SUMMARY REPORT

for the

DEVELOPMENT OF A REGIONAL PLAN FOR AQUIFER STORAGE AND RECOVERY AND OFF CHANNEL STORAGE IN THE GOLDEN CRESCENT REGION OF TEXAS

Submitted by:

Submitted to

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List of Acronyms and Abbreviations

AACE	Association for the Advancement of Cost Engineering
AF	acre-foot / acre feet
AFY	acre-feet per year
ASR	Aquifer Storage and Recovery
COA	Certificate(s) of Adjudication
DBP	disinfection by-product(s)
DFund	Texas Water Development Fund

DOR	Drought of Record
DWSRF	Drinking Water State Revolving Fund
EST	Elevated Storage Tank
ft/ft	feet per foot
ft^2	square feet
FY	fiscal year
GBRA	Guadalupe-Blanco River Authority
GCDs	groundwater conservation districts
GMA	Groundwater Management Area
gpm	gallons per minute
LNRA	Lavaca-Navidad River Authority
mg/L	milligrams per liter
MGD	million gallons per day
mgd	million gallons per day
msl	mean sea level
O&M	operations and maintenance
OCS	off-channel storage
psi	pound(s) per square inch
SP	State Participation Program
SWIFT	State Water Implementation Fund for Texas
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TDS	total dissolved solids
TWDB	Texas Water Development Board
UIC	Underground Injection Control
Victoria CGCD	Victoria County Groundwater Conservation District
WIF	Water Infrastructure Fund
WTP #3	Water Treatment Plant No. 3 (City of Victoria)
WTP #4	Water Treatment Plant No. 4 (City of Victoria)
WTP	Water Treatment Plant

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Summary Report

1 Background and Introduction

The ongoing drought has had a significant impact on water utilities, wholesale water providers and industries, including those within the Gold Crescent Region of Texas, centered on the City of Victoria. During the last fifty years, water providers within the region have developed a diverse inventory of surface water and groundwater supply sources, but meeting future water demand requirements will be challenging as municipal and industrial use continues to increase, even during periods of drought.

In order to address these issues in a strategic manner, a group of water providers and users in the region joined together to evaluate the potential for using Aquifer Storage and Recovery (ASR) and off-channel storage (OCS) as water management strategies. The evaluation focused on the use of ASR and OCS projects to stretch existing water supplies and improve reliability, especially during periods of severe drought. The focus of the evaluation was to maximize the efficient use of existing surface water rights in the Guadalupe River Basin.

For this current evaluation effort, the Study Area consisted of Victoria, Jackson and Calhoun Counties. The study Participants included:

- City of Victoria (Victoria or the “City”)
- Lavaca-Navidad River Authority (LNRA)
- Victoria County Groundwater Conservation District (Victoria CGCD)
- Guadalupe-Blanco River Authority (GBRA)
- Port of Victoria

The purpose of this ***Summary Report*** is to document the initial feasibility assessment of ASR and OCS as water management strategies for the Study Area. This ***Summary Report*** is organized as follows:

- Sections 2 through Section 10 address the ASR evaluation that is discussed in detail in a separate report that is **Appendix A** to this Summary.
- Section 11 and Section 12 address the infrastructure requirements for Victoria (including OCS) and project funding options that are discussed in detail in the separate report that is **Appendix B** to this Summary.

This regional evaluation project was partially funded by a Regional Facility Planning Grant from the Texas Water Development Board (TWDB). Victoria was the applicant for the grant. The City’s application was in response to a Request for Proposals published in the *Texas Register* on October 5, 2012.

2 ASR Workshop and Participant Objectives

The ASR segment of the project began with an ASR workshop to acquaint all of the Participants with ASR technology, the disciplines required to plan and implement an ASR project, and the approximately 26 applications of ASR being used around the world. During the September 12, 2013 ASR Workshop, the study team discussed potential ASR applications that might be beneficial for each Participant, with emphasis on the priorities of Victoria and GBRA where the current sources of treated water and primary potential storage sites are located. Subsequently, LNRA provided a list of the applications most appropriate to Jackson County where the study focused on addressing the fundamental question of whether the aquifer formations in the county are conducive for ASR storage.

The prioritized ASR applications identified by Victoria include:

1. Seasonal storage to meet peak demands
2. Long-term storage to increase reliability during a drought
3. Deferring expansion of the City's Water Treatment Plant (WTP) or construction of a second WTP
4. Emergency storage for use during severe flooding or other service interruptions
5. Reduction in disinfection by-product (DBP) concentrations

The prioritized ASR applications identified by GBRA in Calhoun County include:

1. Seasonal storage to meet peak demands which would serve to delay expansion of the Port Lavaca WTP
2. Emergency storage for use during hurricanes and other similar events
3. Long-term storage
4. Reduction in DBP concentrations

The prioritized ASR applications for LNRA in Jackson County include:

1. Long-term storage to serve as a drought management tool
2. Seasonal storage to supplement existing supplies
3. Emergency storage for use during events that could interrupt deliveries through LNRA's raw water pipeline systems.

3 Water Supply Reliability

For this evaluation project, water supply reliability is defined in terms of the number of days during a repeat of the Drought of Record (DOR) that water system demands can be fully met, as a percentage of the total number of days during the DOR. For the ASR modeling and analysis the period of record from January 1, 1940 to December 31, 2012 was selected. This period was selected because it included the DOR for the Study Area, which extended from 1947 to 1957, as well as one of the driest single years on record (2011).

With adequate ASR capacity, it is reasonable to expect to achieve 100 percent reliability, in terms of both water quantity and water quality. Without ASR, surface water storage or a supplemental groundwater source, utility systems that are dependent on run-of-river water supplies are unlikely to achieve 100 percent reliability. For an ASR system, achieving water quantity reliability entails having sufficient water volume in storage (the "Target Storage Volume" or TSV) and installed ASR well recovery capacity so that peak day demands can be met during the DOR. The TSV is the sum of the volume of stored water that will be recovered for use, plus a buffer zone volume that is left in the aquifer to separate the stored water from the native groundwater. TSV is discussed in more detail in Section 7.1.1 of Appendix A. Water quality reliability entails having sufficient water stored prior to the DOR so that recovered water quality from ASR wells meets drinking water standards throughout the drought without further treatment (other than re-disinfection to restore the required chorine or chloramine residual).

4 Raw Water Supply Sources for Victoria and GBRA

The Participants agreed that this evaluation would focus on the water available for potential ASR storage from existing run-of-river water rights. Under current Texas Commission on Environmental Quality (TCEQ) regulations, water from surface water sources must be treated to drinking water standards prior to recharge in an ASR well. For this study, Victoria's raw water is treated at the Victoria WTP. For GBRA, raw water is treated at the Port Lavaca WTP.

Victoria owns seven water rights permits or Certificates of Adjudication (COA) from TCEQ which total approximately 27,000 acre-feet per year (AFY). The priority dates range from 1918 to 1993. The largest permit (Permit No. 5466B for 20,000 AFY) has the most junior priority date. Because of the priority dates and/or the special conditions in the permits and COAs, the Victoria water rights are not reliable during a repeat of the DOR. **Table 4-1** in Appendix A summarizes the seven water rights, the priority dates, the quantity available and other information.

GBRA owns or jointly owns nine senior water rights totaling over 175,500 AFY of authorized diversions. The priority dates range from 1941 to 1952. For the purposes of this feasibility study, the study team analyzed the potential for ASR as a management strategy assuming that all of the raw water needed to meet system demands would be diverted and treated under GBRA's most junior water right (COA No. 5178). Using this approach provides an extremely conservative assessment of supply options for GBRA, even during a repeat of the DOR. In reality, GBRA can supply the Port Lavaca WTP with its more senior COAs which provide a "firm" supply during a repeat of the DOR.

5 Raw Water Supply Source for Port of Victoria/Victoria Navigation District

The Victoria County Navigation District (the "Navigation District") retained from a water rights sale to Victoria the non-consumptive portion of TCEQ Permit No. 3606. The permit provides for the Navigation District to construct a 132-acre foot reservoir in order to divert for non-consumptive industrial purposes up to 5,000 AFY. All of the diverted water must be returned to the Victoria Barge Canal, with no allowance for consumptive uses such as evaporation. The off-channel reservoir site is owned by the Port of Victoria, but the reservoir has not yet been constructed. The permit is a relatively junior water right, having a priority date of July 10, 1978.

Given the non-consumptive requirements of the permit, it cannot be used as a source of supply for treatment and storage in an ASR wellfield. However, water recovered from ASR storage at another location could serve as a viable alternative supply so that the Navigation District and Port of Victoria can comply with the terms of the permit.

6 Hydrogeology

The hydrogeology of potential ASR storage sites within the Study Area are discussed in Section 6 of Appendix A. The focus of the technical groundwater evaluation is on the characteristics that are most relevant to an ASR project. These most important characteristics include: the size, continuity and permeability of sand beds; the continuity and thickness of clay beds; the direction, magnitude and temporal consistency of the hydraulic gradient; the location of existing wells, their expected pumping rates and their potential to impact an ASR wellfield; potential sources of contamination such as waste injection wells; and overall water quality. **Figure 6-1** shows the three specific areas considered for ASR storage in this feasibility study. These three locations were selected because of their proximity to existing water treatment and supply infrastructure and/or their proximity to potential users of the stored water.

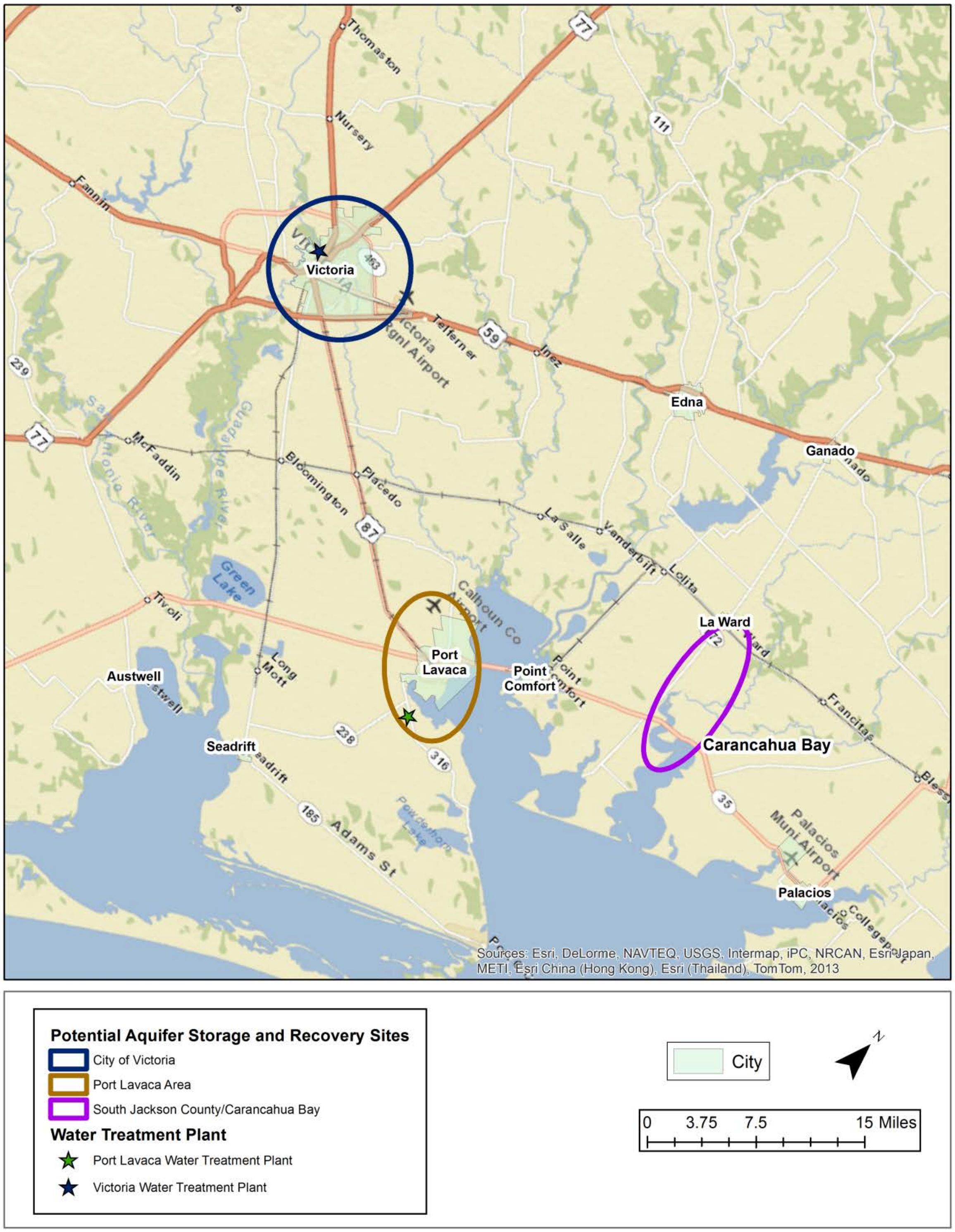

Figure 6-1. Location of Potential Aquifer Storage and Recovery Sites

All three of the potential ASR sites overlie the Gulf Coast Aquifer System. In Appendix A, **Table 6-1** shows the stratigraphy of the Gulf Coast Aquifer in the Study Area. The primary formations of interest are the Beaumont, Lissie and Willis geologic units of the Chicot Aquifer; and the Upper Goliad geologic unit of the Evangeline Aquifer.

The evaluation concluded that at all three sites, the hydrogeology is conducive to successful implementation of an ASR project. A primary reason for the suitability of the sites is the sandy deposits that comprise the aquifer formations in the area. The study team's analyses of the lithologic sequences indicate that sand beds with thicknesses greater than 40 feet are prevalent. Based on analyses of transmissivity values from aquifer tests, the thicker sand beds in the formations typically have hydraulic conductivity values between 8 ft/day and 40 ft/day, which translate into transmissivity values between 320 ft^2/day and 1,600 ft^2/day for a 40-foot thick sand bed. Application of the Theis solution for pumping groundwater from deposits within this transmissivity range indicates sustainable pumping rates between 160 gpm to 800 gpm for a pressure head of about 200 feet (86.7 psi) and a single 40-foot sand bed. Two or more sand layers may be screened in a single ASR well, thereby achieving goals for acceptable well recharge and recovery rates, and associated pressure and drawdown.

For each of the three sites the following five topics are discussed in Appendix A: 1) targeted geological formation; 2) frequency and thickness of sand beds, 3) potential migration of the injected water; 4) adverse impacts from existing wells, and 5) water quality.

The following paragraphs summarize the characteristics for each of the sites.

6.1 City of Victoria

One of the most attractive locations for ASR wells in Victoria is near the Victoria WTP, but at locations away from any municipal wells that will be used by the City on a regular, continuing basis. Any uncertainty about the impact of municipal wells is manageable because the pumping of these wells is within Victoria's control. The aquifer properties of the Upper Goliad Formation underlying the City are characterized with a high level of confidence as a result of transmissivity estimates from 15 aquifer tests, consistency in the lithology and sand bed profiles from 14 geophysical logs, and measurements of water quality.

In Victoria, the targeted formation is the Upper Goliad Formation at approximately -200 ft msl to -1,000 ft msl. Sand beds with thicknesses of at least 40 feet are prevalent. ASR wells would likely be screened in the middle to lower sections of the Formation.

6.2 GBRA/Calhoun County

One of the attractive locations for ASR wells in Calhoun County is between the city of Port Lavaca and GBRA's Port Lavaca WTP. Among the positive features of this site are a low potential for groundwater migration, primarily as a result of the low regional gradients. Based on the lithology, the target zone for injection will likely be between -400 ft msl and -1,100 ft msl. This vertical interval intersects three formations: the lower Lissie Formation, the Willis Formation, and/or the Upper Goliad Formation. The targeted zones are characterized by changing conditions that are depth-dependent. Conditions that are expected to change with depth include total dissolved solids (TDS) concentration, the frequency and permeability of the sand beds, and the height of the water column above the top of the screen.

6.3 Southern Jackson County

The investigation of southern Jackson County was performed without a preferred ASR storage location such as a WTP or a potable water distribution system. There are numerous suitable sites for ASR in southern Jackson County, particularly in the vicinity of Carancahua Bay. Among the positive features of this area are a low potential for groundwater migration, primarily as a result of the low regional gradients, and a relatively well-characterized lithology and stratigraphy. The targeted interval for ASR wells is between -300 ft msl and -1,050 ft msl. This vertical interval intersects three formations: the lower Lissie Formation, the Willis Formation, and/or the Upper Goliad Formation. The targeted zones are characterized by changing conditions that are depth-dependent. Conditions that are expected to change with depth include TDS concentration, the frequency and permeability of the sand beds, and the height of the water column above the top of the screen.

6.4 Port of Victoria

As a result of the favorable hydrological conditions in the Study Area, the potential ASR sites may be expanded over time beyond the three discussed above. Among the locations where ASR may prove beneficial is near the Port of Victoria's property near the Victoria Barge Canal. A review of the hydrogeologic information in the vicinity indicates that the Port's property has attractive conditions that make it conducive to ASR storage. There are numerous sand beds in the Chicot and Evangeline aquifers between the elevations of -200 ft msl and -1,300 msl. Resistivity profiles indicate that the TDS concentrations are less than 1,500 mg/L above -1,300 ft msl. Other favorable conditions include a relatively flat hydraulic gradient of about 0.0003 ft/ft (1.5 ft/mile), no evidence of significant pumping in the vicinity, and no Class II injection wells within several miles.

7 ASR Modeling and Preliminary Basis for Design

For assessment of ASR feasibility, the study team prepared spreadsheet models for both the Victoria and the GBRA storage locations. The purpose of the models was to provide a tool for determining the feasibility, conceptual design and cost of the ASR facilities needed to reliably meet each entity's projected demands, while remaining consistent with the underlying water rights. The ASR models compared daily water availability and daily water demand in order to determine how much water must be stored in an ASR wellfield, and what recharge and recovery rates are required. The needed recharge and recovery rates determine the required number and size of ASR wells. For both Victoria and GBRA, seven options were evaluated using the model for each entity. These options represented a range of baseline water demands and operating scenarios.

Historic daily water use data were provided by Victoria and GBRA. Maximum day, minimum day and average daily water demands for each year are summarized in Appendix A in **Table 3-1**. The year 2011 was initially selected as a conservative "base year" for water demand projections because it was a very dry year. For each day during the "base year," the projected 2040 demand was estimated by multiplying the demand for that day by a factor of 1.26, corresponding to a projected increase in water demand of 8 percent per decade. The 8 percent per decade demand forecast was recommended by Victoria. For consistency, it was also used for GBRA.

A linear increase in water demand was assumed for each year between 2014 and 2040. After 2040 daily water demand was assumed to remain the same as in 2040. This provided the opportunity to evaluate storage volume requirements to ensure water supply reliability during the DOR and a hypothetical study period that excluded the DOR.

As the ASR model analysis proceeded, it became evident that the base year projection using 2011 tended to overestimate the ASR facilities required, the associated TSV and the number of years required to achieve the required TSV. Accordingly, some of the alternative options used a more typical base year (2008). Projections to 2040 from this alternate base year also utilized the same 1.26 factor and the same linear increase in water demand.

Tables 7-1 and **7-2** in Appendix A summarize the results of the ASR modeling for Victoria and GBRA, respectively. For each option, the tables show: the WTP size; the storage volumes needed to reliably meet the projected demands; the minimum ASR recharge and recovery capacities (in MGD) needed to meet the projected demands; and the maximum number of continuous days of recharge and recovery during the study period.

The results summarized in these two tables and the hydrogeologic characteristics in the storage sites (discussed in Section 6 above and in Appendix A) formed the basis for the conceptual design of ASR wellfields for Victoria and GBRA. These conceptual designs were used for the estimates of probable cost discussed in Section 8 below.

8 Costs and Economics

8.1 Cost of Stored Water

In order to estimate the cost to treat and store potable water in an ASR wellfield, operations and maintenance (O&M) expenses were compared to the quantity of water produced (or to be produced) in the same time period. The study team analyzed actual FY 2013 O&M expenses for the Victoria WTP, and FY 2014 budgeted O&M expenses for GBRA's Port Lavaca WTP. The actual volume of treated water produced was used to calculate the unit cost of stored water for Victoria, and the water projected to be produced was used to calculate the unit cost of stored water for GBRA. The objective of this analysis is to understand the "marginal" cost for producing and treating additional surface water from the Guadalupe River at the Victoria WTP and at the Port Lavaca WTP for ASR storage and subsequent recovery.

The O&M cost analysis showed that the cost to store available water in an ASR wellfield from the Victoria WTP is about $0.42 per 1,000 gallons, or $136 per AF. The cost to store available water in an ASR wellfield from the Port Lavaca WTP is about $0.66 per 1,000 gallons, or $214 per AF. The higher cost at the Port Lavaca WTP is primarily due to: the need for one additional plant operator in order to make use of the available plant capacity on a 24/7 basis; and the GBRA Canal System delivery charge for transporting raw water from the Guadalupe River to the WTP. If the additional operator is not needed at the Port Lavaca WTP, the marginal cost for the Port Lavaca WTP would be about $0.58 per 1,000 gallons, or $188 per AF.

8.2 Construction Costs

In Appendix A the estimates of probable capital (construction) cost are based on the ASR modeling and preliminary basis for design described in Section 7. The basis for design for Victoria and GBRA are shown below in **Table 8-1** and **Table 8-2**, respectively. The feasibility study-level cost estimates are considered to be Association for the Advancement of Cost Engineering (AACE) Class 4 (low range of -15 percent to -30 percent, and high range of +20 percent to +50 percent). The study team used costing methods comparable to those used for the TWDB regional planning process, augmented with actual information from recent ASR projects.

Table 8-1. Victoria ASR – Basis for Design Cost Estimation

		Location(s)	Well Construction							Original
			Casing Depth (ft)	Casing Dia. (in)	Screen (ft)	Screen (in)	Bottom of Well (ft)	Recharge Rate (gpm)	Recovery Rate (gpm)	Pump Test (gpm)
Phase 1	**Feasibility Assessment**									
Phase 2	**Test Well Program**									
One new ASR well		Victoria SWTP	450	20	240	12	1,000	850	1,750	
Retrofit 1 existing well		WTP#3 Well 14	435	18	239	10	1,017	800	1,400	1,560
One storage zone monitoring well		SWTP	300	6	200	6	800	-	-	
Two Chicot Aquifer monitoring wells		SWTP, WTP#3	70	4	30	4	100	-	-	
Continuous wireline core hole		SWTP					1,000			
Phase 3	**ASR Wellfield Development**									
Nine new ASR wells		SWTP	450	20	240	12	1,000	850	1,750	
Retrofit 5 existing wells		WTP#3 Well 15	420	18	254	10	1,034	800	1,400	1,670
		WTP#3 Well 16	420	18	280	10	1,010	800	1,400	1,557
		WTP#3 Well 17	420	18	181	10	828	800	1,400	1,529
		WTP#3 Well 18	545	18	263	10	1,036	800	1,400	1,529
		WTP#3 Well 19	450	18	270	10	1,068	800	1,400	1,520

Table 8-2. GBRA ASR – Basis for Design Cost Estimation

		Well Construction						
		Casing Depth (ft)	Casing Dia. (in)	Screen (ft)	Screen (in)	Bottom of Well (ft)	Recharge Rate (gpm)	Recovery Rate (gpm)
Phase 1	**Feasibility Assessment**							
Phase 2	**Test Well Program**							
Three ASR Wells		300	12	150	6	500	130	300
		400	12	150	6	700	130	300
		600	12	150	6	1100	130	300
Three storage zone monitoring wells		300	6	150	6	500	0	0
		400	6	150	6	700	0	0
		600	6	150	6	1100	0	0
Three shallow monitoring wells		50	6	20	4	100	0	0
Four continuous wireline core holes						1,100		
Phase 3	**ASR Wellfield Development**							
Twelve ASR wells		To be determined						
Phase 4	**ASR Wellfield Expansion**							
Fifteen ASR wells		To be determined						

A summary of the estimated cost for Victoria is shown in **Table 8-2** in Appendix A. The total construction costs for the Victoria ASR system are estimated to be $14.5 million. The total project costs, including construction, engineering, permitting, environmental studies, land acquisition, interest during construction and contingency expenses are estimated to be $21.1 million in March 2014 dollars (including the Phase 2 testing program). The estimated total annual cost for the ASR project (including debt service, O&M expenses and pumping energy cost) is $1.5 million. This would provide 25 MGD of ASR recovery capacity and 18 MGD of recharge capacity, and would firm up Victoria's run-of-river water rights through a repeat of the DOR. These capital cost estimates do not include the marginal cost of stored water that is discussed above in Section 8.1.

In Appendix A the summary of GBRA's estimated capital costs is shown in **Table 8-4**. The total construction costs for the GBRA Port Lavaca ASR system are estimated to be $22.1 million. The total project costs, including construction, engineering, permitting, environmental studies, land acquisition, interest during construction and contingency expenses are estimated to be $32.6 million in March 2014 dollars (including the Phase 2 testing program). The total annual cost for the ASR project (including debt service, O&M expenses and pumping energy cost) is $2.4 million. ASR recharge capacity at build-out would be 5 MGD. These capital cost estimates do not include the marginal cost of stored water that is discussed above in Section 8.1, or any improvements needed to get the Port Lavaca WTP up to its rated capacity.

9 Permitting, Environmental and Institutional Considerations

Section 9 of Appendix A discusses the authorizations that will be required to permit one or more ASR systems for the Participants and the institutional issues related to implementation of those systems. The following paragraphs summarize the information found in Appendix A.

Within the Study Area, the primary regulatory agencies include TCEQ, the Victoria County Groundwater Conservation District, the Calhoun County Groundwater Conservation District and the Texana Groundwater Conservation District (Jackson County). All three groundwater districts are located within Groundwater Management Area (GMA) 15.

ASR wells typically used for both recharge and recovery are subject to permitting requirements based upon the source of water to be injected and the aquifer in which the water is to be stored. The primary regulatory requirements relate to TCEQ's administration of underground injection of water, and surface water diversion permitting; and the regulation of recharge and recovery (pumping) of water by the groundwater districts listed above.

As this report is being prepared, individual legislators and groups (including the Texas Water Conservation Association) are working on draft legislation to be introduced in the Texas Legislature during the 2015 session. The purpose of this proposed legislation is to enhance the ability of water utilities to implement ASR projects and to stimulate the development of such projects.

9.1 TCEQ: UIC Class V Injection Well Permitting

Aquifer storage that is accomplished using an injection well is regulated by the federal Underground Injection Control (UIC) Program administered by TCEQ. A well that is used to inject water for storage in an ASR project is defined as an "Aquifer storage well" and is classified as a Class V Injection Well. Accordingly, all ASR injection wells must be permitted pursuant to Chapter 27, Texas Water Code, and Chapter 331, Title 30 of the Texas Administrative Code.

9.2 TCEQ: Surface Water-Related Authorizations

The source of the water to be stored in the proposed ASR systems would be surface water diverted and treated under COAs and permits from TCEQ. Using State-owned surface water as the supply source for an ASR project triggers additional statutory requirements under Chapter 11 of the Texas Water Code, as well as applicable TCEQ rules. Under current regulations, the Victoria and GBRA water rights must be amended to authorize full-scale use of the water for injection and recovery. In order to amend the water rights, Victoria and GBRA must submit to TCEQ the information required for a Class V injection well, including a map or plat showing the location of the injection facility and the aquifer in which the water will be stored.

9.3 Groundwater Conservation Districts

As stated above, there are three groundwater conservation districts (GCDs) within the Study Area. The districts are consistent with the county boundaries of Victoria, Jackson and Calhoun Counties. Some of the rules related to administration, application procedures and requirements, and hearing procedures can be expected to apply to the implementation of ASR wells and wellfields. However, at this time none of the GCD technical rules specifically address ASR or artificial recharge. Therefore, it will be important for the Participants to work closely with each of the districts to amend and amplify the rules in a manner that achieves the GCDs' objectives while facilitating the implementation of ASR.

9.4 Environmental Issues and Permitting

The major environmental issues and key considerations related to ASR include the following:

- Native groundwater quality is an important consideration. The number and condition of the oil and gas brine disposal wells in portions of the Study Area are a concern. Water quality will be an important consideration, and sampling should be one of the tasks in the next phase of implementing an ASR project.
- Issues related to TDS, iron and manganese in the Gulf Coast Aquifer can be an important consideration. Again, additional water quality sampling will be an important consideration in the next phase of any project.
- Based on this preliminary evaluation, it appears that with proper design of facilities and O&M practices, viable ASR projects can be implemented in the Study Area.

Because ASR wells and wellfields have small footprints and limited environmental impacts, the major permitting issues related to an ASR project typically involve the construction of pipelines to and from the wellfield. The environmental permitting requirements that could apply to such pipelines are discussed in detail in Section 9 of Appendix A.

10 Conclusions and Recommendations

10.1 Hydrogeology Conclusions

The hydrogeologic investigation during this first-phase feasibility study determined the viability of implementing an ASR wellfield at all three proposed locations.

The hydrogeologic conditions near Victoria are known to a high level of confidence as a result of the City's installation, testing, and operation of fifteen high-capacity municipal wells, and Victoria CGCD's well registration and well monitoring programs. The hydrogeologic characteristics are well suited for ASR facilities. Among the favorable ASR sites are several near the Victoria WTP. Near the treatment plant, there is no evidence that the recharge, storage, and recovery of stored water would be hindered by potential sources of contamination or pumping from existing wells.

The hydrologic conditions near Port Lavaca are known to a moderate level of confidence. Within the vicinity of the Port Lavaca WTP there are locations where surface contamination sources from nearby aquaculture operations and/or shallow groundwater pumping could potentially cause problems with efficient ASR operations. As a result, the proposed ASR facilities are located close to the Port Lavaca WTP, but away from the areas of shallow groundwater pumping and possible contamination.

The availability of hydrologic data in Jackson County varies but there are several areas where the conditions are known with a moderately high level of confidence. One of these areas is in the vicinity of Carancahua Bay. Among the positive features of this possible site are a low potential for the migration of stored water and a relatively well-characterized lithology and stratigraphy.

10.2 Victoria ASR Wellfield Conclusions

The following paragraphs summarize the major conclusions for the Victoria portion of the Study Area. A full list of the conclusions and a more detailed discussion are found in Sections 7 and 10 of Appendix A.

- Victoria's ASR objectives can be met utilizing the existing water treatment plant's rated capacity of 25.2 MGD.
- The volume of stored water that needs to be recovered during a repeat of the DOR ranges from 4,600 AF to 82,900 AF, depending upon the assumptions underlying each of the options.
- The ASR TSV (which includes the buffer zone water) that needs to be achieved in order to meet seasonal peaking objectives is 53,900 AF, however this volume would be inadequate for a repeat of the DOR. The total storage volume required to meet demands during a repeat of the DOR ranges from 9,300 to 168,100 AF, depending on the option.
- The ASR wellfield design capacity for all options is controlled by the required recharge capacity, which ranges between 18.3 MGD and 26.0 MGD.
- The City's five goals for an ASR program can be achieved.

An ASR wellfield is viable in the area of Victoria. Based upon the summary of ASR model results shown in **Table 7-1** of Appendix A, a preliminary basis of design for the ASR wellfield is to provide a recharge capacity of 19.0 MGD. This will require approximately 16 ASR wells. The potential ASR well locations and approaches include: Victoria WTP; Water Treatment Plant No. 3 (WTP #3); conversion of selected existing production wells to ASR wells; construction of new ASR wells at new sites, and construction of new ASR wells at currently-abandoned production well sites. The recovery capacity of these wells will exceed the minimum required recovery rate since the critical factor controlling ASR facilities design capacity for Victoria is the recharge rate.

10.3 GBRA ASR Wellfield Conclusions

Various options were evaluated for ASR development in Calhoun County, primarily in the vicinity of GBRA's Port Lavaca WTP. In Appendix A, Section 7.2.1 describes the assessment of options related to a repeat of the DOR utilizing only GBRA's most junior water right. In reality, GBRA can provide adequate raw water to the Port Lavaca WTP during a repeat of the DOR using its more senior certificates of adjudication. Therefore, the ASR analysis in this report is extremely conservative.

Subject to additional data collection and testing, an ASR wellfield appears to be viable at the Port Lavaca WTP. ASR wellfields are also viable in the Study Area west-northwest of Port Lavaca and between the Port Lavaca WTP and Bloomington. Such wellfields should be able to meet GBRA's projected 2040 water demands with 100 percent reliability and at relatively low cost compared to other treated water supply alternatives. Starting an ASR program at the Port Lavaca WTP, rather than more remote locations with somewhat better hydrogeologic characteristics, is justified because the concept eliminates the right-of-way, pipeline and pumping costs associated with such a remote location. More distant ASR wellfields with less challenging hydrogeologic conditions may be very viable if future growth in water demand occurs between Port Lavaca and Victoria.

The following paragraphs summarize the major conclusions for the GBRA/Calhoun County portion of the Study Area. A full list of the conclusions and a more detailed discussion are found in Sections 7 and 10 of Appendix A.

- GBRA's ASR objectives can be met utilizing the existing treatment plant's rated capacity of 6.1 MGD.
- The volume that needs to be recovered during a repeat of the DOR ranges from 9,300 AF to 14,500 AF, depending upon the assumptions underlying each of the options.
- The ASR TSV (including the buffer zone water) required to meet demands during a repeat of the DOR ranges from 18,500 AF to 29,100 AF.
- The ASR wellfield design capacity for all options is controlled by the required recharge capacity, which ranges from 4.7 MGD to 6.1 MGD. It is likely that ASR wellfield recharge design capacity would be about 5.0 MGD.
- Further investigation of groundwater production at a nearby aquaculture operation is needed prior to confirming the viability of the Port Lavaca WTP property as an ASR wellfield site. If a significant cone of depression already exists in the sand intervals that are suggested for ASR storage, it may be necessary to relocate the ASR wellfield to another site.
- It appears that GBRA's four goals for an ASR program in Calhoun County can be achieved.

An ASR recharge capacity of 5.0 MGD was selected as the basis of design for the GBRA facilities. This will require approximately 30 wells due to the hydrogeologic conditions in the area. Hydrogeologic conditions in the Port Lavaca area are deemed to be suitable for ASR, although they offer more challenges than the conditions in the Victoria area. The suggested location for a second phase assessment is at the GBRA Port Lavaca WTP, rather than a more remote location.

10.4 General Recommendations

Because of the regulatory issues discussed in Section 9 of Appendix A, the first step toward implementation of ASR systems in the Study Area should be early and continual coordination with the applicable GCDs in Victoria, Jackson and Calhoun Counties. Rules will need to be written and/or amended in order to get the required permits to drill the initial demonstration wells and to implement an ASR project.

Eventually the surface water rights owned by Victoria and GBRA must be amended to authorize use of the water for recharge and recovery, but a temporary authorization for the Phase 2 testing programs may not be necessary. Regulations in 30 TAC §295.21(b) state that a water right permit is not required for the first phase of an ASR project that proposes temporary storage of appropriated surface water in an aquifer for testing, subsequent retrieval and beneficial use if the diversion and purpose is covered by an existing water right. A clarifying discussion with TCEQ should be one of the first steps in Phase 2 of any ASR project in the Study Area.

10.5 City of Victoria Recommendations

If a decision is made to proceed with further investigation of ASR, Victoria should implement an ASR test program at two sites: the Victoria WTP; and at WTP #3. This test/demonstration program would include construction, testing and operation of one new full-size ASR well at the Victoria WTP and retrofitting of one existing production well at or near WTP #3. The first phase of ASR wellfield construction would represent approximately 10 percent of the planned ultimate scale of development.

The first step in this demonstration program would be a continuous wireline core obtained at the Victoria WTP to a depth of 1,100 feet. This core analysis would provide good understanding of the depths and thicknesses of sand and clay layers beneath the sites, and their associated geochemical and geotechnical properties. The program would also include two monitor wells, supplementing monitoring at other existing production wells in the area surrounding each location. The number and location of ASR wells and monitor wells may be adjusted based upon results of the initial core hole at the Victoria WTP site. The estimated cost for the Phase 2 demonstration program is $3.6 million. This initial cost is included in the estimate of probable project costs discussed in Section 8 above.

Operating experience gained with these first two ASR wells would provide a basis for subsequent design of wellfield expansion facilities. Victoria should also continue coordinating with the Port of Victoria so that potential opportunities for joint use of the City's water supply can be explored.

10.6 GBRA Recommendations

If a decision is made to proceed with further investigation of ASR viability, GBRA should implement an ASR test/demonstration program at the Port Lavaca WTP. Continuous wireline cores would first be obtained at each property corner to a depth of 1,100 feet, providing good understanding of the depths and thicknesses of sand and clay layers beneath the site, and their associated geochemical and geotechnical properties. The number and location of ASR wells and monitor wells may be adjusted based upon results of these initial core holes.

Following confirmation with the corings, the Phase 2 program would include construction and testing of three full-size ASR wells. The three wells would be constructed in sand intervals between 300 and 500 feet, 400 and 700 feet, and 600 to 1,100 feet, respectively. The first phase of ASR wellfield construction would represent about 10 percent of the planned ultimate scale of development. The estimated cost for the Phase 2 demonstration program using permanent facilities is $6.7 million. If temporary piping is used, the total estimated cost for the testing program is $4.9 million. The higher initial cost is included in the estimate of probable project costs discussed in Section 8 above.

The possible locations for the ASR wells would be at or near three of the four property corners at the Port Lavaca WTP. The test program would also include approximately five monitor wells, needed to provide a basis for design of expanded ASR wellfield facilities at this site. Three of these monitor wells would be close to three of the ASR wells. One monitoring well would be constructed at the remaining property corner, and one additional monitoring well would be constructed near the center of the property. Operating experience gained at this site with the first three ASR wells would provide a basis for subsequent design of wellfield expansion facilities at this site or other locations.

11 Infrastructure Assessment for Victoria ASR Feasibility

11.1 City of Victoria – Public Water System Infrastructure Assessment

A system of ASR wells serving Victoria would be located at sites that allow easy hydraulic integration of the ASR wells into the City's existing water distribution system, by requiring minimal infrastructure improvements. Location of the ASR system at the Victoria WTP, WTP #3, and WTP #4 would permit the utilization of existing storage tanks and service pumps. **Figure 1.1** in Appendix B shows the City of Victoria water distribution system and the general location of potential areas for ASR wells.

The Victoria WTP is located on the west side of the city near the Guadalupe River. Under normal operating conditions the River Water Pump Station transfers raw water from the Guadalupe River to the OCS ponds located on the southwest side of the river. The River Water Pump Station also has the capability of pumping directly to the Victoria WTP. There is also a Raw Water Pump Station with the capability to pump water from the OCS ponds to the Victoria WTP. A schematic of the City's treatment and pumping systems is shown in **Figure 1.2** of Appendix B.

At the Victoria WTP the High Service Pump Station pumps treated water to Elevated Storage Tank No. 4 (EST #4) and to EST #6 in the High Pressure Zone of the water distribution system. The Medium Service Pump Station pumps treated water to WTP #3, located in the Low Pressure Zone. Service pump stations are also located in the distribution system at WTP #3 which serves the Low Pressure Zone and to WTP #4 that serves the High Pressure Zone.

As described in Section 7.0 above and in detail in Appendix A, an ASR system for Victoria was modeled for both the base year conditions (represented by the year 2008) and dry year conditions (represented by the year 2011). The simulations were carried out through the year 2040 and assumed a water demand increase of 8 percent per decade. Based on these demands a comparison between the dry year condition of 2011 and 2040, and Victoria's existing treatment and pumping capacities was performed. Pump stations were compared based on their firm pumping capacity (i.e., pumping capacity with the largest unit out of service). **Table 11-1** below shows the results of these comparisons.

Based on a comparison of the water demands and the pumping and treatment capacities, the main areas of concern for Victoria are the firm pumping capacities of the Raw Water Station and the combined firm pumping capacities of WTP #3 and WTP #4. When compared to the 2040 maximum day demand of 24.888 MGD, these facilities' firm pumping capabilities fall just below that maximum day demand. At some point in the future and prior to 2040, it is recommended that the City increase the firm pumping capacity of the Raw Water Pump Station and the combined capacities of WTP #3 and WTP #4 beyond the 2040 maximum day demand of 24.888 MGD.

Table 11-1. City of Victoria - Comparison of System Demands vs. Pumping & Treatment Capacities.

	DEMANDS				PUMPING/TREATMENT CAPACITIES				
	2040 MAX DAY	2040 AVG DAY	2011 MAX DAY	2011 AVG DAY	RIVER WATER PUMP STATION[A]	RAW WATER PUMP STATION[A]	SWTP	HIGH SVC + MED SVC PUMPS @ SWTP	SVC PUMPS @ WP #3 + WP #4
gpm	17,283	10,432	13,717	8,279	22,900	16,200	17,500	18,400	15,700
MGD	24.888	15.022	19.752	11.922	32.98	23.33	25.20	26.50	22.61
AFY	27,880	16,828	22,127	13,355	36,940	26,132	28,230	29,681	25,326

Notes:

A. Pump rates based on estimated pump capacities received from City of Victoria staff; as noted by staff these rates may vary depending on river level and the OCS pond levels.

1. Values in MGD for 2011 Max Day and Avg Day are from Table 3-1 in Final Report.
2. 2040 values = 2011 values * 1.26 (as described in the Final Report).
3. Pumping capacities shown are Firm Capacities (pumping with largest pump out of service).
4. Cells in yellow are below 2040 Max Day values.

11.2 City of Victoria – Off-Channel Storage Infrastructure Assessment

Victoria's water system includes OCS opposite the City on the west side of the Guadalupe River. The OCS system includes a total of 11 abandoned gravel pits that are located on the southwest side of the City. These gravel pits are now an integral part of the City's water treatment system, providing for the storage and settling of raw water pumped from the Guadalupe River by the River Water Pump Station. The existing OCS pond system is shown on **Figures 1.3** and **1.4** of Appendix B.

In 2011 Victoria commissioned a consultant to evaluate the OCS ponds. For this 2014 infrastructure assessment, that 2011 study report was reviewed and its recommendations were evaluated as part of this planning effort.

The original study concluded that there is a significant volume in the existing OCS ponds that is currently not readily useful. Connection channels or pipes between the OCS ponds were constructed at elevations too high to allow for the pumping of the entire volume of water stored in the ponds. These issues and the connectivity between the ponds are discussed in more detail in the following paragraphs.

As discussed above, the Raw Water Pump station pumps water from OCS Pond 8 to the Victoria WTP. OCS Pond 8 is connected by a 48 inch diameter pipe to OCS Pond 4. In turn, OCS Pond 4 is connected by an open channel to OCS Pond 3. Together, OCS Ponds 3, 4, and 8 provide a total of approximately 775 AF of "useful" storage, although their total volume is approximately 1,336 AF.

The OCS system also includes ponds that are not currently connected to OCS Ponds 3, 4, or 8. At the present time, when additional raw water is needed, it is necessary for Victoria to use a portable pump to transfer water among these ponds. Victoria most commonly uses OCS Ponds 5, 6, and 7 for this purpose. These three unconnected ponds provide approximately 1,311 AF of additional raw water storage volume.

The ASR Feasibility Report in Appendix A includes different conceptual design scenarios assuming a minimum available OCS storage volume of at least 2,000 AF. It is recommended that improvements be made to the OCS pond system so that it will provide a minimum of 2,000 AF of raw water storage that is accessible to the Raw Water Pump Station at OCS Pond 8 without the need for transfers with a portable pump.

To meet the goal of having 2,000 AF of readily-accessible raw water storage in the OCS ponds, the following recommendations should be implemented as part of any ASR system improvements:

1. The existing channel between OCS Pond 3 and OCS Pond 4 should be lowered. Also, the existing pipe between OCS Pond 4 and OCS Pond 8 should be replaced with a similar diameter pipe installed at the lowest possible elevation between those two ponds.
2. OCS Ponds 5, 6, and 7 should be connected to the existing system to eliminate the need for pumping to get access to the storage. The connection can be accomplished by the installation of a pipe between OCS Ponds 7 and 8, and the construction of connection channels between OCS Ponds 5 and 6, and OCS Ponds 6 and 7.

Based on these recommended improvements, the OCS system would include storage volumes in OCS Ponds 3, 4, 5, 6, 7, and 8 that could be directly pumped by the Raw Water Pump Station. Following the above recommendations would result in the OCS ponds having a total volume of 2,527 AF of usable storage (see **Table 11-2** below for details).

Table 11-2. Off-Channel Storage (OCS) System "Useful" Volumes.

Recommendation #		Storage (AF)
	Existing "Useful" Storage (in OCS Ponds 3, 4, and 8)	775
1.	"Useful" Storage Added to OCS Ponds 3, 4, and 8	441
2.	"Useful" Storage Added by OCS Ponds 5, 6, and 7	1,311
	Total "Useful" Raw Water Storage in OCS System	2,527

The 2011 study included a cost estimate that the connection improvements in OCS Ponds 3, 4, and 8 could be constructed for approximately $0.6 million. The study estimated that the connection of OCS Ponds 5, 6, and 7 could be constructed for approximately $1.6 million. The total construction cost for these recommended improvements would therefore be approximately $2.2 million in 2011 dollars.

11.3 Port of Victoria/Victoria County Navigation District - Infrastructure Assessment

As discussed above in Section 5, the Navigation District has a TCEQ permit that authorizes the diversion of up to 5,000 AFY of water for non-consumptive industrial purposes. The permit requires the use of a 132-AF reservoir to store the diverted water, however at the time this report was finalized the reservoir had not been constructed. The permit also requires that all diverted water be returned to the Victoria Barge Canal after it has been used. Another special condition of the permit includes a requirement that the Navigation District will operate and maintain an alternative source of water supply that has sufficient capacity to compensate for any consumptive use of water.

The Navigation District operates a public water supply system (TCEQ PWS 2350051). The system is classified by the TCEQ as a non-transient, non-community public water system. It consists of two groundwater wells that have a combined rated capacity of 170 gpm (274 AFY). For calendar year 2009 the system actually pumped an average of 5.43 gpm (8.75 AF). Consumptive use of permitted water that exceeds the PWS's capacity places the Navigation District in the position of violating the non-consumptive requirement in its permit. An ASR system could serve as an additional source of reliable supply to meet the stipulations of the TCEQ permit.

At the present time the Navigation District does not own consumptive surface water rights that could be used as a source of supply for treatment and storage in an ASR system. Therefore, instead of developing an ASR system at the Port of Victoria site, an option would be for the Navigation District to obtain from Victoria any water needed to make up for consumptive use of its permit. An ASR system developed by the City would firm up Victoria's water supply thereby creating the opportunity for the Navigation District to purchase reliable water from the City.

In order to deliver water from the City, a water line from Victoria's water distribution system to the Port of Victoria would need to be constructed. This interconnecting pipeline would be approximately 8.7 miles long and would connect to the City's system near the intersection of Port Lavaca Drive and US Highway 59 North. A 16 inch diameter pipeline should allow the interconnection without the need for a booster pump station. The interconnecting line is estimated to cost approximately $4,665,000 in 2014 dollars.

12 Financing Options for Implementation

Financing options for the projects discussed in this ***Summary Report*** can involve several sources, including the public bond market, and state and federally subsidized programs. The following subsections discuss some identified options for funding the proposed projects. This discussion focuses on general terms and conditions of financing because there are numerous factors that can enter into a final loan agreement.

12.1 Public Bond Market

Most of the Participants have financed water improvements using long-term bond financing. The rates and terms of such bond issues are typically negotiated or sold on a competitive basis. The typical term for such loans is 20 to 25 years, and interest rates are based on the credit of the borrower and the prevailing rates for similar types of securities. For Victoria, the loans can be secured through a pledge of ad valorem taxes, utility revenues, or a combination of both taxes and revenues. For the river authorities, the loans must be secured through a pledge of utility revenues.

12.2 Texas Water Development Board

The TWDB offers several financing programs for water-related infrastructure. The TWDB programs include both federally-subsidized interest rate programs and state-supported programs. The federally-subsidized programs include the Drinking Water State Revolving Fund (DWSRF). State-supported programs include the Texas Water Development Fund (DFund) the State Participation Program (SP), the Water Infrastructure Fund (WIF), and the newly-approved State Water Implementation Fund for Texas (SWIFT).

12.2.1 Drinking Water State Revolving Fund

The DWSRF is a federally-subsidized program that reduces interest rates to qualified public agency borrowers that qualify for assistance. Additional loan forgiveness can also be approved for specific “green” initiatives which include energy and water conservation. The interest rate subsidy will reduce the borrowing costs by lowering the interest rates below market rates. Typical loans are for a 20 year term.

Financial assistance from the DWSRF can be utilized for: water treatment facilities, distribution systems, upgrade or replacement of water infrastructure, to address standards from the Safe Drinking Water Act, consolidation of systems, purchasing additional water supply capacity, source water protection projects, and eligible green project reserve components.

12.2.2 Texas Water Development Fund

The DFund is a state-backed program that offers qualified borrowers the same interest rate as the State of Texas. The term of the loan is typically 20 to 30 years with interest rates based on the cost of borrowing by the TWDB. The DFund offers the advantage of being able to fund projects with multiple, eligible water and wastewater related purposes in one loan. This program offers the most flexible eligibility requirements and can be used for multiple purposes including: water supply, water transmission and distribution, water conservation, water quality, flood control and municipal solid waste.

12.2.3 State Participation Program

Under the State Participation Program the TWDB becomes a temporary partner in a regional project when the local sponsor(s) are unable to pay the total debt service for an optimally-sized facility. The TWDB may acquire an ownership interest in both the facilities and the water rights. The project sponsor(s) are required to repurchase the TWDB ownership interest in the project under a repayment schedule that allows for the deferral of principal and interest payments. The amount of funding that is available is dependent on appropriations from the Texas Legislature. Principal and interest payment deferrals are typically for 10 years, with repayment based on simple interest accrued during the deferral period.

12.2.4 Water Infrastructure Fund

The WIF offers state loans for up to 20 years at a subsidized interest rate below the TWDB cost of funds. Loans can be used for the planning, design and construction of projects identified in the State Water Plan. Projects funded by the WIF must be identified strategies in the most recent Plan. The amount of available funding is dependent on appropriations from the Texas Legislature.

12.2.5 State Water Implementation Fund for Texas

The SWIFT program was established by the Texas Legislature and approved by the voters in November of 2013. It is designed to help fund projects in the State Water Plan. Available funding will be allocated based on a point system and will be used as part of an overall funding strategy to implement projects. Eligible projects include conservation and reuse, desalination of groundwater and seawater, building new pipelines, and developing new reservoirs and well fields, as well as other water related projects. By legislative mandate 20 percent of the SWIFT funds must be used for conservation and reuse, and 10 percent must be used for rural communities and agricultural conservation projects.

Appendix A

Victoria Area ASR Feasibility Study

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Victoria Area ASR Feasibility Study
Final Report

July 2014

Prepared for:

Naismith Engineering, Inc

By

INTERA Geosciences & Engineering

ASR Systems

ARCADIS

STATE OF TEXAS
STEVE C YOUNG
GEOLOGY
231
LICENSED
PROFESSIONAL GEOSCIENTIST

Steven C. Young, PG
Texas No. 231

7-11-2014

David Pyne, P.E.
Texas No. 91405

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Acronyms and Abbreviations

µg/L	micrograms per liter
AFY	acre-feet per year
ARCADIS	ARCADIS U.S., Inc.
ASR	Aquifer Storage and Recovery
bgs	below ground surface
CB	Carancahua Bay
cfs	cubic feet per second
CGC GAM	Central Gulf Coast Groundwater Availability Model
City	City of Victoria
COA	Certificates of Adjudication
CSA	Cross-Section A
CSB	Cross-Section B
CV	City of Victoria
DBP(s)	disinfection by-product(s)
DOR	Drought of Record
Eh	measure of the oxidation reduction potential
ft msl	feet mean sea level
ft	feet
ft/ft	feet per foot
ft^2	square feet
GBDS	Gulf Basin Depositional Synthesis
GBRA	Guadalupe-Blanco River Authority
GCD	Groundwater Conservation District
gpm	gallons per minute
K	hydraulic conductivity
LNRA	Lavaca-Navidad River Authority
mg/L	milligram per liter
MGD	million gallons per day
Navigation District	Victoria County Navigation District
OCS	off-channel storage
ORP	oxidation reduction potential
Participants	City of Victoria, Lavaca-Navidad River Authority, Victoria County Groundwater Conservation District, Guadalupe-Blanco River Authority, Port of Victoria
pH	measure of the relative abundance of the hydrogen ion in solution
PL	Port Lavaca
PLWTP	Port Lavaca Water Treatment Plant

ppm	parts per million
Project	Feasibility assessment of ASR as a water management strategy for the Study Area
psi	pounds per square inch
PWS	public water supply
SCi	specific capacity during well injection
SCp	specific capacity during pumping/production
Study Area	Victoria, Jackson and Calhoun Counties
SWAP	Source Water Assessment Program
T	transmissivity
TCEQ	Texas Commission on Environmental Quality
TDS	total dissolved solids
TSR	terminal storage reservoir
TSV	target storage volume
TWDB	Texas Water Development Board
USGS	U.S. Geological Survey
VFD	variable frequency drive
Victoria	City of Victoria
WAM	Water Availability Model
WTP	Water Treatment Plant

Executive Summary

1.0 Background and Introduction

The recent Texas drought has had a significant impact on water utilities, wholesale water providers and industries, including those within the region centered on the City of Victoria, Texas. During the last fifty years, water providers within the region have developed a diverse mix of surface water and groundwater sources, but meeting future water requirements will be challenging as demands continue to grow, especially during periods of drought.

In order to address these issues in a strategic manner a group of water providers and users in the region joined together to evaluate the potential of using Aquifer Storage and Recovery (ASR) and/or off-channel storage (OCS) as water management strategies. The evaluation focused on the use of ASR and OCS projects to stretch existing water supplies, improve reliability and maximize the efficient use of existing surface water rights in the Guadalupe River Basin.

For this current evaluation effort, the Study Area consisted of Victoria, Jackson and Calhoun Counties. The study Participants included:

- City of Victoria (Victoria)
- Lavaca-Navidad River Authority (LNRA)
- Victoria County Groundwater Conservation District
- Guadalupe-Blanco River Authority (GBRA)
- Port of Victoria

The purpose of this report is to document the initial feasibility assessment of ASR as a water management strategy for the Study Area (the "Project"). [OCS is evaluated in a separate report prepared by others.] The Project consisted of assessing the near-term and long-term feasibility of ASR by identifying both technical and non-technical issues, and potential ASR projects within the Study Area. This report includes sufficient information to support any needed regulatory authorizations to develop a demonstration test program in Phase 2 and one or more operational projects in Phase 3.

The report is organized with the following major areas of emphasis:

- A description of the ASR workshop in which the Participants identified their respective ASR objectives.
- The definition of water supply reliability used for the Project.
- The raw water supply sources analyzed in the Project.
- A discussion of the hydrogeology of the Gulf Coast Aquifer within the Study Area and the aquifer's suitability for ASR development.
- A description of the ASR modeling used for developing conceptual ASR designs and cost estimates.

- A discussion of the estimated costs and economics of the potential ASR projects.
- A discussion of the permitting, environmental and institutional considerations.
- Conclusions and recommendations.

2.0 ASR Workshop and Participant Objectives

During an ASR Workshop the study team discussed potential ASR applications that might be beneficial for each Participant, with emphasis on the priorities of Victoria and GBRA where the current sources of supply and primary potential storage locations are located. Subsequently, the LNRA provided a list of the applications most applicable to Jackson County where the study focused on addressing the fundamental question of whether the aquifer formations in the county are conducive for ASR storage.

The prioritized list of ASR applications for Victoria include:

1. Seasonal storage to meet peak demands
2. Long-term storage to increase reliability during a drought
3. Deferring expansion of the City's WTP or construction of a second WTP
4. Emergency storage for use during severe flooding or other events
5. Reduction in disinfection by-product (DBP) concentrations

The prioritized list of ASR applications for GBRA in Calhoun County include:

1. Seasonal storage to meet peak demands which would serve to delay expansion of the Port Lavaca WTP
2. Emergency storage for use during hurricanes and other events
3. Long-term storage
4. Reduction in DBP concentrations

The prioritized list of ASR applications for LNRA in Jackson County include:

1. Long-term storage to serve as a drought management tool
2. Seasonal storage to supplement existing supplies
3. Emergency storage for use during events that could interrupt deliveries through LNRA's pipeline systems.

3.0 Water Supply Reliability

Water supply reliability is defined in terms of the number of days during a repeat of the Drought of Record (DOR) that water system demands can be fully met, as a percentage of the total number of days during the DOR. For this analysis the period of record from January 1, 1940, to December 31, 2012 was selected. This period was selected because it included the

DOR for the Study Area, which extended from 1947 to 1957, as well as one of the driest years on record (2011).

With adequate ASR capacity, it is reasonable to expect to achieve 100 percent reliability, in terms of both water quantity and water quality. Without ASR, OCS or a supplemental groundwater, water systems dependent on run-of-river water supplies are unlikely to achieve 100 percent reliability. Water quantity reliability entails having sufficient water volume in storage (the "Target Storage Volume" or TSV) and installed ASR well recovery capacity so that peak day demands can be achieved during the DOR. The TSV is the sum of the volume of stored water that will be recovered for use, plus the buffer zone volume that is left in the aquifer to separate the stored water from the native groundwater. The TSV is discussed in more detail in Section 7.1.1 of the report. Water quality reliability entails having sufficient water stored prior to the DOR so that recovered water quality from ASR wells meets drinking water standards throughout the DOR, following re-disinfection to restore the required residual.

4.0 Raw Water Supply Sources for Victoria and GBRA

The Participants agreed that this evaluation would focus on the water available for potential ASR storage from existing surface water rights. Under Texas Commission on Environmental Quality (TCEQ) regulations, water from surface water sources must be treated to drinking water standards prior to recharge in an ASR well. For Victoria, the raw water would be treated at the Victoria WTP. For GBRA, the raw water would be treated at the Port Lavaca WTP.

Victoria owns seven permits or Certificates of Adjudication (COA) from TCEQ which total approximately 27,000 acre-feet per year (AFY). The priority dates range from 1918 to 1993. The largest permit (Permit No. 5466B for 20,000 AFY) has the most junior priority date. Because of the priority dates and/or the special conditions in the permits and COAs, the Victoria water rights are not reliable during a repeat of the DOR. Table 4-1 in the report describes the seven water rights, the priority dates, and the diversion information.

GBRA owns or jointly owns nine senior water rights totaling over 175,500 AFY of authorized diversions. The priority rates range from 1941 to 1952. For the purposes of this feasibility study, the study team analyzed the potential for ASR as a management strategy assuming that all of the water would be diverted and treated under GBRA's most junior water right (COA No. 5178). This provides an extremely conservative assessment of supply options, especially during a repeat of the DOR. In reality, GBRA can supply the Port Lavaca WTP from its other COAs during a repeat of the DOR.

5.0 Raw Water Supply Source for Port of Victoria

The Victoria County Navigation District (the "Navigation District") retained from a sale to Victoria the non-consumptive portion of TCEQ Permit No. 3606. The permit provides for the owner to construct a 132-acre foot reservoir in order to divert for non-consumptive industrial purposes up to 5,000 AFY. All of the diverted water must be returned to the Victoria Barge Canal, with no allowance for consumptive use. The off-channel reservoir site is owned by the Port of Victoria, but the reservoir has not yet been constructed. The permit has a priority date of July 10, 1978.

Given the non-consumptive requirements of the permit, it cannot be used as a source of supply for treatment and storage in an ASR wellfield. However, water recovered from ASR storage could serve as a viable alternative supply so that the Navigation District and Port of Victoria can comply with the terms of the permit.

6.0 Hydrogeology

In Section 6 the hydrogeology of the portions of the Study Area containing the potential ASR sites is described, with a focus on the characteristics that are most relevant to an ASR project. The most important characteristics include: the size, continuity and permeability of sand beds; the continuity and thickness of clay beds; the direction, magnitude and temporal consistency of the hydraulic gradient; the location of existing wells, their expected pumping rates and their potential impact on an ASR wellfield; potential sources of contamination such as waste injection wells; and water quality. **Figure ES-1** shows the three specific areas considered for ASR storage in this feasibility study. These three locations were selected because of their proximity to existing water treatment and supply infrastructure and/or their proximity to potential users of the stored water.

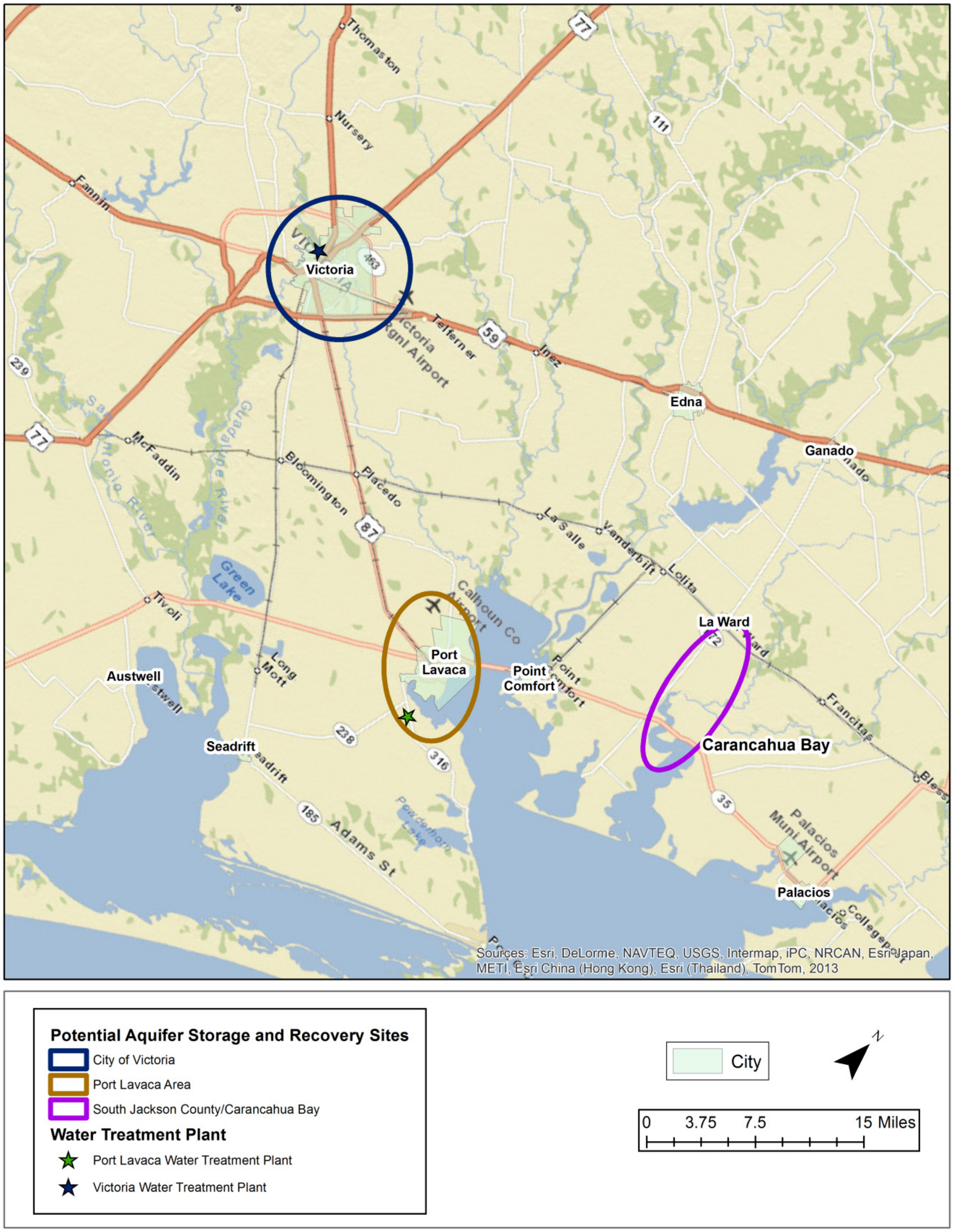


Figure ES-1. Location of Potential Aquifer Storage and Recovery Sites

All three of the potential ASR sites overlie the Gulf Coast Aquifer System. Table 6-1 shows the stratigraphy of the Gulf Coast Aquifer in the Study Area. The primary formations of interest are the Beaumont, Lissie and Willis geologic units of the Chicot Aquifer; and the Upper Goliad geologic unity of the Evangeline Aquifer.

At all three sites, the hydrogeology is conducive to successful implementation of ASR projects. A primary reason for the suitability of the sites is the sandy deposits that comprise the aquifer formations in the area. The study team's analyses of the lithologic sequences indicate that sand beds with thicknesses greater than 40 feet are prevalent. Based on analyses of transmissivity values from aquifer tests, the thicker sand beds in the formations typically have hydraulic conductivity values between 8 ft/day and 40 ft/day, which translate into transmissivity values between 320 ft^2/day to 1,600 ft^2/day for a 40-foot sand bed. Application of the Theis solution for pumping groundwater from deposits within this transmissivity range indicates sustainable pumping rates that range between 160 gpm to 800 gpm for a pressure head of about 200 feet (or 86.7 psi) and a single 40-foot sand bed. Two or more sand layers may be screened in a single ASR well, thereby achieving goals for acceptable well recharge and recovery rates, and associated pressure and drawdown.

For each of the three sites the following five topics were discussed in Section 6: 1) targeted geological formation; 2) frequency and thickness of sand beds, 3) potential migration of the injected water; 4) adverse impacts from existing wells, and 5) water quality.

The following paragraphs summarize the characteristics for each of the sites.

<u>Victoria</u>

One of the attractive locations for ASR wells in the City of Victoria is near the Victoria Water Treatment Plant (WTP), but away from any municipal wells that will be used by the City on a regular, continuing basis. Any uncertainty about the impact of municipal wells is manageable because the pumping of these wells is in the City's control. The aquifer properties of the Upper Goliad Formation underlying the City are characterized at a high level of confidence as a result of transmissivity estimates from 15 aquifer tests, consistency in the lithology and sand bed profiles from 14 geophysical logs, and measurements of water quality.

<u>GBRA/Calhoun County</u>

One of the attractive locations for ASR wells is between the city of Port Lavaca and GBRA's Port Lavaca WTP. Among the positive features of this site are a low potential for groundwater migration, primarily as a result of the low regional gradients. Based on the lithology the target zone for injection will likely be between -400 ft msl and -1100 ft msl. This vertical interval intersects three formations: the lower Lissie Formation, the Willis Formation, and/or the Upper Goliad Formation. The targeted zone is characterized by changing conditions that are depth-dependent. Conditions that are expected to change with depth include TDS concentrations, the frequency and permeability of the sand beds, and the height of the water column above the top of the screen.

<u>Southern Jackson County</u>

The investigation of southern Jackson County was performed without a preferred ASR storage location, such as a WTP or facilities within a water distribution system. There are numerous suitable sites for ASR in southern Jackson County, particularly in the vicinity of Carancahua Bay. Among the positive features of this are a low potential for groundwater migration primarily as a result of the low regional gradients, and a relatively well-characterized lithology and stratigraphy. The targeted interval for ASR wells is between -300 ft msl and -1050 ft msl. This vertical interval intersects three formations: the lower Lissie Formation, the Willis Formation, and/or the Upper Goliad Formation. The targeted zone is characterized by changing conditions that are depth-dependent. Conditions that are expected to change with depth include TDS concentrations, the frequency and permeability of the sand beds, and the height of the water column above the top of the screen.

Port of Victoria

As a result of the favorable hydrological conditions in the Study Area, the potential ASR sites may be expanded over time beyond the three discussed above. Among the locations where ASR may prove beneficial is near the Port of Victoria. A review of the hydrogeologic information indicates that the Port's property has attractive conditions that make it conducive to ASR. There are numerous sand beds in the Chicot and Evangeline aquifers between the elevations of -200 ft msl and -1300 msl, and resistivity profiles indicate that the TDS concentrations are less than 1,500 mg/L above -1300 ft msl. Other favorable conditions include, a relatively flat hydraulic gradient of about 0.0003 ft/ft (1.5 ft/mile), no evidence of significant pumping in the vicinity, and no Class II injection wells within several miles.

7.0 ASR Modeling and Preliminary Basis for Design

For assessment of ASR feasibility, the study team prepared a spreadsheet model for both the Victoria and GBRA storage locations. The purpose of the models was to provide a tool for determining the feasibility, conceptual design and cost of the ASR facilities needed to reliably meet each entity's projected demands while remaining consistent with the underlying water rights. The ASR models compared daily water availability and daily water demand in order to determine how much water must be stored in an ASR wellfield, and what recharge and recovery rates are required. The recharge and recovery rates determine the required number and size of ASR wells. For both Victoria and GBRA seven options were evaluated using the models. These options represented a range of baseline water demands and operating scenarios.

