Technical Note 15-04

AQUIFER STORAGE AND RECOVERY IN TEXAS: 2015

by

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Executive Summary

Aquifer storage and recovery is a well-established technology to improve the management of water resources in the state. Aquifer storage and recovery has been defined as "…the storage of water in a suitable aquifer through a well during times when water is available, and the recovery of water from the same well during times when it is needed." In 2009, the Texas Water Development Board (TWDB) commissioned a study to assess the technical, economic, and regulatory factors of aquifer storage and recovery. The study also made recommendations to advance aquifer storage and recovery in the state.

Statutes and rules governing aquifer storage and recovery in Texas can be grouped into three categories. These include (1) appropriation of water rights and permit requirements for surface water to be used in an aquifer storage and recovery system, (2) requirements for aquifer storage and recovery wells to be approved for use as Class V injection wells, and (3) powers given to groundwater conservation districts to regulate groundwater pumping. In almost all instances, water targeted for storage in an aquifer storage and recovery system must be treated to meet drinking water standards prior to injection.

Aquifer storage and recovery activities in Texas began in the 1940s in El Paso and Amarillo. Three entities used the strategy in the 1960s and 1970s, but the facilities have since ceased operation. The El Paso Water Utilities facility began operating in 1985 and is still in use today. The TWDB funded studies in the 1990s which aided the development of the City of Kerrville and San Antonio Water System projects. Presently, there are two strict aquifer storage and recovery facilities (City of Kerrville and the San Antonio Water System) and one hybrid aquifer storage and recovery facility (El Paso Water Utilities) in Texas, serving the cities of Kerrville, San Antonio, and El Paso.

The 2012 State Water Plan includes aquifer storage and recovery as a recommended water management strategy for six regional planning groups (Region E – Far West Texas, Region G, Region H, Region J – Plateau, Region K – Lower Colorado, and Region L – South Central Texas). If implemented, all of these strategies would yield an estimated 80,869 acre-feet of new water supplies by the year 2060. This is about 0.9 percent of all proposed new water supplies. The TWDB is monitoring an additional 10 entities that are evaluating the strategy for future use.

This report provides a summary of past, current, and future aquifer storage and recovery activities in Texas. The goal of this report is to help inform Texans about the potential benefits of aquifer storage and recovery and advance its successful implementation throughout the state.

Introduction

Aquifer storage and recovery is an established water management strategy that has been successfully implemented in Europe, the Middle East, and Australia. In the United States there are approximately 133 aquifer storage and recovery systems (Pyne, 2013). Florida leads the country with 37 active systems. In Texas, there are two strict (the City of Kerrville facility and the Twin Oaks Aquifer Storage and Recovery facility in San Antonio) and one hybrid (El Paso Water Utilities) aquifer storage and recovery facilities.

Aquifer storage and recovery (commonly referred to as ASR) is a method of storing water underground when it is available and retrieving it later when needed. If properly engineered and operated, the water stored in an aquifer storage and recovery system is not subject to the evaporative losses encountered in surface storage reservoirs and remains available for future use. Furthermore, aquifer storage and recovery systems have a small footprint relative to surface-water reservoirs. Aquifer storage and recovery is important because it creates a new and reliable water supply to meet demand during future water shortages.

One of the missions of the Texas Water Development Board (TWDB) is to inform and educate the community about innovative water management tools. The primary objective of this report is to provide an overview of past and current aquifer storage and recovery activities in Texas. The report summarizes the available information on regulations, historical activities, current facilities, and ongoing studies on aquifer storage and recovery. This technical note documents activities obtained from research and personal communications conducted by the TWDB, but may not be exhaustive. The report will be updated periodically to maintain its relevance.

Background

This section describes terms and methods used in various forms of storing and recovering water from the subsurface. The section also includes a summary of a 2011 TWDB-funded report that assessed the state of aquifer storage and recovery in Texas.

Methods and Terms

Numerous methods exist to artificially introduce water into the subsurface. Three common methods are enhanced surface infiltration, vadose zone well infiltration, and well injection. Enhanced surface infiltration involves holding water above a pervious land surface for a longer period or greater surface area than would occur naturally and allowing water to percolate through the surface to an underlying aquifer. This is accomplished with engineered spreading basins or by damming natural water courses. Its application is limited to areas with permeable geology between the surface and the aquifer. Engineered basins may require recurring maintenance to clear silt and biological materials to prevent clogging the infiltration surface. El Paso Water Utilities uses spreading basins to recharge the Hueco Bolson Aquifer with reclaimed water (Malcolm Pirnie, 2011).

In vadose zone well infiltration, relatively shallow, large-diameter wells, completed above the water table, facilitate infiltration. Water is pumped into the wells and allowed to seep into the subsurface.

Advantages of this method compared to spreading basins include the need for a relatively small land area per unit water recharged and its applicability in areas where the surface is impervious. Like spreading basins, vadose zone infiltration wells also require maintenance to manage physical and biological clogging (National Research Council, 2008). The City of Surprise, Arizona, uses 15 vadose zone wells to recharge groundwater with reclaimed water (Diane Arthur, City of Surprise, personal communication, 2014).

Finally, in well injection, water is injected using a well into a subsurface geological formation that can receive and store the water. Aquifer storage and recovery systems use wells that can both inject water into an aquifer and recover that water at a later time. The technology has various definitions. For example, the Texas Commission on Environmental Quality defines an aquifer storage well as a well that is "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" (30 TAC §331.2). In this definition, injection and recovery does not need to occur at the same well. The National Academy of Sciences requires that for a system to be considered an aquifer storage and recovery system, injection and recovery must occur from the same well (National Research Council, 2008). With the exception of the El Paso Water Utilities system, all studies and projects discussed in this report use the same well for injection and recovery.

Other terms used in conjunction with well injection include aquifer recharge, managed aquifer recharge, managed underground storage, and aquifer storage transfer and recovery. Aquifer recharge (AR) is the intentional introduction of water into an aquifer. It may use any method, and the water may not be recovered. If left underground, the introduced water may serve to reduce subsidence, prevent salt water intrusion, or serve some other beneficial use.

Managed aquifer recharge (MAR) is synonymous with aquifer recharge and is commonly applied in Europe and Australia (National Research Council, 2008). The National Research Council created the term managed underground storage (MUS) and defines it as "purposeful recharge of water into an aquifer system for intended recovery and use as an element of long-term water resource management." Any method of recharge may be used (National Research Council, 2008).

Aquifer storage transfer and recovery (ASTR) systems have the injection and recovery points at different locations. The purpose of the horizontal transfer of water is to attenuate microbial and chemical contamination (Maliva and Missimer, 2010). This process is also sometimes called hybrid aquifer storage and recovery.

Definitions

Terminology frequently used in this report is summarized below for reference. Study types are listed in increasing level of complexity. Well performance and storage terms then follow.

Preliminary evaluation: Indicates that a purveyor is contemplating aquifer storage and recovery and has considered basic concepts such as source water, target storage aquifer, type of beneficial use, and cost.

Phase 1 study: More extensive analysis than preliminary evaluation. Requires investigation of hydrogeological considerations including existing local well test data, water quality, well construction, and geophysical well log analysis (TWDB, 1997).

Phase 2 study: Indicates a comprehensive evaluation requiring drilling and testing of pumping and monitor wells to develop site specific hydraulic and water quality data (TWDB, 1997).

Recovery efficiency: The percentage of recharged water recovered. It is a function of the hydraulic properties of the storage aquifer, native water chemistry, and buffer zone establishment (Maliva and Missimer, 2010).

Specific capacity: The pumping flow rate per unit change in water level at the well. The units used in this report are gallons per minute per foot. Specific capacity during recharge is less than in recovery (Naismith, 2014).

Buffer zone: A zone of mixed water at the interface of the injected, or recharge, water and native groundwater. In most instances, the native groundwater is of lower quality than the recharge water and therefore undesirable for recovery. The volume of recharge water in the zone is called the buffer volume. More water is recharged than recovered during early aquifer storage and recovery operations to establish this zone (Naismith, 2014).

Target storage volume: The amount of water stored in the aquifer to meet project goals. It is the sum of buffer volume and the volume that will be recovered (Pyne, 2005).

Benefits and Challenges

Aquifer storage and recovery systems can serve as an alternative to surface reservoirs. They have three principal advantages related to evaporation, inundation, and sedimentation.

Water stored in an aquifer storage and recovery system does not experience evaporative loss. While water injected to establish the buffer zone is not recoverable and some water may drift from storage due to hydraulic gradients, over the life of a project most of the stored water is available for recovery. Surface storage reservoirs in Texas, on the other hand, lose a large amount of water to evaporation. A 2015 TWDB study of 114 reservoirs in the state concluded that in 2011, a historically dry year, 8.3 million acre-feet of water was lost to evaporation (Zhu and others, in review). In an average year, 7.2 million acre-feet of stored water is lost. This average annual water loss is approximately 21 percent of the total combined available storage in Texas reservoirs (33.8 million acre-feet) and 40 percent of the annual Texas water demand (18 million acre-feet) reported in the 2012 State Water Plan.

Another advantage of aquifer storage and recovery is that it eliminates the need to inundate large areas of land. For example, a modestly sized Texas reservoir (capacity of 36,500 acre-feet) has an inundated area of about 2,515 acres. Only a small fraction of this area would be lost if aquifer storage and recovery were implemented.

Aquifer storage and recovery systems are also not affected by sedimentation where suspended solids in streamflows settle to the bottom of surface reservoirs and reduce storage capacity. The 2007 State Water Plan documented that sedimentation accounts for a decrease in surface storage of 0.27 percent annually. While this percentage is small, the loss is approximately 90,000 acre-feet annually and amounts to 13 percent of storage capacity over a 50-year period.

Aquifer storage and recovery can also provide cost benefits. Water treatment and distribution systems need to meet peak demands. Water stored in an aquifer storage and recovery system commonly requires only disinfection when recovered because it is already treated to drinking water standards prior to storage. This recovered water can then be used to meet peak demands. As a result, it can eliminate the need to expand a water treatment plant, resulting in capital cost savings. Furthermore, if the recovery well is sited near a utility's demand centers and is used to meet peak demands, smaller capacity pipelines can be used, resulting in cost savings.

Aquifer storage and recovery systems do have some disadvantages compared to surface-water reservoirs. Because aquifer storage and recovery facilities are limited by treatment and pumping capacity, they do not offer flood control. Also, if water is stored in an aquifer that has native groundwater containing less than 10,000 milligrams of total dissolved solids, the injected water must be treated to meet primary drinking water standards. This makes aquifer storage and recovery more expensive, especially for applications such as irrigation or power plant cooling where potable water may not be required.

