individual well worksheets for determining the net sand thickness of the Bigford Formation in study area wells

AMOCO PRODUCTION COMPANY
#8 BRUNI MINERAL TRUST Elevation: GL: 481.5', K.B. 500', Log measured from KB
Approximate location: 4.5 miles East of Laredo: also see scout ticket for a more precise location

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	1955	1455	881	0.54
Reklaw Formation	2836	2336	94	
Massive Carrizo Member	2989	2489	846	
Wilcox-Carrizo Member	3835	3335	798	
Carrizo Formation	2930	2430	1703	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Bigford Formation	1965	1970	5
	1976	1990	14
	2020	2032	12
	2047	2067	20
	2070	2085	15
	2096	2107	11
	2120	2130	10
	2140	2151	11
	2170	2181	11
	2206	2218	12
	2233	2274	41
	2280	2290	10
	2293	2320	27
	2330	2372	42
	2440	2480	40
	2484	2546	62
	2564	2572	8
	2580	2650	70
	2690	2749	59
Total net sand (ft.)			**480**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: AMOCO PRODUCTION COMPANY
#1 KILLAM-HURD-AMOCO "F"   Elevation. GL 506', K.B. 519, Log measured from KB
Approximate location: 4 miles NE of Laredo: also see scout ticket for a more precise location

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	2495	1976	805	0.58
Reklaw Formation	3300	2781	180	
Massive Carrizo Member	3530	3011	690	
Wilcox-Carrizo Member	4220	3701	880	
Carrizo Formation	3480	2961	1620	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Bigford formation	2507	2516	9
	2521	2580	59
	2582	2600	18
	2626	2662	36
	2686	2765	79
	2792	2830	38
	2840	2850	10
	2865	2874	9
	2882	2892	10
	2920	2932	12
	2942	3030	88
	3040	3085	45
	3090	3102	12
	3150	3190	40
Total net sand (ft.)			**465**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: AMOCO PRODUCTION COMPANY
#1 J.C. TREVINO, JR. Elevation: GL: 422', K.B. 440', Log measured from KB
Approximate location: North side of the city of Laredo: Also 2672' FSWL & 608' FNL of T. Rodriguez, A-268, Porc 24, Webb County, Texas

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	1506	1066	798	0.63
Reklaw Formation	2304	1864	90	
Massive Carrizo Member	2462	2022	744	
Wilcox-Carrizo Member	3206	2766	806	
Carrizo Formation	2394	1954	1618	

Net Sand and Sonic Derived Porosity

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand	Dt sonic	Porosity (sonic)	Porosity feet (sonic)	Porosity (N)	Porosity (D)	(Porosity (CP)
Bigford Formation	1506	1508	2	92.0	0.27	0.5	0.29	0.22	0.255
	1518	1542	24	89.0	0.26	6.2	0.29	0.22	0.255
	1545	1549	4	97.0	0.30	1.2	0.29	0.24	0.265
	1568	1574	6	92.0	0.27	1.6	0.27	0.245	0.2575
	1578	1612	34	94.0	0.28	9.6	0.28	0.23	0.255
	1616	1626	10	89.0	0.26	2.6	0.29	0.22	0.255
	1638	1646	8	87.5	0.25	2.0	0.27	0.22	0.245
	1662	1680	18	92.0	0.27	4.9	0.3	0.2	0.25
	1690	1698	8	95.5	0.29	2.3	0.3	0.27	0.285
	1700	1740	40	90.0	0.26	10.6	0.26	0.23	0.245
	1776	1804	28	89.0	0.26	7.3	0.28	0.23	0.255
	1806	1814	8	92.0	0.27	2.2	0.29	0.23	0.26
	1819	1868	49	87.0	0.25	12.2	0.26	0.22	0.24
	1883	1892	9	93.0	0.28	2.5	0.28	0.2	0.24
	1894	1897	3	95.0	0.29	0.9	0.29	0.2	0.245
	1948	1972	24	87.0	0.25	6.0	0.26	0.22	0.24
	1978	1990	12	88.0	0.25	3.1	0.27	0.24	0.255
	1996	2012	16	85.0	0.24	3.8	0.28	0.2	0.24
	2028	2108	80	85.0	0.24	19.2	0.26	0.22	0.24
	2143	2202	59	85.0	0.24	14.1	0.27	0.21	0.24
	2221	2274	53	93.0	0.28	14.7	0.3	0.24	0.27
	2289	2292	3	90.0	0.26	0.8	0.3	0.23	0.265
	2299	2304	5	85.0	0.24	1.2	0.24	0.18	0.21
Total net sand (feet) & porosity feet			**503**			**129.6**			

Average porosity values calculated from both sonic log and crossplot (CP) from neutron and density log data **0.26** **0.25**

OPERATOR: C.F. BRAUN & CO.
WELL: #1 HILLTOP Elevation: GL: 491', K.B. 510', Log measured from KB
Approximate location: Adjacent to E/side Laredo Townsite: also 1120 FSL & 300' FWL of J.D. Trevino Porc 33, A-3084, Webb County, Texas

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	1732	1222	867.0	0.63
Reklaw Formation	2599	2089	95.0	
Massive Carrizo Member	2758	2248	768.0	
Wilcox-Carrizo Member	3526	3016	876.0	
Carrizo Formation	2694	2184	1708.0	

Net Sand and Sonic Derived Porosity

(sonic log quality is very poor - values are approximate)

Stratigraphic unit	Depth from	Depth to	Net Sand	Dt sonic	Porosity (sonic)
Bigford Formation	1746	1759	13	89.0	0.26
	1793	1805	12	85.0	0.24
	1827	1832	5	83.0	0.23
	1853	1859	6	83.0	0.23
	1862	1875	13	no value- log quality problem	
	1882	1923	41	82.0	0.22
	1944	1981	37	83.0	0.23
	1987	1998	11	no value - log quality problem	
	2002	2029	27	80.0	0.21
	2035	2085	50	80.0	0.21
	2092	2103	11	87.0	0.25
	2108	2128	20	82.0	0.22
	2131	2144	13	85.0	0.24
	2147	2158	11	87.0	0.25
	2195	2240	45	83.0	0.23
	2244	2304	60	85.0	0.24
	2309	2323	14	82.0	0.22
	2333	2403	70	85.0	0.24
	2405	2411	6	85.0	0.24
	2414	2423	9	86.0	0.24
	2442	2475	33	86.0	0.24
	2485	2495	10	87.0	0.25
	2499	2525	26	84.0	0.23
Total net feet of sand			**543**		

Sidewall core analysis:
Porosity = 274 & Permeability = 81.6 md. @2489'
Porosity = 275 & Permeability = 61.9 md. @2499'
Porosity = .269 & Permeability = 84 md. @2509'

Net sand definition:

Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: COLUMBUS ENERGY CORP.
#1 RICHTER UNIT Elevation: GL: 438', K.B. 453, Log measured from KB
Approximate location: 1.5 miles South of Laredo: also see scout ticket for a more precise location

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	1488	1035	782	0.49
Reklaw Formation	2270	1817	96	
Massive Carrizo Member	2427	1974	788	
Wilcox-Carrizo Member	3215	2762	875	
Carrizo Formation	2366	1913	1724	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Bigford formation	1488	1504	16
	1540	1610	70
	1650	1685	35
	1698	1710	12
	1730	1780	50
	1800	1838	38
	1842	1859	17
	1910	1928	18
	1950	1960	10
	1965	1970	5
	1973	1985	12
	2000	2050	50
	2057	2074	17
	2081	2094	13
	2120	2142	22
	2155	2199	44
Total net sand (ft.)			**385**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: GOOD HOPE REFINERIES, INC.
#1 KILLAM & HURD Elevation: GL: 532', K.B. 546', Log measured from KB
Approximate location: 5 miles East of Laredo: also see scout ticket for a more precise location

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	2592	2046	908	0.62
Reklaw Formation	3500	2954	104	
Massive Carrizo Member	3654	3108	791	
Wilcox-Carrizo Member	4445	3899	850	
Carrizo Formation	3604	3058	1691	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Bigford Formation	2600	2627	27
	2662	2693	31
	2714	2760	46
	2776	2790	14
	2795	2811	16
	2816	2837	21
	2844	3031	187
	3036	3042	6
	3055	3091	36
	3110	3147	37
	3156	3190	34
	3210	3248	38
	3271	3308	37
	3360	3394	34
Total net sand (ft.)			**564**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: GULF OIL CORP.
#1 D.D. RAMOS Elevation: GL: 447', K.B. 462', Log measured from KB
Approximate location: 2 miles East of Laredo: also see scout ticket for a more precise location

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	2110	1648	815	0.62
Reklaw Formation	2925	2463	95	
Massive Carrizo Member	3080	2618	772	
Wilcox-Carrizo Member	3852	3390	858	
Carrizo Formation	3020	2558	1690	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Bigford Formation	2135	2139	4
	2160	2196	36
	2204	2258	54
	2280	2350	70
	2368	2419	51
	2422	2470	48
	2560	2579	19
	2584	2740	156
	2745	2750	5
	2778	2815	37
	2827	2850	23
			503

Total net sand (ft.)

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: KILLAM & HURD, LTD.
#1-P25 ORALIA CANTU

Elevation: GL: 545', K.B. 559', Log measured from KB

Approximate location: 5 miles NE of Laredo: also 660' FNWL & 55200' FNEL of J. F. Garcia Porc 25, A-50, Webb County, Texas

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	2222	1663	800	0.70
Reklaw Formation	3022	2463	96	
Massive Carrizo Member	3178	2619	770	
Wilcox-Carrizo Member	3948	3389	837	
Carrizo Formation	3118	2559	1667	

Net Sand and Sonic Derived Porosity

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand	Dt sonic	Porosity (sonic)	Porosity feet
Bigford Formation	2222	2232	10	87	0.25	2
	2242	2260	18	90	0.26	5
	2260	2272	12	85	0.24	3
	2272	2294	22	90	0.26	6
	2312	2343	31	88	0.25	8
	2356	2372	16	86	0.24	4
	2372	2376	4	95	0.29	1
	2398	2458	60	88	0.25	15
	2360	2378	18	91	0.27	5
	2487	2543	56	85	0.24	13
	2547	2562	15	91	0.27	4
	2562	2594	32	87	0.25	8
	2625	2637	12	93	0.28	3
	2637	2643	6	88	0.25	2
	2673	2694	21	89	0.26	5
	2697	2712	15	92	0.27	4
	2723	2854	131	88	0.25	33
	2875	2911	36	92	0.27	10
	2911	2940	29	85	0.24	7
	2946	2953	7	88	0.25	2
	2956	2964	8	87	0.25	2
Total net sand (feet) & porosity feet			**559.0**			**143**
Average porosity from sonic log calculations					**0.256**	

KILLAM & HURD
#1-P24 FEE Elevation: GL: 538', K.B. 552', Log measured from KB
Approximate location: 6 miles NE of Laredo: also see scout ticket for a more precise location

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	2228	1676	802	0.70
Reklaw Formation	3030	2478	102	
Massive Carrizo Member	3190	2638	765	
Wilcox-Carrizo Member	3955	3403	790	
Carrizo Formation	3132	2580	1613	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Bigford formation	2230	2238	8
	2255	2310	55
	2327	2360	33
	2369	2380	11
	2405	2478	73
	2485	2550	65
	2560	2597	37
	2638	2644	6
	2680	2870	190
	2892	2927	35
	2930	2977	47
Total net sand (ft.)			**560**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20% Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements

OPERATOR: LAREDO WATER WORKS
#1 LAREDO WATER WORKS (WATER WELL) Elevation: GL: 411', K.B. 421', Log measured from KB
Approximate location: LAREDO : Appears to be in E. Garza Survey #1238, A-425,Webb County, Texas

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	1254	833	806.0	0.58
Reklaw Formation	2060	1639	103.0	
Massive Carrizo Member	2232	1811	Not penetrated	
Wilcox-Carrizo Member	Not penetrated		Not penetrated	
Carrizo Formation	2163	1742	Not penetrated	

Net Sand and Sonic Derived Porosity

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Bigford Formation	1270	1275	5
	1280	1296	16
	1300	1305	5
	1340	1344	4
	1380	1400	20
	1410	1415	5
	1450	1508	58
	1520	1574	54
	1577	1601	24
	1677	1682	5
	1725	1865	140
	1879	1898	19
	1906	1930	24
	1935	1970	35
	1990	2045	55
Total net sand (feet)			**469**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, SP, and resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: LOBO RESOURCES, LTD.
WELL: #2 LAREDO AIR FORCE BASE Elevation: GL: 497', K.B. 515', Log measured from KB
Approximate location:1 mile NE of Laredo:also 1435' FNEL & 3751 FNWL of Vidaurri Rafael Survey #1020; A-780, Webb County, Texas

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	1878	1363	820	0.58
Reklaw Formation	2698	2183	97	
Massive Carrizo Member	2858	2343	768	
Wilcox-Carrizo Member	3626	3111	840	
Carrizo Formation	2795	2280	1671	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Bigford Formation	1892	1940	48
	1965	1970	5
	1986	2000	14
	2010	2024	14
	2090	2117	27
	2135	2145	10
	2170	2190	20
	2200	2238	38
	2250	2260	10
	2315	2346	31
	2356	2520	164
	2550	2617	67
	2634	2660	26
Total net sand (ft.)			**474**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, SP, and resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: LOUISIANA LAND & EXPLORATION COMPANY
WELL:#1 A.F. MULLER Elevation: GL: 485', K.B. 516', Log measured from KB
Approximate location: 4 miles NW of Laredo: also 660' FSEL & 1802' FSWL of J. Garcia Porc 19, A-47, Webb County, Texas

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	1515	999	818	0.52
Reklaw Formation	2333	1817	61	
Massive Carrizo Member	2470	1954	721	
Wilcox-Carrizo Member	3191	2675	736	
Carrizo Formation	2394	1878	1533	

Net Sand and Sonic Derived Porosity

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Bigford Formation	1530	1550	20
	1607	1620	13
	1614	1660	46
	1710	1741	31
	1760	1813	53
	1817	1830	13
	1910	1927	17
	1980	2005	25
	2025	2050	25
	2052	2068	16
	2084	2110	26
	2140	2189	49
	2191	2200	9
	2210	2266	56
	2293	2300	7
	2310	2331	21
Total net sand (ft.)			**427**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

MICHAEL PETROLEUM CORP.
#1 HURD-PEKO-GARCIA UNIT   Elevation: GL: 562, K.B. 580', Log measured from KB
Approximate location: 4 miles SE of Laredo: also see scout ticket for a more precise location

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	2226	1646	824	0.54
Reklaw Formation	3050	2470	100	
Massive Carrizo Member	3200	2620	811	
Wilcox-Carrizo Member	4011	3431	860	
Carrizo Formation	3150	2570	1721	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Bigford Formation	2245	2260	15
	2270	2284	14
	2290	2297	7
	2305	2350	45
	2385	2415	30
	2437	2470	33
	2475	2527	52
	2555	2580	25
	2638	2644	6
	2648	2692	44
	2700	2740	40
	2750	2775	25
	2783	2849	66
	2910	2949	39
Total net sand (ft.)			**441**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: PE MEX (FRONTERA)
#101 LAREDO Elevation: KB: 445', Log measured from KB
Approximate location: In Mexico about 2 mile west of Laredo, Texas: also nealy approximately 3 miles SW of Laredo Water Works Well #1

Formation and/or Member Tops

Stratigraphic unit	Top (meters)	Top (feet)	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	303	994	549	771	0.61
Reklaw Formation	538	1765	1320	98	
Massive Carrizo Member	587	1926	1481	742	
Wilcox-Carrizo Member	813	2667	2222	739	
Carrizo Formation	568	1864	1419	1542	

Net Sand

Stratigraphic unit	Depth from (meters)	Depth to (meters)	Net Sand (meters)	Net sand (feet)
Bigford Formation	303.0	307.5	4.5	15
	309.0	311.5	2.5	8
	323.0	324.0	1.0	3
	325.0	326.0	1.0	3
	329.0	340.0	11.0	36
	345.0	347.0	2.0	7
	348.0	349.0	1.0	3
	352.5	359.0	6.5	21
	364.0	374.0	10.0	33
	376.5	390.0	13.5	44
	404.0	407.5	3.5	11
	429.0	436.5	7.5	25
	439.0	451.0	12.0	39
	454.0	463.5	9.5	31
	368.5	370.0	1.5	5
	475.5	486.0	10.5	34
	490.0	492.0	2.0	7
	493.0	510.0	17.0	56
	512.0	538.0	26.0	85
Total net sand (ft.)				**468**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: SANCHEZ O'BRIEN &W.O.C.,INC.
WELL:#1 JACAMAN Elevation: GL: 455', K.B. 470', Log measured from KB
Approximate location: 3 miles NE of Laredo: also 359' FSEL & 1608' FSWL of R. S. Rumsey Survey #1022, A-654, Webb County, Texas

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	2100	1630	822	0.62
Reklaw Formation	2922	2452	98	
Massive Carrizo Member	3080	2610	780	
Wilcox-Carrizo Member	3860	3390	864	
Carrizo Formation	3020	2550	1704	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Bigford formation	2116	2138	22
	2142	2150	8
	2200	2208	8
	2224	2239	15
	2241	2250	9
	2270	2305	35
	2312	2336	24
	2340	2350	10
	2357	2366	9
	2370	2409	39
	2418	2425	7
	2432	2450	18
	2470	2488	18
	2511	2539	28
	2541	2560	19
	2589	2751	162
	2772	2810	38
	2816	2860	44
Total net sand (ft.)			**513**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: SANCHEZ O'BRIEN
WELL: #3 JACAMAN Elevation: GL: 470', K.B. 482', Log measured from KB
Approximate location: 4.5 miles E of Laredo: also 990' FSL & 10007' FSL of Jose Trevino Porc 31, A-3116, Webb County, Texas

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	1909	1427	821	0.60
Reklaw Formation	2730	2248	100	
Massive Carrizo Member	2891	2409	779	
Wilcox-Carrizo Member	3670	3188	839	
Carrizo Formation	2830	2348	1679	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Bigford formation	1932	1977	45
	1994	2000	6
	2006	2030	24
	2038	2053	15
	2065	2070	5
	2100	2145	45
	2159	2194	35
	2225	2240	15
	2255	2273	18
	2360	2380	20
	2389	2449	60
	2457	2550	93
	2576	2649	73
	2669	2698	29
	2700	2705	5
	2711	2719	8
Total net sand (ft.)			**496**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: SANCHEZ-O'BRIEN & W.O.C.,INC.
#1 A.F. MULLER GAS UNIT — Elevation: GL: 468', K.B. 484', Log measured from KB
Approximate location: 2 miles NE of Laredo: also see scout ticket for a more detailed location

Formation and/or Member Tops

<u>Stratigraphic unit</u>	**Top**	**Top (subsea)(-)**	**Gross thickness**	**Net sand/gross sand interval**
Bigford Formation	1855	1371	810	0.59
Reklaw Formation	2665	2181	99	
Massive Carrizo Member	2828	2344	770	
Wilcox-Carrizo Member	3598	3114	842	
Carrizo Formation	2764	2280	1676	

Net Sand

<u>Stratigraphic unit</u>	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Bigford formation	1870	1910	40
	1935	1946	11
	1956	1960	4
	1966	1970	4
	1974	1981	7
	2036	2110	74
	2130	2170	40
	2178	2209	31
	2309	2314	5
	2320	2384	64
	2391	2409	18
	2415	2460	45
	2465	2485	20
<u>Total net sand (ft.)</u>	2510	2584	74
	2600	2640	<u>40</u>
			477

<u>Net sand definition:</u>
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: SANCHEZ O'BRIEN
#1 ALFREDO VILLARREAL GAS UNIT   Elevation: GL: 467', K.B. 482', Log measured from KB
Approximate location: City of Laredo, 1603' FSL & 1251' FEL of Laredo City Survey, A-239, Webb County, Texas

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	1544	1062	862	0.67
Reklaw Formation	2406	1924	96	
Massive Carrizo Member	2564	2082	768	
Wilcox-Carrizo Member	3332	2850	858	
Carrizo Formation	2502	2020	1688	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Bigford formation	1570	1616	46
	1656	1740	84
	1764	1795	31
	1800	1840	40
	1848	1901	53
	1920	1948	28
	1960	1970	10
	2006	2050	44
	2060	2080	20
	2082	2100	18
	2108	2214	106
	2220	2230	10
	2249	2337	88
Total net sand (ft.)			**578**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

SANCHEZ-O'BRIEN
#1 WEBB COUNTY Elevation: GL: 474', K.B. 486', Log measured from KB
Approximate location: 3 miles East of Laredo: also see scout ticket for a more precise location

Formation and/or Member Tops

<u>Stratigraphic unit</u>	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	2091	1605	839	0.59
Reklaw Formation	2930	2444	104	
Massive Carrizo Member	3094	2608	760	
Wilcox-Carrizo Member	3854	3368	864	
Carrizo Formation	3034	2548	1684	

Net Sand

<u>Stratigraphic unit</u>	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Bigford Formation	2100	2109	9
	2130	2158	28
	2189	2210	21
	2232	2274	42
	2293	2335	42
	2350	2359	9
	2366	2401	35
	2421	2438	17
	2440	2452	12
	2465	2480	15
	2493	2510	17
	2520	2584	64
	2597	2600	3
	2614	2640	26
	2645	2696	51
	2700	2760	60
	2791	2829	38
	2850	2860	10
<u>Total net sand (ft.)</u>			**499**

TRANSAMERICAN NATURAL GAS CORP.
#12 SCHWARZ Elevation: GL: 607, K.B. 628', Log measured from KB
Approximate location: 4.5 miles SE of Laredo: also see scout ticket for a more precise location

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	2524	1896	818	0.52
Reklaw Formation	3342	2714	83	
Massive Carrizo Member	3480	2852	812	
Wilcox-Carrizo Member	4292	3664	901	
Carrizo Formation	3425	2797	1768	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Bigford Formation	2555	2640	85
	2690	2765	75
	2770	2800	30
	2809	2821	12
	2825	2851	26
	2882	2919	37
	2929	2982	53
	2990	3024	34
	3050	3072	22
	3086	3098	12
	3110	3140	30
	3211	3222	11
Total net sand (ft.)			**427**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

APPENDIX B

Individual well worksheets for determining the net sand thickness of the Massive Carrizo Member of the Carrizo Formation in study area wells

AMOCO PRODUCTION COMPANY
#8 BRUNI MINERAL TRUST Elevation: GL: 481.5', K.B. 500', Log measured from KB
Approximate location: 4.5 miles East of Laredo: also see scout ticket for a more precise location

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	1955	1455	881	
Reklaw Formation	2836	2336	94	
Massive Carrizo Member	2989	2489	846	0.42
Wilcox-Carrizo Member	3835	3335	798	
Carrizo Formation	2930	2430	1703	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Massive Carrizo Member of the	3070	3097	27
Carrizo Formation	3109	3126	17
	3153	3163	10
	3185	3195	10
	3210	3220	10
	3215	3270	55
	3318	3372	54
	3382	3420	38
	3427	3437	10
	3450	3485	35
	3490	3518	28
	3541	3552	11
	3610	3629	19
	3635	3648	13
	3707	3722	15
	3740	3746	6
Total net sand (ft.)			**358**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: AMOCO PRODUCTION COMPANY
#1 KILLAM-HURD-AMOCO "F" Elevation: GL: 506', K.B. 519, Log measured from KB
Approximate location: 4 miles NE of Laredo: also see scout ticket for a more precise location

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	2495	1976	805	
Reklaw Formation	3300	2781	180	
Massive Carrizo Member	3530	3011	690	0.54
Wilcox-Carrizo Member	4220	3701	880	
Carrizo Formation	3480	2961	1620	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Massive Carrizo Member of the	3530	3548	18
Carrizo Formation	3550	3560	10
	3567	3576	9
	3624	3698	74
	3700	3735	35
	3750	3758	8
	3790	3810	20
	3855	3892	37
	3930	3940	10
	3960	3998	38
	3938	3950	12
	4060	4086	26
	4134	4164	30
	4170	4200	30
	4203	4218	15
Total net sand (ft.)			**372**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: C.F. BRAUN & CO.
WELL: #1 HILLTOP Elevation: GL: 491', K.B. 510', Log measured from KB
Approximate location: Adjacent to E/side Laredo Townsite: also 1120 FSL &300' FWL of J.D. Trevino Porc33, A-3084, Webb County, Texas

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	1732	1222	867.0	0.63
Reklaw Formation	2599	2089	95.0	N/A
Massive Carrizo Member	2758	2248	768.0	0.50
Wilcox-Carrizo Member	3526	3016	876.0	N/A
Carrizo Formation	2694	2184	1708.0	N/A