Historic daily water use data were provided by Victoria and GBRA. Maximum day, minimum day and average daily water demands for each year were summarized in Table 3-1 in the report. The year 2011 was initially selected as a conservative "base year" for water demand projections since it was a very dry year. For each day during the "base year," the projected 2040 demand was estimated by multiplying the demand for that day by a factor of 1.26, corresponding to a projected increase in water demand of 8 percent per decade. The 8 percent per decade demand forecast was recommended by Victoria, and for consistency it was also used for GBRA.

A linear increase in water demand was assumed for each year between 2014 and 2040. After 2040 daily water demand was assumed to remain the same as in 2040. This provided the opportunity to evaluate storage volume requirements to ensure water supply reliability during the DOR and a hypothetical study period that excluded the DOR.

As the ASR model analysis proceeded, it became evident that the base year projection using 2011 tended to overestimate the ASR facilities required, the associated TSV and the time required to achieve the TSV. Accordingly, some of the alternative options included starting with a more typical base year (2008). Projections to 2040 from this alternate base year also utilized the same 1.26 factor and the same linear increase in water demand.

Tables 7-1 and 7-2 in the report summarize the results of the ASR modeling for Victoria and GBRA, respectively. For each option, the tables show: the WTP size; the storage volumes needed to reliably meet the projected demands; the minimum ASR recharge and recovery capacities (in MGD) needed to meet the projected demands; and the maximum number of continuous days of recharge and recovery during the study period.

The results summarized in these two tables and the hydrogeologic characteristics in the storage locations (discussed in Section 6) formed the basis for the conceptual design of ASR wellfields for Victoria and GBRA. These conceptual designs were used for the estimates of probable cost in Section 8.

8.0 Costs and Economics

Cost of Stored Water

In order to estimate the cost to treat and store water in an ASR wellfield, the study team analyzed actual FY 2013 actual expenses for the Victoria WTP and FY 2014 budgeted expenses for GBRA's Port Lavaca WTP. The volume of treated water produced or to be produced during the same time periods was used to calculate the unit cost of stored water. The objective of this analysis was to understand the "marginal" cost for producing and treating additional surface water from the Guadalupe River at the Victoria WTP and the Port Lavaca WTP for ASR storage and subsequent recovery.

The O&M cost analysis showed that the cost to store available water in an ASR wellfield from the Victoria WTP is about $0.42 per 1,000 gallons, or $136 per AF. The cost to store available water in an ASR wellfield from the Port Lavaca WTP is about $0.66 per 1,000 gallons, or $214 per AF. The higher cost at the Port Lavaca WTP is primarily due to: the need for one additional plant operator in order to make maximum use of the available capacity on a 24/7 basis; and the Canal System delivery charge for transporting raw water from the Guadalupe River to the WTP. If the additional operator is not needed at the Port Lavaca WTP, the marginal cost for the Port Lavaca WTP would be about $0.58 per 1,000 gallons, or $188 per AF.

Construction Costs

The estimates of probable cost in the report are based on the ASR modeling and preliminary basis for design described in Section 7. The basis for design for Victoria and GBRA are shown in Tables 8-1 and 8-3, respectively. The feasibility study-level cost estimates are considered to be Association for the Advancement of Cost Engineering (AACE) Class 4 (low range of -15 percent to -30 percent, and high range of +20 percent to +50 percent). The study team used costing methods comparable to those used for the TWDB regional planning process, augmented with actual information from recent ASR projects.

A summary of the estimated cost for Victoria is shown in Table 8-2 in the report. The total capital costs for the Victoria ASR system are estimated to be $14.5 million. The total project costs, including engineering, permitting, environmental studies, land acquisition, interest during construction and contingency expenses are estimated to be $21.1 million in March 2014 dollars. This would provide 25 MGD of ASR recovery capacity and 18 MGD of recharge capacity. The cost estimates do not include the marginal cost of stored water that is discussed above.

A summary of GBRA's estimated costs is shown in Table 8-4 in the report. The total capital costs for the GBRA Port Lavaca ASR system are estimated to be $22.1 million. The total project costs, including engineering, permitting, environmental studies, land acquisition, interest during construction and contingency expenses are estimated to be $32.6 million in March 2014 dollars. ASR recharge capacity at build-out would be 5 MGD. The cost estimates do not include the marginal cost of stored water that is discussed above, or any improvements needed to get the Port Lavaca WTP up to its rated capacity.

9.0 Permitting, Environmental and Institutional Considerations

This section of the report discusses the authorizations that will be required to permit one or more ASR systems for the Participants and the institutional issues related to implementation of those systems. Within the Study Area, the primary regulatory agencies include TCEQ, the Victoria County Groundwater Conservation District, the Calhoun County Groundwater Conservation District and the Texana Groundwater Conservation District (Jackson County). All three groundwater districts are located within Groundwater Management Area (GMA) 15.

ASR wells typically used for both recharge (injection) and recovery (pumping) are subject to permitting requirements based upon the source of water to be injected and the aquifer in which the water is to be stored. The primary regulatory requirements relate to TCEQ's administration of underground injection of water, and surface water diversion permitting; and the regulation of recharge and production (recovery) of water by the groundwater districts listed above.

TCEQ: UIC Class V Injection Well Permitting

Aquifer storage that is accomplished using an injection well is regulated by the federal Underground Injection Control ("UIC") Program administered by TCEQ. A well that is used to inject water for storage in an ASR project is defined as an "Aquifer storage well" and is classified as a Class V Injection Well. Accordingly, all ASR injection wells must be permitted pursuant to Chapter 27, Texas Water Code, and Chapter 331, Title 30 of the Texas Administrative Code.

TCEQ: Surface Water-Related Authorizations

The source of the water to be stored in the proposed ASR systems would be surface water diverted and treated under COAs and permits from TCEQ. Using State-owned surface water as the supply source for an ASR project triggers additional statutory requirements under Chapter 11 of the Water Code, as well as applicable TCEQ rules. The Victoria and GBRA water rights must be amended to authorize use of the water for injection and recovery. In order to amend the water rights, Victoria and GBRA must submit to TCEQ the information required for a Class V injection well, and a map or plat showing the location of the injection facility and the aquifer in which the water will be stored.

<u>Groundwater Conservation Districts</u>

As stated above, there are three groundwater conservation districts within the Study Area. The districts are consistent with the county boundaries of Victoria, Jackson and Calhoun Counties. Some of the rules related to administration, application procedures and requirements, and hearing procedures can be expected to apply to the implementation of ASR wells and wellfields. However, none of the GCD technical rules specifically address ASR or artificial recharge. Therefore, it will be important for the Participants to work with each of the districts to amend and amplify the rules in a manner that achieves the districts' objectives while facilitating the implementation of ASR.

<u>Environmental Issues and Permitting</u>

The major environmental issues and key considerations related to ASR include the following:

- Native water quality is an important consideration. The number and condition of the oil and gas brine disposal wells in portions of the Study Area are a concern. Water quality sampling will be an important consideration in the next phase of the project.
- Issues related to TDS, iron and manganese in the Gulf Coast Aquifer can be an important consideration. Again, additional water quality sampling will be an important consideration in the next phase of the project. With proper design of facilities and O&M practices, viable ASR projects can be implemented in the Study Area.

Because ASR wells and wellfields have small footprints and limited environmental impacts, the major permitting issues related to an ASR project typically involve the construction of pipelines to and from the wellfield. In Section 9 of the report the environmental permitting requirements that could apply to such pipelines are discussed.

10.0 Conclusions and Recommendations

<u>Hydrogeology Conclusions</u>

The hydrogeologic conditions near Victoria are known to a moderately high level of confidence as a result of the City's installation, testing, and operation of fifteen high-capacity municipal wells, and Victoria County GCD's well registration and well monitoring programs. The hydrogeologic characteristics are well suited for ASR facilities. Among the favorable ASR sites are several near the Victoria WTP. Near the treatment plant, there is no evidence that the recharge, storage, and recovery of stored water would be hindered by potential sources of contamination or pumping from existing wells.

The hydrologic conditions near Port Lavaca are known to a moderate level of confidence. Within the vicinity of the Port Lavaca WTP there are locations where surface contamination sources from nearby aquiculture operations and/or shallow pumping could potentially cause problems with efficient ASR operations. As a result, the proposed ASR facilities are located close to the Port Lavaca WTP, but away from the areas of shallow groundwater pumping and possible contamination.

The availability of hydrologic data in Jackson County varies but there are several areas where the conditions are known with moderately high level of confidence. One of these areas is in the vicinity of Carancahua Bay. Among the positive features of this potential site are a low potential for the migration of stored water and a relatively well-characterized lithology and stratigraphy.

<u>Victoria ASR Wellfield Conclusions</u>

The following paragraphs summarize the major conclusions for the Victoria portion of the Study Area. A full list of the conclusions and a more detailed discussion is found in Section 7 of the report.

- Victoria's ASR objectives can be met utilizing the existing water treatment plant rated capacity of 25.2 MGD.
- The volume of stored water that needs to be recovered during a repeat of the DOR ranges from 4,600 AF to 82,900 AF, depending upon the assumptions underlying each of the options.
- The ASR TSV that needs to be achieved in order to meet seasonal storage objectives is 53,900 AF, however this volume would be inadequate for a repeat of the DOR. The total storage volume required to meet demands during a repeat of the DOR ranges from 9,300 to 168,100 AF, depending on the option.
- The ASR wellfield design capacity for all options is controlled by the required recharge capacity, which ranges between 18.3 and 26.0 MGD. It is likely that the ASR wellfield recharge design capacity would be about 19 MGD.
- The City's five goals for an ASR program can be achieved.

An ASR wellfield is viable in the area of the City of Victoria. Based upon the summary of ASR model results shown in Table 7-1, a preliminary basis of design for the ASR wellfield is to provide a recharge capacity of 19.0 MGD. This will require approximately 16 ASR wells. The potential ASR well locations and approaches include: Victoria WTP; Water Treatment Plant No. 3; conversion of selected existing production wells to ASR wells; construction of new ASR wells at new sites, and construction of new ASR wells at existing abandoned production well sites. The recovery capacity of these wells will exceed the targeted recharge rate since the critical factor controlling ASR facilities design capacity for Victoria is the recharge rate.

<u>GBRA ASR Wellfield Conclusions</u>

Various options were evaluated for ASR development in Calhoun County, primarily in the vicinity of the GBRA Port Lavaca WTP. Section 7.2.1 of the report describes the assessment of options related to a repeat of the DOR utilizing only GBRA's most junior water right. In reality, GBRA can provide raw water to the Port Lavaca WTP during a repeat of the DOR using its more senior certificates of adjudication. Therefore, the ASR analysis in this report is extremely conservative.

Subject to additional data collection and testing, an ASR wellfield appears to be viable at the Port Lavaca WTP. ASR wellfields are also viable in the Study Area west-northwest of Port Lavaca and between the Port Lavaca WTP and Bloomington. Such wellfields should be able to meet the projected 2040 water demands with 100 percent reliability and at relatively low cost compared to other water supply alternatives. Starting an ASR program at the Port Lavaca WTP is justified because this concept eliminates the right-of-way, pipeline and pumping costs associated with a remote location. However, more distant ASR wellfields with less challenging hydrogeologic conditions may be very viable if future growth in water demand occurs between Port Lavaca and Victoria.

The following paragraphs summarize the major conclusions for the GBRA/Calhoun County portion of the Study Area. A full list of the conclusions and a more detailed discussion is found in Section 7 of the report.

- GBRA's ASR objectives can be met utilizing the existing treatment plant rated capacity of 6.1 MGD.
- The volume that needs to be recovered during a repeat of the DOR ranges from 9,300 to 14,500 AF, depending upon the assumptions underlying each of the options.
- The ASR TSV required to meet demands during a repeat of the DOR ranges from 18,500 AF to 29,100 AF.
- The ASR wellfield design capacity for all options is controlled by the required recharge capacity, which ranges from 4.7 MGD to 6.1 MGD. It is likely that ASR wellfield recharge design capacity would be about 5 MGD.
- Further investigation of groundwater production at a nearby aquaculture operation is needed prior to confirming the viability of the GBRA Port Lavaca WTP property for an ASR wellfield. If a significant cone of depression already exists in the sand intervals that are suggested for ASR storage, it may be necessary to relocate the ASR wellfield to another site.
- It appears that GBRA's four goals for an ASR program in Calhoun County can be achieved.

An ASR recharge capacity of 5.0 MGD was selected as the basis of design for the GBRA facilities. This will require approximately 30 wells. As described in Section 6, hydrogeologic conditions in the Port Lavaca area are deemed to be suitable for ASR, although they offer more challenges than the conditions in the Victoria area. The suggested location for a second phase assessment is at the GBRA Port Lavaca WTP.

<u>General Recommendations</u>

Because of the regulatory issues discussed in Section 9, the first step toward implementation of ASR systems in the Study Area should be early and continual coordination with the applicable groundwater districts in Victoria, Jackson and Calhoun Counties. Rules will need to be written and/or amended in order to get the required permits to drill the initial test wells and to implement an ASR project.

Eventually the surface water rights owned by Victoria and GBRA must be amended to authorize use of the water for injection and recovery, but a temporary authorization for the Phase 2 testing programs may not be necessary. 30 TAC §295.21(b) states that a water right permit is not required for the first phase of an ASR project that proposes temporary storage of appropriated surface water in an aquifer for testing, subsequent retrieval and beneficial use if the diversion and purpose is covered by an existing water right. A clarifying discussion with TCEQ should be one of the first steps in Phase 2 of any ASR project in the Study Area.

City of Victoria Recommendations

If a decision is made to proceed with further investigation of ASR, Victoria should implement an ASR test program at two sites: the Victoria WTP; and at WTP No. 3. The test program would include construction, testing and operation of one new full-size ASR well at the WTP and one retrofit of an existing production well at or near WTP No. 3. The first phase of ASR wellfield construction would represent approximately 10 percent of the planned ultimate scale of development. Continuous wireline cores would first be obtained to a depth of 1,100 feet, providing good understanding of the depths and thicknesses of sand and clay layers beneath the site, and their associated geochemical and geotechnical properties. The test program would also include two monitor wells, supplementing monitoring at other existing production wells in the area surrounding each location. The number and location of ASR wells and monitor wells may be adjusted based upon results of an initial core hole at the Victoria WTP site. Operating experience gained with the first two ASR wells would provide a basis for subsequent design of wellfield expansion facilities.

Victoria should also continue coordinating with the Port of Victoria so that potential opportunities for joint use of the City's water supply can be explored.

GBRA Recommendations

If a decision is made to proceed with further investigation of ASR viability, GBRA should implement an ASR test program at the Port Lavaca WTP. Continuous wireline cores would first be obtained at each property corner to a depth of 1,100 feet, providing good understanding of the depths and thicknesses of sand and clay layers beneath the site, and their associated geochemical and geotechnical properties. The number and location of ASR wells and monitor wells may be adjusted based upon results of the initial core holes.

Following confirmation with the corings, the test program would include construction and testing of three full-size ASR wells that would be placed into operation. The three wells would be constructed in sand intervals between 300 and 500 feet, 400 and 700 feet, and 600 to 1,100 feet, respectively. The first phase of ASR wellfield construction would represent about 10 percent of the planned ultimate scale of development. A possible general location may be at or near three of the four property corners at the Port Lavaca WTP. The test program would also include approximately five monitor wells, as needed to provide a basis for design of expanded ASR wellfield facilities at this site. Three of these monitor wells would be close to the three adjacent ASR wells. One more monitoring well would be constructed at the remaining property corner and one would be constructed near the center of the property. Operating experience gained at this site with the first three ASR wells would provide a basis for subsequent design of wellfield expansion facilities at this site or other locations.

1.0 Background and Introduction

The recent drought in Texas has had a significant impact on water utilities, wholesale water providers and industries, including those within the Golden Crescent area of south central Texas. The region is centered on the City of Victoria, Texas. During the last fifty years, water providers within the area have developed a diverse mix of surface water and groundwater sources. However, meeting future demands will be challenging for municipal and industrial water users as demands continue to grow, especially if drought conditions continue.

In order to address these issues in a strategic manner several water providers and users in the area have joined together to evaluate the potential of using Aquifer Storage and Recovery (ASR) and/or off-channel storage (OCS) as water management strategies. The evaluation would focus on the potential of using ASR and OCS projects to stretch existing water supplies, improve reliability and maximize the efficient use of existing surface water rights in the Guadalupe River Basin.

For this current effort, the study area consisted of Victoria, Jackson and Calhoun Counties (the "Study Area"). The participating entities (the "Participants") included:

- City of Victoria
- Lavaca-Navidad River Authority
- Victoria County Groundwater Conservation District
- Guadalupe-Blanco River Authority
- Port of Victoria

ASR has been extensively applied for water resources management and conservation in water-short regions around the world. In concept, ASR can include the storage of drinking water, treated surface water, reclaimed wastewater or groundwater from other aquifers. In its basic concept, water is stored underground in a suitable aquifer through wells and is recovered when needed from the same wells. Within the United States, ASR has proven itself to be efficient and cost effective, and it has much less environmental impact than traditional surface reservoir storage. At the present time there are approximately 133 well fields operating in 22 states within the United States. There are currently three operational ASR systems in Texas; these systems are located in El Paso, Kerrville and San Antonio.

ASR is typically implemented in three phases. Phase 1 is the Feasibility Assessment and Report; Phase 2 is the Testing and Monitoring Program; and Phase 3 is the Implementation of an operational ASR well or wellfield.

The purpose of this report is to document the initial feasibility assessment of ASR as a water management strategy for the Study Area (the "Project"). OCS is not addressed in this report because that strategy was evaluated by another study team. The Project consisted of assessing the near-term and long-term feasibility of ASR by identifying both technical and non-technical issues and potential ASR projects within the Study Area. This report includes sufficient information to support any needed regulatory authorizations to develop a demonstration project in Phase 2 and one or more operational projects in Phase 3.

The report is organized with the following major areas of emphasis:

- A description of the ASR workshop in which the Participants ASR objectives were defined.
- The definition of water supply reliability used for the Project.
- The raw water supply sources analyzed in the Project.
- A discussion of the hydrogeology of the Gulf Coast Aquifer within the Study Area and its suitability for ASR development.
- A description of the ASR modeling used for developing conceptual ASR designs and cost estimates.
- A discussion of the estimated costs and economics of the Project.
- A discussion of the permitting, environmental and institutional considerations.
- Conclusions and recommendations.

The Project study team for the ASR assessment consisted of ARCADIS U.S., Inc.; ASR Systems, LLC; and INTERA Inc. The scope of work approved by the Texas Water Development Board (TWDB) for the Project consisted of the following major tasks:

- Project Management and General Protocols
- Kickoff Meeting/Conference Call and Public Meeting No. 1
- Initial Data Collection
- Advanced Data Collection, ASR Workshop and Public Meeting No. 2
- Alternative Assessment Analysis
- Analysis of ASR Sources of Supply and Storage Requirements
- Evaluation of Potential ASR Storage Locations
- Conceptual Basis of Design Plan and Cost Estimates
- Analysis of Permitting, Environmental and Institutional Issues
- Economic Analysis
- Final Report and Public Meeting No. 3

The major areas of emphasis for analyzing specific ASR storage locations and requirements, and required facilities are the City of Victoria and its service area, and Guadalupe-Blanco River Authority's (GBRA) service area in Calhoun County. These specific locations were chosen for initial assessment because of existing water treatment and distribution infrastructure.

For Jackson County, the Project focused on answering the fundamental question of whether the aquifer(s) in the county is viable for ASR development.

2.0 ASR Workshop and Objectives

The purposes of the ASR Workshop with all of the Participants were to: (i) review the fundamental aspects of ASR and its various applications; (ii) gather and discuss any outstanding data, reports and existing plans on Participant water systems, facilities and programs; (iii) evaluate potential ways in which ASR might become a part of the Participants' water management strategies; (iv) confirm potential sources of water supply and storage locations gathered in other tasks; (v) discuss potential permitting, environmental and socio-economic issues that might enter into an ASR project; and (vi) confirm the Participants' budget, rate and financial information needed for the study.

The primary desired outcome of an ASR workshop is a prioritized list of the most important ASR applications for each Participant. This information forms the basis for the development of the ASR model(s) used to prepare a conceptual basis of design for any proposed ASR systems.

The Workshop also included a tour of the City of Victoria's surface water treatment plant (WTP) and one of the city's operational groundwater wells. At a later date, the ARCADIS project manager also toured GBRA's Port Lavaca WTP.

During the Workshop the study team discussed potential ASR applications that might be beneficial for each of the Participants, with emphasis on the priorities of the City of Victoria (the "City" or "Victoria") and GBRA where the sources of supply and primary potential storage locations are located. Subsequently, the Lavaca-Navidad River Authority (LNRA) provided a list of the applications most applicable to Jackson County where the study focused on addressing the fundamental question of whether the aquifer formations in the county are conducive for ASR storage.

The prioritized list of ASR applications for Victoria included:

1. Seasonal storage to meet peak demands
2. Long-term storage to increase reliability during a drought
3. Deferring expansion of the City's WTP or construction of a second WTP
4. Emergency storage for use during severe flooding or other events
5. Reduction in disinfection by-product (DBP) concentrations

The prioritized list of ASR applications for GBRA included:

1. Seasonal storage to meet peak demands which would serve to delay expansion of the Port Lavaca WTP
2. Emergency storage for use during hurricanes and other events
3. Long-term storage
4. Reduction in DBP concentrations

The prioritized list of ASR applications for LNRA/Jackson County included:

1. Long-term storage to serve as a drought management tool
2. Seasonal storage to supplement existing supplies
3. Emergency storage for use during events that could interrupt deliveries through LNRA's pipeline systems.

During the Workshop the group also discussed potential locations for ASR wells. These could include:

- The area within the city limits/service area of the City of Victoria, particularly the following locations:
  - Victoria WTP
  - Water Plant No. 3
  - North part of distribution system
  - East part of the distribution system toward the Victoria County Airport, including the airport property

- The Port Lavaca WTP property (or the closest viable storage location between the Port Lavaca WTP and the community of Bloomington, TX)
- The southeastern portion of Jackson County (east and southeast of Lake Texana toward LNRA's industrial and municipal customers near Point Comfort)

Attachment A is a Summary of the Workshop and site visits.

3.0 Water Supply Reliability

Water supply reliability is defined in terms of the number of days during a repeat of the Drought of Record (DOR) that system demands would be fully met, as a percentage of the total number of days during the DOR. For this analysis the period of record from January 1, 1940, to December 31, 2012, has been selected. This period was selected because it included the DOR for the Study Area, which extended from 1947 to 1957, as well as one of the driest years on record (2011).

With adequate ASR capacity, it is reasonable to expect to achieve 100 percent reliability, in terms of both water quantity and water quality. Without ASR or a supplemental groundwater supply, a water system dependent on run-of-river water supplies is unlikely to achieve 100 percent reliability, implying the possible need for periodic water use restrictions in order to match water demands to available supplies during droughts.

The Participants may wish to accept a lower target than 100 percent for reliability during the DOR, in which case ASR capacity and that of other facilities would be slightly reduced, with associated cost savings. For example, 95 percent reliability would entail having insufficient capacity to fully meet peak demands for six months during the DOR, all or most of which would probably be continuous. Because of the anticipated relatively small incremental cost for achieving 100 percent instead of 95 percent reliability with ASR, the higher target is utilized for planning purposes in the Project. During preliminary design of facilities in Phase 2, this assumption should be reevaluated.

Water **quantity** reliability entails having sufficient water volume in storage, including installed ASR well recovery capacity plus supplemental off-channel storage (OCS) or terminal reservoir storage, so that peak day demands can be achieved during the DOR. Well capacity, whether ASR wells or production wells, can help to achieve water quantity reliability. Water **quality** reliability entails having sufficient water stored prior to the DOR so that recovered water quality from ASR wells meets drinking water standards throughout the DOR, following re-disinfection to restore the required residual. OCS reservoirs will probably be depleted during a repeat of the DOR. If insufficient water volume has been stored in ASR wells prior to the DOR, adequate flow of water recovered from the ASR wells may continue, however the water quality will tend to deteriorate, reflecting an increasing blend of treated drinking water with ambient (native) groundwater that may contain elevated concentrations of iron, manganese, brackish water and possibly other constituents. Water customers may notice the change in quality as the source water transitions from the ASR storage source to the more native groundwater source. Under such conditions retreatment of the water recovered from ASR storage, in addition to restoration of the disinfectant residual, may be required. A utility management decision is appropriate, evaluating the tradeoffs between investing capital for construction and maintenance of ASR post-treatment facilities that may be operated very infrequently; or accepting the risks associated with supplying variable water quality to customers, or alternatively investing in sufficient ASR recharge capacity so that the target storage volume (TSV) for ASR can be achieved more rapidly. [The TSV is the sum of the volume of stored water that will be recovered for use, plus the buffer zone volume that is left in the aquifer to separate the stored water from the native groundwater. The TSV is discussed in more detail in Section 7.1.1.] This would ultimately be a tradeoff between increased water costs for customers versus increased reliance upon water use restrictions and other water conservation measures that may need to be implemented during any dry periods prior to formation of the TSV.

OCS such as the 10 gravel pits at Victoria and the Terminal Storage Reservoir at the GBRA Port Lavaca WTP help to meet reliability goals but usually can provide only a few weeks of supply during a severe drought, and may not be useful during an emergency. Storage with ASR wells can provide several months of supply, usually at much lower capital and operating cost. Other options for achieving the same reliability goal include having multiple sources of supply, potentially including interconnections with adjacent water utility systems.

Providing sufficient ASR recharge capacity entails restoring and maintaining the TSV after a normal seasonal recovery period. It also entails building the TSV initially in an acceptable period of time. For unconsolidated aquifers such as the Chicot and Evangeline aquifers in the Study Area, installed recharge capacity will most likely determine the required number of ASR wells. System reliability will steadily increase during the initial period when ASR storage volume is building toward the TSV. If this occurs during early years when demands are lower, the TSV will be achieved more rapidly. If ASR wellfield development is deferred to later years when demands are higher, it is more likely that expansion of water treatment capacity and other facilities will be required in order to achieve acceptable levels of reliability in a reasonable time period.

For the ASR Model developed for this analysis, an Initial Storage Volume is calculated so that the TSV is achieved prior to the beginning of the DOR. An informed decision can then be made as to how many years would be considered reasonable for achieving the TSV. A long period of many years' duration would entail the least capital investment but also reduced reliability during that period. A short period of just a few years' duration may entail increased capital investment for ASR wells and perhaps expanded water treatment capacity in order to achieve 100 percent reliability as rapidly as possible.

Table 3-1 shows the water demands for the City of Victoria and for GBRA during 2008 to 2012, including maximum day demands, minimum day demands and average day demands for each year. The year 2011 was one of the driest years on record, with resulting low river flows and high water demand. This year was selected as the baseline year for projecting water demands to 2040, using an increase of 8 percent per decade, as was recommended by the City of Victoria. Daily water demands during 2011 were increased linearly to 2040 for the ASR Model analysis described subsequently in this report. This is considered to be a conservative projection of water needs, resulting in conservative estimates of storage volume requirements. An alternative analysis was also conducted using 2008 water demands. Calendar Year 2008 was a more typical year in terms of river flows and water demands. Comparison of the ASR Model results for the two base years provides a frame of reference for decisions regarding ASR storage volume requirements, system reliability and ASR facilities capacity.

Table 3-1: Water Demands for City of Victoria and GBRA during 2008 to 2012

Year	**Maximum Day Demand (MGD)**	**Minimum Day Demand (MGD)**	**Average Day Demand (MGD)**
CITY OF VICTORIA RAW WATER PUMPAGE, 2008 - 2012			
2008	17.068	6.043	10.042
2009	18.175	5.158	10.872
2010	16.028	6.265	9.683
2011	19.752	6.922	11.922
2012	18.050	6.999	10.648
GBRA - PLWTP DAILY WATER PRODUCTION, 2008 - 2012			
2008	2.296	0.931	1.472
2009	2.658	1.028	1.506
2010	2.482	1.233	1.794
2011	3.569	1.365	2.204
2012	2.657	1.094	1.821

4.0 Raw Water Supply Sources for Victoria and GBRA

For the purposes of this Project, the Participants agreed that the water supplies available for potential ASR storage would be existing surface water rights that could be used for treatment and delivery to an ASR wellfield for subsequent recovery. Under the Texas Commission on Environmental Quality (TCEQ) regulations, water from these sources of supply must be treated to drinking water standards prior to recharge in an ASR well. For Victoria, the raw water will be treated at the Victoria WTP. For GBRA, the raw water will be treated at the Port Lavaca WTP.

<u>City of Victoria</u>

The City of Victoria owns seven permits or Certificates of Adjudication (COA) from the TCEQ which total approximately 27,000 acre-feet per year (AFY). The priority dates range from 1918 to 1993, with the largest, Permit No. 5466B (for 20,000 AFY), having the most junior priority date. Because of the priority dates and/or the special conditions in the permits and COAs, the Victoria water rights are not reliable during a repeat of the DOR. **Table 4-1** below shows the seven water rights, the priority dates, and the diversion information. Several of the permits are in the process of being amended to authorize diversion at Victoria. For the purposes of the Project, the study team assumed that those amendments have been authorized by TCEQ.

Table 4-1: Summary of Existing Victoria Water Rights

COA/Permit	Priority Date(s) (yr/mo/day)	Maximum Diversion Rate		Maximum Annual Use	Special Condition(s)
		cfs	MGD[1]	AFY	
3844A	1918/08/06	9.80	6.37	608	Streamflow of Guadalupe @ Seguin > 9.8 cfs[2]
3858A	1951/06/27	4.40	2.86	1,000	
3860A	1951/08/15	8.91	5.79	260	Streamflow limits at Victoria vary by month
3862A	1951/12/12	12.62	8.20	262.70	Monthly streamflow thresholds
4117A	1984/04/02	1.67	1.08	200	Streamflow limits at Victoria vary by month
5466B	1993/05/28	150.00	97.50	20,000	Streamflow limits at Victoria vary by month
3606A	1978/07/10	13.40	8.71	4,676	P3895 in WAM Streamflow limits at Victoria vary by month

[1] Diversion rate in MGD is shown for reference only. Sustained diversions on a daily basis cannot be made at that rate.

[2] COA 3844A current diversion point is located downstream of Seguin, which is upstream of the USGS gauge at Victoria. The COA was modeled as if diversions occur at Victoria.

Guadalupe-Blanco River Authority

GBRA owns or jointly owns nine senior water rights totaling over 175,500 AFY of authorized diversions. The priority rates range from 1941 to 1952. The authorized diversion points are all at GBRA's Saltwater Barrier and Diversion Dam which is near Tivoli, TX downstream of Victoria. The most senior COAs are reliable during a repeat of the DOR (i.e. they are "firm" supplies). However, the most junior COA (No. 5178) is not firm. For the purposes of this feasibility study, the study team analyzed the potential for ASR as a management strategy assuming that all of the water is being diverted and treated under COA No. 5178. This provides an extremely conservative assessment of supply options, especially during a repeat of the DOR. In reality, GBRA can supply the Port Lavaca WTP from its other COAs during a repeat of the DOR

COA 5178 is jointly owned by GBRA and DOW/Union Carbide. It has a priority date of January 7, 1952 and a maximum annual use of 106,000 AFY for municipal, industrial and irrigation purposes. The maximum authorized diversion rate is 264.35 cfs. It should be noted that by aggregating all nine GBRA/DOW water rights, the maximum authorized diversion rate is 622 cfs.

5.0 Raw Water Supply Source for Port of Victoria

The Victoria County Navigation District (the "Navigation District") has retained the non-consumptive portion of Permit 3606. The permit provides for the owner to construct a 132-acre foot reservoir in order to divert for non-consumptive industrial purposes up to 5,000 AFY. All of the diverted water must be returned to the Victoria Barge Canal, with no allowance for consumptive loss. The off-channel reservoir site is owned by the Port of Victoria, but the reservoir has not yet been constructed. The permit has a priority date of July 10, 1978.

The Navigation District has applied for an amendment to Permit 3606 (Application for Permit 3606B) to recognize that the Navigation District has conveyed all of the consumptive rights under Permit 3606 to the City of Victoria but has retained the non-consumptive portion. TCEQ has completed the hydrology, conservation and environmental reviews of the application and has issued a draft permit amendment. That draft permit includes special conditions requiring the Navigation District to maintain and operate an alternative source of supply with sufficient capacity to compensate for any consumptive use of water; and to further amend the permit to authorize the alternative source of water.

Given the non-consumptive requirements of Permit 3606B, it cannot be used as a source of supply for treatment and storage in an ASR wellfield. However, water recovered from ASR storage could serve as a viable alternative supply in order for the Navigation District and Port of Victoria to comply with the terms of the draft permit.

6.0 Hydrogeology

In this section, the hydrogeology of the Study Area containing the potential ASR sites is described, with a focus on the characteristics that are most relevant to a potential ASR project. The most important characteristics include the size, continuity and permeability of sand beds; the continuity and thickness of clay beds; the direction, magnitude and temporal consistency of the hydraulic gradient; the location of existing wells and their expected pumping rates; potential sources of contamination such as waste injection wells; and water quality. For the purposes of this discussion, the Study Area includes Victoria, Jackson, and Calhoun counties. **Figure 6-1** shows the three specific areas considered for ASR potential in this phase. The three sites are marked by ovals in **Figure 6-1** and will be referred to in this section as the City of Victoria, Port Lavaca, and South Jackson County sites. These three locations were selected because of their proximity to existing water treatment and supply infrastructure and/or their proximity to potential users of the stored water.

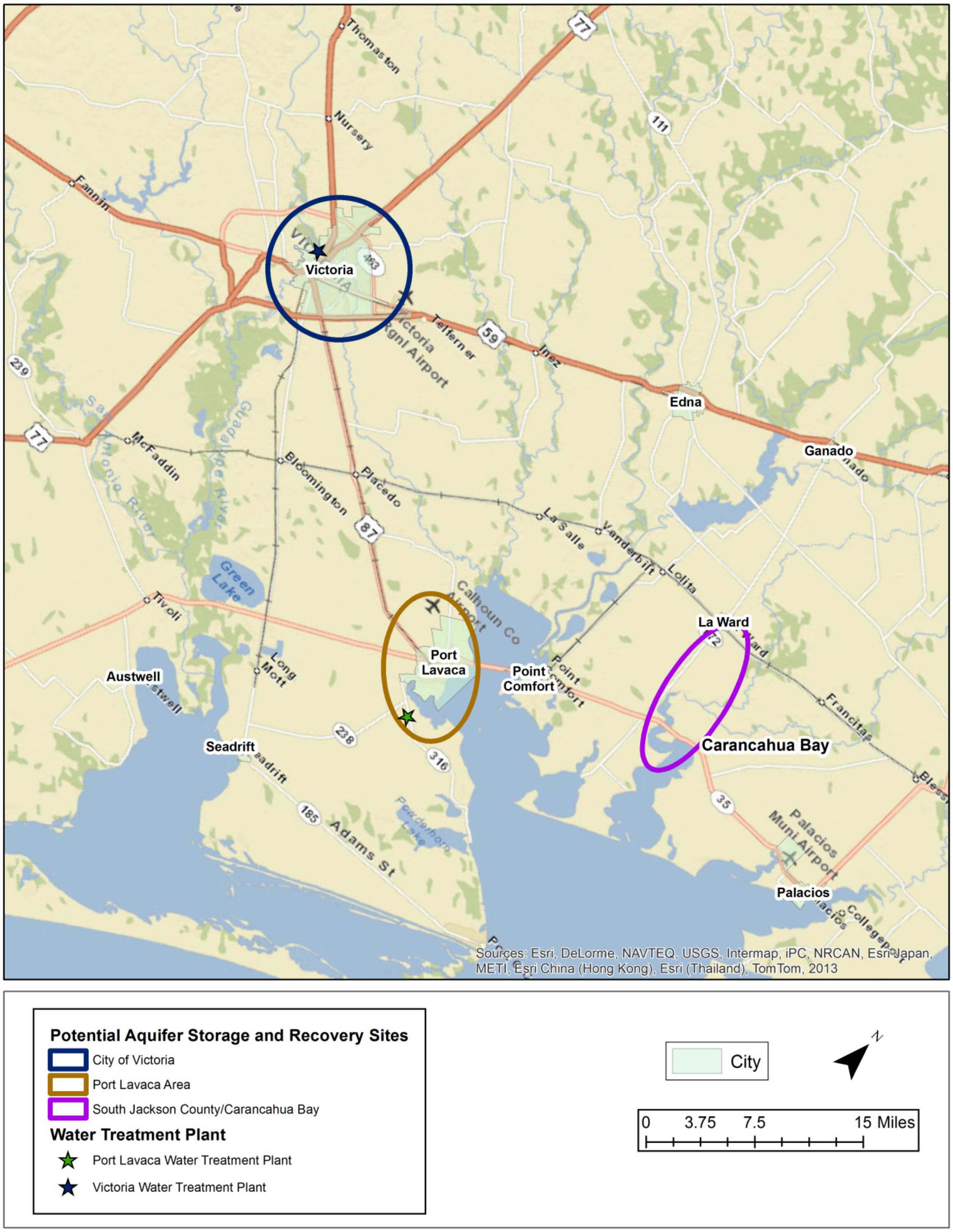


Figure 6.1: Locations of Potential Aquifer Storage and Recovery Sites

6.1 Gulf Coast Aquifer System

The three potential ASR sites overlie the Gulf Coast Aquifer System. As shown in **Table 6-1**, the Gulf Coast Aquifer System encompasses all stratigraphic units above the Vicksburg Formation (George and others, 2011, Young and others 2010; 2012). Sediments of the Gulf Coast aquifer were deposited in a fluvial-deltaic or shallow marine environment (Sellards and others, 1932). Repeated sea-level transgression and regression and basin subsidence caused development of cyclical sedimentary deposits composed of discontinuous sand, silt, clay, and gravel (Sellards and others, 1932; Kasmarek and Robinson, 2004). Most of the sediments of the Gulf Coast aquifer thicken toward the Gulf of Mexico. Faults that remained active during sedimentation (growth faults) contributed to additional sediment accumulations over short lateral distances in some areas (Verbeek and others, 1979).

Table 6-1: Simplified Stratigraphic and Hydrogeologic Chart of the Northwestern Gulf of Mexico Basin, Texas Coastal Zone (Galloway and others, 1991; Sharp and others, 1991; Young and others, 2010).

ERA	Epoch		Est. Age (M.Y)	Geologic Unit	Hydrogeologic Unit
Cenozoic	Pleistocene		0.7	Beaumont	CHICOT AQUIFER
			1.6	Lissie	
	Pliocene		3.8	Willis	
	Miocene	Late	11.2	Upper Goliad	EVANGELINE AQUIFER
			14.5	Lower Goliad	
		Middle	17.8	Upper Lagarto	
				Middle Lagarto	BURKEVILLE
		Early		Lower Lagarto	JASPER AQUIFER
			24.2	Oakville	
	Oligocene		32	Frio	CATAHOULA
			34	Vicksburg	

Although the Gulf Coast sediments are generally comprised of sequences of interbedded sandstones and shales that lack distinctive regional extent (Galloway and others, 1991), geological formations are definable based on regional scale correlations related to the cyclical deposition of facies. Today it is recognized that depositional facies associations and distribution depend upon interrelated controls. The most important include sedimentary processes, sediment supply, climate, tectonics (earth movements), sea level changes, biological activity, water chemistry, and volcanic activity.

6.1.1 Gulf Coast Stratigraphy

The Gulf Coast Aquifer System is comprised of, from shallowest to deepest, the Chicot Aquifer, the Evangeline Aquifer, the Burkeville confining unit or Middle Lagarto Formation, and the Jasper Aquifer, with parts of the Catahoula Formation acting as the Catahoula Confining System. The definitions and boundaries of these units that comprise the Gulf Coast Aquifer System are an on-going area of research and modification. The two approaches that have been used to define the Gulf Coast stratigraphy are lithostratigraphy (Baker, 1979; Strom and others, 2003) and chronostratigraphy (Young and others, 2010; 2012). Although the two approaches have much in common, the two approaches can and have produced notable differences in how the Gulf Coast hydrogeological units are defined. Since results from both a lithostratigraphic standpoint and chronostratigraphic standpoint are important to our interpretation of the data, a brief discussion of the differences between chronostratigraphic and lithostratigraphic correlation techniques is included here.

Lithostratigraphic correlation relies on the interpretation from well logs of formation lithologies and boundaries between different lithologies (mud on sand, for example) and then correlating those boundaries between wells. Athick marine shore-zone sand, for example, would be correlated to other thick marine sands based on lithology and position within the vertical profile. In creating this lithocorrelation, the chronology of the deposition of the marine sands is not considered. Until the 1980s, most well log correlation in the oil and gas industry was lithostratigraphic, but with the advent of sequence stratigraphy, new conceptual tools became available to correlate layers that may display varying lithologies but were deposited during a specific time interval under distinct environmental conditions. Such chronostratigraphic layers are more likely to be internally integrated hydrogeologic systems because they account for the presence of fine grain and low permeability sediments that often separate the more permeable units. From the perspective of modeling groundwater flow, a lithostratigraphic approach tends to overestimate the correlation and connection among litho-units compared to a chronostratigrapic approach.

The most prevalent geologic structure used in the Gulf Coast since 2000 is the Source Water Assessment Program (SWAP) dataset (Strom and others, 2003a,b,c). The SWAP dataset was used as the primary source of geologic structure for the development of the Central Gulf Coast Groundwater Availability Model (CGC GAM) (Chowdhury and others, 2004). Pioneering work by Baker (1979) established an accurate stratigraphic foundation for the SWAP dataset.

Among the limitations of the SWAP dataset is that it does not delineate the geological formations that comprise the Chicot, Evangeline, and Jasper aquifers and its documentation lacks specific analysis of geophysical logs to support delineation of the aquifers into their geological formations. In order to improve the geological structure of groundwater models developed after the CGC GAM, the Texas Water Development Board (TWDB) funded two research projects (Young and others, 2010; 2012) that used chronostratigraphic correlations to replace the SWAP geological surfaces and to define the geological formations that comprise the Chicot, Evangeline, and Jasper Aquifers. Young and others (2010; 2012a) defined ten geological units in the Gulf Coast Aquifer System. **Table 6-1** provides a stratigraphic chart for these ten geological units. The Chicot Aquifer includes, from the shallowest to deepest, the Beaumont and Lissie Formations of Pleistocene age and the Pliocene-age Willis Formation. The Evangeline Aquifer includes the upper Goliad Formation of earliest Pliocene and late Miocene age, the lower Goliad Formation of middle Miocene age, and the upper unit of the Lagarto Formation (a member of the Fleming Group) of middle Miocene age. The Jasper Aquifer includes the lower Lagarto unit of early Miocene age, the early Miocene Oakville sandstone member of the Fleming Group, and portions of the Oligocene-age Catahoula Formation.

Figure 6-2 shows the location of two cross-sections that will be used to illustrate the Gulf Coast stratigraphy within areas of the Study Area. Cross section or transect A-A'-A" cuts through the mid-section of Victoria County and dog legs east after it enters Calhoun County and terminates near Port Lavaca. Transect B-B' cuts through the southeast region of Jackson County and terminates near Carancahua Bay. **Figures 6-3 and 6-4** provide geological cross-sections for these two transects. The differences in the bottom surfaces of the aquifers as defined by the SWAP (represented as the CGC GAM) and the revised TWDB stratigraphy are most evident in cross-section A-A'-A" and these differences are greatest toward the down-dip extent near the Gulf of Mexico. Up dip of point A', the difference in the elevation of the bottom of the Evangeline Aquifer is about 1000 feet. Such a large difference is partly explained by the lack of paleomarkers used in the development of the lithofacies-based SWAP dataset. Paleomarkers include fossils in deposits that can be used to age date the deposits. In development of the TWDB chronostratigraphy, paleomarkers in off-shore geophysical logs were extensively used to ensure that the sequence stratigraphy and chronostratigraphic correlations (geological surfaces) were within concepts and methods used by the Gulf Basin Depositional Synthesis Project (GBDS). The GBDS project (Galloway, 1989b; Galloway and others, 2000; and Galloway, 2005) was conducted by the Texas Bureau of Economic Geology and funded by a consortium of petroleum companies to characterize the Cenozoic depositional history of the Gulf of Mexico Basin.

Throughout this section, both the aquifer boundaries defined by SWAP (Strom and others, 2003a,b,c) and the geological formation boundaries defined by the TWDB study (Young and others, 2010) are used. Whenever geological formations are discussed, these units are defined by the TWDB study. Whenever aquifers are discussed, their boundaries are defined by the SWAP study.

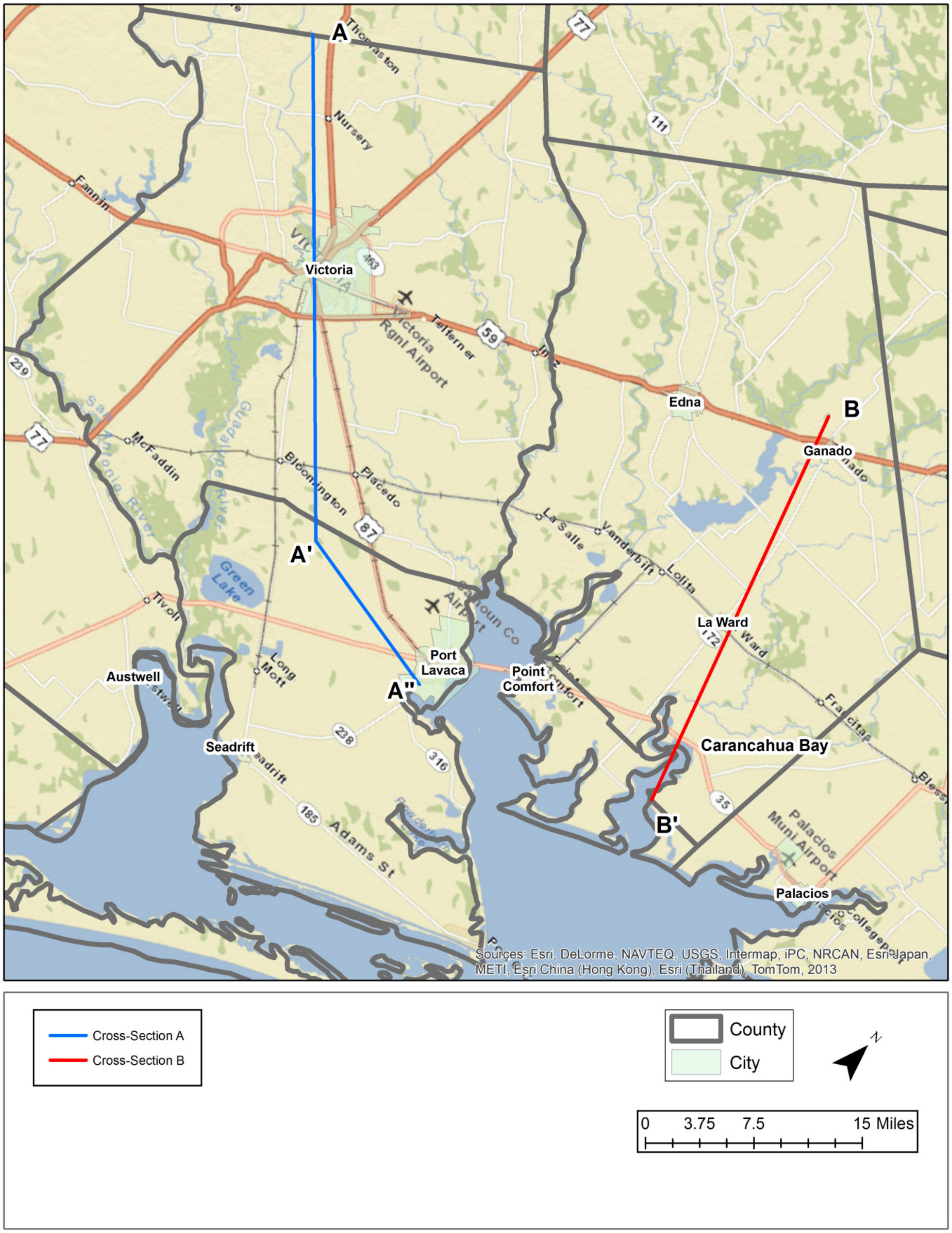


Figure 6.2: Location of Cross Section A-A' in Victoria and Calhoun Counties and Cross Section B-B' in Southern Jackson County

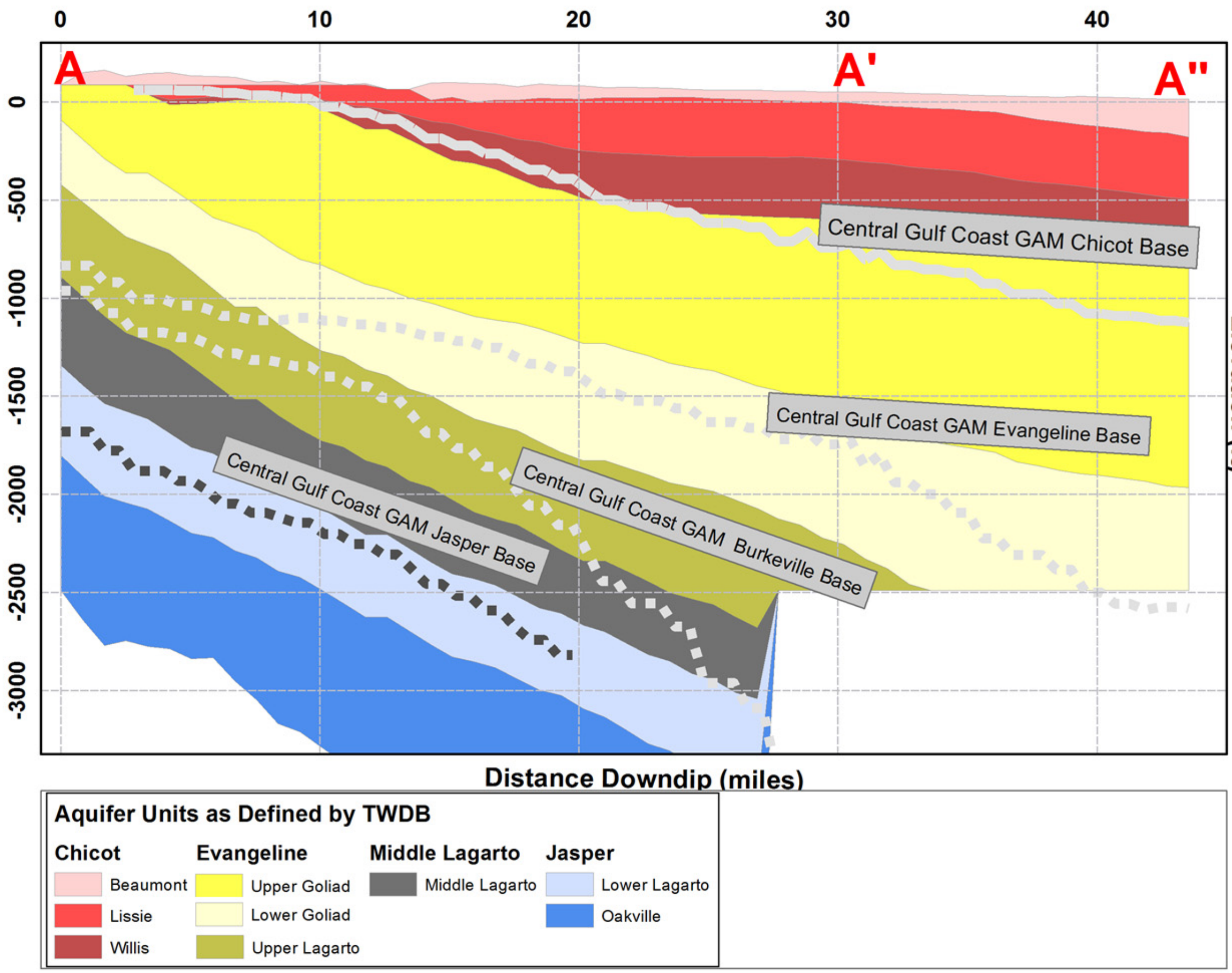


Figure 6.3: Profile of Geological Units and Aquifers from the TWDB Study (Young and others, 2010) and of Aquifers from the SWAP Study (Strom and others, 2003) that comprise the Gulf Coast Aquifer System along Cross Section A-A'

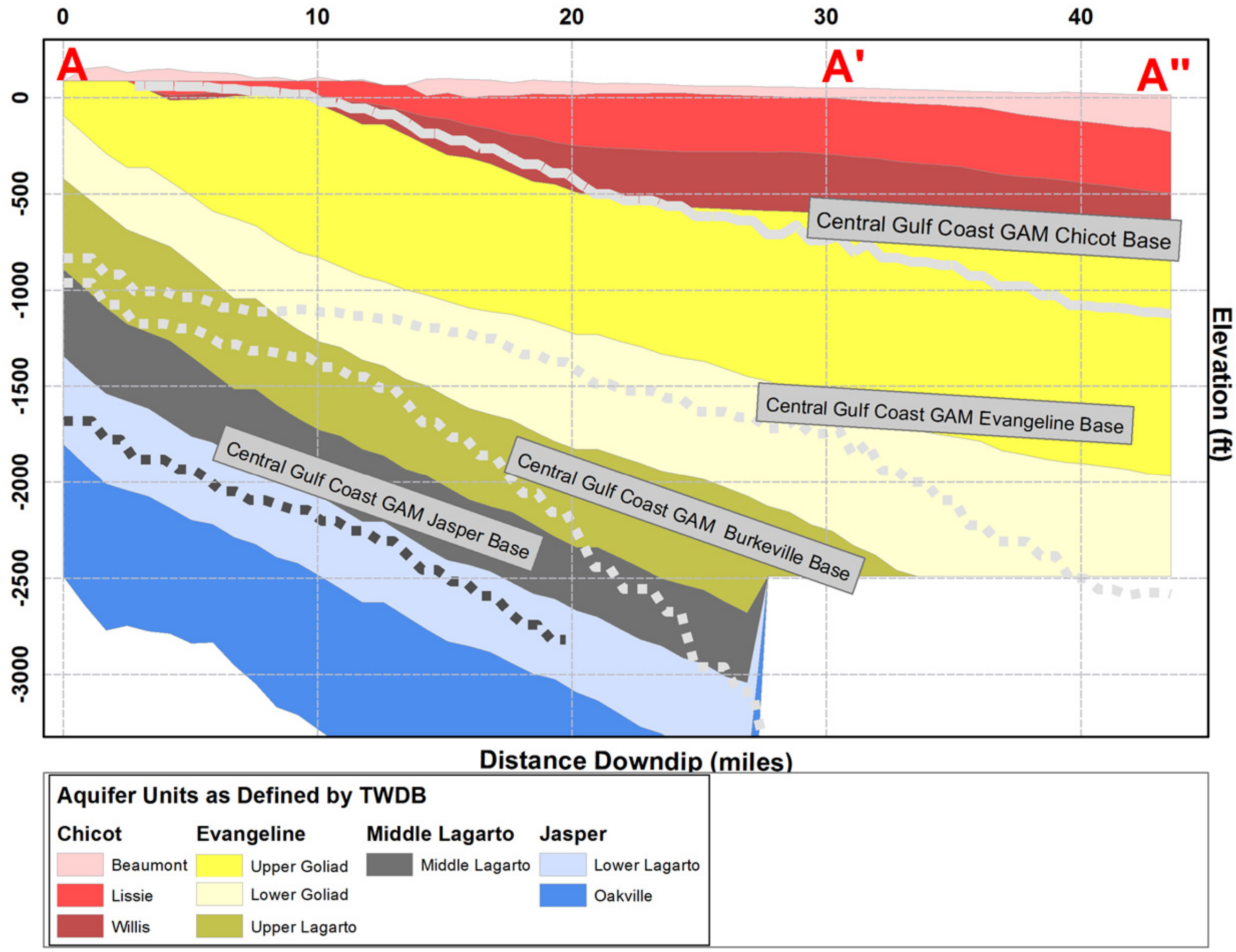


Figure 6.4: Profile of Geological Units and Aquifers from the TWDB Study (Young and others, 2010) and of Aquifers from the SWAP Study (Strom and others, 2003) that comprise the Gulf Coast Aquifer System along Cross Section B-B'

6.1.2 Sand and Clay Bed Thicknesses

Figure 6-5 shows the location of 21 geophysical logs that were analyzed to identify sand and clay beds along transects A-A'-A" and B-B' in the Study Area. **Figures 6-6 and 6-7** show the picks of sand and clay beds at the geophysical locations shown in **Figure 6-5**. For each geophysical log, a resistivity curve is plotted on the right hand side of the log markers and a spontaneous potential curve is plotted on the left hand side. Sand beds are shown as light brown and the clay beds are shown as black. For the evaluation of potential ASR storage locations, the vertical structure and the continuity among the sandy and the clayey deposits is important. To help estimate the dip and correlation of the sand beds shown in **Figures 6-6 and 6-7**, the top and bottom of geological surfaces from Young and others (2010) are shown. The changes in the vertical location of these picks can be used to help estimate the dip and correlation among the sand beds.

Our analysis of the geophysical logs suggests that there are favorable locations for ASR storage at all three potential sites shown in **Figure 6-1** and at other sites in the Study Area. At an ASR site, thick and continuous sands are desirable because that promotes a uniform penetration of injected water over a target zone and a withdrawal with minimal mixing between the injected water and the native groundwater. Visual inspection of transect A-A'-A" (**Figure 6-6**) indicates the following:

- The thickest geological formation shown in the upper 1,200 feet is the Upper Goliad, which represents the upper Evangeline Aquifer. This geological unit averages about 800 feet in thickness among the wells.
- For the Upper Goliad and younger geological units there are considerable sand beds throughout the unit, but notable differences occur in the thickness and frequency of the sand beds among the logs. For instance, for log CSA-2, the highest percent sand and the thickest sand beds occur in the upper portion of the Upper Goliad at elevations between -100 feet mean sea level (ft msl) and -300 ft msl. However, for log CSA-5, the highest percent of sand and thickest sand beds occur in the mid to lower portion of the Upper Goliad between -750 ft msl and -1000 ft msl.
- In the Evangeline Aquifer, the frequency and thickness of the sand beds in the Lower Goliad Formation are much less than in the Upper Goliad Formation. Therefore, the Upper Goliad Formation is expected to be considerably more permeable than the Lower Goliad Formation.
- In the Chicot Aquifer, the frequency and thickness of the sand beds in the Willis Formation is less than in the Lissie Formation. Therefore, the Lissie Formation is expected to be more permeable than the Willis Formation.
- Sand bed thicknesses greater than 40 feet occur throughout the cross-section and for the Upper Goliad and younger formations. For both the Upper Goliad Formation and the Lissie Formation, sand bed thicknesses greater than 100 feet occur in several logs.
- Analysis of the deflections in the resistivity curves indicate that the total dissolved solids (TDS) concentration is less than 1,500 parts per million (ppm) or milligram per liter (mg/L) in the sand beds in the Upper Goliad and younger geologic formations above an

elevation of -1500 ft msl for logs CSA-1 through CSA-7. A significant increase in the TDS concentration above 1,500 mg/L appears to occur between geophysical logs CSA-7 and CSA-8 at about -1500 ft msl. At log CSA-11, the TDS concentration is less than 1,500 mg/L only for the portion of the Chicot aquifer above -300 ft msl. [1]

Visual inspection of transect B-B' (**Figure 6-7**) indicates the following:

- The thickest geological formation shown in the upper 1,200 feet is the Upper Goliad, which represents the upper Evangeline Aquifer. This geological unit has an average thickness of about 800 feet.

[1] The 1,500 mg/L concentration for TDS is an arbitrary reference point for this study and is not intended as an indication as to whether ASR might be viable.

- Analysis of the deflections in the resistivity curves indicates that the Upper Goliad sand beds contain groundwater with a TDS greater than 1,500 mg/L south of log CSB-3; however, north of log CSB-2, the Upper Goliad sand beds contain groundwater with a TDS less than 1,500 mg/L.
- Sand bed thicknesses of greater than 100 feet occur in all geological formations except for the Beaumont Formation in the Upper Chicot Aquifer.

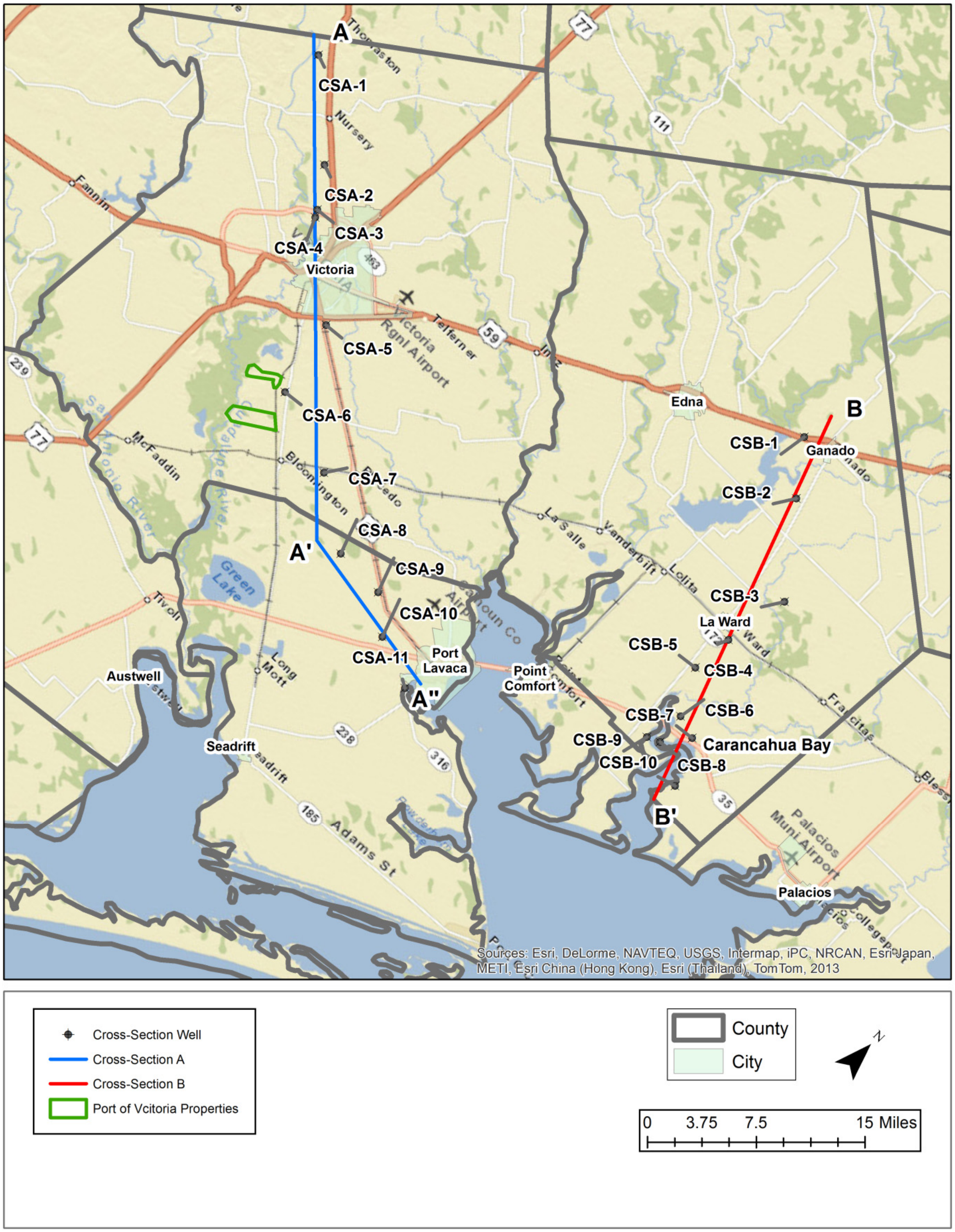


Figure 6.5: Location of Geophysical Logs along Cross Section A-A' and B-B'

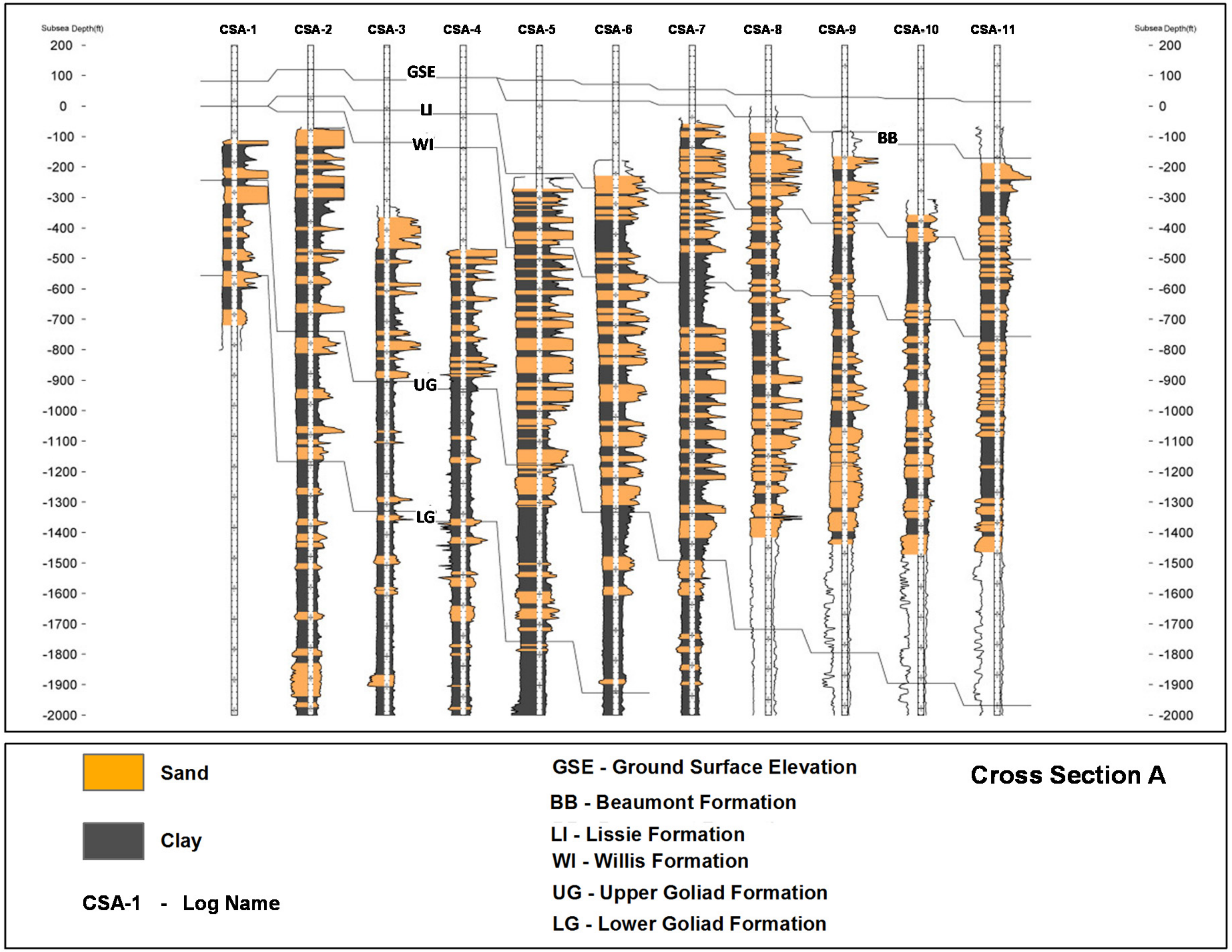


Figure 6.6: Vertical Distribution of Sand and Clay Beds along Cross Section A at 11 Geophysical Log Locations

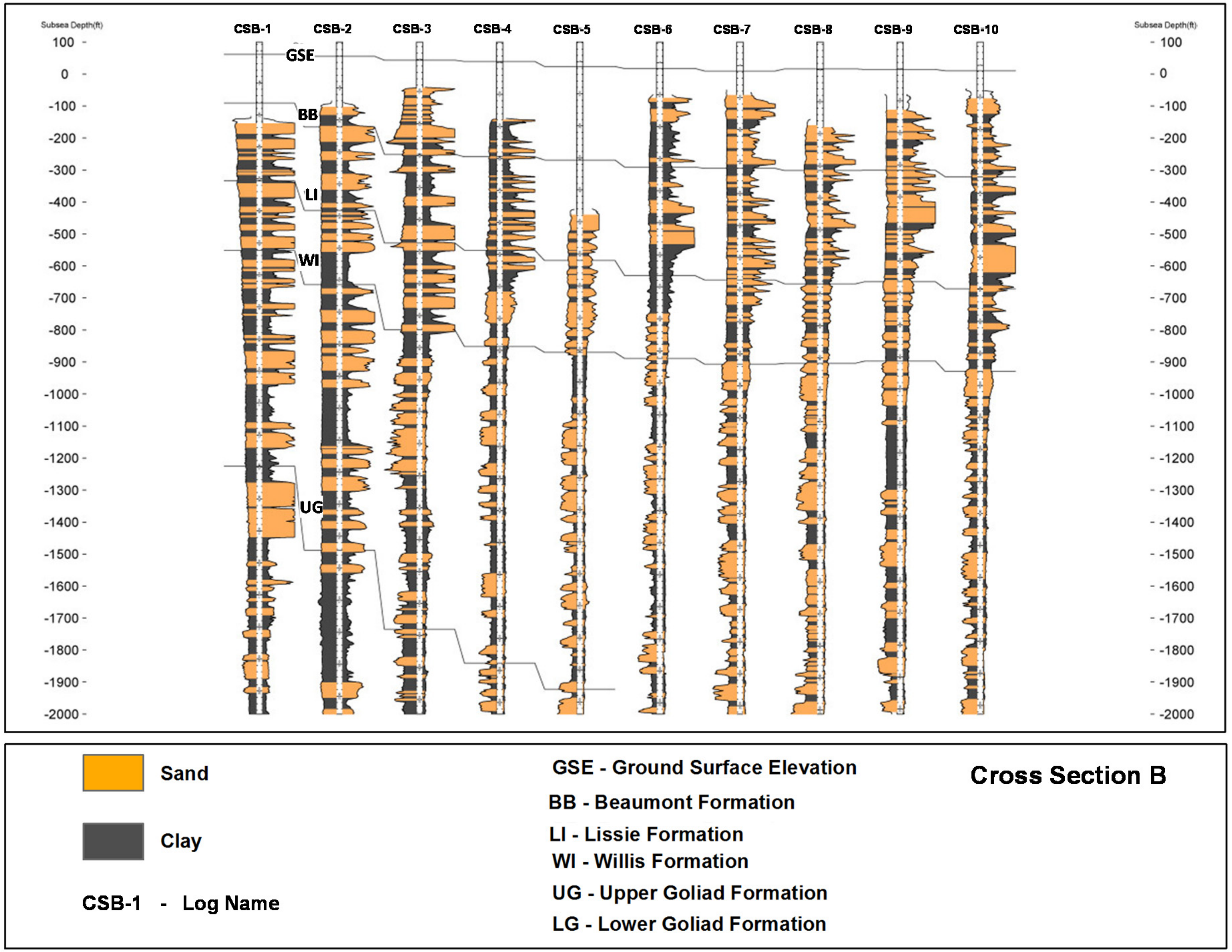


Figure 6.7: Vertical Distribution of Sand and Clay Beds along Cross Section B at 11 Geophysical Log Locations

Figure 6-8 shows the location of 14 geophysical logs located near the City of Victoria. These 14 logs can be divided into a northern group of logs (Logs CV-1 through CV-6) and a southern group of logs (Logs CV-7 through CV-14). As shown in **Figure 6-9**, the northern set of logs provides no information on the Chicot Aquifer because they start below an elevation of -300 ft msl. The 14 logs show that the Lower Goliad formation contains significantly less sand than the Upper Goliad. Whereas most of the Upper Goliad formation has a sand percentage greater than 65 percent and has a considerable number of sand beds greater than 40 ft thick, the Lower Goliad contains less than 20 percent sand and has very few sand beds greater than 40 ft thick.