2011 Aquifer Storage and Recovery Assessment Report

In 2009, the TWDB funded a $102,000 study (TWDB Contract No. 0904830940) to assess the status of aquifer storage and recovery in the state and to determine the reasons for this well-established water management solution not being used more in Texas. The study provided insight into the opinions of water purveyors in the state on aquifer storage and recovery as well as recommendations to aid in aquifer storage and recovery implementation (Malcolm Pirnie, 2011).

For the study, the contractor conducted a survey of 22 utilities (responses received from 17 utilities), 10 of which had considered aquifer storage and recovery. The utilities were asked questions related to their need for additional water storage. For the 10 utilities that has considered ASR, the primary concerns noted were

- ability to recover stored water,
- quality of recovered water,
- cost effectiveness of aquifer storage and recovery, and
- potential for others to recover the stored water.

The ability to recover stored water can be affected by migration and mixing with native water. Migration, the movement of stored water away from the point of injection due to hydraulic gradients, is an important consideration in the design and operation of an aquifer storage and recovery system, especially when the water is planned to be stored for long periods. The effect on recovery efficiency needs to be addressed during the development phase of a project. Water quality concerns also need to be considered as part of the migration issue, especially in cases where native water quality is low.

The study also concluded that reliable information on the operation and maintenance costs for aquifer storage and recovery systems was lacking. Utilities typically aggregate these costs with other water system costs making it difficult to determine the costs of an aquifer storage and recovery system. Differentiating these costs could provide valuable information to entities considering the technology.

Protection of stored water was also a concern. Facilities have used storage zones that are difficult to access and administrative means such as land ownership and municipal ordinances to address the issue. Protection of stored water continues to be a subject of legislative focus.

Some of the regulatory modifications that were suggested to make conditions more favorable for implementation of aquifer storage and recovery in Texas included

- amending Chapter 11 (Texas Water Code) to increase opportunities to appropriate and store water in aquifer storage and recovery systems;
- facilitating permitting of surface-water diversions on a seasonal basis;
- expressly stating in Chapter 11 (Texas Water Code) the percentage of stored water that may be required to be left in the aquifer by a groundwater conservation district;
- amending Chapter 36 (Texas Water Code) to require groundwater conservation districts to accept Class V injection permits as the only authorization needed for aquifer storage and recovery project; and
- amending Chapter 36 (Texas Water Code) to prohibit groundwater conservation districts from restricting aquifer storage and recovery operators from pumping stored water.

Regulatory

This section describes the statutes and rules that govern aquifer storage and recovery systems.

Source Water Permitting Requirements

In 1995, the 74th Legislature passed House Bill 1989 to include provisions for aquifer storage and recovery in Chapter 11 of the Texas Water Code (TWC). The bill stated that aquifer storage and recovery projects would enhance conservation by minimizing evaporative losses, reduce environmental impacts associated with surface reservoirs, and enhance the groundwater resources of the state.

The statute calls for temporary permitting by the Texas Commission on Environmental Quality for pilot programs (TWC §11.153) and permanent permitting upon successful completion (TWC § 11.154). Regulations state that any aquifer storage and recovery project must comply with the rules of any groundwater conservation district that has jurisdiction at the well field.

House Bill 1989 also mandated that the Commission complete feasibility studies of seven potential storage formations in eight counties resulting in 16 evaluations. In 1997, the TWDB compiled findings in a report to the 75th legislature. Of the 16 evaluations, 12 were found to likely not be favorable storage formations, primarily because of low well yields. Four were technically promising, but in three of the four evaluations, typical groundwater production proved less costly than aquifer storage and recovery. The only evaluation where aquifer storage and recovery was implemented was in the Carrizo-Wilcox Aquifer in Bexar County which is being used for the San Antonio Water System's Twin Oaks Aquifer Storage and Recovery facility.

Additionally, House Bill 1989 required the TWDB to study the aquifers of the state to determine suitable areas for aquifer storage and recovery projects and report on findings biannually. In response, the TWDB partially funded Phase 1 and 2 studies for the Brownsville Public Utilities Board (completed in 1997) and the City of Laredo (completed in 1999). Portions of the funds were used for a watershed management plan study for the Sabine River Authority which was completed in 1999. The TWDB also funded a Phase 1 study for San Antonio Water System that was completed in 1998. All studies indicated aquifer storage and recovery was feasible but warranted more detailed evaluation. The Brownsville Public Utilities Board, the City of Laredo, and the Sabine River Authority decided not to move forward with aquifer storage and recovery projects. The Phase 1 study of the San Antonio Water System led to the construction of the current Twin Oaks Aquifer Storage and Recovery facility. Biennial reports were provided to the 75th and 76th Texas legislatures in 1997 and 1999, respectively. The reporting requirement was rescinded by House Bill 1378 in 2003.

Underground Injection Wells

Water for aquifer storage and recovery systems is injected into the subsurface using U.S. Environmental Protection Agency Class V injection wells under that agency's Underground Injection Control program. The purpose of Class V injection well regulations in Texas is to "…to maintain the quality of fresh water in the state to the extent consistent with the public health and welfare…" (TWC §27.003). The Texas Commission on Environmental Quality enforces construction, operating, and monitoring requirements for Class V injection wells per 30 TAC Chapter 331, Subchapters H and K. Two primary operating requirements on water quality that affect aquifer storage and recovery design and operations (30 TAC §331.184) are:

(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.

(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).

These requirements have been interpreted as requiring recharge water to be treated to primary drinking water standards prior to injection and continuing to meet all U.S. Environmental Protection Agency primary drinking water standards while in storage. The added expense of treating water to meet drinking water standards makes aquifer storage and recovery less attractive for some applications such as irrigation where water of potable quality is not needed.

Groundwater Conservation Districts

Groundwater conservation districts were first authorized in 1949 under the authority of Article III, Section 52 and Article XVI, Section 59, of the Texas Constitution. This authority is now contained in Chapter 36 of the Texas Water Code. The purpose of the legislation is to "provide for the conservation, preservation, protection, recharging, and prevention of waste of groundwater, and of groundwater reservoirs or their subdivisions," and "is the preferred method of groundwater management" (TWC Chapter 36). While state law specifies that groundwater below a landowner's property belongs to the landowner, it also authorizes districts to regulate the permitting, spacing, and production from wells in their jurisdiction. Aquifer storage and recovery wells may be regulated by a groundwater conservation district if the well field is within its jurisdiction.

As of February 2015, there were 98 groundwater conservation or subsidence districts in the state. Eighteen districts have rules on aquifer storage and recovery (Table 1). Some, such as the Edwards Aquifer Authority, have extensive rules while many other districts have only limited rules. The ability of a district to alter its regulations has been noted as a significant impediment to aquifer storage and recovery development in Texas (Malcolm Pirnie, 2011).

Table 1. Groundwater conservation district rules for aquifer storage and recovery.

Districts with rules for aquifer storage and recovery projects	**Most recent year published**
Corpus Christi Aquifer Storage and Recovery Conservation District	2008
Edwards Aquifer Authority	2014
Evergreen Underground Water Conservation District	2009
Irion County Water Conservation District	2006
Jeff Davis County Underground Water Conservation District	2006
Medina County Groundwater Conservation District	2013
Plum Creek Conservation District	2009
Sterling County Underground Water Conservation District	2009
Sutton County Underground Water Conservation District	2003
Wintergarden Groundwater Conservation District	2007
Districts with rules for aquifer recharge facilities	
Gonzales County Underground Water Conservation District	2010
Guadalupe County Groundwater Conservation District	2011
Hemphill County Underground Water Conservation District	2013
Permian Basin Underground Water Conservation District	1993
Uvalde County Underground Water Conservation District	2010
Districts with rules for both aquifer storage and recovery and recharge facilities	
Lipan-Kickapoo Water Conservation District	2007
Real-Edwards Conservation and Reclamation District	2013
Districts with existing aquifer storage and recovery projects	
Headwaters Groundwater Conservation District	2014
Districts with rules explicitly prohibiting aquifer storage and recovery projects	
None found	

Source: Compiled from various groundwater conservation district rules.

Aquifer Storage and Recovery Activities in Texas

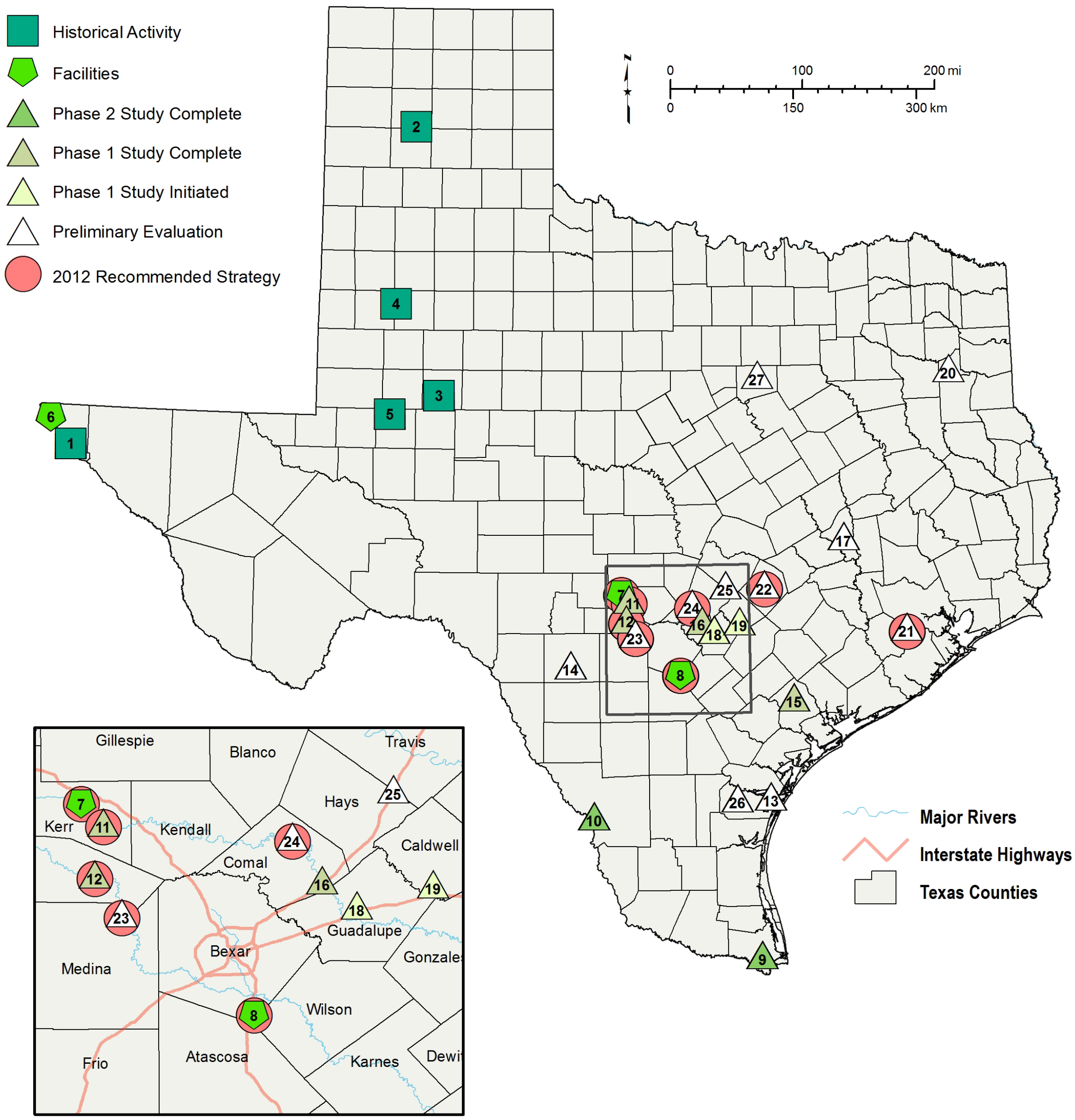
Aquifer storage and recovery is an established water management strategy that has been successfully implemented in Europe, the Middle East, and Australia. In the United States, there are approximately 133 aquifer storage and recovery systems (Pyne, 2013). Florida leads the country with 37 active systems (Joe Haberfeld, Florida Department of Environmental Protection, personal communication, 2014).