Net Sand and Sonic Derived Porosity

Stratigraphic unit	Depth from	Depth to	Net Sand	Dt sonic	Porosity (sonic)	*(sonic log quality is very poor - values are approximate)*
Massive Carrizo Member	2760	2769	9	82.0	0.22	
of Carrizo Formation	2787	2794	7	80.0	0.21	
	2797	2802	5	80.0	0.21	
	2804	2809	5	78.0	0.20	
	2822	2831	9	80.0	0.21	
	2848	2854	6	84.0	0.23	
	2872	2885	13	81.0	0.22	
	2889	2896	7	79.0		
	2900	2905	5	84.0	0.23	
	2915	2938	23	81.0	0.22	*Sidewall core analysis:*
	2966	2997	31	84.0	0.23	Porosity = .271 @2922'
	3001	3009	8	82.0	0.22	
	3015	3039	24	83.0	0.23	
	3059	3066	7	81.0	0.22	
	3069	3072	3	80.0	0.21	
	3074	3079	5	79.0	0.21	
	3085	3110	25	80.0	0.21	
	3117	3124	7	81.0	0.22	
	3148	3211	63	81.0	0.22	Porosity = .264 & Permeability = 74.9md. @3156'
	3247	3278	31	76.0	0.19	
	3282	3302	20	80.0	0.21	
	3317	3337	20	81.0	0.22	Porosity = .277 & Permeability = 54.6md. @3326'
	3339	3343	4	76.0	0.19	
	3379	3392	13	78.0	0.20	Porosity = .286 & Permeability = 116 md. @3382'
	3407	3418	11	77.0	0.19	
	3483	3487	4	79.0	0.21	
	3508	3526	18	76.0	0.19	Porosity = .238 & Permeability = 10.8md. @3509'
Total net sand (ft.)			383			Porosity = .257 & Permeability = 49.3md. @3511'

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: COLUMBUS ENERGY CORP.
#1 RICHTER UNIT Elevation: GL: 438', K.B. 453, Log measured from KB
Approximate location: 1.5 miles South of Laredo: also see scout ticket for a more precise location

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	1488	1035	782	
Reklaw Formation	2270	1817	96	
Massive Carrizo Member	2427	1974	788	0.45
Wilcox-Carrizo Member	3215	2762	875	
Carrizo Formation	2366	1913	1724	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Massive Carrizo Member of the	2457	2470	13
Carrizo Formation	2484	2510	26
	2520	2526	6
	2577	2586	9
	2590	2604	14
	2640	2668	28
	2670	2680	10
	2690	2710	20
	2720	2730	10
	2786	2864	78
	2870	2893	23
	2914	2920	6
	2950	2969	19
	2975	2991	16
	3010	3030	20
	3060	3065	5
	3090	3119	29
	3172	3190	18
	3195	3200	5
Total net sand (ft.)			**355**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: LOBO RESOURCES, LTD.
WELL: #2 LAREDO AIR FORCE BASE Elevation: GL: 497', K.B. 515', Log measured from KB
Approximate location:1 mile NE of Laredo:also 1435' FNEL & 3751 FNWL of Vidaurri Rafael Survey #1020; A-780, Webb County, Texas

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	1878	1363	820	
Reklaw Formation	2698	2183	97	
Massive Carrizo Member	2858	2343	768	0.46
Wilcox-Carrizo Member	3626	3111	840	
Carrizo Formation	2795	2280	1671	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Massive Carrizo Member of the	2890	2915	25
Carrizo Formation	2920	2923	3
	2930	2940	10
	2950	2988	38
	3016	3034	18
	3040	3080	40
	3090	3120	30
	3130	3152	22
	3201	3225	24
	3270	3311	41
	3330	3340	10
	3350	3368	18
	3420	3450	30
	3472	3497	25
	3570	3580	10
	3598	3610	12
Total net sand (ft.)			**356**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, SP, and resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: GOOD HOPE REFINERIES, INC.
#1 KILLAM & HURD   Elevation: GL: 532', K.B. 546', Log measured from KB
Approximate location: 5 miles East of Laredo: also see scout ticket for a more precise location

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	2592	2046	908	
Reklaw Formation	3500	2954	104	
Massive Carrizo Member	3654	3108	791	0.44
Wilcox-Carrizo Member	4445	3899	850	
Carrizo Formation	3604	3058	1691	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Massive Carrizo Member of the	3702	3717	15
Carrizo Formation	3730	3780	50
	3795	3803	8
	3812	3837	25
	3844	3854	10
	3859	3870	11
	3910	3925	15
	3932	3940	8
	3954	3968	14
	3974	3991	17
	4005	4020	15
	4050	4087	37
	4110	4156	46
	4186	4201	15
	4207	4224	17
	4251	4267	16
	4276	4285	9
	4288	4294	6
	4299	4310	11
Total net sand (ft.)			**345**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: GULF OIL CORP.
#1 D.D. RAMOS Elevation: GL: 447', K.B. 462', Log measured from KB
Approximate location: 2 miles East of Laredo: also see scout ticket for a more precise location

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	2110	1648	815	
Reklaw Formation	2925	2463	95	
Massive Carrizo Member	3080	2618	772	0.55
Wilcox-Carrizo Member	3852	3390	858	
Carrizo Formation	3020	2558	1690	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Massive Carrizo Member of the	3115	3120	5
Carrizo Formation	3123	3130	7
	3132	3139	7
	3176	3212	36
	3239	3280	41
	3312	3350	38
	3360	3372	12
	3410	3461	51
	3470	3525	55
	3550	3634	84
	3650	3670	20
	3678	3690	12
	3700	3725	25
	3810	3823	13
	3830	3838	8
	3841	3850	9
Total net sand (ft.)			**423**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: KILLAM & HURD, LTD. ORALIA CANTU
#1-P25 ORALIA CANTU Elevation: GL: 545', K.B. 559', Log measured from KB
Approximate location: 5 miles NE of Laredo: also 660' FNWL & 55200' FNEL of J. F. Garcia Porc 25, A-50, Webb County, Texas

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-	Gross thickness	Net sand/gross interval
Bigford Formation	2222	1663	800	
Reklaw Formation	3022	2463	96	
Massive Carrizo Member	3178	2619	770	0.66
Wilcox-Carrizo Member	3948	3389	837	
Carrizo Formation	3118	2559	1667	

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net sand	Dt	Porosity (Sonic)	Por ft. (Sonic)
Massive Carrizo Member	3208	3234	26	82.0	0.22	5.80
of the Carrizo Formation	3238	3244	6	79.0	0.21	1.23
	3256	3273	17	82.0	0.22	3.79
	3278	3314	36	83.0	0.23	8.23
	3318	3328	10	85.0	0.24	2.39
	3331	3335	4	87.0	0.25	1.00
	3349	3381	32	87.0	0.25	7.99
	3390	3400	10	87.0	0.25	2.50
	3404	3490	86	86.5	0.25	21.27
	3557	3586	29	85.0	0.24	6.94
	3586	3626	40	81.0	0.22	8.69
	3629	3651	22	85.0	0.24	5.27
	3675	3702	27	81.5	0.22	5.94
	3708	3742	34	84.0	0.23	7.96
	3754	3762	8	82.0	0.22	1.78
	3769	3772	3	81.0	0.22	0.65
	3788	3832	44	82.0	0.22	9.81
	3875	3890	15	81.0	0.22	3.26
	3894	3904	10	81.0	0.22	2.17
	3908	3948	40	81.0	0.22	8.69
	3956	3966	10	83.0	0.23	2.29
Total net sand (feet) & porosity feet			**509**			**117.7**

Average porosity from sonic log calculations **0.231**

KILLAM & HURD
#1-P24 FEE Elevation: GL: 538', K.B. 552', Log measured from KB
Approximate location: 6 miles NE of Laredo: also see scout ticket for a more precise location

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	2228	1676	802	
Reklaw Formation	3030	2478	102	
Massive Carrizo Member	3190	2638	765	0.65
Wilcox-Carrizo Member	3955	3403	790	
Carrizo Formation	3132	2580	1613	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Massive Carrizo Member of the	3190	3200	10
Carrizo Formation	3218	3246	28
	3250	3259	9
	3270	3278	8
	3290	3349	59
	3362	3370	8
	3380	3391	11
	3400	3411	11
	3420	3459	39
	3465	3506	41
	3510	3517	7
	3533	3545	12
	3570	3609	39
	3612	3653	41
	3690	3716	26
	3720	3736	16
	3746	3760	14
	3765	3778	13
	3790	3800	10
	3804	3836	32
	3890	3910	20
	3922	3952	30
	3970	3980	10
Total net sand (ft.)			**494**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: LAREDO WATER WORKS
#1 LAREDO WATER WORKS (WATER WELL) Elevation: GL: 411', K.B. 421', Log measured from KB
Approximate location: LAREDO : Appears to be in E. Garza Survey #1238, A-425, Webb County, Texas

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	1254	833	806.0	.58
Reklaw Formation	2060	1639	103.0	
Massive Carrizo Member	2232	1811	Not penetrated	
Wilcox-Carrizo Member	Not penetrated		Not penetrated	
Carrizo Formation	2163	1742	Not penetrated	

Net Sand and Sonic Derived Porosity

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Massive Carrizo Member of the	2257	2286	29
Carrizo Formation	2290	2297	7
	2300	2306	6
	2321	2341	20
	2381	2392	11
	2402	2426	24
	2450	2465	15
	2475	2485	10
Total net sand penetrated (feet)			**122**

Total net sand (feet) cannot be determined from this well because entire Massive Carrizo Member
of the Carrizo Formation was not penetrated

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, SP, and resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: LOUISIANA LAND & EXPLORATION COMPANY
WELL:#1 A.F. MULLER Elevation: GL: 485', K.B. 516', Log measured from KB
Approximate location: 4 miles NW of Laredo: also 660' FSEL & 1802' FSWL of J. Garcia Porc 19, A-47, Webb County, Texas

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	1515	999	818	0.52
Reklaw Formation	2333	1817	61	
Massive Carrizo Member	2470	1954	721	0.36
Wilcox-Carrizo Member	3191	2675	736	
Carrizo Formation	2394	1878	1533	

Net Sand and Sonic Derived Porosity

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Massive Carrizo Member of	2484	2496	12
the Carrizo Formation	2500	2530	30
	2538	2550	12
	2580	2595	15
	2605	2615	10
	2641	2650	9
	2652	2657	5
	2662	2669	7
	2700	2710	10
	2720	2739	19
	2746	2754	8
	2760	2770	10
	2810	2820	10
	2840	2856	16
	2860	2880	20
	2900	2910	10
	3015	3028	13
	3054	3071	17
	3150	3168	18
	3170	3180	10
Total net sand (ft.)			**261**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

MICHAEL PETROLEUM CORP.
#1 HURD-PEKO-GARCIA UNIT Elevation: GL: 562, K.B. 580', Log measured from KB
Approximate location: 4 miles SE of Laredo: also see scout ticket for a more precise location

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	2226	1646	824	
Reklaw Formation	3050	2470	100	
Massive Carrizo Member	3200	2620	811	0.25
Wilcox-Carrizo Member	4011	3431	860	
Carrizo Formation	3150	2570	1721	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Massive Carrizo Member of the	3276	3300	24
Carrizo Formation	3307	3317	10
	3327	3340	13
	3360	3370	10
	3386	3392	6
	3408	3412	4
	3430	3441	11
	3453	3475	22
	3543	3550	7
	3570	3580	10
	3588	3610	22
	3660	3670	10
	3730	3740	10
	3793	3800	7
	3815	3824	9
	3843	3860	17
	3920	3930	10
Total net sand (ft.)			**202**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: PE MEX (FRONTURA)
#101 LAREDO
Elevation: KB: 445', Log measured from KB
Approximate location: In Mexico about 2 mile west of Laredo, Texas: also nealy approximately 3 miles SW of Laredo Water Works Well #1

Formation and/or Member Tops

Stratigraphic unit	Top (meters)	Top (feet)	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	303.0	994	549	771	0.61
Reklaw Formation	538.0	1765	1320	98	
Massive Carrizo Member	587.0	1926	1481	742	0.46
Wilcox-Carrizo Member	813.0	2667	738	739	
Carrizo Formation	568.0	1864	1419	1542	

Net Sand and Sonic Derived Porosity

Stratigraphic unit	Depth from (meters	Depth to (meters)	Net Sand (meters)	Net sand (feet)
Massive Carrizo Member of	594.0	613	19.0	62
Carrizo Formation	617.5	621	3.5	11
	625.0	627	2.0	7
	636.0	640	4.0	13
	642.0	643	1.0	3
	652.5	654	1.5	5
	655.0	667	12.0	39
	669.0	673	4.0	13
	681.0	683	2.0	7
	703.0	706	3.0	10
	708.5	716	7.5	25
	718.0	720	2.0	7
	723.0	728	4.5	15
	737.0	740	3.0	10
	746.0	751	5.0	16
	751.5	753	1.5	5
	753.5	756	2.5	8
	757.5	761	3.5	11
	766.0	777	11.0	36
	789.0	792	3.0	10
	793.0	794	1.0	3
	802.0	809	7.0	23
Total net sand (ft.)				**340**

Net sand definition:

Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: SANCHEZ O'BRIEN & W.O.C., INC.
WELL: #1 JACAMAN Elevation: GL: 455', K.B. 470', Log measured from KB
Approximate location: 3 miles NE of Laredo: also 359' FSEL & 1608' FSWL of R. S. Rumsey Survey #1022, A-654, Webb County, Texas

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	2100	1630	822	
Reklaw Formation	2922	2452	98	
Massive Carrizo Member	3080	2610	780	0.53
Wilcox-Carrizo Member	3860	3390	864	
Carrizo Formation	3020	2550	1704	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Massive Carrizio Member of the	3080	3090	10
Carrizo Formation	3113	3128	15
	3169	3224	55
	3260	3280	20
	3296	3311	15
	3320	3328	8
	3330	3350	20
	3359	3371	12
	3400	3418	18
	3430	3440	10
	3450	3460	10
	3480	3527	47
	3540	3590	50
	3612	3621	9
	3645	3670	25
	3672	3682	10
	3702	3732	30
	3802	3850	48
Total net sand (ft.)			**412**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: SANCHEZ O'BRIEN
WELL: #3 JACAMAN   Elevation: GL: 470', K.B. 482', Log measured from KB
Approximate location: 4.5 miles E of Laredo: also 990' FSL & 10007' FSL of Jose Trevino Porc 31, A-3116, Webb County, Texas

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	1909	1427	821	
Reklaw Formation	2730	2248	100	
Massive Carrizo Member	2891	2409	779	0.42
Wilcox-Carrizo Member	3670	3188	839	
Carrizo Formation	2830	2348	1679	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Massive Carrizo Member of	2926	2959	33
Carrizo Formation	2962	2972	10
	2990	3040	50
	3044	3049	5
	3054	3060	6
	3070	3115	45
	3137	3160	23
	3162	3167	5
	3180	3185	5
	3228	3236	8
	3240	3250	10
	3282	3290	8
	3314	3320	6
	3325	3345	20
	3449	3498	49
	3510	3540	30
	3610	3628	18
	3640	3660	20
Total net sand (ft.)			**351**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: SANCHEZ-O'BRIEN & W.O.C.,INC.
#1 A.F. MULLER GAS UNIT   Elevation: GL: 468', K.B. 484', Log measured from KB
Approximate location: 2 miles NE of Laredo: also see scout ticket for a more detailed location

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	1855	1371	810	
Reklaw Formation	2665	2181	99	
Massive Carrizo Member	2828	2344	770	0.45
Wilcox-Carrizo Member	3598	3114	842	
Carrizo Formation	2764	2280	1676	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Massive Carrizo Member of the	2856	2888	32
Carrizo Formaiton	2891	2900	9
	2905	2912	7
	2939	2970	31
	2973	2982	9
	2994	3060	66
	3070	3100	30
	3105	3126	21
	3131	3139	8
	3165	3171	6
	3240	3278	38
	3281	3287	6
	3383	3428	45
	3452	3462	10
	3544	3554	10
	3569	3586	17
Total net sand (ft.)			**345**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.

OPERATOR: SANCHEZ O'BRIEN
#1 ALFREDO VILLARREAL GAS UNIT Elevation: GL: 467', K.B. 482', Log measured from KB
Approximate location: City of Laredo, 1603' FSL & 1251' FEL of Laredo City Survey, A-239, Webb County, Texas

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	1544	1062	862	
Reklaw Formation	2406	1924	96	
Massive Carrizo Member	2564	2082	768	0.49
Wilcox-Carrizo Member	3332	2850	858	
Carrizo Formation	2502	2020	1688	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Massive Carrizo Member of the	2592	2608	16
Carrizo Formation	2611	2625	14
	2644	2660	16
	2704	2712	8
	2720	2748	28
	2771	2796	25
	2802	2811	9
	2820	2860	40
	2870	2880	10
	2885	2890	5
	2900	2920	20
	2929	2940	11
	2953	3000	47
	3005	3019	14
	3025	3050	25
	3080	3090	10
	3109	3115	6
	3123	3150	27
	3184	3208	24
	3217	3222	5
	3291	3310	19
Total net sand (ft.)			**379**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured

SANCHEZ-O'BRIEN
#1 WEBB COUNTY   Elevation: GL: 474', K.B. 486', Log measured from KB
Approximate location: 3 miles East of Laredo: also see scout ticket for a more precise location

Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	2091	1605	839	
Reklaw Formation	2930	2444	104	
Massive Carrizo Member	3094	2608	760	0.56
Wilcox-Carrizo Member	3854	3368	864	
Carrizo Formation	3034	2548	1684	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Massive Carrizo Member of the	3186	3217	31
Carrizo Formation	3221	3227	6
	3231	3236	5
	3239	3250	11
	3261	3296	35
	3334	3355	21
	3376	3386	10
	3415	3422	7
	3427	3472	45
	3478	3487	9
	3490	3538	48
	3550	3630	80
	3656	3702	46
	3720	3740	20
	3800	3818	18
	3825	3851	26
	3855	3866	11
Total net sand (ft.)			**429**

TRANSAMERICAN NATURAL GAS CORP.
#12 SCHWARZ Elevation: GL: 607, K.B. 628', Log measured from KB
Approximate location: 4.5 miles SE of Laredo: also see scout ticket for a more precise location

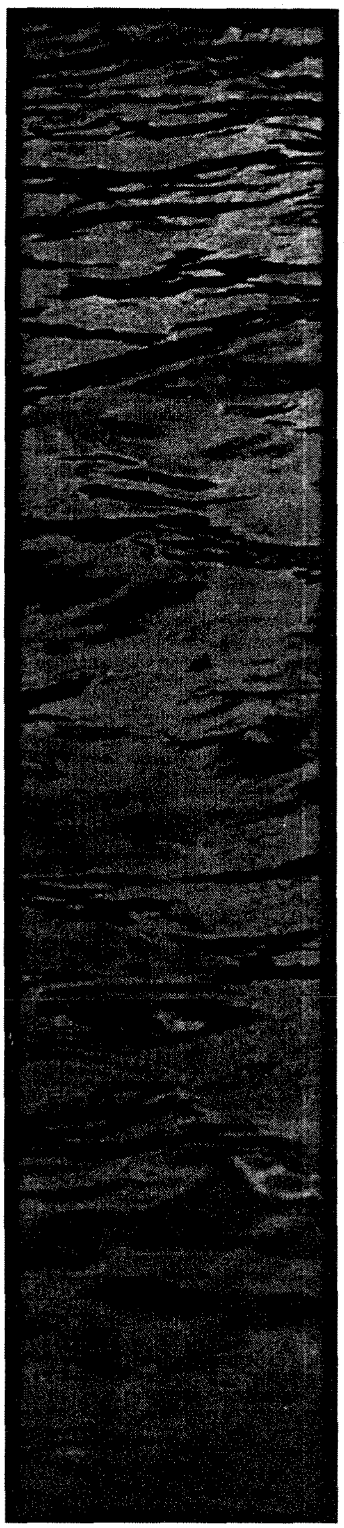
Formation and/or Member Tops

Stratigraphic unit	Top	Top (subsea)(-)	Gross thickness	Net sand/gross sand interval
Bigford Formation	2524	1896	818	
Reklaw Formation	3342	2714	83	
Massive Carrizo Member	3480	2852	812	1.17
Wilcox-Carrizo Member	4292	3664	901	
Carrizo Formation	3425	2797	1768	

Net Sand

Stratigraphic unit	Depth from (feet)	Depth to (feet)	Net Sand (feet)
Massive Carrizo Member of the	3559	3582	23
Carrizo Formation	3590	3602	12
	3683	3690	7
	3703	3721	18
	3735	3780	45
	3800	3807	7
	3838	3860	22
	3872	3898	26
	3907	3922	15
	3932	3950	18
	3953	3955	2
	3969	3980	11
	3988	3997	9
	4000	4010	10
	4018	4022	4
	4029	4032	3
	4045	4050	5
	4070	4078	8
	4090	4097	7
	4118	4131	13
	4143	4157	14
	4217	4229	12
	4240	4250	10
	4265	4281	16
Total net sand (ft.)			**951**

Net sand definition:
Net sand = estimated net porous sand which is interpreted to possess porosity equal to or greater than 20%, this is based upon sonic log derived porosity, sidewall core analysis, and SP resistivity curve responses over zones where sonic logs and/or sidewall core analysis reveal porosity is equal to or exceeds 20%. Wells possessing only resistivity logs are compared to wells with porosity logs and other data and zones exhibiting similar curve shapes, values, and signatures where calculated porosity has been determined to be 20% or greater are interpreted to be net sand. Net sand values for wells possessing no porosity logs are based upon the assumption that there is continuity in porosity and permeability where log responses can be correlated between wells with calculated or measured data and those having only resistivity and SP measurements.



Technical Memorandum No. 2

Underground Injection Control and Surface Water Permits

DEN/7936.DOC

Underground Injection Control and Surface Water Use Permits

City of Laredo ASR Feasibility Study

PREPARED FOR: City of Laredo

PREPARED BY: CH2M HILL

DATE: March 29, 1996

Summary

1. A water right or amendment to an existing water right is not required for Phase I of an ASR study (which as defined by the TNRCC includes Steps 1A through 1G of the approved Scope of Work included in the original grant application) if the entity performing the study holds an existing water right that authorizes the diversion and use of water for which the entity intends to ultimately use the water.
2. However, written notification to the executive director of the TNRCC not later than 60 days prior to the proposed storage of any water is required, along with submission of information required for a Class V injection well and a map or plat showing the location of the aquifer in which surface water will be stored, and the proposed depth and location of all injection facilities and retrieval wells.
3. Before an entity can inject or store waters derived from surface waters of the state in an aquifer not specifically stipulated in HB 1989, even only for testing purposes, the TWDB must make a "suitability" determination, and communicate that finding to the TNRCC.
4. Full-scale implementation of ASR for the City of Laredo will require TNRCC authorization by permit or permit amendment after the TNRCC has determined that the feasibility study phase of the project has been successful.

Discussion

The TNRCC has promulgated draft rules for implementation of HB 1989. These rules are summarized below. Until these rules are finalized and officially adopted, they are subject to change. The TWDB also has involvement in the process, as discussed below.

These rules contain requirements that were not in place at the time the original scope of work was prepared. However, these are relatively minor and can be accomplished within the amended budget.

HB 1989

The use of waters derived from surface waters of the State of Texas for injection and recovery in an aquifer storage and recovery project requires a permit from the Texas Natural Resource Conservation Commission (TNRCC). HB 1989 (see Attachment 2A), signed into law on June 5, 1995, limits the availability of new permits for ASR projects to the following areas of Texas:

1. The Anacacho, Austin Chalk, and Glen Rose Limestone aquifers in Bexar and Medina Counties;
2. The Carrizo-Wilcox aquifer in Bexar, Webb, Smith, Wood, Rains, and Van Zandt Counties;
3. The Hickory and Ellenberger aquifers in Gillespie County;
4. The Gulf Coast Aquifer in Cameron and Hidalgo counties;
5. Areas designated by the TNRCC as "critical areas", pursuant to Sec. 35.008 of the Texas Water Code; and,
6. Other appropriate areas of the state designated by the TWDB in accordance with Sec. 11.155 (b)(3) of the Texas Water Code.

The City's project falls into the second category, i.e., the Carrizo-Wilcox aquifer in Webb County.