Based on a distribution of sand beds in **Figure 6-9**, all of the formations younger than the Lower Goliad Formation in **Figure 6-9** would be suitable for ASR storage. The most suitable sites are where sand beds greater than 40 feet thick are bounded by clay beds 20 or more feet thick. For logs CV-1 through CV-6, sand beds thicker than 40 feet in the Upper Goliad Formation are prevalent between the elevations of -300 ft msl and -600 ft msl and between the elevation of -700 ft msl and -900 ft msl. For logs CV-6 through CV-14, sand beds thicker than 40 feet in the Upper Goliad Formation are prevalent between the elevations of -650 ft msl and -800 ft msl and between the elevations of -900 ft msl and –1000 ft msl. The offset in the sand bed intervals between the northern and the southern set of logs is a result of the dip associated with the Upper Goliad Formation deposits. In the south portion of the City of Victoria, the Willis Formation contains sand beds thicker than 40 feet between the elevations of-300 ft msl and -450 ft msl.

Figure 6-10 shows the location of geophysical logs in the vicinity of Port Lavaca and Carancahua Bay. The Port Lavaca logs in **Figure 6-11** overlap with some logs in transect A-A'-A" and provide additional resolution in the Port Lavaca area. The Carancahua Bay logs in **Figure 6-11** overlap with some logs in transect B-B' and provide additional resolution in the area of Carancahua Bay.

In the Port Lavaca Area, the geophysical signatures from logs PL-2, PL-3, and PL-4 (west Port Lavaca) suggest that below an elevation of about -350 ft msl, the groundwater has TDS concentrations above 1,500 mg/L and that the most continuous and thickest sand beds occur in the Lissie Formation and in the Upper Goliad Formation. In the Lissie Formation, sand beds with thicknesses greater than 40 feet are present between elevations -100 ft msl and -400 ft msl. In the Upper Goliad formation, sand beds with thicknesses greater than 40 feet are present between elevations -1100 ft msl and -1900 ft msl. Slightly south of Port Lavaca, the signatures in log PL-5 indicate that numerous 10-20 foot sand beds exist between -400 ft msl to -1100 ft msl. At log PL-5, sand beds greater than 40 feet thick are most prevalent below -1400 ft msl. A potentially important feature in **Figure 6-11** is that all of the logs for Port Lavaca indicate multiple intervals where the clay beds are between 50 and 200 feet. These clay beds are potentially important as confining units that hydraulically isolate the groundwater below the clay beds from the changes in water levels and groundwater flows caused by pumping in the wells above the clay beds. In addition, the clay beds would help protect the groundwater beneath the clay beds from any groundwater contamination above the clay beds.

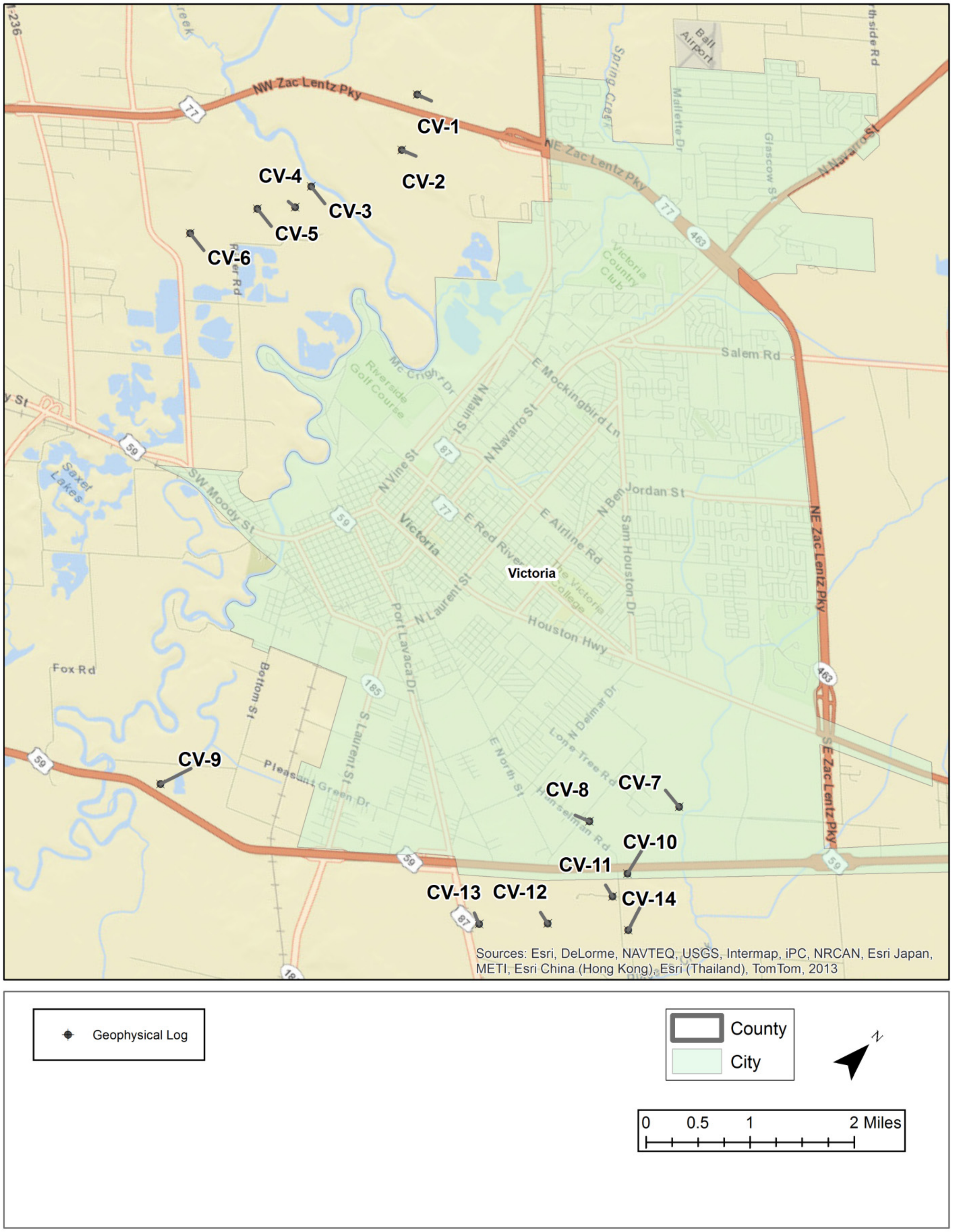


Figure 6.8: Location of Geophysical Logs in the Vicinity of the City of Victoria

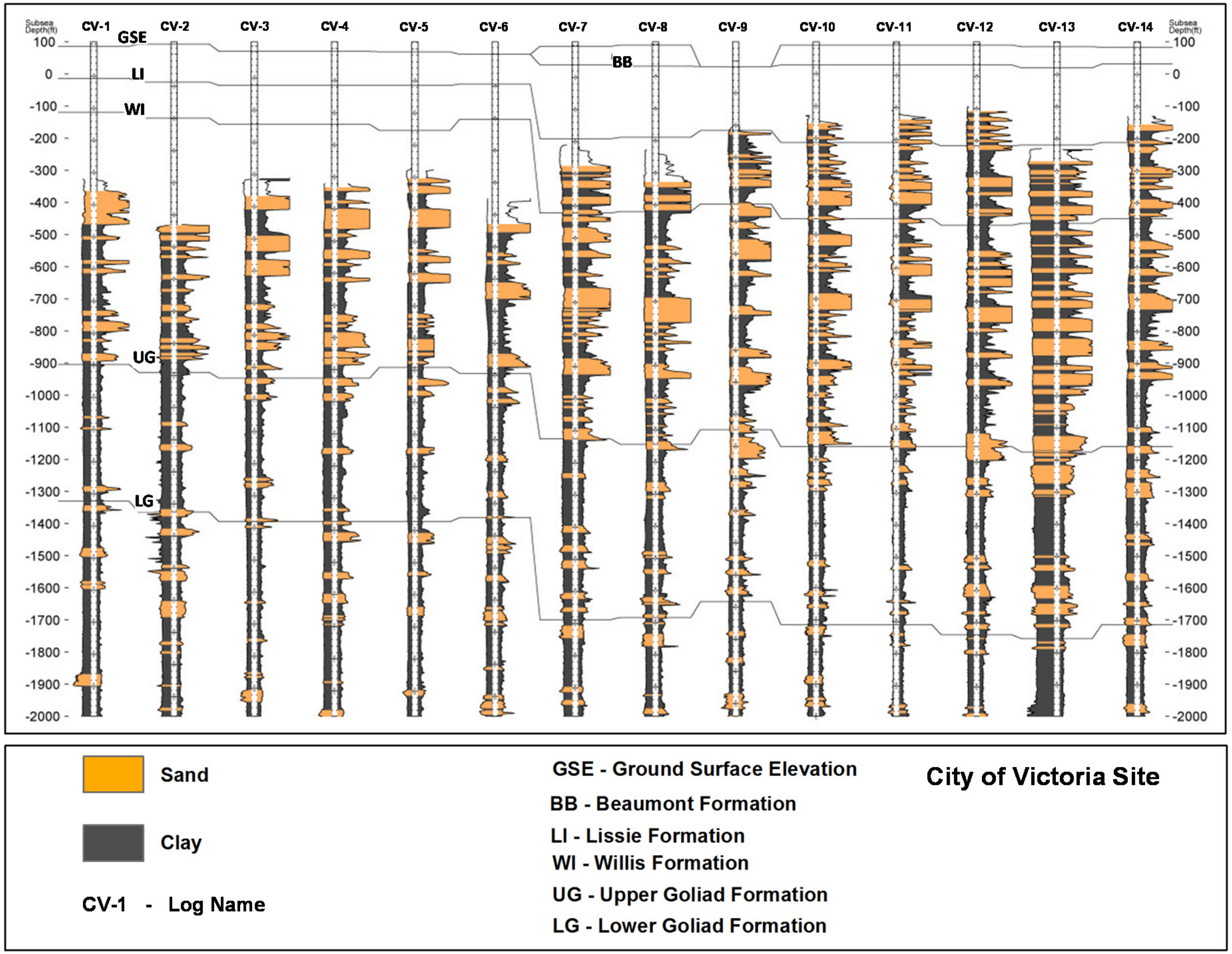


Figure 6.9: Vertical Distribution of Sand and Clay Beds in the Vicinity of the City of Victoria at 14 Geophysical Log Locations

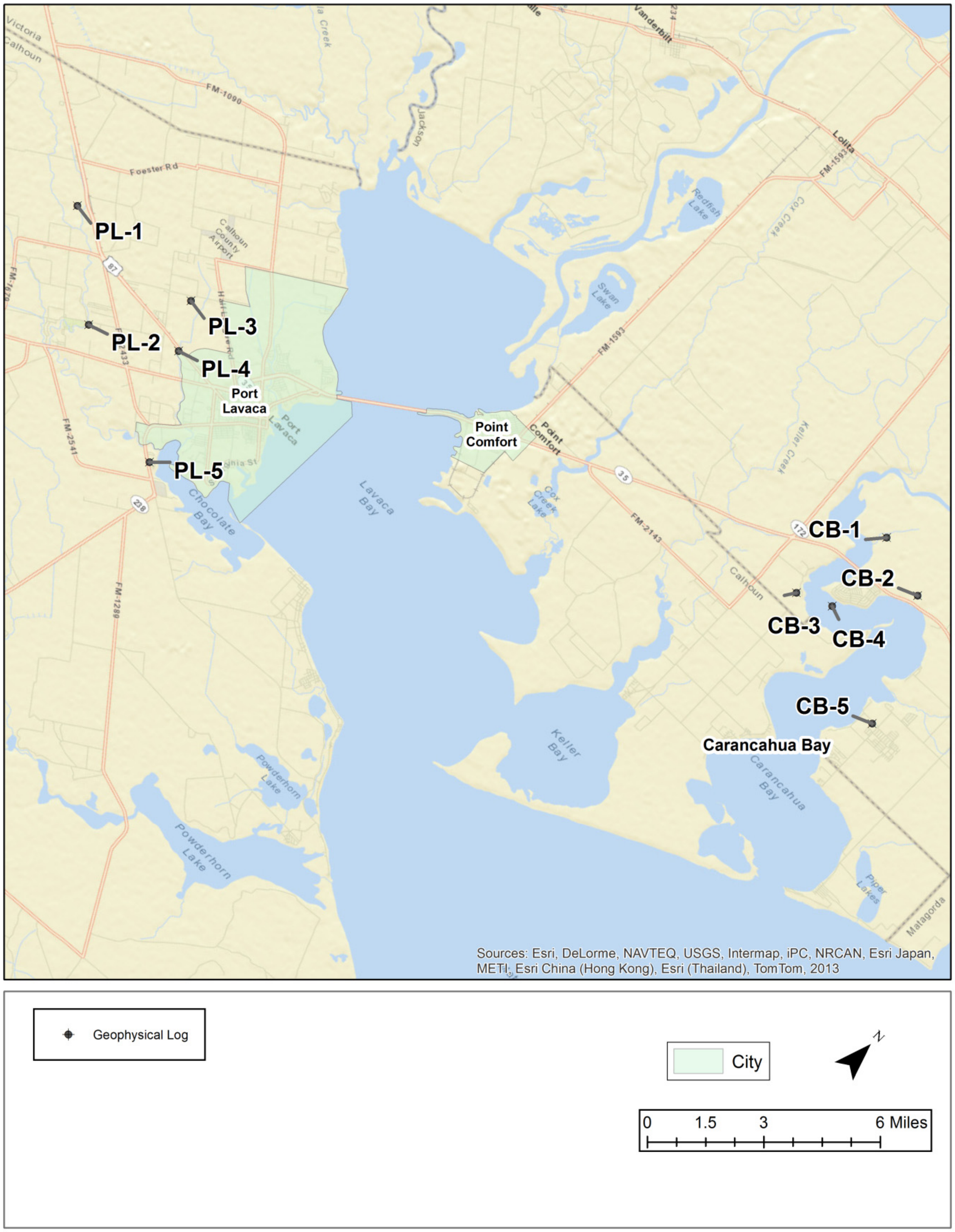


Figure 6.10: Location of Geophysical Logs in the Vicinity of the Port of Lavaca and in the Vicinity of the Carancahua Bay

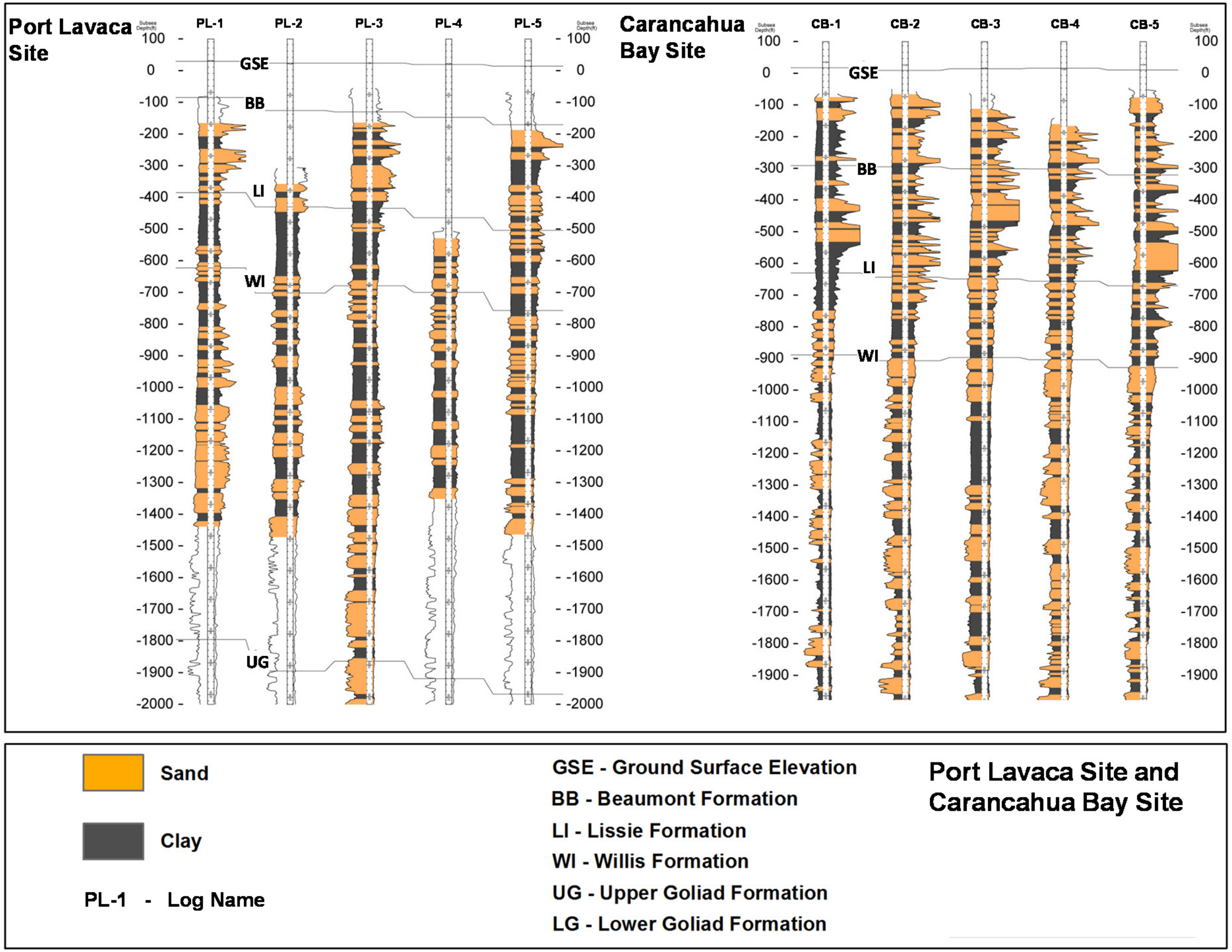


Figure 6.11: Vertical Distribution of Sand and Clay Beds in the Vicinity of Port Lavaca at 5 Geophysical Log Locations and in the Vicinity of Caranchua Bay at 5 Geophysical Log Locations

Near Carancahua Bay, the geophysical signatures in **Figure 6-11** suggest that below an elevation of -600 ft msl to -800 ft msl, the groundwater TDS concentrations are higher than 1,500 mg/L, that all of the geological units contain considerable sands, and that sand bed thicknesses greater than 100 ft occur in the Lissie and Upper Goliad Formations. In the Upper Goliad Formation, the thick sand beds are most prevalent between -900 ft msl and -1000 ft msl. Below an elevation of -1000 ft msl, the sand beds with thickness greater than 40 feet occupy about 30 percent of the Upper Goliad and are relatively well distributed vertically except at the log CB-3, where there appears to be primarily clays between elevations -1100 ft msl and -1300 ft msl.

6.2 Water Levels

Among the issues of concern for an ASR project is the migration of stored water away from the injection site over time. One of the factors that affects the rate that groundwater migrates is hydraulic gradient. At an ASR well site, a low average hydraulic gradient is desirable so that the groundwater will have a tendency not to move away from its injection point.

Figures 6-12 and 6-13 show the well locations in the TWDB groundwater database that have at least one measurement of water level for the Chicot Aquifer and the Evangeline Aquifer, respectively. **Figure 6-12** shows that less than fifteen wells in Victoria County have more than two water level measurements. **Figure 6-13** shows that there are no wells in Calhoun County and only three wells south of State Highway 59 in Jackson County with more than two water level measurements in the Evangeline Aquifer. Our attempts to produce credible hydraulic head contours based on measured well data for several time periods were unsuccessful because of the lack of data and the unknown effects of pumping wells on groundwater flow. In order to characterize the hydraulic gradients and the water levels, the CGC GAM was used to produce maps of water levels, and the water level measurements were used to construct hydrographs.

6.2.1 Contours of Simulated Water Levels

Figures 6-13 through 6-16 show the contours of the water levels predicted by the CGC GAM for the Chicot and Evangeline aquifers for 1995 and 2000. These contours provide the best set of information with which to estimate the direction of groundwater flow. All three plots show similar water level contours. In the areas of Port Lavaca and southern Jackson County, the regional hydraulic gradients are relatively flat for both the Chicot and Evangeline aquifers. However, in the vicinity of the City of Victoria the influence of pumping is evident and the regional hydraulic gradients in the Evangeline Aquifer are about 50 times greater than at the Port Lavaca and South Jackson County ASR sites. By examining the simulated water levels at the individual grid cells in the CGC GAM, estimates of the hydraulic gradients in the Evangeline Aquifer were developed — the average regional hydraulic gradient in the City of Victoria is between 0.002 to 0.005 ft/ft (10 to 26 ft/mile), whereas in the vicinity of Port Lavaca and in the Southern Jackson County sites, the regional hydraulic gradients range between 0.00004 ft/ft and 0.00007 ft/ft (0.2 to 0.4 ft/mile).

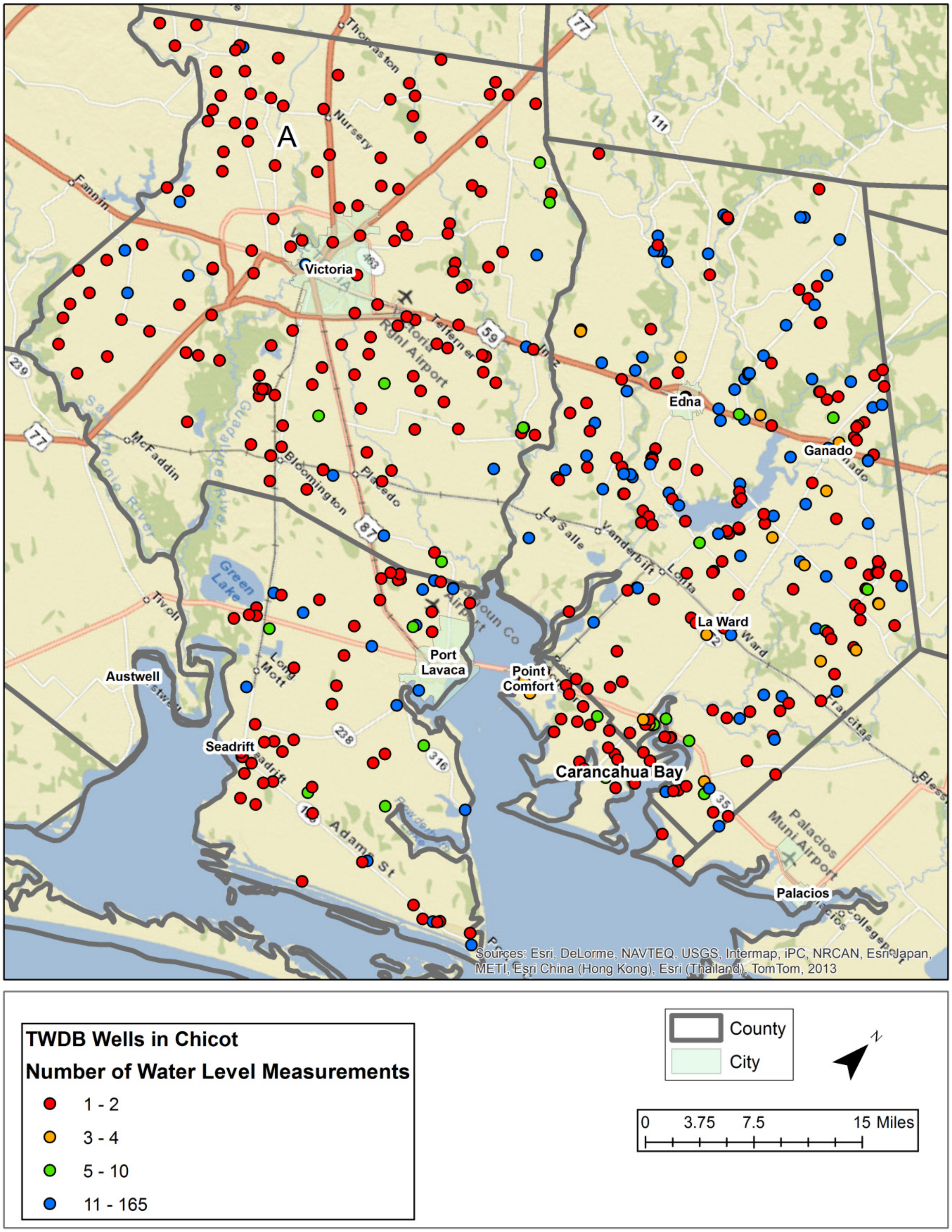


Figure 6.12: Location of Wells in the Chicot Aquifer with at least one Water Level Measurement in the TWDB Groundwater Database

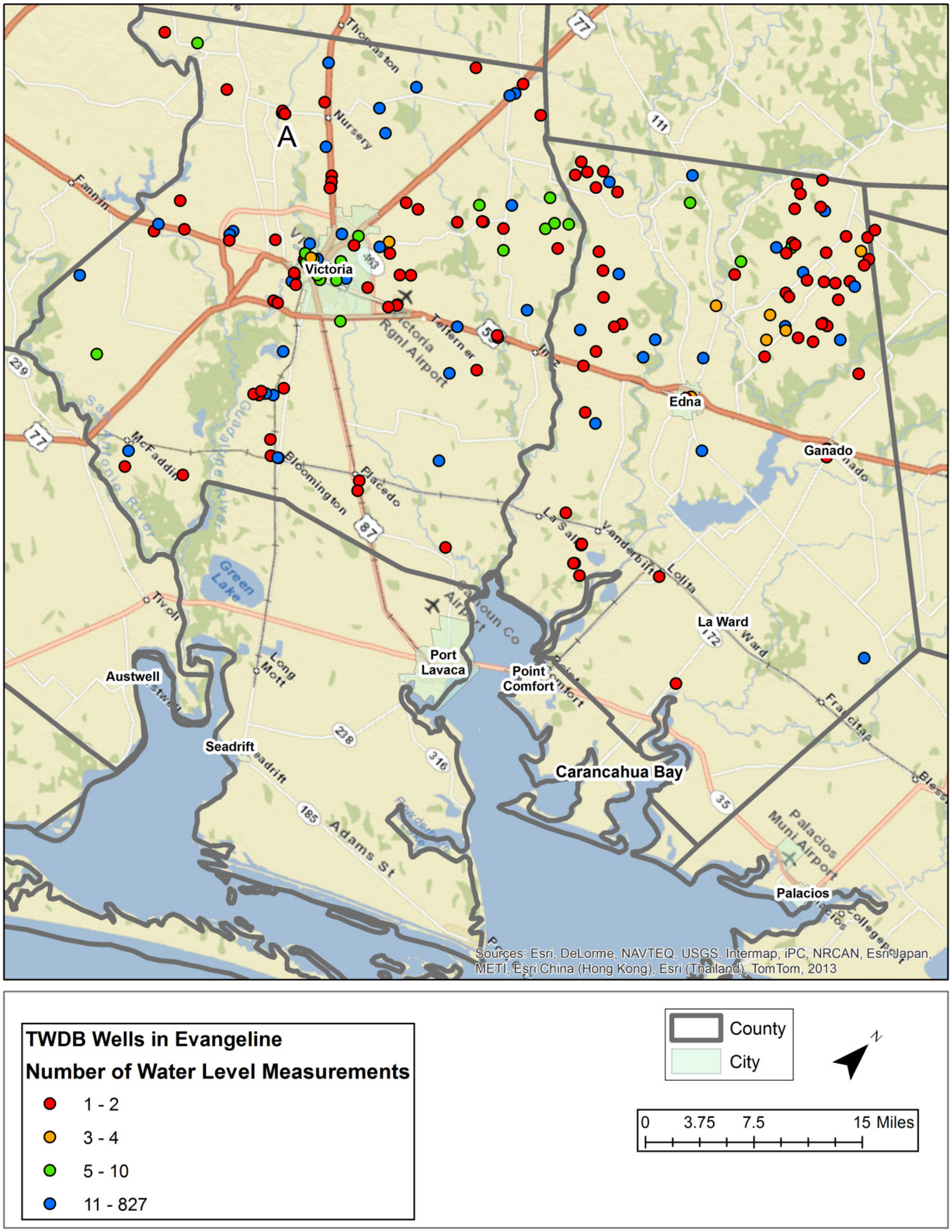


Figure 6.13: Location of Wells in the Evangeline Aquifer with at least one Water Level Measurement in the TWDB Groundwater Database

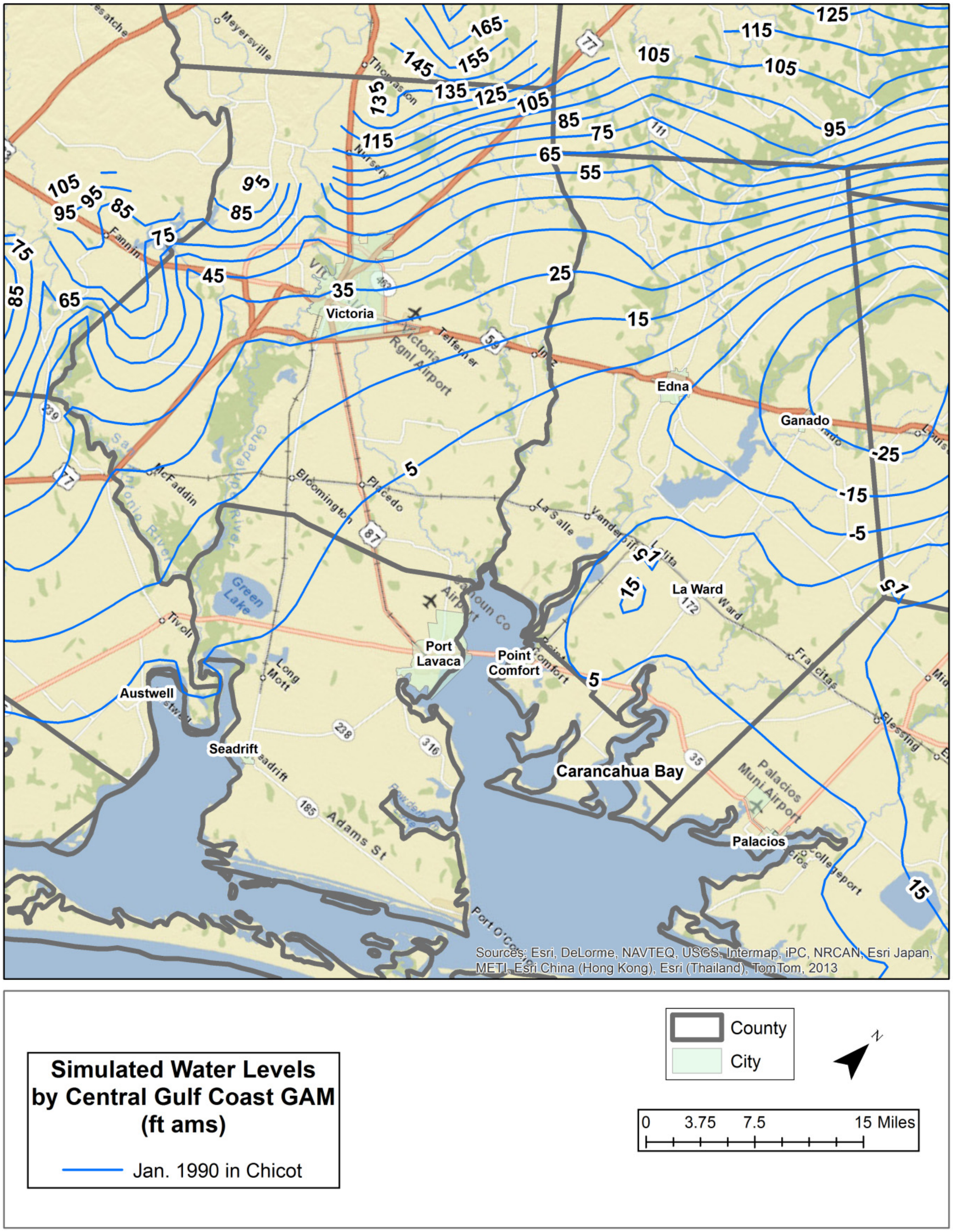


Figure 6.14: Simulated Water Levels in the Chicot Aquifer in 1995 from the Calibration Run for the Central Gulf Coast GAM (Chowdhury and others, 2004)

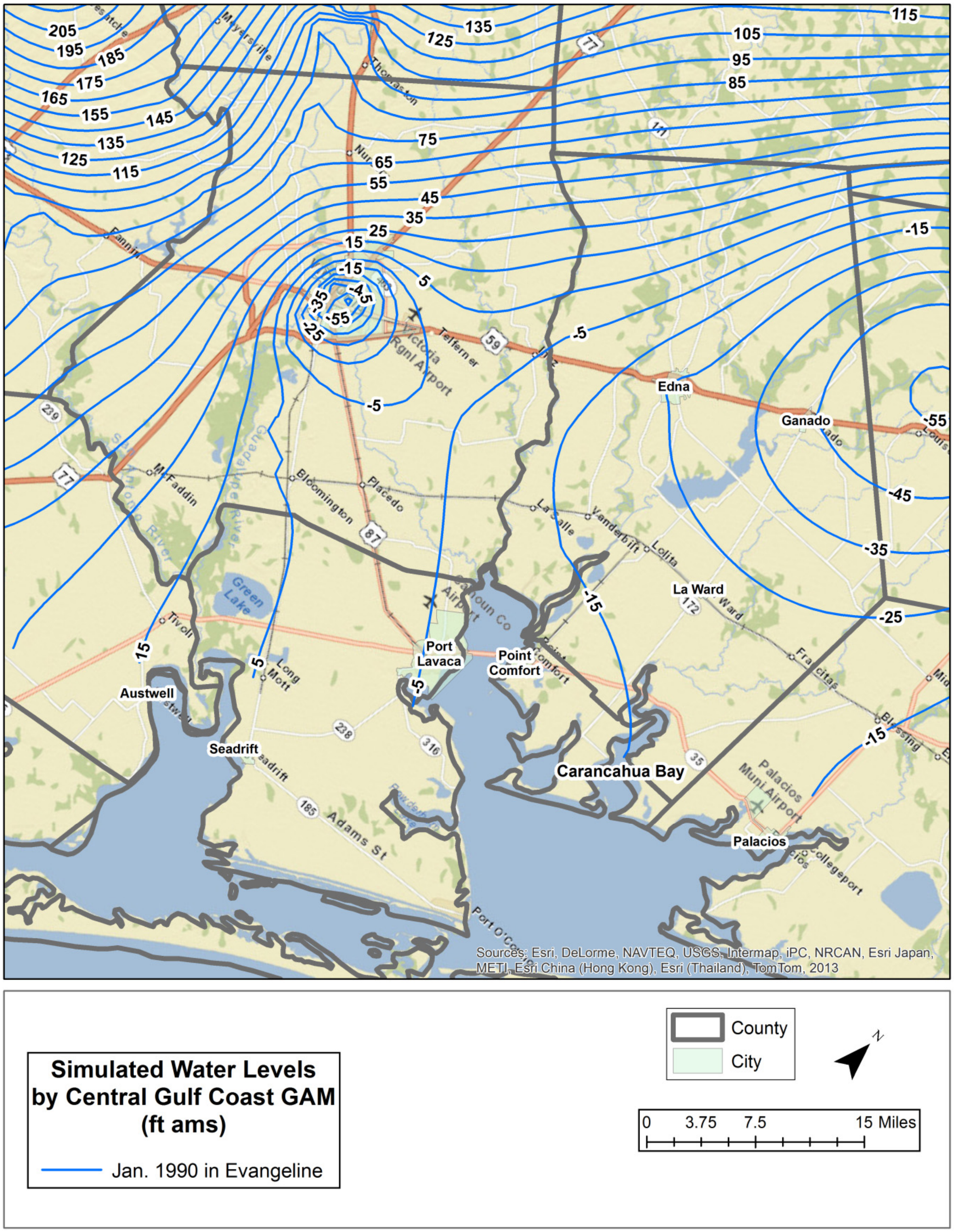


Figure 6.15: Simulated Water Levels in the Evangeline Aquifer in 1995 from the Calibration Run for the Central Gulf Coast GAM (Chowdhury and others, 2004)

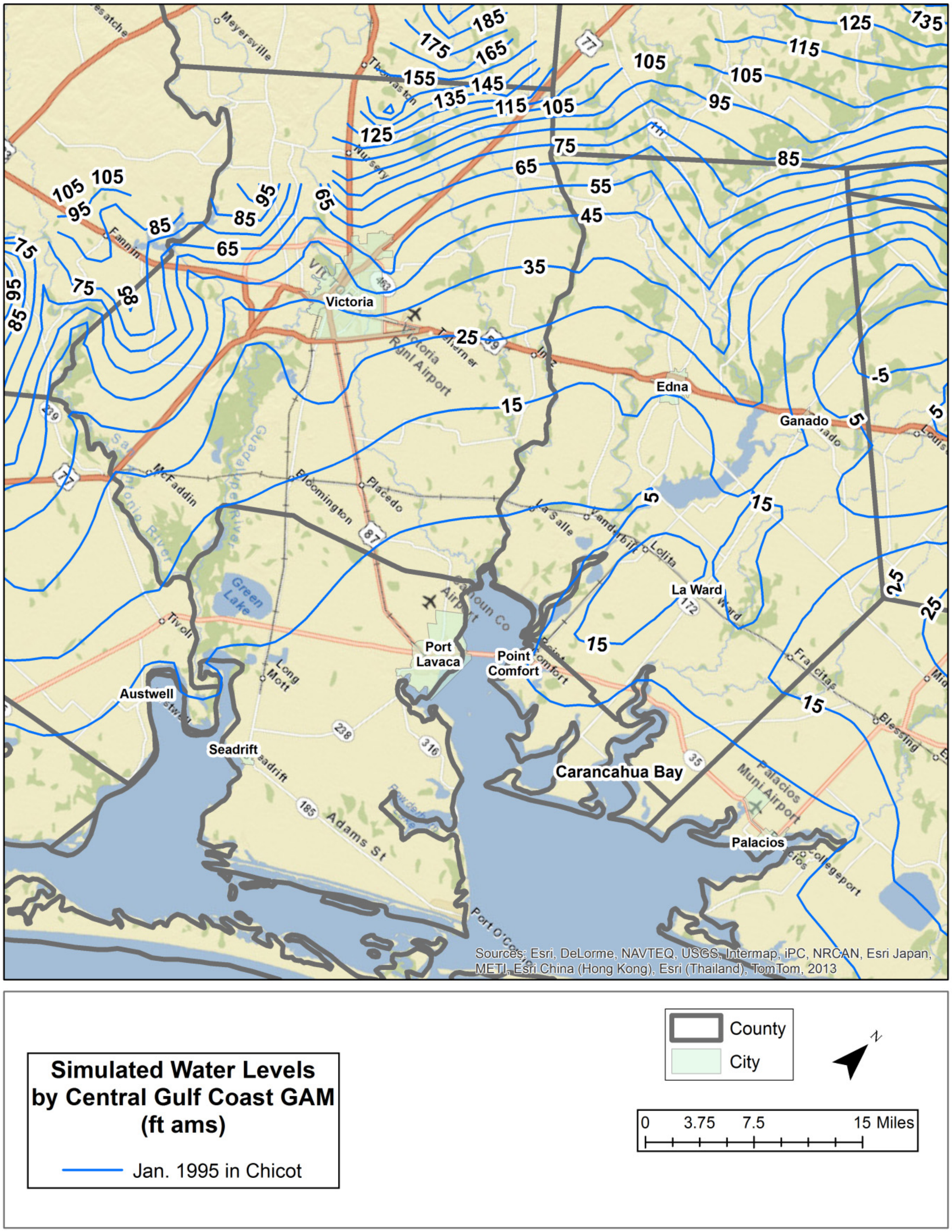


Figure 6.16: Simulated Water Levels in the Chicot Aquifer in 2000 from the Calibration Run for the Central Gulf Coast GAM (Chowdhury and others, 2004)

The primary cause for the high hydraulic gradients and cone of depression in the Evangeline Aquifer near the City of Victoria is pumping from municipal wells that averaged about 10,000 AFY from 1980 to 2000. After the year 2000, the average pumping rate was significantly reduced because the City of Victoria converted its water supply from exclusively groundwater to primarily surface water in July 2001. The city's goal is to have only 10 percent of its water supply to be pumped from groundwater. From 2001 to 2010, the average pumping rate was estimated at about 2,000 AFY. To simulate potential impact from the reduction in pumping, the CGC GAM simulation performed by Chowdhury and others (2004) was extended from 2000 to 2010. The model files for this run were developed by using the 1999 model recharge and pumping rates for the period of 2000 to 2010 with the one exception of reducing the pumping from the public water supply wells (PWS) for the City of Victoria. The pumping rate for wells in the vicinity of the City of Victoria was reduced by about 90 percent in the Evangeline from 13,606 AFY to 1,361 AFY.

Figures 6 -17 and 6-18 show the simulated water table for 2010 based on the reduction in the City of Victoria pumping discussed above. The figures show that the cone-of-depression is absent in the Evangeline aquifer as a result of a recovery in the water table. As a result of the reduced pumping and recovery from 2000 to 2010 in the vicinity of Victoria, the regional hydraulic gradient in the Evangeline Aquifer is decreased by a factor of about 20, from an average of about 0.003 ft/ft (15 ft/mile) in 2000 to about 0.0008 ft/ft (4 ft/mile) in 2010.

6.2.2 Hydrographs of Measured Water Levels

To help characterize the hydrogeology at the potential ASR storage sites, hydrographs were constructed for wells with at least five water level measurements. **Figure 6-20** shows hydrographs for the City of Victoria site. The water level measurements were obtained from the TWDB groundwater database except for measurements taken in December 2013 at wells 8009411, 8009410, and 8009408 in **Figure 6-20**. These three water level measurements were obtained as part of this study. Among the observations that are relevant to evaluating this site for ASR storage potential are:

- The recovery of water levels after the year 2000 as a result of a reduction in pumping is evident in wells 8009411, 8009408, 8009410, and 7916302. At these wells the average rise in water level from the year 2000 to years after 2008 is about 50 feet.
- Within the boundaries of the city, water level elevations measured after 2008 average about 10 ft msl, which is approximately 90 feet below land surface. Thus, if water levels rose over 90 feet, a few of these wells would become artesian and could possibly flow at the surface.
- Within the boundaries of the city, most of the wells have well screens that cover at least 500 feet and intersect the Evangeline Aquifer between the elevations of -300 ft msl and -800 ft msl.

Figure 6-21 shows the hydrographs for the Port of Lavaca storage site. Among the observations relevant to evaluating this site for ASR potential are:

- All of the wells intersect the Chicot Aquifer and the majority of the wells terminate above -300 ft msl. A review of the geophysical logs in **Figure 6-11** indicates that TDS concentrations greater than 1,500 mg/L are prevalent below an elevation of -350 ft msl.
- The elevation of the water levels in the Chicot is generally within 10 to 20 feet of the surface. Thus, if water levels rose over 10 feet, a few of these wells would become artesian and could possibly flow at the surface if not properly designed to hold pressure at the wellhead.
- Between 1990 to 2010, the majority of wells (8027601, 8027501, 8019503, 8019802, 8019506, and 8018601) show a general rise in water levels.

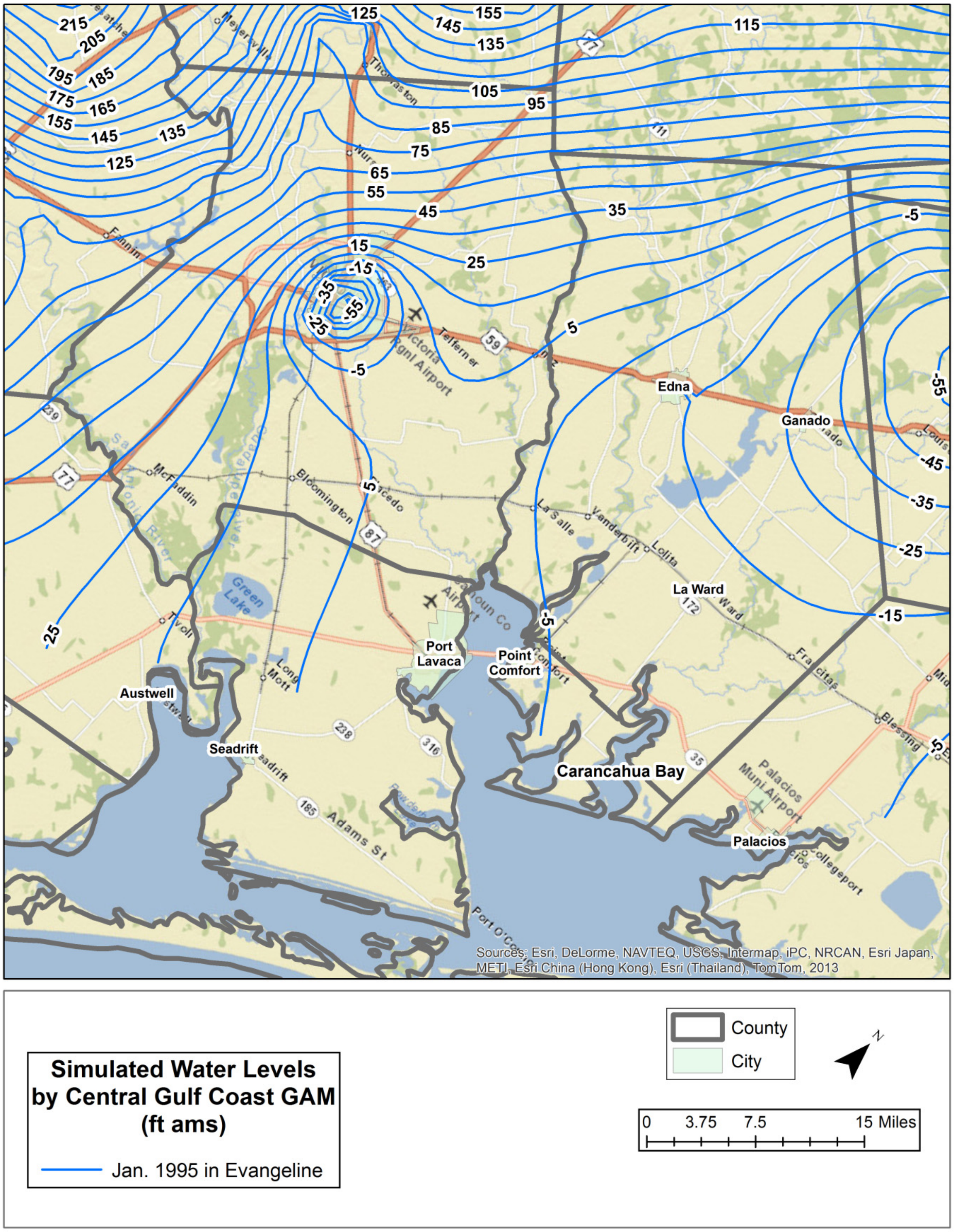


Figure 6.17: Simulated Water Levels in the Evangeline Aquifer in 2000 from the Calibration Run for the Central Gulf Coast GAM (Chowdhury and others, 2004)

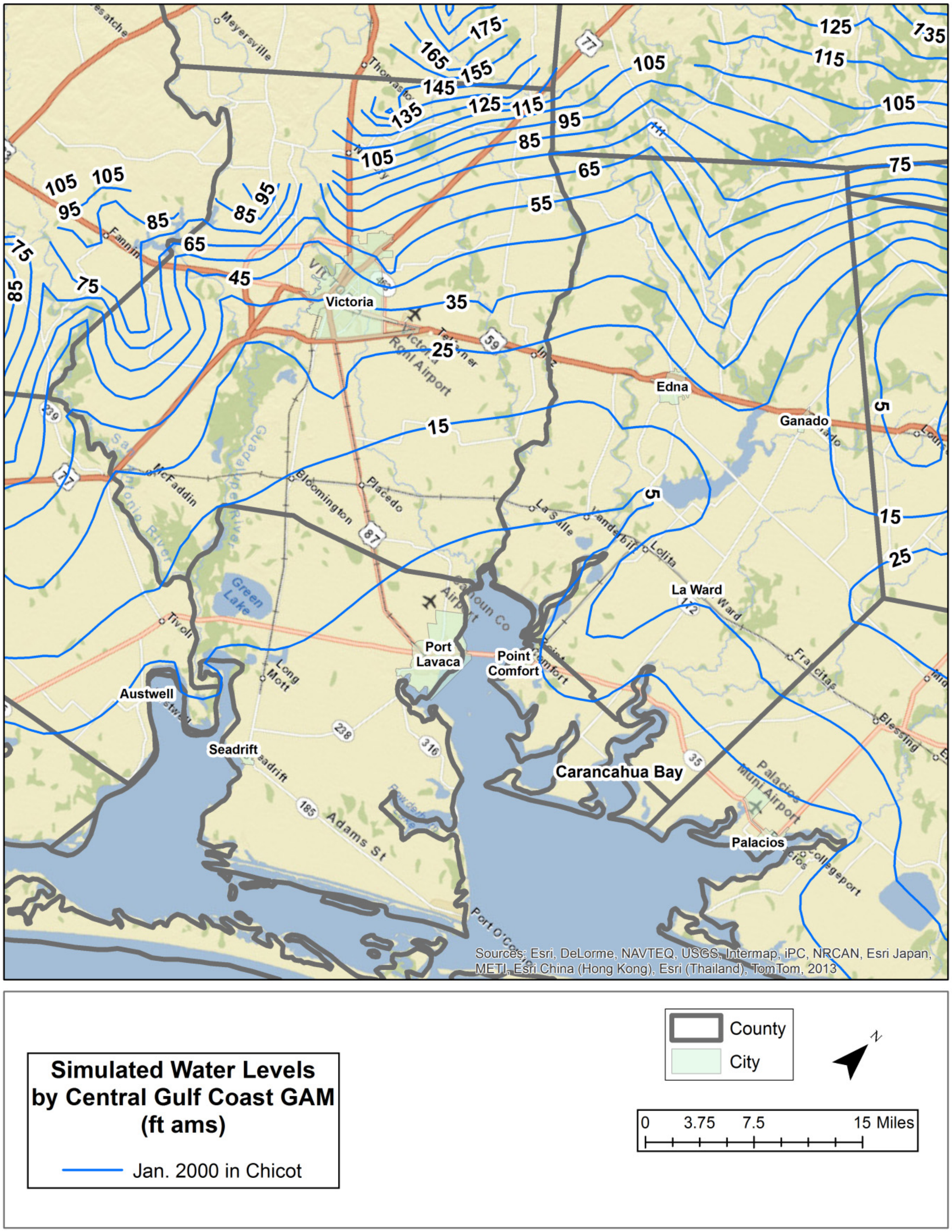


Figure 6.18: Simulated Water Levels in the Chicot Aquifer in 2010 from the Central Gulf Coast GAM Run

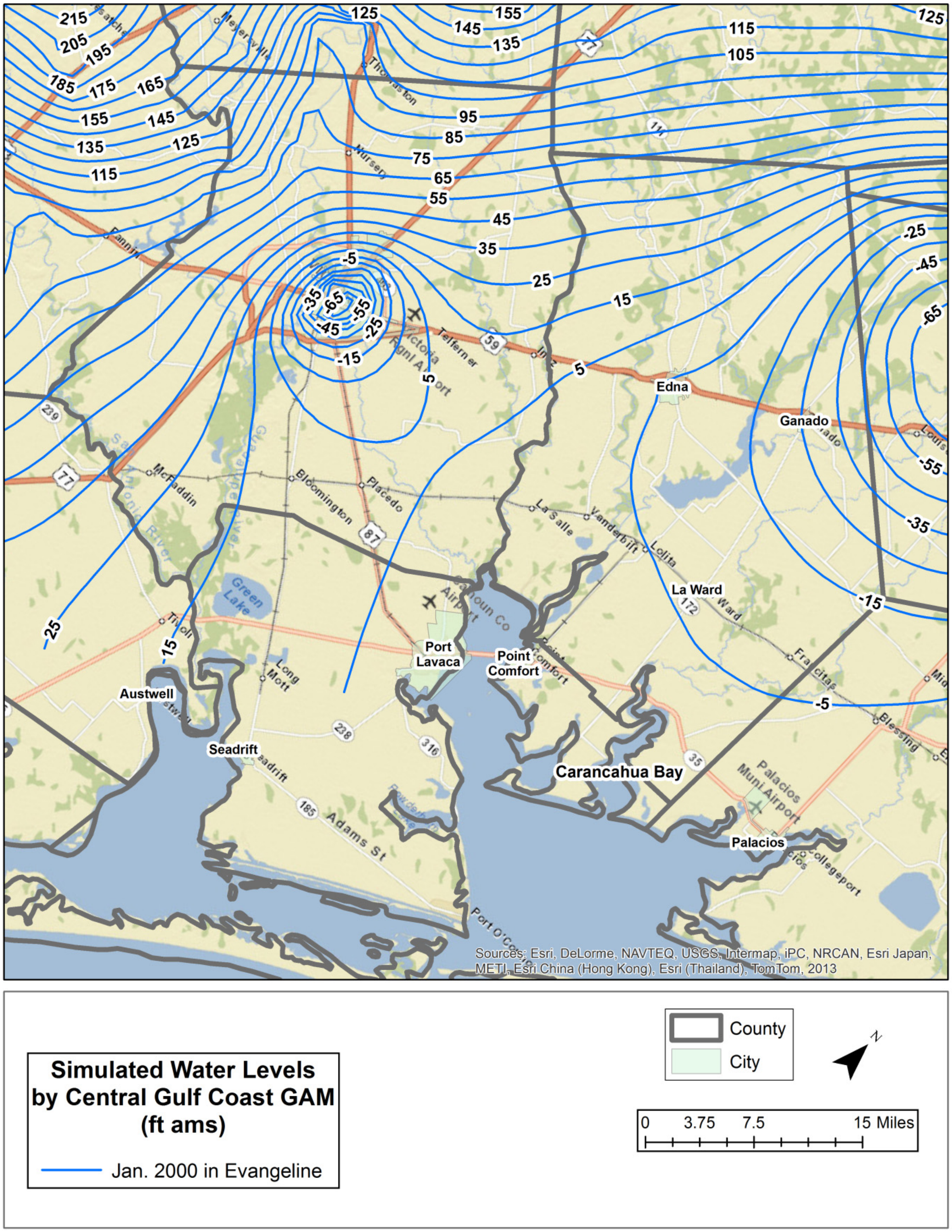


Figure 6.19: Simulated Water Levels in the Chicot Aquifer in 2010 from the Central Gulf Coast GAM Run

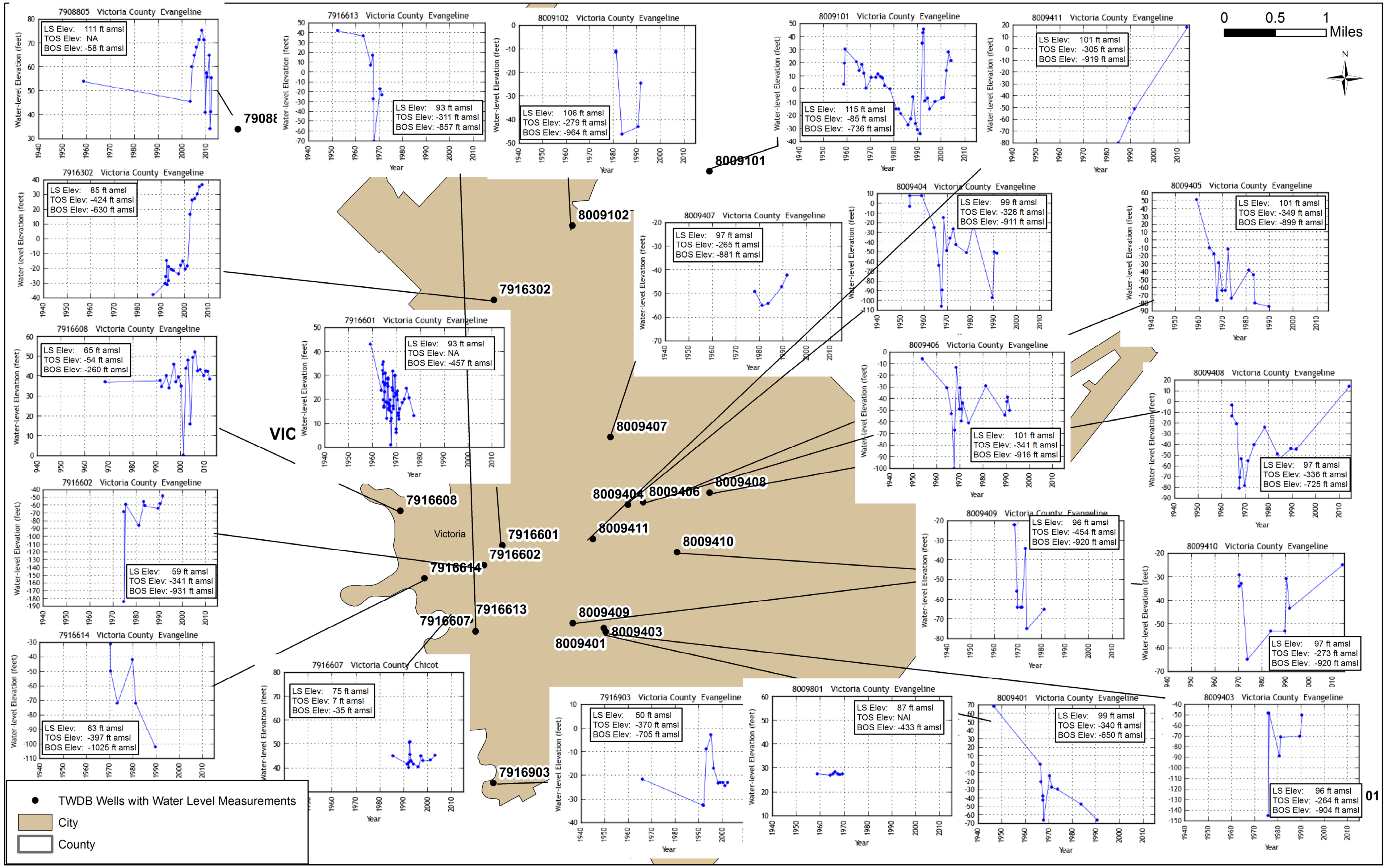


Figure 6.20: Hydrographs for Wells in the Vicinity of the City of Victoria that have at least Five Water Level Measurements in the TWDB Groundwater Database

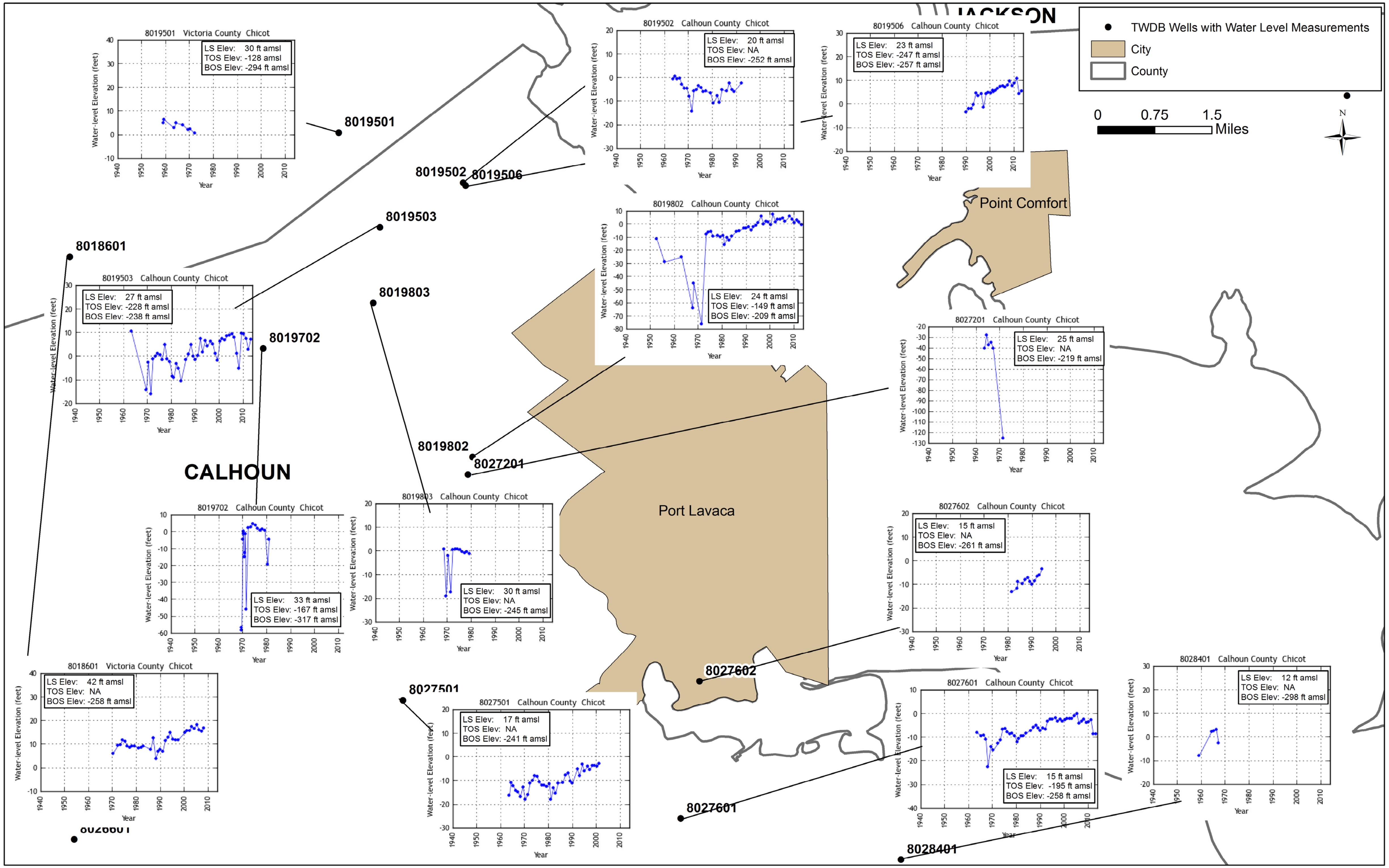


Figure 6.21: Hydrographs for Wells in the Vicinity of the Port Lavaca that have at least Five Water Level Measurements in the TWDB Groundwater Database

6.3 Transmissivity and Hydraulic Conductivity

Transmissivity, symbolically represented as "T", and hydraulic conductivity, symbolically represented as "K", are properties of an aquifer that describe the ease with which a fluid (usually water) can move through pore spaces, solution channels or fractures. It depends on the pore structure of the aquifer deposits, the degree of saturation, and the density and viscosity of the fluid. The transmissive properties of an aquifer are important to an ASR site because they affect the amount of energy required to inject and to withdraw water, and how quickly the transfer of water into and out of the aquifer can occur.

6.3.1 Definitions

In the mid-1800s the French engineer Henry Darcy successfully quantified several factors controlling ground water movement. These factors are expressed in an equation that is commonly known as Darcy's Law.

$$Q = K * A * (dh/dl) \tag{6.1}$$

Where

Q = discharge (volume of water per unit time)

K = hydraulic conductivity (volume of water per area per time)

A = cross-sectional area (at right angle to the groundwater flow direction)

dh/dl = hydraulic gradient (change of water level head per unit distance)

The hydraulic gradient term in Darcy's equation can be thought of as the slope of the water table (which is the change of the water pressure) divided by the distance over which that change takes place. Darcy's equation is the principal equation solved by groundwater models to predict the direction and magnitude of groundwater flow.

For many practical problems in water resources, transmissivity is a term often used by drillers and engineers who are trying to produce groundwater. Transmissivity is the aquifer parameter used to describe the transmissive properties of the aquifer at a given location. Transmissivity is calculated by multiplying the saturated thickness of the aquifer by the hydraulic conductivity (Equation 6.2).

$$T = b * K \tag{6.2}$$

Where:

T = transmissivity (volume of water per unit width per unit time)

b = thickness of the aquifer (length)

K= hydraulic conductivity (volume of water per unit area per unit time)

6.3.2 Transmissivity Values

Estimates of transmissivity for an aquifer are most commonly obtained from the analysis of aquifer pumping tests. Aquifer pumping tests involve pumping a well and measuring the drawdown response in the pumping well and/or observation wells. The design, implementation, and analysis of the pumping tests affect how accurately the calculated transmissivity values reflect the transmissivity of the aquifer system.

Our review of USGS and TWDB reports reveal 85 transmissivity values for the three county Study Area. **Table 6-2** provides these values. The 85 transmissivity values were obtained from tabulated lists of transmissivity values from a hydrogeologic report for Jackson County (Baker, 1965), a hydrogeologic report for Victoria and Calhoun Counties (Marvin and others, 1962), and a compilation of results from aquifer pumping tests for Texas assembled by Myers (1969).

In **Table 6-2**, the pumping tests are identified by a Well ID associated with the pumping well. Most of the pumping wells were identified in the hydrogeologic reports by a TWDB state well number. For these wells the latitude and longitude for each well were obtained from the TWDB groundwater database. The wells without a state well number in **Table 6-2** were assigned an ID that begins with “9999” and have the word “Study” as the source for the ID name. The latitude and longitude for these wells are based on the maps in the hydrogeological reports showing their locations. Out of the 85 transmissivity values, 62 are for the Chicot Aquifer and 23 are for the Evangeline Aquifer. These were augmented by an additional 18 transmissivity values from Evangeline wells in Victoria County. The additional transmissivity values were extracted from a report that INTERA prepared for the Victoria County Groundwater Conservation District (GCD) (Young, 2014). The Well IDs for these 18 wells are the same IDs used by the TCEQ to identify these wells.

