Aquifer Storage and Recovery

Preliminary Investigation and Feasibility Analysis

Step 1 Report

Prepared for the

San Antonio Water System

And the

Bexar Metropolitan Water District

Prepared by

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Mr. Mike Brinkmann
San Antonio Water System
1001 E. Market St
San Antonio, TX 78205

Subject: Aquifer Storage and Recovery - Preliminary Investigation and Feasibility Analysis Report

Dear Mr. Brinkmann:

CH2M HILL is pleased to transmit this final Step 1 Report of the Aquifer Storage and Recovery (ASR) Feasibility Study. All review comments have been addressed and responses have been incorporated into the final report as appropriate.

This has been a very rewarding project and one that is important to SAWS and BexarMet. ASR is a viable and cost effective potable water storage option for both SAWS and BexarMet. This technology can reduce the peak withdrawal rates from the Edwards Aquifer during summer months, and provide long-term drought mitigation.

We look forward to working with SAWS and BexarMet on subsequent phases of this important project.

Sincerely,

CH2M HILL

Michael Anglea

J. Michael Anglea, P.E.
Project Manager

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Glossary

Alluvium. Deposits originating from the operations of rivers, including sediments laid down in river beds, fans at the foot of slopes, etc.

Anhydrite. A mineral consisting of anhydrous (without water) calcium sulfate.

Anion. An ion that bears a negative charge.

Aquifer. Any zone below the surface of the earth, which stores, transmits, and yields water in sufficient quantities for human use.

Aquitard. Geologic strata sufficiently permeable to transmit water vertically into or from a confined aquifer.

Artesian aquifer. An aquifer where the water is confined under pressure between two layers of confinement.

Argillaceous. Applied to all rocks or substances composed of clay minerals.

Artesian head. The measure of the pressure of groundwater in an artesian aquifer, or the amount of height the water level would rise above the top of the aquifer in a well.

"bad water line." The southern boundary of water in the Edwards artesian aquifer with a total dissolved solid concentration less than 1,000 milligrams per liter.

"bank" water. To store water underground, as in an ASR system, in amounts in excess of anticipated short-term recovery requirements to meet more long-term needs.

Base flow. Stream flow originating from groundwater discharge or groundwater runoff.

Bentonite. A sedimentary rock largely composed of the clay mineral montmorillonite. The rock has the ability to absorb large amounts of water and swell.

Bioclastic. Rocks consisting of fragmented organic remains.

Brackish. A description of water quality, used to indicate water with a moderate dissolved solids content (slightly "salty"). Often, brackish is used to describe groundwater with a TDS of 3,000 mg/L to 10,000 mg/L.

Buffer volume. In ASR operations, the stored volume in excess of the usable recovery volume as part of maintaining the storage "bubble."

Calcareous. Containing calcium carbonate.

Carbonate aquifer. An aquifer within carbonate rock. Typical carbonate rock includes limestone and dolomite.

Cation. An ion that bears a positive charge.

Chert. A variety of quartz that occurs in layers, lenses, or nodules in limestones and shales.

Cobbles. A classification of rock size between a pebble and a boulder, between 64 millimeters and 256 millimeters.

Colloid. A fine-grained material, such as clay, which is held in suspension.

Colluvium. Loose deposits at the foot of a slope or cliff brought on by the action of gravity.

Contamination potential. The susceptibility of an aquifer to contamination, usually from the surface. This is characterized by the amount of confinement protecting the aquifer from above and below.

Demand curves. A chart of water demands over time.

Disinfection by-product. A group of chemical compounds created as a result of disinfection of potable water, many of which are suspected cancer-causing agents.

Dip. The angle at which a geologic layer or stratum is inclined from the horizontal.

Distance-drawdown curve. A plot of the drop in water level versus distance from a well as a result of pumping.

Dolomite. A carbonate rock with a large proportion of magnesium, also known as magnesian limestone.

Drawdown. The amount of drop in water level from the original, or static, water level as a result of the pumping of a well.

Eh. The oxidation-reduction potential of water. Measured with a hydrogen electrode, in units of millivolts.

Evaporite. Sediments that are deposited as a result of the evaporation of the solvent, as with salts being left behind after the evaporation of seawater.

Fault blocks. A body of rock bounded by one or more faults.

Fault. Fractures in the earth's crust accompanied by movements.

Flaggy. Strata, or geologic layers, from 10 millimeters to 100 millimeters thick.

Flocculent. A substance that causes smaller particles to group, or clump together.

Fluviatile. Belonging to a river or produced by river action.

Formation contacts. The boundary between two geologic formations.

Fossiliferous. Containing organic remains.

Friable. Easily crumbled, as with rock that is poorly cemented.

Glauconitic. A green mineral commonly found in sedimentary rocks of marine origin.

Groundwater. Water contained underground within an aquifer.

Gypsum. A common mineral of evaporites, used in the making of plaster of Paris.

Hematite. A mineral that is the principal ore of iron.

Hydraulic conductivity. The volume of water at the prevailing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. Typically expressed in feet per day.

Hydrograph. A plot of water level, flow, or velocity as a function of time. With groundwater, a hydrograph is often used in the analysis of historical trends in aquifer water level.

Igneous rock. Rock formed by the solidification of hot mobile material called magma.

Indurated. Rock hardened by heat, pressure, or cementation.

Leached. A process in which a material is dissolved from a solid to a liquid through contact.

Leakance. Describes the hydraulic resistance of an aquitard and is equal to the hydraulic conductivity of the aquitard in the vertical direction divided by the saturated thickness of the aquitard.

Lenticular. Having the shape of a lens, with the maximum thickness in the center, and thinning towards the edges.

Lignite. A brownish-black coal originating from vegetal matter, which is further transformed than peat, but not as far as bituminous coal.

Limestone. A bedded sedimentary deposit composed primarily of calcium carbonate.

Limonite. A group of hydrous ferric oxides, which may include hematite.

Marl. A soft calcareous clayey rock easily weathered.

Mounding. The rise in water level as result of recharge to an aquifer, as with an ASR well.

Muscovite. A mineral that is a member of the mica group; includes colors of white, red, or green as found in granite.

Native groundwater. The groundwater that occupied the storage zone before ASR was initiated, also the groundwater that surrounds the ASR storage "bubble."

Native water quality. The measure of the water quality of the native groundwater; usually compared to the recharge water quality.

Outcrop. An exposure of bedrock or strata through the overlying soil.

pH. The measure of the acidity of water, with a pH of 7 being considered neutral. A lower pH indicates a more acidic solution.

Potentiometric surface. A surface that represents static head. As related to an aquifer, it is defined by the levels to which water rises in tightly cased wells.

Pyrite. A mineral known as "fool's gold" composed of iron and sulfur.

Raw water. Water that is used in its current state, without additional treatment.

Recharge. The injection of water underground for storage in an aquifer, as in ASR operations.

Recovered Water. Water pumped from an ASR well after recharge has occurred. Typically consists of a mixture of stored water and formation water.

Recovery. The withdrawal of stored water from underground.

Rock cores. Cylindrical samples of rock typically collected by drilling.

Sandstone. A cemented sediment composed of quartz grains.

Semi-confined. An aquifer bound by one or two aquitards.

Shale. A sediment formed by laminated material primarily of clay grade (less than 1/256 millimeters in size).

Siderite. A mineral composed of iron carbonate.

Siltstone. A very fine grained rock consisting of particles of silt grade (1/16 millimeters to 1/256 millimeters in size).

Specific capacity. A measure of well capacity defined as the amount of well yield per foot of water level drawdown in the pumped well.

Static water level. The groundwater level prior to the start of pumping.

Storage zone matrix. The surrounding rock of the storage zone.

Storativity. The measure of the volume of water yielded per unit horizontal aquifer area per unit drop in the piezometric surface (confined aquifers).

Stratification. The separation into layers, as with groundwater of different density.

Total dissolved solids (TDS). An indicator of a water's salinity, defined as the mass of dissolved solids per unit volume of water (commonly expressed in mg/L).

Transmissivity. The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient.

Unctuous. Having a fatty or oily appearance.

Executive Summary

The result of recent legislative and institutional changes affecting the management of the Edwards Aquifer is that use of the aquifer must be reduced from historical levels. Senate Bill 1477 passed by the Texas legislature in the 1993 legislative session mandated this reduction. The requirements of this mandate are being carried out through a withdrawal permit program developed by the Edwards Aquifer Authority. The mandate affects all users throughout the region regardless of the type of use. The Edwards Aquifer is the historical and sole source of supply of potable water for the major source for the San Antonio Water System and the Bexar Metropolitan Water District.

Both SAWS and BexarMet have put into place significant conservation and reuse programs with dramatic results. Per capita water use has been reduced significantly. SAWS is developing a program to recycle up to 35,000 acre feet of water from the water recycling centers. This represents a direct reduction in the amount of potable water needed from the Edwards Aquifer. Even so, future needs for potable water will continue to exceed the amount of water that is authorized to be withdrawn from the Edwards Aquifer. Any alternative supply of either groundwater or surface water will require treatment before distribution to users.

SAWS and BexarMet have undertaken the task of developing additional supplies of potable water from sources other than the Edwards Aquifer. BexarMet is developing a surface water supply from Medina Lake. And, SAWS and BexarMet have entered into an agreement with the Guadalupe Blanco River Authority to acquire a limited amount of potable water from Canyon Lake. SAWS is also exploring the possibility of acquiring Edwards Aquifer withdrawal rights from other authorized users.

From a water management standpoint, SAWS and BexarMet desire to minimize the impact on Edwards Aquifer water levels resulting from pumping during the summer periods. An additional goal is protection against severe Edwards Aquifer withdrawal limitations put in place during extended periods of drought.

In order to accommodate the goals of SAWS and BexarMet, an on-demand source of potable water from other than the Edwards Aquifer is required. This on-call demand can be satisfied by either providing peak demand capacity in treatment and supply facilities or significant volumes of stored potable water that can be drawn upon during periods of peak demand. Protection from periods of extended drought will most likely require storage of large volumes of either raw or treated water, regardless of the source of supply. During periods of extended drought, it is likely that alternative supply sources will also be stressed and may be limited.

Traditionally, large volumes of raw or potable water have been stored in natural or man-made surface water lakes or reservoirs. In today's environment, the permitting and development of surface storage facilities is very costly and takes many years. An alternative to surface storage of large volumes of water is aquifer storage and recovery (ASR). ASR is the recharge of treated drinking water into an aquifer, which acts as an underground storage reservoir. As needed, water is recovered from natural storage in the aquifer. The same well is used for both recharge and recovery.

Recharge of water usually takes place when available water exceeds demand and when water quality is acceptable. Recovery occurs during "dry" periods to meet peak or emergency demands caused by long-term drought conditions, limited treatment plant capacity, or by poor raw water quality. Upon recovery, disinfection is usually the only supplementary treatment required. Typically, all of the stored water is recovered.

ASR technology has been in use for many years in different forms and applications. ASR is being used extensively on the eastern coast of the United States, throughout Florida, and in California. The technology is also being used in inland regions for potable water storage. A potable water storage ASR facility was developed in Kerrville, Texas, for the Upper Guadalupe River Authority in the early 1990s. This is the only operating direct potable water ASR facility in Texas today. Feasibility studies for Brownsville, Laredo, Austin, Fredericksburg, and for the Lower Colorado River Authority are in various stages.

In the summer of 1996, SAWS and BexarMet submitted a joint grant application to the Texas Water Development Board (TWDB) to assist in the funding of an ASR Feasibility Investigation. The report that follows presents the findings and recommendations of the first step of a three-step investigation. This phase has consisted of assembling and evaluating existing information relating to historical and projected water use, water availability, alternative sources of water, future permit limitations, existing well development data, and the characterization of the geologic formations within Bexar County. The purpose of this initial phase has been to determine, with a limited commitment of time and financial resources, whether SAWS and BexarMet could benefit from the use of ASR technology and whether the chemistry of the potential source water and the geochemistry of the various groundwater storage zones are compatible.

The findings of the Step 1 investigation indicate that there is a beneficial use for ASR in SAWS' and BexarMet's future water strategy. This use can be for the storage of potable water in remote parts of the service areas where distribution systems may be limited in capacity. ASR can also reduce summer peak withdrawal of water from the Edwards Aquifer and large volume storage of potable water can be achieved as long-term drought protection. Finally, ASR can be used as a method to store supplies of water available to SAWS or BexarMet during periods when the supply exceeds demand. This will allow SAWS and BexarMet to make maximum use of their permitted water supplies.

Preliminary analyses indicate that the maximum use of ASR for SAWS and BexarMet would be 28,000 ac-ft/yr and 9,000 ac-ft/yr, respectively. This would allow both agencies the opportunity to maximize the utilization of their permitted water rights while minimizing the impact of withdrawals from the Edwards Aquifer. Larger ASR storage capacity is possible and could provide protection during extended periods of drought. The cost of ASR stored water ranges from $82 per acre-foot to $398 per acre-foot.

There are many potential groundwater storage zones underlying Bexar County. These have all been evaluated and the most promising have been identified and recommended for further evaluation in subsequent phases of the investigation.

The next phase of the investigation will consist of the development of a series of test wells into the preferred geologic formations to confirm formation characteristics and further evaluate, through laboratory analysis, compatibility of potential source waters and the geochemistry of the various formations.

A third and final step to the feasibility investigation is the development of one or more prototypical ASR wells. These would be full sized injection and recovery wells that would confirm full scale compatibility. These wells would be fully operational and become the initial ASR wells in a complete system of wells.

Section 1 Introduction

Overview

The availability and quality of water for the San Antonio region has long been a topic of discussion and significant legislative and legal action. The entire region of the Edwards aquifer is now under the jurisdiction of the newly established Edwards Aquifer Authority (EAA). The EAA has as its principal guidance Senate Bill 1477 as passed by the 1993 Texas Legislature. As a result, users of the Edwards aquifer, (irrigators, municipal, commercial, and industrial) are being required to obtain permits for future use. Additionally, SB 1477 requires a phased reduction in overall pumping from the aquifer. At the same time, San Antonio Water System (SAWS) demands and Bexar Metropolitan Water District (BexarMet) demands are projected to increase by 46 percent and 82 percent, respectively, over the next 20 years. Development of alternative sources of potable water supplies and storage strategies will be necessary to ensure the continued economic sustainability of the region.

The San Antonio area has made significant progress in reducing the per capita demand. Over the past few years, while the region has been growing, the daily per capita demand has actually declined. Water conservation initiatives, such as public education, plumbing fixture retrofits, and greater use of native landscape materials, are largely responsible for this reduction.

Storing water for seasonal needs and long-term drought situations would reduce the demand on the Edwards aquifer when Comal and San Marcos springs are experiencing low flows. However, large volume storage in ground level tanks or surface reservoirs is costly. Also, long lead times are required to permit and construct surface water reservoirs and environmental impacts can be prohibitive.

One strategy to enhance availability of potable water supplies is a water management technique known as aquifer storage and recovery (ASR). The ASR concept works by storing water through wells constructed in water bearing geologic formations. Water is typically produced for storage during times of the year (or long-term drought cycle) when excess supply or water treatment capacity is available. When water demands are high and supplies are insufficient to meet demands, the stored water is recovered from the same wells, redisinfected, and distributed. The ASR concept works well when an abundance of water is available for a limited period. Experience with ASR systems has also demonstrated that ASR systems can typically be implemented for substantially less cost and impact to the environment than conventional alternatives to meet peak water demand or provide large volume storage.

This report represents the findings of the first phase of the ASR investigation for management of the SAWS and BexarMet potable supplies. The investigation relied exclusively on existing information including water use records, existing population and demand projections, geologic and hydrologic reports and databases, verbal communication, and other associated information. Results suggest that ASR may be a viable option for SAWS and BexarMet to meet future water demands at a lower cost than other alternatives under consideration. However, this conclusion is based on several assumptions that must be verified through field testing as part of a Phase II program. The subsequent sections of this report describe conceptually how ASR could be implemented to provide a significant portion of future water demands. Also included are approximate costs for implementation and steps necessary to confirm the proposed operation.

Report Organization

This investigation was documented in a series of technical memoranda that address topics necessary to evaluate ASR feasibility and develop conceptual applications. These memoranda are included in the appendices to this report. The report sections that follow summarize the more detailed memoranda and focus the findings toward ASR feasibility and applications for the San Antonio area. Technical memoranda included in the appendices are listed as follows:

- Source Water Assessment
- Groundwater Assessment
- ASR Applications and Feasibility
- Water Storage and Supply Options
- Underground Injection Control and Surface Water Use Permits

Section 2 Source Water Assessment

The SAWS and BexarMet water supply systems share similar characteristics. Both currently rely solely on groundwater, with SAWS using wells in the Edwards aquifer exclusively. BexarMet draws lesser amounts from other aquifers such as the Trinity and Carrizo-Wilcox in addition to the Edwards.

Description of the San Antonio Water System

The SAWS service area is divided into 14 service levels that represent the pressure planes needed to provide adequate system pressures. Pumping capacities for each service level are shown in Table 2-1. Transfers between service levels are limited to moderate volumes of water moved between adjacent levels. It is currently not possible to move large volumes of water quickly from one side of the system to the other. Generally, water demands are met with wells local to the demands. All of the SAWS service area is contained within Bexar County (Figure 2-1).

Table 2-1 SAWS Pumping Capacity

Service Level	Primary Pumping Station Capacity (million gallons per day)		Secondary Pumping Station Capacity (million gallons per day)
	High Service	Wells	Wells
3	183	200	0
4	217	171	47
5	42	48	22
5A	30	64	0
6	52	102	5
7	110	103	4
8	8	5	8
9	0	0	5
Total	**642**	**693**	**91**

Note: Service Levels 1, 2, 10, 10A, 11, 11A, and 14 do not have wells. Booster pumping from adjacent levels is used to meet water demands for these levels.

Description of the BexarMet Water System

The BexarMet service areas, shown in Figure 2-2, represent geographic divisions of the water system. The service area boundaries are not contiguous, so it follows that water cannot be moved between service areas. The service areas are supplied by individual wells or well groups that pump into storage tanks or directly into the distribution system. Pumping capacities for each service area are shown in Table 2-2.

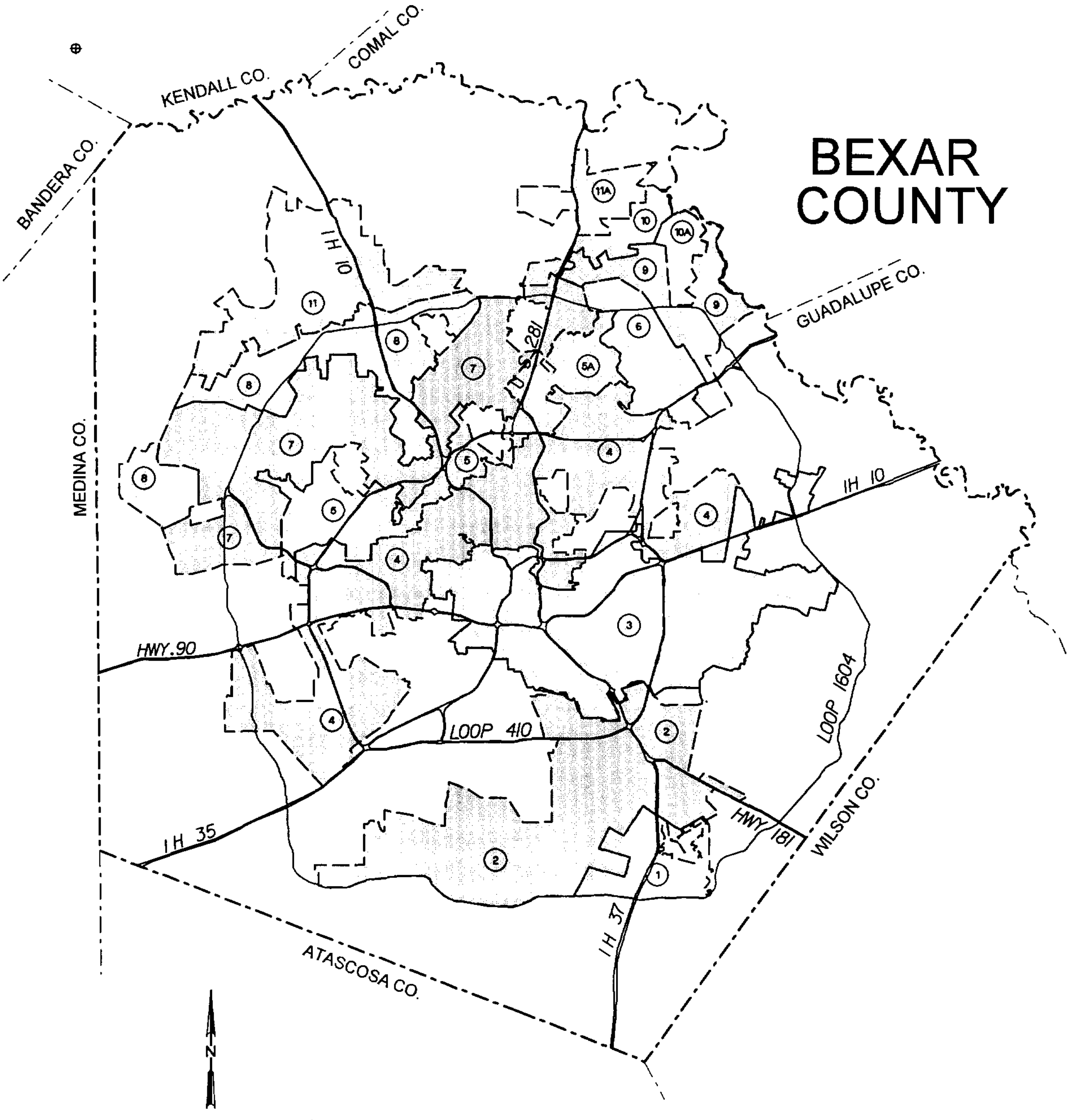

FIGURE 2.1
SAWS Service Levels

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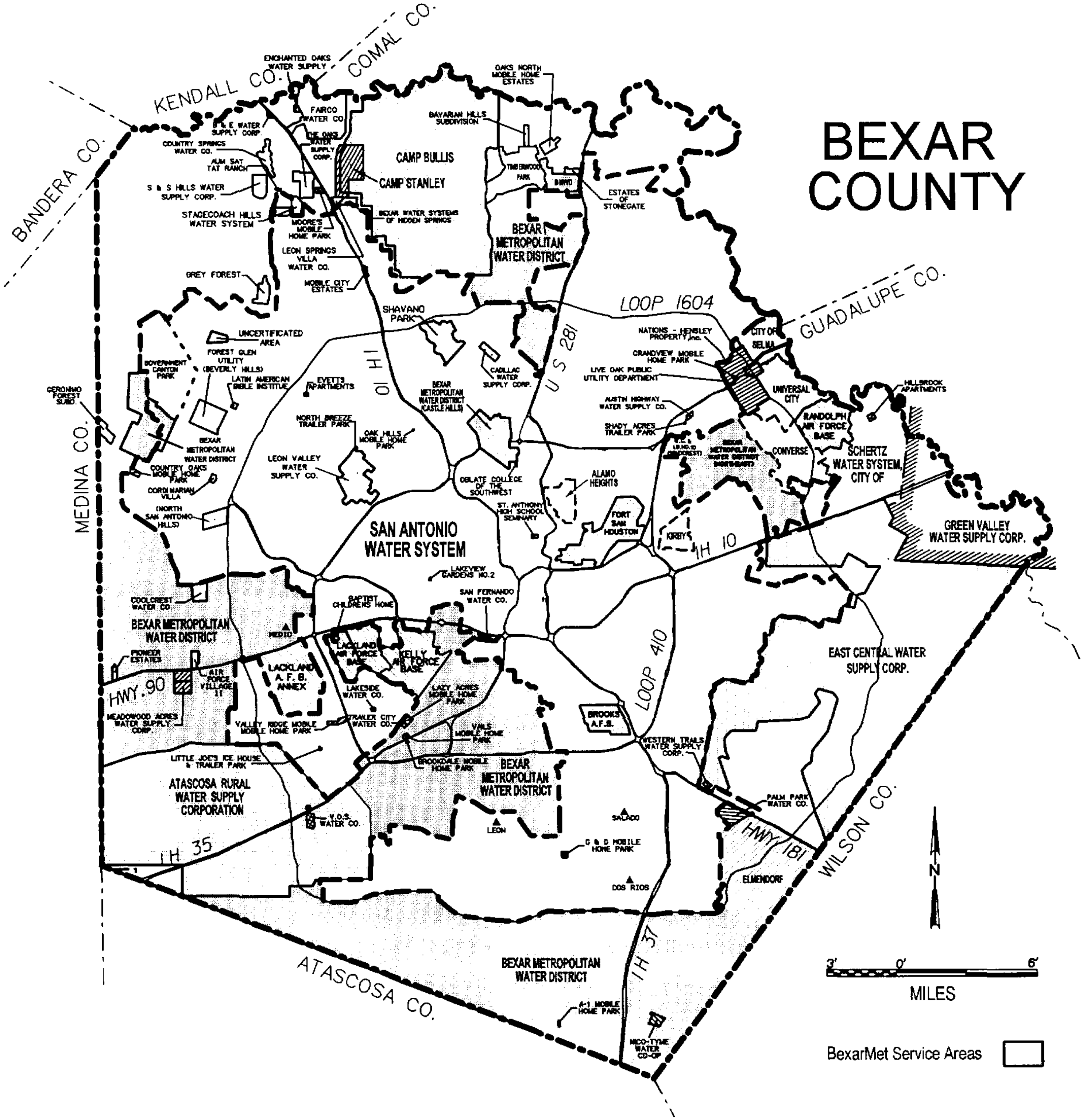

FIGURE 2.2
BexarMet Service Areas

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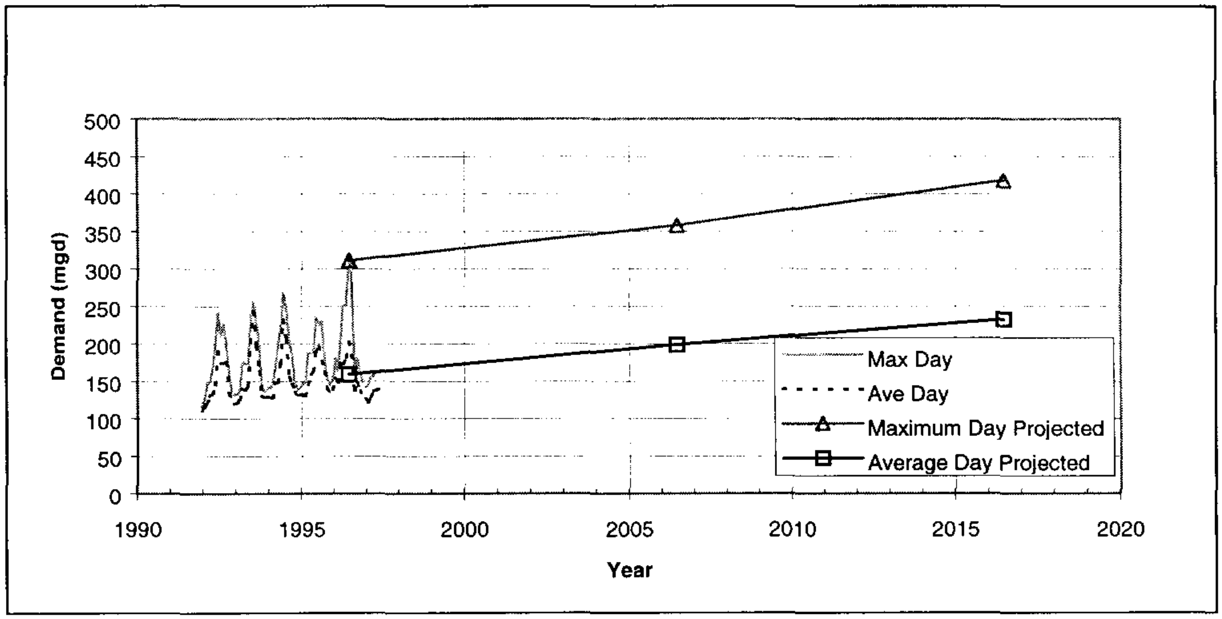
Table 2-2 BexarMet Pumping Capacity

Service Area	Well Capacity (million gallons per day)
Castle Hills	11.9
Hill Country	10.7
Northeast	18.8
Total Northwest	12.0
Southeast	2.6
Southside	54.1
Total	**110.1**

Historic and Projected Water Demands

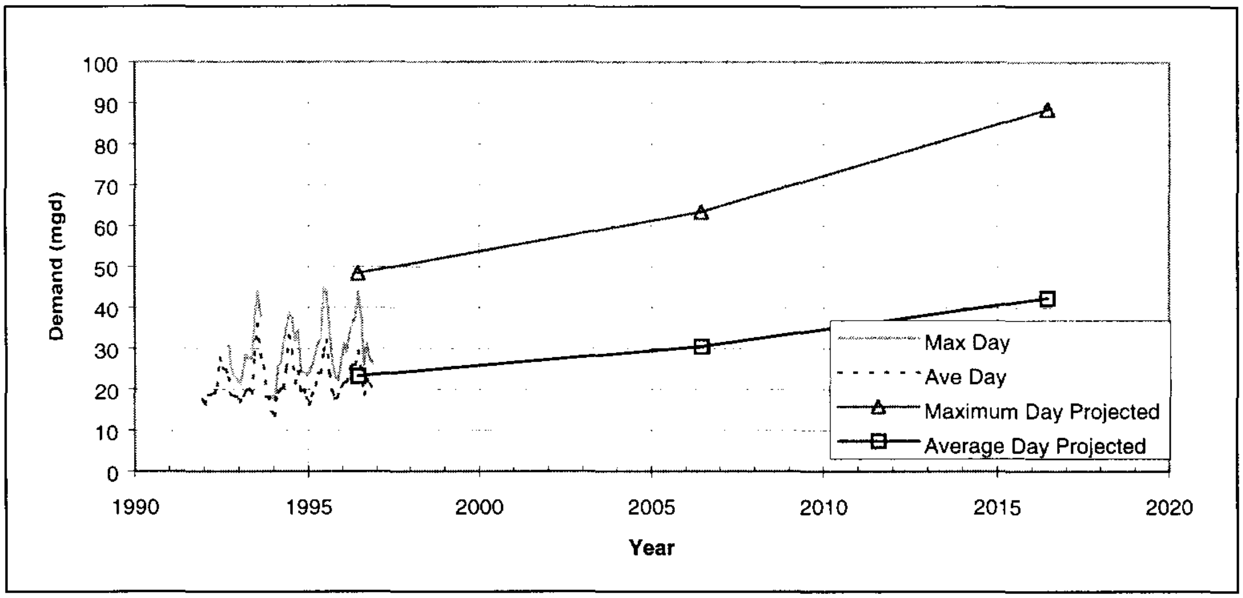
Figure 2-3 shows historic and projected demands for SAWS. A ratio of maximum day to average annual demand of 1.80 was used to develop future demands. SAWS has sufficient *pumping* capacity (total well capacity of 784 mgd) to meet the projected maximum day demand of 418 mgd for the year 2016.

FIGURE 2-3 SAWS HISTORIC AND PROJECTED DEMANDS



The same information for BexarMet is shown in Figure 2-4. A ratio of maximum day to average annual demand of 2.1 was used to project future demands. Like SAWS, the BexarMet system has sufficient *pumping* capacity (total well capacity of 110 mgd) to meet the projected maximum day demand of 88.5 mgd for the year 2016.

FIGURE 2-4 BEXARMET HISTORIC AND PROJECTED DEMANDS



Future Regulatory Requirements

The Edwards Aquifer Authority (EAA) is currently developing rules to regulate groundwater withdrawals from the Edwards aquifer. The purpose of the rules is to protect this natural resource and, in doing so, to protect the related social and economic interests dependent on the aquifer.

The aquifer rules require permits for most groundwater users and will set limits on the volume of groundwater that may be withdrawn on an annual basis. The limits will take the form of maximums and the amounts are subject to Critical Period Rules.

Critical periods (defined as periods of low aquifer levels) are identified in the EAA rules. The critical periods will be tied to water levels in three benchmark wells, which represent average aquifer conditions in three geographic areas of the aquifer.

Potential Alternative Water Supplies

SAWS and BexarMet must develop alternative sources for future water supply. This is a part of the SAWS Water Resources Strategy which is developed around a commitment to properly manage the water resources of the Edwards Aquifer. At this time, selecting future sources of supply is only at the conceptual stage. The most discussed near-term sources of surface water supply are Canyon Lake, the Guadalupe River, the Medina River, Medina Lake, and Lake Dunlap. The SAWS and BexarMet water resources strategy includes a commitment to managing the water resources of the Edwards Aquifer.

Although each of these potential supplies is a possibility, there are significant institutional, water rights, and water quality issues unique to each source. In each case, treatment of the surface water to potable standards would be required. Each potential supply also has its own limitations relative to existing water rights and jurisdictional control. It is noted, however, that SAWS has entered into an agreement with the Guadalupe Blanco River Authority (GBRA) to participate in a project to bring treated water from Canyon Lake into Western Comal County as well as the Bexar County area. Other water purveyors are expected to participate in this project. However, the 2,000 acre-feet per year of water BexarMet and SAWS will receive from this project are only a small fraction of the amount required annually by SAWS and BexarMet customers. This project does, though, represent a breakthrough in inter-agency cooperation to resolve a long-standing regional water supply shortage. This project illustrates a long-standing benefit resulting from regional, interagency cooperation for solving regional water and environmental issues.

BexarMet, in cooperation with the Bexar Medina Atascosa Counties Water Control and Improvement District #1 (WCID #1), has been successful in amending the Medina Lake water use permit to allow a portion of lake water to be developed as a drinking water supply. BexarMet has developed a water treatment plant on the Medina River to take advantage of this source.

Additionally, BexarMet has contracted with Canyon Regional Water Authority for up to 4,000 acre-ft/year of treated water from the Authority's Lake Dunlap Plant. This water may be used in BexarMet's Northwest Service Area and others.

A cooperative approach is key/critical to address the regional water supply issue. As regional water supply planning proceeds under Senate Bill 1, other source water supply options will be identified and evaluated. Canyon Regional Water Authority is a potential BexarMet supplier.

ASR Applications

If these future sources are developed to include an ASR system, several benefits could result. Generally, the alternative supply sources could be stored in other area aquifers during times of surplus and withdrawn to supplement permitted Edwards aquifer base and maximum withdrawals. Specific examples include storing seasonal stream flows during high runoff events, storing higher quality waters when production quality and quantity can vary seasonally, or capturing and storing other waters that would go unused if large volume storage were not available.

Many ASR applications store water for later use to meet peak or maximum day demands. In these applications, water production facilities generally have inadequate capacity to meet the high peak production rates required for the short duration maximum day events. Constructing and operating ASR wells to meet peak demands allows for smaller conventional water production and treatment facilities. Resulting cost savings can be substantial.

The SAWS and BexarMet systems currently have considerable excess peak pumping capacity. If the water systems were allowed to pump their wells without restriction, moving water from one service area to another within each system would be the major planning concern for ASR.

However, the EAA regulations will limit both water systems to a maximum annual withdrawal from the Edwards aquifer and critical period restrictions may further limit production during drought years. A potential ASR application in this case could include supplementing peak period base flows with ASR pumping, thereby reducing peak day withdrawals from the Edwards aquifer. By adding ASR pumping to the base flow, the portion of the Edwards pumping contributing to the maximum day production would decrease and could even fall within the restrictions during critical periods.

Section 3 Groundwater Assessment

Of equal importance to source water considerations in successful implementation of ASR is the selection of a suitable storage zone. The Groundwater Assessment includes a general characterization of the geologic formations of Bexar County, a description of the principal aquifers of Bexar County, and a preliminary screening of the available storage zones to identify the most promising aquifer storage zones in the study area. General geochemical compatibility of the selected storage zones and various source waters is also evaluated. A complete copy of the Groundwater Assessment Technical Memorandum can be found in the Groundwater Assessment appendix.

Study Area

Bexar County, which defines the study area, is located in south-central Texas approximately 125 miles northwest of the Gulf of Mexico and 125 miles northeast of the Texas-Mexico border. Bexar County, comprising approximately 1,250 square miles, is bordered on the southeast by Wilson County, on the southwest and west by Atascosa and Medina Counties, and on the north and northeast by Bandera, Kendall, Comal, and Guadalupe Counties.

The topography of Bexar County can be divided into three general geologic provinces (from north to south): the Edwards Plateau, the Balcones Fault Zone or Balcones Escarpment, and the Gulf Coastal Plain (Arnow, 1959). The Balcones Fault Zone, which divides the Edwards Plateau from the Gulf Coastal Plain, is a series of primarily normal faults that trend from the southwest to the northeast across the central part of the county. Major drainage features crossing the Balcones Fault Zone include the San Antonio River and tributaries of the Medina River and Cibolo Creek. The plateau, which also dips slightly to the southeast, serves as the headwaters for numerous small streams and creeks, including Cibolo, Balcones, Culebra, Leon, and Salado creeks. The Gulf Coastal Plain dips into the southeast inside the study area at an approximate rate of 150 feet per mile. The coastal plain is primarily drained by the San Antonio River, the Medina River, and by Cibolo Creek.

The climate in Bexar County is generally warm and semi-arid with mild winters and hot summers. Winter temperatures average 10 degrees Celsius (°C) with infrequent freezes, and summer temperatures average 29° C with daily maximums generally in excess of 32° C. The average precipitation in San Antonio is just over 30 inches per year with the greatest rainfall occurring during May, June, September, and October.

Geology and Hydrogeology of Bexar County

The following geologic descriptions for formations in Bexar County have been adapted from Arnow, 1959; Ashworth, 1983; Barnes, 1983; Marquardt and Rodriguez, Jr., 1977; and W.E. Simpson Co., 1993. The nomenclature used in this report is consistent with that used by the Bureau of Economic Geology, as presented in the *Geologic Atlas of Texas, San Antonio Sheet, Revised 1983*. For clarification, formations with more than one commonly used name are listed with both names. Table 3-1 summarizes the characteristics of the geologic formations of Bexar County.

General water-bearing characteristics of the geologic units, including typical well yield and water quality, are presented as an indication of the potential for ASR development. The following categories are used to describe the general ranges of these parameters:

Well Yield

Small:	Less than 100 gallons per minute (gpm)
Moderate:	100 to 500 gpm
Large:	More than 500 gpm

Water Quality

Good:	Less than 1,000 milligrams per liter (mg/L) total dissolved solids (TDS)
Moderate:	1,000 to 3,000 mg/L TDS
Poor:	3,000 to 10,000 mg/L TDS
Saline:	Greater than 10,000 mg/L TDS

The eight major aquifer units in the Bexar County study include (in descending order):

- Carrizo aquifer
- Wilcox aquifer
- Austin Chalk aquifer
- Edwards aquifer
- brackish Edwards aquifer
- upper Trinity aquifer
- middle Trinity aquifer
- lower Trinity aquifer

Figures 3-1 and 3-2, cross-section C-C′, are generalized north to south cross-sections through the central part of the county. Figure 3-3 shows the location of the cross-section and the location and designation of wells used to create the cross-section. The cross-section was generated from geophysical log data acquired in the general vicinity of the section and is an approximate representation of county geology. The attached Groundwater Assessment Technical Memorandum summarizes the location and references for data used to develop the cross-section.

Geologic formations, major faulting, and principal aquifers are identified on the cross-section. Formation contacts are dashed due to the general and approximate nature of the section. Major faults mapped by the Bureau of Economic Geology are presented as solid lines. Faults that were interpreted based on changes in formation elevation are dashed.

Preliminary Storage Zone Evaluation

Existing hydrogeologic and water demand estimates were incorporated into an evaluation matrix developed to help identify the most promising storage zones in the study area. The matrix presents the estimated parameter range for six criteria relating to the feasibility of

Table 3-1

Geologic Formations and Their Water-Bearing Properties

System	Series	Group	Stratigraphic Unit	Hydrologic Unit	Approximate Thickness	Character of Material	Water Supply Properties
Quaternary	Holocene and Pleistocene		Alluvium (Qal) Fluviatile Terrace Deposits (Qt) Leona Formation (Qle)	Discontinuous Surfical Aquifer	45	Floodplain deposits, gravel, sand, silt, and clay	In places yields water for stock and domestic wells
Quaternary or Tertiary	Pleistocene or Plicene		Uvalde Gravel (T-Qu)	NA	25	Caliche cemented gravel with well rounded cobbles of chert, quartz, limestone, and igneous rock	Not known to yield water to wells in Bexar County
Tertiary	Eocene	Claiborne	Queen's City Sand (Eqc)	Aquifer	100	Sandstone and siltstone, fine to medium grained, massive, well sorted, noncalcareous, may be finely laminated or crossbedding	Yields moderate supplies of potable water
			Reklaw Formation (Er)	Confining	50-200	Sandstone and clay, sandstone fine to medium grained, abundant hematite, muscovite, and glaconite, thin bedded to massive, well developed crossbedding	Yields small amounts of water at the outcrop.
			Carrizo Sand (Ec)	Aquifer	100-800	Medium to very coarse grained sandstone, friable to locally indurated, noncalcareous, thick bedded	Yields moderate supplies of potable water
		Wilcox	Wilcox Group (Ewi)	Aquifer	500-800	Mudstone with varying amounts of sandstone and lignite, glaconitic in upper and lower parts, massive to thin bedded	Yields moderate supplies of good to poor quality water
		Midway	Midway Group (Emi)	Confining	400-500	Clay and sand, glauconitic in lower zones, argillaceous, poorly sorted, phosphatic nodules and pebbles common in lowermost part	Not known to yield water to wells in Bexar County
Cretaceous		Navarro	Navarro Group and Marlbrook Marl (Kknm)		700	Marl, clay, sandstone and siltstone, glauconitic, with concretions of limonite and siderite; fine grained sandstone and siltstone with concretions of hard bluish grey siliceous limestone	Not known to yield water to wells in Bexar County

Adapted from Arnow (1959), W.E. Simpson Co. (1993), and Barnes (1983).

Table 3-1

Geologic Formations and Their Water-Bearing Properties

System	Series	Group	Stratigraphic Unit	Hydrologic Unit	Approximate Thickness	Character of Material	Water Supply Properties
Cretaceous	Gulf		Anacacho Limestone (Kac)	Confining	120	Limestone and marl, thick bedded, fossiliferous, sandy, some volcanic rock fragments, and weathered, rusty, bentonite beds	Not known to yield water to wells in Bexar County
			Pecan Gap (Kpg)		150-200	Chalk and chalky marl, more calcareous westward	Not known to yield water to wells in Bexar County
			Austin Chalk (Kau)	Aquifer	175-225	Chalk, mostly microgranular calcite, alternates with marl, local bentonite seams, sparsely glaconitic, pyrite nodules in part weathered to limonite	Yields small to large volumes of good to poor quality water
			Eagle Ford Group (Kef)	Confining	30-50	Shale, siltstone, fine grained sandstone and flaggy limestone	Not known to yield water to wells in Bexar County
	Comanche	Washita	Buda Limestone (Kbu)	Aquifer	40-70	Fine grained bioclastic limestone, commonly glauconitic, pyritiferous, hard, massive, poorly bedded to nodular	Yields sufficient water near the outcrop for stock and domestic use
			Del Rio Clay (Kdr)	Confining	40-60	Calcareous and gypserfous clay, pyrite common, blocky,	Not known to yield water to wells in Bexar County
			Georgetown Limestone (Ked)	Edwards Aquifer	450-500	Hard massive limestone and agrillaceous limestone	Yields moderate to large quantities of fresh water in updip section. Water becomes highly mineralized in southern part of the county
			Person Formation (Ked)			Hard, massive, fine to course grained limestone, abundant chert	
		Fredricksburg	Kainer Formation (Ked)			Hard, massive, fine to coarse grained limestone, abundant chert, some marly clay and shale	

Adapted from Arnow (1959), W.E. Simpson Co. (1993), and Barnes (1983).

Table 3-1

Geologic Formations and Their Water-Bearing Properties

System	Series	Group	Stratigraphic Unit	Hydrologic Unit	Approximate Thickness	Character of Material	Water Supply Properties
	Comanche	Trinity	Upper Glen Rose (Kgru)	Upper Trinity Aquifer	500	Resistant, impure, fossiliferous, limestone with alternated beds of resistant and nonresistant shale, nodular marl, and two distinct evaporite beds	Yields small quantities of relatively mineralized water
			Lower Glen Rose (Kgrl)	Middle Trinity Aquifer	300	Massive, folliliferous limestone grading upward into thin beds of limestone, dolomite, marl and shale	Yields small to large quantities of fresh to slightly saline water
			Hensell Sand Member (Kh) / Bexar Shale (Kbs)		80	Upper half sandy glauconitic limestone, lower half mostly fine grained argillaceous, calcareous sandstone/Marl calcareous shale and shaley limestone to silty dolomite	
			Cow Creek Limestone Member (Kcc)		80	Massive fossiliferous off-white limestone with local thinly beded layers of sand, shale, and lignite	
			Hammet Shale Member (Khs) / Pine Island Shale (Kpi)	Confining	50	Fossiliferous, calcareous and dolomitic shale with thinly interbedded layers of limestone and sand	Not known to yield water
	Pre-Comanche		Sligo Limestone Member (Ks)	Lower Trinity Aquifer	150	Sandy dolomitic limestone	Yields small to moderate quantities of slightly saline to saline water
			Hosston Sand Member (kho)		220	Red and white conglomerate, sandstone, claystone, shale, dolomite, and limestone	Yields small to moderate quantities of slightly saline to saline water
Pre-Cretaceous Rocks						Folded shale, hard massive dolomite, limestone, sandstone and slate	Not known to yield water to wells in Bexar County

Adapted from Arnow (1959), W.E. Simpson Co. (1993), and Barnes (1983).

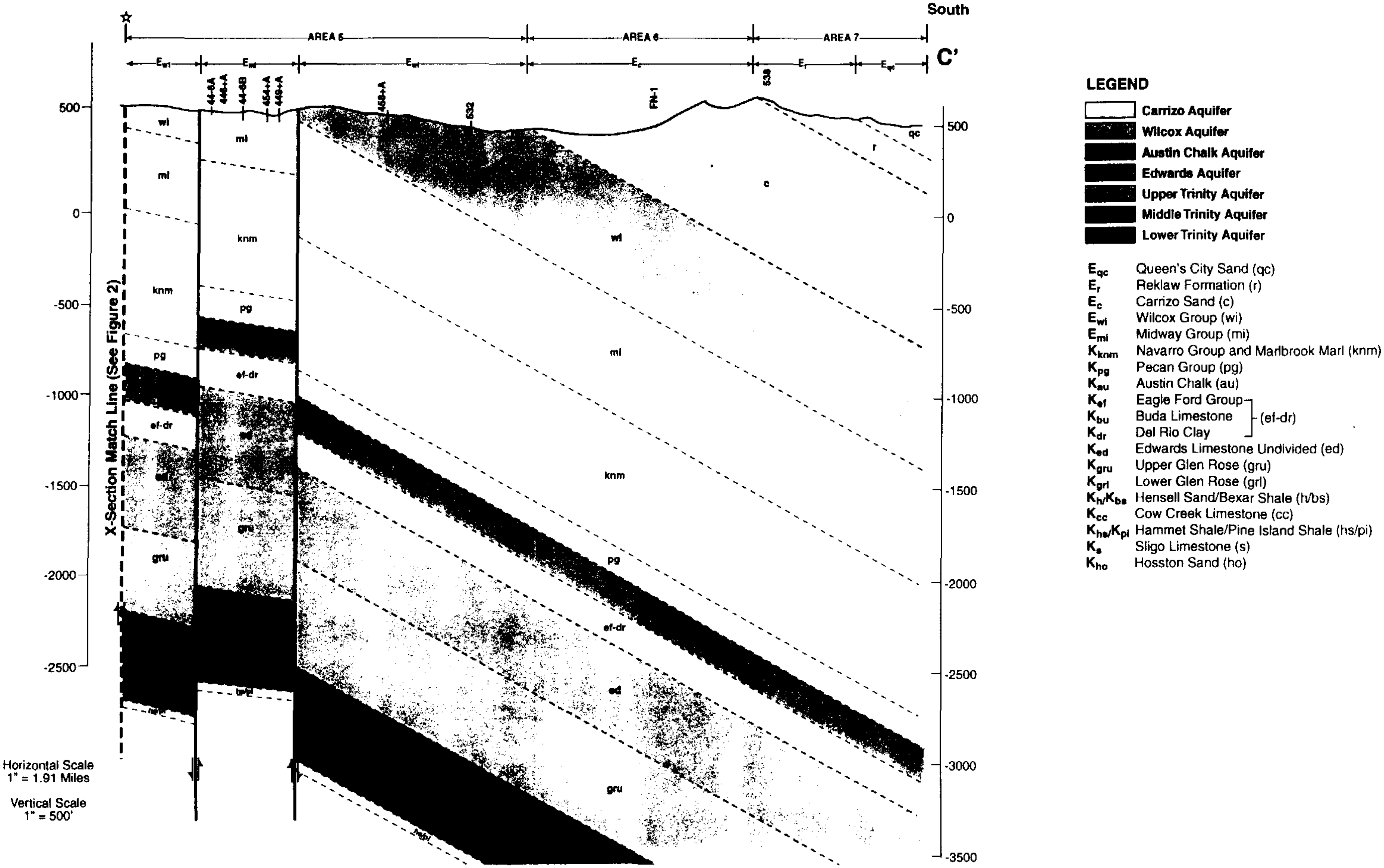


FIGURE 3-2
Bexar County Cross Section C - C' (view to east)

CH2MHILL

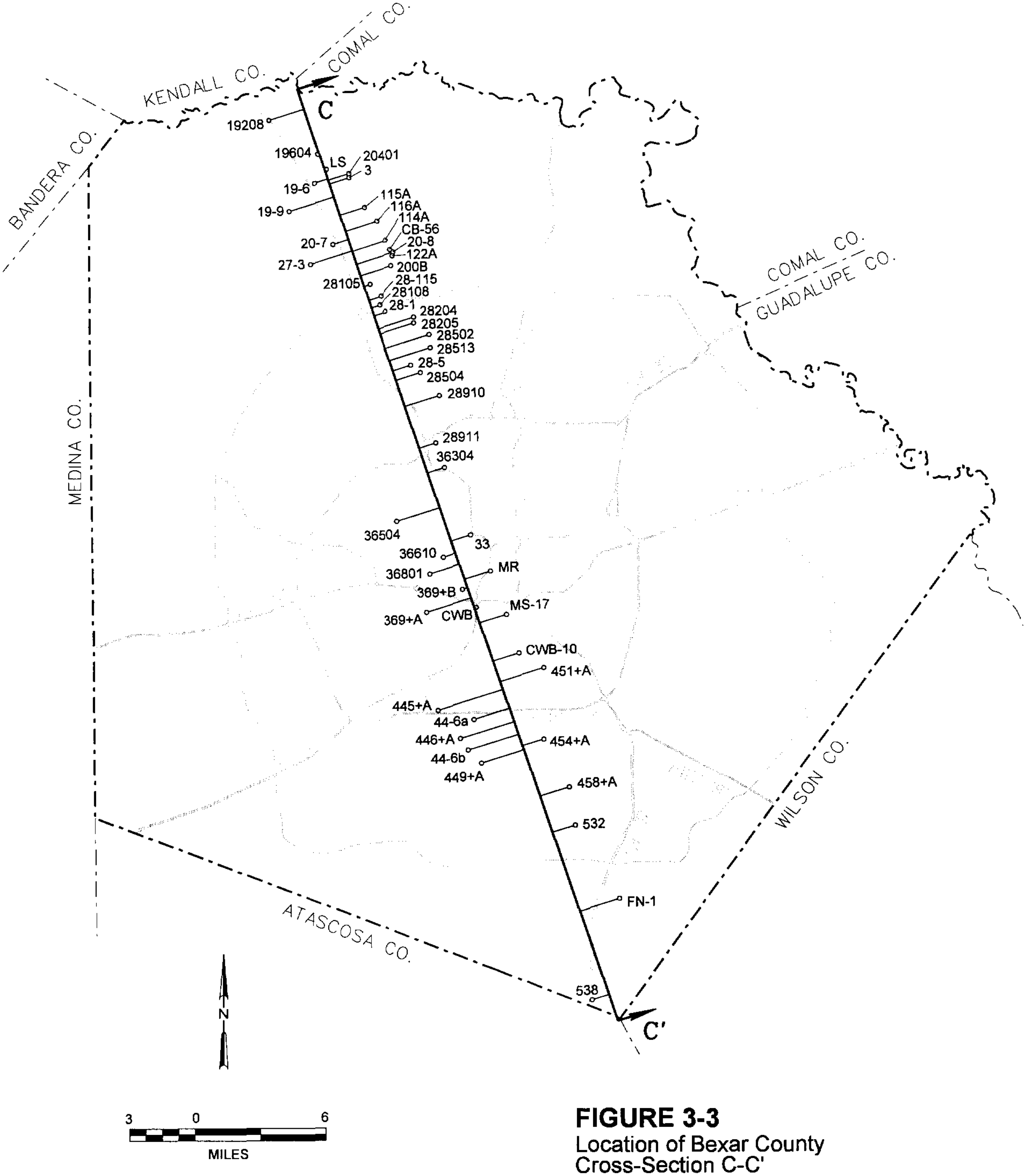


FIGURE 3-3
Location of Bexar County
Cross-Section C-C'

ASR development. Criteria ratings were assigned for the 34 available storage zones included in the evaluation. The six most promising storage zones identified through this evaluation provided a focus for the geochemical compatibility assessment and subsequent feasibility analyses.

Geographic Subdivisions

The study area was divided into seven geographic areas to limit the range of aquifer characteristics within each area. These geographic areas were established based primarily on the occurrence of specific aquifer units. These seven areas, shown in Figure 3-4, are identified along the top of the cross-section. The determination and relevance of each geographic area is discussed as part of the preliminary storage zone screening.

The seven geographic areas and corresponding available ASR storage zones are identified as follows:

Area 1

This portion of the study area lies north of the Edwards aquifer recharge zone. The upper, middle, and lower Trinity Aquifers are considered to be potential ASR storage zones in Area 1.

Area 2

Area 2 generally corresponds to the zone of effective recharge to the Edwards aquifer. Storage zones available for ASR development in the area include the upper, middle, and lower Trinity Aquifers.

Area 3

In Area 3, under normal hydrologic conditions, the Edwards aquifer transitions from a water table (unsaturated) to an artesian aquifer. The Austin Chalk outcrops over the western portion of this area and is considered a potential storage zone along with the Trinity Group aquifers.

Area 4

This portion of the study area is bounded on the north by the Edwards aquifer transition zone (Area 3) and on the south by the "bad water line." The bad water line occurs where the Edwards aquifer contains water in excess of 1,000 mg/L TDS. The Austin Chalk and the Trinity Group aquifers are potential ASR storage zones in this Area.

Area 5

Bounded by the bad water line to the north and the northern extent of the Carrizo Sand outcrop to the south, Area 5 includes the Brackish Edwards (TDS > 1,000 mg/L) aquifer. In addition to the Brackish Edwards, the Wilcox Group, the Austin Chalk, and the Trinity Group aquifers are considered potential ARS storage zones.

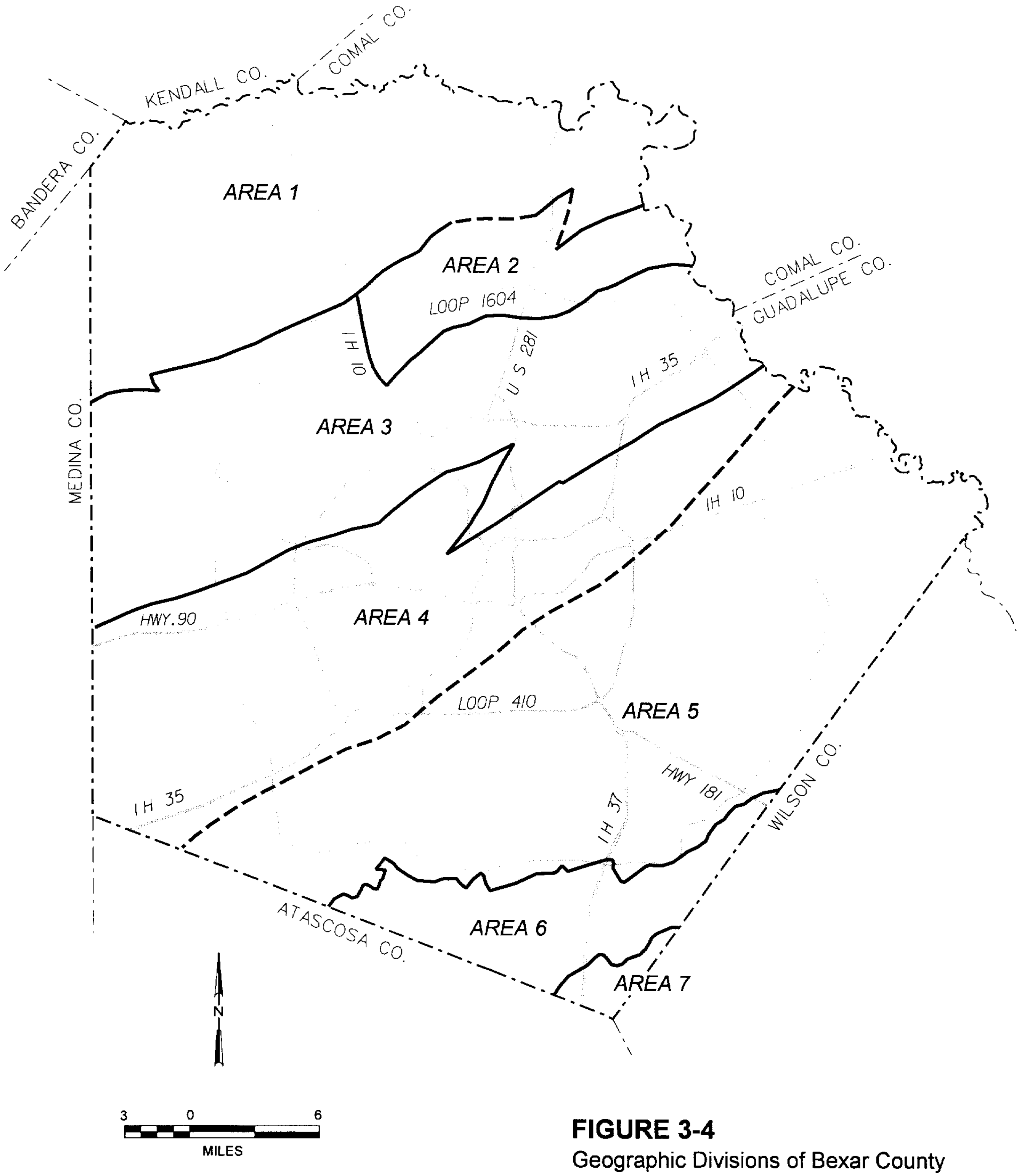


FIGURE 3-4
Geographic Divisions of Bexar County

Area 6

This area generally coincides with the Carrizo Sand outcrop. In addition to the unconfined Carrizo aquifer, the Wilcox Group, Austin Chalk, Brackish Edwards, and Trinity Group aquifers represent potential ASR storage zones in Area 6.

Area 7

The northern limit of Area 7 coincides with the northern extent of the confined Carrizo aquifer in Bexar County. Other potential storage zones in Area 7 include the Wilcox Group, Austin Chalk, Brackish Edwards, and the Trinity Group aquifers. Area 7 is very small in comparison to the other subdivisions of the study area, occupying approximately 10 square miles of the southern tip of Bexar County.

Screening Criteria

The following six screening criteria were used to evaluate the potential storage zones in the study area:

- Potential well yield
- Native water quality
- Surface contamination potential
- Existing aquifer usage
- Average daily area demand
- Total depth

Criteria ratings for each of the potential ASR storage zones in the study area are listed in Table 3-2. Also included in the table are the assumed ranges of parameter values defining each classification. Based on the information presented in Table 3-2, the following six storage zones are recommended for further assessment:

- Area 1: Middle Trinity Aquifer
- Area 1: Lower Trinity Aquifer
- Area 3: Middle Trinity Aquifer
- Area 5: Brackish Edwards Aquifer
- Area 6: Wilcox Group
- Area 7: Carrizo Aquifer

Although the screening process focused on the most promising individual storage zones within the study area, the cost-effectiveness of alternatives can be enhanced by developing a "stacked" ASR system at a site. For example, the Area 5: Brackish Edwards alternative may also use an ASR well in the Austin Chalk. Once piping and other facilities are in place to fully develop the ASR potential for the primary storage zone at a given site, the additional cost of storing water at the same site in overlying and underlying aquifers may be competitive. Opportunities for multi-zone development and combined use of geographically unique storage zones are discussed in Section 3, ASR Applications and Feasibility.