Aquifers Not Stipulated In HB 1989

The TWDB staff has determined that injection or storage of water derived from the surface waters of the state in aquifers other than those stipulated in HB 1989, even if those aquifers overlie or underlie a stipulated aquifer and even if only for testing purposes, will require that the TWDB make a "suitability" determination under HB 1989. The TNRCC has concurred with the TWDB on this issue. The TWDB will make this determination of suitability based upon two things: (1) a TWDB-developed list of cities/towns in the state that are anticipated to grow over the next 20 years and which might be able to use ASR as a tool (not yet prepared by the TWDB), and (2) the information submitted by a potential applicant for a "suitability" ruling. (A copy of the TWDB's draft application requirements are contained in Attachment 2D). The TWDB staff intends to take the above procedure to the Board in April for approval.

TNRCC Proposed Rules

The specific requirements for water rights procedures for ASR wells are given in Attachment 2C. The requirements for a Class V injection well are listed in Attachments 2B and 2D. Most of the Attachment 2B and 2D requirements deal with construction and closure standards.

Phases–ASR projects are divided into Phase I and Phase II projects by the draft TNRCC rules. Phase I of an ASR project according to the TNRCC definitions is determination of feasibility of ASR for storage and retrieval for beneficial use. Phase II is the long-term implementation of ASR once it has been determined to be successful.

Definitions–The definition of an aquifer storage and retrieval project as proposed for adoption by the TNRCC is:

> "Aquifer Storage and Retrieval Project–project with two phases that anticipates the use of a Class V aquifer storage well, as defined in Sec. 331.2 of this title (relating to Definitions), for injection into a geologic formation, group of formations or part of a

formation that is capable of underground storage of appropriated surface water for subsequent retrieval and beneficial use. Phase I of the project is to determine feasibility for ultimate storage and retrieval for beneficial use. Phase II of the project requires commission authorization by permit or permit amendment after the commission has determined that Phase I of the project has been successful."(Texas Register, March 1, 1996, p. 1653)

Submittals Required for TNRCC–A water right or amendment to an existing water right is not required for Phase I of an ASR project if the applicant holds an existing water right that authorizes the diversion and use of water for which the applicant intends to ultimately use the water. However, written notification to the executive director of the TNRCC not later than 60 days prior to the proposed storage of water is required, along with submission of information required for a Class V injection well and a map or plat showing the location of the aquifer in which surface water will be stored, and the proposed depth and location of all injection facilities and retrieval wells.

Effect on City of Laredo ASR Project–The City has existing water rights which authorize the diversion and use of water for municipal purposes, which is the use for which the City ultimately intends to use the water stored underground. Therefore, the City must only provide written notification to the executive director of the TNRCC, the Class V injection well information, and the map, all within 60 days of the intended first storage test to be conducted in the Carrizo-Wilcox aquifer.

No water derived from surface waters of the state may be injected or stored, even for testing purposes, in any other aquifer above or below the Carrizo-Wilcox without a suitability finding from the TWDB, as described above..

Upon completion of Phase I, a new water right or an amendment to one of the City's existing water rights will be required before the long-term operation of an ASR system can be implemented.

Attachments:

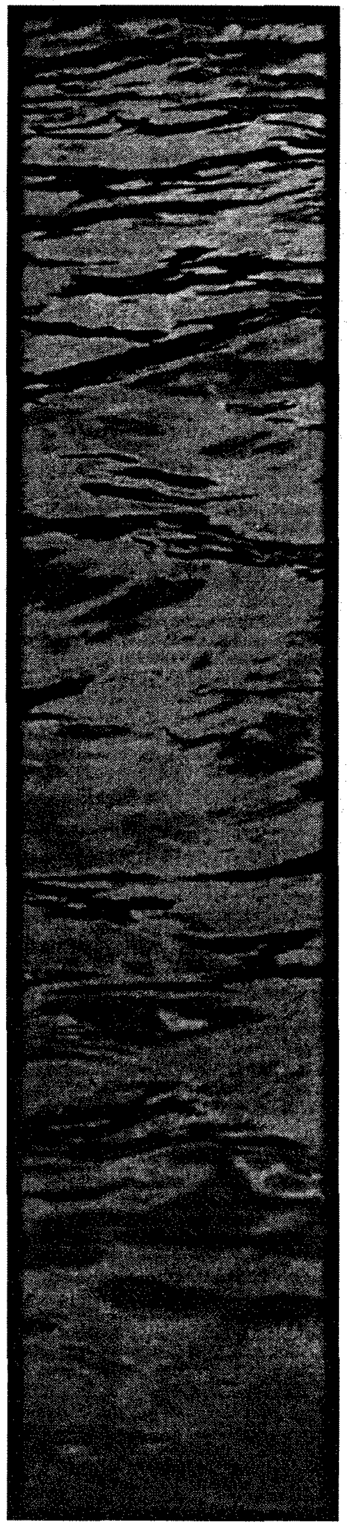
ATTACHMENT 2A–HB 1989

ATTACHMENT 2B–Subchapter H, Standards for Class V Wells (Sec. 331.131-.133)

ATTACHMENT 2C–(Proposed) Chapter 295. Water Rights, Procedural. Subchapter A, Requirements of Water Use Permit Applications; Chapter 297. Water Rights, Substantial. Subchapter A, Definitions; Subchapter B, Classes of Permits; Subchapter C. Types of Uses; Subchapter A. Definitions (Texas Register, pp. 1650-1654, March 1, 1996).

ATTACHMENT 2D–(Proposed) Chapter 331. Underground Injection Control. Subchapter A. General Provisions. Subchapter K, Additional Requirements for Class V Aquifer Storage Well (Texas Register, pp. 2173-2176, March 19, 1996).

ATTACHMENT 2E- Application Criteria for TWDB Consideration of ASR Pilot Study/Demonstration Project Suitability (February 26, 1996)



Attachment 2A

suspended, and this rule is hereby suspended, and that this Act take effect and be in force according to its terms, and it is so enacted.

Passed by the House on March 30, 1995: Yeas 144, Nays 0, 2 present, not voting; the House concurred in Senate amendments to H.B. No. 1583 on May 19, 1995: Yeas 123, Nays 0, 2 present, not voting; passed by the Senate, with amendments, on May 18, 1995: Yeas 31, Nays 0.

Approved June 5, 1995

Effective July 1, 1995

CHAPTER 309

H.B. No. 1989

AN ACT

relating to the underground storage of appropriated water incidental to a beneficial use.

Be it enacted by the Legislature of the State of Texas:

SECTION 1. The legislature finds that:

(1) the underground storage of appropriated water, incidental to a beneficial use, is a beneficial use of water;

(2) the use of aquifers for storage of appropriated water:

(A) enhances the conservation and protection of appropriated water by minimizing seepage and evaporation losses;

(B) reduces the incidental environmental impacts associated with the construction of conventional water storage facilities such as aboveground reservoirs; and

(C) enhances and protects groundwater resources;

(3) the underground storage of appropriated water maximizes the conservation and beneficial use of water resources;

(4) the storage of appropriated water in aquifers recognizes existing property rights, including the rights of a landowner in groundwater;

(5) the storage of appropriated water in aquifers recognizes the authority and jurisdiction of an underground water conservation district;

(6) the use of aquifers for storage of appropriated water may reduce a portion of the economic burden on taxpayers and utility ratepayers associated with the construction of conventional water storage facilities;

(7) the successful storage of appropriated water underground has been demonstrated in Kerr County by the Upper Guadalupe River Authority in the Hosston-Sligo Aquifer; and

(8) the Texas Natural Resource Conservation Commission and the Texas Water Development Board are encouraged to evaluate additional aquifers within the state to identify the potential for storage of appropriated water underground to maximize and enhance the future availability and beneficial use of the water resources of the state.

SECTION 2. Subchapter D, Chapter 11, Water Code, is amended by adding Sections 11.153, 11.154, and 11.155 to read as follows:

Sec. 11.153. PILOT PROJECTS FOR STORAGE OF APPROPRIATED WATER IN AQUIFERS. (a) The commission shall investigate the feasibility of storing appropriated water in various types of aquifers around the state by encouraging the issuance of temporary or term permits for pilot demonstration projects for the storage of appropriated water for subsequent retrieval and beneficial use in the following aquifers in the specified counties:

(1) the Anacacho, Austin Chalk, and Glen Rose Limestone aquifers in Bexar County and Medina County;

(2) the Carrizo-Wilcox aquifer in Bexar, Webb, Smith, Wood, Rains, and Van Zandt counties;

(3) the Hickory and Ellenberger aquifers in Gillespie County; and

(4) the Gulf Coast aquifer in Cameron and Hidalgo counties.

(b) A permit described by Subsection (a) must be for only the duration of the pilot project to provide the commission and the board further opportunity to evaluate the storage of appropriated water in aquifers for subsequent retrieval and beneficial use.

(c) At the conclusion of a pilot project, a permit holder may file an appropriate application for a permit or permit amendment. After considering the success of the project and the criteria set out in Section 11.154, the commission shall determine whether to issue a permit or permit amendment authorizing the continued storage of appropriated water in the aquifer.

(d) A final order granting a permit or amendment to a permit authorizing the storage of appropriated water in aquifers for subsequent beneficial use, other than for the pilot projects authorized by this section, may not be issued before June 1, 1999.

(e) The board shall participate in the study of the pilot projects authorized by Subsection (a). The pilot projects are eligible for grants from the water loan assistance fund established by Section 15.101. The board may authorize use of money from the research and planning fund established by Section 15.402 to participate in the study of pilot projects.

Sec. 11.154. PERMITS TO STORE APPROPRIATED WATER IN AQUIFERS. (a) An application filed with the commission to undertake a pilot project under Section 11.153 must include:

(1) the information required for an application for a permit or permit amendment to appropriate state water;

(2) all information required for an application for a permit for a Class V injection well without requiring a separate hearing or notice; and

(3) a map or plat showing the injection facility and the aquifer in which the water will be stored.

(b) If the application is for a permit or permit amendment to store appropriated water in an underground water reservoir or a subdivision of an underground water reservoir, as defined by Chapter 52, that is under the jurisdiction of an underground water conservation district:

(1) the applicant shall:

(A) provide a copy of the application to each underground water conservation district that has jurisdiction over the reservoir or subdivision;

(B) cooperate with the districts that have jurisdiction over the reservoir or subdivision to ensure compliance with the rules of each district;

(C) cooperate with each district that has jurisdiction over the reservoir or subdivision to develop rules regarding the injection, storage, and withdrawal of appropriated water stored in the aquifer; and

(D) comply with the rules governing the injection, storage, or withdrawal of appropriated water stored in the reservoir or subdivision that are adopted by a district that has jurisdiction over the reservoir or subdivision; and

(2) the commission shall require that any agreement the applicant reaches with a district that has jurisdiction over the reservoir or subdivision regarding the terms for the injection, storage, and withdrawal of appropriated water be included as a condition of the permit or permit amendment.

(c) On completion of a pilot project and receipt of an appropriate application for a permit or an amendment to an existing permit, the commission shall evaluate the success of the pilot project for purposes of issuing a final order granting a permit or permit amendment authorizing the storage of appropriated water incident to a beneficial use. The commission shall consider whether:

(1) the introduction of water into the aquifer will alter the physical, chemical, or biological quality of native groundwater to a degree that the introduction would:

(A) render groundwater produced from the aquifer harmful or detrimental to people, animals, vegetation, or property; or

(B) require treatment of the groundwater to a greater extent than the native groundwater requires before being applied to that beneficial use;

(2) the water stored in the receiving aquifer can be successfully harvested from the aquifer for beneficial use; and

(3) the permit holder has provided evidence that reasonable diligence will be used to protect the water stored in the receiving aquifer from unauthorized withdrawals to the extent necessary to maximize the permit holder's ability to retrieve and beneficially use the stored water without experiencing unreasonable loss of appropriated water.

(d) In making its evaluation under Subsection (c), the commission may consider all relevant facts, including:

(1) the location and depth of the aquifer in which the stored water is located;

(2) the nature and extent of the surface development and activity above the stored water;

(3) the permit holder's ability to prevent unauthorized withdrawals by contract or the exercise of the power of eminent domain;

(4) the existence of an underground water conservation district with jurisdiction over the aquifer storing the water and the district's ability to adopt rules to protect stored water; and

(5) the existence of any other political subdivision or state agency authorized to regulate the drilling of wells.

(e) A permit to store appropriated water in an underground water reservoir or subdivision, as defined by Chapter 52, shall provide as a condition to the permit that the permit holder shall:

(1) register the permit holder's injection and recovery wells with an underground water conservation district that has jurisdiction over the reservoir or subdivision, if any; and

(2) each calendar month, provide the district, if any, with a written report showing for the previous calendar month:

(A) the amount of water injected for storage; and

(B) the amount of water recaptured for use.

Sec. 11.155. AQUIFER STORAGE PILOT PROJECT REPORTS. (a) On completion of each pilot project, the board and the commission jointly shall:

(1) prepare a report evaluating the success of the project; and

(2) provide copies of the report to the governor, lieutenant governor, and speaker of the house of representatives.

(b) The board shall make other studies, investigations, and surveys of the aquifers in the state as it considers necessary to determine the occurrence, quantity, quality, and availability of other aquifers in which water may be stored and subsequently retrieved for beneficial use. The board shall undertake the studies, investigations, and surveys in the following order of priority:

(1) the aquifers identified in Section 11.153(a);

(2) areas designated by the commission as "critical areas" under Section 52.053; and

(3) other areas of the state in a priority to be determined by the board's ranking of where the greatest need exists.

(c) Not later than January 1 of each odd-numbered year, the board shall prepare and provide to the legislature a report that includes at least the following information:

(1) the progress of the pilot projects authorized under this subchapter and of any related project;

(2) the results of the board's studies of the other aquifers of the state during the preceding biennium; and

(3) the anticipated appropriation from general revenues necessary to investigate other aquifers in the state during the upcoming biennium.

SECTION 3. (a) The change in law made by this Act applies only to an application made on or after the effective date of this Act for a permit or a permit amendment for a pilot project to appropriate water and to store appropriated water in an aquifer identified in this Act.

(b) A permit issued by the commission authorizing the storage of appropriated water in an aquifer incident to a beneficial use before the effective date of this Act or an application for a permit or permit amendment to appropriate water that includes authorization to store appropriated water in an underground structure filed before the effective date of this Act is not affected by the changes in law made by this Act.

SECTION 4. The importance of this legislation and the crowded condition of the calendars in both houses create an emergency and an imperative public necessity that the constitutional rule requiring bills to be read on three several days in each house be suspended, and this rule is hereby suspended, and that this Act take effect and be in force from and after its passage, and it is so enacted.

Passed by the House on April 28, 1995: Yeas 136, Nays 0, 2 present, not voting; the House concurred in Senate amendments to H.B. No. 1989 on May 18, 1995: Yeas 144, Nays 0, 1 present, not voting; passed by the Senate, with amendments, on May 15, 1995: Yeas 31, Nays 0.

Approved June 5, 1995.

Effective June 5, 1995.

CHAPTER 310

H.B. No. 2015

AN ACT

relating to statutory changes to obtain delegation to Texas of the National Pollutant Discharge Elimination System.

Be it enacted by the Legislature of the State of Texas:

SECTION 1. Subchapter C, Chapter 5, Water Code, is amended by adding Section 5.053, as effective upon delegation of NPDES permit authority, to read as follows:

Sec. 5.053. ELIGIBILITY FOR MEMBERSHIP. (a) A person is not eligible to serve on the commission if the person or the person's spouse:

(1) is employed by or participates in the management of a business entity or other organization regulated by the commission or receiving funds from the commission;

(2) owns, controls, or has, directly or indirectly, more than a 10 percent interest in a business entity or other organization regulated by the commission or receiving funds from the commission; or

(3) uses or receives a substantial amount of tangible goods, services, or funds from the commission.

(b) In addition to the eligibility requirements in Subsection (a) of this section, persons who are appointed to serve on the commission for terms which expire after August 31, 2001, must comply at the time of their appointment with the eligibility requirements established under 33 U.S.C. Sections 1251-1387, as amended.

SECTION 2. Section 26.017, Water Code, is amended to read as follows:

Sec. 26.017. COOPERATION. The commission shall:

suspended, and this rule is hereby suspended, and that this Act take effect and be in force according to its terms, and it is so enacted.

Passed by the House on March 30, 1995: Yeas 144, Nays 0, 2 present, not voting; the House concurred in Senate amendments to H.B. No. 1583 on May 19, 1995: Yeas 123, Nays 0, 2 present, not voting; passed by the Senate, with amendments, on May 18, 1995: Yeas 31, Nays 0.

Approved June 5, 1995

Effective July 1, 1995

CHAPTER 309

H.B. No. 1989

AN ACT

relating to the underground storage of appropriated water incidental to a beneficial use.

Be it enacted by the Legislature of the State of Texas:

SECTION 1. The legislature finds that:

(1) the underground storage of appropriated water, incidental to a beneficial use, is a beneficial use of water;

(2) the use of aquifers for storage of appropriated water:

(A) enhances the conservation and protection of appropriated water by minimizing seepage and evaporation losses;

(B) reduces the incidental environmental impacts associated with the construction of conventional water storage facilities such as aboveground reservoirs; and

(C) enhances and protects groundwater resources;

(3) the underground storage of appropriated water maximizes the conservation and beneficial use of water resources;

(4) the storage of appropriated water in aquifers recognizes existing property rights, including the rights of a landowner in groundwater;

(5) the storage of appropriated water in aquifers recognizes the authority and jurisdiction of an underground water conservation district;

(6) the use of aquifers for storage of appropriated water may reduce a portion of the economic burden on taxpayers and utility ratepayers associated with the construction of conventional water storage facilities;

(7) the successful storage of appropriated water underground has been demonstrated in Kerr County by the Upper Guadalupe River Authority in the Hosston-Sligo Aquifer; and

(8) the Texas Natural Resource Conservation Commission and the Texas Water Development Board are encouraged to evaluate additional aquifers within the state to identify the potential for storage of appropriated water underground to maximize and enhance the future availability and beneficial use of the water resources of the state.

SECTION 2. Subchapter D, Chapter 11, Water Code, is amended by adding Sections 11.153, 11.154, and 11.155 to read as follows:

Sec. 11.153. PILOT PROJECTS FOR STORAGE OF APPROPRIATED WATER IN AQUIFERS. (a) The commission shall investigate the feasibility of storing appropriated water in various types of aquifers around the state by encouraging the issuance of temporary or term permits for pilot demonstration projects for the storage of appropriated water for subsequent retrieval and beneficial use in the following aquifers in the specified counties:

(1) the Anacacho, Austin Chalk, and Glen Rose Limestone aquifers in Bexar County and Medina County;

(2) the Carrizo-Wilcox aquifer in Bexar, Webb, Smith, Wood, Rains, and Van Zandt counties;

(3) the Hickory and Ellenberger aquifers in Gillespie County; and

(4) the Gulf Coast aquifer in Cameron and Hidalgo counties.

(b) A permit described by Subsection (a) must be for only the duration of the pilot project to provide the commission and the board further opportunity to evaluate the storage of appropriated water in aquifers for subsequent retrieval and beneficial use.

(c) At the conclusion of a pilot project, a permit holder may file an appropriate application for a permit or permit amendment. After considering the success of the project and the criteria set out in Section 11.154, the commission shall determine whether to issue a permit or permit amendment authorizing the continued storage of appropriated water in the aquifer.

(d) A final order granting a permit or amendment to a permit authorizing the storage of appropriated water in aquifers for subsequent beneficial use, other than for the pilot projects authorized by this section, may not be issued before June 1, 1999.

(e) The board shall participate in the study of the pilot projects authorized by Subsection (a). The pilot projects are eligible for grants from the water loan assistance fund established by Section 15.101. The board may authorize use of money from the research and planning fund established by Section 15.402 to participate in the study of pilot projects.

Sec. 11.154. PERMITS TO STORE APPROPRIATED WATER IN AQUIFERS. (a) An application filed with the commission to undertake a pilot project under Section 11.153 must include:

(1) the information required for an application for a permit or permit amendment to appropriate state water;

(2) all information required for an application for a permit for a Class V injection well without requiring a separate hearing or notice; and

(3) a map or plat showing the injection facility and the aquifer in which the water will be stored.

(b) If the application is for a permit or permit amendment to store appropriated water in an underground water reservoir or a subdivision of an underground water reservoir, as defined by Chapter 52, that is under the jurisdiction of an underground water conservation district:

(1) the applicant shall:

(A) provide a copy of the application to each underground water conservation district that has jurisdiction over the reservoir or subdivision;

(B) cooperate with the districts that have jurisdiction over the reservoir or subdivision to ensure compliance with the rules of each district;

(C) cooperate with each district that has jurisdiction over the reservoir or subdivision to develop rules regarding the injection, storage, and withdrawal of appropriated water stored in the aquifer; and

(D) comply with the rules governing the injection, storage, or withdrawal of appropriated water stored in the reservoir or subdivision that are adopted by a district that has jurisdiction over the reservoir or subdivision; and

(2) the commission shall require that any agreement the applicant reaches with a district that has jurisdiction over the reservoir or subdivision regarding the terms for the injection, storage, and withdrawal of appropriated water be included as a condition of the permit or permit amendment.

(c) On completion of a pilot project and receipt of an appropriate application for a permit or an amendment to an existing permit, the commission shall evaluate the success of the pilot project for purposes of issuing a final order granting a permit or permit amendment authorizing the storage of appropriated water incident to a beneficial use. The commission shall consider whether:

(1) the introduction of water into the aquifer will alter the physical, chemical, or biological quality of native groundwater to a degree that the introduction would:

(A) render groundwater produced from the aquifer harmful or detrimental to people, animals, vegetation, or property; or

(B) require treatment of the groundwater to a greater extent than the native groundwater requires before being applied to that beneficial use;

(2) the water stored in the receiving aquifer can be successfully harvested from the aquifer for beneficial use; and

(3) the permit holder has provided evidence that reasonable diligence will be used to protect the water stored in the receiving aquifer from unauthorized withdrawals to the extent necessary to maximize the permit holder's ability to retrieve and beneficially use the stored water without experiencing unreasonable loss of appropriated water.

(d) In making its evaluation under Subsection (c), the commission may consider all relevant facts, including:

(1) the location and depth of the aquifer in which the stored water is located;

(2) the nature and extent of the surface development and activity above the stored water;

(3) the permit holder's ability to prevent unauthorized withdrawals by contract or the exercise of the power of eminent domain;

(4) the existence of an underground water conservation district with jurisdiction over the aquifer storing the water and the district's ability to adopt rules to protect stored water; and

(5) the existence of any other political subdivision or state agency authorized to regulate the drilling of wells.

(e) A permit to store appropriated water in an underground water reservoir or subdivision, as defined by Chapter 52, shall provide as a condition to the permit that the permit holder shall:

(1) register the permit holder's injection and recovery wells with an underground water conservation district that has jurisdiction over the reservoir or subdivision, if any; and

(2) each calendar month, provide the district, if any, with a written report showing for the previous calendar month:

(A) the amount of water injected for storage; and

(B) the amount of water recaptured for use.

Sec. 11.155. AQUIFER STORAGE PILOT PROJECT REPORTS. (a) On completion of each pilot project, the board and the commission jointly shall:

(1) prepare a report evaluating the success of the project; and

(2) provide copies of the report to the governor, lieutenant governor, and speaker of the house of representatives.

(b) The board shall make other studies, investigations, and surveys of the aquifers in the state as it considers necessary to determine the occurrence, quantity, quality, and availability of other aquifers in which water may be stored and subsequently retrieved for beneficial use. The board shall undertake the studies, investigations, and surveys in the following order of priority:

(1) the aquifers identified in Section 11.153(a);

(2) areas designated by the commission as "critical areas" under Section 52.053; and

(3) other areas of the state in a priority to be determined by the board's ranking of where the greatest need exists.

(c) Not later than January 1 of each odd-numbered year, the board shall prepare and provide to the legislature a report that includes at least the following information:

(1) the progress of the pilot projects authorized under this subchapter and of any related project;

(2) the results of the board's studies of the other aquifers of the state during the preceding biennium; and

(3) the anticipated appropriation from general revenues necessary to investigate other aquifers in the state during the upcoming biennium.

SECTION 3. (a) The change in law made by this Act applies only to an application made on or after the effective date of this Act for a permit or a permit amendment for a pilot project to appropriate water and to store appropriated water in an aquifer identified in this Act.

(b) A permit issued by the commission authorizing the storage of appropriated water in an aquifer incident to a beneficial use before the effective date of this Act or an application for a permit or permit amendment to appropriate water that includes authorization to store appropriated water in an underground structure filed before the effective date of this Act is not affected by the changes in law made by this Act.

SECTION 4. The importance of this legislation and the crowded condition of the calendars in both houses create an emergency and an imperative public necessity that the constitutional rule requiring bills to be read on three several days in each house be suspended, and this rule is hereby suspended, and that this Act take effect and be in force from and after its passage, and it is so enacted.