Table 6-2: Transmissivity Values Obtained from Hydrogeologic Reports

Well Name		County	Projection (NAD 83)		Grd Surf. (ft msl)	Screen Depth (ft)		Sreen Len.(ft)	Tran.	Hydr. Cond.	Frac. of Screen	
ID/Number	Source		Latitude	Longitude		Top	Bottom		(ft2/day)	(ft/day)	Chic.	Evang.
6650801	TWDB	Jackson	29.1397	-96.8011	40	229	886	657	5784	8.8	0.08	0.92
6651202	TWDB	Jackson	29.2283	-96.7058	38	100	720	620	7828	12.6	0.43	0.57
6651305	TWDB	Wharton	29.2300	-96.6336	41	225	1010	785	3111	3.8	0.3	0.7
6651505	TWDB	Jackson	29.2083	-96.6825	41	300	627	327	5398	16.5	0.34	0.66
6651509	TWDB	Jackson	29.2081	-96.6883	41	170	729	559	8290	14.8	0.43	0.57
6651604	TWDB	Jackson	29.2056	-96.6286	38	240	663	423	4460	10.5	0.55	0.45
6651801	TWDB	Jackson	29.1628	-96.6831	37	100	616	516	1157	2.2	0.65	0.35
6651903	TWDB	Jackson	29.1494	-96.6544	34	100	618	518	2082	4.0	0.71	0.29
6651904	TWDB	Jackson	29.1467	-96.6461	34	110	592	482	7455	15.5	0.76	0.24
6652407	TWDB	Jackson	29.1761	-96.6081	34	280	960	680	7545	11.1	0.37	0.63
6652504	TWDB	Wharton	29.2053	-96.5492	34	218	745	527	7699	14.6	0.62	0.38
6652705	TWDB	Jackson	29.1286	-96.5997	29	308	812	504	8689	17.2	0.47	0.53
6652706	TWDB	Jackson	29.1264	-96.6050	29	180	743	563	8817	15.7	0.63	0.37
6652907	TWDB	Jackson	29.1369	-96.5297	27	130	490	360	5951	16.5	1.00	0.00
6658702	TWDB	Calhoun	29.0083	-96.8650	32	140	600	460	4936	10.7	0.22	0.78
6658801	TWDB	Jackson	29.0197	-96.8136	27	133	663	530	6015	11.3	0.36	0.64

Well Name		County	Projection (NAD 83)		Grd Surf. (ft msl)	Screen Depth (ft)		Sreen Len.(ft)	Tran.	Hydr. Cond.	Frac. of Screen	
ID/Number	Source		Latitude	Longitude		Top	Bottom		(ft2/day)	(ft/day)	Chic.	Evang.
6658903	TWDB	Jackson	29.0181	-96.7839	26	205	695	490	6041	12.3	0.31	0.69
6659303	TWDB	Jackson	29.0961	-96.6478	28	70	607	537	18123	33.7	0.80	0.20
6659308	TWDB	Jackson	29.1222	-96.6475	30	221	755	534	6877	12.9	0.51	0.49
6659501	TWDB	Jackson	29.0644	-96.6925	27	153	666	513	4653	9.1	0.61	0.39
6659601	TWDB	Jackson	29.0758	-96.6328	25	250	843	593	6144	10.4	0.48	0.52
6659901	TWDB	Jackson	29.0183	-96.6647	23	183	628	445	7545	17.0	0.74	0.26
6660106	TWDB	Jackson	29.0997	-96.6119	28	210	570	360	4820	13.4	0.92	0.08
6660201	TWDB	Jackson	29.1172	-96.5439	27	154	669	515	10437	20.3	0.95	0.05
6660205	TWDB	Jackson	29.1061	-96.5436	26	97	224	127	12553	98.8	1.00	0.00
6660505	TWDB	Jackson	29.0775	-96.5583	23	135	316	181	14910	82.4	1.00	0.00
6660505	TWDB	Jackson	29.0775	-96.5583	23	135	316	181	14910	82.4	1.00	0.00
6660603	TWDB	Jackson	29.0694	-96.5022	23	64	274	210	5717	27.2	1.00	0.00
6660603	TWDB	Jackson	29.0694	-96.5022	23	54	274	220	5717	26.0	1.00	0.00
6660608	TWDB	Jackson	29.0803	-96.5075	24	112	234	122	7099	58.2	1.00	0.00
6660608	TWDB	Jackson	29.0803	-96.5075	24	112	234	122	7099	58.2	1.00	0.00
6660609	TWDB	Jackson	29.0781	-96.5075	24	42	130	88	18717	212.7	1.00	0.00
6660703	TWDB	Jackson	29.0186	-96.5842	15	132	513	381	7494	19.7	1.00	0.00
6660705	TWDB	Jackson	29.0183	-96.6203	22	132	513	381	7794	20.5	1.00	0.00
6660902	TWDB	Jackson	29.0411	-96.5133	19	1185	1291	106	1118	10.5	0.00	1.00
6660902	TWDB	Jackson	29.0411	-96.5133	19	1135	1291	156	1118	7.2	0.00	1.00
6661702	TWDB	Jackson	29.0117	-96.4839	19	227	315	88	17095	194.3	1.00	0.00
6661702	TWDB	Jackson	29.0117	-96.4839	19	127	315	188	17095	90.9	1.00	0.00
6661803	TWDB	Jackson	29.0183	-96.4314	19	105	317	212	11364	53.6	1.00	0.00
6661803	TWDB	Jackson	29.0183	-96.4314	19	67	317	250	11364	45.5	1.00	0.00
8002601	TWDB	Jackson	28.9514	-96.7714	22	165	849	684	8278	12.1	0.41	0.59
8003202	TWDB	Jackson	28.9767	-96.7078	21	194	880	686	17352	25.3	0.43	0.57
8003301	TWDB	Jackson	28.9825	-96.6458	21	970	1195	225	3470	15.4	0.00	1.00
8004403	TWDB	Jackson	28.9519	-96.6003	17	222	679	457	4884	10.7	0.84	0.16
8005310	TWDB	Jackson	28.9897	-96.3908	17	115	210	95	8907	93.8	1.00	0.00
8005507	TWDB	Jackson	28.9439	-96.4472	15	178	795	617	13239	21.5	1.00	0.00
8005701	TWDB	Jackson	28.9053	-96.4989	15	120	429	309	5643	18.3	1.00	0.00
8006101	TWDB	Jackson	28.9981	-96.3636	20	85	550	465	11440	24.6	1.00	0.00
8006102	TWDB	Jackson	28.9692	-96.3678	18	104	364	260	8817	33.9	1.00	0.00
8006703	TWDB	Jackson	28.8778	-96.3350	12	154	590	436	10154	23.3	1.00	0.00
8006704	TWDB	Jackson	28.8875	-96.3678	13	146	430	284	13470	47.4	1.00	0.00
8010101	TWDB	Calhoun	28.8667	-96.8608	27	270	880	610	10411	17.1	0.27	0.73
8010701	TWDB	Calhoun	28.7750	-96.8722	23	160	450	290	6015	20.7	1.00	0.00
8011201	TWDB	Jackson	28.8669	-96.6783	15	117	572	455	6812	15.0	1.00	0.00
8012502	TWDB	Jackson	28.8097	-96.5489	11	90	330	240	9225	38.4	1.00	0.00
8013404	TWDB	Jackson	28.8258	-96.4672	11	150	510	360	955	2.7	1.00	0.00
8013404	TWDB	Jackson	28.8258	-96.4672	11	130	510	380	955	2.5	1.00	0.00
8013901	TWDB	Jackson	28.7900	-96.3847	6	240	775	535	5775	10.8	1.00	0.00
8013901	TWDB	Jackson	28.7900	-96.3847	6	140	775	635	5775	9.1	1.00	0.00
8014103	TWDB	Jackson	28.8353	-96.3608	9	200	752	552	9692	17.6	1.00	0.00
8014401	TWDB	Jackson	28.8239	-96.3617	9	150	710	560	16838	30.1	1.00	0.00
8019501	TWDB	Calhoun	28.6897	-96.7061	9	158	324	166	2725	16.4	1.00	0.00
8020803	TWDB	Calhoun	28.6594	-96.5508	6	250	359	109	3890	35.7	1.00	0.00

Well Name		County	Projection (NAD 83)		Grd Surf. (ft msl)	Screen Depth (ft)		Sreen Len.(ft)	Tran.	Hydr. Cond.	Frac. of Screen	
ID/Number	Source		Latitude	Longitude		Top	Bottom		(ft2/day)	(ft/day)	Chic.	Evang.
8021201	TWDB	Jackson	28.7250	-96.4444	6	412	467	55	2555	46.5	1.00	0.00
8021601	TWDB	Jackson	28.6861	-96.3853	11	317	635	318	3155	9.9	1.00	0.00
8021601	TWDB	Jackson	28.6861	-96.3853	11	317	635	318	3155	9.9	1.00	0.00
8022501	TWDB	Jackson	28.6994	-96.3233	4	288	370	82	2648	32.3	1.00	0.00
9999129	Study	Calhoun	28.5580	-96.7770	29	185	269	84	4313	51.3	1.00	0.00
9999227	Study	Calhoun	28.6250	-96.6830	23	162	233	71	2139	30.1	1.00	0.00
9999325	Study	Calhoun	28.5040	-96.5990	10	252	359	107	2139	20.0	1.00	0.00
9999327	Study	Calhoun	28.6670	-96.5670	2	260	375	115	3342	29.1	1.00	0.00
99991003	Study	Victoria	28.8700	-96.9590	119	270	330	60	11630	193.8	0.42	0.58
99991021	Study	Victoria	28.8200	-96.9850	97	160	450	290	3476	12.0	0.43	0.57
99991021	Study	Victoria	28.8200	-96.9850	97	153	324	171	3476	20.3	1.00	0.00
99991102	Study	Victoria	28.8670	-96.8570	68	270	330	60	11096	184.9	1.00	0.00
99991118	Study	Victoria	28.7760	-96.8670	65	160	450	290	6233	21.5	1.00	0.00
99991815	Study	Victoria	28.6890	-96.7090	26	155	324	169	2807	16.6	1.00	0.00
99991921	Study	Victoria	28.5410	-97.0020	50	135	798	663	7086	10.7	0.53	0.47
99991922	Study	Victoria	28.5480	-97.0060	67	185	1003	818	7648	9.3	0.68	0.32
99991923	Study	Victoria	28.8210	-96.9850	98	435	1000	565	7327	13.0	0.00	1.00
99991924	Study	Victoria	28.8680	-96.9640	114	200	881	681	10441	15.3	0.86	0.14
99991925	Study	Victoria	28.6790	-96.9480	68	587	1029	442	8612	19.5	0.00	1.00
99991926	Study	Calhoun	28.2810	-96.9840	98	420	1020	600	5219	8.7	0.17	0.83
99991927	Study	Calhoun	28.3330	-96.4590	0	270	310	40	2888	72.2	0.00	1.00
99991928	Study	Calhoun	28.6260	-96.6410	16	173	233	60	1752	29.2	1.00	0.00
G2350001B	TCEQ	Victoria	28.6474	-96.8952	56	784	996	212	10512	20.1	0.00	1.00
G2350002A	TCEQ	Victoria	28.8210	-96.9843	97	442	1000	558	6018	10.8	0.00	1.00
G2350002B	TCEQ	Victoria	28.8207	-96.9876	97	425	1010	585	6461	11.0	0.00	1.00
G2350002D	TCEQ	Victoria	28.8222	-96.9735	94	433	801	368	4437	12.1	0.00	1.00
G2350002F	TCEQ	Victoria	28.8305	-96.9895	98	362	978	616	6712	10.9	0.00	1.00
G2350002G	TCEQ	Victoria	28.8162	-96.9923	97	406	1020	614	5468	8.9	0.00	1.00
G2350002H	TCEQ	Victoria	28.8123	-97.0018	73	400	1044	644	5601	8.7	0.00	1.00
G2350002I	TCEQ	Victoria	28.8108	-97.0198	49	460	1048	588	7480	12.7	0.00	1.00
G2350002J	TCEQ	Victoria	28.8127	-97.0098	73	400	990	590	10088	17.1	0.00	1.00
G2350002M	TCEQ	Victoria	28.8017	-96.9906	88	360	1000	640	3786	5.9	0.00	1.00
G2350002N	TCEQ	Victoria	28.8608	-96.9931	109	385	1070	685	18153	12.5	0.00	1.00
G2350002O	TCEQ	Victoria	28.8639	-96.9769	118	556	1124	568	9414	16.6	0.00	1.00
G2350005C	TCEQ	Victoria	28.8317	-96.9231	92	496	526	30	1772	59.1	0.00	1.00
G2350006B	TCEQ	Victoria	28.6886	-96.8213	49	425	490	65	7180	110.5	0.00	1.00
G2350014B	TCEQ	Victoria	28.6756	-96.9568	61	595	1045	450	6337	14.1	0.00	1.00
G2350014C	TCEQ	Victoria	28.6767	-96.9503	61	241	442	201	2033	10.1	0.00	1.00
G2350054A	TCEQ	Victoria	28.8815	-97.1723	189	235	255	20	1293	64.7	0.00	1.00
G2350056A	TCEQ	Victoria	28.7843	-97.0433	59	230	250	20	272	13.6	0.00	1.00

The locations of 103 transmissivity values in **Table 6-2** are shown in **Figures 6-22 and 6-23**. In these figures, the transmissivity distributions from the CGC GAM model are compared to the transmissivity values obtained from the literature. Among the points of interest in these two figures are:

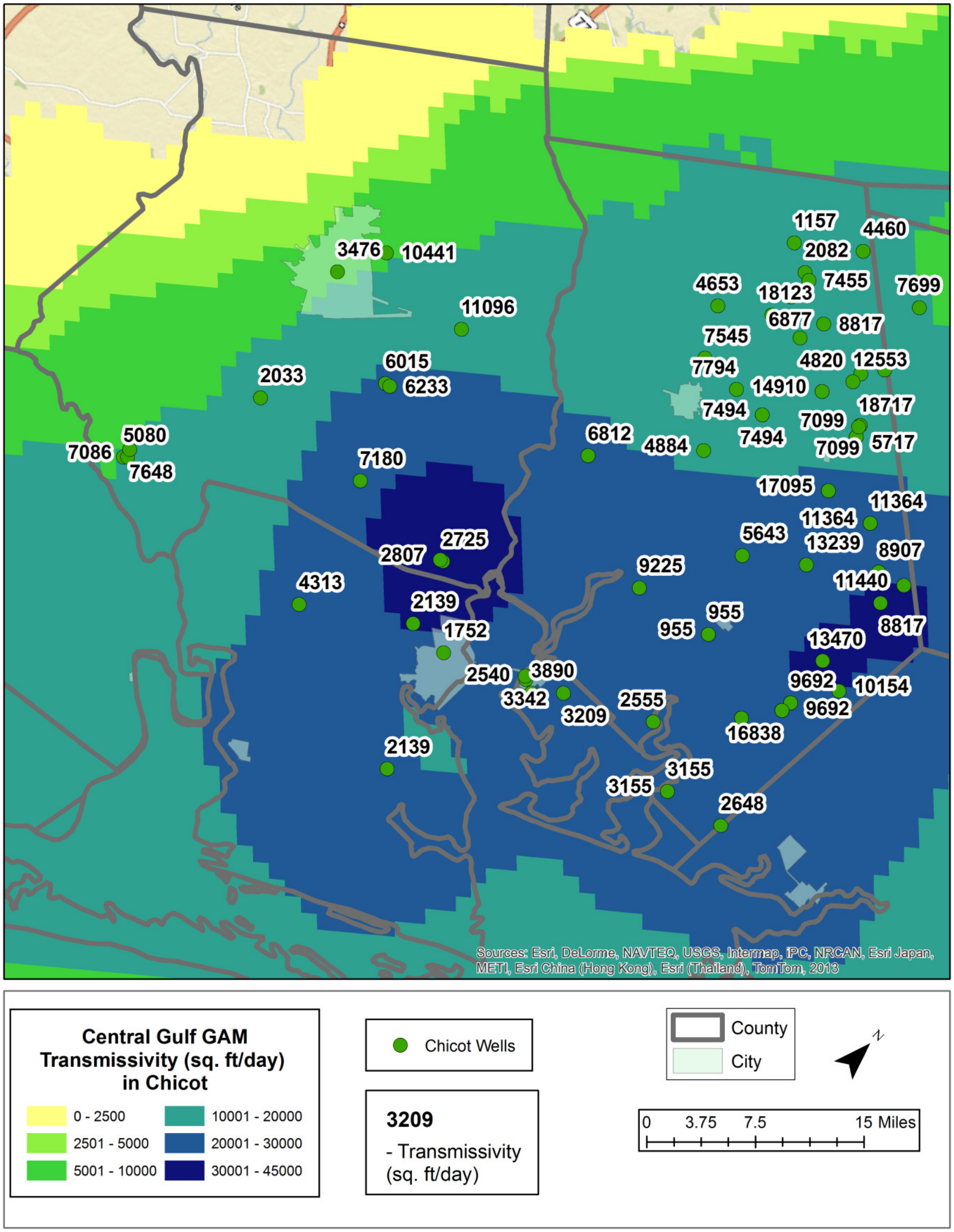


Figure 6.22: The Central Gulf Coast GAM Transmissivity Field and Transmissivity Values Calculated from Aquifer Pumping Tests for the Chicot Aquifer

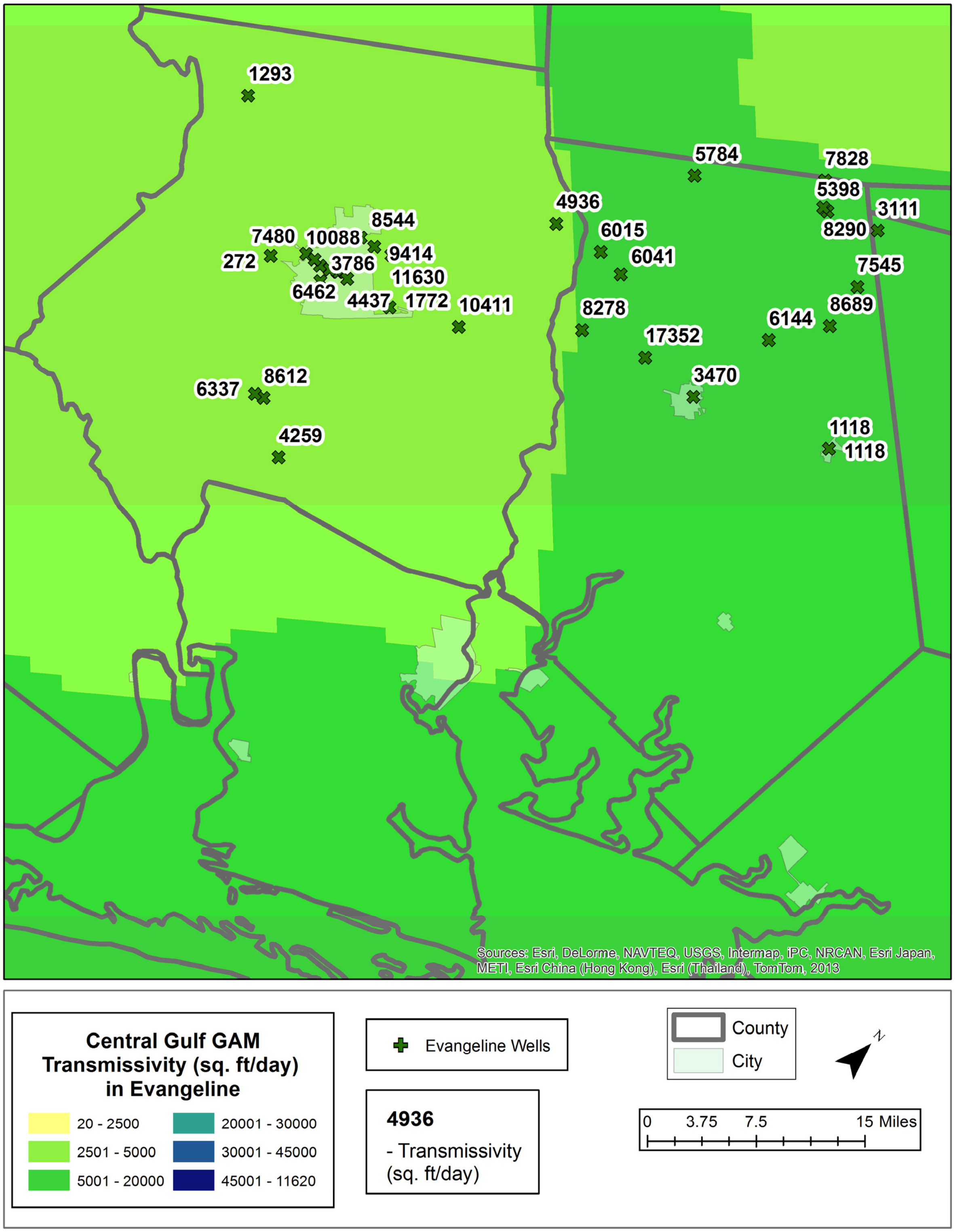


Figure 6.23: The Central Gulf Coast GAM Transmissivity Field and Transmissivity Values Calculated from Aquifer Pumping Tests for the Chicot Aquifer

- The smoothness and gradual transitions among transmissivity values in the CGC GAM distribution are not reflected in the transmissivity values from pumping tests.
- In **Figure 6-22**, where the CGC GAM has its highest Chicot transmissivity values (> 30,000 ft2/day), there are four measured Chicot transmissivity values between 1,700ft2/day and 2,800 ft2/day. The difference between the two sets of transmissivity values is more than a factor of 10.
- For the Chicot and the Evangeline aquifers, the measured transmissivity values are typically significantly lower than the CGC GAM transmissivity values at the locations where aquifer tests have been analyzed

One of the main reasons for the poor correlation between the measured and modeled transmissivity values in **Figures 6-22 and 6-23** is that most of the pumping wells are not screened across the entire thickness of the aquifer. Typically, the well screens are much shorter than the aquifer thickness so that the full aquifer is not adequately tested in the pumping test. In addition, the wide range of screen lengths from 20 to 690 feet introduces variability because the results of the aquifer tests are sensitive to both the size and location of the vertical portion of the aquifer intersected by the pumping well.

A method used by hydrogeologists to estimate hydraulic conductivity from aquifer pumping test data is to divide the calculated transmissivity value by the well screen length of the pumping well. For instance, a transmissivity value of 1,000 ft2/day divided by a well screen length of 100 feet yields a hydraulic conductivity value of 10 ft/day. This procedure is used by Myers (1969), who compiled an extensive set of transmissivity values from aquifer pumping tests in Texas. In their development of a regional groundwater flow model of the Gulf Coast Aquifer System, Young and Kelley (2006) considered the well screen length as an important criteria for evaluating how accurately hydraulic conductivities calculated from aquifer pumping test data reflect the properties of the entire aquifer thickness of the test location. By grouping approximately 500 hydraulic conductivity values calculated from aquifer pumping tests into bins based on different well screen lengths, Young and Kelley (2006) generated the results in **Table 6-3**. These results indicate that the calculated hydraulic conductivity values for the Chicot and Evangeline aquifers are inversely correlated to well screen length for well screen lengths less than about 300 feet. Based on the results in **Table 6-2** and other supporting data, Young and Kelley (2006) conclude that well screen length should be considered when developing estimates of average hydraulic conductivity from transmissivity values from aquifer pumping tests. The general relationship in **Table 6-3** is attributed to: (i) a general tendency for drillers to preferentially place shorter well screens in the thicker and more permeable sands of the aquifer, and (ii) shorter well screens typically withdraw water from the aquifer across a much larger vertical interval than intersected by the well screen, which thus leads to an overestimate of transmissivity for the vertical interval intersected by the well screen. An important implication regarding the information in **Table 6-3** is that aquifer pumping tests at wells that have well screen lengths of several hundred feet provide more reliable estimates of transmissivity and average hydraulic conductivity values for the entire aquifer thickness than aquifer pumping tests at wells with smaller well screen lengths.

Table 6-3: Sensitivity of Calculated Hydraulic Conductivity from Aquifer Pumping Tests for the Chicot and Evangeline Aquifers to Well Screen Length (from Young and Kelley, 2006)

Range of Well Screen Lengths	Average Hydraulic Conductivity Value (feet/day)	Number of Measurements
less than 25 feet	306	13
25 feet to 50 feet	104	8
50 feet to 150 feet	48	79
150 feet to 300 feet	38	59
300 feet to 600 feet	17	139
greater than 600 feet	14	99

The methodology used by Young and Kelley (2006) was applied to the transmissivity values shown in **Table 6-3** to produce the results in **Table 6-4**. The relationship between average hydraulic conductivity and screen length in **Table 6-4** has similar trends to those shown in **Table 6-3**. Based on additional review of the information, two criteria were used to filter the hydraulic conductivity values calculated from transmissivity values that would be used to characterize the Chicot and Evangeline aquifers. One criterion was a minimum screen length of 380 feet. The other criterion was that at least 70 percent of the well screen needed to be located in either the Chicot or Evangeline Aquifer. Application of these two conditions as filters produced the 33 hydraulic conductivity values in **Table 6-5**.

Table 6-4: Sensitivity of Calculated Hydraulic Conductivity from Aquifer Pumping Tests for the Chicot and Evangeline Aquifers to Well Screen Length in the Study Area

Range of Well Screen Lengths	Average Hydraulic Conductivity Value (feet/day)	Number of Measurements
50 feet to 150 feet	81	14
150 feet to 300 feet	37	42
300 feet to 600 feet	15	18
greater than 600 feet	12	17

Figures 6-24 and 6-25 show the spatial location of the hydraulic conductivity values in **Table 6-5**. Fourteen (14) of the hydraulic conductivity values in **Table 6-5** are for the Chicot aquifer and 19 hydraulic conductivity values are for the Evangeline Aquifer. Eleven (11) of these values are calculated from aquifer test data from municipal wells used by the City of Victoria (Young, 2014). **Figure 6-26** shows the location of these 11 municipal wells in addition to the other seven municipal wells for which transmissivity values were calculated.

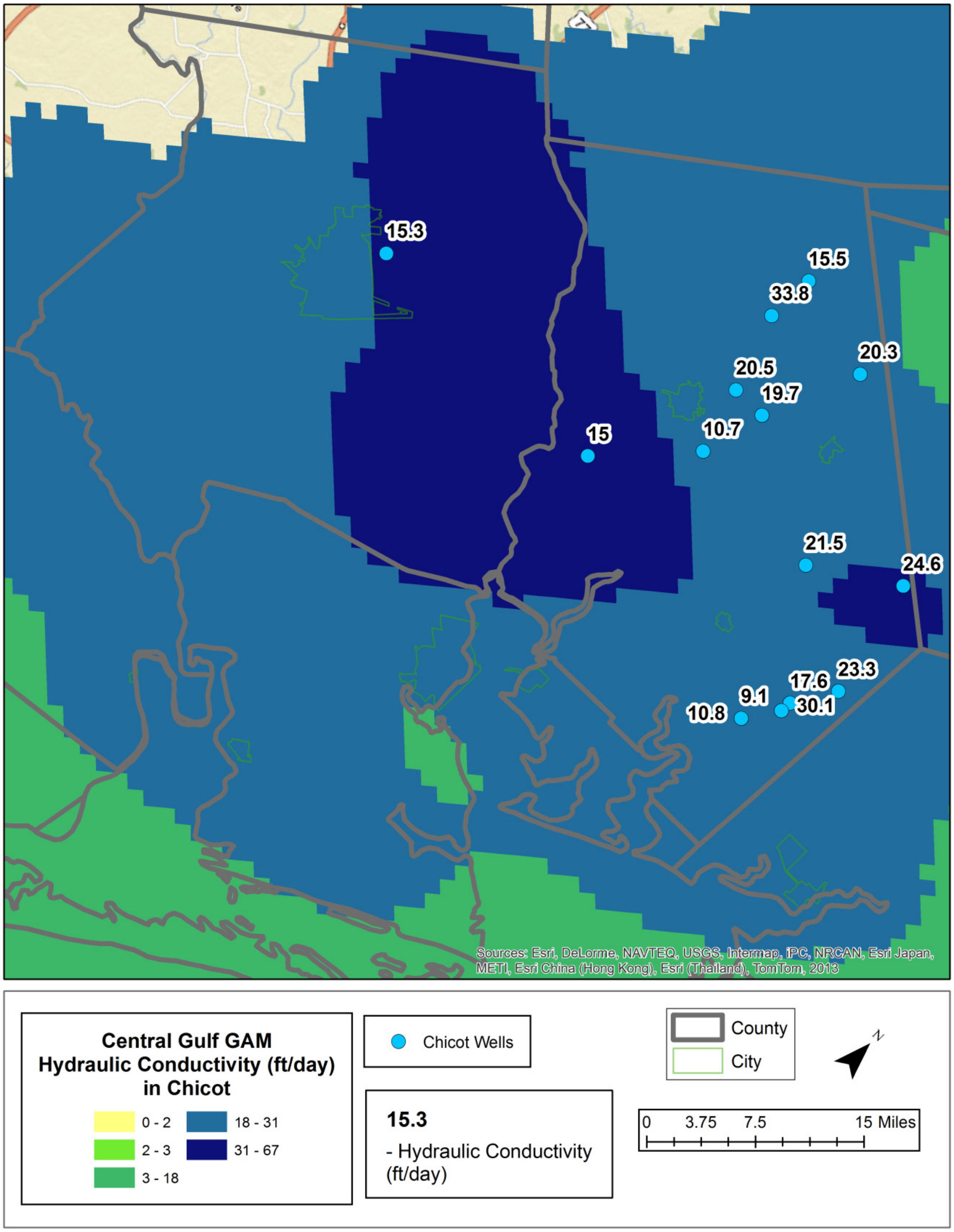


Figure 6.24: The Central Gulf Coast GAM Hydraulic Conductivity Field and Hydraulic Conductivity Values Calculated from Aquifer Pumping Tests with a Pumping Well Screen Greater than 380 feet for the Chicot Aquifer

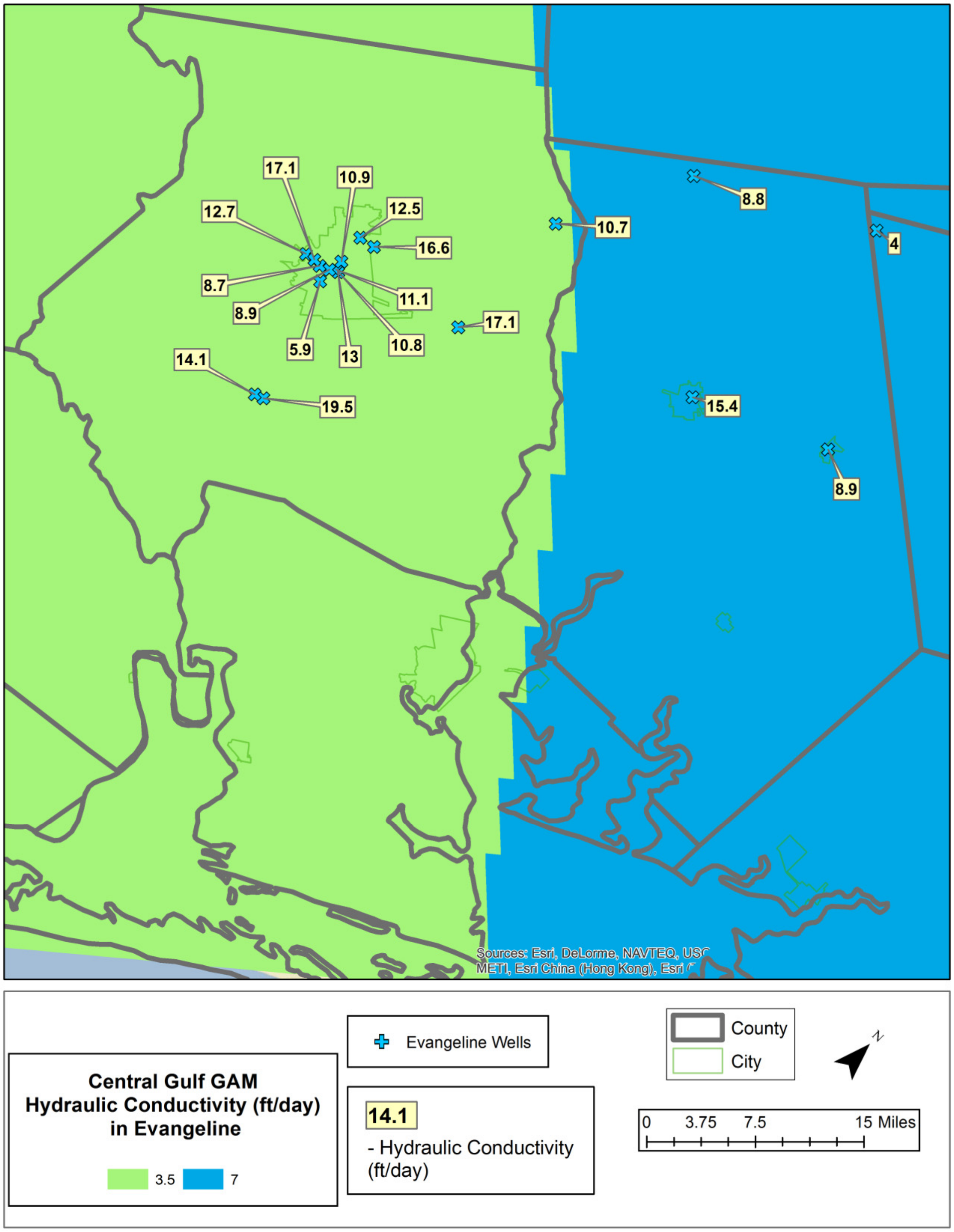


Figure 6.25: The Central Gulf Coast GAM Hydraulic Conductivity Field and Hydraulic Conductivity Values Calculated from Aquifer Pumping Tests with a Pumping Well Screen Greater than 380 feet for the Evangeline Aquifer

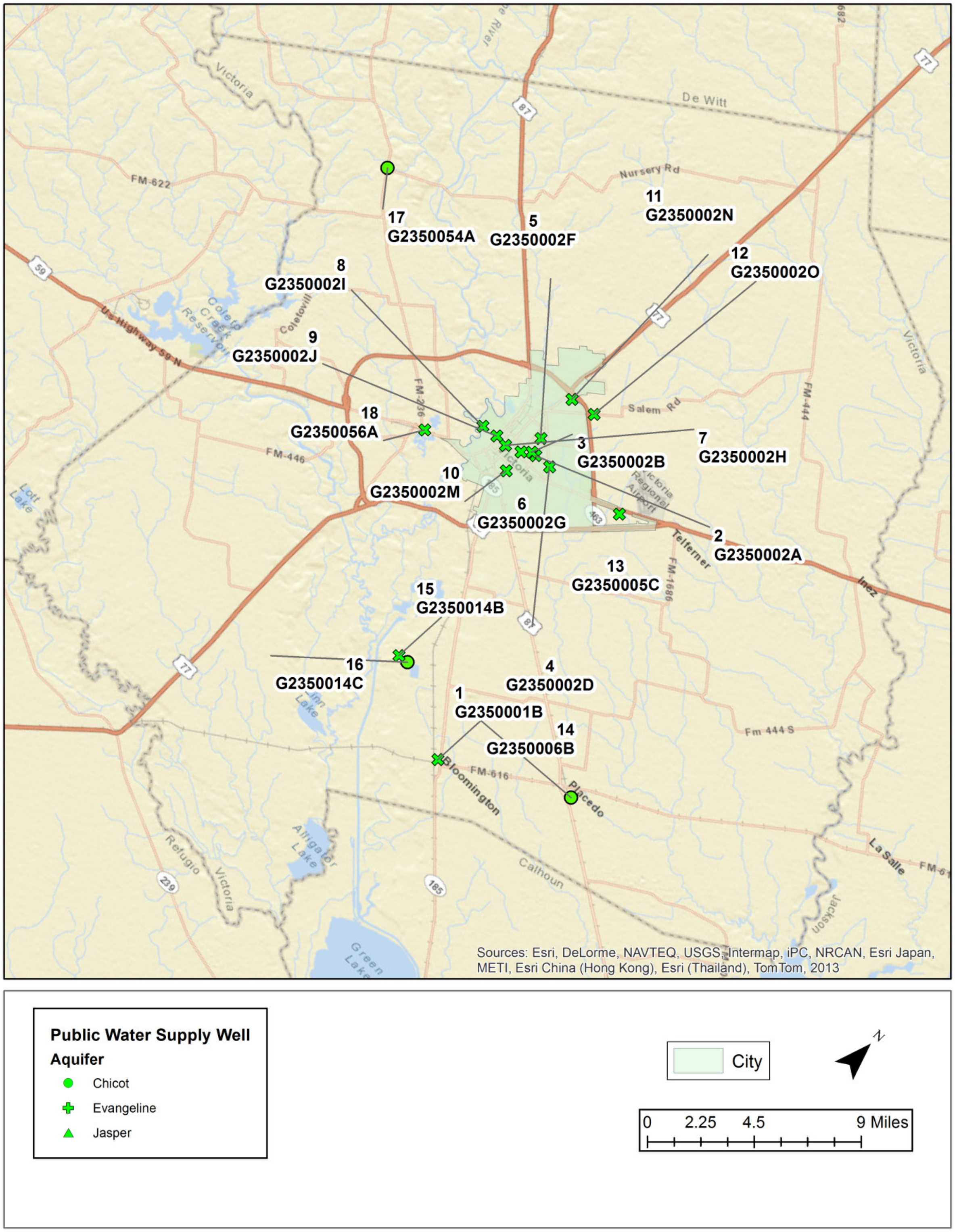


Figure 6.26: Location of the 18 Public Water Supply (PWS) Wells where Transmissivity Values were Calculated from Aquifer Pumping Tests Data in the Evangeline Aquifer in Victoria County

The Chicot Aquifer hydraulic conductivity values are primarily from Jackson County and have an arithmetic average and geometric average of 19.8 ft/day and 19.9 ft/day, respectively. The Evangeline hydraulic conductivity values are primarily from Victoria County and have an arithmetic average and geometric average of 11.9 ft/day and 11.0 ft/day, respectively. For most of the study area, the CGC GAM's hydraulic conductivity values for the Chicot Aquifer are between 18 ft/day to 67 ft/day. The 14 calculated hydraulic conductivity values for the Chicot Aquifer from pumping tests range between 9.9 ft/day and 33.7 ft/day. In their report describing the development of the CGC GAM, Chowdhury and others (2004) do not compare measured and modeled hydraulic conductivity values for the Chicot Aquifer and do not comment on the reasonableness of the GCG GAM spatial distribution shown in **Figure 6-24**. Based on our analysis for this study, there are no field tests to support hydraulic conductivity values above 31 ft/day for the Chicot Aquifer in the large area in Figure 6-24 where the CGC GAM has hydraulic conductivity values between 31 ft/day and 67 ft/day. However, outside of this "high-K" zone, our calculated hydraulic conductivity values are generally consistent with the CGC GAM average hydraulic conductivity values for the Chicot Aquifer.

For the entire Study Area, the CGC GAM's hydraulic conductivity value for the Evangeline Aquifer is either 3.5 ft/day or 7 ft/day. The dividing line between the two zones is aligned with the boundary between Victoria County and Jackson County. The 19 calculated hydraulic conductivity values for the Evangeline Aquifer from pumping tests range between 4 ft/day and 19.5 ft/day. In their report describing the development of the CGC GAM, Chowdhury and others (2004) do not compare measured and modeled hydraulic conductivity values for the Evangeline Aquifer and do not comment on the reasonableness of the GCG GAM spatial distribution shown in **Figure 6-25**. Based on our analysis for this study, we concluded that the GCG GAM average hydraulic conductivity for the Evangeline Aquifer is too low for Victoria County; is too low for Calhoun County; but may be appropriate for Jackson County.

In some situations, the hydraulic conductivity of the sand beds is an important design factor. In order to estimate the hydraulic conductivity of the sand, the assumption is made that all of the formations of interest are composed of about 50 percent sand and 50 percent clay and that the clay deposits provide a negligible contribution to the bulk or average hydraulic conductivity of the entire aquifer. For these two assumptions, a reasonable estimate of the hydraulic conductivity of the sand is therefore double the average hydraulic conductivity of the aquifer. Using the previously determined average hydraulic conductivity of about 20 ft/day in the Chicot Aquifer and 10 ft/day in the Evangeline Aquifer, the estimated average hydraulic conductivity for the sand beds is about about 40 ft/day and 20 ft/day in the Chicot Aquifer and Evangeline Aquifer, respectively.

Table 6-5: Hydraulic Conductivity Values Calculated from Transmissivity Values in Table 6-2 after Filtering for Well Screen Criteria

Well ID	County	Projection (NAD 83)		Screen Length (ft)	Hydr. Cond (ft/day)	Aquifer
		Latitude	Longitude			
6651904	Jackson	29.1467	-96.6461	482	15.5	Chicot
6659303	Jackson	29.0961	-96.6478	537	33.7	Chicot
6660201	Jackson	29.1172	-96.5439	515	20.3	Chicot
6660703	Jackson	29.0186	-96.5842	381	19.7	Chicot
6660705	Jackson	29.0183	-96.6203	381	20.5	Chicot
8004403	Jackson	28.9519	-96.6003	457	10.7	Chicot
8005507	Jackson	28.9439	-96.4472	617	21.5	Chicot
8006101	Jackson	28.9981	-96.3636	465	24.6	Chicot
8006703	Jackson	28.8778	-96.3350	436	23.3	Chicot
8011201	Jackson	28.8669	-96.6783	455	15.0	Chicot
8013901	Jackson	28.7900	-96.3847	635	9.9	Chicot
8014103	Jackson	28.8353	-96.3608	552	17.6	Chicot
8014401	Jackson	28.8239	-96.3617	560	30.1	Chicot
99991924	Victoria	28.8680	-96.9640	681	15.3	Chicot
6650801	Jackson	29.1397	-96.8011	657	8.8	Evangeline
6651305	Wharton	29.2300	-96.6336	785	4.0	Evangeline
6658702	Victoria	29.0083	-96.8650	460	10.7	Evangeline
6660902	Jackson	29.0411	-96.5133	156	8.9	Evangeline
8003301	Jackson	28.9825	-96.6458	225	15.4	Evangeline
8010101	Victoria	28.8667	-96.8608	610	17.1	Evangeline
99991923	Victoria	28.8210	-96.9850	565	13.0	Evangeline
99991925	Victoria	28.6790	-96.9480	442	19.5	Evangeline
G2350002A	Victoria	28.8210	-96.9843	558	10.8	Evangeline
G2350002B	Victoria	28.8207	-96.9876	585	11.0	Evangeline
G2350002F	Victoria	28.8305	-96.9895	616	10.9	Evangeline
G2350002G	Victoria	28.8162	-96.9923	614	8.9	Evangeline
G2350002H	Victoria	28.8123	-97.0018	644	8.7	Evangeline
G2350002I	Victoria	28.8108	-97.0198	588	12.7	Evangeline
G2350002J	Victoria	28.8127	-97.0098	590	17.1	Evangeline
G2350002M	Victoria	28.8017	-96.9906	640	5.9	Evangeline
G2350002N	Victoria	28.8608	-96.9931	685	12.5	Evangeline
G2350002O	Victoria	28.8639	-96.9769	568	16.6	Evangeline
G2350014B	Victoria	28.6756	-96.9568	450	14.1	Evangeline

6.4 Existing Water Wells and Groundwater Pumping

For an ASR project, existing wells are a concern because their pumping can adversely impact the storage and withdrawal of stored ASR water. If existing wells are sufficiently close to the ASR wells, their pumping could directly withdraw a portion of the stored water and/or accelerate the movement of the stored water away from the ASR wells. Among the desirable attributes for an ASR project is to have the network of existing wells sufficiently separated from the ASR sites so that pumping at the existing wells has a negligible impact on the average hydraulic gradients at the ASR sites. The goal of this section is to review the readily available information on the spatial distribution of existing wells, pumping rates, and/or permits for the Study Area.

6.4.1 Spatial Distribution of Wells

The three primary sources of publicly available data sets for wells in Texas are the TWDB groundwater database, the TWDB submitted driller reports database, and groundwater conservation district databases. **Figure 6-27** shows the locations of wells in the Study Area based on information from the TWDB groundwater database. **Figures 6-28 and 6-29** show the location of wells in the TWDB submitted driller reports database. **Figure 6-30** shows the location of the permitted wells in the Victoria County GCD groundwater database. For Calhoun or Jackson counties, wells from a GCD database are not plotted. Calhoun County has an active, but unconfirmed GCD, and at this time there is no database. Although the Texana GCD has a well database for Jackson County, the Texana GCD database contains very similar information as the TWDB databases.

Prior to discussing the well locations in **Figures 6-27 through 6-30**, a few explanations about the illustrated databases are warranted. The TWDB groundwater database shown in **Figure 6-27** is maintained by the TWDB to help monitor groundwater conditions. Although it contains most of the major wells in the state, its inventory does not nearly reflect the total number of wells. Based on INTERA's experience with performing water resource investigations, the TWDB groundwater database may contain less than 20 percent of the total wells in a county. This percentage is based on previous comparisons between the number of drilling logs on file for a study area and the number of wells contained in the TWDB database. Most of the wells that are not in the TWDB study are domestic and livestock wells. The well locations shown in **Figures 6-28 and 6-29** are based on submitted drillers' logs since 2001. Since 2001, the TWDB has been entering the well data into a digital database. For wells installed before 2001, the driller logs exist as scanned pdf files. Manually entering well data from scanned driller logs is beyond the scope of this preliminary feasibility study. In **Figure 6-28**, the plotted wells are those that require a permit from the Victoria County GCD. Typically, a permit is required for a well that is capable of pumping more than about 17.4 gpm (25,000 gallons/day). The amount of the permit is based on the anticipated pumping and is expressed as AFY. One gpm is equivalent to 1.62 AFY. Thus, the 17.4 gpm is equivalent to pumping about 28 AFY.

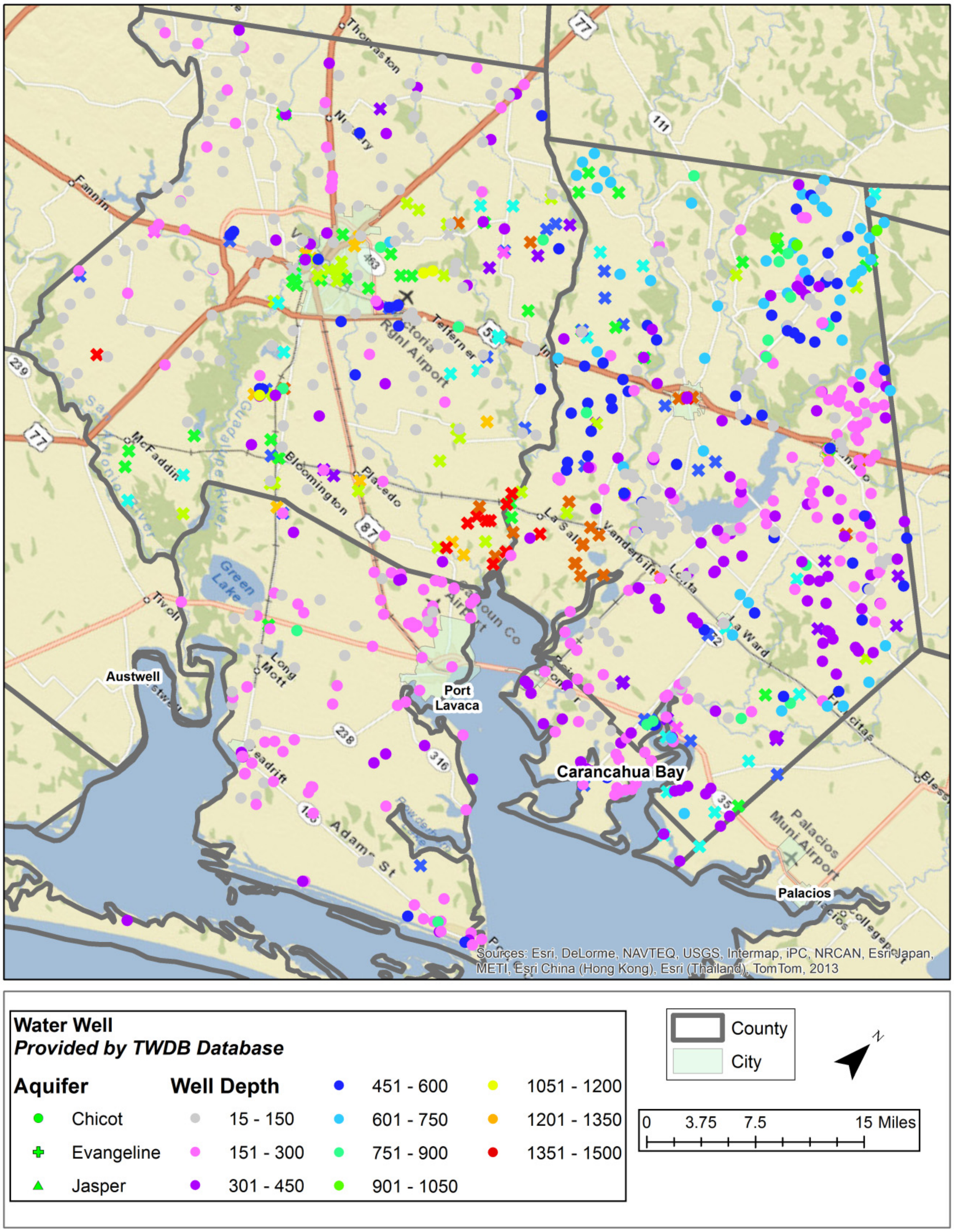


Figure 6.27: Location of Wells from the TWDB Groundwater Dataset that are Located in Victoria, Calhoun, and Jackson Counties

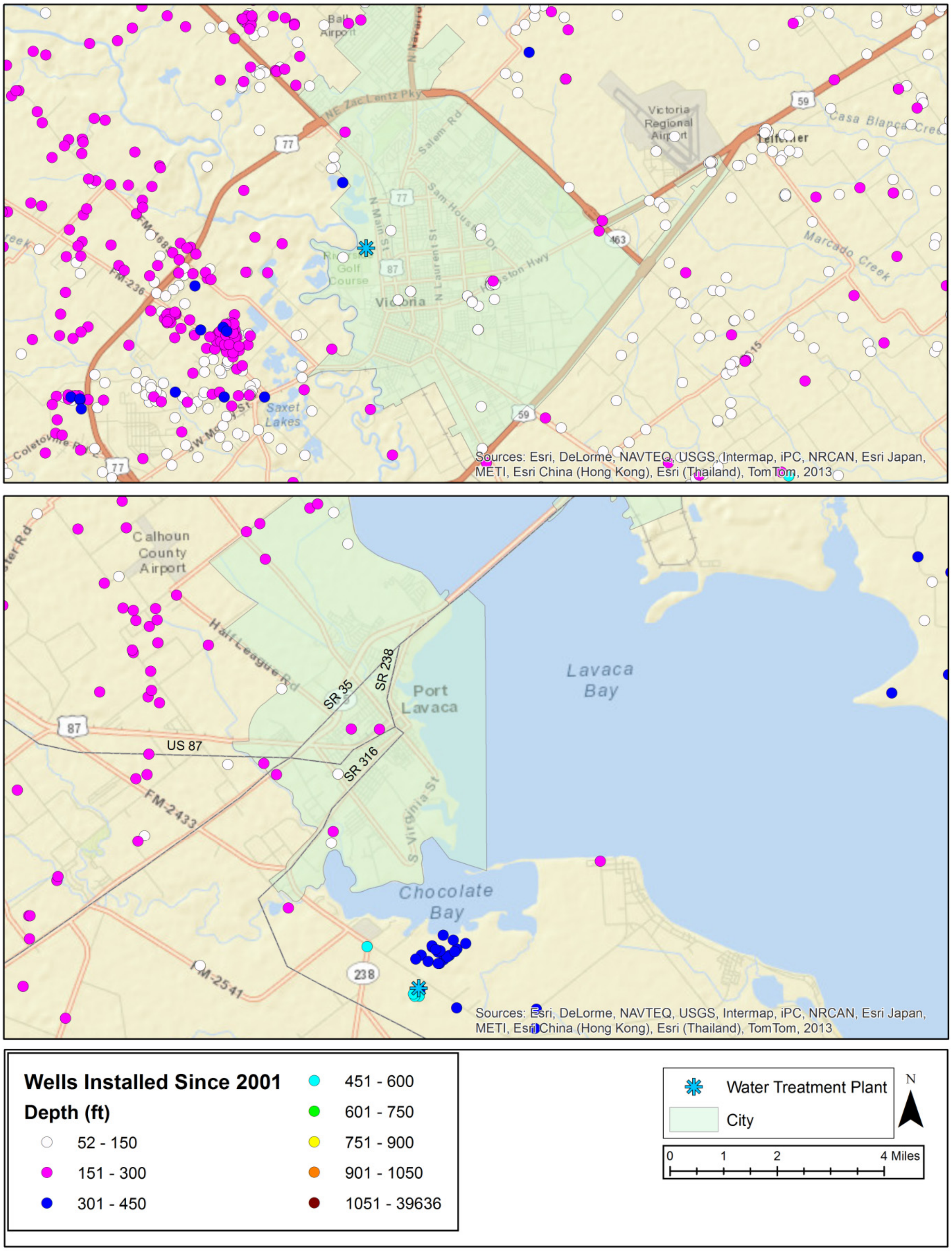


Figure 6.28: Location of Wells Installed Since 2000 near the City of Victoria and Port Lavaca

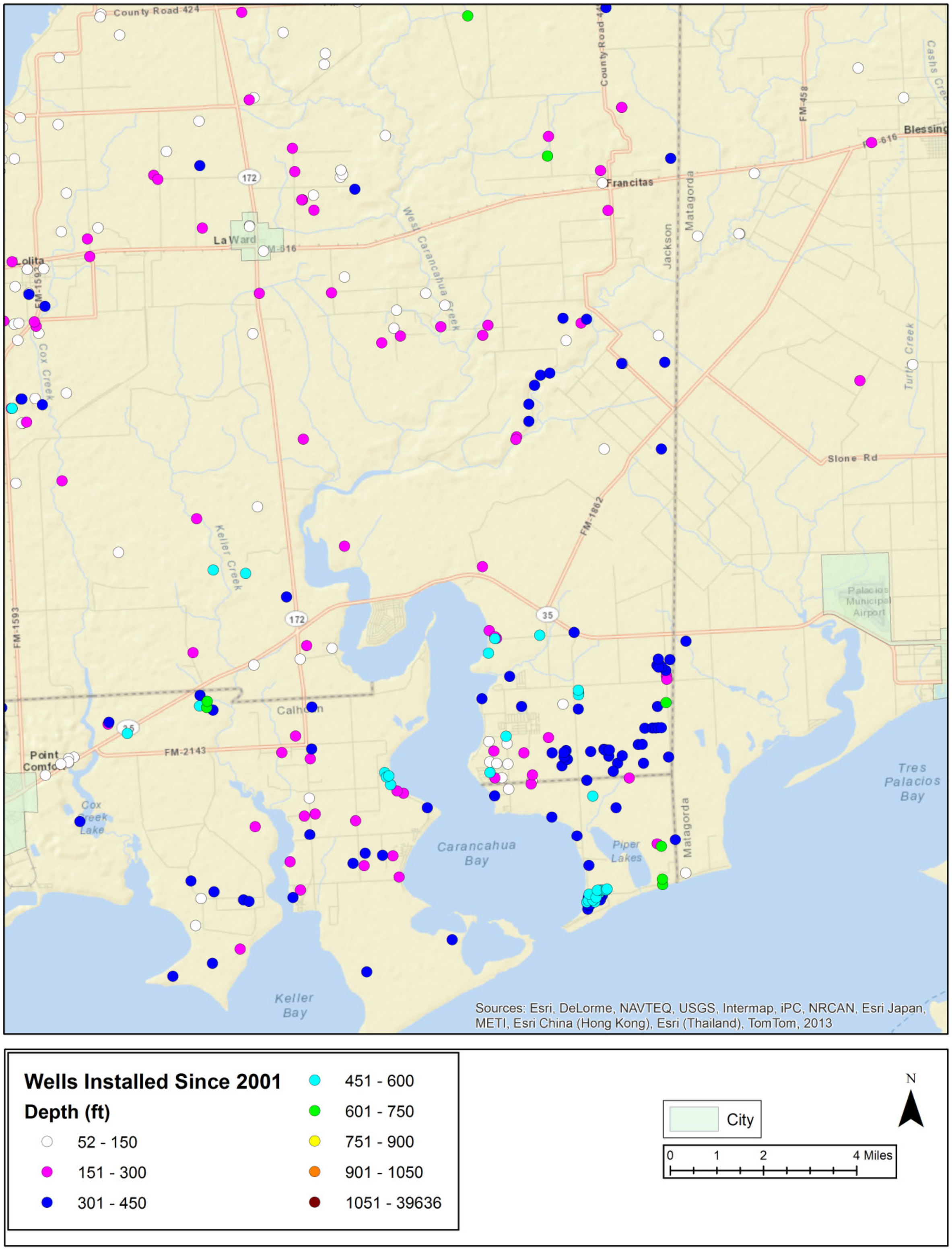


Figure 6.29: Location of Wells Installed Since 2000 near the Carancahua Bay and Southern Jackson County

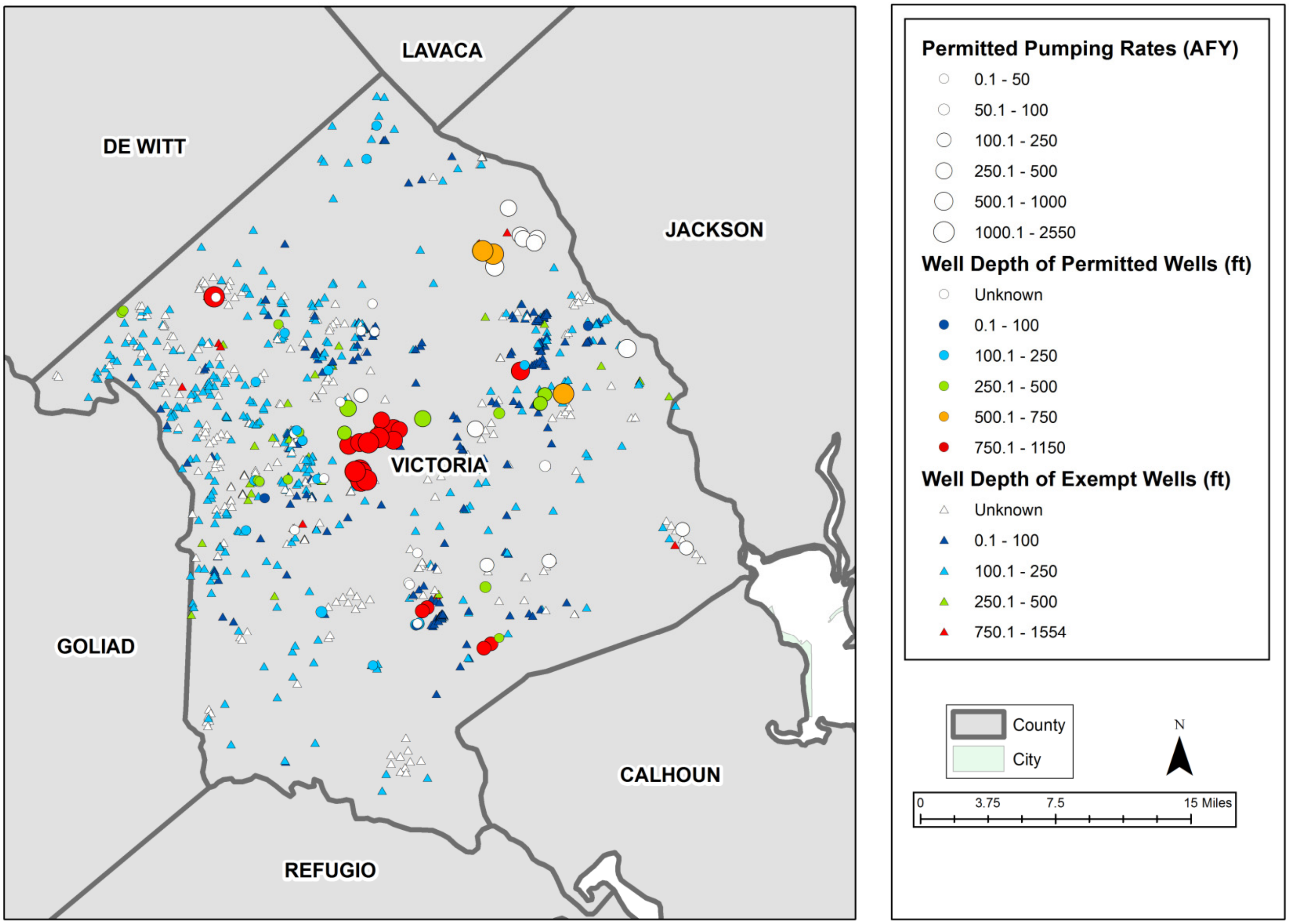


Figure 6.30: Location of Permitted and Exempt Wells based on the Victoria County Groundwater Conservation District Well Inventory

6.4.2 Spatial and Temporal Distribution of Pumping

Three sources of publicly available data sets for pumping in Texas are the historical pumping and TWDB's water use survey databases, the historical pumping files developed for the groundwater availability models, and the pumping reports that the GCDs generate for their permitted wells.

Figures 6-31 and 6-32 show the pumping rates that Chowdhury and others (2004) use in the CGC GAM to simulate water levels in 1999. The year 1999 is the latest year that Chowdhury and others (2004) simulated pumping for the model. One of the data sources used to generate these pumping distributions is the TWDB historical pumping records, which are shown in **Figures 6-33 and 6-34**. Based on the information in **Figures 6-33 and 6-34**, the summation of all the pumping for the CGC GAM in **Figures 6-31 and 6-32** for Victoria, Jackson, and Calhoun counties should total 26,775 AFY, 52,335 AFY, and 9,902 AFY, respectively.

6.4.3 Discussion of the Distribution of Existing Wells and Pumping

<u>Calhoun County</u>

In Calhoun County, the total groundwater pumping has been less than 2,000 AFY since 1997. **Figures 6-31 and 6-32** indicate that the majority of pumping occurs in the Chicot Aquifer in the vicinity of Port Lavaca. Because of the relatively few shallow wells in the Port Lavaca area, there is an opportunity to locate ASR well fields away from existing wells in the Lissie and Willis Formations, or to locate ASR wells near existing wells but deeper in the Upper Goliad Formation. South of Port of Lavaca near GBRA's Port Lavaca Water Treatment Plant (WTP), the documented water wells are generally deeper than they are nearer the city of Port Lavaca. About 20 wells (see **Figure 6-28**) have been drilled to a depth of about 450 feet below ground surface (bgs) and a few drilled to a depth of 600 feet bgs after the year 2001. As a result of the date of their installation, pumping at these well locations is not reflected in the spatial pumping distribution shown for 1999. Based on the presumption that modest pumping would occur at these new wells in the future, the opportunity should exist for ASR wells as long as they are away from the capture zone for any wells near the Port Lavaca WTP.

<u>Jackson County</u>

In Jackson County, the groundwater use is dominated by agriculture and a large part of the irrigation is for rice farming. Rice farming is seasonal and occurs primarily between March and September. Over this six-month period, the pumping occurs primarily during four to six flooding events during the six-month growing season. The majority of the pumping in the southern Jackson County area between LaWard and Carancahua Bay is in the Chicot Aquifer. In this general area, about 80 percent of the well depths are shallower than 600 feet. In southern Jackson County there is a low probability that existing wells would adversely impact ASR wells at depths below 700 feet, and there may be opportunities to successfully operate ASR wells in the permeable deposits of the Lissie (at depths of 300 to 700 feet) in areas of low agricultural pumping. A potential concern that will need to be further investigated is the pumping locations associated with the significant rise in agricultural pumping from about 40,000 AFY in 2010 to about 90,000 AFY in 2011. The 2011 spike in pumping is likely linked to drought conditions in Texas and not an indication of a major paradigm shift in long-term pumping. Nonetheless, the potential impacts of such spikes in pumping need to be fully understood prior to selecting any ASR sites.

<u>Victoria County</u>

In **Figures 6-31 and 6-32**, the highest rate of pumping in the three-county Study Area in 1999 occurs in the Evangeline Aquifer as a result of pumping from the 10 municipal wells operated by the City of Victoria. **Figure 6-30** shows the location of the exempt wells in Victoria County, as well as the wells permitted by the Victoria County GCD. As shown in simulated water levels by the CGC GAM (see **Figures 6-14 and 6-15**) and measured water levels (see **Figure 6-20**), drawdown values over 90 feet result from City of Victoria pumping.

As previously stated, the City anticipates continued use of surface water as its primary source of supply, with the goal of reducing groundwater pumping in the Evangeline Aquifer by approximately 90 percent after 2000. However, as a result of recurring drought conditions since 2010, the City has needed to use more groundwater in years with low surface water availability. **Table 6-6** lists the pumping reported for each well to the Victoria County GCD since 2009. The reported municipal pumping shown in **Table 6-6** is about 6,500 AFY in both 2011 and 2013. This rate is about three times the average pumping rate of 1,950 AFY for the years 2009, 2010, and 2012. The pumping that occurred during 2011 and 2013 is the result of an informal agreement that the City has with TCEQ. This agreement allows the City to divert surface water at the Victoria WTP diversion point during times when water would otherwise not be available for lawful diversion so long as the City pumps the same volume of groundwater into the Guadalupe River to replace the diverted surface water. The City is in the process of seeking TCEQ permit amendments to authorize such an arrangement on a more permanent basis.

The implementation of any ASR well field(s) within the City of Victoria must be done with consideration of the City's plans for future groundwater production. While it appears unlikely that any drinking water stored in ASR wells located within the City of Victoria would migrate laterally away from the City, it will be important to monitor local water levels and may be necessary to manage the distribution of pumping from the City's production wells so that the stored water remains close to the ASR wells and is therefore available for recovery when needed.