Table 3-2

Storage Zone Evaluation Matrix

		Selection Criteria					
Area	Aquifer	Potential Well (1) Yield	Native Water (2) Quality	Surface (3) Contamination Potential	Existing Well (4) Density	Average (5) Daily Area Demand	Total (6) Depth (ft bls)
1	Upper Trinity	Small to Moderate	Good to Moderate	High	Low to Moderate	Low	LS-700
	Middle Trinity	Moderate	Good	Low	Low to High	Low	350-1250
	Lower Trinity	Moderate	Good to Moderate	Low	Low to Moderate	Low	775-1650
2	Upper Trinity	Small	Moderate	Moderate	Low	Low	500-950
	Middle Trinity	Moderate	Good to Moderate	Low	Low to Moderate	Low	975-1450
	Lower Trinity	Moderate	Moderate	Low	Low	Low	1350-1850
3	Austin Chalk	Moderate	Good to Moderate	Moderate to High	Low	High	LS-625
	Upper Trinity	Small	Moderate	Low	Low	High	850-1650
	Middle Trinity	Moderate	Good to Moderate	Low	Low	High	1450-2125
	Lower Trinity	Moderate	Moderate	Low	Low	High	1850-2525
4	Austin Chalk	Small to Moderate	Good to Moderate	Low to Moderate	Low	High	350-1525
	Upper Trinity	Small	Moderate to Poor	Low	Low	High	1375-2675
	Middle Trinity	Small	Moderate to Poor	Low	Low	High	1825-3175
	Lower Trinity	Small	Moderate to Poor	Low	Low	High	2200-3575
5	Wilcox Group	Moderate	Good to Moderate	High	Moderate	Medium	LS-950
	Austin Chalk	Small to Moderate	Good to Moderate	Low	Low	Medium	400-2350
	Brackish Edwards	Moderate	Moderate to Poor	Low	Low	Medium	975-3050
	Upper Trinity	Small	Moderate to Poor	Low	Low	Medium	1500-3575
	Middle Trinity	Small	Moderate to Poor	Low	Low	Medium	2050-4100
	Lower Trinity	Small	Moderate to Poor	Low	Low	Medium	2400-4350

Notes:

(1) Potential Well Yield — Increasing Feasibility ↑
Large: greater than 500 gpm
Moderate: 100 to 500 gpm
Small: less than 100 gpm

(2) Native Water Quality — Increasing Feasibility ↑
Good: less than 1000 mg/l TDS
Moderate: 1000 to 3000 mg/l TDS
Poor: 3000 to 10,000 mg/l TDS
Saline: greater than 10,000 mg/l TDS

(3) Surface Contamination Potential — Increasing Feasibility ↑
Low
Moderate
High

(4) Existing Well Density — Increasing Feasibility ↑
Low: less than 1 user per 2 1/2 minute quadrangle
Moderate 1 to 10 users per 2 1/2 minute quadrangle
High: greater than 10 users per 2 1/2 minute quadrangle

(5) Average Daily Area Demand — Increasing Feasibility ↑
High: greater than 50 mgd
Medium: 10 to 50 mgd
Low: less than 10 mgd

(6) Relative feasibility decreases with total depth.

Table 3-2

Storage Zone Evaluation Matrix

		Selection Criteria					
Area	Aquifer	Potential (1) Well Yield	Native Water (2) Quality	Surface (3) Contamination Potential	Existing Well (4) Density	Average (5) Daily Area Demand	Total (6) Depth (ft bls)
6	Carrizo	Moderate	Good	High	Low to Moderate	Low	LS-800
	Wilcox Group	Moderate	Good to Moderate	Moderate	Low to Moderate	Low	775-1450
	Austin Chalk	Small	Moderate to Poor	Low	Low	Low	2475-3100
	Brackish Edwards	Moderate	Poor to Saline	Low	Low	Low	3150-3750
	Upper Trinity	Small	Poor to Saline	Low	Low	Low	3700-4300
	Middle Trinity	Small	Poor to Saline	Low	Low	Low	4200-4900
	Lower Trinity	Small	Poor to Saline	Low	Low	Low	4550-5300
7	Carrizo	Large	Good	Low	Low to Moderate	Low	850-1150
	Wilcox Group	Moderate	Moderate	Low	Low	Low	1500-1800
	Austin Chalk	Small	Moderate to Poor	Low	Low	Low	3150-3475
	Brackish Edwards	Moderate	Saline	Low	Low	Low	3800-4175
	Upper Trinity	Small	Saline	Low	Low	Low	4350-4725
	Middle Trinity	Small	Saline	Low	Low	Low	5000-5375
	Lower Trinity	Small	Saline	Low	Low	Low	5350-5725

Notes:

(1)	Potential Well Yield	Increasing Feasibility ↑	Large: greater than 500 gpm Moderate: 100 to 500 gpm Small: less than 100 gpm
(2)	Native Water Quality	Increasing Feasibility ↑	Good: less than 1000 mg/l TDS Moderate: 1000 to 3000 mg/l TDS Poor: 3000 to 10,000 mg/l TDS Saline: greater than 10,000 mg/l TDS
(3)	Surface Contamination Potential	Increasing Feasibility ↑	Low Moderate High
(4)	Existing Well Density	Increasing Feasibility ↑	Low: less than 1 user per 2 1/2 minute quadrangle Moderate 1 to 10 users per 2 1/2 minute quadrangle High: greater than 10 users per 2 1/2 minute quadrangle
(5)	Average Daily Area Demand	Increasing Feasibility ↑	High: greater than 50 mgd Medium: 10 to 50 mgd Low: less than 10 mgd

(6) Relative feasibility decreases with total depth.

Geochemical Compatibility

Aquifer storage and recovery involves storing treated water underground for future recovery. During storage, the chemical characteristics of the treated water can be altered. Therefore, water quality issues must be thoroughly investigated during performance of the feasibility study. Water quality issues addressed in the preliminary geochemical assessment include the following:

- Source water and storage zone native water chemical characteristics
- Potential reactions between the treated source water and storage zone native water
- Potential reactions between the treated source water and storage zone matrix
- Changes in stored water quality and its compatibility with treated water in the distribution system

The most restrictive use of recovered water will be for public drinking water, and the quality must meet drinking water standards and aesthetic expectations of the public. Water quality is also important to ASR operations. Chemical reactions (precipitation of solids or bacterial growth) and physical reactions (stratification due to density differences) can affect injection and recovery efficiency.

As presented in the preliminary storage zone evaluation, the most promising storage zones were identified by applying several generalized screening criteria, including storage zone water quality as indicated by the TDS concentration. The goal of the preliminary geochemical assessment is to characterize the selected storage zone/source water combinations and to highlight potential adverse reactions that could impact ASR feasibility.

The preliminary geochemical assessment included six potential storage zones and five potential source waters. The availability of storage zone native water chemical data varied greatly in both the number of analyses and the range in parameter value within a given zone. In addition, only generalized information on storage zone matrix mineralogy was available in the literature.

Although source water chemical analytical summaries are generally more comprehensive than the groundwater analyses, three of the five potential source waters are currently untreated. This presents the opportunity to customize the selected treatment processes to meet ASR requirements; however, this also limits the definition of finished water characteristics. The relatively large range in groundwater quality, combined with uncertainties in source water chemical properties and aquifer mineralogy, dictated that a qualitative geochemical analysis be conducted. A more rigorous approach involving thermodynamic equilibrium computer modeling may be warranted if conditions are borderline and site-specific data become available. A detailed evaluation of source water chemistry is presented in the attached Groundwater Assessment Technical Memorandum.

Source Water Chemistry

The following five potential recharge water sources were included in the assessment:

- Raw water from Medina Lake near San Antonio
- Raw water from the Medina River at the Bexar Metropolitan (BexarMet) pilot water treatment plant site near San Antonio

- Raw water from Canyon Lake near New Braunfels
- Treated water from the Canyon Regional Water Authority (CRWA), New Braunfels
- Treated Edwards aquifer water supplied by the San Antonio Water System (SAWS)

The water chemistry for the five sources, summarized in Table C-1 of the Source Water Assessment appendix, was obtained from various existing databases. There is little difference between the treated SAWS water, treated CRWA water, and the raw water chemistry from Medina Lake and Canyon Lake. The implication is that any of these four sources could be interchanged or mixed in any proportion, and the resultant water chemistry would be within the variability of individual sources. These four sources are collectively referred to as the low TDS sources in the following paragraphs. The raw water chemistry of the Medina River source is sufficiently different that it is evaluated independently of the other four source waters.

Recovered water directed to distribution will have essentially the same water chemistry as water used for recharge. Even if source water in the distribution system is different from water that was stored, there should be no adverse reactions in the distribution system as a result of mixing, at least for the four low TDS sources. However, the water from the first cycles for storage zones with poorer quality native groundwater may be slightly to significantly different from the recharge water. Recovered water chemistry and major ion concentrations may not meet drinking water standards or client expectations. This potential is proportional to the mineralogical complexity of the storage zone matrix as commonly manifested in high TDS, low pH, and/or the prevalence of reducing conditions.

Experience has shown that after the initial test cycles, the entire recharge water volume can be recovered with a water chemistry very similar to the recharge water. The initial cycles are conducted to evaluate both the hydraulic response to recharge and reactions with stored water. Problems encountered during testing can often be controlled or eliminated by modifying operating procedures.

Recharge Water/Storage Zone Compatibility

The preliminary compatibility evaluation of the five source waters with each of the six potential storage zones was completed using the generalized native water quality information (summarized in Table C-2, Groundwater Assessment appendix). Storage zone mineralogy was also considered because soluble constituents in the storage zone can degrade stored water quality, rendering it useless for the intended purpose. Similar chemical characteristics of the Medina Lake, Canyon Lake, CRWA, and SAWS source waters permitted these sources to be evaluated as a group, substantially reducing the effective number of source/storage zone combinations.

Area 1: Middle Trinity Storage Zone

The middle Trinity aquifer in Area 1 is dominantly hosted by the Hensell Sand, a sandy glauconitic limestone, and the lower member of the Glen Rose Limestone. Glauconitic sands commonly contain fluorapatite (fluorinated calcium-phosphate mineral), which may be the origin of the elevated dissolved fluoride in the native groundwater from this aquifer. Evaporite minerals, such as gypsum and anhydrite, are also common.

The honeycombed nature of this aquifer suggests that the primary permeability is through solution features, including fractures and joints within the sandy limestone with lesser permeability in uncemented sands. Recharge with the four low TDS sources and their mixtures could create several potential changes in the storage zone such as the precipitation of calcium carbonate or iron oxyhydroxide. The least potential for calcium carbonate precipitation will occur in locations where the native groundwater contains less than 400 mg/L TDS, has a pH less than 8, and is under oxidizing conditions. Oxidizing conditions are generally indicated by an oxidation-reduction potential (Eh) higher than plus 200 millivolts (mv). The potential for calcium carbonate precipitation may decrease if pyrite or siderite are part of the aquifer mineralogy. Since both minerals react to reduce the pH, calcium carbonate precipitation will also be reduced. The oxidation of the pyrite and siderite will also form a colloid and flocculent but should not significantly affect permeability through larger solution features or joints unless there is a significant amount of either pyrite or siderite present in the aquifer.

Recharge with the Medina River water, which has higher calcium and alkalinity and higher pH, would tend to increase the potential for calcium carbonate precipitation. If the water treatment does not remove most of the iron (probably part of the total suspended sediments), the iron oxyhydroxide could present a considerable problem in the finer joints and the uncemented sands. At the higher concentration of iron (4 mg/L), even the larger joints in the storage zone would eventually show a reduced permeability.

The higher nutrients dissolved in this recharge water would exacerbate both the calcium carbonate precipitation and potential plugging by iron oxyhydroxide as the microbial activity may increase. Long-term storage (years) of the BexarMet water (as currently characterized) is not recommended in this aquifer, particularly within or near areas in which the native groundwater is under reducing conditions.

The site-specific distribution of TDS, pH, and sulfate in the middle Trinity aquifer in Area 1 should be determined during field exploration. Areas with a native water TDS less than 400 mg/L, a sulfate concentration less than about 25 mg/L, and 7.5 and 8.0 pH are most desirable. Areas with an Eh of +200 mv or higher (any plus mv reading of the ORP meter) within areas of low TDS, low sulfate, and moderate pH would also appropriately recharge this aquifer. ASR systems can be successfully operated in less favorable portions of the middle Trinity in Area 1; these areas, however, will require more thorough investigation during site selection and more care in conducting the initial recharge cycles.

Rock cores should be obtained during well construction and hydraulic and mineralogical characteristics defined. This investigation is recommended prior to any recharge in a new area to further limit potential obstacles not apparent from the published native groundwater chemistry and regional lithologic descriptions. The particle size and distribution, plus laboratory vertical and horizontal permeability, are significant physical characteristics to be defined by laboratory testing. The species, abundance, and distribution of iron and clay minerals are also particularly important. The bulk ion exchange capacity of the clays in the aquifer and ions in exchangeable positions should be included in the laboratory analyses. The additional testing will be especially important in areas where higher TDS, lower pH, and/or reducing conditions are prevalent.

Area 1: Lower Trinity Storage Zone

The lower Trinity aquifer in Area 1 comprises a lower sand and clay member (Hosston Sand) and an upper sandy dolomitic limestone (Sligo). The sand appears to be oxidized based on the red and white coloration so that most of the glauconite and pyrite has probably been removed from the more permeable sands. The clays may still retain some pyrite.

Recharge with the low TDS calcium-bicarbonate sources and their mixture can present a potential ion exchange and TDS problem. If the clays are sodium-type, some destabilization of the clays in the sands is possible. If the clays become destabilized, they may migrate into the pore space and reduce the permeability of the aquifer. Similarly, the low TDS of the recharge water may destabilize the clays that are currently saturated with relatively high TDS native groundwater.

The oxidized recharge water may react with pyrite and/or siderite in the aquifer and that would initially increase the TDS, lower the pH, and perhaps result in elevated manganese concentrations in the recovered water. The elevated TDS of the native groundwater may be inherited from reactions along the groundwater flow paths. The dominance of sulfate, even in the native groundwater containing the lowest TDS (930 mg/L), suggests that this is probable.

The higher sodium and sulfate concentrations of the untreated Medina River water presents less of a potential problem than the four low TDS recharge sources. The ion exchange potential of the Medina River recharge water should be less given the higher TDS; also, the clays would probably be more stable with this recharge source. However, diluting the Medina River water with the low TDS water from the other sources would reduce this potential benefit.

Of major importance in any subsequent field effort is a complete analysis of the treated Medina River water and the native groundwater from a well at the actual recharge location. Cores of the lower Trinity aquifer should be acquired or investigated to determine the hydraulic characteristics and mineralogy of the aquifer materials (as suggested for the Area 1: Middle Trinity storage zone). Both the iron and clay mineralogy help determine the success of ASR in this storage zone.

The initial recharge should be relatively slow to allow the aquifer clays to adjust to the ion exchange and lower TDS without becoming destabilized. A buffer volume of recharged water should be left in the aquifer. The clays will eventually become irreversibly dominated by calcium in the ion exchange position. The more stable calcium-dominated structure also enhances the permeability of the storage zone matrix.

The substandard quality of the native groundwater prohibits recovery in excess of the stored volume. Recovery may also be complicated by the relatively high temperature of groundwater in the aquifer (22 to 24 °C) if the recharge water temperature is less than about 15 °C. The number of cycles necessary to condition the storage zone and recover acceptable quality water will largely depend on the local storage zone mineralogy.

Area 3: Middle Trinity Storage Zone

Recharge of the low TDS source waters to the low TDS, calcium-bicarbonate type groundwater would have the same potential problems identified for the low TDS calcium-bicarbonate type water of the middle Trinity in Area 1. One exception, however, is that there is little to no chance that calcium carbonate will precipitate in the low pH (6.5) groundwater. Higher TDS native groundwater will have an increased potential for calcium carbonate precipitation where the recharge and native groundwater mix directly.

Potential reactions between the Medina River recharge water and both native groundwater and aquifer minerals is about the same as for the low TDS sources in the middle Trinity aquifer in Area 3.

Site-specific rock cores and complete laboratory analyses of the groundwater are of particular importance in the middle Trinity in Area 3. Evaporite beds and sections of the aquifer near these beds should be cased off in an ASR well. Also, significant confinement should separate the evaporite beds from the recharge intervals to isolate the soluble evaporite minerals.

The recommendations for the lower Trinity aquifer in Area 1 are also applicable for the Area 3: Middle Trinity storage zone. Large temperature differences between the recharge and native water will similarly promote mixing in all water types except the calcium-bicarbonate type.

Area 5: Brackish Edwards Storage Zone

The Edwards aquifer is dominated by limestone with some argillaceous limestone in the upper Georgetown Formation. Permeability is assumed to be through fissures and joints associated with solution features.

With both low TDS and Medina River recharge sources, there is a potential for precipitation of calcium carbonate where the recharge and native groundwater mix. However, given the relatively high secondary permeability of this aquifer, this should not present a significant problem. Considerable mixing between the recharge water and the native groundwater can be expected as a result of the temperature differences between the two water sources as well as the relatively high permeability of this storage. Although the storage zone may transmit water more efficiently than Trinity storage zones, more cycles may be required before the recovered water is of an acceptable water chemistry.

During future testing, rock cores or cuttings from this portion of the Edwards aquifer should be analyzed to confirm that there is not a significant amount of pyrite nor are there blue clay beds in the target ASR interval. More complete water analyses would be necessary for both the recharge and native groundwater prior to any recharge.

There is considerable experience with recharging carbonate aquifers containing brackish to saline native groundwater. The first few short recharge cycles will allow an estimate of the eventual recovery. A buffer zone of recharged water is sometimes used if mixing between the recharge and native groundwater is an issue. Therefore, more than a few major ASR cycles may be required to produce potable recovered water. Given the relatively low TDS in this storage zone, developing a sufficient buffer may be easily achieved.

Area 6: Wilcox Group Storage Zone

The Wilcox Group is dominated by mudstone and sand containing lignite and glauconite. As discussed in the above subsections, this unit may contain fluorapatite as a source of dissolved fluoride and the lignite may contain the iron sulfide mineral marcasite.

With low TDS sources and mixtures, the relatively low pH of the groundwater, as well as the probable presence of pyrite, suggest that calcium carbonate precipitation where the recharge and native groundwater mix is probably not a problem with this recharge source. However, if the pyrite is dispersed throughout the sands as fine-grained cement, the precipitation could occur, reducing storage zone permeability. If the pyrite is confined to the mudstone, a more probable condition, then exposure to recharge water would be minimal and this problem would be minimized. In either case, recovered water may have a slight to moderate increase in TDS (calcium and sulfate) through the oxidation of pyrite. The first few short cycles will determine the increase in either case.

Clay stability may be an additional problem if pyrite is dispersed in the sands. The clays can become very unstable with a decrease in pH created by oxidation of pyrite, which can lead to plugging of the pores. The severity of plugging is directly related to the amount of pyrite present and exposure of the pyrite to the recharge water.

Recharge with the Medina River source could result in precipitation of calcium carbonate, depending on the distribution of pyrite within the aquifer matrix. The above discussion on the ramifications of the pyrite oxidation also pertain to injection with this source. Precipitation of iron oxyhydroxide flocculent could reduce storage zone permeability. Similarly, mobilization of clay due to an increase in pH could result in irreparable plugging.

Rock cores and more complete aquifer and groundwater characterization for locations of interest should be collected before recharging the Wilcox Group in Area 6. It is probable that the pyrite is essentially limited to the mudstone and that the clays will remain stable; however, the potential for aquifer damage warrants more investigation before recharging these sands.

Area 7: Carrizo Sand Storage Zone

The Carrizo Sand is a noncalcareous, medium to coarse-grained sand. The lack of carbonates in the sands is a decided advantage for ASR. However, the localized presence of elevated levels of iron oxyhydroxide suggests the historical, if not current, presence of pyrite.

Nitrate is very low in this storage zone and trace amounts of pyrite may denitrify both the low TDS and Medina River recharge water, resulting in a lower nitrate concentration in the recovered water. Sufficient storage time will be important to maximize this beneficial reaction.

The recovered water may be slightly to significantly lower in pH. There may also be a slight increase in sulfate and a decrease in bicarbonate concentration compared with the recharge water. The degree of change and number of cycles needed to recover nearly the same water chemistry as the recharge source water depends on the amount and degree of interaction between the pyrite and recharge water in the storage zone.

If pyrite is present in trace amounts, any of these sources can be used to recharge the Carrizo Sand. If, on the other hand, pyrite is present in significant amounts, recharge by any of the sources could create a potential plugging problem due to formation of iron oxyhydroxide flocculent. The severity of the problem would be directly proportional to the amount of pyrite present and the relative exposure to the oxidizing recharge water.

Coring and complete groundwater and source water analyses should be obtained before this aquifer is recharged. Water samples from a well in close proximity to any proposed ASR site could prove useful in assessing the amount and exposure of pyrite in the storage zone prior to site selection. Clay stability should not be a serious problem. However, rock cores should be collected to confirm the amount and type of clay present. If pyrite is present in only trace amounts, a few cycles will achieve acceptable recovery efficiencies.

Disinfection Byproducts

When evaluating chemical compatibility of potable waters and groundwaters, the effects of disinfectant(s) must also be considered. Disinfectants are added to the potable or drinking water to kill any potential water-borne pathogens and to protect the water as it is transmitted through pipelines to individual residences and businesses. A trade-off of this protection is the fact that the disinfectant can react with organic matter (referred to as precursors) in the water to form disinfection byproducts (DBPs), some of which are considered probable carcinogens and/or present other chronic health concerns.

The DBPs are controlled by reducing the organic matter before the disinfectants are applied to the water or by using a disinfectant like chloramine that is not as reactive with the organic matter. Fortunately, most groundwaters have very low organic content and thus very little to react with chlorine. For example, the trihalomethanes (THMs) reported for the City of San Antonio for the Edwards aquifer water is about 15 ug/l, which is well below the standard of 100 ug/l. Therefore, DBPs are mainly only a concern for treating and storing surface waters with higher organic components.

Complete reaction between the chlorine and organic matter can take 48 to 72 hours before the THMs are stable. Therefore, any time water is stored that has a chlorine residual and available organic matter, there is a concern that the THMs will increase. This is of particular concern for surface waters stored for a very short period of time.

To address this issue, the American Water Works Association Research Foundation (AWWARF) completed a DBP field investigation of ASR systems. The investigation reviewed five ASR systems in the United States, including the ASR system in Kerrville, Texas (Pyne, et. al., 1996). The data they collected suggest that THMs and haloacetic acids (HAAs) are actually removed from the chlorinated drinking water during aquifer storage over a period of several weeks, improving water quality. For example after 71 days of storage, THMs in recovered water had been reduced below 60 ug/l from the initial stored THMs of 120 ug/l, and the HAAs dropped from over 100 ug/l to an undetectable amount. A biological mechanism is suggested, including DBP removal under both anoxic and aerobic conditions.

Based upon this information, development of DBPs is not generally a concern for groundwater sources due to low organic content, and aquifer storage and recovery actually reduces DBPs.

Section 4 ASR Applications and Feasibility

As presented in Section 3 (Groundwater Assessment), the most promising storage zones were identified based on a number of criteria including potential well yield, native water quality, surface contamination potential, existing well density, average daily area demand, and total well depth. Although several potential adverse chemical reactions were identified in the qualitative geochemical evaluation, none of the storage zone/sources water combinations were eliminated from further consideration.

Conceptual ASR applications addressing seasonal and extended period (drought) water supply needs were developed for each of the six storage zones. Estimates of individual well capacity and area-wide potential are developed for each storage zone. Seasonal and drought storage volumes are computed assuming future availability of a suitable source water.

The estimated costs of implementing ASR are presented for each storage zone. Cost estimates/calculations include capital and operation and maintenance (O&M) expenditures to assess the total cost of ASR water. These costs, combined with the estimated well capacities and annual storage potential, were used to develop unit costs for ASR water that are compared with other water supply options in Section 5, Other Water Storage and Supply Options.

Conceptual ASR Applications

Integrating ASR as a strategy to meet seasonal and long-term water supply demands must consider the transitory distribution of demands and supplies. Existing and projected demands, which are relatively well defined, are summarized in Section 2, Source Water Assessment. However, the origin and availability of the various source waters, including the Edwards aquifer, have yet to be determined. The conceptual applications, therefore, assume that a suitable source water will be available for storing and recovering using ASR techniques.

Seasonal Peak Supply

The primary goal of ASR is to reduce maximum pumping from Edwards Aquifer in light of good resource management. It is anticipated that pumping restrictions will generally limit peak summer withdrawals when Edwards aquifer levels are near an annual minimum. The following seasonal applications could serve to augment supplies during the summer peak period:

- Source water would be stored at a relatively constant rate beginning in November and continuing through March. During this period, Edwards aquifer levels are usually recovering or are near annual highs, and system demands are below annual average rates. Water would be stored at a rate approximately equal to the design recovery rate.
- April would be a transition period when ASR wells would be converted from a recharge to a recovery mode.

- Water would be recovered at a relatively constant rate from the beginning of May through September. Edwards aquifer levels generally reach an annual minimum in mid-to-late summer when water demands are also near annual maximum rates.
- October would be a transition period when ASR wells would be converted from a recovery to a recharge mode.

Drought Supply

It is probable that, due to low Edwards aquifer levels, pumping restrictions may limit Edwards withdrawals for extended periods. A repeat of the 1948 to 1957 drought would likely require recovery to continue into the normal recharge period or the opportunity to recharge could be eliminated all together. To evaluate drought operations, a continuous 24-month recovery period was selected.

ASR Well Capacity

The design capacity of an ASR well depends on the rate and duration of recharge and recovery. Although the water quality of several of the storage zones under consideration meets drinking water standards, recovery in excess of the volume stored should not routinely occur; however, the opposite condition is desirable. Aggressive storage may result in an annual surplus that, when repeated over a period of years, could provide for drought supplies. The seasonal peak supply application generally affords an opportunity to "bank" water during multi-year periods of below average demand for withdrawal during drought periods.

The two primary factors influencing ASR well recharge/recovery rate are the storage static water level and specific capacity. The depth to water was estimated from published potentiometric surface maps for the Area 1: Lower and Middle Trinity options and the Area 7: Carrizo option. Information available in these maps was used as a guide in determining representative static water levels for the Area 3: Middle Trinity and Area 6: Wilcox storage zones, respectively. Historical water level elevations in the freshwater portion of the Edwards aquifer were used to estimate corresponding levels in the downgradient, brackish Edwards.

Specific capacity, defined as the well yield divided by the resulting drawdown in the pumped well, is a convenient measure of potential well capacity. Estimates of specific capacity of the six storage zone options were based primarily on specific capacity testing. Values of specific capacity from well test were also compared with values of specific capacity computed from regional transmissivity ranges using the relationship presented in Driscoll (1986). Resulting specific capacities varied from 1.0 gallons per minute per foot (gpm/ft) of drawdown in the Area 1: Lower Trinity storage zone to 40 gpm/ft in the Area 7: Carrizo.

Values of specific capacity derived from testing or estimated from regional transmissivity values are applicable to pumping wells. Recharge specific capacities are generally lower and were estimated at 0.8 times the recovery value, based on experience at other ASR sites. In determining the maximum allowable recharge rate for each of the storage zones, the estimated static water level (depth to water) was added to the maximum allowable recharge pressure and the sum was multiplied by the estimated recharge specific capacity. The maximum allowable recharge was balanced against the maximum recovery rate, which is limited by the available drawdown and was computed as the allowable drawdown multiplied by the recovery specific capacity. A complete discussion of the derivation of representative design recharge and recovery rates is included in Appendix C.

To evaluate ASR feasibility and estimating costs of ASR water, it was assumed that the design recharge rate and recover rate are equal. This condition is consistent with the equivalent recharge and recovery cycles conceived for the seasonal ASR application. Balanced recharge and recovery rates would result in efficient use of ASR infrastructure. Design rates are summarized in Table 4-1.

Table 4-1 ASR Design Capacity and Area-wide Potential

	Storage Zone					
Parameter	**Area 1 Middle Trinity**	**Area 1 Lower Trinity**	**Area 3 Middle Trinity**	**Area 5 Brackish Edwards**	**Area 6 Wilcox**	**Area 7 Carrizo**
Design Rate per Well (gpm)	500	300	600	900	500	2,000
System Capacity (mgd)	67	183	115	33	122	3
Annual Storage (ac-ft) [1]	22,208	36,369	42,952	19,689	40,438	3,959

Notes:
[1] Assumes 5 month recharge and recovery cycle.

Area-wide ASR Potential

The area-wide ASR potential was determined for both seasonal and drought (24 months) applications. The area-wide potential is generally a function of:

- Effective area within each of the geographic areas available for development of ASR sites
- Well spacing necessary to control interference between adjacent ASR wells
- ASR well design rate

The effective area within each of the six geographical areas was estimated as a percentage of the total area minus areas that were determined to be unsuitable or unavailable for ASR development. Areas were excluded based on the existence of wells completed in the same storage zone as that proposed for ASR development (as indicated by TWDB records). Large tracts of land owned by the federal government were also excluded. A reduction factor of 0.8 was applied to the net area to account for inefficiencies in well layout and the existence of undocumented wells completed in the ASR storage zones.

Significant areas were excluded in Area 1 where there are numerous existing wells completed in the middle Trinity aquifer. Camp Bullis was also eliminated from the available area. In anticipation of possible "stacked" ASR storage zones in Area 1 (middle and lower Trinity storage zones), existing wells completed in either of the potential storage zones were used to compute the excluded area. The remaining geographic areas contained a relatively small number of existing wells and did not have any large federal land parcels that would complicate ASR development.

The Area 5: Brackish Edwards option differs from the other applications in that the wells are distributed along a line offset three miles south of the "bad water" delineation. A two-mile portion of this line traverses Brooks Air Force Base and was eliminated from consideration. The remaining length, approximately 26.9 miles, was assumed to be available for development.

Well Spacing

The allowable well spacing determines the number of ASR wells that can be operated within a given area and is a factor in estimating area-wide potential. Wells must be spaced at sufficient distance from one another so that the drawdown or mounding impact from adjacent wells does not significantly reduce well capacity. The well spacing necessary to limit well interference to acceptable levels depends on storage zone properties, the design recovery rate, and the distribution of the ASR well sites. The estimated well spacings were used as an indicator of area-wide ASR potential. Wells will likely be installed in isolated, more closely spaced clusters separated by relatively large distances.

Storage zone properties that determine the horizontal extent of well impacts are primarily transmissivity, leakance, and storativity. Values of transmissivity were derived from specific capacity estimates used in developing well capacities. Values of transmissivity were increased by a factor of 1.5 for storage zones where fractures and fissures account for the majority of the aquifer permeability. These storage zones include the Trinity and Edwards aquifer options. The Wilcox and Carrizo aquifers, however, have a more uniform matrix and transmissivity values estimated from well tests should generally correlate more closely with regional values of transmissivity. Assumed regional values of transmissivity ranged from 3,000 gallons per day per foot (gpd/ft) to 80,000 gpd/ft for the Area 1: Lower Trinity and Area 7: Carrizo storage zones, respectively.

Regional values of leakance were estimated from confining unit properties presented in the literature or were based on professional judgement. Leakance, in combination with the head differential across the confining units, defines the movement of water from aquifer units above and below the storage zone in response to recharge or recovery. A leakance value of $1x10^{-5}$ ft/d/ft was assigned to the Trinity aquifer and brackish Edwards storage zones. The Area 6: Wilcox and Area 7: Carrizo storage zones are less confined and a leakance value of $1x10^{-4}$ ft/d/ft was used to estimate well impacts.

Storativity of a saturated confined aquifer is the volume of water released from storage per unit surface area of the aquifer per unit decline in the potentiometric surface. Values of storativity for the three Trinity storage zones were estimate at $3x10^{-4}$ ft^3/ft^3 using the relationship developed by Lohman (1972) for confined aquifers. Storativity values of $5x10^{-4}$ ft^3/ft^3 and $1x10^{-4}$ ft^3/ft^3 were obtained from the literature for the Carrizo and Edwards storage zones, respectively. A value of $5x10^{-4}$ was assumed for the Wilcox, given the equivalent thickness and porosity of the Carrizo.

Based on analytical equations developed by Hantush and Jacob (1955), estimates of well impacts were developed at various distances from a well operated at the design rate, at the end of the assumed five-month recovery cycle. Allowable impacts at adjacent wells were limited to 5 percent of the corresponding well drawdown for storage zone options with the potential for numerous wells laid out in a grid pattern. This type of grid pattern applied to the Trinity and Wilcox storage zones. Since Brackish Edwards wells would likely be installed in a linear configuration, and the Carrizo option would support only a small number of wells, the potential for well communication is limited, and a 10 percent overlap in drawdown impacts was permitted. Using this approach, storage zone water levels would rise and fall approximately 41 feet (on average) along the line of ASR wells in the Brackish Edwards option. The least impacts would occur in the Carrizo where the average seasonal impact would average less than 11 feet.

System Capacity

To calculate area-wide ASR capacity, the number of wells that could be reasonably operated within the geographic area was estimated. Assuming the wells are installed on a uniform grid pattern at the defined well spacing, an average area per well was determined. The number of wells that could be developed was computed by dividing the effective area by the average area per well. The area-wide capacity was estimated as the number of wells times the design rate per well. Multiplying the area-wide capacity by the five-month operational cycle yielded the annual storage volume. The maximum number of wells in each geographic area and the total seasonal production are listed in Table 4-1.

Although not listed in Table 4-1, developing both middle and lower Trinity wells at each Area 1 site is an option for maximizing site capacity. Assuming that an additional lower Trinity well were installed at each Area 1: Middle Trinity site, a combined site capacity of 800 gpm would be possible. The area-wide seasonal storage for a "stacked" option in Area 1 would be approximately 35,500 ac-ft as compared with 22,208 ac-ft and 36,369 ac-ft for separate middle and lower Trinity options, respectively. The actual site capacity for a stacked alternative in Area 1 would likely be reduced due to communication between the two storage zones.

Drought Capacity

The approach described above was also used to determine drought capacity of the systems conceived for the annual application. The only variable changed in the drought evaluation was the duration of the recovery cycle. The withdrawal period was increased from 5 months to 24 months, and the distance-drawdown curves for each storage zone option were recomputed.

Results of this analysis indicated that system drawdowns approached an equilibrium condition by the end of the five-month recovery cycle, and withdrawals are satisfied by leakage from the vertically contiguous aquifer units. Therefore, at the well spacing defined for the seasonal application, long-term recharge or recovery would be possible with minimal reduction in system capacity. However, water quality degradation may limit extended period recovery if leakage from contiguous aquifer units is of an unacceptable quality. The apparent potential for drawdown impacts to propagate to overlying or underlying zones would tend to reduce the design capacity of ASR wells completed in contiguous zones. The potential for reduced capacity would have to be considered in evaluating "stacked" installations where storage zones were vertically contiguous.

Estimated Costs

Reasonable estimates of the major costs associated with implementing ASR were prepared to facilitate comparisons with other water supply and storage alternatives. Implementation costs include capital cost associated with designing, constructing, and rehabilitating facilities and normal O&M costs. The comparison (Section 5) focuses on the marginal cost of ASR water, which is a function of the capital and O&M costs divided by the volume of water produced.

Capital and O&M costs estimates were developed for a typical ASR installation within each storage zone. The number, diameter, well casing length, and casing material varies from one storage zone to the next. There are also significant differences in well depth, completion type, motor type and rating, and design rate. However, well depth, completion interval, and drilling difficulty will vary across each storage zone, impacting the actual cost of ASR implementation. Subsequent phases of the ASR investigation will provide the information necessary to refine design criteria, system configuration, operating cycles, and implementation costs.

The Area 5 Brackish Edwards option is unique in that each ASR well will be equipped with a booster pump on the recharge pipe to bring the wellhead pressure to approximately 140 psi. The additional recharge pressure is necessary to overcome the relatively high head in the Brackish Edwards anticipated during recharge periods. Using only distribution system pressure (60 psi), the design recharge rate would be limited to approximately 300 gpm. Details of the conceptual facility design are presented in the Groundwater Assessment appendix.

Capital costs are summarized in Table 4-2 for each storage zone option. These costs assume that several well sites will be connected with manifold piping to a centralized storage tank where recovered water will be disinfected and re-pumped to the distribution system. To estimate costs associated with ASR, the tank sites and primary pumping stations are assumed to exist. Costs for manifold piping and centralized disinfection equipment are computed as a percentage of site improvement costs. Developing the sites in clusters reduces the number of storage zone monitoring wells required and it is assumed that one monitoring well will be installed for every two ASR wells.

Well construction and engineering costs in Table 4-2 are representative of a large-scale ASR program. Engineering costs associated with prototype well design and testing could be three to five times as expensive. Additional testing would also inflate construction costs by as much as 50 percent for the prototype facility.

O&M considerations are marginally more complex than for conventional production wells. Some of the unique elements considered in developing O&M costs for ASR systems includes periodic changes in operation (recharge to recovery), backflushing during recharge to maintain well capacity, maintenance of adequate disinfection residual, and accelerated pump wear. Electrical costs of $0.06 per kilowatt-hour were assumed based on the current SAWS utility rate structure for baseload facilities. Results of this analysis indicate O&M costs would range from a low of $0.11 per 1,000 gallon for the Area 7: Carrizo option to a high of $0.34 per 1,000 gallons for the Area 1: Lower Trinity storage zone. Table 4-2 lists the estimated annual O&M cost per well. A detailed breakdown of O&M related costs is provided in the Groundwater Assessment appendix.

Table 4-2 Summary of ASR Development Costs

	Storage Zone					
Parameter	**Area 1 Middle Trinity**	**Area 1 Lower Trinity**	**Area 3 Middle Trinity**	**Area 5 Brackish Edwards**	**Area 6 Wilcox**	**Area 7 Carrizo**
Land and Site Improvements						
Building	$50,000	$50,000	$50,000	$50,000	$50,000	$62,500
Land (1 ac.)	$10,000	$10,000	$20,000	$20,000	$5,000	$5,000
Pump, Column, and Motor	$26,000	$29,000	$37,000	$32,000[1]	$21,000	$42,000
Wellhead Piping	$56,250	$56,250	$75,000	$75,000	$56,250	$93,750
Site Work	$25,000	$20,000	$25,000	$25,000	$25,000	$25,000
Subtotal	$167,250	$165,250	$207,000	$202,000	$157,250	$228,250
Misc. Improvements (20%)	$33,000	$33,000	$41,000	$40,000	$31,000	$46,000
Total	$200,2500	$177,750	$248,000	$242,000	$188,250	$274,250
ASR and Monitoring Well						
ASR Well	$166,000	$249,000	$751,000	$515,000	$148,000	$245,000
Monitoring Well	$76,000	$114,000	$360,000	$218,000	$66,000	$60,000
Aggregate Total(ASR and ½ MW)	$204,000	$306,000	$931,000	$624,000	$181,000	$275,000
Engineering and Permitting						
15% of Site and Construction Costs	$59,000	$74,000	$174,000	$127,000	$55,000	$82,000
Capital Cost per Facility	$463,250	$578,250	$1,353,000	$993,000	$424,250	$631,250
Capital Cost/10 mgd ($1000's)	$6,434	$13,385	$15,660	$7,662	$5,892	$2,192
Capital Cost/gpd Capacity	$0.64	$1.34	$1.57	$0.77	$0.59	$0.22
Annual Cost per Well						
Capital (25 yr. @ 8%)	$46,311	$56,655	$124,976	$93,268	$42,720	$62,731
O&M ($0.06/kw-hr)	$26,743	$22,574	$32,910	$41,390	$20,821	$46,445
Total	$73,054	$79,229	$157,886	$134,658	$63,541	$109,176
Annual Production (ac-ft)	331.5	198.9	397.8	596.6	331.5	1325.8
Cost per ac-ft	$220	$398	$397	$226	$192	$82

Notes:

[1] Includes booster pump to recharge at the design rate.

Also included in Table 4-2 are the annualized costs for a typical ASR well in each storage zone and the marginal cost per acre-foot assuming a five-month operational cycle. Components of the annual costs are the amortized capital expenditures and O&M costs. The analysis does not consider the cost of distribution system improvements necessary to integrate ASR water into the system, since other water supply options listed in Section 5 would require similar upgrades that are not accounted for in the associated unit cost. In addition, the unit cost of source water must be added to the marginal cost of ASR to arrive at the total cost for water produced.

Based on the above assumptions, the marginal cost of water produced from ASR ranges from $82 per ac-ft in the Area 7: Carrizo option to $398 per ac-ft for the Area 1: Lower Trinity option. The marginal cost of ASR water, in conjunction with the estimated annual storage volume presented in Table 4-2, provides a gauge by which to evaluate other water supply and storage alternatives. The cost of ASR water for a stacked middle and lower Trinity site in Area 1 can be estimated from the marginal costs presented in Table 4-2. Assuming an additional 198.9 ac-ft per year (unit cost $398 per ac-ft) could be produced by completing a lower Trinity well at each middle Trinity site, the effective cost for the stacked alternative would be $287 per ac-ft.

ASR System Alternatives

Possible system alternatives to enable the SAWS and BexarMet water systems to meet future demands were identified using annual water demand projections and calculated monthly variations. These water demand projections, when considered in combination with the Edwards aquifer pumping restrictions, indicate that both utilities will require additional water supplies to meet customer needs in the future. For these system alternatives, the additional water required was assumed to be imported from outside the system area.

Four scenarios were conceptualized for each utility. These include:

- Conventional Uniform Import Supply alternative
- Conventional Seasonal Import Supply alternative
- Typical ASR alternative
- Maximum ASR alternative

The first two scenarios used a conventional approach to supply future demands, while the other two scenarios used ASR as an innovative water supply technology to help meet future demands.

Conventional Alternatives

The two conventional alternatives assumed delivery of imported supplies to each water system either under a uniform monthly delivery schedule (the Conventional Uniform Import Supply alternative) or a seasonal monthly schedule (the Conventional Seasonal Import Supply alternative). These schedules were proposed in the Trans-Texas Water program, referenced in the Source Water Assessment Technical Memorandum prepared for this project.

The conventional alternatives assume that an imported volume of water equal to the volume required is available from one source, and that the source supplying the water is the Lake Dunlap alternative G-37, as described in the Trans-Texas Water program reports. This may not be entirely applicable for the SAWS system, however, because it could require almost 63,000 acre-feet of imported supplies in the year 2016. This volume exceeds the Lake Dunlap referenced supply volume of 44,348 acre-feet for SAWS. The simplifying assumptions made for these conceptual alternatives, however, are within the level of accuracy of the alternatives.

The uniform monthly delivery schedule assumes that imported water would be delivered to each water system at a constant monthly rate throughout the year, as presented in Tables 4-3 and 4-4 for SAWS and BexarMet, respectively. The seasonal delivery schedule assumes that imported water is delivered at a rate that varies each month. Peak months would be July and August, with 17 percent of the total annual volume being delivered each month. In contrast, only 3.1 percent of the total annual volume would be delivered in February.

TABLE 4-3
Comparison of Alternatives to Meet 2016 SAWS Demands

Edwards Volume Pumped	*193,944*	*Ac-ft*
Volume of Imported Supplies	*62,608*	*Ac-ft*
Maximum Day Demand	*418.0*	*mgd*
Average Day Demand	*232.2*	*mgd*

Alternatives	**Imported Supply Use**			**Edwards Aquifer Use**			**ASR Use**			**Total**
	Avg Annual (mgd)	Max Day (mgd)	Max/Avg Ratio	Avg Annual (mgd)	Max Day (mgd)	Max/Avg Ratio	Volume Stored (acre-ft)	Max Inj (mgd)	Max Rec (mgd)	Cost ($/ac-ft)
Conventional (Uniform Import Rate)	56.7	56.7	1.00	175.5	361.4	2.06 (July)	0	0	0	$122
Conventional (Seasonal Import Rate)	56.7	115.6	2.04 (July)	175.5	302.4	1.72 (July)	0	0	0	$155
Typical ASR (Uniform Avg. Monthly Edwards Pumping)	56.7	56.7	1.00	175.5	285.9	1.63 (July)	17,500	41	75	$139
Maximum ASR (Maximum Imported Storage)	56.7	56.7	1.00	175.5	255.1	1.45 (May)	27.99	57	111	$150

Notes:
1) Costs for imported supplies from Lake Dunlap, G37 Alternative ($268/acre-ft uniform delivery, $403/acre-ft seasonal delivery.
2) Costs for ASR taken as average of six alternatives ($253/acre-ft)

The Conventional Uniform Import Supply alternative would bring in a steady uniform supply to be added to the existing aquifer supply. The water demand variation for the two systems would remain the same, except that 56.7 mgd would be added to the SAWS system and 22.7 mgd would be added to the BexarMet system each month. Maximum day aquifer pumpage would be highest in July for each system; the maximum day aquifer pumping/average annual aquifer pumping ratios would be 2.06 and 3.34 for the SAWS and BexarMet systems, respectively. System costs per acre-foot of water delivered were calculated from the Lake Dunlap alternative costs ($268/acre-foot) for the imported water, and $75 per acre-foot for local groundwater.

TABLE 4-4
Comparison of Alternatives for Year 2016
Demands BexarMet

Edwards Volume Pumped	*21,718*	*Ac-ft*
Volume of Imported Supplies	*25,096*	*Ac-ft*
Maximum Day Demand	*88.5*	*mgd*
Average Day Demand	*42.4*	*mgd*

Alternatives	Imported Supply Use			Edwards Aquifer Use			ASR Use			Total
	Avg Annual (mgd)	Max Day (mgd)	Max/Avg Ratio	Avg Annual (mgd)	Max Day (mgd)	Max/Avg Ratio	Volume Stored (acre-ft)	Max Inj (mgd)	Max Rec (mgd)	Cost ($/ac-ft)
Conventional (Uniform Import Rate)	22.7	22.7	1.00	19.7	65.8	3.34 (July)	0	0	0	$178
Conventional (Seasonal Import Rate)	22.7	46.3	2.04 (July)	19.7	47.4	2.41 (Mar)	0	0	0	$251
Typical ASR (Uniform Avg. Monthly Edwards Pumping)	22.7	22.7	1.00	19.7	50.8	2.58 (July)	3,400	10	15	$197
Maximum ASR (Maximize Imported Storage)	22.7	22.7	1.00	19.7	49.3	2.50 (Mar)	9,100	22	30	$228

Notes:
Costs for imported supplies from Lake Dunlap, G37 Alternative ($268/acre-ft uniform delivery, $403/acre-ft seasonal delivery.
Costs for ASR taken as average of six alternatives ($253/acre0ft)

The Trans-Texas Water Program indicates that water importation at a seasonal rate is possible, with higher rates and volumes during peak demand months. Again, imported supplies would be added to aquifer pumpage to meet demands. Bringing in imported supplies, however, is more expensive. The effect of the seasonal import would be to reduce maximum pumpage on the aquifer to 302.4 mgd for SAWS and 47.4 mgd for BexarMet, with a corresponding reduction in the maximum/average pumping ratios to 1.72 and 2.41 for SAWS and BexarMet, respectively. Because the volume of imported water for the BexarMet system is high relative to demands, however, the effect of seasonal imported water also would shift maximum aquifer pumping from July to March. System costs for this alternative would likely increase because of the higher costs associated with the seasonal imported water.

ASR Alternatives

Two ASR alternatives were developed for this study: the Typical ASR alternative and the Maximum ASR alternative. In the Typical ASR alternative, an ASR system would be used to store imported water during low-demand months. The goal would be a constant average monthly withdrawal rate from the aquifer throughout the year. Imported water would be used to supplement aquifer withdrawals to meet demands, and excess imported water would be diverted to ASR storage. During high-demand months, the ASR system would be pumped to supplement the aquifer and imported supplies. The system would be operated to meet maximum day demands with the aquifer while still maintaining the target monthly withdrawal.

The Typical ASR application would reduce SAWS maximum day demand on the aquifer to 285.9 mgd. The maximum/average annual aquifer pumping ratio would be reduced to 1.63, and maximum aquifer pumping would occur in July. Because of the higher volume of imported water used in the BexarMet system relative to the water pumped from the aquifer, the maximum/average annual aquifer pumping ratio for BexarMet would be 2.58. This is slightly higher than it would be with the imported seasonal alternative (2.41). Maximum aquifer pumping would occur in July. As shown in Tables 4-3 and 4-4, unit costs for this alternative are less expensive than using imported water to meet seasonal peaks.

The Maximum ASR alternative would attempt to store the maximum volume of imported water for recovery during the peak-demand months. The goal would be to reduce the peaks on the aquifer to the greatest extent practical during the summer months. Substantial imported supplies would be diverted to ASR storage from November through April. For the SAWS system, this would represent virtually all of the imported water during this period.

The BexarMet Maximum ASR alternative would not divert all imported supplies because the imported supplies comprise a larger portion of BexarMet's total supply. If BexarMet diverted all of its imported supplies in this alternative, high aquifer pumping peaks would be needed in the winter months, and these would result in high maximum day/annual average aquifer pumping ratios. A more beneficial practice may be to reverse the pumping peaks and take advantage of the aquifer water available at that time. A more conservative approach was taken in this study, however, which would substantially reduce summer peaks and even out aquifer pumping.

The Maximum ASR alternative would reduce maximum day aquifer pumping to 255.1 mgd for SAWS and 49.3 mgd for BexarMet. This alternative is also one of the lowest cost alternatives, at $150 per acre-foot and $228 per acre-foot for SAWS and BexarMet, respectively.

Alternate Well Design

As indicated in the cost analysis, well capacity has a dramatic impact on ASR economics. Well capacity in the Trinity Group and Brackish Edwards storage zone is determined primarily by the number of fractures and fissures intercepted by the well bore. Most fractures occur in the vertical plane and are difficult to penetrate with standard (vertical) well drilling methods. However, horizontal wells have a greatly increased occurrence of fracture penetration and typically have much greater production.

Horizontal drilling techniques have been used for decades in boring tunnels, coring for minerals, production of oil and gas, and most recently, remediation of hydrocarbon contaminated groundwater. A recent municipal water well application was cited in the October 1997 *Water Well Journal*. The Le-Ax Water District near The Plains, Ohio, had a Ranney® radial collector well capable of producing a long-term sustained yield of 3531 gpm with a specific capacity of approximately 355 gpm/ft. Communication with local drillers indicates that, although horizontal drilling has not been used to construct water wells in the vicinity of Bexar County, the technology could be applied to water wells in consolidated formations such as the Trinity Group and Austin Chalk. Horizontal drilling is used extensively throughout Texas in the Austin Chalk trend since the mid-1980s to obtain higher oil and gas production than can be accomplished from vertical wells.

Halliburton Drilling Systems, an expert in direction drilling, was contacted to obtain their opinion on applying directional drilling to the water well industry and to further evaluate the potential for directional drilling applications in the Bexar County area. Mr. Derrick Lewis, Operations Manager, and Mr. John Jordan of Halliburton Drilling Systems were interviewed to obtain their opinions and pricing information. Both Mr. Lewis and Mr. Jordan thought directional drilling techniques could be applied to the water well industry. Both also thought the additional cost to drill about 2,000 linear feet of horizontal borehole would be between $72,000 and $80,000. Oil and gas production from horizontal wells can reach 800 percent of that produced from a vertical well within the same formation. Normally, an increase of 300 to 500 percent can be expected.

Potential problems associated with a horizontal ASR well include reduced recovery efficiency and greater aerial extent of stored water. In storage zones with substandard water quality, it is important to minimize mixing with native groundwater. Recharge through long, relatively small diameter borehole constructed with a horizontal well will greatly increase the stored water interface, requiring significantly more water to create an adequate buffer. Protection of the stored water will also be more costly if surface rights must be acquired.

Stored Water Migration

Movement of stored water in response to adjacent users or regional groundwater flow can reduce the availability of stored water for future recovery. Migration can be particularly problematic for drought applications where water may be stored for several years before recovery is initiated. Regional groundwater flow velocities were estimated for each storage zone option to assess the impact of regional groundwater movement on recovery efficiency.

The potential impact of stored water migration was quantified by offsetting an idealized stored water plume by the one-year groundwater flow distance. The portion of the stored water distribution outside of the original delineation was used as an indicator of potential loss. Significant movement would be less of a concern in non-potable storage zones and the impacts would be mitigated using the cluster concept anticipated for this project. Annual offsets in the six storage zones are well within acceptable limits, especially for the non-potable zones.

Protection Strategies

Section 11.154©(3), Texas Water Code, requires the applicant for an ASR permit show "reasonable diligence" in protecting appropriated surface water from unauthorized withdrawal during storage. However, with the exception of Edwards aquifer users within the EAA jurisdiction, property owners in the state of Texas generally have the legal right to capture all available "percolating waters" beneath their property (T.C. Ry Co. v. East, 1904). Unfortunately, there is currently no distinction made between native groundwater and water stored using ASR, even for appropriated surface water. There are, however, numerous mechanisms available to SAWS and BexarMet that would limit unauthorized withdrawal of stored water. These include:

- Well location and design considerations

- Ordinances
- Lease or purchase of storage zone right
- Purchase of overlying property
- Formation of an underground water district
- Establishment of a special purpose district

Well location and design considerations provide a significant level of protection for the Area 1: Middle and Lower Trinity and Area 5: Brackish Edwards options. The native water quality in these storage zones is of sufficiently poor quality that is unsuitable for most uses. As a result, very few existing wells are completed in these zones. Construction of a new well specifically targeting stored water would likely tap only the outer edge of the stored water plume and recovered water quality would quickly decline as a greater proportion of native water was intercepted.

Section 34-570 of the City of San Antonio code already restricts construction of new water supply wells where SAWS water service is currently provided or where service could be extended at a cost equal to or less than the cost of a well. This ordinance effectively limits access to water stored beneath areas actively served by SAWS. Only the Area 6: Wilcox and Area 7: Carrizo applications could not currently benefit from this protection.

Storage zone characteristics for potable storage zone alternatives indicate that annual volumes of stored water will extend no more than 372 feet radially from the ASR well (Area 1: Middle Trinity, Table 4-3), restricting access to stored water. However, the relatively limited area necessary to control the surface right makes the lease or purchase of the right to pump water from the target storage zone feasible.

Bexar County is entirely in the EAA jurisdiction. However, the EAA only has jurisdiction over the Edwards aquifer. Mr. Edmond McCarthy, an attorney with McGinnis, Lochridge and Kilgore, L.L.P., suggested that a separate groundwater district whose boundaries are coterminous with Bexar County could regulate drilling and well operation in the storage zones of interest. The ability to regulate well construction would be particularly useful in areas outside the City of San Antonio limits.

The Bexar Metropolitan Water District, which was created by the legislature (Article 8280-126, Tex. Rev. Civ. Stat. Ann.), has authority to control, conserve, protect, preserve, distribute and utilize the underground water situated within its boundaries. The District's boundaries are coterminous with Bexar County. However, due to the specific language in Chapter 36, Texas Water Code, it may be prudent for BexarMet to specifically acquire the powers authorized under Chapter 36 to ensure it had the necessary rulemaking authority to protect water stored in an ASR project.

Section 5 Potential Additional Water Storage and Supply Options

The major water supply source in the San Antonio area is the Edwards aquifer. Although this water supply source is an abundant fresh water resource, the aquifer does have a finite water supply capacity. In recognition of these limits, pumping restrictions for the Edwards aquifer will soon be implemented through the EAA, and many utilities dependent on the aquifer may require additional water sources to meet a portion of their existing and future water demands.

Considering current estimates of Edwards aquifer pumping limits and water demand projections, SAWS could face a shortfall of almost 29,000 acre-feet in the year 2006, and 66,000 acre-feet in the year 2016. Similarly, if BexarMet is limited to their historical average pumping of 21,718 acre-feet, a shortfall of over 12,000 acre-feet could be realized in the year 2006 and almost 26,000 acre-feet in the year 2016.

Different water strategies will need to be implemented to meet the anticipated shortfall in Edwards supplies. Additional supplies include importing water as well as water conservation and reuse. Although ASR could also play an important role in the region's water use and management, the water supply shortfalls will require additional supplies.

Several options for future additional supplies are being considered by the two agencies. Conservation and range practices are also being put into place and ASR is being considered as part of the overall water management practice. A condensed discussion of each follows; a detailed discussion is included in the Other Options appendix.

Future Sources of Supply

Selection and development of future sources of supply for the San Antonio area currently in the conceptual stages. Most sources of supply for the area have been identified under different programs, of which the largest and most detailed is the Trans- Texas Water Program - West Central Study Area.

Water supply options that have been presented under the Trans-Texas Program are first presented in this section, followed by a discussion of the sources under consideration by BexarMet. This list of water resource projects is, in no way, a commitment from SAWS to use these projects as a part of their water resource plan. The following projects are listed to provide a frame of reference for the comparison of the estimated cost of water from these projects in relation to ASR.

Additionally, this is not intended to be a complete listing of potential supplies and other than the Canyon Lake to North Bexar County described below, no commitments have been made by SAWS to pursue other sources of supply.

Guadalupe River Diversion at Lake Dunlap to Mid-Cities and Bexar County with Regional Water Treatment Plant (G-37)

Guadalupe River water would be diverted at Lake Dunlap to a regional water treatment plant near Marion. The alternative contemplates diverting and treating 50,000 acre-feet of water annually. Water would be delivered to eight locations, including SAWS, at a uniform rate of approximately 44.6-mgd.

SAWS would obtain either 47,839 or 44,348 acre-feet from the alternative. Prior to the year 2020, it is anticipated that other project participants will not need their allotment and SAWS could receive most of the water supply. By the year 2020, the supply to SAWS would be expected to drop to 44,348 acre-feet.

Total annual cost for water provided to SAWS for this alternative is $257 per acre-foot and $268 per acre-foot, respectively. Costs are presented in 1996 dollars for treated water delivered to the Stahl Pump Station site and include both capital and O&M costs.

Purchase (or Lease) of Edwards Irrigation Water for Municipal and Industrial Use (L-15)

The Edwards aquifer is used as a source for irrigation water in parts of Uvalde, Medina, and Bexar counties. Existing irrigation uses that will be permitted under the EAA withdrawal limits could be available for sale or lease to a water utility if the irrigator desired to give up his right to all or a portion of his water. The sale of irrigation rights will be dictated by the laws of supply and demand. If the price that a water utility is willing to pay is high enough, irrigators will offer water rights for sale.

It was estimated that 68,900 acre-feet could be available. The cost of this water for purchase or lease would depend on the irrigator's original farm yield, and the reduction associated with water conservation or conversion to dry land farming. It is estimated that the farm value per acre-foot of Edwards water produced is approximately $210 per acre-foot per year.

Cibolo Reservoir (S-15D)

The Cibolo Reservoir is a proposed reservoir on Cibolo Creek in Wilson County, located about eight miles east of Floresville. This water supply alternative is presented in the Trans-Texas Water Program and provides treated water to the SAWS system and other users in the San Antonio area. The alternative obtains raw water from a new dam and reservoir. An intake and pump station would be located on the reservoir and raw water would be delivered to a treatment plant located in south Bexar County.

The alternative consists of diverting and treating 32,300 acre-feet of water annually. Water would be delivered to the south Bexar County WTP at a uniform rate of approximately 29-mgd. The total annual cost for water provided to SAWS for this alternative is estimated at $1,127 per acre-foot.

Other Alternatives

Additionally, SAWS is considering other alternatives for future supply. One of these is obtaining treated surface water from Canyon Lake. SAWS has contracted with the

Guadalupe-Blanco River Authority and San Antonio River Authority to obtain additional water supplies. It is expected that at least 2,000 acre-feet of water per year would be provided by this project.

BexarMet

Most of the alternatives discussed above provide water to more than one end user. It is likely that BexarMet could obtain some level of water supply from most of the above alternatives through wholesale contracts. In this way, the above general discussion and range of costs also apply to the BexarMet system.

