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Strategy Options for Meeting Attainment Frequencies for the Estuaries

Final Report

Prepared for
Texas Water Development Board
Guadalupe, San Antonio, Mission, and Aransas Rivers and Mission, Copano, Aransas, and San Antonio Bays Basin and Bay Area Stakeholder Committee

Prepared by
San Antonio Bay Partnership, Inc.,
Trungale Engineering & Science, and
ASR Systems LLC

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PURSUANT TO SENATE BILL 1 AS APPROVED BY THE 83RD TEXAS LEGISLATURE, THIS STUDY REPORT WAS FUNDED FOR THE PURPOSE OF STUDYING ENVIRONMENTAL FLOW NEEDS FOR TEXAS RIVERS AND ESTUARIES AS PART OF THE ADAPTIVE MANAGEMENT PHASE OF THE SENATE BILL 3 PROCESS FOR ENVIRONMENTAL FLOWS ESTABLISHED BY THE 80TH TEXAS LEGISLATURE. THE VIEWS AND CONCLUSIONS EXPRESSED HEREIN ARE THOSE OF THE AUTHORS AND DO NOT NECESSARILY REFLECT THE VIEWS OF THE TEXAS WATER DEVELOPMENT BOARD.

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EXECUTIVE SUMMARY

San Antonio Bay is a large (205 mi^2/531 km^2) estuarine complex located on the mid-Texas coast, at the terminus of the San Antonio/Guadalupe River watershed. It is connected to the Gulf of Mexico by Cedar Bayou in Mesquite Bay, and by channels in Matagorda Bay to the north and the Aransas-Corpus Christi Bay complex to the south.

An estuary is where a river flows into coastal waters, mixing freshwater with seawater, and producing a highly variable, but extremely productive environment. The availability of the seawater component of the estuarine mixing zone is relatively a constant, so the freshwater inflow volumes largely determine the amount and extent of the mixing which occurs, and the resulting ecological conditions. The quantity and timing of freshwater inflows are governed by the complex combination of climate/meteorology, hydrology/hydrogeology, water diversions, and, increasingly, federal, state and local water resources management policies.

Senate Bill 3 (SB 3) (80th Texas Legislature, 2007) established a framework for identifying and promulgating environmental flow standards throughout Texas. As part of this process, scientific experts and regional stakeholders developed and submitted recommendations for both in-stream flow and estuary inflow standards. The Texas Commission on Environmental Quality (TCEQ) adopted environmental flow standards for the Guadalupe, San Antonio, Mission, and Aransas basins, effective August 30, 2012. These flow standards also include freshwater inflow standards for the Guadalupe and San Antonio River (into San Antonio Bay) and the Mission and Aransas Rivers (into Mission, Copano, and Aransas Bays).

This report presents the results of a study of potential strategies to increase the frequency at which the seasonal goals for freshwater inflow (FWI) volumes are met or exceeded in San Antonio Bay. These goals have been determined by a panel of experts to be supportive of a sound ecological environment. The purpose of this effort is to provide information and guidance to the stakeholder process which continues to play a role in advising the TCEQ regarding potential strategies which, if implemented, might increase the seasonal availability of FWI's and improve the achievement of Strategy Target Frequencies (STF) for San Antonio Bay.

Modeling of freshwater inflows to San Antonio Bay using the Region L WAM without wastewater return flows reveals that over the period of record (1934-89) those flows fail to meet the STFs for the three month spring period (March – May) in 16 of the 55 years, but that a supplemental supply of 90,000 ACFT during this period would reduce the number of these shortfalls to just 5 years, which satisfies the spring STF. Similarly, in 3 years of the historical record, the bay would receive virtually no inflows for the three month summer period (July - September), and very close to zero in another 3 or 4 years. Reducing the summer shortfalls to the STF goal of no more than 4 times over the period of record would require supplemental flows equal to about 40,000 ACFT.

Based on the volumes of FWIs identified as being required to achieve the spring and summer STFs, further analysis looked at how acquiring water rights for environmental flow purposes, largely through the dedication of wastewater return flows and the use of unappropriated flows and using Aquifer Storage and Recovery (ASR) for temporary storage of water for managed releases, could increase STF attainment goals. This analysis generated values for the "recharge rate" (the rate at which water would need to be diverted from the river, treated and stored in ASR wells), and the "recovery rate" (the managed release of water from aquifer storage) required to provide enough water to either fully or partially offset FWI shortfalls in the amounts and frequencies which occurred in the period of record. These values then helped define the scale of an ASR project, or projects, required to implement these strategies, in full or in increments. Planning level cost estimates, implementation steps and policy recommendations are presented.

1. INTRODUCTION

This report presents strategies to increase the frequency at which the targets for freshwater inflow (FWI) volumes, which have been determined by a panel of experts to be supportive of a sound ecological environment in San Antonio Bay, are met or exceeded. The study includes estimates of the timing and volumes of additional freshwater inflows necessary to meet Strategy Target Frequencies (STF) defined by the Guadalupe, San Antonio, Mission, and Aransas Rivers and Mission, Copano, Aransas, and San Antonio Bays Basin and Bay Area Stakeholder Committee (GSA-BBASC). STF define the percent of time various FWI levels should be met or exceeded over a long term period of record.

The report quantifies freshwater volumes that could be made available to supplement FWI for San Antonio Bay with the implementation of a strategy based on the dedication of wastewater return flows and unappropriated water, and the use of Aquifer Storage and Recovery (ASR) to allow managed releases timed to achieve specific STF goals. The strategy has been simulated using the Guadalupe San Antonio (GSA) Water Availability Model (WAM) and other appropriate tools to demonstrate how it could be implemented and how the benefits in terms of increases in FWI during critical periods are demonstrated. Planning level cost estimates and implementation plans comparable to those used in Senate Bill 1 (SB1) regional water planning have been prepared. This work was funded by the Texas Water Development Board (TWDB) and performed on behalf of the GSA-BBASC.

The purpose of this effort is to provide information and guidance to the GSA-BBASC and Texas Commission on Environmental Quality (TCEQ) regarding potential strategies which, if implemented, might increase the seasonal availability of FWI's and improve the achievement of STF's for San Antonio Bay.

1.1 OVERVIEW OF THE SENATE BILL 3 ENVIRONMENTAL FLOWS PROCESS

Senate Bill 3 (SB 3) (80th Texas Legislature, 2007) established a framework for identifying and promulgating environmental flow standards throughout Texas. As part of this process, the BBASC (comprised of regional stakeholders) and a Basin and Bay Expert Science Team (BBEST; comprised of regional scientific experts) were established. The GSA-BBEST submitted a report containing environmental flow recommendations in March 2011, and the GSA-BBASC submitted their report and recommendations in September 2011. Following a public comment period, TCEQ adopted environmental flow standards for the Guadalupe, San Antonio, Mission, and Aransas basins, effective August 30, 2012. These flow standards, found in Subchapter D of Chapter 298 of the Texas Administrative Code (TAC), include freshwater inflow standards for the Guadalupe and San Antonio River (into San Antonio Bay) and the Mission and Aransas Rivers (into Mission, Copano, and Aransas Bays). The Guadalupe River contributes about two-thirds of the inflow to San

Antonio Bay, with the San Antonio River making up the other one-third -- inflow from areas around the bay periphery contribute less than 5% of total inflow.

SB 3 has provisions for continued evaluation of environmental flow standards. In support of this effort, the 83rd Texas legislature set aside $2 million to assist the TWDB and several BBASCs (from different basins) with further evaluations of environmental flows and the associated standards.

1.2 STUDY AREA

The San Antonio Bay/Guadalupe Estuary System, one of seven major estuaries along the Texas coast, is a large (205 mi^2/531 km^2) estuarine complex located between Matagorda and Aransas Bays and at the terminus of the San Antonio/Guadalupe River watersheds. The estuarine complex is composed of San Antonio Bay and a number of secondary and tertiary bays: Espiritu Santo Bay, Hynes Bay, Guadalupe Bay, Mesquite Bay, Carlos Bay, Ayres Bay, Mission Lake, and Pringle Lake. It is connected to the Gulf of Mexico by Pass Cavallo and the Matagorda Ship Channel entrance to Matagorda Bay to the north, and by the Aransas Pass/Corpus Christi Ship Channel entrance to the Aransas-Corpus Christi Bay complex to the south, as well as Cedar Bayou, which connects Mesquite Bay to the Gulf of Mexico.

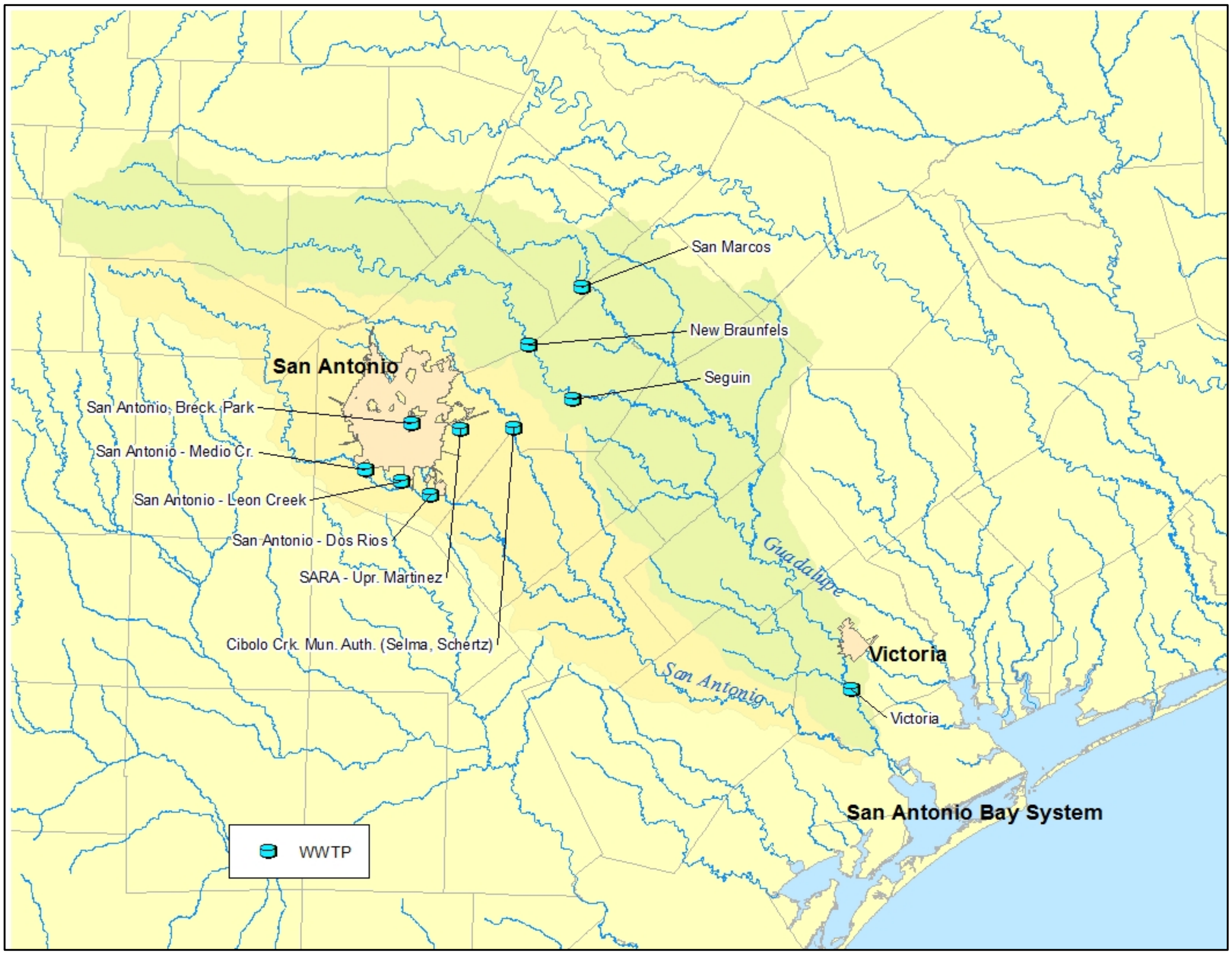


Figure 1-1 Map of San Antonio Bay System and Contributing Drainage Area

Figure 1-1 shows the two major watersheds contributing FWI to the San Antonio Bay system, the Guadalupe and San Antonio (GSA) river basins, which join just before entering the bay. These two watersheds drain nearly 11,000 square-miles (25,000 km^2) of South-Central Texas, extending from the headwaters in the Edwards Plateau, past the springs of the Balcones Escarpment, and across the broad coastal plain. The Guadalupe River contributes about two-thirds of the inflow to San Antonio Bay, with the San Antonio River making up the other one-third. Inflow from areas around the bay periphery contribute less than 5% of total inflow (Ward, 2010). Figure 1-1 also shows the location of the 10 largest wastewater treatment plants contributing to flow in the GSA basins.

While freshwater inflow standards have been adopted for the Mission-Copano-Aransas, the inflows to these bays have not been highly altered and it is expected that they will continue to meet the STF for the foreseeable future. Thus only the San Antonio Bay freshwater inflow needs are addressed in this study.

2 DETERMINATION OF VOLUMES AND TIMING OF FRESHWATER INFLOWS NEEDED TO MEET STRATEGY TARGET FREQUENCIES

The first step in developing strategies to increase the frequency of meeting freshwater inflow targets for the estuary is to understand how much water is needed. This requires a clear understanding of the targets that have been adopted as flow standards. These standards are fairly complex, including both seasonal volumes and target frequencies at which these inflows should occur. The next step is to estimate how much water will be flowing into the bay in the absence of the implementation of any strategies to augment inflow. The freshwater inflow resulting from this 'baseline' condition is simulated in the GSA WAM. Once these two preliminary steps are completed, the predicted inflow can be compared to the standards to calculate the shortfall. Strategies can then be developed to fully satisfy this shortfall, subject to water availability and cost, or to demonstrate the incremental benefits of strategies that only meet a portion of the shortfall.

2.1 OVERVIEW OF THE SAN ANTONIO BAY FRESHWATER INFLOW STANDARDS

The TCEQ has adopted rules for a multi-tiered suite of freshwater inflow standards for the Guadalupe and the Mission-Aransas Estuaries. These standards are defined as seasonal volumes of freshwater inflow and the long term attainment frequencies at which these volumes should occur. The standards for the Guadalupe Estuary, spring and summer, respectively, are provided in the rules in 30 TAC §298.380(a)(3) *(Table 2-1)* and 30 TAC §298.380(a)(4) *(Table 2-2)*, below.

Table 2-1 Bay and Estuary Freshwater Inflow Standards for the San Antonio Bay System for the Spring Season

Inflow Regime	Inflow Quantity (February) (af)	Inflow Quantity (March-May) (af)	Strategy Target Frequency
Spring 1	N/A	550,000-925,000	at least 12% of the years
Spring 2	N/A	375,000-550,000	at least 12% of the years
Spring 3	N/A	275,000-375,000	N/A
Spring 4	greater than 75,000	150,000-275,000	N/A
Spring 5	less than 75,000	150,000-275,000	N/A
Spring 6	N/A	0-50,000	no more than 9% of the years
Spring 2 and Spring 3 combined	N/A	N/A	at least 17% of the years
Spring 4 and Spring 5 combined	N/A	N/A	less than 67% of the total

(af=acre feet)

Table 2-2 Bay and Estuary Freshwater Inflow Standards for the San Antonio Bay System for the Summer Season

Inflow Regime	Inflow Quantity (June) (af)	Inflow Quantity (July- September) (af)	Strategy Target Frequency
Summer 1	N/A	450,000-800,000	at least 12% of the years
Summer 2	N/A	275,000-450,000	at least 17% of the years
Summer 3	N/A	170,000-275,000	N/A
Summer 4	greater than 40,000	75,000-170,000	N/A
Summer 5	less than 40,000	75,000-170,000	N/A
Summer 6	N/A	50,000-75,000	N/A
Summer 7	N/A	0-50,000	no more than 6% of the years
Summer 2 and Summer 3 combined	N/A	N/A	at least 30% of the years
Summer 4 and Summer 5 combined	N/A	N/A	Summer 5 no more than 17% of the total
Summer 6 and Summer 7 combined	N/A	N/A	no more than 9% of the years

(af=acre feet)

As briefly noted above, the watersheds contributing inflow for Mission and Aransas Bay are largely undeveloped and inflows under the status quo are expected to fully satisfy these targets, thus these freshwater inflow targets are not considered in this study.

Tables 2-1 and 2-2 include a column labeled “Strategy Target Frequency”. It is important to note that the Strategy Target Frequency (STF) is not considered as part of the water rights permitting process. These STF values are to be used solely for the purpose of pursuing voluntary strategies to provide additional freshwater inflow to the bays and estuaries. Since this study develops voluntary strategy options for meeting attainment frequencies for the Guadalupe Estuary; the STF values will be the primary focus. These frequencies were derived based on historical inflows for the period from 1941-2009. It is worth noting the period of record can have a significant effect on the number of shortfalls and the percent of time shortfalls occur. Since the WAM models will be used to determine availability of water for the ASR project and to estimate the FWI under this strategy, the 1934-1989 period of record will be used.

2.2 MODELING ASSUMPTIONS IN THE GUADALUPE SAN ANTONIO WATER AVAILABILITY MODEL

The GSA WAM is a computer-based simulation model capable of predicting the amount of freshwater inflow that would enter San Antonio Bay under a specified set of water management assumptions. These assumptions are defined based on the context in which the GSA WAM model is being used. For permitting perpetual and term water rights, the TCEQ maintains two official state versions of the model (referred to as Run 3 and Run 8 respectively). For perpetual water right applications TCEQ uses Run 3 in which all diversions are assumed to occur at the full amount authorized in their water rights permits and all of the water diverted is assumed to be fully reused (none returned to the stream). TCEQ makes this assumption to ensure that new permits for water do not rely on the use of water that is not legally required to be discharged upstream. This highly conservative approach underestimates future inflows because most water rights holders do not currently exercise the full amount that they are authorized; they use significantly less, and a significant percentage of the water that is diverted is subsequently returned to the stream in the form of wastewater or irrigation return flows. Furthermore, most of the treated effluent historically discharged in the Guadalupe-San Antonio River Basin is groundwater based.

Within the SB1 regional water planning program, the South Central Texas (Region L) Regional Water Planning Group has modified the TCEQ Run 3 version of the GSA WAM. The modeling assumptions included in the “Region L WAM” include effluent discharge / return flow in the Guadalupe - San Antonio River Basin reported for 2006 and adjusted for current SAWS direct recycled water commitments; Edwards Aquifer withdrawals; critical period management, and resulting springflows consistent with the Edwards Aquifer Habitat Conservation Plan (Phase I) developed through the Edwards Aquifer Recovery Implementation Program, and several modifications affecting operations of specific water rights (RWP 2016). Since this current study is intended to be a planning-level analysis, the Region L WAM was obtained from the Region L technical consultant and is used as the starting point for defining baseline conditions for the strategies considered in this study.

The inclusion of return flows in the baseline simulation is an important consideration. If they are included, return flows may be diverted by senior water rights or they may contribute to inflows to the San Antonio Bay. TCEQ's baseline model (Run 3) excludes return flows in part because once water has been diverted from the stream, water rights holders are not required, absent specific conditions included in their permit, to return that flow to the stream. Since the strategy that is presented in this report includes the dedication of return flows, it is appropriate to exclude return flows from the baseline and then add those return flows that are part of the strategy back into the model. This approach serves to make explicit the proposal that return flows would be appropriated or in some other manner legally set aside for use in augmenting freshwater inflows.

2.3 FREQUENCY OF MEETING STF GOALS ASSUMING BASELINE MODEL

The frequency of meeting STF goals is presented in a manner similar to the way the results were presented in the GSA-BBASC report (Tables 3.3-2 and 3.3-3 in GSA-BBASC 2011) as a set of estuary assessment summary tables. Table 2-3, below, presents results showing how often the various FWI standards are achieved for the 56 years in the period of record. Inflow levels have been changed from letters (A', A, B…) to numbers (1, 2, 3. . .) to be consistent with adopted TCEQ rules. Table 2-3 also omits the joint attainment targets which were modified slightly by the TCEQ; however, it is expected that satisfaction of single criteria measures results in satisfaction of joint criteria measures. Also, these tables are based on a different period of record than the BBASC report, which used 1941-1989.

The cells highlighted in red in Table 2-3, below, indicate GSA BBEST recommendations for seasons that the particular scenario fails to meet the attainment frequency criteria at levels that are cause for concern with regard to the ability to sustain a "sound ecological environment." Although the standards adopted by TCEQ include 6 to 7 target flow volumes per season plus several combined measures, as a practical matter it is only the lowest inflow values that fail to meet the STF values under even the conservative (excluding return flows) baseline water availability assumptions. Spring Level 6 (or D in the BBEST/BBASC reports) calls for a combined inflow of 150,000 ACFT in Mar – May (G1 period) for Rangia clams (*Rangia cuneata)*. The STF goal is that in no more than 9% of the years should the combined inflow Mar – May be less than 150,000 ACFT. When this percent target is applied to the 56 year (1934-1989) period of record available in the Region L WAM, the 9% target means that flows should be less than 150,000 ACFT in no more than 5 years. Region L WAM without effluent results indicate that the total spring season flows are below 150,000 ACFT in 16 years, 11 years more often than desired under the STF goals.

Table 2-3 Summary of the Baseline Scenario Attainment Performance for the G1 and G2 Suite (Spring and Summer Periods) of Guadalupe Estuary Inflow Criteria (See notes at bottom)

G1 -Spring

Counts	Criteria G1 Attainment (no. years 1934-89)							
Scenario	1	2	3	4	5	6		sum
REGL2016_BASEwoEff	12	9	2	5	5	16		56

Attainment	Single G1 criteria attainment (% of yrs.)						
Scenario	1	2	3	4	5	6	
goal	>=12%	>=12%				<=9%	
REGL2016_BASEwoEff	21.4%	16.1%	3.6%	8.9%	8.9%	28.6%	

G2 - Summer

Counts	Criteria G2 Attainment (no. years 1934-89)							
Scenario	1	2	3	4	5	6	7	sum
REGL2016_BASEwoEff	8	10	7	10	5	2	9	56

Attainment	Single G2 criteria attainment (% of yrs.)						
Scenario	1	2	3	4	5	6	7
goal	>=12%	>=17%					<=6%
REGL2016_BASEwoEff	14.3%	17.9%	12.5%	17.9%	8.9%	3.6%	16.1%

Notes: Counts of seasons (=years) that fall in each inflow category. Attainment performance for the portions of the criteria that are stand-alone measures (e.g. occurrence of G1-A >12% of years).
Attainment performance is highlighted with a color scheme indicated below

Cell color scheme	criteria met	criteria nearly met. rounding & period of record change probable causes.	criteria not met, departure from BBEST recommendations not great	criteria not met, departure of concern from BBEST recommendations

Similarly for the summer (G2), the target of concern is the lowest. Level 7 (or DD in the BBEST/BBASC reports) calls for a combined inflow of 50,000 ACFT in Jul – Sep for Oysters (*Crassostrea virginica)*. The STF goal is that in no more than 6% of the years should the combined inflow Jul – Sep be less than 50,000 ACFT. When this percent target is applied to the 56 year (1934-1989) period of record available in the Region L WAM, the 6% target means that flows should be less than 50,000 ACFT in no more than 3 years. Region L WAM without effluent results indicate that the total summer season flows are below 50,000 ACFT during 9 years, or 6 years more often than desired under the STF goals.