Passed by the House on April 28, 1995: Yeas 136, Nays 0, 2 present, not voting; the House concurred in Senate amendments to H.B. No. 1989 on May 18, 1995: Yeas 144, Nays 0, 1 present, not voting; passed by the Senate, with amendments, on May 15, 1995: Yeas 31, Nays 0.

Approved June 5, 1995.

Effective June 5, 1995.

CHAPTER 310

H.B. No. 2015

AN ACT

relating to statutory changes to obtain delegation to Texas of the National Pollutant Discharge Elimination System.

Be it enacted by the Legislature of the State of Texas:

SECTION 1. Subchapter C, Chapter 5, Water Code, is amended by adding Section 5.053, as effective upon delegation of NPDES permit authority, to read as follows:

Sec. 5.053. ELIGIBILITY FOR MEMBERSHIP. (a) A person is not eligible to serve on the commission if the person or the person's spouse:

(1) is employed by or participates in the management of a business entity or other organization regulated by the commission or receiving funds from the commission;

(2) owns, controls, or has, directly or indirectly, more than a 10 percent interest in a business entity or other organization regulated by the commission or receiving funds from the commission; or

(3) uses or receives a substantial amount of tangible goods, services, or funds from the commission.

(b) In addition to the eligibility requirements in Subsection (a) of this section, persons who are appointed to serve on the commission for terms which expire after August 31, 2001, must comply at the time of their appointment with the eligibility requirements established under 33 U.S.C. Sections 1251–1387, as amended.

SECTION 2. Section 26.017, Water Code, is amended to read as follows:

Sec. 26.017. COOPERATION. The commission shall:

Attachment 2B

the resources necessary to close, plug, or abandon the well;

(4) the plugging and abandonment plan submitted in the technical report accompanying the application;

(5) any additional information reasonably required by the executive director for the evaluation of the proposed injection well or project.

Source: The provisions of this §331.122 adopted to be effective May 13, 1986, 11 TexReg 1987.

Cross References: This Section cited in 30 TAC §305.45, (relating to Contents of Application for Permit); 30 TAC §305.49, (relating to Additional Contents of Application for an Injection Well Permit).

SUBCHAPTER H. STANDARDS FOR CLASS V WELLS

§ 331.131. Applicability

The sections of this subchapter apply to all new Class V injection wells under the jurisdiction of the Texas Water Commission.

Source: The provisions of this §331.131 adopted to be effective May 13, 1986, 11 TexReg 1988.

§ 331.132. Construction Standards

(a) All Class V wells shall be completed in accordance with the following specifications, unless otherwise authorized by the commission.

(b) For all Class V wells, a form provided by the executive director or the form of the Water Well Drillers Board shall be completed and submitted to the executive director.

(c) The annular space between the borehole and the casing shall be filled from ground level to a depth of not less than 10 feet below the land surface or well head with cement slurry. In areas of shallow, unconfined groundwater aquifers, the cement need not be placed below the static water level. In areas of shallow, confined groundwater aquifers having artesian head, the cement need not be placed below the top of the water-bearing strata.

(d) In all wells where plastic casing is used, a concrete slab or sealing block shall be placed above the cement slurry around the well at the ground surface.

(1) The slab or block shall extend at least two feet from the well in all directions and have a minimum thickness of four inches and shall be separated from the well casing by a plastic or mastic coating or sleeve to prevent bonding of the slab to the casing.

(2) The surface of the slab shall be sloped to drain away from the well.

(3) The top of the casing shall extend a minimum of one foot above the original ground surface or known flood elevation.

(e) In wells where steel casing is used, a slab or block as described in subsection (d)(1) of this section will be required above the cement slurry, except when a pitless adapter is used.

(1) Pitless adapters may be used in such wells, provided that:

(A) the adapter is welded to the casing or fitted with another suitably effective seal; and

(B) the annular space between the borehole and the casing is filled with cement to a depth not less than 15 feet below the adapter connection.

(2) The casing shall extend a minimum of one foot above the original ground surface or known flood elevation.

(f) All wells, especially those that are gravel packed, shall be completed so that aquifers or zones containing waters that are known to differ significantly in chemical quality are not allowed to commingle through the borehole-casing annulus or the gravel pack and cause quality degradation of any aquifer zone.

(g) The well casing shall be capped or completed in a manner that will prevent pollutants from entering the well.

(h) When undesirable water is encountered in a Class V well, the undesirable water shall be sealed off and confined to the zone(s) of origin.

Source: The provisions of this §331.132 adopted to be effective May 13, 1986, 11 TexReg 1988.

§ 331.133. Closure Standards

(a) It is the responsibility of the landowner or person having the well drilled, deepened, or otherwise altered, to plug or have plugged, under standards set forth in these sections, a Class V well which is to be abandoned.

(b) Closure shall be accomplished by removing all of the removable casing and the entire well filled with cement to land surface.

(c) In lieu of the procedure in subsection (b) of this section and if the use of a Class V well that does not contain undesirable water is to be permanently discontinued, the well may be filled with fine sand, clay, or heavy mud followed by a cement ug extending from land surface to a depth of not less than 10 feet.

(d) In lieu of the procedure in subsection (b) of this section and if the use of a Class V well that does contain undesirable water is to be permanently discontinued, either the zone(s) containing undesirable water or the fresh water zone(s) shall be isolated with cement plugs and the remainder of the wellbore filled with sand, clay, or heavy mud to form a base for a cement plug extending from land surface to a depth of not less than 10 feet.

Source: The provisions of this §331.133 adopted to be effective May 13, 1986, 11 TexReg 1988.

SUBCHAPTER I. FINANCIAL RESPONSIBILITY

Authority: The provisions of this Subchapter I issued under the Texas Water Code, §§5.103, 5.105, and 27.109.

§ 331.141. Definitions

The following words and terms, when used in this chapter, shall have the following meanings, unless the context clearly indicates otherwise and are also used in the specifications for the financial test for plugging and abandonment. The definitions are intended to represent the common meanings of the terms as they are generally used by the business community.

Current closure cost estimate—The dollar amount of financial assurance currently approved by the commission to ensure the proper closing, plugging, and abandoning of injection operations.

Current liabilities—Obligations whose liquidation is reasonably expected to require the use of existing resources properly classifiable as current assets or the creation of other current liabilities.

Current plugging cost estimate—The most recent of the estimates prepared in accordance with §331.143(a)-(c) of this title (relating to Cost Estimate for Plugging and Abandonment).

Parent corporation—A corporation which directly owns at least 50% of the voting stock of the corporation which is the injection well owner or operator; the latter corporation is deemed a subsidiary of the parent corporation.

Permittee—The owner and/or operator of injection well facilities authorized by rule or authorized by a valid commission permit.

Plugging and abandonment plan—The plan for plugging and abandonment prepared in accordance with the requirements of §331.46 of this title (relating to Wording of the Instruments).

Assets—All existing and all probable future economic benefits obtained or controlled by a particular entity.

Current assets—Cash or other assets or resources commonly identified as those which are reasonably expected to be realized in cash or sold or consumed during the normal operating cycle of the business.

Independently audited—An audit performed by an independent certified public accountant in accordance with generally accepted accounting principles.

Liabilities—Probable future sacrifices of economic benefits arising from present obligations to transfer assets or provide services to other entities in the future as a result of past transactions or events.

Net working capital—Current assets minus current liabilities.

Net worth—Total assets minus total liabilities and is equivalent to owner's equity.

Tangible net worth—The tangible assets that remain after deducting liabilities; such assets would not include intangibles such as goodwill and rights to patents or royalties.

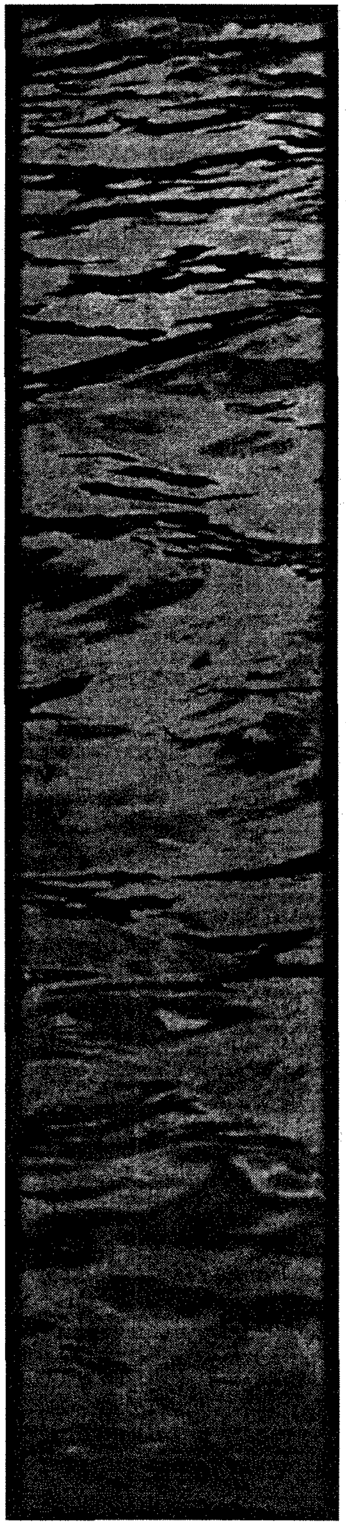
Source: The provisions of this §331.141 adopted to be effective October 16, 1992, 17 TexReg 6780.

§ 331.142. Financial Responsibility

(a) The permittee shall secure and maintain a performance bond or other equivalent form of financial assurance or guarantee approved by the commission as identified in §331.144 of this title (relating to Financial Assurance for Plugging and Abandonment) to ensure the closing, plugging, abandonment, and post-closure care of the injection operation in the manner prescribed by the commission. The assurance may cover more than one well or operation. For new hazardous waste disposal wells, financial security shall be obtained at least 60 days prior to the commencement of drilling operations for the well. For other injection wells, financial security shall be obtained prior to the injection of fluids.

(b) The requirement to maintain financial responsibility is enforceable regardless of whether the requirement is a condition of the permit.

Source: The provisions of this §331.142 adopted to be effective October 16, 1992, 17 TexReg 6780.



Attachment 2C

numbers, and such information as continuing education completed, and type of practice

(c) The board shall not renew a license until it receives [the completed license renewal form and] the renewal fee[,] and evidence that the licensee has complied with applicable continuing education requirements.

(d)-(f) (No change.)

This agency hereby certifies that the proposal has been reviewed by legal counsel and found to be within the agency's legal authority to adopt.

Issued in Austin, Texas, on February 21, 1996.

TRD-9602551

James O. Mathis, Ed.D.

Chair

Texas State Board of Examiners of Professional Counselors

Earliest possible date of adoption: April 1, 1996

For further information, please call: (512) 458-7236

♦ ♦ ♦

TITLE 30. ENVIRONMENTAL QUALITY

Part I. Texas Natural Resource Conservation Commission

Chapter 295. Water Rights, Procedural

Subchapter A. Requirements of Water Use Permit Applications

Additional Requirements for the Storage of Appropriated Surface Water in Aquifers

30 TAC §295.21, §295.22

The Texas Natural Resource Conservation Commission (TNRCC or commission) proposes new §295.21 and §295.22, concerning additional requirements for storage of appropriated surface water in aquifers under Texas Water Code §§11.153-11.155.

The proposed rules will implement recent legislation in House Bill 1989 (Regular Session, 74th Legislature, 1995) which directs the TNRCC to investigate the feasibility of storing appropriated surface water in various aquifers around the state by encouraging the issuance of permits for aquifer storage and retrieval projects, as defined in proposed new §297.1 of this title (relating to Definitions), which would store appropriated surface water in specific aquifers for subsequent retrieval and beneficial use.

Pursuant to House Bill 1989, proposed new §295.21, Aquifer Storage and Retrieval Projects, will limit the applicability of new permits for aquifer storage and retrieval projects authorizing the underground storage of appropriated surface water for subsequent retrieval and beneficial use to the following areas: 1) the Anacacho, Austin Chalk, and Glen Rose Limestone aquifers in Bexar and Medina counties; 2) the Carrizo-Wilcox aquifer in Bexar, Webb, Smith, Wood, Rains, and Van Zandt counties; 3) the Hickory and Ellenberger aquifers in Gillespie County; 4) the Gulf Coast aquifer in Cameron and Hidalgo counties; 5) areas designated by the commission as "critical areas" pursuant to §35.008 of the Texas Water Code; and 6) other appropriate areas of the state designated by the Texas Water Development Board in accordance with §11.155 (b)(3) of the Texas Water Code.

Proposed new §295.21 will also clarify that a water right or amendment to an existing water right will not be required for Phase I of an aquifer storage and retrieval project to determine the ultimate feasibility of the project if the applicant holds an existing water right or valid contract with a water right holder that authorizes the diversion and use of water for which the applicant plans to ultimately use the water. However, written notification to the executive director will be required along with the submission of information required for a Class V injection well authorization and a map or plat showing the location of the aquifer in which surface water will be stored and the proposed depth and location of all injection facilities and retrieval wells. Upon completion of Phase I of the project, a water right or an amendment to an existing water right will be required for further long-term authorization to store appropriated surface water in an aquifer for subsequent retrieval and beneficial use.

In accordance with House Bill 1989 (1995), proposed new §295.21 further states that this section does not apply to any existing permit or permit amendment issued by the commission or any administrative complete application for a permit or permit amendment filed with the commission prior to the June 5, 1995, effective date of the legislation.

Proposed new §295.22 will provide the requirements for information to be submitted with a permit application for Phase I of an aquifer storage and retrieval project requesting the underground storage of surface water for subsequent retrieval and beneficial use. In addition to the information required by Chapter 295 of this title (relating to Water Rights, Procedural), the application must include: all information required for an application for authorization of a Class V injection well; a map or plat showing the location of the aquifer in which the surface water will be stored and the proposed depth and location of all injection facilities and retrieval wells; and, if applicable, a letter from the Texas Water Development Board indicating an area has been designated in accordance with §11.155 (b)(3) of the Texas Water Code. This proposed new section would also require additional information in an application for storage of surface water within the jurisdiction of an underground water conservation district.

Steve Minick, Strategic Planning and Appropriations Division, has determined that for the first five years the proposed sections are in effect there are no significant fiscal implications anticipated for state or local governments as a result of enforcing or administering the proposed sections.

Mr. Minick has also determined that for each of the first five years the sections as proposed are in effect the public benefit anticipated as a result of enforcement of and compliance with the proposed sections will be the clarification and streamlining of the permitting process for aquifer storage and retrieval projects. There are also no economic costs anticipated for any person, including small business, required to comply with the sections as proposed.

A public hearing on the proposal will be held March 22, 1996, at 10:00 a.m. in Room 2210 of TNRCC Building F located at 12100 Park 35 Circle, Austin. The hearing is structured for the receipt of oral or written comments by interested persons. Individuals may present oral statements when called upon in the order of registration. Open discussion within the audience will not occur during the hearing; however, a TNRCC staff member will be available to discuss the proposal 30 minutes prior to the hearing and will answer questions before and after the hearing.

Written comments on the proposal should mention Log Number 95160-295-WT and may be submitted to Lutrecia Oshoko, Texas Natural Resource Conservation Commission, Office of Policy and Regulatory Development, MC 205, P.O. Box 13087, Austin, Texas 78711-3087, (512) 239-4640. Please fax comments to (512) 239-5687. Written comments must be received by 5:00 p.m., 30 days from the date of publication of this proposal in the *Texas Register*. For further information, please contact James Kowis at (512) 239-4900.

Persons with disabilities who have special communication or other accommodation needs who are planning to attend the hearing should contact the agency at (512) 239-4900. Requests should be made as far in advance as possible.

The new rules are proposed under the Texas Water Code, §5.103, and §5.105, which authorize the TNRCC to adopt any rules necessary to carry out its powers and duties under the Texas Water Code and other laws of Texas and to establish and approve all general policy of the commission.

The proposed new rules implement the Texas Water Code, §§11.153-11.155, which authorize the TNRCC to investigate the feasibility of storing appropriated water in various aquifers around the state by encouraging the issuance of permits for aquifer storage and retrieval projects which would store appropriated water for subsequent retrieval and beneficial use.

§295.21 Aquifer Storage and Retrieval Projects

(a) For the purposes of this chapter, aquifer storage and retrieval projects that propose the underground storage of appropriated surface water for subsequent retrieval and beneficial use shall be limited to the following areas:

(1) the Anacacho, Austin Chalk, and Glen Rose Limestone aquifers in Bexar County and Medina County,

(2) the Carrizo-Wilcox aquifer in Bexar, Webb, Smith, Wood, Rains and Van Zandt Counties,

(3) the Hickory and Ellenberger aquifers in Gillespie County,

(4) the Gulf Coast aquifer in Cameron and Hidalgo counties,

(5) areas designated by the commission as "critical areas" under §35.008 of the Texas Water Code, and

(6) other areas of the state designated by the Texas Water Development Board in accordance with §11.155 (b)(3) of the Texas Water Code.

(b) Except as provided by subsection (c) of this section, the applicant shall file the appropriate application and obtain the issuance of a temporary or term permit under Chapter 297 of this title (relating to Water Rights, Substantive) and the necessary authorization under Chapter 331 of this title (relating to Underground Injection Control) prior to commencement of construction of Phase I of an aquifer storage and retrieval project, as defined in §297.1 of this title (relating to Definitions).

(c) A water right permit is not required for Phase I of an aquifer storage and retrieval project that proposes the temporary storage of appropriated surface water in an aquifer for subsequent retrieval and beneficial use if the diversion and purpose of use (e.g., municipal, industrial, etc.) of the surface water is covered by an existing water right. The water right holder or person holding a valid contract with a water right holder shall notify the executive director, in writing, of the proposed temporary storage and shall submit the information required by §295.22 of this title (relating to Additional Requirements for Storage of Surface Water for Subsequent Retrieval and Beneficial Use) with the written notification not later than 60 days prior to the proposed storage of water in an applicable aquifer. Upon completion of Phase I of the project, an amendment to the existing water right is required for permanent authorization to store appropriated surface water in an aquifer for subsequent retrieval and beneficial use.

(d) This section does not apply to any existing permit or permit amendment issued by the commission or to any administratively complete application for a permit or permit amendment filed with the commission prior to June 5, 1995.

§295.22 Additional Requirements for the Underground Storage of Surface Water for Subsequent Retrieval and Beneficial Use

In addition to the information required by Subchapter A of this chapter (relating to Requirements of Water Use Permit Application), the appropriate permit application must include:

(1) all information required for an application for a permit for a Class V injection well (under 30 TAC Chapters 305 and 331)

(2) a map or plat showing the proposed depth and location of all injection facilities, retrieval wells and the aquifer in which the water will be stored;

(3) if applicable, a letter from the Texas Water Development Board indicating an area has been designated in accordance with §11.155 (b)(3) of the Texas Water Code, and

(4) if applicable, the application for storage of surface water in an underground water reservoir or a subdivision of an underground water reservoir, as defined by Chapter 35 of the Texas Water Code, that is under the jurisdiction of an underground water conservation district, must include:

(A) evidence acknowledging service, by certified mail, of a copy of the application or notification submitted in accordance with §295.21 of this title (relating to Aquifer Storage and Retrieval Projects) to the underground water conservation district having jurisdiction over the aquifer, and

(B) a copy of an agreement, if any, reached by the applicant with the underground water conservation district reflecting the applicant's consent to cooperate in the development of, and abidance with, the rules governing the injection, storage or retrieval of appropriated surface water in the underground water reservoir or a subdivision thereof.

This agency hereby certifies that the proposal has been reviewed by legal counsel and found to be within the agency's authority to adopt.

Issued in Austin, Texas, on February 21, 1996.

TRD-9602444

Kevin McCalla

Director, Legal Division

Texas Natural Resource Conservation Commission

Earliest possible date of adoption: April 1, 1996

For further information, please call: (512) 239-4640

Chapter 297. Water Rights, Substantial

The Texas Natural Resource Conservation Commission (TNRCC or commission) proposes amendments to §§297.1, 297.13, and 297.19, and new §297.30, concerning permits for the storage of appropriated surface water in aquifers under Texas Water Code §§11.153 - 11.155, permit exemptions for irrigation of certain historic cemeteries under Texas Water Code §11.1422, and surface coal mining sedimentation control structures under Texas Water Code §11.142(c).

Proposed amendments to §§297.1, 297.13, and 297.19 will implement recent legislation in House Bill (HB) 1989 (1995) that directs the TNRCC to investigate the feasibility of storing appropriated surface water in various aquifers around the state by encouraging the issuance of temporary or term permits aquifer storage and retrieval projects that would allow storage of appropriated surface water for subsequent retrieval and beneficial use.

Proposed new §297.30 will implement recent legislation in HB 475 (1995) and Senate Bill 651 (1995) that provides water right permitting exemptions for irrigation of certain historic cemeteries and for surface coal mining sedimentation control structures, respectively.

Proposed amendment to §297.1, Definitions, will add and define the term "aquifer storage and retrieval project" as a project with two phases that anticipates the use of a Class V aquifer storage well for injection into a geologic formation, group of formations, or part of a formation that is capable of underground storage of appropriated surface water for subsequent retrieval and beneficial use.

Proposed amendments to §297.13, Temporary Permit under Texas Water Code §§11.138 and 11.153-11.155, and proposed amendments to §297.19, Term Permit, under Texas Water Code §§11.1381 and 11.153- 11.155, will clarify that these two sections are applicable to temporary or term permits, respectively. Such temporary or term permit would be required to determine feasibility (Phase I) of an aquifer storage and retrieval project, unless the diversion and type of use is previously authorized under an existing water right or valid contract.

Proposed new §297.30, Permit Exemptions for Use of State Water for Irrigation of Certain Historic Cemeteries and for Sedimentation Control Structures Within Surface Coal Mining Operations, will provide water right permitting exemptions for irrigation of certain historic cemeteries and for sedimentation control structures associated with surface coal mining operations. This proposed new section will also allow the executive director or watermaster to order an exempt cemetery, subject to an appeal to the commission, to restrict the diversion if the executive director or watermaster determines that the diversion is harming a downstream water right acquired prior to the May 23, 1995 effective date of the legislation.

Steve Minick, Strategic Planning and Appropriations Division, has determined that for the first five years the sections as proposed are in effect there are no significant fiscal implications anticipated for state or local governments as a result of enforcing or administering the proposed sections.

Minick has also determined that for each of the first five years the proposed rules are in effect the public benefits anticipated as a result of enforcement of and compliance with the proposed sections will be the clarification and streamlining of the permitting process for aquifer storage and retrieval projects, and the elimination of water right permitting requirements for the specific uses of irrigation of historic cemeteries or construction and maintenance of sedimentation control structures within surface coal mining areas. There are no economic costs anticipated for any person, including any small business, required to comply with the sections as proposed.

A public hearing on the proposal will be held March 22, 1996, at 10:00 a.m. in Room 2210 of TNRCC Building F located at 12100 Park 35 Circle, Austin. The hearing is structured for the receipt of oral or written comments by interested persons. Individuals may present oral statements when called upon in the order of registration. Open discussion within the audience will not occur during the hearing; however, a TNRCC staff member will be available to discuss the proposal 30 minutes prior to the hearing and will answer questions before and after the hearing.

Written comments on the proposal should mention Log Number 95160-295-WT and may be submitted to Lutrecia Oshoko, Texas Natural Resource Conservation Commission, Office of Policy and Regulatory Development, MC 205, P.O. Box 13087, Austin, Texas 78711-3087, (512) 239-4640. Please fax comments to (512) 293-5687. Written comments must be received by 5:00 p.m., 30 days from the date of publication of this proposal in the Texas Register. For further information, please contact James Kowis at (512) 239-4900.

Persons with disabilities who have special communication or other accommodation needs who are planning to attend the hearing should contact the agency at (512) 239-4900. Requests should be made as far in advance as possible.

Subchapter A. Definitions

28 TAC §297.1

The new rule is proposed under the Texas Water Code, §5.103, and §5.105, which authorize the TNRCC to adopt any rules necessary to carry out its powers and duties under the Texas Water Code and other laws of Texas and to establish and approve all general policy of the commission.

The proposed new and amended rules implement the Texas Water Code, §§11.153-11.155, which direct the TNRCC to investigate the feasibility of storing appropriated surface water in various aquifers around the state by encouraging the issuance of permits for aquifer storage and retrieval projects (Phase I) that would propose to store appropriated water in specific aquifers for subsequent retrieval and beneficial use. The proposed rules also implement the Texas Water Code, §11.142(c), and §11.1422, which provide water right permitting exemptions for surface coal mining sedimentation control structures and for irrigation of certain historic cemeteries, respectively.

§297.1. Definitions.

The following words and terms, when used in this chapter and in Chapter 295 of this title (relating to Water Rights Rules, Procedural), shall have the following meanings, unless the context clearly indicates otherwise.