BexarMet has also contracted with the Canyon Regional Water Authority to obtain up to 4,000 acre-feet of treated water from the authority's Lake Dunlap WTP. Additionally, BexarMet is developing surface water supplies in the Medina River basin to serve a 9-mgd WTP. Construction of the WTP is expected to be completed in early 1999.

Conservation and Reuse

Conservation and reuse will play an important role in reducing water demands. Water saved through conservation, or that obtained through reuse, offsets some amount of future supply need. The Trans-Texas Water Program studied potential conservation and reuse practices for the area to estimate the volume of water that could be saved through these practices and at what cost.

Water Conservation

Water conservation has the potential to reduce the public's use of freshwater without adversely affecting the quality of life or economic development. This can be done through public education and through the use of selected plumbing fixtures. These combined measures include installation of water efficient appliances, revised landscaping practices, and modification of personal behavior to control potential waste.

In the Edwards aquifer region, it was estimated that 34 gallons of water per person per day could be saved by implementing conservation practices. The water savings would require a cost of $11.47 per person, which includes public education, water audits and leak repair, assistance with conservation landscaping, and assistance with replacement of selected plumbing fixtures. The volume of water saved projected to the year 2006 is 50,000 acre-feet for SAWS and 8,400 acre-feet for BexarMet.

Reuse

Reuse of treated effluent can provide water for irrigation, which reduces the demand on potable supplies. SAWS currently has plans to reuse 35,000 to 50,000 acre-feet of effluent per year by the year 2008. The City is already using recycled water for irrigation of the Mission del Lago Golf Course. Recycled water is also being used as cooling water by City Public Service. Currently under design and construction are pumping and transmission facilities along the west and east sides of the City that will deliver recycled water for a variety of uses. These routes generally follow the Leon Creek and Salado Creek watersheds. The sources of recycled water are the Leon Creek, and Salado and Dos Rios Water Recycling Centers.

ASR Considerations

As discussed previously, if water demand projections are realized, and if the EAA withdrawal limits are placed on the Edwards aquifer as expected, SAWS and BexarMet will require additional water supplies to meet future demands. Options for water supply presented in the previous section include bringing additional surface and groundwater supplies into the area and reducing demands by implementing conservation practices and reusing treated wastewater.

An additional technique to manage existing and future supplies is through the use of ASR. This technique can be used to optimize water treatment and delivery facilities by allowing operation of these facilities near the design capacity. It is important to note that ASR does not provide the needed volumes of water, but can be used to enhance availability and make the most efficient use of the resources.

Alternatives discussed above all provide a uniform rate of delivery to the area. The existing Edwards aquifer supply will continue to provide an annual volume of water. However, during droughts and other low aquifer conditions, allowable aquifer withdrawals may be limited and substantial imported supplies will be required to meet demands. If water system planning were to proceed assuming the minimum guaranteed Edwards supply, substantial imported supplies would be needed. Under these conditions, a large portion of permitted Edwards water would go unused as a result of not being able to capture Edwards supplies during low demand months in the winter and spring.

An ASR system that could provide seasonal, or annual storage of about 20,000 acre-feet treated water annually would significantly benefit both SAWS and BexarMet. The ASR system would include a series of wells and piping to take water from the different sources, store the water, and later recover the water by pumping the wells. ASR capacity would supplement the imported supplies and allowed Edwards pumping in the summer months, and would be used to store surplus imported water in the winter.

ASR systems are currently being considered for six unique storage zones. The storage zones are those defined in the Groundwater Assessment Technical Memorandum completed as a component of this project. The marginal costs and estimated annual capacity for the ASR option currently being considered are listed below.

Area/Aquifer	Annual Volume of Storage	Annual Cost
1: Middle Trinity	22,208 acre-feet	$220 / acre-foot
1: Lower Trinity	36,369 acre-feet	$398 / acre-foot
3: Middle Trinity	42,952 acre-feet	$397 / acre-foot
5: Brackish Edwards	19,689 acre-feet	$226 / acre-foot
6: Wilcox	40,438 acre-feet	$192 / acre-foot
7: Carrizo	3,959 acre-feet	$82 / acre-foot

It is important to note that the above costs are additional costs that must be added to the cost of the water stored. For example, if water from Canyon Lake at an original cost of $ 412 per acre-foot were stored in the Area 1 Middle Trinity storage zone, the final cost of that water would be $632 per acre-foot. If Edwards aquifer water were used for storage at $75 per acre-foot, the final cost would be $295 per acre-foot. However, if an ASR system is used, less imported supplies will be needed to meet the same peak demand.

Additionally, water stored in ASR systems is not subjected to evaporation losses as in surface reservoir systems, and much less land area is required. An ASR storage alternative is environmentally friendly as impacts to land areas are minimized. Surface reservoir costs are also much higher than ASR systems with general costs being in the range of $1,000 to $5,000 per acre-foot of water stored. Water storage in tanks or buried concrete structures can cost in the range of several tens of thousands of dollars per acre-foot of water stored.

A more detailed discussion can be found in the Other Options appendix.

Section 6 UIC and Surface Water Use Permits

An ASR project developed under the rules and regulations of the Texas Water Development Board (TWDB) and the Texas Natural Resource Conservation Commission (TNRCC) contemplates the storage of surface waters in an underground aquifer formation. As a result, developing ASR projects is currently governed by certain surface water rights and underground injection requirements. The rules and regulations are included in various legislative statutes and administrative rules.

The pertaining section of the appendix includes specific pertinent sections of legislation and administrative codes.

TNRCC Rules

The TNRCC rules define ASR projects in two phases:

> "Aquifer Storage and Retrieval Project-A 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."

Under the above definition, the entire three-step process defined in the TWDB grant application for the SAWS/BexarMet ASR Feasibility Investigation falls within the definition of Phase I.

Effect on SAWS and BexarMet. SAWS and BexarMet have existing surface water rights that authorize the diversion and use of water for municipal purposes, the use ultimately intended for the water stored underground. In neither case, however, are the existing surface water rights developed into potable water supplies at this time. For ASR testing purposes, the only source of potable water is water that is currently in the SAWS and BexarMet distribution systems that is not from a surface water source. The TWDB and TNRCC have both indicated that the use of the current distribution system supply, which is Edwards aquifer water, should meet with their respective agencies' approval. Final approval will be granted at the same time as approval for a specific test injection program. Since a formal permit is not required for Phase I, SAWS and BexarMet must only provide the executive director of the TNRCC with written notification, the Class V injection well information, and a map, all not later than 60 days prior to the time the intended first storage test is to be conducted.

Operating Requirements. The TNRCC water quality requirement for Class V injection wells states that injected water must meet the quality criteria prescribed by the commission's drinking water standards. This section of the regulations does not stipulate the source of water to be injected.

Upon completion of the Feasibility Investigation (Phase I), a new water right or an amendment to an existing water right will be required before the long-term operation of an ASR system (Phase II) can be implemented using surface water as the source of supply.

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 well. A detailed listing of Phase I and Phase II submittal requirements is included in Attachment P6 of the UIC and Surface Water Use Permit Appendix.

Permitting/Protection Issues

The ability to control and limit unauthorized pumping of stored water is essential to the ultimate success of any ASR system. Following is a list of actions that SAWS and Bexar Met may wish to consider as ASR system development progresses.

- consider ordinances that would prohibit wells within the jurisdictional limits of each if public supplied water were available. Also, SAWS and BexarMet may wish to adopt all existing TNRCC well regulations as ordinances so that enforcement of such regulations could be initiated by SAWS or BexarMet rather than relying on state agencies.
- investigate creation of underground water districts (or revision of BexarMet's authority) for aquifers that are appropriate and feasible for ASR use. Such districts have greater, but limited, powers to control well locations and amounts pumped.
- seek legislative action creating special protection for injected waters.
- develop procedures for condemnation of storage rights under tracts of land to be used for ASR storage. Damages to landowners would likely be positive, i.e., a net benefit to a landowner would theoretically occur rather than a damage. This is because injected water would raise the water level in other wells in the area, thereby reducing pumping costs to other native groundwater well users in the same aquifer. Also, recovery of injected water by the City could be limited to the amount injected, thus lessening the effect on surrounding water levels.

Suggested Permitting Approach

SAWS and BexarMet should defer pursuit of long-term permits until Steps 2 and 3 of this investigation prove the feasibility of ASR. Following the successful demonstration of feasibility, SAWS and BexarMet would need to apply to TNRCC to establish or amend existing water rights to allow long-term storage of State of Texas surface waters in the ASR system.

Section 7 Summary and Recommendations

Source Water Assessment

The SAWS and BexarMet water supply systems share similar characteristics. Both currently rely solely on groundwater, with SAWS using wells in the Edwards aquifer exclusively. BexarMet draws lesser amounts from other aquifers such as the Trinity and Carrizo-Wilcox in addition to the Edwards.

The SAWS service area is divided into 14 service levels (pressure planes). Transfers between service levels are limited to moderate volumes of water moved between adjacent levels. Generally, water demands are met with wells local to the demands. There are six noncontiguous BexarMet service areas, representing geographic divisions of the water system. Water cannot be moved between service areas. The service areas are supplied by individual wells or well groups that pump into storage tanks or directly into the distribution system.

SAWS has sufficient *pumping* capacity (total well capacity of 756 mgd) to meet the projected maximum day demand of 418 mgd for the year 2016. Like SAWS, the BexarMet system has sufficient *pumping* capacity (total well capacity of 110 mgd) to meet the projected maximum day demand of 88.5 mgd for the year 2016. However, the EAA is currently developing rules to regulate groundwater withdrawals. The purpose of the rules is to protect this natural resource and, in doing so, to protect the related social and economic interests dependent on the aquifer.

The aquifer rules will require permits for most groundwater users and will set limits on the volume of groundwater that may be withdrawn. The limits will take the form of base withdrawals and will probably be set as permitted annual volumes. The definition of "base withdrawal" has not yet been written into the rules. Therefore, it is not clear how withdrawal rates can vary within the permitted year. Additionally, critical periods (defined as periods of low aquifer levels) will be identified in the EAA rules. Pumping limits during critical periods will be tied to water levels in three benchmark wells, which represent average conditions in three geographic areas of the aquifer.

Given the EAA rules limiting pumping from the Edwards aquifer, SAWS and BexarMet must develop alternative sources for future water supply. At this time, selecting future sources of supply is only at the conceptual stage. The most discussed near-term sources of surface water supply are Canyon Lake, the Guadalupe River, the Medina River, Medina Lake, and Lake Dunlap. Although each of these potential supplies is a possibility, there are significant institutional, water rights, and water quality issues unique to each source.

If these future sources are developed including an ASR system, several benefits could result. Generally, the alternative supply sources could be stored in other area aquifers during times of surplus and withdrawn to supplement permitted Edwards aquifer base and maximum withdrawals. Specific examples include storing seasonal stream flows during high runoff events, storing higher quality waters when production quality and quantity can vary seasonally, or capturing and storing other waters that would go unused if large volume storage were not available. Moving water from one service area to another within each system would be the major planning concern for ASR.

Groundwater Assessment

As part of the Groundwater Assessment, aquifer characteristics, groundwater and source water geochemistry, and the distribution of groundwater wells in Bexar County were summarized and used to evaluate the available ASR zones. The following six potential storage zones, designated by geographic area and aquifer, were selected for more detailed assessment:

- Area 1 - Middle Trinity Aquifer
- Area 1- Lower Trinity Aquifer
- Area 3 - Middle Trinity Aquifer
- Area 5 - Brackish Edwards Aquifer
- Area 6 - Wilcox Group
- Area 7 - Carrizo Aquifer

A preliminary compatibility evaluation of the five source waters with each of the potential storage zones was completed using the generalized native water quality information. Aquifer mineralogy was also considered in the compatibility assessment. The five source waters include:

- Raw water from Lake Medina near San Antonio
- Raw water from the Medina River at the Bexar Metropolitan (BexarMet) pilot water treatment plant site near San Antonio
- Raw water from Canyon Lake near New Braunfels
- Treated water from the Canyon Regional Water Authority (CRWA), New Braunfels
- Treated Edwards aquifer water supplied by the San Antonio Water System (SAWS)

Similar chemical characteristics of the Lake Medina, Canyon Lake, CRWA, and SAWS source waters permitted these sources to be evaluated as a group, substantially reducing the effective number of source/storage zone combinations. The qualitative geochemical analysis suggests that although adverse reactions are possible, each of the six storage zones is probably suitable for ASR development. A detailed, sites-specific investigation will be required to quantify the potential for adverse chemical and physical reactions at each ASR test site selected for further study.

Potential problems in the Trinity Group aquifers in Areas 1 and 3 include precipitation of calcium carbonate, iron oxyhydroxide colloid formation, and clay destabilization, all of which can reduce well efficiencies. There is also a potential for increased sulfate in the recovered water, which would only affect the initial cycles.

The major potential problem with the Brackish Edwards storage zone in Area 5 is mixing with the relatively poor quality native water. Calcium carbonate precipitation is possible but is less of a concern than in the Trinity Group zones due to the higher secondary porosity in the brackish Edwards.

The Wilcox and Carrizo storage zones in Areas 6 and 7, respectively, have the potential for increased sulfate in the recovered water. Plugging due to iron oxyhydroxide colloid formation is also a potential problem in these zones. Clay stability associated with pH changes could occur in the Wilcox Group storage zone but should not be a problem in the Carrizo Sand.

Disinfectants are added to the potable or drinking water to kill any potential water-borne pathogens. A trade-off of this protection is the formation of disinfection byproducts, some of which are considered probable carcinogens and/or present other chronic health concerns. However, a recent study by the American Water Works Association Research Foundation found that aquifer storage and recovery actually reduces disinfection byproducts.

ASR Applications and Feasibility

Conceptual ASR applications addressing seasonal and extended period (drought) water supply needs were developed for each of the six storage zones. Estimates of individual well capacity and area-wide potential are developed for each storage zone. Seasonal and drought storage volumes are computed assuming future availability of suitable source water.

A five-month recharge and recovery cycle was assumed as a seasonal application, which could provide additional supplies during the summer peak period. However, a repeat of the 1948 to 1957 drought would likely require recovery to continue into the normal recharge period or the opportunity to recharge could be eliminated altogether. To evaluate drought operations, a continuous 24-month recovery period was selected.

The design capacity of an ASR well depends on the rate and duration of recharge and recovery. The two primary factors influencing ASR well recharge/recovery rate are the storage static water level and specific capacity. Representative values of specific capacity and static water level elevation were derived using the available literature and experience in the area. Design capacities ranged from 300 gpm for the Area 1: Lower Trinity to 2,000 gpm for the Carrizo option.

The area-wide ASR potential was determined for both seasonal and drought (24 months) applications. The area-wide potential is generally a function of the effective area within each of the geographic areas available for development of ASR, well spacing, and ASR well design rate. The effective area within each of the six geographical areas was estimated as a percentage of the total area minus those areas that were determined to be unsuitable or unavailable for ASR development. Wells were spaced such that the drawdown or mounding impact from adjacent wells did not significantly reduce well capacity.

The estimated cost of implementing ASR is presented for each storage zone. Cost estimates include capital and O&M expenditures to assess the total cost of ASR water. These costs, combined with the estimated well capacities and annual storage potential, were used to develop unit costs for ASR water that are compared with other water supplies.

Capital and O&M cost estimates were developed for a typical ASR installation within each storage zone assuming large-scale ASR implementation. The number, diameter, well casing length, and casing material varies from one storage zone to the next. However, well depth, completion interval, and drilling difficulty will vary across each storage zone, impacting the actual cost of ASR implementation. Subsequent phases of the ASR investigation will provide the information necessary to refine design criteria, system configuration, operating cycles, and implementation costs.

O&M considerations are marginally more complex than for conventional production wells. Some of the unique elements considered in developing O&M costs for ASR systems include periodic changes in operation (recharge to recovery), backflushing during recharge to maintain well capacity, maintenance of adequate disinfection residual, and accelerated pump wear. Analyses indicate O&M costs would range from a low of $0.11 per 1,000 gallons for the Area 7: Carrizo option to a high of $0.34 per 1,000 gallons for the Area 1: Lower Trinity storage zone. The marginal cost of water produced from ASR, including capital costs, ranges from $82 per acre-foot (ac-ft) in the Area 7: Carrizo option to $398 per ac-ft for the Area 1: Lower Trinity option. Development of horizontal wells as a means of increasing well capacity, and the associated cost impacts, were also presented.

Four scenarios each were conceived for SAWS and BexarMet to compare costs of additional sources with and without ASR management. Projected 2016 demands were met with alternate uniform and seasonal variations of imported water rate. Results indicate that ASR can be used to reduce seasonal Edwards withdrawal peaks or even shift the peaks to low demand months when Edwards water is most available. The marginal cost associated with ASR is also less than the cost of using imported water to meet seasonal peak demands, especially when Edwards withdrawals are restricted.

Movement of stored water in response to adjacent users or regional groundwater flow can reduce the availability of stored water for future recovery, particularly when water is stored for several years before recovery is initiated. The potential impact of stored water migration was quantified by offsetting an idealized stored water plume by the one-year groundwater flow distance. Significant movement would only be an issue in non-potable storage zones and the impacts would be mitigated using the cluster concept developed for this project. Annual offsets in the six storage zones are well within acceptable limits, especially for the non-potable zones.

Protection of stored water will need to be addressed to successfully implement a large-scale ASR program. Numerous mechanisms that would limit unauthorized withdrawal of stored water are available. Well location and design considerations provide a significant level of protection. In addition, City of San Antonio code already restricts construction of new water supply wells where SAWS water service is currently provided or where service could be extended at a cost equal to or less than the cost of a well. This ordinance effectively limits access to water stored beneath areas actively served by SAWS. Applications not covered by either of these mechanisms may require lease or purchase of the right to pump water to restrict access or an underground water district may need to be formed.

Potential Additional Water Storage and Supply Options

The primary water supply source for the San Antonio area is the Edwards aquifer. Because of growing demand throughout the region and restrictions on withdrawals from the Edwards aquifer, it has become necessary that major water users develop alternative sources of supply as well as conservation and reuse programs in order to meet future needs. SAWS and BexarMet have a leadership role in the transition process.

Both SAWS and BexarMet have initiated aggressive conservation programs that have resulted in significant reduction in the per capita water usage. SAWS is also implementing a water recycling program that will deliver 35,000 acre-feet per year of water suitable for non-potable uses, reducing Edwards aquifer withdrawals by an equivalent amount.

In addition, both SAWS and BexarMet are pursuing the acquisition and development of alternative supplies of water. Many different schemes have been identified and evaluated under the Trans-Texas Water Program work recently completed. Senate Bill 1, passed by the 1997 Texas legislature, calls for the planning and development of water resources on a regional basis. Although this effort is just beginning, SAWS and BexarMet have recently entered into agreements that will provide treated surface water to each within the next few years. BexarMet, in co-operation with the Bexar Medina Atascosa Irrigation District, is developing treatment facilities for Medina Lake water. Both SAWS and BexarMet have entered into an agreement with the Guadalupe Blanco River Authority for the delivery of treated water from Canyon Lake.

As water planning proceeds, numerous additional storage and supply alternatives will be identified and evaluated.

Underground Injection Control and Surface Water Use Permits

The Texas Water Development Board and Texas Natural Resources Conservation Commission govern aquifer storage and recovery system development and operation. Feasibility investigations, including prototypical ASR well construction and testing, are authorized by rule and do not require permits (although advanced notification is required). ASR injection and recovery wells must conform to Class V well construction standards.

State regulations contemplate that surface waters will be the source water for ASR systems. A water right or an amended water right is not required during the feasibility investigation phase of ASR system development. However, a new water right or an amended water right will be required for the long-term operation of an ASR system.

In addition to the requirements mentioned above, it will be important that SAWS and BexarMet have the necessary legal and institutional controls in place to prevent unauthorized withdrawal of ASR water developed by each. This could be a combination of ordinances, well development permitting if not already in place, and acquisition or lease of land over ASR sites if not already owned.

Recommendations

Results of this preliminary feasibility investigation indicate that ASR could provide several benefits to SAWS and BexarMet. These benefits are achievable at a significantly lower cost and with less environmental impact than other water supply and storage options under consideration. Therefore, it is recommended that Step 2 of the ASR feasibility investigation be initiated in the following storage zones:

- Area 1: Middle Trinity
- Area 6: Wilcox
- Area 7: Carrizo

The purpose of the Step 2 program is to refine estimated parameter values and confirm assumptions made in the preliminary analysis. Of particular interest are the site-specific groundwater quality profiles, aquifer hydraulic and mineralogical characteristics, and static water level elevations. Results of water quality testing will determine the degree of geochemical modeling necessary in Step 2 to address outstanding compatibility issues.

The first task under Step 2 of the project will be selection of a suitable site or sites within each of the storage zones for the development of test borings. In addition to the location and capacity of existing distribution system infrastructure and the availability of property owned or under the control of the City of San Antonio or BexarMet, hydrogeologic considerations also guide selection of test sites. Evidence of lineament and fracture trends will be used to locate the test site in Area 1: Middle Trinity storage zone in an effort to maximize well capacity. Seismic or other surface geophysical techniques will likely be used to screen candidate sites in the Area 6: Wilcox zone. The Carrizo aquifer is relatively homogeneous and engineering considerations, rather than variations in aquifer characteristics, will tend to drive site selection.

A single test boring will be completed at each test site. Testing will include discrete water quality sampling and analysis, rock coring and analysis, and borehole geophysical logging under both static and pumping conditions. The Area 1: Middle Trinity site will be drilled using air rotary methods to minimize formation plugging. Abundant sand and silt deposits will dictate use of mud rotary drilling to advance the Area 6 and Area 7 test borings. Jetting combined with air lifting will be used to develop the monitoring well prior to pump testing. Use of directional drilling technology would not be appropriate for development of the Step 2 wells, but should be considered once ASR technology has been successfully demonstrated.

Test results will be used to determine the design of the monitoring well that will be completed in each test boring. Limited testing will be conducted on the monitoring wells to evaluate aquifer specific capacity and to measure static water levels. The monitoring wells will not be designed for recharge and cycle testing will not occur until a prototype ASR well is design and constructed during Step 3 of the feasibility investigation.

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Aquifer Storage Recovery (ASR) Feasibility Study: Source Water Assessment

PREPARED FOR: San Antonio Water System (SAWS)
Bexar Metropolitan Water District (BexarMet)

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DATE: February 6, 1998

Introduction

The existing water supply facilities and projected water demands were reviewed for the San Antonio Water System (SAWS) and Bexar Metropolitan Water District (BexarMet). The review, part of the Aquifer Storage Recovery (ASR) Feasibility Investigation, is needed to assess the potential for ASR to leverage future SAWS and BexarMet water supplies.

This *Technical Memorandum* presents an overview of the SAWS and BexarMet water systems, historic and projected water demands, the distribution of these demands across the service areas, and potential additional water supply options. Based on this general understanding of each utility's demand and supply situation, preliminary ASR applications are presented. This *Technical Memorandum* is divided into the following sections:

- Existing Water Systems
- Historic Water Demands
- Projected Water Demands
- Future Regulatory Requirements
- Potential ASR Source Waters
- ASR Considerations

Existing Water Systems

SAWS

The existing SAWS water supply system relies solely on groundwater pumped from the Edwards aquifer through wells. The freshwater Edwards aquifer is an extensive limestone aquifer that underlies portions of the SAWS service area and has the capability of yielding large volumes of fresh water to wells. A more thorough discussion of the Edwards aquifer is included in the *Groundwater Assessment Technical Memorandum* that was completed as part of this study

The SAWS service area lies completely within Bexar County. The service area is divided into 14 service levels that represent the required pressure planes needed to provide system pressures within the desired limits for a potable water system. Within each service level there are primary, secondary, and booster pumping stations. These pumping stations are described in the following three paragraphs.

Primary pumping stations consist of one or more wells at a location that pump or flow by artesian head to a ground storage reservoir. The flow from these wells is regulated to provide a desired water level in the reservoir. High service pumps transfer the water out of the reservoir and into the distribution system piping at system pressure.

Secondary pumping stations consist of individual wells which pump at system pressure directly into the distribution system piping. Secondary pumping stations are located throughout the water system and are used primarily to maintain system pressures during periods of high demand.

Booster pumping stations are located in several of the service levels and are used to transfer water from certain service levels to others. In some service levels, transfers are used to supplement limited well capacity, and in other service levels transfers represent the only source of water for the level. Service levels requiring augmentation are typically outside of the freshwater Edwards aquifer zone.

At this time, transfer, between service levels are limited to moderate volumes of water moved between adjacent service levels. It is not currently possible to move large volumes of water quickly from one side of the system to the other. Generally, water demands are met with supplies local to the demands.

The service levels, along with their respective high service and well pumping capacities, are listed below. The service level locations and boundaries are shown on **Figure 1**.

The data in the **Table 1** were obtained from a draft memorandum titled, "Working Paper No. 2 Workshop, October 28, 1997, 1:30 p.m." For some of the service levels, well capacities were listed for more than one level. In these cases, listed capacities were apportioned equally to the levels.

BexarMet

The BexarMet water system also relies exclusively on groundwater for water supply. Similar to the SAWS system, substantial groundwater supplies are pumped from the Edwards aquifer. However, the Trinity and the Carrizo-Wilcox aquifers are used in portions of the service area where the Edwards is not present or is of poor quality. Less than seven percent of the total Bexar Met demand was met by withdrawals from these two aquifers in 1996. With the exception of a small number of customers in Atascosa County, the BexarMet service area is located within Bexar County.

Bexar Met is currently developing a surface water treatment plan along the Medina River. The 9-million gallon per day (mgd) plant will supplement groundwater supplies in the southern service areas. The plant is scheduled for completion in December, 1999.

The BexarMet water system is divided into six main service areas, although subdivisions within the main areas exist as well. The Total Northwest and Southeast Service Areas consists of several sub-areas each. For discussion purpose, the Total Northwest and Southeast Service Areas will include the following sub-areas:

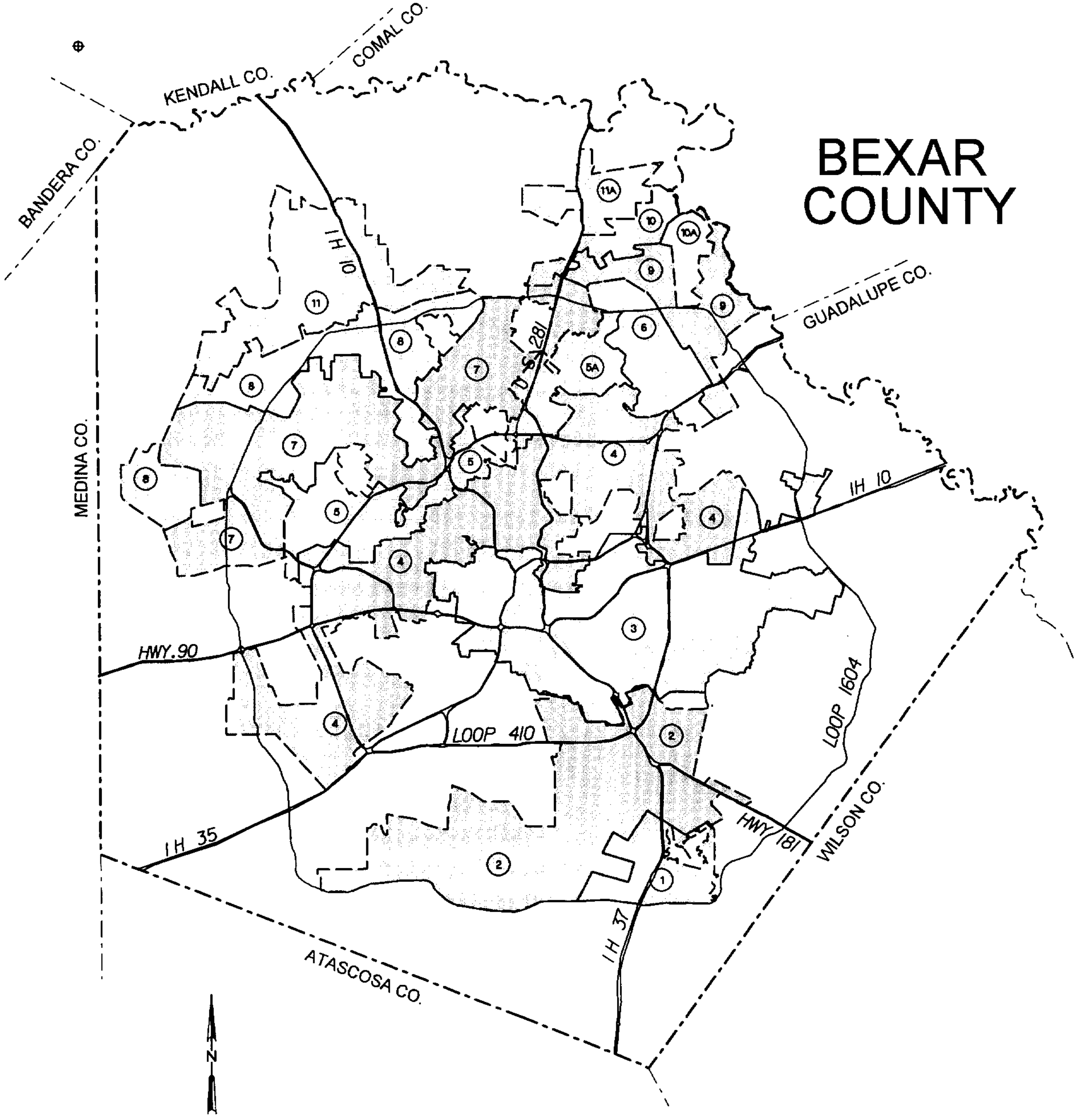

FIGURE 1
SAWS Service Levels
Source Water Assessment

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- **Total Northwest:** Northwest, Chaparral, Texas Research Park, and Cagnon
- **Southeast:** Palo Alto Park, Palo Alto, South Oak, Windys, Hickory, Pleasant Oaks, Silver Mountain, Oak South, Primrose, Shalimar, Kings Point, Twin Valley, and Timberwood

TABLE 1
SAWS Pumping Capacity

Service Level	Primary Pumping Station Capacity (million gallons per day)		Secondary Pumping Station Capacity (million gallons per day)
	High Service	Wells	Wells
1	0	0	0
2	0	0	0
3	183	200	0
4	217	171	47
5	42	48	22
5A	30	64	0
6	52	102	5
7	110	103	4
8	8	5	8
9	0	0	5
10	0	0	0
10A	0	0	0
11	0	0	0
11A	0	0	0
14	0	0	0
Total	**642**	**693**	**91**

The service areas, shown in Figure 2, are principally geographic divisions of the water system, and the service area boundaries are not contiguous. It follows that it is not possible to move water between service areas. The service areas are supplied by individual wells or well groups that pump into storage tanks or directly into the distribution system.

The service areas and their respective well capacities are listed in **Table 2**. The data in **Table 2** were obtained from **Tables 4-1** through **4-12** of the *1997 BexarMet Storage & Production Facility Capital Improvements Report.*

TABLE 2
BexarMet Pumping Capacity

Service Area	Well Capacity (million gallons per day)
Castle Hills	11.9
Hill Country	10.7
Northeast	18.8
Total Northwest	12.0
Southeast	2.6
Southside	54.1
Total	**110.1**

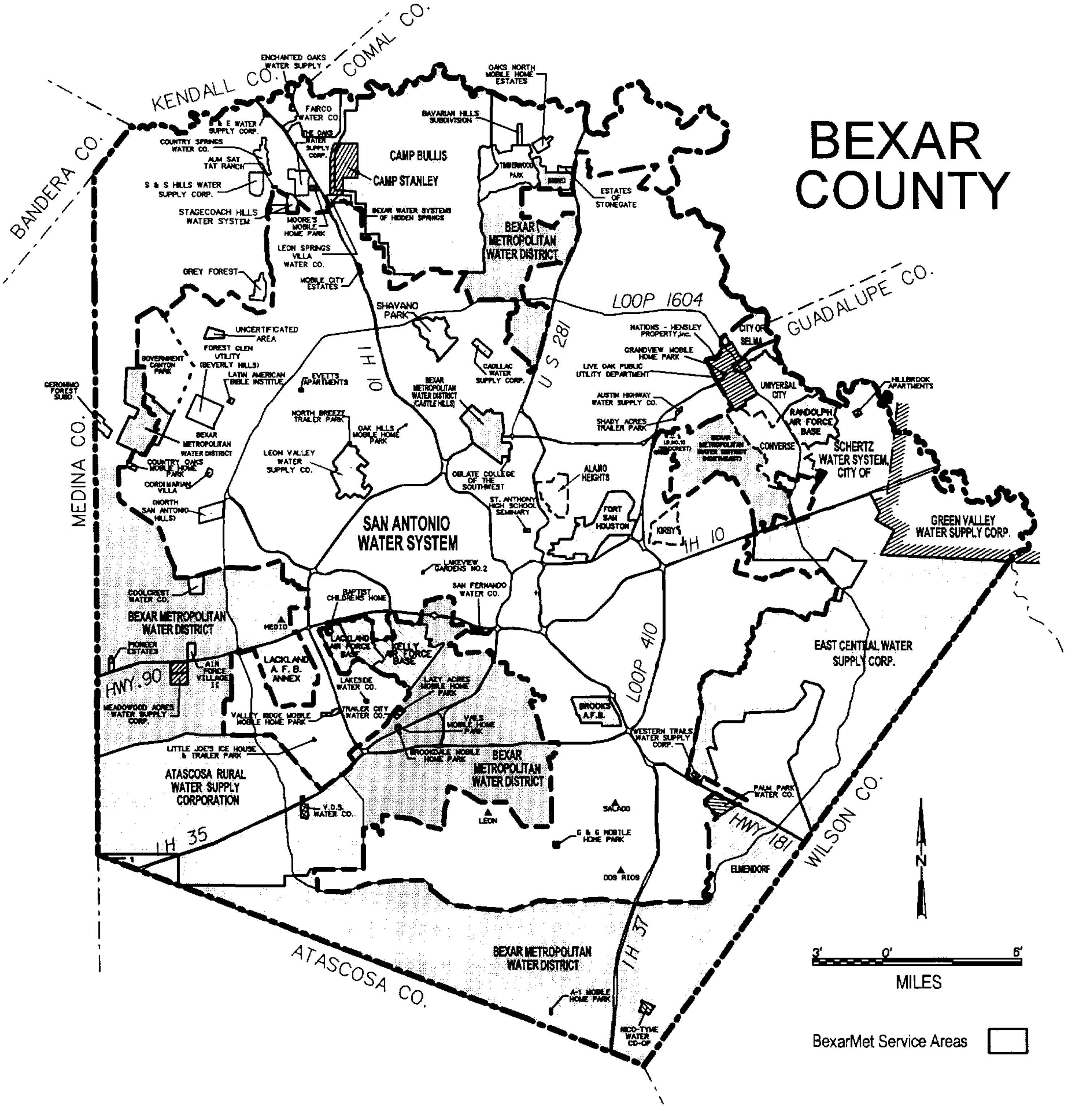

FIGURE 2
BexarMet Service Areas
Source Water Assessment

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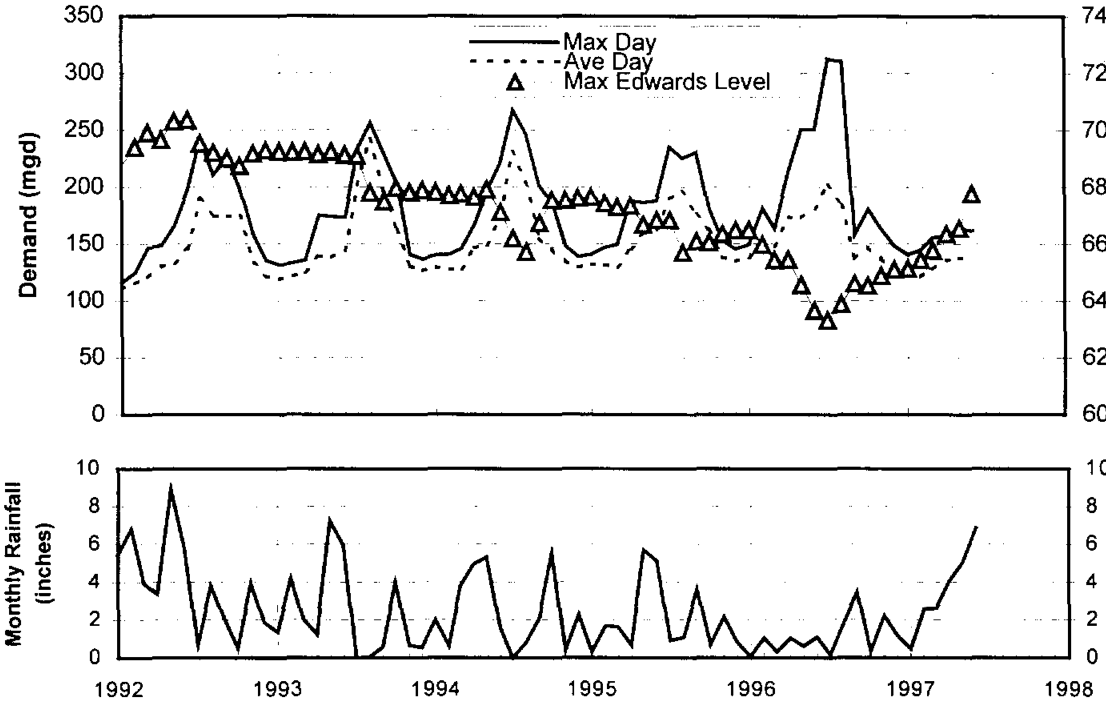
Historic Water Demands

SAWS

Monthly water demands from 1992 through 1996 were reviewed for the SAWS water system. Historic monthly average demands and monthly maximum day demands were obtained from monthly pumpage data. These historic water demands are presented in **Figure 3** along with monthly rainfall, and Edwards aquifer water levels as observed in benchmark well J-17.

FIGURE 3
Historic Rainfall, Edwards Levels, and SAWS Demands



The monthly average demands shown in **Figure 3** represent the average rate of water use over the month expressed in million gallons of water per day (mgd). The monthly maximum day values represent the maximum volume of water produced over one day during the month.

Water demands on the system appear to vary inversely to precipitation between 1992 and 1995 and do not show a distinctive increase or decrease over the time period. However, in 1996, a substantial increase in water use is observed. The increase in water use corresponds to a decrease in annual rainfall and principally occurs as an increase in maximum day usage during the summer months. The magnitude of maximum day usage was increased by a City ordinance which restricted residential irrigation to weekend days. This ordinance has since been modified to distribute residential irrigation throughout the week.

The historic water demands observed between 1992 and 1996 were averaged and normalized to produce a typical water demand distribution based on historical use. To obtain the typical distribution, the monthly average and monthly maximum day demands were averaged over the five-year period then divided by the five-year average annual demand for the same period. The result is a set of monthly factors that describe the typical variation in monthly demand for any given year as a function of the historical or projected average annual demand. The typical demand distribution is presented in **Figure 4**.

FIGURE 4
SAWS Typical Demand Distribution

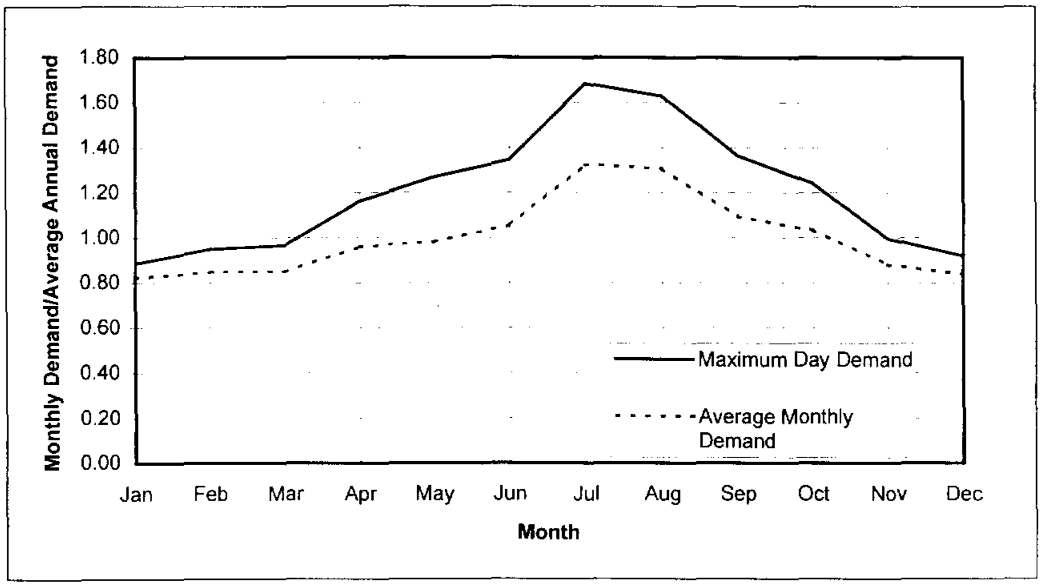


Figure 4 shows that monthly water demands are typically higher than the annual average in the SAWS water system during June, July, August, September, and October. The maximum day demand typically occurs during the month of July, and the average ratio of maximum day demand to average annual demand was 1.7.

The water demand distribution in the individual service levels for 1996 was obtained from "Working Paper No. 2 Workshop, October 28, 1997, 1:30 p.m." Values for water demands in each service level show the distribution of water use through the SAWS system. By comparing these values with the overall well capacity in each service level, the water supply needs can be assessed. These values, presented in **Table 3**, show that the SAWS system well capacity is adequate to meet current needs. It must be noted that although the total well capacity appears to be adequate, regulations regarding the use of the Edwards aquifer are currently being developed and these regulations will directly affect SAWS' ability to use existing wells in the future.

It is important to note that Service Levels 1, 2, 10, 10A, 11, 11A, and 14 do not have well capacity within the areas and booster pumping from adjacent levels is used to meet the water demands.

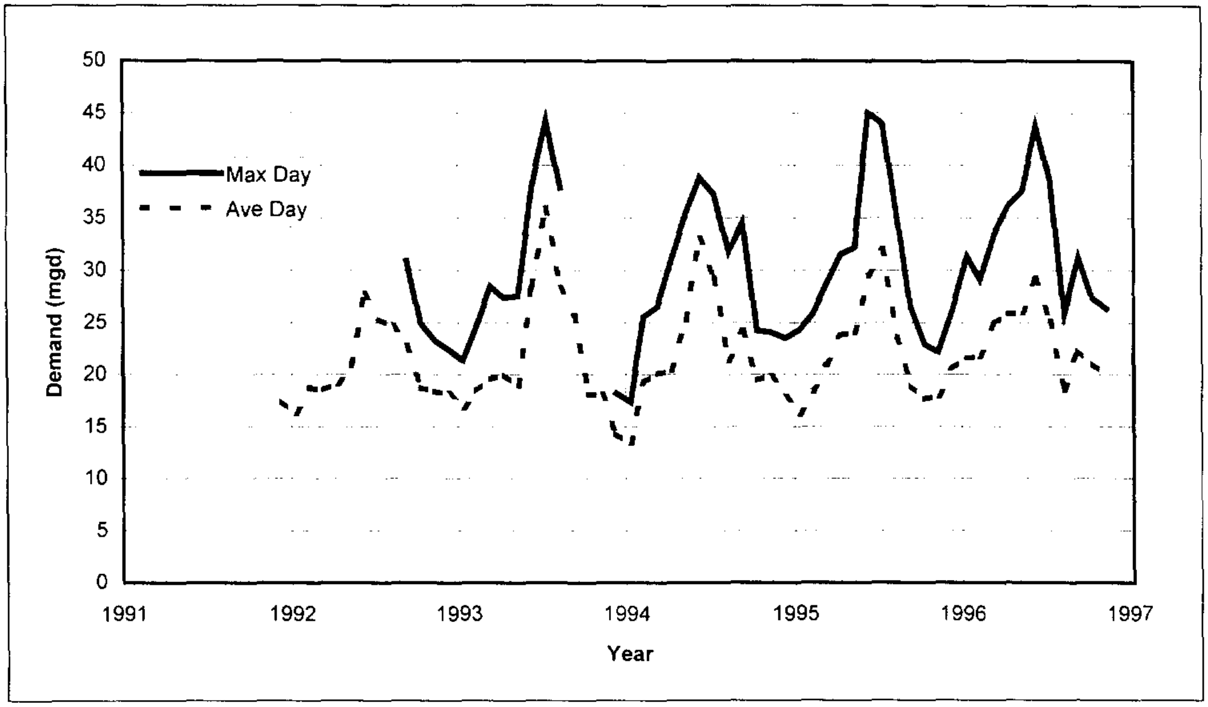
TABLE 3
SAWS 1996 Demands

Service Level	Total Well Capacity (million gallons per day)	1996 Average Annual Demand (million gallons per day)	1996 Maximum Day Demand (million gallons per day)
1	0	0.30	0.53
2	0	1.93	3.68
3	185	38.94	72.87
4	203	49.42	89.96
5	114	11.77	24.41
5A	105	9.79	22.43
6	67	7.07	16.12
7	64	28.71	59.19
8	13	7.09	13.60
9	5	2.62	5.23
10	0	0.27	0.58
10A	0	0.01	0.03
11	0	0.76	1.55
11A	0	0.11	0.23
14	0	0.41	0.83
Total	**756**	**159.20**	**311.24**

BexarMet

Monthly water demands from 1992 through 1996 were also reviewed for the BexarMet water system. Historical monthly average demands and monthly maximum day demands were obtained from monthly pumpage data for the different service areas and sub-areas within the BexarMet system. However, for several of the sub-areas in the water system, the historical data is incomplete. Historical water demands for the entire BexarMet system are presented in **Figure 5**, and the breaks in the demand curves represent time periods where incomplete data did not allow the calculation of a representative demand value.

FIGURE 5
BexarMet Historical Water Demands



The monthly average demands shown in **Figure 5** represent the average rate of water use over the month. The monthly maximum day values represent the maximum volume of water produced over one day during the month. Water demands on the system vary and show no distinctive trend over the time period. Even during the 1996 low rainfall year, a substantial increase in water use is not observed.

The historical water demands observed between 1992 and 1996 were averaged and normalized to produce a typical water demand distribution based on historical use. To obtain the typical distribution, the monthly average and monthly maximum day demands were first averaged over the five-year period then divided by the five-year average annual demand for the same period. The result is a set of monthly factors that describe the typical variation in monthly demand for any given year as a function of the historical or projected average annual demand. **Figure 6** presents the typical demand distribution for the BexarMet system.

FIGURE 6
BexarMet Typical Demand Distribution

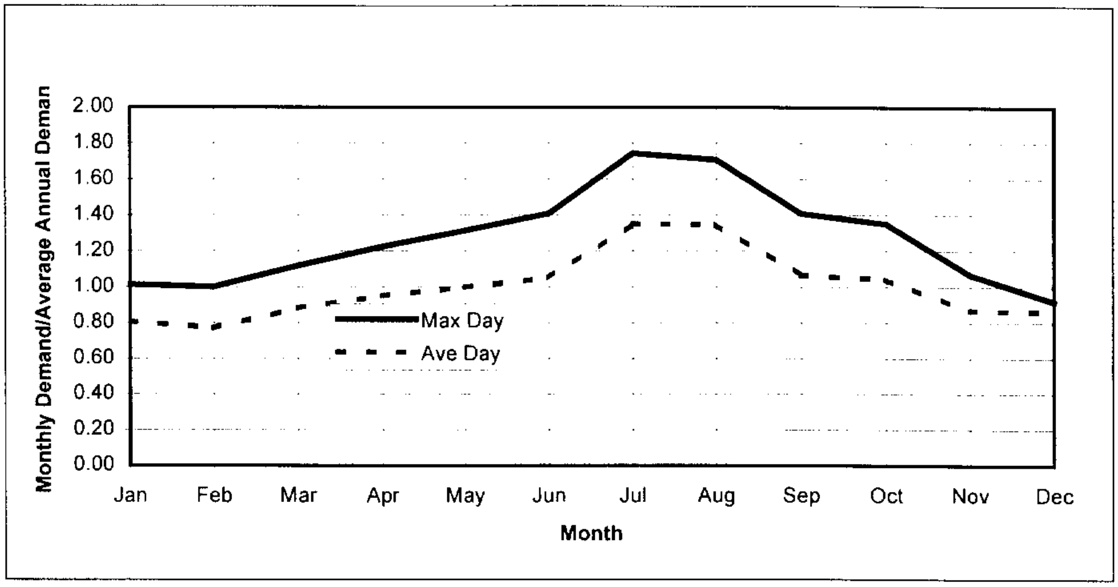


Figure 6 also shows that monthly water demand variation is similar to the SAWS system variation. Demands are typically higher than the annual average in the BexarMet water system during June, July, August, September, and October. The maximum day demand typically occurs during the month of July and the average ratio of maximum day demand to average annual demand was 1.8. However, the water demands experienced during 1992 did not appear typical of the later years. This may be due to incomplete data sets that influenced the calculations substantially this year. The average maximum day demand to average annual demand ratio increases to 1.9 if data from 1992 is excluded. This value is considered more representative of the BexarMet system.

The distribution of water demand in the individual service areas for 1996 was obtained from the *BexarMet Storage & Production Facility Capital Improvements Report.* Values for water demands in each service area show the distribution of water use through the BexarMet system. By comparing these values with the overall well capacity in each service area, the water supply needs can be assessed. These values, presented in **Table 4**, show that the BexarMet system well capacity is adequately meets current needs.

It must be noted that although the total well capacity appears to be adequate, regulations regarding the use of the Edwards aquifer are currently being developed. These regulations will directly affect BexarMet's ability to use existing wells in the future.

TABLE 4
BexarMet 1996 Demands

Service Area	Total Well Capacity (million gallons per day)	1996 Average Annual Demand (million gallons per day)	1996 Maximum Day Demand (million gallons per day)
Castle Hills	11.9	1.7	4.3
Hill Country	10.7	3.0	7.0
Northeast	18.8	3.1	7.3
Total Northwest	12.0	3.5	5.8
Southeast	2.6	1.0	2.0
Southside	54.1	11.0	22.0
Total	**110.1**	**23.3**	**48.3**

Projected Water Demands

SAWS

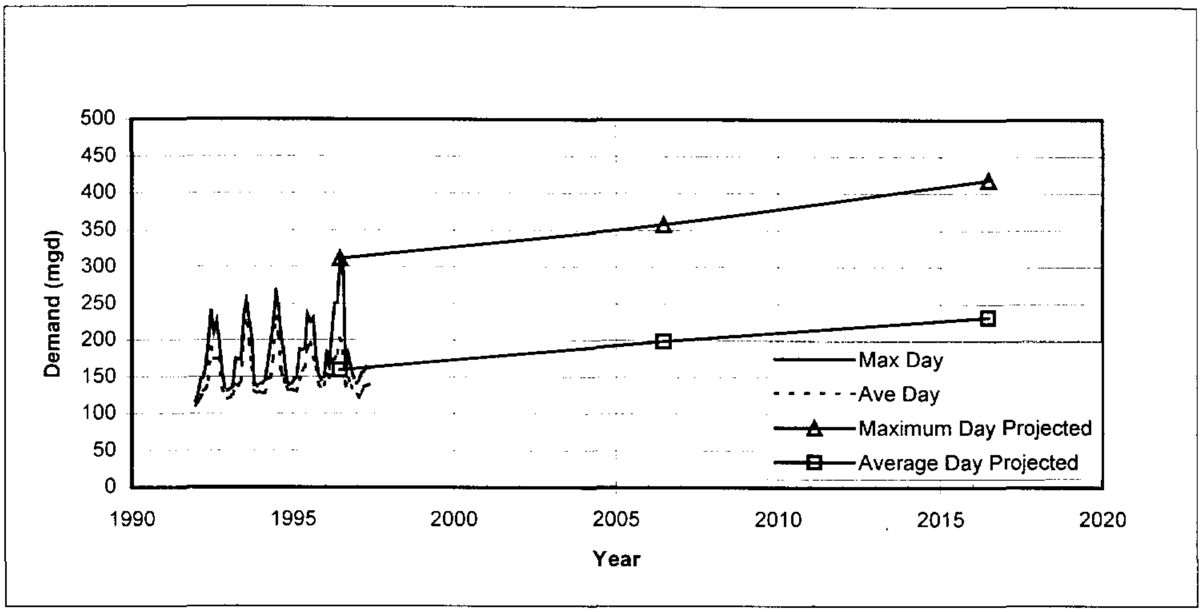
Water demand projections obtained from the SAWS "Working Paper No. 2 Workshop, October 28, 1997, 1:30 p.m." were used to evaluate future demands. Average annual, average monthly, and maximum day demands were projected into the future for the 15 service levels. Demands were projected for the years 2006 and 2016. A maximum day to average annual demand ratio of 1.80 was used by SAWS for these future demands. These demand projections are listed in **Table 5** and are also presented with the historic system demands in **Figure 7**.

TABLE 5
SAWS Projected Demands

Service Level	Average Day (million gallons per day)			Maximum Day (million gallons per day)		
	1996	2006	2016	1996	2006	2016
1	0.30	0.32	0.34	0.53	0.52	0.55
2	1.93	2.20	2.74	3.68	3.85	4.77
3	38.94	43.34	46.83	72.87	74.33	80.10
4	49.42	57.99	65.10	89.96	96.77	108.33
5	11.77	14.79	17.56	24.41	28.13	33.30
5A	9.79	13.19	15.59	22.43	27.71	32.66
6	7.07	8.21	10.06	16.12	17.14	20.96
7	28.71	41.10	50.37	59.19	77.66	94.93
8	7.09	10.53	13.54	13.60	18.52	23.75
9	2.62	4.12	5.74	5.23	7.55	10.48

Service Level	Average Day (million gallons per day)			Maximum Day (million gallons per day)		
10	0.27	0.60	0.83	0.58	1.16	1.60
10A	0.01	0.02	0.03	0.03	0.04	0.06
11	0.76	1.40	2.06	1.55	2.61	3.83
11A	0.11	0.37	0.53	0.23	0.68	0.98
14	0.41	0.64	0.93	0.83	1.19	1.73
Total	**159.20**	**198.82**	**232.25**	**311.24**	**357.86**	**418.03**

FIGURE 7
SAWS Historical and Projected Demands



The above demands indicate that considering well capacity alone, the SAWS system (total well capacity of 784 mgd) has sufficient capacity to meet the projected maximum day demand of 418 mgd for the year 2016. However, regulations are being developed regarding the use of the Edwards aquifer, and these regulations will limit the allowable volume and rate of withdrawals.

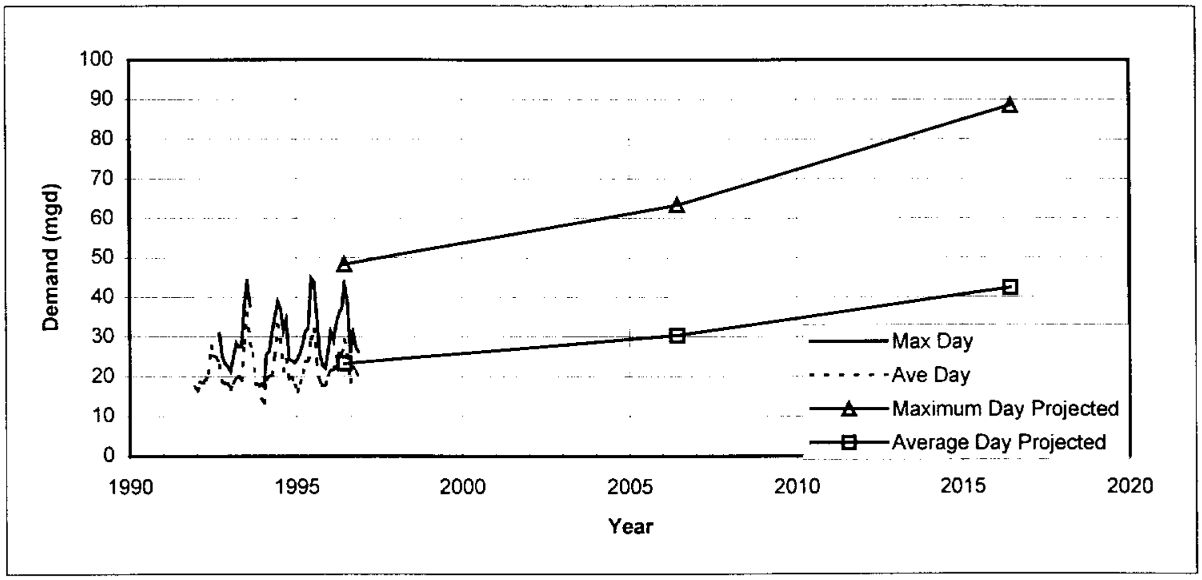
BexarMet

Water demand projections obtained from the *BexarMet Storage & Production Facility Capital Improvements Report* were used to evaluate future demands. Average annual, average monthly, and maximum day demands were projected into the future for the six service areas. Demands were projected for the years 2006 and 2016. A maximum day to average annual demand ratio of 2.1 was used by BexarMet for these future demands. These demand projections are listed in **Table 6** and are also presented with the historic system demands in **Figure 8**.

TABLE 6
BexarMet Projected Demands

Service Area	Average Day (million gallons per day)			Maximum Day (million gallons per day)		
	1996	**2006**	**2016**	**1996**	**2006**	**2016**
Castle Hills	1.68	1.71	1.75	4.33	4.40	4.51
Hill Country	3.02	5.87	10.63	7.01	13.64	24.69
Northeast	3.09	3.84	5.08	7.27	9.03	11.95
Total Northwest	3.45	4.53	6.34	5.79	7.60	10.63
Southeast	1.04	1.49	2.24	1.98	2.82	4.23
Southside	11.03	13.01	16.34	21.95	25.89	32.50
Total	**23.32**	**30.46**	**42.37**	**48.32**	**63.37**	**88.50**

FIGURE 8
BexarMet Historical and Projected Demands



The above demands indicate that considering well capacity alone, the BexarMet system (total well capacity of 110 mgd) has sufficient capacity to meet the projected maximum day demand of 88.5 mgd for the year 2016. However, because the service areas are not adjacent to one another, excess water supply capacity in one area be available to other areas that may have insufficient water supply capacity. BexarMet has plans to increase facility capacities to appropriate levels, where necessary.

Future Regulatory Requirements

The Edwards Aquifer Authority (EAA) is currently developing rules to protect environmental concerns and regulate groundwater withdrawals from the Edwards aquifer. The purpose of the rules is to protect this natural resource and, in doing so, to protect the related economic and social interests dependent on the aquifer.

The aquifer rules will require permits for most groundwater users and will set limits on the volume of groundwater that may be withdrawn on an annual basis. The limits will take the form of maximums and the amounts are subject to the Critical Period Rules.

Recently SAWS was provided their first-year withdrawal from the EAA. The permitted volume of annual withdrawal for the SAWS system is 193,944 acre-ft. This volume would have been adequate to meet 1997 SAWS demands (approximately 178, 340 acre-ft). However, demand projections indicate SAWS will require a total water volume of 222,720 acre-ft in 2006 and 260,170 acre-ft in 2016.

Additionally, critical periods (defined as periods of low aquifer levels) will be identified in the EAA rules. The low levels are thought to reduce spring flows from the aquifer. The critical periods will be tied to water levels in three benchmark wells, which represent average aquifer conditions in three geographic areas of the aquifer. The following are the three benchmark wells currently proposed:

1. The J-17 well, which represents aquifer conditions in Bexar, Comal, Hays, Caldwell, and Guadalupe Counties
2. The Medina well, which represents aquifer conditions in Medina and Atascosa Counties
3. The J-27 well, which represents aquifer conditions within the boundaries of the EAA that are in Uvalde County.

Four stages are currently being proposed for the critical periods; each stage represents a progressive reduction in the maximum allowable aquifer withdrawals. Maximum allowable withdrawals will be reduced during critical periods by only allowing maximum withdrawals equal to a set multiplier times the permitted base withdrawal.

At this time, the definition of "maximum allowable withdrawal" has not yet been written into the rules. It is therefore not clear for what period of time a maximum allowable withdrawal can take place or if the duration of withdrawal will be regulated.