Had effluent return flows been included in the baseline Region L WAM analysis, the spring Level 6 target would not have been met in 14 years and the summer Level 7 target would not have been met in 7 years.

2.4 SUPPLEMENTAL FLOWS NEEDED TO FULLY SATISFY STF ATTAINMENT FREQUENCIES BASED ON REGION L WAM WITHOUT EFFLUENT

Figure 2-1 shows a time series of the projected freshwater inflow shortfalls in the spring assuming the Region L WAM without effluent. If the years with the maximum shortfalls are excluded, since the STF does not call for 100% attainment, then a supplemental supply of 90,000 ACFT could reduce the spring shortfalls to just 5 years, or the target specified in the STF.

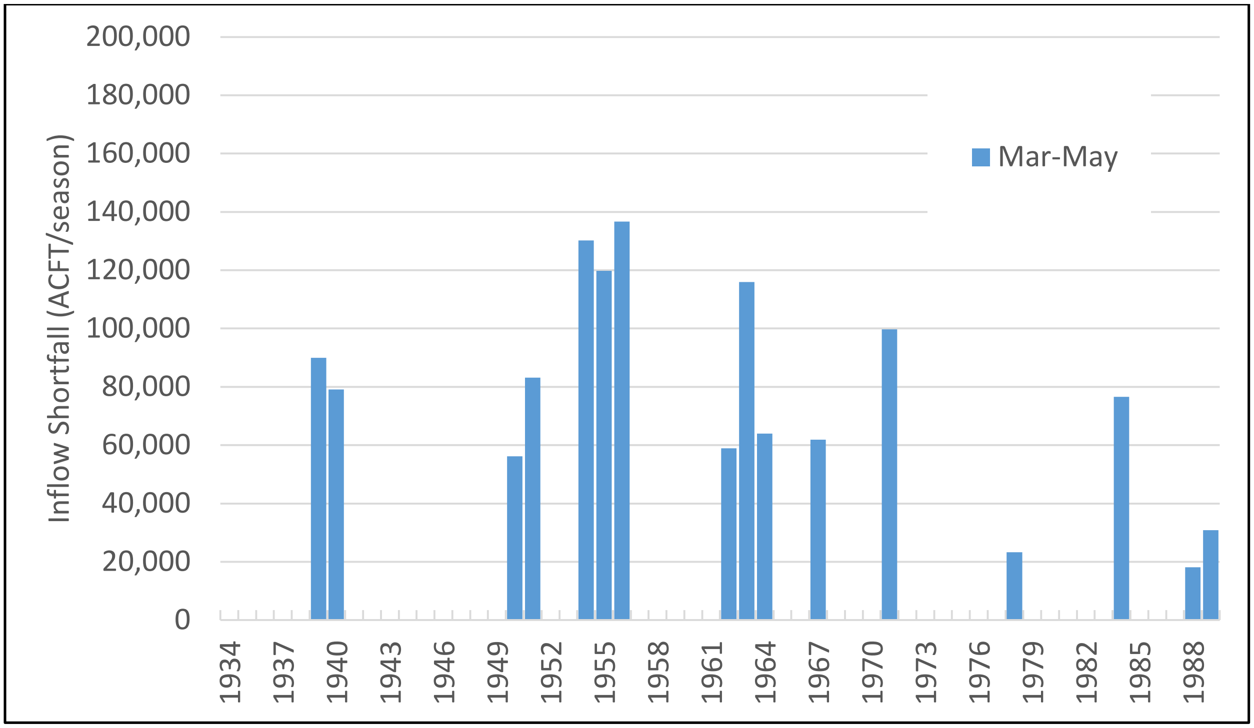


Figure 2-1 Spring Shortfalls for Freshwater Inflow Target

The summer shortfalls are shown in Figure 2-2. A notable issue for the summer shortfalls is that when there is a shortfall, that shortfall is, in the majority of years, close to the entire 50,000 ACFT target.

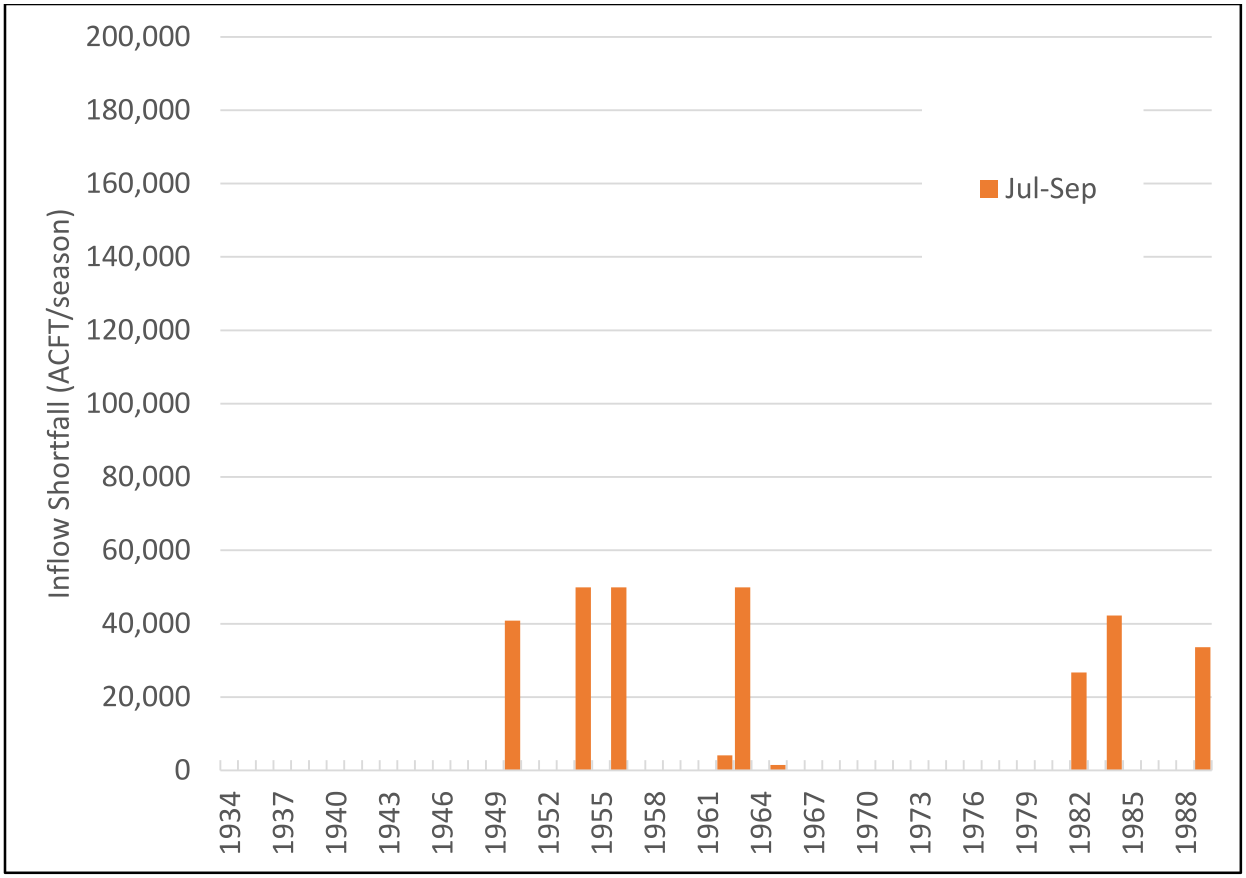


Figure 2-2 Summer Shortfalls for Freshwater Inflow Target

According to the WAM, if permits are fully exercised and there are no return flows, then in a repeat of the historical record inflows to the bay would be essentially zero for three months during the summer in 3 years, and very close to zero in another 3 or 4 years. Reducing the summer shortfalls to the target of 4 times would require supplemental flows equal to about 40,000 ACFT. A combined supplemental inflow level of 98,000 ACFT for the spring and 43,000 ACFT for the summer would be necessary in order to achieve the STF targets.

3 IDENTIFICATION OF STRATEGIES TO PROVIDE ADDITIONAL FRESHWATER INFLOWS DURING TIMES OF DROUGHT

The proposed strategy to increase the frequency at which the STF goals are met includes two parts:

1. Acquiring access to water rights for environmental flow purposes through the dedication of wastewater return flows, the set aside of existing water rights and the appropriation of new water permits,
2. Increasing storage of water for managed releases for environmental flows (Aquifer Storage and Recovery (ASR))

The first component builds on previous work included in the BBASC report (Appendix G *Report on Strategies to Meet Environmental Flow Standards* by National Wildlife Federation – with *WAM-Based Hydrologic Analyses of Strategies to Meet SB3 Environmental Flow Standards for the Guadalupe Estuary,* prepared by Intera).

This previous study evaluated the potential availability of water for environmental flows for a number of strategies within three general categories: dedication of wastewater return flows, acquiring a “Dry Year Option” on irrigation water rights, and accessing “underutilized” existing water rights. Based on the results of this prior evaluation and the more recent changes made to some of the permits included in the analysis, it was decided that the present study would focus on the potential amounts of water available through the dedication of waste water return flows, the set aside of existing water rights and the acquisition of new water rights permits.

A comprehensive strategy option based on these components has been developed and evaluated to determine how much additional freshwater inflow can be provided to the bay during critical periods.

3.1 INCREASING STORAGE OF WATER FOR RELEASES FOR ENVIRONMENTAL FLOWS USING AQUIFER STORAGE AND RECOVERY (ASR)

3.1.1 OVERVIEW OF AQUIFER STORAGE AND RECOVERY (ASR) AS A WATER MANAGEMENT TOOL

General description of ASR and its various applications

ASR is defined as the storage of water in a suitable aquifer through a well during times when water of suitable quality is available for storage, and recovery of the stored water when it is needed, usually from the same well. More than 500 ASR wells are operating in the United States, in about 25 states and approximately 175 ASR wellfields. Most of these wells store drinking water, while a growing number store highly treated reclaimed water or surface water. A few ASR wells store groundwater from a different aquifer at the same location, or from the same aquifer at a different location. ASR wells have been operating in the USA since 1969 and are utilized in many other countries to achieve a variety of goals. Principal goals include:

1. Achieving water supply sustainability and reliability through providing seasonal storage from wet months to dry months within a given year;
2. Long-term storage, or "water banking," to meet demands with high reliability during severe droughts, and
3. Emergency storage for those systems reliant upon water sources that are vulnerable to interruption.

Twenty-five other ASR goals have been identified to date, one of which is to meet environmental flow requirements by augmenting dry weather flows and maintaining lake levels. Most ASR wells are designed and operated to meet a primary goal plus one or more secondary goals. Aquifers utilized for ASR storage usually contain fresh water, however in almost all cases there is at least one water quality constituent in the native groundwater that is not wanted in the water recovered from ASR storage, such as iron, manganese, hydrogen sulfide, nitrate, arsenic, and salt. About a quarter of all ASR wellfields utilize brackish aquifers for storage, with total dissolved solids concentrations up to 20,000 mg/l. Storage of drinking water in a seawater aquifer has been successfully demonstrated at two locations, one of which is operational. ASR well depths range from about 100 feet to 3,000 feet. Individual well yields range from about 0.5 MGD to 8.0 MGD (1.5 to 24 AF/D). The largest ASR wellfield is at Las Vegas, with a recovery capacity of 157 MGD (482 AF/D).

The principal driver for ASR implementation is cost-effectiveness. ASR solutions for meeting water management needs typically have capital costs that are less than half that of other alternatives and, in many cases, the savings have been as much as 90%. Other drivers include the relatively small footprint required for ASR wells; the ability to add wells one or more at a time to meet changing needs as opposed to having to finance a major capital expansion program; and proven performance at a large and increasing number of sites nationwide.

Some factors have tended to hold back ASR implementation. Principal among these has been the regulatory framework for ASR at the Federal and State level. This regulatory framework was promulgated prior to the development of all but the earliest ASR wells and did not adequately reflect ASR needs, constraints and opportunities. During the last few years, significant changes in policy, laws and regulations have been implemented that have helped to clear the roadblocks to ASR in many states. In 2015, the 84th Texas Legislature passed ASR legislation (Acts 2015, 84th R.S., Ch. 505, General and Special Laws of Texas) which addressed and resolved many of the issues that had previously hindered the ability to store water underground in Texas.

An important change in policy at the Federal level was implemented in 2013, providing individual states with greater discretion to implement ASR programs that best meet each State's overall needs. In particular, this change in policy reflected acceptance by the Environmental Protection Agency (EPA) that federal law regarding Underground Injection Control (UIC) provides adequate time and distance for water stored underground to benefit from natural physical, microbial and geochemical processes that improve water quality during aquifer storage. Measurement of compliance with drinking water standards may therefore be evaluated at a reasonable distance from the ASR well, not at the ASR well prior to injection. Each state can then determine, on a case by case basis, the reasonable distance that is acceptable. As will be discussed subsequently in this report in greater detail, this Federal policy change facilitates achievement of environmental flow targets for Texas by potentially providing for treatment of river water with bank filtration prior to storage in ASR wells along the river banks during average and high flow periods, for recovery of the stored water during dry periods to supplement flows to the estuaries.

ASR Applications to Augment Environmental Flows

One of the 28 ASR applications identified to date is for augmentation of environmental flows, such as supplementing flows to rivers and estuaries during dry weather periods and also for maintaining lake and other surface water levels. This has been a primary goal of ASR at one site in Florida and a secondary goal at a few sites, mostly in western states and Canada, usually in conjunction with a primary goal of urban water supply. At some other sites this ASR application has been proposed but not yet implemented. Some examples are presented below.

Florida Everglades

The Florida site is for the Comprehensive Everglades Restoration Program. As originally envisioned about 1998, a total of 333 ASR wells would store and recover 1.7 billion gallons per day (5,200 AF/D), reducing flood flow discharges to tide and augmenting dry weather flows and water levels. ASR demonstration wells and associated facilities were constructed and tested at two sites in South Florida, storing water in the Upper Floridan Aquifer, which is a karst limestone, confined aquifer. At one site the storage aquifer is fresh while at the other site it is brackish. After several years of construction and cycle testing, the U.S. Army Corps of Engineers released a final report on ASR test program results during 2014 (USACE, 2014). A subsequent peer review by the National Research Council resulted in a report (NRC, 2015) that included the following in its summary:

> *The Aquifer Storage and Recovery (ASR) Regional Study resolved many uncertainties about large-scale application of ASR in South Florida and developed tools and an impressive knowledge base to support future ASR projects, if implemented, but the research identified several new questions, and some key uncertainties remain. This chapter presents the*

> *committee's assessment of the highest-priority uncertainties that need to be resolved before large-scale implementation of ASR is considered. These uncertainties could be addressed across a range of scales, from continued operation and cycle testing of existing pilot project wells to an incremental adaptive management approach (NRC, 2007, 2008), where a few ASR well clusters are constructed and operated to provide some restoration benefits while building knowledge and resolving critical uncertainties to inform future project implementation.*

Key uncertainties and future research needs were described in detail in the NRC report and are as follows:

- Operations to maximize recovery and reduce water quality impacts
- Ecotoxicology and Ecological Risk Assessment
- Understanding phosphorus reduction potential
- Disinfection, and
- Cost and Performance of ASR Compared to Other Alternatives

Other Florida ASR Projects to Achieve Environmental Goals

Florida passed legislation during 2013 to prohibit discharge of wastewater effluent to ocean outfalls by 2025, except as a backup to established reuse systems that beneficially use the reclaimed wastewater except during wet weather periods when demand for reclaimed water is greatly reduced, and during emergencies. Most of these outfalls are in southeast Florida, discharging to the Gulf Stream which flows close to shore. This densely populated area has limited opportunity for use of very large volumes of treated wastewater for irrigation or cooling purposes. Furthermore, during the summer rainy season there is no demand for water for irrigation. As a result, it is anticipated that storage of high quality reclaimed water and filtered surface water in brackish aquifers through ASR wells will become widespread, creating a large, underground fresh water reservoir in the Upper Floridan Aquifer.

This aquifer is increasingly utilized for water supply via brackish water reverse osmosis treatment, supplementing traditional water supplies from shallow wells in the Surficial Aquifer, which is fresh. Both aquifers are heavily pumped, creating salt water intrusion issues due to the proximity of salt water in coastal areas. This is compounded by growing concerns regarding anticipated sea level rise in this low elevation coastal area. Consequently recharging the brackish aquifer with fresh water will help to create a sustainable water supply. The Florida Department of Environmental Protection (FDEP) recently issued an operating permit to the City of West Palm Beach for recharge of high quality surface water into the brackish Upper Floridan Aquifer following filtration to remove particulates, but not requiring disinfection of the recharge water. Issuance of this permit reflected site-specific consideration of water quality risks and potential environmental benefits. A significant factor in the decision process was the documented natural attenuation of microbiota during ASR storage and the significant distance to adjacent wells producing water from the same storage aquifer.

In addition, the Florida water management districts and the FDEP are continuing efforts to encourage increased reuse of highly treated wastewater in other parts of the state that do not rely on ocean outfalls but discharge to surface waters. ASR wells have been permitted and are under construction or in operation in central Florida (Polk County) and in northwest Florida (Destin) for seasonal storage of reclaimed water in fresh and slightly brackish aquifers. Other similar projects are in development.

Salt River Project, Salado Springs, Arizona

Environmental mitigation requirements for a new power generation facility in northern Arizona included restoration of a 35-acre saline wetland area that has about one acre of pools from former spring discharges that have been adversely impacted by regional groundwater pumping. The aquifer and springs have extremely high concentrations of metals and arsenic but the aquifer water quality is better than the water quality in the pools. The surrounding area is desert and is devoid of vegetation. The source water for seasonal ASR recharge is snow melt from a local farm irrigation canal that is full of bacteria and debris. ASR wells have been constructed and tested and equipping of the wells with permanent wellhead pumps, piping and treatment facilities is underway. Seasonally-available surface water from the irrigation canal will receive treatment via a settling pond, bank filtration, chlorination, 5-micron filtration, acidification, pre-injection storage and then pumping to the ASR wells. Recovered water from the ASR wells will not receive further treatment prior to discharge to the wetland. The stored water will be recovered during dry months to help maintain a viable wetland habitat. The design diversion rate from the canal is 1,500 GPM (6.6 AF/D). Each of the two ASR wells pumps 900 GPM and recharges at 450 GPM. Water will be pumped from the irrigation canal to the wells and the springs during May to September. During October to April water from the ASR wells will be recovered to the wetlands.

Upper Catherine Creek Recharge Feasibility Study, Grand Ronde Model Watershed, La Grande, Oregon.

A current project for the Grande Ronde Model Watershed (GRMW) has evaluated the feasibility of using aquifer recharge to enhance summertime stream flows in upper Catherine Creek for fish passage and thermal refuge for ESA-listed anadromous fish species. Upper Catherine Creek provides critical fish habitat for listed Chinook salmon and steelhead runs in the upper Grande Ronde River basin and also is the source of irrigation supply for a significant portion of the La

Grande Basin. While water rights with priority dates after 1900 generally are regulated off in early summer, portions of the stream below major irrigation diversions still experience low summer flows and high temperatures, which affect migrating fish passage and juvenile survival.

The pre-feasibility fatal flaw analysis (which was completed with matching Oregon Water Resources Department grant funding) evaluated the use of shallow alluvial sediment and/or Columbia River Basalt aquifers to store winter flows from Catherine Creek and return the water to the creek in the summer when stream flows are insufficient to sustain fish habitat and passage. A 20 mile stretch of the stream was screened to identify potentially favorable locations, and identified a possible pathway for obtaining authorization to access water for storage. OWRD support was obtained for the pathway. Preliminary results suggest that diverting winter flows through the alluvial aquifer for filtration credits, and storing the water via ASR wells in the underlying basalt flows may be feasible and could provide up to 10 cubic feet per second (CFS) of cooler water to the stream during a 4-month period in the summer. Another alternative under consideration is using ASR to store water in basalt aquifers further downstream, near major irrigation diversions, and replace water diverted from the stream for irrigation during the summer with the ASR recovered water.

The pre-feasibility study included developing a regulatory permitting framework for accessing water for storage and protecting the additional flows in-stream from other users; evaluating potential hydrogeologic fatal flaws; assessing infrastructure needs; developing a project implementation plan and planning level costs.

GRMW and funding partners, the Freshwater Trust and National Fish and Wildlife Foundation, worked with other stakeholders, including the US Bureau of Reclamation, Oregon Water Resources Department and the Bonneville Power Authority to evaluate key aspects of the aquifer recharge streamflow enhancement concept, including commissioning a technical review by the U.S. Geological Survey. A detailed geologic reconnaissance and geophysical survey was conducted by Groundwater Solutions Inc., focusing on a potentially favorable area in preparation for test drilling to assess the basalt aquifer storage properties and alluvial aquifer connection with Catherine Creek.

Columbus, Georgia

During the period 2008 to 2013 a detailed plan was developed to resolve the “Tri-State Water Wars” between Florida, Georgia and Alabama using ASR technology. Florida wishes to protect estuarine ecosystems in Apalachicola Bay, particularly its oyster population, from upstream diversions in Georgia. Alabama wishes to protect its water supplies coming in from Georgia via the Coosa River, and Georgia wishes to maintain the right to divert all water needed for urban and agricultural purposes. Litigation has been underway since 1990 and is continuing. Periodic droughts have resulted in substantial reductions in flow crossing from Georgia to Florida. While the reductions are typically blamed upon population growth in the Atlanta Metropolitan Area, the greatest impact by far is from agricultural diversions in southwest Georgia, pulling water directly from the rivers and tributaries and also from shallow aquifers that are directly connected to these surface waters.