In Texas, activities on aquifer storage and recovery date back to the 1940s and 1950s with studies in El Paso and Amarillo (Sundstrom and Hood, 1952; Moulder and Frazer, 1957). In the 1960s, operational systems were in place in Texas (TWDB, 1997; Malcolm Pirnie, 2011). In 1995, the passage of House Bill 1989 by the 74th Texas Legislature established the statutory framework for aquifer storage and recovery and called for further studies of potential aquifer storage and recovery applications in Texas.

Currently, there are two aquifer storage and recovery facilities (the City of Kerrville facility and the Twin Oaks Aquifer Storage and Recovery facility in San Antonio) and one hybrid aquifer storage and recovery facility (El Paso Water Utilities) in Texas.

Six regional water planning groups recommended aquifer storage and recovery as a water management strategy in the 2012 State Water Plan. These strategies are expected to produce 80,869 acre-feet of new water supply in decade 2060. In comparison, the 2007 State Water plan included strategies to produce only 28,860 acre-feet.

The TWDB is monitoring 10 entities that are currently evaluating aquifer storage and recovery for future use. Past and current aquifer storage and recovery activities in Texas are listed in Figure 1. Details of the projects shown in Figure 1 such as the project name, the TWDB contract number, and regional water planning group are provided in Table 2.



Source: Compiled from various sources.

Figure 1. **Aquifer storage and recovery activity in Texas; numbers in symbols represent a project described in Table 2.**

Table 2. Project name and regional water planning areas for projects shown in Figure 1.

Historical Activity		
Project number	**Project name (TWDB contract or project number)**	**Regional water planning area**
1	City of El Paso	E
2	City of Amarillo	A
3	Colorado River Municipal Water District	F
4	High Plains	O
5	City of Midland	F
Facilities		
6	El Paso Water Utilities	E
7	City of Kerrville (91483788)	J
8	San Antonio Water System (97483215)	L
Phase 2 Study Complete		
9	Brownsville Public Utilities Board (95483133)	M
10	City of Laredo (96438170)	M
Phase 1 Study Complete		
11	Kerr County (0704830695)	J
12	Bandera County (0704830695)	J
13	City of Corpus Christi	N
14	City of Uvalde (1348321575)	L
15	City of Victoria (1348321576)	L
16	New Braunfels Utilities	L
Phase 1 Initiated		
17	City of College Station	G
18	Guadalupe-Blanco River Authority Mid-Basin (21698)	L
19	Luling Water Treatment Plant (21698)	L
Preliminary Evaluation		
20	Sabine River Authority (97483214)	D
21	Missouri City Groundwater Reduction Plan	H
22	Lower Colorado River Authority	K
23	Medina Lake Firm Up	L
24	Storage Above Canyon Reservoir	L
25	Barton Springs/Edwards Aquifer Conservation District	L,K
26	Robstown-Driscoll Regional Facility	N
27	Trinity Aquifer in Johnson County	G

Source: Compiled from various sources.

Early Studies in Texas

Studies and applications of aquifer storage and recovery systems in Texas occurred many years before the three existing facilities were built. Starting in the late 1940s, the U.S. Geological Survey and partners evaluated aquifer response to well-induced recharge and recovery in the El Paso and Amarillo areas.

City of El Paso

From 1947 to 1952, the U.S. Geological Survey, the Texas Board of Water Engineers, and the City of El Paso collaborated on the earliest known evaluation of aquifer storage and recovery in Texas (Sundstrom and Hood, 1952). The city hoped that recharging the aquifer with surface water would alleviate the problem of declining water levels due to pumping. The intent of the study was to evaluate the ability to recharge, store, and recover treated Rio Grande source water from the Hueco Bolson Aquifer during the winter months.

Recharge and recovery experiments were performed during the winter months from 1947 to 1951 at the city's Montana well field. Testing was not performed in 1949 because the surface-water plant was down for maintenance. Four wells were used to recharge 270 acre-feet of treated water from November 1950 to February 1951. Recovery began shortly after the completion of recharge and 674 acre-feet of water was extracted.

The percentage of stored water to native water in the recovered water was calculated using relative sulfate ion concentrations as an indicator. Significant mixing was noted with the percentage of stored water falling below 50 percent after 245 acre-feet of recovery. This was a result of recovering 100 percent of the injected water during the summer irrigation season continually after each previous recharge cycle and not establishing a buffer zone.

Data were provided for aquifer response at one of the test wells. During various recharge events, the water levels at the well increased between 44 and 50 feet. There was very little storage time so water-level changes with time were not noted. Pumping tests during initial construction in 1928 indicated a specific capacity of 18.1 gallons per minute per foot. By the end of the experiment in 1952, 542 acre-feet of water had been injected into the well and the specific capacity was 17.8 gallons per minute per foot. The consistency in specific capacity measurements indicated that well plugging was not an issue during the experiment.

The study concluded that four wells, spaced 1,500 feet apart, could successfully recharge at a combined rate of six million gallons per day for an indefinite period. It further concluded that such action would counteract the water-table declines during recovery. We could not find information on follow-up actions that El Paso may have taken as a result of the experiments.

City of Amarillo

Between 1954 and 1955, the U.S. Geological Survey in coordination with the City of Amarillo and the Texas Board of Water Engineers conducted a study similar to that of El Paso (Moulder and Frazor, 1957). Amarillo's population was increasing at a rapid rate requiring future pipeline transmission capacity from remote well fields to be sized to meet greater peak demands. City planners believed that if water could be stored locally, these pipelines could be sized to meet average demand resulting in cost saving. In this context, the city was considering aquifer storage as a lower cost alternative to conventional storage facilities. The elimination of evaporative losses and increased remote well field utilization were also viewed as benefits to using aquifer storage and recovery.

The goal of the Amarillo study was to evaluate the practicality of recharging the aquifer through existing wells, analyze aquifer storage and flow characteristics, assess the effect of aquifer storage on water levels, and evaluate recovery efficiency. The source water used in the study originated from the Ogallala Aquifer, which was also the storage aquifer. The McDonald well field was chosen because it was the closest (0.75 miles) to the city.

The experiments were performed using two recharge and recovery wells (B-25 and B-26) at the McDonald well field. Six monitoring wells were also installed at varying distances from the injection wells to monitor the influence of pumping on area water levels.

The injected and native water quality was similar, making it difficult to determine the volume of each in the recovered water. Sodium chloride was introduced into the recharge water during the later phase of recharge to increase its chloride concentration and allow it to be differentiated from the native water. Under current-day regulations, increasing the total dissolved solids of injected water would not be allowed.

Only one recharge and recovery cycle was used for the experiment, during the low demand time period from November 1954 to March 1955. During the period, 405 acre-feet and 353 acre-feet were recharged into B-25 and B-26, respectively. Pumping rates varied from 200 to 1,000 gallons per minute. There was no evidence of well plugging during the experiment.

Water levels at the injection wells rose 85 feet during the recharge phase of the experiment. A water-level rise was also detected at the monitoring wells with the amount of rise decreasing with distance from the point of injection. The rise in water level dissipated rapidly after recharge ceased indicating good subsurface flow performance throughout the study area. A monitor well located 0.6 miles from the injection site showed no change in water level during recharge, indicating that the recharge mound had a limited spatial extent.

After recovery commenced (the wells had been idle for between 5 and 10 days), data was collected from well B-25 to estimate recovery efficiency. During the final phase of recharge, 276 acre-feet of chloride-enriched water had been recharged and 307 acre-feet was subsequently recovered. Estimated relative proportions of early- and late-phase recharge in the recovered water were calculated. Data indicated that between 78 and 90 percent of the late phase recharge water had been recovered by the completion of the experiment. Significant mixing of water was also evident. This was expected because the experiment did not establish a buffer zone between the native and injected water.

The experiment produced favorable findings. The wells did not show any signs of well plugging during operation. Water levels responded as expected and monitor well data indicated good flow away from the point of injection. The recovery phase demonstrated that the stored water could be recovered. As in the case of the El Paso project, we could not find follow-up action that Amarillo may have taken as a result of the experiment.

Early Applications in Texas

Much of the discussion related to aquifer storage and recovery in Texas focuses on existing facilities in El Paso, Kerrville, and San Antonio. However, the TWDB is aware of three other water purveyors that employed aquifer storage and recovery technology before the term was even created. From the mid-1960s to 1990s, aquifer storage and recovery methods were used by the Colorado River Municipal Water District, several municipalities in the High Plains, and the City of Midland.

Colorado River Municipal Water District

The Colorado River Municipal Water District operated an aquifer storage and recovery system from 1963 to 1970 (Malcolm Pirnie, 2011). The J.B. Thomas Reservoir was the source of the recharge water that was piped to the Martin County Well Field located northwest of Stanton, Texas. The district had excess pipeline capacity during the winter months and stored the water in the Ogallala Aquifer. Water was recovered during the summer months to meet peak demands for the City of Odessa. This is the only aquifer recharge system in Texas known to have injected untreated surface water. Such activity today would violate regulatory requirements.

Injection operations ran from December 1963 to March 1964 at an average rate of 1.8 million gallons per day, placing 500 acre-feet into storage. Injection capacity increased to 2.25 million gallons per day in 1966 and to 3.2 million gallons per day in 1968. The District's operating report for 1966 stated that the system "has proved to be both economical and a satisfactory method of operation." The District had over 1,100 acre-feet of water in storage by the end of 1968 and reported very high recovery efficiencies.