Potential ASR Source Waters

SAWS and BexarMet must develop alternative sources for future water supply. If these future sources are developed with a potential ASR system, many possible benefits exist including, storage of alternative supplies during surplus periods, overall cost advantages of ASR systems, and reduction in aquifer pumping during critical periods. Generally, the alternative supply sources could be stored in other area aquifers during times of surplus and withdrawn to supplement permitted Edwards aquifer base and maximum withdrawals.

At this time, selecting future sources of supply is only in the conceptual stage. However, possible supply sources in the region could be available to both BexarMet and SAWS. The following discussion presents these possible sources and discusses potential applications for the two water systems. The most discussed near-term sources of surface water supply are:

- Canyon Lake
- Guadalupe River
- Medina River
- Medina Lake
- Lake Dunlap

Although each of these potential sources of supply are possibilities, there are significant institutional, water rights, and water quality issues unique to each source. In each case, treatment of the surface water to potable standards would be required. Each also has it's own limitations relating to existing water rights and jurisdictional control. It is noted, however, that SAWS has entered into an agreement with the Guadalupe Blanco River Authority (GBRA), to participate in a project to bring potable quality water into the San Antonio area from Canyon Lake. Other water purveyors will also be participating in this project. SAWS would receive 2,000 acre feet of water per year. This is but a small fraction of the annual requirement of SAWS customers. This project does, however, represent a breakthrough in inter-agency cooperation to begin to resolve a long standing regional water supply shortage that has become more critical with increased regional growth and periodic drought conditions. This has been further accentuated with the pumping limits placed on withdrawals from the Edwards aquifer.

BexarMet, in cooperation with the Bexar Medina Atascosa Counties Irrigation District (BMA), has been successful in amending the Medina Lake water use permit to allow a portion of lake water to be developed as a drinking water supply. BexarMet is currently developing a water treatment plant on the Medina River to take advantage of this source.

Additionally, BexarMet has contracted with Canyon Regional Water Authority for up to 4,000 acre-ft/year of treated water from the authority's Lake Dunlap Plant. This water may be used in BexarMet's northwest service area and others.

The other sources mentioned involve various combinations of interagency cooperation, inter-basin transfer, water rights allocations, and technical development issues. In one form or another, these have all been incorporated into the West-Central study area of the Trans-Texas project.

Only recently has there developed a cooperative approach to addressing the regional water supply issue. As regional water supply planning proceeds under Senate Bill 1, other source water supply options will be identified and evaluated. Supply options could likely be combined with ASR to maximize the benefits of each.

ASR Considerations

ASR can be applied to water utility operation in several different ways. Because it is a management tool, ASR cannot produce additional supplies of water, although it works very well in storing surplus water that may otherwise go unused. Typical ASR applications include storing seasonal stream flows during high runoff events, storing higher quality waters when production quality can vary seasonally, or capturing and storing other waters that would go unused if large volume storage is not available.

Many ASR applications store water for later use to meet peak or maximum day demands. In these types of applications, water production facilities generally have inadequate capacity to meet the high peak production rates required for the short duration maximum day events. Constructing and operating ASR wells to meet peak demands allows for smaller conventional water production and treatment facilities and cost savings can be substantial.

The water systems being considered herein are somewhat different from the those in the above example. The SAWS and BexarMet systems currently have substantial excess peak capacity. As discussed previously, SAWS has a current total well production capacity of approximately 784 mgd, and BexarMet has approximately 110 mgd. Projected maximum day demands for the year 2016 are 418 mgd and 89 mgd for SAWS and BexarMet, respectively. If the water systems were allowed to pump their wells without restriction, moving water from one service area to another within each system would be the major planning concern.

However, the EAA regulations will limit both water systems to a maximum annual withdrawal from the Edwards aquifer. A potential ASR application in this case could include managing the available water such that peak period base flows are supplemented with ASR pumping, reducing peak day withdrawals from the Edwards aquifer. By adding ASR pumping into the base flow, the portion of the Edwards pumping making up the maximum day production decreases and could even fall within the restrictions during the critical periods.

San Antonio Water System (SAWS)/Bexar Metropolitan (BexarMet) Aquifer Storage and Recovery (ASR) Feasibility Study: Groundwater Assessment

PREPARED FOR:	Bexar Metropolitan Water District and San Antonio Water System
PREPARED BY:	CH2M HILL
DATE:	January 5, 1998

Summary and Recommendations

This Groundwater Assessment Technical Memorandum presents a summary of aquifer characteristics groundwater, and source water geochemistry, and the distribution of groundwater wells in Bexar County. The results of this investigation are incorporated in the Storage Zone Evaluation Matrix presented in Table 2. Of the alternatives presented in this matrix, the following six potential storage zones, designated by geographic area and aquifer, were selected for more detailed assessment:

- Area 1 - Middle Trinity Aquifer
- Area 1- Lower Trinity Aquifer
- Area 3 - Middle Trinity Aquifer
- Area 5 - Brackish Edwards Aquifer
- Area 6 - Wilcox Group
- Area 7 - Carrizo Aquifer

A preliminary compatibility evaluation of the five source waters with each of the potential storage zones was completed using the generalized native water quality information. Aquifer mineralogy was also considered in the compatibility assessment. The five source waters include:

- Raw water from Lake Medina near San Antonio, Texas
- Raw water from the Medina River at the Bexar Metropolitan (BexarMet) pilot water treatment plant site near San Antonio, Texas
- Raw water from Canyon Lake near New Braunfels, Texas
- Treated water from the Canyon Regional Water Authority (CRWA), New Braunfels, Texas
- Treated Edwards aquifer water supplied by the San Antonio Water System (SAWS)

Similar chemical characteristics of the Lake Medina, Canyon Lake, CRWA, and SAWS source waters permitted these sources to be evaluated as a group, substantially reducing the effective number of source/storage zone combinations. The qualitative geochemical analysis suggests that although adverse reactions are possible, each of the six storage zones is probably suitable for ASR development.

Potential problems in the Trinity Group aquifers in Area 1 and 3 include precipitation of calcium-carbonate, iron oxyhydroxide colloid formation, and clay destabilization, all of which can reduce well efficiencies. There is also a potential for increased sulfate in the recovered water which would only affect the initial cycles.

The major potential problem with the Brackish Edwards storage zone in Area 5 is mixing with the relatively poor quality native water. Calcium-carbonate precipitation is possible but is less of a concern than in the Trinity Group zones due to the higher secondary porosity in the brackish Edwards.

The Wilcox and Carrizo storage zones in Area 6 and 7, respectively, have the potential for increased sulfate in the recovered water. Plugging due to iron oxyhydroxide colloid formation is also a potential problem in these zones. Clay stability associated with pH changes could occur in the Wilcox Group storage zone but should not be a problem in the Carrizo Sand.

A detailed, sites-specific investigation will be required to quantify the potential for adverse chemical and physical reactions at each ASR test site selected for further study. Typical testing would include installing test borings and collecting rock cores for mineralogical and hydraulic analysis. The test borings are often completed as monitoring wells, yielding water quality, water level, and aquifer permeability data.

Given that no serious obstacles were identified in the geochemical assessment, conceptual ASR applications will be developed for all six storage zones. Potential area-wide recharge and recovery rates and annual storage volumes will be estimated based on average well yield, aquifer permeability, and land availability. Capital and operation and maintenance costs for the conceptual applications will also be prepared and unit costs will be compared with costs for other proposed water supply alternatives. The results of these will be included in the SAWS/BexarMet Preliminary ASR Investigation and Feasibility Analysis final report.

Introduction

This Technical Memorandum (TM) summarizes the findings of the Groundwater Assessment task of the Aquifer Storage and Recovery (ASR) Preliminary Investigation and Feasibility Analysis. The Groundwater Assessment includes a general characterization of the geologic formations of Bexar County, a description of the principal aquifers of Bexar County, and a preliminary screening of the available storage zones to identify the most promising aquifer storage zones in the study area. General geochemical compatibility of the selected storage zones and various source waters was then investigated to complete this task.

Location of the Study Area

Bexar County, which defines the study area, is located in south-central Texas approximately 125 miles northwest of the Gulf of Mexico and 125 miles northeast of the Texas-Mexico border. Bexar County, comprising approximately 1,250 square miles, is bordered on the southeast by Wilson County, on the southwest and west by Atascosa and Medina Counties and on the north and northeast by Bandera, Kendall, Comal, and Guadalupe Counties.

Topography and Drainage

The topography of Bexar County can be divided into three general geologic provinces (from north to south): the Edwards Plateau, the Balcones Fault Zone or Balcones Escarpment, and the Gulf Coastal Plain (Arnow, 1959).

The Balcones Fault Zone, which divides the Edwards Plateau from the Gulf Coastal Plain, is a series of primarily normal faults that trend from the southwest to the northeast across the central part of the county. The greatest concentration of faulting occurs in a zone approximately 10 miles in width along this central trend. Fault blocks underlying this zone are composed primarily of limestone and shale beds that dip slightly to the southeast; in this area land surface elevations range from 700 to 1,100 feet. Major drainage features crossing the Balcones Fault Zone include the San Antonio River and tributaries of the Medina River and Cibolo Creek.

The Edwards Plateau, which is on the upthrown side of the Balcones Fault Zone, is underlain by a series of limestone beds that also dip slightly to the southeast. Land surface elevations range from 1,900 to 1,100 feet. This plateau serves as the headwaters for numerous small streams and creeks, including Cibolo, Balcones, Culebra, Leon, and Salado Creeks.

The Gulf Coastal Plain ranges in elevation from 700 to 450 feet in Bexar County. It is underlain by beds of marl, clay, and poorly consolidated sand that dip to the southeast at an approximate rate of 150 feet per mile. The coastal plain is primarily drained by the San Antonio and Medina Rivers and by Cibolo Creek.

Climate

The climate in Bexar County is generally warm and sub-humid with mild winters and hot summers. Winter temperatures average 10 degrees Celsius (°C) with infrequent freezes, and summer temperatures average 29° C with daily maximums generally in excess of 32° C. The average precipitation in San Antonio is just over 30 inches per year with the greatest rainfall occurring during May, June, September, and October.

Geology of Bexar County

The following geologic descriptions for formations in Bexar County have been adapted from Ashworth, 1983; W.E. Simpson, 1993; Bureau of Economic Geology, 1983; Marquardt and Rodriguez, Jr., 1977; and Arnow, 1959. Strata are presented chronologically from oldest to youngest in age. The nomenclature is consistent with that used by the Bureau of Economic Geology, as presented in the *Geologic Atlas of Texas, San Antonio Sheet, Revised 1983*. For clarification, formations with more than one commonly used named are listed with both names. Table 1 summarizes the characteristics of the geologic formations of Bexar County.

Figures 1 through 4, cross-sections W-W′, C-C′ and E-E′, are generalized north to south cross-sections through the west, central and east parts of the county, respectively. Figure 5 shows the location of each cross-section and the location and designation of wells used to create each cross-section. These cross-sections were generated from geophysical log data acquired in the general vicinity of each section. Appendix A summarizes the location and reference for data used to develop the generalized cross-sections.

It is important to recognize that each cross-section is an approximate representation of each area of the county. The sections have been used to develop a basic understanding of general depths, thickness, and lateral extent of the various formations across Bexar County. These cross-sections are not to be interpreted as exact representations of the subsurface along the line of the section.

Geologic formations, major faulting, and principle aquifers are identified on each cross-section. Formation contacts are dashed due to the general and approximate nature of the sections. Major faults mapped by the Bureau of Economic Geology are presented as solid lines. Faults that were interpreted based on changes in formation elevation are dashed.

The study area was divided into seven geographic areas to help evaluate the available storage zones. These geographic areas were established based primarily on the occurrence of specific aquifer units. These seven areas, shown in Figure 6, are identified along the top of each cross-section. The determination and relevance of each geographic area is discussed in detail in this TM as part of the preliminary storage zone screening.

General water-bearing characteristics of the geologic units, including typical well yield and water quality, are presented as an indication of the potential for ASR development. The following categories are used to describe the general ranges of these parameters:

<u>Well Yield</u>

Small:	Less than 100 gallons per minute (gpm)
Moderate:	100 to 500 gpm
Large:	More than 500 gpm

Table 1

Geologic Formations and Their Water-Bearing Properties

System	Series	Group	Stratigraphic Unit	Hydrologic Unit	Approximate Thickness	Character of Material	Water Supply Properties
Quaternary	Holocene and Pleistocene		Alluvium (Qal) Fluviatile Terrace Deposits (Qt) Leona Formation (Qle)	Discontinuous Surfical Aquifer	45	Floodplain deposits, gravel, sand, silt, and clay	In places yields water for stock and domestic wells
Quaternary or Tertiary	Pleistocene or Plicene		Uvalde Gravel (T-Qu)	NA	25	Caliche cemented gravel with well rounded cobbles of chert, quartz, limestone, and igneous rock	Not known to yield water to wells in Bexar County
Tertiary	Eocene	Claiborne	Queen’s City Sand (Eqc)	Aquifer	100	Sandstone and siltstone, fine to medium grained, massive, well sorted, noncalcareous, may be finely laminated or crossbedding	Yields moderate supplies of potable water
			Reklaw Formation (Er)	Confining	50-200	Sandstone and clay, sandstone fine to medium grained, abundant hematite, muscovite, and glaconite, thin bedded to massive, well developed crossbedding	Yields small amounts of water at the outcrop.
			Carrizo Sand (Ec)	Aquifer	100-800	Medium to very coarse grained sandstone, friable to locally indurated, noncalcareous, thick bedded	Yields moderate supplies of potable water
		Wilcox	Wilcox Group (Ewi)	Aquifer	500-800	Mudstone with varying amounts of sandstone and lignite, glaconitic in upper and lower parts, massive to thin bedded	Yields moderate supplies of good to poor quality water
		Midway	Midway Group (Emi)	Confining	400-500	Clay and sand, glauconitic in lower zones, argillaceous, poorly sorted, phosphatic nodules and pebbles common in lowermost part	Not known to yield water to wells in Bexar County
Cretaceous		Navarro	Navarro Group and Marlbrook Marl (Kknm)		700	Marl, clay, sandstone and siltstone, glauconitic, with concretions of limonite and siderite; fine grained sandstone and siltstone with concretions of hard bluish grey siliceous limestone	Not known to yield water to wells in Bexar County

Adapted from Arnow (1959), W.E. Simpson Co. (1993), and Barnes (1983).

Table 1

Geologic Formations and Their Water-Bearing Properties

System	Series	Group	Stratigraphic Unit	Hydrologic Unit	Approximate Thickness	Character of Material	Water Supply Properties
Cretaceous	Gulf		Anacacho Limestone (Kac)	Confining	120	Limestone and marl, thick bedded, fossiliferous, sandy, some volcanic rock fragments, and weathered, rusty, bentonite beds	Not known to yield water to wells in Bexar County
			Pecan Gap (Kpg)		150-200	Chalk and chalky marl, more calcareous westward	Not known to yield water to wells in Bexar County
			Austin Chalk (Kau)	Aquifer	175-225	Chalk, mostly microgranular calcite, alternates with marl, local bentonite seams, sparsely glaconitic, pyrite nodules in part weathered to limonite	Yields small to large volumes of good to poor quality water
			Eagle Ford Group (Kef)	Confining	30-50	Shale, siltstone, fine grained sandstone and flaggy limestone	Not known to yield water to wells in Bexar County
	Comanche	Washita	Buda Limestone (Kbu)	Aquifer	40-70	Fine grained bioclastic limestone, commonly glauconitic, pyritiferous, hard, massive, poorly bedded to nodular	Yields sufficient water near the outcrop for stock and domestic use
			Del Rio Clay (Kdr)	Confining	40-60	Calcareous and gypserfous clay, pyrite common, blocky,	Not known to yield water to wells in Bexar County
			Georgetown Limestone (Ked)	Edwards Aquifer	450-500	Hard massive limestone and agrillaceous limestone	Yields moderate to large quantities of fresh water in updip section. Water becomes highly mineralized in southern part of the county
			Person Formation (Ked)			Hard, massive, fine to course grained limestone, abundant chert	
		Fredricksburg	Kainer Formation (Ked)			Hard, massive, fine to coarse grained limestone, abundant chert, some marly clay and shale	

Adapted from Arnow (1959), W.E. Simpson Co. (1993), and Barnes (1983).

Table 1

Geologic Formations and Their Water-Bearing Properties

System	Series	Group	Stratigraphic Unit	Hydrologic Unit	Approximate Thickness	Character of Material	Water Supply Properties
	Comanche	Trinity	Upper Glen Rose (Kgru)	Upper Trinity Aquifer	500	Resistant, impure, fossiliferous, limestone with alternated beds of resistant and nonresistant shale, nodular marl, and two distinct evaporite beds	Yields small quantities of relatively mineralized water
			Lower Glen Rose (Kgrl)	Middle Trinity Aquifer	300	Massive, folliliferous limestone grading upward into thin beds of limestone, dolomite, marl and shale	Yields small to large quantities of fresh to slightly saline water
			Hensell Sand Member (Kh) / Bexar Shale (Kbs)		80	Upper half sandy glauconitic limestone, lower half mostly fine grained argillaceous, calcareous sandstone/Marl calcareous shale and shaley limestone to silty dolomite	
			Cow Creek Limestone Member (Kcc)		80	Massive fossiliferous off-white limestone with local thinly beded layers of sand, shale, and lignite	
			Hammet Shale Member (Khs) / Pine Island Shale (Kpi)	Confining	50	Fossiliferous, calcareous and dolomitic shale with thinly interbedded layers of limestone and sand	Not known to yield water
	Pre-Comanche		Sligo Limestone Member (Ks)	Lower Trinity Aquifer	150	Sandy dolomitic limestone	Yields small to moderate quantities of slightly saline to saline water
			Hosston Sand Member (kho)		220	Red and white conglomerate, sandstone, claystone, shale, dolomite, and limestone	Yields small to moderate quantities of slightly saline to saline water
Pre-Cretaceous Rocks						Folded shale, hard massive dolomite, limestone, sandstone and slate	Not known to yield water to wells in Bexar County

Adapted from Arnow (1959), W.E. Simpson Co. (1993), and Barnes (1983).

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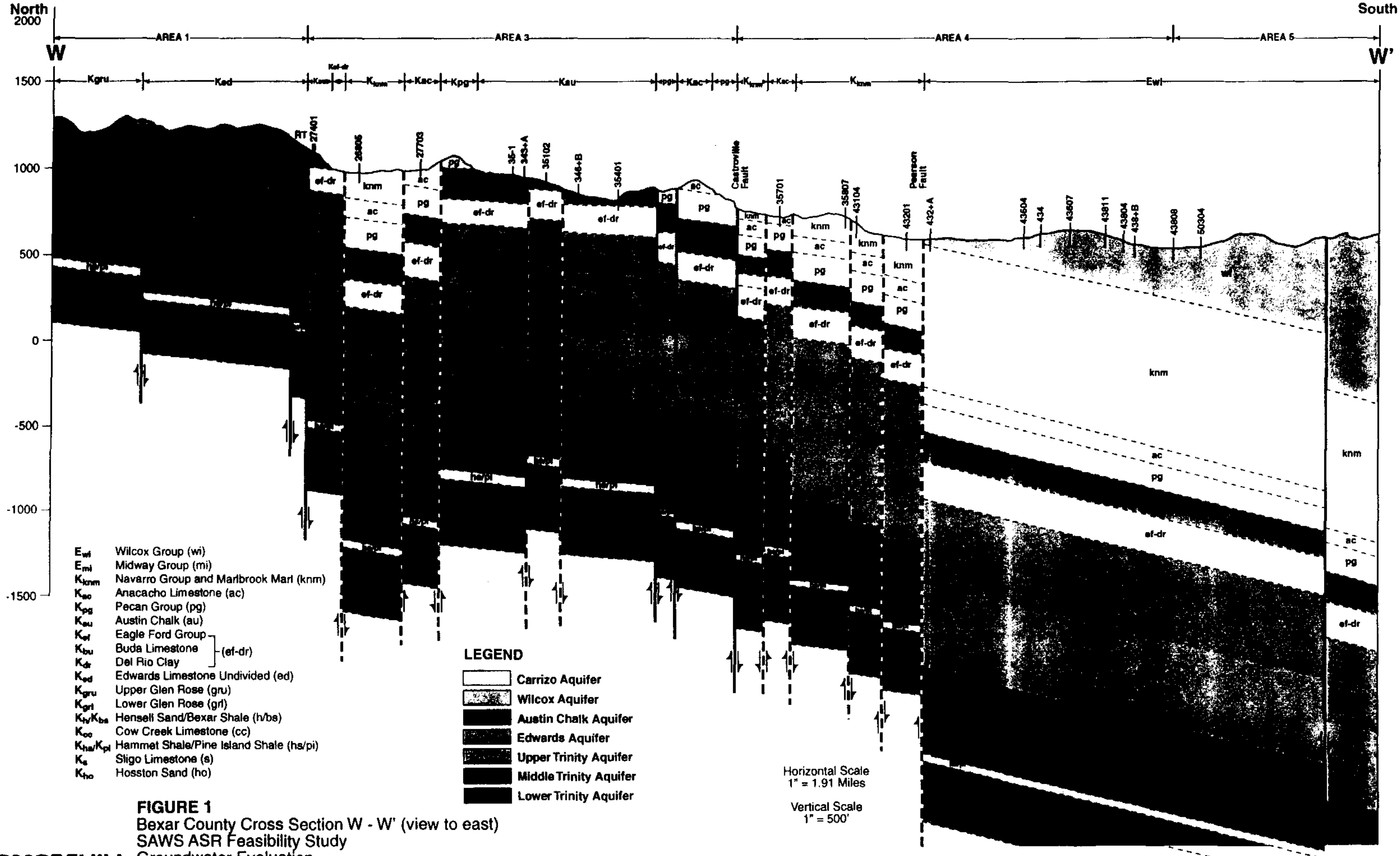

E_{wi}	Wilcox Group (wi)
E_{mi}	Midway Group (mi)
K_{knm}	Navarro Group and Marlbrook Marl (knm)
K_{ac}	Anacacho Limestone (ac)
K_{pg}	Pecan Group (pg)
K_{au}	Austin Chalk (au)
K_{ef}	Eagle Ford Group (ef-dr)
K_{bu}	Buda Limestone (ef-dr)
K_{dr}	Del Rio Clay (ef-dr)
K_{ed}	Edwards Limestone Undivided (ed)
K_{gru}	Upper Glen Rose (gru)
K_{grl}	Lower Glen Rose (grl)
K_{h}/K_{bs}	Henseli Sand/Bexar Shale (h/bs)
K_{cc}	Cow Creek Limestone (cc)
K_{hs}/K_{pi}	Hammet Shale/Pine Island Shale (hs/pi)
K_{s}	Sligo Limestone (s)
K_{ho}	Hosston Sand (ho)

LEGEND

- ☐ Carrizo Aquifer
- ▨ Wilcox Aquifer
- ■ Austin Chalk Aquifer
- ▨ Edwards Aquifer
- ▨ Upper Trinity Aquifer
- ■ Middle Trinity Aquifer
- ■ Lower Trinity Aquifer

FIGURE 1
Bexar County Cross Section W - W' (view to east)
SAWS ASR Feasibility Study
Groundwater Evaluation

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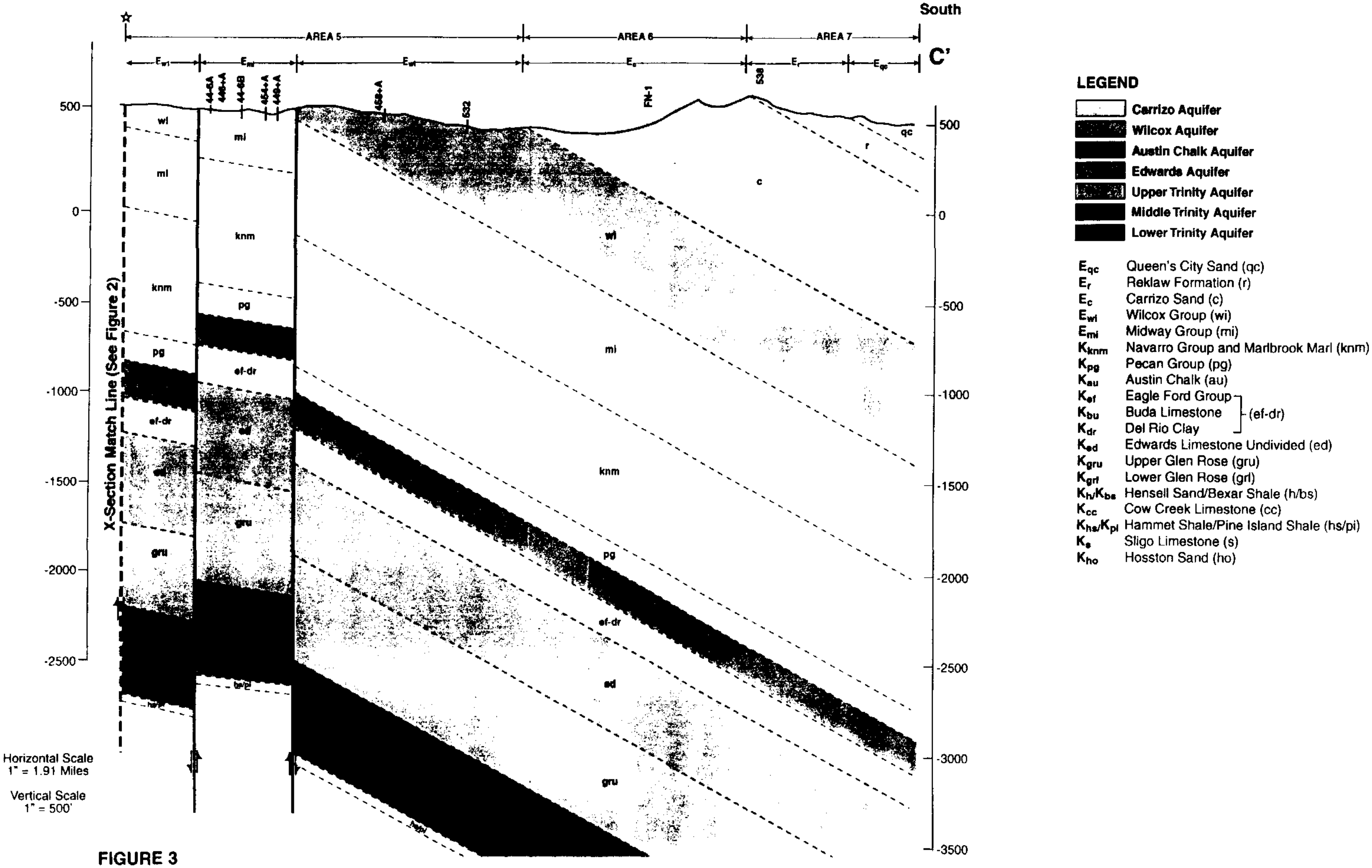

FIGURE 3
Bexar County Cross Section C - C' (view to east)
SAWS ASR Feasibility Study
Groundwater Evaluation

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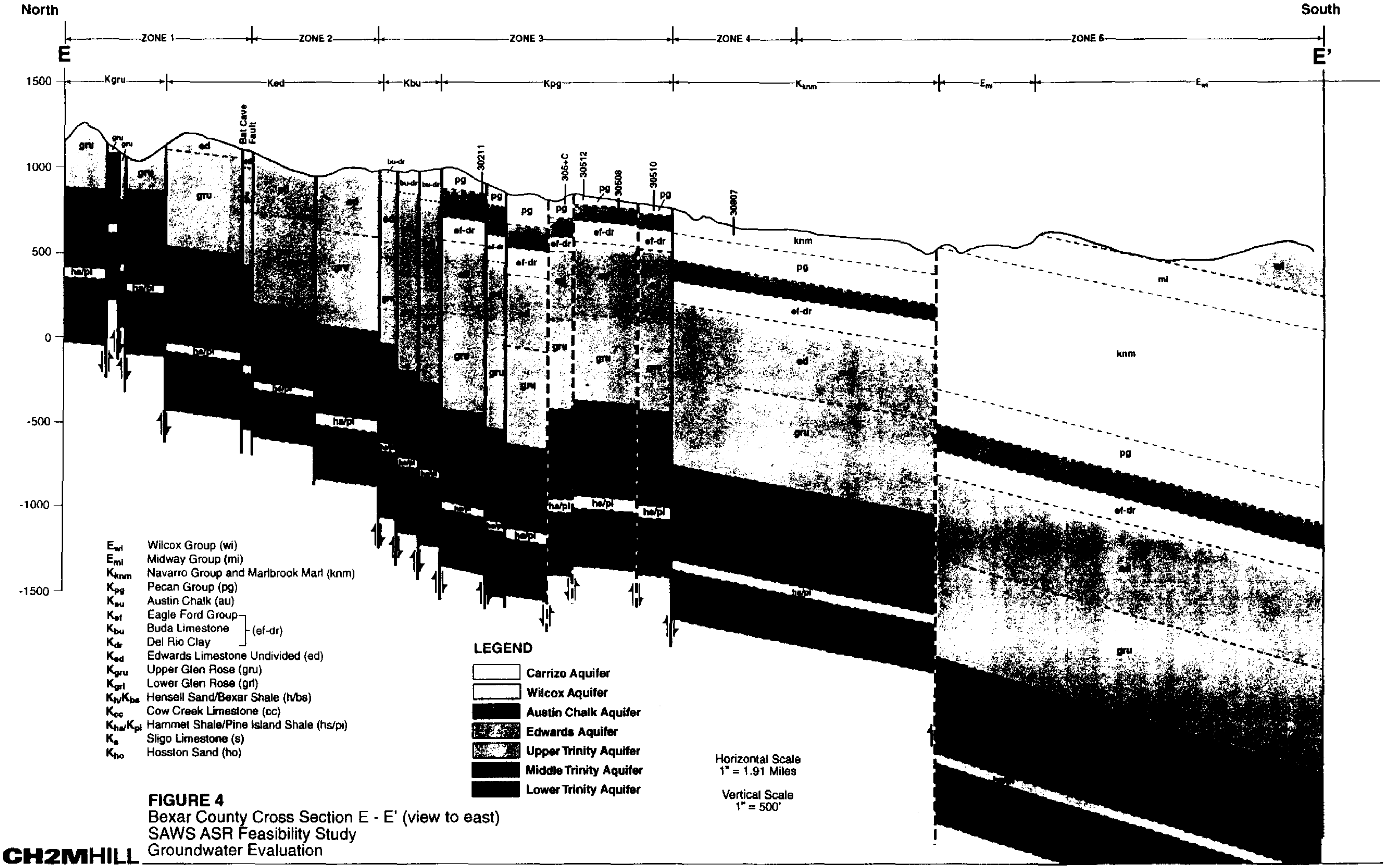

FIGURE 4
Bexar County Cross Section E - E' (view to east)
SAWS ASR Feasibility Study
Groundwater Evaluation

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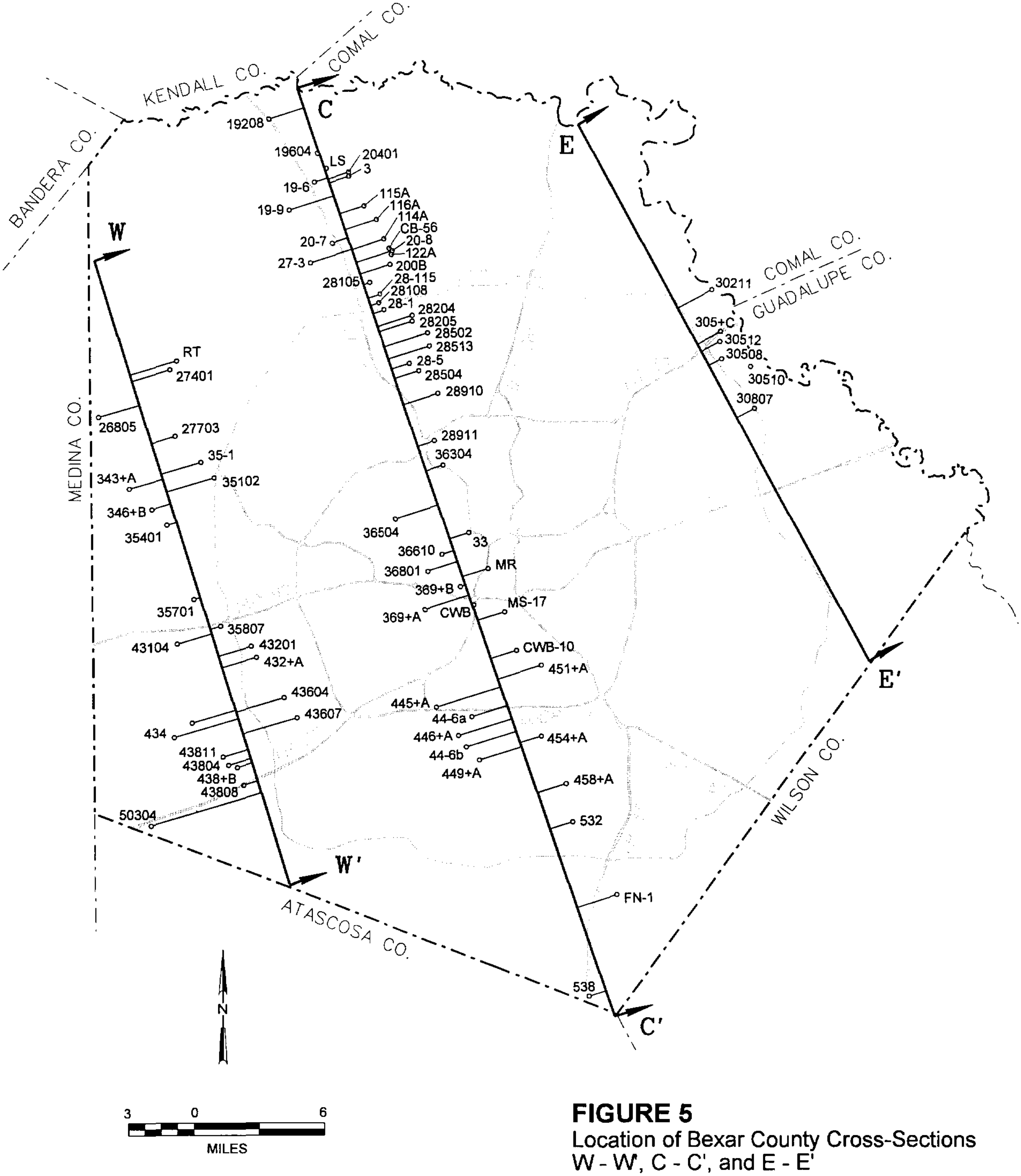

FIGURE 5

Location of Bexar County Cross-Sections
W - W', C - C', and E - E'

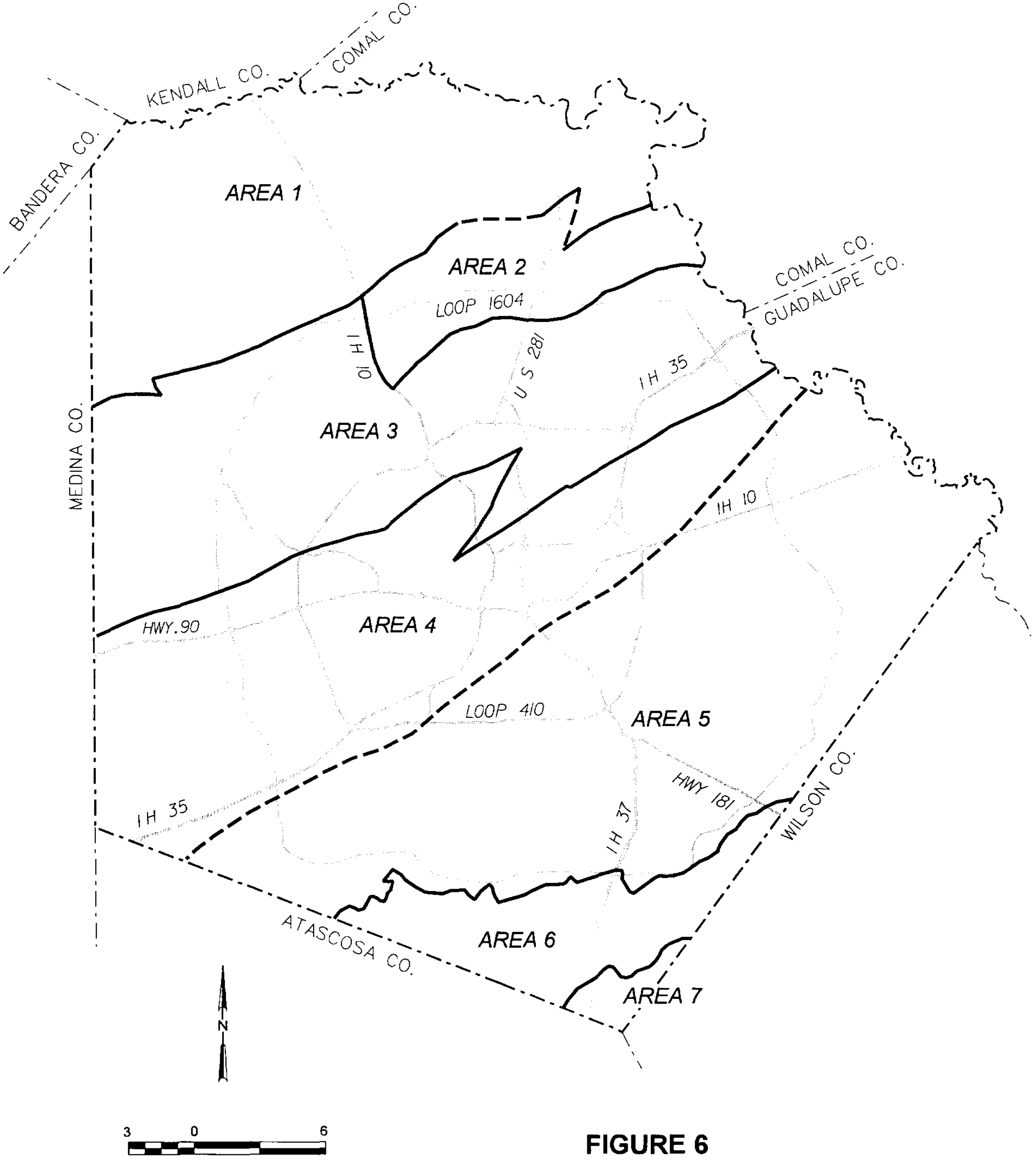

FIGURE 6

Geographic Divisions of Bexar County

Water Quality

Good:	Less than 1,000 milligrams per liter (mg/L) total dissolved solids (TDS)
Moderate:	1,000 to 3,000 mg/L TDS
Poor:	3,000 to 10,000 mg/L TDS
Saline:	Greater than 10,000 mg/L TDS

Pre-Cretaceous Rocks

No rocks older than Cretaceous age out-crop in Bexar County, nor have any Pre-Cretaceous rocks been documented as a significant source of water in Bexar County. Therefore, Pre-Cretaceous formations were not addressed as part of the Groundwater Assessment.

Cretaceous System

Lower Cretaceous Stratigraphy

Hosston Sand (Kho)

The Hosston Sand consists of a red and white conglomerate sandstone and claystone that becomes more shaley and dolomitic downdip. Sands are medium- to fine-grained quartz and tightly cemented in areas. The Hosston Sand is approximately 220 feet thick and composes the lower member of the lower Trinity aquifer, which yields small to moderate quantities of good to poor quality water to wells in Bexar County.

Sligo Limestone (Ks)

The Sligo is a sandy, dolomitic limestone with occasional interbedded shale. It is the upper member of the lower Trinity aquifer, which yields small to moderate quantities of good to poor quality water to wells in Bexar County. This limestone is approximately 150 feet thick.

Hammet Shale (Khs)/Pine Island Shale (Kpi)

The Pine Island Shale is the outcrop equivalent of the Hammet Shale, which is a dark blue to gray, fossiliferous, calcareous, and dolomitic shale with thinly interbedded layers of limestone and sand. The Hammet Shale is the confining unit between the lower and middle Trinity aquifers. It is approximately 50 feet thick and is not known to yield water in Bexar County.

Cow Creek Limestone (Kcc)

The Cow Creek is a massive, fossiliferous, off-white limestone with locally thinly bedded layers of sand, shale, and lignite. This limestone is honeycombed where groundwater movement has enlarged joints and fissures. The Cow Creek Limestone is approximately 80 feet thick and is the lower member of the middle Trinity aquifer. This unit produces small to moderate quantities of good to moderate quality water to wells in Bexar County.

Hensell Sand (Kh)/Bexar Shale (Kbs)

The upper part of the Hensell is a sandy, glauconitic, honeycombed limestone and the lower half is a fine-grained, argillaceous, calcareous, sandstone. The Hensell Sand grades into the Bexar Shale in the downdip sections. The Bexar Shale is characterized by marl, calcareous shale, and shaley limestone to silty dolomite. The Hensell Sand/Bexar Shale is approximately 80 feet thick and composes the middle unit of the middle Trinity aquifer. The middle Trinity yields small to moderate quantities of good to moderate quality water to wells in Bexar County.

Lower Glen Rose (Kgrl)

The lower Glen Rose, approximately 300 feet thick, is composed of massive, fossiliferous limestone grading upward into thin beds of limestone, dolomite, marl, and shale. It is the upper unit of the middle Trinity aquifer that yields small to moderate quantities of good to moderate quality water to wells in Bexar County.

Upper Glen Rose (Kgru)

The upper Glen Rose is characterized by laterally continuous beds of resistant, impure, fossiliferous limestone alternating with non-resistant blue shale and nodular marl. The upper Glen Rose, approximately 500 feet thick, also contains two distinct evaporite beds. The upper Glen Rose comprises the upper Trinity aquifer and generally yields small to moderate quantities of good to moderate quality water to wells in Bexar County.

Edwards Limestone Undivided (Ked)

For the purpose of this report, references to the Edwards Limestone (Ked) will include the following three formations: the Kainer Formation , composed of hard, massive, fine- to coarse-grained limestone with abundant chert and some marly clay and shale; the Person Formation, composed of hard, massive, fine- to coarse-grained limestone; and the Georgetown Limestone, which is hard, massive, and argillaceous. The Edwards Limestone is 450 to 500 feet thick. It yields moderate to large quantities of good quality water in the updip section. Water becomes highly mineralized in the southern part of the county.

Upper Cretaceous Stratigraphy

Del Rio Clay (Kdr)

The Del Rio is a medium gray, blocky, calcareous, gypsiferous clay. It has some thin, lenticular beds of calcareous siltstone and commonly contains pyrite. The Del Rio Clay is 40 to 60 feet thick and serves as the upper confining layer for the Edwards aquifer. It is not known to yield water to wells in Bexar County.

Buda Limestone (Kbu)

The Buda is a fine grained, bioclastic limestone. Its common characteristics include that it is poorly bedded to nodular; glauconitic, pyritiferous, hard, and massive; and usually 40 to 70 feet thick. It is relatively impermeable, but produces sufficient water near the outcrop for stock and domestic use.

Eagle Ford Group (Kef)

The Eagle Ford Group is composed of shale, siltstone, fine-grained sandstone, and flaggy limestone. It is generally light yellow to brown and 30 to 50 feet in thickness. It is not known to yield water in Bexar County.

Austin Chalk (Kau)

The Austin is primarily a microgranular calcite chalk with alternating layers of marl. It is sparsely glauconitic with local bentonite seams and pyrite nodules in part weathered to limonite. The Austin Chalk generally yields small to moderate quantities of good to moderate quality water to wells in the outcrop area.

Pecan Gap (Kpg)

The Pecan Gap is a light yellow to yellowish-brown chalky marl that becomes thinner and more calcareous in western Bexar and eastern Medina County. West of Medina County, the Pecan Gap is included with the Austin Chalk. The Pecan Gap, 150 to 200 feet thick, is not known to produce water in Bexar County.

Anacacho Limestone (Kac)

The Anacacho is a cross-bedded, fossiliferous limestone alternating with beds of marl. It contains some volcanic rock fragments and weathered, rusty, bentonite beds. It only exists in western Bexar County as a thinning layer becoming transitional to the Pecan Gap. It has a maximum thickness of 120 feet and is not known to yield water to wells in the county.

Navarro Group and Marlbrook Marl Undivided (Kknm)

The upper part of this formation is composed of glauconitic marl and clay with concretions of limonite and siderite and a fine-grained sandstone and siltstone with concretions of hard, bluish-gray limestone. The lower part is a montmorillonitic, unctuous, greenish-gray to brownish-gray clay. The Navarro Group and Marlbrook Marl have a total thickness of approximately 700 feet and are not known to yield water in Bexar County.

Tertiary System

Eocene Series

Midway Group (Emi)

The Midway Group is composed primarily of clay and sand. The formation is glaconitic, argillaceous, and poorly sorted, with phosphatic nodules and pebbles in the lower part. It becomes more sandy as it grades upward into the Wilcox Group. The Midway is 400 to 500 feet thick and not known to yield water in Bexar County.

Wilcox Group (Ewi)

The Wilcox Group is characterized by mudstone with varying amounts of sandstone and lignite. It is characterized by glauconite in both upper and lower parts, with thin to massive bedding. It is approximately 500 to 800 feet thick and gradational with the underlying Midway Group. The Wilcox Group yields moderate supplies of good to moderate quality water to wells in Bexar County.

Carrizo Sand (Ec)

The Carrizo is a medium- to very coarse-grained, noncalcareous, sandstone. It is friable to indurated with thick beds and local iron-oxide banding. The Carrizo Sand is 100 to 800 feet thick and yields moderate to large supplies of good quality water to wells in Bexar County.

Reklaw Formation (Er)

The Reklaw is a fine- to medium-grained sandstone and silty clay. The sandstone contains abundant hematite, glauconite, and muscovite. It is friable to indurated with thin to massive beds and well developed cross-bedding. The Reklaw Formation is 50 to 200 feet thick and yields small amounts of water at the outcrop.

Queen's City Sand (Eqc)

The Queen's City Sand is a fine- to medium-grained, noncalcareous, friable to indurated, massive, cross-bedded, sandstone with thin interbeds of clay and siltstone. The Queen's City Sand is less than 100 feet thick in Bexar County. The groundwater yield is unknown in Bexar County.

Tertiary-Quaternary System

Uvalde Gravel (T-Qu)

The Uvalde Gravel is a caliche cemented gravel with well-rounded cobbles of chert, quartz, limestone, and igneous rock. It contains occasional boulders up to one foot in diameter. The Uvalde occupies topographically high areas not associated with present drainage features. The Uvalde Gravel is up to 25 feet thick and is not known to yield water in Bexar County.

Quaternary System

Alluvium (Qal), Fluviatile Terrace Deposits (Qt), and Leona Formation (Qle)

The quaternary alluvium, fluviatile terrace deposits, and Leona Formation are gravel, sand, silt, and clay deposits that include slope wash, alluvial fan deposits, alluvium, and colluvium from Edwards Plateau and Balcones Escarpment drainage. In some areas, these deposits make up a discontinuous surficial aquifer up to 45 feet in thickness that can yield sufficient water for stock and domestic use.

General Geologic Structure

The sedimentary formations of Bexar County generally strike in a northeast direction and dip to the southeast towards the Gulf of Mexico. In the Edwards Plateau and Balcones Fault Zones, the average dip of the rocks is 10 to 15 feet per mile or less. In the Coastal Plain area, on the downthrown side of the Balcones Escarpment in southern Bexar County, formational dip increases to over 150 feet per mile. Faulting in the Balcones Escarpment zone consists of a wide range of small to large faults that are often concentrated in small geographic areas. Faults have been traced up to 25 miles, but many are small step faults within a narrow zone. Displacements of up to 600 feet have been measured on some larger faults. Fault traces are predominantly straight, suggesting nearly vertical fault planes. Faults generally trend northeast (parallel to strike) but some branches and intersections have been mapped (Arnow, 1959).

Principle Aquifers of Bexar County

Carrizo Aquifer

The Carrizo aquifer formation outcrops in a band across southern Bexar County. The Carrizo aquifer becomes confined in the southernmost tip of Bexar County in an area approximately 10 square miles in size. In both the confined and unconfined zones, the Carrizo supplies water for local domestic and stock use. Measured transmissivity in the Carrizo aquifer ranges from 30,000 to 240,000 gallons per day per foot (gpd/ft). Water quality is good with TDS concentrations generally less than 500 mg/L.

Wilcox Aquifer

The Wilcox aquifer is unconfined in the outcrop area in southern Bexar County. It becomes confined further in southern Bexar County below the Carrizo and Reklaw Formations. In both the outcropping and confined areas, the Wilcox serves as an aquifer for both domestic and public supply. Measured transmissivities range from 500 to 100,000 gpd/ft. Water quality ranges from 270 to 1200 TDS, often with high concentrations of iron.

Austin Chalk

The Austin Chalk outcrops intermittently in north-central Bexar County and becomes confined toward the northeastern part of the county and downdip in the southern part of the county. Its use is limited in the confined areas of eastern Bexar County due to the availability of public water supply in this area. In the southern part of the county, the Austin Chalk is commonly a natural reservoir for oil and gas. Transmissivity for the Austin Chalk aquifer in Bexar County is unknown. Water quality is estimated to range from 500 to greater than 1,000 mg/L TDS.

Edwards Aquifer

The Edwards aquifer outcrops in north and northeast Bexar County. The outcrop area serves primarily as the recharge zone for the confined and semi-confined areas in central and south-central Bexar County. The confined Edwards aquifer is the primary water source for the San Antonio metropolitan area and provides the majority of the water used for public supply. Measured transmissivities in the fresh water portion of the Edwards aquifer range from 1,000 gpd/ft to in excess of 1,000,000 gpd/ft. Water quality in this zone is good with TDS generally being less than 300 mg/L.

Brackish Edwards Aquifer

The Brackish Edwards aquifer is arbitrarily delineated as the part of the Edwards aquifer where the TDS of the water exceeds 1,000 mg/L. The line designating this change in water quality trends southwest to northeast through the south central area of Bexar County. The line corresponds to the boundary between Area 4 and Area 5 (as shown in Figure 6). Measured transmissivities in the brackish portion of the Edwards aquifer range from 4,000 to 90,000 gpd/ft. Water quality varies from as little as 1,000 mg/L TDS to in excess of 10,000 mg/L TDS.

Upper Trinity Aquifer

The upper Trinity aquifer is composed of the upper Glen Rose Formation. It provides small to moderate supplies of water along its outcrop in north and northwestern Bexar County. The upper Trinity aquifer, confined throughout the rest of Bexar County, generally is not used as a water source in these areas due to availability of public supply water and water from the middle Trinity aquifer. Measured transmissivities in the upper Trinity aquifer in north Bexar County range from 30 to 24,000 gpd/ft. Water quality ranges from 300 to 3,200 mg/L TDS.

Middle Trinity Aquifer

The middle Trinity aquifer is composed of the lower Glen Rose, Hensell Sand, and Cow Creek Formations. It outcrops in small areas in northern Bexar County and is primarily used for water supply in confined sections in the north and north-central parts of the county. Measured transmissivities range from 10 to 40,000 gpd/ft. Water quality ranges from 200 to 2,600 mg/L TDS.

Lower Trinity Aquifer

The lower Trinity aquifer is made up of the Sligo and Hosston Formations and is confined throughout the study area. It is used occasionally in the north and northeastern parts of the county as a domestic water source, secondarily to the shallower middle and upper Trinity Aquifers. Measured transmissivities range from 300 to 11,000 gpd/ft. Water quality varies from 900 mg/L to 2,600 mg/L TDS.

Preliminary Storage Zone Evaluation

Existing hydrogeologic and water demand estimates were incorporated into an evaluation matrix developed (Table 2) to help select the most promising storage zones in the study area. The matrix presents the estimated parameter range for six criteria relating to the feasibility of ASR development. Criteria ratings were assigned for the 34 available storage zones included in the evaluation. The six most promising storage zones identified through this evaluation provided a focus for the geochemical compatibility assessment and subsequent analyses to be conducted under the Preliminary Investigation and Feasibility Analysis (Step 1).

Geographic Subdivisions

As shown in Figure 6, the study area was subdivided into seven geographic areas based primarily on the occurrence and availability of storage zones (i.e., aquifer units). Due to the extensive faulting and general trend of increasing formation depth and decreasing native water quality in the downdip direction, the relative potential for ASR development in a given aquifer varies greatly between geographic areas. Subdividing the study area into geographic areas was necessary to sufficiently limit the range of selection criteria parameter values for each aquifer unit. This resulted in more meaningful comparison of available alternatives.

The seven geographic areas, and available ASR storage zones, are briefly described in the following paragraphs.

Table 2

Storage Zone Evaluation Matrix

		Selection Criteria					
Area	Aquifer	Potential Well (1) Yield	Native Water (2) Quality	Surface (3) Contamination Potential	Existing Well (4) Density	Average (5) Daily Area Demand	Total (6) Depth (ft bls)
1	Upper Trinity	Small to Moderate	Good to Moderate	High	Low to Moderate	Low	LS-700
	Middle Trinity	Moderate	Good	Low	Low to High	Low	350-1250
	Lower Trinity	Moderate	Good to Moderate	Low	Low to Moderate	Low	775-1650
2	Upper Trinity	Small	Moderate	Moderate	Low	Low	500-950
	Middle Trinity	Moderate	Good to Moderate	Low	Low to Moderate	Low	975-1450
	Lower Trinity	Moderate	Moderate	Low	Low	Low	1350-1850
3	Austin Chalk	Moderate	Good to Moderate	Moderate to High	Low	High	LS-625
	Upper Trinity	Small	Moderate	Low	Low	High	850-1650
	Middle Trinity	Moderate	Good to Moderate	Low	Low	High	1450-2125
	Lower Trinity	Moderate	Moderate	Low	Low	High	1850-2525
4	Austin Chalk	Small to Moderate	Good to Moderate	Low to Moderate	Low	High	350-1525
	Upper Trinity	Small	Moderate to Poor	Low	Low	High	1375-2675
	Middle Trinity	Small	Moderate to Poor	Low	Low	High	1825-3175
	Lower Trinity	Small	Moderate to Poor	Low	Low	High	2200-3575
5	Wilcox Group	Moderate	Good to Moderate	High	Moderate	Medium	LS-950
	Austin Chalk	Small to Moderate	Good to Moderate	Low	Low	Medium	400-2350
	Brackish Edwards	Moderate	Moderate to Poor	Low	Low	Medium	975-3050
	Upper Trinity	Small	Moderate to Poor	Low	Low	Medium	1500-3575
	Middle Trinity	Small	Moderate to Poor	Low	Low	Medium	2050-4100
	Lower Trinity	Small	Moderate to Poor	Low	Low	Medium	2400-4350

Notes:

(1)	Potential Well Yield	Increasing Feasibility ↑	Large: greater than 500 gpm Moderate: 100 to 500 gpm Small: less than 100 gpm
(2)	Native Water Quality	Increasing Feasibility ↑	Good: less than 1000 mg/l TDS Moderate: 1000 to 3000 mg/l TDS Poor: 3000 to 10,000 mg/l TDS Saline: greater than 10,000 mg/l TDS
(3)	Surface Contamination Potential	Increasing Feasibility ↑	Low Moderate High
(4)	Existing Well Density	Increasing Feasibility ↑	Low: less than 1 user per 2 1/2 minute quadrangle Moderate 1 to 10 users per 2 1/2 minute quadrangle High: greater than 10 users per 2 1/2 minute quadrangle
(5)	Average Daily Area Demand	Increasing Feasibility ↑	High: greater than 50 mgd Medium: 10 to 50 mgd Low: less than 10 mgd

(6) Relative feasibility decreases with total depth.

Table 2

Storage Zone Evaluation Matrix

		Selection Criteria					
Area	Aquifer	Potential (1) Well Yield	Native Water (2) Quality	Surface (3) Contamination Potential	Existing Well (4) Density	Average (5) Daily Area Demand	Total (6) Depth (ft bls)
6	Carrizo	Moderate	Good	High	Low to Moderate	Low	LS-800
	Wilcox Group	Moderate	Good to Moderate	Moderate	Low to Moderate	Low	775-1450
	Austin Chalk	Small	Moderate to Poor	Low	Low	Low	2475-3100
	Brackish Edwards	Moderate	Poor to Saline	Low	Low	Low	3150-3750
	Upper Trinity	Small	Poor to Saline	Low	Low	Low	3700-4300
	Middle Trinity	Small	Poor to Saline	Low	Low	Low	4200-4900
	Lower Trinity	Small	Poor to Saline	Low	Low	Low	4550-5300
7	Carrizo	Large	Good	Low	Low to Moderate	Low	850-1150
	Wilcox Group	Moderate	Moderate	Low	Low	Low	1500-1800
	Austin Chalk	Small	Moderate to Poor	Low	Low	Low	3150-3475
	Brackish Edwards	Moderate	Saline	Low	Low	Low	3800-4175
	Upper Trinity	Small	Saline	Low	Low	Low	4350-4725
	Middle Trinity	Small	Saline	Low	Low	Low	5000-5375
	Lower Trinity	Small	Saline	Low	Low	Low	5350-5725

Notes:

(1) Potential Well Yield — Increasing Feasibility ↑
Large: greater than 500 gpm
Moderate: 100 to 500 gpm
Small: less than 100 gpm

(2) Native Water Quality — Increasing Feasibility ↑
Good: less than 1000 mg/l TDS
Moderate: 1000 to 3000 mg/l TDS
Poor: 3000 to 10,000 mg/l TDS
Saline: greater than 10,000 mg/l TDS

(3) Surface Contamination Potential — Increasing Feasibility ↑
Low
Moderate
High

(4) Existing Well Density — Increasing Feasibility ↑
Low: less than 1 user per 2 1/2 minute quadrangle
Moderate 1 to 10 users per 2 1/2 minute quadrangle
High: greater than 10 users per 2 1/2 minute quadrangle

(5) Average Daily Area Demand — Increasing Feasibility ↑
High: greater than 50 mgd
Medium: 10 to 50 mgd
Low: less than 10 mgd

(6) Relative feasibility decreases with total depth.

Area 1

This portion of the study area lies north of the Edwards aquifer recharge zone. Geologic formations which comprise the Edwards aquifer in downdip sections are isolated on hill tops where incised stream channels have effectively bisected these formations. Groundwater in the Edwards Formation discharges locally through seeps and springs, limiting transmission of recharge water to downdip portions of the Edwards aquifer. The upper Trinity aquifer and, to a lesser extent, the Middle Trinity aquifer outcrop in Area 1. Only the upper, middle, and lower Trinity Aquifers are considered to be potential ASR storage zones in Area 1.

Area 2

Located in the northeast part of Bexar County, Area 2 generally corresponds to the zone of effective recharge to the Edwards aquifer. Due to the complex faulting through the Balcones Fault Zone in central Bexar County and erosion of the formations that comprise the Edwards aquifer, Area 2 is not present in western Bexar County. Storage zones available for ASR development in the area include the upper, middle, and lower Trinity Aquifers.

Area 3

Through Area 3, the Edwards aquifer transitions from a water table (unsaturated) to an artesian aquifer under normal hydrologic conditions. The water table portion of the Edwards aquifer generally has lower well yields and is more susceptible to contamination from surface sources than the artesian sections. The Austin Chalk outcrops over the western portion of this area and is considered a potential storage zone along with the Trinity Group aquifers.

Area 4

This portion of the study area is bounded on the north by the Edwards aquifer Transition Zone (Area 3) and on the south by the "bad water line." The bad water line occurs where the Edwards aquifer contains water in excess of 1,000 mg/L TDS. The Austin Chalk in this area is generally confined and is considered a potential ASR storage zone, in addition to the Trinity Group aquifers.

Area 5

Bounded by the bad water line to the north and the northern extent of the Carrizo Sand outcrop to the south, Area 5 includes the Brackish Edwards aquifer zone. The Edwards aquifer water generally exceeds 1,000 mg/L TDS in this area. In addition to the Brackish Edwards, the Wilcox Group, the Austin Chalk, and the Trinity Group Aquifers are considered potential ARS storage zones. The Wilcox Group exists in the southern portion of Area 5 and is unconfined.

Area 6

This area generally coincides with the Carrizo Sand outcrop. In addition to the unconfined Carrizo aquifer, the Wilcox Group, Austin Chalk, Brackish Edwards, and Trinity Group Aquifers represent potential ASR storage zones in Area 6. The Wilcox Group is confined throughout this area.