An ASR solution was developed in detail, storing water underground during normal and high flows and recovering to the river during low flows. The proposed solution included land access, diversion intake and bank filtration facilities, well locations, pipelines, power line rights of way, discharge structures, phased implementation, and an initial testing program to confirm design details. A private company, Etowah Water Bank LLC, was formed to develop and implement the program and to operate the resulting wellfield facilities. A team was formed and selected to design, construct, finance and place the very large wellfield facilities into operation within five years, pursuant to a public private partnership. For unknown reasons, ASR initial testing was then changed by the State of Georgia to an alternate, inferior site from a hydrogeologic perspective, test results from which were not encouraging, primarily due to low well yields. The project was recently cancelled, ostensibly due to the poor test results but more likely due to opposition from local agricultural interests after learning that the stored water would be earmarked for downstream conveyance, not for increased local agricultural water supply.

San Antonio Water System (SAWS) Twin Oaks ASR Facility

This highly successful ASR wellfield is the largest in Texas and the third largest in the United States, with 60 MGD (184 AF/D) of wellfield recovery capacity. Two construction phases, in 2000 and 2006, developed the ability to store drinking water from the Edwards Aquifer during normal and wet months, for recovery during dry months and extreme droughts. Storage occurs 30 miles south of San Antonio in the Carrizo-Wilcox Aquifer, which is a semi-confined sand aquifer about 200 feet thick. The wellfield is on 3,200 acres of land, a small portion of which is required for construction and operation of wellfield facilities while the remainder is leased out for agricultural purposes. It includes 29 ASR wells and seven Carrizo Aquifer production wells. Storage volumes to date have reached about 100,000 AF. During the recent drought, ASR facilities enabled SAWS to reduce local pumpage in San Antonio from the Edwards Aquifer, substituting water recovered from ASR storage. This change in operations raised local groundwater levels in the Edwards Aquifer and increased springflows at San Marcos and Comal Springs, thereby achieving spring flow goals and increasing protection for endangered species pursuant to the Edwards Aquifer Habitat Conservation Plan (EAHCP). This also augmented downstream environmental flows to the San Antonio Bay Estuary system.

Recent ASR Phase I Feasibility Study for the Victoria, Texas Region

A Phase I ASR feasibility assessment report was recently prepared (NEI et al, 2014) for the City of Victoria, Texas and the surrounding region, including an area served by the Guadalupe-Blanco River Authority's (GBRA) surface water treatment plant outside Port Lavaca, Texas. The City of Victoria vicinity was determined to be ideally suited for ASR, with excellent hydrogeologic characteristics. The City's existing water rights, diversion and treatment facilities can be utilized to store a substantial quantity of drinking water underground, sufficient to meet projected 2040 water needs with high reliability without the need for expanding the existing water treatment plant, capacity of which with minor improvements is 25.2 MGD (77 AF/D). ASR wellfield facilities would include up to 16 ASR wells in the Evangeline Aquifer, Upper Goliad Formation, with screen settings between -400 and -1,000 feet mean sea level. Native groundwater quality is relatively fresh, with total dissolved solids (TDS) concentrations generally below 700 mg/l. Ten of these ASR wells would be located at the surface water treatment plant, close to the Guadalupe River, plus retrofit of up to six existing water supply wells in the City's service area to ASR wells.

A daily ASR simulation model was developed and utilized to test seven different scenarios for projected water demands, reliability goals, and water treatment plant capacities. Required volumes for recovery ranged from 5,000 to 83,000 AF while ASR recovery capacities ranged from 20 to 25 MGD (61 to 77 AF/D). The maximum duration of continuous recharge was 426 days while the maximum duration of continuous recovery was 259 days. For the ten ASR wells at the surface water treatment plant, spacing would be about 1,000 feet. A theoretical calculation suggests that the radial extent of the stored water might extend up to about 4,900 feet from the center of the wellfield. Almost all of this would be within City-owned property while the remainder is within the City's jurisdiction.

For Port Lavaca, an ASR wellfield would also work. However individual well yields would be relatively low and native groundwater quality would be brackish, not fresh. A small ASR wellfield meeting projected urban water supply needs would be viable and cost-effective, however a large wellfield meeting environmental flow needs would not likely be viable. With a few improvements, the existing 4.8 MGD water treatment plant capacity could be increased to 6.1 MGD. Recovered water volume from ASR storage ranged from 9,000 to 15,000 AF during evaluation of seven different operational alternatives, and ASR recovery rates ranged from 3.8 to 4.5 MGD. Thirty wells would be required. ASR wells would be constructed in three sand intervals within the Lower Chicot aquifer at depths of 300 to 1,100 feet. TDS concentrations in this interval are believed to be between 3,000 mg/l and 5,000 mg/l.

The flow rates required during ASR recovery to meet environmental flow needs are large. The regional ASR study indicates that the coastal aquifers along the Guadalupe and San Antonio Rivers become more fine-grained as the rivers approach the coast, with lower well yields and increasing salinity. The best location for one or more ASR wellfields to meet urban and environmental flow needs in this coastal area will tend to be more inland, such as along a reach of the Guadalupe River just upstream and downstream of the City of Victoria.

4 MODELING AND ANALYSIS TO AUGMENT FRESHWATER

Analysis to determine how various strategies could be implemented to augment freshwater inflows to better achieve the estuarine attainment frequencies (STF) identified in the TCEQ flow standards involved several iterations of the WAM and post processing spreadsheets (FRAT and Aquifer Water Balance Model). Through this process available sources of water were identified including both currently unappropriated water and water made available from existing sources. A monthly time series of volumes available at a point of diversion for aquifer storage and subsequent recovery and at the mouth of the bay was created through an execution of the WAM. A spreadsheet tool (FRAT) maintained by TPWD was used to determine the portion of these flows that would need to remain in the stream per SB3 rules. The remaining available flows were then used in an aquifer water balance model to determine the recharge and recovery rates that would be needed to satisfy specific freshwater inflow goals including the STF. These sections document the WAM and spreadsheet analysis. The issues described in this section are focused on water availability and do not address the various policy and cost issues that would need to be addressed to be able to implement this recommendation.

4.1 WAM MODELING INCLUDING WASTEWATER DEDICATION

WAM modeling is used to determine how much water is available for diversion and how much remains in the streams at specific locations based on a set of assumptions. In a normal WAM simulation, the volumes available for diversion and remaining in streams represent unappropriated flows that are not allocated to existing water rights. While it is conceivable, given sufficiently large infrastructure that an ASR project, which relies solely on unappropriated flows, could be developed to meet the STF goals, the costs of such a project can be reduced significantly if a dependable source of available supply, in addition to unappropriated flows, can also be included. A firm, dependable supply allows for infrastructure to be sized more efficiently and provides some supply at all times. The proposal in this report therefore is to acquire additional dependable supplies to supplement unappropriated flows. Several options for additional supplies were evaluated in the Intera report to the BBASC (Appendix G *Report on Strategies to Meet Environmental Flow Standards* by National Wildlife Federation – with *WAM-Based Hydrologic Analyses of Strategies to Meet SB3 Environmental Flow Standards for the Guadalupe Estuary,* prepared by Intera). These included use of currently underutilized water rights, dry year option lease of irrigation rights and dedication of wastewater return flows. Some of the irrigation rights that were identified in the earlier study are apparently multi-purpose rights and many of them have been converted to other purposes in the most recent version of the Region L WAM.

Likewise, several of the rights that were identified as underutilized are apparently being considered as part of other water management strategies. After reviewing the Intera report it appears that a wastewater dedication alternative is the most promising.

The Intera report identified two alternatives for dedicating portions of the wastewater return flows from the 10 largest wastewater treatment plants (WWTPs) in the Guadalupe and San Antonio River Basins. In this study, the portion of return flow dedication was calculated to provide 10,000 ACFT per year just downstream of the Victoria gage. After accounting for channel losses, a dedication of 63.2% of the current return flows from the four largest WWTPs in the Guadalupe basin provides this volume of supply (Table 4-1). The existing return flows in Table 4-1 were extracted from the Region L WAM that was obtained from Region Ls technical consultant. For the purposes of this report, it is assumed that all of these dedicated wastewater flows would be made available through bed and banks permits. While allows for special conditions to be applied to such permits, in this study the diversion of these dedicated return flows at Victoria were modeled without subjecting them to the SB3 instream flow standards.

Table 4-1 Dedication of Wastewater Return Flows.

Jurisdiction / Discharger	Existing Return Flows	Guadalupe	San Antonio	Dedication	Guadalupe	San Antonio
Victoria	6,603	6,603	0	4,171	4,171	0
New Braunfels	4,889	4,889	0	3,088	3,088	0
San Marcos	4,740	4,740	0	2,994	2,994	0
Seguin	3,088	3,088	0	1,950	1,950	0
San Antonio - Dos Rios	72,005	0	72,005	38,942	0	38,942
San Antonio - Leon Creek	29,242	0	29,242	15,815	0	15,815
San Antonio - Medio Cr.	7,645	0	7,645	4,135	0	4,135
SARA - Upper Martinez	5,956	0	5,956	3,762	0	3,762
San Antonio, Breck. Park	4,250	0	4,250	2,685	0	2,685
Cibolo Creek Mun. Auth. (Selma, Schertz)	4,042	0	4,042	2,553	0	2,553
TOTAL (10 largest*)	142,459	19,319	123,140	80,096	12,204	67,892
Channel Loss Factor		18.0%	31.1%		18.0%	31.3%
TOTAL to Estuary (SA) or Victoria (Guad.) after Channel Losses		15,836	84,827		10,004	46,632

* Total of all return flow in the Guadalupe and San Antonio Basins = 157,160

This same percentage (63.2%) was applied to return flows from the six largest WWTPs in the San Antonio Basin, with the exception of the three SAWS WWTPs (Dos Rios, Leon Creek, and Medio Creek). Return flows from the SAWS WWTPs up to 50,000 ACFT/YR are used by CPS Energy. Therefore, the return flow dedication for this strategy from the SAWS WWTPs is only 54.1% with the rest remaining for CPS Energy. Dedication of return flows from the San Antonio basin for this strategy ensures that these flows are delivered to the Guadalupe Estuary without being diverted by other intervening water rights holders. The dedication of these San Antonio basin flows does not provide the same level of benefit as return flow from the Guadalupe Basin because unlike the return flows from the Guadalupe basin, which are available for diversion from the river to recharge the aquifer and then can be released specifically when needed, the return flow from the San Antonio Basin enters the bay throughout the year whether there is an inflow shortfall or not. These dedications from San Antonio basin WWTP do however provide baseline inflow in all years, and reduce the shortfall volume in low inflow periods. The decision to consider only return flow from the Guadalupe as being available for aquifer recharge is based on the site information available for the Victoria area, which is upstream of the Guadalupe and San Antonio River confluence. It is conceivable that other alternatives could be developed, possibly using a pipeline to bring water from the San Antonio River or developing wellfields at a site on the San Antonio River. Other existing WWTP return flows that are not dedicated to FWI were not included in the model. This is conceptually consistent with the baseline scenario which does not include return flows.

The decision to dedicate 63.2% of return flow to this project is admittedly arbitrary. It is not however possible to evaluate every option and this value provides a reasonable starting place. Ultimately other sources or different amounts may prove more practical. In order to provide context and assess the benefit of this dedication, models were also set up to assume no return flows and 100% of the return flows from the 10 largest treatment plants.

Having established the basic conceptual approach of using unappropriated flow and a dedication of firm return flows, the mechanics of the WAM modeling were to first specify the locations at which this water is made available. For the strategy proposed in this report there are two locations of interest. The first is the location on the Guadalupe River from which water will be diverted for aquifer recharge and the second is the point at which the river enters the bay. The river diversion would be just downstream of the Victoria gage (USGS 08176500 - WAM control point CP15). The Guadalupe River enters the San Antonio Bay system at the Guadalupe Estuary (WAM control point CPEST).

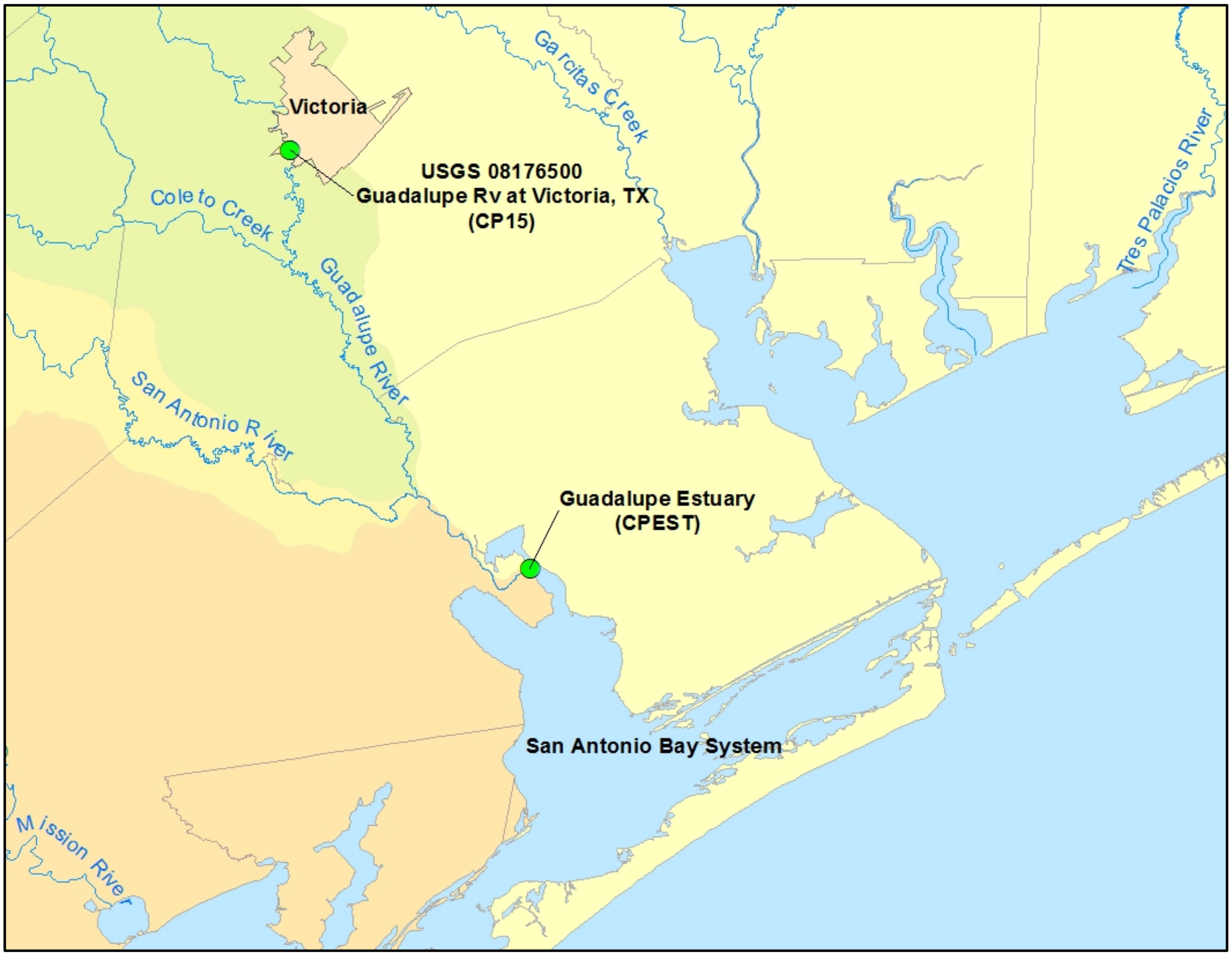


Figure 4-1 Map Indicating Location of Guadalupe River Water Rights Diversion Point (CP 15) and Combined Guadalupe and San Antonio Rivers Discharge Point into San Antonio Bay (CPEST)

At both of these control points, the Region L WAM model has been modified to deliver water that would be dedicated from return flows from upstream waste water treatment plants and to set aside currently unappropriated water for freshwater inflows. For the wastewater dedication water, the modeling approach developed by Intera (GSA BBASC 2011) as part of the BBASC alternatives analysis was ported into the Region L WAM. This modeling code adds return flows at the locations of the WWTPs and routes these return flows downstream to the appropriate locations (control points) in order to properly account for channel loss. This coding also insures that these dedicated flows are not available for diversions by intervening water rights holders. For the four WWTPs in the Guadalupe basin, wastewater return flows are routed to the control point just downstream of the Victoria gage.

The amount of unappropriated water available for diversion at Victoria or set aside at the Guadalupe Estuary, in excess of these dedicated flows, is reported in the standard WAM outputs and is used as inputs to the Aquifer Water Balance model described below. Diversions of unappropriated water downstream of the Victoria gage are made subject to the SB3 instream flow requirements at Victoria. Since the aquifer water balance model requires daily inputs, the amount of water available for diversion near Victoria is calculated outside of the WAM using the Flow Regime Application Tool (FRAT) software program maintained by the Texas Parks and Wildlife Department (TPWD). The FRAT program is an Excel spreadsheet model that was originally developed by HDR Engineering during the SB3 process for application in the Sabine Neches River Basin to simulate water supply projects subject to SB3 type environmental flow recommendations. The program has been generalized for other basins by TPWD. The FRAT program uses WAM outputs (regulated and unappropriated flows) and daily flow distribution patterns to calculate how much water must be passed on a daily basis subject to the various instream flow requirements and hydrologic condition trigger conditions.

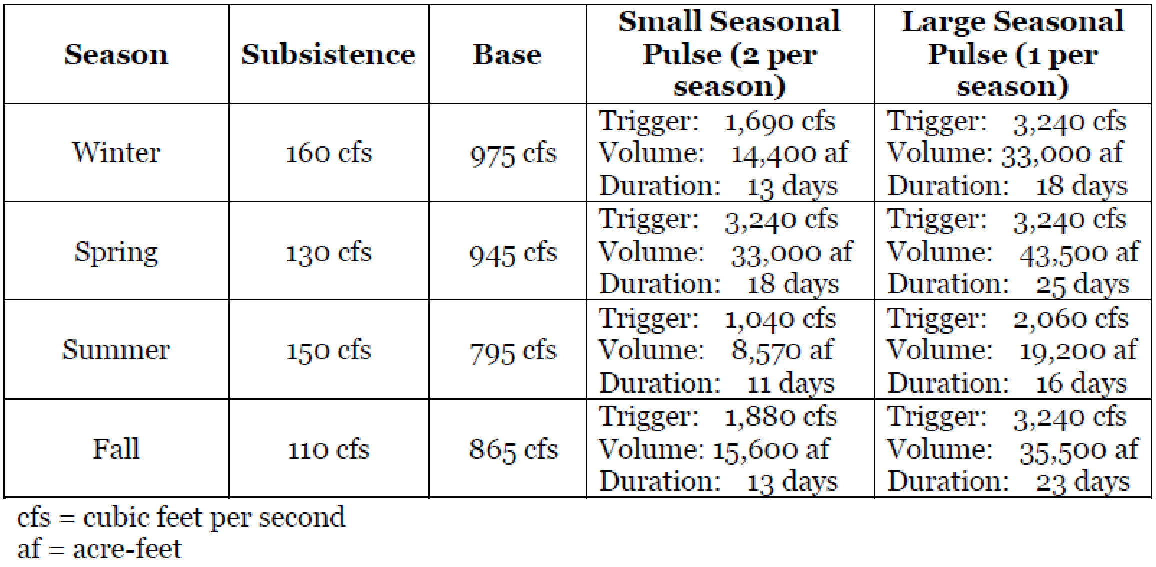
4.2 AQUIFER WATER BALANCE MODEL

The Aquifer Water Balance (AWB) model is a spreadsheet model which uses outputs from the WAM and FRAT programs, to determine how much water can be diverted from the river, subject to availability constraints including environmental flow requirements, stored in the aquifer, and then recovered from the aquifer in order to augment freshwater inflows during times when the standards would not otherwise be satisfied. Model parameters including aquifer capacity and initial volume, recharge rate (which includes river diversion, treatment and injection rates) and aquifer recovery rate can be adjusted to meet desired attainment goals including those identified in the STF or some lessor value.

The AWB model operates on a daily time step. A daily distribution pattern is used to convert WAM monthly output to a daily time step. Monthly regulated flows calculated in the WAM at a new control point (WW2AS) inserted just downstream of the USGS gage on the Guadalupe River at Victoria (CP15) and at the Guadalupe Estuary (CPEST) and monthly unappropriated flows at the WW2AS control point were converted to daily flows based on the daily distribution patterns developed for previous BBASC work and documented in *Hydrologic Time Series for verification and refinement of flow regime recommendations* (KCR 2011). These daily distribution patterns (one for each of the two sites) were derived from the USGS gage records (with missing periods filled in from nearby gages or provided by GSA BBEST). The daily unappropriated flows for the WW2AS site were calculated because they are used to determine how much water must be passed at this site to honor senior water rights, a required input for the FRAT program. Note - one of the outputs from the Region L WAM is the monthly volume of water from the WWTP plants in the Guadalupe Basin that would be dedicated for diversion in the ASR project. For the subsequent analysis described below, these return flows are assumed to be constant within each month. These flows are also assumed to be diverted prior to the FRAT analysis, which is applied only to the potential new diversion, and are not assumed to be subject to the environmental flow requirements.

The FRAT model used daily regulated flows and the amount of water that must be passed for senior water rights (regulated minus unappropriated flows) and applies the environmental standards to determine how much water must be passed for the environmental flow standards. The environmental flow standards for the Victoria site (Table 4-2)were applied to the site just downstream of this gage (control point WW2AS) to determine how much water could be diverted for aquifer storage at this location.

Table 4-2 Instream flow rules for USGS Gage 08176500, Guadalupe River at Victoria (30 TAC §298.380(c)(9))



Season	Subsistence	Base	Small Seasonal Pulse (2 per season)	Large Seasonal Pulse (1 per season)
Winter	160 cfs	975 cfs	Trigger: 1,690 cfs Volume: 14,400 af Duration: 13 days	Trigger: 3,240 cfs Volume: 33,000 af Duration: 18 days
Spring	130 cfs	945 cfs	Trigger: 3,240 cfs Volume: 33,000 af Duration: 18 days	Trigger: 3,240 cfs Volume: 43,500 af Duration: 25 days
Summer	150 cfs	795 cfs	Trigger: 1,040 cfs Volume: 8,570 af Duration: 11 days	Trigger: 2,060 cfs Volume: 19,200 af Duration: 16 days
Fall	110 cfs	865 cfs	Trigger: 1,880 cfs Volume: 15,600 af Duration: 13 days	Trigger: 3,240 cfs Volume: 35,500 af Duration: 23 days

cfs = cubic feet per second
af = acre-feet

Although the FRAT program could be capable, with minor modifications, of determining this diversion, owing to some of the other complexities related to diversion, storage, and recovery and the timing of the desired diversion, only the pass-through values calculated in FRAT were extracted and then imported into the AWB model.

The AWB model was developed specifically for this study. This model takes the Region L WAM outputs, converted to daily values, and the FRAT pass-through values to determine how much can be recovered from aquifer storage to augment freshwater inflow during low flow periods.