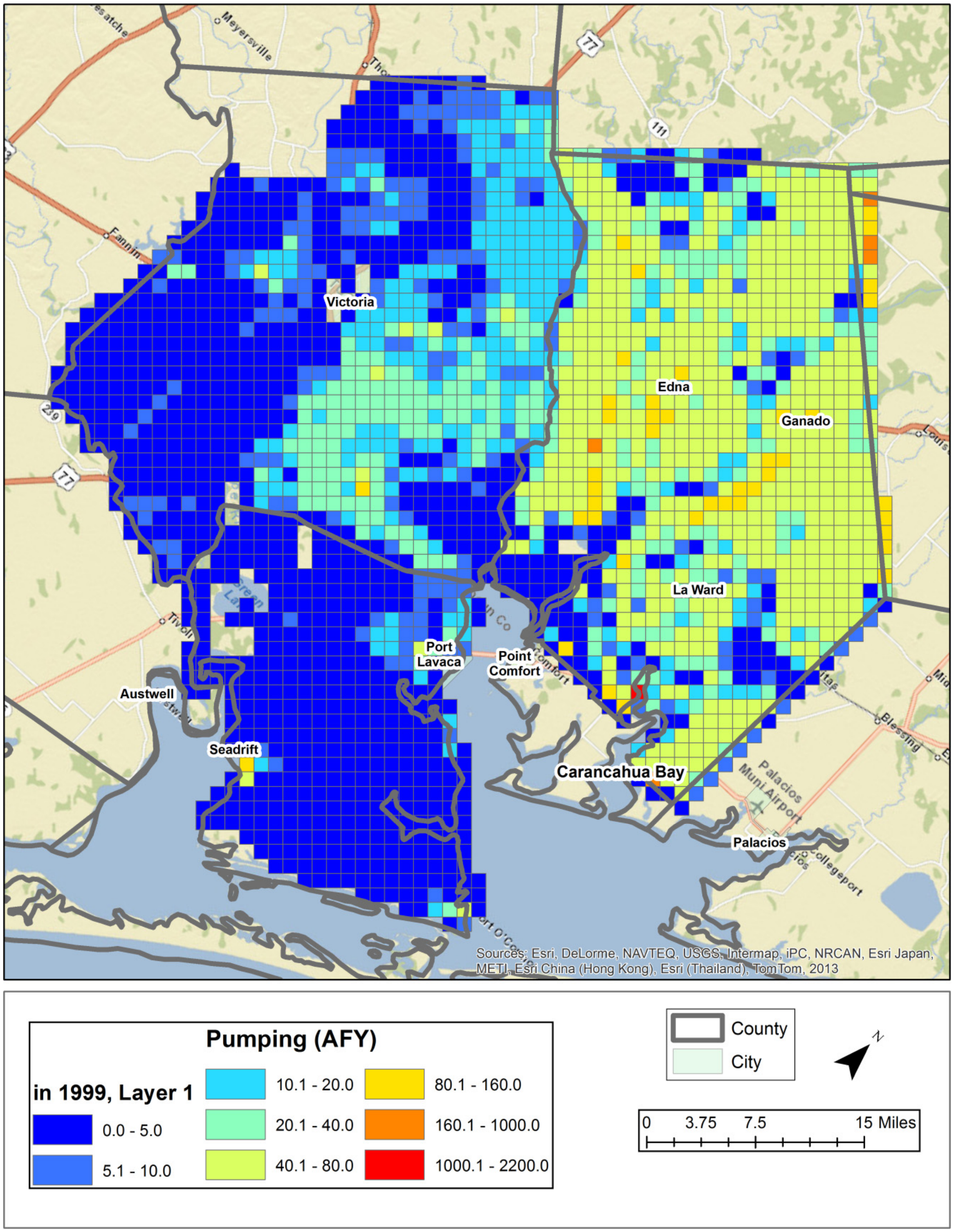


Figure 6.31: Spatial Distribution of Pumping in the Chicot Aquifer (Model Layer 1) for 1999 in the Central Gulf Coast GAM

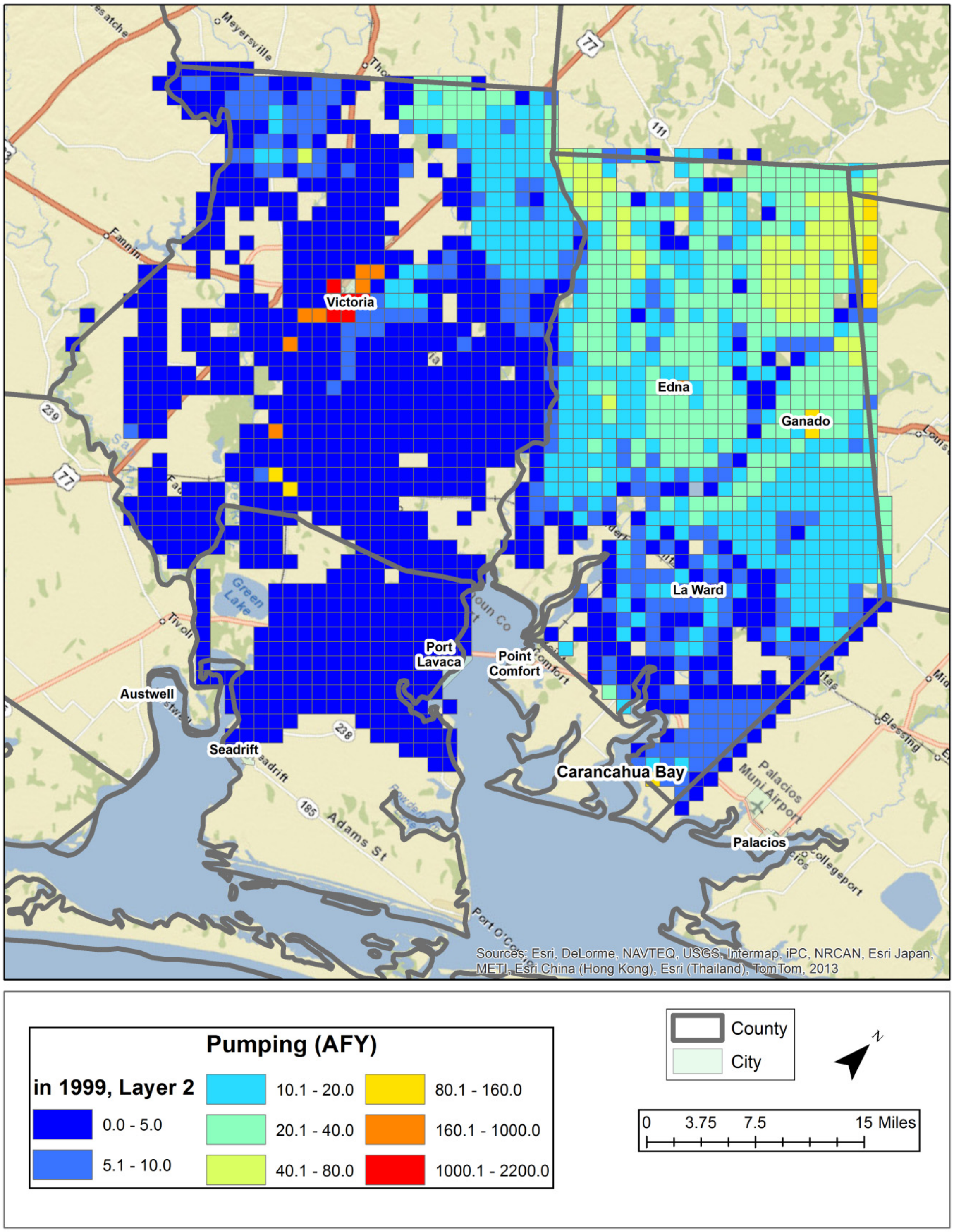
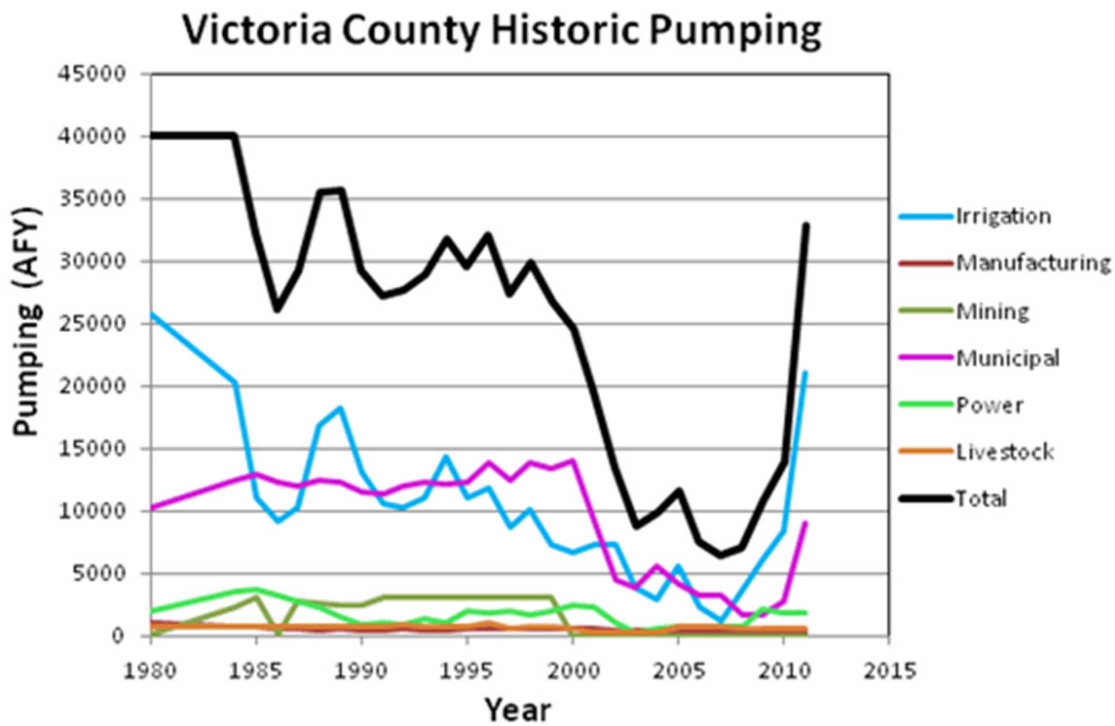


Figure 6.32: Spatial Distribution of Pumping in the Evangeline Aquifer (Model Layer 2) for 1999 in the Central Gulf Coast GAM



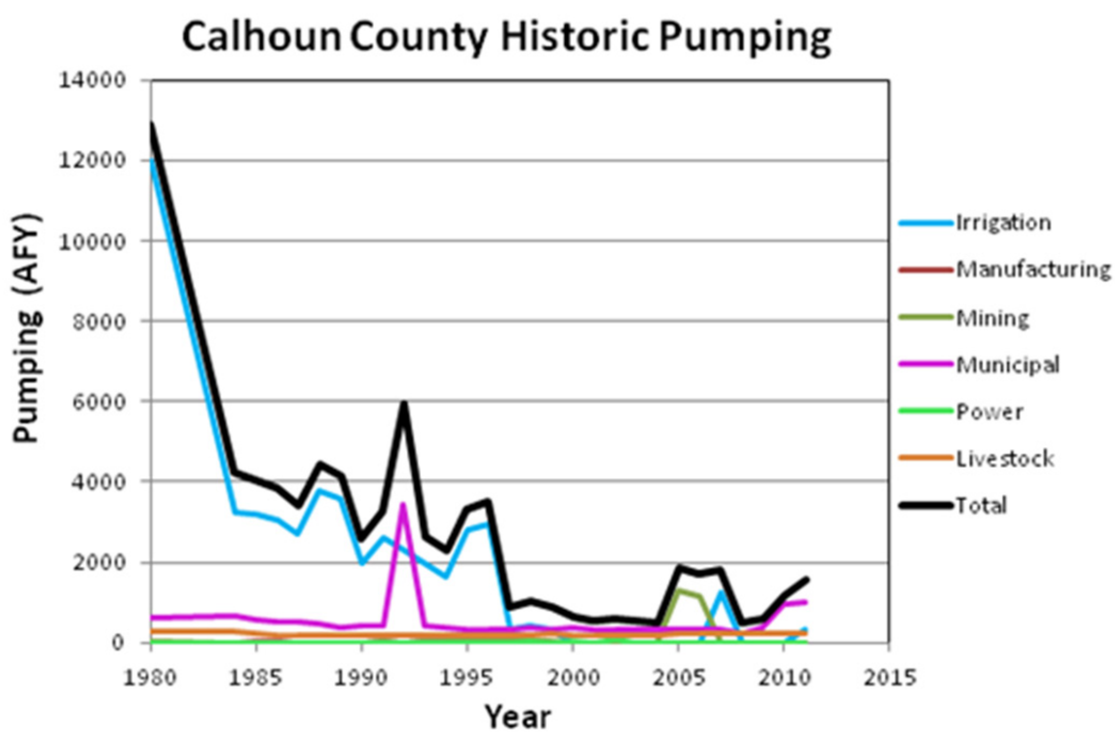
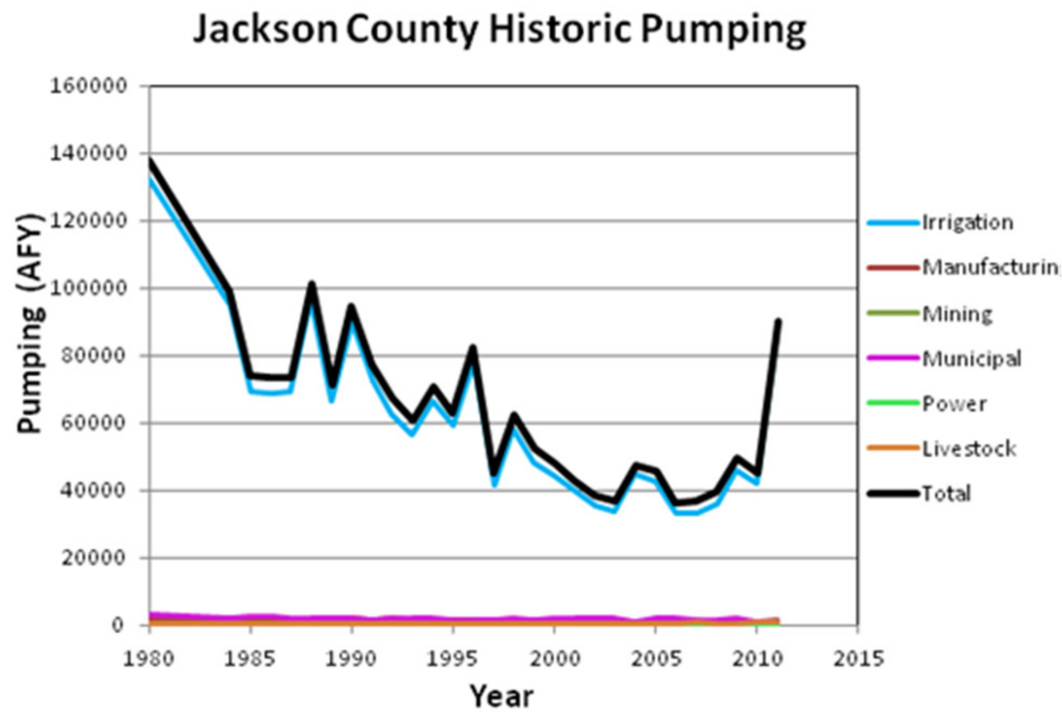


Figure 6.33: Temporal Distribution of Pumping by User Type for Victoria and Calhoun Counties from 1980 to 2011 based on the TWDB's Historical Pumping Database



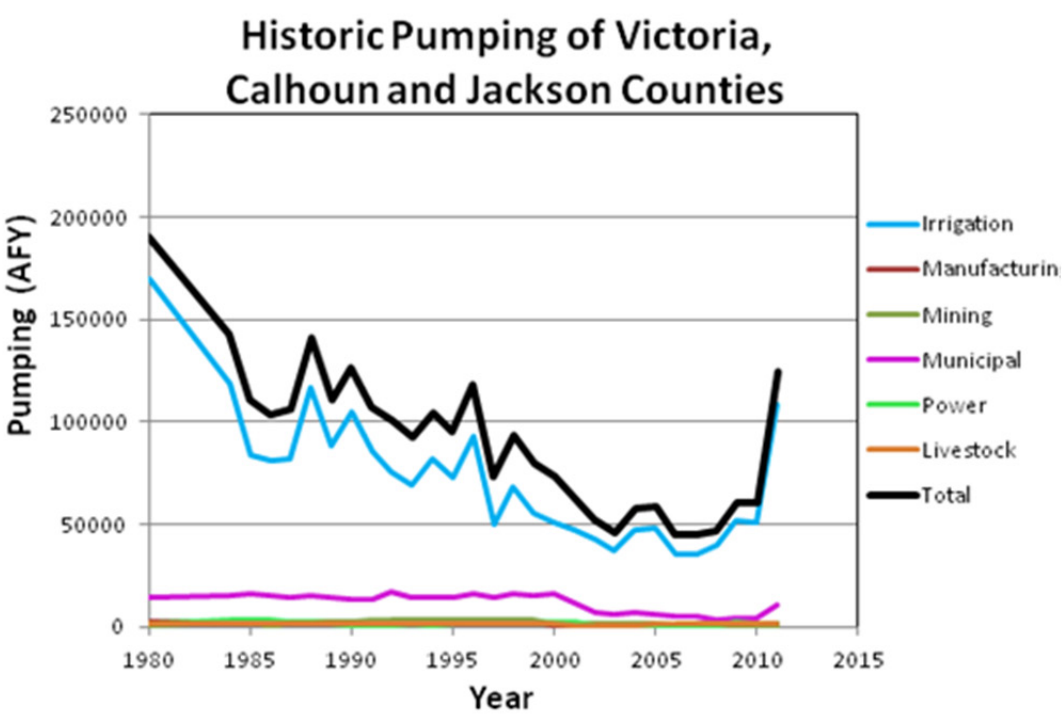


Figure 6.34: Temporal Distribution of Pumping by User Type for Jackson County and the Total Pumping for Victoria, Jackson, and Calhoun Counties from 1980 to 2011 based on the TWDB's Historical Pumping Databases

As shown in **Table 6-6**, the pumping among the 10 City of Victoria wells since 2009 is not equally distributed. Wells No. 9, 11, 13, and 14 account for over 80 percent of the pumping. If this use pattern continues, it appears that any ASR wells may be best located away from the these municipal production wells Based on the northern group of logs for the City of Victoria (see **Figure 6-9**), there should be ample sands in the Upper Goliad Aquifer north of the Victoria WTP to develop a successful ASR well field.

Table 6-6: Quarterly Pumping Amounts (Acre-Feet) Reported by the Victoria County GCD for Permitted Wells in the vicinity of the City of Victoria

Time Period	City of Victoria Wells											Non City of Victoria Wells					Total
	5	6	7	8	9	10	11	12	13	14	510	240	306	307	308	532	
2009 - Q1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2009 - Q2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2009 - Q3	45	13	13	42	70	59	81	4	86	72	0	0	0	0	0	0	485
2009 - Q4	1	0	0	0	312	0	332	0	0	1	0	0	0	0	0	0	648
2010 - Q1	0	0	0	0	609	0	661	0	0	0	0	0	0	0	0	0	1271
2010 - Q2	0	0	0	0	541	0	193	0	0	0	0	0	0	0	0	0	737
2010 - Q3	0	0	0	0	235	0	0	0	0	0	0	0	0	0	0	0	235
2010 - Q4	0	0	0	0	356	0	0	0	0	0	0	0	0	0	0	0	358
2011 - Q1	0	0	0	0	0	0	0	0	0	0	0	0	26	0	0	0	28
2011 - Q2	0	1	0	0	485	0	388	0	1	1	0	0	74	0	0	0	950
2011 - Q3	475	577	281	273	519	287	508	211	710	483	0	4	115	0	0	0	4443
2011 - Q4	0	0	0	0	502	0	332	0	0	0	0	0	0	0	48	0	883
2012 - Q1	0	0	0	0	496	0	261	0	0	0	0	0	3	3	18	0	782
2012 - Q2	0	0	0	0	476	0	106	0	0	0	0	0	9	9	53	0	655
2012 - Q3	0	0	0	0	360	0	203	0	0	0	0	0	9	9	54	0	636
2012 - Q4	0	0	0	0	14	0	0	0	0	0	0	0	6	6	38	0	65
2013 - Q1	1	1	1	0	0	0	0	0	0	1	23	0	0	40	0		66
2013 - Q2	0	0	0	0	45	0	0	0	0		23	0	0	0	0	73	141
2013 - Q3	291	203	332	127	1947	176	2070	363	479	364	35	0	0	0	0		6387
Total 2009	45	14	13	43	**382**	59	**413**	5	**87**	**73**	0	0	0	0	0	0	1133
Total 2010	1	1	1	1	**1741**	1	**854**	1	**1**	**1**	0	0	0	0	0	0	2601
Total 2011	476	579	282	274	**1505**	288	**1228**	212	**711**	**484**	0	4	214	0	48	0	6304
Total 2012	1	1	0	0	**1346**	0	**570**	0	**0**	**1**	0	0	27	27	163	0	2138
Total 2013	292	204	332	127	**1992**	176	**2070**	363	**479**	**365**	81	0	0	40	0	73	6595

6.5 Water Quality

A benefit of ASR is that the water can potentially be stored for long periods of time without substantial deterioration in water quality. Provided that water in the ASR buffer zone is not withdrawn, the water quality of the native groundwater is often not a major concern. For this reason, aquifers with lesser quality, such as brackish aquifers, can serve as good storage aquifers. Since TCEQ requires that water to be injected into an ASR well be treated to drinking water standards (30 TAC 290), post-treatment requirements for the stored water are minimal. In fact, water quality can improve for certain parameters, such as currently regulated and un-regulated disinfection by-products (DBPs).

Nevertheless, water quality for the stored and recovered water must be considered in the design and implementation of an ASR project to optimize operation and address the potential for stored water quality to result in mobilization of trace constituents in the storage aquifer, particularly related to a change in pH or oxidation/reduction (redox) conditions in the storage zone.

The following sections describe the currently available information on native groundwater quality in the Study Area.

6.5.1 Total Dissolved Solids Concentrations

Figure 6-35 shows the spatial distribution of TDS in the Study Area. The TDS values are from the TWDB groundwater database, and they represent averages of the measurements from each well. The federal secondary drinking water standard for TDS is 500 mg/L and water with a TDS less than 1,000 mg/L is considered as fresh water by the TWDB. In the Gulf Coast Aquifer System TDS values are generally expected to increase with depth and with increased distance from the groundwater recharge area (Young and others, 2014). The general trend of increasing TDS concentrations with depth at Port Lavaca and Carancahua Bay is reflected in general decreasing values of resistivity of the sand beds with depth shown in **Figure 6-11**. Based on the geophysical logs just west and south of Port Lavaca, TDS concentrations transition from fresh water (< 1,000 mg/L TDS) to slightly saline water (between 1,000 mg/L and 3,000 mg/L TDS) at a depth of about 300 feet bgs. Measurements of TDS concentrations of the Class II injection wells in **Figure 6-38** are consistent with that observation. Within the City of Lavaca and closer to the bay, TDS values between 1,900 mg/L and 2,500 mg/L occur in wells with depths above 300 feet bgs. South of Port Lavaca and near the Port Lavaca WTP, a TDS value of about 3,500 mg/L occurs in a well with a depth of 450 feet bgs. For the Port Lavaca area and near the WTP, a conservative estimate for the TDS concentrations is that the Lissie and Willis formations in the Chicot Aquifer range between 1,000 mg/L and 2,500 mg/L, and TDS concentrations in the Upper Goliad formation in the Evangeline Aquifer range between 3,000 mg/L and 5,000 mg/L.

Near the upper reaches of Carancahua Bay, TDS concentrations below 600 mg/L are consistently reported for wells that have depths less than 450 feet bgs and for most wells with depths less than 750 feet bgs. This observation is consistent with the resistivity profiles shown in **Figure 6-11**. In these logs, sand beds as deep as -700 feet bgs (see logs CB-2 and CB-5) contain freshwater as evidenced by resistivity measurements greater than 20 ohms. The reasons attributed for this relatively deep fresh water is that the Lissie formation is about 200 feet deeper at Carancahua Bay than it is at Port Lavaca. In the vicinity of Carancahua Bay, a conservative estimate for the TDS concentration for the Lissie Formation is less than 700 mg/L; for the Willis formation between 700 mg/L and 1,500 mg/L; and for the Upper Goliad formation between 2,500 mg/L and 5,000 mg/L.

In the vicinity of the City of Victoria, TDS concentrations less than 700 mg/L are consistently reported for wells that have depths less than 1,000 feet. At this potential site, the TDS concentrations are conservatively estimated to be below 1,000 mg/L for all of the geological formations that comprise the Chicot Aquifers, as well as the Upper Goliad Formation.

As indicated previously, many ASR wells store drinking water in brackish aquifers. While lower TDS concentrations are preferred, ambient groundwater concentrations up to about 8,000 mg/L have been demonstrated to be viable. A few locations store fresh water in saline aquifers with TDS concentrations exceeding 10,000 mg/L and one location stores fresh water in a seawater aquifer. Other factors are important besides TDS concentrations, not the least of which are the thickness and the degree of vertical confinement of the storage aquifer.

6.5.2 Iron and Arsenic Concentrations

Iron concentrations are a concern to an ASR project because of potential problems with ferric hydroxide precipitate causing plugging during recharge and with meeting drinking water standards during recovery, particularly if the buffer zone is not maintained during operation. The secondary drinking water standard for iron is 0.3 milligrams per liter (mg/L) or 300 micrograms per liter (µg/L). The primary drinking water standard for arsenic is 10 µg/L .

From a review of the iron and arsenic concentrations in **Figures 6-36 and 6-37**, those constituents do not appear to pose any potential concerns for the design and operation of a successful ASR project. Neither the distribution of iron nor arsenic concentrations are at levels that should require special design or operational considerations. Normal design and operational measures should be sufficient to manage any elevated iron and/or arsenic concentrations that are encountered.

At the City of Victoria, iron concentrations (see **Figure 6-36**) range from 50 µg/L to 688 µg/L in the Evangeline wells. It appears that the iron measurements (70 µg/L, 50 µg/L and 70 µg/L) in the three wells closest to the Guadalupe River are notably lower than three iron measurements (120 µg/L, 688 µg/L, and 200 µg/L) away from the river. In addition to the TWDB measurements, eight additional iron concentration measurements were obtained from laboratory report sheets from the City of Victoria. These eight measurements ranged from 190 µg/L to 960 µg/L and averaged 290 µg/L.

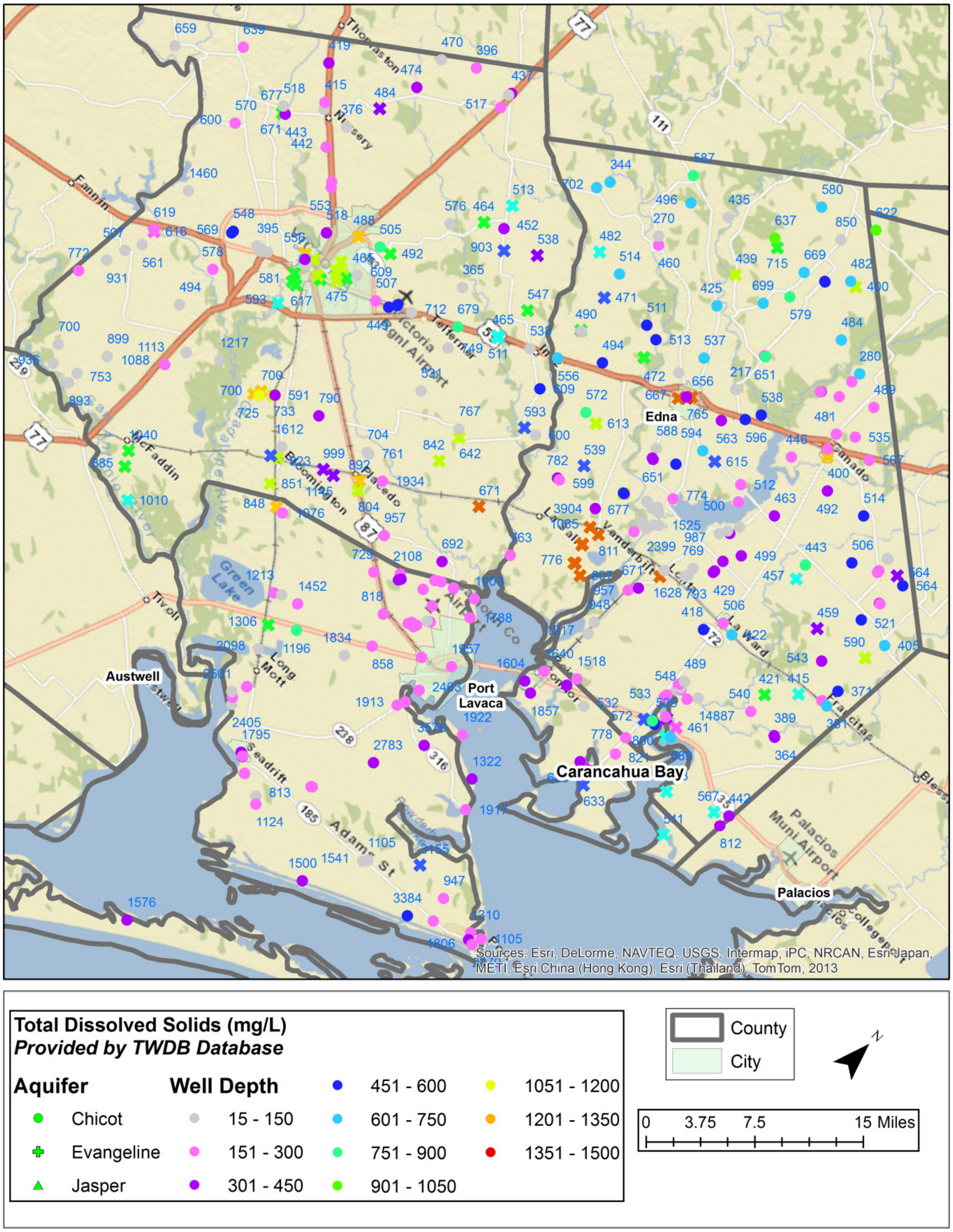


Figure 6.35: Spatial Distribution of Total Dissolved Solids Concentration based on Measurements from the TWDB Groundwater Database

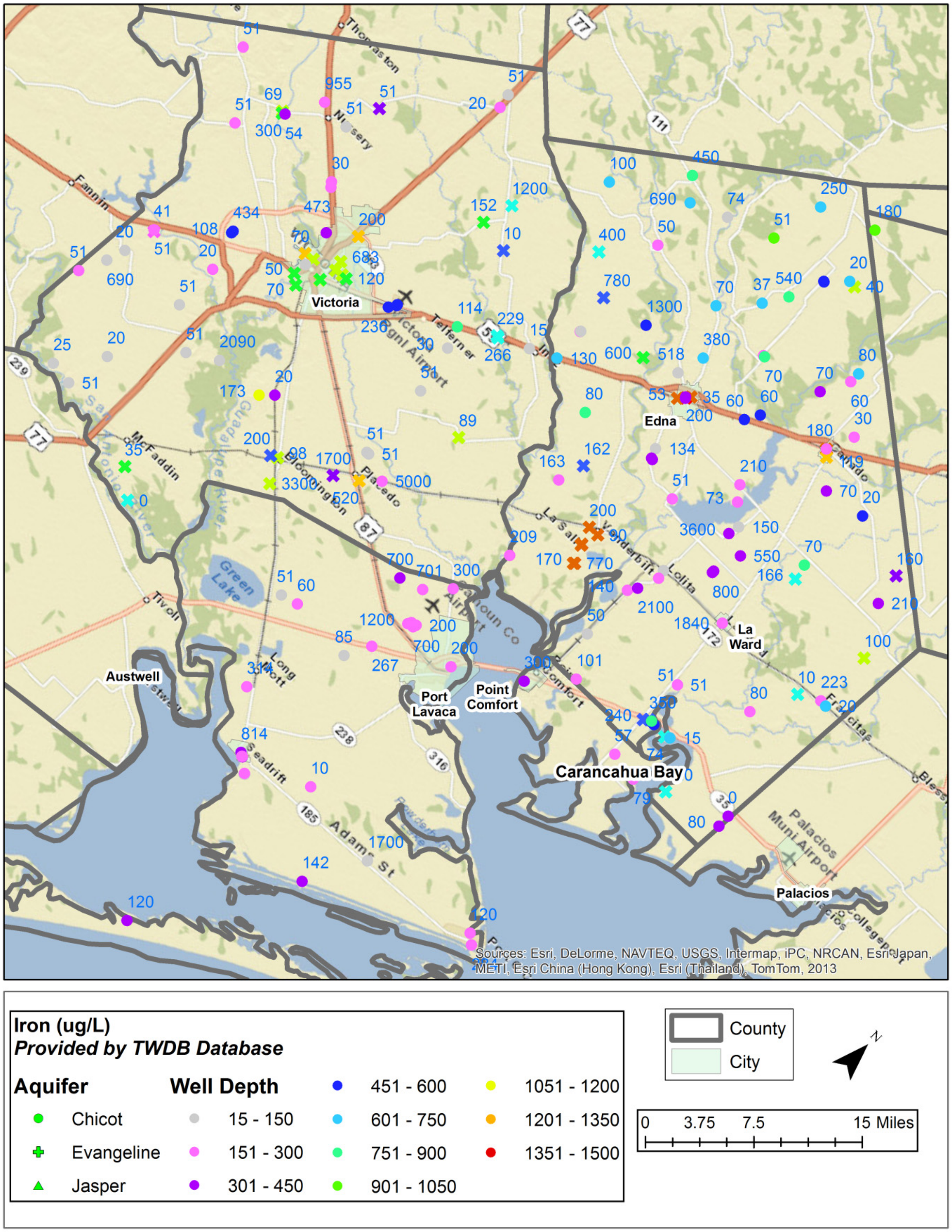


Figure 6.36: Spatial Distribution of Iron Concentration based on Measurements from the TWDB Groundwater Database

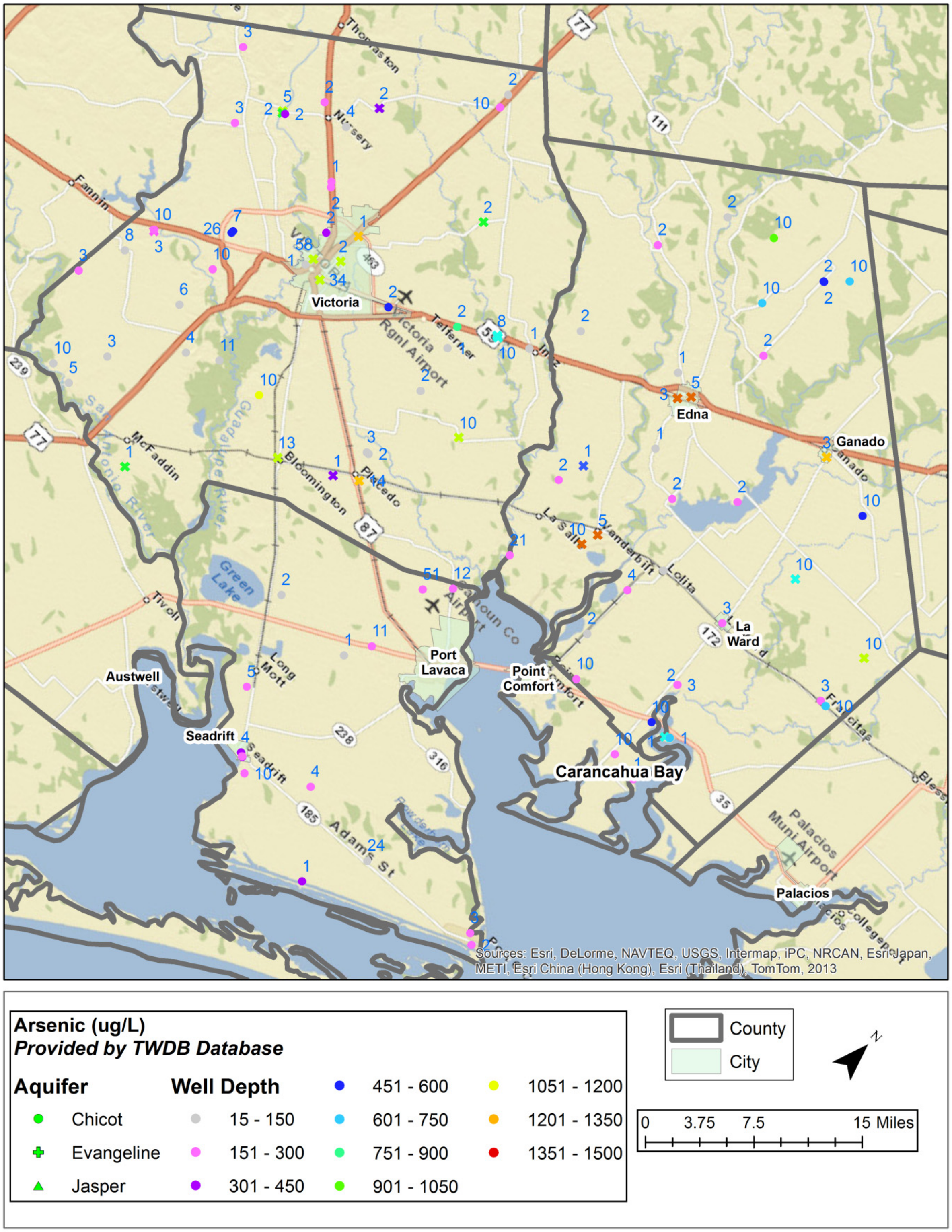


Figure 6.37: Spatial Distribution of Arsenic Concentration based on Measurements from the TWDB Groundwater Database

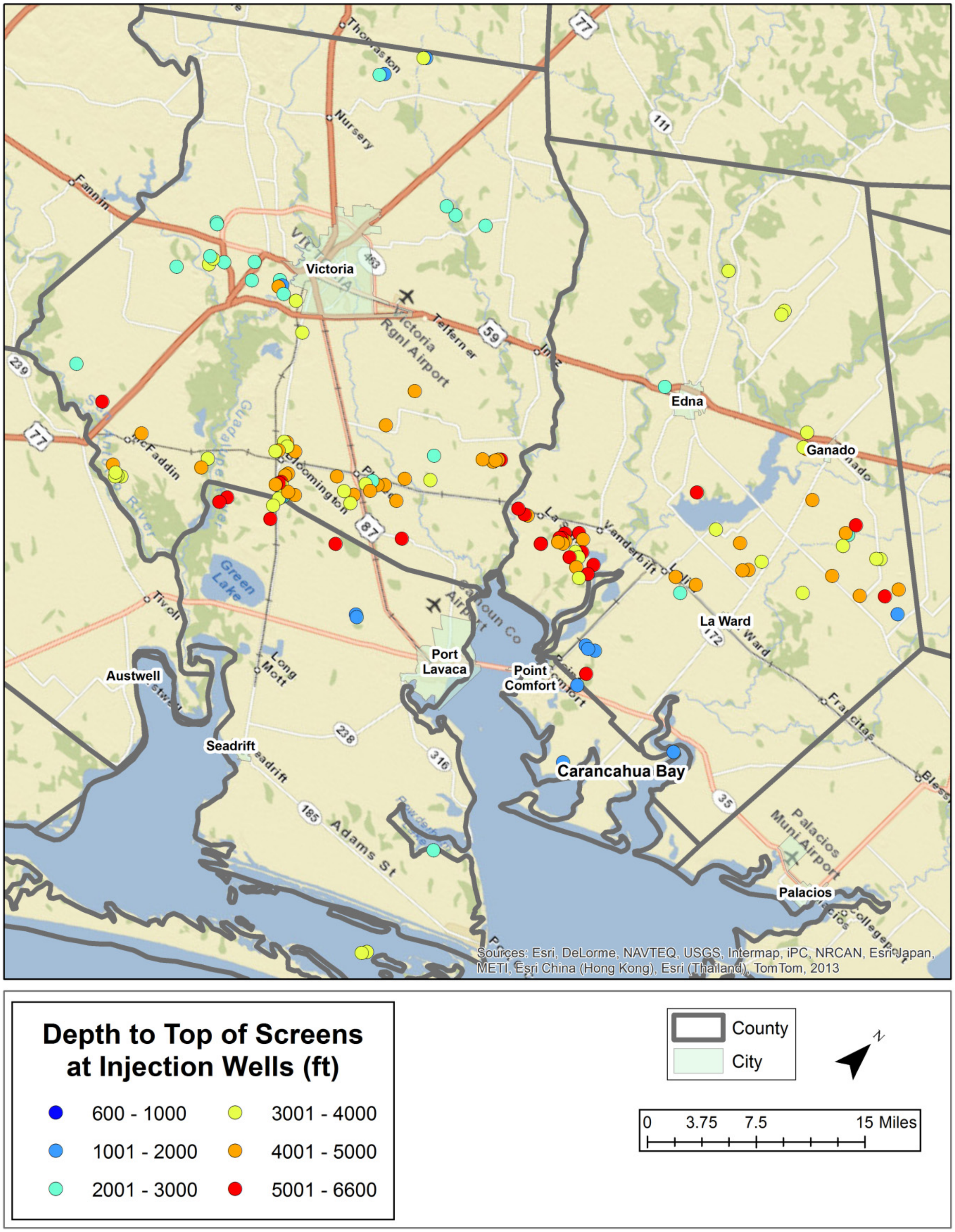


Figure 6.38: Spatial Distribution of Class II Injection Wells

In **Figure 6-37**, there are six arsenic measurements for the Evangeline Aquifer underlying the City of Victoria. These values range from 1 µg/L to 58 µg/L and average 20 µg/L. This average concentration exceeds the primary drinking water standard. As indicated at many other ASR sites with arsenic-bearing minerals in the storage aquifer, operational measures can usually be implemented to ensure that arsenic is not present at unacceptable concentrations in the recovered water. Specifically, formation and maintenance of a buffer zone around each ASR well is usually effective for ensuring acceptable recovered water quality, including arsenic concentrations. Situations where this approach is not effective are those where vertical confinement of the storage aquifer is inadequate, causing rapid vertical movement of water into the storage aquifer, close to the ASR well, during recovery. With the thick clay layers evident in the Study Area, this situation is not expected. Experience has shown that any mobilized arsenic tends to attenuate fairly rapidly with time, with distance from the ASR well, with successive operating cycles, and with increasing cumulative storage volume. Significant lateral movement of any mobilized arsenic in the storage aquifer is not expected. Successful performance of ASR wells would need to be confirmed locally through construction and testing of one or more ASR demonstration wells.

Near Port Lavaca, there are four measurements of iron concentrations in the Chicot Aquifer. These range from 1,200 µg/L to 200 µg/L and average 575 µg/L. There are no measurements of iron or arsenic concentrations in the Evangeline Aquifer. For the Chicot Aquifer, there are three arsenic measurements that range from 11 µg/L to 51 µg/L and average 24 µg/L. Although the available data is limited, average iron and arsenic concentrations near Port Lavaca exceed drinking water standards.

Around Carancahua Bay, there are four iron concentrations measured in the Chicot Aquifer. They range from 51 µg/L to 350 µg/L and average 133 µg/L. In the Evangeline there are three measured iron concentrations. They range from 74 µg/L to 420 µg/L and average 245 µg/L. Away from the Bay and in Southern Jackson County, the iron concentrations range from 150 µg/L to 1840 µg/L in the Chicot Aquifer and from 10 µg/L to 166 µg/L in the Evangeline Aquifer. Around Carancahua Bay and Southern Jackson County, the measured arsenic concentrations are equal to or below 10 µg/L for both the Chicot and Evangeline Aquifers.

A potential concern with ASR operations is the mobilization of arsenic in the subsurface in response to changes in geochemistry of the aquifer caused by the introduction of the water into the subsurface. Changes in the pH and Eh[2] of the groundwater can affect the solubility of compounds such as pyrite that may contain arsenic and the adsorptive capacity of minerals such as iron oxides that can retain arsenic. For a situation where the injected water reduces the Eh of the groundwater system, the potential exists for iron oxides to release arsenic into the groundwater as a result of a decrease in the strength of geochemical bonds between arsenic

[2] pH is a measure of the relative abundance of the hydrogen ion in solution. Most natural waters have a pH between 6 and 8. pH values greater and less than 7 provide an indication of the acidity and basicity of water, respectively. Eh is measured in millivolts and is a measure of the oxidation reduction potential (ORP). Eh is a measure of the tendency of a chemical species to acquire electrons. A solution with a lower (more negative) reduction potential will have greater tendency to provide electrons to a reactions than would a solution with a higher (more positive) reduction potential.

and iron oxides. For a situation where the injected water increases the Eh of the groundwater system, the potential exists for some of the arsenic contained in pyrite to be released into the groundwater because of the increased solubility of pyrite.

At the three potential ASR sites, the injected water will be, or will most likely be, treated surface water. From data received from GBRA and Victoria, it is anticipated that the treated surface water will have a pH between 7 and 8, be characterized by oxidizing conditions with dissolved oxygen concentrations between 2 mg/l and 10 mg/L. If such water is injected into an aquifer containing pyrite with reducing conditions, the opportunity exists for pyrite to be dissolved and for arsenic to be mobilized. In Florida, several ASR facilities observed increases in arsenic levels during the cycle testing phase. These observed increases in arsenic concentrations have been attributed to pyrite dissolution caused by water being injected into aquifer systems with reduction potential that range between 0 and -400 millivolts. For these situations in Florida, detailed monitoring has demonstrated that arsenic attenuates naturally to below drinking water standards due to time (weeks), distance (up to about 200 feet), increasing cumulative storage volume, and successive ASR cycles. Furthermore, evaluation of the Florida case studies provides us with the knowledge base for managing arsenic concentrations by developing an adequate buffer zone as part of the cyclic testing program.

ASR projects in Florida, as well has other studies, have shown that pyrite concentrations are spatially variable and predictions of arsenic mobilization are difficult because of the complexity of the geochemical reactions. Despite this complexity and uncertainty, a relative measure of the potential for arsenic mobility is possible with data from the Victoria ASR site based on available field data. In the Lower Goliad formation near the City of Victoria water quality data from the TWDB groundwater database over the last 20 years were used to characterize groundwater in the Lower Goliad Formation, which is the geological unit for the proposed ASR wells.. These data provide an average dissolved oxygen concentration of 2 mg/l, an average pH of 7.6, and an average oxidation reduction potential of -0.7 millivolts. Using these average values, groundwater in the Lower Goliad Formation is characterized by a neutral pH and a slightly oxidizing environment (based on the dissolved oxygen concentrations). The treated surface water from the Guadalupe River is estimated to have a pH of about 7.4 and a dissolved oxygen concentration between 3 mg/l and 10 mg/L. Based on our understanding of the ASR field measurements of arsenic mobility in Florida, and the relatively simple operational measures required to form and maintain a buffer zone around an ASR well, there is a relatively low potential for arsenic concentrations to exceed drinking water standards of 10 ug/L after cycle testing has been completed. In addition, if the arsenic does approach 10 ug/L our experience has demonstrated that any proposed ASR system can be designed and operated in a manner that would permit natural attenuation to reduce arsenic to acceptable levels.

6.5.3 Injection Wells and Other Potential Sources of Contamination

When oil and gas are extracted from the subsurface, large amounts of brine are typically brought to the surface. Often saltier than seawater, this brine can also contain toxic metals and radioactive substances. Class II injection wells are used to inject fluids brought to the surface in connection with oil and natural gas operations and the storage of hydrocarbons. **Figure 6-38** shows the locations of the Class II injection wells in the Study Area.

Class II injection wells can adversely impact an ASR project if their injected fluids contaminate groundwater. Undesirable contamination could occur if leakage occurs as a result of an improper seal or a corroded casing, or mishandling of the waste at ground surface. In addition, there is the possibility that sufficient pressure in the subsurface could cause an upswelling of contaminates/brines along ground faults. Young and others (2014) present evidence of upswelling of brines from geopressured zones of the Catahoula along growth faults in the Gulf Coast Aquifer System in both Texas and Louisiana.

Figure 6-38 shows that there are no Class II injection wells in the vicinity of Port Lavaca. NearCarancahua Bay there is only one Class II injection well. Its injection zone begins at a depth between 1,000 feet bgs and 2,000 feet bgs. At the southern perimeter of the City of Victoria, there are six Class II injection wells. Three of these injection wells have injection zones that begin at depths between 1,000 feet bgs and 3,000 feet bgs. As a general rule, ASR wells should not be located within 0.5 miles of any Class II injection well. In addition, prior to considering placing an ASR well within 0.5 miles of a Class II injection well, a thorough investigation of the injection well's construction, waste stream, history of operations, as well as geological faults should be performed.

An aquaculture operation approximately 0.5 miles north of Port Lavaca WTP has potential to contaminate shallow groundwater if discharges from the aquaculture ponds have chemicals or pollutants that leach into the ground. This operation is run by R&G Fish Farm LLC under state General Aquaculture Permit No. TXG 130000. The Farm's permit number is TXG 130024. The facility overlies the location of the 18 wells shown in **Figure 6-28** that are near Chocolate Bay and have a depth less than 450 feet. Visual inspection of aerial photography reveals that there are more than 25 ponds that spread across approximately 0.13 square miles.

6.6 Evaluation of the Hydrogeology at the Potential ASR Sites

At all three potential ASR sites, the hydrogeology is conducive to successful implementation of ASR projects. A primary reason for the suitability of the sites is the sandy deposits that comprise the upper Evangeline Aquifer and lower Chicot Aquifer. Our analyses of the lithologic sequences indicate that sand beds with thicknesses greater than 40 feet are prevalent. Based on analyses of transmissivity values from aquifer tests, the thicker sand beds in the Upper Goliad, Lissie, and Willis formations typically have hydraulic conductivity values between 8 ft/day and 40 ft/day, which translate into transmissivity values between 320 ft^2/day to 1,600 ft^2/day for a 40-foot sand bed. Application of the Theis solution for pumping groundwater from deposits within this transmissivity range indicates sustainable pumping rates that range between 160 gpm to 800 gpm for a pressure head of about 200 feet (or 86.7 psi) and a single 40-foot sand bed. Two or more sand layers may be screened in a single ASR well, achieving goals for acceptable well recharge and recovery rates, and associated pressure and drawdown.

For each of the three sites the following five topics will be discussed: 1) targeted geological formation; 2) frequency and thickness of sand beds, 3) potential migration of the injected water; 4) adverse impacts from existing wells, and 5) water quality.

6.6.1 City of Victoria

One of the attractive locations for ASR wells in the City of Victoria is near the Victoria WTP, but away from any municipal wells that will be used by the City on a regular basis. Any uncertainty about the impact of municipal wells is manageable because the pumping of these wells is in control of the City. The aquifer properties of the Upper Goliad Formation underlying the City are characterized at a high level of confidence as a result of transmissivity estimates from 15 aquifer tests, consistency in the lithology and sand bed profiles from 14 geophysical logs, and considerable measurements of water quality. Discussed below is a summary of the key findings at this potential site.

<u>Targeted Geological Formation</u>

The Upper Goliad Formation contains the deposits that would be screened for the ASR wells. The initial ASR wells will likely be located near the Victoria WTP, unless operational considerations dictate other locations. In this vicinity the top and bottom of the Upper Goliad Formation occur at approximately -200 ft msl and -1000 ft msl, respectively. In order to promote conditions that will facilitate drawdown up to 300 feet during pumping, the ASR wells will be screened in the middle to lower sections of the Formation.

<u>Sand Beds</u>

Based on an analysis of the geophysical logs, sand beds with thicknesses of at least 40 feet are prevalent. For a 400-foot well screen, the total length of sand beds that will be intersected should be between 150 ft and 225 ft. The hydraulic conductivity of the sand should average about 24 ft/day. As a result, for a 400-foot well screen the transmissivity of the intersected sands should be between 3,600 ft^2/day and 5,400 ft^2/day.

<u>Migration Rate</u>

By multiplying the average hydraulic conductivity by a horizontal hydraulic gradient and then dividing by the effective porosity, an estimate of the average groundwater velocity can be calculated. From analysis of simulated water levels from the CGC GAM, a regional hydraulic gradient of approximately between 0.0005 ft/ft and 0.001 ft/ft is estimated for a scenario where the City's average pumping is about 1,400 AFY (see Section 6.2). Using a sand bed hydraulic conductivity of 24 ft/day and an effective porosity of 0.25, the migration rate is estimated to range between 17.5 ft/year and 35 ft/year. However, if the City actively manages the well operation to minimize the magnitude of the hydraulic gradient in the vicinity of the stored water, the migration rate of the stored water would likely be significantly less than 17.5 ft/year.

Existing Wells

The impact that the City's municipal wells will have on future groundwater movement is a concern at this time because of the many unknowns associated with the City's well field operations. However, the City has the ability to fully control the pumping at these wells and to operate its well field in a manner that is not detrimental to the operation of an ASR system. Besides the municipal wells, there are no other wells whose pumping pose a potential problem to a managing the ASR "bubbles" of stored water.

Water Quality

In the vicinity of the City's municipal well field and the WTP, there are no known sources of contamination in the Upper Goliad. No notable contamination sources near the surface have been identified. Additionally, there are no Class II injection wells within a 10 mile radius; the measured concentrations of iron and arsenic are generally acceptable (one measured arsenic concentration of 58 µg/L); and the expected TDS concentrations are between 500 mg/L and 600 mg/L.

6.6.2 Port Lavaca

One of the attractive locations for ASR wells near Port Lavaca is between the City and the Port Lavaca WTP and a few miles inland from the bay. Among the positive features of this site are a low potential for groundwater migration, primarily as a result of the low regional gradients. Based on the lithology interpreted from log PL-5 (**Figure 6-11**) the target zone for injection will likely be between -400 ft msl and -1100 ft msl. This vertical interval intersects three formations: the lower Lissie Formation, the Willis Formation, and/or the Upper Goliad Formation. The targeted zone is characterized by changing conditions that are depth-dependent. Conditions that are expected to change with depth include TDS concentrations, the frequency and permeability of the sand beds, and the height of the water column above the top of the screen.

Targeted Geological Formation

A few miles north of the Port Lavaca WTP and a few miles inland of the bay, the targeted zone for ASR wells is between -400 ft msl and -1100 ft msl. This 700 ft interval intersects the Lissie and Willis formation of the Chicot Aquifer and the Upper Goliad formation of the Evangeline Aquifer.

Sand Beds

Based on log PL-5 in **Figure 6-11**, sand beds are prevalent and their typical thicknesses are between 10 feet and 20 feet. In the vertical interval of interest, there are no results from aquifer tests. As a consequence, hydraulic conductivity of the sand beds needs to be extrapolated from other tests. A conservative estimate is that hydraulic conductivity value is about 12 ft/day for sands in the Lissie Formation and about 5 ft/day for sands in the upper region of the Upper Goliad Formation.

<u>Migration Rate</u>

By multiplying the average hydraulic conductivity by a horizontal hydraulic gradient and then dividing by the effective porosity, an estimate of the average groundwater velocity can be calculated. From analysis of simulated water levels from the CGC GAM, the regional hydraulic gradient of 0.00006 ft/ft is estimated (see Section 6.2). Using a sand bed hydraulic conductivity of 8.5 ft/day and an effective porosity of 0.25, the migration rate is estimated to be about 1 ft/year.

<u>Existing Wells</u>

Near the Port Lavaca WTP and about a mile north of the water treatment plant, about 20 wells have been installed since 2001. Most of these wells have depths that are less than 470 feet bgs. Among the options to manage any potential adverse impacts associated with pumping of these wells, the ASR wells could be located farther inland and west of these well locations (see **Figure 6-28**) or placed below the Lissie Formation.

<u>Water Quality</u>

The primary water quality issue of potential concern is the TDS, although elevated concentrations of iron and arsenic may be present in the storage aquifer. It is presumed that the TDS of the targeted groundwater zone will be between 1,500 mg/L and 5,000 mg/L. With adequate confinement of the sand beds between clay layers it should be possible to implement a successful ASR program. If ASR facilities are proposed for the Port Lavaca WTP, the adjacent aquaculture operation will have to be evaluated in more detail.

6.6.3 Southern Jackson County

Our investigation of Southern Jackson County was performed without a preferred ASR storage location, such as a water treatment plant or facilities within a water distribution system. Our analysis suggests that there are numerous suitable sites for ASR in southern Jackson County and particularly in the vicinity of Carancahua Bay. For the purpose of this report, we have selected an attractive site that is reflective of the favorable hydrogeological conditions near and around Carancahua Bay. The location selected is near the location of log CB-3 (**Figure 6-10**). Among the positive features of this site are a low potential for groundwater migration primarily as a result of the low regional gradients and a relatively well-characterized lithology and stratigraphy. Comparison of the geophysical signatures and lithologies from log CB-3 and nearby log CB-4 (see **Figures 6-11 and 6-10**) are well correlated. Their good correlation provides a high level of confidence for targeting a production zone. Based on the information extracted from logs CB-3 and CB-4, the targeted interval for ASR wells is between -300 ft msl and -1050 ft msl. This vertical interval intersects three formations: the lower Lissie Formation, the Willis Formation, and/or the Upper Goliad Formation. The targeted zone is characterized by changing conditions that are depth-dependent. Conditions that are expected to change with depth include TDS concentrations, the frequency and permeability of the sand beds, and the height of the water column above the top of the screen.

<u>Targeted Geological Formation</u>

Near the location of log CB-3, the targeted interval for ASR wells is between -300 ft msl and -1050 ft msl. This 850 ft interval intersects the Lissie and Willis formation of the Chicot Aquifer and the Upper Goliad formation of the Evangeline Aquifer.

<u>Sand Beds</u>

Based on logs CB-3 and CB-4 in **Figure 6-11**, sand beds are prevalent and their typical thicknesses are between 10 feet and 60 feet. In the vertical interval of interest, there are no results from nearby aquifer tests. As a consequence, hydraulic conductivity of the sand beds needs to be extrapolated from other tests. A conservative estimate is that the hydraulic conductivity is about 18 ft/day for sands in the Lissie Formation and is about 5 ft/day for sands in the upper region of the Upper Goliad Formation.

<u>Migration Rate</u>

There is insufficient water level data to determine a reliable estimate of a regional horizontal hydraulic gradient near log CB-3. Based on the results of the simulated water levels in this area from the CGC GAM in Section 6.2, the gradient is expected to be less than 0.0001ft/ft (0.5 ft per mile). Based on an assumed porosity of 0.25 for the sands and a hydraulic conductivity estimate of about 10 ft/day, the estimated migration rate of stored water away from the ASR wells is less than 2 ft/year.

<u>Existing Wells</u>

Within a few miles south of the location of log CB-3, **Figure 6-29** shows six wells with depths less than 600 feet bgs. The pumping estimates in the CGC GAM indicate relatively low pumping in this area. A suitable location for an ASR facility is within a few miles of the location of log CB-3; that location would not be adversely impacted by the pumping of nearby wells.

<u>Water Quality</u>

The primary water quality issue of concern is the TDS, but the quality of water near Carancahua Bay appears to be generally better than at similar depths near Port Lavaca. Based on the interpretation of the log CB-3, water with a TDS of less than 1,000 mg/L is expected to occur regularly to about -500 ft msl. Below an elevation of -600 ft msl the targeted groundwater zone will likely have a TDS concentration between 1,500 mg/L and 5,000 mg/L.

6.6.4 Port of Victoria

As a result of the favorable hydrological conditions in the Study Area, the potential ASR sites in the Study Area may be expanded over time beyond the three discussed above. Among the locations where ASR may prove beneficial is near the Port of Victoria. **Figure 6-5** shows several of the major Port of Victoria properties. These properties are in close proximity to geophysical log CSA-6. A review of all of the information in this section indicates that the Port of Victoria has attractive hydrogeological conditions that make it conducive to ASR. A lithologic profile in log CSA-6 (see **Figure 6-7**) indicates numerous sand beds in the Chicot and Evangeline aquifers between the elevations of -200 ft msl and -1300 msl and a resistivity profile for log CSA-16 indicates that the TDS concentrations are less than 1,500 mg/L above -1300 ft msl. Other favorable conditions include, a relatively flat hydraulic gradient of about 0.0003 ft/ft (1.5 ft/mile), no evidence of large pumping in the vicinity, and no Class II injection wells within several miles.

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7.0 ASR Modeling and Preliminary Basis for Design

7.1 Victoria Area

The Study Area in Victoria County includes the service area of the City of Victoria and the properties owned by the Port of Victoria. The Port's properties are located just south of the City adjacent to the Victoria Barge Canal.

7.1.1 City of Victoria ASR Model Description

An spreadsheet model has been prepared, the purpose of which is to provide a tool for determining the feasibility, conceptual design and cost of ASR facilities to provide water supply reliability to meet projected demands while remaining consistent with the City of Victoria's existing water rights. This ASR model essentially compares daily water availability and daily water demand in order to determine how much water must be stored in an ASR well field, and what recharge and recovery rates are required. "Water supply reliability" is defined as meeting 100 percent of daily water demands with water meeting all drinking water standards during a hydrologic repeat of the period of record, including the DOR. Seven options (A through G) have been evaluated using the model. These options represent a range of operating scenarios for consideration. The options are described in detail in Section 7.1.4 below.

Model input data include the following:

Period of Record. This is the actual, historic record of daily river flows, as measured at the United States Geological Survey (USGS) gage 08176500 on the Guadalupe River at Victoria. For this report the portion of the period of record that was utilized is from January 1, 1941, to December 31, 2012.

Study Period. This is a simulated record of projected daily water demands extending from the present (2014) to 2040, with water demands increasing linearly at an assumed 8 percent per decade. For the simulations, daily water demands after 2040 were assumed to remain the same as in 2040. The selected "base year" for water demand projections was 2011, which was a very dry year. Projections were also analyzed for a more typical base year, 2008. For each of these years (2011, 2008) the daily distribution of water demands for that year was assumed to occur in 2014 and was then projected forward to 2040. A linearly-increasing factor was applied for each subsequent year after 2014, steadily increasing the water demand.

Daily water demand records, Calendar Years 2008 through 2012 (million gallons per day, MGD). The data provided by the City included raw water pumped to the Victoria WTP and treated water supplied from the Victoria WTP to the distribution system. The difference between the two data sets averages about 0.3 MGD and constitutes normal water treatment operational losses such as due to filter backwashing. The difference also includes any groundwater pumped to the water treatment plant from the two nearby City wells, such as during times when source water from the OCS is highly turbid. For the ASR analysis, the raw water demands were utilized.

<u>Daily flow availability from the Guadalupe River, 1941 through 2012, at the City of Victoria diversion intake structure (cubic feet per second, CFS)</u>. Daily flow records at the USGS Gage at Victoria were utilized as a starting point. The flows were adjusted to reflect estimated upstream diversions from the river during the period of record, creating a set of unimpaired river flows. Senior water rights holders, upstream and downstream, were then assumed to take all of their water available from the river pursuant to each of their water rights, utilizing the assumed monthly distribution of water demands that underlies the Water Availability Model (WAM) that is used by the TCEQ. For Victoria, the assumed monthly WAM distribution of the City's available water rights was added back to the remaining flow available from the river, creating a set of daily water availability data for Victoria, prior to the City's proposed diversions pursuant to the ASR Model. Diversion capacity is assumed to equal WTP capacity.

<u>Water Treatment Plant Capacity (MGD)</u>. The current rated capacity of the City's WTP, 25.2 MGD, was utilized for most of the analyses. Sustained operating capacity is currently about 21 MGD, however it is assumed that with an upgrade to the chemical feed system, and possibly other minor process adjustments, a treatment rate of 25.2 MGD could be sustained. A reasonable goal would be to demonstrate that the existing WTP capacity, in conjunction with ASR and the City's existing off-channel reservoir storage, is adequate to meet projected 2040 demands. However, if the required TSV is substantial and would require an inordinate amount of time to achieve, then increasing the water treatment capacity would potentially accelerate the storage of **treated** drinking water underground in ASR wells. Similarly, expansion of OCS capacity would accelerate storage of **untreated** water. Expansion of the WTP may then be required in order to meet water demands during a repeat of the DOR. This would also require expansion of the ASR wellfield in order to get the additional water into storage during times when it is available. Achieving water supply reliability for the City's service area depends upon achieving and maintaining sufficient water in storage, so the more rapidly this can be achieved, or restored following a major drought, the better.

<u>Filter for high river flows (CFS)</u>. The ASR Model includes an option for not diverting water when river flows exceed a given flow rate. This could be applicable for situations where river water quality during flood conditions has high turbidity or is otherwise difficult to treat, or other operational constraints. For Victoria, the high flow constraint was set at 400,000 CFS, which exceeds the highest recorded flow on record that occurred during the 1998 flood. For the current analysis this is therefore not a constraint. Raw water diversions from the Guadalupe River are routed through ten former gravel pits which provide off-channel storage in addition to turbidity reduction.

<u>Filter for low river flows (CFS)</u>. The ASR Model includes an option for not diverting water when river flows are below a given flow rate. This is not an unusual situation for water treatment facilities relying upon run-of-river water supplies. Reasons typically include source water quality that is difficult to treat, such as high concentrations of algae, color, manganese, total organic carbon, bromate and other constituents. For Victoria, the low flow constraint was set at zero. It is assumed that the City will divert any available water within its water rights, and within the capacity of the Victoria WTP, so long as there is any flow in the river, and so long as

the cumulative total storage volume is less than the sum of the OCS capacity plus the ASR TSV. If the river flow is less than the WTP capacity, any available river flow will be diverted. If the river flow is less than the minimum rate at which the WTP can be operated (6 MGD), it is assumed that the shortfall will first be obtained from the OCS. At such time as the OCS has been emptied, ASR recovery will commence. If the TSV has been achieved, diversions are assumed to equal service area water demand.

<u>Off-Channel Storage Capacity (acre feet, AF).</u> Victoria has an existing OCS system with an assumed current storage capacity of at least 2,000 AF. This is actually a collection of ten gravel pits in close proximity on the west side of the Guadalupe River, across from the City's WTP. The City has indicated that it may be possible to increase the storage capacity to as much as 4,000 AF. For the purpose of this analysis the current OCS storage volume is assumed to be full at the beginning of the study period. Water losses may be reasonably expected due to evaporation, transpiration and seepage during a drought, however it is assumed that sufficient OCS total storage capacity is provided so that active storage of 2,000 AF is available.

During periods when insufficient or no diversions from the river are possible, water is assumed to be withdrawn first from the OCS for treatment and distribution, prior to recovering water from ASR storage. During periods following a drought when diversions from the river are once again possible, it is assumed that the OCS will be filled first, followed by adding to ASR storage. It is important to keep in mind that water stored in the OCS requires full treatment prior to distribution or ASR storage. It is assumed in this study that water stored in ASR wells requires only restoration of the disinfectant (chloramine) residual prior to distribution. Increased reliance on ASR storage therefore reduces the need for WTP expansion to meet projected demands.

<u>Water Rights (acre-feet per year, AFY)</u>. As discussed above, the sum of the City's existing water rights is 27,006.7 AFY. ASR diversions from the Guadalupe River are checked daily in the model to ensure that the City's water right constraints are not exceeded. Once this volume has been diverted, treated and either stored or consumed during any given year, no further diversions are allowed. Instead, service area water demands are met from storage.

<u>Initial Volume in Storage (acre feet, AF)</u>. This includes the OCS volume plus the TSV for the ASR wellfield. The DOR for the Guadalupe River Basin occurred from 1947 to 1957. Since the period of record used for the Project begins only six years prior to the beginning of the DOR, an ASR Model analysis that begins with zero water in storage will typically fail to meet water supply reliability criteria since insufficient water would have been added to storage during the first six years. An equivalent DOR occurring toward the end of the period of record would have a much longer time within which to accumulate storage volume, potentially affecting the design, operation and cost of ASR wellfield facilities and associated diversion and treatment capacity requirements. Assuming an initial total volume of water in storage provides a consistent basis for assessing this analysis constraint. The City can then evaluate how much time it wishes to spend to achieve the ASR TSV, thereby ensuring water supply reliability. In general, the shorter the selected time to achieve the TSV, or to restore the TSV following a DOR, the higher the cost for ASR and related facilities required to meet that goal.

A primary goal of the iterative analysis procedure that is utilized for the ASR Model is to minimize the Initial Storage Volume while ensuring 100 percent reliability.

<u>Target Storage Volume (TSV) for the ASR wells (AF)</u>. This value is adjusted during the ASR Model iterative analysis process. A performance goal is to set the ASR TSV so that 50 percent of this volume remains at the end of the DOR. Fifty percent is a conservative placeholder assumption, to be refined based upon operational experience. This remaining volume is referred to as the "Buffer Zone", separating the stored drinking water from the surrounding native groundwater in the storage aquifer. The Buffer Zone is a one-time addition of water to the well. It is formed and maintained, and is not recovered. Operational experience with the San Antonio Water System (SAWS) ASR wellfield since 2004 suggests that, for that location in the Carrizo-Wilcox Aquifer, a 30 percent buffer zone volume is sufficient to ensure that recovered water quality meets all drinking water standards. The 50 percent factor for this Project is therefore considered to be conservative. Once achieved, the TSV is intended to be sufficient to ensure that, during a repeat of the DOR, service area water demands can be met with 100 percent reliability without additional treatment (other than disinfection). The ASR model includes an option to adjust the buffer zone volume as a percentage of the ASR TSV, enabling evaluation of the sensitivity of the results to variations in this assumption.

An important, related consideration in selection of the TSV is the lateral rate of movement of the stored water under the natural regional gradient, or any changes in that gradient caused by local or regional groundwater production. Where the lateral rate of movement is small, such as a few feet per year, the impact upon the availability of stored drinking water in ASR wells is likely to be small. However, for locations and storage aquifers where the lateral rate of movement is large, such as several hundred feet per year, the value of ASR for long-term storage may be reduced while the value for seasonal storage may be essentially unaffected. Deeper aquifers are often utilized for ASR storage since they tend to have slower lateral velocities. For the purpose of this analysis, a 50 percent buffer zone assumption probably provides a significant margin of safety to accommodate some lateral movement of stored water.

<u>Reliability (percent)</u>. The ASR Model is utilized to achieve 100 percent water **quantity** and water **quality** reliability, which is defined as the number of days during a study period that the ASR cumulative storage volume stays above the buffer zone volume divided by the number of days for ASR recovery. For example, if the buffer zone volume is 10,000 AF and the cumulative storage volume during a study period, including a severe drought, never drops below 10,000 AF, 100 percent system reliability would be achieved. For any such days it is presumed that, although recovery of stored water from the ASR wells will continue to be viable, the quality of the recovered water may deteriorate, potentially requiring treatment in addition to disinfection in order to meet drinking water standards. Any change in water quality from treated surface water to native groundwater may become apparent to water customers. The target level of reliability is an input variable to the model. All options except Option D assume 100 percent reliability. Option D evaluates the impact of reducing the reliability goal to 95 percent. A similar supplemental analysis is provided for Option E.

Buffer Zone Volume Divided by ASR Target Storage Volume. This ratio is an input variable for the ASR Model. For all options, a ratio of 0.5 is utilized, however for Options A and E an alternate scenario is also considered, utilizing a ratio of 0.3.