Aquifer Storage and Retrieval Project—project with two phases that anticipates the use of a Class V aquifer storage well, as defined in §331.2 of this title (relating to Definitions), for injection into a geologic formation, group of formations or part of a formation that is capable of underground storage of appropriated surface water for subsequent retrieval and beneficial use. Phase I of the project is to determine feasibility for ultimate storage and retrieval for beneficial use. Phase II of the project requires commission authorization by permit or permit amendment after the commission has determined that Phase I of the project has been successful.

This agency hereby certifies that the proposal has been reviewed by legal counsel and found to be within the agency's authority to adopt.

Issued in Austin, Texas, on February 21, 1996.

TRD-9602445
Kevin McCalla
Director, Legal Division
Texas Natural Resource Conservation Commission
Earliest possible date of adoption: April 1, 1996
For further information, please call: (512) 239-4640

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Subchapter B. Classes of Permits

28 TAC §297.13, §297.19

The amendments to these sections are proposed under the Texas Water Code, §5.103 and §5.105, which provide the Texas Natural Resource Conservation Commission with the authority to adopt rules necessary to carry out its powers and duties under the code and the laws of the state.

§297.13. Temporary Permit Under Texas Water Code, §11.138 and §11.153 - 11.155.

A temporary permit, as its name implies, is short-lived in nature and designed for purposes of a temporary nature. A temporary permit may not be granted for a period of time exceeding three years. This permit does not vest in the holder any permanent right to the use of state water and expires in accordance with its terms. (It is primarily designed for those persons who require state water for highway construction, oil or gas well drilling projects, **evaluation of Phase I of an aquifer storage and retrieval project and other types of short duration projects.**) Temporary permits may be issued for beneficial purposes to the extent that they do not interfere with or adversely affect prior appropriations or vested rights on a stream. The period of time to use water authorized by a temporary permit which was initially granted for a period of less than three years may be extended, but in no event shall the entire period exceed three years nor shall an extension of time seek a change of diversion rate, diversion point, or additional water.

§297.19. Term Permit **under Texas Water Code, §§11.1381 and 11.153 - 11.155.**

The commission may grant a permit for a limited term of years when it determines that inadequate water is available in the source of supply on a perpetual basis to satisfy an application but that adequate water is available on a limited basis due to the underutilization of existing water rights in the source of supply. **The commission may grant a permit under this section for an aquifer storage and retrieval project as defined in §297.1 of this title (relating to Definitions).**

This agency hereby certifies that the proposal has been reviewed by legal counsel and found to be within the agency's authority to adopt.

Issued in Austin, Texas, on February 21, 1996.

TRD-9602446
Kevin McCalla
Director, Legal Division
Texas Natural Resource Conservation Commission
Earliest possible date of adoption: April 1, 1996
For further information, please call: (512) 239-4640

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Subchapter C. Types of Uses

28 TAC §297.30

This new section is proposed under the Texas Water Code, §5.103 and §5.105, which provides the Texas Natural Resource Conservation Commission with the authority to adopt rules necessary to carry out its powers and duties under the code and the laws of the state.

§297.30. Permit Exemptions for Use of State Water for Irrigation of Certain Historic Cemeteries and for Sedimentation Control Structures within Surface Coal Mining Operations.

(a) Permit Exemption for Use of State Water for Irrigation of Certain Historic Cemeteries.

(1) Without obtaining a water use permit from the commission, a tax-exempt non-profit corporation that owns a cemetery may divert from a stream not more than 200 acre-feet of water each year to irrigate the grounds of the cemetery if the cemetery:

(A) borders the stream; and

(B) is more than 100 years old.

(2) If the executive director, or a watermaster who has jurisdiction over the stream from which a cemetery diverts water under this section, determines that the diversion will harm a person downstream of the cemetery who acquired a water right before May 23, 1995, the executive director or the watermaster may order the cemetery to restrict the diversion to the extent and duration of the harm. The executive director may also request appropriate commission action.

(3) Any person dissatisfied with the action taken by the executive director or the watermaster pursuant to paragraph (2) of this subsection may appeal to the commission for relief.

(b) Permit Exemption to Use State Water for Sedimentation Control Purposes within a Surface Coal Mining Operation. Without obtaining a permit from the commission, a person may construct or maintain a reservoir for the sole purpose of sedimentation control as part of a surface coal mining operation under the Texas Surface Coal Mining and Reclamation Act (Art 5920-11, Vernon's Texas Civil Statutes).

This agency hereby certifies that the proposal has been reviewed by legal counsel and found to be within the agency's authority to adopt.

Issued in Austin, Texas, on February 21, 1996.

TRD-9602447
Kevin McCalla
Director, Legal Division
Texas Natural Resource Conservation Commission
Earliest possible date of adoption: April 1, 1996
For further information, please call: (512) 239-4640

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Subchapter A. Definitions

28 TAC §331.2, §331.11

The new rules are proposed under the Texas Water Code, §§5.103, 5.105, and 27.019, and Texas Health and Safety Code, §361.017 and §361.024, which authorize the TNRCC to adopt any rules necessary to carry out its powers and duties under the Texas Water Code and other laws of Texas and to establish and approve all general policy of the commission.

The proposed rules implement the Texas Water Code, §§11.153-11.155, which authorize the TNRCC to investigate the feasibility of storing appropriated water in various aquifers around the state by encouraging the issuance of permits for Phase I of aquifer storage and retrieval projects for the storage of appropriated water in certain aquifers for subsequent retrieval and beneficial use.

§331.2 Definitions

The following words and terms, when used in this chapter, shall have the following meanings, unless the context clearly indicates otherwise.

Aquifer Storage Well—A Class V injection well used for the injection of water into a geologic formation, group of formations or part of a formation that is capable of underground storage of water for later retrieval and beneficial use.

§331.11 Classification of Injection Wells

(a) Injection wells within the jurisdiction of the commission are classified as follows.

(1) Class I.

(A) Wells used by generators of hazardous wastes or owners or operators of hazardous waste management facilities to inject hazardous waste, other than Class IV wells.

(B) Other industrial and municipal waste disposal wells which inject fluids beneath the lower-most formation which within one quarter mile of the wellbore contains an underground source of drinking water.

(2) Class III. Wells which inject for extraction of minerals, including:

(A) mining of sulfur by the Frasch process;

(B) solution mining of minerals which includes sodium sulfate, sulfur, potash, phosphate, copper, uranium and other minerals which can be mined by this process.

(3) Class IV. Wells used by generators of hazardous wastes or of radioactive wastes, by owners or operators of hazardous waste management facilities, or by owners or operators of radioactive waste disposal sites to dispose of hazardous wastes or radioactive wastes into or above a formation which within one quarter mile of the wellbore contains an underground source of drinking water.

(4) Class V. Injection wells within the jurisdiction of the commission, but not included in Classes I, III, or IV. Class V wells include, but are not limited to:

(A)-(J) (No change.)

(K) Aquifer storage wells used for the injection of water for storage and subsequent retrieval for beneficial use.

(b) (No change.)

This agency hereby certifies that the proposal has been reviewed by legal counsel and found to be within the agency's authority to adopt.

Issued in Austin, Texas, on February 21, 1996.

TRD-9602448
Kevin McCalla
Director, Legal Division
Texas Natural Resource Conservation Commission
Earliest possible date of adoption: April 1, 1996
For further information, please call: (512) 239-4640

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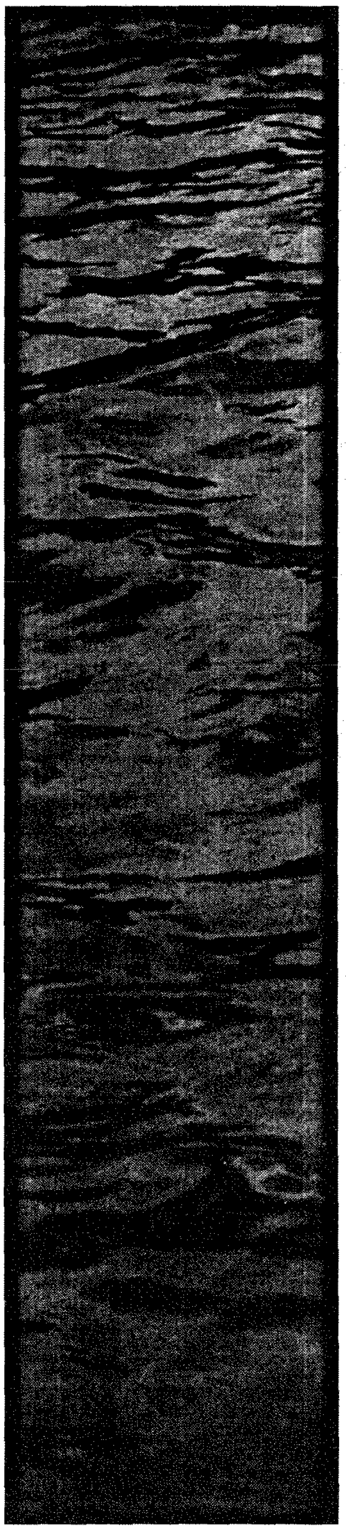

Attachment 2D

substantive changes are proposed in this recodification.

Chapter 305, Subchapter E is proposed for repeal. Rules contained in that subchapter will be recodified in Chapters 50 and 55, and in the new Chapter 39, when proposed.

Chapter 339 is proposed to be repealed in its entirety.

Chapter 340 is amended to consolidate requirements for pump installers from Chapter 339 with those of water well drillers in Chapter 340. In addition, references to the former Water Well Drillers Board are changed to commission or Water Well Drillers Advisory Council (council) as appropriate. Enforcement rules are deleted and references made to the proposed new Chapters 70 and 80. Additional changes are proposed to reflect recent changes in the statutory authority of the council, and to delete sections that are duplicated in new Chapter 5.

Chapter 341, which was the former Water Well Drillers Board procedures for enforcement and hearings, is proposed to be repealed in its entirety and these council proceedings will be governed by new Chapters 70 and 80.

Persons seeking help in comparing this rule proposal and recodification to the existing rules, can obtain a redlined/strikeout version of this package and disposition/derivation tables from the commission. Please contact David Bolduc at (512) 239-1000 for a copy of this information.

Stephen Minick, Strategic Planning and Appropriations Division, has determined that for the first five-year period the sections are in effect there will be no significant fiscal implications for state or local government as a result of enforcing or administering the sections.

Mr. Minick also has determined that for each year of the first five years the sections are in effect the public benefit anticipated as a result of enforcing the sections will be improvement in the hearings process and for contested matters before the commission and enhanced consistency in the conduct of administrative proceedings for state agencies. There will be no effect on small businesses. There is no anticipated economic cost to persons who are required to comply with the sections as proposed.

The proposed rule revisions are intended to clarify, streamline, and recodify the procedural rules of the agency. The commission prepared a takings impact assessment of these rules and determined that the proposal will not create any burden on private real property rights.

A public hearing on the proposal will be held April 18, 1996, at 9:00 a.m. in Room 131E of TNRCC Building C, located at 12100 North IH-35, Park 35 Circle, Austin. The hearing is structured for the receipt of oral or written comments by interested persons. Individuals may present oral statements when called upon in order of registration. Open discussion within the audience will not occur during the hearing; however, a TNRCC staff member will be available to discuss the proposal 30 minutes prior to the hearing and answer questions before and after the hearing.

Written comments not presented at the hearing may be submitted to the TNRCC Office of Policy and Regulatory Development in Austin through April 18, 1996. Material received by the TNRCC Office of Policy and Regulatory Development by 4:00 p.m. on that date will be considered by the commission prior to any final action on the proposal. Please mail comments to Lisa Martin, Office of Policy and Regulatory Development, MC 205, P.O. Box 13087, Austin, Texas 78711-3087, and reference Rules Tracking Log Number 95123-263-AD. Please fax comments to (512) 239-4808. Copies of the revision are available from the Office of Policy and Regulatory Development, located at 12100 Park 35 Circle, Building F, Austin, and at all TNRCC regional offices. For further information, please contact Randall Terrell at (512) 239-0577.

Persons with disabilities who have special communication or other accommodation needs who are planning to attend the hearing should contact the agency at (512) 239-4900. Requests should be made as far in advance as possible.

The repeals are proposed under the Texas Water Code, §§5.103, 5.105, 13.041, 26.011, 27.019, 32.009, 33.007, and 34.006 and Texas Health and Safety Code, §§341.002, 341.031, 361.011, 361.017, 361.024, 366.012, 382.017, 401.011, 401.051, and 401.412, which authorize the commission to adopt any rules necessary to carry out its powers and duties under the Water Code and other laws of Texas and to establish and approve all general policy of the commission.

The proposed repeals implement Texas Water Code, §§5.103, 5.105, 13.041, 26.011, 27.019, 32.009, 33.007, and 34.006 and Texas Health and Safety Code, §§341.002, 341.031, 361.011, 361.017, 361.024, 366.012, 382.017, 401.011, 401.051, and 401.412.

§305.91. Applicability.

§305.92. Action on Applications.

§305.93. Action on Application for Permit.

§305.94. Action on Application for Production Area Authorization.

§305.95. Action on Application for Renewal.

§305.96. Action on Application for Amendment or Modification.

§305.97. Action on Application for Transfer.

§305.98. Scope of Proceedings.

§305.99. Commission Action.

§305.100. Notice of Application.

§305.101. Notice of Hearing.

§305.102. Notice by Publication.

§305.103. Notice by Mail.

§305.104. Radio Broadcasts.

§305.105. Request for Public Hearing.

§305.106. Response to Comments.

§305.107. Public Meeting and Notice Requirements.

This agency hereby certifies that the proposal has been reviewed by legal counsel and found to be within the agency's authority to adopt.

Issued in Austin, Texas, on March 6, 1996.

TRD-9603253

Kevin McCalla
Director, Legal Services Division
Texas Natural Resource Conservation Commission

Proposed date of adoption: May 1, 1996

For further information, please call: (512) 239-1966

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Chapter 331. Underground Injection Control

(Editor's Note: The following proposed sections were inadvertently omitted from the March 1, 1996, issue of the Texas Register. The Texas Natural Resource Conservation Commission submitted these proposals on February 21, 1996. The earliest possible date of adoption is April 1, 1996.)

The Texas Natural Resource Conservation Commission (TNRCC or commission) proposes amendments to §331.2 and §331.11, and new §§331.181-331.186, concerning additional standards and requirements for Class V aquifer storage wells.

The proposed rules will implement recent legislation in House Bill 1989

(1995) that directs the TNRCC to investigate the feasibility of storing appropriated water in various aquifers around the state by encouraging the issuance of temporary or term permits for aquifer storage and retrieval projects that would store appropriated water in certain aquifers for subsequent retrieval and beneficial use.

Proposed amendment to §331.2, Definitions, would add a definition for the term "aquifer storage well."

Proposed amendment to §331.11, Classification of Injection Wells, would clarify that an aquifer storage well is a Class V injection well.

New §§331.181-331.186, Subchapter K, concerning Additional Requirements for Class V Aquifer Storage Wells, is being proposed to assure protection of the ground water resources in the state and to specify the requirements for Class V aquifer storage wells which will be used in Phase I (pilot demonstration phase) of an aquifer storage and retrieval project.

Proposed new §331.181, Applicability, states that the requirements contained in proposed new §§331.182- 331.186 are applicable to all Class V injection wells used for aquifer storage and are in addition to the requirements in §§331.131-331.133 of this chapter.

Proposed new §331.182, Area of Review, would provide the standards applicable to Class V aquifer storage wells for the identification and review of activities in the project area that may affect the injection operation.

Proposed new §331.183, Construction and Closure Standards, would provide the construction standards applicable to Class V aquifer storage wells including design criteria, plans and specification requirements, construction performance standards, and well construction and well workover or closure supervision requirements.

Proposed new §331.184, Operating Requirements, would provide the operating requirements applicable to Class V aquifer storage wells with the primary objectives of preventing the wells from being operated in a manner that creates a hazard to any underground sources of drinking water (USDW) and preventing leakage from the well into unauthorized zones.

Proposed new §331.185, Monitoring and Reporting Requirements, specifies the operating functions to monitored, the monitoring frequency, and the elements to be reported to the executive director applicable to Class V aquifer storage wells. In addition, a final report on all required construction, testing and evaluation of data from Phase I of the project shall be submitted to the executive director within 45 days of the completion of Phase I of the project.

Proposed new §331.186, Additional Requirements for Final Project Authorization, provides for the additional requirements for Class V aquifer storage wells for data acquisition and facility construction during the pilot demonstration project, Phase I, that would be sufficient for an evaluation of the project under an application for the final project, Phase II, authorization. The additional requirements would require as-built construction information, logging and testing results, modeling results, and any additional information which might reasonably affect the operation of the injection well and its affect on underground sources of drinking water.

Steve Minick, Strategic Planning and Appropriations Division, has determined that for the first five years the sections as proposed are in effect there are no fiscal implications anticipated for state or local governments as a result of enforcing or administering the proposed rules.

Mr. Minick also has determined that for each of the first five years the sections as proposed are in effect the public benefits anticipated as a result of enforcement of and compliance with the sections will be the clarification and streamlining of the permitting process for aquifer storage and retrieval projects. There are no economic costs anticipated for any person, including any small business, required to comply with the sections as proposed.

A public hearing on the proposal will be held March 22, 1996, at 10:00 a.m. in Room 2210 of TNRCC Building F, located at 12100 Park 35 Circle, Austin. The hearing is structured for the receipt of oral or written comments by interested persons. Individuals may present oral statements when called upon in the order of registration. Open discussion within the audience will not occur during the hearing; however, a TNRCC staff member will be available to discuss the proposal 30 minutes prior to the hearing and will answer questions before and after the hearing.

Written comments on the proposal should mention Log Number 95160-295-WT and may be submitted to Lutrecia Oshoko, Texas Natural Resource Conservation Commission, Office of Policy and Regulatory Development, MC 205, P.O. Box 13087, Austin, Texas 78711-3087, (512) 239-4640. Please fax comments to (512) 239-5687. Written comments must be received by 5:00 p.m., 30 days from the date of publication of this proposal in the *Texas Register*. For further information, please contact James Kowis at (512) 239-4900.

Persons with disabilities who have special communication or other accommodation needs who are planning to attend the hearing should contact the agency at (512) 239-4900. Requests should be made as far in advance as possible.

Subchapter A. General Provisions

• 30 TAC §331.2, §331.11

The amendments are proposed under the Texas Water Code, §§5.103, 5.105, and 27.019, and Texas Health and Safety Code, §361.017 and §361.024, which authorize the TNRCC to adopt any rules necessary to carry out its powers and duties under the Texas Water Code and other laws of Texas and to establish and approve all general policy of the commission.

The proposed rules implement the Texas Water Code, §§11.153-11.155, which authorize the TNRCC to investigate the feasibility of storing appropriated water in various aquifers around the state by encouraging the issuance of permits for Phase I of aquifer storage and retrieval projects for the storage of appropriated water in certain aquifers for subsequent retrieval and beneficial use.

§331.2. Definitions. The following words and terms, when used in this chapter, shall have the following meanings, unless the context clearly indicates otherwise.

Aquifer Storage Well–A Class V injection well used for the injection of water into a geologic formation, group of formations or part of a formation that is capable of underground storage of water for later retrieval and beneficial use.

§331.11. Classification of Injection Wells.

(a) Injection wells within the jurisdiction of the commission are classified as follows.

(1)-(3) (No change.)

(4) Class V. Injection wells within the jurisdiction of the commission, but not included in Classes I, III, or IV. Class V wells include, but are not limited to:

(A)-(J) (No change.)

(K) Aquifer storage wells used for the injection of water for storage and subsequent retrieval for beneficial use.

(b) (No change.)

This agency hereby certifies that the proposal has been reviewed by legal counsel and found to be within the agency's authority to adopt.

Issued in Austin, Texas, on February 21, 1996.

TRD-9603044 Kevin McCalla
Director, Legal Division
Texas Natural Resource Conservation Commission

Earliest possible date of adoption: April 1, 1996

For further information, please call: (512) 239-4640

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Subchapter K. Additional Requirements for Class V Aquifer Storage Wells

- 30 TAC §§331.181-331.186

The new sections are proposed under the Texas Water Code, §§5.103, 5. 105, and 27.019, which provides the Texas Natural Resource Conservation Commission with the authority to adopt rules necessary to carry out its powers and duties under the code and laws of the state.

§331.181. Applicability. In addition to the requirements of Subchapter H of this chapter (relating to Standards for Class V Wells), the requirements of this subchapter apply to all Class V aquifer storage wells.

§331.182. Area of Review. The area of review for a Class V aquifer storage well is the area determined by a radius of 1/4 mile from the proposed or existing wellbore. In the application for authorization, the applicant shall provide information on the activities within the area of review including the following factors and their adverse impacts, if any, on the injection operation:

(1) location of all artificial penetrations that penetrate the interval to be used for aquifer storage, including but not limited to: water wells and abandoned water wells from TNRCC well files or ground water district files; oil and gas wells and saltwater injection wells from the Railroad commission files; and waste disposal wells/other injection wells from the TNRCC disposal well files;

(2) completion and construction information, where available, for identified artificial penetrations; and

(3) site specific, significant geologic features, such as faults and fractures.

§331.183. Construction and Closure Standards. All Class V aquifer storage wells shall be designed, constructed, completed and closed to prevent, commingling, through the wellbore and casing, of injection waters with other fluids outside of the authorized injection zone; mixing through the wellbore and casing of fluids from aquifers of substantively different water quality; and infiltration through the wellbore and casing of water from the surface into ground water zones.

(1) Plans and specifications. Except as specifically required in the terms of the Class V aquifer storage well authorization, the drilling and completion of a Class V aquifer storage well shall be done in accordance with the requirements of §331.132 of this title (relating to Construction Standards) and the closure of a Class V aquifer storage well shall be done in accordance with the requirements of §331.133 of this title (relating to Closure Standards).

(A) If the operator proposes to change the injection interval to one not reviewed during the authorization process, the operator shall notify the executive director immediately. The operator may not inject into any unauthorized zone.

(B) The executive director shall be notified immediately of any other changes, including but not limited to, changes in the completion of the well, changes in the setting of screens and changes in the injection intervals within the authorized injection zone.

(2) Construction materials. Casing materials for Class V aquifer storage wells shall be constructed of materials resistant to corrosion.

(3) Construction and workover supervision. All phases of any aquifer storage well construction, workover or closure shall be supervised by qualified individuals who are knowledgeable and experienced in practical drilling engineering and who are familiar with the special conditions and requirements of injection well and water well construction.

§331.184. Operating Requirements.

(a) All Class V aquifer storage wells shall be operated in such a manner that they do not present a hazard to or cause pollution of an underground source of drinking water.

(b) Injection pressure at the wellhead shall not exceed a maximum which shall be calculated so as to assure the pressure in the injection zone does not cause movement of fluid out of the injection zone.

(c) The owner or operator of an aquifer storage well that has ceased operations for more than two years shall notify the executive director 30 days prior to resuming operation of the well.

(d) The owner or operator shall maintain the mechanical integrity of all wells operated under this section.

(e) The quality of water to be injected must meet the quality criteria prescribed by the commission's drinking water standards as provided in Chapter 290 of this title (relating to Water Hygiene).

§331.185. Monitoring and Reporting Requirements.

(a) The following must be monitored at the required frequency and reported to the executive director on a quarterly basis or a schedule to be agreed upon by the executive director:

(1) monthly average injection rates;

(2) monthly injection volumes;

(3) monthly average injection pressures;

(4) monthly water quality analyses; and

(5) other information as determined by the executive director as necessary for the protection of underground sources of drinking water.

(b) A final report for Phase I of a project must be submitted to the executive director within 45 days of the completion of Phase I of a project addressing items in §331.186 of this title (relating to Additional Requirements Necessary for Final Project Authorization).

§331.186. Additional Requirements Necessary for Final Project Authorization. Upon completion of the aquifer storage well, the following information shall be obtained during the first phase of the project and submitted along with the application for final authorization:

(1) as-built drilling and completion data on the well;

(2) all logging and testing data on the well;

(3) formation fluid analyses;

(4) injection fluid analyses;

(5) injectivity and pumping tests determining well capacity and reservoir characteristics;

(6) hydrogeologic modeling, with supporting data, predicting mixing zone characteristics and injection fluid movement and quality; and

(7) other information as determined by the executive director as necessary for the protection of underground sources of drinking water.

This agency hereby certifies that the proposal has been reviewed by legal counsel and found to be within the agency's authority to adopt.

Issued in Austin, Texas, on February 21, 1996.