Area 7

The northern limit of Area 7 coincides with the northern extent of the confined Carrizo aquifer in Bexar County. Other potential storage zones in Area 7 include the Wilcox Group, Austin Chalk, Brackish Edwards, and the Trinity Group Aquifers. Area 7 is very small in comparison to the other subdivisions of the study area, occupying approximately 10 square miles of the southern tip of Bexar County.

Screening Criteria

The following six screening criteria were used to evaluate the potential storage zones in the study area:

- Potential well yield
- Native water quality
- Surface contamination potential
- Existing aquifer usage
- Average daily area demand
- Total depth

Potential well yield is a significant factor relating to the effective volume of storage possible and the ultimate cost of stored water. Water must be stored at sufficiently high rates to make maximum use of available source water. Conversely, system recovery rates must be adequate to meet projected demands. Since individual well storage and recovery rate are significant factors in determining the number of wells necessary to meet system design capacity, potential well yield also directly impacts capital costs and operational complexity. Based on current aquifer levels in the available storage zones, recovery rate (i.e., well yield) will generally control the required number of ASR wells as opposed to recharge rate. In general, ASR feasibility increases with increased well yield.

The ability to recover the stored water with minimal degradation in water quality is another important characteristic of a storage zone. Stored water degradation could result from either mixing the stored water with substandard native waters, geochemical reactions, or dissolution of undesirable constituents in the aquifer matrix. Storage zone water quality, as indicated by the TDS concentration, serves as a useful screening criteria to gage relative recoverability and associated ASR feasibility.

Surface contamination can also impact recoverability and the feasibility of ASR system operation. The potential for surface contamination of stored water was correlated with the occurrence and general competency of confinement indicated on representative geologic cross-sections presented in Figures 1 through 4. Confined storage zones were generally assigned a low contamination potential, while unconfined storage zones were assigned a moderate to high contamination potential, depending on the general permeability of the confining strata. Areas known to have experienced contamination in the past (i.e., Edwards aquifer in the vicinity of the Culebra Anticline) were assigned a high potential for contamination.

The number of existing users per 2.5 minute quadrangle (approximately 2.9 miles multiplied by 2.5 miles) was estimated as a gage of the potential for stored water competition. As the density of production wells increases, protecting stored water becomes a concern and implementing ASR requires additional measures to minimize loss. The density of existing groundwater users was assessed by plotting the location of wells included in the Texas Water Development Board groundwater database. These plots are presented in Appendix B as Figures B-1 through B-9.

Although the plots of existing wells included a relatively small number of non-production wells, such as test and monitoring wells, the displayed data reasonably indicates the density of water wells completed in each of the potential storage zones. This criterion was not weighted heavily in the overall evaluation because relief mechanisms are available to protect the stored water.

Total depth of the storage zone and proximity to demand centers, as indicated by the average daily area demand, are significant factors in determining the unit cost of ASR water. In general, the cost of ASR rises and the relative benefit of ASR declines with increasing well depth and distance from demand centers. Although cost per well is a function of the design rate, constructability, and total depth, depth is a reasonable indicator of construction cost. The proximity to demands is relevant only as differentiater between storage zones that are otherwise equivalent.

Storage Zone Evaluation Matrix

Criteria ratings for each of the potential ASR storage zones in the study area are listed in Table 2. Also included in the table are the assumed ranges of parameter values defining each classification. Based on the information presented in Table 2, the following six storage zones are recommended for further assessment.

Area 1/MiddleTrinity Aquifer

This storage zone offers moderate well yield at relatively shallow well depth. Storage zone water quality is generally good, which reduces complications associated with mixing and indicates that the aquifer matrix mineralogy may be conducive to ASR development. Although Area 1 demands are low, rapid growth is occurring, which should increase demands over the long term. Short-term utilization of ASR in Area 1 would incorporate a distribution system expansion program to connect the new capacity into the regional network.

As shown in Figures B-1, B-2, and B-3, middle Trinity wells of record are concentrated along the Interstate 10 corridor west of Camp Bullis and west of State Highway 281, along Borgfeld Road. However, large expanses of Area 1 have low middle Trinity well densities, and competition issues would be more easily resolved than in areas of high utilization.

The surface contamination potential is considered to be low where this storage zone is overlain by the low permeability upper Glen Rose formation. However, the middle Trinity aquifer does outcrop in extreme north Bexar County, along Cibolo Creek. The contamination potential in this area would be considerably higher.

Area 1/Lower Trinity Aquifer

The lower Trinity aquifer in Area 1 provides adequate available storage volume (i.e., saturated thickness combined with land availability) and medium well yields at a relatively shallow completion depth which should minimize ASR water unit costs. In addition, complications due to mixing the source water with native groundwater should not be significant since the storage zone water quality is likely to be in the moderate range. The number of existing users is also not prohibitive due to the availability of the shallower and better quality middle Trinity aquifer ; this aquifer is the primary source of local supply for a large portion of Area 1.

The contamination potential for this storage zone is considered to be low. Developing an ASR facility in this storage zone would, however, require extensive distribution system enhancements to accommodate the new point source/sink since area demands are in the low range.

Area 3/Middle Trinity Aquifer

Adequate available storage volume and medium well yield, combined with good to moderate water quality and a low contamination potential, justify further investigation into the middle Trinity storage zone in Area 3. The ASR unit cost for this alternative is also minimized by the medium well yield, relatively shallow well completion, and high area demands. The general availability of Edwards aquifer water, either from area wells or from the regional distribution system, has limited the number of competing users to a manageable level.

Area 5/Brackish Edwards Aquifer

Medium well yield, adequate available storage volume, relatively shallow completion depth, and geographic location (proximity to demands) support selecting this storage zone for additional analysis. Native water quality in this storage zone is considered to be moderate to poor; however, this may not significantly impact long-term recoverability. Due in part to the marginal water quality, competing users are not a significant issue with this option. Also, adequate confinement is present to minimize the risk from surface contamination.

ASR development in this storage zone would focus on the portion of Area 5 within 3 miles of the bad water line. The TDS concentration in this narrow band of Area 5 generally ranges from 1,000 mg/L to 5,000 mg/L. The total depth of the storage zone would also be minimized by locating the system near the updip boundary of the area.

Area 6/Wilcox Group

This storage zone option provides adequate available storage volume, medium well yield, and relatively shallow completion depth. Since this formation has historically provided potable water to Area 6 users, mixing should not be a significant concern. However, the potential for competing users will need to be considered in developing an ASR project. Also, average daily area demands are low, requiring significant conveyance facilities to integrate an ASR system into the regional distribution system. Since the Wilcox Group is confined by only the Carrizo Sand over most of Area 6, a relatively moderate potential exists for contamination.

Area 7/Carrizo Aquifer

The confined Carrizo storage zone in Area 7 represents the largest potential well yields in the study area, projected to exceed 1,500 gpm. In addition, well depths are comparable to the other promising storage zones in the study area suggesting that ASR unit costs for individual wells may be relatively low compared to other options. Other positive attributes of this storage zone include good native water quality and a relatively low contamination potential.

Competition with existing users in this storage zone is low to moderate, which complicates developing a large-capacity ASR system. In addition, a low area demand increase the overall cost of ASR implementation since the water would have to be transported a greater distance from the storage site to the areas of higher demand. It should also be noted that Area 7 is relatively small compared to other subdivisions in the study area, which may limit the available storage in this aquifer.

Multi-Zone Development

Although this investigation focuses on the most promising combinations of aquifer and geographic location within the study area, it should be noted that the cost-effectiveness of an alternative can be enhanced by "stacking" ASR storage zones at a given site. For example, the Area 5 Brackish Edwards aquifer alternative may also use ASR wells in the Austin Chalk. Once piping and other facilities are in place to fully develop the ASR potential for the primary storage zone at a given site, the additional cost of storing water at the same site in overlying and underlying aquifers may be acceptable, even if these aquifers are lower yield. Opportunities for multi-zone development and combined use of geographically unique storage zones will be discussed briefly in the technical memorandum summarizing results of the ASR Applications and Feasibility task.

Geochemical Compatibility

Aquifer storage recovery involves storing treated water underground for future recovery. During storage, the chemical characteristics of the treated water can be altered. Therefore, water quality issues must be thoroughly investigated during performance of the feasibility study. Water quality issues addressed in the geochemical assessment include the following:

- Source water and storage zone native water chemical characteristics
- Potential reactions between the treated source water and storage zone native water
- Potential reactions between the treated source water and storage zone matrix
- The extent of change in stored water quality and its compatibility with treated water in the distribution system

The most restrictive use of recovered water will be for public drinking water, and the quality must meet drinking water standards and aesthetic expectations of the public. Water quality is also important to the process operation. Chemical reactions (precipitation of solids or bacterial growth) and physical reactions (stratification due to density differences) can affect injection and recovery efficiency.

As presented in the *Preliminary Storage Zone Evaluation*, the most promising storage zones were identified by applying several generalized screening criteria, including storage zone water quality as indicated by the TDS concentration. The goal of the preliminary geochemical assessment is to characterize the selected storage zone/source water combinations and to highlight potential adverse reactions that could impact ASR feasibility. Once potential problems are identified, they can be avoided by modifying existing treatment processes or tailoring future treatment plant designs to address constituents of concern. Similarly, ASR well operations can be structured to minimize degradation of recovered water quality or reduced well efficiency. However, severe incompatibility may justify eliminating a storage zone/source water alternative from further consideration in this project.

The preliminary geochemical assessment included six potential storage zones and five potential source waters. The availability of storage zone native water chemical data varied greatly in both the number of analyses and the range in parameter value within a given zone. In addition, only generalized information on storage zone matrix mineralogy was included in the literature.

Although source water chemical analytical summaries are generally more comprehensive than the groundwater analyses, three of the five potential source waters are currently untreated. This presents the opportunity to customize the selected treatment processes to meet ASR requirements for the raw water sources; however, this also limits the definition of finished water characteristics. The relatively large range in groundwater quality, combined with uncertainties in source water chemical properties and aquifer mineralogy, dictated that a qualitative geochemical analysis be conducted. A more rigorous approach involving thermodynamic equilibrium computer modeling may be warranted if conditions are borderline and site-specific data become available.

Source Water Chemistry

The following five potential recharge water sources were included in the assessment:

- Raw water from Lake Medina near San Antonio, Texas
- Raw water from the Medina River at the BexarMetropolitan (BexarMet) pilot water treatment plant site near San Antonio, Texas
- Raw water from Canyon Lake near New Braunfels, Texas
- Treated water from the Canyon Regional Water Authority (CRWA), New Braunfels, Texas
- Treated Edwards aquifer water supplied by the San Antonio Water System (SAWS)

The water chemistry for the five sources, summarized in Table C-1 of Appendix C, was obtained from various existing databases. There is little difference between the treated SAWS water, treated CRWA water, and the raw water chemistry from Lake Medina and Canyon Lake. The implication is that any of these four sources could be interchanged or mixed in any proportion, and the resultant water chemistry would be within the variability of individual sources.

Lake Medina, Canyon Lake, CRWA, and SAWS Source Waters

These four sources are calcium-bicarbonate water chemistry types having TDS of less than 300 mg/L (Table C-1). The waters are (or will be after treatment) oxidized by incorporating atmospheric oxygen. Based on the low dissolved oxygen (DO) concentration of 0.6 mg/L, Canyon Lake water is probably under reducing conditions during some part of the year. Reduced water may contain significant amounts of iron, manganese, and total organic carbon (TOC). The metals, and to some extent the TOC, should be eliminated by treating the water which will reduce precipitation problems during storage. Treating the raw water would probably not significantly affect the major ion chemistry of the three raw water sources. However, treating the water is particularly important with respect to ASR because it would likely provide a significant benefit by reducing and/or removing both inorganic and organic total suspended solids.

Ammonia and nitrate in these source waters are relatively low compared to the native groundwater. Phosphorous (orthophosphate) analyses are not available for these sources but is assumed to be low from the range in pH and calcium concentration. Therefore, other nutrients (ammonia, nitrate, and treated water TOC) are expected to be sufficiently low enough so that they do no present a significant obstacle to ASR operation. A residual chlorine of about 1.0 mg/L (or similar disinfectant) should be present in the recharge water to reduce microbial activity in the vicinity of the well bore, which can cause plugging.

With the exception of pH and temperature, other ions and characteristics do not appear to present significant problems relative to ASR. At the upper pH ranges (greater than a pH of 8.2) and temperatures reported, there may be the potential for some calcium-carbonate precipitation when these waters mix, but the total precipitation may not be sufficient to cause plugging problems in the carbonate-matrix storage zones. However, the finer flow paths in the sand-matrix storage zones may present a problem. Similarly, calcium-carbonate precipitation could collect in the distribution system (assuming that the different source waters will mix in the distribution system) and has a potential to eventually become part of the total suspended solids loading. This would increase the required frequency of back-washing during recharge cycles.

The similarity of the basic major ion chemistry between the treated Edwards source and CRWA treated water and between the Lake Medina and Canyon Lake raw water suggests that these sources are probably the better sources to mix with the Edwards SAWS source. More information on the Edward aquifer chemistry and equilibrium calculations for individual locations will be necessary to give a definitive answer; however, the preliminary analysis, based on the water chemistries summarized in Table C-1, suggest that the waters appear compatible.

Recharge water originating from surface sources will tend to be on the cooler end of the seasonal range, between 10 and 30°C, since recharge will probably occur in cooler months when water use is at a minimum. Recharge with the cooler water will result in more mixing with the native groundwater, which is generally in the range between 20 and 25°C. The cooler water is denser and more viscous than the warmer groundwater and will tend to follow more highly permeable preferential flow paths in the aquifer during recharge. The more dense recharge water will also tend to stratify, sinking toward the base of the storage zone during extended storage intervals. This stratification results in an elevated native water content in the recovered water.

Medina River Source Water

The estimated raw water chemistry from the Medina River is somewhat different from the other four sources. Based on estimates used to design the pilot water treated plant currently in operation, Medina River water may range from a calcium-bicarbonate to a calcium-bicarbonate-sulfate water chemistry type with a TDS ranging from 250 to 600 mg/L and a pH ranging from 7.5 to 8.5 (Table C-1). Mixing this higher TDS and higher pH water with one of the above four water sources will likely result in calcium carbonate precipitation. Similarly, iron oxyhydroxide, and aluminum in the form of clays would probably precipitate. However, these solids would be removed during treatment if the waters were mixed prior to treatment. Also, the potential for solids formation may be lessened by reducing the TDS concentration and lowering the pH of the Medina River water during treatment by BexarMet. The final finished water from this source should be completely analyzed, and compatibility with other treated source waters and native groundwater should be reevaluated before recharging.

Ammonia (0.3 mg/L), nitrate (5 mg/L), and TOC (10 mg/L) maximum concentrations suggest that this water contains an elevated nutrient concentration. Treating this water may or may not remove a significant amount of these nutrients, but mixing could dilute them. A residual 1.0 mg/L dissolved chlorine (or other disinfectant) should be maintained when using this source, even in a mixture with the other four sources. The disinfectant residual will control microbial growth in the vicinity of the well bore, which can reduce well efficiency.

Recovered Water Compatibility in the Distribution System

Recovered water directed to distribution will have essentially the same water chemistry as water used for recharge. Even if source water in the distribution system is different than water that was stored, there should be no adverse reactions in the distribution system as a result of mixing, at least for the four low TDS sources. However, the water from the first cycles for storage zones with poorer quality native groundwater may be slightly to significantly different than the recharge water. Recovered water chemistry and major ion concentrations may not meet drinking water standards or client expectations. This potential is proportional to the mineralogical complexity of the storage zone matrix as commonly manifested in high TDS, low pH, and/or the prevalence of reducing conditions.

Experience has shown that after the initial test cycles, the entire recharge water volume can be recovered with a water chemistry very similar to the recharge water. The initial cycles are conducted to evaluate both the hydraulic response to recharge and reactions with stored water. Problems encountered during testing can often be controlled or eliminated by modifying operating procedures.

An important objective of the initial cycles is also to condition the aquifer so that the recovered water chemistry is essentially the same as the recharge water chemistry. Although the interim water chemistry cannot be exactly predicted, ASR projects involving similar storage zone mineralogies have achieved full recovery of stored water in a moderate number of cycles.

Recharge Water/Storage Zone Compatibility

The preliminary compatibility evaluation of the five source waters with each of the six potential storage zones was completed using the generalized native water quality information (summarized in Table C-2 of Appendix C). Storage zone mineralogy was also considered because soluble constituents in the storage zone can degrade stored water quality, rendering it useless for the intended purpose. Similar chemical characteristics of the Lake Medina, Canyon Lake, CRWA, and SAWS source waters permitted these sources to be evaluated as a group, substantially reducing the effective number of source/storage zone combinations. These four sources are collectively referred to as the low TDS sources in the following paragraphs.

Area 1/Middle Trinity Storage Zone

The middle Trinity aquifer in Area 1 is dominantly hosted by the Hensell Sand, a sandy glauconitic limestone, and the lower member of the Glen Rose Limestone. Glauconitic sands commonly contain fluorapatite (fluorinated calcium-phosphate mineral), which may be the origin of the elevated dissolved fluoride in the native groundwater from this aquifer. Evaporite minerals, such as gypsum and anhydrite, are also common.

The native groundwater is a calcium-bicarbonate water chemistry type below about 500 mg/L TDS, changing to a magnesium-calcium-bicarbonate type between 500 and about 900 mg/L TDS where it becomes a calcium-sulfate type (Table C-2). This is a typical water chemistry evolution in carbonate-dominated sand aquifers with increasing TDS (TDS generally increasing with distance from the recharge area and with depth). The source of the sulfate is likely evaporite minerals common in the Glen Rose. Additionally, given the apparent low pH, the iron-sulfide mineral pyrite may exist in trace to moderate amounts in the sand zones that trend to shale. Alternately, the shale probably contains minor amounts of pyrite and contributes to the sulfate concentration through slow oxidation of pyrite exposed to the groundwater. The pH ranges from slightly less than neutral 6.9 to a moderately alkaline 8.5. The temperature averages 20° C but ranges from 13 to 24° C. Nitrate is relatively elevated, averaging 4.3 mg/L, but ranging from less than 0.04 to 27 mg/L; fluoride can be as high as 2.5 mg/L but averages about 1 mg/L.

The groundwater probably ranges from a moderately oxidized condition with an oxidation reduction potential (Eh) of plus (+) 400 millivolts (mv) to a moderately reduced condition with a measured Eh of minus (-) 64 mv. The measured dissolved iron concentration can range as high as 0.2 mg/L with a total iron range as high as 0.3 mg/L. These ranges may be conservative because iron can become very soluble and mobile in groundwater under reducing conditions, particularly if the pH is less than neutral. However, one location with a low pH, 6.9 and an Eh of 100 mv contained less than 0.01 mg/L dissolved iron. Given the carbonate nature of this aquifer, the ferrous-iron-carbonate, siderite, may also be present.

Zinc is elevated in this groundwater ranging from 0.02 to 11.7 mg/L; the aluminum, manganese, cadmium, and selenium where present, however, are at very low concentrations. The higher zinc concentrations are highly anomalous and may be associated with well casings if made of galvanized steel. Regardless of the source, zinc should not create a problem for ASR.

Low TDS Sources and Mixtures. The common honey-combed nature of this aquifer suggests that the primary permeability is through solution features, including fractures and joints within the sandy limestone with lesser permeability in uncemented sands. Recharge with the four low TDS sources and their mixtures could create several potential changes in the storage zone.

Calcium-Carbonate Precipitation. If the TDS of the native groundwater is greater than 400 to 500 mg/L, calcium-carbonate may be precipitated in the mixing zone between the recharge water and the native groundwater. The amount of calcium-carbonate precipitated will increase with a rise in TDS. Calcium-carbonate precipitation is less likely to where the native groundwater contains less than 400 mg/L TDS, has a pH less than 8, and is under oxidizing conditions (Eh higher than plus 200 mv).

Iron Oxyhydroxide. The potential for calcium-carbonate precipitation may decrease if pyrite or siderite are part of the aquifer mineralogy. The recharge water, because of its oxidized to highly oxidized condition, will form sulfuric acid from pyrite oxidation and reduce the pH by oxidizing ferrous iron in the pyrite and siderite to ferric iron. Since both minerals react to reduce the pH, calcium-carbonate precipitation will also be reduced. The acid will be neutralized by reacting with the calcium-carbonate in both the aquifer matrix and the potential precipitate resulting in a higher calcium-sulfate percentage in the recovered water. The oxidation of the pyrite and siderite will also form an iron oxyhydroxide colloid and flocculent. The iron oxyhydroxide may present a potential plugging problem in uncemented sands but should not significantly affect permeability through larger solution features or joints unless there is a significant amount of either pyrite or siderite present in the aquifer.

Medina River Recharge Source. Recharge with the Medina River water with higher calcium and alkalinity and higher pH would tend to increase the potential for calcium carbonate precipitation. If the water treatment does not remove most of the iron (probably part of the total suspended sediments), the iron oxyhydroxide could present a considerable problem in the finer joints and the uncemented sands. At the higher concentration of iron (4 mg/L), even the larger joints in the storage zone would eventually show a reduced permeability.

The higher nutrients dissolved in this recharge water would exacerbate both the calcium carbonate precipitation and potential plugging by iron oxyhydroxide as the microbial activity may increase. Long-term storage (years) of the BexarMet water (as currently characterized) is not recommended in this aquifer, particularly within or near areas in which the native groundwater is under reducing conditions.

Future Considerations. The distribution of TDS, pH, and sulfate in the middle Trinity aquifer in Area 1 should be considered to determine the more favorable areas for recharge. Areas with a native water TDS less than 400 mg/L, a sulfate concentration less than about 25 mg/L, and 7.5 and 8.0 pH are most desirable. The groundwater Eh in this area should be determined in the field. Areas with an Eh of +200 mv or higher (any plus mv reading of the ORP meter) within areas of low TDS, low sulfate, and moderate pH would also appropriately recharge this aquifer. ASR systems can be successfully operated in less favorable portions of the middle Trinity in Area 1; these areas, however, will require more thorough investigation during site selection and more care in conducting the initial recharge cycles.

Rock cores should be obtained and hydraulic characteristic and mineralogical testing should be performed. This investigation is recommended prior to any recharge in a new area to further limit potential obstacles not apparent from the published native groundwater chemistry and regional lithologic descriptions. The particle size and distribution, plus laboratory vertical and horizontal permeability, are significant physical characteristics to be defined by laboratory testing. The species, abundance, and distribution of iron and clay minerals are also particularly important. The bulk ion exchange capacity of the clays in the aquifer and ions in exchangeable positions should be included in the laboratory analyses. The additional testing will be especially important in areas where higher TDS, lower pH, and/or reducing conditions are prevalent.

Results of laboratory work on the cores serve as a basis for determining the number and type of recharge cycles needed at the selected location. The impact of significant variations in recharge water pH and chemistry on recoverability can also be tested prior to recharge using detailed information available from the cores. The cores are invaluable where compatibility is marginal, as indicated by thermodynamic equilibrium calculations, or where an unforeseen condition occurs during actual recharge.

Area 1/Lower Trinity Storage Zone

The lower Trinity aquifer in Area 1 comprises a lower sand and clay member (Hosston Sand) and an upper sandy dolomitic limestone (Sligo). The sand appears to be oxidized based on the red and white coloration so that most of the glauconite and pyrite has probably been removed from the more permeable sands. The clays may still retain some pyrite.

The three analyses representing the native groundwater in this aquifer (Table C-2) indicate a slightly brackish TDS ranging from 960 to 2430 mg/L and a pH ranging from 7.5 to 7.9. The water is a sodium-calcium-sulfate to sodium-sulfate water chemistry type, transitioning with increasing TDS. The sodium dominance in the groundwater chemistry suggests that the clays attached to the aquifer sands may have sodium as the major exchangeable ion. Sodium clays (ribbon-like structure) are less stable than calcium clays (sheet-like structure). The sodium clay reactivity depends on the distance from the source of recharge and the mineralogical composition of the sand particles. Calcium replaces sodium by ion exchange so that, near the recharge area, the clays may be calcium dominant even where the mineralogy would ordinarily form a sodium clay.

The calcium and magnesium concentrations and percentages suggest that both the lower sand and the upper dolomitic limestone are productive. The calcium and magnesium ratio suggests that the water is in equilibrium with dolomite, as well as with limestone.

There are no available metals data or Eh values. However, given the dominance of sulfate in this native groundwater and the relatively low pH, iron and manganese concentrations may be elevated, and the Eh may be oxidizing in this storage zone. The origin of the sulfate may be pyrite within the clay and pyrite and/or siderite in the dolomitic limestone. Other metals concentrations will depend on their associated concentrations in the pyrite.

Nitrate (less than 0.4 mg/L) occurs at the lowest concentration of the six potential storage zones included in the assessment. This factor, and the relatively low pH, suggests that the other nutrients may also be low in this storage zone.

Low TDS Sources and Mixtures. Recharge with the low TDS calcium-bicarbonate sources and their mixture can present a potential ion exchange and TDS problem. If the clays are sodium clays, the calcium will exchange with the sodium on the clay minerals. This may result in some destabilization of the clays in the sands. If the clays become destabilized, they may migrate into the pore space and reduce the permeability of the aquifer. Similarly, the low TDS of the recharge water may destabilize the clays that are currently saturated with relatively high TDS native groundwater.

The oxidized recharge water may react with pyrite and/or siderite in the aquifer and that would initially increase the TDS, lower the pH, and perhaps result in elevated manganese concentrations in the recovered water. The elevated TDS of the native groundwater may be inherited from reactions along the groundwater flow paths. The dominance of sulfate, even in the native groundwater containing the lowest TDS (930 mg/L), suggests that this is probable.

Medina River Recharge Source. The higher sodium and sulfate concentrations of the untreated Medina River water presents less of a potential problem than the four low TDS recharge sources. The ion exchange potential of the Medina River water recharge water should be less given the higher TDS; also, the clays would probably be more stable with this recharge source. However, diluting the Medina River water with the low TDS water from the other sources would reduce this potential benefit.

Future Considerations. Of major importance is a more complete analysis of the Medina River water and the native groundwater from a well at the actual recharge location. Cores of the lower Trinity aquifer should be acquired or investigated to determine the hydraulic characteristics and mineralogy of the aquifer materials (as suggested for the Area 1/middle Trinity storage zone). Both the iron and clay mineralogy help determine the success of ASR in this storage zone.

The initial recharge should be relatively slow to allow the aquifer clays to adjust to the ion exchange and lower TDS without becoming destabilized. A buffer volume of recharged water should be left in the aquifer. This means that not all of the initial recharge water should be recovered from the aquifer to further stabilize the clay minerals in the aquifer. The clays will eventually become irreversibly dominated by calcium in the ion exchange position. The more stable calcium-dominated structure also enhances the permeability of the storage zone matrix.

The substandard quality of the native groundwater prohibits recovery in excess of the stored volume. Recovery may also be complicated by the relatively high temperature of groundwater in the aquifer (22 to 24 °C) if the recharge water temperature is less than about 15 °C. The number of cycles necessary to condition the storage zone and recovered acceptable quality water will largely depend on the local storage zone mineralogy.

Area 3/Middle Trinity Storage Zone

Glauconitic sands commonly contain fluorapatite (fluorinated calcium-phosphate mineral), which may be the origin of the elevated dissolved fluoride in the native groundwater from this aquifer. Evaporite minerals, such as gypsum and anhydrite, are also common.

Due to the historically low utilization of the middle Trinity aquifer in Area 3, the availability of water quality and mineralogy data is extremely limited. Analytical data from wells classified as undifferentiated Trinity aquifer wells by the Texas Water Development Board (TWDB) were used in the absence of more representative information. These data, summarized in Table C-2 of Appendix C, likely reflect characteristics of the water in the upper and middle Trinity Aquifers. The wells are located along the boundary of Areas 1 and 2 with Area 3 (shown in Appendix B figures). The lack of representative data introduces additional uncertainty in the results of the compatibility assessment.

Based on the limited data available, the native groundwater from the upper two units of the Trinity aquifer has a complex chemistry, as would be expected from the minerals present in the aquifers. The TDS ranges from 285 to 2,200 mg/L with a pH range from slightly acidic 6.5 to slightly alkaline 8.2. Native groundwater with a TDS of less than about 400 mg/L is a calcium-bicarbonate water chemistry type transitioning to a magnesium-sulfate water from about 700 to 1,100 mg/L TDS, a sodium-calcium-sulfate water at about 1,400 mg/L, and, finally, a calcium-sulfate water from about 1,500 to 2,200 mg/L TDS.

The low TDS calcium-bicarbonate water type includes both the minimum and maximum pH values. The calcium-sulfate water chemistry type can have at least two origins: pyrite and the evaporitic calcium-sulfate mineral (i.e., gypsum). Given the near-neutral pH of the groundwater, most of the calcium-sulfate is probably coming from the evaporites in these groundwater locations. The magnesium-sulfate water chemistry is probably in a transition zone between equilibrium with calcium-carbonate and equilibrium with calcium-sulfate. The sodium-calcium-sulfate may be a result of cation exchange downdip of the recharge area but may also be associated with minor gypsum dissolution.

Both the average fluoride and nitrate concentrations are elevated at an 2.5 mg/L (range 0.2 to 4.2) and 4.2 mg/L (less than 0.1 to 8.9), respectively. The higher fluoride concentrations are generally associated with the higher TDS groundwaters where calcium is complexed with sulfate. Extremes in pH and nitrate are coincident with the low TDS calcium-bicarbonate type groundwater. This association suggests the occurrence of shallow recharge in which the gypsum from the evaporite beds has leached into the groundwater.

There is only one dissolved metal ion analysis (filtered sample) and only one total metal ion analysis (unfiltered sample). These analyses suggest that iron can be as high as 0.23 mg/L; aluminum, 0.2 mg/L; and zinc, 1.7 mg/L. Given the high sulfate concentration, future testing should include a filtered sample to analyze for dissolved metals in the groundwater. The relatively high zinc concentration, consistent with the zinc concentrations found in the middle Trinity in Area 1, may be leached from galvanized steel well casings. Regardless of origin, the zinc concentration is not a problem for ASR.

Low TDS Sources and Mixtures. Recharge of the low TDS source waters to the low TDS, calcium-bicarbonate type groundwater would have the same potential problems identified for the low TDS calcium-bicarbonate type water of the middle Trinity in Area 1. One exception, however, is that there is little to no chance that calcium-carbonate will precipitate in the low pH (6.5) groundwater. Higher TDS native groundwater will have an increased potential for calcium-carbonate precipitation where the recharge and native groundwater mix directly.

Fluoride should not be a problem in recovered water since the calcium-bicarbonate water chemistry will tend to precipitate calcium-fluoride (the mineral fluorite). Fluoride in the recovered water should be about 1.5 mg/L. Nitrate in the native water should be displaced ahead of the stored water and may be only slightly higher in the recovered water than in the recharge water.

Medina River Source. Potential reactions between this recharge water and both native groundwater and aquifer minerals is about the same as for the low TDS sources in the middle Trinity aquifer in Area 3.

Future Considerations. Cores and more complete laboratory analyses of the groundwater are of particular importance in the middle Trinity in Area 3. Evaporite beds and sections of the aquifer near these beds should be cased off in an ASR well. Also, significant confinement should separate the evaporite beds from the recharge intervals to isolate the soluble evaporite minerals.

The recommendations for the lower Trinity aquifer in Area 1 are also applicable for the Area 3/Middle Trinity storage zone. Large temperature differences between the recharge and native water will similarly promote mixing in all water types except the calcium-bicarbonate type.

Area 5/Brackish Edwards Storage Zone

The Edwards aquifer is dominated by limestone with some argillaceous limestone in the upper Georgetown Formation. Permeability is assumed to be through fissures and joints associated with solution features.

As implied by the aquifer designation, the native groundwater from the Brackish Edwards has an elevated TDS averaging 4,720 (ranging from 4,290 to 5,310) mg/L, with an average pH of 6.9 (essentially neutral for the temperature). The groundwater is a mixed calcium-sodium-sulfate to a sodium-calcium-sulfate water chemistry type below about 5,000 mg/L TDS and a sodium-calcium-chloride water-type above about 5,000 mg/L TDS, as the solubility of calcium-sulfate is exceeded.

With the exception of nitrate, the concentrations of most of the major and minor ions are higher in the Brackish Edwards than in the other storage zones under consideration. This is probably due to the depth of this part of the Edwards aquifer and high groundwater temperatures that ranges from 32 to 47 °C. Relatively poor circulation in the Brackish Edwards aquifer also contributes to the high level of dissolved constituents.

Low TDS and Medina River Recharge Sources. There is a potential for precipitation of calcium-carbonate where the recharge and native groundwater mix. However, given the relatively high secondary permeability of this aquifer, this should not present a significant problem.

There will probably be considerable mixing between the recharge water and the native groundwater as a result of the temperature differences between the two and nature of the permeability in this storage zone. Although the storage zone may transmit water more efficiently than Trinity storage zones, more cycles may be required before the recovered water is of an acceptable water chemistry.

Future Considerations. Cores or cuttings from this portion of the Edwards aquifer should be analyzed to confirm that there is not a significant amount of pyrite nor are there blue clay beds in the target ASR interval. More complete water analyses would be necessary for both the recharge and native groundwater prior to any recharge.

There is considerable experience with recharging carbonate aquifers containing brackish to saline native groundwater. The first few short recharge cycles will allow an estimate of the eventual recovery. A buffer zone of recharged water is sometimes used if mixing between the recharge and native groundwater is an issue. Therefore, more than a few major ASR cycles may be required to produce potable recovered water. Given the relatively low TDS in this storage zone, developing a sufficient buffer may be easily achieved.

Area 6/Wilcox Group Storage Zone

The Wilcox Group is dominated by mudstone and sand containing lignite and glauconite. As discussed in the above subsections, this unit may contain fluorapatite as a source of dissolved fluoride and the lignite may contain the iron sulfide mineral marcasite.

Groundwater from the Wilcox Group in Area 6 contains an average 385 mg/L TDS, ranging from 286 mg/L to 450 mg/L, with a neutral to slightly alkaline pH of 7.6 (range 7.0 to 8.1). The groundwater is a calcium-bicarbonate to a calcium-sodium-bicarbonate water chemistry type. The increase in sodium may be at least partially due to ion exchange but the primary source is likely from recharge containing higher sodium and chloride. The chloride percentage increases with TDS as bicarbonate decreases and sulfate essentially remains constant. The elevated nitrate (average 2.7 mg/L, range from less than 0.04 mg/L to 8.0 mg/L) supports recharge as the major source of sodium and chloride.

The dissolved iron concentration of 472 micrograms per liter (µg/L) and dissolved manganese of 0.08 mg/L strongly suggest that pyrite is present in the mudstones and possibly the sands of this storage zone. The only slightly oxidized Eh of 190 mv and the total iron concentration support this conclusion. Other metals are below their respective detection limits.

Low TDS Sources and Mixtures. The relatively low pH of the groundwater, as well as the probable presence of pyrite, suggest that calcium-carbonate precipitation where the recharge and native groundwater mix is probably not a problem with this recharge source. However, if the pyrite is dispersed throughout the sands as fine-grained cement, the precipitation of iron oxyhydroxide flocculent in the pores of the sands could occur, reducing storage zone permeability. If the pyrite is confined to the mudstone, a more probable condition, then exposure to recharge water would be minimal and this problem would not occur.

In either case, recovered water may have a slight to moderate increase in TDS (calcium and sulfate) through the oxidation of pyrite. The increase depends on the amount and manner in which the pyrite is dispersed in the aquifer matrix. The first few short cycles will determine the increase in either case.

Clay stability may be an additional problem if pyrite is dispersed in the sands. The clays can become very unstable with a decrease in pH created by oxidation of pyrite. This instability can lead to plugging of the pores. The severity of plugging is directly related to the amount of pyrite present and exposure of the pyrite to the recharge water.

Medina River Recharge Source. Recharge with this source may or may not have potential for the precipitation of calcium-carbonate; this depends on the distribution of pyrite within the aquifer matrix. The above discussion on the ramifications of the pyrite oxidation also pertains to injection with this source. Perception of iron oxyhydroxide flocculent could reduce storage zone permeability. Similarly, mobilization of clay due to an increase in pH could result in irreparable plugging.

Future Considerations. Cores and more complete aquifer and groundwater characterization for locations of interest should be collected before recharging the Wilcox Group in Area 6. It is probable that the pyrite is essentially limited to the mudstone and that the clays will remain stable; however, the potential for aquifer damage warrants more investigation before recharging these sands.

Area 7/Carrizo Sand Storage Zone

The Carrizo Sand is a noncalcareous, medium- to coarse-grained sand. The lack of carbonates in the sands is a decided advantage for ASR. However, the localized presence of elevated levels of iron oxyhydroxide suggest the historical, if not current, presence of pyrite.

The native groundwater is a sodium-calcium-chloride to sodium-chloride water chemistry type with an acidic pH ranging from 5.0 to 6.4 (average 5.9) but a low TDS ranging from 130 mg/L to 170 mg/L. The dominance of chloride suggests that pyrite is probably not present in sufficient amounts to cause significant problems for ASR. In fact, the acidic pH created by a trace amount of pyrite may be beneficial in that calcium-carbonate precipitation is unlikely to occur. The low TDS supports the presence of only trace amounts of pyrite at the locations represented by the three sampling points (Table C-2). The dissolved iron concentration of 654 µg/L and the slightly elevated dissolved aluminum and manganese concentrations (0.05 mg/L and 34 µg/L, respectively) further suggest that pyrite is still present in the aquifer. However, the Eh of 384 mv indicates pyrite only exists in trace amounts or is found in lower permeability strata since the water is highly oxidized.

Low TDS and Medina River Recharge Sources. Nitrate is very low in this storage zone probably because of denitrification by the ferrous iron, pyrite, and also because of the acidic nature of the groundwater. Trace amounts of pyrite may continue to denitrify the recharge water, resulting in a lower nitrate concentration in the recovered water. Sufficient storage time will be important to maximize this beneficial reaction.

The recovered water may be slightly to significantly lower in pH. There may also be a slight increase in sulfate and a decrease in bicarbonate concentration compared with the recharge water. The degree of change and number of cycles needed to recover nearly the same water chemistry as the recharge source water depends on the amount and degree of interaction between the pyrite and recharge water in the storage zone.

If pyrite is present in trace amounts, any of these sources can be used to recharge the Carrizo Sand. If, on the other hand, pyrite is present in significant amounts, recharge by any of the sources could create a potential plugging problem due to formation of iron oxyhydroxide flocculent. The severity of the problem would be directly proportional to the amount of pyrite present and the relative exposure to the oxidizing recharge water.

Future Considerations. Cores and more complete groundwater and source water analyses should be collected before this aquifer is recharged. Water samples from a well in close proximity to any proposed ASR site could provide useful chemistry information, particularly regarding pH and Eh, to assess the amount and exposure of pyrite in the storage zone prior to site selection. Clay stability should not be as serious a potential problem in this storage zone because it may be in the Wilcox Group due to the acidic nature of the groundwater. However, cores should be collected to confirm the amount and type of clay present. If pyrite is present in only trace amounts, only a few cycles will be needed to achieve acceptable recovery efficiencies.

Disinfection Byproducts

When evaluating chemical compatibility of potable waters and groundwaters, the effects of disinfectant(s) must also be considered. Disinfectants are added to the potable or drinking water to kill any potential water-borne pathogens and to protect the water as it is transmitted through pipelines to individual residences and businesses. A trade-off of this protection is the fact that the disinfectant can react with organic matter (referred to as precursors) in the water to form disinfection byproducts (DBPs), some of which are considered probable carcinogens and/or present other chronic health concerns.

Little is known about the occurrence of most DBPs. As detection equipment and techniques become more advanced, additional DBPs may be identified and regulated in the future. Currently only one group of DBPs is regulated. This group of DBPs is referred to as trihalomethanes (THMs) and is regulated as a group not to exceed 100 ug/l in drinking water. New proposed standards for THMs will most likely lower this level to 80 ug/l and will add three new groups to the DBP list. The new groups include five haloacetic acids (HAAs), bromate, and chlorite. The DBPs that form are dependent on the disinfectant being used. Chlorine and chloramines are the predominate disinfectants used in drinking water and the dominate DBPs of concern when chlorine and chloramines are used are THMs and HAAs.

The DBPs are controlled by reducing the organic matter before the disinfectants are applied to the water or by using a disinfectant like chloramines that is not as reactive with the organic matter. Fortunately, most groundwaters have very low organic content and thus very little to react with chlorine. For example, the THMs reported for the City of San Antonio for the Edwards Aquifer water is about 15 ug/l which is well below the standard of 100 ug/l. Therefore, DBPs are mainly only a concern for treating and storing surface waters with higher organic components.

Complete reaction between the chlorine and organic matter can take 48 to 72 hours before the THMs are stable. Therefore, anytime water is stored that has a chlorine residual and available organic matter, there is a concern that the THMs will increase. This is of particular concern for surface waters stored for very short period.

To address this issue, the American Water Works Association Research Foundation (AWWARF) completed a DBP field investigation of ASR systems. The investigation reviewed five ASR systems in the United States, including the ASR system in Kerrville, Texas (Pyne, et. al., 1996). The data they collected suggest that THMs and HAAs are actually removed from the chlorinated drinking water during aquifer storage over a period of several weeks, improving water quality. For example after 71 days of storage, THMs in recovered water had been reduced below 60 ug/l from the initial stored THMs of 120 ug/l, and the HAAs dropped from over 100 ug/l to an undetectable amount. A biological mechanism is suggested, including DBP removal under both anoxic and aerobic conditions.

Based upon this information, development of DBPs is not generally a concern for groundwater sources due to low organic content, and aquifer storage and recovery actually reduces DBPs. Formation of DBPs remains a surface water treatment issue.

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Technical Memorandum
Groundwater Assessment
Appendix A

Table A-1
Cross-Section W-W' Data

State ID (1)	Other ID (1)	Latitude	Longitude	Report
68-26-805	--	293114	984754	M and E, x-sect 5
68-27-401	--	293309	984439	M and E, x-sect 6
68-27-703	El Sueno #1	293027	984427	M and E, x-sect 6
68-35-102	--	292845	984241	M and E, x-sect 6
68-35-401	--	292650	984451	M and E, x-sect 5
68-35-701	--	292346	984339	M and E, x-sect 5
68-35-807	--	292240	984227	M and E, x-sect 5
68-43-104	Gordon, Meadowood Acres	292157	984426	TDWR Report 239,1979, x-sect D-D'
68-43-201	--	292150	984103	M and E, x-sect 5
68-43-604	--	291945	983933	M and E, x-sect 5
68-43-607	--	291855	983860	M and E, x-sect 5
68-43-804	--	291700	984208	M and E, x-sect 4
68-43-808	--	291610	984127	M and E, x-sect 4
68-43-811	--	291720	984224	M and E, x-sect 4
68-50-304	--	291433	984542	M and E x-sect 3
--	35-1 (68-35-1)	292924 (2)	984317 (2)	TWDB Report 296
--	68-34-3+A	292819	984633	M and E, x-sect 5
--	68-34-6+B	292728	984531	M and E, x-sect 5
--	68-43-2+A	292124	984050	M and E, x-sect 5
--	68-43-4 (Coastal States #1/M&E)	291809	984436	TWDB Report 296
--	68-43-8+B	291654	984145	M and E, x-sect 4
--	RT (Ranch Town)	293330 (2)	984421 (2)	TDWR Report 239,1979, x-sect B-B'

Notes:
1) First two digits (i.e., 68) and seperator dashes omitted in Figure 5 well labels
2) Latitude and longitude estimated from report graphics

Table A-2
Cross-Section C-C'
Data

State ID (1)	Other ID (1)	Latitude	Longitude	Report
68-19-208	--	294316	984001	TWDB Report 339
68-19-604	--	294153	983750	TWDB Report 339
68-20-401	--	294107	983623	TWDB Report 339
68-28-105	--	293635	983540	TWDB Report 339
68-28-108	--	293547	983513	TWDB Report 339
68-28-204	--	293530	983312	P.A.Watterreus, UTSA Thesis 1992
68-28-205	--	293504	983326	M and E, x-sect 8
68-28-502	--	293437	983243	P.A.Watterreus, UTSA Thesis 1992
68-28-504	--	293304	983309	M and E, x-sect 8
68-28-513	--	293404	983240	P.A.Watterreus, UTSA Thesis 1992
68-28-910	--	293208	983217	M and E, x-sect 8
68-28-911	SAWS Barbet Rd No. 1	293012	983229	USGS Bulletin 5911
68-36-304	SAWS Vance Jackson Rd. well	292912	983204	USGS Bulletin 5911
68-36-504	--	292701	983420	M and E, x-sect 7
68-36-610	--	292533	983211	W.G. Stein, UTSA Thesis 1993 from Maclay and Small, 1984
68-36-801	--	292453	983250	M and E, x-sect 7
--	3	294056 (2)	983621 (2)	TWC Bulletin 6409, x-sect B-B'
--	114a / 68-20-114a	293824 (2)	983443 (2)	P.A.Watterreus, UTSA Thesis 1992
--	115a / 68-20-115a	293945 (2)	983539 (2)	P.A.Watterreus, UTSA Thesis 1992
--	116a / 68-20-116a	293913 (2)	983506 (2)	P.A.Watterreus, UTSA Thesis 1992
--	122a / 68-20-122a	293751 (2)	983424 (2)	P.A.Watterreus, UTSA Thesis 1992
--	19-6 / 68-19-6	294044 (2)	983758 (2)	W. E. SIMPSON
--	19-9	293937 (2)	983908 (2)	W. E. SIMPSON
--	20-7 / 68-20-7	293816 (2)	983709 (2)	W. E. SIMPSON
--	20-8 / 68-20-8gf1	293756 (2)	983421 (2)	W. E. SIMPSON
--	200b / 68-20-200b	293719 (2)	983422 (2)	P.A.Watterreus, UTSA Thesis 1992
--	27-3 / 68-27-3	293728 (2)	983810 (2)	W. E. SIMPSON
--	28-1 / 68-28-1	293532 (2)	983456 (2)	W. E. SIMPSON
--	28-115 / 68-28-115	293607 (2)	983508 (2)	W. E. SIMPSON
--	28-5 / 68-28-5	293322 (2)	983337 (2)	W. E. SIMPSON
--	33 / City of San Antonio	292626 (2)	983056 (2)	TDWR Report 239,1979, x-sect D-D'
--	44-6a / 68-44-6(a)	291856 (2)	983053 (2)	TWDB Report 296
--	44-6b / 68-44-6(b)	291742 (2)	983110 (2)	TWDB Report 296
--	68-36-9+A	292319	983259	M and E, x-sect 7
--	68-36-9+B	292414	983120	M and E, x-sect 7
--	68-44-5+A	291919	983231	M and E, x-sect 6
--	68-44-6+A	291810	983130	M and E, x-sect 6
--	68-44-9+A	291710	983034	M and E, x-sect 6
--	68-45-1+A (Reinhardt #1 Chic Haven Courts)	292101	982741	W.G. Stein, UTSA Thesis 1993 from Maclay and Small, 1984

Table A-2
Cross-Section C-C'
Data

--	68-45-4+A (Parker and McGuire #1Goad)	291807	982744	W.G. Stein, UTSA Thesis 1993 from Maclay and Small, 1984
--	68-45-8+A (Arnold #1 Goeth)	291610	982636	W.G. Stein, UTSA Thesis 1993 from Maclay and Small, 1984
--	68-53-2 (H and J # 1 Wright)	291438	982620	W.G. Stein, UTSA Thesis 1993 from Maclay and Small, 1984
--	68-53-8 (H&J & Wilson #1 Chapaty)	290733	982541	USGS Bulletin 5911
--	CB-56	293759	983425	W.E SIMPSON
--	CWB-10/CWB Mission Station No.10	292139 (2)	982849 (2)	TDWR Report 239,1979, x-sect B-B'
--	CWB / San Antonio City Water Board	292327 (2)	983043 (2)	TDWR Report 239,1979, x-sect B-B'
--	FN-1/F.M. Frasher - P.G. Northrup et al, W.I. Whitt no.1	291138 (2)	982422 (2)	USGS Bulletin 5911
--	LS / U S Gov't water well Leon Springs	294117 (2)	983724 (2)	USGS Bulletin 5911
--	MR / SAWS Mistletoe and Ripley St. water well	292459 (2)	983003 (2)	USGS Bulletin 5911
--	MS-17 / SAWS Market St. No. 17 water well	292311 (2)	982918 (2)	USGS Bulletin 5911

Notes:
1) First two digits (i.e., 68) and seperator dashes omitted in Figure 5 well labels
2) Latitude and longitude estimated from report graphics

Table A-3
Cross-Section E-E'
Data

State ID	Other ID	Latitude	Longitude	Report
68-30-211	--	293618	981940	M and E, x-sect 11
68-30-508	--	293329	981914	TWDB Report 296
68-30-510	--	293311	981803	M and E, x-sect 11
68-30-512	--	293411	981919	TWDB Report 296
68-30-807	--	293129	981744	M and E, x-sect 11&
--	68-30-5+C	293437	981915	M and E, x-sect 11

Note: First two digits (i.e., 68) and seperator dashes omitted in Figure 5 well labels

Technical Memorandum
Groundwater Assessment
Appendix B

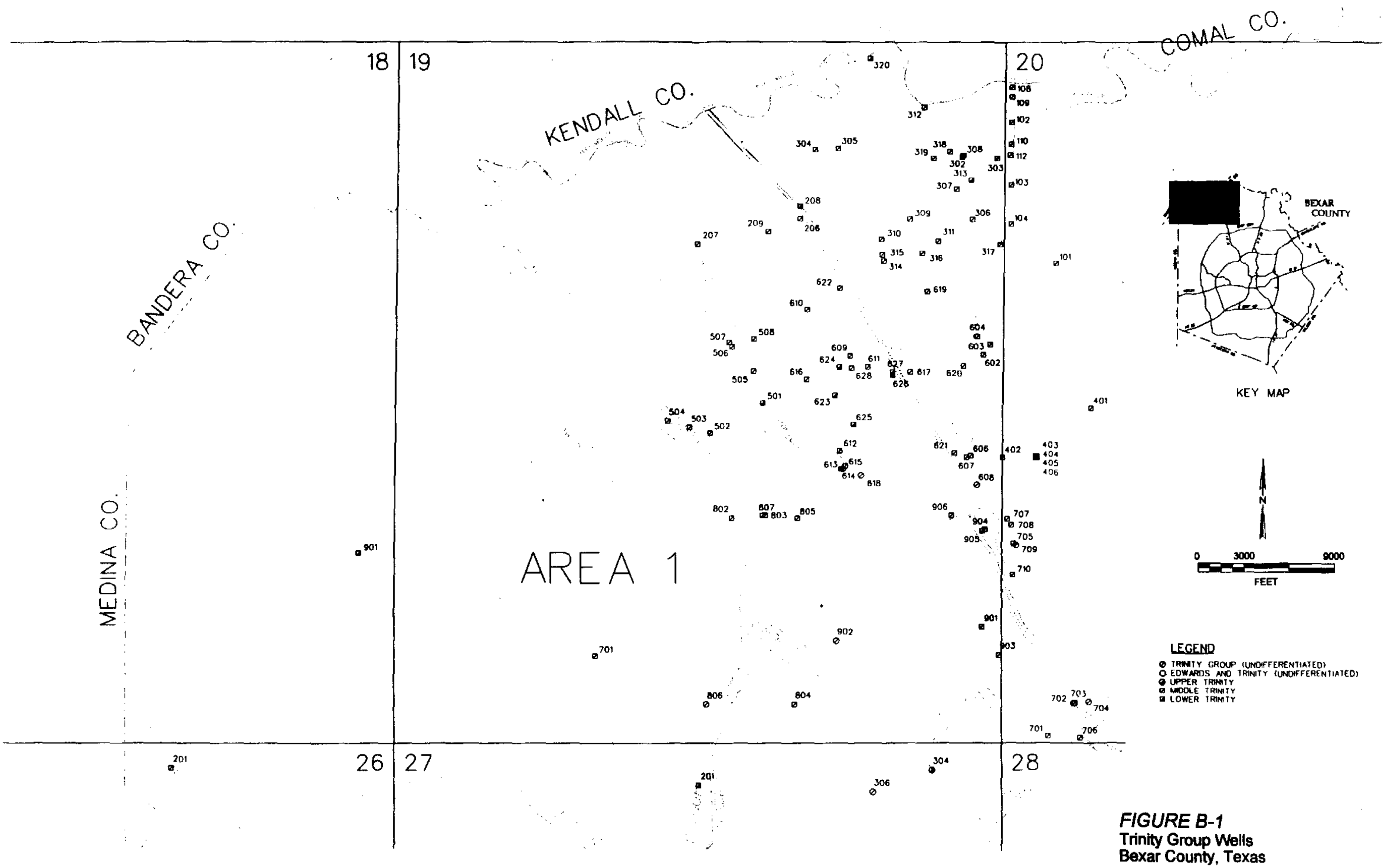

FIGURE B-1
Trinity Group Wells
Bexar County, Texas

Source: Texas Water Development Board Ground-Water Data System, extracted September 1997.

AUS/GRAPHICS\WBL\SAWS\ASR\CH2MMfig3.dgn
11-DEC-1997

CH2MHILL

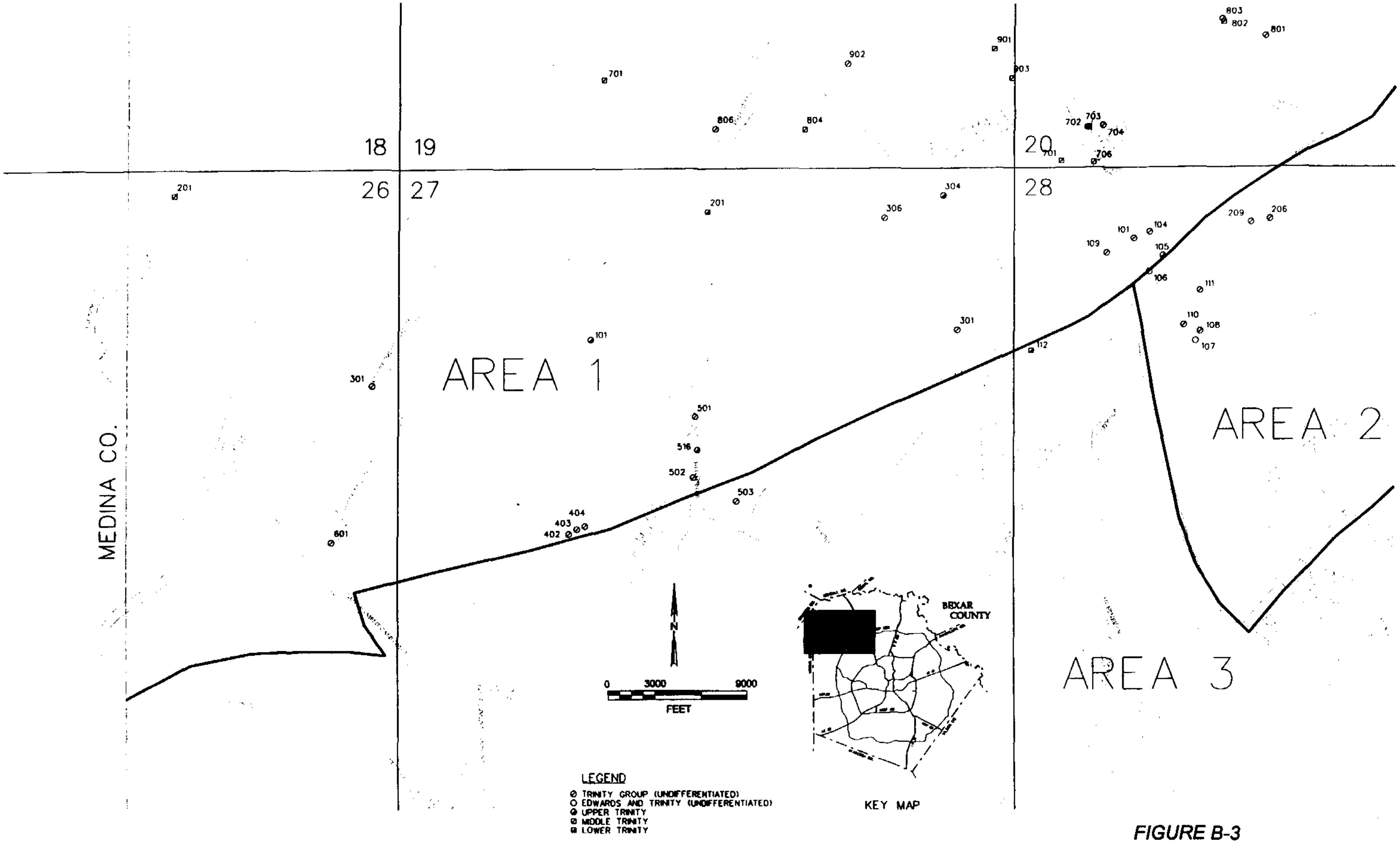

FIGURE B-3
Trinity Group Wells
Bexar County, Texas

Source: Texas Water Development Board Ground-Water Data System, extracted September 1997.

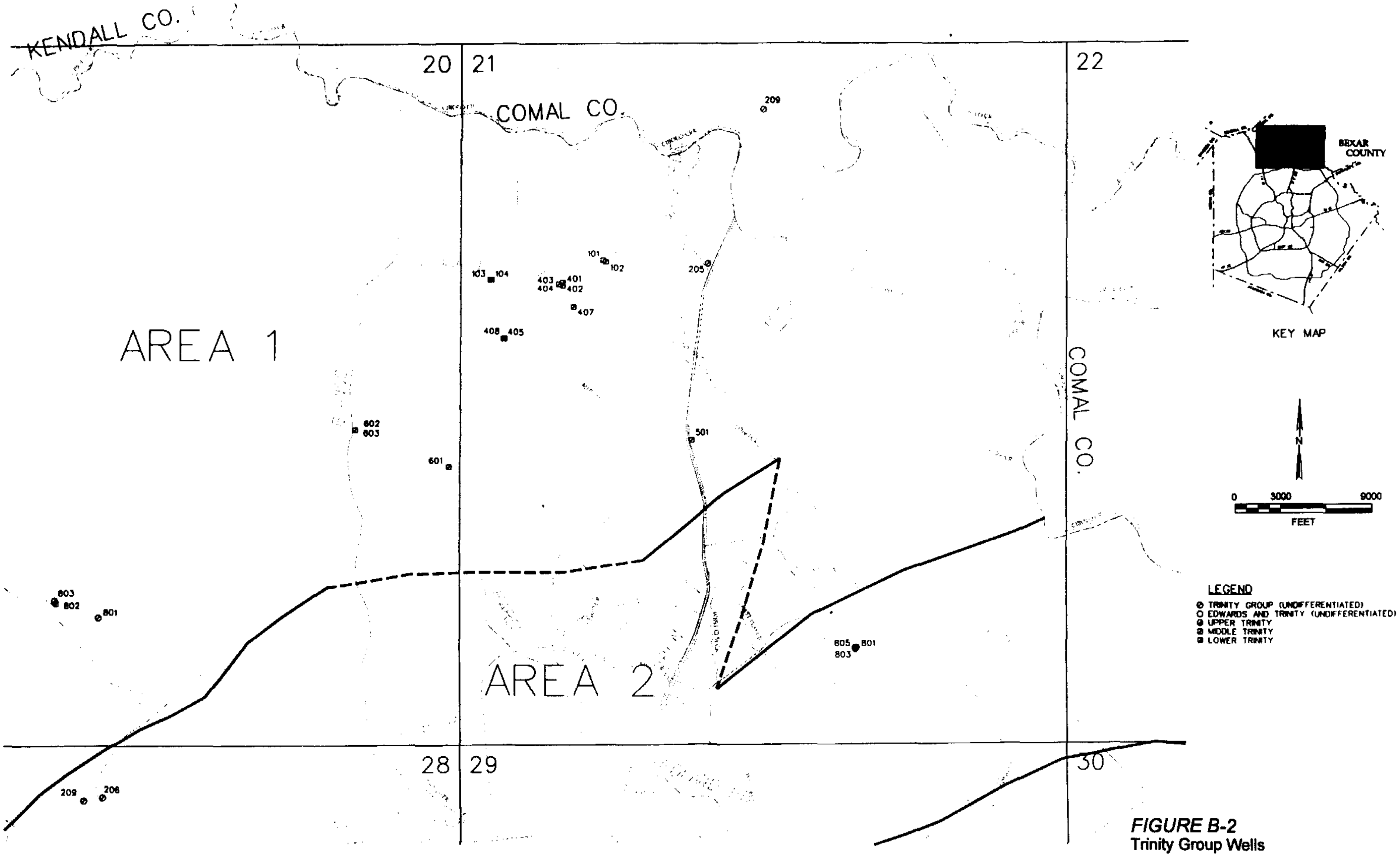

FIGURE B-2
Trinity Group Wells
Bexar County, Texas

Source: Texas Water Development Board Ground-Water Data System, extracted September 1997.