An early and important decision point in the development of the AWB model had to do with the level of detail that would be included in the calculations. At a conceptual level it would be possible, based on the WAM output, to know with perfect foresight how much supplemental volume would be required in each upcoming season. Thus if the WAM results indicated a spring shortfall of 10,000 acft in a particular year the, AWB model could be set up to begin recovering water from the aquifer on May 1 at a rate of 10,000/92 ACFT/d (where 92 is the number of days in the spring system). In this way the model could be used to determine theoretical operational parameters for recharge and recovery rates. At a level of a conceptual study, understanding these limits can provide insight as to the efficiency of an operation plan, however in real time this level of foresight is not reasonable. Therefore a simple, yet reasonable operations approach was implemented in the model. This operations approach is as follows:

1. The simulation assumes that the aquifer starting storage is 100,000 ACFT on January 1, 1934.
2. Dedicated return flows are simulated first. The dedicated return flows from the San Antonio Basin are assumed not available for diversion by existing water rights and contribute to the total regulated flows at the Guadalupe Estuary (CPEST). Dedicated return flows from the Guadalupe Basin are diverted, for ASR storage, just downstream of Victoria and are also not available for diversion by intermediate water rights, nor are these diversions assumed subject to the environmental flow requirements at Victoria. In the daily analysis these flows are assumed to be constant within each month.
3. For the first 15 days of each season the aquifer recovery target is determined based on the inflows in the 15 days prior to the beginning of the season compared to 1/6 of the total seasonal target (150,000/6 and 50,000/6 for spring and summer respectively). This is done to ensure that river flows are not captured in a season that is currently in a dry condition.
4. The freshwater inflow needs in the spring (150,000 ACFT from Mar-May and 50,000 ACFT from Jul-Sep) are evaluated on the 15th and last day of each month. If the cumulative inflow up until that time is less than the cumulative needed on that day then a shortfall is determined and that volume shortfall is recovered from the aquifer at a constant rate over the next 15 days (subject to existing storage being available from the ASR wellfield). This means that if a shortfall occurs on the last day of the season, the makeup water is provided in the 15 days after the season ends. While this is not precisely consistent with the rules as written, it is consistent with how deliveries of water to meet freshwater inflow targets have been applied in other basin in Texas (LCRA, Nueces).
5. Once ASR recovery (pumping of water out of the aquifer back to the river to augment FWI) has begun in a season, water is not diverted and stored again in that season even if high flows occur. This is a conservative approach and could potentially be modified (e.g. if cumulative inflows at the check dates is greater than some factor of the target on these dates, aquifer recharge might recommence). Also during recovery operations, wastewater dedicated from Guadalupe plants remains in the stream and is passed downstream to the Estuary.
6. When the system is not in ASR recovery operations, water is diverted from the Guadalupe River, just downstream of Victoria to recharge the aquifer. Diversions are made first accounting for water available from wastewater dedications and second from

unappropriated water, subject to existing environmental flow requirements. Total diversion is limited by the user defined recharge rate.

Since the exact details of how this project might be operated are somewhat beyond the scope of this report, the AWB model was also executed assuming perfect foresight (i.e. knowledge on the first day of each season of what the total amount of supplemental water will be required for the upcoming season). The parameters derived for this analysis provide theoretical limits as to how much the project operations could be improved with a more efficient real time operations program.

4.3 ASR PARAMETERS NEEDED TO FULLY SATISFY STF GOALS

Based on water availability, as determined by the modified Region L WAM and subjected to the environmental flow requirements in FRAT, recharge and recovery rates necessary to meet the BBASC STF goals were be determined using the AWB model. Since the STF goals require that spring inflows are below 150,000 ACFT no more than 5 times in the WAM period of record, the recovery rate required to meet the STF goals is the value necessary to meet the supplemental inflows in the in the 6th driest spring. The iteration process to determine the necessary recovery rate begins by setting a high recharge rate such that available supply from the aquifer is not a limitation, and decreasing the recovery rate until only five springs in the period of record have a total season inflow of less than 150, 000 ACFT. Satisfying the 150,000 ACFT spring inflow target in all but 5 years requires that the project be able to supply 356 MGD. Once the recovery rate is determined, the recharge rate can be decreased until it provides just enough supply to keep the aquifer full so that it can meet the recovery needs in all but the 5 driest years, in this case 39 MGD.

Figure 4-2 shows the aquifer response to meeting the FWI targets in all but 5 years. The aquifer storage trace line is defined by the right axis, labeled “ASR storage,” and depicts the volume of water in aquifer storage at the end of each day in the period of record. The bars showing the amount of water needed to meet the target inflows and their values are associated with the left axis, labeled “ACFT/D.” Notably, the aquifer storage would be completely depleted during the height of a repeat of the 1950’s and 1960’s droughts. Interestingly in 1952 and 1953, aquifer storage is completely depleted in the early spring of each year however late season floods in May ended up satisfying the FWI targets in both of those years. The recharge rate is defined by the volume of water that would need to be stored between 1968-71 to refill the aquifer so that there is sufficient supply to meet the FWI needs in 1972. At a rate lower than 39 MGD the storage at the end of 1971 would not be sufficient to meet the needs in the following years.

The above example is based on the daily operations strategy described above. Assuming perfect foresight (knowing how much water will be need to be supplemented in each season at the beginning of each season) would allow for a recovery rate to be decreased from 356 MGD to 342 MGD and still meet the goal of no more than 5 springs with total inflow of less than 150,000 ACFT.

4.4 QUANTIFICATION OF FRESHWATER INFLOW BENEFITS RESULTING FROM SMALLER INCREMENTAL PROJECTS

The preceding analysis is intended to demonstrate how the STF goals could be fully satisfied by an ASR project combined with a dedication of about 62.3% of the wastewater that is currently discharged to the system. The costs associated with this configuration of the project and the legal and policy challenges associated with its implementation are discussed below, however these and other factors may influence the BBASC to recommend smaller alternative or incremental strategies.

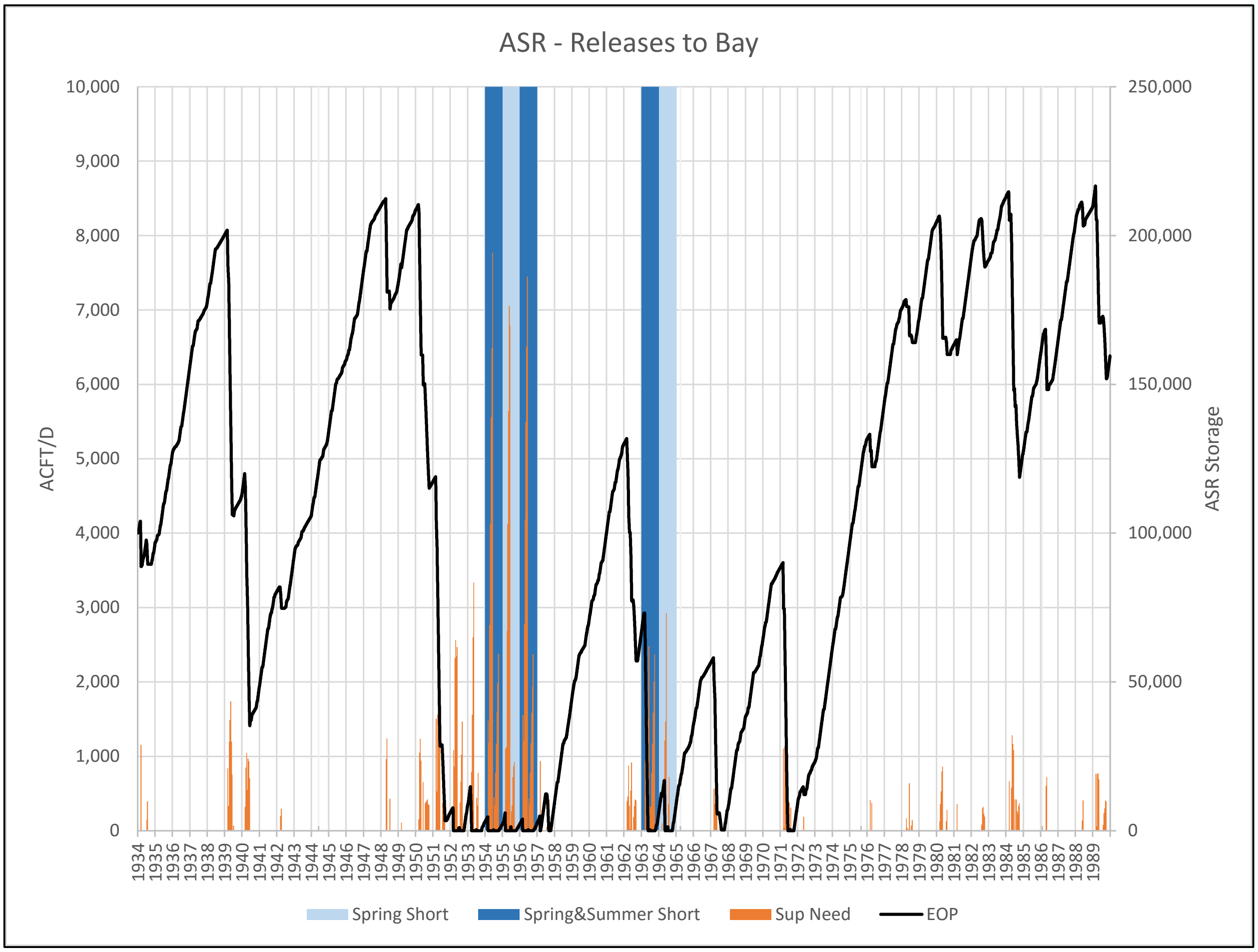


Figure 4-2 Aquifer Response to Freshwater Inflow Augmentation to Achieve STF Goals (5 Spring / 3 Summer Shortfalls)

The following section presents several alternative, smaller, configurations and is intended to demonstrate the incremental benefits that might be achieved with the development of smaller, less expensive options. The following section addresses this issue from several perspectives.

One way to frame the question is to determine what configuration would be required to achieve a specific alternative target frequency. For example the GSA-BBASC may decide that a reasonable short term goal would be to meet the spring targets in all but 10 of the years and the summer targets in all but 3 of the years. In this case the AWB Model can be used to determine that this objective could be achieved with an aquifer recharge rate of 33 MGD and a recovery rate of 289 MGD. Similar to Figure 4-2, above, Figure 4-3 shows the aquifer response to a project configured to achieve this lower goal of not exceeding 10 failures in the spring and 3 failures in the summer.

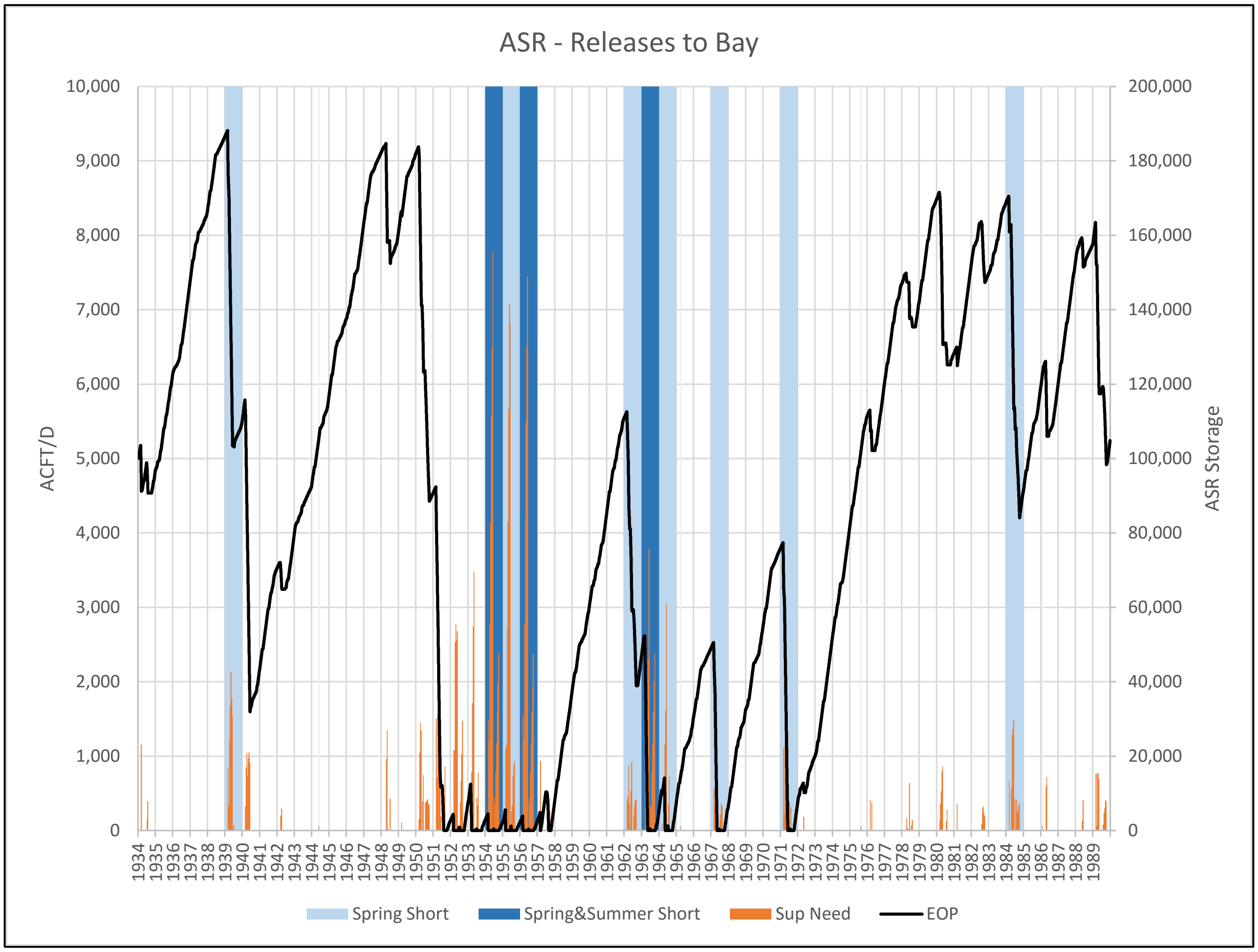


Figure 4-3 Aquifer Response to Freshwater Inflow Augmentation to Achieve Alternate STF Goals (i.e., not exceeding 10 Spring / 3 Summer Shortfalls)

Another way to frame the management question would be to determine what level of FWI attainment frequency could be achieved based on a pre-defined project configuration. The primary determinant of the cost of the ASR project is the high recovery rate. The GSA-BBASC may decide that rather than pursuing a project with a recovery rate of 289 MGD, they might recommend a project with a smaller capacity, perhaps as a first phase to a more ambitious future project. For example, what level of attainment could be achieved with the implementation of a project with a recovery rate of 144 MGD? Even with perfect forecasting, a project configured with a recovery rate of 144 MGD would, at best, be capable of supplying 40,750 ACFT in the spring season. Since most of the spring seasons in which a shortfall occurs experience shortfalls of greater than 40,750 ACFT, this size project would have a very limited benefit in terms of increasing attainment frequencies. Figure 4-4 again shows the aquifer response in this case based on a scenario that limits recovery rate to 144 MGD. While summer shortfalls are small enough that they could be fully satisfied under this scenario (summer shortfalls are reduced from 7 to 1 years), the recovery rate is too small to significantly reduce the number of spring shortfalls which are only reduced from 16 to 14 years under this scenario.

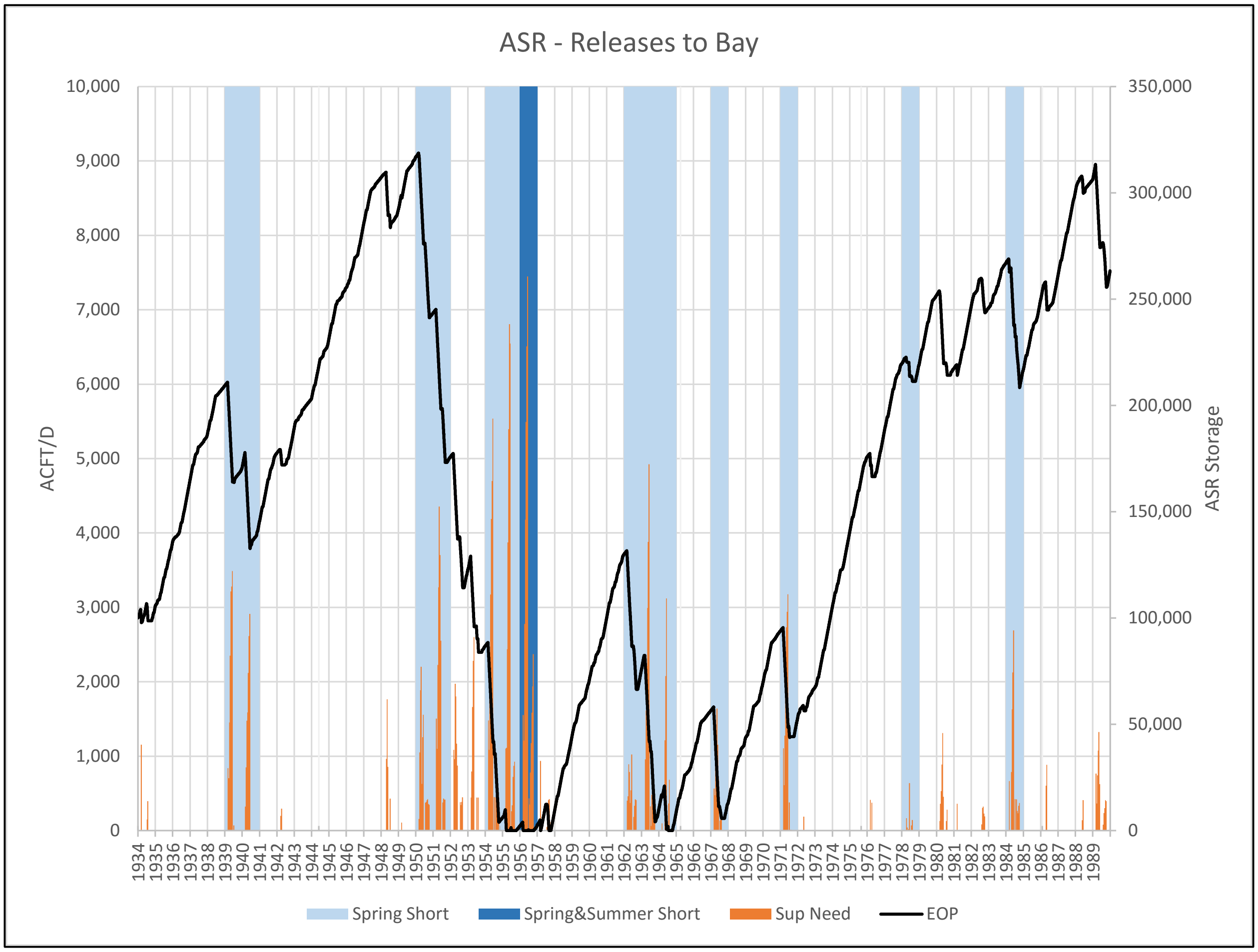


Figure 4-4 Aquifer Response to Freshwater Inflow Augmentation Limited by a 144 MGD Recovery Rate (Result: 14 Spring / 1 Summer Shortfalls)

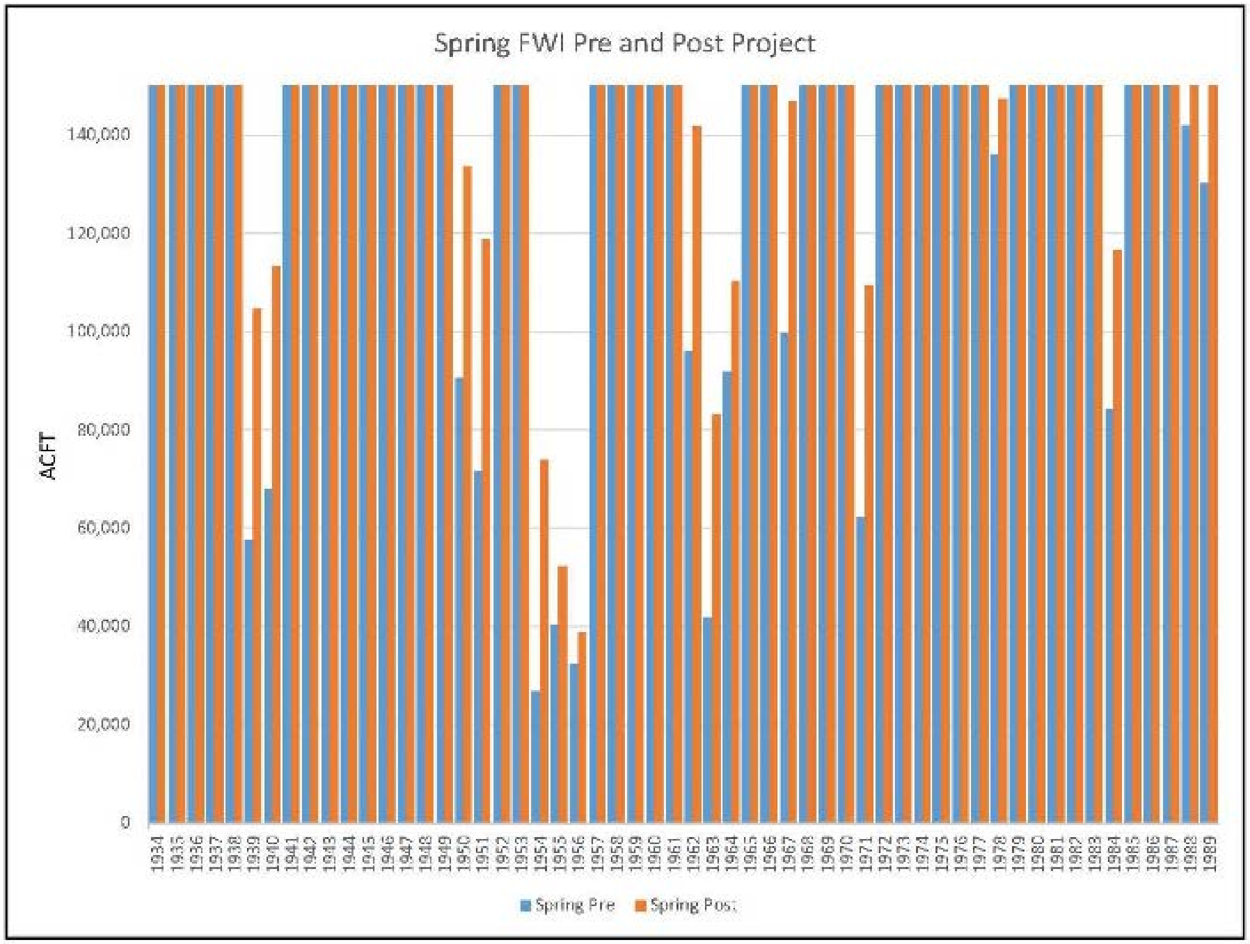


Figure 4-5 San Antonio Bay Spring FWI: Pre and Post ASR Project

While this lower recharge rate significantly limits the ability of the project to reduce the number of times FWI are less than the seasonal target, the benefit of such a project would be to reduce the magnitude of the shortfalls which then do occur. Figure 4-5, above, shows the spring FWI pre- and post- implementation of the ASR project with a 144 MGD recovery rate. While it is true that there are few years in which the project is able to supply a sufficient amount of water to bring the total spring inflow up to 150,000 ACFT (1988 and 1989 and almost 1977), nonetheless, in many years spring inflows would be significantly increased. The average spring inflow, in years when the target was not being met prior to the implementation of the project, was about 72,000 ACFT. After implementation of this ASR project this value jumps to 104,000 ACFT. In the summer the 50,000 ACFT seasonal target is achieved in all but one year, 1956 (Figure 4.6), below.