In 1969, a new pipeline was built to integrate the newly constructed E.V. Spence Reservoir. This redesign eliminated the excess pipeline capacity. As a result, aquifer storage and recovery operations were discontinued and all stored water was recovered by 1970.

More recently, the water district has been re-evaluating aquifer storage and recovery as a strategy in the district's future water plans, perhaps in conjunction with brackish water desalination. However, the district does have concerns about protecting the stored water from use by others and the possible migration of the water from their well fields (Malcolm Pirnie, 2011).

High Plains

Aquifer storage and recovery was also implemented by the communities of Lamesa, Levelland, and Lubbock in the early 1970s (TWDB, 1997). Treated water from Lake Meredith was stored in the Ogallala Aquifer. The pricing arrangement for the communities' water supply was on a "take or pay" basis. The communities paid fixed pumping and treatment costs regardless of how much water from Lake Meredith they used. Because their demand was below the level of contracted supply at this time, they decided to take their full allocation and store the excess water. However, by the mid-1980s, water demand increased such that there was no excess supply and the aquifer storage and recovery practice was discontinued.

City of Midland

Beginning in the 1970s, the City of Midland used aquifer storage and recovery to maximize well production near the city (TWDB, 1997). The city's McMillan Well Field, which pumped water from the Ogallala Aquifer, was more productive than its Airport Terminal Field, which drew water from the Antlers Formation of the Edwards-Trinity (High Plains) Aquifer. However, the Airport Terminal Field was closer to the city than the McMillan Well Field.

Water from the McMillan Well Field was used to recharge the Airport Field, which increased water levels and productivity of the Airport Terminal wells. The increased well yield aided the city in meeting peak demands. One study notes that operations ceased when increased water demand outstripped excess supply available for recharge (TWDB, 1997).

However, Midland may have discontinued the aquifer storage and recovery operations because of concerns with protecting the stored water and possible perchlorate contamination at the storage well field (Malcolm Pirnie, 2011).

House Bill 1989 Studies

House Bill 1989, 74th Texas Legislature, authorized the use of TWDB funds for aquifer storage and recovery feasibility studies. In fiscal years 1996 and 1997, the TWDB allocated $500,000 from the Water Assistance Fund to the Research and Planning Fund to support these studies. The TWDB also provided $216,000 of in-kind services through the use of the TWDB's drill rig, rig personnel, and well-logging equipment. The addition of $161,000 of federal funds increased the total funding effort to $877,000. Studies were funded for the Brownsville Public Utilities Board, the City of Laredo, the Sabine River Authority, and the San Antonio Water System.

Brownsville Public Utilities Board

In June 1995, the TWDB provided $225,000 (TWDB Contract No. 95483133) to the Brownsville Public Utilities Board to perform a Phase 2 evaluation of the feasibility of aquifer storage and recovery. An additional in-kind contribution of $117,000 consisting of use of the TWDB drilling rig, rig crew, and well-logging equipment was added to the grant. The total cost of the study was $450,000, and the final report was completed in September 1997 (CH2M Hill, 1997).

The Brownsville Public Utilities Board sought to maximize the use of water rights and minimize the water treatment plant capacity needed to meet peak demands. The water source was the Rio Grande. The utility had some senior water rights but also a junior right (Permit 1838) for 40,000 acre-feet. The study found that an aquifer storage and recovery system with a recovery capacity of between 10 and 15 million gallons per day would allow the effective use of the Utility's junior rights. Stored water could be diverted during high flow periods and recovered during high demand periods to meet project goals.

The capacity of the water treatment plant was 40 million gallons per day. Projections indicated that peak demand would exceed that capacity by 2005. The study concluded that a peak demand of 49 million gallons per day could be met with aquifer storage and recovery, deferring the expansion of the water treatment plant beyond 2012.

Three storage zones within the Gulf Coast Aquifer (the Gravel, Intermediate, and Lower Zones) were investigated. The Gravel Zone was the shallowest, most documented, and demonstrated good water quality and well yields. Therefore, it was chosen for a test drilling program (CH2M Hill, 1996a).

The TWDB participated in the test drilling program and performed the drilling and lithological and geophysical log analysis. A team drilled six borings and installed three monitoring wells over a seven-month period beginning in October 1995. Results indicated that the water quality was compatible with existing water in the distribution system and well yields were good in some areas but with high spatial variability. The study recommended the development of a prototype aquifer storage and recovery well in the Gravel Zone (CH2M Hill, 1997). Since completing the feasibility study, no additional work is known to have been conducted by the Brownsville Public Utilities Board.

City of Laredo

The TWDB funded a Phase 2 aquifer storage and recovery study for the City of Laredo (TWDB Contract No. 96438170). The grant was approved in November 1995 for $200,000 with an additional $99,000 of in-kind services including a drilling rig, rig staffing, and well log analysis. Completed in January 1999, the total cost of the study was $485,000 (CH2M Hill, 1999).

The City of Laredo had relied solely on the Rio Grande for water supply. Future increases in population and water demand would exceed the City’s water rights. The City was also concerned about potential curtailment of its water rights in times of drought. Therefore, the City evaluated the potential for storing excess Rio Grande water in an aquifer storage and recovery system to fully utilize its water rights. Three geological formations were initially selected as potential storage zones. These were identified as the Laredo, Bigford, and Carrizo formations. Evaluation of well yield, formation depth, and water quality determined that the Laredo Formation was the most viable storage option. It was chosen for further study using test wells (CH2M Hill, 1996b).

The TWDB contributed equipment and staff to perform the test drilling program in the Laredo Formation. The program entailed analyzing samples from 17 existing water wells and installing four test wells, each with an associated monitoring well. High injection pressures were needed for recharge, and testing confirmed the wells had a high propensity to plug. Chemical analyses suggested that calcium was precipitating as calcium carbonate in the aquifer.

The study concluded that aquifer storage and recovery was possible although transmissivity and physical plugging of the storage zone were concerns. Recommendations for future evaluations of aquifer storage and recovery included investigations of methods to increase well yield, pretreatment options to minimize calcium precipitation, and implementation of ordinances to protect stored water from withdrawal by others (CH2M Hill, 1999). No further evaluation of aquifer storage and recovery is known to have been undertaken by the City of Laredo.

Sabine River Authority

An evaluation of aquifer storage and recovery was a component of a comprehensive watershed management plan for the Sabine River Authority. A $36,000 TWDB grant (TWDB Contract No. 97483214) was approved in September 1996. The total cost of the project was $486,000, and the plan was completed in December 1999 (Freese and Nichols, 1999).

Five municipalities were evaluated for aquifer storage and recovery with two, Kilgore and Canton, selected for further study. Both municipalities had existing groundwater wells, surface-water rights, and water treatment plants. This reduced the capital expenditures for a pilot aquifer storage and recovery system. Deferring water treatment expansion needed to meet peak demand and mitigating groundwater level declines were the reasons for investigating aquifer storage and recovery.

Source water for both systems would be treated Sabine River water from the existing water distribution systems. Existing production wells could be retrofitted for injection. The storage formations would be the Carrizo Sand for the Kilgore project and the Wilcox Formation for the Canton project.

Chemical compatibility testing was recommended to ensure injected water would not affect the aquifer. Preliminary cost estimates were developed to modify existing production well field infrastructure for recharge and recovery pump testing. These modifications would cost approximately $100,000 for Kilgore and $50,000 for Canton. No known follow-up evaluations for aquifer storage and recovery were undertaken by water purveyors within the Sabine River Authority's area.

San Antonio Water System

The Edwards Aquifer has historically been the sole water supply source for San Antonio. In 1993, Senate Bill 1477 authorized the Edwards Aquifer Authority. The Authority has the jurisdiction to place restrictions on the total annual pumpage from the Edwards Aquifer and mandate pumping curtailment during times when aquifer water levels or springflows are low.

San Antonio needed to investigate additional supply sources to meet the legislative requirements, minimize effects of withdrawal from the Edwards, and still provide sufficient supply during times of drought. In September 1996, the TWDB partially funded a Phase 1 aquifer storage and recovery feasibility study for the San Antonio Water System (TWDB Contract No. 97483215). The TWDB grant was for $200,000 and the total study cost was $1,009,000. The study was completed in April 1998 (CH2M Hill, 1998).

Six potential storage zones were considered: the Carrizo Aquifer, Wilcox Group, brackish Edwards Aquifer, Upper Trinity Aquifer, Middle Trinity Aquifer, and Lower Trinity Aquifer. Evaluation criteria included potential well yield, native water quality, surface contamination potential, existing well density, area demand, and total depth. The study concluded that the Carrizo Aquifer in southern Bexar County was the best candidate. In 2004, the project was developed into the Twin Oaks Aquifer Storage and Recovery facility and is discussed at length on page 21.

Texas Facilities

Texas currently has two strict aquifer storage and recovery facilities, serving the municipalities of Kerrville and San Antonio. A third facility in El Paso uses a hybrid aquifer storage and recovery system that has different injection and recovery wells.

El Paso Water Utilities

Although commonly considered an aquifer storage and recovery project, the system used by El Paso Water Utilities differs from a typical aquifer storage and recovery system in that recharge and recovery are not done from the same well. As such, the El Paso system may also be termed an aquifer storage, transfer, and recovery system or a hybrid system.

Much of the water used by El Paso is sourced from the Rio Grande with additional groundwater supplies from the Hueco-Bolson and Mesilla Bolson aquifers. A 1979 TWDB study found that El Paso's future water supplies were limited and action was needed to diversify its supplies.

Development on the northeast side of the city warranted a wastewater treatment plant in the area. The process of piping the treated effluent 20 miles through the city for discharge into the Rio Grande was costly. However, an existing production well field near the proposed plant site had been exhibiting groundwater level declines of about three feet per year. As a result of the installed hybrid aquifer storage and recovery system used in conjunction with the treatment plant, the utility saved the cost of piping the discharge and helped slow groundwater level declines to one foot per year as of 2011.

The 12 million-gallons-per-day Fred Hervey Water Reclamation Plant, which treats wastewater to potable standards, was constructed near the existing well field. Most of the treated water is used for irrigation and power plant cooling. The remaining water is either injected via wells or placed into spreading basins to infiltrate into the Hueco-Bolson Aquifer. The injected water is later recovered from production wells located approximately one-half mile down gradient of the injection sites. Estimated transit time for the water from the injection points to the recovery points is about five years. El Paso uses groundwater rights ownership between the injection and recovery wells to protect stored water from being pumped by others.

The initial injection well field consisted of 10 wells constructed of galvanized casing and screens and began operating in 1985. High levels of chloride in the recharge water caused significant corrosion and by 1992 all wells had failed. These were replaced by four wells constructed of PVC casing and screens. As of 2014, two of these wells had also failed. One failure was the result of a well-screen collapse; the other was suspected of failing for similar reasons. The two remaining wells continue to operate properly.