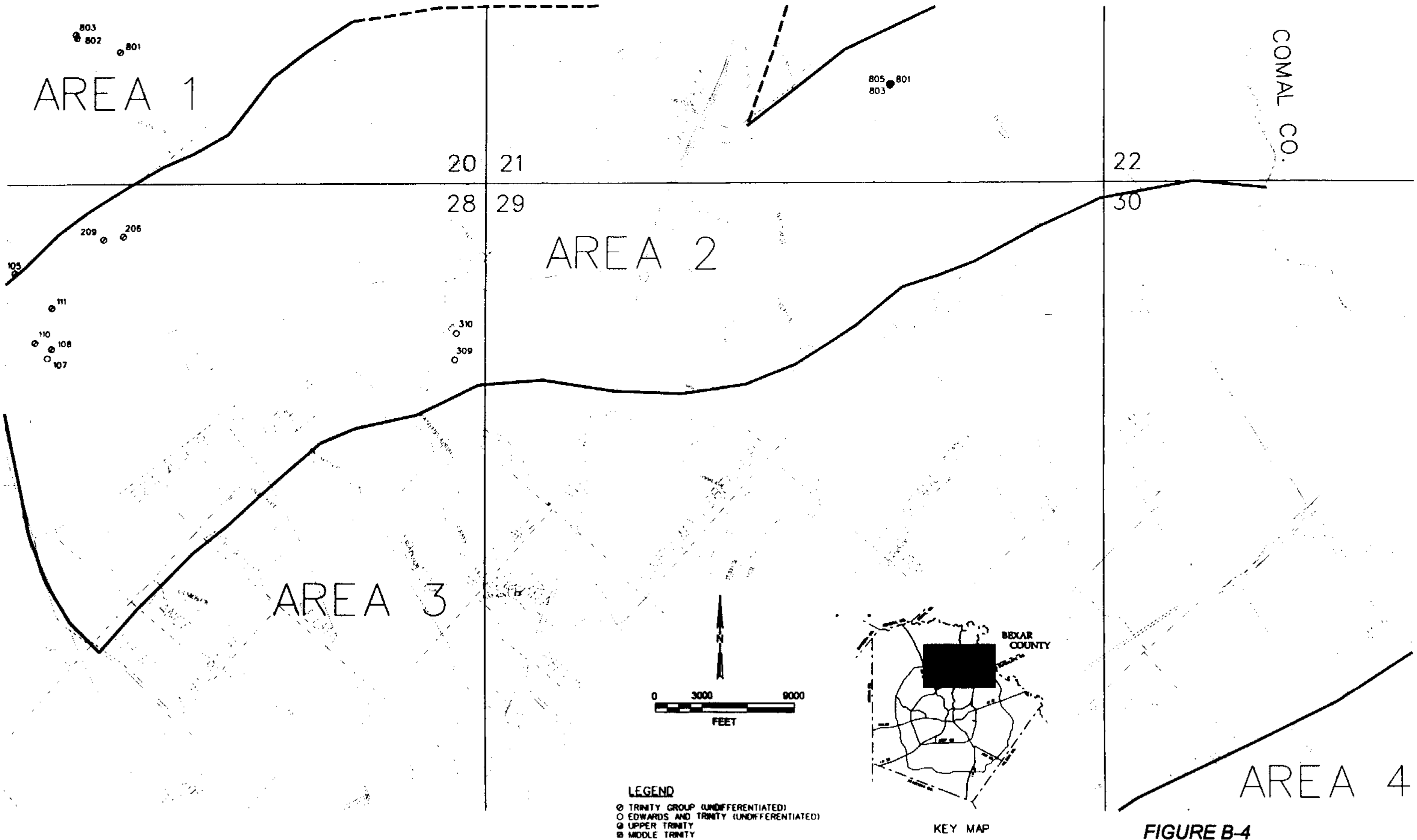

FIGURE B-4
Trinity Group Wells
Bexar County, Texas

Source: Texas Water Development Board Ground-Water Data System, extracted September 1997.

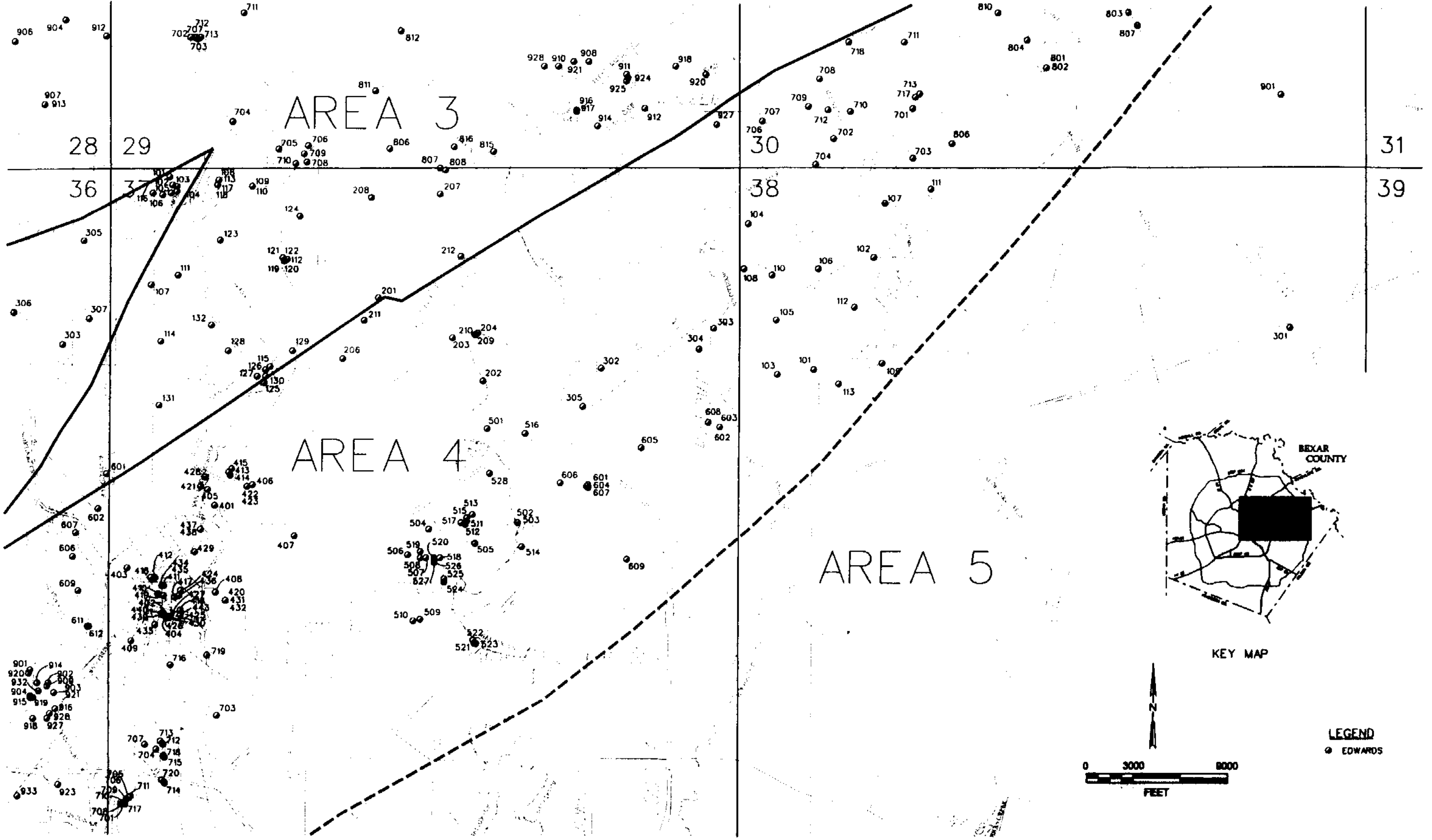

FIGURE B-5
Edwards Wells
Bexar County, Texas

Source: Texas Water Development Board Ground-Water Data System, extracted September 1997.

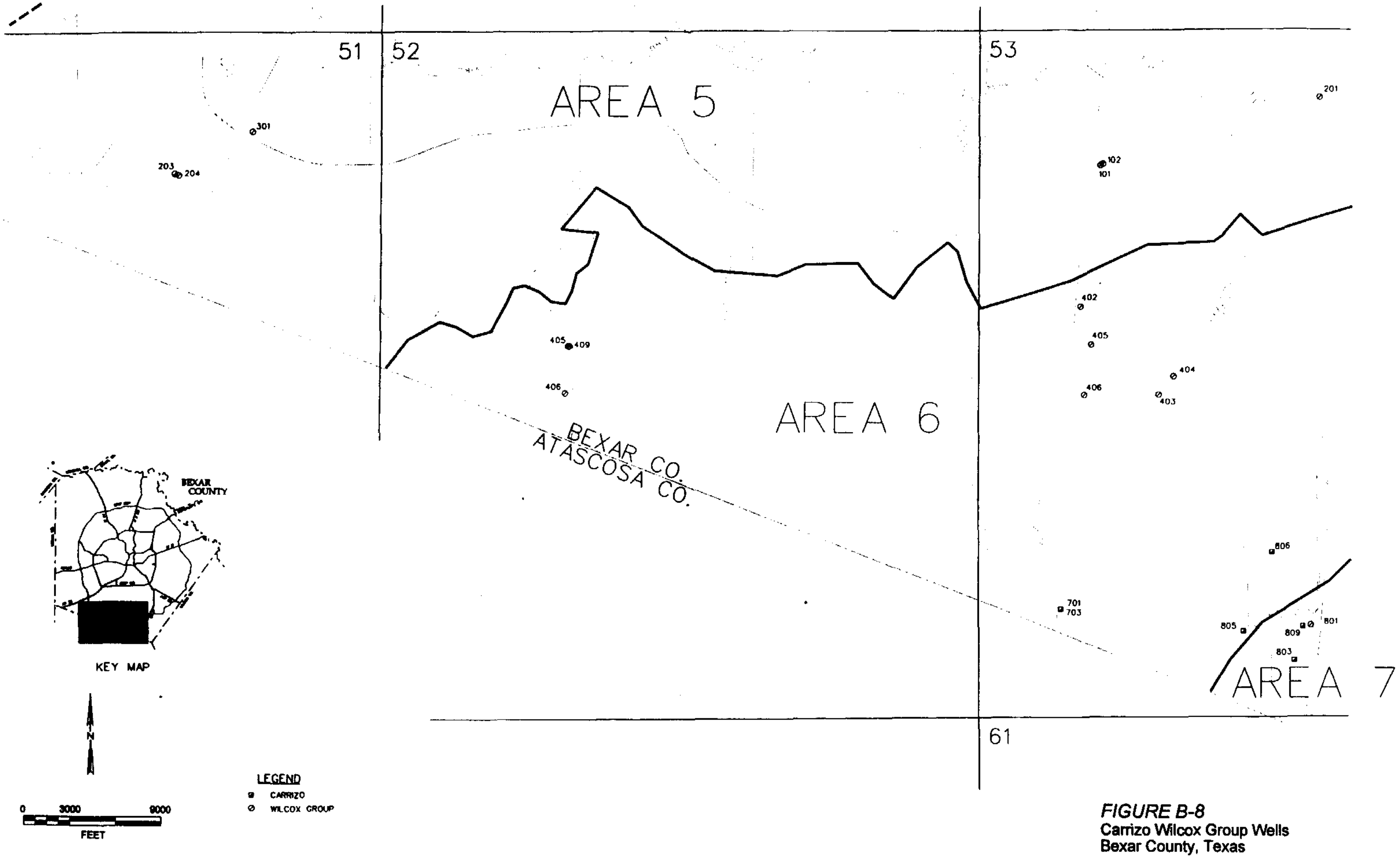

FIGURE B-8
Carrizo Wilcox Group Wells
Bexar County, Texas

Source: Texas Water Development Board Ground-Water Data System, extracted September 1997.

AUS\GRAPHICS\WBL\SAWS\ASR\CH2M\fig1.dgn
11-DEC-1997

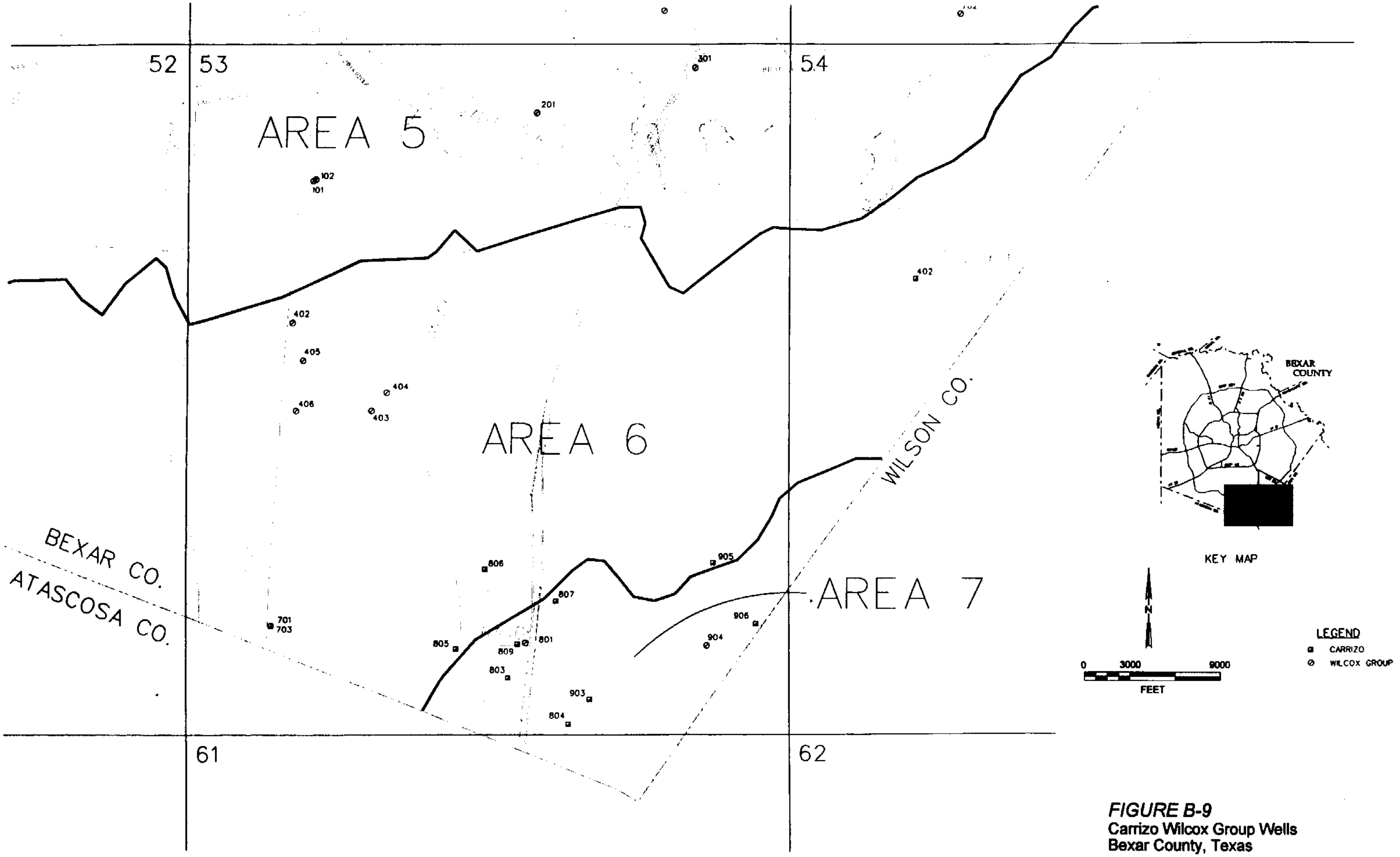

FIGURE B-9
Carrizo Wilcox Group Wells
Bexar County, Texas

Source: Texas Water Development Board Ground-Water Data System, extracted September 1997.

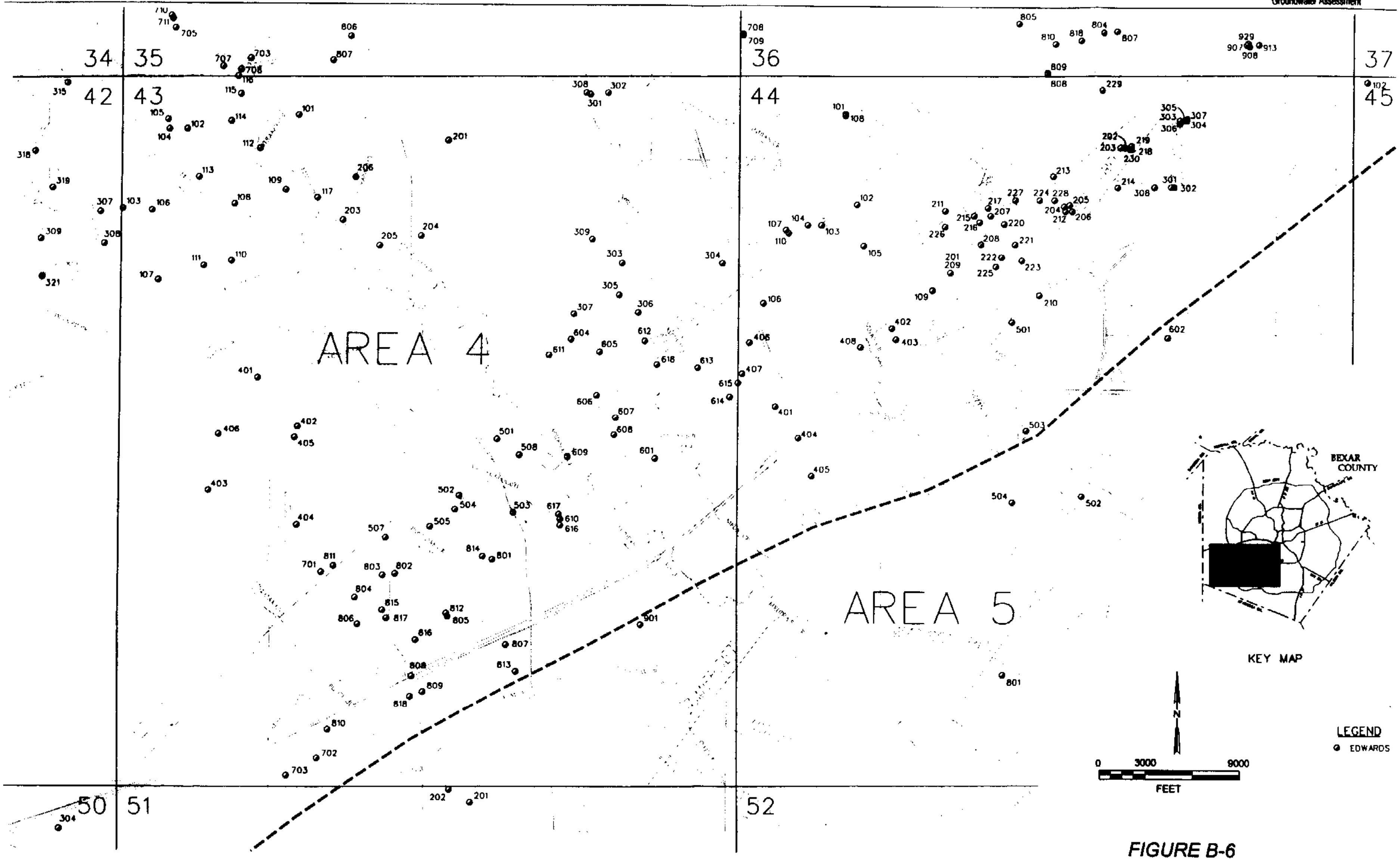

FIGURE B-6
Edwards Wells
Bexar County, Texas

Source: Texas Water Development Board Ground-Water Data System, extracted September 1997.

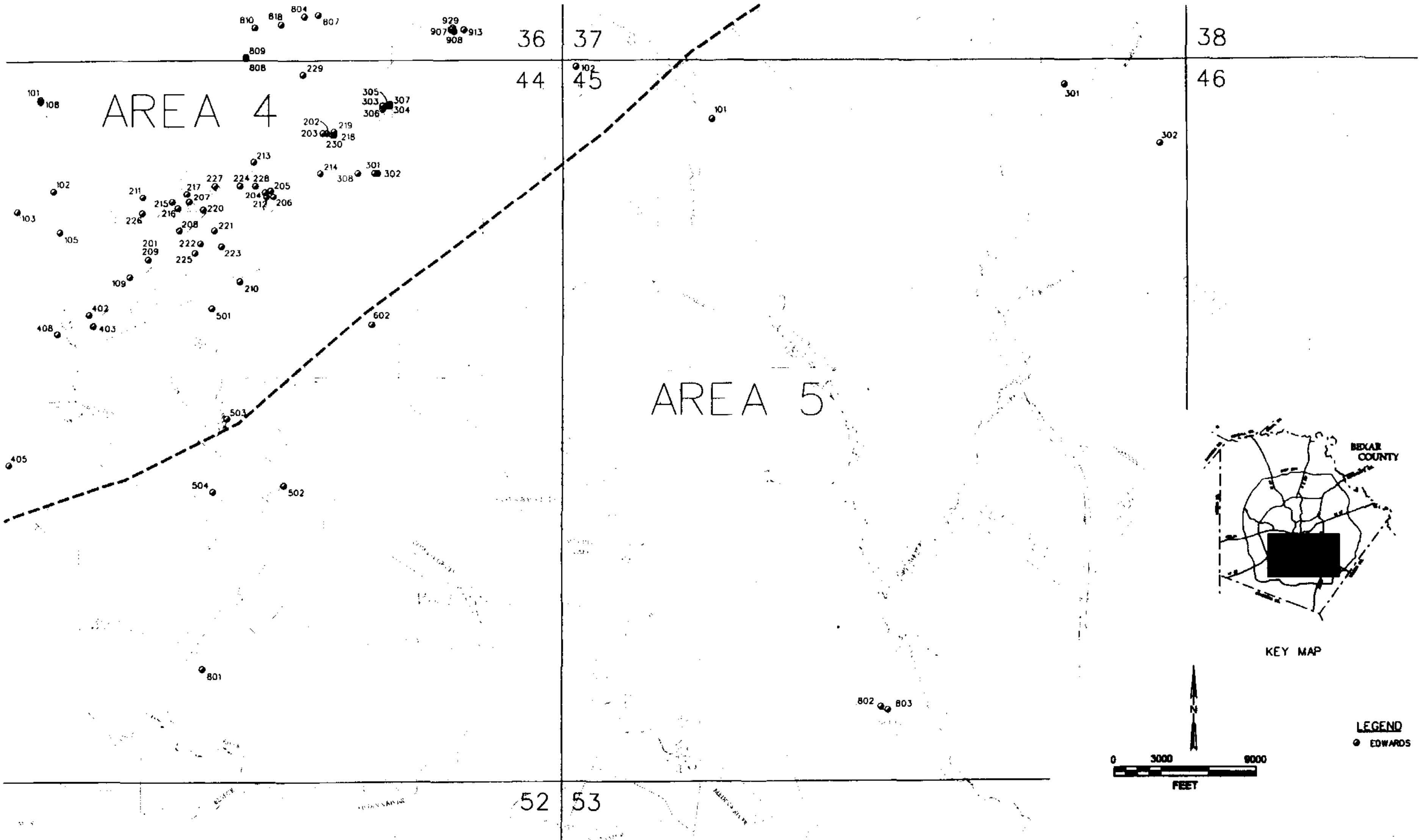

FIGURE B-7
Edwards Wells
Bexar County, Texas

Source: Texas Water Development Board Ground-Water Data System, extracted September 1997.

Technical Memorandum
Groundwater Assessment
Appendix C

Table C-1
Source Water Characteristics

		Source					
Parameter	Units	Lake Medina (1)	Canyon Lake (2)	CRWA (3)	NBU (6)	BexarMet (4)	SAWS (5)
Total Alkalinity (as CaCO3)	mg/l	115 - 182	140-160	179	166-232		228
Total Dissolved Solids	mg/l	205 - 268	194-212	263	226-294	250 - 600	297
Turbidity	Jackson Candle	2 - 5				10 - 140 (ntu)	
Color	Platinum-Cobalt	0 - 5				3 - 7	
Specific Conductance	umhos/cm	351 - 463	358-376	504	450-576		
pH (field)	pH	7.5 - 8.3	7.4-8.4	7.7	7.6-8.2	7.5 - 8.5	
Temperature (field)	deg C	12 - 27.5	12.5-20.5			10 - 30	
Dissolved Oxygen (field)	mg/l	9.7 - 10.2	0.6-9.8				
Chloride	mg/l	11 - 18	16	23	16-22	10 - 40	17
Fluoride	mg/l	0.1 - 0.4	0.2	0.2	0.2-1.3	0.3	0.2
Sulfate	mg/l	35 - 64	19	37	22-23		28
Carbonate alkalinity	mg/l			0	0		0
Bicarbonate alkalinity	mg/l			218	203-283	125 - 250	279
Total silica	mg/l	7.5 - 12	9.6-11			10 - 12	
Calcium	mg/l	42 - 68	35-42	59	49-80	70 - 100	82
Magnesium	mg/l	12 - 18	17	17	17-18	20 - 30	14
Sodium	mg/l	5.6 - 9.8	10-11	15	10-12	30 - 40	10
Potassium	mg/l	1.6 - 2.5	1.7-1.9				
Iron	ug/l	0	<3	<10	<4-<20	30 - 4000	<4
Aluminum	ug/l			150	<20-128		<20
Copper	ug/l	0		6	<2-<6		3
Manganese	ug/l	5	<1-1	<8	<0.5-<8	ND - 50	<0.5
Zinc	ug/l	3		<20	<5-8		<5
Cadmium	ug/l	0		<0.2	<0.1-<0.2		<0.1
Selenium	ug/l	1		2.9	<4		<2
Total Hardness	mg/l	170 - 230	160-170	218	197-270	125 - 350	263
Non-carbonate hardness	mg/l	36 - 74	17-18				
Nitrate	mg/l	0 - 0.6	0.11	0.68	0.23-1.86	<1 - 5	1.8
Ammonia	mg/l	0.08 - 0.1	<0.01-0.02			0.2 - 0.3	
Total organic carbon	mg/l	1 - 3				2 - 12	
Chloroform	ug/l	5.2					<.0.5
Bromodichloromethane	ug/l	7.7					<0.5
Dibromochloromethane	ug/l	4.5					1
Bromoform	ug/l	<0.5					1.3
Total Trihalomethane	ug/l						15.3

Notes:

(1) U.S.G.S. station 08179500, Medina Lake near San Antonio, Texas
24 raw water samples, collected from 2-10-70 to 1-25-84

(2) U.S.G.S. station 08167700,Canyon Lake near New Braunfels, Texas
3 raw water samples, collected from 2-24-94 to 8-24-94

(3) Canyon Regional Water Authority (CRWA), New Braunfels, Texas
1 treated water sample, collected 4-22-97

(4) BexarMet Pilot Plant estimated raw water, Medina River, San Antonio, Texas

(5) San Antonio Water System (SAWS), San Antonio, Texas
summary of treated water compliance data for 1993, Edwards aquifer

(6) New Braunfels Utilities (NBU), New Braunfels, Texas
3 treated water samples, collected from 12-21-94 to 3-25-96

Table C-2

Groundwater Analytical Data

State Well Number	Year	Temp (C)	Si (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Carbonate (mg/l)	Bicarb. (mg/l)	Sulfate (mg/l)	Cl (mg/l)	F (mg/l)	Nitrate (mg/l)	pH	TDS	Phenol Alk.
Area 1/																
Middle																
Trinity																
6819207	1976		12	101	51	8		0	424.68	99	16	2.4	0.7	7.9	498	0
6819303	1977		11	89	21	10		0	336.82	17	20	0.4	8	7.6	342	0
6819305	1977		10	125	23	21		0	406.38	59	37	0.6	< 0.4	7.5	475	0
6819307	1994	24	12	73	30	16	3.2	0	323.39	50	23	0.54	1.59	7.01	370	0
6819316	1995															
6819504	1977		11	89	31	12		6	317.29	80	13	0.8	2.3	8.4	401	5
6819508	1995															
6819602	1994	22	11	87	24	8.1	1.9	0	344.14	20	17	0.68	4.73	6.89	345	0
6819606	1973			107	16	9		0	355.12	24	16	0.3	6	7.4	352	0
6819607	1973			87	31	15		0	388.07	18	19	0.6	13	7.5	374	0
6819610	1976		12	70	28	6	2	0	323.39	17	10	0.6	1.5	7.7	306	0
6819611	1976		12	112	12	11		0	350.24	12	19	0.3	27	8.2	377	0
6819612	1976			63	47	38		0	361.22	98	22	2.5	< 0.4	7.8	448	0
6819615	1976			64	49	37		0	361	100	22	2.5	0.8	7.7	452	0
6819619	1995															
6819627	1995															
6819628	1996															
6819701	1974	16	14	93	19	8		0	300.21	60	12	0.4	4	7.9	358	0
6819802	1974	19	19	83	13	7		0	291.66	11	14	0.2	6	7.6	296	0
6819803	1986	13	12	60	45	27	7	6	334.37	84	20	1.7	1.06	8.4	428	5
6819804	1976		11	110	46	12		0	301.43	223	14	0.6	3.8	7.9	568	0
6819807	1994	23	12	60	46	29	8.6	0	349.02	93	22	1.8	<0.04	7.17	447	0
6819906	1995															
6820402	1973			79	27	7		0	334	18	13	0.5	4.9	7.6	313	0
6820601	1986	17	12	61	45	14	6	0	374.65	58	11	1.5	0.04	8.3	392	0
6820701	1976		12	195	64	10	5	0	303.87	492	13	1.8	< 0.4	7.5	942	0
6820706	1973															
6821101	1978															
6821103	1984			69	42	12		6	345.36	62	12	1.4	0.53	8.4	374	5
6821104	1984			64	44	13		7.2	346.58	64	12	1.4	0.44	8.5	376	6
6821401	1984			65	25	6		0	291.66	20	12	0.4	5.36	8.3	277	0
6821402	1984			77	24	6		0	325.83	22	12	0.4	5.22	8.3	306	0
6821403	1994	22	11	89	20	6	1.9	0	344.14	20	14	0.39	5.35	7.19	338	0
6821404	1976			94	17	6		0	325.83	24	12	0.3	7	7.9	320	0
6821408	1980															

Notes:

1) Not known if sample was filtered
2) Well Number 6827502 Data from 1969
3) Well Number 6827503 Data from 1978, filtered sample
4) Well Number 6838301 Data from 1971
5) Well Number 6845301 Data from 1970
6) Well Number 6845901 Data from 1973

Source: Texas Water Development Board Ground-Water Data System, extracted September 1997.

Table C-2

Groundwater Analytical Data

State Well Number	Year	Temp (C)	Si (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Carbonate (mg/l)	Bicarb. (mg/l)	Sulfate (mg/l)	Cl (mg/l)	F (mg/l)	Nitrate (mg/l)	pH	TDS	Phenol Alk.
Area 1/ Lower Trinity																
6819208	1977	22	10	111	62	200		0	246.51	528	173	1	<0.4	7.9	1206	0
6819302	1977		13	310	169	232		0	255.05	1350	231	1.7	<0.4	7.5	2432	0
6819501	1977	24	8	50	25	250		0	296.54	267	182	1.2	<0.4	7.9	929	0
Area 3/ Upper-Middle Trinity																
6827402	1994	24	3.78	178.4	117	12	10	0	273.36	543	45	4.2		7.3	1057	0
6827403	1994	24	4.56	438	144	13	8.8	0	253.83	1428	20	4.17		7.1	2194	0
6827404	1994	19	4.2	121	92	11	7	0	283.12	349	50	4.17		7.3	789	0
6827502	1994	24	3.96	367	67	16	2.5	0	285.56	861	50	2.35		7	1525	0
6827503	1992	22	11	87	15	7.2	1	0	292.88	20	15	0.2	8.9	6.5	309	0
6828101	1975		14	156	74	185	13	0	274.58	700	126	1.2	3.5	7.8	1407	0
6828109	1977			64	30	7		0	306.31	22	11	1.1	<0.1	8.2	285	0
Area 5/ Brackish Edwards																
6838301	1976	32		570	190	950	53	0	305.09	1800	1600			6.9	5313	0
6845301	1973			640	220			0	276.08	1950	970			6.8		0
6845302	1972	39	25	680	210	460	29	0	294	1990	990	3.1	0.4	6.7	4543	0
6845802	1971	47	24	650	210	455	27	0	260	1980	800	4.4	0.6	6.8	4291	0
6845901	1974			670	210			0	260.07	1960	760			7.2		0
Area 6/ Wilcox																
6852405	1990	26	22	73	22	49	12	0	292.88	62	64	1.27	<0.04	7.04	450	0
6852406	1983			49	15	35	7	0	217.22	35	38	0.4	<0.04	8.1	286	0
6852409	1975			91	11	42	10	0	240.41	62	76	0.6	8	7.7	418	0
Area 7/ Carrizo																
6853804	1972	24	10	16	5	22	8	0	34.17	24	47	<0.1	<0.4	6.4	149	0
6853809	1990	25	37	11	3.2	28	8.6	0	7.32	27	54	0.08	0.04	5.08	173	0
6853906	1970		25	12	4	17	4	0	35.39	16	32	0.1	<0.4	6.3	127	0

Notes:

1) Not known if sample was filtered
2) Well Number 6827502 Data from 1969
3) Well Number 6827503 Data from 1978, filtered sample
4) Well Number 6838301 Data from 1971
5) Well Number 6845301 Data from 1970
6) Well Number 6845901 Data from 1973

Source: Texas Water Development Board Ground-Water Data System, extracted September 1997.

Table C-2

Groundwater Analytical Data

State Well Number	Total Alk.	Total Hardness	Specific Cond.	Eh (field) mV	Iron (ug/L)	Al (ug/L)	Mn (ug/L)	Zn (mg/L)	Cd (mg/L)	Se (mg/L)	Non-carb. Hardness (mg/L)	Ammonia (mg/L as N)	Comment
Area 1/													
Middle													
Trinity													
6819207	348	461	936		20		50						
6819303	276	308	650										
6819305	333	406	900										
6819307	265	308	640	6.9	< 10	< 40	< 1	13.8	< 0.5	4		0.01	Filtered Sample
6819316					48.5	< 20	5.2	21.8	< 0.1	< 4			
6819504	270	349	750										
6819508					326	< 20	2.9	22.8	< 0.1	< 4			
6819602	282	318	551	-97.3	< 10	< 40	< 1	72	< 0.5	< 4		0.02	Filtered Sample
6819606	291	332	680		40		< 50						
6819607	318	344	750		< 20		< 50						
6819610	265	289	580										
6819611	287	328	690										
6819612	296	350	900		< 20		< 50						Note 1
6819615	295.82	361	906		60		< 50						
6819619					278	< 20	19.1	1620	< 0.1	< 4			
6819627					154	< 20	7.7	11700	0.7	< 4			
6819628					60	< 40	46	550	< 0.2	< 2			
6819701	246	310	650										
6819802	239	260	540										
6819803	284	334	815										
6819804	247	463	1036										
6819807	286	342	715	-100.9	197	< 40	1.5	124	< 0.5	< 4		0.29	Filtered Sample
6819906					237	< 20	1.3	484	< 0.1	< 4			
6820402	273.69	308	616		60		< 50						
6820601	307	337	760										
6820701	249	750	1722										
6820706					< 20		< 50						
6821101											36	0.03	Note 1
6821103	293	345	755		190		< 20	1000					Note 1
6821104	296	340	770		< 20		< 20						Note 1
6821401	239	264	564		170		< 20	160					
6821402	267	290	620		300		< 20	170					
6821403	282	305	553	-263.8	< 10	< 40	< 1	27.6	< 0.5	< 4		0.02	Filtered Sample
6821404	267	304	625		40		< 50						
6821408					30		< 20	280					

Notes:

1) Not known if sample was filtered
2) Well Number 6827502 Data from 1969
3) Well Number 6827503 Data from 1978, filtered sample
4) Well Number 6838301 Data from 1971
5) Well Number 6845301 Data from 1970
6) Well Number 6845901 Data from 1973

Source: Texas Water Development Board Ground-Water Data System, extracted September 1997.

Table C-2

Groundwater Analytical Data

State Well Number	Total Alk.	Total Hardness	Specific Cond.	Eh (field) mV	Iron (ug/L)	Al (ug/L)	Mn (ug/L)	Zn (mg/L)	Cd (mg/L)	Se (mg/L)	Non-carb. Hardness (mg/L)	Ammonia (mg/L as N)	Comment
Area 1/													
Lower													
Trinity													
6819208	202	532	2384										
6819302	209	1468	4600										
6819501	243	228	1755										
Area 3/													
Upper-													
Middle													
Trinity													
6827402	224	937	1560										South Area 1, note 1
6827403	208	1695	2400										South Area 1, note 1
6827404	232	694	1150										South Area 1, note 1
6827502	234	1208	1730		230 (2)	200 (2)	10 (2)	1700 (2)			738 (2)		South Area 1, note 1
6827503	240	278	528		20 (3)			10 (3)	1 (3)		21 (3)		Filtered Sample
6828101	225	693	2604										South Area 1
6828109	251	282	568		30		<20						South Area 1
Area 5/													
Brackish													
Edwards													
6838301	250	2204	7330		60 (4)		30 (4)						
6845301	226.23	2502	5770		50 (5)	300 (5)		20 (5)					
6845302	240.92	2573	5840		20		10						
6845802	213.05	2500	5550		10	300	30						
6845901	213.11	2535	5190		400 (6)		<10 (6)						
Area 6/													
Wilcox													
6852405	240	273	750	9.7	472	<50	80	<20	<10	<2		0.11	Filtered Sample
6852406	178	184	572		920		60	<20					
6852409	197	272	820		20		50						
Area 7/													
Carrizo													
6853804	28	60	274										
6853809	6	40	270	183.7	654	50	24	34	<10	<2		0.04	Filtered Sample
6853906	29	46	213										

Notes:

1) Not known if sample was filtered
2) Well Number 6827502 Data from 1969
3) Well Number 6827503 Data from 1978, filtered sample
4) Well Number 6838301 Data from 1971
5) Well Number 6845301 Data from 1970
6) Well Number 6845901 Data from 1973

Source: Texas Water Development Board Ground-Water Data System, extracted September 1997.

Aquifer Storage and Recovery (ASR) Applications and Feasibility

PREPARED FOR:	BexarMetropolitan Water District and San Antonio Water System
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DATE:	February 2, 1998

Introduction

As presented in the *Groundwater Assessment Technical Memorandum* (January 5, 1998), the most promising storage zones were identified based on a number of criteria including potential well yield, native water quality, surface contamination potential, existing well density, average daily area demand, and total well depth. A qualitative geochemical compatibility assessment was also conducted for five potential water sources. Although several potential adverse chemical reactions were identified, the assessment results did not eliminate any of the potential storage zone/sources water combinations from further consideration. The following six most promising storage zones were identified in the *Groundwater Assessment Technical Memorandum*:

- Area 1: Middle Trinity
- Area 1: Lower Trinity
- Area 3: Middle Trinity
- Area 5: Brackish Edwards
- Area 6: Wilcox
- Area 7: Carrizo

This *Technical Memorandum* presents conceptual aquifer storage and recovery (ASR) applications that could be implemented in the six storage zones to address seasonal and extended period (drought) water supply needs. Estimates of individual well capacity and area-wide potential are developed for each storage zone. Seasonal and drought storage volumes are computed assuming future availability of a suitable source water.

The estimated cost of implementing ASR is presented for each storage zone. Cost opinions include capital and operation and maintenance (O&M) expenditures to assess the total cost of ASR water. These costs, combined with the estimated well capacities and annual storage potential, were used to develop unit costs for ASR water that will be compared with other water supply options in Task 1.4, Potential Additional Water Storage and Supply Options.

Conceptual ASR Applications

Integrating ASR as a strategy to meet seasonal and long-term water supply demands must consider the transitory distribution of demands and supplies. Existing and projected demands, which are relatively well defined, are being summarized in the Source Water

Assessment currently underway. However, the origin and availability of the various source waters, including the Edwards aquifer, have yet to be determined. The conceptual applications, therefore, assume that a suitable source water will be available for storing and recovering using ASR techniques.

Seasonal Peak Supply

The primary goal of ASR for the San Antonio Water System (SAWS) and Bexar Metropolitan Water District (BexarMet) is to provide a cost-competitive water source to meet demands when Edwards aquifer withdrawals are curtailed by Edwards Aquifer Authority (EAA) regulating actions. It is anticipated that pumping restrictions will generally limit peak summer withdrawals when Edwards aquifer levels are near an annual minimum. The following seasonal applications could serve to augment supplies during the summer peak period:

- Source water would be stored at a relatively constant rate beginning in November and continuing through March. During this period, Edwards aquifer levels are usually recovering or are near annual highs, and system demands are below annual average rates. Water would be stored at a rate approximately equal to the design recovery rate.
- April would be a transition period when ASR wells would be converted from a recharge to a recovery mode.
- Water would be recovered at a relatively constant rate from the beginning in May through September. Edwards aquifer levels generally reach an annual minimum in mid to late summer when water demands are also near annual maximum rates.
- October would be a transition period when ASR wells would be converted from a recovery to a recharge mode.

Drought Supply

It is probable that, due to low Edwards aquifer levels, pumping restrictions will limit Edwards withdrawals for extended periods. A repeat of the 1948 to 1957 drought would likely require recovery to continue into the normal recharge period or the opportunity to recharge could be eliminated all together. To evaluate drought operations, a continuous 24-month recovery period was selected.

ASR Well Capacity

The design capacity of an ASR well depends on the rate and duration of recharge and recovery. Although the water quality of several of the storage zones under consideration meet drinking water standards, recovery in excess of the volume stored should not routinely occur; however, the opposite condition is desirable. Aggressive storage may result in an annual surplus that, when repeated over a period of years, could provide for drought supplies. The seasonal peak supply application generally affords an opportunity to "bank" water during multi-year periods of below average demand for withdrawal during drought periods.

To evaluate ASR feasibility and estimating costs of ASR water, it was assumed that the design recharge rate and recover rate are equal. This condition is consistent with the equivalent recharge and recovery cycles conceived for the seasonal ASR application. Balanced recharge and recovery rates would result in efficient use of ASR infrastructure.

The design recharge and recovery rate was determined by the lesser of the two rates. The rates are primarily a function of the static water level in the storage zone and the transmissivity of the storage zone. The design recharge capacity may also be limited by the available recharge head, as is the case with the Area 3: Middle Trinity, Area 5: Brackish Edwards, and Area 6: Wilcox options. The maximum recharge pressure was assumed to be 150 pounds per square inch (psi) for the Area 5: Brackish Edwards option to increase the well capacity which was severely limited by high storage zone water levels. Maximum allowable recharge pressures were reduced below the estimated distribution system pressure of 60 psi where hydraulic fracturing of the storage zone or confining units could occur.

Static Water Level

Storage zone water levels (i.e., potentiometric surface elevations) in the three Trinity aquifer options were estimated from mapping included in the *North Bexar County Water Resources Study* (W.E. Simpson Co., 1993). Water level measurements were obtained in the spring of 1992 and are believed to be higher than normal due to above average rainfall in 1991 and early 1992. Representative water level elevations would likely be slightly lower than those presented in the maps. Representation depths to water for each of the storage zones are presented in **Table 1**, along with documentation of the design recharge and recovery rates.

Middle Trinity aquifer water levels in 1992 were approximately 1200 feet (ft) mean sea level (msl) near the Bandera County line, dipping to less than 600 ft msl along the boundary between Area 1 and Area 2 in eastern Bexar County. Lower Trinity aquifer levels mirrored middle Trinity levels, but varied from over 950 ft msl to less than 600 ft msl. Water level elevations were subtracted from corresponding land surface elevations to determine the static water level, in feet below land surface (bls), presented in **Table 1**. Although no Area 3: Middle Trinity water level information was available in the *North Bexar County Water Resources Study* (W.E. Simpson Co., 1993), limited water level records contained in the Texas Water Development Board (TWDB) database suggest that middle Trinity levels are generally closer to land surface in Area 3 than in Area 1.

Water levels for the brackish Edwards aquifer in Area 5 were obtained from a composite hydrograph for the period 1910 through 1990 (Maclay, 1995). The Edwards aquifer near monitoring well (MW) J-17 fluctuated between approximately 700 and 615 ft msl during this period; seasonal levels generally fluctuate from approximately 680 to 650 ft msl during this period. Since recharge will generally occur when the aquifer is near the seasonal high and recovery will occur when water levels are near seasonal lows, variable static water levels were assumed for the Area 5-Brackish Edwards option, as presented in **Table 1**.

Carrizo aquifer water level mapping prepared by Klemt, *et. al.* (1976) was used to estimate the depth to water in both the Area 7: Carrizo and Area 6: Wilcox storage zones. The mapping presents spring 1970 conditions, which do not reflect recent additional withdrawals from Carrizo in Atascosa and Wilson counties. However, the portion of the Carrizo in Bexar County is very close to the recharge area, and the additional withdrawals in Atascosa and Wilson counties would have a negligible impact in Bexar County. Because the Wilcox Group and Carrizo Sand are hydraulically connected (Klemt, *et. al.* 1976), the same water level elevation was assumed for the Wilcox as that indicated in the Carrizo aquifer mapping.

TABLE 1
ASR Well Design Capacity

	Storage Zone					
	Area 1 Middle Trinity	**Area 1 Lower Trinity**	**Area 3 Middle Trinity**	**Area 5 Brackish Edwards**	**Area 6 Wilcox**	**Area 7 Carrizo**
Recharge						
Specific Capacity (gpm/ft)[1]	2.0	0.8	1.6	3.2	2.4	32.0
Static Water Level (ft bls)	300	400	250	-40	150	150
Maximum Recharge Pressure (psi)	60	60	60	150	27	20
Maximum Recharge Rate (gpm)	877	431	622	981	510	6,278
Design Recharge Rate (gpm)	500	300	600	900	500	2,000
Recovery						
Specific Capacity (gpm/ft)	2.5	1.0	2.0	4.0	3.0	40.0
Static Water Level (ft bls)	300	400	250	20	150	150
Top of Storage Zone (ft bls)	517	917	1,517	1,633	400	300
Maximum Drawdown (ft)[2]	200[3]	300	450	680	250[3]	50[3]
Maximum Recovery Capacity (gpm)	500	300	900	2,720	750	2,000
Design Recovery Rate (gpm)	500	300	600	900	500	2,000
Design Pumping Lift (ft)	500	700	550	245	317	200
Number of wells required for 10 mgd recovery rate	14	24	12	8	14	4

Notes:
[1]Computed as 80 percent of recovery specific capacity.
[2]Greater of:
- Depth to top of storage zone minus static water level
- 700 bls minus static water level

[3]Storage zone is partially saturated in portions of the area

Specific Capacity

Estimates of specific capacity of the six storage zone options were based primarily on specific capacity testing. Specific capacity, defined as the well yield divided by the resulting drawdown in the pumped well, is a convenient measure of potential well capacity. A summary of specific capacity testing performed in the study area is summarized in **Appendix A**.

Values of specific capacity from test results were compared with values of specific capacity computed from regional transmissivity values. The following illustrates the relationship between specific capacity and aquifer transmissivity for confined aquifers, as presented by Driscoll (1986):

$$S.C. = \frac{T}{2000}$$

where, S.C. = specific capacity (gallons per minute per feet [gpm/ft])
T = aquifer transmissivity (gallons per day per feet [gpd/ft])

The units of the coefficient are gpd/gpm.

The middle Trinity transmissivity values range from 1,000 to 10,000 gpd/ft, but locally may be as high as 35,000 gpd/ft in Area 1 (W.E. Simpson Co., 1993). These values generally translate to a specific capacity range of 0.5 to 5.0 gpm/ft. A value of 2.5 gpm/ft was assumed for the Area 1: Middle Trinity storage zone based on these values, test values in **Appendix A**, and the experience of Ed Miller (Pape-Dawson Engineers) with several recent groundwater development projects. Mr. Miller has consistently achieved middle Trinity well specific capacities 3 to 20 times the assumed value of 2.5 gpm/ft by locating the wells at the intersection of surface lineament expressions. It is anticipated that this technique would be used to site ASR wells in Area 1, maximizing well capacity. A value of 2.0 gpm/ft was assumed for the middle Trinity in Area 3, as estimated from tests in Appendix A. The lower specific capacity, as compared to Area 1, is consistent with the general understanding that the middle Trinity aquifer becomes less permeable in downdip sections.

The W.E. Simpson Co. (1993) reported that regional values of transmissivity in the lower Trinity in Area 1 generally range between 300 and 1,000 gpd/ft. This translates to specific capacity values between 0.15 and 0.5 gpm/ft. The selected value of 1.0 gpm/ft for this storage zone more closely matches values of specific capacity in **Appendix A** and reflects the experience of Mr. Miller in developing wells in the lower Trinity.

The specific capacity for the Area 5: Brackish Edwards option is based on a transmissivity values of 5,000 (Perez, 1986) and 11,600 gpd/ft (William F. Guyton Assoc., 1986) for the brackish portions of the Edwards aquifer in the San Antonio. These values of transmissivity translate to specific capacities of 2.5 and 5.8 gpm/ft, respectively. The transmissivity of the brackish or saline Edwards is much lower than the transmissivity near the downdip limit of freshwater, which can be as great as 15,000,000 gpd/ft (Maclay and Small, 1984). The specific capacity value of 4.0 gpm/ft listed in **Table 1** is believed to represent the upper 200 ft of the brackish Edwards (above the regional dense member). Developing ASR would likely be limited to the upper portion of the brackish Edwards due to decreasing water quality and transmissivity with depth in this portion of the Edwards (William F. Guyton Assoc., 1986).

The specific capacity of the Area 7: Carrizo storage zone (40 gpm/ft) reflects the values of specific capacity in **Appendix A** and is quite conservative when compared to a regional transmissivity value of approximately 200,000 gpd/ft (Klemt, *et. al.* 1976) for southern Bexar County. This regional value of transmissivity translates to a specific capacity of approximately 100 gpm/ft. The value of 3.0 gpm/ft for the Area 5: Wilcox is based solely on specific capacity testing documented in **Appendix A**.

It should be noted that the values of specific capacity derived from testing or estimated from regional transmissivity values are applicable to pumping wells. Recharge specific capacity was estimated at 0.8 times the recovery value based on experience at other ASR sites. The lower value of recharge specific capacity is likely related to realigning mobile particles in the aquifer matrix that reduces aquifer permeability during recharge. The effective recharge specific capacity is also lower due to plugging of the borehole by suspended solids in the stored water. In determining the maximum allowable recharge rate for each of the storage zones in **Table 1**, the estimated static water level (depth to water) was added to the maximum allowable recharge pressure, and the sum was multiplied by the estimated recharge specific capacity.

The maximum allowable recharge was balanced against the maximum recovery rate, which is limited by the available drawdown. The resulting design recharge and recovery rate is summarized in **Table 1**. Also included in **Table 1** is the number of wells necessary to deliver 10 million gallons per day (mgd) of capacity, which is an indicator of the operational complexity of an equivalent ASR system.

Areawide ASR Potential

The areawide ASR potential was determined for both seasonal and drought (24 months) applications. The following factors help to determine ASR potential:

- Effective area within each of the geographic areas available for development of ASR sites
- Well spacing necessary to control interference between adjacent ASR wells
- ASR well design rate

Effective Area

The effective area within each of the six geographical areas was estimate as:

$$A_{EFF} = (A_T - A_X)\ 0.8$$

where,
A_{EFF} = Effective area (square miles [mi^2])
A_T = Total geographic area (mi^2)
A_x = Excluded area (mi^2)

Areas were excluded based on the existence of wells completed in the same storage zone as that proposed for ASR development (as indicated by TWDB records). Large tracts of land owned by the federal government were also excluded.

A 2,000-foot buffer was delineated around existing wells to compute the exclusion area. Where existing wells were closely spaced, entire blocks were excluded. A reduction factor of 0.8 was applied to the net area (A_T - A_X) to account for inefficiencies in well layout and the existence of undocumented wells completed in the ASR storage zones.

Significant areas were excluded in Area 1 where there are numerous existing wells completed in the middle Trinity aquifer. Camp Bullis was also eliminated from the available area. In anticipation of possible "stacked" ASR storage zones in Area 1(middle and lower Trinity storage zones), existing wells completed in either of the potential storage zones were used to compute the excluded area. The remaining geographic areas contained a relatively small number of existing wells and did not have any large federal land parcels which would complicate ASR development. **Table 2** summarizes the effective area computation.

The Area 5: Brackish Edwards option differs from the other applications in that the wells are distributed along a line offset three miles south of the "bad water" delineation. Values in **Table 2** are actually lengths along this line. A two-mile portion of this line traverses Brooks Air Force Base (AFB) and was eliminated from consideration. The remaining length, approximately 26.9 miles, was assumed to be available for development.

TABLE 2
ASR Production and Storage Capacity

Parameter	Storage Zone Area 1 Middle Trinity	Area 1 Lower Trinity	Area 3 Middle Trinity	Area 5 Brackish Edwards	Area 6 Wilcox	Area 7 Carrizo
Effective Area						
Total Area (mi^2)	181	181	253	33.6[1]	63	5.4
Exclusions (mi^2)	36.2	36.2	50.6	6.7[1]	12.6	1.1
Effective Area (mi^2)	144.8	144.8	202.4	26.9[1]	50.4	4.3
Well Spacing						
Transmissivity (gpd/ft)	7,500	3,000	6,000	12,000	6,000	80,000
Leakance (1/day)	1.0E-05	1.0E-05	1.0E-05	1.0E-05	1.0E-04	1.0E-04
Storativity (ft^3/ft^3)	3.0E-04	3.0E-04	3.0E-04	1.0E-04	5.0E-04	5.0E-04
Drawdown Overlap	5%	5%	5%	10%	5%	10%
Spacing (ft)	7,700	4,700	7,000	4,300	3,400	6,000
System Capacity						
Area per Well (mi^2)	2.13	0.79	1.76	0.66[1]	0.41	1.29
Number of Wells	67	183	115	33	122	3
Design Rate per Well (gpm)	500	300	600	900	500	2,000
System Capacity (mgd)	48.2	79.0	93.3	14.3	105.4	8.6
Annual Storage (ac-ft)	22,208	36,369	42,952	19,689	40,438	3,959

Notes:
[1] Units in miles for the Brackish Edwards application

Well Spacing

Wells must be spaced at sufficient distance from one another so that the drawdown or mounding impact from adjacent wells does not significantly reduce well capacity. The well spacing necessary to limit well interference to acceptable levels depends on storage zone properties, the design recovery rate, and the distribution of the ASR well sites. Storage zone properties that determine the horizontal extent of well impacts are primarily transmissivity, leakance, and storativity. Values of transmissivity were derived from specific capacity values presented in **Table 1** using the following relationship:

$$T = 2000\,S.C.$$

where, T = transmissivity (gpd/ft)
S.C. = specific capacity (gpm/ft)

Values of transmissivity computed using the above equation were increase by a factor of 1.5 for the storage zones where fractures and fissures account for the majority of the aquifer permeability. These storage zones include the Trinity and Edwards aquifer options. The Wilcox and Carrizo aquifers, however, have a more uniform matrix and transmissivity values estimated from well tests should generally correlate more closely with regional values of transmissivity.

Regional values of leakance were estimated from confining unit properties or based on professional judgement. Leakance defines the movement of water from aquifer units above and below the storage zone in response to recharge or recovery. Leakance for the Trinity options were estimated from vertical permeability values of the Hammet Shale, which separates the middle and lower Trinity aquifer, and the clays and marls of the upper member of the Glen Rose Limestone, which separate the middle and upper Trinity aquifers. Values of vertical permeability range from 0.001 gallons per day per feet squared (gpd/ft^2) to 0.02 gpd/ft^2 for these confining sequences (W.E. Simpson Co., 1993) and thickness range from approximately 50 feet for the Hammet Shale to more than 500 feet for the upper member of the Glen Rose Limestone. Using this range of vertical permeability and a thickness of 50 feet for the Hammet Shale, leakance values of $3\text{x}10^{-6}$per day to $5\text{x}10^{-5}$ per day were computed. Although the middle Trinity storage zone would likely have a higher net leakance due to the presents of the overlying upper Trinity aquifer, a value of $1\text{x}10^{-5}$ per day was assumed for all the Trinity group aquifers.

Leakance information on the brackish section of the Edwards aquifer was unavailable in the literature. A value of $1\text{x}10^{-5}$ was assumed, given the opportunity for leakance across the Del Rio Clay above and the regional dense member of the Person Formation of the Edwards aquifer below the Area 5: Brackish Edwards storage zone.

As stated by Klemt, *et. al.* (1976), the Wilcox Group and Carrizo Sand are hydraulically connected in some areas, and the term "Carrizo-Wilcox aquifer" is often used to refer to the combined units. No leakance values were identified to quantify the potential for interformational movement of water between the Wilcox and Carrizo. However, the assumed value of $1\text{x}10^{-4}$ per day for leakance is believed to be conservative for estimating well spacing requirements in these two storage zones.

Storativity of a saturated confined aquifer is the volume of water released from storage per unit surface area of the aquifer per unit decline in the potentiometric surface. Values of storativity for the three Trinity storage zones were estimate using the relationship developed by Lohman (1972) for confined aquifers:

$$S = \text{Thickness x } 10^{-6}/\text{ft}$$

where, S = storativity (dimensionless)
Thickness = thickness of the storage zone (ft)

Using this relationship, the Trinity storage zones were assigned a storativity of $3\text{x}10^{-4}$. Values of storativity are summarized in **Table 2**.

Storativity values were obtained from the literature for the Carrizo and Edwards storage zones. Klemt, *et. al.* (1976) reported a value of $5\text{x}10^{-4}$ for the confined Carrizo, and the brackish Edwards is reported to be approximately $1\text{x}10^{-4}$ (Perez, 1986). A value of $5\text{x}10^{-4}$ was assumed for the Wilcox given the equivalent thickness and porosity of the Carrizo.

Based on analytical equations developed by Hantush and Jacob (1955), estimates of drawdown were developed at various distances from a pumped well at the end of the assumed 5 month recovery cycle. Allowable drawdown at adjacent wells was established at 5 percent of the corresponding well drawdown for storage zone options with the potential for numerous wells laid out in a grid pattern. This type of grid pattern applied to the Trinity and Wilcox storage zones. Since brackish Edwards wells would likely be installed in a linear configuration, and the Carrizo option would support only a small number of wells, the potential for well communication is limited, and a 10 percent overlap in drawdown impacts was permitted. The resulting well spacings are summarized in **Table 2**.

System Capacity

To calculate areawide ASR capacity, the number of wells that could be reasonably operated within the geographic area was estimated. Assuming the wells are installed on a uniform grid pattern at the defined well spacing, an average area per well was determined. The number of wells that could be developed was computed by dividing the effective area in **Table 2** by the average area per well. The areawide capacity was estimated as the number of wells times the design rate per well. Multiplying the areawide capacity by the five-month operational cycle yielded the annual storage volume. These computations are summarized in **Table 2.**

For the Area 5: Brackish Edwards option, the wells are spaced every 0.81 miles, on average, along a line parallel to the "bad water" line. Given that the effective length of this line is approximately 26.9 miles, 33 wells could be completed in this storage zone in Bexar County.

Although not listed in **Table 2**, developing both middle and lower Trinity wells at each Area 1 site is an option for maximizing site capacity. Assuming that an additional lower Trinity well was installed at each Area 1: Middle Trinity site, a combined site capacity of 800 gpm would be possible. The areawide seasonal storage for a "stacked" option in Area 1 would be approximately 35,500 ac-ft as compared with 22,208 ac-ft and 36,369 ac-ft for separate middle and lower Trinity options, respectively. The actual site capacity for a stacked alternative in Area 1 would likely be reduced due to communication between the two storage zones.