Lastly, as discussed above, the decision to dedicate 62.3% of wastewater return flows for non-SAWS WWTP and 54.1% for SAWS WWTP for this alternative is somewhat arbitrary. In order to better understand the impact of this dedication the AWB model was run assuming zero return

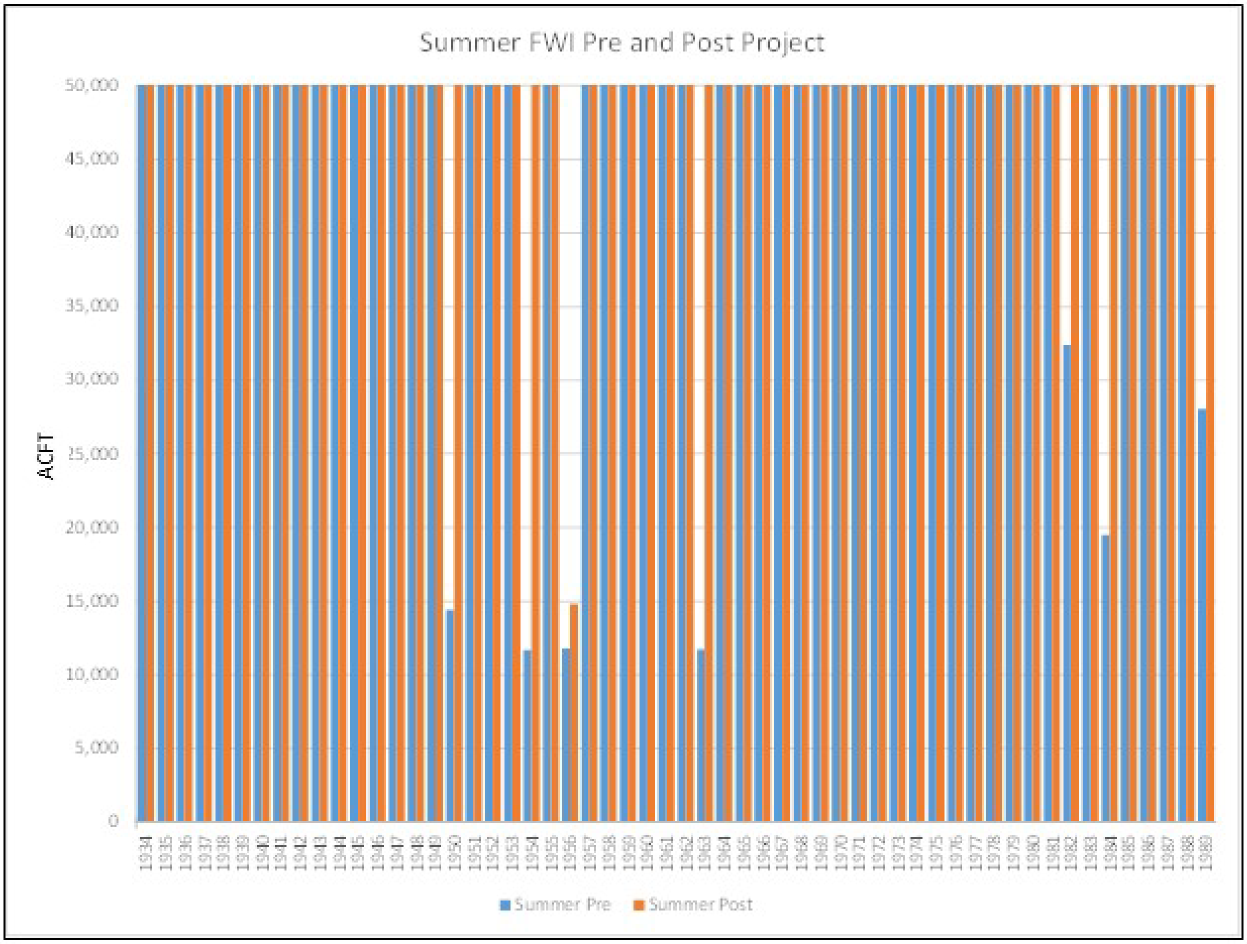


Figure 4-6 San Antonio Bay Summer FWI: Pre and Post ASR Project

flow and also returning 100% of the return flows from the 10 largest WWTPs being dedicated to the project. When the model is run assuming zero return flow, this means that no return flows from the San Antonio basin are provided directly to the bay, and, as a result, the total shortfall that needs to be made up in the sixth worst year is higher than in the 62.3%/54.1% dedication scenario described above. As a result the recovery rate needs to be increased from 356 MGD to 404 MGD to be able to satisfy the larger shortfall. The other effect of not having any dedicated return flows is that the recharge rate needs to be increased from 39 MGD to 91 MGD to capture larger flow events since the constant flow from the WWTPs is not being used to recharge the aquifer.

Increasing wastewater dedications to 100% has the opposite effect. Since more water is being passed directly to the bay from plants in the San Antonio basin, the shortfall than needs to be made up from ASR recovery decreases the required recovery rate from 356 MGD to 315 MGD. Likewise the recharge rate required also drops (from 39 MGD to 28 MGD) since the aquifer is more often and to a greater degree refilled by the larger dedicated return flows.

4.5 DESIGNING AN ASR SYSTEM TO INCREASE STORAGE OF WATER FOR RELEASES FOR ENVIRONMENTAL FLOWS

Depending upon reasonable alternative assumptions discussed previously in this report regarding availability of return flows to supplement unappropriated river flows during the period of record, the rate of recovery from ASR storage may need to be in a range of 315 to 404 MGD in order to achieve Strategic Target Frequencies. Lesser flow rates would also be beneficial. For current planning purposes, a target ultimate recovery rate of 360 MGD is assumed, recognizing that any such ASR wellfield facilities would be implemented in successive phases, each of which would build upon, and benefit from, experience gained in earlier phases. Similarly, understanding of coastal ecosystem requirements and salinity patterns will evolve during the ASR wellfield development period, providing an improved basis for adjustment of the wellfield conceptual design in successive phases.

4.5.1 ASR WELLFIELD CONCEPTUAL DESIGN

Water storage would occur in the Evangeline Aquifer at depths of about 400 to 1,000 feet below mean sea level. Well and wellfield characteristics determined previously for the 2013 City of Victoria ASR feasibility study (NEI et al., 2014) are assumed to apply throughout the area considered for the environmental flows wellfield. Individual ASR well recovery rates are assumed to average 2 MGD (6.1 AF/D). For the purposes of this conceptual plan, the project area would extend along the Guadalupe River, north and south of Victoria, approximately 12 linear miles in each direction (not miles along the river bank), for a total length of about 25 miles. It is assumed that ten well clusters, each with 18 ASR wells, would be located in a line along the river bank, with a spacing of at least 2 miles between the centers of each well cluster. The actual number of well clusters, and number of wells per cluster, would be adjusted during facilities design to match site specific constraints and opportunities. At the center of the wellfield would be the planned ASR wellfield for the City of Victoria, which would store treated drinking water from its surface water treatment plant. A center spacing of at least 2.5 miles would separate the City’s ASR wellfield from adjacent environmental flow wellfield clusters to the north and south. Operations for the City’s ASR wellfield would include not only water banking, similar to the environmental flows ASR wellfield, but also seasonal water storage and recovery. Wells within each cluster could be on either or both sides of the river, depending on land availability and other factors. Each cluster of wells would have two parallel lines of wells with nine wells in each line, spaced 1,000 feet apart and connected to a single, common header pipeline 8,000 feet long, parallel to the river.

Wellfield facilities would be located within the river flood plain. Consequently potential conflicts with other land uses should be reduced. Land acquisition, long term leases and rights-of-way will be needed for ASR well sites, bank filtration well sites, discharge structures, pipelines, power lines and access roads. While land acquisition for the entire area encompassed by each well cluster is one option, negotiation of a long-term lease may also be acceptable. A wellfield protection area (WPA) would probably need to be established surrounding each well cluster, or around the entire wellfield area, providing adequate protection of the stored water from contamination or from pumping out by surrounding well owners.

A pipeline connection between adjacent well clusters would not be necessary. However, if provided between adjacent well cluster pairs, it would enhance operational flexibility and system reliability by providing redundancy of key components. Maintenance and repairs could then be facilitated by routing flows to or from an adjacent well cluster.

At the south end of the wellfield, a possible connection to the existing Mary Rhodes pipeline that brings water from Lake Texana to Corpus Christi would potentially provide the opportunity for supplementing recharge flows at times when conveyance capacity of the Mary Rhodes pipeline may be underutilized. Such an arrangement would not only enhance environmental flow operations but may also improve water supply reliability for the Corpus Christi area.

Adjustment of recovery flow rates from the entire wellfield would be achieved by starting up or shutting down ASR operations at well clusters, while flexibility would also be provided to adjust flow rates from individual wells within each cluster. Figure 4-7 shows the general location of the proposed ASR wellfields while Figure 4-8 shows a conceptual layout for a representative ASR well cluster. Actual wellfield facility locations and designs would depend upon considerations that are beyond the scope of this conceptual plan.

Figure 4-7 General Location of Proposed Wellfields near Victoria, Texas

4.5.2 MONITOR WELLS

Monitor wells would be provided within each cluster to keep track of water levels and pressures, and also changes in water quality during recharge and recovery operations. These would be constructed not only at different depths of discrete sand intervals within the storage aquifer but also in overlying aquifers, including the water table. Property line monitor wells would also be provided, tracking water levels and water quality. For conceptual planning purposes it is assumed that each cluster would include ten monitor wells, or possibly ten monitoring intervals in a smaller number of multi-zone monitor wells.

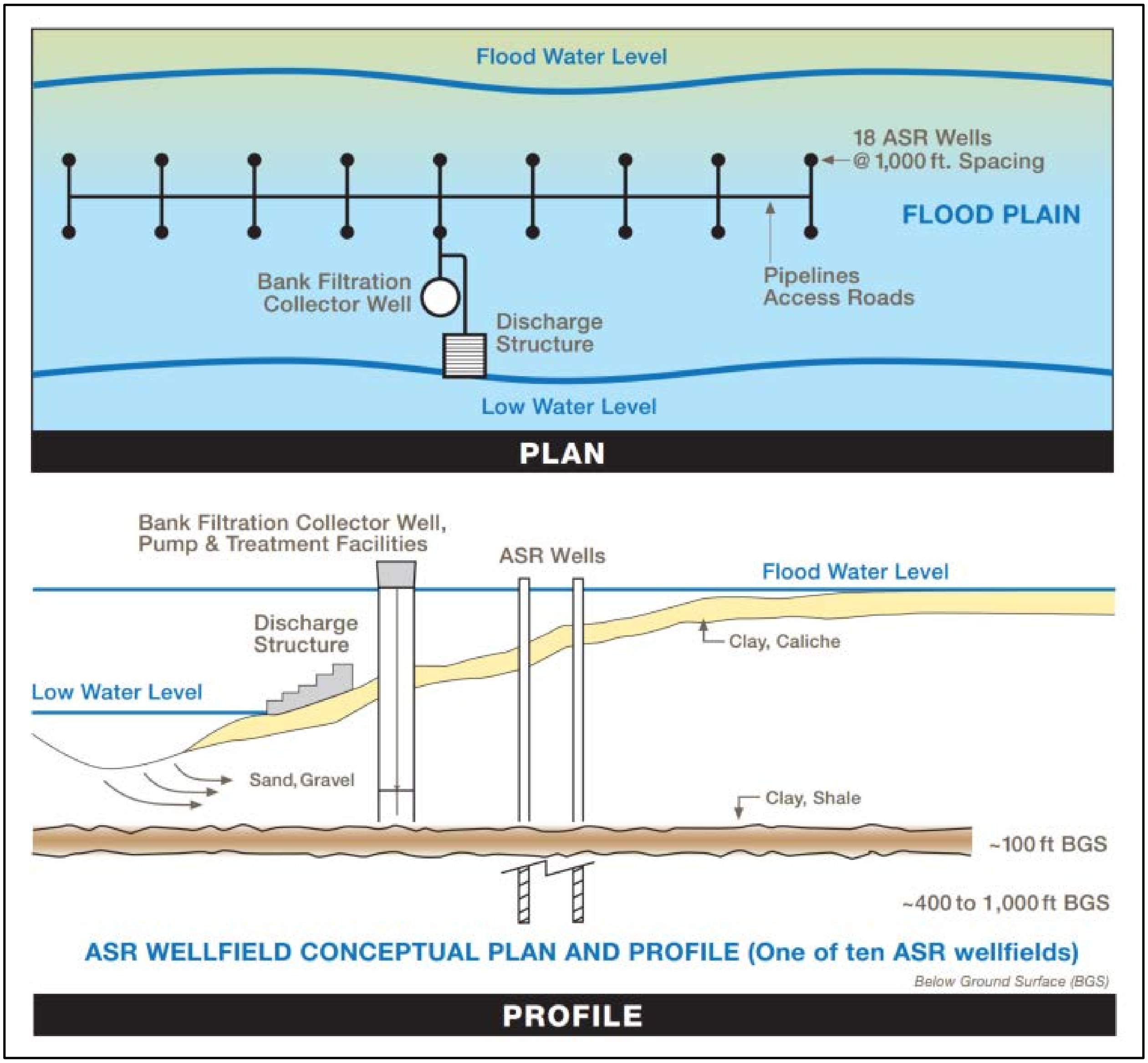


Figure 4-8 ASR Wellfield Conceptual Plan and Profile

4.5.3 HYDROGEOLOGY

A complete analysis of the hydrogeology of the aquifer system in the Victoria area is included with the 2014 Victoria ASR Feasibility Study (ARCADIS, 2014) and is not duplicated herein. Six well logs from that report were reviewed, all of which are located very close to the Guadalupe River and within the study area to the north and south of Victoria. They indicate the presence of sand and gravel deposits, with some references to "boulders," to depths of between about 60 and 100 feet, overlain by a thin layer of material variously described as "soil," "clay," "sandy clay" or "caliche" with a typical depth of about 15 feet, up to 24 feet maximum thickness. The depth of the river channel bottom, and the hydraulic continuity between the river and the underlying sand and gravel deposits, remains to be determined through field investigations. The regional hydrogeologic framework for these coastal alluvial deposits would suggest that aquifers and confining layer thicknesses may trend thicker and deeper in a southerly direction, however whether that change is significant in the 25-mile study area is unclear. Available well logs and geologic cross-sections suggest that any trend would be minor.

Underlying these shallow alluvial deposits were alternating layers of “clay,” “shale,” “sticky shale,” “gumbo,” “caliche” and “sand” to depths of at least 400 feet. This would comprise the semi-confining layer separating the shallow alluvial deposits from the underlying Evangeline Aquifer, which would be the ASR storage interval from 400 to about 1,000 feet depth below mean sea level. Testing will be needed to establish the “leakance” characteristics of this semi-confining layer.

4.5.4 WATER QUALITY

Suitable water quality will be required for storage in ASR wells. For practical, operational reasons it will be necessary to ensure that no particulates such as sand, clay, fish, weeds and algae are present in the recharge water since they would cause well clogging. Some clogging of ASR wells is normal and is removed by periodic backflushing of each well, however if the particulate loading is too great, backflushing frequency would become a significant operational challenge.

Water quality will also have to meet requirements of applicable rules established by TCEQ for storage of water underground to meet environmental flow and other goals. The point of reference would be primary and secondary drinking water standards, with particular focus on microbial standards such as coliform bacteria. ASR precedents exist in other states for providing variances or water quality criteria exemptions for selected primary or secondary constituents in certain cases, particularly where recharge water quality is better than groundwater quality and/or where a sufficient distance is provided around an ASR well so that natural underground physical, microbial and geochemical processes may occur, providing adequate treatment to meet the standards. The “sufficient distance” may be established on a case-by-case basis, considering several factors, not the least of which would be land ownership or control, lease arrangements or institutional controls established in the surrounding area. For ASR projects in Texas, it will be necessary to acquire or lease sufficient land area around an ASR wellfield, and/or provide controls such as through establishment of a Wellfield Protection Area (WPA) through agreements with adjacent landowners so that the stored water is protected against contamination and also protected from diversion by other surrounding property owners by pumping of adjacent wells in the same aquifer. It is likely that the same WPA would provide sufficient opportunity for natural treatment processes that would meet applicable water quality standards. Water quality standards for which exemptions or waivers have been issued have included coliform bacteria, which is a primary standard, and total dissolved solids (TDS) and color, both of which are secondary standards. Primary standards relate to public health while secondary standards are related to esthetics, not health.

4.5.5 WATER TREATMENT BY BANK FILTRATION

Construction and operation of conventional surface water treatment facilities at each well cluster, with treatment processes similar to those provided by the City of Victoria, would ensure drinking water quality prior to recharge, but would be expensive. It is possible that this expense could make attainment of environmental flow goals with ASR storage to be non-viable. Instead it is proposed to utilize bank filtration treatment to improve the quality of the river water so that it is acceptable for aquifer recharge, relying on natural underground treatment processes. Bank filtration is commonly applied globally for water treatment purposes, often as a pre-treatment process for potable water supplies. The technical feasibility of bank filtration in the vicinity of Victoria would need to be confirmed through appropriate field investigations, however the prevalence of sand and gravel pits in this area, combined with review of available well logs, suggests that bank filtration may be feasible and should be considered.

Natural subsurface treatment as the water moves from the Guadalupe River to the bank filtration well is expected to remove or to substantially reduce particulates, taste, odor, total organic carbon, turbidity, microbiota and cyanotoxins. It is possible that some increase in iron and manganese concentrations also may occur in the bank filtration water, depending upon changes in the oxidation-reduction potential of the water as it moves from the river bottom to the bank filtration well.

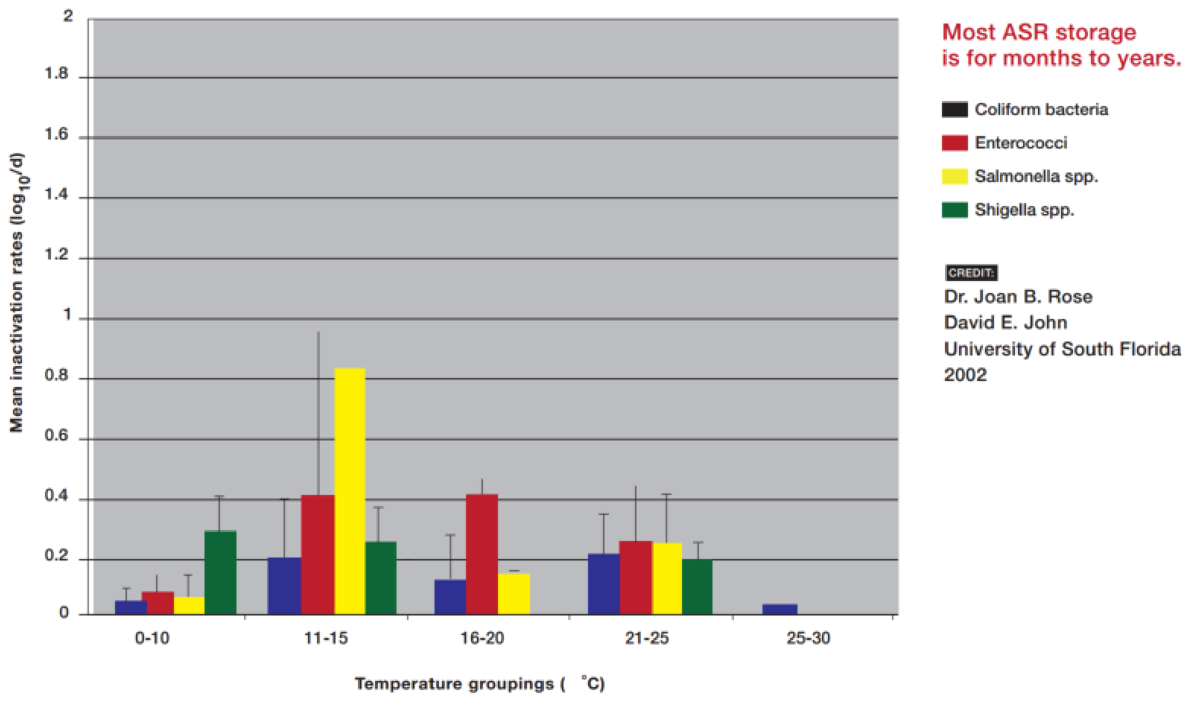
Bank filtration has been widely utilized in Europe for decades to improve the quality of surface water prior to water treatment and distribution. At least several hundred communities rely upon bank filtration as a part of their water treatment process. As a percentage of total drinking water production in selected European countries, bank filtration provides for treatment of 7 percent of the water in the Netherlands; 16 percent for Germany; 40 percent for Hungary; 48 percent for Finland; 50 percent for France; and 80 percent for Switzerland. Bank filtration in Europe is typically designed for water quality improvement. For example, in Germany, the travel time requirement for water movement through shallow sands is at least 50 days in order to provide disinfection of potable water supplies. The use of chlorine for disinfection is illegal in Germany.

In the United States, bank filtration is also utilized but to a lesser extent. Total installed bank filtration capacity in the U.S. is more than 600 MGD, with the largest system, Sonoma County Water Agency, California, accounting for about 100 MGD. Other notable bank filtration examples include Des Moines, Iowa; Louisville, Kentucky; Cincinnati and Oxford, Ohio; Boise, Idaho; Iowa City, Iowa; Cedar Rapids, Iowa; Ukiah, California; Kalama, Washington and Kennewick, Washington. Interest in this relatively simple and inexpensive treatment technology is increasing, however. Bank filtration in the U.S. has evolved differently than in Europe. Most installations are designed as raw water supply intakes, operating at relatively high flux rates and short travel times, typically less than 20 days. Improvement in raw water quality is typically viewed as a useful, incidental benefit but not as a primary reason for constructing these systems. For water treatment, greater reliance is placed upon conventional water treatment plant process design.