TRD-9603045 Kevin McCalla
Director, Legal Division
Texas Natural Resource Conservation Commission

Earliest possible date of adoption: April 1, 1996

For further information, please call: (512) 239-4640

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Chapter 336. Radiation Rules

Source Material Recovery and Radioactive Substance Disposal

• 30 TAC §336.8

The Texas Natural Resource Conservation Commission (TNRCC) proposes new §336.8, concerning adoption of a Memorandum of Understanding (MOU) between the Railroad Commission of Texas (RCT), and the Texas Department of Health (TDH), and the TNRCC relating to jurisdiction over uranium surface mining, ore milling, and mill tailings disposal.

The MOU defines the respective jurisdictions of the agencies and provides for coordination of responsibilities. The respective authorities of the TDH and TNRCC are covered under the Texas Health and Safety Code, Chapter 401, and the authorities of the RCT are covered under the Texas Natural Resources Code, Chapter 131.

The MOU amends an existing MOU between the TDH and RCT which has been effective since August 5, 1988. The amendment of the MOU is necessary because of the transfer of regulatory jurisdiction for responsibilities covered under the existing agreement. Senate Bill 2, First Called Session, 72nd Texas Legislature, Chapter 3, 1991, Texas General Laws 4, transferred the jurisdiction for disposal of radioactive substances from the TDH to the Texas Water Commission, a predecessor agency to the TNRCC, effective March 1, 1992. Senate Bill 1043, 73rd Texas Legislature, Chapter 992, 1993, Texas Session Laws 4343, transferred jurisdiction over source material recovery and processing from the TDH to the TNRCC effective September 1, 1993.

The new MOU incorporates the changed regulatory jurisdiction between the TDH and the TNRCC with respect to uranium ore milling and tailings disposal. In addition, the new MOU incorporates the legislative mandate placing jurisdiction under the TNRCC for uranium ore milling operations and tailings disposal impoundments. This results in a more efficient regulatory program for milling and tailings disposal placed in a single agency, in conformance with the statutes, whereas the existing agreement provides for joint jurisdiction with the RCT. The new MOU provides for exchanges of information by the three agencies and coordination and cooperation to assure the highest level of technical expertise in the regulatory programs.

Stephen Minick, Strategic Planning and Appropriations Division, has determined that for the first five-year period this section as proposed is in effect there are no significant fiscal implications anticipated for state or local governments as a result of administration or enforcement of the section.

Mr. Minick also has determined that for the first five-year period this section as proposed is in effect the public benefit anticipated as a result of administration of and compliance with the section will be a clarification of the respective responsibilities of state agencies relating to surface mining of uranium, ore milling, and tailings disposal; more cost-effective regulation of these activities; and elimination of duplicative regulatory efforts without reduction in the levels of environmental protection. There are no economic costs anticipated for any person or small businesses required to comply with this section as proposed.

The commission has prepared a Takings Impact Assessment for this proposed new section pursuant to Texas Government Code, Annotated, §2007.043. The following is a summary of that Assessment. The specific purpose of the new section is to implement Senate Bill 2, First Called Session, 72nd Texas Legislative, and Senate Bill 1043, 73rd Texas Legislative session, to clearly delineate jurisdictional responsibilities and delete duplicative regulatory efforts. The new section will substantially advance this specific purpose by placing jurisdiction for uranium ore milling operations and tailings disposal in the TNRCC. Promulgation and enforcement of this new section will not affect private real property which is the subject of the rules because the amendment is an interagency agreement that simply outlines specific jurisdictions.

Written comments on the proposal should mention Log Number 95067-336-WS and may be submitted to Bettie Mabry Bell, TNRCC Office of Policy and Regulatory Development, MC205, Texas Register Team, P.O. Box 13087, Austin, Texas 78711-3087. Written comments may be faxed to (512) 239-4808 and must be received by 5:00 p.m., 30 days from the date of publication of this proposal in the Texas Register. For further information, please contact Betty Rogers, Waste Policy and Regulations Division, (512) 239-0048.

The new section is proposed under the Health and Safety Code, §401.412(c), which provides the TNRCC with the authority to adopt rules and guidelines reasonably necessary to exercise its authority over the disposal of radioactive substances and source material recovery and processing.

There are no other codes, rules or statutes that will be affected by this proposal.

§336.8. Memorandum of Understanding between Railroad Commission of Texas, Texas Department of Health, and Texas Natural Resource Conservation Commission Regarding Uranium Surface Mining, Uranium Ore Milling, and Tailings Ponds and Impoundments.

(a) Now therefore, the Railroad Commission of Texas (RCT), the Texas Department of Health (TDH), and the Texas Natural Resource Conservation Commission (TNRCC) hereby agree to the following:

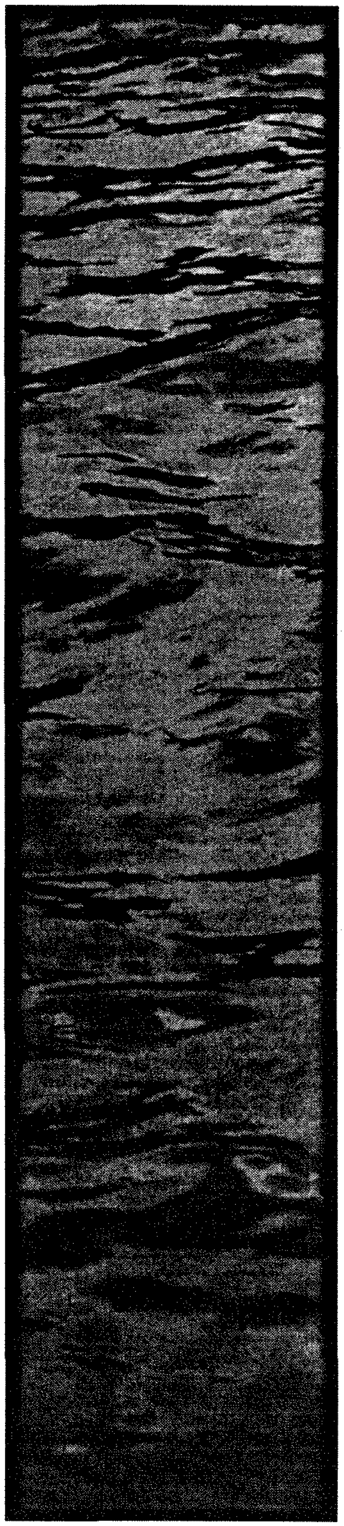
(1) Uranium surface mining.

(A) The RCT shall have responsibility for permitting and enforcement activities, including reclamation, for all uranium surface mining facilities. The regulation of uranium exploration and surface mining activities by the RCT shall cover non-radiological aspects of all exploration activity and open pit mining and shall be enforced through its adopted rules. The RCT shall ensure that the proposed activities meet the RCT standards; determine the adequacy of pre-operational information provided by the applicant; assess the degree of environmental impact that would result from the proposed activity; issue permits and permit revisions and renewals; enforce all the RCT permit conditions and standards, including the maintenance of financial assurance for activities for which the RCT is directly responsible.

(B) The RCT and the TDH shall be jointly responsible, from both radiological and non-radiological considerations, for regulation of releases and disposal of mine effluents, mine drainages, and other wastes resulting from uranium surface mining. Regulation relating to all surface discharges of effluents or other liquid or solid streams from the mining areas shall be determined in cooperation with TNRCC. The RCT shall have the primary responsibility for regulation of reclamation and revegetation activities and for subsequent release of the land affected by mining. The TDH will perform confirmatory radiological surveys of the reclaimed areas and advise the RCT of its findings.

(2) Uranium ore milling.

(A) The TNRCC shall have responsibility for licensing and enforcement activities for the ore milling process plant facilities starting from the raw ore receipt and storage to the packing for transportation of the uranium oxide concentrate. The TNRCC shall ensure the proposed activities meet TNRCC standards; determine the adequacy of radiological and non-radiological pre-operational information provided, and assess the impact of proposed activities on public health and safety and the environment; review the applicant's design, construction, operation, monitoring,



Attachment 2E

2/29/96

For a project site to be considered for designation for potential suitability for Aquifer Storage and Recovery (ASR) study and pilot demonstration, the Project Sponsor should submit to the Texas Water Development Board (TWDB) staff an initial feasibility report, based on available information, that would provide some early-on indication of ASR being a suitable tool to meet the Sponsor's water utility needs, as well as addressing some of the geologic and water management issues that would also affect project feasibility.

With the information provided in the report and the TWDB's own data and expertise, Board staff will, in coordination with the Project Sponsor, make a positive or negative finding of the project being suitable for further ASR study and pilot project demonstration. This TWDB staff finding is for the sole purpose of providing information to the Texas Natural Resource Conservation Commission for regulatory consideration and **does not** constitute any funding or in-kind study support commitment on the part of the TWDB.

Required information in the initial feasibility report to be submitted to the TWDB:

(1) Name, address, and contact person representing the Project Sponsor,

(2) Citation of legal authority/powers to fund, construct and operate such facility,

(3) Description of the proposed site of pilot project investigation (please provide specific mapped locations),

(4) Description of the utility's current or future water infrastructure needs and how the intended use of such ASR capability would address these needs, answering the following questions as appropriate, i.e. does ASR for this project have the potential to:

a. increase the available supply through seasonal availability and capture?
b. help meet peak distribution demands?
c. forestall expansion of existing treatment facilities?
d. alleviate the need to develop alternative storage reservoirs?
e. decrease environmental concerns by reducing seasonal diversion?

(5) Documentation that a suitable source of water is currently available or has reasonable feasibility of being obtained.

(6) Demonstration that water treatment capacity is available to produce water for the ASR project.

(7) Documentation of favorable subsurface reservoir conditions.

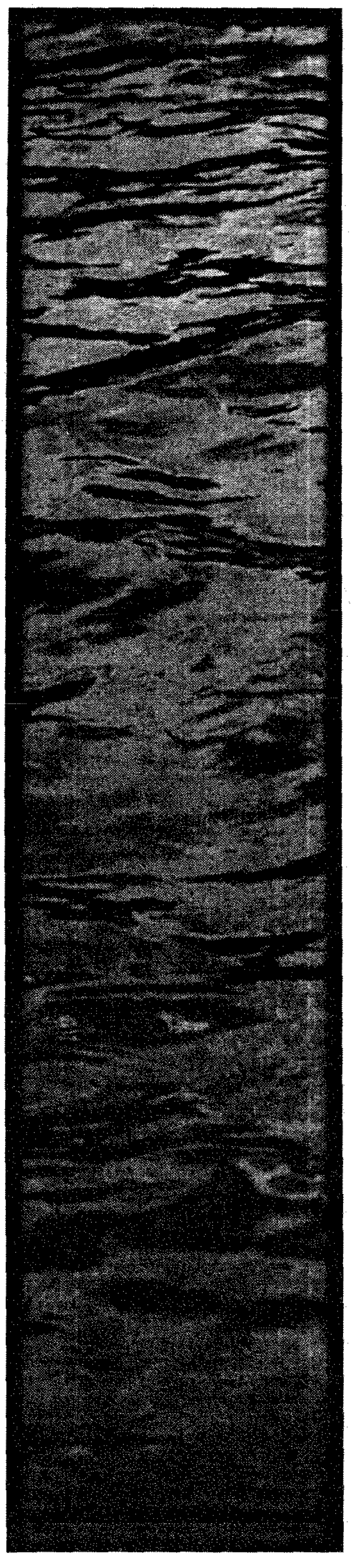
(8) Demonstrate a favorable comparison of ASR against competitive supply/storage options.

(9) The Sponsor's current or proposed regulatory authority or method for controlling unintended ground-water use by others of the ASR facility.

(10) If project is planned in an underground water conservation district, provide copy of notice to the district and any conditions to be imposed on the project by the district.

(11) Describe the water quality of the planned-introduced water and the general quality of the receiving aquifer.

During conduct of any later ASR pilot feasibility studies or test operations, provide TWDB staff current copies of any significant project status or study reports, as produced (as the TWDB and TNRCC are required by law to prepare a joint report to the Legislature evaluating the success of each ASR project).



Technical Memorandum No. 3
Preliminary Geochemical Evaluation

Preliminary Geochemical Evaluation

PREPARED FOR: The City of Laredo

PREPARED BY: CH2M HILL

DATE: June 10, 1996

Summary

A preliminary geochemical evaluation was conducted to assess potential reactions for the City of Laredo Aquifer Storage Recovery (ASR) project. The ASR project is investigating the feasibility of storing City of Laredo potable water in the brackish aquifers underlying the City's service area. Existing water quality data on the City water and the brackish aquifers were evaluated to assess the compatibility of storing the City potable water in these aquifers.

This preliminary geochemical evaluation finds that the best application for aquifer storage using City of Laredo potable water will probably be in wells located in portions of the aquifers that produce groundwater with a pH of less than 8. The ASR cycle testing should be structured so the initial recharge cycles are conducted slowly to allow the clay minerals in the aquifer to adjust to a change in exchangeable ion and lower total dissolved solids (TDS). Furthermore, a buffer of recharge water should be allowed to remain in the aquifer between cycles. This should be accomplished by recovering a volume less than the total amount recharged during the initial cycles. This should control the problem of changing the exchangeable ion on the clay minerals in the aquifer with each recharge cycle and reduce the potential for repeated calcium carbonate precipitation at and near the wellbore. Recharge to wells producing groundwater with an alkaline pH (equal to or higher than 8), should be carefully evaluated, particularly for the deep aquifer. Recharge to these wells has a high probability of potential fatal flaws involving both clay instability and calcium carbonate precipitation. If recharge to wells with the higher pH is considered, additional treatment of the City water or pretreatment of the aquifer may be required.

It is recommended that the iron and aluminum concentration in the finished water from Water Treatment Plant No. 2 be reanalyzed. It is further recommended that orthophosphate be analyzed on the representative recharge water from both treatment plants. Wells considered for recharge should be reanalyzed for a complete suite of parameters (particularly including field parameters) before a final decision is made to select the aquifer location for recharge testing.

Discussion

A geochemical review of the water chemistry representing seven shallow and two deep groundwater analyses and the proposed recharge water from two treatment plants were used in this preliminary evaluation. The shallow wells range to a depth of 550 feet and the deep wells extend over a depth interval from 1,796 to 3,265 feet. The shallow well groundwater chemistry was collected between 1961 and 1994 and the deep well groundwater chemistry was collected in 1976 and 1993. The values used are those presented in Table 3, Technical Memorandum No. 1. A copy of this table is attached. The recharge water chemistry was collected in December 1994 and is presented in Table 2, Technical Memorandum No. 4, a copy of which is attached to this document.

Recharge Water

The major ion chemistry of the recharge water from the two water treatment plants (WTP No. 1 and No. 2) is very similar in essentially all parameters. The recharge water is a sodium-sulfate-chloride water chemistry type with a TDS of about 800 milligrams per liter (mg/L) and a relatively alkaline pH of 8.

The trace element chemistry is at least partially different, particularly iron and aluminum. The iron concentration of 0.247 mg/L in the recharge water from WTP No. 2 probably represents either a total concentration (unfiltered sampled) and/or a sequestered iron concentration (polyphosphate). This iron concentration is at least double what is possible in a relatively oxidized water released by a water treatment plant and needs to be confirmed. If this is a true iron concentration, recharge into a fine-grained sand, and especially a sandstone, may present a plugging problem when the iron becomes an iron oxyhydroxide in the aquifer.

Aluminum in water from WTP No. 2 with a concentration of 3.85 mg/L may represent water treatment with alum. The alum tends to polymerize in the treated water and takes a considerable amount of time to precipitate in the water supply system because it has a very low rate of precipitation. Use of this water for recharge into a fine sand, especially a sandstone, will probably present an irreversible plugging problem with time. A medium sand aquifer will probably also be irreversibly affected but it will take more time. The polymerized aluminum tends to become lodged in the pore throats of the aquifer particles beginning at and extending a relatively short distance from the wellbore. Plugging increases as the pore throats become clogged resulting in a decline in permeability that eventually makes the well unusable. It is unlikely that the plugging will extend more than a few tens of feet around the wellbore so the aquifer is not generally significantly affected.

Shallow Groundwater

The shallow groundwater shows considerable variability in water chemistry. However, the groundwater chemistry can be divided into two sets based on pH. The pH is a very important parameter when recharge is being considered because it controls the precipitation of calcium carbonate. A pH of 8 or above has a tendency to precipitate calcium carbonate if the recharge water is a calcium-dominant water chemistry type and the groundwater is a bicarbonate-carbonate chemistry type. Three of the shallow aquifer wells with a relatively complete analysis have a groundwater with a pH of less than 8 (85-37-702, 85-20-703, and 85-20-901) and two have a pH of greater than 8 (85-29-301 and 85-28-601).

Shallow Groundwater with a pH of Less Than Eight

The groundwaters with a pH of less than 8 are a sodium-sulfate water chemistry type with a mean TDS of 2,320 mg/L and a mean pH of 7.6. The mean upper screen depth of this groundwater is a moderate 257 feet with a standard deviation of almost 200 feet indicating a probable laterally variable location in the basin.

The groundwater has a mean calcium concentration of 92 mg/L, magnesium concentration of 61 mg/L, but a sodium concentration of 930 mg/L. This cation chemistry suggests that the clays in the aquifer are probably a sodium smectite but this needs to be confirmed. Recharge with the above calcium-rich recharge water chemistry type will cause an ion exchange with this clay in the aquifer and may have a tendency to destabilize the clay. This potential problem may be exacerbated by the relatively dilute recharge water compared with the in situ groundwater.

This potential problem can be controlled by a slow recharge rate for the initial cycles and not allowing the in situ groundwater to come near the wellbore (leave a residual amount of recharge water in the aquifer). A slow recharge rate will allow the clays to accommodate to the change in exchangeable ion chemistry and the dilution of the water exposed to the clay. The dilute recharge water will tend to cause the clay lattice to open up more than a recharge water with a higher TDS. This opening up of the clay lattice allows more effective exchange. The exchange itself changes the clay structure from a ribbon-like sodium smectite structure to a plate-like calcium smectite structure which is more stable. The slow recharge allows this structural change to occur with a minimum of flow through the pore (slow exchange) which generally allows the change to occur without the clay migrating into the pore throat of the aquifer particles.

Recovery of more water than was recharged means that the in situ groundwater will be brought back through the previously changed clay structure and reverse the structural change to its original sodium-smectite structure. A reversal from a calcium-smectite structure to a sodium-smectite structure may result in considerable clay instability with the result that the clays on the aquifer particles will migrate into the pore-throats of the aquifer near the wellbore. This migration would result in an irreversible decrease in permeability near the well and perhaps the loss of the well.

The recharge water mixing with the in situ groundwater will probably result in a reversal in the ion exchange and some precipitation of calcium carbonate which can exacerbate the above potential problem (particularly if polymerized aluminum is present in the recharge water). The amount of calcium carbonate precipitated in this mixture is probably not going to result in a significant amount of precipitation (probably not reduce the permeability around the well). However, if the in situ groundwater is continually brought back to the wellbore, even if the clays remain stable (unlikely probability), the precipitates will tend to build up at and near the wellbore and result in lower permeability around the wellbore with each recharge-recovery cycle.

Shallow Groundwater with a pH of Eight or Higher

The two wells with in situ groundwater with a pH of 8 or higher (85-29-301 and 85-28-601) are a sodium-chloride-sulfate water chemistry type with a mean TDS of 2,340 mg/L and a mean pH of 8.71. The two wells have a shallower mean upper screen depth of 190 feet (standard deviation of only 33 feet) than the above shallow lower pH wells. Furthermore, the major cations are lower (particularly the calcium concentrations) than in the lower pH wells. Similarly, the alkalinity and sulfate are lower. However, the chloride concentration is about twice as high (mean of 589 mg/L versus a mean of 262 mg/L). These analyses need to be confirmed because it is unusual for a shallower groundwater to have a higher chloride than a deeper groundwater and the difference in groundwater chemistry is achieved with almost no change in TDS.

Recharge into this groundwater will have all the previously discussed potential problems but a much higher probability of a large amount of calcium-carbonate precipitation where the recharge water and in situ groundwater mix. An estimated 150 to 200 mg/L calcium carbonate may precipitate from the recharge water where the two water mix. This amount can become a problem relatively quickly in fine-grained sand aquifers and relatively slowly in more coarser grained aquifers.

Use of the wells with an in situ groundwater with a pH equal to or over 8 must be carefully considered because of the above problems.

Deep Aquifer

Groundwater in the deep aquifer is a sodium-bicarbonate water chemistry type with a mean TDS of 2,340 mg/L and a mean pH of 8.71. This groundwater has the same problems as the shallow aquifer with a pH equal to or higher than 8 but has a potential to be more of a potential fatal flaw. The change in the clay mineral structure in the aquifer and precipitation of calcium carbonate is of considerably more concern in this aquifer. An estimated 150 to 200 mg/L calcium carbonate would potentially be precipitated where this groundwater and the recharge water mix in the aquifer. The sulfate concentration in the groundwater is not sufficiently high to provide much complexing to reduce the amount of precipitation.

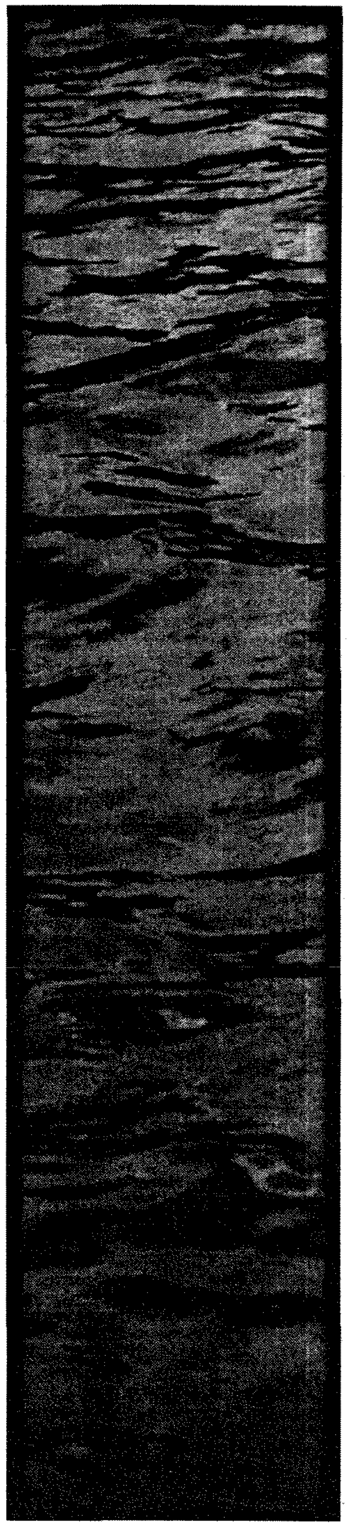
Table 2
Water Quality Analyses
City of Laredo
Laboratory: Texas Dept. of Health, Austin, TX

Parameter	Raw	WTP No. 1	WTP No. 2
	7/22/92	12/13/94	12/13/94
Calcium	70	72	81
Chloride	101	153	158
Fluoride	0.6	1	1
Magnesium	14	26	25
Nitrate (as N)	0.36	0.11	0.09
Sodium	94	158	169
Sulfate	184	269	302
Total Hardness (CaCO3)	235	285	304
pH (units)	7.4	8.1	8
Conductivity (umhos/cm)	1850	1467	1570
Alkalinity (CaCO3)	103	119	120
Bicarbonate	126	145	146
Carbonate	0	0	0
Total Dissolved Solids	531	755	813
Barium	0.078	0.0951	0.102
Iron	0.03	<.004	0.247
Manganese	<0.02	0.0018	<0.01
Aluminum	NR	0.221	3.85
Zinc	<0.02	0.0083	<0.02
Arsenic	<0.01	<0.002	0.0069

Note: Results in mg/l unless noted.
NR = Not reported.