Drought Capacity

The approach described above was used to determine drought capacity of the systems conceived for the annual application. The only variable changed in the drought evaluation was the duration of the recovery cycle. The withdrawal period was increased from 5 months to 24 months, and the distance-drawdown curves for each storage zone option were recomputed.

Results of this analysis indicated that system drawdowns approach an equilibrium condition by the end of the five-month recovery cycle, and withdrawals are satisfied by leakage from the vertically contiguous aquifer units. Therefore, at the well spacing defined for the seasonal application, long-term recharge or recovery would be possible with minimal reduction in system capacity. However, water quality degradation may limit extended period recovery if leakage from contiguous aquifer units is of an unacceptable quality. The apparent potential for drawdown impacts to propagate to overlying or underlying zones would tend to reduce the design capacity of ASR wells completed in contiguous zones. The potential for reduced capacity would have to be considered in evaluating "stacked" installations where storage zones were vertically contiguous.

Estimated Costs

Reasonable estimates of the major costs associated with implementing ASR were prepared to facilitate comparisons with other water supply and storage alternatives. Implementation costs include capital cost associated with designing, constructing, and rehabilitating facilities and normal O&M costs. The estimated cost presented in this *Technical Memorandum* will be compared against costs for other water supply options identified in Task 1.4, Potential Additional Water Storage and Supply Options.

Comparing this alternative with other alternatives will likely be based on the marginal cost of ASR water, which is a function of the capital and O&M costs divided by the volume of water produced. Capital and O&M costs estimates were developed for a typical ASR installation within each storage zone. However, well depth, completion interval, and drilling difficulty will vary across each storage zone, impacting the actual cost of ASR implementation. Confidence in the associated unit costs for ASR water is further affected by the myriad assumptions inherent in well capacity estimates. The relatively high degree of uncertainty at this phase of the ASR feasibility evaluation should be considered in comparing ASR with other alternatives. Subsequent phases of the ASR investigation will provide the information necessary to refine design criteria, system configuration, operating cycles, and implementation costs.

Conceptual Facility Design

ASR wells designs were adapted to the individual storage zones. The number, diameter, well casing length, and casing material varies from one storage zone to the next. Similarly, there are significant differences in well depth, completion type, motor type and rating, and design rate. The well details are summarized in **Table 3**.

Note that the Area 5 Brackish Edwards option is unique in that each ASR well will be equipped with a booster pump on the recharge pipe to bring the wellhead pressure to approximately 140 psi. The additional recharge pressure is necessary to overcome the relatively high head in the brackish Edwards anticipated during recharge periods. Using only distribution system pressure (60 psi), the design recharge rate would be limited to approximately 300 gpm.

Capital and O&M costs are summarized in **Table 4** for each storage zone option. It is assumed that each site will include an ASR well enclosed in a pre-engineered metal building. Instrumentation is limited to pressure and flow measurement for both recharge and recovery. Since the ASR wells will be operated almost continuously during the recharge and recovery cycles, extensive automation of the wells was not anticipated.

Several well sites will be connected with manifold piping to a centralized storage tank where recovered water will be disinfected and re-pumped to the distribution system. To estimate costs associated with ASR, the tank sites and primary pumping stations are assumed to exist. Costs for manifold piping and centralized disinfection equipment are computed as a percentage of site improvement costs.

Developing the sites in clusters reduces the number of storage zone MWs required. It is assumed that one MW will be installed for every two ASR wells. **Appendix B** contains ASR and MW construction cost summaries for each storage zone option.

TABLE 3
ASR Well Construction Details

	Storage Zone					
ASR Well	**Area 1 Middle Trinity**	**Area 1 Lower Trinity**	**Area 3 Middle Trinity**	**Area 5 Brackish Edwards**	**Area 6 Wilcox**	**Area 7 Carrizo**
Design Capacity (gpm)	500	300	600	900	500	2,000
Intermediate Casing						
Material	---	---	Steel	---	---	---
Diameter (in)	---	---	24	---	---	---
Set Depth (ft bls)	---	---	400	---	---	---
Final Casing						
Material[1]	Sch 80 PVC	Epoxy-Coated Steel	Epoxy-Coated Steel	Epoxy-Coated Steel	Sch 80 PVC	Epoxy-Coated Steel
Diameter (in)	12	12	16	16	12	24
Set Depth (ft bls)	517	917	1,517	1,633	400	300
Completion						
Type	Open Hole	Open Hole	Open Hole	Open Hole	Screen	Screen
Total Depth (ft bls)	850	1,250	1,850	1,833	800	700
Pump						
Type	Sub[2]	Sub[2]	Sub[2]	Sub[2]	Sub[2,3]	Surface
Motor (hp)	83	69	109	76	54	141
Set Depth (ft bls)	550	750	600	295	367	250
Wellhead						
Piping Diameter (in)	6	6	8	8	6	10

Notes:
[1] Steel final casing strings are threaded to reduce coating damage during installation.
[2] Submersible pump.
[3] Includes booster pump to recharge at the design rate.

TABLE 4
Facility Capital Costs

Component	**Area 1 Middle Trinity**	**Area 1 Lower Trinity**	**Area 3 Middle Trinity**	**Area 5 Brackish Edwards**	**Area 6 Wilcox**	**Area 7 Carrizo**
Well House	$50,000	$50,000	$50,000	$50,000	$50,000	$62,500
Land (1 ac.)	$10,000	$10,000	$20,000	$20,000	$5,000	$5,000
Pump Motor (misc.)	$14,250	$12,750	$20,900	$12,400	$10,960	$12,750
Pump Assembly	$3,500	$5,000	$4,100	$2,700	$2,700	$5,500
Pump Column	$8,250	$11,250	$12,000	$5,900	$7,340	$23,750
Wellhead Piping	$56,250	$56,250	$75,000	$75,000	$56,250	$93,750
Booster Pump	N/A	N/A	N/A	$10,350	N/A	N/A

Component	Area 1 Middle Trinity	Area 1 Lower Trinity	Area 3 Middle Trinity	Area 5 Brackish Edwards	Area 6 Wilcox	Area 7 Carrizo
Site Work	$25,000	$20,000	$25,000	$25,000	$25,000	$25,000
ASR Well	$166,000	$249,000	$751,000	$515,000	$148,000	$245,000
Monitoring Well	$76,000	$114,000	$360,000	$218,000	$66,000	$60,000

Table 5 summarizes the design life and rehabilitation schedule used to compute annualized capital costs. Replacement costs for capital items are assumed to be the same as those presented in **Table 5.** Costs for well rehabilitation were estimated at $50,000 per occurrence. Motor overhaul costs were uniformly applied at a cost $2,000.

TABLE 5
Design Life

Component	Maintenance Schedule
Well House	Every 25 years
Pump Motor Overhaul	Every 15 years
Pump Assembly	Every 15 years
Pump Column	Every 10 years
Wellhead Piping	Every 25 years
Well Rehabilitation	Every 10 years

The average annual cost (A) are computed based on a design life of 25 years (n), an interest rate of 8 percent (i), and the total present value of associated costs (P). The total present value of associated costs (P) is the summation of future expenditures adjusted for the time value of money. The economic formula to convert future to present value is defined below:

$$P = F(P/F, i\%, n)$$

where,
F = future worth value
P = present worth value
n = design life
i = interest rate

Annualized capital costs for each of the six storage zone options are summarized in **Table 6.**

TABLE 6
Equivalent Annual Cost

Aquifer Zone	Present Worth	Capital Recovery (P to A)
Area 1-Middle Trinity	$494,357	$46,311
Area 1-Lower Trinity	$604,781	$56,655
Area 3-Middle Trinity	$1,334,092	$124,976
Area 5-Brackish Edwards	$995,619	$93,268
Area 6-Wilcox	$456,023	$42,720
Area 7-Carrizo	$669,635	$62,731

Operation and Maintenance

O&M considerations are marginally more complex than for conventional production wells. Some of the unique elements considered in developing O&M costs for ASR systems includes periodic changes in operation (recharge to recovery), backflushing during recharge to maintain well capacity, maintenance of adequate disinfection residual, and accelerated pump wear. A detailed breakdown of O&M related costs is provided in **Appendix C**.

O&M costs assume injection through the pump column and/or well annulus and reverse impeller spin during recharge through the pump. Electrical costs of $0.06 per kilowatt-hour were assumed based on the current SAWS utility rate structure for baseload facilities. Results of this analysis indicate O&M costs would range from a low of $0.11 per 1,000 gallon for the Area 7: Carrizo option to a high of $0.34 per 1,000 gallons for the Area 1: Lower Trinity storage zone.

Annualized Costs

Table 7 summarizes the site development and annualized costs for a typical ASR well in each storage zone. Well construction and engineering costs in **Table 7** are representative of a large-scale ASR program. Engineering costs associated with prototype well design and testing could be three to five times as expensive. Additional testing would also inflate construction costs by as much as 50 percent for the prototype facility.

Components of the annual costs are the amortized capital expenditures and O&M costs. The analysis does not consider the cost of distribution system improvements necessary to integrate ASR water into the system since other water supply options listed in Section 5 would require similar upgrades which are not accounted for in the associated unit cost. In addition, the unit cost of source water must be added to the marginal cost of ASR to arrive at the total cost for water produced.

Based on the above assumptions, the marginal cost of water produced from ASR ranges from $82 per ac-ft in the Area 7: Carrizo option to $398 per ac-ft for the Area 1: Lower Trinity option. The marginal cost of ASR water, in conjunction with the estimated annual storage volume presented in **Table 2**, provides a gage by which to evaluate other water supply and storage alternatives.

The cost of ASR water for a stacked middle and lower Trinity site in Area 1 can be estimated from the marginal costs presented in **Table 7**. Assuming an additional 198.9 ac-ft per year (unit cost $398/ac-ft) could be produced by completing a lower Trinity well at each middle Trinity site, the effective cost for the stacked alternative would be $287 per ac-ft.

TABLE 7
Summary of ASR Development Costs

	Storage Zone					
Parameter	**Area 1 Middle Trinity**	**Area 1 Lower Trinity**	**Area 3 Middle Trinity**	**Area 5 Brackish Edwards**	**Area 6 Wilcox**	**Area 7 Carrizo**
Land and Site Improvements						
Building	$50,000	$50,000	$50,000	$50,000	$50,000	$62,500
Land (1 ac.)	$10,000	$10,000	$20,000	$20,000	$5,000	$5,000
Pump, Column, and Motor	$26,000	$29,000	$37,000	$32,000[1]	$21,000	$42,000
Wellhead Piping	$56,250	$56,250	$75,000	$75,000	$56,250	$93,750
Site Work	$25,000	$20,000	$25,000	$25,000	$25,000	$25,000
Subtotal	$167,250	$165,250	$207,000	$202,000	$157,250	$228,250
Misc. Improvements (20%)	$33,000	$33,000	$41,000	$40,000	$31,000	$46,000
Total	$200,2500	$177,750	$248,000	$242,000	$188,250	$274,250
ASR and Monitoring Well						
ASR Well	$166,000	$249,000	$751,000	$515,000	$148,000	$245,000
Monitoring Well	$76,000	$114,000	$360,000	$218,000	$66,000	$60,000
Aggregate Total(ASR and ½ MW)	$204,000	$306,000	$931,000	$624,000	$181,000	$275,000
Engineering and Permitting						
15% of Site and Construction Costs	$59,000	$74,000	$174,000	$127,000	$55,000	$82,000
Capital Cost per Facility	$463,250	$578,250	$1,353,000	$993,000	$424,250	$631,250
Capital Cost/10 mgd ($1000's)	$6,434	$13,385	$15,660	$7,662	$5,892	$2,192
Capital Cost/gpd Capacity	$0.64	$1.34	$1.57	$0.77	$0.59	$0.22
Annual Cost per Well						
Capital (25 yr. @ 8%)	$46,311	$56,655	$124,976	$93,268	$42,720	$62,731
O&M ($0.06/kw-hr)	$26,743	$22,574	$32,910	$41,390	$20,821	$46,445
Total	$73,054	$79,229	$157,886	$134,658	$63,541	$109,176
Annual Production (ac-ft)	331.5	198.9	397.8	596.6	331.5	1325.8
Cost per ac-ft	$220	$398	$397	$226	$192	$82

Notes:
[1] Includes booster pump to recharge at the design rate.

ASR System Alternatives

Possible system alternatives to enable the SAWS and BexarMet water systems to meet future demands were identified using annual water demand projections and calculated monthly variations. These water demand projections, when considered in combination with the Edwards Aquifer pumping restrictions, indicate that both utilities will require additional water supplies to meet customer needs in the future. For these system alternatives, the additional water required was assumed to be imported from outside the system area.

This study conceptualized four scenarios were conceptualized for each utility. The first two scenarios used a conventional approach to supply future demands, while the other two scenarios used ASR as an innovative water supply technology to help meet future demands.

Conventional Alternatives

The two conventional alternatives assumed delivery of imported supplies to each water system either under a uniform monthly delivery schedule (the Conventional Uniform Import Supply alternative) or a seasonal monthly schedule (the Conventional Seasonal Import Supply alternative). These schedules were proposed in the Trans-Texas Water program, referenced in the Source Water Assessment Technical Memorandum prepared for this project.

The conventional alternatives assume that an imported volume of water equal to the volume required is available from one source, and that the source supplying the water is the Lake Dunlap alternative G-37, as described in the Trans-Texas Water program reports. This may not be entirely applicable for the SAWS system, however, because it could require almost 63,000 acre-feet of imported supplies in the year 2016. This volume exceeds the Lake Dunlap referenced supply volume of 44,348 acre-feet for SAWS. The simplifying assumptions made for these conceptual alternatives, however, are within the level of accuracy of the alternatives.

The uniform monthly delivery schedule assumes that imported water would be delivered to each water system at a constant monthly rate throughout the year, as presented in **Tables 8 and 9** for SAWS and BexarMet, respectively. The seasonal delivery schedule assumes that imported water is delivered at a rate that varies each month. Peak months would be July and August, during each of which 17 percent of the total annual volume would be delivered. In contrast, only 3.1 percent of the total annual volume would be delivered in February.

TABLE 8
Conceptual Alternatives to Meet 2016 SAWS Demands

Edwards Aquifer Volume Pumped	193,944 acre-feet
Volume of Imported Supplies	62,608 acre-feet
Maximum Day Demand	418.0 mgd
Average Day Demand	232.2 mgd

Alternatives	Imported Supply Use			Edwards Aquifer Use			ASR Use			Total
	Average Annual (mgd)	Max Day (mgd)	Max Ave Ratio	Average Annual (mgd)	Max Day (mgd)	Max Ave Ratio	Volume Stored (acreft)	Max Injection (mgd)	Max Recovery (mgd)	Cost ($/acrft)
Conventional (Uniform Input Rate)	56.7	56.7	1.00	175.5	361.4	2.06(Jul)	0	0	0	$122.10
Conventional (Seasonal Input Rate)	56.7	115.6	2.04(Jul)	175.5	302.4	1.72(Jul)	0	0	0	$155.04
Typical ASR (Uniform Avg. Edwards Pumping	56.7	56.7	1.00	175.5	285.9	1.63(Jul)	17,500	41	75	$136.36
Maximum ASR (Maximum Imported Storage)	56.7	56.7	1.00	175.5	255.1	1.45(May)	27,900	57	111	$144.83

Notes:

1) Costs for imported supplies from Lake Dunlap, G37 Alternative ($268/acre-ft uniform delivery, $403/acre-ft seasonal delivery.
2) Costs for ASR taken as average of six alternatives ($253/acre-ft)

TABLE 9
Conceptual Alternatives to Meet 2016 BexarMet Demands

Edwards Aquifer Volume Pumped	21,718 acre-feet
Volume of Imported Supplies	25,096 acre-feet
Maximum Day Demand	88.5 mgd
Average Day Demand	42.4 mgd

Alternatives	Imported Supply Use			Aquifer Use[3]			ASR Use			Total
	Average Annual (mgd)	Max Day (mgd)	Max Ave Ratio	Average Annual (mgd)	Max Day (mgd)	Max Ave Ratio	Volume Stored (acreft)	Max Injection (mgd)	Max Recovery (mgd)	Cost ($/acrft)
Conventional (Uniform Input Rate)	22.7	22.7	1.00	19.7	65.8	3.34(Jul)	0	0	0	$178
Conventional (Seasonal Input Rate)	22.7	46.3	2.04(Jul)	19.7	47.4	2.41(Mar)	0	0	0	$251
Typical ASR (Uniform Avg. Edwards Pumping	22.7	22.7	1.00	19.7	50.8	2.58(Jul)	3,400	10	15	$194
Maximum ASR (Maximum Imported Storage)	22.7	22.7	1.00	19.7	49.3	2.50(Mar)	9,100	22	30	$219

Notes:

1) Costs for imported supplies from Lake Dunlap, G37 Alternative ($268/acre-ft uniform delivery, $403/acre-ft seasonal delivery.
2) Costs for ASR taken as average of six alternatives ($253/acre0ft)
3) Aquifer use for BexarMet includes Wilcox, Trinity, and Edwards Aquifers

The Conventional Uniform Import Supply alternative would bring in a steady uniform supply to be added to the existing aquifer supply. The water demand variation for the two systems would remain the same, except that 56.7 mgd would be added to the SAWS system and 22.7 mgd would be added to the BexarMet system each month. Maximum day aquifer pumpage would be highest in July for each system; the maximum day aquifer pumping/average annual aquifer pumping ratios would be 2.06 and 3.34 for the SAWS and BexarMet systems, respectively. System costs per acre-foot of water delivered were calculated from the Lake Dunlap alternative costs ($268/acre-foot) for the imported water, and $75 per acre-foot for local groundwater.

The Trans-Texas Water Program indicates that water importation at a seasonal rate is possible, with higher rates and volumes during peak demand months. Again, imported supplies would be added to aquifer pumpage to meet demands. Bringing in imported supplies, however, is more expensive. The effect of the seasonal import would be to reduce maximum pumpage on the aquifer to 302.4 mgd for SAWS and 47.4 mgd for BexarMet, with a corresponding reduction in the maximum/average pumping ratios to 1.72 and 2.41 for SAWS and BexarMet, respectively. Because the volume of imported water for the BexarMet system is high relative to demands, however, the effect of seasonal imported water also would shift maximum aquifer pumping from July to March. System costs for this alternative would likely increase because of the higher costs associated with the seasonal imported water. **Figures 1 and 2** show the relative contributions of Edwards and imported water necessary to meet 2016 monthly average demands for SAWS under the uniform and seasonal delivery alternatives, respectively. **Figures 3 and 4** show the corresponding BexarMet supply and demand distributions.

FIGURE 1
SAWS Year 2016 Conventional Supply Alternative
Uniform Import Supply Rate

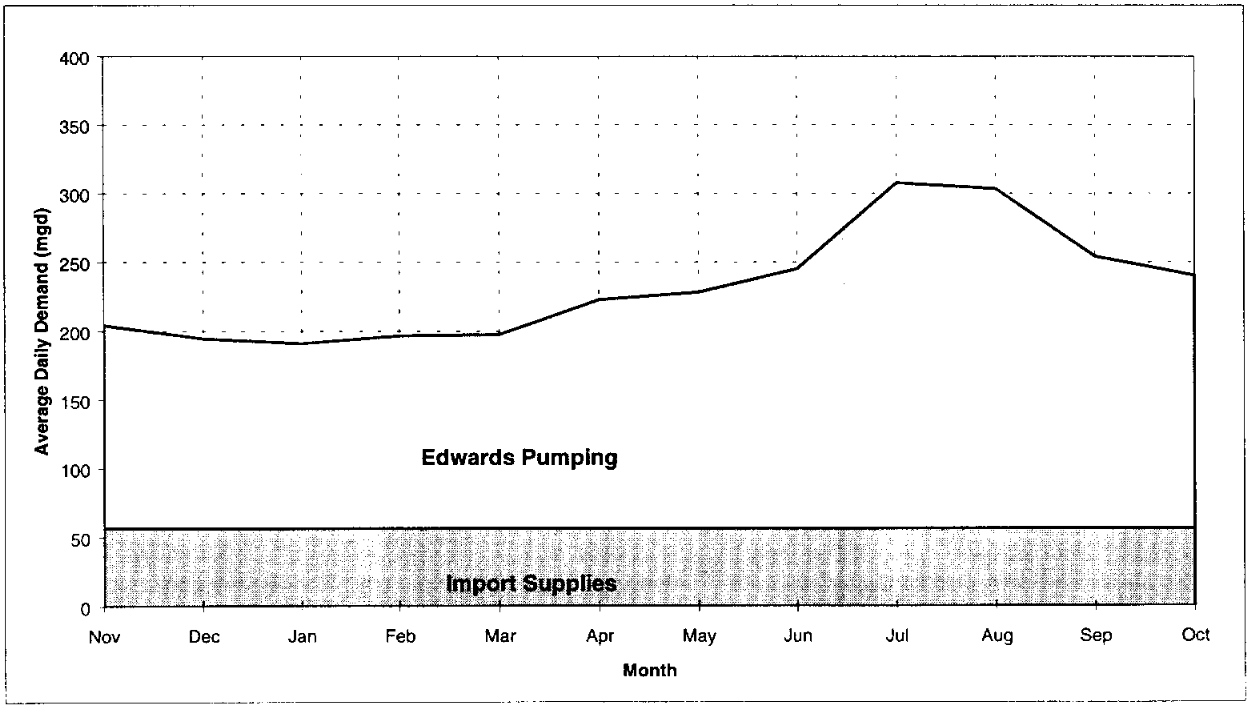


FIGURE 2
SAWS Year 2016 Conventional Supply Alternative
Seasonal Import Supply Rate

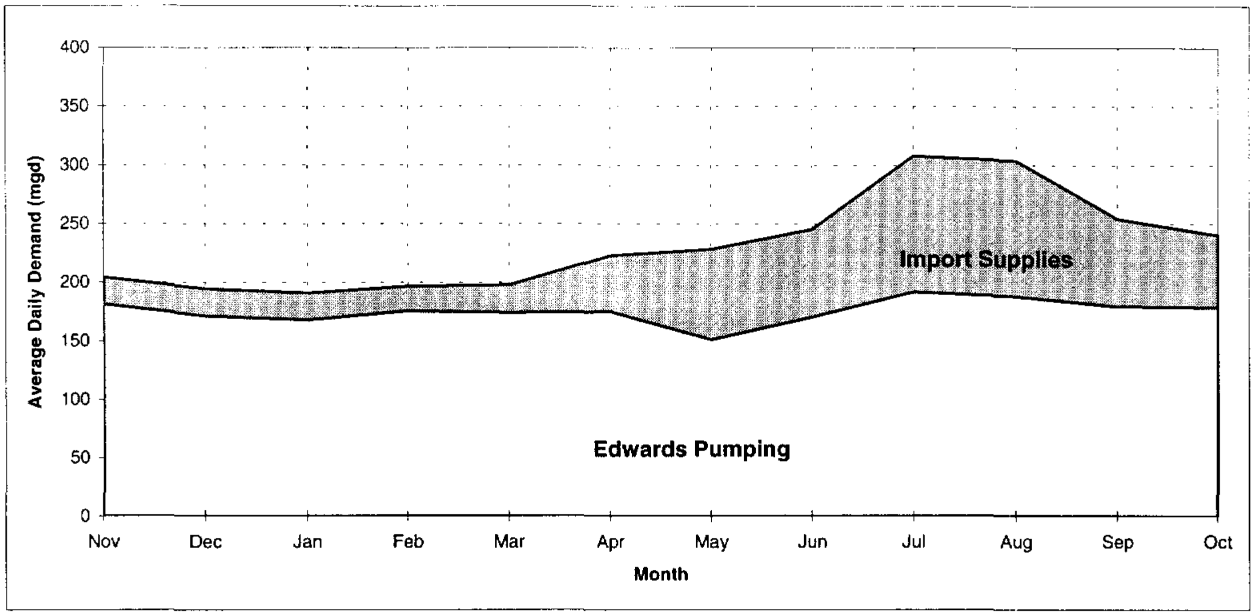


FIGURE 3
BexarMet Year 2016 Conventional Supply Alternative
Uniform Import Supply Rate

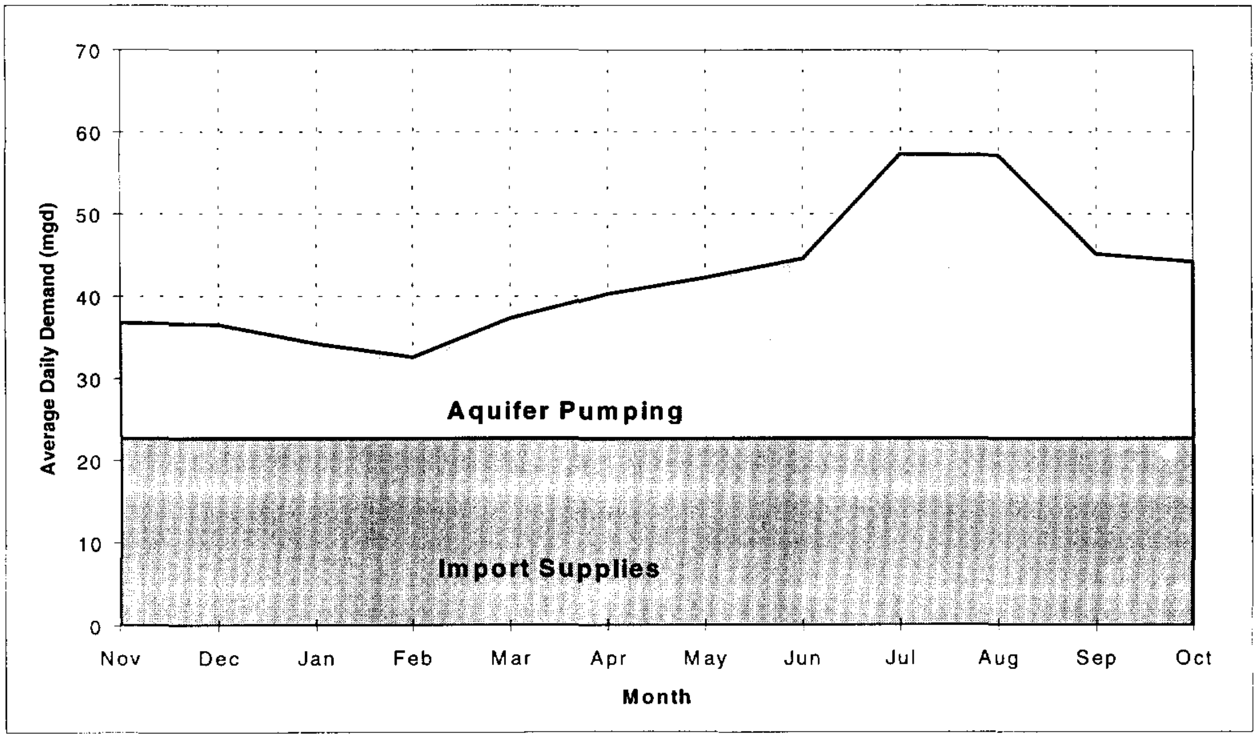
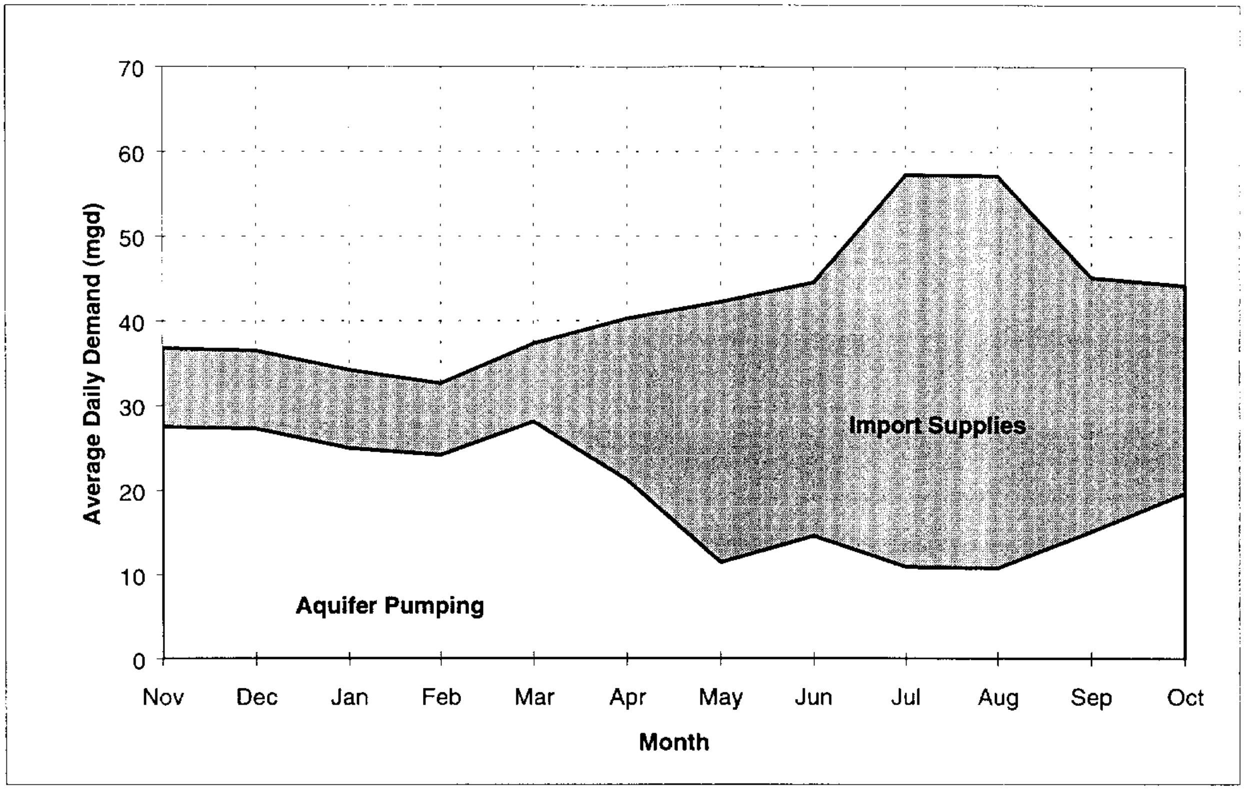


FIGURE 4
BexarMet Year 2016 Conventional Supply Alternative
Seasonal Import Supply Rate



ASR Alternatives

Two ASR alternatives were developed for this study: the Typical ASR alternative and the Maximum ASR alternative. In the Typical ASR alternative, an ASR system would be used to store imported water during low-demand months. The goal would be a constant average monthly withdrawal rate from the aquifer throughout the year. Imported water would be used to supplement aquifer withdrawals to meet demands, and excess imported water would be diverted to ASR storage. During high-demand months, the ASR system would be pumped to supplement the aquifer and imported supplies. The system would be operated to meet maximum day demands with the aquifer while still maintaining the target monthly withdrawal.

The Typical ASR application would reduce SAWS's maximum day demand on the aquifer to 285.9 mgd. The maximum/average annual aquifer pumping ratio would be reduced to 1.63, and maximum aquifer pumping would occur in July. Because of the higher volume of imported water used in the BexarMet system relative to the water pumped from the aquifer, the maximum/average annual aquifer pumping ratio for BexarMet would be 2.58. This is slightly higher than it would be with the imported seasonal alternative (2.41). Maximum aquifer pumping would occur in July. As shown in Tables 8 and 9, unit costs for this alternative are less expensive than using imported water to meet seasonal peaks.

The Maximum ASR alternative would attempt to store the maximum volume of imported water for recovery during the peak-demand months. The goal would be to reduce the peaks on the aquifer to the greatest extent practical during the summer months. Substantial imported supplies would be diverted to ASR storage from November through April. For the SAWS system this would represent virtually all of the imported water during this period.

The BexarMet Maximum ASR alternative would not divert all imported supplies because the imported supplies comprise a larger portion of BexarMet's total supply. If BexarMet diverted all of its imported supplies in this alternative, high aquifer pumping peaks would be needed in the winter months, and these would result in high maximum day/annual average aquifer pumping ratios. A more beneficial practice may be to reverse the pumping peaks and take advantage of the aquifer water available at that time. A more conservative approach was taken in this study, however, which would substantially reduce summer peaks and even out aquifer pumping. **Figures 5 and 6** show the relative contributions of Edwards and imported water necessary to meet 2016 monthly average demands for SAWS under the typical and maximum ASR alternatives, respectively. **Figures 7 and 8** show the corresponding BexarMet supply and demand distributions.

FIGURE 5
SAWS Year 2016
Typical ASR Alternative

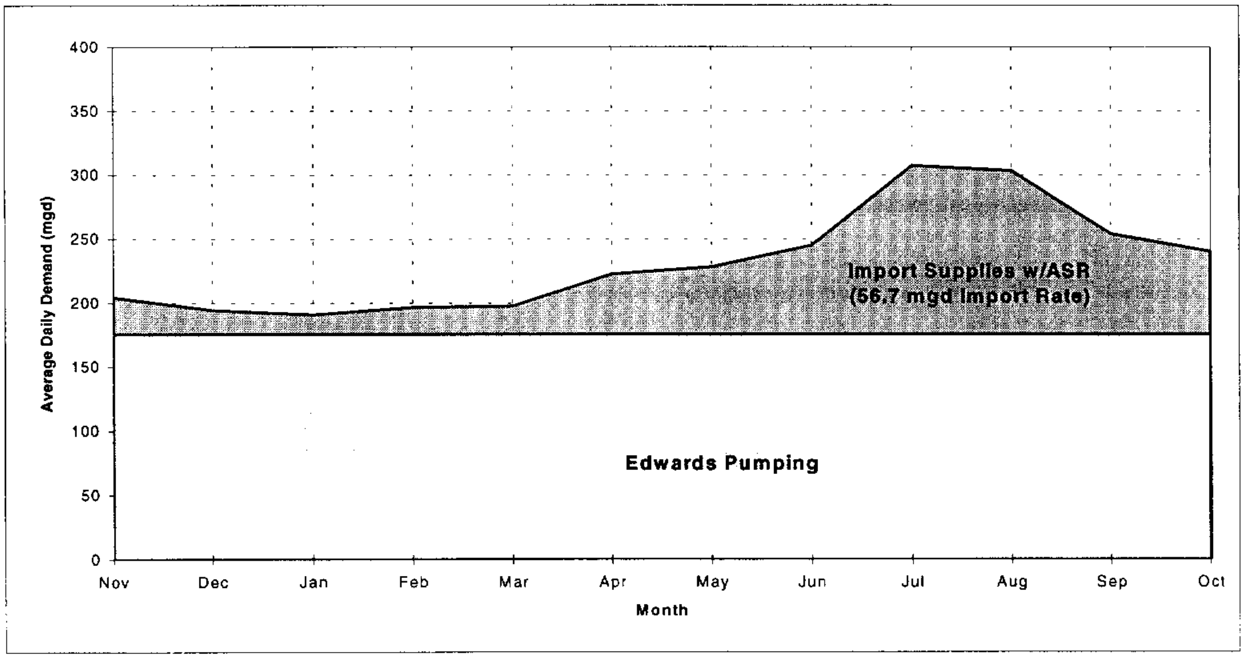


FIGURE 6
SAWS Year 2016 Maximum ASR Alternative

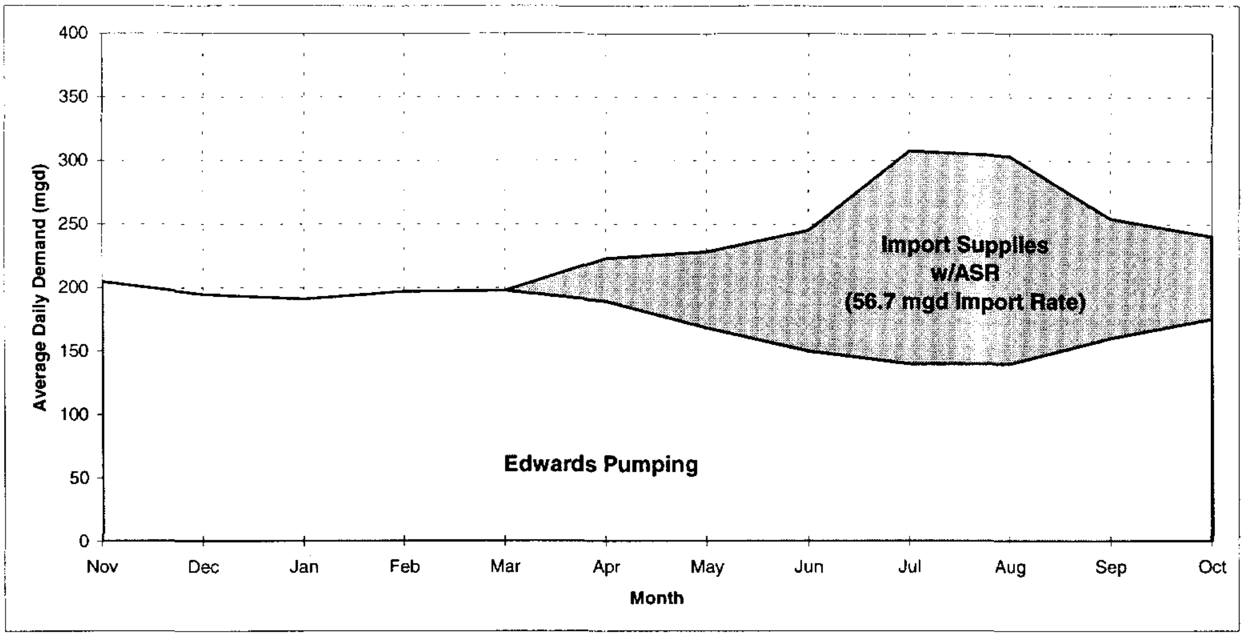


FIGURE 7
BexarMet Year 2016
Typical ASR Alternative

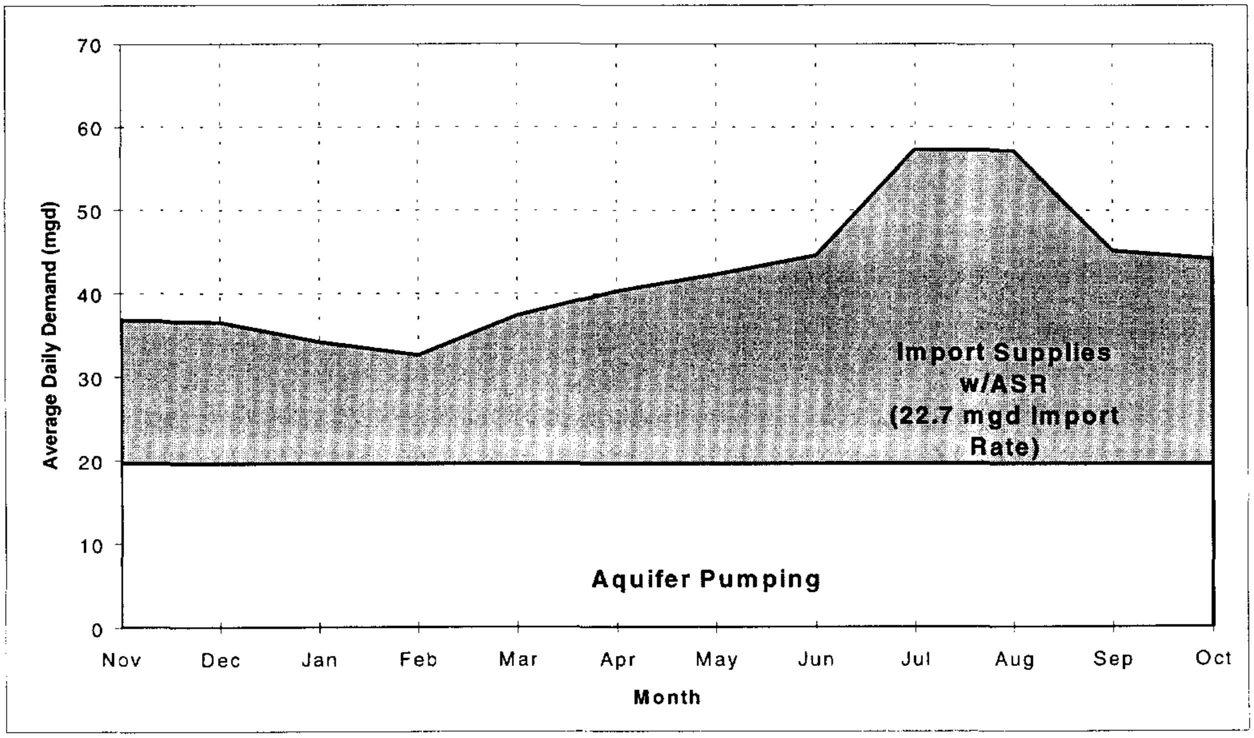
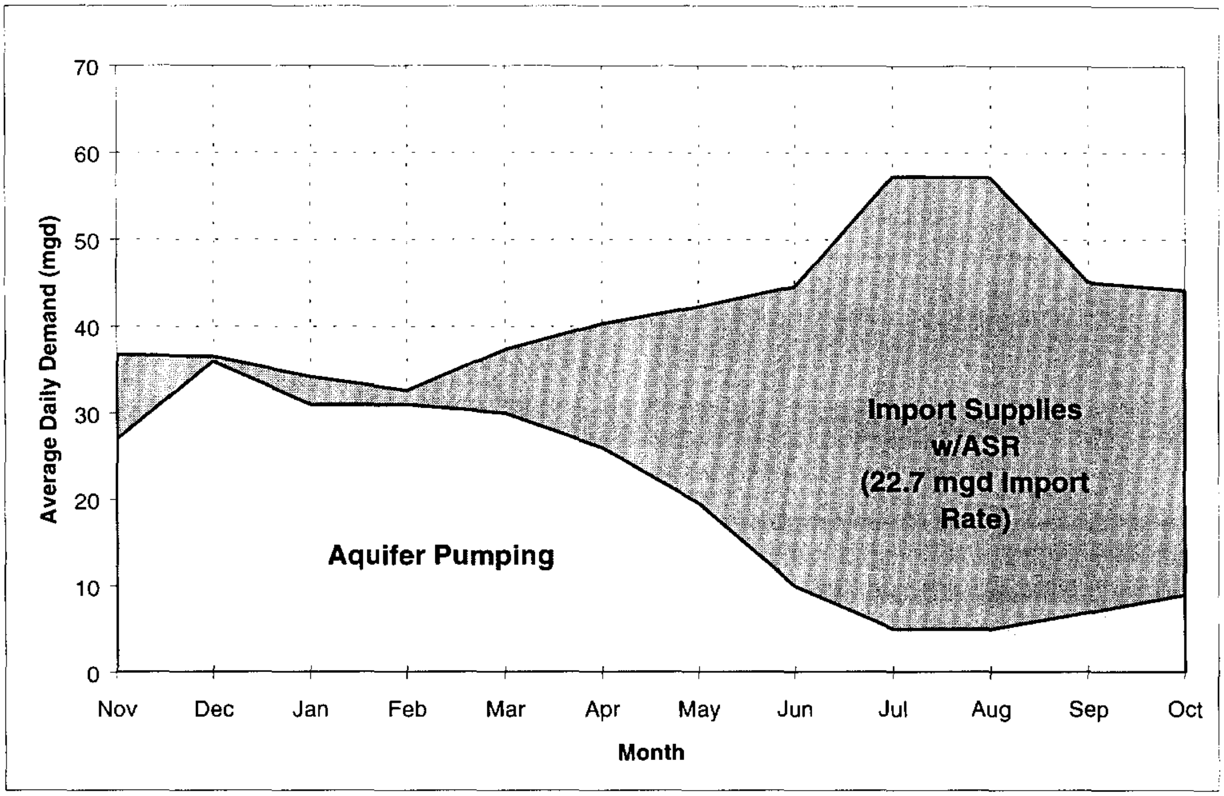


FIGURE 8
BexarMet Year 2016
Maximum ASR Alternative



The Maximum ASR alternative would reduce maximum day aquifer pumping to 255.1 mgd for SAWS and 49.3 mgd for BexarMet. This alternative is also one of the lowest cost alternatives, at $150 per acre-foot and $228 per acre-foot for SAWS and BexarMet, respectively.

Stored Water Migration

Movement of stored water in response to adjacent users or regional groundwater flow can reduce the availability of stored water for future recovery. Migration can be particularly problematic for drought applications where water may be stored for several years before recovery is initiated. Regional groundwater flow velocities were estimated for each storage zone option to assess the impact of regional groundwater movement on recovery efficiency.

Ambient groundwater flow velocity can be computed as:

$$v = \frac{K i}{\phi}$$

where,
v = velocity (ft/d)
K = hydraulic conductivity (ft/d)
i = hydraulic gradient (ft/ft)
ϕ = effective porosity

Values of hydraulic conductivity were derived by dividing regional storage zone transmissivity (Table 2) by the average storage zone thickness. The magnitude of hydraulic gradients were estimated for the Trinity storage zones using potentiometric surface mapping presented by the W.E. Simpson Co. (1993). Carrizo aquifer water level mapping (Klemt, et. at., 1976) was used to determine representative values of hydraulic gradient in the Carrizo and Wilcox storage zones. Values of effective porosity were estimated at 0.1 for the Trinity storage zones, and 0.2 and 0.25 for the Wilcox and Carrizo, respectively.

Computed velocities were compared with reported groundwater flow rates in the Trinity Group aquifers in northern Bexar County (W.E. Simpson Co., 1993). Results of this analysis were used to refine velocities estimates for the Area 1: Middle and Lower Trinity storage zone options shown in Table 8. This evaluation did not include the Area 5: Brackish Edwards option due to the very low circulation evident in the elevated dissolved solids content of the native water.

The potential impact of stored water migration was quantified by offsetting an idealized stored water plume by the one-year groundwater flow distance. The portion of the stored water distribution outside of the original delineation was used as an indicator of potential loss. Significant movement would only be an issue in non-potable storage zones and the impacts would be mitigated using the cluster concept developed for this project. The radial extent of the stored water plume and the annual percentage offset are listed in **Table 10.** Annual offsets in the six storage zones are well within acceptable limits, especially for the non-potable zones. This calculation indicates the movement of water stored in these areas due to existing groundwater gradients is expected to be minor and the stored water should be available for withdrawal when needed.

TABLE 10
Annual Migration Potential

	Area 1 Middle Trinity	Area 1 Lower Trinity	Area 3 Middle Trinity	Area 6 Wilcox	Area 7 Carrizo
Ambient Flow Velocity (ft/yr)	50	10	40	10	35
Stored Water Extent (ft)	372	288	407	188	294
One-Year Offset (%)	8.1	2.2	6.1	3.4	7.3

Protection Strategies

Section 11.154(c)(3), Texas Water Code, requires the applicant for an ASR permit show "reasonable diligence" in protecting appropriated surface water from unauthorized withdrawal during storage. However, with the exception of Edwards aquifer users within the EAA jurisdiction, property owners in the state of Texas generally have the legal right to capture all available "percolating waters" beneath their property (T.C. Ry. Co. v. East, 1904). Unfortunately, there is currently no distinction made between native groundwater and water stored using ASR, even for appropriated surface water. There are, however, numerous mechanisms available to SAWS and BexarMet which would limit unauthorized withdrawal of stored water. These include:

- Well location and design considerations
- Ordinances
- Lease or purchase of storage zone right
- Purchase of overlying property
- Formation of an underground water district
- Establishment of a special purpose district

Well location and design considerations provide a significant level of protection for the Area 1: Middle and Lower Trinity and Area 5: Brackish Edwards options. The native water quality in these storage zones is of sufficiently poor quality that is unsuitable for most uses. As a result, very few existing wells are completed in these zones. Construction of a new well specifically targeting stored water would likely tap only the outer edge of the stored water plume and recovered water quality would quickly decline as a greater proportion of native water was intercepted.

Section 34-570 of the City of San Antonio Code already restricts construction of new water supply wells where SAWS water service is currently provided or where service could be extended at a cost equal to or less than the cost of a well. This ordinance effectively limits access to water stored beneath areas actively served by SAWS. Only the Area 6: Wilcox and Area 7: Carrizo applications could not currently benefit from this protection.

Storage zone characteristics for potable storage zone alternatives indicate that annual volumes of stored water will extend no more than 372 feet radially from the ASR well (Area 1: Middle Trinity, Table 8), restricting access to stored water. However, the relatively limited area necessary to control the surface right makes the lease or purchase of the right to pump water from the target storage zone feasible.

Bexar County is entirely in the EAA jurisdiction. However, the EAA only has jurisdiction over the Edwards aquifer. Mr. Edmond McCarthy, an attorney with McGinnis, Lochridge and Kilgore, L.L.P., suggested that a separate groundwater district whose boundaries are coterminous with Bexar County could regulate drilling and well operation in the storage zones of interest. The ability to regulate well construction would be particularly useful in areas outside of the City of San Antonio limits.

The Bexar Metropolitan Water District, which was created by the legislature (Article 8280-126, Tex. Rev. Civ. Stat. Ann.), has authority to control, conserve, protect, preserve, distribute and utilize the underground water situated within its boundaries. The District's boundaries are coterminous with Bexar County. However, due to the specific language in Chapter 36, Texas Water Code, it may be prudent for BexarMet to specifically acquire the powers authorized under Chapter 36 to insure it had the necessary rulemaking authority to protect water stored in an ASR project.

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Technical Memorandum
Applications and Feasibility
Appendix A

APPENDIX A
Specific Capacity Testing Summary

Storage Zone	Well	Average Pumping Rate (gpm)	Pumping Time (min)	Specific Capacity (gpm/ft)	Reference
Area 1: Middle Trinity					
	AY-68-19-6ci5	103	180	1.7	N. Bexar Co. Water Resources Study, EUWD,1993
	AY-68-20-1da1	103	180	3.5	N. Bexar Co. Water Resources Study, EUWD,1993
	AY-68-20-3ig4	15	180	1.8	N. Bexar Co. Water Resources Study, EUWD,1993
	AY-68-20-4ed9.1	100	180	14.0	N. Bexar Co. Water Resources Study, EUWD,1993
	AY-68-20-8da4	350	20	14.0	N. Bexar Co. Water Resources Study, EUWD,1993
	6819303	20	60	1.1	TWDB Ground-Water Data System
	6819616	67	---	0.3	TWDB Ground-Water Data System
	6819901	25	420	0.4	TWDB Ground-Water Data System
	6820601	60	240	2.6	TWDB Ground-Water Data System
Area 1: Lower Trinity					
	AY-68-19-3fe1	76	180	0.6	N. Bexar Co. Water Resources Study, EUWD,1993
	6819501	150	840	0.7	TWDB Ground-Water Data System
	6819623	100	---	0.4	TWDB Ground-Water Data System
	6819624	154	---	2.0	TWDB Ground-Water Data System
	6819625	182	---	1.1	TWDB Ground-Water Data System
Area 3: Upper-Middle Trinity					
	6828104	450	---	1.3	TWDB Ground-Water Data System
	6828106	800	---	4.3	TWDB Ground-Water Data System
Area 5: Brackish Edwards					
	6845901	800	300	6.7	TWDB Ground-Water Data System
Area 6: Wilcox					
	6852405	200	270	1.1	TWDB Ground-Water Data System
	6852406	15	240	0.2	TWDB Ground-Water Data System
	6853403	700	---	>3.5	TWDB Ground-Water Data System
	6853404	700	---	>3.5	TWDB Ground-Water Data System
	6853405	1440	120	3.6	TWDB Ground-Water Data System
	6853406	550	---	5.5	TWDB Ground-Water Data System
Area 7: Carrizo					
	6853803	2000	120	80	TWDB Ground-Water Data System
	6853804	900	---	>18	TWDB Ground-Water Data System
	6853807	2420	---	31	TWDB Ground-Water Data System
	6853905	2200	---	39	TWDB Ground-Water Data System

Technical Memorandum
Applications and Feasibility
Appendix B

APPENDIX B
Well Construction Cost Estimation Summary

Project: SAN ASR
Application: Area 1/Middle Trinity ASR Well
Design Rate: 500 gpm

ASR Well Details	Setting Depth (ft bls)	Effective Bore Hole Dia. (in)	Nominal Casing Dia. (in)	Comment
Final Casing	517	20	12	Sch 80 PVC Casing
Screen				
Open Hole	850	12		

Item	Description		Quantity	Units	Price	Total
1)	Mobilization/Demobilization		-	LS	$10,000	$10,000
2)	Drilling:	20 in.	517	LF	$80	$41,360
3)		12 in.	333	LF	$48	$15,984
4)	Final Casing		517	LF	$36	$18,612
5)	Cement (neat)		795	SK	$15	$11,925
6)	Screen		-	LF		$0
7)	Gravel		-	CF		$0
8)	Geophysical logging		-	LS	$5,000	$5,000
9)	Acidization		10,000	GAL	$2.50	$25,000
	Subtotal					*$127,881*
10)	Misc. materials/services (10% of Subtotal)					$12,788
11)	Contingency (20% of Subtotal)					$25,576
	Total Well Cost					***$166,245***

Monitoring Well Details	Setting Depth (ft bls)	Effective Bore Hole Dia. (in)	Nominal Casing Dia. (in)	Comment
Final Casing	517	12	6	Steel
Screen				
Open Hole	850	6		

Item	Description		Quantity	Units	Price	Total
1)	Mobilization/Demobilization		-	LS	$10,000	$10,000
2)	Drilling:	12 in.	517	LF	$48	$24,816
3)		6 in.	333	LF	$24	$7,992
4)	Final Casing		517	LF	$20	$10,340
5)	Cement (neat)		336	SK	$15	$5,040
6)	Screen		-	LF		$0
7)	Gravel		-	CF		$0
	Subtotal					*$58,188*
8)	Misc. materials/services (10% of Subtotal)					$5,819
9)	Contingency (20% of Subtotal)					$11,638
	Total Well Cost					***$75,644***

APPENDIX B
Well Construction Cost Estimation Summary

Project: SAN ASR
Application: Area 1/Lower Trinity ASR Well
Design Rate: 300 gpm

ASR Well Details	Setting Depth (ft bls)	Effective Bore Hole Dia. (in)	Nominal Casing Dia. (in)	Comment
Final Casing	917	20	12	Threaded epoxy-coated steel
Screen				
Open Hole	1250	12		

Item	Description		Quantity	Units	Price	Total
1)	Mobilization/Demobilization		-	LS	$10,000	$10,000
2)	Drilling:	20 in.	917	LF	$80	$73,360
3)		12 in.	333	LF	$53	$17,582
4)	Final Casing		917	LF	$43	$39,431
5)	Cement (neat)		1,411	SK	$15	$21,165
6)	Screen		-	LF		$0
7)	Gravel		-	CF		$0
8)	Geophysical logging		-	LS	$5,000	$5,000
9)	Acidization		10,000	GAL	$2.50	$25,000
	Subtotal					*$191,538*
10)	Misc. materials/services (10% of Subtotal)					$19,154
11)	Contingency (20% of Subtotal)					$38,308
	Total Well Cost					***$249,000***

Monitoring Well Details	Setting Depth (ft bls)	Effective Bore Hole Dia. (in)	Nominal Casing Dia. (in)	Comment
Final Casing	917	12	6	Steel Casing
Screen				
Open Hole	1250	6		

Item	Description		Quantity	Units	Price	Total
1)	Mobilization/Demobilization		-	LS	$10,000	$10,000
2)	Drilling:	12 in.	917	LF	$48	$44,016
3)		6 in.	333	LF	$20	$6,660
4)	Final Casing		917	LF	$20	$18,340
5)	Cement (neat)		595	SK	$15	$8,925
6)	Screen		-	LF		$0
7)	Gravel		-	CF		$0
	Subtotal					*$87,941*
8)	Misc. materials/services (10% of Subtotal)					$8,794
9)	Contingency (20% of Subtotal)					$17,588
	Total Well Cost					***$114,323***

APPENDIX B
Well Construction Cost Estimation Summary

Project: SAN ASR
Application: Area 3/Middle Trinity ASR Well
Design Rate: 600

ASR Well Details	Setting Depth (ft bls)	Effective Bore Hole Dia. (in)	Nominal Casing Dia. (in)	Comment
Casing 1	400	30	24	Steel
Final Casing	1517	24	16	Threaded epoxy-coated steel
Open Hole	1850	16		

Item	Description		Quantity	Units	Price	Total
1)	Mobilization/Demobilization		-	LS	$20,000	$20,000
2)	Drilling:	30 in.	400	LF	$120	$48,000
3)		24 in.	1,117	LF	$252	$281,484
4)		16 in.	333	LF	$70	$23,443
5)	Casing 1		400	LF	$80	$32,000
6)	Final Casing		1,517	LF	$57	$86,469
7)	Cement (neat)		3,247	SK	$15	$48,705
8)	Gravel		785	CF	$10	$7,850
9)	Geophysical logging		-	LS	$5,000	$5,000
10)	Acidization		10,000	GAL	$2.50	$25,000
	Subtotal					*$577,951*
11)	Misc. materials/services (10% of Subtotal)					$57,795
12)	Contingency (20% of Subtotal)					$115,590
	Total Well Cost					***$751,337***

Monitoring Well Details	Setting Depth (ft bls)	Effective Bore Hole Dia. (in)	Nominal Casing Dia. (in)	Comment
Casing 1	400	18	12	Steel
Final Casing	1517	12	6	Steel
Open Hole	1850	6		

Item	Description		Quantity	Units	Price	Total
1)	Mobilization/Demobilization		-	LS	$20,000	$20,000
2)	Drilling:	18 in.	400	LF	$72	$28,800
3)		12 in.	1,117	LF	$126	$140,742
4)		6 in.	333	LF	$26	$8,791
5)	Casing 1		400	LF	$67	$26,800
6)	Final Casing		1,517	LF	$20	$30,340
7)	Cement (neat)		1,266	SK	$15	$18,990
8)	Gravel		265	CF	$10	$2,650
	Subtotal					*$277,113*
9)	Misc. materials/services (10% of Subtotal)					$27,711
10)	Contingency (20% of Subtotal)					$55,423
	Total Well Cost					***$360,247***

APPENDIX B

Well Construction Cost Estimation Summary

Project: SAN ASR
Application: Area 5/Brackish Edwards ASR Well
Design Rate: 900 gpm

ASR Well Details	**Setting Depth (ft bls)**	**Effective Bore Hole Dia. (in)**	**Nominal Casing Dia. (in)**	**Comment**
Final Casing	1633	24	16	Threaded epoxy-coated steel
Screen				
Open Hole	1833	16		

Item	**Description**		**Quantity**	**Units**	**Price**	**Total**
1)	Mobilization/Demobilization		-	LS	$20,000	$20,000
2)	Drilling:	24 in.	1,633	LF	$106	$172,445
3)		16 in.	200	LF	$168	$33,600
4)	Final Casing		1,633	LF	$57	$93,081
5)	Cement (neat)		3,140	SK	$15	$47,100
6)	Screen		-	LF		$0
7)	Gravel		-	CF		$0
8)	Geophysical logging		-	LS	$5,000	$5,000
9)	Acidization		10,000	GAL	$2.50	$25,000
	Subtotal					*$396,226*
10)	Misc. materials/services (10% of Subtotal)					$39,623
11)	Contingency (20% of Subtotal)					$79,245
	Total Well Cost					***$515,094***

Monitoring Well Details	Setting Depth (ft bls)	Effective Bore Hole Dia. (in)	Nominal Casing Dia. (in)	Comment
Final Casing	1633	12	6	Steel
Screen				
Open Hole	1833	6		

Item	**Description**		**Quantity**	**Units**	**Price**	**Total**
1)	Mobilization/Demobilization		-	LS	$20,000	$20,000
2)	Drilling:	12 in.	1,633	LF	$53	$86,222
3)		6 in.	200	LF	$63	$12,600
4)	Final Casing		1,633	LF	$20	$32,660
5)	Cement (neat)		1,060	SK	$15	$15,900
6)	Screen		-	LF		$0
7)	Gravel		-	CF		$0
	Subtotal					*$167,382*
8)	Misc. materials/services (10% of Subtotal)					$16,738
9)	Contingency (20% of Subtotal)					$33,476
	Total Well Cost					***$217,597***

APPENDIX B
Well Construction Cost Estimation Summary

Project: SAN ASR
Application: Area 6/Wilcox ASR Well
Design Rate: 500 gpm

ASR Well Details	Setting Depth (ft bls)	Effective BoreHole Dia. (in)	Nominal Casing Dia. (in)	Comment
Final Casing	400	20	12	Sch 80 PVC Casing
Screen	800	12	10	SS
Open Hole				