Recently, El Paso has started using its six spreading basins more extensively. The rate of water injected has decreased from an annual average of approximately 4,400 acre-feet during the first five years of operation to 830 acre-feet for the five year period ending in 2013. By the end of 2013, El Paso Water Utilities had injected a total of 70,843 acre-feet of reclaimed water into the Hueco-Bolson Aquifer.

The injection wells at El Paso remain a key tool for the operation of the plant, but spreading basins are the preferred future recharge method as long as land with favorable hydrogeology and location is available (Vick Pedregon, El Paso Water Utilities, personal communication, 2014).

City of Kerrville

The first strict aquifer storage and recovery facility in Texas currently operating was built in Kerrville. The facility diverts water from the Guadalupe River, treats the surface water to potable standards, and stores it in the Lower Trinity Aquifer. The City of Kerrville relied heavily on the Hosston-Sligo Formation of the Trinity Aquifer for water supply, but declines in groundwater levels necessitated a diversification of their water supplies. Conjunctive use of surface water with aquifer storage and recovery was explored and determined to be a suitable option (CH2M Hill, 1988).

The TWDB partially funded a series of studies in the amount of $100,000 (TWDB Contract No. 91483788) to evaluate the use of aquifer storage and recovery for the city. Additional in-kind support was provided through the use of a TWDB drill rig, rig crew, and geophysical well logging equipment. The evaluation began in 1987, and the feasibility study was completed in 1992 (CH2M Hill, 1992). The first well was constructed in 1990 with a capacity of 1.7 million gallons per day. The system did not become operational until 1998 because of litigation with local kayakers who objected to flow diversions from the Guadalupe River. A second well with a recovery capacity of 1 million gallons per day became operational in 2002. Typically, aquifer recharge occurs between September and May and the water is subsequently recovered during the summer to meet peak demand. Water retrieved from the aquifer is chlorinated and pumped into the distribution system. City staff calculated that use of aquifer storage and recovery instead of an off-channel reservoir has saved the municipality between $26 and $30 million (Malcolm Pirnie, 2011).

Kerrville is located within the jurisdictional area of the Headwaters Groundwater Conservation District. The district has no rules on aquifer storage and recovery. According to the general manager of the district, it has no plans to establish such rules. The district operates under an informal agreement with Kerrville where the City reports cumulative net stored water to the District. Only water recovered in excess of water injected is counted against Kerrville's existing groundwater production permits (Gene Williams, Headwaters Conservation District, personal communication, 2014). Kerrville's aquifer and storage wells are located within the its city limits. City ordinances require that any private well drilled within these boundaries adheres to public drinking water standards. The high costs required to meet these standards serve as a disincentive to drilling private wells in the area.

Kerrville included expanding its aquifer storage and recovery system as a recommended water management strategy in the 2011 Region J (Plateau) Regional Water Plan (which is part of the 2012 State Water Plan). In support of this plan, a third well was drilled, but a portion of the drill stem became lodged in the productive section of the well and could not be recovered. Resulting well performance was poor and the well is currently decommissioned. As of 2014, Kerrville was in the process of converting a production well with a capacity of 1 million gallons per day to the aquifer storage and recovery system. After the well is integrated, the total system recovery capacity will increase to 3.65 million gallons per day. The additional well capacity and a planned expansion of the surface-water treatment plant from a capacity of 5.5 to 7.0 million gallons per day should enable the City's storage goal of 4,600 acre-feet. In 2014, the actual net storage was approximately 2,100 acre-feet because of the limits on the time and volume of water that is permitted for diversion from the river. The water managers of Kerrville consider aquifer storage and recovery to be a highly beneficial component of their water management plan (Grant Terry, City of Kerrville, personal communication, 2014).

San Antonio Water System

The plant serving San Antonio is called the Twin Oaks Aquifer Storage and Recovery facility and has been reported to be the third largest aquifer storage and recovery facility in the United States after systems in Las Vegas, Nevada, and Calleguas, California (Malcom Pirnie, 2011). However, based on recovery and current stored capacity, the Twin Oaks facility is presently the second largest aquifer storage and recovery system in the country (Table 3). It is located about 30 miles south of the city in Bexar County.

Table 3. Largest aquifer storage and recovery systems in the United States.

Facility	Recovery capacity (million gallons per day)	Stored capacity (acre-feet)
Las Vegas, Nevada	200	341,000
San Antonio, Texas	60	70,000
Calleguas, California	40	35,000

Sources: Erin Cole (Las Vegas Valley Water District, personal communication, 2014), Malcom Pirnie (2011), Roberto Macias (San Antonio Water System, personal communication, 2014), Bryan Bondy (Calleguas Municipal Water District, personal communication, 2014).

In years past, the San Antonio Water System was highly reliant on the Edwards Aquifer and had approximately 250,000 acre-feet of water rights. However, these water rights are curtailed by the Edwards Aquifer Authority in times of drought. The San Antonio Water System had additional sources, but these supplemental supplies were expensive. For example, during 2008, the System spent $60 million on alternative supplies. It decided to investigate aquifer storage and recovery as a less expensive means to firm up its water availability from the Edwards Aquifer (Malcolm Pirnie, 2011).

An early evaluation of aquifer storage and recovery for San Antonio was partially funded by a $200,000 TWDB grant (TWDB Contract Number 97483215) in 1996. The Phase 1 study was completed in 1998 (CH2M Hill, 1998). Consideration was given to six locations and five aquifer formations before finalizing on the current system which provides the lowest cost for transmission, site development, and operation. Source water for the system is from the Edwards Aquifer and storage is in the Carrizo Formation of the Carrizo-Wilcox Aquifer. The water is treated to potable standards (chlorine and fluoride) and piped 42 miles to the facility for storage.

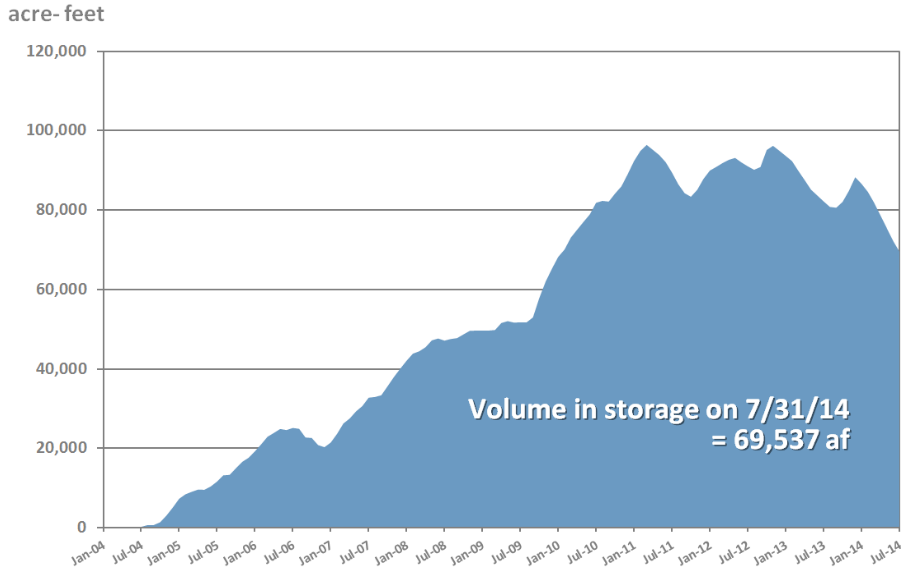
The facility was developed in two phases. Construction of the first phase began in 2002 and became operational in 2004. It consisted of 3 Carrizo production wells, 17 aquifer storage and recovery wells, and a 30 million-gallons-per-day treatment plant. In addition to recovered Edwards Aquifer water, the facility produces native Carrizo Aquifer water that requires treatment prior to distribution. Treatment is required because of the low pH (5.5) and elevated levels of iron, manganese and hydrogen sulfide in the native water. The second phase was implemented in 2009 and added 12 aquifer storage and recovery wells and 4 production wells. It also expanded the capacity of the treatment plant to 60 million gallons per day. Presently, the system includes 29 aquifer storage and recovery wells, 7 production wells, and 15 monitoring wells.

Well recharge rates range from 1,800 to 2,500 gallons per minute and well recovery rates range from 1,200 to 2,000 gallons per minute. Although the facility has the capacity to treat 60 million gallons per day, the average recovery rate is approximately 20 million gallons per day. As of July 2014, the facility was recovering 40 million gallons per day.

The initial operational plan for the facility was to pump native Carrizo Aquifer water for an extended period to generate a cone of depression at the site to alleviate concerns about offsite migration of the stored water. However, local landowners opposed the plan due to concerns about lowering water levels and drying up existing wells in the area. Some of this opposition came from adjoining landowners within the jurisdiction of the Evergreen Underground Water Conservation District, and there was a public movement to have the District annex the area of the aquifer storage and recovery facility. In response to the landowner's opposition, the San Antonio Water System entered into an interlocal agreement with the Evergreen Underground Water Conservation District in 2002 to begin operations in recharge mode and not pump more than 6,400 acre-feet per year of native water from the System's existing production wells. Other terms included provisions that, should the District annex the well field, no additional fees would be charged for aquifer storage and recovery operations, and that the San Antonio Water System would mitigate effects to potentially impacted well owners. As a result, the San Antonio Water System lowered the levels of pumps in 33 wells owned by adjacent landowners and drilled 59 new wells. The associated cost of the mitigation was $5.3 million.

Recharge operations began in 2004 and the first recovery occurred in summer 2006. Recharge resumed in late 2006 and continued until early 2011, achieving a cumulative storage volume of more than 90,000 acre-feet. The severe drought that began in 2011 required using the stored water, and as of July 2014, cumulative storage had decreased to approximately 70,000 acre-feet (Figure 2). The plan was to switch back to recharge mode in the latter part of 2014 (Roberto Macias, San Antonio Water System, personal communication, 2014).

The San Antonio Water System purchased land overlying the aquifer with the stored water to protect it from being pumped by other entities. Aquifer storage and recovery was initially envisioned to assist in meeting peak seasonal demand but has shifted to a long-term drought management tool. The utility considers aquifer storage and recovery to be a highly successful part of their water management strategies portfolio (Darren Thomas, San Antonio Water System, personal communication, 2014).



Source: San Antonio Water System 2014.

Figure 2. Twin Oaks Aquifer Storage and Recovery facility's cumulative storage from 2004 to 2014 (af = acre-feet).