Table 3
Summary of Inorganic Water Quality Analyses - Water Wells, Laredo, TX
Laredo Aquifer Storage and Recovery Project

Zone:	Shallow Aquifer								Deep Aquifer		
Well Designation:	85-37-703	85-29-301	85-37-702	85-20-901	85-29-401	85-29-1D	85-28-601	85-37-402	RO Well	85-28-901	85-29-202
Date Sampled:	5/10/61	2/17/86	4/12/94	4/20/94	4/14/94	3/19/84	4/19/94	5/10/61	9/15/93	8/2/53	1/31/76
Screen Interval (ft):	97-177	167-200	200-250	475?	240-300	530-550	214-231	207	1796-1916	2442	3215-3245
Constituents:											
Laboratory pH, units	7.5	8.7	7.86	7.45	8.92		8.72	7.4	9.24	8.1	8.8
Total Dissolved Solids, mg/L	2890	3090	2080	1975	1350		1590	2314	1506		3050
Total Alkalinity, mg/L ($CaC0_3$)		208	333.4	283	270.6		196		2275		1590
Total Hardness, mg/L ($CaC0_3$)	1170	29	175	175	8		12	633	18	37	20
Specific Conductance, µmhos	3660	3250	3160	2480	1960		2420	3330	2800	6940	4720
Cations: (mg/L)											
Boron				1.96			1.96				
Calcium	205	9	34	36			3.6	92			5
Magnesium	159	1	21	3.4			0.71	103	.15		2
Potassium		2	7.5	5.8			2.8	7.4			
Silica		12	14	19			14				11
Sodium	1513	1103	677	601			566	536	639		1230
Anions: (mg/L)											
Bicarbonate	430	234	406.9	345.4	291.2		222.1	402	1388		1760
Bromine/Bromide			1.4	1.3			1.83				
Carbonate		9	0	0	19.2		252		244	1600	1.89
Chloride	200	763	322	264		500	415	305	450	1650	790
Flouride	0.4	1	1.78	.3			.34	1.6	2.4		3.5
Nitrate	.0	.09	.02	.11			<0.01				<0.4
Sulfate	1580	1110	758	846			415	1050	220	3.9	54
Metals: (µg/L)											
Aluminum			<20	<20			<20				
Arsenic			<16	<8			<4				
Barium			17.7	12.4			14.8				
Cadmium			<2	2.2			<2				
Chromium			<10	<10			<10				
Copper			<10	10.6			<10		<0.1		
Iron			42.8	<10			160		1.3		
Lead			<5	<5			<5				
Manganese			39.3	3.4			6.2		<0.05		
Strontium			2860	1320			237				
Zinc			71.6	22.6			<10		<0.5		



Technical Memorandum No. 4
Water Demand and Water Availability Overview

Water Demand and Water Availability Overview

PREPARED FOR: The City of Laredo

PREPARED BY: CH2M HILL

DATE: June 10, 1996

Introduction

Water supply, demand, and quality data provided by the City of Laredo were evaluated to assess the potential for Aquifer Storage Recovery (ASR) use and benefits. This memorandum is divided into four elements:

- Existing Water System
- Existing and Future Demands
- Raw Water Availability
- Water Quality

Existing Water System

The City of Laredo obtains raw water for treatment from the Rio Grande River which flows along the southwestern edge of the City. Water is pumped directly from the river to the Jefferson and Columbia Water Treatment Plants (WTPs). The Jefferson WTP actually consists of two separate plants, WTP 1 (upper) and WTP 2 (lower) that are located side by side and adjacent to the Rio Grande in the City of Laredo (Figure 1). The Columbia plant, which is located north and west of the City, is a small WTP outside of the service area used to provide potable water to a guard station at the northern bridge to Mexico. Following recently completed distribution system improvements, a previous WTP, the Del Mar WTP, was decommissioned and is no longer used for treatment.

Two raw water intake/pumping stations exist at the Jefferson Street location. The older of the two intakes was constructed in the 1920s and houses three pumps with a combined total capacity of 18 mgd. The other intake at the Jefferson Street site was constructed in the 1950s and houses four pumps with a combined total capacity of 47.5 mgd. The combined total raw water pumping capacity of the two pumping stations is 65.5 mgd. The firm capacity of the stations can be considered the pumping capacity with the largest unit at each station out of service. The firm raw water pumping capacity is then 43 mgd. The raw water pumping stations pump directly to the WTPs. There are no raw water storage facilities at the Jefferson Street facility.

A third intake/pumping station is planned for the Jefferson Street facility. This station is expected to be on-line sometime during 1997 and is planned for a total pumping capacity of 60 mgd. This addition will increase the total raw water pumping capability to over 125 mgd. The firm capacity of the new intake/pumping station is not known at this time.

The Jefferson WTPs use conventional surface water treatment processes consisting of coagulation, flocculation, sedimentation, filtration, and disinfection. Alum is the primary coagulant. The water is disinfected using chloramines.

The treatment capacity of the two WTPs located at the Jefferson Street site is limited by State permit to a combined rate of 84 mgd. The hydraulic capacity of WTP 2 is about 18.5 mgd and is limited by flow through the aeration basin. The hydraulic capacity of WTP 1 is about 64 mgd as limited by flow through the clarifiers.

The distribution system has four primary service levels. The Jefferson treatment plant high service pumps feed the low service level. Booster pumping stations are used to pump water from the low service level to the other three service levels; high, Milmo, and Del Mar. The distribution system also includes the ground and elevated storage tanks shown in Figure 1.

The Columbia WTP has a separate intake near the WTP. The firm capacity of the Columbia system is 0.5 mgd. The former Del Mar WTP was capable of treating up to 2 mgd of water.

The City also operates the 0.93 mgd North Laredo Wastewater Reclamation Plant to generate up to 4.2 acre-feet/year of water to irrigate the Laredo Country Club and Casa Blanca County Golf Courses. The City is also constructing a reverse osmosis (RO) WTP to treat brackish groundwater from the Santa Isabal well north of the City along Columbia/Mines Road. Once complete, the Santa Isabal treatment plant is expected to produce 1 mgd or more from wells constructed in the Carrizo Sands formation.

Existing and Future Demands

The rate at which water is produced and pumped from the WTPs to satisfy customer demand is typically referred to in terms of maximum day and average day demands. The maximum day demand is the maximum volume of water produced and pumped from the WTPs over the period of one day during a given month or year. The average day demand is the average production of water from the WTPs over a given month or year. It is important to note that although water demand can be expressed as rate of water production over a day's time, production rates are seldom this constant. Water production rates vary over a given day by as much as two or more times above or below the maximum day demand for shorter periods. Surface or elevated water storage tanks are typically filled during the lower demand periods of the day and used to meet peak maximum hour demands.

Historic average and maximum treated water demands are presented in Figure 2 and illustrate steady increases over the last 35 years. A linear best fit trend line was plotted through the data and shows that average day demand has been increasing by 0.8 mgd per year and maximum day by 1.3 mgd per year. For this report, the historic trend line projections were extrapolated to the year 2030. These projections indicate that the average raw water demand will exceed the City's current water rights allocation by the year 2005.

The permitted treatment capacity of the Jefferson WTPs is a combined rate of 84 mgd. This capacity is seen to enable the City to treat water to meet demands well into the future. However, the treated water must be delivered to points in the City with water needs, and as seen in Figure 1, these points can be a substantial distance from the centralized WTPs.

Currently, the City is able to treat and distribute treated water throughout the distribution system under maximum day conditions. Growth in the City is occurring in the northern and southern areas and is resulting in increased water demands in those areas. Development is ongoing in areas east of the airport, and new water service to the Colonias through the outlying areas of the City is increasing the need to transport treated water further from the central WTPs. Within the next several years, additional booster pump stations, pipelines, and system storage will be required to adequately serve the areas experiencing growth. These capital improvements have not yet been specifically identified but will be required to provide an adequate level of treated water service throughout the distribution system.

The seasonal variation in water demand over the course of the year is another important factor in assessing the applicability of ASR in a given water system. ASR enables a utility to store a large volume of treated water most often used to supplement seasonal peak water supplies. Water demands on the City of Laredo's system over the 4-year period of 1992 through 1995 were used to estimate the typical annual variation in water demands.

The historical raw water demand data indicate that over the 4-year period, approximately 12.5 percent of the raw water pumped into the treatment plants is lost. Evapotransporation of water in the treatment basins, in-plant water use, and meter discrepancies may account for some of the differences. The result is that approximately 88.5 percent of the water rights pumped from the Rio Grande are accounted for as treated water pumped into the distribution system for potable consumption.

Monthly average and maximum day treated water demands were used to calculate a demand factor, or ratio, of monthly demand to average annual raw water demand typical for the 4-year time period. Raw water demand was included in the calculation for comparison purposes and for subsequent use in adjusting the projected treated water demands back to raw water needs. The demand factor shown in Figure 3 is a multiplier that can be used to obtain values for the illustrated water demands. To interpret the figure, multiply the corresponding demand factor times the average annual treated water demand to obtain the required value. For example, if the average annual treated water demand for 1994 was 27 mgd, the expected monthly treated water demand for June would be 27 times about 1.1, or 30 mgd.

The demand pattern shown in Figure 3 indicates water demands are highest during the period from May through September, peaking in July. Low demand season typically occurs during the period from mid-October through April. It is important to note that average raw water demands are less than the treated maximum day demands. This indicates the need to either increase the raw water pumpage appreciably during maximum day demand periods, or rely on storage. Because the City's system does not have raw water storage capacity, frequent changes in raw water pumping rates appear to be required. An ASR system or other large volume reservoir system could serve to significantly reduce the variability of these pumping rates over the course of a season.

Based on increases in both population and water demand, the Texas Water Development Board (TWDB) along with the Texas Natural Resource Conservation Service (TNRCC) and the Texas Parks and Wildlife Department have identified the TWDB population projections that assume a migration rate of 1.0 as the most likely future growth scenario. Two TWDB projections through year 2050 are shown on Figure 4 and include average annual demand projections for: 1) below normal rainfall conditions with no water conservation and, 2) average rainfall conditions with advanced water conservation practiced. These two projections provide upper and lower limits for a range of scenarios developed by the TWDB.

Raw Water Availability

Surface water from the Rio Grande river is pumped by the City of Laredo under existing water rights. The City also has established a financing mechanism which is designed to build funds for the specific purpose of acquiring additional water rights. The City of Laredo currently holds rights to 39,837.133 acre-feet of municipal water rights from the Amistad/Falcon Reservoir system on the Rio Grande river. This water right is derived from the originally adjudicated water right and subsequent purchased water rights as shown in Table 1.

Table 1

Rio Grande Water Rights

City of Laredo
Certificate of Adjudication 23-3997

Date	Source of Right	Quantity (acre-feet)
8/14/85	Original Municipal Rights	28,420.000
1/11/93	Additional Municipal Rights	1,476.000
through	Converted Class A Irrigation Rights x 0.50	3,659.657
4/16/96	Converted Class B Irrigation Rights x 0.40	6,281.476
4/22/96	**Current Total Water Rights**	**39,837.133**

Laredo is located in Reach IV of the Middle Rio Grande or the portion of the river between Amistad and Falcon Reservoirs. The total amount of water in storage in this section of the Rio Grande is considered to be the total of the storage in both reservoirs, and water is continuously transferred from Amistad to Falcon Reservoir. There is usually sufficient water being transferred through the Middle Rio Grande to supply the requested diversions without making any specific additional releases from Amistad Reservoir to meet municipal diversion requests.

The City of Laredo requests their diversion from the Rio Grande by placing a weekly call to the Watermaster's office. For example, in May 1996, the City was requesting about 20,000 gpm or 44 cfs per week. This quantity will be gradually increased during the summer and decline again in the fall. The actual diversion amount is measured at the river pumping plant in Laredo. This amount is cumulatively charged against the City's water rights.

There is no maximum allowable diversion rate for the City's water rights, but they must balance current demands with expected future demands and attempt to end the year with at least a minimal balance in their water rights account. Therefore, timing diversions is not a critical issue, but total annual rights for diversion from the Rio Grande is potentially a significant issue. The municipal water right holders have never been prorated an amount of water in storage less than their full water right since the completion of the adjudication of the waters of the Rio Grande which began in 1983.

No-Charge Water

There are times when pumping may be designated as "no-charge" by the watermaster, or the diversion amounts are not charged against the permit holders' authorized amount of water rights. Because Amistad and Falcon are treated together in terms of total storage, this can only occur in the Middle Rio Grande when both Amistad and Falcon reservoirs are full. This has occurred one time since adjudication, and lasted from about October 1991, until April 1993, or for about 18 months.

Drought Considerations

The Rio Grande watershed and those who rely on the Rio Grande for water supply are currently experiencing a drought. Texas' share of storage remaining in Falcon Reservoir at the end of April 1996, was 286,180 acre-feet or 18 percent of the Texas conservation storage capacity. Texas' share of storage remaining in Amistad Reservoir at the end of April 1996, was 963,120 acre-feet or 54 percent of the Texas conservation storage capacity. These quantities are well above the minimum storage volumes identified in TAC, Title 30, Part I., Chapter 303, Operation of the Rio Grande, for the municipal reserve (225,000 ac-feet) and the operating reserve (275,000 to 380,000 acre-feet). The irrigation and other accounts are only allocated water after the municipal and operating reserves are satisfied. When the operating reserve drops below 150,000 acre-feet the watermaster may make negative allocations from the irrigation and mining accounts to bring the operating reserve up to 150,000 acre-feet. When the total irrigation allocation drops below 50,000 acre-feet, no water will be allocated for irrigation.

This system is designed to protect the municipal water rights holders, but does not insure that municipal rights will be fully available in a severe drought. The watermaster has the authority to prorate water rights or take other actions (set maximum diversion rates) necessary to prevent the waste of water or alleviate emergencies. There may be times when the full authorization of municipal rights may not be available due to the volume of water in storage. It is during these times that water stored in another system may be desirable to make up the difference in what is available from the river.

Water Rights Market

A free market in water rights operates along the Rio Grande in Texas. Water rights may be freely bought and sold under annual contracts or permanently between the Middle and Lower Rio Grande. Currently, municipal water rights cost $750 per acre-foot. As described earlier, Laredo's average raw water use has increased approximately 0.8 mgd or 900 acre-feet per year. This translates to approximately $675,000 per year in new water rights.

Laredo has adopted Ordinance 91-0-100 which authorizes the collection of funds related to development of new lots to cover the cost of acquiring additional water rights, or authorizes the developer to acquire the water rights for the lots to be developed. The City may take advantage of the opportunity to acquire significant water rights when water is plentiful and the demand is low, such as the period in 1991 and 1992 when there was no-charge water available.

Water Quality

The quality of the City's raw and treated water was documented through WTP records and State of Texas analyses reports. Analytical data from daily samples (January 1991 through October 1995) of raw and treated water were obtained from the City. Alkalinity, pH, calcium, magnesium, chloride, sulfate, hardness and turbidity were reported for the raw and treated water. The chlorine residual was reported for the clarifier, flocculator, and tap.

The State of Texas periodically collects water quality samples for general minerals from the City's system for water quality analysis. A partial set of these records was obtained from the City and is summarized in Table 2.

Analysis of the raw and finished water turbidity results indicate that water quality varies seasonally with pulses of high turbidity (greater than 100 NTU) water over several day periods being more common in late spring and fall (Figure 5). The high turbidity water is often more difficult to treat to below a regulatory standard of 0.5 NTU. Raw water turbidity values over 300 NTU were strongly correlated with finished water samples that exceeded the 0.5 NTU standard.

General ASR Applications

The above information concerning present and future water demands, water system capacities, water rights, and water quality variations was used to identify conceptually how an ASR system may apply to the City's long-term water needs.

The existing water system could utilize ASR capacity in the northern portion of Laredo to help meet peak demands from continued growth. If ASR is shown to be feasible through testing, this application could postpone or eliminate the need to construct a North Laredo WTP. An ASR application may also help alleviate flow or pressure constraints within the outlying portions of the distribution system and would allow the City to operate the WTP at a more even production rate.

Analysis of current and projected water demands indicates that approximately a 10-mgd ASR capacity could be utilized to help meet the City's seasonal peak demand. This rate represents the ASR storage and recovery capacity that could be utilized seasonally to maintain somewhat constant rates of production at the WTP. Furthermore, if the storage zone is capable of storing large volumes of water, long-term ASR storage may be useful in possibly extending the effective life of the current water right, as well as provide a large volume of water to meet emergency or drought demands. Aquifer storage could also be used to store large volumes of excess treated water during future no-charge periods, should they occur.

The evaluation of raw and finished water turbidity data suggest that another ASR benefit could be recovering treated drinking water to meet a portion of system demand when raw water quality makes treatment more difficult. This application would allow lower filter loading rates and ultimately higher quality leaving the WTP.

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NR = Not reported.