Item	Description		Quantity	Units	Price	Total
1)	Mobilization/Demobilization		-	LS	$10,000	$10,000
2)	Drilling:	20 in.	400	LF	$30	$12,000
3)		12 in.	400	LF	$18	$7,200
4)	Final Casing		400	LF	$36	$14,400
5)	Cement (neat)		710	SK	$15	$8,520
6)	Screen		400	LF	$140	$56,000
7)	Gravel		374	CF	$10	$1,060
8)	Geophysical logging		-	LS	$5,000	$5,000
	Subtotal					*$114,180*
9)	Misc. materials/services (10% of Subtotal)					$11,418
10)	Contingency (20% of Subtotal)					$22,836
	Total Well Cost					***$148,434***

Monitoring Well Details	Setting Depth (ft bls)	Effective BoreHole Dia. (in)	Nominal Casing Dia. (in)	Comment
Final Casing	400	12	6	Steel
Screen	800	12	6	Slotted Steel
Open Hole				

Item	Description		Quantity	Units	Price	Total
1)	Mobilization/Demobilization		-	LS	$10,000	$10,000
2)	Drilling:	12 in.	400	LF	$18	$7,200
3)		12 in.	400	LF	$18	$7,200
4)	Final Casing		400	LF	$20	$8,000
5)	Cement (neat)		240	SK	$15	$3,600
6)	Screen		400	LF	$30	$12,000
7)	Gravel		259	CF	$10	$2,590
	Subtotal					*$50,590*
8)	Misc. materials/services (10% of Subtotal)					$5,059
9)	Contingency (20% of Subtotal)					$10,118
	Total Well Cost					***$65,767***

APPENDIX B
Well Construction Cost Estimation Summary

Project: SAN ASR
Application: Area 7/Carrizo ASR Well
Design Rate: 2000 gpm

ASR Well Details	Setting Depth (ft bls)	Effective BoreHole Dia. (in)	Nominal Casing Dia. (in)	Comment
Final Casing	300	32	24	Threaded Epoxy-Coated Steel
Screen	700	24	16	SS
Open Hole				

Item	Description		Quantity	Units	Price	Total
1)	Mobilization/Demobilization		-	LS	$10,000	$10,000
2)	Drilling:	32 in.	300	LF	$48	$14,400
3)		24 in.	400	LF	$36	$14,400
4)	Final Casing		300	LF	$86	$25,800
5)	Cement (neat)		745	SK	$15	$11,175
6)	Screen		400	LF	$250	$100,000
7)	Gravel		768	CF	$10	$7,680
8)	Geophysical logging		-	LS	$5,000	$5,000
	Subtotal					*$188,455*
9)	Misc. materials/services (10% of Subtotal)					$18,846
10)	Contingency (20% of Subtotal)					$37,691
	Total Well Cost					***$244,992***

Monitoring Well Details	Setting Depth (ft bls)	Effective BoreHole Dia. (in)	Nominal Casing Dia. (in)	Comment
Final Casing	300	12	6	Steel
Screen	700	12	6	Slotted Steel
Open Hole				

Item	Description		Quantity	Units	Price	Total
1)	Mobilization/Demobilization		-	LS	$10,000	$10,000
2)	Drilling:	12 in.	300	LF	$18	$5,400
3)		12 in.	400	LF	$18	$7,200
4)	Final Casing		300	LF	$20	$6,000
5)	Cement (neat)		180	SK	$15	$2,700
6)	Screen		400	LF	$30	$12,000
7)	Gravel		259	CF	$10	$2,590
	Subtotal					*$45,890*
8)	Misc. materials/services (10% of Subtotal)					$4,589
9)	Contingency (20% of Subtotal)					$9,178
	Total Well Cost					***$59,657***

Technical Memorandum
Applications and Feasibility
Appendix C

APPENDIX C
Operations and Maintenance Costs

Application: Area 1/Middle Trinity ASR Well
Assumptions:
ASR wells per 10 mgd: 14 wells
Pumping Rate: 500 gpm
Inject through pump column and/or annulus using system pressure
Allow reverse spin when injecting through pump
Pumping setting: 550 ft bls (50 ft lower than design drawdown level)
Motor: 83 hp
Annual operation period: 5 months in/out

Activity	Per Well Number Comp's	Per Well Frequency (Years)	Unit Cost	Average Annual Cost per Well
Maintenance				
Pump Maintenance				
Pull Pump for Service	1	5	$5,000	$1,000
Pump Work	1	5	$2,000	$400
Shipping	1	5	$1,000	$200
Instruments and Controls				
Calibrated/Service Components	10	0.5	$50	$1,000
Replace flowmeter element	1	5	$2,000	$400
Replace Pressure Transmitters	1	10	$500	$50
Replace water level transducer	1	10	$1,000	$100
Misc. Components	1	1	$1,000	$1,000
Routine Maintenance				
Lube and check, paint, and clean				
1 man, 8 hrs/day	0.5	1	$40,000	$1,429
Supplies (Lube, small parts)	1	1	$500	$500
Operation				
Electrical Costs				
Electrical hp	104	0.42	$0.06	$16,950
Routine Operations				
1 man, 8 hrs/day	0.5	1	$40,000	$1,429
Truck 10,000 miles/yr	1	1	$5,000	$357
Other Contractors/Engineering	1	1	$20,000	$1,429
Water Quality	1	1	$1,000	$71
Administration	0.1	1	$60,000	$429
			Total Cost/year	$26,743
			$ per 1000 gal	$0.24

APPENDIX C
Operations and Maintenance Costs

Application: Area 1/Lower Trinity ASR Well
Assumptions:
ASR wells per 10 mgd: 24 wells
Pumping Rate: 300 gpm
Inject through pump column and/or annulus using system pressure
Allow reverse spin when injecting through pump
Pumping setting: 750 ft bls (50 ft lower than design drawdown level)
Motor: 69 hp
Annual operation period: 5 months in/out

Activity	Per Well Number Comp's	Per Well Frequency (Years)	Unit Cost	Average Annual Cost Per Well
Maintenance				
Pump Maintenance				
Pull Pump for Service	1	5	$5,000	$1,000
Pump Work	1	5	$2,000	$400
Shipping	1	5	$1,000	$200
Instruments and Controls				
Calibrated/Service Components	10	0.5	$50	$1,000
Replace flowmeter element	1	5	$2,000	$400
Replace Pressure Transmitters	1	10	$500	$50
Replace water level transducer	1	10	$1,000	$100
Misc. Components	1	1	$1,000	$1,000
Routine Maintenance				
Lube and check, paint, and clean				
1 man, 8 hrs/day	0.75	1	$40,000	$1,250
Supplies (Lube, small parts)	1	1	$500	$500
Operation				
Electrical Costs				
Electrical hp	86	0.42	$0.06	$14,091
Routine Operations				
1 man, 8 hrs/day	0.75	1	$40,000	$1,250
Truck 10,000 miles/yr	1	1	$5,000	$208
Other Contractors/Engineering	1	1	$20,000	$833
Water Quality	1	1	$1,000	$42
Administration	0.1	1	$60,000	$250
			Total Cost/year	$22,574
			$ per 1000 gal	$0.34

APPENDIX C
Operations and Maintenance Costs

Application: Area 3/Middle Trinity ASR Well
Assumptions:
ASR wells per 10 mgd: 12 wells
Pumping Rate: 600 gpm
Inject through pump column and/or annulus using system pressure
Allow reverse spin when injecting through pump
Pumping setting: 600 ft bls (50 ft lower than design drawdown level)
Motor: 109 hp
Annual operation period: 5 months in/out

Activity	Per Well Number Comp's	Per Well Frequency (Years)	Unit Cost	Average Annual Cost Per Well
Maintenance				
Pump Maintenance				
Pull Pump for Service	1	5	$5,000	$1,000
Pump Work	1	5	$2,000	$400
Shipping	1	5	$1,000	$200
Instruments and Controls				
Calibrated/Service Components	10	0.5	$50	$1,000
Replace flowmeter element	1	5	$2,000	$400
Replace Pressure Transmitters	1	10	$500	$50
Replace water level transducer	1	10	$1,000	$100
Misc. Components	1	1	$1,000	$1,000
Routine Maintenance				
Lube and check, paint, and clean				
1 man, 8 hrs/day	0.5	1	$40,000	$1,667
Supplies (Lube, small parts)	1	1	$500	$500
Operation				
Electrical Costs				
Electrical hp	136	0.42	$0.06	$22,260
Routine Operations				
1 man, 8 hrs/day	0.5	1	$40,000	$1,667
Truck 10,000 miles/yr	1	1	$5,000	$417
Other Contractors/Engineering	1	1	$20,000	$1,667
Water Quality	1	1	$1,000	$83
Administration	0.1	1	$60,000	$500
			Total Cost/year	$32,910
			$ per 1000 gal	$0.25

APPENDIX C
Operations and Maintenance Costs

Application: Area 5/Brackish Edwards ASR Well
Assumptions:
ASR wells per 10 mgd: 8 wells
Pumping Rate: 900 gpm
Inject through pump column and/or annulus using system pressure
Allow reverse spin when injecting through pump
Pumping setting: 295 ft bls (50 ft lower than design drawdown level)
Motor (out): 76 hp
Motor (in): 52 hp
Annual operation period: 5 months in/out

Activity	Per Well Number Comp's	Per Well Frequency (Years)	Unit Cost	Average Annual Cost Per Well
Maintenance				
Pump Maintenance				
Pull Pump for Service	2	5	$5,000	$2,000
Pump Work	2	5	$2,000	$800
Shipping	2	5	$1,000	$400
Instruments and Controls				
Calibrated/Service Components	10	0.5	$50	$1,000
Replace flowmeter element	1	5	$2,000	$400
Replace Pressure Transmitters	1	10	$500	$50
Replace water level transducer	1	10	$1,000	$100
Misc. Components	1	1	$1,000	$1,000
Routine Maintenance				
Lube and check, paint, and clean				
1 man, 8 hrs/day	0.5	1	$40,000	$2,500
Supplies (Lube, small parts)	1	1	$500	$500
Operation				
Electrical Costs				
In (Electrical hp)	65	0.42	$0.06	$10,619
Out (Electrical hp)	95	0.42	$0.06	$15,521
Routine Operations				
1 man, 8 hrs/day	0.5	1	$40,000	$2,500
Truck 10,000 miles/yr	1	1	$5,000	$625
Other Contractors/Engineering	1	1	$20,000	$2,500
Water Quality	1	1	$1,000	$125
Administration	0.1	1	$60,000	$750
			Total Cost/year	$41,390
			$ per 1000 gal	$0.21

APPENDIX C
Operations and Maintenance Costs

Application: Area 6/Wilcox ASR Well
Assumptions:
ASR wells per 10 mgd: 14 wells
Pumping Rate: 500 gpm
Inject through pump column and/or annulus using system pressure
Allow reverse spin when injecting through pump
Pumping setting: 367 ft bls (50 ft lower than design drawdown level)
Motor: 54 hp
Annual operation period: 5 months in/out

Activity	Per Well Number Comp's	Per Well Frequency (Years)	Unit Cost	Average Annual Cost Per Well
Maintenance				
Pump Maintenance				
Pull Pump for Service	1	5	$5,000	$1,000
Pump Work	1	5	$2,000	$400
Shipping	1	5	$1,000	$200
Instruments and Controls				
Calibrated/Service Components	10	0.5	$50	$1,000
Replace flowmeter element	1	5	$2,000	$400
Replace Pressure Transmitters	1	10	$500	$50
Replace water level transducer	1	10	$1,000	$100
Misc. Components	1	1	$1,000	$1,000
Routine Maintenance				
Lube and check, paint, and clean				
1 man, 8 hrs/day	0.5	1	$40,000	$1,429
Supplies (Lube, small parts)	1	1	$500	$500
Operation				
Electrical Costs				
Electrical hp	68	0.42	$0.06	$11,028
Routine Operations				
1 man, 8 hrs/day	0.5	1	$40,000	$1,429
Truck 10,000 miles/yr	1	1	$5,000	$357
Other Contractors/Engineering	1	1	$20,000	$1,429
Water Quality	1	1	$1,000	$71
Administration	0.1	1	$60,000	$429
			Total Cost/year	$20,821
			$ per 1000 gal	$0.19

APPENDIX C
Operations and Maintenance Costs

Application: Area 7/Carrizo ASR Well
Assumptions:
ASR wells per 10 mgd: 4 wells
Pumping Rate: 2000 gpm
Inject through pump column and/or annulus using system pressure
Allow reverse spin when injecting through pump
Pumping setting: 250 ft bls (50 ft lower than design drawdown level)
Motor: 141 hp
Annual operation period: 5 months in/out

Activity	Per Well Number Comp's	Per Well Frequency (Years)	Unit Cost	Average Annual Cost Per Well
Maintenance				
Pump Maintenance				
Pull Pump for Service	1	5	$5,000	$1,000
Pump Work	1	5	$2,000	$400
Shipping	1	5	$1,000	$200
Instruments and Controls				
Calibrated/Service Components	10	0.5	$50	$1,000
Replace flowmeter element	1	5	$2,000	$400
Replace Pressure Transmitters	1	10	$500	$50
Replace water level transducer	1	10	$1,000	$100
Misc. Components	1	1	$1,000	$1,000
Lube and check, paint, and clean				
1 man, 8 hrs/day				
Supplies (Lube, small parts)	0.25	1	$40,000	$2,500
	1	1	$500	$500
Operation				
Electrical Costs				
Electrical hp	176	0.42	$0.06	$28,795
Routine Operations				
1 man, 8 hrs/day	0.25	1	$40,000	$2,500
Truck 10,000 miles/yr	1	1	$5,000	$1,250
Other Contractors/Engineering	1	1	$20,000	$5,000
Water Quality	1	1	$1,000	$250
Administration	0.1	1	$60,000	$1,500
			Total Cost/year	$46,445
			$ per 1000 gal	$0.11

Aquifer Storage Recovery Feasibility Study: Potential Additional Water Storage and Supply Options

PREPARED FOR:	San Antonio Water System Bexar Metropolitan Water District
PREPARED BY:	CH2M HILL
DATE:	February 24, 1998

Purpose and Scope

The major water supply source in the San Antonio area is the Edwards aquifer. Although this water supply source is an abundant fresh water resource, the aquifer does have a finite water supply capacity. In recognition of these limits, pumping restrictions for the Edwards aquifer will soon be implemented through the Edwards Aquifer Authority (EAA); and many utilities dependent on the aquifer may require additional water sources to meet a portion of their existing and future water demands.

Considering current estimates of Edwards aquifer pumping limits and water demand projections, San Antonio Water System (SAWS) could face a shortfall of almost 29,000 acre-feet in the year 2006, and 66,000 acre-feet in the year 2016. Similarly, if Bexar Metropolitan Water District (BexarMet) is limited to their historic average pumping of 21,718 acre-feet, a shortfall of over 12,000 acre-feet could be realized in the year 2006, and almost 26,000 acre-feet in the year 2016.

Different water strategies will have to be implemented to meet the anticipated shortfall in Edwards supplies. Additional supplies include importing water, as well as water conservation and reuse. Although aquifer storage and recovery could also play an important role in the region's water use and management, the water supply shortfalls will require additional supplies.

This technical memorandum presents several options for future additional supplies and includes a discussion of how conservation and reuse can work to reduce demands. Additionally, future supply options and management practices are compared to the cost and benefits of an aquifer storage recovery (ASR) implementation. This information is divided into the following sections:

- Future Sources of Supply
- Conservation and Reuse
- ASR Considerations

Future Sources of Supply

Selection and development of future sources of supply for the San Antonio area currently in the conceptual stages. Most sources of supply for the area have been identified under different programs, of which the largest and most detailed is the Trans- Texas Water Program - West Central Study Area.

Water supply options that have been presented under the Trans-Texas Program are first presented in this section, followed by a discussion of the sources under consideration by BexarMet. This list of water resource projects is, in no way, a commitment from SAWS to use these projects as a part of their water resource plan. The following projects are listed to provide a frame of reference for the comparison of the estimated cost of water from these projects in relation to ASR.

Additionally, this is not intended to be a complete listing of potential supplies and other than the Canyon Lake to North Bexar County described below, no commitments have been made by SAWS to pursue other sources of supply.

Guadalupe River Diversion at Lake Dunlap to Mid-Cities and Bexar County with Regional Water Treatment Plant (G-37)

This water supply alternative is also presented in the Trans-Texas Water Program and provides treated water to several delivery points, including SAWS. Guadalupe River water would be diverted at Lake Dunlap to a regional water treatment plant near Marion. An intake and pump station would be provided at Lake Dunlap, as well as pumping and transmission facilities to deliver treated water.

The alternative contemplates diverting and treating 50,000 acre-feet of water annually. Water would be delivered to eight locations, including SAWS, at a uniform rate of approximately 44.6 mgd. The annual volume of water and the rate of delivery will be divided among the eight locations as follows:

Location	Annual Delivery Amount (Acre-feet)	Delivery Rate (mgd)
Spring Hill WSC	123	0.11
Crystal Clear WSC	476	0.43
Marion	87	0.08
Cibolo	160	0.17
Green Valley SUD	1,624	1.98
Schertz	2,612	2.33
Garden Ridge	570	0.51
SAWS	47,839/44,348	44.6

The above table shows that SAWS would obtain either 47,839 or 44,348 acre-feet from the alternative. Prior to the year 2020, it is anticipated that other project participants will not need their allotment and SAWS could receive most of the water supply. By the year 2020, the supply to SAWS would be expected to drop to 44,348 acre-feet.

The system would be designed to provide water to SAWS at a rate of approximately 45 mgd. Delivery to the SAWS system would be at a uniform rate of the total annual volume of water each month. Delivery to the SAWS system would be via the Stahl Pump Station in northeast Bexar County.

Total annual cost for water provided to SAWS for this alternative is tabulated below. Costs are presented in 1996 dollars for treated water delivered to the Stahl Pump Station site and includes both capital and operation and maintenance cost. The total land area estimated to be impacted by this alternative is 136 acres.

Location	Annual Volume (Acre-feet)	Unit Cost ($/acre-foot)
SAWS – Stahl	47,839	$ 257
SAWS – Marshall	44,348	$ 268

Purchase (or Lease) of Edwards Irrigation Water for Municipal and Industrial Use (L-15)

The Edwards aquifer is used as a source for irrigation water in parts of Uvalde, Medina, and Bexar Counties. A study was conducted for the Trans-Texas Water Program to estimate probable quantities of Edwards irrigation water that may be available to transfer to municipal or industrial water rights.

Existing irrigation uses that will be permitted under the EAA withdrawal limits could be available for sale or lease to a water utility if the irrigator desired to give up his right to all or a portion of his water. The sale of irrigation rights will be dictated by the laws of supply and demand. If the price that a water utility is willing to pay is high enough, irrigators will offer water rights for sale. The study in the Trans-Texas Water Program applied the following logic to this situation to estimate how much water may be available through irrigation right purchase or lease, and at what cost the water would be offered.

It is proposed that irrigation water could be available for sale under either of three general scenarios:

1. An irrigator will apply conservation to his farming methods and sell or lease irrigation water no longer needed while farming the same irrigated area.
2. An irrigator will reduce a portion of his irrigated area to allow for water sale or lease.
3. An irrigator will sell or lease all of his water and convert his previously irrigated area to dry land crops.

Considering the above scenarios for irrigators to sell or lease water for municipal or industrial use, it was estimated that 68,900 acre-feet could be available. The cost of this water for purchase or lease will depend on the irrigators original farm yield, and the reduction associated with water conservation or conversion to dry land farming. It is estimated that the farm value per acre-foot of Edwards water produced is approximately $ 210 per acre-foot per year. These values are presented in the following table. The total land area estimated to be impacted by this alternative is 27,233 acres.

Source	Annual Volume (Acre-feet)	Unit Cost ($/acre-foot)
Purchase Irrigation Rights	68,900	$ 210

Cibolo Reservoir (S-15C)

The Cibolo Reservoir is a proposed reservoir on Cibolo Creek in Wilson County, located about 8 miles east of Floresville. This water supply alternative is presented in the Trans-Texas Water Program and provides treated water to the SAWS system and other users in the San Antonio area. The alternative obtains raw water from a new dam and reservoir; an intake and pump station would be located on the reservoir and raw water would be delivered to a treatment plant located in south Bexar County.

The alternative consists of diverting and treating 32,300 acre-feet of water annually. Water would be delivered to the south Bexar County WTP at a uniform rate of approximately 29 mgd. The annual volume of water and the rate of delivery will be as follows:

Location	Annual Delivery Amount (Acre-feet)	Delivery Rate (mgd)
SAWS	32,300	29

Included in this alternative are: finished water pumping from the WTP and transmission piping (to transfer the finished water to the existing distribution system). The total annual cost for water provided to SAWS for this alternative is tabulated below. The costs are presented in 1996 dollars for treated water delivered to the existing distribution system and includes both capital and operation and maintenance cost. The total land area estimated to be impacted by this alternative is 16,700 acres.

Location	Annual Volume (Acre-feet)	Unit Cost ($/acre-foot)
SAWS - Distribution	32,300	$ 1,127

Other Alternatives

Additionally, SAWS is considering other alternatives for future supply. One of these is obtaining treated surface water from Canyon Lake. SAWS has contracted with the Guadalupe-Blanco River Authority and San Antonio River Authority to obtain additional water supplies. It is expected that at least 2,000 acre-feet of water per year would be provided by this project.

BexarMet

The above alternatives for future water supplies in the San Antonio area were obtained from the Trans-Texas Water Program. Most of the alternatives discussed provided water to more than one end user, including SAWS. It is likely that BexarMet could obtain some level of water supplies from most of the above alternatives through wholesale contracts. In this way, the above general discussion and range of costs also apply to the BexarMet system.

BexarMet has also contracted with the Canyon Regional Water Authority to obtain up to 4,000 acre-feet of treated water from the authority's Lake Dunlap WTP. Additionally, BexarMet is developing surface water supplies in the Medina River basin to serve a 9 mgd WTP. Construction of the WTP is expected to be completed in early 1999.

Conservation and Reuse

Conservation and reuse will play an important role in reducing water demands. Water saved through conservation, or that obtained through reuse, offsets some amount of future supply need. The Trans-Texas Water Program studied potential conservation and reuse practices for the area to estimate what volume of water could be saved through these practices and at what cost. This section presents a summary of these findings.

Water Conservation (L-10)

Water conservation has the potential to reduce the public's use of freshwater without adversely affecting the quality of life or economic development. This can be done through public education and through the use of selected plumbing fixtures. These combined measures include installation of water efficient appliances, revised landscaping practices, and modification of personal behavior to control potential waste.

In the Edwards aquifer region, it was estimated that 34 gallons of water per person per day could be saved by implementing conservation practices. The water savings would require a cost of $ 11.47 per person, which includes public education, water audits and leak repair, assistance with conservation landscaping, and assistance with replacement of selected plumbing fixtures. The volume of water savings and the associated costs considering the projected population for the year 2006 are listed below. There are no land areas expected to be impacted by this alternative.

Utility	Population	Annual Water Savings	Annual Cost
SAWS	1,314,458	50,000 acre-feet	$ 302/acre-foot
BexarMet	221,353	8,400 acre-feet	$ 302/acre-foot

Reuse (L-13A)

Reuse of treated effluent can provide water for irrigation, which reduces the demand on potable supplies. SAWS currently has plans to reuse 35,000 to 50,000 acre-feet of effluent per year by the year 2008. The City is already using recycled water for irrigation of the Mission del Lago Golf Course. Currently under design and construction are pumping and transmission facilities along the west and east sides of the City that will deliver recycled water for a variety of uses. These routes generally follow the Leon Creek and Salado Creek watersheds. The sources of recycled water are the Leon Creek, and Salado and Dos Rios Water Recycling Centers.

The volumes of reuse water and the associated cost is listed below. There are no land areas expected to be impacted by this alternative.

Utility	Reuse Water Volume by 2008	Annual Cost

SAWS	35,000 to 50,000 acre-feet	$ 400/acre-foot

ASR Considerations

As discussed previously, if water demand projections are realized, and if the EAA withdrawal limits are placed on the Edwards aquifer as expected, SAWS and BexarMet will require additional water supplies to meet future demands. Options for water supply presented in the previous section include bringing additional surface and groundwater supplies into the area and reducing demands by implementing conservation practices and reusing treated wastewater.

An additional technique to manage existing and future supplies is through the use of ASR. This technique can be used to optimize water treatment and delivery facilities by allowing operation of these facilities near the design capacity. It is important to note that ASR does not provide the needed volumes of water, but can be used to enhance availability and make the most efficient use of the resources.

Alternatives discussed above all provide a uniform rate of delivery to the area. The existing Edwards aquifer supply will continue to provide an annual volume of water. However, during droughts and other low aquifer conditions, allowable aquifer withdrawals may be limited and substantial imported supplies will be required to meet demands. If water system planning were to proceed assuming the minimum guaranteed Edwards supply, substantial imported supplies would be needed. Under these conditions, a large portion of permitted Edwards water would go unused as a result of not being able to capture Edwards supplies during low demand months in the winter and spring.

ASR can maximize the benefit of imported supplies by storing the surplus that is in excess of that available from the Edwards. During times of reduced Edwards availability, ASR can be used to supplement the imported supplies. This type of application could result in the more complete use of the permitted Edwards supply.

An ASR system that could provide seasonal storage of about 20,000 acre-feet treated water annually would significantly benefit both SAWS and BexarMet. The ASR system would include a series of wells and piping to take water from the different sources, store the water, and later recover the water by pumping the wells. ASR capacity would supplement the imported supplies and allowed Edwards pumping in the summer months, and would be used to store surplus imported water in the winter.

ASR systems are currently being considered for six unique storage zones. The storage zones are those defined in the Groundwater Assessment Technical Memorandum completed as a component of this project. The marginal costs and estimated annual capacity for the ASR option currently being considered are listed below.

Area/Aquifer	Annual Volume of Storage	Annual Cost
1: Middle Trinity	22,208 acre-feet	$ 193 / acre-foot
1: Lower Trinity	36,369 acre-feet	$ 323 / acre-foot
3: Middle Trinity	42,952 acre-feet	$ 320 / acre-foot
5: Brackish Edwards	19,689 acre-feet	$ 189 / acre-foot

6: Wilcox	48,522 acre-feet	$ 155 / acre-foot
7: Carrizo	3,959 acre-feet	$ 71/acre-foot

Land areas impacted by the ASR application will depend on the number of wells required for each alternative. It is assumed that one acre of land will be required for each well site, and depending on the final storage zone(s) used, that up to 100 ASR wells would be required to provide 20,000 acre-feet per year.

Depending on the demand variations for the utility and the allowed use of Edwards aquifer water, significantly less imported water would be needed and substantial cost savings could be realized using an ASR system.

TECHNICAL MEMORANDUM **CH2MHILL**

Aquifer Storage Recovery (ASR) Feasibility Investigation: Underground Injection Control and Surface Water Use Permits

PREPARED FOR:	San Antonio Water System (SAWS) Bexar Metropolitan Water District (BexarMet)
PREPARED BY:	CH2M HILL
DATE:	February 4, 1998

Introduction

An aquifer storage recovery (ASR) project developed under the rules and regulations of the Texas Water Development Board (TWDB) and the Texas Natural Resource Conservation Commission (TNRCC) contemplates the storage of surface waters in an underground aquifer formation. As a result, developing ASR projects is currently governed by certain surface water rights and underground injection requirements. The rules and regulations are included in various legislative statutes and administrative rules.

The TNRCC has promulgated rules for the implementation of House Bill (HB) 1989, which initially addressed ASR and was passed by the Texas Legislature in 1995. HB 1989 was subsequently amended by Senate Bill (SB) 1, which was adopted into law by the Texas Legislature during the 1997 session. Pertinent legislation, rules, and regulations are summarized below.

HB 1989 and SB 1

Using waters derived from surface waters of the State of Texas for other than test injection and recovery in an ASR project requires a permit from the TNRCC. HB 1989 established certain requirements and stipulated specific aquifers within the State for which permits for the purpose of ASR would be allowed. SB 1 amended HB 1989, deleting the reference to specific counties and aquifers, thus allowing the permitting and development of ASR projects anywhere within the State. A TWDB "suitability" determination, as required by HB 1989, was removed with the adoption of SB 1. The key provisions of HB 1989 and SB 1 are included here as Appendices A and B.

TNRCC Rules

The TNRCC rules define ASR projects in two phases:

> "Aquifer Storage and Retrieval Project-A 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."(30 TAC Chapter 297).

Under the above definition, the entire three-step process defined in the TWDB grant application for the SAWS/BexarMet ASR Feasibility Investigation falls within the definition of Phase I.

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 well (30 TAC Chapter 295, Subchapter A).

Operating Requirements. The TNRCC water quality requirements for Class V injection wells states that injected water must meet the quality criteria prescribed by the commission's drinking water standards. This section of the regulations does not stipulate the source of water to be injected (30 TAC Chapter 331, Subchapter K).

Effect on SAWS and BexarMet. SAWS and BexarMet have existing surface water rights that authorize the diversion and use of water for municipal purposes, which is the use for which both ultimately intend to use the water stored underground. In neither case, however, are the existing surface water rights developed into potable water supplies at this time. For ASR testing purposes, the only source of potable water is water that is currently in the SAWS and BexarMet distribution systems that is not from a surface water source. The TWDB and TNRCC have both indicated that the use of the current distribution system supply, which is Edward's Aquifer water, should meet with their agencies approval. Final approval will come at the time a request is made to approve a specific test injection program. Since a formal permit is not required for Phase I, SAWS, and BexarMet must only provide written notification to the executive director of the TNRCC, the Class V injection well information, and a map, all within 60 days of the intended first storage test to be conducted.

Upon completion of the Feasibility Investigation (Phase I), a new water right or an amendment to an existing water right will be required before the long-term operation of an ASR system can be implemented using surface water as the source of supply.

Appendices:

Appendix A- HB 1989

Appendix B- SB 1

Appendix C- 30 TAC, Chapter 297, Water Rights, Substantial, Subchapter A, Definitions; Subchapter B, Classes of Permits.

Appendix D- 30 TAC, Chapter 331, Underground Injection Control, Subchapter A, General Provisions, 331.2 - Definitions; 331.11 - Classification of Injection Wells; Subchapter H.

H. Standards for Class V Wells; Subchapter K. Additional Requirements for Class V Aquifer Storage Wells.

Attachment P5 - 30 TAC, Chapter 295, Water Rights, Procedural, Subchapter A, Requirements of Water Use Permit Applications, Requirements for the Storage of Appropriated Surface Water in Aquifers, 295.21 - 295.22.

Appendix F - Submittal Requirements

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~~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:~~

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of this requirement.

SECTION 4.02. Subchapter D, Chapter 11, Water Code, is amended by adding Sections 11.1501 and 11.151 to read as follows:

Sec. 11.1501. CONSIDERATION AND REVISION OF PLANS. In considering an application for a permit to store, take, or divert surface water, or for an amendment to a permit, certified filing, or certificate of adjudication, the commission shall consider the state water plan and any approved regional water plan for the area or areas in which the water is proposed to be stored, diverted, or used.

Sec. 11.151. EFFECTS OF PERMITS ON GROUNDWATER. In considering an application for a permit to store, take, or divert surface water, the commission shall consider the effects, if any, on groundwater or groundwater recharge.

SECTION 4.03. Section 11.153, Water Code, is amended by amending the section heading and Subsections (a) and (d) 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~~].

(d) The commission shall only issue a [~~A~~] final order granting a permit or amendment to a permit authorizing the storage of appropriated water in aquifers for subsequent beneficial use where completed pilot projects or historically demonstrated projects have been shown to be feasible under the criteria provided in Sections 11.154(c) and (d)[~~, other than for the pilot projects authorized by this section, may not be issued before June 1, 1999~~].

SECTION 4.04. Subsections (a), (b), (c), and (e), Section 11.154, Water Code, are amended to read as follows:

(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 a groundwater [~~an underground water~~] reservoir or a subdivision of a groundwater [~~an underground water~~] reservoir, as defined by Chapter 36 [~~52~~], that is under the jurisdiction of a groundwater [~~an underground water~~] conservation district:

(1) the applicant shall:

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

(B) cooperate with each district [~~the districts~~] that has [~~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, and [~~or~~] withdrawal of appropriated water stored in the reservoir or subdivision that are adopted by each [~~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 from an applicant with a completed pilot or historically demonstrated project, 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.

(e) A permit to store appropriated water in a groundwater [~~an underground water~~] reservoir or subdivision, as defined by Chapter 36 [~~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 a groundwater [~~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.

SECTION 4.05. Subsection (b), Section 11.155, Water Code, is amended to read as follows:

(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 described [~~identified~~] in Section 11.153(a);

(2) areas designated by the commission as "priority groundwater management [~~critical~~] areas" under Section 35.008 [~~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.

SECTION 4.06. Subsection (b), Section 11.173, Water Code, is amended to read as follows:

(b) A permit, certified filing, or certificate of adjudication or a portion of a permit, certified filing, or certificate of adjudication is exempt from cancellation under Subsection (a) of this section:

(1) to the extent of the owner's participation in the Conservation Reserve Program authorized by the Food Security Act, Pub.L. No. 99-198, Secs. 1231-1236, 99 Stat. 1354, 1509-1514 (1985) or a similar governmental program; or

(2) if any portion of the water authorized to be used pursuant to a permit, certified filing, or certificate of adjudication has been used in accordance with a regional water [~~management~~] plan approved pursuant to Section 16.053 of this code [~~by the commission~~].

SECTION 4.07. Subdivision (6), Section 15.001, Water Code, is amended to read as follows:

(6) "Project" means:

(A) any undertaking or work, including planning activities and work to obtain regulatory authority at the local, state, and federal level, to conserve, convey, and develop [~~surface or subsurface~~] water resources in the state, to provide for the maintenance and enhancement of the quality of the water of the state, to provide nonstructural and structural flood control, drainage, subsidence control, recharge, chloride control, brush control, precipitation enhancement, and desalinization, to provide for the acquisition of water rights and the repair of

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~~ing to Water Rights Rules, Procedural), shall have the following meanings, unless the context clearly indicates otherwise.~~

~~Appropriations—The process or series of operations by which an appropriative right is acquired. A completed appropriation thus results in an appropriative right; the water to which a completed appropriation in good standing relates is appropriated water.~~

~~Appropriative right—The right to impound, divert, or use a specific quantity of state water acquired by law.~~

Aquifer Storage and Retrieval Project—A 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.

~~Baseflow or normal flow—The portion of streamflow uninfluenced by recent rainfall or flood runoff and is comprised of springflow, seepage, discharge from artesian wells or other groundwater sources, and the delayed drainage of large lakes and swamps. (Accountable effluent discharges from municipal, industrial, irrigation, or other uses of ground or surface waters may be included at times.)~~

~~Beneficial use—Use of the amount of water which is economically necessary for a purpose authorized by law, when reasonable intelligence and reasonable diligence are used in applying the water to that purpose.~~

~~Certificate of adjudication—An instrument evidencing a water right issued to each person adjudicated a water right in conformity with the provisions of the Texas Water Code, §11.323, or the final judgment and decree in State of Texas v. Hidalgo County Water Control and Improvement District 18, 443 S.W.2d 728 (Texas Civil Appeals—Corpus Christi 1969, writ ref. n.r.e.).~~

~~Certified filing—A declaration of appropriation or affidavit which was filed with the State Board of Water Engineers under the provisions of the 33rd Legislature, 1913, General Laws, Chapter 171, §14, as amended.~~

~~Claim—A sworn statement filed pursuant to the Texas Water Code, §11.303.~~

~~Commencement of construction—An actual, visible step beyond planning or land acquisition, which forms the beginning of the ongoing (continuous) construction of a project in the manner specified in the approved plans and specifications, where required, for that project. The action must be performed in good faith with the bona fide intent to proceed with the construction.~~

~~Commission—The Texas Water Commission.~~

~~Conservation—Those practices, techniques, and technologies that will reduce the consumption of water, reduce the loss or waste of water, improve the efficiency in the use of water, or increase the recycling and reuse of water so that a water supply is made available for future or alternative uses.~~

~~Dam—Any artificial structure, together with any appurtenant works, which impounds water. All structures which are necessary to impound a single body of water shall be considered as one dam. A structure used only for diverting water from a watercourse by gravity is a diversion dam.~~

~~Diffused surface water—Water on the surface of the land in places other than watercourses. Diffused water may flow vagrantly over broad areas coming to rest in natural depressions, playa lakes, bogs, or marshes. (An essential characteristic of diffused water is that its flow is short-lived.)~~

~~Director or executive director—The executive director or an acting executive director of the Texas Water Commission, or any authorized individual designated by the executive director to act in his place for the commission, unless a direct authorization from the executive director or acting executive director is required by the Texas Water Code or these sections.~~

~~District—Any district or authority created by authority of the Texas Constitution, either Article III, §52(b)(1) and (2), or Article XVI, §59.~~

~~Domestic use—Use of water by an individual or a household used for drinking, washing, or culinary purposes; for irrigation of lawns, or of a family garden and/or orchard when the produce is not sold; for watering of domestic animals; and for water recreation for which no consideration is given or received. If the water is diverted, it must be diverted solely through the efforts of the user.~~

~~other bodies of surface water, natural or artificial, inland or coastal, fresh or salt, navigable or nonnavigable, and including the beds and banks of all watercourses and bodies of surface water, that are wholly or partially inside or bordering the state or inside the jurisdiction of the state.~~

~~Watercourse—A definite channel of a stream in which water flows within a defined bed and banks, originating from a definite source or sources. (The water may flow continuously or intermittently, and if the latter, with some degree of regularity, depending on the characteristics of the sources.)~~

~~Water right—A right acquired under the laws of this state to impound, divert, or use state water.~~

~~Watershed—A term used to designate the area drained by a stream and its tributaries, or the drainage area upstream from a specified point on a stream.~~

~~Water supply—Any body of water, whether static or moving, either on or under the surface of the ground, available for beneficial use on a reasonably dependable basis.~~

~~Source: The provisions of this §297.1 adopted to be effective May 29, 1986, 11 TexReg 2327; amended to be effective December 16, 1987, 12 TexReg 4531; amended to be effective June 25, 1990, 15 TexReg 3415; amended to be effective May 3, 1993, 18 TexReg 2558; amended to be effective June 28, 1996, 21 TexReg 5442.~~

~~Cross References: This Section cited in 30 TAC §295.21, (relating to Aquifer Storage and Retrieval Projects); 30 TAC §297.19, (relating to Term Permit under Texas Water Code, §§11.138 and 11.153-11.155); 30 TAC §297.29, (relating to Permit Exemption To Use State Water for Emergency Use).~~

SUBCHAPTER B. CLASSES OF PERMITS

~~§ 297.11. Permit under the Texas Water Code, §11.121~~

~~A Texas Water Code, §11.121, permit authorizes the appropriation of state water on a repetitive year-round basis or for a term of years. If for a term of years, it does not vest the holder with any permanent water right and expires under its own terms.~~

~~Source: The provisions of this §297.1.1 adopted to be effective May 29, 1986, 11 TexReg 2330.~~

~~§ 297.12. Seasonal Permit under the Texas Water Code, §11.137~~

~~A seasonal permit limits the diversion of state water to the portion or portions of the calendar year stated in the permit. (This type of permit is usually granted where irrigation is desired for seasonal crops or where the applicant proposes to appropriate water to fill an off-channel reservoir during the wet season for later use.)~~

~~Source: The provisions of this §297.12 adopted to be effective May 29, 1986, 11 TexReg 2330.~~

§ 297.13. Temporary Permit under the 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.

Source: The provisions of this §297.13 adopted to be effective May 30, 1986, 11 TexReg 2330; amended to be effective June 28, 1996, 21 TexReg 5442.

Cross References: This Section cited in 30 TAC §281.17, (relating to Notice of Receipt of Application and Declaration of Administrative Completeness).

~~§ 297.14. Contractual Permit~~

~~A contractual permit authorizes the use of state water where the source of supply is water lawfully authorized for the use of another person and a written agreement has been entered into with said person. The permit is for a period of time limited by the contract, and no permanent right is acquired by the holder. Although some contractual permits are still in existence, they are no longer being issued by the commission. See Subchapter J of this chapter (relating to Water Supply Contracts and Amendments).~~

~~Source: The provisions of this §297.14 adopted to be effective May 30, 1986, 11 TexReg 2330.~~

~~§ 297.15. Permit under the Texas Water Code, §11.143~~

~~A Texas Water Code, §11.143, permit authorizes anyone owning a dam or reservoir on his or her~~

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Appendix D

SUBCHAPTER A. GENERAL PROVISIONS

~~§ 331.1. Purpose, Scope, and Applicability~~

~~(a) The purpose of this chapter is to implement the provisions of the Injection Well Act, Texas Water Code, Chapter 27, as it applies to the commission, consistent with the policy of the Act stated in §27.003.~~

~~(b) This chapter applies to all injection wells and activities within the commission's jurisdiction.~~

~~Source: The provisions of this §331.1 adopted to be effective May 13, 1986, 11 TexReg 1980.~~

§ 331.2. Definitions

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

Abandoned well—A well whose use has been permanently discontinued or a well for which, after appropriate review and evaluation by the commission, there is no reasonable expectation of a return to service.

Activity—The construction or operation of an injection well or of pre-injection facilities, and includes processing, storage, and disposal of waste.

Affected person—Any person whose legal rights, duties, or privileges may be adversely affected by the proposed injection operation for which a permit is sought.

Annulus—The space in the wellbore between the injection tubing and the long string casing and/or liner.

Annulus pressure differential—The difference between the annulus pressure and the injection pressure in an injection well.

Aquifer—A geological formation, group of formations, or part of a formation that is capable of yielding a significant amount of water to a well or spring.

Aquifer restoration—The process of achieving or exceeding the water quality levels established by the commission for a permit/production area.

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.

Area permit—An injection well permit which thorizes the construction and operation of two more similar injection wells within a specified area.

Artificial liner—The impermeable lining of a lagoon, pond, reservoir, or other impoundment that is made of a synthetic material such as butyl rubber, chlorosulfonated polyethylene, elasticized polyolefin, polyvinyl chloride (PVC), other man-made materials, or other similar materials.

Baseline quality—The parameters and their concentrations that describe the local groundwater quality of an aquifer prior to the beginning injection activities.

Baseline well—A well from which groundwater is analyzed to define baseline quality in the permit area (regional baseline well) or in the production area (production area baseline well).

Buffer area—The area between any mine area boundary and the permit area boundary.

Caprock—A geologic formation typically ov ing the crest and sides of a salt stock. The caprock consists of a complex assemblage of minerals cluding calcium carbonate ($CaCO_3$), anhydrite ($CaSO_4$), and accessory minerals. Caprocks contain lost circulation zones characterized by layers of high porosity and permeability.

Captured facility—A manufacturing or tion facility that generates an industrial solid or hazardous waste that is routinely stored, cessed, or disposed of on a shared basis integrated waste management unit owned, ed by, and located within a contiguous manuf ing complex.

Cement—A substance generally introduced slurry into a wellbore which sets up and between the casing and borehole and/or casing strings to prevent movement of fluids or adjacent to a borehole, or a similar subst used in plugging a well.

Cementing—The operation whereby ceme introduced into a wellbore and/or forced the casing.

Commercial facility—A Class I permittee operates one or more commercial injection

Commercial UIC Class I well facility—Any management facility that accepts hazardous nonhazardous industrial solid waste, for dispo a UIC Class I injection well, for a charge, exce captured facility or a facility that accepts

~~Reg 10099; amended to be effective June 13, 1996, 21 TexReg 5000.~~

~~Cross References: This Section cited in 30 TAC §331.7, (relating to Permit Required); 30 TAC §331.81, (relating to Applicability); 30 TAC §331.121, (relating to Class I Wells).~~

~~§ 331.10. Inventory of Wells Authorized by Rule~~

~~(a) Within one year after January 1, 1982, or prior to construction, the owner, operator, and driller of an injection well facility shall submit to the executive director an inventory for each facility containing:~~

~~(1) the name of the facility;~~

~~(2) the name and address of legal contact;~~

~~(3) the ownership of the facility;~~

~~(4) the nature, type and operating status of the injection well(s); and~~

~~(5) the location, depth, and construction of each well.~~

~~(b) Drillers of injection wells authorized by rule may inventory wells by submission of either a form to be provided by the executive director or the form of the Water Well Drillers Board.~~

~~(c) Failure to comply with this section shall constitute grounds for termination of authorization by rule.~~

~~Source: The provisions of this §331.10 adopted to be effective May 13, 1986, 11 TexReg 1980; amended to be effective July 5, 1989, 14 TexReg 3047.~~

§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 any 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) air conditioning return flow wells used to return to the supply aquifer the water used for heating or cooling in a heat pump;

(B) cesspools or other devices that receive wastes, which have an open bottom and sometimes have perforated sides;

(C) cooling water return flow wells used to inject water previously used for cooling;

(D) drainage wells used to drain surface fluid, primarily storm runoff, into a subsurface formation;

(E) dry wells used for the injection of wastes into a subsurface formation;

(F) recharge wells used to replenish the water in an aquifer;

(G) salt water intrusion barrier wells used to inject water into a freshwater aquifer to prevent the intrusion of salt water into the fresh water;

(H) sand backfill wells used to inject a mixture of water and sand, mill tailings or other solids into mined out portions of subsurface mines;

(I) septic system wells used:

(i) to inject the waste or effluent from a multiple dwelling, business establishment, community or regional business establishment septic tank; or

(ii) for a multiple dwelling, community or regional cesspool.

(J) subsidence control wells (not used for the purpose of oil or natural gas production) used to inject fluids into a non-oil or gas producing zone to reduce or eliminate subsidence associated with the overdraft of fresh water;

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

~~(K) plans (including maps) for meeting the minimum monitoring requirements of the rules;~~

~~(L) expected changes in pressure, native fluid displacement, direction of movement of injection fluid; and~~

~~(M) contingency plans to cope with all shut-ins or well failures so as to prevent the migration of contaminating fluids into fresh water;~~

~~(3) whether the applicant will assure, in accordance with §§331.141-331.147 of this title (relating to Financial Responsibility), through a performance bond or other appropriate means, the resources necessary to close, plug or abandon the well;~~

~~(4) the closure plan, in accordance with §331.46 of this title (relating to Closure Standards), 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; amended to be effective January 1, 1995, 19 TexReg 10099.~~

~~**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 plug 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 liabilitie and is equivalent to owner's equity.

Tangible net worth—The tangible assets that re main after deducting liabilities; such assets woul not include intangibles such as goodwill and right to patents or royalties.

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

Cross References: This Section cited in 30 TAC §331.9, (relatin to Injection Authorized by Rule); 30 TAC §331.36, (relating Financial Assurances); 30 TAC §331.68, (relating to Post-Closu Care); 30 TAC §331.121, (relating to Class I Wells); 30 T §331.122, (relating to Class III Wells); 30 TAC §331.171, (relati to Post-Closure Care).

~~§331.46 of this title (relating to Closure Standards).~~

~~(b) The owner or operator shall:~~

~~(1) continue and complete any corrective action required under §331.44 of this title (relating to Corrective Action Standards);~~

~~(2) continue to conduct any groundwater monitoring and subsidence monitoring required under the permit until pressure in the injection interval reaches equilibrium with the salt stock. The executive director may extend the period of post-closure monitoring if he determines that the well or cavern may endanger an underground source of drinking water or freshwater aquifer;~~

~~(3) submit a survey plat to the local zoning authority designated by the executive director. The plat shall indicate the location of the well relative to permanently surveyed benchmarks, the depth of the cavern ceiling and floor, and the maximum cavern radius. A copy of the plat shall be submitted to the underground injection control (UIC) staff of the Austin office of the Texas Water Commission;~~

~~(4) provide appropriate notification and information to such state and local authorities as have authority over drilling activities to enable such state and local authorities to impose appropriate conditions on subsequent drilling activities that may penetrate the well's confining or injection zone;~~

~~(5) retain for a period of five years following well closure records reflecting the nature, composition, and volume of all injected materials. The executive director shall require the owner or operator to deliver the records to the executive director at the conclusion of the retention period, and all records shall thereafter be retained at a location designated by the executive director for that purpose.~~

~~Source: The provisions of this §331.171 adopted to be effective June 22, 1992, 17 TexReg 4097; amended to be effective January 7, 1995, 19 TexReg 10099.~~

SUBCHAPTER K. ADDITIONAL REQUIREMENTS FOR CLASS V AQUIFER STORAGE WELLS

§ 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.

Source: The provisions of this §331.181 adopted to be effective June 28, 1996, 21 TexReg 5443.

§ 331.182. Area of Review

The area of review for a Class V aquifer storage well is the area determined by a radius of ¼ 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.

Source: The provisions of this §331.182 adopted to be effective June 28, 1996, 21 TexReg 5443.

§ 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.

Source: The provisions of this §331.183 adopted to be effective June 28, 1996, 21 TexReg 5443.

§ 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).

Source: The provisions of this §331.184 adopted to be effective June 28, 1996, 21 TexReg 5443.

§ 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).

Source: The provisions of this §331.185 adopted to be effective June 28, 1996, 21 TexReg 5443.

§ 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.

Source: The provisions of this §331.186 adopted to be effective June 28, 1996, 21 TexReg 5443.

Cross References: This Section cited in 30 TAC §331.185, (relating to Monitoring and Reporting Requirements).

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Appendix E

§ 295.14. Signature of Applicant

The application shall be signed as follows.

(1) If the applicant is an individual, the application shall be signed by the applicant or the applicant's duly appointed agent. An agent shall provide written evidence of his or her authority to represent the applicant. If the applicant is an individual doing business under an assumed name, the applicant shall attach to the application an assumed name certificate from the county clerk of the county in which the principal place of business is located.

(2) A joint application shall be signed by each applicant or each applicant's duly authorized agent, with written evidence of such agency to be submitted with the application. If land is owned by both husband and wife, each shall sign the application. Joint applicants shall select one among them to act for and represent the others in pursuing the application with the commission, with written evidence of such representation to be submitted with the application.

(3) If the application is by a partnership, the application shall be signed by one of the general partners. If the applicant is a partnership doing business under an assumed name, it shall attach to the application an assumed name certificate from the county clerk of the county in which the principal place of business is located.

(4) If the applicant is an estate or guardianship, the application shall be signed by the duly appointed guardian or representative of the estate, and a current copy of the letters issued by the court shall be attached to the application.

(5) If the applicant is a corporation, public district, county, municipality, or other corporate entity, the application shall be signed by a duly authorized official. Written evidence in the form of bylaws, charters, or resolutions which specify the authority of the official to take such action shall be submitted. A corporation may file a corporate affidavit as evidence of the official's authority to sign.

(6) If the applicant is acting as trustee for another, the applicant shall sign as trustee and in the application shall disclose the nature of the trust agreement and give the name and current address of each trust beneficiary.

Source: The provisions of this §295.14 adopted to be effective May 28, 1986, 11 TexReg 2324.

§ 295.15. Sworn Application Required

Each applicant shall subscribe ~~and swear~~ to the application before ~~any person~~ entitled to administer oaths, who shall ~~also sign his~~ or her name and affix his or ~~her~~ seal of office to ~~the~~ application.

~~Source: The provisions of this §295.15 adopted to be effective May 28, 1986, 11 TexReg 2324.~~

REQUIREMENTS FOR THE STORAGE OF APPROPRIATED SURFACE WATER IN AQUIFERS

§ 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.

Source: The provisions of this §295.21 adopted to be effective June 28, 1996, 21 TexReg 5441.

Cross References: This Section cited in 30 TAC §295.22, (relating to Additional Requirements for the Underground Storage of Surface Water for Subsequent Retrieval and Beneficial Use).

§ 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 Chapters 305 and 331 of this title (relating to Consolidated Permits and Underground Injection Control));

(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.

Source: The provisions of this §295.22 adopted to be effective June 28, 1996, 21 TexReg 5441.

Cross References: This Section cited in 30 TAC §295.21, (relating to Aquifer Storage and Retrieval Projects).

~~ADDITIONAL REQUIREMENTS~~
~~FOR IRRIGATION~~

~~§ 295.31. Ownership Information Required; Exceptions~~

~~An applicant, seeking the use of state water for irrigation of particular tracts of land, shall be required to offer proof to substantiate his or her ownership of the land, except as otherwise provided herein. This section does not apply to an applicant which is a water corporation, water district, river authority, or governmental entity authorized to supply water to others.~~

~~**Source:** The provisions of this §295.31 adopted to be effective May 28, 1986, 11 TexReg 2324.~~

~~§ 295.32. Documents and Information To Be Submitted~~

~~(a) An application to irrigate particular tracts of land shall contain the following information concerning the lands proposed to be irrigated:~~

~~(1) the original land survey or grant, the abstract number, and the name of the county in which the land is located;~~

~~(2) an aerial photograph, plat, or map submitted in accordance with §295. 123 of this title (relating to Content Requirements of Maps) showing the tract of land within which a specified number of acres will be irrigated;~~

~~(3) a copy of the deed describing the applicant's land, showing recording information from the county deed records;~~

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Appendix F

Submittal Requirements

Rules adopted by the TNRCC divide ASR projects into Phase I and Phase II. Phase I is determination of feasibility of ASR for storage and retrieval for beneficial use. Phase I includes the installation and operation of a demonstration well. Phase II is the long-term implementation of ASR once it has been determined to be successful.

Phase I Requirements

A new water right or an amendment to an existing water right is not required for Phase I of an ASR project if the applicant currently holds an existing water right and if the applicant does not intend to change the purpose of use of the water stored in the ASR project to be different than that in the water right. However, written notification to the executive director of the TNRCC, not later than 60 days prior to the proposed storage of water, is required. That notification shall include the following information (Section 295.21 (c) and HB1989) :

1. all information required for an application for a permit or permit amendment to appropriate state water, which includes (Section 295.22):
    a. all information required for an application for a permit for a Class V injection well;
    b. 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; and
    c. if applicable, a letter from the Texas Water Development Board indicating an area has been designated in accordance with Section 11.155(b)(3) of the Texas Water Code;
    d. if applicable, the application for storage of surface water in an underground water reservoir or a subdivision of an underground water reservoir that is under the jurisdiction of an underground water conservation district. This must include:
        i) evidence acknowledging service, by certified mail, of a copy of the application or notification submitted in accordance with Section 295.21 to the underground water conservation district having jurisdiction over the aquifer; and
        ii) 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 of appropriated surface water in the underground water reservoir or a subdivision thereof.
2. all information required for application for a permit for a Class V injection well (covered above in (1)(a)); and
3. a map or plat showing the injection facility and the aquifer in which surface water will be stored (covered above in (1)(b)).

Phase I Special Requirements

If the project requirements are to store appropriated water in a groundwater reservoir or a subdivision of a groundwater reservoir, as defined by Chapter 36, that is under the jurisdiction of a groundwater conservation district, the applicant shall (Section 11.154(b)):

1. provide a copy of the application to each groundwater conservation district that has jurisdiction over the reservoir or subdivision;
2. cooperate with each district that has jurisdiction over the reservoir or subdivision to ensure compliance with the rules of each district;
3. 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
4. comply with the rules governing the injection, storage, and withdrawal of appropriated water stored in the reservoir or subdivision that are adopted by each district that has jurisdiction over the reservoir or subdivision.

In addition, the TNRCC shall require that any agreement that 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.

ASR wells fall under the Class V injection well category of the Underground Injection Control (UIC) program. Although the demonstration well is "authorized by rule," and therefore requires no permit, constraints are placed on the construction, operation, and closure of such wells. These constraints must be adhered to for the construction of both Phase I and Phase II ASR wells (Section 331.131 through 331.133 and 331.181 through 331.184).

1. The area of review is defined as a 1/4-mile radius around the well bore.
2. Information on activities within the area of review including adverse impacts, if any, on the injection operation:
   a. location of all artificial penetrations that penetrate to the interval to be used for ASR storage
   b. completion and construction information, where available, for all artificial penetrations
   c. site specific significant geologic features such as faults and fractures
3. Construction and closure standards must include design, construction, completion and closure to prevent commingling, through the wellbore and casing, of injection waters with other fluids outside of the authorized injection zone; mixing through the wellbore casing of fluids from aquifers of substantially different water quality; infiltration through the wellbore and casing of water from the surface.
   a. Plans, specifications, and construction must be in accordance with Section 331.132
   b. No injection may occur into unauthorized injection zones

   c. The executive director must be notified immediately of any changes, including but not limited to, well completion issues, screen settings, and changes in injection intervals
   d. Casing materials must be constructed of materials resistant to corrosion
   e. All phases of construction must be supervised by qualified individuals
   f. Well closure must be in accordance with Section 331.133.

4. Operating requirements include:
   a. All Class V aquifer storage wells will be operated so they do not present a hazard to or cause pollution of an underground source of drinking water
   b. Injection pressures at the wellhead shall not cause movement of fluid out of the injection zone
   c. A well shut down for more than two years cannot be re-started without 30-day notice to the executive director
   d. Mechanical integrity of wells will be maintained
   e. The quality of water injected must meet drinking water standards as provided in Chapter 290

Phase I Data Gathering

During operation of the Phase I ASR well (demonstration project), the following must be monitored at the required frequency and reported to the executive director of TNRCC on a quarterly basis or a schedule to be agreed upon by the executive director (Section 331.185):

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.

Reporting Phase I Results

Upon completion of Phase I, which includes drilling and testing of the ASR test well, under Section 331.185 a Class V injection well permit holder is required to submit within 45 days of the completion of the Phase I study an application for final authorization to the executive director and shall include items in Section 331.186, which are:

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.

Phase II

Phase II Requirements

The October 4, 1996, Texas Register contains proposed rules for implementation of Phase II of ASR projects within the state. These rules cover the additional permitting and technical procedures and requirements a project sponsor will have to complete in order to obtain a Phase II (permanent authorization) permit for an aquifer storage and retrieval project which would store appropriated surface water in an aquifer. The following summarizes the proposed Phase II rules:

1. An applicant must file a permit application and obtain a permit prior to injection of appropriated surface water.
2. The application will not be accepted for processing by the TNRCC until the applicant has obtained necessary authorizations and has successfully completed a Phase I project.
3. The application must include:
   a. a copy of the final report of the Phase I study
   b. an operations plan for the life of the project detailing:
      i) injection rates and volumes;
      ii) frequency of injection periods;
      iii) retrieval rates and volumes;
      iv) radial distances of travel from the injection wells on an annual basis;
      v) maximum extent of travel for the life of the project; and,
      vi) location of all injection, retrieval and monitoring wells.
   c. a report identifying any potential impacts to artificial penetrations within one-quarter mile of the perimeter of the buffer zone
   d. a proposed monitoring plan that would address the quality of the water injected and retrieved and the water levels of the receiving body of underground water within the perimeter of the buffer zone and within one-quarter mile of the perimeter of the buffer zone
   e. how the waters injected and retrieved will be measured and reported
   f. other information as determined by the executive director as necessary
   g. applicants lacking the power of condemnation proposing to store state water in and withdraw it from underneath or to place any installation upon the land of another, must also provide the names and addresses of the affected landowners, and a copy of a duly acknowledged written easement, consent or license, or a written lease or other agreement

   h. overall plan of the project area
   i. names and locations of storage zones
   j. general direction of flow in the proposed storage zones
   k. cross sections and profiles of the storage zones and confining layers
   l. operating depths of all injection and retrieval facilities
   m. location of any Critical Area as defined under Chapter 294
   n. location of a buffer zone surrounding the land surface area under which the underground storage of state water will occur and beyond which pumpage by other wells will not interfere or significantly affect the movement or storage of state water
   o. location and ownership of domestic, public water supply, irrigation or commercial wells within one quarter mile of the perimeter of the buffer zone

4. An operations report will be required on the five year anniversary of the permit, and every ten years thereafter, or more frequently as determined by the executive director, that includes:
   a. describe efforts to protect the state water stored in the receiving aquifer from unauthorized withdrawals
   b. describe efforts to maximize the retrieval and beneficial use of the stored water without experiencing unreasonable losses of state water
   c. any potential or real impacts realized by the project
   d. all data, information and analyses associated with any monitoring done in accordance with the project
   e. a comparison of actual movement of injected state water with the modeling projections submitted with the application for permit
   f. an assessment of the project in terms of protection of ground water quality
   g. any additional information the executive director determines is necessary for the protection of underground sources of drinking water