Aquifer Storage and Recovery Strategies in the 2012 State Water Plan

Six regional water planning groups include aquifer storage and recovery as a recommended water management strategy in the 2012 State Water Plan. The strategy is expected to create an additional supply volume of 80,869 acre-feet in decade 2060 (Table 4). This is almost three times the planned decade 2060 volume of the 2007 State Water Plan's 28,860 acre-feet. Initial decade unit costs and project capital costs for the recommended water management strategies are listed in Table 5.

The recommended water management strategies in regional water planning areas E, G, and L are partially infiltration basin projects. These projects are expected to produce 32,785 acre-feet of water by decade 2060, approximately 40 percent of the total volume for all aquifer storage and recovery projects. A summary of the aquifer storage and recovery projects in each regional planning group is included in the following sections.

Table 4. Regional water planning groups with aquifer storage and recovery listed as a recommended water strategy in the 2012 State Water Plan.

Region	Initial use decade	Decade 2060 volume (acre-feet per year)	Cities/entities/water user group
E	2020	5,000	El Paso Water Utilities
G	2010	6,208	Haskell and Knox counties
H	2020	4,147	Missouri City
J	2010	4,864	City of Kerrville, Bandera and Kerr counties
K	2040	10,000	Lower Colorado River Authority
L	2010	50,650	San Antonio, Cibolo, Kendall County
Total Volume		80,869	

Source: TWDB 2012 State Water Plan.

Table 5. Volumes and costs of recommended aquifer storage and recovery water strategies in the 2012 State Water Plan.

Project name (Regional water planning area)	Volume; acre-feet (initial decade)	Initial decade unit cost ($/acre-foot/year)	Capital costs
Missouri City Groundwater Reduction Plan (H)	4, 147 (2020)	$1,110	$58,967,437
City of Kerrville (J)	2,240 (2010)	$364	$6,650,000
Kerr County (J)	1,124 (2020)	$1,416	$17,005,100
Bandera County (J)	500 (2020)	$2,079	$19,654,900
Lower Colorado River Authority (K)	10,000 (2040)	$3,802	$168,711,000
San Antonio Water System (L)	3,800 (2010)	$0	$0
Medina Lake Firm Up (L)	9,933 (2010)	$1,749	$146,237,000
Storage Above Canyon Reservoir (L)	3,140 (2020)	$3,161	$37,326,000

Source: TWDB Regional Water Planning Data Web Interface.

Region H Regional Water Planning Area

The Region H 2011 Regional Water Plan lists aquifer storage and recovery as a component of Missouri City's groundwater reduction plan starting in decade 2020. Water sources, target storage aquifers, recovery capacities, and aquifer storage and recovery component costs are not specified in the plan.

Region J (Plateau) Regional Water Planning Area

Three aquifer storage and recovery projects are listed as recommended water management strategies in the 2011 Region J (Plateau) Regional Water Plan. These include projects in Kerr County, Bandera County, and the City of Kerrville. The City of Kerrville's expansion of its aquifer storage and recovery system is discussed on page 20.

The Phase 1 feasibility studies in Kerr and Bandera counties were funded in part by a $192,000 TWDB grant (TWDB Contract No. 0704830695). The purposes of the Kerr County strategy are to improve utilization of existing surface-water rights of local entities and to diversify supply to some entities that rely solely on groundwater (Freese and Nichols, 2009a). The source water would be from the Guadalupe River using an existing 2,000 acre-feet water right and acquisition of an additional 1,029 acre-feet right. The storage target is the Lower Trinity Formation of the Trinity Aquifer which is the same formation being used by the City of Kerrville. The project entails building a 4 million-gallon-per-day treatment plant and a 16 million-gallon terminal reservoir located on the Guadalupe River near Center Point. The plan proposes two aquifer storage and recovery wells with a combined recovery capacity of 2.5 million gallons per day. The aquifer storage and recovery component cost of $806,000 is approximately five percent of the total capital cost.

The City of Bandera and surrounding areas are solely dependent on the Trinity Aquifer for supply (Freese and Nichols, 2009b). Since the 1950s, water levels in the Lower Trinity Aquifer have declined by 350 feet, raising concerns about the long-term viability of the aquifer as a source of water. Diversification of water supply sources, such as surface water and aquifer storage and recovery, are being evaluated. Bandera County has an agreement with the Bexar-Medina-Atascosa Water Control and Improvement District #1 for 5,000 acre-feet per year of surface water from the Medina River. The project includes building a 6.7 million-gallons-per-day water treatment plant and two aquifer storage and recovery wells with a combined recovery rate of 1 million gallons per day. The Lower Trinity Aquifer is the storage target. The aquifer storage and recovery component cost of $908,000 is approximately five percent of the total capital cost.

Region K (Lower Colorado) Regional Water Planning Area

The Lower Colorado River Authority proposes diverting water from the Colorado River in Bastrop County and storing it in the Carrizo-Wilcox Aquifer. The proposed infrastructure includes 2 miles of transmission piping, a 20 million-gallons-per-day treatment plant, a high-service pump station, a 20-mile pipeline to the aquifer storage and recovery well field, and 12 aquifer storage and recovery wells. The wells would be spaced at one-mile intervals, completed at depths of 650 feet, and have individual recovery capacities of 1.4 million gallons per day. The aquifer storage and recovery well field costs are not documented.

Region L (South Central Texas) Regional Water Planning Area

Three aquifer storage and recovery projects are listed as recommended water management strategies in the Region L (South Central Texas) Regional Water Plan. The first is a phased expansion of the San Antonio Water System. This system is presented on page 21. The projected volume is 3,800 acre-feet starting in decade 2010, increasing to 16,000 acre-feet in decade 2020. The strategy is included at no additional cost.

The other projects are called Medina Lake Firm-Up and Storage Above Canyon Reservoir. Using source water from the Medina River, the Medina Lake strategy envisions an aquifer storage and recovery system in the Carrizo-Wilcox Aquifer. The plan would be developed by the Bexar Metropolitan Water District (acquired by the San Antonio Water System in 2012), the Benton City Water Supply Corporation, and potentially other entities. The project includes diversion and pump facilities, a two-way transmission pipeline, 10 aquifer storage and recovery wells each with a capacity of 1.1 million gallons per day, and 30,000 acre-feet of storage. The aquifer storage and recovery well field cost, $18,619,000, is 13 percent of total capital expenditures.

The Storage Above Canyon Reservoir strategy is intended to increase water supplies for water user groups in Kendall and Comal counties. The project involves diverting water from the Guadalupe River and storing it in off-channel reservoirs or in an aquifer storage and recovery system. The Lower Trinity Aquifer is the target storage zone. The model assumes an initial storage of 10,000 acre-feet and 10 wells with capacities of 0.5 million gallons per day each. Results indicate firm yield of 3,140 acre-feet of water starting in decade 2020. Additional project components include an intake and pump station, transmission pipeline, well field, and a water treatment plant. The aquifer storage and recovery well field cost, $4,306,000, is 12 percent of the total capital cost.

Other Aquifer Storage and Recovery Investigations

Other aquifer storage and recovery projects not in the 2012 State Water Plan are also being evaluated by entities interested in its potential application. The TWDB is monitoring 10 such projects. A number of those considering aquifer storage and recovery have indicated that it will be included in their 2016 regional water plans.

Barton Springs/Edwards Aquifer Conservation District

A study by Smith and others (2013) recommended aquifer storage and recovery as a potential water management strategy in the district. The District, which overlies portions of Hays, Travis, Caldwell, and Bastrop counties, is authorized to manage the Barton Springs Segment of the Edwards Aquifer. The district rules require maintaining a minimum spring flow of 6.5 cubic feet per second at Barton Springs in Austin, Texas. The district believes spring flows may fall below this target during times of extreme drought, even with a 50 percent curtailment of permitted pumping. Lower water levels may also negatively impact pumping wells; therefore, the District needed to identify alternative water sources.

Smith and others (2013) identified 11 possible water management options, some of which include aquifer storage and recovery. The study was conceptual in nature so specific storage volumes and recharge and recovery rates were not explored in detail. The aquifer storage and recovery concept would allocate water from the Edwards Aquifer during times of available supply and store that water either in the Trinity Aquifer or the saline zone of the Edwards Aquifer.

The Trinity Aquifer has the potential to be used as both a typical groundwater production source as well as a storage target for an aquifer storage and recovery system. There are existing production wells in the Trinity Aquifer within the District's jurisdiction. Water demand is expected to increase in the eastern section of the district so a storage target in the vicinity is seen as ideal. However, Trinity Aquifer wells are more costly than Edwards Aquifer wells in this area and likely less productive. The District sees potential for the use of Trinity Aquifer storage zones in the western area of the district, but systems in this area would likely be smaller (John Dupnik, Barton Springs/Edwards Groundwater Conservation District, personal communication, 2014).

The saline zone of the Edwards Aquifer is on the eastern side of the district. Groundwater in the saline zone has a total dissolved solids concentration ranging from 1,000 to 15,000 milligrams per liter. The saline zone is primarily composed of limestone and is separated from the fresh water zone by geologic faults. Estimated well yields in the area are approximately 1,000 gallons per minute, sufficient for aquifer storage and recovery applications.

The Barton Springs/Edwards Aquifer Conservation District has a unique permitting process to promote aquifer storage and recovery systems. The District's rules and bylaws include a provision for Class D permits, which allow withdrawals exclusively for aquifer storage and recovery projects. The District has managed available groundwater of 16 cubic feet per second, or 11,600 acre-feet annually, available for permitting under unconstrained weather conditions. Class D permits are allocated 1,450 acre-feet of that amount. These permits are fully curtailed during Stage II or more restrictive operating conditions. In this way, the district fosters permitting for aquifer storage and recovery development only at times when supply is available without placing risk on historical users.

The District has budgeted $160,000 to install a test well in the eastern area of the district on land owned by Texas Disposal Systems. The district continues to see aquifer storage and recovery as a beneficial strategy and is working to facilitate partnerships and share information with water purveyors in the region to promote aquifer storage and recovery opportunities (John Dupnik, Barton Springs/Edwards Groundwater Conservation District, personal communication, 2014).

City of College Station

The City of College Station is conducting a preliminary evaluation of aquifer storage and recovery to maximize future potable wastewater reuse (LBG-Guyton, 2013). Several storage aquifers are available including the Sparta, Queen City, and Carrizo-Wilcox (Carrizo Sand and Simsboro Formation) aquifers. The Simsboro Formation is specifically selected for the current feasibility studies because of its high productivity. Well depth is approximately 3,800 feet which is uncharacteristically deep for aquifer storage and recovery systems. The total dissolved solids concentration in the native water is approximately 8,000 milligrams per liter. The moderately saline nature of the water will increase the total storage volume needed to mitigate salinity concerns with the recovered water.