With the above input data, the ASR Model is utilized to estimate the TSV required, and associated capacity of ASR wellfield facilities, in order that projected water demands during the study period will be met with 100 percent reliability during a repeat of the period of record, including the DOR. The data set of water available from the river for each day during the 71-year period of record is first filtered to ensure that high and low flow constraints are met. It is then filtered to make sure that the cumulative volume diverted up to the previous day does not exceed the City's water rights. The resulting set of flows is then filtered to ensure that, during low flow periods when the river flow is less than the Victoria WTP capacity, any flow exceeding the low flow constraint is diverted. Cumulative diversions are then tabulated, in both AF and million gallons (MG). Service area water demands are projected to 2040 assuming that the base year is either a drought year (2011, Option A) or a more typical year (2008, Option E). Daily water demands for the selected base year are multiplied by a factor of 1.26 to estimate 2040 demands, representing a projected increase in water demand of 8 percent per decade. A linear annual increase in water demands is assumed during this period. Projected daily demands for each day of the year are then utilized for each year of the simulated study period, based upon the distribution of daily demands in the base year. For each day, the difference between diverted flow and service area projected water demand is determined. If demand is less than the diverted flow, the difference is added to storage. The City's OCS is filled first, followed by the ASR wellfield. If demand is greater than supply, then water is recovered from storage to help meet demands. The OCS is drawn down first, followed by ASR storage. Cumulative storage is then tabulated, in both MG and AF. If the cumulative storage volume reaches the ASR TSV, no additional water is added to storage. Instead, the volume of water diverted is only sufficient to meet daily demands. A count of the number of continuous days of recharge and of recovery is then determined, providing a basis for estimating the longest number of continuous days of ASR recharge and of ASR recovery that would occur during a repeat of the period of record. The maximum rate of recharge, and of recovery, during the period of record then defines the ASR wellfield recharge or recovery capacity that is needed.

The total storage volume required to meet reliability goals is the sum of the ASR TSV plus any OCS storage. This total volume must be available at the beginning of a repeat of the DOR. Since the DOR occurred only six years after the beginning of the historic period of record, this analysis calculates a hypothetical initial storage volume that would be needed so that the total storage volume has been achieved within the first six years. Participants can then make an informed decision regarding how much capital investment should be made, and when, for ASR, OCS and WTP capacity, with consideration of other criteria such as achieving system water quality and reliability goals within a reasonable period of time.

Victoria currently has about 2,000 AF of OCS capacity, providing storage for untreated water. The ASR Model accounts for this storage. It is assumed that all of the existing OCS capacity is effectively able to supplement the required TSV for the ASR wells. Consequently, if the total storage volume is estimated at, for example, 10,000 AF, it is assumed that 2,000 AF would be off-channel reservoir storage and 8,000 AF of ASR storage would be needed. During a drought it is assumed that the OCS capacity would be drawn down first, thereby minimizing evaporation, transpiration and seepage losses. This would then be followed by recovery from ASR storage. Design capacity of the ASR facilities is unaffected. Only the TSV for the ASR wells varies, depending upon model input assumptions. It is likely that the ASR wellfield would be constructed in two or more phases. During operation of the first phase facilities, stress tests would most likely be conducted for the ASR storage facilities, providing a basis for refinement of these current planning assumptions prior to design of subsequent wellfield expansion phases. A similar stress test could be conducted for the OCS.

For the ASR Model, input data assumptions are made for each of the above parameters. The assumed Initial Storage Volume and Total Storage Volume are then adjusted as needed so that water demands are reliably met during the selected study period while maintaining the required minimum volume in the buffer zone. For any selected model run, an optimal solution would be that which meets these criteria while minimizing the Initial Storage Volume and the ASR TSV. The ASR Model iterates automatically, converging on the optimal solution for each set of input data.

7.1.2. Water Demand Projections

Daily water demands were provided by the City of Victoria for calendar years 2008 through 2012. Maximum day, minimum day and average daily water demands for each year are summarized in **Table 3-1**. The year 2011 was selected as a “base year” for water demand projections since this was a very dry year, resulting in water demands that were higher than normal. For each day during the “base year,” the projected 2040 demand was estimated by multiplying the demand for that day by a factor of 1.26, corresponding to a projected increase in water demand of 8 percent per decade, beginning in 2014 and ending in 2040. A linear increase in water demand was assumed for each year between 2014 and 2040. After 2040 daily water demand was assumed to remain the same as in 2040. This provided the opportunity to evaluate storage volume requirements to ensure water supply reliability during a hypothetical study period that excluded the DOR, namely the period from 1958 to 2012. This is Option C, discussed below.

As the ASR Model analysis proceeded, it became evident that the base year projection using 2011 would tend to overestimate the ASR facilities required; the associated TSV; and the time required to achieve the TSV. Accordingly, some of the alternative scenarios that were considered included selecting a more typical base year, such as 2008. Projections to 2040 from this alternate base year also utilized the same 1.26 factor and the same linear increase in water demand. Analysis of both scenarios provides part of the framework for consideration of ASR alternatives for the City.

2008 was a Leap Year whereas 2011 was not. Adjustments to the water demand projections for the period of record, where necessary, were made by either deleting water demands for February 29 or by duplicating water demands for March 1 of each year.

7.1.3. ASR Objectives for the City of Victoria

At an ASR Workshop held in Victoria on September 12, 2013, a list of ASR objectives for the City was prepared and prioritized. The list was selected by the City following discussion of 27 known applications to date for different ASR wellfields globally. Following is the prioritized list:

- Seasonal storage to meet peak demands
- Long-term storage to increase reliability during a drought
- Deferring expansion of the City's WTP, or construction of a second WTP
- Emergency storage for use during flooding or other events
- Reduction in DBP concentrations

This list has guided the following analysis of water supply options for the City, utilizing ASR storage to help meet projected demands. The first three goals are addressed directly in the following ASR Model analyses. The last two goals are addressed implicitly, as follows:

Emergency Storage – The duration of an emergency event has not been previously defined. A suggested assumption for planning purposes is that such an event might last for up to 30 days. Such an event could possibly result from flooding that contaminates the OCS, requiring that all water supplied to the City's service area would need to be obtained either from existing groundwater supply wells (with the associated water quality issues) or from ASR storage. Such conditions would be less likely to occur during summer, peak demand months. If the emergency occurred during the summer, the City would likely impose water use restrictions. Therefore, it is assumed that water demands during the emergency event would equal average day demands. The rate at which water would be required from ASR storage would be up to about 15 MGD in 2040. This is less than the anticipated design recovery capacity of the ASR wellfield. The volume of water required for recovery is up to about 1,400 AF (15 MGD for 30 days, converted to acre feet). Unless the planned emergency occurs during the first three years of an ASR program, the water should be available for recovery if needed.

Disinfection By-product Attenuation - Most ASR wellfields utilize deep, confined and semi-confined aquifers for ASR storage. The upper Evangeline aquifer under consideration for ASR storage at Victoria fits this description. Water quality in such aquifers is usually characterized by a lack of oxygen, and corresponding oxidation reduction potential (ORP) that is quite low. Extensive research has consistently documented that, under such conditions, DBPs attenuate naturally due to subsurface microbial activity. Two DBPs of particular interest are haloacetic acids (HAAs) and trihalomethanes (THMs) and their associated formation potentials when water is initially disinfected with chlorine, or when the chlorine residual is restored following ASR recovery. The rate of attenuation for HAAs is rapid and is due to **aerobic** microbial activity, stimulated by oxygen in the recharge water. Typically HAA attenuation to zero occurs within a few days of ASR storage, as is the HAA Formation Potential (HAAFP). Similarly, THMs typically attenuate to zero within a few weeks of storage, due to **anaerobic** microbial activity that becomes prevalent in the subsurface after the oxygen in the recharge water has been consumed by subsurface microbial activity and geochemical reactions. THM Formation

Potential (THMFP) is substantially reduced, but usually not eliminated. When the chlorine residual in the recovered water from an ASR well is restored, the THM concentration will increase, but not by very much. ASR storage typically lasts for months to years. Consequently DBP attenuation is achieved as a side benefit of ASR storage, and at no additional cost. Water recovered from ASR wells located at or close to the Victoria WTP can be blended with water being produced at the WTP during times of the year when meeting EPA and State primary drinking water standards for DBPs is a challenge. This is often during summer months when water temperatures are elevated. Similarly, water recovered from ASR wells located elsewhere within the service area can be blended with water in the distribution system, thereby achieving DBP standards. This can be a highly cost-effective solution for meeting the recently-enacted Stage Two DBP requirements.

For ASR storage in aquifers that contain oxygen, or have elevated ORP values, HAA attenuation may be reasonably anticipated however THM attenuation is not expected unless other constituents in the recharge water, or conditions in the aquifer, set up circumstances favoring THM attenuation. This situation is not expected for the Victoria area.

7.1.4. ASR Model Results for Meeting 2040 Projected Water Demands

Table 7-1 provides a summary of ASR Model results for the City of Victoria. A brief description for each of the options follows. Additional options besides those discussed below may also be evaluated using the ASR Model. All model results in the following summary have been rounded to the nearest 100 AF. Options A, B, C and D all utilize daily demands during 2011 as the baseline for water demand projections. Options E, F and G utilize 2008 as the baseline.

Table 7-1: Summary of ASR Model Results for Meeting Projected 2040 Water Demands – City of Victoria

Option	Description	WTP Capacity (MGD)	Initial Storage Vol. OCR + ASR (AF)	Total Storage Volume (AF)	Off-Channel Reservoir Volume (AF)	ASR Storage Volume (AF) Target Storage Volume	ASR Storage Volume (AF) Available For Recovery	ASR Storage Volume (AF) Buffer Zone	ASR Storage Volume (AF) Projected At End Of DOR Recovery (4)	ASR Recharge Capacity (MGD)	ASR Recovery Capacity (MGD)	Maximum Duration Recharge (Days)	Maximum Duration Recovery (Days)
<u>2011 (Dry Year) Baseline Water Demand</u>													
A	Baseline Option	25.2	105,180	168,060	2,000	166,060	83,030	83,030	82,938	18.3	24.9	336	259
B	Option A with zero initial ASR volume	25.2	2,000	FAILURE									
C	Option A for seasonal and normal annual variability; not DOR	25.2	2,000	55,900	2,000	53,900	26,950	26,950	26,918	18.3	24.9	426	259
D	Option A but with 95% reliability, not 100%	25.2	96,770	168,060	2,000	166,060	83,030	83,030	71,662	18.3	24.9	336	259
<u>2008 (Normal Year) Baseline Water Demand</u>													
E	Option A, but with lower baseline water demands	25.2	3,500	11,250	2,000	9,250	4,625	4,625	4,644	19.2	21.0	230	251
F	Option E, but with zero initial ASR volume	25.2	2,000	PARTIAL FAILURE (See Note 5)									
G	Option E, but with WTP expansion	32	2,000	9,300	2,000	7,300	3,650	3,650	3,652	26.0	19.6	230	251

Notes: 1. OCS is assumed to be full at the beginning of the study period and to be drawn down first, prior to recovering from ASR wells.

2. When additional water is available for diversion, the OCS is filled first, followed by ASR.
3. Initial Storage Volume includes OCS plus ASR storage
4. For Option C, the value is the minimum storage volume during the study period (1958 to 2012), not during the DOR
5. Recovery of a significant portion of the ASR buffer zone risks water quality deterioration and the possible need for treatment beyond redisinfection
6. Initial ASR recharge rates during the first six years of ASR operations average 9,600 AFY for Option A and 1,100 AFY for Option E

Option A

This is intended as the baseline option against which other options may be compared.

In this option, it is assumed that an Initial Storage Volume is available prior to beginning the ASR Model analysis. This analytical approach resolves the problem of testing the reliability of a proposed water storage option against a repeat of the period of record, if the assumed DOR occurs near the beginning of that period because sufficient storage has previously been achieved. A decision can then be made as to the appropriate amount of time that should be provided to achieve the TSV, considering water supply reliability during years when the ASR TSV has not been achieved or restored; ASR facilities costs; phasing of implementation; water demand projections; and other factors.

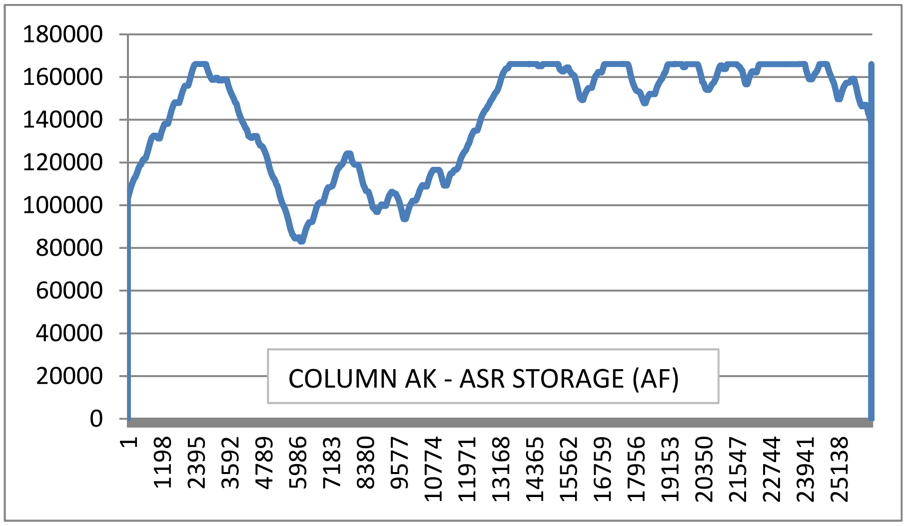
An Initial Storage Volume of 105,200 AF is required for Option A. With all ASR facilities constructed and in operation this would require about 11 years to achieve, utilizing water that is typically available for storage during the early years of a repeat of the period of record. During the approximately six-year time period between the beginning of the study period and a repeat of the DOR, the total cumulative storage volume increases to 168,100 AF. During the DOR the stored water volume drops to 82,900 AF, a drop of about 50 percent, thereby preserving the buffer zone.

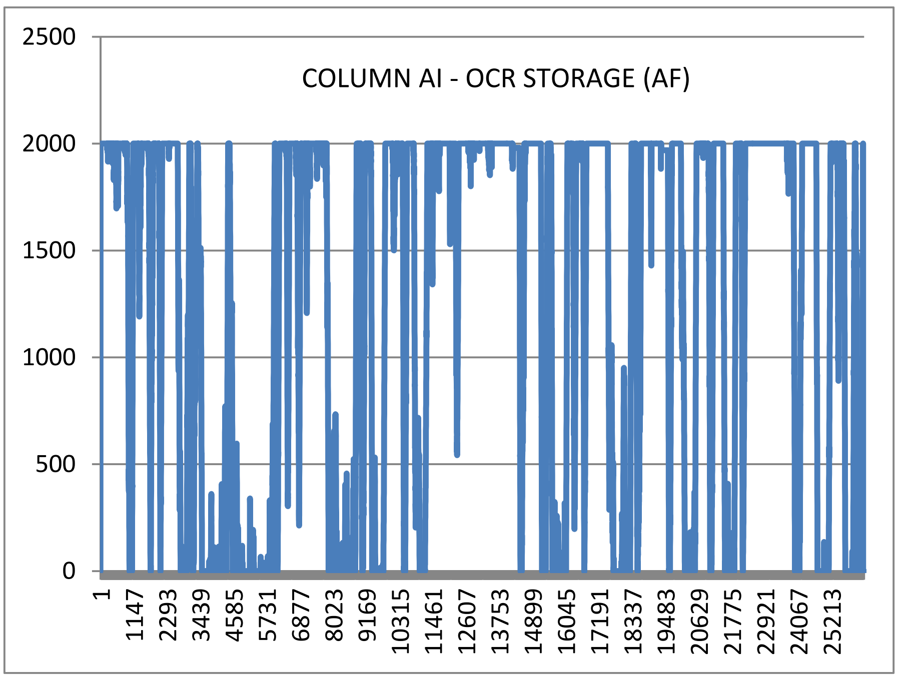
The ASR TSV for this option is 166,060 AF. OCS provides an additional 2,000 AF. If operational experience ultimately suggests that the buffer zone volume actually required is closer to 30 percent instead of 50 percent of the ASR TSV, then the Initial Storage Volume would be reduced to 62,000 AF and could be achieved within seven years. The ASR TSV would be reduced to about 125,000 AF. The buffer zone volume estimate, as a percentage of the ASR TSV, is based upon experience at other ASR wellfields in similar aquifers. The 50 percent assumption is considered to be conservative for planning purposes.

The large initial and ASR storage volumes reflect the Option A assumption that projected water demands are based upon 2011, which was a dry year with low river flows and elevated water demands. Consequently there would be generally less water available for storage and more water required from storage, compared to normal years. The net effect of this would be to substantially increase estimated storage volume requirements. Option A is therefore considered to be conservative.

Figure 7-1 shows the projected cumulative storage volume during the study period. This is shown for the ASR wellfield, the OCS reservoirs, and the combination of both methods of storage.

With this option, maximum recharge duration is 336 days. The maximum recovery duration is 259 days. The maximum recharge rate is 18.3 MGD while the maximum recovery rate is 24.9 MGD.





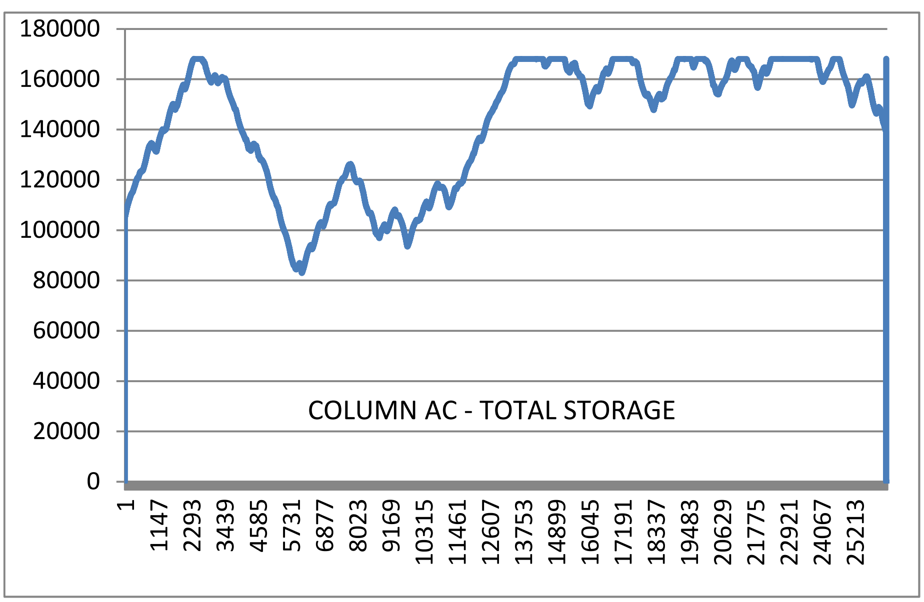


Figure 7.1. City of Victoria, Option A – Storage (AF) vs Time (Days, 1941 to 2012)

The specific capacity of a well is defined as the flow rate in gallons per minute, either during injection or pumping, divided by the increase or decrease in water level. Until better data is available to guide the wellfield design, a reasonable assumption is that the specific capacity during well injection (SCi) is half of that during pumping (SCp). This is based upon operational experience at numerous ASR wellfields in unconsolidated aquifers. Accordingly, the maximum recharge rate controls the wellfield design. For planning purposes, it would be necessary to provide ASR wellfield facilities that have a design recharge capacity of 18.3 MGD.

In reality, an ASR program would most likely start with an ASR Demonstration Project, constituting Phase 2 of an ASR Wellfield Development Program. (This report constitutes a Phase 1 ASR Feasibility Assessment). One or more ASR wells and associated monitor wells would be constructed and tested. Data from these wells would indicate the local ratio for SCi to SCp. The design of the wellfield would then be adjusted. For unconsolidated, confined and semi-confined aquifers such as those in the vicinity of the City of Victoria, typical SCi/SCp ratios range from 30 percent to 80 percent. Wellfield expansion would then proceed in two or more phases, as part of the ASR Wellfield Development Program. Operating experience with each expansion phase would then provide an improved basis of design for the subsequent phase.

Option B

This option is similar to Option A except that it is assumed that the Initial Storage Volume is only 2,000 AF, provided by the OCS, and that zero volume is initially available from the ASR wells. During the approximately six-year period between the beginning of the study period and the onset of a repeat of the DOR, ASR storage would increase to about 60,000 AF, half of which would be considered the buffer zone. However water needs during a repeat of the DOR would then draw this volume down to zero, eliminating the buffer zone and producing native groundwater. Adequate water flow rate and volume would be available for recovery. However, water quality of the recovered water from ASR storage would deteriorate, transitioning from treated surface water to native groundwater. System reliability would be only 38 percent. Following the end of the DOR, the total storage volume would never achieve the total storage volume required to ensure 100 percent reliability during any subsequent repeat of the DOR. Option B would therefore fail.

Option C

The ASR objectives for the City of Victoria include seasonal and emergency storage, respectively. Accordingly, Option C was evaluated. Option C is similar to Option A except that the DOR is excluded from the study period. The analysis therefore only addresses water supply reliability during the period from 1958 to 2012. However, this shortened study period also had some significant dry years, particularly near the beginning and at the end. The initial and total storage volume requirements are significantly less than those for Option A. The ASR wellfield design capacity is unchanged.

This is an incomplete potential solution for meeting the City of Victoria projected water needs since water utility systems in Texas are required to conduct water supply planning to meet a repeat of the DOR. Nevertheless, the results of this analysis provide a useful point of reference for judging the most appropriate, long-term course of action for the City to eventually achieve this goal. With minimal capital investment to achieve sustained operation at the 25.2 MGD rated capacity of the WTP, seasonal and emergency storage requirements would be quickly met with 100 percent reliability. With continued addition of treated drinking water to ASR storage, system reliability for a potential repeat of the DOR would steadily improve and, over a period of several more years, the same 100 percent level of reliability would eventually be attained for a repeat of the DOR.

Option D

Option D is similar to Option A except that the water supply reliability goal is relaxed. Instead of achieving 100 percent water supply reliability the goal is reduced to 95 percent. ASR total storage volume requirements are the same. Initial Storage Volume requirements are reduced from 105,200 AF in Option A to 96,800 AF in Option D.

Option D is not recommended, however it provides a useful reference point. During the early years of an ASR program when the cumulative storage volume is less than the TSV, reliability will be less than 100 percent. It will still be greater than the current system reliability during a repeat of the DOR, and will steadily improve with time. With no additional capital investment, 100 percent water supply reliability can be achieved with an ASR wellfield by forming and maintaining a TSV. This is not the case for water systems that are totally dependent upon run-of-river surface water sources that are subject to calls from holders of senior water rights during droughts, and associated water losses due to evaporation, transpiration and seepage from reservoirs and conveyance canals.

The ability to achieve 100 percent reliability with ASR storage at relatively small additional cost compared to achieving a lower level of reliability appears relatively advantageous, particularly since it reduces the risk of having to deal with a water shortage or a deterioration in water quality provided to customers.

Option E

An alternative, less-conservative assumption for planning purposes is that the study period is based upon more typical years for water demand, such as 2008, rather than a dry year such as 2011. With this assumption the projected water demands are reduced; more water is available for storage utilizing existing facilities capacity, less water is required to meet demands during recovery, and storage volume requirements are therefore reduced. However a small increase in ASR wellfield design capacity is needed in order to recharge higher flow rates when they are available for storage.

As shown in **Table 7-1,** initial storage volume would reduce to 3,500 AF, compared to 105,200 AF with Option A. ASR TSV would be 9,200 AF compared to 166,100 AF for Option A. However, ASR wellfield recharge design capacity would increase to 19.2 MGD, compared to 18.3 MGD for Option A. The rate at which water would need to be added to storage would average 1,100 AFY during the first six years, in order to meet demands during a repeat of the DOR. Since more water will actually be available for storage, it is likely that Victoria would elect to form the ASR TSV as rapidly as possible, most likely within less than two years.

If the reliability goal is reduced to 95 percent, the initial storage volume would reduce to 3,100 AF.

If no improvements are made to the Victoria WTP and the sustained treatment capacity remains at its current rate of 21 MGD, the Initial Storage Volume would increase to about 8,000 AF and the ASR TSV would increase to about 13,600 AF in order to achieve 100 percent reliability. The recharge rate during the first few years could decline to an average of about 850 AFY so almost 10 years of recharge may be needed to achieve the Initial Storage Volume. More likely the ASR TSV would be formed much more rapidly.

Option F

This option is similar to Option E except that it is assumed that no initial water is in ASR storage. System reliability declines to 76 percent since a significant portion of the buffer zone would need to be pumped out during a repeat of the DOR.

Option G

Although the City of Victoria water banking objectives can be achieved with the existing diversion and water treatment plant rated capacity, supplemented by ASR wells, the time required to initially achieve the TSV, or to restore the TSV following a drought, is several years. The risk of having an unreliable water supply may be relatively small now, however as water demand steadily increases, the risk of failure will increase and may become unacceptable, particularly if ASR storage has not commenced. The risk of failure can be reduced by expanding the water treatment plant capacity and thereby enabling the City to capture, treat and store more water when it is available, accelerating formation or restoration of the TSV. Option G includes expanding the water treatment plant from 25.2 to 32.0 MGD, and providing 2,000 AF initial storage volume in the OCS, but zero initial volume in ASR storage.

With this option, the required ASR TSV reduces to 7,300 AF, compared to 9,200 AF in Option E. ASR wellfield recharge design capacity would increase to 26.0 MGD in order to be able to store water at higher recharge rates whenever this water is available.

Compared to other options, this option would enhance overall system reliability by more rapidly achieving the TSV required prior to, and restoring it after, a repeat of the DOR. However the associated cost for the water treatment plant expansion and for a larger ASR wellfield would probably be greater than for the other options. This underscores the advantage of not waiting too long to start ASR wellfield development. Delay is more likely to necessitate the need for a greater capital investment in treatment and storage capacity.

7.1.5 Summary of ASR Model Results – City of Victoria

Option A is the baseline option against which the other options may be compared. The assumptions implicit in this option are conservative. Other options evaluate various different assumptions such as starting with zero initial ASR storage volume; water treatment plant expansion; projecting water demands based upon 2008; and meeting the City's primary ASR objective, seasonal water storage, but not meeting all demands during a repeat of the DOR.

Table 7-1 shows a summary of the results from the ASR Model for each of the options described above. A few observations are pertinent:

- Victoria's ASR objectives can be met utilizing the existing water treatment plant rated capacity of 25.2 MGD, recognizing that some chemical feed and perhaps other improvements would be needed to facilitate sustained operation at this production rate.
- The time required to achieve the Initial Storage Volume ranges from 11 years for Option A to less than one year for Option E. ASR objectives cannot be met with 100 percent reliability utilizing the current sustained operating capacity of the existing WTP which is 21 MGD.
- The volume that needs to be recovered during a repeat of the DOR ranges from 4,600 AF to 82,900 AF, depending upon the set of assumptions underlying each of the options that were considered. The upper end of this range reflects the junior priority dates and special conditions in the largest of Victoria's water rights, and 2040 water demand projections based upon the distribution of daily demands experienced in 2011. The lower end of the range is based upon 2040 water demand projections based upon the distribution of daily demands experienced in 2008. Increasing the water treatment plant capacity further reduces the storage volume requirements and therefore the time required to store sufficient water prior to, or immediately following a repeat of the DOR. It is important to understand that this is only the recovered water volume. An additional buffer zone volume is needed so that recovered water quality meets all drinking water standards, other than the need for disinfection to restore the chloramine residual. The recovered water volume plus the buffer zone volume constitutes the ASR TSV.
- The ASR TSV that needs to be achieved in order to meet seasonal storage objectives is 53,900 AF (Option C), however this would be inadequate for a repeat of the DOR. The total storage volume required to meet demands during a repeat of the DOR ranges from 9,300 to 168,100 AF. Of this amount, 2,000 AF is assumed to be available from the OCS, whether for seasonal storage or for long-term storage.
- The ASR wellfield design capacity for all options is controlled by the required recharge capacity, which ranges between 18.3 and 26.0 MGD. The upper end of this range is associated with a 32 MGD water treatment plant capacity while the lower end of the range is associated with the existing 25.2 MGD WTP capacity. Since ASR is often viewed as an opportunity to avoid the high cost of WTP expansion, or construction of a second WTP, it is likely that ASR wellfield recharge design capacity would be about 19 MGD.
- Maximum duration of recharge periods ranges from 230 to 426 days. The maximum duration of recovery periods ranges from 251 to 259 days. Even during the DOR there are significant opportunities for replenishing storage volume.
- The number of years during the 71-year period of record when water rights limitations restrict diversion and treatment of water prior to the end of the year varies between

three and eight. The upper end of the range reflects the junior priority dates of the City's water rights and is also associated with treatment plant expansion. For each of these three to eight years, the number of days when diversions are restricted is small, as is the overall impact upon cumulative storage volumes.

- Early implementation of an ASR wellfield development program would take advantage of the large difference between current available Victoria WTP capacity and available water from the Guadalupe River. This would increase the rate of adding water to ASR storage, thereby reducing the time required to achieve the TSV. Conversely, deferring implementation of an ASR program would steadily reduce the rate at which water can be stored, reflecting a projected steady increase in water demand. This would tend to increase the need for expansion of WTP capacity.
- The City's five goals for an ASR program can be achieved.

Additional options, or combinations of options, may be evaluated relatively easily using the ASR Model. The model may also be enhanced to incorporate other features such as supplemental supply from conventional production wells; diversion capacity different than WTP capacity; operational constraints; and different projected water demands and treatment capacities.

7.1.6 ASR Wellfield Conceptual Design – City of Victoria

Based upon the summary of ASR model results shown in **Table 7-1**, a preliminary basis of design for the ASR wellfield is to provide recharge capacity of 19.0 MGD. This will require several ASR wells. Possible ASR well locations are discussed below, including at the Victoria WTP; Water Treatment Plant No. 3 located on Red River Street (WTP#3); conversion of selected existing production wells to ASR wells; construction of new ASR wells at new sites, and construction of new ASR wells at existing abandoned production well sites. The recovery capacity of these wells will exceed the targeted recharge rate since the critical factor controlling ASR facilities design capacity for Victoria is the recharge rate.

A suggested approach to ASR wellfield development would be to implement the program in phases. This ASR Phase 1 Feasibility Assessment report constitutes the first phase. The second phase would be to construct and place into operation ASR wells and related facilities at two or more locations. One of these would be a retrofit of an existing production well while the second ASR well would be new. Comparison of well performance would then be a useful guide for further ASR wellfield development in subsequent phases. New ASR wells have unique design features to improve their performance relative to a retrofit of conventional production wells, particularly those that may be decades old. However, retrofit of an existing production well is typically less expensive than construction of a new ASR well.

ASR Well Conceptual Design

As described in Section 6, Hydrogeology, current depth to static water level in three of the City's production wells (Wells 17, 20 and 25) was measured during December 2013. The depth to water level was 82 to 83 feet. As shown in **Figure 6-33**, local groundwater withdrawals for municipal purposes have declined substantially since operation began at the Victoria WTP in

July 2001. Partial recovery of groundwater levels has therefore occurred, however a local depression in the regional potentiometric surface for the upper Evangeline Aquifer most likely remains due to municipal, agricultural and other withdrawals. Based upon these three measurements and other information provided in Section 6, it is assumed that static water level for the Victoria area is at a depth of approximately 90 feet bgs, or about 10 feet above mean sea level (msl), and that a "bowl" exists in the potentiometric surface so that water stored underground would not likely flow away from the area.

The study team proposes that ASR wells would be constructed in the upper Evangeline Aquifer, Upper Goliad formation, at typical screen settings of -400 to -1,000 ft msl. Native groundwater quality is relatively fresh, with TDS concentrations generally below 700 mg/L. Sand intervals comprise approximately 50 percent of the formation thickness, with several intervals exceeding 40 feet thickness. ASR wells would be screened opposite most of this section, thereby maximizing individual well yield and accepting the probably substantial amount of vertical flow and mixing that would occur during ASR operations. A reasonable goal would be to screen at least 200 feet of sands in each ASR well. Expected average hydraulic conductivity for these sand beds is about 24 ft/day, so transmissivity is estimated at 4,800 ft^2/day. Recovery specific capacity, SCp, is estimated to average about 16 gpm/ft. SCp is the increase in production rate per foot of drawdown.

During recharge, flow distribution between the screen intervals will preferentially favor the sand intervals that are the most transmissive and least clogged. Assuming that clogging occurs, the sand intervals receiving flow during extended recharge periods will tend to change with time, with water always following the path of least resistance. During extended storage periods, flow within the borehole will tend to move slowly from sand intervals with higher head to those with lower head. During recovery, any well clogging will tend to reverse and flow will derive preferentially from sand intervals with the greatest transmissivity. Friction losses from vertical flow within any wells with a long, narrow well screen will likely be significant, favoring flow to and from shallower sand intervals over deeper sand intervals. All of these processes will tend to mix the stored water with the surrounding ambient water in the aquifer. However, as the surrounding ambient water quality becomes increasingly like the recharge water, the effect upon recovered water quality will become increasingly insignificant. The stored water bubble extends several hundred feet from each ASR well and then coalesces with water stored in adjacent ASR wells, potentially extending beyond the boundary of the wellfield.

For preliminary conceptual design and costing purposes it is assumed that an initial, new ASR well would have a 20-inch diameter, 304 stainless steel inner casing to a depth of 450 feet; a telescoping 12-inch well screen and blank pipe section extending to 1,000 feet, including 240 feet of well screen and gravel pack; and a riser pipe extending up inside the bottom 50 feet of the well casing. The top of the annulus between the riser pipe and the inner casing would be sealed with a packer. If the well is sufficiently productive, such a well design could sustain a production rate of 2.5 MGD and a recharge rate of 1.2 MGD. Victoria's existing production wells typically produce 2 MGD. The pump column assembly would probably need to include a downhole control valve to prevent cascading and air entrainment during recharge periods. Cascading can rapidly clog an ASR well, in addition to setting up microbiological and geochemical issues that contribute to further clogging. Experience gained with this ASR well design would then guide well design for subsequent expansion phases.

Retrofit of an existing production well for ASR purposes would be constrained by the design and condition of the well. Carbon steel cased wells tend to experience accelerated corrosion during ASR operations. The corrosion products contribute to well clogging. Periodic backflushing of such wells has to deal with disposal of rusty water at high rates for longer periods such as one to two hours, as compared with typically up to 20 minutes with stainless steel, PVC or fiberglass-cased wells. Depending on the method of construction, older wells may not have a sufficient seal at the surface, capable of withstanding wellhead pressures occurring during well recharge. This can limit recharge flow rates so that water levels do not rise above land surface.

Number of ASR Wells Required

In the absence of more specific data, the SCi, is assumed to be 60 percent of SCp. Accordingly, injection specific capacity is estimated to be 9.6 gpm/ft. This ratio is based upon experience at other ASR wellfields in unconsolidated (sand and clay) aquifers. The ratio may range from 30 percent to 80 percent, however 60 percent is a reasonable starting assumption for this productive aquifer. More productive wells such as those at Victoria often have a higher ratio of SCi to SCp as compared with less productive wells such as those at Port Lavaca. Once local specific data from ASR well testing are obtained, this estimate may be updated. With a static water level of about 10 ft msl and an SCi of 9.6 gpm/ft, a recharge rate of 850 gpm (1.2 MGD) would require an individual well recharge pressure of 88 ft above static water level, which is approximately at land surface. Any interference with adjacent ASR wells, or reduction in local groundwater production, would tend to either increase this wellhead pressure or reduce the injection rate. Such an injection pressure is well within the range of recharge pressures at other ASR wellfields.

A more important consideration for ASR well design is the drawdown available by pumping an ASR well to remove any accumulated suspended solids that can clog a well during extended recharge periods. The drawdown achievable by pumping the well should exceed the increase in head that occurs during recharge. With a target recovery rate of 2 MGD (1,400 gpm), matching local experience with production wells, the drawdown would be 1,400 gpm /16 gpm/ft = 88 feet. The available drawdown is much greater. This would be the difference between a static water level of +10 ft msl and a pumping water level of about 50 feet above the bottom of the well casing, or about 250 ft bgs, or -150 ft msl. The difference is up to 160 ft, greatly exceeding the expected drawdown. The opportunity is therefore readily available to set the pump deeper in the well and be able to pump at a higher rate for brief periods, if necessary to purge any particulates that may have accumulated in the well during recharge.

For current preliminary design purposes it is assumed that individual ASR well recharge and recovery rates would average 850 gpm and 1,400 gpm, respectively, and that pumps would be designed to produce water on a short term basis at a higher recovery rate of 1,750 gpm to facilitate periodic backflushing and well redevelopment. Such operations would typically occur every few weeks and would require pumping for one to two hours. Exact procedures and frequency would be worked out through initial testing in Phase 2 and would then be handled automatically through a SCADA system. Assuming 19 MGD of ASR wellfield recharge capacity, and 1.2 MGD of recharge capacity for each well, the required ultimate number of ASR wells would be 16. If initial performance indicates that higher recharge rates could be sustained without cumulative clogging, or if the SCi/SCp ratio turns out to be greater than 0.6, recharge could be increased, reducing the required ultimate number of ASR wells.

Suggested Well Locations

Victoria Water Treatment Plant

A logical location for several ASR wells is on City-owned property at or near the Victoria WTP, facilitating operation and maintenance of the ASR facilities, and effective integration into the City's water supply system. The City owns significant property adjacent to the WTP that is used for public recreation and related purposes. Storage of a large volume of drinking water deep beneath these properties in order to ensure 100 percent water supply reliability for the residents and businesses of Victoria during a repeat of the DOR would appear to be a worthwhile and reasonable objective. Assuming an average spacing between ASR wells of about 1,000 feet, at least 10 ASR well sites could easily be located within this area. However other locations within the service area would also provide supplemental benefits. For current conceptual design purposes it is assumed that 10 ASR wells would be located within the area of the Victoria WTP, and 6 additional wells would be located elsewhere in the City's distribution system. With phased expansion of an ASR program, the opportunity will be available to adjust this plan as appropriate during successive phases.

Following construction, ASR well parcels have a very small footprint. A typical ASR wellhead would include a small well house containing all or most of the wellhead facilities, plus paved access and a fence or wall around it, and with an enclosed area of less than 0.2 acre. All pre- and post-treatment of the water could be conducted at the Victoria WTP or other city facilities, so there would be no chemical deliveries to each well. Any discharge of water to waste from each well, such as during pump testing, periodic backflushing or well redevelopment, could be conveyed either back to the WTP or to the river. Power supply to the wells, and the SCADA controls, could be underground.

Conversion of Existing Production Wells

The City has 10 production wells, of which six are potentially available for retrofit to ASR wells. Two of the 10 wells (City Well ID Nos. 19 and 21) are active production wells while eight wells are for standby purposes and also for groundwater exchange (pumping groundwater into the river during low flow periods in exchange for an equal volume of surface water diverted from the river for public water supply purposes). Four additional production wells have been plugged. Four of the six wells that are potentially available for ASR conversion are located at or near WTP#3, adjacent to a pumping station and large diameter piping. WTP#3 also is supplied by eight of the production wells and has the capability to disinfect the recovered ASR water. Providing ASR capacity at this location would provide several operational benefits for the City. The remaining two wells that are potentially available for ASR conversion are Nos. 19 and 21, both of which pump water to the headworks of the Victoria WTP when needed.

During recent dry years (2011, 2013) the City has relied upon groundwater exchange to supply up to 6,595 AF of additional surface water in 2013, pursuant to an agreement with TCEQ. This represents approximately one-quarter of the City's surface water rights. Continued reliance upon such an exchange could set up the eventual need for WTP expansion to meet projected increase in water demand. Phased transition to ASR instead of groundwater exchange will eliminate the need for expansion of the Victoria WTP prior to 2040 and will ensure 100 percent water supply reliability during droughts. Furthermore, drinking water quality during droughts would be consistent since the water would all be treated surface water instead of a varying blend of treated surface water and groundwater.

For the purpose of this conceptual design, it is assumed that all six of the wells that are available for ASR conversion are converted to ASR. This process would start with City of Victoria Well Numbers 14, 15, 16 and 17 at or near WTP#3, leaving Wells 19 and 21 available for either pumping to the WTP or to the river as part of a groundwater exchange. Wells 19 and 21 could later be converted to ASR. [The City of Victoria well numbers discussed above correspond to VCGCD Well Numbers 5, 6, 7, 8, 9 and 11, respectively.]

The wells at WTP#3 are old wells, ranging in age from 44 to 61 years. It will be important to confirm their condition prior to ASR conversion. Following a baseline pumping test to confirm well hydraulic performance with the existing equipment, the pump would be removed from the well and inspected. Geophysical logs, including a video log, would be obtained. If necessary, well rehabilitation will be conducted to improve well performance. ASR potential performance will then be evaluated to confirm viability. The well would then be re-equipped for ASR purposes, utilizing to the extent possible the existing facilities. Injection and recovery tests will then be performed to establish baseline hydraulic and water quality conditions for ASR, following which the well would be placed back into operation.

New ASR Wells in the Distribution System

New ASR wells could also be constructed at key locations within the distribution system, close to major transmission pipelines and/or treated water storage reservoirs. Suitable locations would be at WTP#3 and also in the northern portion of the service area.

Existing Well 14 is located at the WTP#3 site. This well is 61 years old. If inspection indicates that the well condition is unsuitable for ASR conversion, then this well could be plugged and abandoned and a new ASR well could be constructed at the same site.

It is possible that one or more of the abandoned well sites may be suitable for construction of a new ASR replacement well, taking advantage of existing pipeline conveyance capacity at each such location.

Radial Extent of Stored Water

The volume of water to be stored ultimately in ASR wells in order to achieve reliability goals and other objectives will depend upon future investigations, initial ASR operations, and decisions by the City. It appears likely that the volume will be within a broad range of 9,200 AF (Option E) to 166,100 AF (Option A). The number of ASR wells may also vary but within a narrower range, depending primarily upon the hydraulic characteristics of the wells during extended recharge periods. For current purposes it is assumed that 16 ASR wells will be required and that the ASR TSV will be 166,100 AF.

The TSV for each ASR well will average 10,381 AF. Assuming a 240 ft total thickness of the sand intervals screened in each well, and a bulk porosity of 25 percent for these sands, the theoretical surface area underlain by the ASR TSV for each well will be 173 acres. This is equivalent to a radial extent of 1,560 feet. Half of this volume will constitute the buffer zone, separating the stored drinking water from the surrounding ambient groundwater. The radial extent of the water considered to be available for recovery would be 1,100 feet. This is the theoretical radial extent. Actual radial extent will depend upon actual sand porosity and thickness, the degree of vertical confinement above and below the storage aquifer, and the volume of water in storage, which will be less than the TSV during ASR recovery periods and during early years when the TSV is being formed.

For an ASR wellfield such as that proposed for the Victoria WTP site, the ASR storage bubbles around each ASR well will tend to coalesce, forming a large subsurface reservoir of drinking water that will extend beyond the boundary of the wellfield. For an assumed 10 ASR wells, the TSV would total 103,810 AF. The radial extent of the stored drinking water, including the buffer zone, would theoretically extend up to 4,900 feet from the center of the wellfield. A significant portion of this area would underlie City-owned property to the west, north and south of the Victoria WTP. All or most of the remaining surrounding area is within the City limits, providing the opportunity for the City to be able to protect its subsurface drinking water reservoir from construction and operation of new wells in the upper Evangeline Aquifer by other entities.

Considering the significant radial distances of the stored water volumes around each ASR well or around an ASR wellfield, it is apparent that lateral movement of the stored water bubble at rates of a few feet, or a few tens of feet per year due to local or regional gradient of the potentiometric surface in the storage aquifer is not likely to be a significant operating constraint. Furthermore, the City has the ability to manage the distribution of production from the various ASR wells and production wells so that lateral movement remains acceptably small.

Monitoring of Water Levels

For the upper Evangeline aquifer beneath Victoria, the “bowl” in the potentiometric surface that exists due to current groundwater production will tend to trap any water stored in ASR wells so that it does not leave the area. However, the water may move laterally away from each ASR well due to changes in the local hydraulic gradient. As described in Section 6, the expected rate of lateral movement is small when compared to the radius of the stored water bubble around each ASR well, and around each ASR wellfield. Monitoring of water levels and well production rates for ASR wells and also for production wells will become increasingly important as the ASR wellfield expands. A few additional monitor wells will likely be needed, supplementing water level measurements in existing wells. The City has the ability to redistribute its own groundwater production in order to manage local gradients of the potentiometric surface.

Monitoring of water levels will also be appropriate during recharge periods. Any existing or new wells penetrating the storage aquifer may tend to flow at the surface if water levels rise above land surface and if the wellhead is not adequately sealed. The well inventory referenced in Section 6 of this report should be updated to determine the location of any wells penetrating the storage aquifer that may be impacted by ASR operations. Provision for mitigation of any adverse effects may then be appropriate.

Phase Two ASR Demonstration Program

It is suggested that the Phase 2 ASR Demonstration Program would include construction of one new ASR well at the Victoria WTP and ASR retrofit of one existing production well at or near WTP#3. One new monitor well would be constructed at each site, prior to ASR well construction, and would be completed as a storage zone monitor well. An ASR cycle testing program would be implemented at each site, followed by ASR operations, providing a basis of design for subsequent phased ASR expansion.

It is possible that the well selected for retrofitting near WTP#3 may turn out to be inappropriate for ASR conversion, such as due to a possible poor condition of the casing or screen. The Demonstration Program should be planned with sufficient flexibility that, in such an event, one or more additional existing wells would then be evaluated for ASR retrofitting. Another possibility would be to evaluate all six existing wells and proceed immediately to retrofit all of those that are appropriate for ASR operations.

7.1.7 Conclusions and Recommendations – City of Victoria

An ASR wellfield is viable for the City of Victoria. Such a wellfield should be able to meet projected 2040 water demands with 100 percent reliability and at relatively low cost compared to other water management strategies such as building more off channel storage.

If a decision is made to proceed with further investigation of ASR viability, the City should implement an ASR test program at two sites: the Victoria WTP and at WTP#3. The test program would include construction, testing and operation of one new full-size ASR well at the WTP and one retrofit of an existing production well at or near WTP#3. The first phase of ASR wellfield construction would represent approximately 10 percent of the planned ultimate scale of development. The test program would include approximately two storage zone monitor wells, supplementing monitoring at other existing production wells in the area surrounding each location. Two very shallow monitor wells would also be constructed to check for any local rise in the water table during extended recharge periods. The number and location of ASR wells and monitor wells may be adjusted based upon results of an initial core hole at the Victoria WTP site. Continuous wireline cores would first be obtained to a depth of 1,100 feet, providing good understanding of the depths and thicknesses of sand and clay layers beneath the site, and their associated geochemical and geotechnical properties. Operating experience gained with the first two ASR wells would provide a basis for subsequent design of wellfield expansion facilities, achieving ASR goals for the City of Victoria.

7.2 GBRA/Calhoun County Area

For Calhoun County, the Study Area was focused on the city of Port Lavaca; GBRA's Port Lavaca WTP and the surrounding area; and the transect between the Port Lavaca WTP and the Port of Victoria, near Bloomington, TX.

7.2.1 GBRA Port Lavaca - ASR Model Description

A spreadsheet model has also been prepared for GBRA, the purpose of which is to provide a tool for determining the feasibility, conceptual design and cost of ASR facilities to provide water supply reliability to meet projected demands while remaining consistent with GBRA's existing Lower Basin water rights. "Water supply reliability" is defined as meeting 100 percent of daily water demands with water meeting all drinking water standards during a repeat of the period of record, including the DOR. As discussed below in the subsection related to Water Rights, the GBRA/Calhoun County area is subjected to a DOR analysis because: (i) this study assumes that raw water is available solely from GBRA's most junior water right; and (ii) the study team needed to keep a consistent approach within the Study Area. In reality, the Port Lavaca WTP has access to other senior water rights that can meet its demands during a repeat of the DOR.

Seven options (A through G) have been evaluated for GBRA using the model. These options represent a range of operating scenarios. The options are described in detail in Section 7.2.4 below.

Model input data includes the following:

Period of Record. This is the actual, historic record of daily water flows. For this report the portion of the period of record that was utilized is from January 1, 1941, to December 31, 2012.

Study Period. This is a simulated record of projected daily water demands extending from the present (2014) to 2040. For this initial feasibility assessment the GBRA water demands were increased linearly at an assumed 8 percent per decade (the same rate of growth assumed for Victoria). For the simulations, daily water demands after 2040 were assumed to remain the same as in 2040. The selected "base year" for water demand projections was 2011, which was a very dry year. Projections were also analyzed for a more typical base year, 2008. For each of these years (2011, 2008) the daily distribution of water demands for that year was assumed to occur in 2014 and was then projected forward to 2040. A linearly-increasing factor was applied for each subsequent year after 2014, steadily increasing the water demand.

Daily water demand records, Calendar Years 2008 through 2012 (million gallons per day, MGD). The data provided by GBRA for the Port Lavaca WTP included treated water supplied from the WTP to the distribution systems of GBRA's three wholesale customers.

Daily flow availability from the Guadalupe River, 1941 through 2012, at the GBRA diversion intake structure near Tivoli, TX (cubic feet per second, CFS). Daily flow records at the USGS Gages for the Guadalupe River at Victoria and for the San Antonio River at Goliad were utilized as a starting point. The flows were adjusted to reflect estimated upstream diversions from the river during the period of record, creating a set of unimpaired river flows. Following the prior appropriation doctrine, senior water right holders, including GBRA when applicable, were then assumed to take all of the water available from the river pursuant to each of their water rights, utilizing the assumed monthly distribution of water demands that underlies the Water Availability Model (WAM) that is used by TCEQ.

Water Treatment Plant Capacity (MGD). The current rated capacity of the City's WTP, 6.1 MGD, was utilized for most of the analyses. Sustained operating capacity is currently about 4.8 MGD, however it is assumed that with an upgrade to the raw water pumping capacity, and possibly other minor system improvements, a treatment rate of 6.1 MGD could be sustained. A reasonable goal would be to demonstrate that the existing Port Lavaca WTP capacity, in conjunction with the Terminal Storage Reservoir at the WTP, is adequate to meet projected 2040 demands. However, if the required TSV is substantial and would require an inordinate amount of time to achieve, then increasing the water treatment capacity to 7.25 MGD would potentially accelerate the storage of treated drinking water underground in ASR wells. Similarly, provision of any new off-channel reservoir capacity would accelerate storage of untreated water. Expansion of the Port Lavaca WTP and the ASR wellfield may then be required in order to treat and store the additional water when it is available. The ASR Model can also be utilized to evaluate the overall water supply reliability and system performance if the current sustained capacity of 4.8 MGD is not increased. Achieving water supply reliability for GBRA's service area depends upon achieving and maintaining sufficient water in storage, so the more rapidly this can be achieved, or restored following a major drought, the better.

Filter for high river flows (CFS). The ASR Model includes an option for not diverting water when river flows exceed a given flow rate. This could be applicable for situations where river water quality during flood conditions has high turbidity or is otherwise difficult to treat, or other operational constraints. For GBRA, the high flow constraint was set at 400,000 CFS, which exceeds the highest recorded flow on record that occurred during the 1998 flood. For the current analysis this is therefore not a constraint.

Filter for low river flows (CFS). The ASR Model includes an option for not diverting water when river flows are below a given flow rate. This is not an unusual situation for water treatment facilities relying upon surface water supplies. Reasons typically include source water quality that is difficult to treat. For GBRA, the low flow constraint was set at zero. It is assumed that GBRA will divert any available water within its water rights, and within the capacity of the WTP, so long as there is any flow in the river, and so long as the cumulative storage volume is less than the ASR TSV plus storage in the Terminal Storage Reservoir. If the river flow is less than the WTP capacity, any available river flow will be diverted. If the Guadalupe River flow is less than the minimum rate at which the Port Lavaca WTP can be operated (1.2 MGD), it is assumed that the shortfall will first be obtained from the Terminal Storage Reservoir. At such time as the Terminal Storage Reservoir has been emptied, ASR recovery will commence. If the ASR TSV has been achieved, diversions are assumed to equal service area water demand.

Terminal Storage Reservoir (TSR) (acre feet, AF). GBRA has an existing terminal storage reservoir with a capacity of approximately 44 MG (135 AF). For the purpose of this analysis the TSR storage volume is assumed to be full at the beginning of the study period. During periods when insufficient or no diversions from the river are possible, water is assumed to be withdrawn first from the TSR for treatment and distribution, prior to recovering water from ASR storage. During periods following a drought when diversions from the river are once again possible, it is assumed that the TSR will be filled first, followed by adding to ASR storage.

It is important to keep in mind that water stored in the TSR requires full treatment prior to distribution or ASR storage. Water stored in ASR wells requires only restoration of the disinfectant residual prior to distribution. Increased reliance on ASR storage therefore reduces the need for a WTP expansion to meet projected demands.

GBRA is pursuing an additional off-channel reservoir (OCR) to further firm up its Lower Basin water rights. The ASR Model can be utilized to evaluate the effect upon water system performance associated with addition of different amounts of OCR storage as a component of the total storage requirements to achieve 100 percent reliability during the DOR.

Water Rights (acre feet per year, AFY). For purposes of this analysis, only GBRA's most junior water right (COA 18-5178) is used as a source of supply. As discussed above, using only COA 5178 disregards GBRA's ability to meet DOR water demands from its more senior water rights. To provide an even more conservative evaluation, the study team assumed that no stored water is delivered from Canyon Reservoir under existing contracts to meet Calhoun County municipal water demand. ASR diversions from the Guadalupe River are checked daily in the model to ensure that the GBRA water right constraints are not exceeded. Once this volume has been diverted, treated and either stored or consumed during any given year, no further diversions are allowed. Instead, service area water demands are met from storage.

Initial Volume in Storage (acre feet, AF). This includes the existing TSR volume at the Port Lavaca WTP plus the TSV for the ASR wellfield. The DOR for the Guadalupe River Basin occurred from 1947 to 1957. Since the period of record begins only six years prior to the beginning of the DOR, an ASR Model analysis that begins with zero water in storage will typically fail to meet water supply reliability criteria since insufficient water would have been added to storage during the first six years. An equivalent DOR occurring toward the end of the period of record would have a much longer time within which to accumulate storage volume, potentially affecting the design, operation and cost of ASR wellfield facilities and associated diversion and treatment capacity requirements. Assuming an initial total volume of water in storage provides a basis for assessing this analysis constraint. GBRA can then evaluate how much time it wishes to spend to achieve the ASR TSV for its service area, thereby ensuring water supply reliability. In general, the shorter the selected time to achieve the TSV, or to restore the TSV following a DOR, the higher the cost for ASR and related facilities required in order to meet that storage goal. For the ASR Model, the Initial Volume in Storage is adjusted as part of an iterative process, along with adjustment of the ASR Target Storage Volume, in order to achieve 100 percent reliability with the least storage volume.

Target Storage Volume (TSV) for the ASR wells (AF). This value is adjusted during the ASR Model iterative analysis process. The goal is to set the TSV so that 50 percent of this volume remains at the end of the DOR. Fifty percent is a conservative placeholder assumption, to be refined based upon operational experience. This volume is referred to as the "Buffer Zone", separating the stored drinking water from the surrounding ambient native groundwater in the storage aquifer. The buffer zone is a one-time addition of water to the well. It is formed and maintained, and is not recovered. Operational experience with the San Antonio Water System (SAWS) ASR wellfield since 2004 suggests that, for that location in the Carrizo-Wilcox aquifer, a 30 percent buffer zone volume is sufficient to ensure that recovered water quality meets all drinking water standards. The 50 percent factor is therefore considered to be conservative. Once achieved, the TSV is intended to be sufficient to ensure that, during a repeat of the DOR, service area water demands can be met with 100 percent reliability without additional treatment (other than disinfection). The ASR model includes an option to adjust the buffer zone volume as a percentage of the TSV, enabling evaluation of the sensitivity of the results to variations in this assumption.

An important, related consideration is the lateral rate of movement of the stored water under the natural regional gradient, or any changes in that gradient caused by local or regional groundwater production. Where the lateral rate of movement is small, such as a few feet per year, the impact upon the availability of stored drinking water in ASR wells is likely to be small. However, for locations and storage aquifers where the lateral rate of movement is large, such as several hundred feet per year, the value of ASR for long-term storage may be reduced while the value for seasonal storage may be essentially unaffected. Deeper, confined aquifers are often utilized for ASR storage since they tend to have slower lateral velocities. For the purpose of this analysis, a 50 percent buffer zone assumption probably provides a margin of safety to accommodate some lateral movement of stored water.

Reliability (percent). The ASR Model is utilized to achieve 100 percent reliability, which is defined as the number of days during a study period that the ASR cumulative storage volume stays above the buffer zone volume, divided by the number of days for ASR recovery. For example, if the buffer zone volume is 10,000 AF and the cumulative storage volume during a study period, including a severe drought, never drops below 10,000 AF, 100 percent system reliability would be achieved. For any such days it is presumed that, although recovery of stored water from the ASR wells will continue to be viable, the quality of the recovered water may deteriorate, potentially requiring treatment in addition to disinfection in order to meet drinking water standards. The target level of reliability is an input variable to the model. All options except Option D assume 100 percent reliability. Option D evaluates the impact of reducing the reliability goal to 95 percent. A similar supplemental analysis is provided for Option E.

Buffer Zone Volume Divided by ASR Target Storage Volume. This ratio is an input variable for the ASR Model. For all options a ratio of 0.5 is utilized, however for Options A and E an alternate scenario is also considered, utilizing a ratio of 0.3.

With the above input data, the ASR Model is utilized to estimate the total storage volume required, and associated capacity of ASR wellfield facilities, in order that projected water demands and water quality goals during the study period will be met with 100 percent reliability during a repeat of the period of record, including the DOR.

The data set of water available from the Guadalupe River at Tivoli for each day during the 71-year period of record is first filtered to ensure that high and low flow constraints are met. It is then filtered to make sure that the cumulative volume diverted up to the previous day does not exceed the GBRA water rights. The resulting set of flows is then filtered to ensure that, during low flow periods when the river flow is less than the Port Lavaca WTP capacity, any flow exceeding the low flow constraint is diverted. Cumulative diversions are then tabulated, in both acre feet (AF) and million gallons (MG). Service area water demands are projected from 2014 to 2040 assuming that the base year is either a drought year (2011, Option A) or a more typical year (2008, Option E). Daily water demands for the selected base year are multiplied by a factor of 1.26 to estimate 2040 demands, representing a projected increase in water demand of 8 percent per decade. A linear annual increase in water demands is assumed during this period. Projected daily demands for each day of the year are then utilized for each year of the simulated study period, based upon the distribution of daily demands in the base year. For each day, the difference between the flow available for diversion and service area projected water demand is determined. If demand is less than the diverted flow, the difference is added to storage. The existing TSR is filled first, followed by the ASR wellfield. If the demand is greater than supply, then water is recovered from storage to help meet demands. The TSR storage is emptied first, followed by ASR storage. Cumulative storage is then tabulated, in both MG and AF. If the cumulative storage volume reaches the TSV, no additional water is added to storage. Instead, the volume of water diverted is only sufficient to meet daily demands. A count of the number of continuous days of recharge and of recovery is then determined, providing a basis for estimating the longest number of continuous days of ASR recharge and of ASR recovery that would occur during a repeat of the period of record. The maximum rate of recharge, and of recovery, during the period of record then defines the ASR wellfield recharge or recovery capacity that is needed. The average annual rate at which water is added to storage during the first six years, prior to beginning the DOR, is then determined.

It is likely that the GBRA ASR wellfield would also be constructed in two or more phases, generally matching increases in service area demands. Most likely one or more initial ASR test wells would be constructed and placed into operation, providing operating data to support design of an expanded wellfield. During operation of the first phase facilities, stress tests would most likely be conducted for the ASR storage facilities, providing a basis for refinement of these current planning assumptions prior to design of subsequent wellfield expansion phases.

Input data assumptions are made for each of the above parameters. The assumed Initial Storage Volume and ASR Target Storage Volume are then adjusted as needed so that water demands are met with 100 percent reliability during the selected study period while maintaining the required minimum volume (ie: half of the ASR TSV) in the buffer zone. For any selected model run, an optimal solution would be that which meets these criteria while minimizing the Initial Storage Volume and also the ASR Target Storage Volume. The ASR Model converges on this optimal solution automatically for each set of input variables.

7.2.2 GBRA Port Lavaca - Water Demand Projections

Daily water demands were provided by GBRA for the Port Lavaca WTP for calendar years 2008 through 2012. Maximum day, minimum day and average daily water demands for each year are summarized in **Table 3-1**. As with Victoria, the year 2011 was selected as a "base year" for water demand projections since this was a very dry year, resulting in water demands that were higher than normal. For each day during the "base year," the projected 2040 demand was estimated by multiplying the demand for that day by a factor of 1.26, corresponding to a projected increase in water demand of 8 percent per decade, beginning in 2014 and ending in 2040. A linear increase in water demand was assumed for each year between 2014 and 2040. After 2040, daily water demand was assumed to remain the same as in 2040. This provided the opportunity to evaluate storage volume requirements to ensure water supply reliability during a hypothetical study period that excluded the DOR, namely the period from 1958 to 2012. There were several dry spells during this shortened study period, particularly near the beginning and also at the end.

As the ASR Model analysis proceeded, it became evident that the base year projection would tend to overestimate the ASR facilities required for GBRA as it did for Victoria; the associated TSV; and the time required to achieve the TSV. Accordingly, some of the alternative scenarios that were considered included selecting a more typical base year, 2008. Projections to 2040 from this alternate base year also utilized the same 1.26 factor and the same linear increase in water demand. Analysis of both scenarios provides part of a framework for consideration of ASR options.

The water demand projections for GBRA by decade are shown in **Table 7-2**.

2008 was a Leap Year whereas 2011 was not. Adjustments to the water demand projections for the period of record, where necessary, were made by either deleting water demands for February 29 or by duplicating water demands for March 1 of each year.

Table 7-2: Projected GBRA Water Demand by Decade

	2008 Base Year		2011 Base Year	
Year	Max Day (MGD)	Ave Day (MGD)	Max Day (MGD)	Ave Day (MGD)
2014	2.3	1.5	3.6	2.2
2020	2.4	1.5	3.7	2.3
2030	2.6	1.6	4.0	2.5
2040	2.9	1.9	4.5	2.8

7.2.3 ASR Objectives for GBRA

At an ASR Workshop held in Victoria on September 12, 2013, a list of ASR objectives for GBRA was prepared and prioritized. The list was selected following discussion of 27 known applications to date for different ASR wellfields globally. Following is the prioritized list of ASR applications for GBRA:

1. Seasonal storage to meet peak demands which would serve to delay expansion of the Port Lavaca WTP
2. Emergency storage for use during hurricanes and other events (with the requirement to design ASR facilities in such a way that they could be inundated)
3. Long-term storage
4. Reduction in disinfection by-product (DBP) concentrations

This list has guided the following analysis of water supply options for GBRA, utilizing ASR storage to help meet projected demands. The first and third goals are addressed directly in the following ASR Model analyses. The remaining two goals are addressed implicitly, as follows:

Emergency Storage – The duration of an emergency event has not been previously defined. A suggested assumption for planning purposes is that such an event might last for up to 30 days. Such an event could possibly result from a hurricane, causing coastal flooding that contaminates GBRA's diversion and canal systems which provide the raw water supply, and requiring that all water supplied to GBRA's service area would need to be obtained either from the existing TSR or from ASR storage. Under such emergency conditions it is likely that water use restrictions would be imposed. Therefore, it is assumed that water demands during the emergency event would equal average day demands or less. Using average day demand, the rate at which water would be required from ASR storage would be up to about 2.7 MGD in 2040. This is less than the anticipated design recovery capacity of the ASR wellfield so no additional facilities would be needed to meet this objective. The volume of water required for recovery during an emergency is up to about 250 AF. Unless the planned emergency occurs during the first three years of an ASR program, when facilities are probably still coming on line, adequate water should be available for recovery if needed. The ASR Model indicates that expected annual average rates at which water will be added to storage are in the range of 2,800 to 3,200 AFY during about the first six years of operation with all ASR facilities constructed. A higher rate would also be possible, accelerating achievement of the ASR TSV.

Disinfection Byproduct (DBP) Attenuation - Most ASR wellfields utilize deep, confined and semi-confined aquifers for ASR storage. The Chicot and Evangeline aquifers under consideration for ASR storage near Port Lavaca fit this description. Water quality in such aquifers is usually characterized by a lack of oxygen, and oxidation reduction potential (ORP) that is quite low. Extensive research has consistently shown that, under such conditions, DBPs attenuate naturally due to subsurface microbial activity. Two DBPs of particular interest are haloacetic acids (HAAs) and trihalomethanes (THMs) and their associated formation potentials when water is initially disinfected with chlorine, or when the chlorine residual is restored following ASR recovery. The rate of attenuation for HAAs is rapid and is due to aerobic microbial activity, stimulated by oxygen in the recharge water. Typically HAA attenuation to zero occurs within a few days of ASR storage, as is the HAA Formation Potential (HAAFP). THMs typically attenuate to zero within a few weeks of storage, due to anaerobic microbial activity that becomes prevalent in the subsurface after the oxygen in the recharge water has been consumed by subsurface microbial activity and geochemical reactions. THM Formation Potential (THMFP) is substantially reduced, but usually not eliminated. When the chlorine residual in the recovered water from an ASR well is restored, the THM concentration will increase, but not by very much. ASR storage typically lasts for months to years. Consequently DBP attenuation is achieved as a cost-effective side benefit of ASR storage. Water recovered from ASR wells located at or close to the Port Lavaca WTP can be blended with water being produced at the WTP during times of the year when meeting EPA and State primary drinking water standards for DBPs is a challenge. This is often during summer months when water temperatures are elevated. Similarly, water recovered from ASR wells located elsewhere within the service area can be blended with water in the distribution system, thereby achieving DBP standards. This can be a highly cost-effective solution for meeting the recently-enacted Stage Two DBP requirements.

For ASR storage in aquifers that contain oxygen, or have elevated ORP values, HAA attenuation may be reasonably anticipated however THM attenuation is not expected unless other constituents in the recharge water, or conditions in the aquifer, set up circumstances favoring THM attenuation. This situation is not expected in the Port Lavaca area.

7.2.4 ASR Model Results for Meeting 2040 Projected Water Demands – GBRA Port Lavaca

Table 7-3 provides a summary of ASR Model results for GBRA in Calhoun County. A brief description for each of these options follows. Additional options besides those discussed below may also be evaluated using the ASR Model. All model results in the following summary have been rounded to the nearest 100 AF. Options A, B, C and D all utilize daily demands during 2011, a dry year, as the baseline for water demand projections. Options E, F and G utilize 2008, a more typical year, as the baseline.

Table 7-3. Summary of ASR Model Results for Meeting Projected Water Demands – GBRA – Calhoun County

Option	Description	WTP Capacity (MGD)	Initial Storage Vol. TSR + ASR (AF)	Total Storage Volume (AF)	Term. Stor. Reservoir Volume (AF)	ASR Storage Volume (AF)				ASR Recharge Capacity (MGD)	ASR Recovery Capacity (MGD)	Maximum Duration		Reliability (%)
						Target Storage Volume	Available For Recovery	Buffer Zone	Projected Minimum Storage Vol.			Recharge (Days)	Recovery (Days)	
2011 (Dry Year) Baseline Water Demand														
A	Baseline Option	6.1	11,010	29,200	135	29,065	14,533	14,533	14,562	4.7	4.5	295	271	100
B	Option A with zero initial ASR volume	6.1	135	FAILURE										68
C	Option A for seasonal and normal annual variability; not DOR	6.1	10,620	29,200	135	29,065	14,533	14,533	14,530	4.7	4.5	308	272	100
D	Option A but with 95% reliability, not 100%	6.1	6,200	24,900	135	24,765	12,383	12,383	12,319	4.7	4.5	295	271	95
2008 (Normal Year) Baseline Water Demand														
E	Option A, but with lower baseline water demands	6.1	760	21,700	135	21,565	10,783	10,783	10,784	5	3.8	253	251	100
F	Option E, but with zero initial storage volume	6.1	0	21,700	135	21,565	10783	10783	10,024	5	3.8	253	251	96
G	Option E, but with WTP expansion	7.25	135	18,650	135	18,515	9,258	9,258	9,271	6.1	3.8	225	251	100

Notes: 1. Terminal Storage Reservoir (TSR) storage, plus any additional Off-Channel Reservoir (OCR) storage, is assumed to be full at the beginning of the study period and to be drawn down first, prior to recovering from ASR wells.

2. When additional water is available for diversion, the Terminal Storage Reservoir plus any new OCR storage is filled first, followed by ASR.

3. Initial Storage Volume includes Terminal Storage Reservoir plus any new OCR storage plus ASR storage

4 Average Initial Recharge Rates (AFY) range from 2803 to 2843 AFY for Options A, B, C & D. For Options E, F & G they range from 2856 to 3201 AFY.

5 Buffer Zone is assumed to be 50% of the ASR Target Storage Volume.

6 Reliability is (Number of days during ASR recovery when the cumulative ASR volume is less than the buffer zone volume)/(Number of days of ASR recovery)

7 Initial ASR recharge rates during the first six years of ASR operations average 2,800 AFY for Option A and 3,200 AFY for Option E

Option A

This is intended as the baseline option against which other options may be compared.