The United States Environmental Protection Agency (EPA) has indicated a willingness to consider 0.5 or 1.0 log cycle reduction for *Cryptosporidium*, associated with travel distances of 25 and 50 ft, respectively, for those communities implementing effective bank filtration treatment with unconsolidated sand aquifers and greater than 85 percent of the soil samples with $d_{10}<1.5$mm, as indicated in the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). Travel distances are measured relative to the 100-year flood level. This is a conservative regulatory position regarding the effectiveness of bank filtration treatment to remove microbiota, designed to ensure that conventional post-treatment is also implemented for drinking water systems. However, it is an indication of the increasing level of interest in this technology that EPA is willing to provide some credit for the demonstrated efficacy of this technology. Higher removal efficiencies are typically expected. To achieve credit for any higher level of microbial attenuation, site-specific data are required. The rule also provides for *Cryptosporidium* samples to be alternatively collected from the bank filtration intake rather than from the source water. At Victoria, this would probably demonstrate at least three log cycle reduction.

The “hyporheic zone,” which is the interface between surface water and groundwater in bank filtration systems (Tufenkji et al, 2002), is characterized by four types of biogeochemical reactions: electron transfer, weathering, ion exchange and gas exchange. Gradients occur in light, temperature, pH, oxidation-reduction potential, oxygen and organic carbon. Microbial activity in this zone is substantial, causing a reduction in oxygen content that, in some situations, may cause the water to become reducing. Microbial activity in this zone also creates biofilms and releases gases, the net effect of which can be to reduce the vertical hydraulic conductivity of the soils within this zone and provide a more effective trap for fine particles filtered out of the surface water. This can potentially lead to clogging of the river bottom sediments in the vicinity of the bank filtration intake. Scouring during high flow events then periodically removes this clogging layer, restoring bank filtration well capacity.

Retention time as the water moves from the river bottom to the bank filtration intake and then to ASR storage is an important factor in achieving water quality improvement. Attenuation of pathogenic microbiota, in particular, depends substantially upon the travel duration and temperature. As shown in Figures 4-8 and 4-9, a literature search regarding the fate of microbiota during ASR storage (Rose and John, 2002; John and Rose, 2005) indicated that the attenuation rates for selected conservative indicator bacteria and viruses under different temperature conditions are quite rapid. In general, under temperatures prevalent in south Texas, attenuation rates are approximately 5 days per log cycle. At lower temperatures, slower attenuation rates occur.

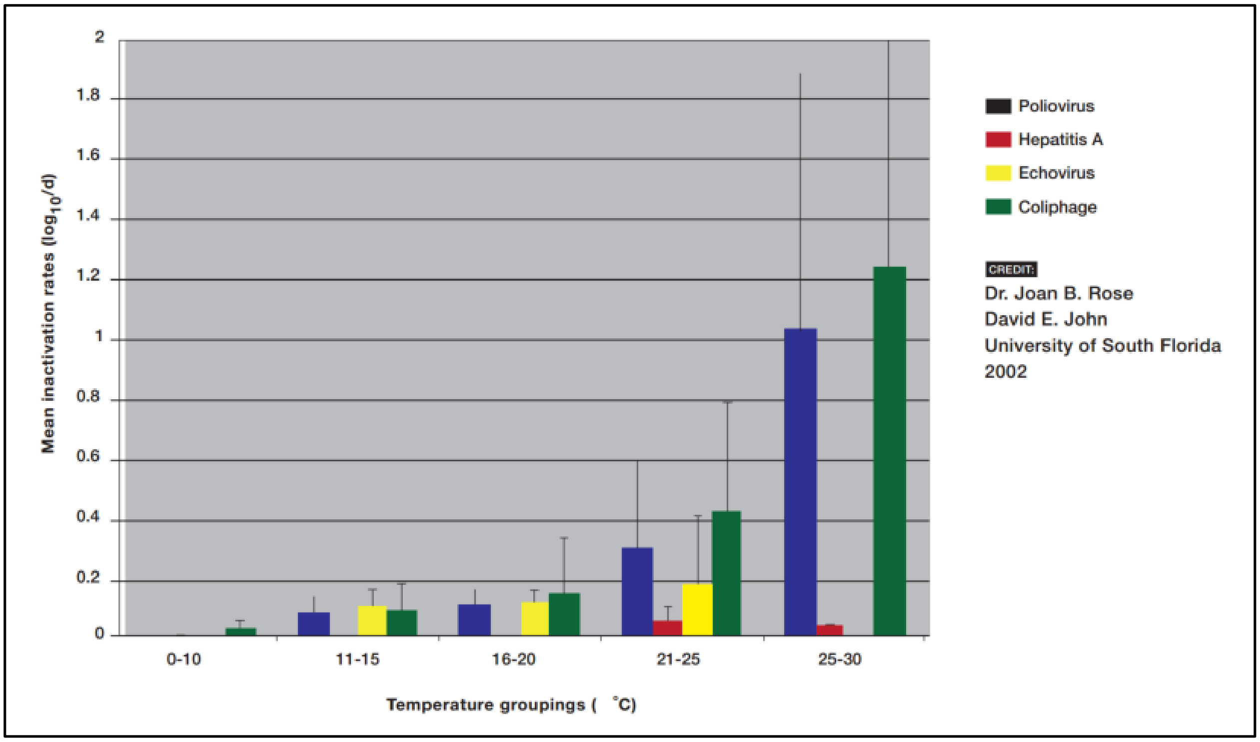


Most ASR storage is for months to years.

CREDIT:
Dr. Joan B. Rose
David E. John
University of South Florida
2002

Error bars reflect standard deviation of rate values observed in each temperatire group.

Figure 4-9 Bacteria Mean Inactivation Rates in Temperature Groups



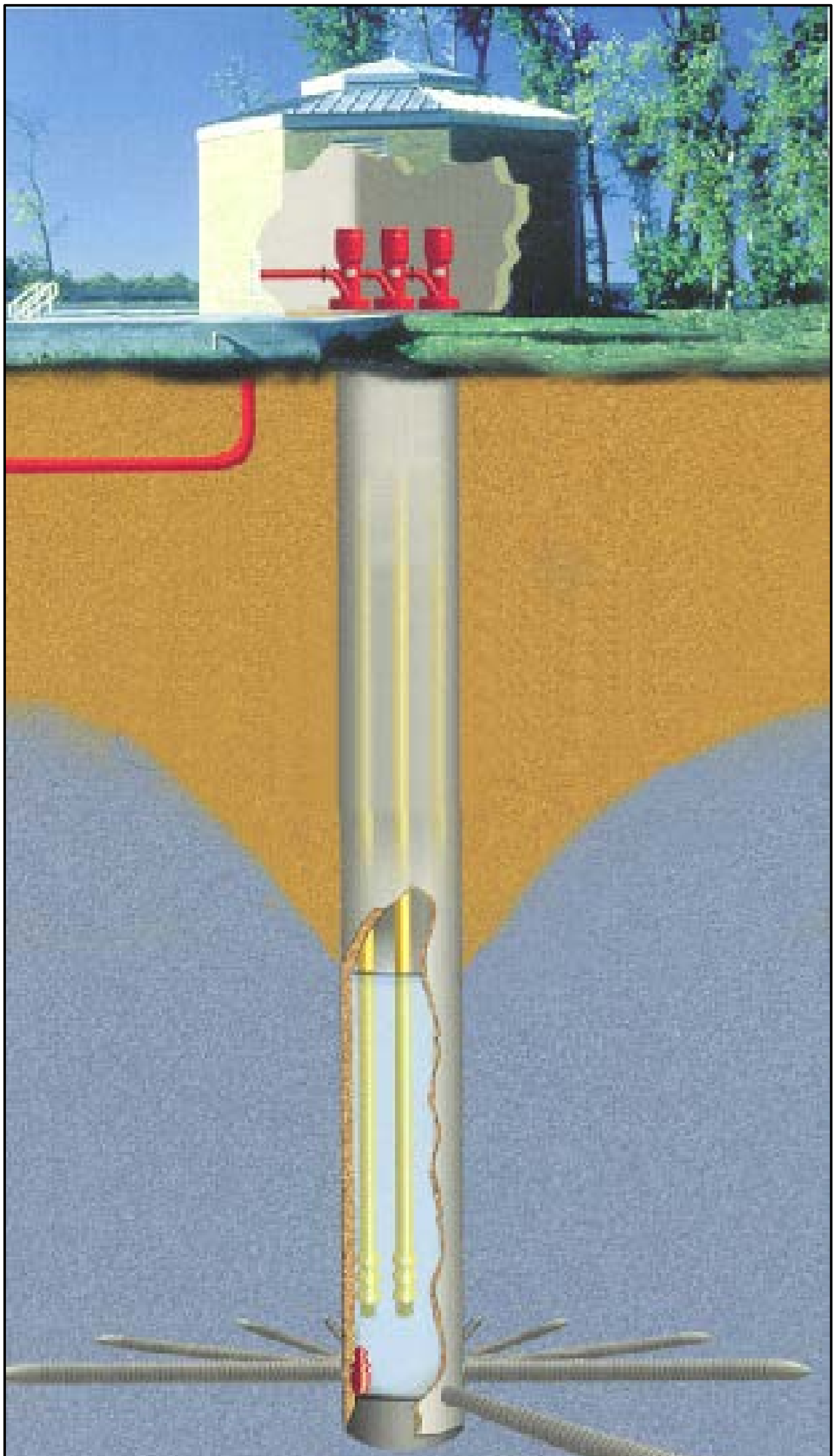
CREDIT:
Dr. Joan B. Rose
David E. John
University of South Florida
2002

Figure 4-10 Virus Mean Inactivation Rates in Temperature Groups

Removal of microorganisms at three different riverbank filtration sites in the Netherlands ranged from 3.3 to 3.9 log cycles for different bacteria, viruses and protozoa at one site, during 7 days of travel time through 43 ft of alluvial material (Tufenkji et al, 2002). At a second site, 3.1 to 6.2 log cycles were removed during 15 days of travel time through 98 ft of alluvium. Similarly, on the Rhine River, dissolved organic carbon concentrations declined approximately 50 percent during 30 days' travel time, as measured over a period of five years. Most of the treatment occurs in the first few feet to tens of feet of travel (Melin, 2003; Ray, 1999; Wang, 2002; Wett, 2003); however, not all organic substances are removed. Some pesticides, pharmaceuticals and halogenated organic compounds can move through the hyporheic zone if they are present in the source water. A recent analysis of bank filtration removal efficiency for TOC at five U.S. bank filtration sites (Ohio River – 2 sites, Greater Miami River, Wabash River, Missouri River) indicated source water quality of 2 to 6 mg/l and bank filtration well water quality of 0.7 to 2.6 milligrams per liter (mg/l) (Carollo, 2002). Overall TOC removal efficiency at the 5 sites averaged about 62 percent.

Numerous sources are available addressing water quality changes during bank filtration, many of which are included in the reference list provided at the end of this report. A representative source from the U.S. is for Cincinnati, Ohio, for which an investigation presents data on organics removal (TOC, UV$_{254}$, and trihalomethane [THM] formation potential) related to travel distance from the Ohio River through a sand and gravel aquifer (Vogt et al, 2003). TOC removal was 39 percent at 5 to 10 ft; 54 percent at 31 ft, and 89 percent at 88 ft. UV$_{254}$ showed 37 percent removal at 5 to 10 ft; 57 percent removal at 31 ft, and 95 percent removal at 88 ft. THM formation potential showed 56 percent removal at 5 to 10 ft, 70 percent removal at 31 ft, and 94 percent removal at 88 ft. Similarly, turbidity is shown to decline at this site from less than 2 to 400 ntu in the source water (median about 12.6 nephelometric turbidity units [ntu]), to a maximum of 1.5 ntu at a depth of 2 ft and an average of 0.4 ntu at this monitoring depth (Schijven et al, 1999, 2001). Ninety-five percent of the samples collected from a horizontal collector well at a distance of at least 49 ft below the riverbed showed less than 0.2 ntu turbidity.

As indicated above, the flood plain of the Guadalupe River near Victoria includes several sand and gravel pits. Available information from well logs suggests that the base of these alluvial deposits is at a depth of approximately 60 to 100 feet. It is likely that the deposits become slightly more fine-grained in a southerly direction within the study area, probably providing improved water treatment but also reducing permeability and therefore reducing flow rates to a bank filtration well. For the purpose of this conceptual design, it is assumed that bank filtration would be viable and would be utilized for diversion and treatment of the recharge water. One bank filtration well would be constructed for each well cluster. A typical diagram of a bank filtration well is shown in Figure 4-11, next page.



(Figure courtesy of Ranney Collector Wells – a Layne-Christensen Company)

Figure 4-11 Typical Diagram for a Bank Filtration Collector Well

As described in previous sections, ten 6 MGD bank filtration wells would provide 60 MGD, which is sufficient water for aquifer recharge to meet environmental flow needs. Sixty MGD is approximately the middle of the range of diversion flow rates needed if zero or 100% of wastewater return flows are made available for environmental flow purposes. Any higher yield for individual bank filtration wells would provide increased operational flexibility to divert water only at preferred times when river water quality is the best, and would accelerate formation of the target storage volume at each site at the beginning of ASR operations, or at other times during or following dry periods when the cumulative storage volume is less than the target storage volume.

A possible future alternative approach to a vertical bank filtration "Collector Well," as described above, would be a horizontal directionally-drilled (HDD) bank filtration well, probably extending along the river bank near the base of the surficial aquifer, or perhaps from one side of the river to the other. The technology exists to construct such a well, however none have been constructed to date in the USA. Two such wells have been constructed in the Netherlands, but at a relatively small scale. HDD pipelines with diameters up to about 48-inches and lengths up to a few thousand feet are fairly common in the USA. Constructing a screened well within such a pipeline, equipped with a pump, motor and column pipe, and then withdrawing most of the pipeline to expose the well screen, is probably feasible but has yet to be demonstrated.

For conceptual planning and budgeting purposes, product water from the bank filtration wells would be disinfected to provide a small chlorine residual to control downhole microbial activity within the well screen and adjacent gravel pack, and then followed by filtration through 5-micron filtration canisters with continuous automatic backwashing, prior to recharge into the ASR wells. This additional filtration step in the treatment process may or may not be required, however until such time as soil borings, cores and grain size distribution curves are available from one or more representative sites, it is assumed that such additional filtration would further improve water quality in the ASR recharge water and reduce operational requirements for periodically backflushing the wells.

Each site would also be provided with a discharge structure to convey the water recovered from the ASR wells to the river during dry periods. Recovery from each wellfield cluster would be at a flow rate up to 36 MGD (110 AF/D). Water would be cascaded over a series of steps to provide aeration.

All aboveground facilities would be located in the river flood plain, requiring elevation on platforms to above the flood level. Figure 4-12 shows a photograph of a 2 MGD ASR well at Hilton Head Island, South Carolina at a site where the land surface elevation is 7 feet below the flood elevation. The wellhead facilities are elevated on a platform.

Figure 4-12 ASR Well on Platform at Hilton Head Island, South Carolina

5 ASR WELLFIELD IMPLEMENTATION PLAN

5.1 PHASED WELLFIELD DEVELOPMENT

The ASR wellfield would be developed in multiple phases. The initial phase would include preliminary investigations to determine the following:

1. Surficial Aquifer Hydrogeologic Investigations. Soil borings and water samples would be obtained at one or more selected locations along the proposed wellfield alignment in order to confirm surficial aquifer depth and lithology, and grain size distribution at selected depths. At one selected, representative site, bank filtration will be simulated with a Surficial Aquifer production well and associated monitor wells, pumping water for a sufficient duration to establish that a significant portion of the produced water originated from the river. Water samples will be obtained to compare river water quality with produced water quality. This would be a pilot program, to be confirmed through construction and testing of a full scale bank filtration well in Task 3.

2. Evangeline Aquifer Hydrogeologic Investigations. These investigations would be conducted for aquifers and confining layers below the Surficial Aquifer in order to estimate their hydraulic continuity with the river, as measured by leakance of the Evangeline Aquifer and overlying semi-confined aquifers. It will be important to confirm that water stored in the Evangeline Aquifer will not flow back into the river during ASR recharge operations, and that water discharged to the river during ASR recovery operations will not flow back into the aquifer system, other than normal channel losses. An initial desktop study would include preparation of a simulation model of the local aquifer system to predict water level changes associated with planned ASR wellfield operations. In general, aquifer water levels will be slightly higher in the immediate vicinity of the ASR wellfield due to extended periods of recharge at low flow rates. During droughts, aquifer water levels will be lower due to recovery at high flow rates. Groundwater quality will also become fresher, since the TDS of the recharge water would be less than for the native groundwater. In a subsequent task, the simulation model would be recalibrated by results from pump tests on selected initial ASR wells to confirm aquifer hydraulic characteristics and to update the model predictions.
3. Bank Filtration and ASR Well Demonstration Program. At a selected site in the study area, adjacent to the Guadalupe River, construct, equip and test a full size bank filtration demonstration well with associated monitor wells and a production capacity of at least 6 MGD, or whatever is potentially available at the site. The objective would be to confirm hydraulic continuity between the river and a vertical well constructed to the base of the Surficial Aquifer, approximately 90 feet deep, and also to evaluate changes in water level and water quality as water moves from the river to the well during an extended pumping period. Probable pumping duration would be several months in order to clearly establish that produced water originated from the river during the test period. Site-specific data regarding water treatment provided by bank filtration operations would be pertinent to obtaining regulatory approval from TCEQ. As part of the same demonstration program, construct and test at least one ASR well and selected monitor wells, recharging filtered water and recovering the water to the river for a sufficient period of time to confirm concept viability and to develop design and operational guidelines for subsequent expansion of the program to other wells and to other wellfield sites. Conduct pump tests on ASR wells to confirm aquifer hydraulic characteristics. Monitor performance during initial operations and then update the groundwater model. Incorporate any changes in environmental flow targets into an update of the conceptual design for remaining wellfield facilities.
4. ASR Wellfield Feasibility Assessment and Conceptual Design Report. Compared to the present report, this would be a more comprehensive and detailed evaluation of ASR wellfield feasibility, addressing typical elements of such a study. These include

delineation and prioritization of project objectives; trends and variability in recharge water flows, recovered water demands, and water quality; confirmation of the target storage volume, design recharge flow rate and design recovery flow rate; hydrogeology and geochemistry; conceptual facilities design and preliminary cost estimate; cycle testing program; ASR program implementation plan; legal, regulatory and institutional/governance issues. This report would be an update of the current preliminary feasibility assessment, incorporating the results of Tasks 1 and 2. The report would provide not only a firm basis for facilities design for the first cluster of ASR wells, but also a firm basis for regulatory consideration of TCEQ permits that would be required for ASR wellfield construction and operation to meet environmental flow goals. A draft report would be prepared following Task 2 and a final report would be prepared following Task 3.

5. Water rights acquisition. These would be junior water rights for diversion of unappropriated river water during times of normal and high flows. They would also include return flows, to the extent that they may be made available for the purpose of achieving environmental flow goals. As indicated previously in this report, other water rights may also be purchased, leased or donated for environmental flow purposes.
6. Secure sites for wells and wellfield facilities, sufficient to meet ultimate project goals.
7. Design, construct and place into operation the first ASR wellfield cluster of 16 additional ASR wells, discharge structure and related facilities. Monitor performance during initial operations and then update the groundwater model. Incorporate any changes in environmental flow targets into an update of the conceptual design for remaining wellfield facilities.
8. Design, construct, place into operation and monitor performance for the remaining ASR wellfield facilities. These would be constructed in phases to match available funding and evolving understanding of water management needs.

5.2 PRELIMINARY COST ESTIMATE

5.2.1 ASR WELL COSTS

ASR wellfield facilities will include ASR wells, monitor wells, bank filtration wells, discharge structures, pumps, motors, wellhead piping, distribution piping, disinfection, road access, electrical power, instrumentation, and control systems. Wells will be located in enclosures and on platforms to elevate wellhead facilities above the flood levels. Bank filtration, chlorination and 5-micron filtration of recharge flows will be provided, and also a trickle flow during any extended storage periods when no recharge and no recovery is occurring for more than about two weeks. Trickle flow rates are typically about 2 to 10 GPM per well, sufficient to turn over the water column in the well at least once per day. The chlorine dose will be low, sufficient to maintain a small chlorine residual within the well casing and screen and thereby help to control well clogging due to downhole microbial activity

Typical unit capital costs for ASR wellfield facilities, including both construction and engineering costs, range from about $0.50 per gallon per day of recovery capacity to $2.00/GPD, with an average of $1.14/GPD (Pyne, 2006, 2010). The principal factor impacting the unit cost is the well yield. Higher yield wells tend to have lower unit costs. ASR well yields typically range between 0.5 MGD and about 4 MGD. For the Victoria area, a well yield of about 2 MGD is expected, which is about average.

A second factor impacting the ASR unit capital cost is well depth. Shallower wells have lower unit costs than deeper wells. ASR wells range from as shallow as about 100 feet and as deep as about 3,000 feet. For the Victoria area, the anticipated screen intervals in the Evangeline Aquifer range between -400 and -1,000 feet msl. These are about average depths for ASR wells.

A third factor impacting the unit capital cost is the number of wells to be constructed and equipped. Economies of scale are such that designing, permitting, constructing and equipping several wells is less expensive per well than the same tasks for a single well. This would be a very large wellfield, or series of wellfields, so there would be significant economies of scale. As a result, this would tend to reduce unit costs.

The San Antonio Water System (SAWS) Twin Oaks ASR wellfield, with a recovery capacity of 60 MGD, had a unit capital cost of $0.87 per gpd of recovery capacity (Malcolm Pirnie, Inc., et al, 2011). Construction occurred in two phases, the first in 2000 and the second in 2006. This included a provision for land acquisition and initial wellfield mitigation costs, but excluded the cost of a 30-mile transmission pipeline from San Antonio to the wellfield site. It also excluded the cost of a 30 MGD water treatment plant, the need for which occurs whenever the proportion of native groundwater flow in the water recovered from ASR storage is sufficiently high so that elevated concentrations of iron, manganese and hydrogen sulfide occur in the recovered water, rendering it unsuitable for drinking water purposes except following treatment. Neither of these facilities would be needed for the proposed ASR wellfield near Victoria to supplement environmental flows to San Antonio Bay.

For current planning purposes, a reasonable 2015 unit capital cost estimate for ASR wellfield construction, including all wellfield facilities listed above, would be $1.10 per gallon per day (gpd) of recovery capacity. This would include a 10% contingency allowance.