The targeted well field site is the Lick Creek Park located within the city limits. The site is thought to be sufficiently large to contain the storage volume, is owned by the city, and would provide protection from other users. The site is under the jurisdiction of the Brazos Valley Groundwater Conservation District. The District does not presently have rules related to aquifer storage and recovery, but is considering developing them.

The initial plan is to treat 6 million gallons per day of wastewater to required drinking water quality standards, recharge the aquifer during the cooler months when demand is low, and recover water from the system to augment supplies for peak demand during the summer months. Capital costs are forecast to be high. Alternative aquifer storage options are now being investigated.

City of Corpus Christi

An aquifer storage and recovery study was completed for the City of Corpus Christi in 2005 (LNV Engineering and Carollo Engineers, 2005). It focused on incorporating an aquifer storage and recovery system into the city's infrastructure. The TWDB completed a study in 2012 that provided geologic characterization data to aid in well field site assessment (Meyer, 2012).

The 2005 assessment was part of a larger infrastructure study and was evaluated within that context. The first goal of the aquifer storage and recovery component included postponement of plant expansion at the O.N. Stephens Water Treatment Plant. Potable water from the plant would be stored during off-peak times and recovered during peak demand. The recovered water would be delivered directly to distribution, reducing peak demand requirements of the treatment plant.

The aquifer storage and recovery system would also provide backup supply capability during maintenance of one of four 40 million-gallons-per-day treatment trains at the plant. A recovery capacity of 40 million gallons per day was used for the analysis. Demand analysis concluded a target storage volume of approximately 3,067 acre-feet would be needed to meet project goals.

The study identified five potential sites along an east-west line within the city limits. Siting the well field to the west of the city would reduce drilling and pumping costs because the storage zones are shallower. Placing the well field to the east on Mustang Island would be more costly to build and operate but would aid in maintaining distribution system pressures during peak demand periods.

The study focused on the Chicot and Evangeline formations of the Gulf Coast Aquifer as potential storage units. All potential sites are within the jurisdiction of the Corpus Christi Aquifer Storage and Recovery Conservation District. The District is unique in Texas in that it has rules that demarcate property to be used for an aquifer storage and recovery storage area. Drilling of wells not used for an aquifer storage and recovery system is prohibited within one mile of these areas without special provisions.

The 2012 TWDB study assessed the hydrogeology of the area for aquifer storage and recovery application. The study concluded that many of the sand units could potentially serve as aquifer storage and recovery candidates. It recommended that an extensive test drilling program would be required to collect site specific information. Some samples of native groundwater did contain elevated levels of contaminants such as radionuclides, hydrocarbons, and arsenic, which would need to be evaluated as part of the aquifer storage and recovery project development plan.

City of Uvalde

The City of Uvalde is currently conducting an aquifer storage and recovery feasibility study (CDS Muery, 2014). The study is being partly funded ($44,000) by the TWDB through a regional facility planning grant (TWDB Contract Number 1348321575). The city and the surrounding areas rely heavily on the Edwards Aquifer for water supplies. The area is under the jurisdiction of the Edwards Aquifer Authority for the Edwards Aquifer and the Uvalde County Underground Water Conservation District for non-Edwards Aquifer sources. These sources include the Trinity and Edwards-Trinity (Plateau) aquifers, and the Buda and Austin Chalk formations.

Uvalde currently has 5,190 acre-feet of water rights to the Edwards Aquifer. Water demand is expected to increase to 6,300 acre-feet by 2020. In addition, pumping from the Edwards Aquifer can be curtailed by up to 44 percent in times of drought. These challenges have compelled the City to explore aquifer storage and recovery as a means of increasing water supply. This strategy would enable the city to maximize allowable use of groundwater supplies during wet periods and recover stored water during drought periods, relieving stress on the area's aquifers. Future expansion of the aquifer storage and recovery system would provide water supplies to the towns of Knippa and Sabinal.

The Carrizo Wilcox Aquifer, located 30 miles to the south of Uvalde in neighboring Zavala County, may have good hydrogeological conditions to serve as a storage zone for the system. The targeted formation is the Carrizo Sands which the study notes has demonstrated good performance for the San Antonio Water System's aquifer storage and recovery facility. The Edwards Aquifer was precluded as a water source for the system because export of water from the Edwards Aquifer out of Uvalde County is prohibited by Edwards Aquifer Authority's authorizing legislation (Edwards Aquifer Authority Act, §1.34).

Demonstrated well yield from the Trinity or Edwards-Trinity (Plateau) aquifers is poor in the area so the Austin Chalk and Buda Formation were selected as candidate water source formations. There are some high production wells in these units to the west and southwest of the city and geochemical compatibility with the existing Edwards source water is generally good. Production wells could either be constructed or existing wells could be purchased. Upgrading any existing agricultural wells to public water supply standards is a concern because of more strict construction standards. The target of 4,000 acre-feet per year of production could be accomplished with three 850 gallon-per-minute wells with a fourth well recommended as a reserve. This supply would need to be permitted by the Uvalde County Underground Water Conservation District and will likely require a modification to the District's desired future conditions.

The Wintergarden Groundwater Conservation District has jurisdiction over the proposed aquifer storage and recovery site. The District has registration and reporting requirements for aquifer storage and recovery wells but no other restrictions or rules to protect stored water from extraction by other users.

The aquifer storage and recovery plan was accepted by the Uvalde City Council in October 2014 and will be submitted to Region L for inclusion in the 2016 regional water plan (Mike Roetzel, CDS Muery, personal communication, 2014).

City of Victoria

In 2013, the TWDB provided a $135,000 grant (TWDB Contract No. 1348321576) to the City of Victoria from the Research and Planning Fund for the purpose of regional water supply facility planning (Naismith Engineering, 2014). While the study evaluated several water management strategies in a three-county area, the focus was on the potential application of aquifer storage and recovery for the City of Victoria.

The City of Victoria and the surrounding area have diverse water supply sources. Concerns stemming from the recent drought coupled with a future increase in water demand led the city to evaluate aquifer storage and recovery to maximize use of existing water supplies, increase reliability, and defer expansion or construction of additional water treatment plant facilities.

The target storage zone is the Upper Goliad Formation of the Evangeline Aquifer. Existing aquifer data indicate favorable hydrogeological conditions to support a recovery rate of up to 2 million gallons per day per well. Arsenic in some groundwater samples exceeded the maximum contaminant level and will need to be addressed as a design consideration. It is believed that proper establishment and management of the aquifer storage and recovery buffer zone would allow recovered water to be placed into distribution without treatment other than disinfection. To provide a conservative design margin for buffer zone management, the buffer zone volume was assumed to be equal to the volume of water that needs to be recovered for supply purposes.

Victoria has surface-water rights of approximately 27,000 acre-feet per year from the Guadalupe River. However, the largest water permit of 20,000 acre-feet has a junior priority of 1993, making it a highly unreliable source. The City of Victoria also has 10 operational high volume water wells and 11,000 acre-feet of permitted pumping from the Victoria County Groundwater Conservation District. Limited by the quality of the water, groundwater constitutes only about 10 percent of the total water supply. Victoria can, to an extent the City is limited by the terms of its surface-water permits, augment minimum flow requirements by pumping groundwater into the Guadalupe River during low flow periods.

The study team developed a conceptual model to forecast total storage volume and recovery capacity to meet project goals. The model assumed 2,000 acre-feet of off channel storage, eight percent decadal demand increase, and target storage volume of twice the amount that would be recovered. Seven aquifer storage and recovery scenarios were considered for conceptual modeling. The models accounted for normal-year and dry-year demand patterns, differing initial aquifer storage and recovery storage volumes, seasonal demand and drought-of-record demand, and water treatment plant capacity. The projected target storage volume ranged widely from 7,300 to 166,060 acre-feet. The sensitivity factors with the greatest impact were whether the initial baseline demand pattern was from an extremely dry year (2011) or a normal year (2008), and whether the aquifer storage and recovery supply was required to meet seasonal or drought-of-record demands. The medium scenario required target storage of 53,900 acre-feet and a recovery capacity of 24.9 million gallons per day (Table 6).

Table 6. Storage and recovery capacity requirements for City of Victoria.

Scenario	Target storage volume (acre-feet)	Recovery capacity (million gallons per day)
Dry Year Demand	166,060	24.9
Medium Scenario	53,900	24.9
Normal Year/Seasonal Demand	7,300	19.6

Source: Naismith Engineering (2014).

The TWDB reviewed and provided comment on the draft Phase I feasibility study in mid-summer 2014. The City of Victoria stated in October 2014 that it would present its findings to the city council for consideration in December 2014 (Jerry James, City of Victoria, personal communication, 2014).

Guadalupe-Blanco River Authority Mid-Basin Project

The Guadalupe-Blanco River Authority Mid-Basin Project is a recommended water management strategy in the 2011 Region L (South Central Texas) Regional Water Plan. However, the project plan did not include an aquifer storage and recovery component. The newest plan does include aquifer storage and recovery as a key storage component (Freese and Nichols, 2013). The TWDB provided a $4.4 million loan from the Water Infrastructure Fund to assist in project planning (TWDB Project No. 21698).

The goal of the project is to increase firm water supplies by 50,000 acre-feet for customers of the Guadalupe-Blanco River Authority in Hays, Caldwell, Comal, and Guadalupe counties. The population and associated water demands are expected to double in the next 50 years. The authority studied nine water supply options to address future long term water needs. The four water supply sources considered included

- additional groundwater from the Carrizo-Wilcox Aquifer in Gonzales County,
- additional water rights and intake and pump facilities for the Guadalupe River,
- off-channel reservoirs, and
- aquifer storage and recovery.

The nine variations were scored from least to most favorable against nine criteria. The three options that included aquifer storage and recovery as a component scored more favorably than other options. Aquifer storage and recovery was found to meet long-term needs and daily peak demand with smaller water treatment facilities. The most favorable option calls for a phased implementation to develop necessary infrastructure capacity as needed (Table 7).

Table 7. Summary aquifer storage and recovery operating parameters.

Phase	Year	Well count	Water treatment plant capacity (million gallons per day)	Project yield (acre-feet)
1	2018	12	27	15,000
2	2030	20	45	25,000
3	2040	26	57	32,000
4	2050	30	66	37,000
5	2060	40	90	50,000

Source: Freese and Nichols (2013).

Source water for the aquifer storage and recovery project would be from the Guadalupe River near Gonzales, Texas. In 2008, the authority applied for Permit 12378 from the Texas Commission on Environmental Quality. Ten contested case hearing requests were filed. The current application would need to be amended to include aquifer storage and recovery as a use. A surface-water treatment plant would be built at the aquifer storage and recovery well field site northwest of Gonzales and would have an initial capacity of 27 million gallons per day increasing to 90 million gallons per day by 2060.