In this option, it is assumed that an Initial Storage Volume is available prior to beginning the ASR Model analysis. This analytical approach resolves the problem of testing the reliability of a proposed water storage option against a repeat of the period of record, if the assumed DOR occurs near the beginning of that period because sufficient storage has previously been achieved. A decision can then be made as to the appropriate amount of time that should be provided to achieve the TSV, considering concerns regarding ensuring water supply reliability during years when the ASR TSV has not been achieved or restored; ASR facilities costs; phasing of implementation; and other factors.

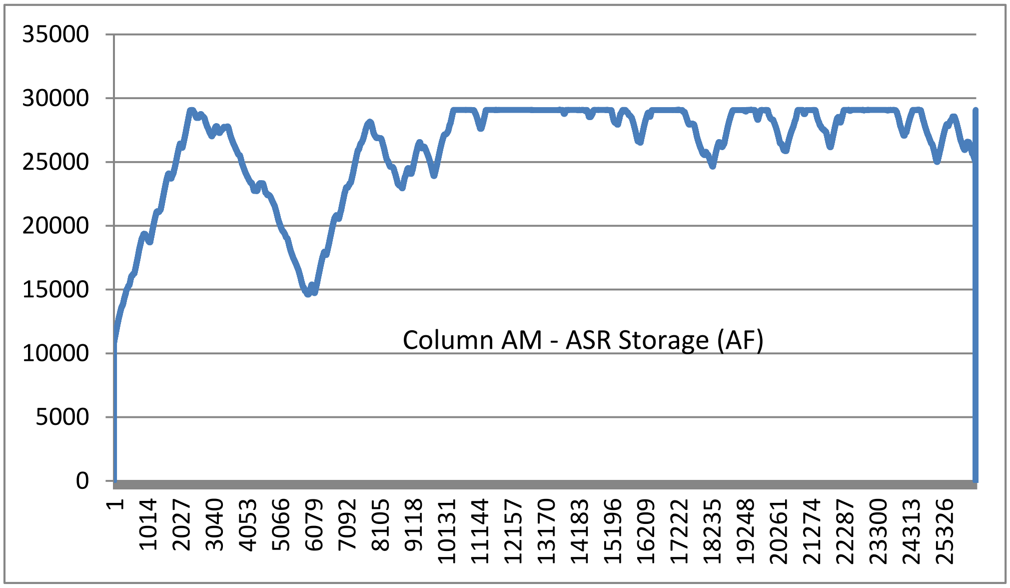
An Initial Storage Volume of 11,000 AF is required for Option A. With all ASR facilities constructed and in operation this would require about four years to achieve, utilizing water that is typically available for storage during the early years of a repeat of the period of record. During the approximately six-year time period between the beginning of the study period and a repeat of the DOR, the total cumulative storage volume increases to 29,200 AF. During the DOR the stored water volume drops to 14,600 AF, a drop of 50 percent, thereby preserving the buffer zone.

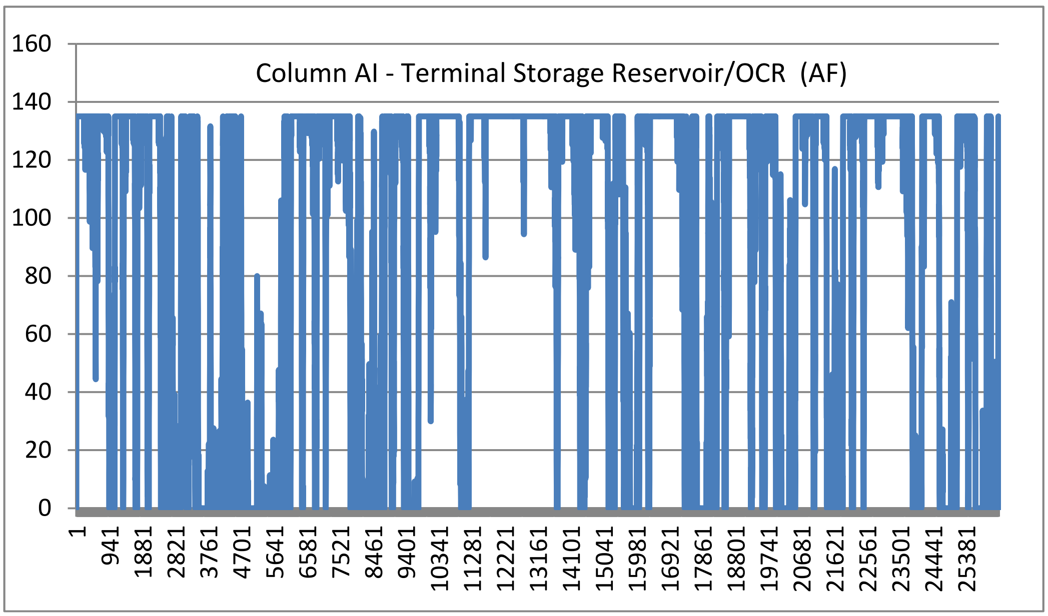
The ASR TSV for this option is 29,100 AF. The TSR at the Port Lavaca WTP provides an additional 135 AF of storage. If operational experience ultimately suggests that the buffer zone volume actually required is closer to 30 percent instead of 50 percent of the ASR TSV, then the Initial Storage Volume would be reduced to 2,500 AF and could be achieved within one year. The ASR TSV would be reduced to about 20,800 AF. The buffer zone volume estimate, as a percentage of the ASR TSV, is based upon experience at other ASR wellfields in similar aquifers.

Figure 7-3 shows the projected cumulative storage volume during the study period. This is shown for the ASR wellfield, the TSR, and the combination of both methods of storage. If an off channel reservoir is added in the future, the associated volume could be added to the TSR volume and the ASR Model analysis could be updated.

With this option, maximum recharge duration is 295 days. The maximum recovery duration is 271 days. The maximum recharge rate is 4.7 MGD while the maximum recovery rate is 4.5 MGD.

The specific capacity of a well is defined as the flow rate in gallons per minute, either during injection or pumping, divided by the increase or decrease in water level. Until better data are available to guide the wellfield design, a reasonable assumption is that the specific capacity during well injection (SCi) is half of that during pumping (SCp). Accordingly, the maximum recharge rate controls the wellfield design. For planning purposes, it will be necessary to provide ASR wellfield facilities that have a design recharge capacity of 4.7 MGD.





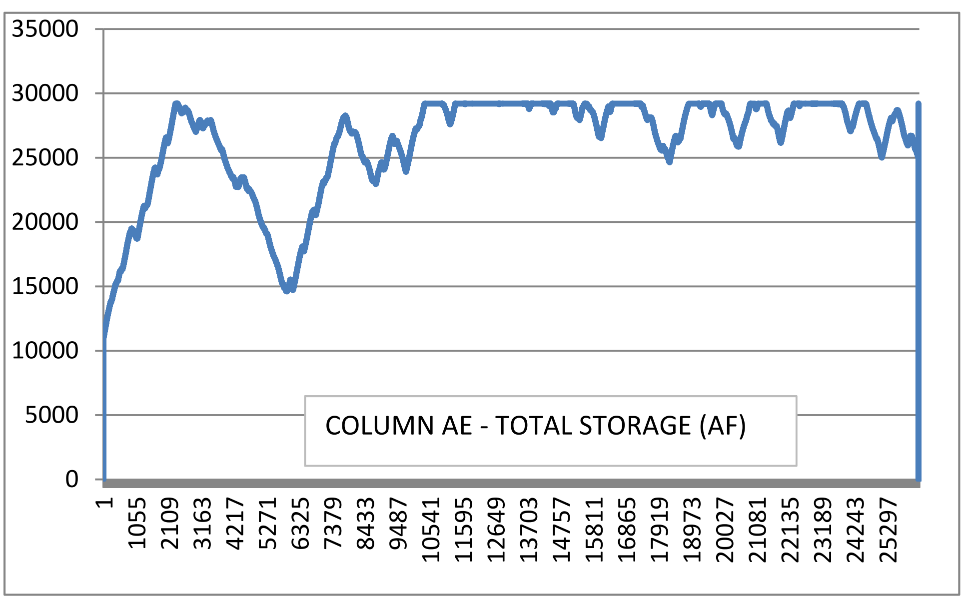


Figure 7.2. Port Lavaca, ASR Option A – Storage (AF) vs Time (Days, 1941 to 2012)

In reality, an ASR program would most likely start with an ASR Demonstration Project, constituting Phase 2 of an ASR Wellfield Development Program. (This report constitutes a Phase 1 ASR Feasibility Assessment). One or more ASR wells and associated monitor wells would be constructed and tested. Data from these wells would indicate the local ratio for SCi to SCp. The design of the wellfield would then be adjusted. For unconsolidated, confined and semi-confined aquifers such as those in the vicinity of Port Lavaca, typical SCi/SCp ratios range from 30 percent to 80 percent. Wellfield expansion would then proceed in two or more phases, as part of the ASR Wellfield Development Program. Operating experience with each expansion phase would then provide an improved basis of design for the subsequent phase.

Option B

This option is similar to Option A except that it is assumed that the Initial Storage Volume of only 135 AF is provided by the TSR, and that zero volume is initially available from the ASR wells. During the approximately six-year period between the beginning of the period of record and the onset of a repeat of the DOR, ASR storage would increase to 18,500 AF, half of which would be considered the buffer zone. However water needs during a repeat of the DOR would then draw this volume down to 4,200 AF, significantly impacting the buffer zone. Adequate water flow rate and volume would be available for recovery. However, water quality of the recovered water from ASR storage would probably deteriorate, so this system would fail. System reliability would be only 68 percent. Following the end of the DOR, 17 years would be required to attain the ASR TSV of 29,100 AF. Once attained, this would be sufficient to meet subsequent seasonal and normal annual variability in water storage needs between wet and dry years, as experienced during a repeat of the actual period of record.

Option C

The primary and secondary ASR objectives for GBRA are seasonal and emergency storage, respectively. Accordingly, Option C was evaluated. Option C is similar to Option A, except that the DOR is excluded from the study period. The analysis therefore only addresses water supply reliability during the period from 1958 to 2012. However, this shortened study period also had some significant dry years, particularly near the beginning and at the end. The results are not that dissimilar from those for Option A. The initial storage volume required is reduced but the ASR wellfield design capacity and TSV are unchanged.

This is an incomplete potential solution for meeting the GBRA projected water needs since water utility systems in Texas are required to conduct water supply planning to meet a repeat of the DOR, which occurred during 1947 to 1957. Nevertheless, the results of this analysis provide a useful point of reference for judging the most appropriate, long-term course of action for GBRA to eventually achieve this goal. With minimal capital investment to achieve sustained operation at the 6.1 MGD rated capacity of the Port Lavaca WTP, seasonal and emergency storage requirements would be quickly met with 100 percent reliability. With continued addition of treated drinking water to ASR storage, system reliability for a potential repeat of the DOR would steadily improve and, over a period of several more years, the same 100 percent level of reliability would eventually be attained for a repeat of the DOR. With additional capital investment, the time required to achieve 100 percent reliability for all four GBRA goals could be accelerated.

Option D

Option D is similar to Option A except that the water supply reliability goal is relaxed. Instead of achieving 100 percent water supply reliability, the goal is reduced to 95 percent. ASR storage volume requirements are reduced from 29,100 AF in Option A to 24,800 AF in Option D. Initial Storage Volume requirements are reduced from 11,000 AF in Option A to 6,200 AF in Option D.

Option D is not recommended, however it provides a useful reference point. During the early years of an ASR program when the cumulative storage volume is less than the ASR TSV, reliability will be less than 100 percent. It will still be greater than the current system reliability during a repeat of the DOR, and will steadily improve with time. With no additional capital investment, 100 percent water supply reliability can be achieved with an ASR wellfield by forming and maintaining a TSV. This is not the case for water systems that are totally dependent upon run-of-river water sources that are subject to calls on senior water rights during droughts, and associated water losses due to evaporation, transpiration and seepage from reservoirs and conveyance canals.

The ability to achieve 100 percent reliability with ASR storage at relatively small additional cost compared to achieving a lower level of reliability appears relatively advantageous, particularly since it reduces the risk of having to deal with a water shortage or a deterioration in water quality provided to customers.

Option E

An alternative, less-conservative assumption for planning purposes is that the study period is based upon more typical years for water demand, such as 2008, rather than a dry year such as 2011. With this assumption the projected water demands are reduced; more water is available for storage utilizing existing facilities capacity; and storage volume requirements are therefore reduced. However a small increase in ASR wellfield design capacity is needed in order to recharge higher flow rates when they are available for storage.

As shown in **Table 7-3, the** Initial Storage Volume would be reduced to 800 AF, compared to 11,000 AF with Option A. The ASR TSV would be 21,600 AF compared to 29,100 AF for Option A. However, ASR wellfield recharge design capacity would increase to 5.0 MGD, compared to 4.7 MGD for Option A. The rate at which water could be added to storage would average 3,200 AFY during the first six years in order to have sufficient water in storage prior to a repeat of the DOR. In reality, the ASR TSV could be achieved more rapidly.

If the reliability goal is reduced to 95 percent, no initial storage volume would be required and the ASR TSV would be reduced to 19,600 AF.

If no improvements are made to the WTP and the sustained capacity remains at its current rate of 4.8 MGD, the Initial Storage Volume would increase to 13,300 AF and the ASR TSV would increase to 26,700 AF in order to achieve 100 percent reliability.

Option F

This option is similar to Option E except that it is assumed that initially no water is in storage. System reliability declines slightly to 96 percent.

Option G

Although the GBRA water banking objectives can be achieved with the existing diversion and WTP rated capacity, supplemented by ASR wells, the time required to initially achieve the TSV, or to restore the TSV following a drought, is several years. The risk of having an unreliable water supply may be relatively small now, however as water demand increases, the risk of failure will increase and may become unacceptable, particularly if ASR storage has not commenced. The risk of failure can be reduced by expanding the Port Lavaca WTP and thereby enabling GBRA to capture, treat and store more water when it is available, accelerating formation or restoration of the TSV. Option G includes expanding the water treatment plant from 6.1 to 7.25 MGD and having 135 AF initial storage volume in the TSR, but zero initial volume in ASR storage.

With this option, the required ASR TSV is reduced to 18,500 AF, compared to 21,600 AF in Option E. ASR wellfield recharge design capacity would increase to 6.1 MGD.

Compared to other options, this option would enhance overall system reliability by more rapidly achieving the TSV required prior to, and restoring it after, a repeat of the DOR. However the associated cost for the water treatment plant expansion and for a larger ASR wellfield would most likely be greater than for other alternatives. This underscores the advantage of not waiting too long to start ASR wellfield development. Delay is more likely to necessitate the need for a greater capital investment in treatment and storage capacity.

7.2.5 Summary of ASR Model Results – GBRA Port Lavaca

Option A is the baseline option against which the other options may be compared. Other options evaluate various different assumptions regarding initial storage volume; water treatment plant expansion; projecting water demands based upon 2008; and meeting three of the four GBRA ASR objectives, but not meeting demands during the DOR.

Table 7-3 shows a summary of the results from the ASR Model for each of the options described above. A few observations are pertinent:

- GBRA's ASR objectives can be met utilizing the existing water treatment plant rated capacity of 6.1 MGD, recognizing that some improvements would be needed to facilitate sustained operation at this production rate instead of the current sustained operation rate of 4.8 MGD. In addition, GBRA will need to increase its staff in order to operate the Port Lavaca WTP more hours per day.
- The number of years required to achieve these objectives with 100 percent reliability varies according to a range of assumptions underlying the ASR Model analysis for various options. The Initial Storage Volume required in order to achieve 100 percent

reliability during the study period can be achieved in a reasonable time ranging from less than one year to about four years.

- ASR objectives cannot reasonably be met with 100 percent reliability utilizing the current sustained operating capacity of the Port Lavaca WTP, which is 4.8 MGD. An Initial Storage Volume of about 23,300 AF would be needed. This would require eight years to achieve.
- The volume that needs to be recovered during a repeat of the DOR ranges from 9,300 to 14,500 AF, depending upon the set of assumptions underlying each of the options that were considered. The upper end of this range is associated with 2040 water demand projections based upon the distribution of daily demands experienced in 2011, a dry year. The lower end of the range is based upon 2040 water demand projections based upon the distribution of daily demands experienced in 2008, a more typical year. Increasing the Port Lavaca WTP capacity reduces the storage volume requirements and therefore the time required to store sufficient water prior to, or immediately following a DOR. It is important to understand that this is only the recovered water volume. An additional buffer zone volume is needed so that recovered water quality can meet all drinking water standards. The recovered water volume plus the buffer zone volume constitutes the ASR TSV.
- The ASR TSV required to meet demands during a repeat of the DOR ranges from 18,500 AF to 29,100 AF.
- The ASR wellfield design capacity for all options is controlled by the required **recharge** capacity, which ranges from 4.7 MGD to 6.1 MGD. The upper end of this range is associated with the 7.25 MGD expanded water treatment plant capacity while the lower end of the range is associated with the existing 6.1 MGD rated capacity of the Port Lavaca WTP. Since ASR is often viewed as an opportunity to avoid the high cost of WTP expansion it is likely that ASR wellfield recharge design capacity would be about 5 MGD.
- Maximum duration of recharge periods ranges from 225 to 308 days. The maximum duration of recovery periods ranges from 251 to 272 days. Even during the DOR there are significant opportunities for replenishing storage volume.
- The number of years during the period of record when water rights limitations restrict diversion and treatment of water prior to the end of the year is zero for all options. This is due to the seniority of GBRA's certificate of adjudication.
- Early implementation of an ASR wellfield development program would take advantage of the larger difference between excess treatment plant capacity and available water supply from the river. This would increase the rate of adding water to ASR storage, thereby reducing the time required to achieve the TSV. Conversely, deferring implementation of an ASR program would steadily reduce the rate at which water can be stored, reflecting a projected increase in water demand. This would tend to increase the need for expansion of both water treatment and ASR wellfield capacity.

- Further investigation of groundwater production at the nearby aquaculture operation is needed prior to confirming the viability of the GBRA Port Lavaca WTP property for an ASR wellfield. If a significant cone of depression already exists in the sand intervals that are suggested for ASR storage, it may be necessary to relocate the ASR wellfield to another site. Since long term storage is only a tertiary objective for GBRA, some annual lateral movement of the stored water may be quite acceptable for seasonal storage, which is the primary objective for this location.
- GBRA's four goals for an ASR program in Calhoun County can be achieved.

7.2.6 ASR Wellfield Conceptual Design

An ASR recharge capacity of 5.0 MGD was selected as the basis of design for the GBRA facilities. As described in Section 6, hydrogeologic conditions in the Port Lavaca area are deemed to be suitable for ASR, although they offer more challenges than the conditions in the Victoria area. A suggested location is at the GBRA Port Lavaca WTP which is located at Latitude 28^{o} 33' 23.44" N and Longitude 96^{o} 37' 19.35" W.

Twenty (20) existing water supply production wells are located near the Port Lavaca WTP to the northeast at distances of about 0.5 to 1.0 mile and are primarily utilized for aquaculture operations. Annual production of water from these wells is not known. Based upon available records, these wells are believed to be at depths less than 340 feet. Groundwater production is believed to be intermittent, supplementing water supplies from the adjacent bay when the water becomes too saline.

To minimize well interference and avoid any potential for contamination, ASR wells are assumed to be constructed primarily in the Lower Chicot aquifer at depths between 400 and 700 feet. Sand intervals that would be screened are expected to include a total sand thickness averaging 150 feet within this interval. Based upon an estimated hydraulic conductivity of these sands at 12 ft/day, the transmissivity of this interval should be about 1,800 ft^2/day. Specific capacity during production (SCp) is estimated at 5 gpm/ft. Static water level in an ASR well penetrating this aquifer is assumed to be about 10 feet bgs. Available drawdown during pumping for a single well screened in this interval would be up to about 350 feet. However, several ASR wells would be needed and this would tend to cause interference between the wells. The available drawdown to any individual well would be reduced.

Native groundwater quality in the Lower Chicot aquifer at this location is believed to be brackish, with an estimated TDS concentration of about 3,000 to 5,000 mg/L. Storage of drinking water in such an aquifer should be viable since the salinity is well within the range of successfully operating ASR wellfields in brackish aquifers. Furthermore, the aquifer is expected to be confined above and below by thick clay layers, providing protection from potential upconing or downconing of saline water from underlying or overlying aquifers, and providing good control of the stored water.

Reflecting the low regional hydraulic gradient at this coastal location, lateral movement of the stored water in an ASR wellfield should be negligible. However it is possible that a local gradient may exist, caused by an unknown amount of groundwater production from wells at the nearby aquaculture operation. Well spacing would be determined from an initial test well program, however for planning purposes a spacing of approximately 500 feet is assumed. A reasonable balance is sought between keeping the wells sufficiently far apart so that hydraulic interference is minimized during seasonal storage and recovery operations while at the same time having them close enough together so that the fresh water "bubbles" around each ASR well will tend to coalesce, thereby enhancing rapid achievement of high recovery efficiency. After a few months of ASR recharge operations, the stored water bubble surrounding the ASR wellfield will most likely extend beyond the existing GBRA Port Lavaca WTP property boundary.

Shallower and deeper sand intervals exist at this location. The shallower intervals are assumed to occur at depths of 300 to 400 feet and may therefore be influenced to some extent by production from the aquaculture wells, potentially impacting long-term recovery efficiency. However the lateral velocity would most likely be sufficiently slow so that any adverse effect upon recovery efficiency for seasonal operations would probably be insignificant. Seasonal storage is the primary goal of GBRA for this ASR program while long term storage is a tertiary goal. An advantage of storage in this shallower interval is that ambient groundwater quality may tend to be less brackish, probably in the range of 1,500 to 3,000 mg/L. Deeper sand intervals are also available for storage, particularly at depths of 700 to 1,100 feet. These sands are believed to be less permeable than those in the 400 to 700 foot interval, and ambient groundwater quality may tend to be more brackish, generally increasing with depth.

Figure 7-3: GBRA Port Lavaca Water Treatment Plant Site

While several wellfield development concepts may be considered, the following conceptual plan is suggested. Initially developing an ASR program at the Port Lavaca WTP and storing water in different sand intervals makes the best use of the existing GBRA facilities and property for ASR wellfield development purposes. Such a development concept also eliminates the need for lengthy transmission pipelines. Initial well construction and testing will be required, gathering information to support refinement of this plan. All significant sand intervals between 300 and 1,100 feet in depth will be utilized for ASR storage. Half of the wells will store water between 400 to 700 feet. The remaining wells will be distributed equally between the interval from 300 to 500 feet and the interval between 600 to 1,100 feet. Some overlap between the screen interval depth ranges would provide flexibility to adjust individual well screen designs to match site-specific sand interval depths and thicknesses, providing adequate potential recharge and production capacity for each well. No wells will interconnect all of the sand intervals since that would tend to adversely impact recovered water quality, particularly during early years of ASR operations. Providing discrete storage intervals will provide the opportunity for greater control over ASR wellfield operations.

The ASR TSV estimates for Port Lavaca in **Table 7-3** range from 18,500 AF to 29,100 AF. Of this volume, half would comprise the buffer zone surrounding the stored water volume. The buffer zone is analogous to the walls of a storage tank. Its purpose is to ensure satisfactory recovered water quality from the ASR wellfield. Assuming that the bulk porosity of the sands is about 25 percent and that the total sand thickness between 300 and 1,100 feet averages 400 feet, an ASR bubble would theoretically underlie an area of about 185 to 291 acres, corresponding to a radius of 1,600 to 2,000 feet around the center of the ASR wellfield. The outer half of this stored water volume would comprise the buffer zone. The stored drinking water that is available for recovery would extend to a smaller theoretical radius of 1,130 feet to 1,420 feet with the buffer zone extending farther. Considering the lateral distance to the nearest aquaculture wells, this radius should be sufficient for ASR storage.

For conceptual design purposes it is assumed that GBRA existing property dimensions are approximately 2,400 feet x 1,300 feet, comprising an area of approximately 70 acres. For conceptual planning purposes it is assumed that 30 ASR wells would be constructed at the WTP site. For the depth interval between 400 and 700 feet, eight ASR wells would surround the TSR, at the four corners and at the mid-point of each side. The TSR comprises the westerly half of the property. Some additional land or easements may be required around the TSR for well construction and operation purposes. An additional six ASR wells would be located around the periphery of the easterly half of the existing property, with one additional central well on the south side of the WTP. A total of 15 ASR wells would be constructed on the existing GBRA property in this depth interval. Eight additional ASR wells would be constructed in the interval between 300 and 500 feet and would be located around the TSR, midway between adjacent ASR wells. This location would maximize their distance from the aquaculture wells. Seven additional wells would be located on the eastern half of the property and would be screened in the deeper interval from 600 to 1,100 feet.

It is assumed that, on any given day, 10 percent of the ASR wells (three wells) would not be in operation. This could be due to routine operation and maintenance, periodic well backflushing and/or redevelopment, or other factors. With a design wellfield recharge capacity of 5.0 MGD, each well would be designed to recharge at an average rate of 130 gpm. Assuming that injection specific capacity (SCi) is half the production specific capacity (SCp), then SCi would average 2.5 gpm/ft. It may be somewhat higher for the shallower wells and lower for the deeper wells. Injection pressure for 30 ASR wells would then average 52 feet above the static water level, or 22 psi. Additional pressure will be required in order to overcome well interference, particularly during times when recharge is occurring at close to the design flow rates. This is within normal experience for properly designed ASR wells. Pressure already available from the WTP is greater than the pressure required for wellfield recharge, so pressure reduction will be needed. Wellhead facilities would be elevated above land surface a sufficient distance to meet hurricane storm surge conditions and would be designed to operate normally at such emergency times.

An alternative option for GBRA would be to initially locate 15 wells at the Port Lavaca WTP and to locate 15 additional wells on one or more other sites to be acquired in the Calhoun County service area. The same well spacing of approximately 500 feet would apply. Transmission piping to and from the remote wellfield would need to be capable of conveying water at design recovery rates. Recovery rates from each well would be up to double the recharge rates, however recovery rates from the entire wellfield, or both wellfields combined if there are two sites, would be 4.5 MGD. Further consideration of this alternative option would be appropriate at such time as GBRA may initiate a Phase 2 ASR demonstration program.

Initial ASR investigations would include gathering further information regarding the aquaculture wellfield operations. Assuming that an ASR wellfield at the Port Lavaca WTP site is then still considered viable, continuous wireline coring would be the first step in wellfield construction, probably at the four corners of the GBRA property, plus construction of monitor wells. Geochemical and geotechnical analysis of selected cores would provide the basis for evaluation of the potential for local subsidence to occur as a result of ASR wellfield operations. The ASR storage aquifers are bounded by thick clay layers. These clays may tend to compact due to cyclic ASR operations, seasonally pressurizing and then de-pressurizing the aquifers and intermediate clay layers. Based upon calculations at several ASR sites investigated to date, subsidence is theoretically possible. Land surface elevation changes, if any, may be minor and would be expected to occur within a few tens of feet radius from an ASR well, if they occur at all. No changes in surveyed or observed elevations at operating ASR wells have been noted in unconsolidated aquifers. It would be appropriate to not locate ASR wells too close to existing structures. A separation distance of at least 100 feet is recommended.

All ASR wells would be designed so that key components such as air/vacuum relief valves, electrical and telemetry equipment are above the expected water level elevation during hurricane storm surges. Land surface elevations in the area of the WTP are 14 to 16 feet msl while the storm surge elevation is approximately 22 feet msl. Wellhead flanges will be sealed, and designed to hold anticipated injection pressures. Each well would have a PVC casing and a stainless steel screen. Casing inner diameter of 12 inches will provide flexibility to accommodate expected variability in individual well production rates, possible flanged column pipe, any trickle flow recharge piping, water level measuring tubes, screen riser pipe, etc. Screen inner diameter of 6 inches will provide sufficient capacity to convey water during recharge and recovery while minimizing clogging. Each well will be equipped with a pump, motor and variable frequency drive (VFD). Motors will be selected to facilitate periodic backflushing and well redevelopment operations.

Wellfield piping would be primarily around the periphery of the site, with probably three water pipelines in a single trench, plus underground power supply and telemetry conduits. One pipeline would be for conveyance of drinking water from the WTP to the ASR wells during recharge periods and for conveyance of water from the ASR wells to the WTP during recovery periods. This pipeline would be sized to convey water at rates up to 5.0 MGD with low head loss so that available wellhead pressure is similar for all ASR wells. A small booster pump would be provided so that water circulates in this pipeline during extended periods when no recharge and no recovery is occurring. A second pipeline would convey water from each well to the TSR during periodic backflushing operations that would need to be implemented to reverse any well clogging that occurs and thereby maintain recharge capacity. It is assumed that backflushing would occur every two weeks at each well, would last for one hour, and the process would be automated and controlled by the SCADA system. This backflush pipeline would be provided with an alternate discharge to a local drainage channel in the event that the TSR is full. A third, small-diameter pipeline would convey drinking water at flow rates of about 2 to 5 gpm to each well during extended storage periods lasting in excess of one week, when no recharge and no recovery is occurring at the ASR wells. Maintaining a small chlorine residual in the casing, screen and gravel pack of each ASR well helps to control microbial activity and thereby reduces clogging potential. Further protection against well clogging would be provided through installation of a 5 micron filter on the portion of the drinking water supplied to the wells for recharge. ASR wellfield facilities would also include an all-weather access road to each ASR well. Restoration of the chlorine residual following ASR recovery would be provided using existing disinfection capacity at the Port Lavaca WTP.

7.2.7 Conclusions and Recommendations – GBRA Calhoun County

Subject to additional data collection and testing, an ASR wellfield is viable at the Port Lavaca WTP. An ASR wellfield is also viable in the Study Area west of Port Lavaca and between the Port Lavaca WTP and Bloomington. Such wellfields should be able to meet the projected 2040 water demands assumed in this feasibility study with 100 percent reliability and at relatively low cost compared to other water supply alternatives. Starting an ASR program at the Port Lavaca WTP is justified because this concept eliminates the right-of-way, pipeline and pumping costs associated with a remote location. However, more distant ASR wellfields with less challenging hydrogeologic conditions may be very viable if future growth in water demand occurs between Port Lavaca and Victoria.

If a decision is made to proceed with further investigation of ASR viability, GBRA should implement an ASR test program at the Port Lavaca WTP. Continuous wireline cores would first be obtained to a depth of 1,100 feet, providing good understanding of the depths and thicknesses of sand and clay layers beneath the site, and their associated geochemical and geotechnical properties. The number and location of ASR wells and monitor wells may be adjusted based upon results of initial core holes.

Following confirmation with the corings, the test program would include construction and testing of approximately three full-size ASR wells that would be placed into operation, one each for sand intervals between 300 and 500 feet, 400 and 700 feet, and 600 to 1,100 feet. The first phase of ASR wellfield construction would represent 10 percent of the planned ultimate scale of development. A possible general location may be at or near three of the four property corners. The test program would also include approximately five monitor wells, as needed to provide a basis for design of expanded ASR wellfield facilities at this site. Three of these monitor wells would be close to the three adjacent ASR wells. One more would be at the remaining property corner and one near the center of the property. Operating experience gained at this site with the first three ASR wells would provide a basis for subsequent design of wellfield expansion facilities at this site or other locations, achieving ASR goals for the Port Lavaca area.

8.0 Costs and Economics

8.1 Cost of Stored Water

In order to understand the "marginal" cost for producing and treating additional surface water from the Guadalupe River at the Victoria WTP and the Port Lavaca WTP for ASR storage and subsequent recovery, the study team analyzed actual fiscal year (FY) 2013 expenses for the Victoria WTP and FY 2014 budgeted expenses for GBRA's Port Lavaca WTP. The volume of treated water produced or to be produced during the same time periods was used in the calculation of a unit cost. . Because this drinking water is typically stored during winter months and other off-peak periods when facilities have excess capacity, the true cost of that stored water is based on the marginal variable expenses. These marginal costs typically include electrical power, chemicals, additional maintenance on some equipment (e.g. pumps, motors and chemical feed equipment), and solids/residuals handling. For purposes of this analysis, the study team assumed that additional maintenance would be about 15 percent of the total expenses.

The operations and maintenance (O&M) cost analysis showed that the cost to store available water in an ASR well field from the Victoria WTP is about $0.42 per 1,000 gallons, or $136 per AF. The cost to store available water in an ASR well field from the Port Lavaca WTP is about $0.66 per 1,000 gallons, or $214 per AF. The higher cost at the Port Lavaca WTP is primarily due to: the need for one additional plant operator in order to make maximum use of the available capacity on a 24/7 basis; and the Canal System delivery charge for transporting the raw water from the Guadalupe River to the WTP. If the additional operator is not needed to store sufficient ASR water, the marginal cost for the Port Lavaca WTP would be about $0.58 per 1,000 gallons, or $188 per AF.

8.2 Construction Costs

8.2.1 Introduction

The estimates of probable cost discussed below are based on the ASR modeling and preliminary basis for design described in Section 7. The feasibility study-level cost estimates are considered to be Association for the Advancement of Cost Engineering (AACE) Class 4 (low range of -15 percent to -30 percent, and high range of +20 percent to +50 percent). The study team used costing methods comparable to those used for the TWDB regional planning process, augmented with actual information from recent ASR projects.

8.2.2 City of Victoria/Victoria County

The basis for design for the City of Victoria ASR system includes an ultimate of 16 new or retrofitted ASR wells. The retrofitted wells would be existing City production wells with suitable characteristics for evaluation as an ASR well. The wells are located at the Victoria WTP, and at or near existing City facilities such as WTP No. 3. This approach maximizes the use of the existing City distribution system and eliminates the need for expensive pump stations and pipelines. It also allows the ASR system to take advantage of existing disinfection facilities, eliminating the need for post treatment at the ASR wells. For costing purposes, the study team assumed that 100 feet of new pipeline (with associated valves, meter and ancillary equipment) would be needed to connect each new ASR well to the Victoria distribution system. No such connection is needed for the retrofitted wells.

The study team recommends that the Victoria ASR system be constructed in two phases. Phase 2 follows this Phase 1 feasibility study and is the test well program. In Phase 3 the wellfield will be fully developed.

The Phase 2 testing program includes the construction of one new ASR well at the Victoria WTP; the retrofitting of one existing production well (No. 14) at WTP No. 3; the construction of one monitoring well in the storage zone; the construction of two monitoring wells in the Chicot Aquifer; and the implementation of one continuous wireline coring at the Victoria WTP. **Table 8-1** shows the basis for design for Phases 2 and 3. The total estimated cost for the Phase 2 testing program (including a 30 percent contingency, and engineering) is $3.6 million. A preliminary estimate of the estimated ASR recovery capacity is 4.0 MGD, to be confirmed following well construction and testing.

For each new ASR well, the cost estimate includes ancillary facilities such as a new power supply; SCADA and electrical equipment enclosed in a small building; access road; and security fencing. SCADA facilities are also included in the cost estimate for retrofitted wells, but the other ancillary facilities are not included.

A summary of the Victoria estimated cost is shown in **Table 8-2**. The total capital costs for the Victoria ASR system are estimated to be $14.5 million. The total project costs, including engineering, permitting, environmental study, land acquisition, interest during construction and contingency expenses are estimated to be $21.1 million in March 2014 dollars. This would provide 25 MGD of ASR recovery capacity and 18 MGD of recharge capacity. The cost estimates do not include the marginal cost of stored water that is discussed in Section 8.1.

Table 8-1. Victoria ASR – Basis for Design Cost Estimation

	Location(s)	Well Construction					Recharge Rate (gpm)	Recovery Rate (gpm)	Original Pump Test (gpm)
		Casing Depth (ft)	Casing Dia. (in)	Screen (ft)	Screen (in)	Bottom of Well (ft)			
Phase 1	**Feasibility Assessment**								
Phase 2	**Test Well Program**								
One new ASR well	Victoria SWTP	450	20	240	12	1,000	850	1,750	
Retrofit 1 existing well	WTP#3 Well 14	435	18	239	10	1,017	800	1,400	1,560
One storage zone monitoring well	SWTP	300	6	200	6	800	-	-	
Two Chicot Aquifer monitoring wells	SWTP, WTP#3	70	4	30	4	100	-	-	
Continuous wireline core hole	SWTP					1,000			
Phase 3	**ASR Wellfield Development**								
Nine new ASR wells	SWTP	450	20	240	12	1,000	850	1,750	
Retrofit 5 existing wells	WTP#3 Well 15	420	18	254	10	1,034	800	1,400	1,670
	WTP#3 Well 16	420	18	280	10	1,010	800	1,400	1,557
	WTP#3 Well 17	420	18	181	10	828	800	1,400	1,529
	WTP#3 Well 18	545	18	263	10	1,036	800	1,400	1,529
	WTP#3 Well 19	450	18	270	10	1,068	800	1,400	1,520

Table 8-2. Cost Estimate Summary – City of Victoria ASR

Cost Estimate Summary Water Supply Project Option March 2014 Prices City of Victory ASR		
Item		***Estimated Costs for Facilities***
Capital Costs		
Connection Pipelines	$	298,000
Transmission Pump Station(s)		-
ASR Well System (ASR and Monitoring Wells)		13,629,000
Site Improvements		173,757
SCADA		380,000
Total Capital Cost	**$**	**14,480,757**
Engineering, Legal Costs and Contingencies	$	5,830,800
Environmental & Archaeology Studies		52,000
Land Acquistion and Access		73,000
Interest During Construction (1 year)		662,000
Total Project Cost	**$**	**21,098,557**
Annual Costs		
Debt Service (5 percent, 30 years)	$	1,273,000
Operation and Maintenance		
Wellfields and Related Equipment		139,000
Pumping Energy Cost		107,000
Total Annual Cost	**$**	**1,519,000**

8.2.3 GBRA/Calhoun County

The basis for design for the GBRA/Calhoun County ASR system includes 30 ASR wells at ultimate capacity. As discussed above, the number of wells reflects the characteristics of the storage aquifer at the Port Lavaca WTP. The study team conducted a cursory evaluation of putting the ASR wellfield at a remote location west-northwest of Port Lavaca which has more favorable aquifer characteristics. However, the reduced number of ASR wells did not justify the additional costs for a new pump station, pipeline, stream and road crossings, and rights-of-way and land acquisition.

Therefore, all of the proposed ASR wells and monitoring wells are located at the Port Lavaca WTP. This approach maximizes the use of the existing GBRA property and reduces operation and maintenance expenses. It also allows the ASR system to take advantage of existing disinfection facilities, eliminating the need for post treatment at the ASR wells. Most of the ASR wells are laid out around the periphery of the GBRA property at the Port Lavaca WTP. The purchase of approximately 20 acres of additional land is included in the cost estimate so that adequate access is available for construction and operations.

The study team recommends that the GBRA ASR system be constructed in three phases. Phase 2 follows this Phase 1 feasibility study and is the test well program. In Phases 3 and 4 the wellfield will be fully developed.

In Phase 2, the testing program includes the construction of three ASR wells; the construction of three monitoring wells in the storage zone; the construction of three shallow monitoring wells; and the implementation of four continuous wireline corings. **Table 8-3** shows the basis of design for the ASR facilities in Phase 2. For initial testing, it will be necessary to construct temporary piping for recharge, recovery and backwash of the ASR wells. If temporary piping is used, the total estimated cost for the Phase 2 testing program (including a 30 percent contingency, and engineering) is $4.9 million.

After initial testing and confirmation of feasibility, it may be desirable to construct the pump station improvements to be able to pump water to the test wells; and a portion of the wellfield piping system. The total estimated cost for the Phase 2 testing program using permanent facilities (including a 30 percent contingency, and engineering) is $6.7 million. With these facilities, projected recharge capacity would be about 0.6 MGD while production capacity would be about 1.3 MGD.

For each ASR well, the cost estimate includes ancillary facilities such as power supply; SCADA and electrical equipment; and access roads. Security is provided by a single new fence around the periphery of the GBRA property. Due to the location of the Port Lavaca WTP and its proximity to Lavaca Bay, each of the ASR wells is located on a platform above the historic hurricane surge elevation. In order to get recharge water to each ASR well, a 2.5 mgd pump is added to the existing High Service Pump Station (HSPS) where facilities for one additional pump are already available. From the HSPS, a pipeline manifold has the capacity to distribute water to six ASR wells at once, at a rate of approximately 300 gpm per well. That same pipe system is used to recover stored water from each ASR well and get that water into the existing ground storage tank at the Port Lavaca WTP. The cost estimate also includes a 300 gpm piping system to move backwash water from each ASR well to the TSR, and a recirculation system to maintain fresh water in the wellfield piping.

Table 8-3. GBRA ASR – Basis for Design Cost Estimation

		Well Construction Casing Depth (ft)	Casing Dia. (in)	Screen (ft)	Screen (in)	Bottom of Well (ft)	Recharge Rate (gpm)	Recovery Rate (gpm)
Phase 1	**Feasibility Assessment**							
Phase 2	**Test Well Program**							
Three ASR Wells		300	12	150	6	500	130	300
		400	12	150	6	700	130	300
		600	12	150	6	1100	130	300
Three storage zone monitoring wells		300	6	150	6	500	0	0
		400	6	150	6	700	0	0
		600	6	150	6	1100	0	0
Three shallow monitoring wells		50	6	20	4	100	0	0
Four continuous wireline core holes						1,100		
Phase 3	**ASR Wellfield Development**							
Twelve ASR wells		To be determined						
Phase 4	**ASR Wellfield Expansion**							
Fifteen ASR wells		To be determined						

A summary of the GBRA estimated costs is shown in **Table 8-4**. The total capital costs for the GBRA Port Lavaca ASR system are estimated to be $22.1 million. The total project costs, including engineering, permitting, environmental study, land acquisition, interest during construction and contingency expenses are estimated to be $32.6 million in March 2014 dollars. ASR recharge capacity at build-out would be 5 MGD while meeting projected water demands during ASR recovery. The cost estimates do not include the marginal cost of stored water that is discussed in Section 8.1, or any improvements needed to get the Port Lavaca WTP up to its rated capacity.

Table 8-4. Cost Estimate Summary - GBRA Port Lavaca ASR

Cost Estimate Summary Water Supply Project Option March 2014 Prices GBRA Port Lavaca ASR		
Item		**Estimated Costs for Facilities**
Capital Costs		
Pump Stations	$	1,270,000
Wellfield Piping (Including Backwash)		1,182,000
Well Field (ASR and Monitoring Wells)		18,241,000
Site Improvements		480,366
SCADA		600,000
Pre-Treatment Filtering		322,943
Total Capital Cost	**$**	**22,096,309**
Engineering, Legal Costs and Contingencies	$	9,208,800
Environmental & Archaeology Studies and Mitigation		101,000
Land Acquisition and Related Expenses		141,000
Interest During Construction (1 years)		1,051,000
Total Project Cost	**$**	**32,598,109**
Annual Costs		
Debt Service (5 percent, 30 years)	$	2,021,000
Operation and Maintenance		
Pump Stations and Wellfield		226,000
Pumping Energy Costs		163,000
Total Annual Cost	**$**	**2,410,000**

9.0 Permitting, Environmental and Institutional Considerations

9.1 Introduction

The purpose of this section is to discuss the authorizations that would be required to permit one or more ASR systems for the Participants and the institutional issues related to implementation of those systems. The team has developed this section of the report assuming that water may be stored and subsequently recovered from the Gulf Coast Aquifer. Within the potential storage areas, the primary regulatory agencies would be the TCEQ, the Victoria County Groundwater Conservation District, the Calhoun County Groundwater Conservation District and the Texana Groundwater Conservation District (Jackson County). All three groundwater districts are located within Groundwater Management Area (GMA) 15, and all three districts have engaged Mr. Tim Andruss as the district's General Manager.

This section relies in part on previous work done by ARCADIS and ASR Systems for the Texas Water Development Board (TWDB). The section of the TWDB research report related to legal and regulatory requirements was written primarily by attorney Edmond R. McCarthy, Jr.

As discussed below, ASR wells typically used for both recharge (injection) and recovery are subject to permitting requirements based upon the source of water to be injected and the aquifer in which the water is to be stored. The primary regulatory requirements relate to TCEQ's administration of underground injection of water, and surface water diversion permitting; and the regulation of recharge and production (recovery) of water by the groundwater districts listed above.

9.2 TCEQ: UIC Class V Injection Well Permitting

For purposes of this section of the report, the study team assumes that aquifer storage will be accomplished using an injection well, regulated by the Underground Injection Control ("UIC") Program administered by TCEQ. A well that is used to inject water for storage in an ASR project is defined as an "Aquifer storage well" and is classified as a Class V Injection Well. Accordingly, all ASR injection wells must be permitted pursuant to Chapter 27, Texas Water Code, and Chapter 331, Title 30 of the Texas Administrative Code. The ASR system(s) must comply with the key requirements discussed below when treated surface water or groundwater are being injected. There are additional requirements for the injection of treated wastewater (reclaimed water).

- The implementing agency must obtain an injection well permit, or be authorized by order or rule of the Commission (TCEQ);
- TCEQ may require demonstration of mechanical integrity;
- Injection is not allowed if it would result in pollution of underground drinking water;
- The permit or authorization must include terms necessary to protect fresh water from pollution; and
- The permit or authorization must address unauthorized discharges of chemicals for any associated tankage and equipment.

The operating requirements for Class V injection wells include the following:

- Class V aquifer storage wells must not present a hazard or cause pollution to underground drinking water sources;
- The injection pressure at the wellhead must not cause movement of fluid out of the injection zone;
- If an ASR well has not been in operation for more than two years, the operator must notify TCEQ 30 days prior to resuming operation of the well;
- The owner/operator must maintain the mechanical integrity of all wells; and
- The quality of water injected must meet the Chapter 290 (30 TAC) drinking water standards.

The implementing agency will also be required to follow the monitoring and reporting requirements of TCEQ. The following items are required for Final Project Authorization by TCEQ after completion of the ASR well:

- As-built drilling and completion data on the well;
- All logging and testing data on the well;
- Formation fluid analyses;
- Injection and fluid analyses;
- Injection and pumping test data documenting the well capacity and reservoir characteristics;
- Hydrogeological modeling, with supporting data, predicting mixing zone characteristics and injection fluid movement and quality; and
- Any other information determined by TCEQ to be necessary for the protection of underground sources of drinking water.

The following must be monitored monthly and reported to TCEQ on a quarterly basis:

- Average injection rates;
- Injection and retrieval volumes;
- Average injection pressures; and
- Water quality analyses of injection water.

TCEQ may also require that ASR operator perform other monitoring and reporting, depending on the UIC permit. Essentially, anything else that TCEQ determines must be monitored for the protection of underground sources of drinking water will be monitored and reported.

A final report for the ASR project or feasibility study must be submitted to TCEQ within 45 days of the completion of the project. The report must address the requirements presented in Section 331.186 (30 TAC).

9.3 TCEQ: Surface Water-Related Authorizations

The source of water to be stored in the proposed ASR systems would be surface water diverted and treated under COAs and permits from TCEQ. Using State-owned surface water as the supply source for an ASR project triggers additional statutory requirements under Chapter 11 of the Water Code, as well as applicable TCEQ rules. The water rights must be amended to authorize use of the water for injection and recovery. [A temporary authorization for the testing phase may not be necessary. 30 TAC §295.21(b) states that a water right permit is not required for Phase I of an ASR project that proposes temporary storage of appropriated surface water in an aquifer for testing, subsequent retrieval and beneficial use if the diversion and purpose is covered by an existing water right. A clarifying discussion with TCEQ would be one of the first steps in the Phase 2 of an ASR project.]

In order to amend the water rights, Victoria and/or GBRA must submit to TCEQ the information required for a Class V injection well, and a map or plat showing the location of the injection facility and the aquifer in which the water will be stored. Since the project will likely involve storage of water in an aquifer within the jurisdiction of a groundwater conservation district, the TCEQ applicant is also required to do the following:

- Provide a copy of the application to each groundwater district that is affected;
- Cooperate with each underground water district to ensure compliance with its rules;
- Cooperate with each district to develop rules regarding injection, storage and withdrawal; and
- Comply with any rules adopted by the district governing injection, storage or withdrawal of appropriated water stored in an underground reservoir.

In the event that an applicant enters into some contractual agreement with an underground water district, that agreement must be provided to TCEQ for incorporation as a condition in the permit. In addition to the factors set forth in Chapter 11 of the Water Code that must be considered by TCEQ prior to issuing a permit to appropriate state water pursuant to Section 11.121, in the case of an application to store surface water in an ASR project, TCEQ must consider the following sections under its rules:

1. Whether the introduction of the water into the aquifer will alter the physical, chemical or biological quality of the native groundwater to a degree that would:
   (a) Render the groundwater produced from the aquifer harmful or detrimental;
   (b) Require treatment of groundwater pumped from the aquifer to a greater extent than the native groundwater requires in order for that water to be applied to a beneficial use;
2. Whether water stored in the receiving aquifer can be successfully stored and subsequently retrieved for beneficial use; and
3. Whether reasonable diligence will be used to protect the stored water from unauthorized withdrawals to the extent necessary to maximize the permitee’s ability to retrieve and beneficially use the stored water without experiencing unreasonable losses.

In its evaluation of the three criteria listed above, TCEQ may consider other relevant facts, associated with the ASR project, including:

- The location and depth of the aquifer in which the water will be stored;
- The nature and extent of surface development and activity above the stored water;

- The permittee's ability to prevent unauthorized withdrawals by contract or the exercise of the power of imminent domain;
- The existence of an underground water conservation district with jurisdiction over the aquifer in which the water is to be stored and that district's ability to adopt rules to protect the stored water; and
- The existence of any political subdivision or state agency with authority to regulate the drilling of wells.

Any permit issued for the storage of water in an aquifer within the jurisdiction of a groundwater conservation district must contain a condition that requires the permittee to register its injection and recovery wells. The permit must also contain a condition that requires that the permittee provide a monthly written report to the groundwater district on the amount of water injected for storage and the amount of water recaptured for use.

9.4 Groundwater Conservation Districts

As stated above, there are three groundwater conservation districts within the Study Area. The districts are consistent with the county boundaries of Victoria, Jackson and Calhoun Counties. Some of the rules related to administration, application procedures and requirements, and hearing procedures can be expected to apply to the implementation of ASR wells and well fields. However, none of the district technical rules specifically address ASR or artificial recharge. Therefore, it will be important for the Participants to work with each of the districts to amend and amplify the rules in a manner that achieves the district's objectives while facilitating the implementation of ASR.

The following paragraphs describe the three districts and briefly discuss some of the key rules that might have a bearing on the implementation of ASR within the district. There is generally consistency between the current rules. All of the rules are discussed below from the perspective of a new (non-grandfathered) non-exempt well, well field or well system. Despite the current requirements in the rules, the rules make provision for variances or waivers.

9.4.1 Victoria County Groundwater Conservation District

The Victoria County Groundwater District (the "Victoria GCD") was created by the Texas Legislature in 2005 and subsequently confirmed by the voters in the district. The Management Plan and Rules can be found on the district's website; the website address is: www. vcgcd.org.

The Victoria GCD Management Plan states that the mission of the district is to develop sound water conservation and management strategies to conserve, preserve, protect, and prevent waste of groundwater for the benefit of the county's landowners, citizens, economy, and environment. The mission will be implemented through the acquisition and dissemination of hydrogeological information; development of programs and incentives to conserve and protect groundwater resources; and the adoption and enforcement of fair and appropriate rules.

The latest Victoria GCD's Rules were effective on November 15, 2013. The Rules do include two definitions that make reference to recharge of aquifers within the district, as pasted below:

INJECTION USE means the use of groundwater for the purposes that include:

"4. A recharge well used to replenish the water in an aquifer;." and

"**RECHARGE** means the process of replenishment of groundwater by infiltration of water from sources such as precipitation, streams, rivers, and reservoirs."

The Victoria GCD's Rules discuss in detail the concept of historic use protection for grandfathered wells, well fields and well systems that existed prior to the creation of the district's Rules. It is important to note that the district's Rules state that incorporated municipalities and public water supply entities can consider all of the contiguous land within their corporate limits or certificated service areas (CCNs) to be under their control.

Like most districts, the Victoria GCD requires new wells to be permitted separately for drilling and for production. A transport permit is required for any water that is moved outside the district. However, a transport permit is not required for use within a utility's CCN that straddles the district boundary.

Drilling permits are valid for 180 days. Production permits are valid for up to five years, subject to the renewal provisions. The district requires at least two monitoring wells for well fields and well systems.

The Rules establish spacing requirements related to the distance between the well, wellfield or well system and the nearest well owned by someone other than the permittee. In general the Rules require a minimum spacing of 1 foot per gallon per minute (1.0 ft/gpm) of maximum authorized production capacity.

The Rules establish performance conditions for wells, well fields and well systems related to: drawdown at the property boundary; saltwater intrusion; hydraulic gradient during drought; groundwater/surface water relationships; and TDS water quality at the property boundary.

9.4.2 Texana Groundwater Conservation District

The Texana Groundwater District (the "Texana GCD") was created by the Texas Legislature in 2001 and subsequently confirmed by the voters in the district. The Management Plan and Rules can be found on the district's website; the website address is: www. texanagcd.org.

The Texana GCD Management Plan states that the district will "…manage the supply of groundwater within the District in order to conserve the resource while seeking to maintain the economic viability of all resource user groups, public and private." The Management Plan also sets as a district goal the encouragement of conjunctive development of surface water supplies to meet the needs of water user groups in the district. ASR could be a viable method for implementing conjunctive use without impacting the ability to use native groundwater within Jackson County.

The latest Texana GCD's Rules were effective on February 25, 2011. As with the Victoria GCD rules, historic use is protected, and drilling, production and transport permits are required. Without an extension approved by the board of directors, drilling permits expire in 180 days. An operating or production permit expires in five years, subject to renewal by the district. The

Texana GCD Rules also have a spacing requirement of 1 ft/gpm from the nearest well owned by someone other than the permittee or landowner.

9.4.3 Calhoun County Groundwater District

The Calhoun County Groundwater District (the "Calhoun GCD") was created by the Texas Legislature in 2011. The Calhoun GCD is an active district, but it has not yet been confirmed by the voters. Therefore, there is no management plan or rules. The District's board of directors has begun its process of preparing for a confirmation election in November 2014. The District has adopted a monthly meeting schedule with meetings planned for the last Wednesday of each month. The district's website is www.CalhounCountyGCD.org. The Board is currently comprised of five temporary directors.

The enabling legislation requires that the voters in the county must confirm the district not later than December 31, 2016. When the district is confirmed, the early stage of development provides the Participants an opportunity to get engaged in the creation of the management plan and rules, and to encourage those documents to provide opportunities for ASR development within Calhoun County.

9.5 Institutional Issues

As ARCADIS and ASR Systems identified in their previous research for the TWDB, the most significant challenges to the implementation of ASR in Texas are typically related to institutional and regulatory issues, not technical problems. This preliminary feasibility study has identified several issues that have to be addressed in order for any of the Participants to implement an ASR project in the Study Area, including the injection of water necessary for the test drilling in the next phase. The following paragraphs summarize the major institutional issues and key considerations.

- The TCEQ UIC permit and the TCEQ water rights amendments discussed above are straightforward permitting processes. Processing these permits and amendments takes time and effort, but they are typically not controversial or overly expensive. It is best that the Participants begin these processes as soon as the decision is made to move forward with Phase 2 of an ASR project.
- It is very beneficial that the Victoria GCD is one of the Participants. It is important to begin early and continual coordination with all of the groundwater districts in the Study Area. The coordination process should begin with education for the district board members on ASR, its applications and benefits, and the necessary changes to rules required to implement the next phases. The current rules are directed toward management of the native groundwater in the regulated aquifer(s), not the storage of artificial recharge that will ultimately be recovered when it is needed. The current rules for the Victoria GCD and the Texana GCD have production limits related to maximum well capacity (250 gpm per contiguous acre owned or controlled) and the maximum annual volume that can be pumped (0.5 AFY per contiguous acre owned or controlled). As stated above, the rules also include spacing requirements from adjacent wells. These regulations may be appropriate for management of the native groundwater, but they

are not necessary or appropriate for an ASR project. The operators of the ASR systems proposed in this report will only be recovering the volume of treated drinking water that has previously been stored. The operational objectives are to store the ASR water within reach of the injection/recovery well(s), to establish a permanent buffer zone of treated water that will not be recovered, and to not recover any native groundwater. For maximum efficiency it is typically necessary to space ASR wells as close together as possible so that the storage "bubbles" coalesce. Monitoring wells, meters and water quality sampling will be implemented to provide data to the districts so that these objectives are obtained and documented.

While the issues discussed above are significant, they are not insurmountable. Victoria, GBRA and LNRA operate professional water utilities in the Study Area, and there is no reason that ASR cannot be added as a water management and supply strategy. The treated surface water that would be injected, stored and recovered in an ASR project is typically better quality than the native groundwater in any of the proposed storage formations. The Participants will not recover any more water than they inject, and their primary objective is to only recover the previously-stored drinking water—not native groundwater.

It will be necessary to work with the groundwater districts to amend or expand their respective rules to get segments of an ASR project permitted. The proposed ASR concepts support, rather than contradict, the intent of the various regulations. ASR projects are implemented in phases so that each step builds upon previous success. In this manner, both the ASR operator and the regulatory agencies can be assured that the project is meeting both parties' objectives. Encouraging and facilitating ASR development in the area can help the groundwater districts achieve their goals of conjunctive use. Given the current need to maximize the efficient use of existing water resources, all of the regulatory agencies should be supportive of this effort.

A starting point and foundation for coordination with the groundwater districts can be found in David Pyne's textbook, ***Aquifer Storage Recovery****: A Guide to Groundwater Recharge Through Wells* (2^{nd} Edition, © 2005). Based on Mr. Pyne's long career with successful ASR projects, Sections 6.3 and 6.4 of the book deal with legal and regulatory issues, and a suggested regulatory framework. The following paragraphs summarize some of the key concepts and recommendations:

- As a first step, this Phase 1 feasibility study should be used as part of the basis for educating the groundwater district staffs and board members about the technical aspects and benefits of ASR. TWDB Report 0904830904, *An Assessment of Aquifer Storage Recovery in Texas,* was released in 2011 and is another useful reference, available online.
- ASR operators would need to obtain a drilling permit, an operating permit and, if necessary, a transport permit from the groundwater districts. The nature of those permits should be tailored to an ASR well, rather than a native groundwater production well.
- Texas has ASR-related regulations such as those discussed above. Because the stored water proposed in this report will be treated municipal drinking water, there are also

State and federal regulations related to the quality of the water that will be injected into the aquifer(s). Local groundwater districts do not need to duplicate these requirements.

- Final permitting of an ASR well or wellfield is best deferred until after construction and actual field testing have been performed. ASR performance cannot usually be adequately predicted by modeling, especially regional models like the TWDB GAMs.
- Because ASR is typically developed in progressive phases, regulatory agencies do not need to permit the entire project at one time. The initial steps can relate to well construction and formulation of the ASR testing and monitoring programs, building upon the district's existing requirements. A demonstration process leading to full ASR operations can be part of the second phase.
- The ASR wells should be permitted for both recharge (injection) and recovery. Using the same well facilitates control of the storage "bubble" and allows the well to be periodically backflushed to maintain its capacity.
- ASR systems typically include more monitoring wells and flow meters than are required for a native groundwater production well or wellfield. This monitoring equipment can give additional assurance to the groundwater district that the operator is: not degrading water quality; is not impacting adjacent wells; is only recovering previously-stored drinking water; and is not recovering more water than was injected.
- One of the key issues with ASR in Texas is the operator's right and ability to recover the stored water. The groundwater district should initially permit the operator to recover a significant portion of the cumulative stored water volume, while leaving a buffer zone of treated water in the aquifer to separate the stored drinking water from the native groundwater. A few years may be required to form the Target Storage Volume. During this period water would be stored and only a portion recovered, thereby steadily building the buffer zone. After the buffer zone is established, the district should permit the operator to recover 100 percent of the subsequently injected water so long as native groundwater is not being pumped.
- The Participants should understand that under current Texas law, the districts cannot prevent other permitted or exempt pumpers from capturing the stored ASR water, however there are several ways that the water can be protected. Fortunately, it is reasonably common for the radius of the storage bubble to be immediately around the ASR well, within a few hundred feet. In addition, most storage aquifers are deeper than exempt domestic and livestock wells. Many ASR well fields are storing water in brackish aquifers. Cities can usually protect any water stored within the corporate limits through enactment of ordinances preventing the drilling of private wells in the storage aquifer and within a radius around the wellfield that comprises a Wellfield Protection Area.
- The spacing requirements in the current district rules should not apply to ASR wells because it is usually more efficient to locate ASR wells closer together so the storage bubbles coalesce. Declining native-groundwater levels is typically not a problem because the operator is injecting new water into the aquifer for later recovery. However, the impact of ASR operations on water levels in surrounding areas should be addressed in the permitting process. The permitting should address both the rate of recovery and the potential mounding during injection. This is an issue that can

be adequately evaluated during the testing and demonstration phases by monitoring equipment. Data collected during testing and demonstration can provide a basis for subsequent groundwater modeling, if necessary, to evaluate expected changes in water levels in the surrounding area during recharge and recovery.

- At this time, the Participants do not know exactly what portions of the recommended ASR systems will be implemented, if any. However, if the Participants move forward into Phase 2, it would be prudent to develop reasonably-consistent ASR regulations within the three groundwater districts.
- ASR storage provides natural treatment for DBPs and other constituents due to the residence time in the aquifer and the movement of water through the aquifer. Therefore, compliance with water quality requirements should be measured at monitoring wells within the storage zone, not at the wellhead. This provides the time and distance for natural subsurface treatment processes to occur around the ASR well.
- Because of the diverse objectives of the Participants and the fact that the objectives of ASR operators may change over time, the districts should not place a time limit or a volumetric limit on how the stored water is recovered. For example, one Participant may want to store water over a long period for recovery during the DOR, while another Participant may want to recover the water for peaking or seasonal purposes. To date, 27 different applications of ASR have been identified. Three of these are diurnal storage, seasonal storage, and long-term storage for many years, otherwise known as "water banking."

9.6 Environmental Issues and Permitting

The following paragraphs summarize the major environmental issues and key considerations related to ASR.

- While about one-third of the worldwide ASR storage is located in brackish, saline and poor-quality aquifers, water quality is still an important consideration. The number and condition of the oil and gas brine disposal wells in portions of the Study Area are a concern. Water quality sampling will be an important consideration in the next phase of the project.
- As the Participants know, issues related to TDS, iron and manganese in the Gulf Coast Aquifer can be an important consideration. The study team spent considerable effort evaluating the existing data in an attempt to locate both proposed ASR and proposed production wells in areas to minimize the potential for water quality problems. Again, additional water quality sampling will be an important consideration in the next phase of the project. With proper design of facilities and O&M practices, a viable ASR project can be implemented in the Study Area.

Because ASR wells and well fields have small footprints and limited environmental impacts, the major permitting issues related to an ASR project typically involve the construction of pipelines to and from the wellfield. The following paragraphs summarize the environmental permitting requirements that could apply to such pipelines within the Study Area. Some of these permit issues can be avoided by tunneling under Waters of the United States, rather than open cutting the crossing.

- U.S. Army Corps of Engineers (USACE), Clean Water Act (CWA) Section 404 –USACE regulates the placement of dredge or fill material into waters of the U.S. Nationwide Permit (NWP) 12 Utility Line:
  - Utility Pipelines: Activities required for the construction, maintenance, repair, and removal of utility lines and associated facilities in Waters of the United States, provided the activity does not result in the loss of greater than 0.5 acre of Waters of the United States for each single and complete project.
  - This NWP authorizes the construction, maintenance, or repair of utility lines, including outfall and intake structures, and the associated excavation, backfill, or bedding for the utility lines, in all Waters of the United States, provided there is no change in pre- construction contours. A “utility line” is defined as any pipe or pipeline for the transportation of any gaseous, liquid, liquescent, or slurry substance, for any purpose, and any cable, line, or wire for the transmission for any purpose of electrical energy, telephone, and telegraph messages, and radio and television communication.
- USACE Section 10 Permit – USACE may require, in conjunction with the Section 404 permit, a Section 10 permit for impacts to navigable waters. A navigability determination must be determined by USACE and a Section 10 permit can be incorporated with the Section 404 (at the USACE discretion).
- U.S. Fish and Wildlife Service (USFWS), Threatened and Endangered Species Act – USFWS must ensure that the project is not likely to jeopardize the continued existence of any endangered or threatened species or result in destruction or adverse modification to critical habitat of endangered or threatened species.
- Texas Parks and Wildlife Department (TPWD) Sensitive Species Permit –TPWD must ensure that the project is not likely to jeopardize the continued existence of any endangered or threatened species or result in destruction or adverse modification to critical habitat of endangered or threatened species.
- Section 106 of the National Historic Preservation Act (NHPA) – The Texas Historical Commission evaluates the effects of the project on historical/cultural resources.
- TCEQ Permits:
  - General Stormwater Pollution Prevention Plan Permit (TXR050000): TCEQ requires a Notice of Intent and Stormwater Pollution Prevention Plan (SWPPP) be submitted for any construction impacts greater than 5 acres.
  - Texas 401 Water Quality Certification: Only required under an individual USACE permit; not required for a NWP.
- USACE CWA 408 Flood Control Structures Permit – USACE Section 408 permit is required for all projects that may affect the integrity of flood control structures. Section 408 permits require an independent Safety Assurance Review.
- Federal Emergency Management Agency (FEMA) Flood Control Act Floodplain Notification – FEMA requires a notification (usually on a county level) for any

excavation, construction, or alteration of a floodplain that may impact walls, levees, improved channels or floodways.

- Coastal Zone Management Act (CZMA) Certification – Coastal zone consistency certification is required for any project within the Coastal Zone, which would include the Study Area.
- TPWD Sand and Gravel Permit – TPWD permit is required to "disturb or take" streambed materials from a streambed claimed by the state (including open cut construction).
- TPWD Aquatic Resources Permit – TPWD requires a written Aquatic Resource Relocation Plan and Aquatic Resource Permit to control and limit the impacts to aquatic resources and invasive/exotic species related to dewatering or in-stream activities (including open cut construction).

10.0 Conclusions and Recommendations

10.1 Conclusions

10.1.1 Hydrogeology

For this feasibility level study, the hydrogeological conditions near the City of Victoria are known to a moderately high level of confidence as a result of the City's installation, testing, and operation of fifteen high-capacity municipal wells and Victoria County GCD's well registration and well monitoring programs. These hydrogeological conditions are well suited for ASR facilities. Historical pumping from the municipal wells indicates that wells screened approximately 400 feet across the Upper Goliad formation will provide approximately 16 gpm per foot of drawdown. The relatively high well productivity rate originates from an aquifer interval with TDS concentrations below 1,000 mg/L and with prevalent 40-foot sand beds. Among the favorable ASR sites are several near the Victoria WTP. Near the treatment plant, there is no evidence that the recharge, storage, and recovery of stored water would be hindered by potential sources of contamination or pumping from existing wells.

The hydrological conditions near Port Lavaca are known to a moderate level of confidence. Within the vicinity of the Port Lavaca WTP there are locations where surface contamination sources from nearby aquiculture operations and/or shallow pumping could potentially cause problems with efficient ASR operations. As a result, the proposed ASR facilities are located close to the water treatment plant, but away from the areas of shallow groundwater pumping and possible contamination. The targeted zone for the ASR wells is between -400 ft msl and -1,100 ft msl. Among the uncertainties in this area are the hydraulic conductivity of the sand beds and the TDS concentrations below elevations of -600 ft msl. The hydraulic conductivity of sand beds in the upper and lower portions of this zone is estimated at 12 ft/day and 5 ft/day, respectively. The TDS concentrations for the 700-ft interval is estimated to range between 1,500 mg/L and 5,000 mg/L.

The availability of hydrological data in Jackson County varies but there are several areas where the conditions are known with moderately high level of confidence. One of these areas is in the vicinity of Carancahua Bay. Among the positive features of this potential site are a low potential for the migration of stored water and a relatively well-characterized lithology and stratigraphy. The targeted zone for the potential development of ASR in Carancahua Bay area is between -300 ft msl and -1,050 ft msl. The hydraulic conductivity of sand beds in the upper and lower portions of this zone is estimated near 18 ft/day and near 5 ft/day, respectively. The TDS concentrations for the 750-ft interval is estimated to range between 1,500 mg/L and 5,000 mg/L.

10.1.2 ASR Development for City of Victoria

Five options were evaluated for ASR development in the vicinity of the city of Victoria. Option A was the baseline option against which the other options were compared. The assumptions implicit in Option A are conservative. Other options evaluate various different assumptions such as starting with zero initial ASR storage volume; water treatment plant expansion; projecting water demands based upon a year with average demand; and meeting the City's primary ASR objective, seasonal water storage, but not meeting all demands during a repeat of the DOR.