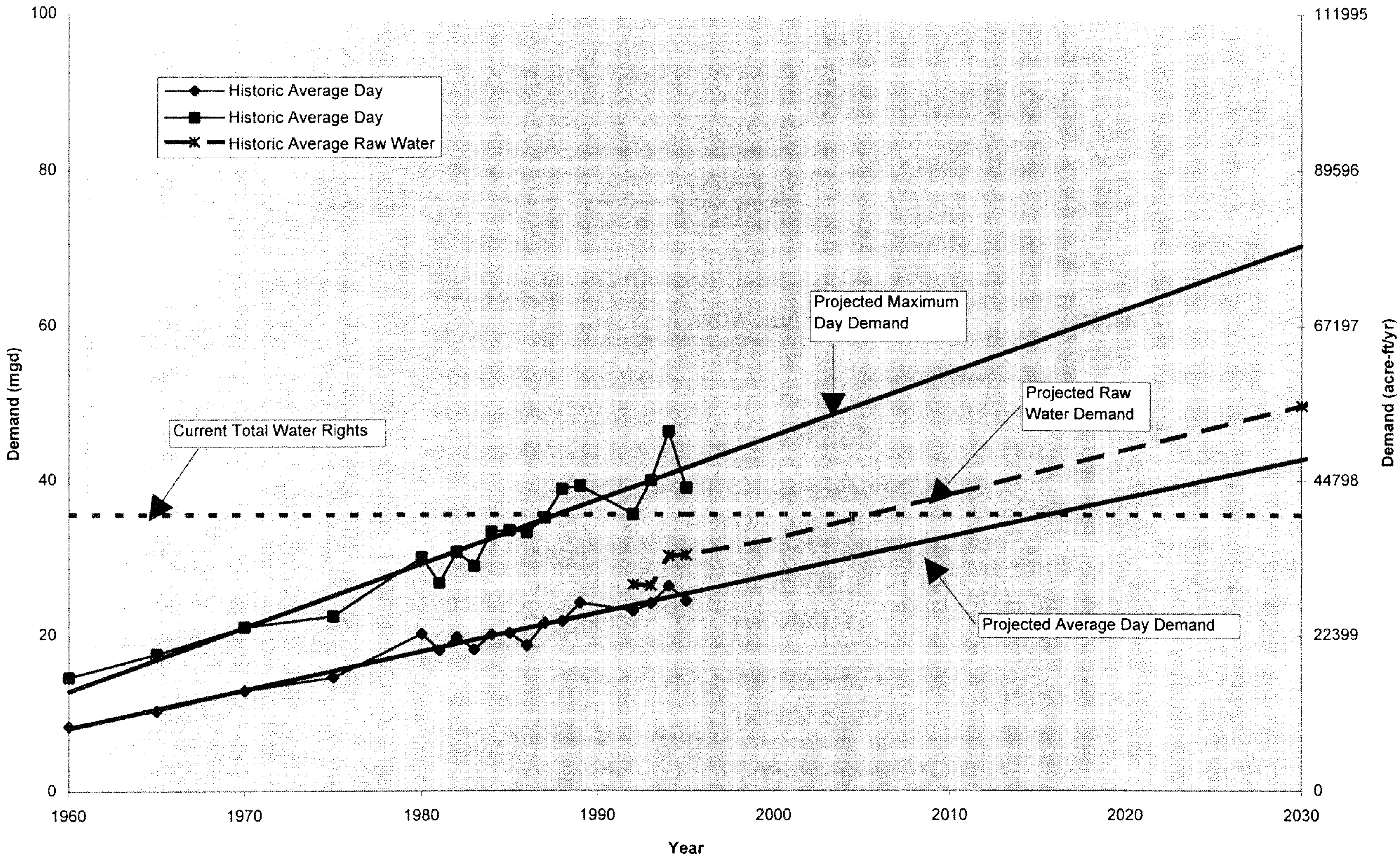

Figure 2 Historic Treated Water Demands and Linear Projections

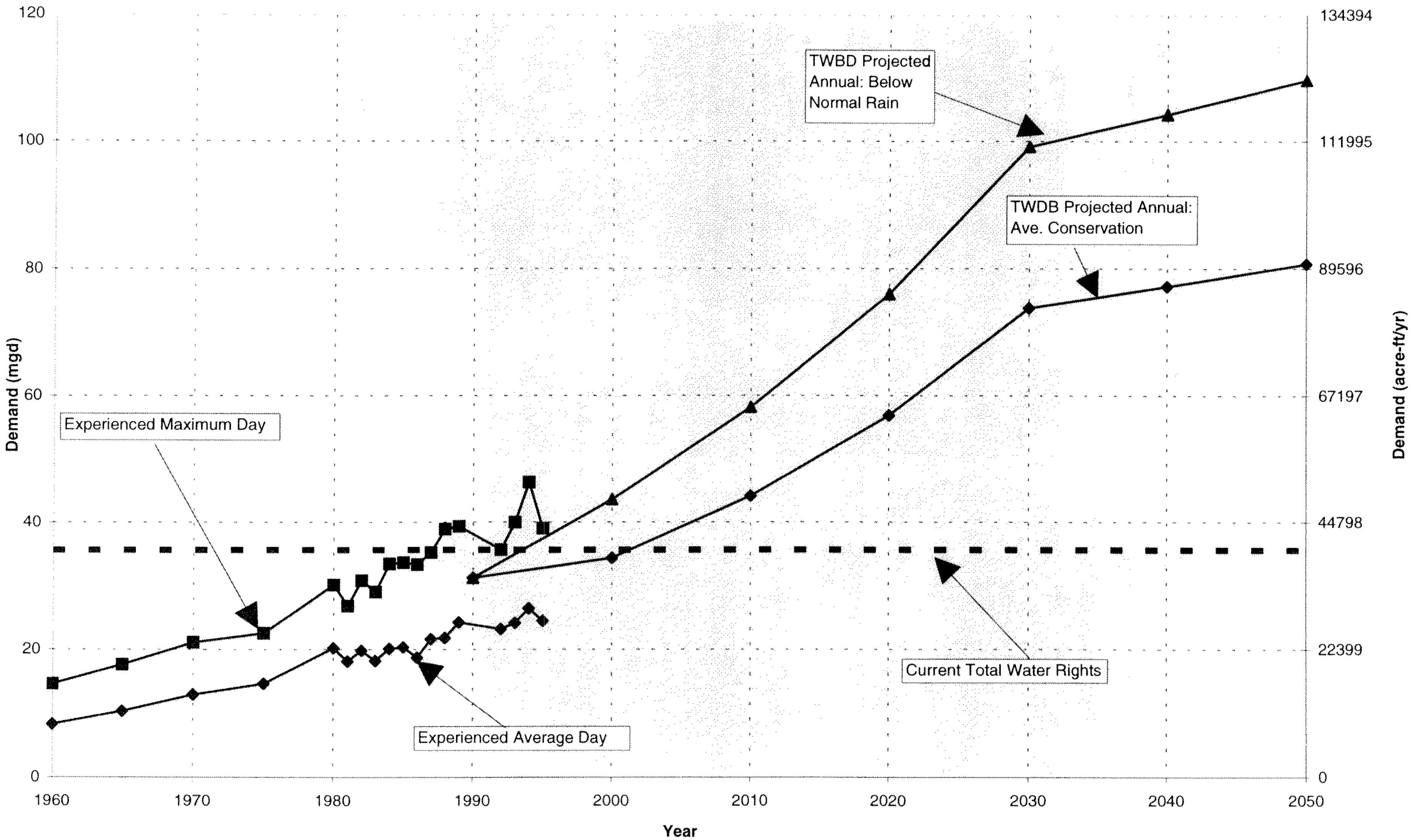

Figure 4 Historic Treated Water Demands and TWDB Projections

LARWTDMD.XLS/Figure 4

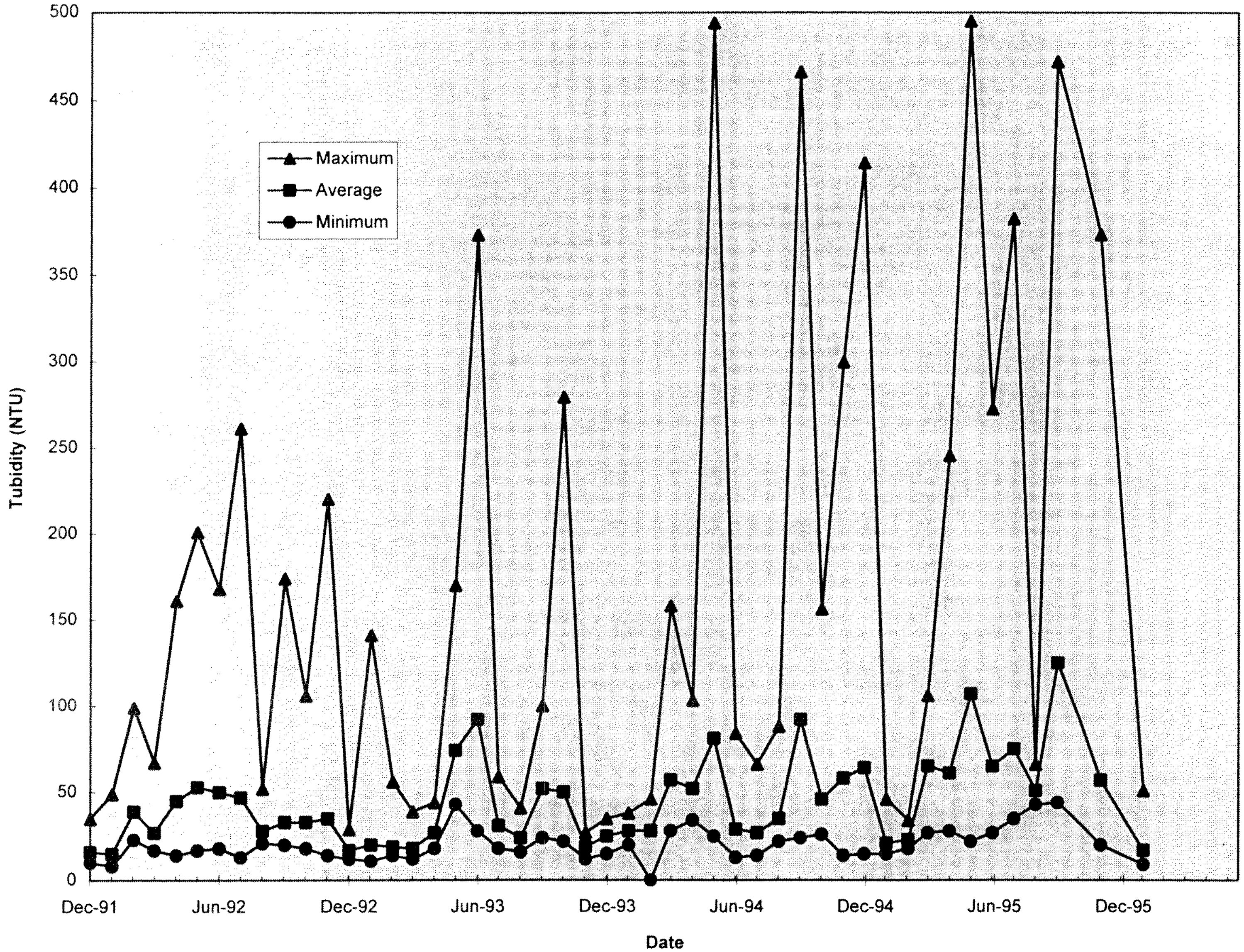

Figure 5 Monthly Raw Water Turbidity

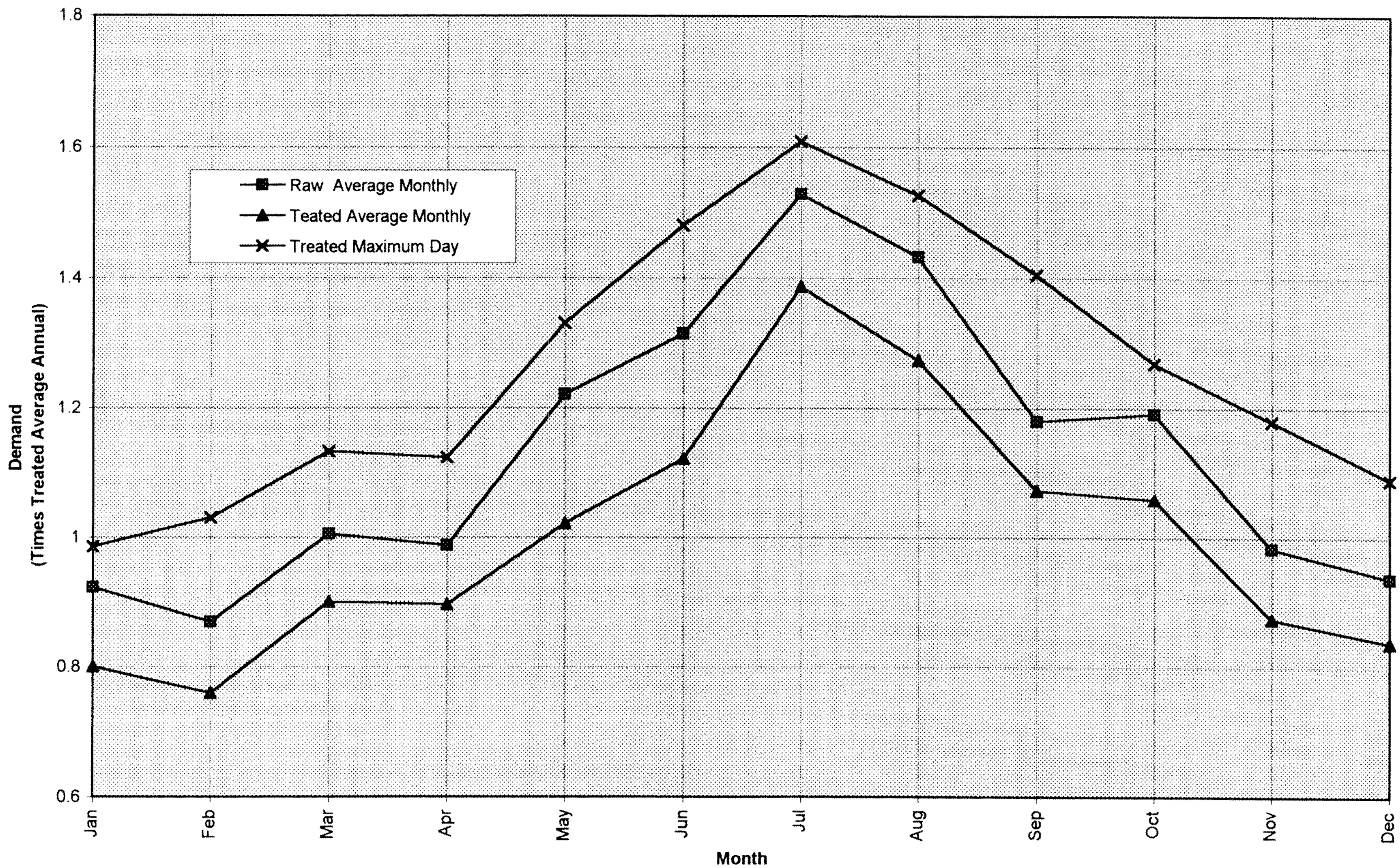

Figure 3 Seasonal Water Demand Variation: 1992 -1995

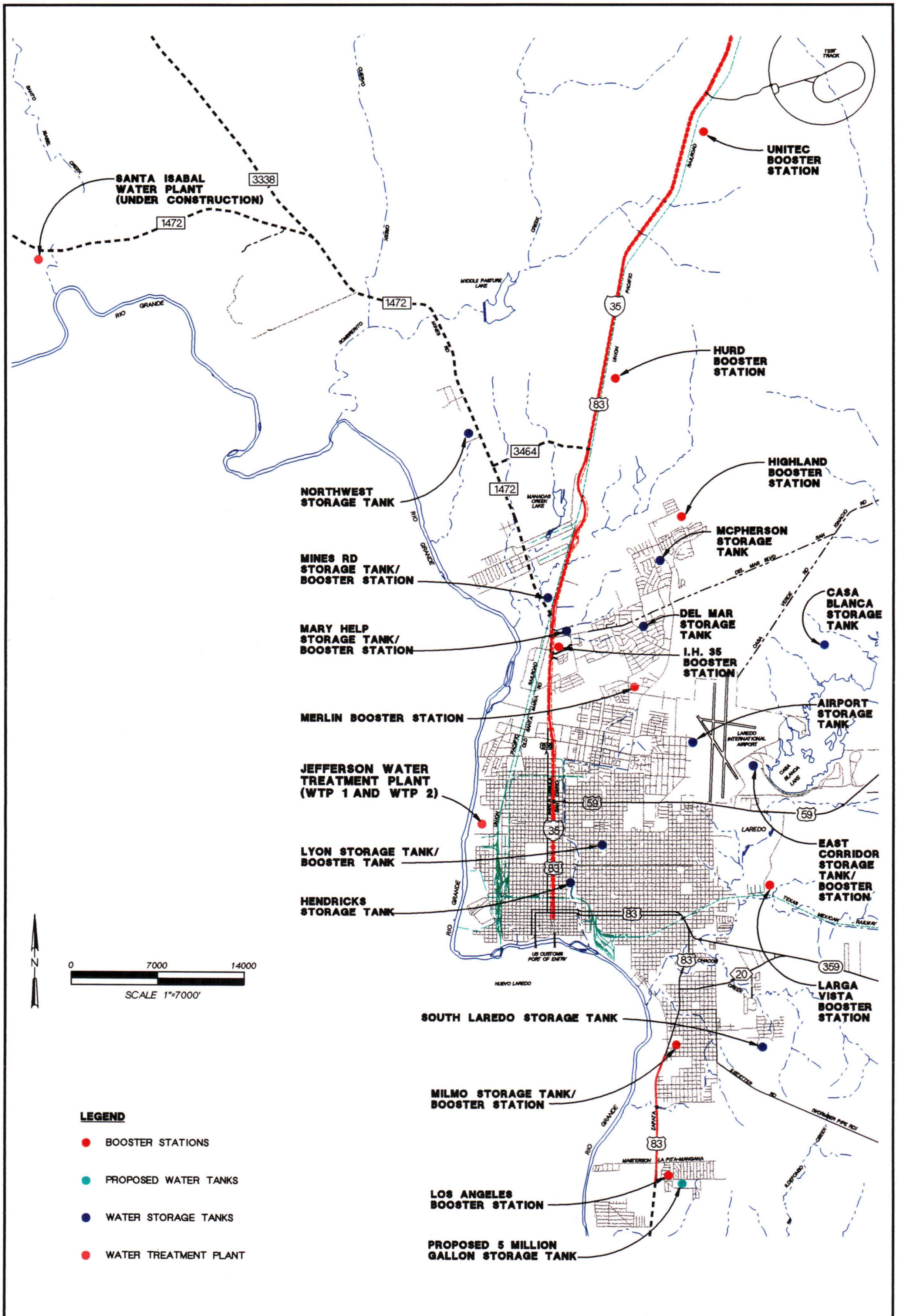

FIGURE 1
FACILITY LOCATIONS
AQUIFER STORAGE AND RECOVERY PROJECT
CITY OF LAREDO, TEXAS

CH2M HILL

8069MAP.DGN

Technical Memorandum No. 5
Potential ASR Applications

DEN/7946.DOC

Potential ASR Applications

PREPARED FOR: City of Laredo

PREPARED BY: CH2M HILL

DATE: June 18, 1996

Purpose and Scope

The City of Laredo has contracted with CH2M HILL to provide a Feasibility Investigation on the applicability of Aquifer Storage and Recovery (ASR) for their water supply system. The complete investigation considered water supply and demand issues, area hydrogeology, water quality, and geochemistry issues to evaluate the preliminary feasibility of ASR. This memorandum was prepared to present how ASR could potentially be utilized for the City considering the previous work.

The topics covered by this memorandum are as follows:

- ASR Conceptual Applications
- Potential ASR Rates and Volumes
- Preliminary Cost Opinion

ASR Conceptual Applications

Conceptual Operation

The ASR concept provides a utility with a large volume of treated water by using groundwater aquifers for storage. Large volumes of treated water are injected into wells when the water is available and later recovered by pumping the wells. The storage is typically applied seasonally by storing water over several months, or, in some applications, over several years.

The City of Laredo is experiencing growth and the associated increase in water demands. The City's current municipal water rights from the Rio Grande River are projected to sustain the water needs until approximately 2005. The water treatment capacity is currently being expanded to a total of 93 million gallons per day (mgd). When construction is complete in 1997, the expanded capacity is projected to supply adequate treated water until about 2015.

Aquifer Storage and Recovery could provide a method for the City to:

- Operate the water system at a more consistent rate and meet seasonal demand peaks with water treated and stored during low demand months

- Operate the filters at a lower loading rate during poor raw water quality events by recovering previously treated water to meet a portion of the demand or to blend with finished water approaching or exceeding turbidity limits

- Treat and store excess current annual water rights enabling the City to purchase more water rights when market conditions are more favorable
- Store large volumes of treated water to supplement longer term or drought demand
- Capture and store excess water during future no-charge water
- Balance distribution system pressure and flow during high demand periods by using ASR to substitute for, or augment, a booster pumping station and storage reservoir

Using conventional operational schedules, water treatment plant (WTP) operation may only run at maximum rates for several days during the peak demand months of summer. This type of operation leaves several months during the year of substantial unused plant capacity. By operating the WTPs at a more consistent rate somewhat higher than that needed to meet average demands, extra treated water could be produced for storage in ASR wells. This water could be recovered on an annual basis to meet peak demands in the summer, or to avoid poor raw water quality intervals following heavy storms.

In addition, ASR facilities may allow the City to store water to meet longer term objectives. To ensure a dependable water supply, the City must buy excess water rights to meet projected demands several years into the future. With ASR the City could divert its full annual water right, and treat and store the excess for later use, thereby extending the effective life of the existing water right. In addition, if ASR facilities were operational during a no-charge water period the City could divert and store as much water as the ASR system could hold for use in the future or to supplement water supply during drought periods.

Water Balance

Historical monthly flows were used to estimate the useful capacity of ASR and how it could potentially operate with the City's system. Historical water use patterns were used to develop typical monthly average and maximum day demands and to project future water demands. A monthly water balance was constructed by determining what rate of constant WTP operation would result in meeting annual average day demands. When average demand was below the constant WTP rate, the excess water was placed in ASR storage and when average demand was above the constant WTP previously treated water was recovered from ASR storage. In reality, operations would not be this simplistic but the exercise allows the estimation of system capacities. For 1997, the breakeven WTP operation rate was about 26.5 mgd and the maximum ASR capacity required was about 10 mgd.

The main limitation on Laredo is the availability and cost of obtaining water supplies to meet long-term and/or drought demands. To simulate long-term ASR operations, the above scenario was modified to operate at a higher, near constant (within 1 mgd per month) rate to treat the entire existing annual water right. The annual excess was placed into ASR storage. Water was recovered annually from ASR storage to supplement peak demands during the summer. The simulation indicated that a 10 mgd ASR facility could extend the effective life of the current municipal water right by at least 10 years.

In a drought, the watermaster could prorate municipal water rights. Estimating the frequency, duration, and severity of droughts in the Amistad-Falcon reservoir system area is beyond the scope of this report. However, the water stored in the long term ASR scenario presented above could benefit the City by providing up to one third of its average day demand (10 mgd) for several weeks or months during a drought.

It is important to note that the water balances were constructed for the purposes of estimating how ASR may work with the existing system and are not represented to be exact simulations. Actual system demands and operational procedures will dictate the actual monthly distribution of water and many different combinations are possible. Following actual ASR cycle testing and the determination of actual ASR rates and recoveries, it will be advisable to conduct a daily water balance simulation to assist with final system layout and design. However, the monthly water balance does demonstrate one potential way in which ASR can work with the existing system to meet higher demands longer into the future.

Potential ASR Rates and Volumes

System Rates

The *Water Demand and Water Availability Overview* (Technical Memorandum No. 4) and the above water balance work, indicates that the City's water supply system could benefit from an ASR system with a 10-mgd recharge and recovery rate. Currently, more than 7,000 acrefeet of excess municipal water rights are projected to be available. Each year thereafter lesser amounts are available until 2008 when the City will exceed its current municipal water right. Assuming ASR capacity could be developed by 1997, the City would need to recharge almost 5 mgd of water continuously for the year to use up the projected excess water right.

The water balance work indicates an ASR system with a maximum recharge and recovery capacity of about 10 mgd is optimum. The average recharge and recovery rate was estimated to be about 4 mgd. The maximum recharge rates would most likely occur during the winter when demands are the lowest and raw water quality is the highest. Maximum recharge rates would also be desired during no-charge water intervals whenever they occur. Maximum recovery rates would most often be during the summer months or during water quality or quantity emergencies.

Individual ASR Well Rates

Work completed for *Progress Report No. 1* on the Laredo area hydrogeology indicate three aquifer zones have potential for ASR applications: Laredo Formation, Bigford Formation, and Carrizo Formation. There was limited data available on the groundwater resources in the Laredo area due to limited use of the groundwater resources. The available data indicate that the aquifers have similar saline to brackish water quality and relatively low transmissivities. The deeper Bigford and Carrizo Formations have higher reported well yields (up to 500 gallons per minute [gpm]) due to more available drawdown. A review of available records indicates that wells completed in the Laredo Formation may yield approximately 300 gpm.

The capital cost difference between wells completed at the Laredo Formation and deeper formations is much greater than the increase in yield. For the above reasons, the Laredo Formation will be considered in the estimate of ASR well rates and overall system size. A drilling and testing program will be required to determine the actual yield of ASR wells completed into the Laredo Formation.

The geologic formations in the Laredo area get thicker but deeper to the southeast. The water bearing sands of the Laredo Formation are found at depths that range from 180 and 825 feet below ground surface. The depth to static water levels range from 12 to 225 feet below ground surface. To simplify calculations and cost estimates assumptions were made for a typical Laredo well, including:

- Average well depth of 650 feet
- Feet of screen
- Static water level of 100 feet
- Recovery rate of 300 gpm per well
- Recharge rate of 250 gpm per well

Using these assumptions, 24 total wells would be needed to supply 10 mgd of water. Several ASR wells could be constructed in different locations within the system to provide different benefits. ASR capacity could provide peak water in growing areas north and south of the City; postpone or eliminate the need for a WTP in the North Laredo area, provide blending water at the WTPs, etc. The most beneficial configuration of ASR wells and capacity can be decided after the drilling and testing program confirms the technical feasibility of ASR.

Injection into ASR wells is typically conducted at rates somewhat less than pumping. This is because of the desire to backflush wells at a rate higher than the injection rate for cleanout purposes. Additionally, the hydraulics of injection usually result in lower injection rates for a corresponding water level change relative to pumping. For these reasons, and to be consistent with the overall system capacities discussed previously, individual injection rates of 250 gpm were assumed.

Conceptual ASR System Configuration

The ultimate ASR system needs to be capable of injecting treated water into the selected storage zone. To accomplish this, the system needs to be located near a source of treated water with an adequate amount of pressure to inject at the required injection rates. This pressure is available in typical distribution system lines and these are assumed to be the source of water for ASR injection.

Recovery of the stored water will generally be back into the distribution system as finished water. It will be necessary to provide disinfection of the recovered flows, compatible with the other treated water in the system. There will also be times during the ASR operations where it will not be possible to return recovered water to the treated water pipelines. This will occur for several minutes following pump startup, and also during backflush times when the ASR wells are periodically pumped during injection to clean out the screens and wellbore. During these operating times, it will be necessary to either discharge the recovered water, or return the water to the WTPs for retreatment.

It follows that the ASR system requirements include a source of treated water at distribution system pressure, a disinfection facility, and either a line to waste or a raw water collection line returning to a WTP. For these reasons, the best places for the ASR system would be at the WTPs, storage tanks, or booster stations.

Hydrogeologic information indicates that the Laredo Formation underlying Laredo varies in terms of both aquifer hydraulic properties and water quality areally and vertically. It will be necessary to conduct substantial field testing to determine if ASR can work for the City, the best depth, and the best areal location for the ASR facilities. For the purposes of this conceptual ASR system configuration, the information currently known was used to evaluate where the most appropriate locations would be for the ultimate ASR facility. This conceptual configuration was developed to provide the City with an idea of how the system may result, and also to estimate general cost levels for system development and construction.

It is not possible at this time to estimate the required final well spacing or configuration for the ASR wells. Current information and experience with other ASR facilities suggest well spacing may be on the order of 800 to 1,200 feet. The well system configuration may be best aligned in rows along local groundwater gradient to allow downgradient capture of stored water if required.

The maximum conceptual ASR system capacity (10 mgd) is approximately one third of the City's average demand. This is approximately 15 to 20 percent of the current Jefferson WTP capacity but many times greater than the Columbia WTP capacity. The City's greatest need for ASR capacity is in the growth areas north and south of the City. For this reason, it is recommended to separate the total ASR capacity into several locations. Half of the capacity could possibly be developed at several strategic locations in the North Laredo area such the North West, McPherson, and Del Mar Storage Tank locations. Similarly, on the south end of Laredo, 5 mgd of ASR capacity could possibly be developed at the South Laredo Storage Tank and in the Los Angeles Booster station areas. In addition, ASR capacity at Jefferson WTP could provide many benefits if the geology is suitable and well interference effects from Nuevo Laredo are not expected. Due to the relatively low yield of individual wells, it would be most cost effective to construct ASR wellfields consisting of several wells sharing a common disinfection and the piping and controls needed to transmit the appropriate recharge and recovery flows. This type of configuration would provide the City added flexibility in system operation as ASR flows would be distributed through the system and not just hydraulically concentrated at one point.

Recharge flows at either of the WTPs would likely be transmitted off the high service piping leaving the WTP. Recovery flows from the ASR wells could be returned to the WTP, either upstream of, or into the clearwell to take advantage of mixing in the tank and existing disinfection facilities. Depending on WTP hydraulics at the time, it could also be possible to pump the ASR recovered water directly into distribution piping. The ASR facilities at the WTP would also include a recovery return line to pump water back through the treatment process. This line would probably be directed back to the raw water intake piping. Additional piping from the ASR facility to the sanitary sewer or other waste area may be required for more extensive well cleaning or testing. These requirements will be evaluated during initial ASR testing and can not be accurately estimated at this point.

ASR facilities located at elevated tank or other system locations would receive injection flows from the distribution system piping near each tank. Recovered flows would be directed back into the tank following disinfection to again allow the recovered water to blend with the system water at that point. It will be necessary to provide a discharge line to sanitary sewers at each tank located ASR system. This piping would be used to discharge initial flush water and the water produced during periodic backflush of the wells.

Another advantage to the City of developing the ASR system at several locations is the flexibility in construction. The City would be well advised to develop the ASR system in stages, adding capacity at different locations, as needed by existing distribution system hydraulics and other system needs. Following this path, the City can work out specific design issues on the first sites, and add sites as needed through the planning period.

Preliminary Cost Opinion

Preliminary costs for the conceptual ASR facilities discussed above were developed. The costs include the design and construction activities to implement the conceptual ASR system. It is assumed these activities begin following the completion of the previously discussed test drilling, and prototype ASR well construction and testing. The costs are considered preliminary in nature as they are based on several assumptions which could change the conceptual facility. These include actual injection and recovery rates sustained by the wells, the number of wells, piping distance requirements, and other assumptions. However, the following estimate was prepared to provide information to the City about the general level of costs associated with this system. The cost estimate is provided in Table 1.

The cost estimate was prepared by considering the major items required for each ASR location and estimating the general magnitude of costs for these items. Contingencies were then applied at 20 percent and engineering and testing costs were estimated at 15 percent of the total.

TABLE 1
Preliminary ASR Cost Estimate
City of Laredo, Texas

Item	Unit	No. Required	Estimated Unit Cost	Estimated total Cost
ASR Well 12-inch dia, 650 ft Total Depth, 100 ft Screen	Each	14	$65,000	$910,000
50 hp Wll Pump and Piping	Each	14	$12,000	$168,000
Collection and Header Piping	Foot	15,000	$32	$480,000
5 mgd Disinfection Facility	Each	1	$150,000	$150,000
I & C Allowance	Each	1	$300,000	$300,000
Miscellaneous Other Construction	10%	1		$201,000
Engineering and Testing	15%	1		$130,000
Contingency	20%	1		$126,000
Total for Each 5 mgd ASR Wellfield				**$2,465,000**
Total for 10 mgd ASR Capacity				**$4,930,000**

Table 2
Water Quality Analyses
City of Laredo
Laboratory: Texas Dept. of Health, Austin, TX

Parameter	Raw	WTP No. 1	WTP No. 2
	7/22/92	12/13/94	12/13/94
Calcium	70	72	81
Chloride	101	153	158
Fluoride	0.6	1	1
Magnesium	14	26	25
Nitrate (as N)	0.36	0.11	0.09
Sodium	94	158	169
Sulfate	184	269	302
Total Hardness (CaCO3)	235	285	304
pH (units)	7.4	8.1	8
Conductivity (umhos/cm)	1850	1467	1570
Alkalinity (CaCO3)	103	119	120
Bicarbonate	126	145	146
Carbonate	0	0	0
Total Dissolved Solids	531	755	813
Barium	0.078	0.0951	0.102
Iron	0.03	<.004	0.247
Manganese	<0.02	0.0018	<0.01
Aluminum	NR	0.221	3.85
Zinc	<0.02	0.0083	<0.02
Arsenic	<0.01	<0.002	0.0069

Note: Results in mg/l unless noted.
NR = Not reported.