The Carrizo Sands within Gonzales County Underground Water Conservation District is the target storage formation. The district does not have specific rules on aquifer storage and recovery, but District Rule 13 addresses recharge wells. Major requirements of this Rule include submittal of construction and operational plans and a technical risk assessment of recharge water to the aquifer. Permits are issued for five-year periods.

In Phase 1 of the aquifer storage and recovery facility, 12 wells, each with a capacity of 1,550 gallons per minute, would be constructed and a buffer zone established. The aquifer storage and recovery system would be available to provide supply in 2030 at the start of Phase 2. The final well field capacity would increase to 40 wells with capacities of 1,550 gallons per minute each in 2060.

Luling Water Treatment Plant and Aquifer Storage and Recovery

A draft study to explore an aquifer storage and recovery system to address water supply needs near Luling and Lockhart, Texas, was completed in 2012 (Freese and Nichols, 2012) The area included Caldwell, northern Hays, and northern Gonzales counties.

The intended purposes of the project are to increase firm yield from Luling's existing run-of-river rights to the San Marcos River, provide supply to meet peak demands, reduce transmission pipeline and groundwater pumping capacity requirements, and provide a long-term drought tolerant source of supply. The study area currently has two supply sources: (1) 4,422 acre-feet of San Marcos run-of-river rights near Luling and (2) well fields (Carrizo-Wilcox Aquifer) in the Lockhart area. An existing water treatment plant removes dissolved iron and manganese and the water is used to provide supply during peak demand. The maximum annual production from these wells was 1,880 acre-feet in 2011. Three options were evaluated (Table 8).

Option 1 includes using the current permitted surface-water supply, increasing water treatment plant capacity at Luling and Lockhart, and building an aquifer storage and recovery system with a recovery capacity of 5.5 million gallons per day. During drought-of-record conditions, this configuration could support an increase in average water demand from 2.4 to 5.3 million gallons per day.

Option 2 includes an additional 7,000 acre foot diversion permit from the San Marcos River. Water intake and treatment facilities at Luling would require expansion, and aquifer storage and recovery capacity would need a recovery capacity of 6.9 million gallons per day. Average daily water supply would be 8.7 million gallons per day, an increase of 3.4 million gallons per day over Option 1.

Option 3 assumes that 25,000 acre-feet per year would be provided from the Guadalupe River Authority Mid-Basin Project discussed on page 31. Operations at the Luling water treatment plant would be discontinued. The intent of this option is to assist with cost estimates of integrating this aquifer storage and recovery option into the larger Mid-Basin Project presented on page 31. The assumed constant supply causes the required recoverable storage volume to be less than Option 2, but the increase in demand increases the required recovery capacity by 12.1 million gallons per day.

Table 8. Luling water treatment plant aquifer storage and recovery options.

	Option 1	**Option 2**	**Option 3**
Total water rights (acre-feet per year)	4,422	11,422	25,000
Supported average demand at 100 percent reliability (million gallons per day)	5.3	8.7	24.7
Supported peak demand at 100 percent reliability (million gallons per day)	9.2	16	47
Target storage volume (acre-feet)	5,600	34,000	9,000
Recoverable storage volume (acre-feet)	2,800	17,000	4,500
Recovery capacity (million gallons per day)	5.5	6.9	19.0

Source: Freese and Nichols (2012).

The Carrizo Sands and Wilcox Group of the Carrizo-Wilcox Aquifer were deemed to be the most viable storage targets. The brackish zone of the Edwards Aquifer was also considered but will need to comply with strict regulatory requirements of the Edwards Aquifer Authority.

Five potential aquifer storage and recovery well field sites were identified in Caldwell and Gonzales counties. Plum Creek Groundwater Conservation District has groundwater production jurisdiction in Caldwell County. District rules 8 and 24 cover both recharge and aquifer storage and recovery activities. Requirements for Rule 8 include submittal of construction and operational plans and a technical risk assessment of recharge to the aquifer. Rule 24 requires applications for aquifer storage and recovery wells to be completed using a form provided by the district. The district has not yet developed this form (Daniel Meyer, Plum Creek Groundwater Conservation District, personal communication, 2014).

Gonzales County Underground Water Conservation District has groundwater management authority in Gonzales County. The district does not have rules on aquifer storage and recovery, but District Rule 13 addresses recharge wells. Requirements include submittal of construction and operational plans and a technical risk assessment of recharge to the aquifer. Permits are issued for a five-year period.

Freese and Nichols (2012) recommends that coordination between the city and the groundwater conservation districts be continued to ensure rules conducive to aquifer storage and recovery are considered. It further recommends that a test drilling program be established with the goals of minimizing infrastructure cost and mitigating the risk of hydrocarbon contamination at potential storage sites.

New Braunfels Utilities

New Braunfels Utilities is a public utility primarily serving Comal County with limited service to eastern Hays and northern Guadalupe counties (Malcolm Pirnie, 2012). The utility has three sources of water including surface-water rights in Canyon Reservoir, run-of-river rights to the Guadalupe River, and groundwater permits from the Edwards Aquifer Authority. These permits total 26,000 acre-feet of water per year. However, a recurrence of the drought of record and Stage IV restrictions on the Edwards Aquifer would reduce supply to 13,300 acre-feet per year. The typical annual demand for the utility is 12,000 acre-feet. Future demand is anticipated to increase 4.5 percent annually, creating a water shortage.

Meeting peak daily demand is also an issue. Peak demand in 2016 is projected to be 25.8 million gallons per day under severe 2011 drought conditions. The current capacity is 21.9 million gallons per day from the surface-water treatment plant and wells. An aquifer storage and recovery system with a recovery capacity of 9 million gallons per day and recoverable storage volume of 7,000 acre-feet would help meet annual and daily peak demands.

Target storage zones include brackish zones of the Edwards Aquifer in the southeast of the area and the Trinity Aquifer in the northwest. Productivity is anticipated to be higher in the Edwards Aquifer, but strict Edwards Aquifer Authority regulations make the permitting process challenging. Existing regulations also do not take into account potential storage in the brackish zone of the aquifer. In the central and northern portions of the Trinity Aquifer, the formations are at shallower depths making storage feasible. Permitting in this aquifer would also be more straightforward. Further testing is required to determine hydraulic and water quality characteristics.

In September 2014, the executive director of Water Services stated that the Utility had decided to pursue storage in the brackish zone of the Edwards Aquifer because of expected higher well yields and lower costs. The first proposed site is southeast of the city near existing distribution pipelines. The largest impediment has been the regulatory constraints of the Edwards Aquifer Authority. The Utility is working with the Edwards Aquifer Authority and the Texas Commission on Environmental Quality to determine how best to address these regulatory concerns (Roger Biggers, New Braunfels Utilities, personal communication, 2014).

Robstown-Driscoll Regional Aquifer Storage and Recovery

The City of Corpus Christi is in the Region N (Coastal Bend) Regional Water Planning Area. Aquifer storage and recovery is not a recommended water management strategy in the 2011 regional water plan, but the strategy was considered for recommendation in the Region's 2001, 2006, and 2011 plans. The goals of the consideration are to improve seasonal availability, maximize available water treatment capacity, and provide a reliable water resource during extended dry periods.

The source water, a combination of surface water from the Nueces and Lavaca river basins, would be piped from the city's distribution system to the aquifer storage and recovery site via a South Texas Water Authority pipeline. Recharge would take place when the source reservoirs (Choke Canyon Reservoir, Lake Corpus Christi, and Lake Texana) have water capacities exceeding 80 percent of conservation storage. The stored water would be distributed to Corpus Christi or to the South Texas Water Authority's regional customers. Planned injection capacity is 10 million gallons per day.

The selected aquifer storage and recovery site is located between the towns of Driscoll and Robstown in Nueces County. The project site is not within a groundwater conservation district. The target storage formation is not indicated in the regional water plan, but the plan states that it is 500 feet below land surface. Based on information in the TWDB Groundwater Database, water wells at that depth are completed in the Evangeline Formation of the Gulf Coast Aquifer.

HDR Engineering employed its Corpus Christi Water Supply Model to perform firm yield simulations under a number of assumptions and operational scenarios. These simulations indicate that more water would be lost to channel losses during the conveyance of additional water from Lake Corpus Christi to the O.N. Stevens Water Treatment Plant than would be saved through evaporation mitigation. For this reason, the aquifer storage and recovery strategy was not recommended in the regional water plan.

Trinity Aquifer in Johnson County

The Region G (Brazos) Regional Water Plan includes a preliminary assessment of an aquifer storage and recovery project in Johnson County, but the project is not a recommended water management strategy. The primary purpose of the project is to store excess capacity from the Lake Granbury Surface Water Advanced Treatment System when available and recover the stored water for delivery to the Johnson County Special Utility District and City of Keene during peak seasonal demand periods. Current estimated supply available for recharge is 1,073 acre-feet per year, increasing to 1,815 acre-feet per year in the 2020 decade.

The target storage formation is the Travis Peak Formation of the Trinity Aquifer. However, most water wells in the area produce water from the shallower Paluxy Formation. The well field would be located between the towns of Godley and Joshua in the northeastern part of Johnson County. This area is located within the boundaries of the Prairielands Groundwater Conservation District. The District has no rules related to aquifer storage and recovery.

The regional water plan recommends chemical analysis be performed to ensure compatibility between the stored water and native water. Well yields in the region of 250 gallons per minute are significantly lower compared to yields in other aquifer storage and recovery facilities or study areas in Texas. The required number of wells is eight in the 2010 decade and 14 in the 2020 decade. The estimated capital cost of $1,171,000 includes the costs of wells, well field pipelines, and interconnections.

Summary

Aquifer storage and recovery is an established and proven water management technology in Texas. This strategy involves injecting available water into subsurface aquifers for storage until the water is needed. Aquifer storage and recovery projects are not subject to evaporative losses, land inundation, and storage capacity losses due to sedimentation, as are surface-water reservoirs. They can also reduce cost by deferring expansion of water treatment plants and distribution systems.

The technology has been successfully used around and the world and approximately 133 aquifer storage and recovery systems presently operate in the United States. In Texas, studies on aquifer storage and recovery began in the state in the 1940s and facilities were built in the 1960s. Today, there are two strict and one hybrid aquifer storage and recovery facilities in the state providing water to the cities of Kerrville, San Antonio, and El Paso.

Aquifer storage and recovery is a recommended water management strategy in six regional water planning areas in the 2012 State Water Plan. If implemented, the projects would produce an estimated 80,869 acre-feet of new water supply in decade 2060 which is about 0.9 percent of all new supplies.

The TWDB is currently monitoring 10 entities known to be considering aquifer storage and recovery. The evaluations that these entities are conducting range from small, preliminary assessments to comprehensive studies. A number of these entities have indicated that aquifer storage and recovery will be included as a strategy in their 2016 regional water plans. This technical note will be updated periodically as new information becomes available.

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