Assuming this unit capital cost of $1.10/gpd of recovery capacity, the ASR wells, monitor wells, associated wellhead facilities and wellfield piping would cost $40 million per well cluster, and $400 million overall for ten well clusters. Total wellfield recovery capacity would be 360 MGD.

5.2.2 BANK FILTRATION AND DISCHARGE STRUCTURE COSTS

The bank filtration well, excluding aboveground pumps, piping and related facilities, is estimated to cost between $2 million and $3 million, depending primarily upon the number and length of laterals required to achieve the target production rate. This is assumed to be at least 6 MGD. An additional $3 million is estimated for the bank filtration aboveground facilities (pumps, piping, disinfection, 5-micron filtration, electrical, controls). Low level disinfection of the water produced from the bank filtration well would maintain a small chlorine residual for water flowing through the 5-micron filter and also to the ASR wells during recharge and storage periods to control microbial activity close to the well screen and gravel pack and thereby reduce well clogging. A discharge structure for the recovered flows from each well cluster would also be provided. Total estimated capital cost estimate for current planning purposes is $6 million per well cluster, or $60 million overall for ten well clusters.

5.2.3 TOTAL PROJECT COSTS

Total project costs, in 2015 dollars, are estimated as shown in Table 5-1, next page. These include capital costs, additional project costs, annual costs and also unit costs. The costs are shown for each phase of wellfield development. The estimated total project cost approximates the unit capital cost estimate of $1.10 per gallon per day of recovery capacity, as discussed above, plus the cost for the bank filtration wells. Notes are provided on the page following Table 5-1, indicating the assumptions underlying the various cost elements.

Table 5-1 Total Project Cost Estimate -- ASR Wellfields for Environmental Flow Augmentation

Project Phases			I	II	III	IV	All Phases
(See Note 1 for Project Phases and Elements)			**Preliminary Hydrogeologic Investigations**	**Bank Filtration and ASR Wells Demonstration Testing and ASR Feasibility Assessment**	**Complete Initial Well Cluster**	**Complete 9 Remaining Well Clusters**	**Total Project Costs**
Capital Costs							
Phase I	Surficial Aquifer		$ 250,000				
	Evangeline Aquifer		$ 250,000				
	Phase I Capital Costs		**$ 500,000**				
Phase II	Bank Filtration Well			$ 5,000,000			
	Two ASR Wells and Wellhead Facilities, 4 MGD			$ 3,000,000			
	Piping and Discharge Structure			$ 1,000,000			
	Cycle Testing (one year)			$ 250,000			
	ASR Feasibility Assessment			$ 300,000			
	Easements for wellfield facilities and subsurface storage	(Note 2)		$ 100,000			
	Phase II Capital Costs			**$ 9,650,000**			
Phase III	Complete initial ASR well cluster, 16 wells, 32 MGD				$ 24,000,000		
	Piping and appurtenances				$ 2,600,000		
	Easements for wellfield facilities and subsurface storage	(Note 2)			$ 300,000		
	Phase III Capital Costs				**$ 26,900,000**		
Phase IV	Bank Filtration Wells (9)					$ 45,000,000	
	ASR Wells (162 wells, 324 MGD)					$ 193,616,667	
	Piping , Discharge Structure and Appurtenances (9)					$ 29,000,000	
	Easements for wellfield facilities and subsurface storage	(Note 2)				$ 3,600,000	
	Phase IV Capital Costs					**$ 271,216,667**	
	Subtotal - Capital Costs		**$ 500,000**	**$ 9,650,000**	**$ 26,900,000**	**$ 271,216,667**	**$ 308,266,667**
Additional Project Costs:							
	Water Acquisition Costs (*Note 3*)		$ -	$ -	$ 500,000	$ 1,500,000	**$ 2,000,000**
	Contingencies (10%)		$ 50,000	$ 965,000	$ 2,690,000	$ 27,121,667	**$ 30,826,667**
	Legal and ROW Acquisition (2%)		$ 10,000	$ 193,000	$ 538,000	$ 5,424,333	**$ 6,165,333**
	Engineering, Surveying, Environmental, Etc (30%)		$ 150,000	$ 2,895,000	$ 8,070,000	$ 81,365,000	**$ 92,480,000**
	Interest During Construction (8%)		$ 40,000	$ 772,000	$ 2,152,000	$ 21,697,333	**$ 24,661,333**
	Total Additional Project Costs:		**$ 250,000**	**$ 4,825,000**	**$ 13,950,000**	**$ 137,108,333**	**$ 156,133,333**
Total Project Costs (Amount to be financed)			**$ 750,000**	**$ 14,475,000**	**$ 40,850,000**	**$ 408,325,000**	**$ 464,400,000**
Annual Costs							
	Debt Service on Capital Costs (5.5% for 20 yrs)		$ 62,759	$ 1,211,258	$ 3,418,301	$ 34,168,362	$ 38,860,681
	O&M						
	Well Field and Pump Maintenance	*(Note 4)*	$ 10,000	$ 50,000	160,000	1,890,000	$ 2,110,000
	Pumping Energy Costs (Note 5)		$ 20,000	$ 93,000	212,000	2,061,000	$ 2,386,000
	Total Annual Cost		**$ 92,759**	**$ 1,354,258**	**$ 3,790,301**	**$ 38,119,362**	**$ 43,356,681**
Unit Costs							
	Available Project Yield (af/yr)	*(Note 6)*		**558**	**4,465**	**45,210**	**50,233**
	Annual Cost of Water ($ per af)			**$ 2,427**	**$ 849**	**$ 843**	**$ 863**
	Annual Cost of Water ($ per 1,000 gals)			**$ 7.41**	**2.92**	**2.58**	**2.67**
	Cost of Water when needed for maintenance of environmental flows	(Note 7) $/AFD		**$ 1,186,475**	**$ 418,545**	**$ 413,201**	**$ 422,951**
		$/GPD		**$ 3.62**	**$ 1.28**	**$ 1.26**	**$ 1.29**

NOTES: Table 5-1	
1) Project Elements ***Phase I:***	Initial hydrogeologic investigations of both the surficial (alluvial) and Evangeline aquifers; will involve installation and operation of small test wells
Phase II:	Installation and operation of a bank filtration well, two ASR wells and monitoring wells, and associated pumps and piping
Phase III:	Installation and operation of 16 ASR wells, monitoring wells and associated pumps and piping, completing the first ASR well cluster
Phase IV:	Installation and operation of nine additional well clusters, each consisting of 1 bank filtration well and 18 ASR wells and associated pumps and piping. This assumes all 9 are constructed simultaneously. In reality, additional well clusters may be added as needed and when funds are available.
2) Land use/storage easement costs	Assumptions: Land use easement required for surface acreages affected (i.e., well sites, pipeline and utility ROW, access roads, etc) and "Storage Easement" for subsurface storage rights
Phase I:	Investigations only, no land/storage easements required
Phase II:	Easements cover 1 bank filtration well & 2 ASR wells, plus access roads and utilities, installed in this
Phase III:	Easements for Phase II facilities extended to cover 16 ASR wells and additional utilities/access roads installed in this phase
Phase IV:	New easements for each of 9 ASR well cluster locations, covering 1 bank filtration wells& 18 ASR wells, and associated utilities and access roads, installed at each location (Easements total $400,000 per location)
3) Water Acquisition Costs	As discussed in the text, it is assumed that the water to be diverted and stored in ASR wellfields will be acquired via the permitting of unappropriated flows and/or the donation of existing water rights; the cost of acquiring these water rights is assumed to be only the legal and engineering/technical costs associated with pursuing an application for a new or amended water right
4) Wellfield and Pump Maintenance	Assumed $5,000/year per MGD of ASR pumping capacity, or $180,000/yr/well cluster of 18 wells, each 2 MGD capacity. Bank filtration well included.
5) Pumping Energy Cost	Bank Filtration: Well Pump Total Dynamic Head (TDH) = 75 ft; Q = 4200 gpm/ well cluster; electricity = $0.10/kwhr; duration = continuous, 3.5 years out of every 4 years ($76,000/yr/well cluster (average)) ASR Recovery: Well Pump TDH = 175 ft; Q = 1400 gpm/well; 18 ASR wells/cluster; eleectricity = $0.10/kwhr; duration = continuous, 0.5 years out of every 4 years ($153,000/yr/well cluster (average)) Total Long Term Average Cost = Average cost over a 4-year period = $229,000/yr/well cluster Phase I estimate is for bank filtration pilot well and Evangeline aquifer ASR test well
6) Available Project Yield	Project Yield is calculated per the following: 6.1 AFD per ASR well x 183 days/year x 1 year out of 4 when stored water would be recovered, on average
7) Cost of Water	Unit Project Cost (in $/GPD)= Total Project Cost divided by ASR Wellfield Recovery Capacity (gallons per day). These Unit Project Costs are typically used for comparing ASR projects -- the national average Unit Project Cost for ASR wells and wellfields is around $1.10/GPD of recovery capacity.

The cost for purchase or lease of land for wellfield facilities is not well known. A very preliminary budget estimate is based on the assumed need for a total of 200 sites for ASR wells, bank filtration wells and discharge structures, each of which is assumed to cost $20,000, including access roads, power lines, pipeline easements, and a provision for mitigation of any potential adverse effects upon adjacent well owners during the initial few years of ASR wellfield operations, such as due to raising or lowering water levels in their wells.

Bank filtration and ASR Demonstration Testing is assumed to include one 6 MGD bank filtration well, complete; two ASR wells, fully equipped and placed into operation; piping and a temporary discharge structure, with one year of cycle testing to demonstrate performance. To complete the initial well cluster, 16 more ASR wells would be added, and associated facilities.

Upon project completion, the estimated total project cost is $464,400,000. Most of the construction is assumed to occur in Phase IV. In reality, this would most likely be distributed over many years or decades, adding well clusters as funds are available.

5.2.4 ANNUAL OPERATING COST

Little reliable information is available regarding operating costs for ASR wellfields. In general, these should be not much different than for conventional production wellfields. However each water utility tends to account for ASR costs in different ways, ranging from including a significant administrative burden for all water utility capital investments, management and operations, to separating out costs specifically associated with operation and maintenance of ASR wells and wellhead facilities. The latter typically include acquisition costs for the water utilized for recharge; electrical power; chemicals; residuals disposal; routine maintenance of the pump, motor and wellhead facilities; provision for periodic equipment replacement and well rehabilitation; permitting; laboratory analyses and regulatory reporting requirements, and maintenance of the instrumentation and control systems. For the proposed environmental flows ASR wellfield, the need for residuals disposal is not anticipated. Permitting costs, including water quality monitoring and reporting, are typically high initially and then decline with time as performance stabilizes, operations become routine, and variability in flows, water levels and water quality becomes well known.

For the proposed wellfield facilities, about 75% of the time the wellfield will be in a recharge mode of operation, at a very low recharge rate averaging about 6 MGD for each well cluster, distributed among 18 ASR wells. This is equivalent to a recharge flow rate averaging 231 GPM/well, compared with an average recovery rate of 1,400 GPM. Other than occasional backflushing of the wells to waste to remove clogging and to ensure reliable performance of the pumping facilities when needed, operation costs should be very low. Routine operations and maintenance, monitoring and reporting will be required. Every few years it may be necessary to redevelop certain wells that may be more prone to well clogging and that may be insufficiently responsive to routine backflushing to restore their hydraulic performance. During infrequent droughts, recovery of the stored water from the ASR wells will be at a variable to high flow rate, probably ranging between 36 and 360 MGD (110 to 1,100 AF/D) for up to six months, approximately one-fourth of the years. For the 55-year period of record from 1934 to 1989, there were 14 years with a shortage of flows to the estuary during spring months, requiring recovery from ASR storage. During summer months there were two years. Electrical power costs at such times will be more significant.

Baseline operation costs would include those years when only recharge is occurring. A suggested reasonable estimate of annual average baseline operating costs is $5,000 per year per MGD of ASR recovery capacity, or about $10,000 per year per ASR well. This would be equivalent to $180,000 per year per well cluster. To this would need to be added the operating cost for a 5 MGD bank filtration well, 5-micron filtration and chlorination of the recharge flows. These are estimated to cost $200,000 per year. Total annual operating cost per well cluster is estimated at

$380,000. This assumes no need for post-treatment other than aeration. Upon wellfield completion, the annual baseline operating cost is estimated at $3,800,000 for all ten well clusters.

During approximately 25% of the years ASR recovery will occur. Operating costs will be greater due to the need for electrical power for pumping water from the ASR wells to the river. A preliminary estimate of the per well electrical cost is $100/day, assuming a flow rate of 1,400 gpm and a pumping lift of 100 feet for discharge to the river. Depending upon the number of wells in operation, and the duration of the recovery period, the seasonal cost for a very dry spring season might be up to $1.4 million for 90 days of environmental flow augmentation. For most years in which ASR recovery occurs, the electrical power cost would be less than this.

Financing ASR wellfield operations would need to include a provision for accumulation of funds during normal and wet years when ASR recharge is occurring so that electrical power costs can be covered during years when ASR recovery is needed.

5.2.5 COST OF WATER RIGHTS FOR USE IN ASR

This study assumed, in its investigation of the potential use of ASR as a means of achieving STFs for the San Antonio Bay/Guadalupe Estuary, the existence of a mechanism allowing the dedication and use of wastewater return flows originating within the GSA Basin. The mechanism would be a “bed and banks” permit from TCEQ providing that these flows could not be diverted for other uses while in transit from their point of origin to the proposed location of use, which was either diversion into ASR storage or inflow into San Antonio Bay.

In actuality, only those return flows discharged into the Guadalupe River basin (approximately 10,000 af/yr) were considered available for diversion into ASR storage. This does not provide the volume necessary, on a daily basis, to recharge ASR storage to the volumes needed for re-deploying the water into the river during drought periods to meet estuarine STFs. Thus, the modeling assumptions also included the diversion and storage of large amounts of currently unappropriated Guadalupe Basin water, which the WAM indicated would be available during certain periods of time.

Despite this key assumption in the modeling, Texas does not yet allow appropriation of <u>new</u> water rights solely for environmental flows (although TCEQ rules governing the adoption and implementation of environmental flow standards, as required in Senate Bill 3, provide for “set-asides” of unappropriated water – if available – to “satisfy the environmental flow standards to the maximum extent reasonable when considering human water needs.” (30 TAC *Sect. 298.1.1.*) An application of this provision of the Texas Water Code has yet to be seen.

An alternative to obtaining a “set-aside” as described above is to acquire, through purchase, lease, or donation, an existing water right and then amend it to include instream flow as an additional authorized use, which is allowed by state law.

Because this route includes amending an existing water right, most of the expenses associated with an effort to obtain a new appropriation still apply, plus any purchase cost which might be involved in a “willing seller, willing buyer” transaction, unless the water right is being donated.

Even though the State established the Texas Water Trust in 1997 “to hold water rights dedicated to environmental flow needs, including instream flows, water quality, fish and wildlife habitat, or bay and estuary inflows” (Tx Water Code, Sect. 15.7031), experience in Texas with the donation of water rights for environmental flows protection is not very encouraging. Currently, only two water rights donations have been “deposited” in the Texas Water Trust: (1) a private donation of two water rights on the Rio Grande River in Hudspeth County, totaling 1,236 af/yr., and (2) a donation by Texas State University of a 33,108 af/yr water right on the San Marcos River/Guadalupe River in Hays County (Hess, 2005; TWDB, 2015a)

The alternative to acquiring a donation of water rights for environmental flows is to utilize “water markets” which may exist for the transfer of water rights. These types of markets function better in some areas of Texas than others, with the most robust markets existing where unique regulatory environments have more clearly defined water rights ownership and removed many of the uncertainties and obstacles normally associated with the acquisition and transfer process (i.e., surface water in the Rio Grande River, and groundwater within the jurisdictional authority of the Edwards Aquifer Authority).

These transactions may range from a simple lease of water rights by another party willing to abide by the existing terms of the permit, to the purchase and amendment of an existing right to allow new uses, diversion points, locations of use and other changes – a process which will now subject the newly amended permit to all of the environmental flow criteria established under SB3. The price paid for the purchase or lease of a water right acquired in the “open market” varies tremendously depending on a number of factors: the relative seniority (“dependability”) of the water right, type and location of authorized uses, location and allowed rate of diversion, and inclusion/absence of flow restrictions. Every transaction is unique, and the availability of information on these transactions is usually limited, so it is extremely difficult to arrive at some kind of “market price” which might be used to estimate the cost of acquiring water rights in this fashion.

In this study the cost estimates for acquiring water rights to be diverted into ASR storage and later withdrawn for use in supplementing FWI volumes during droughts reflect only the expenses which might be associated with 1) amending existing water rights, donated or acquired otherwise, to add authorization for environmental flow use and to change the point of diversion if necessary, 2) applying for the “bed and banks” permit necessary to dedicate wastewater return flows for environmental use, or 3) applying for a new appropriation of water to be used for ASR storage and later deployment for environmental flows (*note: while not currently allowed under state water law, this was the theoretical assumption used in this study*). The $2,000,000 figure used in Section 5.2.3, item 6, reflects an estimate of the legal, administrative and technical/engineering expenses associated with one or more of the above approaches to acquiring the necessary water rights, and other “startup” costs -- it does not include a “purchase cost” for any existing water rights.

6 RECOMMENDATIONS

The results of this study demonstrate, at a conceptual level, how the use of dedicated wastewater return flows and unappropriated water in the Guadalupe-San Antonio River Basin, in combination with the development of Aquifer Storage and Recovery facilities for managing the volume and timing of instream flows, could help realize recently adopted standards and goals for inflows to the San Antonio Bay estuarine system. This work holds promise for how freshwater flows in rivers and streams across Texas can be more effectively managed to achieve instream flow and estuary inflow targets.

However, even if certain basic assumptions included in the evaluation of potential strategies in this study – i.e., the modeling included the dedication of wastewater return flows and the appropriation of new water rights for environmental flows, both of which are controversial issues currently -- could be realized through changes in state water policy and law, there are still other technical and regulatory issues needing attention before these strategies might be ripe for implementation.

The following is a discussion of several technical considerations which should be addressed before making further recommendations about the means of providing supplemental water for environmental flow benefits. Assuming those issues can be resolved, there is also a discussion of the legal and regulatory changes which would facilitate implementation of the proposed strategies, as well as a discussion about potential funding mechanisms and, finally, an outline of an incremental approach which could both move the policy and technical issues forward while achieving some measurable success in providing additional freshwater inflows to San Antonio Bay when they are most needed.

6.1 FURTHER TECHNICAL ANALYSIS

The just completed “desktop” study *simulated* both the hydrologic conditions within the Guadalupe-San Antonio River Basin and the operational parameters of an ASR facility in order to estimate potential changes in the volume and timing of inflows to the San Antonio Bay system.

It also made some general assumptions about the hydrogeologic parameters of the alluvial, or surficial, aquifer system along portions of the lower Guadalupe River where the ASR facilities were assumed to be located.

As promising as these potential strategies may appear based on this work, prior to embarking down the path towards implementation of these strategies, it would be prudent to undertake several additional technical studies, both "desktop" simulations and field tests, in order to 1) provide a "reality check" on the actual impact the modeled addition of freshwater inflows would have on salinities in San Antonio Bay, and 2) verify some of the hydrogeologic assumptions regarding the potential aquifer recharge rates and water quality which could be achieved using bank filtration wells located in the alluvium of the Guadalupe River.

6.1.1 SIMULATE FRESHWATER INFLOWS UNDER DESIRED IMPLEMENTATION PROGRAM IN TXBLEND MODEL TO EVALUATE THE SALINITY BENEFIT OF THE AUGMENTED FLOWS

One of the important underlying assumptions supporting this study was that the timing and amount of inflow recommended in the STFs makes a measurable, beneficial change in the salinity regime within San Antonio Bay, which consequently results in "ecologically sound" conditions as determined by the health of indwelling communities of certain indicator species (i.e., Rangia clams and oysters). The first recommended additional technical study would extend the modeling of the supplemental freshwater inflows from the point of their discharge into San Antonio Bay, which is essentially where Region L WAM model in the current study left them, through the full extent of the estuary in order to assess the changes these inflows would make in the salinity regimes within the bay system as they alter the antecedent salinity conditions created by "baseline" inflows up to that point in time.

Rather than using the GSA or Region L WAM models, which apply hydrologic properties within the rivers and state water law regarding the diversion of surface water to estimate quantities of freshwater available at different locations within the watershed at certain points in time, this proposed analysis would use the Texas Water Development Board's "TxBLEND," a two-dimensional hydrodynamic and salinity transport model developed and calibrated for San Antonio Bay (TWDB, 2015b), to look at salinity zonation throughout the bay system. Using the TxBLEND model, it is possible to compare salinity patterns in the estuary with and without the supplemental inflows provided under the proposed strategies. This information will be useful in assessing the relative ecological value provided by the supplemental inflows available under the proposed strategies. If measurable benefits can be documented, this information would provide further support for implementation of the strategies.

6.1.2 HYDROGEOLOGIC TESTING AND PILOT STUDIES ON USE OF BANK FILTRATION WELLS AND "MODULAR" ASR FACILITIES

As described in Section 5.1, there are several preliminary investigations which should precede the final design and construction of ASR facilities proposed as a means of providing supplemental FWIs during drought periods. These studies focus on determining more accurately the hydrogeologic properties of both the surficial portion of the alluvial aquifer adjacent to the Guadalupe River and the underlying Evangeline Aquifer along the river reach identified in this study as most likely suitable for the development of ASR wellfields. Soil borings, cores and water samples should be obtained to characterize the aquifer parameters for the surficial aquifer and a test well should be installed to simulate the effects of the proposed bank filtration wells and to collect water samples which can identify the source of the well's production – whether it is river water being drawn in as anticipated, or native groundwater, which would indicate no connection to the river has been established by the pumping.

The Evangeline Aquifer is a layer of the Gulf Coast Aquifer underlying the surficial portion of the alluvial aquifer system along the Guadalupe River and the likely zone in which the storage of the surface water would take place. Site specific information on the Evangeline Aquifer will be necessary in order to determine its suitability for ASR in the proposed project area and the requisite design parameters if it is to be utilized. Aquifer investigations should include the development of a groundwater flow simulation model for the targeted portions of the Gulf Coast Aquifer and pump tests to determine site specific aquifer characteristics which can be used to calibrate the simulation model and provide a basis for ASR well sizing and spacing.

If information favorable for the development of the proposed ASR facilities is obtained from these preliminary investigations then the next step should be to conduct a full scale bank filtration well and ASR well demonstration program at a selected location within the proposed study area. Data to be collected in this investigation should be tailored to provide site-specific information regarding water treatment provided by bank filtration and ASR operations which would be pertinent to obtaining regulatory approval from TCEQ.

Assuming the demonstration project proves up the effectiveness of the diversion and treatment of Guadalupe River water by bank filtration wells and the suitability of the Evangeline Aquifer for ASR storage, then this information should be used as a basis for efforts to obtain TCEQ regulatory approval for proposed ASR operations. If these efforts are successful, it would allow the permitting of the demonstration project as the first major step in the development of the infrastructure required to implement strategies proposed in this report.

6.2 POLICY RECOMMENDATIONS

It should again be noted that the apparent effectiveness of the strategies evaluated in this study largely depended on certain assumptions about the availability of, and access to, wastewater return flows and unappropriated streamflow within the GSA Basin as a source of ASR recharge. In addition, the cost effectiveness of the proposed use of ASR to "bank" flows during higher streamflow regimes for later managed release as supplemental FWI's to San Antonio Bay during drought periods depends on the assumed ability to use bank filtration wells to both divert available river flows and provide pretreatment of that water, in conjunction with other pretreatment processes (disinfection, microfiltration), before it goes into ASR storage. However, as neither current Texas water law regarding use of unappropriated water for environmental flow needs, nor TCEQ rules for treatment of surface water prior to injection into an ASR facility currently support these two key assumptions, there will need to be some additional work done to bring about significant changes in state policy before these strategies become feasible. Fortunately, TCEQ rule-making for implementation of the recent ASR legislation (HB655) is in process and is scheduled for completion during mid-2016.

Federal (EPA) policy with regard to Class V ASR wells has recently changed, providing greater discretion to individual states to develop and implement ASR regulations that best meet each state's needs. In particular, this policy change provides for both time and distance for natural treatment processes to occur underground around an ASR well that would enable a wellfield operator to meet applicable primary and secondary drinking water standards within an area that the operator controls. This is deemed by EPA to be consistent with federal law pertaining to Underground Injection Control.

The two areas of changes in Texas water policy being proposed involve amending Texas water law to 1) encourage and facilitate the dedication of wastewater return flows for environmental flow needs, and 2) allow the granting of new non-consumptive water rights for currently available unappropriated flows, and amending existing non-consumptive permits, for the authorized purpose of instream flow and estuarine inflow protection.

Additionally, while it may not involve changes in water law, there should be more emphasis on the development of jointly sponsored, multi-purpose ASR facilities, particularly in association with either new or existing Off-Channel Storage facilities. Integrated operation of surface reservoirs, off-channel storage reservoirs and ASR wells is a powerful water management strategy that benefits from the best attributes of each technology, helping to achieve water supply reliability. Reservoirs can capture water rapidly during high flow events but lose water to evapotranspiration, have substantial environmental and land use impacts, and are expensive. ASR wells typically have very large storage capacities, no evapotranspiration losses, small footprints, no significant adverse environmental impacts, and relatively low costs, but can only recharge and recover water at relatively slow flow rates. Integrated operation would transfer stored water from surface reservoirs to ASR wells during and after flood events and at other times of normal flow. The stored water would then be recovered during dry periods and droughts.

6.2.1 DEDICATION OF WASTEWATER RETURN FLOWS FOR ENVIRONMENTAL FLOW NEEDS

Section 11.042 of the Texas Water Code provides TCEQ authority to issue "bed-and-banks' permits which allow the use of state owned water courses to convey water to an authorized downstream diversion point. Originally these permits only applied to releases of surface water from reservoir storage to a location where the use of that stored water was already authorized. However, in Senate Bill 1, passed in 1997, TCEQ was authorized to issue bed-and-banks permits to entities wishing to transport "reuse water," which could have originated either as state owned surface water or privately owned groundwater, from a point of discharge into state owned water courses to a new diversion point downstream.

These changes to Sect. 11.042 of the Texas Water Code also contain provisions allowing TCEQ to include special conditions on reuse bed-and-banks permits to help maintain instream uses and freshwater inflows to bays and estuaries. However, it is yet unclear whether a bed-and-banks permit can be issued for the express purpose of protecting a discharge of wastewater which is intended only for instream uses or freshwater inflows, as opposed to protecting a discharge intended for subsequent diversion and use at a point downstream. This uncertainty may exist because, as pointed out by knowledgeable observers, "TCEQ has not had many opportunities to explore or implement the provisions of section 11.042 as amended by Senate Bill 1." (McCarthy and Gershon, 2005).

Recommendation: In order to encourage the use of wastewater return flows as a source of supplemental water to increase attainment of estuarine inflow goals, Section 11.042 of the Water Code, and the TCEQ rules adopted to guide the implementation of those changes, need to be amended to clearly grant TCEQ, in addition to the existing authority to grant bed-and-banks permits for downstream conveyance, diversion and use of wastewater return flows for other authorized purposes, the authority to issue bed-and-banks permits for the express purpose of protecting wastewater discharges solely intended to supplement instream flows and provide bay and estuary inflows.

6.2.2 NEW APPROPRIATIONS AND AMENDMENTS OF EXISTING WATER RIGHTS TO MAKE WATER AVAILABLE FOR DIVERSION AND STORAGE IN ASR FACILITIES OPERATED FOR ENVIRONMENTAL FLOW PURPOSES

Several attempts have been made in Texas recently to obtain new water rights authorized primarily for environmental flow protection purposes. While these attempts were all eventually unsuccessful, they wound up generating significant interest within the water supply and environmental communities – interest enough that the Texas Legislature weighed in on the issue, passing S.B. 1639 in 2003. S.B. 1639 put in place a temporary moratorium on the issuance of new permits for instream flow protection and established the "Study Commission on Water for Environmental Flows," which issued a report setting the stage for S.B. 3, the legislation which required the establishment of environmental flow standards for most river basins in Texas. (Hess, op cit.) S.B. 3, however, still did not authorize TCEQ to issue new water rights permits for available unappropriated water if the only use would be environmental flow protection. Instead, it provided that TCEQ could establish "set-asides" of flows for environmental purposes.

The assumptions in this study regarding the modeling of river flows available for diversion into ASR storage included the use of unappropriated water for environmental flow uses, which, as indicated above, does not reflect the current state of water rights law in Texas. However, this particular use of unappropriated water has several characteristics which would set it apart from the purely in-stream uses associated with previous permit applications for new appropriations intended to protect environmental flows.

Recommendations: Foremost, and specifically addressing one of the permitting issues which hindered prior applications, TCEQ should be authorized to issue a new water rights permit for ASR purposes which would include a diversion point, or points, and a maximum diversion rate, just as required for most other water rights permits. In addition, since the water will eventually be recovered from ASR storage and returned to the stream from which it was withdrawn, some protection should be included in order to prevent the diversion of this water by other downstream users before it reaches the estuary. This could involve including a bed-and-banks use provision in the permit, or adding another "diversion point" at the head of estuary, below any other potential diversions.

6.2.3 Promoting the Development of Jointly Sponsored, Multi-Purpose ASR Facilities

While this study assumes the development of new ASR facilities for the specific purpose of storing and managing water for environmental flow purposes, there is also a tremendous opportunity to utilize other new or existing ASR facilities for both municipal/industrial water supply and environmental flows protection. At least five of the Water Management Strategies (WMSs) contained in the Initially Prepared Plan (IPP) for the South Central Texas Regional Water Planning Group (Region L) 2016 Regional Water Plan include an ASR facility, which would function independently or in conjunction with other facilities, particularly Off-Channel Reservoirs (OCRs). (Region L, 2015)

These potential WMSs are mainly for municipal and industrial (M&I) water supply purposes, but at least one, the Edwards Aquifer Habitat Conservation Plan (HCP), relies on an existing ASR facility. In this case, the SAWS Twin Oaks ASR project is used to bank leased Edwards Aquifer water rights and to withdraw that stored water, periodically, in lieu of Edwards Aquifer pumping in order to protect springflow during severe droughts.

Other WMSs in the Region L IPP involve possible combinations of both OCRs and ASR, wherein available streamflow could be diverted quickly into temporary OCR storage during high flow periods, then treated and transferred into longer term ASR storage. By reducing evaporation losses associated with simply using OCR storage and increasing the total storage capacity, this approach results in greater efficiencies and higher firm yields from these projects. Using these facilities to also store water available for environmental flows should be investigated since it would, as the use of the SAWS Twin Oaks ASR demonstrates, provide an opportunity to resolve some of the environmental flow issues which may affect current and future permitting of M&I water supplies.

Several of the WMSs in the Region L IPP, both for ASR and other projects, include multiple potential sponsors and beneficiaries. While large multi-party projects may be more difficult to plan and implement, there have been successes in the past, and as increasing demands and decreasing availability is most certainly in Texas' water future, regional projects may become more the norm rather than the exception. Again, the successful regional, stakeholder-driven process which resulted in the development and adoption of the Edwards Aquifer HCP, and the resulting water supply benefits it affords, provides a model for how a multi-party, regional scale ASR project might be developed and used to provide both environmental flow and water supply benefits.

Recommendation: There should be an initiative to convene stakeholders in the GSA Basin to, first, identify potential regional scale applications of ASR to supplement both M&I water supplies and environmental flows during drought periods and, then, to determine possible institutional arrangements/agreements which could be made to implement one or more of these projects. This process could be part of efforts to resolve disputes over current or future water rights applications or to establish a broader base of participants/beneficiaries in order to finance projects of the scale necessary to resolve the water management challenges facing the region in the near future.

6.3 POTENTIAL FUNDING SOURCES

As identified in the section on cost estimates, using ASR facilities on the Lower Guadalupe River to help resolve the full shortfall in meeting the STFs for inflows to San Antonio Bay would be expensive. Identifying and accessing funding for the cost of a project of this scale seems like an intractable challenge. However, the cost of not attempting to implement these kinds of solutions may, in the long run, be just as expensive, or more so, in terms of the impacts on natural resources and the loss of the economic benefits associated with the environmental services those resources provide to the region, state and nation -- and in terms of the eventual constraint on the development of water supplies for other uses which these environmental impacts may generate.

6.3.1 FEDERAL FUNDING

One potential source of funding that may be an option is the implementation fund which may be available under the RESTORE Act passed in 2012. In response to the environmental economic damages resulting from the Deepwater Horizon oil spill which occurred in the Gulf of Mexico in 2010, Congress passed the federal RESTORE Act, which will direct 80% of civil fines and penalties stemming from the Deepwater Horizon oil spill back to the Gulf Coast Region for ecological and economic restoration.

Although BP recently agreed to a settlement with the federal government regarding the amount of fines and penalties it will pay, there are still significant unknowns about the amount of money that will come to Texas and the timing of when these funds may become available. There is a lengthy list of projects which have already been proposed for funding, with the total funding requests far exceeding any realistic estimate of how much money will find its way to Texas. It is also still unclear exactly how decision-makers will allocate what money will be available. However, given the interest among certain environmental organizations in resolving the environmental flows/B&E (bay and estuary) inflows issues in the GSA basin, the findings in this study could provide the information needed to support an effort to fund and implement these strategies with RESTORE Act funds.

Another argument for federal financial support for implementing this project is that it would serve as an excellent prototype for addressing similar problems in other river basins within the United States. When these problems occur in inter-state river basins, they more directly affect federal interests and responsibilities, and clearly demonstrating an effective solution in Texas could assist federal efforts in those areas.

6.3.2 STATE FUNDING

Water supply development for regional or local uses in Texas are typically funded by the project beneficiaries, but often the funding includes some state financial assistance in terms of planning grants, low interest construction loans, or “state participation” – which involves the state taking an ownership position in a portion of a water supply project in order to ease the burden on the local sponsors in the early years, before the full yield of the project is being used and generating income to cover all the debt service. Most recently, the 83rd Texas Legislature established, and capitalized, in the amount of $2 Billion, the “State Water Implementation Fund for Texas (SWIFT)” to “provide affordable, ongoing state financial assistance for projects in the state water plan.”

This new program provides financial assistance to water providers and other project sponsors through “low-interest loans, extended repayment terms, deferral of loan repayments, and incremental repurchase terms for projects with state ownership aspects.” (TWDB, 2015c).

However, to access any of these forms of financial assistance, the proposed project must be a recommended WMS in the current (2012) Regional Water Plan for the area in which the project or the proposed water use is located. In the 2012 Region L Water Plan, the only ASR project listed as a WMS is the expansion of the SAWS Twin Oaks ASR facility, but it has not been prioritized for SWIFT funding. The several ASR projects contained in the 2016 IPP for Region L will not be eligible for consideration for SWIFT funding assistance until the next Regional Water Plan is formally adopted and included in the 2017 State Water Plan, and only then if the project is one of the recommended and prioritized WMSs.

Even though ASR projects for traditional M&I water supply may eventually be recommended WMSs in Regional Water Plans, and potentially qualify for SWIFT funding assistance, an ASR project solely for the purpose of storing water and managing its release for environmental flow benefits would not be eligible. Current TWDB regional water planning guidelines do not provide for the evaluation of WMSs intended only for environmental flow needs in a SB1 Regional Water Plan, and SWIFT funds require that the project be a recommended, and prioritized WMSs in an adopted regional water plan. A multi-purpose ASR project, providing both M&I water supply and environmental flow benefits might qualify, but under that scenario, the SWIFT funding assistance might only apply to the M&I portion of the project costs.

More specific to making State funds available for ASR, the 84th Texas Legislature appropriated $1 million for TWDB to help advance the use of ASR in Texas. TWDB will use the appropriation to cost-share in the funding of several local or regional ASR projects or studies. TWDB is currently developing application procedures and guidelines for the program and details will be made available on the TWDB website.

6.3.3 LOCAL AND REGIONAL FUNDING

Since the cost of most local and regional water supply projects are ultimately supported by some form of user fee, it is not hard to extrapolate to having the “beneficiaries” of environmental flow projects which provide watershed level benefits bear some or all of the costs of these projects. A good example is the recently adopted Edwards Aquifer HCP, in which entities up and down the GSA Basin have agreed to help defray the annual cost of the program because they benefit either from extended access to Edwards Aquifer water during drought – the result of the recovery of water stored in the SAWS Twin Oaks ASR facility – or increased base flow in the rivers downstream – the result of protecting the flow of Edwards Aquifer springs. While this remarkable agreement for joint funding by regional stakeholders may have come about, in part, because the “blunt axe of federal power” provided by the Endangered Species Act (ESA) hovered over the collective head of the process participants, the lessons learned may include how to identify all of the benefits of efforts which may, at first, appear to be driven only by environmental goals, and then to access local and regional financial support to implement projects which both resolve the environmental issues and provide M&I water supply benefits.

Since the strategies examined in this study are aimed at increasing attainment frequencies with respect to STFs for freshwater inflows to San Antonio Bay, the source of which includes springflow, runoff, and return flows originating across the entire GSA Basin, the sources for the funding required for the implementation of these strategies could, like the Edwards Aquifer HCP funding, span water users across the region.

One potential method of collecting and dedicating funds for these purposes could be for the Legislature to authorize TCEQ to add a line item onto the annual assessments they levy on water rights holders to support the South Texas Watermaster’s Program, which is responsible for managing surface water rights in south central Texas, including the GSA Basin and adjoining coastal basins.

This new fee would only apply to the annual volume of a water right which can be determined to be a consumptive use, thus also creating financial disincentives for water waste and incentives for water conservation, discharge of return flows, and other water management strategies which keep more water in, or return more water to, streams and provide more B&E inflows. Similarly, water rights which are permanently or temporarily designated for instream flows/B&E inflows, and placed into the Texas Water Trust or made available for ASR storage, would be exempt from the fee.

While these fees should be set at a level which would not financially burden water rights holders, or the users who would ultimately pay for the fees in their water rates, they could still provide a steady income source that would eventually be sufficient to sustain bonded indebtedness to build the necessary infrastructure and/or cover annual operating costs for ASR projects providing environmental flow benefits to the entire GSA Basin, including San Antonio Bay. These fees might also serve as a source of “local match” to leverage opportunities for federal and non-governmental organization funding for a share of the cost of these kinds of projects.

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8 REFERENCES

Carollo Engineers, 2002. *CERP ASR/Surface Water Treatment Pilot Study*. Prepared for U.S. Army Corps of Engineers. October 2002.

Environmental Flow Standards for Surface Water, 30 Texas Administrative Code, Chapter 298 – SUBCHAPTER A: GENERAL PROVISIONS, Sect. 298.1.1. Definitions.

Guadalupe, San Antonio, Mission, and Aransas Rivers and Mission, Copano, Aransas, and San Antonio Bays Basin and Bay Area Stakeholders Committee (GSA BBASC). 2011. Environmental Flows Recommendations Report. September 1, 2011.

Guadalupe, San Antonio, Mission, and Aransas Rivers and Mission, Copano, Aransas, and San Antonio Bays Basin and Bay Expert Science Team (GSA BBEST). 2011. Environmental Flows Recommendations Report. March 1, 2011.

Hess, Myron J., 2005. *Instream Flows – An Environmental Perspective on Texas Laws.* Presented at the Texas Water Law Institute, September 28-30, 2005, Austin, Texas.

Intera Geosciences & Engineering, Inc., (2011) WAM-Based Hydrologic Analyses of Strategies to Meet SB3 Environmental Flow Standards for the Guadalupe Estuary (Appendix H of BBASC report) July 5, 2011, Austin Texas.

John, David E.; and Rose, Joan B, 2005. *A Review of Factors Affecting Microbial Survival in Groundwater.* Journal of Environmental Science and Technology. Volume 39, No. 19, pp. 7345-7356, 2005.

Malcolm Pirnie, Inc.; ASR Systems LLC; and Jackson, Sjoberg, McCarthy and Wilson LLC, 2011. *An Assessment of Aquifer Storage and Recovery in Texas.* Report No. 0904830940 prepared for the Texas Water Development Board, February 2011.

McCarthy, Edmond R. and Gershon, Michael A., 2005. *Reuse as a Viable Option in Water Resource Development. In:* Water for Texas; Jim Norwine, John R. Giardino, and Sushma Krishnamurthy, editors. Texas A&M University Press, College Station, Texas. Pp. 218-225.

Melin, Gina, 2003. Editor, Proceedings of the Second International Riverbank Filtration Conference, Cincinnati, OH. National Water Resources Institute. September 2003.

NRC (National Research Council), 2015. Review of the Everglades Aquifer Storage and Recovery Regional Study. Washington D.C.: The National Academies Press.

Naismith Engineering, Inc.; Intera; ASR Systems LLC; and ARCADIS, 2014. *Development of a Regional Plan for Aquifer Storage and Recovery and Off Channel Storage in the Golden*

Crescent Region of Texas. Report No. 1348321576 prepared for the Texas Water Development Board, July 2014.

Pyne, R.D.G., 2010. *Aquifer Storage Recovery: Economics and Recent Technical Advances.* Proceedings of the Seventh International Symposium on Managed Aquifer Recharge, Abu Dhabi, October 2010. http://www.ismar7.org/proceedings/.

Pyne, R.D.G., 2006. Aquifer Storage Recovery: A Guide to Groundwater Recharge Through Wells. ASR Press, 608 p.

Ray, Chittaranjan; Melin, Gina; and Linsky, Ronald B. *Riverbank Filtration: Improving Source-Water Quality.* Proceedings of the First International Riverbank Filtration Conference. Cincinnati, Ohio. National Water Resources Institute and Kluwer Academic Publishers. November 1999.

South-Central Texas Regional Water Planning Group (Region L), 2015. 2016 Initially Prepared Plan. (http://www.regionlTexas.org/current-planning-effort/4th-cycle-planning-efforts-2016-rwp/2015-initially-prepared-plan-ipp/) : Accessed 8-16-15

Rose, Joan B., Ph.D., and John, David E., 2002. "A Review of Factors Affecting Microbial Survival in Ground Water." University of South Florida. 2002.

Schijven, Jack F., 2001. "Virus Removal from Groundwater by Soil Passage: Modeling, Field and Laboratory Experiments." Doctoral Dissertation. Technical University of Delft. 2001.

Schijven, Jack F; Berger, Philip; and Miettinen, Ilkka, 1999. *Removal of pathogens, surrogates, indicators, and toxins using riverbank filtration.* Proceedings of the First Riverbank Filtration Conference. Cincinnati, Ohio. National Water Resources Institute and Kluwer Academic Publishers. 1999.

Texas. Legislature. *Senate Bill 3, Acts 2007, 80th R.S.,ch. 1430, General and Special Laws of Texas* http://www.lrl.state.tx.us/legis/BillSearch/BillDetails.cfm?legSession=80-0&billTypeDetail=SB&billnumberDetail=3&submitbutton=Search+by+bill

Texas. Legislature. *House Bill 655, Acts 2015, 84th R.S., ch. 505, General and Special Laws of Texas.* http://www.lrl.state.tx.us/legis/billsearch/JournalsEtc.cfm?legSession=84-0&billtypeDetail=HB%20&billNumberDetail=655&billSuffixDetail=&startRow=1&IDlist=&unClicklist=&number=100

Tufenkji, Nathalie; Ryan, Joseph N; and Elimelech, Menachem. *The Promise of Bank Filtration.* Environmental Science and Technology. November 1, 2002.

Texas Water Development Board (TWDB), 2015a. http://www.twdb.Texas.gov/waterplanning/waterbank/trust/index.asp : Accessed 8-10-15.

TWDB, 2015b. http://www.twdb.Texas.gov/surfacewater/bays/models/index.asp : Accessed 8-10-15.

TWDB, 2015c http://www.twdb.Texas.gov/financial/programs/SWIFT/index.asp : Accessed 8-16-15.

USACE and SFWMD. 2014. Central and Southern Florida Project Comprehensive Everglades Restoration Plan*: Final Technical Data Report, Aquifer Storage and Recovery Regional Study*. October 2014.

Vogt, Jeffrey; Fromme, William; Whitteberry, Bruce; Gollnitz, William D., 2003. *Organics removal by riverbank filtration at the greater Cincinnati water works site.* Proceedings of the Second International Riverbank Filtration Conference. Cincinnati, Ohio. National Water Resources Institute. September 2003.

Wang, Jack Z.; Hubbs, Stephen A.; and Song, Rengao, 2002. *Evaluation of Riverbank Filtration as a Drinking Water Treatment Process.* AWWA Research Foundation and American Water Works Association. 2002.

Ward, George H., 2010. *Inflows to San Antonio Bay.* Report No. 0900010973 prepared for the Texas Water Development Board. October 2010. https://www.twdb.Texas.gov/publications/reports/contracted_reports/doc/0900010973_Inflow.pdf : Accessed 8-10-15.

Wett, Bernhard, 2003. *Hydraulic sensitivities and reduction potential correlated with the distance between the riverbank and production well.* Presented at the Second International Riverbank Filtration Conference. Cincinnati, Ohio. National Water Research Institute. September 2003.