Table 7-1 shows a summary of the results from the ASR Model for each of the options. The following are the major conclusions:

- Victoria's ASR objectives can be met utilizing the existing water treatment plant rated capacity of 25.2 MGD, recognizing that some chemical feed and perhaps other improvements would be needed to facilitate sustained operation at this production rate.
- At the rated capacity of the Victoria WTP, the time required to achieve the Initial Storage Volume ranges from 11 years for Option A to less than one year for Option E.
- The volume that needs to be recovered during a repeat of the DOR ranges from 4,600 AF to 82,900 AF, depending upon the set of assumptions underlying each of the options. The upper end of this range reflects the junior priority dates and special conditions in the largest of Victoria's water rights, and 2040 water demand projections based upon the distribution of daily demands experienced in 2011. The lower end of the range is based upon 2040 water demand projections based upon the distribution of daily demands experienced in 2008. Increasing the water treatment plant capacity further reduces the storage volume requirements and therefore the time required to store sufficient water prior to, or immediately following a repeat of the DOR.
- The ASR TSV that needs to be achieved in order to meet seasonal storage objectives is 53,900 AF (Option C), however this would be inadequate for a repeat of the DOR. The total storage volume required to meet demands during a repeat of the DOR ranges from 9,300 to 168,100 AF. Of this amount, 2,000 AF is assumed to be available from the OCS.
- The ASR wellfield design capacity for all options is controlled by the required recharge capacity, which ranges between 18.3 and 26.0 MGD.
- The City's five goals for an ASR program can be achieved.

- An ASR system for the City can provide benefits for the Port of Victoria by firming up the City's water supply, thereby offering opportunities for the Port to get reliable potable water from the City and/or the ability to use a portion of the City's consumptive water right.

10.1.3 ASR Development for GBRA Port Lavaca

Various options were evaluated for ASR development in Calhoun County, primarily in the vicinity of the GBRA Port Lavaca WTP. Option A is the baseline option against which the other options may be compared. Other options evaluate various different assumptions regarding initial storage volume; water treatment plant expansion; projecting water demands based upon a year with average demand; and meeting three of the four GBRA ASR objectives. As was discussed above in Section 7.2.1, the assessment of options related to a repeat of the DOR utilize only GBRA's most junior water right. In reality, GBRA can provide raw water to the Port Lavaca WTP during a repeat of the DOR using its more senior certificates of adjudication. Therefore, the discussion below provides an analysis that is extremely conservative.

Subject to additional data collection and testing, an ASR wellfield is viable at the Port Lavaca WTP. An ASR wellfield is also viable in the Study Area west-northwest of Port Lavaca and between the Port Lavaca WTP and Bloomington. Such wellfields should be able to meet the projected 2040 water demands assumed in this feasibility study with 100 percent reliability and at relatively low cost compared to other water supply alternatives. Starting an ASR program at the Port Lavaca WTP is justified because this concept eliminates the right-of-way, pipeline and pumping costs associated with a remote location. However, more distant ASR wellfields with less challenging hydrogeologic conditions may be very viable if future growth in water demand occurs between Port Lavaca and Victoria.

Table 7-2 shows a summary of the results from the ASR Model for each of the options. A summary of the conclusions is listed below:

- GBRA's ASR objectives can be met utilizing the existing water treatment plant rated capacity of 6.1 MGD, recognizing that some improvements would be needed to facilitate sustained operation at this production rate.
- The number of years required to achieve these objectives with 100 percent reliability varies according to a range of assumptions underlying the ASR Model analysis. The Initial Storage Volume required in order to achieve 100 perceent reliability during the study period can be achieved in a reasonable time ranging from less than one year to about four years.
- ASR objectives cannot reasonably be met with 100 percent reliability utilizing the current sustained operating capacity of the Port Lavaca WTP of 4.8 MGD. An Initial Storage Volume of about 23,300 AF would be needed. This would require 8 years to achieve.
- The volume that needs to be recovered during a repeat of the DOR ranges from 9,300 to 14,500 AF, depending upon the set of assumptions underlying each of the options. The

upper end of this range is associated with 2040 water demand projections based upon the distribution of daily demands experienced in 2011. The lower end of the range is based upon 2040 water demand projections based upon the distribution of daily demands experienced in 2008. Increasing the Port Lavaca WTP capacity reduces the storage volume requirements and therefore the time required to store sufficient water prior to, or immediately following a DOR.

- The ASR TSV required to meet demands during a repeat of the DOR ranges from 18,500 AF to 29,100 AF.
- The ASR wellfield design capacity for all options is controlled by the required **recharge** capacity, which ranges from 4.7 MGD to 6.1 MGD. The upper end of this range is associated with the 7.25 MGD expanded water treatment plant capacity while the lower end of the range is associated with the existing 6.1 MGD rated capacity of the Port Lavaca WTP.
- Maximum duration of recharge periods ranges from 225 to 308 days. The maximum duration of recovery periods ranges from 251 to 272 days. Even during the DOR there are significant opportunities for replenishing storage volume.
- Further investigation of groundwater production at the nearby aquaculture operation is needed.
- GBRA's four goals for an ASR program in Calhoun County can be achieved.

10.2 Recommendations

10.2.1 General Recommendations

Because of the regulatory issues discussed in Section 9, the first step toward implementation of an ASR system for the Victoria Area should be early and continual coordination with the applicable groundwater districts in Victoria, Jackson and Calhoun Counties. Rules will need to be written and/or amended in order to get the required permits to drill the initial test wells and to implement an ASR project.

Eventually, the surface water rights owned by Victoria and GBRA must be amended to authorize use of the water for injection and recovery. A temporary authorization for the Phase 2 testing programs may not be necessary. 30 TAC §295.21(b) states that a water right permit is not required for the first phase of an ASR project that proposes temporary storage of appropriated surface water in an aquifer for testing, subsequent retrieval and beneficial use if the diversion and purpose is covered by an existing water right. A clarifying discussion with TCEQ should be one of the first steps in Phase 2 of any ASR project in the Victoria Area.

10.2.2 City of Victoria

If a decision is made to proceed with further investigation of ASR viability, the City should implement an ASR test program at two sites: the Victoria WTP; and at WTP#3. The test program would include construction, testing and operation of one new full-size ASR well at the

WTP and one retrofit of an existing production well at or near WTP#3. The first phase of ASR wellfield construction would represent approximately 10 percent of the planned ultimate scale of development. The test program would also include two monitor wells, supplementing monitoring at other existing production wells in the area surrounding each location. Continuous wireline cores would first be obtained to a depth of 1,100 feet, providing good understanding of the depths and thicknesses of sand and clay layers beneath the site, and their associated geochemical and geotechnical properties. The number and location of ASR wells and monitor wells may be adjusted based upon results of an initial core hole at the Victoria WTP site. Operating experience gained with the first two ASR wells would provide a basis for subsequent design of wellfield expansion facilities, achieving ASR goals for the City of Victoria.

The City should continue coordinating with the Port of Victoria so that potential opportunities for joint use of the City's water supply can be explored.

10.2.3 GBRA

If a decision is made to proceed with further investigation of ASR viability, GBRA should implement an ASR test program at the Port Lavaca WTP. Continuous wireline cores would first be obtained at each property corner to a depth of 1,100 feet, providing good understanding of the depths and thicknesses of sand and clay layers beneath the site, and their associated geochemical and geotechnical properties. The number and location of ASR wells and monitor wells may be adjusted based upon results of initial core holes.

Following confirmation with the corings, the test program would include construction and testing of approximately three full-size ASR wells that would be placed into operation, one each for sand intervals between 300 and 500 feet, 400 and 700 feet, and 600 to 1,100 feet. The first phase of ASR wellfield construction would represent 10 percent of the planned ultimate scale of development. A possible general location may be at or near three of the four property corners. The test program would also include approximately five monitor wells, as needed to provide a basis for design of expanded ASR wellfield facilities at this site. Three of these monitor wells would be close to the three adjacent ASR wells. One more would be at the remaining property corner and one near the center of the property. Operating experience gained at this site with the first three ASR wells would provide a basis for subsequent design of wellfield expansion facilities at this site or other locations, achieving ASR goals for the Port Lavaca area.

ARCADIS

Attachment A

Summary of ASR Workshop

Summary of ASR Workshop for Victoria Regional Plan for ASR and/or Off Channel Storage

September 12, 2013

Table of Contents

List of Figures

BACKGROUND

With partial funding from the Texas Water Development Board (TWDB), the city of Victoria, two river authorities, the Port of Victoria and the Victoria County Groundwater Conservation District (the "Participants") have joined together to evaluate the potential costs, benefits, and institutional issues related to using Aquifer Storage and Recovery (ASR) and/or off-channel storage (OCS) as strategies for improving the reliability of water supplies in the Victoria, Texas area. The proposed project would evaluate the potential of using ASR and OCS projects in addition to the participants' existing supplies to improve system reliability, and maximize the efficient use of existing surface water rights.

The Participants engaged the Naismith Engineering, Inc. (NEI) Team to conduct this first-phase feasibility evaluation. The study team includes Malcolm Pirnie, the Water Division of ARCADIS-US; ASR Systems, LLC; and INTERA, Inc. The study team will conduct a feasibility study to evaluate the practical ASR and OCS applications that might be beneficial to the Participants in their service areas with a focus on developing projects close to the end users and/or treatment facilities. This study will consist of assessing the feasibility of ASR by identifying both technical and non-technical issues and potential ASR projects within the study area. Given the high cost of permitting, acquiring and constructing above ground reservoirs, the assessment of OCS will use existing studies and information, and it will focus on existing opportunities, such as abandoned gravel pits. The resulting evaluation report will include sufficient information to support any needed regulatory authorizations to develop a demonstration project in Phases 2 and 3.

The Participants include:

- City of Victoria (CofV or the "City")
- Port of Victoria (PofV or the "Port")
- Victoria County Groundwater Conservation District (VCGCD)
- Lavaca-Navidad River Authority (LNRA)
- Guadalupe-Blanco River Authority (GBRA)

The Study Area consists of Victoria, Jackson and Calhoun Counties, Texas.

The purposes of this Summary are to describe the data collection effort to date, and to summarize the findings and conclusions of an ASR Workshop and tour conducted in Victoria, Texas on September 12, 2013, and a tour of the Port Lavaca Water Treatment Plant conducted on September 30, 2013. This Summary is a component of Milestone Report No. 1 for the TWDB.

WORKSHOP OBJECTIVES

The project scope of work included an ASR Workshop and site visit with the Participants. The purposes of the workshop are to: (i) review the fundamental aspects of ASR and its various applications; (ii) gather and discuss any outstanding data, reports and existing plans on Participant water systems, facilities and programs; (iii) evaluate potential ways in which ASR might become a part of the Participants' water management strategies; (iv) confirm potential sources of water supply and storage locations gathered in other tasks; (v) discuss potential permitting, environmental and socio-economic issues that might enter into an ASR project; and (vi) confirm the Participants' budget, rate and financial information needed for the study. In the Workshop, the discussion included whether any of the Participants' existing wells have the potential to be converted to an ASR well for testing, or for recharge and production.

The primary desired outcome of an ASR workshop is a prioritized list of the most important ASR applications for each Participant. This information forms the basis for the development of the ASR model(s) used to prepare a conceptual basis of design for any proposed ASR systems.

The Workshop also included a site visit and tour of the City of Victoria's surface water treatment plant (WTP) and one of the City's operational groundwater wells.

Workshop And Tour Participants

Participant Representatives:
Jerry James (CofV)
Lynn Short (CofV)
Jimmy Roach (CofV)
Donald Reese (CofV)
Gary Middleton (South Central Texas Water Advisory Committee/CofV)
Patrick Brzozowski (LNRA)
Doug Anders (LNRA)
Tim Andruss (VCGCD)
Tommy Hill (GBRA)
Charlie Hickman (GBRA)
Herb Wittliff (GBRA)
Stephanie Shelly (GBRA)
Billy Settles (PofV)
David Meesey (TWDB)
Mark Null (USGS)
John Bumgarner (USGS)

Naismith Engineering Team:
James Dodson (NEI)
David Fusilier (NEI)
Fred Blumberg (Malcolm Pirnie/ARCADIS-US)
David Pyne (ASR Systems)
Steve Young (INTERA)

Victoria Tour Participants:
Jerry James
Lynn Short
Jimmy Roach
Herb Wittliff

Stephanie Shelly
Fred Blumberg
David Pyne
David Fusilier

Port Lavaca WTP Tour Participants:
Fred Blumberg
Herb Wittliff
Stephanie Shelly
Don Koble (GBRA)

The sign-in sheet from the Workshop is attached as **Appendix A**.

WORKSHOP SUMMARY

Introduction and Background

After introductory remarks by James Dodson; David Pyne, Steve Young and Fred Blumberg presented: a summary of ASR concepts and applications, with emphasis on those that might be most applicable to the Participants; the hydrogeologic data collection and analysis of the Gulf Coast Aquifer to date, using the Victoria area as an example; the water availability modeling conducted to date, including the water rights used for the simulations; the future water demands and demand centers being used for Victoria and GBRA; and the remaining work related to the ASR portion of the project.

A copy of the presentation is shown in **Appendix B**.

ASR Applications for Participants

The group next discussed potential ASR applications that might be beneficial for the Participants, with emphasis on the priorities of the City of Victoria and GBRA where the sources of supply and primary potential storage locations are located. Subsequently LNRA provided input on the applications most applicable to Jackson County where the study will focus on addressing the fundamental question of whether the aquifer formations in the County are conducive for ASR storage.

The prioritized list of ASR applications for Victoria included:

1. Seasonal storage to meet peak demands
2. Long-term storage to increase reliability during a drought
3. Deferring expansion of the City's WTP or construction of a second WTP
4. Emergency storage for use during severe flooding or other events
5. Reduction in disinfection by-product (DBP) concentrations

The prioritized list of ASR applications for GBRA included:

1. Seasonal storage to meet peak demands which would serve to delay expansion of the Port Lavaca WTP
2. Emergency storage for use during hurricanes and other events (with the requirement to design ASR facilities in such a way that they could be inundated)
3. Long-term storage
4. Reduction in disinfection by-product (DBP) concentrations

The prioritized list of ASR applications for LNRA/Jackson County included:

1. Long-term storage to serve as a drought management tool
2. Seasonal storage to supplement existing supplies
3. Emergency storage for use during events that could interrupt deliveries through LNRA's pipeline systems.

Billy Settles, representing the Port of Victoria, stated that his client's primary need is for raw water for industrial purposes such as cooling and process. The Port does not have existing treatment facilities, although treatment is required prior to ASR storage. The Port has a need for both consumptive and non-consumptive water. The water right owned by the Port is for 5,000 acre-feet per year (ac-ft/yr), but it is 100% non-consumptive. The consumptive portion of the permit (4,676 ac-ft/yr) was sold to the City of Victoria. Jerry James stated that the City is amending the permit to add a diversion point at the City's WTP intake, but the current diversion point at the Port is being retained. Therefore, the consumptive portion of the water right could be used by the Port under some agreement with the City.

General Discussion

The remaining discussion focused on hydrogeology, potential storage locations and the availability of groundwater data. Steve Young stated that the primary formations being considered for storage are the Lissie, Willis and Upper Goliad geologic units. The Lissie and Willis formations are in the Chicot Aquifer, and the Upper Goliad formation is in the Evangeline Aquifer. While reviewing information on total dissolved solids (TDS), there appeared to Tim Andruss that there were some errors in the data. Steve and Tim will discuss the differences and resolve the issue.

The lack of pump test data is always an issue in ASR evaluations. Steve discussed some of the problems with obtaining reliable information on driller's logs and pump tests. Some of these data are available from TCEQ for public water supply wells. GBRA agreed to try to get logs and pump test data from the city of Port Lavaca on the abandoned wells in the area.

Except for grandfathered conditions, private groundwater wells cannot be drilled by residents within the City of Victoria or the City of Port Lavaca.

Potential Locations for ASR Wells

The group next discussed potential locations for ASR wells. These could include:

- The area within the city limits/service area of the City of Victoria, particularly the following locations:
    - Victoria WTP
    - Water Plant No. 3
    - North part of distribution system
    - East part of the distribution system toward the Victoria County Airport, including the airport property
- The Port Lavaca WTP property (or the closest viable storage location between the PLWTP and Bloomington)
- The southeastern portion of Jackson County (east and southeast of Lake Texana toward LNRA's industrial and municipal customers near Point Comfort)

TOUR OF VICTORIA WTP AND WELL SITE

After the Workshop a group toured the Victoria WTP, and one of the Victoria groundwater wells (Well Station 21). The following paragraphs discuss the information gathered during the site visit.

Victoria WTP

The Victoria WTP is a conventional surface water treatment plant with a rated capacity of 25.2 million gallons per day (mgd) located on a site of approximately 60 acres. The plant site is on the east side of the Guadalupe River. (See **Figure 1**.) The treatment capacity that can be sustained on a reliable basis without system improvements is approximately 21 mgd. The rated capacity of 25.2 mgd could be achieved on a sustained basis with the addition of chemical feed system improvements. The minimum flow that can be treated is approximately 6.0 mgd. The system demand in the winter months is approximately 8 mgd.

Figure 1: Victoria WTP

Raw water is diverted on the west bank of the Guadalupe River and routed through a series of 10 ponds (former gravel pits) prior to being pumped across the river to the WTP. The ponds are located on approximately 630 acres of land, and the ponds have an estimated capacity of approximately 4,000 acre-feet.

Raw water enters the WTP at a headworks structure where groundwater from two City wells is sometimes blended to reduce turbidity. The conventional treatment process includes rapid mix, sedimentation and filtration, with the following chemicals being added at points in the process: chlorine dioxide; powdered-activated carbon, chlorine and ammonia, and polychloride. Chlorine and ammonia are added to form chloramines after the sedimentation process, and prior to filtration (6 filters). (See **Figure 2**.) Treated water is stored in two 2.5 million gallon (MG) ground storage tanks at the WTP. Fluoride, caustic (for pH adjustment), and polyphosphate are added prior to pumping from the high service pump station (HSPS). The chloramine disinfection level leaving the WTP is approximately 3.0 milligrams per liter (mg/L). The total organic carbon (TOC) level in the treated water is approximately 0.5 to 1.0 mg/L.

Figure 2: Victoria WTP Filters

The HSPS delivers water into two pressure plains. Treated water is delivered to a 5.5 MG ground storage tank which feeds into the low pressure plain. The City has experienced pressure problems at the edges of the low pressure system. Treated water is delivered into two elevated storage tanks that feed the high pressure system. The City maintains 40 to 55 pounds of pressure in both plains.

Water Plant No. 3 (WP 3) is one of the likely places for ASR storage. WP 3 is located on a 10-acre tract of land in the low pressure plain. Eight wells feed into WP 3, and there are 2 wells on the property. Rechlorination can occur at WP 3.

Victoria Groundwater Wells

The City of Victoria has 10 operational wells in the Chico and Evangeline Aquifers, and 5 wells that have been plugged. Two wells which were constructed in the 1950's (one on Young Street and one on Red River Street) pump directly into the headworks of the WTP. Eight (8) wells are capable of pumping into ground storage at WP 3.

The individual wells are capable of producing approximately 2 mgd each, and the City considers the total aggregate well capacity to be approximately 16 mgd.

During the site visit, the group visited Well Station No. 21, which is one of the wells that pumps to the WTP. Well Station 21 is representative of the other City wells. Photographs of Well Station 21 are shown below as **Figures 3 and 4**.

Figure 3: Victoria Well Station 21

Figure 4: Well Pump at Station 21

TOUR OF PORT LAVACA WTP

A meeting with the GBRA management and a tour of GBRA's Port Lavaca WTP was conducted on September 30, 2013. The Port Lavaca WTP is a conventional surface water treatment plant with a rated capacity of 6.08 mgd located on a site of approximately 86 acres. The plant site is on the west side of Lavaca Bay, south of the city of Port Lavaca. Due to the proximity to the bay, the majority of the plant infrastructure is located on an elevated site, designed above the record hurricane tide surge level. The structures are located at elevation 22.0 feet mean sea level (msl) while natural ground in the area is at 13 feet msl. The relationship between natural ground and the elevated plant site is shown in **Figure 5** below.

Figure 5: Port Lavaca WTP Entrance

The treatment capacity that can be sustained on a reliable basis without system improvements is approximately 4.8 mgd. The rated capacity of 6.08 mgd could be achieved on a sustained basis with the addition of raw water pumping capacity and other system improvements. Based on studies conducted for GBRA, the next logical expansion would bring the capacity to approximately 7.25 mgd. The minimum flow that can be treated is approximately 1.2 mgd.

Peak day demand of 3.6 MG occurred in 2011. The average daily demand in 2011 was 2.2 mgd. The system demand in the winter months is approximately 2 mgd.

Raw water is diverted at GBRA's Saltwater Barrier on the Guadalupe River and routed through a diversion and canal system, a segment of which serves the Port Lavaca WTP. There is a terminal storage reservoir at the WTP with a capacity of approximately 44 MG. The raw water pumps have a total capacity of 9.0 mgd and a capacity of 6.08 mgd with the largest pump out of service.

Raw water enters the WTP at the rapid mix structure where an alum/polymer blend is added at a rate of approximately 100 parts per million (ppm). The conventional treatment process includes rapid mix, flocculation/sedimentation and filtration (5 filters). Filtered water is pumped from a transfer well to one 1 MG concrete ground storage tank (GST). There is also an abandoned steel 1-MG GST on the plant site; that GST is scheduled for demolition. **Figures 6 and 7** show the settling basins, filters and transfer pumps.

Figure 6: PLWTP Settling Basins

Figure 7: PLWTP Filters and Transfer Pumps

In addition to the alum/polymer coagulant, the following chemicals are added during the treatment process: free chlorine and fluoride are added at the end of the settling basin; and liquid ammonium sulfate (LAS) is added at the transfer well. The chloramine disinfection level leaving the WTP is approximately 3.2 mg/L. The total organic carbon (TOC) level in the treated water has been less than 4 mg/L during the recent drought, however it can get as high as 6.5 mg/L.

The HSPS has a total capacity of 9.0 mgd developed from: two 3-mgd pumps; one 2-mgd pump; and one 1-mgd pump. There is a space allotted for the addition of one more HSP in the station. (See **Figure 8**.) The HSPS delivers water into three pressure plains for following three wholesale customers: city of Port Lavaca; Calhoun County Rural Water System (CCRWS); and Port O'Connor Municipal Utility District (POC MUD). The CCRWS experiences pressure problems in the northern part of its system, and GBRA cannot add new connections in areas north of the city at this time. The POC MUD experiences pressure problems during peak use periods in the summer. The HSPS maintains an average of 50 pounds of pressure in all systems.

Figure 8: PLWTP HSPS Showing Spare

During the meeting and tour, the group discussed likely locations for ASR storage. There is more than ample land for an ASR wellfield on parts of the site that are not elevated above the tidal surge elevation. Within the elevated portion of the plant, the most viable option is where the abandoned GST is currently located. As might be expected, the old GST is located adjacent to the HSPS and transmission pipelines leading to the three wholesale customers. **Figure 9** shows the relationship between the HSPS and the two GSTs. Within the CCRWS distribution system, there are several beneficial locations to the west and northwest of Port Lavaca.

Figure 9: PL HSPS and GSTs

The group also discussed a recent development that could impact the location of ASR storage and will have to be investigated. Up to five groundwater wells have recently been drilled adjacent to the north side of the Port Lavaca WTP (the side closest to the HSPS and GSTs). These wells are being used to provide "fresh" water to maintain proper salinity levels for a redfish-growing operation. The main source of supply is brackish water diverted from Lavaca Bay under a TCEQ permit. However, when the bay water is too salty, the wells are pumped to reduce the salinity in the redfish ponds.

ACTION ITEMS FROM WORKSHOP

1	Follow up with the Victoria County Groundwater District on TDS information. (Completed)	Steve Young
2	Confirm that INTERA has well logs and pump tests from City of Victoria (Completed)	Steve Young
3	Try to get well logs and pump tests from City of Port Lavaca (Completed)	GBRA
4	Provide NEI team with GIS map showing Victoria main distribution system pipelines and stations, indicating preferred sites for ASR storage (Completed)	Victoria
5	Provide NEI team with GIS map showing Victoria wells, both operational and capped (Completed)	Victoria
6	Meet with Port of Victoria to discuss project objectives (Completed)	Jerry James and James Dodson

Appendix A

Workshop Sign-in Sheet

Naismith Engineering, Inc

JOB NO.

SHEET NO.

DESCRIPTION Regional ASR Planning Study Workshop

DATE 9-12-13

BY

Name	Affiliation	E-mail
JERRY JAMES	COV	jjames@victoriatx.org
Doug Anders	LNRA	danders@lnra.org
James Dodson	NEI	
DAVID MEESEY	TWDB	david.meesey@twdb.texas.gov
Patrick Brzozowski	lnra	pbrzozowski@lnra.org
DAVID FUSILIER	NEI	dfusilier@naismith-engineering.com
Donald Reese	COV	dreese@victoriatx.org
Lynn Short	COV	lshort@victoriatx.org
Jimmy Roach	COV	jroach@victoriatx.org
MARK NULL	USGS	jmnull@usgs.gov
Billy Settles	POV	bsettles@civilcorp.us
John Bumgarner	USGS	jbumgarner@usgs.gov
DAVID PYNE	ASR SYSTEMS	dpyne@asrsystems.ws
STEVEN Young	INTERA	syoung@intera.com
FRED BLUMBERG	ARCADIS	fred.blumberg@arcadis-us.com
Thomas D Hill	GBRA	thill@gbra.org
TIM ANDRUSS	VCGCD	tim.andruss@vcgcd.org
Charlie Hickman	GBRA	chickman@gbra.org
Stephanie Shelly	GBRA	sshelly@gbra.org
GARY MIDDLETON	SCTWAC	gary.middleton@suddenlink.net
Herb Wittliff	"	hwittliff@gbra.org

Appendix B

Workshop Presentation

ASR Workshop

Victoria Regional Plan for ASR and Off Channel Storage

Naismith Engineering Team

Malcolm Pirnie/ARCADIS-US, Inc.

ASR Systems, LLC

INTERA, Inc.

September 12, 2013

INTERA Geosciences & Engineering

ASR SYSTEMS

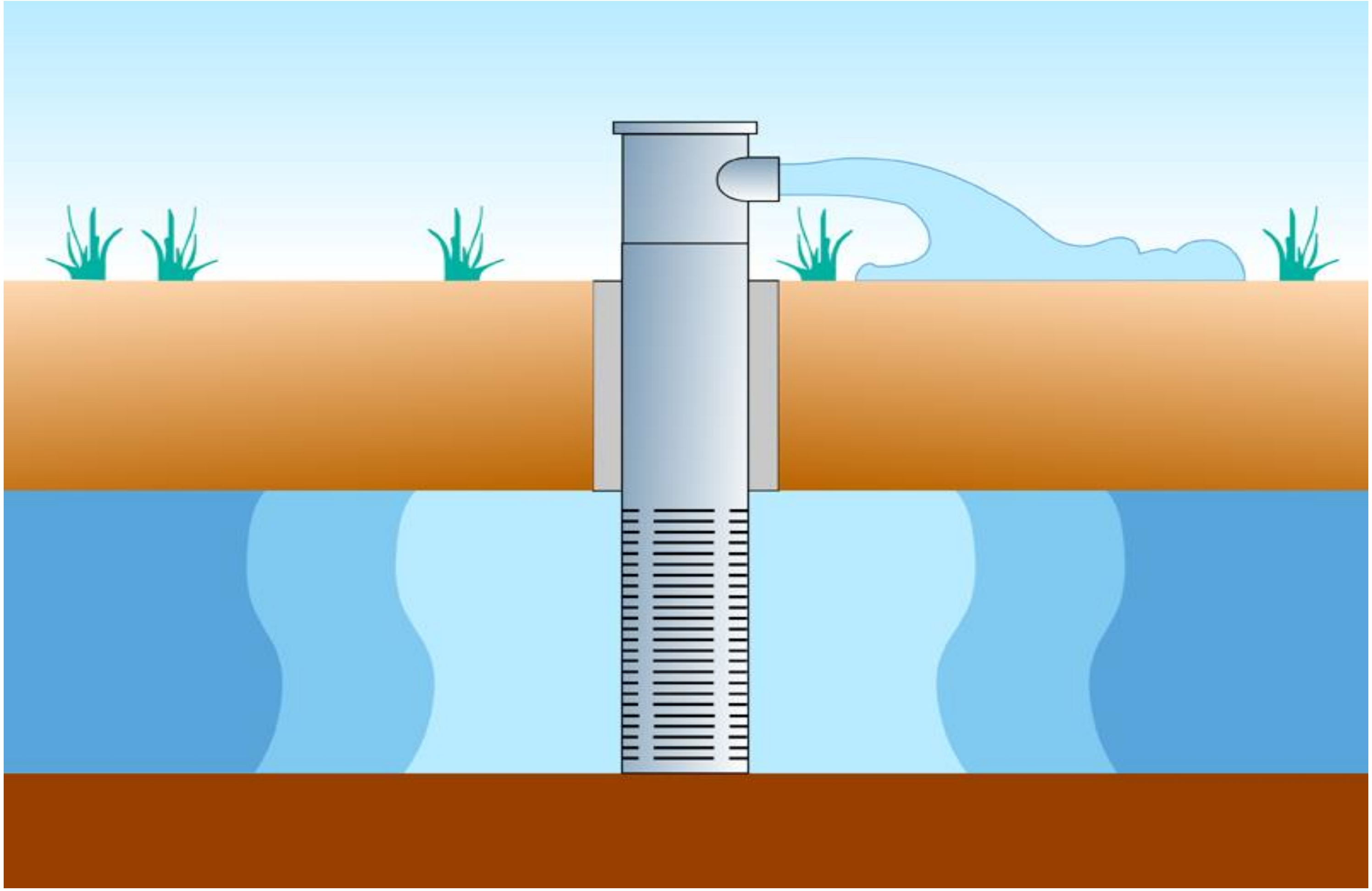
MALCOLM PIRNIE

ARCADIS

Workshop Agenda

- Introductions
- ASR concepts and applications
- Prioritization of applications for this Project
- Hydrogeologic data collection to date
- Confirmation of storage locations for this Project
- Sources of supply and water availability
- Future water demand and demand centers
- Remaining work
- USGS Presentation

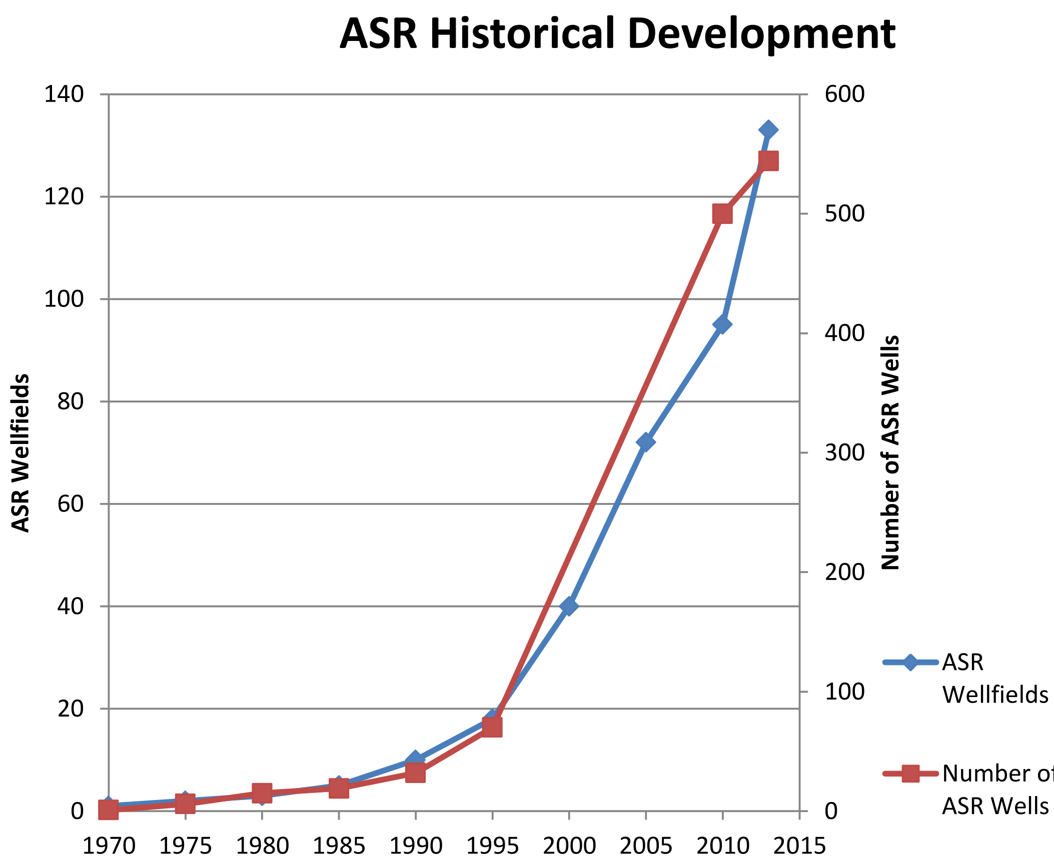
Aquifer Storage Recovery



Storage of water through a well in a suitable aquifer during times when the water is available, and recovery of the stored water from the same well when needed

ASR Development in the U.S.

- Currently (2013) at least 544 ASR wells in at least 133 ASR wellfields in about 22 states*
- Many other countries as well
- 27 different types of ASR applications
- Many different types of water sources for aquifer recharge
- Storage in many different types of aquifers and lithologic settings



***2013 inventory update by Dr Frederick Bloetscher, Florida Atlantic University**

Factors Contributing to Global ASR Implementation

- Economics
  - Typically less than half the capital cost of alternative water supply sources
  - Phased implementation
  - Marginal cost pricing
- Proven Success
  - About 133 wellfields in 22 states with over 544 operating, fully permitted ASR wells
- Environmental and Water Quality Benefits
  - Maintain minimum flows
  - Small storage footprint compared to surface reservoirs
- Adaptability to Different Situations
  - Fresh, brackish or saline storage aquifers
  - Drinking water, reclaimed water, stormwater or groundwater storage
  - Over 27 different applications

Mt Pleasant, SC – Well ASR-2

Broad Range: Water Sources and Storage Zones

Kerrville ASR Well

- Water sources for ASR storage
  - Drinking water
  - Reclaimed water (AZ, TX, FL, NJ, CA)
  - Seasonally-available stormwater
  - Groundwater from overlying, underlying or nearby aquifers
- Storage zones
  - Fresh, brackish and saline aquifers
  - Confined, semi-confined and unconfined aquifers
  - Sand, clayey sand, gravel, sandstone, limestone, dolomite, basalt, conglomerates, glacial deposits
  - Vertical “stacking” of storage zones

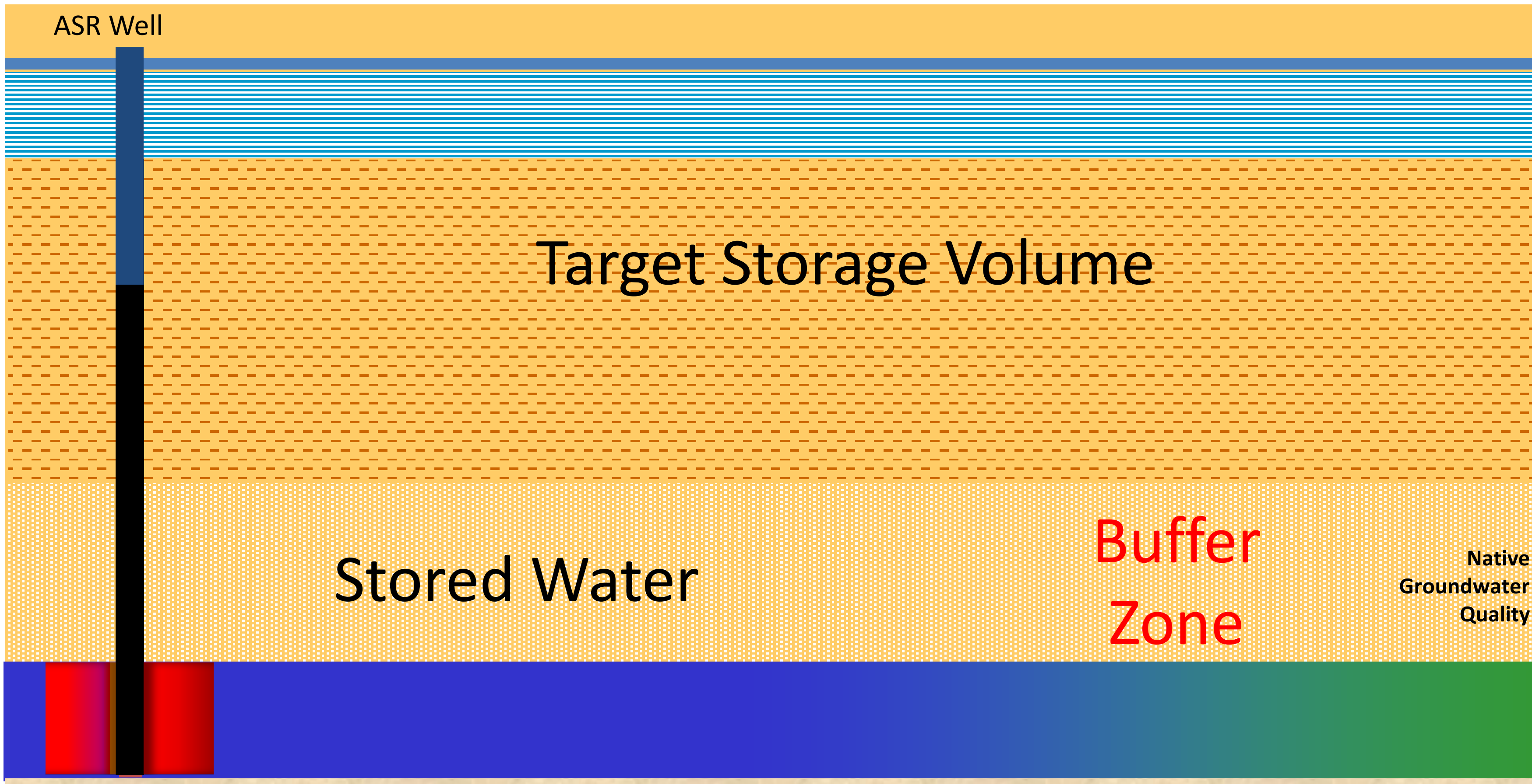
ASR Operating Ranges

- Well depths
  - 30 to 2,700 feet
- Storage interval thickness
  - 20 to 400 feet
- Storage zone Total Dissolved Solids
  - 30 mg/l to 39,000 mg/l
- Storage Volumes
  - 100 AF to 270,000 AF
- Bubble radius less than 1,000 ft
- Individual wells up to 8 MGD capacity
- Wellfield capacity up to 157 MGD

Calleguas MWD, California

ASR Well

Formation and Maintenance of TSV: Achieves Recovered Water Quality Goals



TSV is the sum of the stored water volume and the buffer zone volume. Expressed in MG/MGD of recovery capacity, or in "days"

Phase 1 Feasibility Assessment Discussion Items

- Objectives
- Historic and projected water demands and variability
- Water supply availability
- Water quality variability and treatment requirements
- Storage volume requirements
- Hydrogeology
- ASR conceptual plans
- Economics
- Legal, regulatory, institutional considerations

Beaufort-Jasper WSA, SC

Well ASR-1

Victoria Area
Potential ASR Objectives

Select and Prioritize One or More Pertinent ASR Applications:

- **Seasonal storage**
- **Long-term storage ("water banking")**
- **Emergency storage ("strategic water reserve")**
- **Diurnal storage**
- **Disinfection byproduct reduction**
- Restore groundwater levels
- Control subsidence
- **Maintain distribution system pressures**
- **Maintain distribution system flow**
- Aquifer thermal energy storage (ATES)

Kiawah Island, SC

Denver, CO

Victoria Area
Potential ASR Objectives Cont'd

- Reduce environmental effects of streamflow diversions
- Agricultural water supply
- Nutrient reduction in agricultural runoff
- Enhance wellfield production
- **Defer expansion of water facilities**
- Reclaimed water storage for reuse
- Stabilize aggressive water
- **Hydraulic control of contaminant plumes**
- Maintenance or restoration of aquatic ecosystems

Manatee County, FL – ASR Well, 1983

ACEC Grand Award, 1984

Long-term storage: “Water Banking for the Drought of Record”

- How to estimate the Target Storage Volume (TSV)
- ASR facilities capacity determined by the greater of required recharge capacity or required recovery capacity to provide 100% reliability
- Buffer zone volume as a percentage of the TSV
- “Will the stored water still be there when we need it?”
- Lateral velocity of groundwater in the storage aquifer(s)?
- Proximity of other groundwater users?
- Measures available to protect availability of the stored water

Seasonal Storage

- May be an important secondary benefit of ASR in Texas (in addition to providing storage for DOR)
- Annual benefit, not just once in a lifetime
- Facilitates more efficient use of existing infrastructure, meeting peaks from ASR instead of from water treatment plants and transmission pipelines

Orangeburg SC

Total 6.5 MGD

Two ASR wells in two different aquifers within a single wellhouse

Strategic Storage for Emergencies

- Water systems dependent upon a single source and/or a long transmission pipeline
- Accidental loss, contamination, warfare, terrorism, natural disaster
- Build a strategic water reserve deep underground

Des Moines Water Works, Iowa – 100 MGD WTP
Before and After 1993 Flood

Emergency Storage: Des Moines ASR Objectives

Deepest ASR well in the world – 2700 ft in Jordan Sandstone Aquifer

Retrofit of Existing Abandoned Production Well

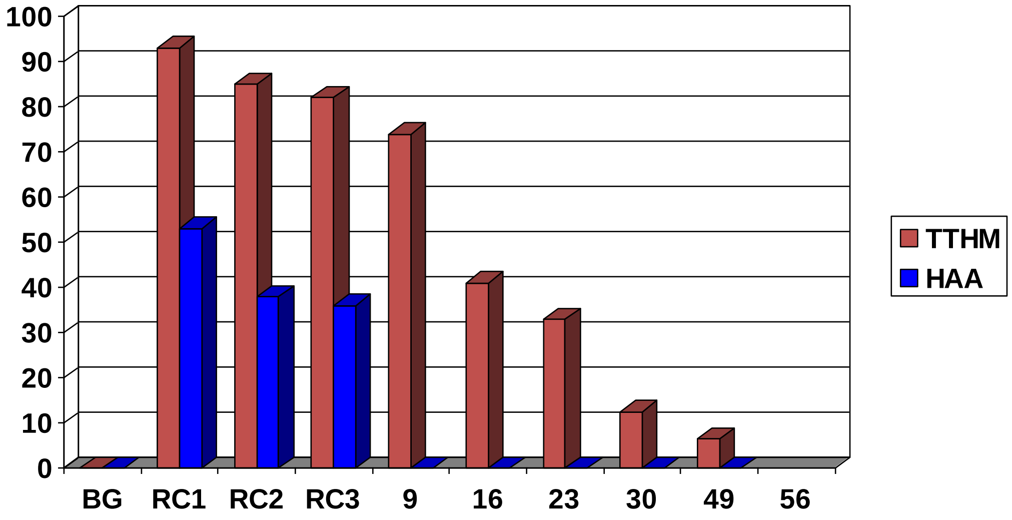
Primary ASR Objective
- Emergency Water Supply
- 30 MGD for 90 days – 2.7 BG

Secondary ASR Objective
- Seasonal Water Storage
- 10 MGD for 90 days – 0.9 BG

Tertiary ASR Objective
- Eliminate need for nitrate removal during spring thaw

Disinfection Byproduct Reduction

- Elimination of Haloacetic Acids and their formation potential in a few days due to aerobic subsurface microbial activity
- Reduction of Trihalomethanes and reduction of their formation potential in a few weeks due to anaerobic subsurface microbial activity



Disinfection Byproduct Attenuation – Centennial WSD, Highlands Ranch, CO

Maintain Pressure, Flow and WQ In Distribution Systems

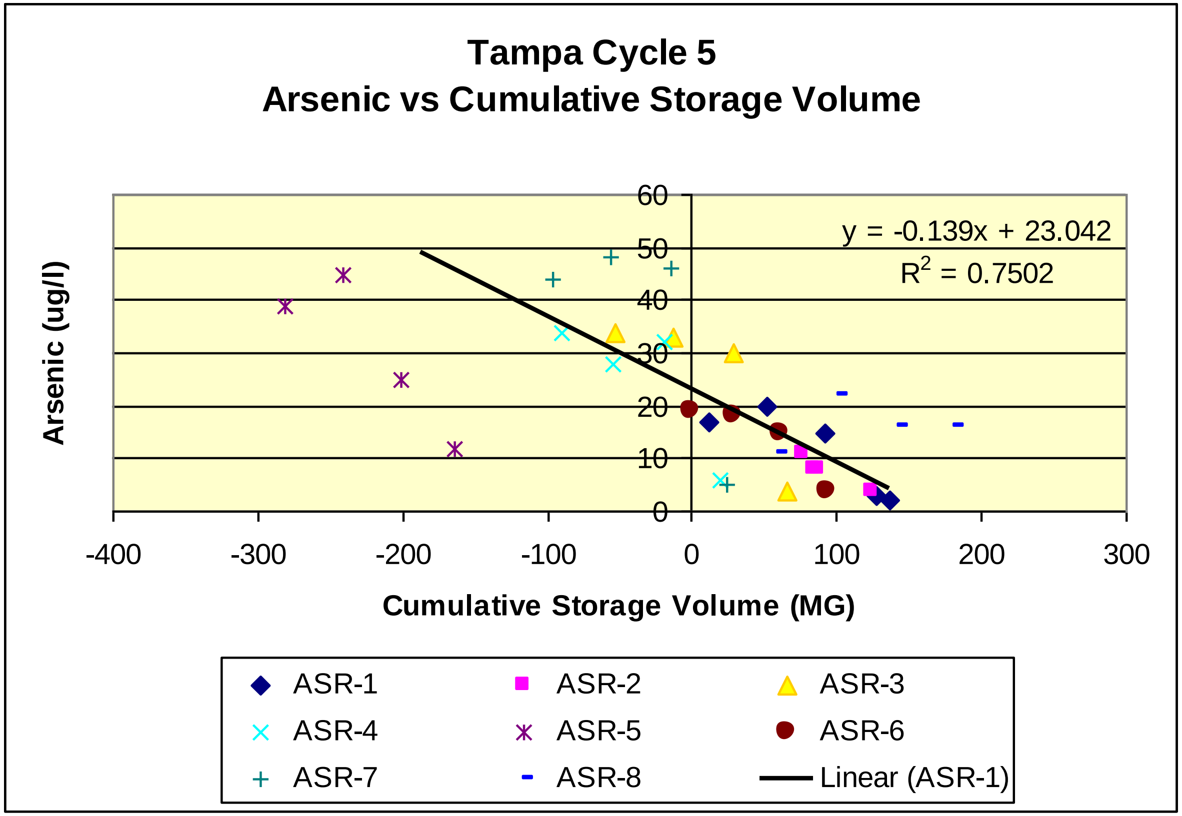
- Locate ASR wells in seasonal low pressure areas:
  - Top of a hill
  - End of a long pipelines
  - Summer beach resort

- Avoid the need for flushing pipelines to waste to maintain water quality in distant portions of a water distribution system

Murray Avenue ASR Well
Cherry Hill, New Jersey

Improve Water Quality

- Arsenic
- Fluoride
- Salinity
- THM and HAA
- Fe and Mn
- H_2S
- N & P
- TOC (carbon sequestration)
- Microbiota
- pH stabilization



Arsenic Decreases as the Cumulative Storage Volume Increases

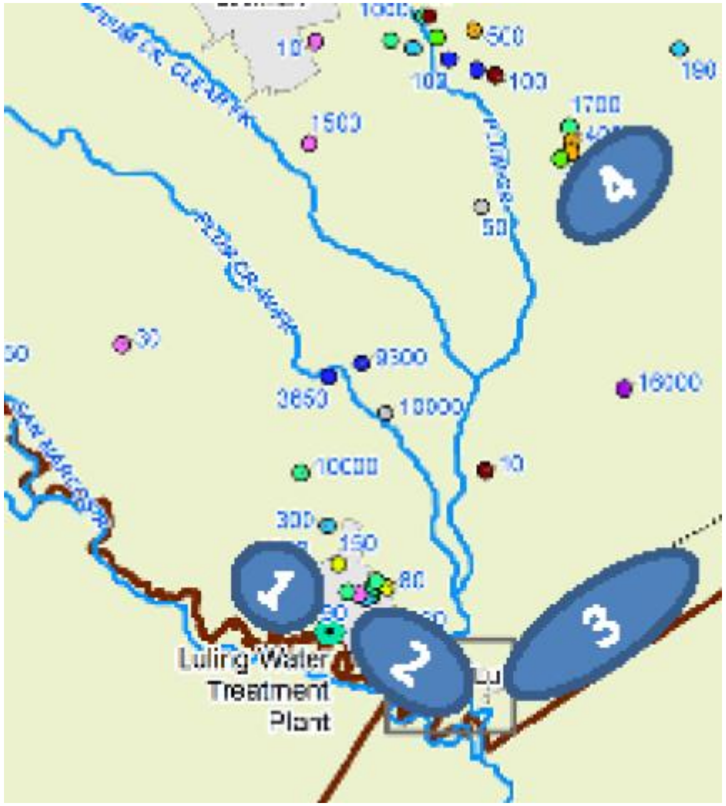
Defer Expansion of Water Facilities

- Operate treatment facilities to meet slightly more than average demands, providing for maintenance periods and times of inadequate supply
- Meet maximum day demands from ASR wells; peak hour demands from elevated and ground storage tanks
- Typically reduce capital costs by >50%

Highlands Ranch, CO
One of 26 ASR wells underground in vaults

Hydraulic Control of Contaminant Plumes

- Oilfield injection wells:
  - Disposal of produced brine water
  - Old, corroded carbon-steel cased wells
- Other contamination sources (nitrates, chlorides, etc)

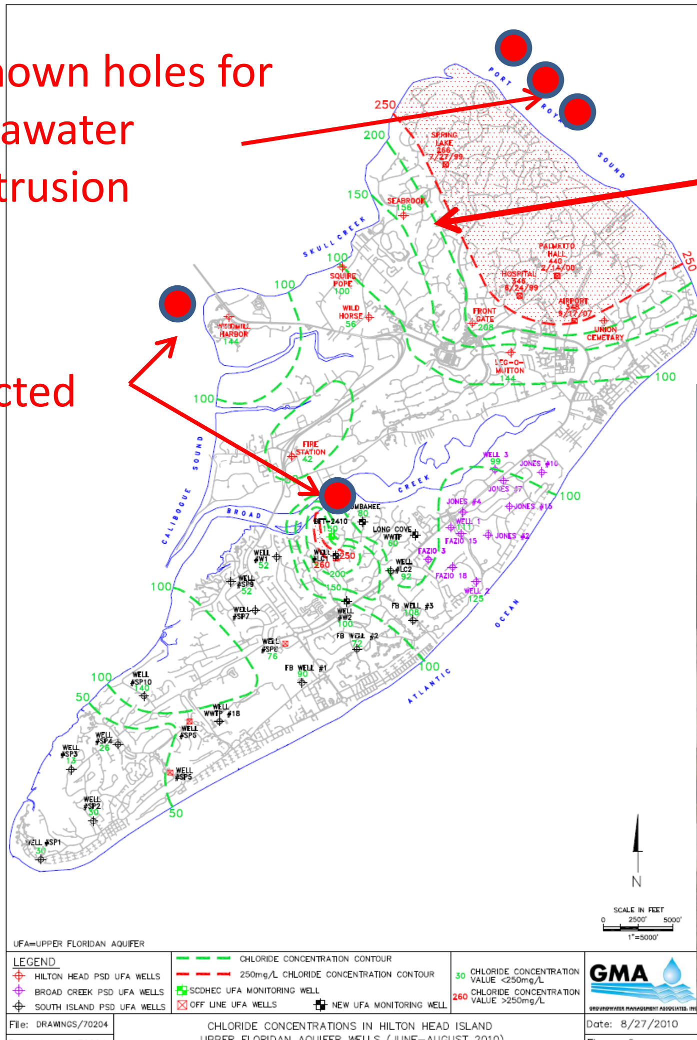


Hilton Head Island
Upper Floridan Aquifer Seawater Intrusion

Known holes for seawater intrusion

HILTON HEAD PSD WELL ASR-1

Suspected holes



OPERATIONAL WITHIN 23 MONTHS

ASR is Cost-Effective

- June 2006 Survey of Florida ASR Costs
  - Based on 11 ASR wellfields in Florida
  - Capital cost includes construction and engineering
  - Unit capital cost: $1.00 per gpd of recovery capacity, within range of $0.50 to $2.00
  - Approximately one-sixth the unit capital cost of surface reservoir storage, within range of 1/3 to 1/30
- San Antonio Water System, TX (2004 to 2006)
  - $1.10 per gpd recovery capacity for 60 MGD ASR wellfield
- NC and SC four ASR wellfields (2012 to 2013)
  - Average: $1.02 per gpd recovery capacity
  - Range: $0.77 to $1.55 per gpd

Capital Cost Comparisons

Source/Storage Option	Typical $/GPD Capacity
Conventional Supply	0.50 – 5.00
ASR	0.50 - 2.00
Brackish Desalination	2.00 – 5.00
Seawater Desalination	7.00 – 12.00
Surface Reservoirs	3.00 – 30.00
Indirect Potable Reuse	7.00 – 25.00

ASR is complementary to other sources, increasing total yield and reliability. With adequate ASR capacity, 100% reliability can be achieved at reasonable capital cost.

ASR Operational Considerations

- Availability and suitability of well sites
- Retrofit of existing wells vs new wells
- Proximity of transmission/distribution pipelines and their conveyance capacity during recharge/recovery
- Disposal of water during testing and operations
- Recharge water quality and variability
- Geochemistry, pre- and post-treatment requirements
- Inventory of nearby wells, owners, depths, uses
- Instrumentation and control system capabilities

Potential ASR Well Locations

- Water treatment plant
- Elevated storage tanks
- Ground storage reservoirs
- Fringes of the distribution system
- Other locations in the service area
- Outlying areas with preferred hydrogeologic suitability

Other Considerations Affecting ASR Feasibility

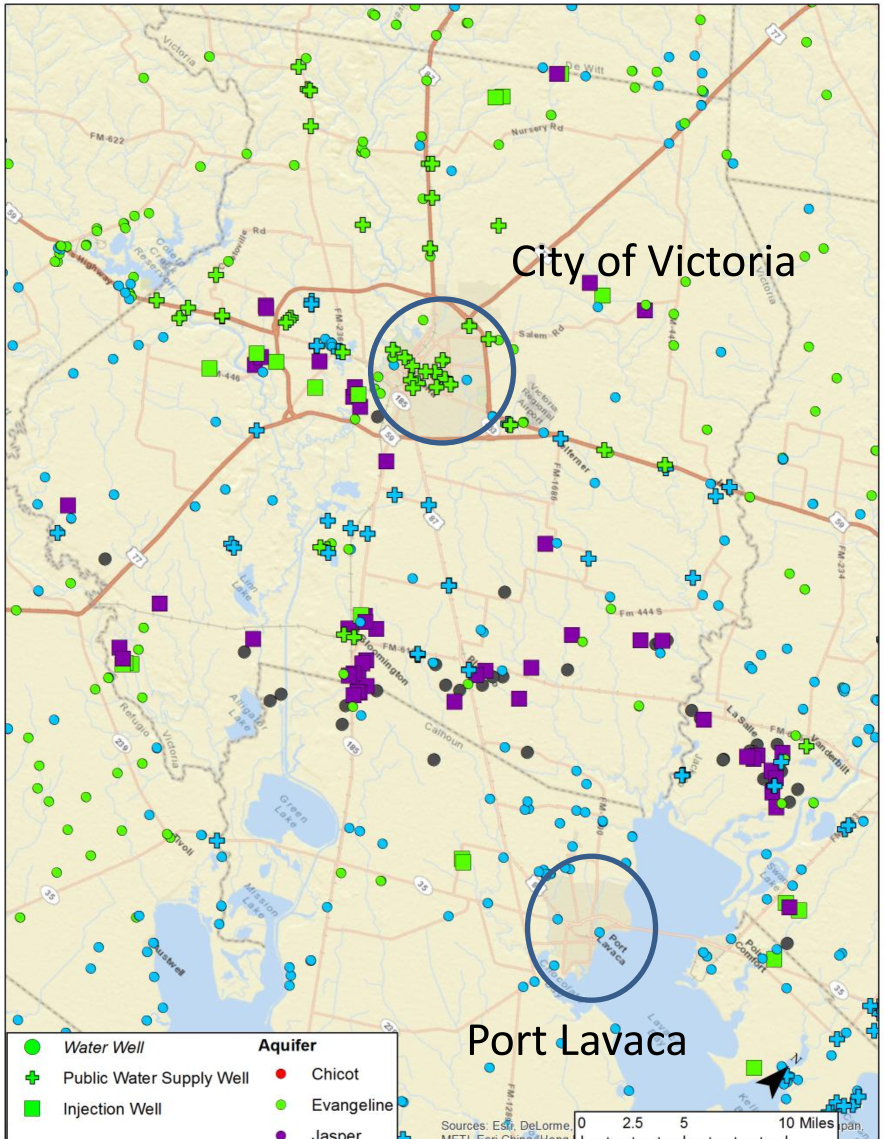
- Water rights
- Legal constraints
- Regulatory constraints
- Institutional constraints
- Funding
- Priority relative to other needs
- Others

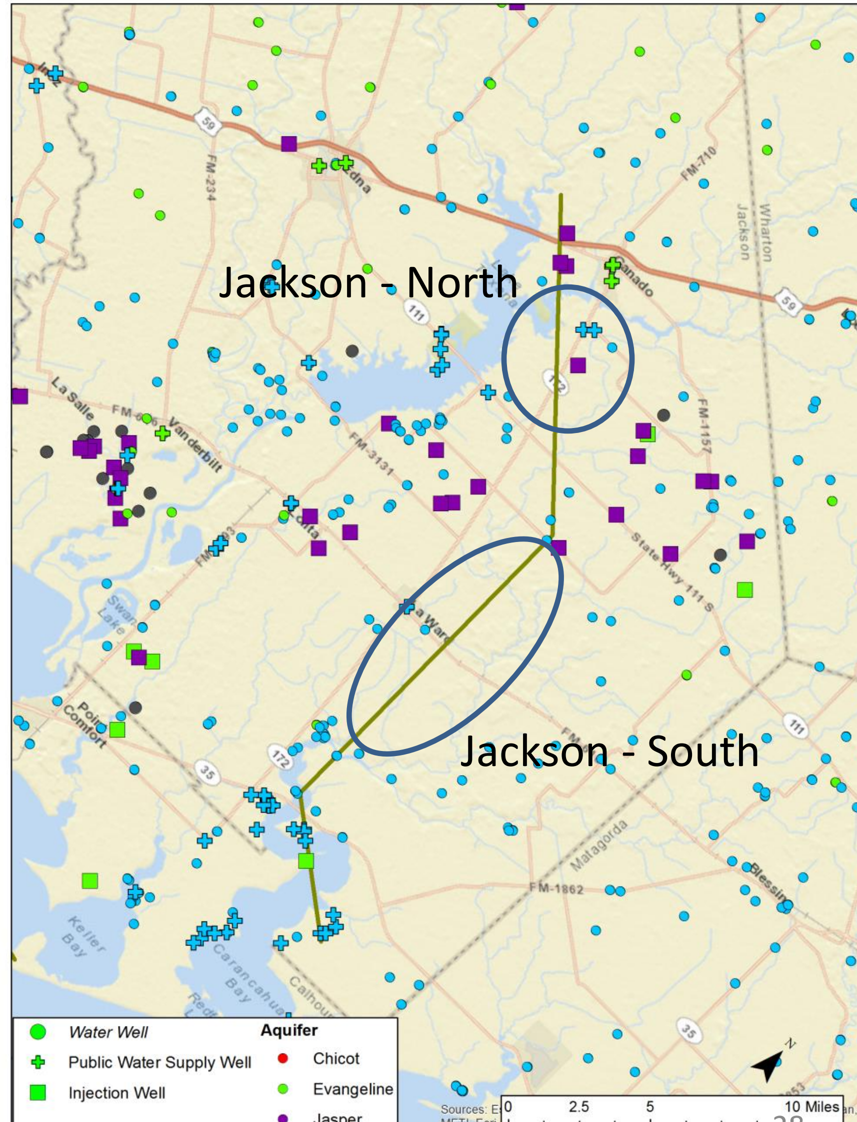
Cocoa, Florida
1 of 10 ASR wells
Operating since 1987

Hydrogeologic Data Collection

- Potential ASR Sites
- Gulf Coast Geology
- Aquifer Hydraulic Properties
- Water Quality Measurements
- Injection Wells and Public Water Supply Wells
- Sand Bed Thickness (Example: City of Victoria)
- Characterization Summary (Example: City of Victoria)
- On-going Work

Potential Aquifer Storage and Recovery Sites

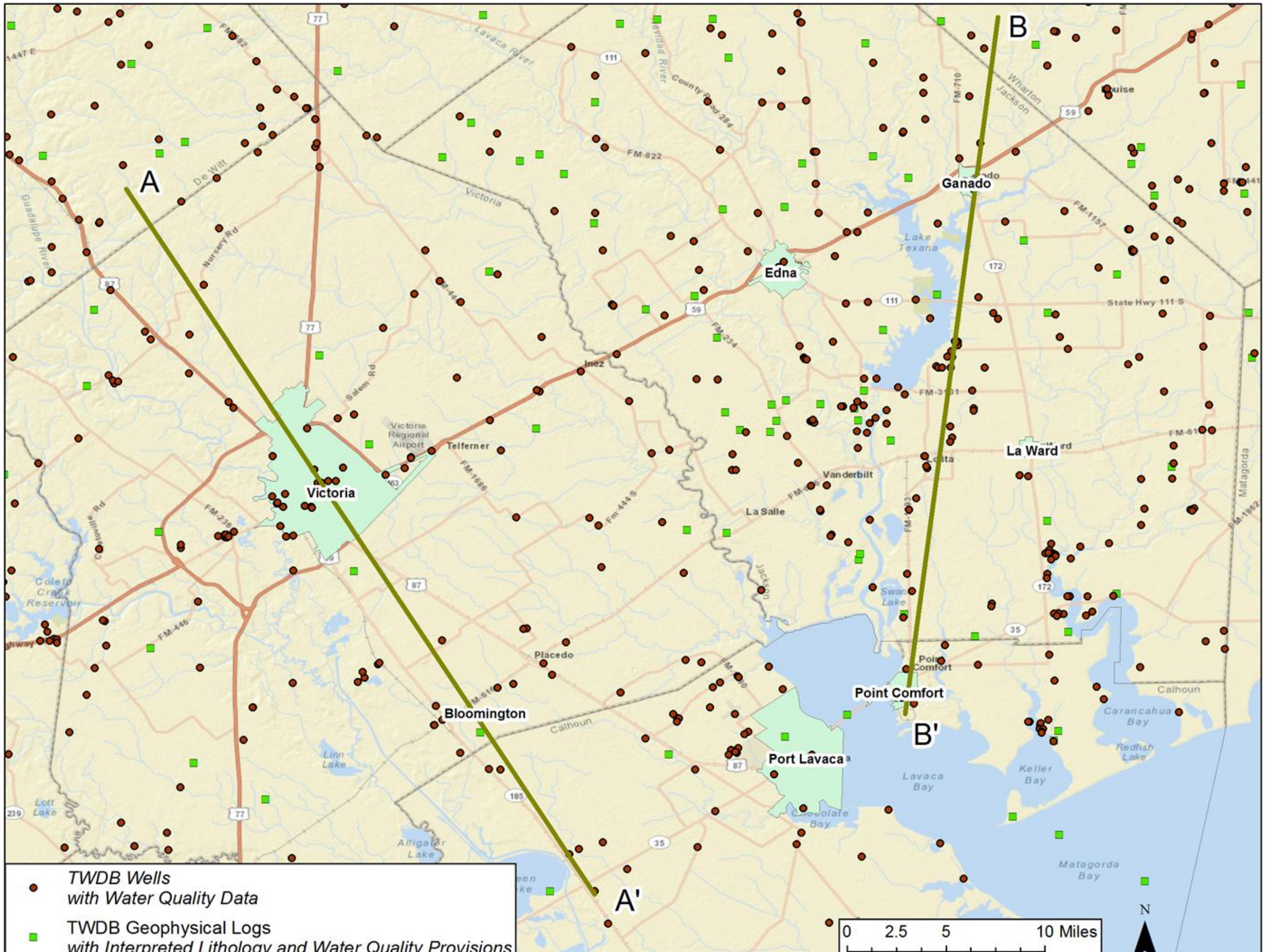




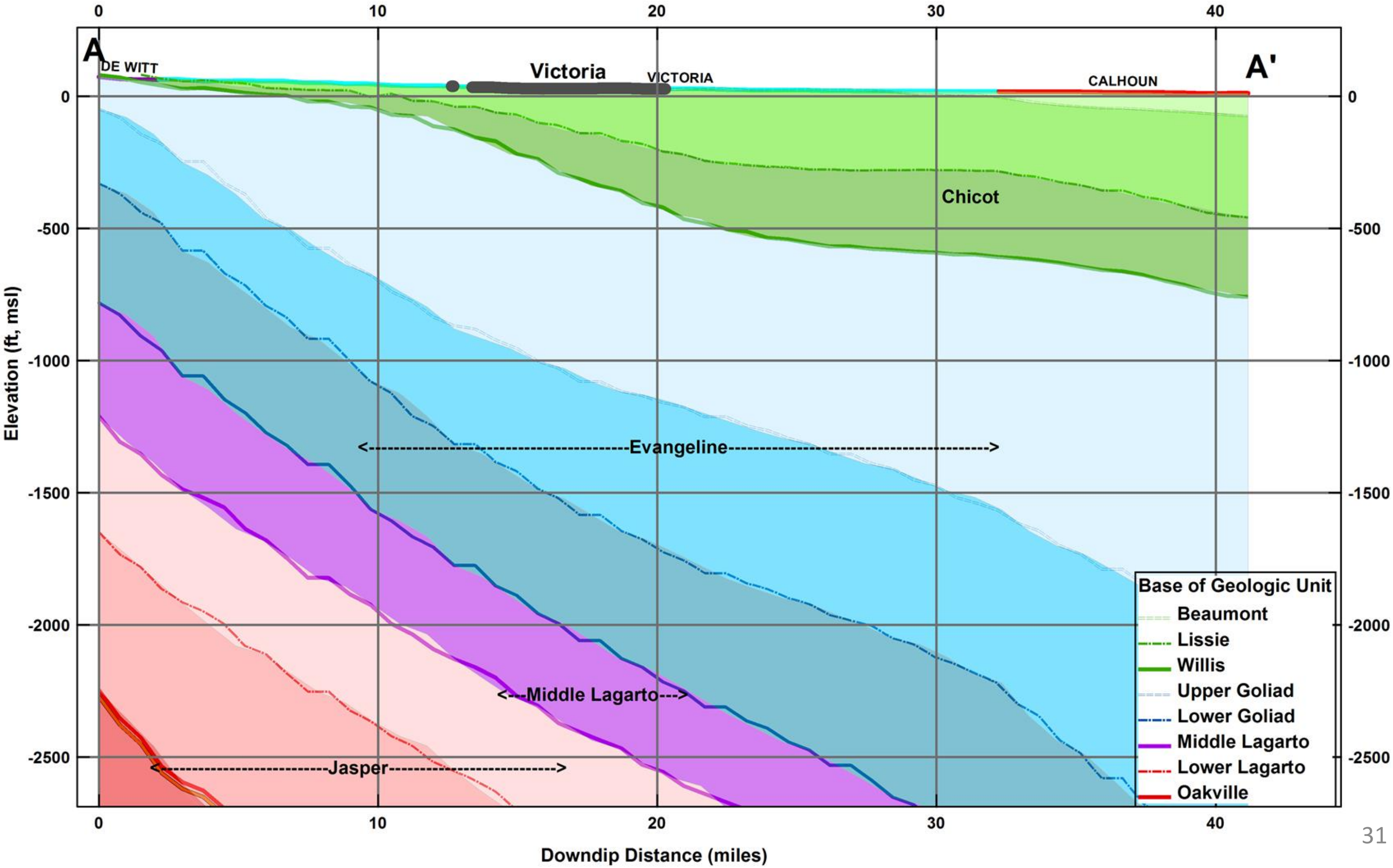
Geological Column

ERA	Epoch		Est. Age (M.Y)	Geologic Unit	Hydrogeologic Unit
Cenozoic	Pleistocene		0.7	Beaumont	CHICOT AQUIFER
			1.6	Lissie	
	Pliocene		3.8	Willis	
	Miocene	Late	11.2	Upper Goliad	EVANGELINE AQUIFER
			14.5	Lower Goliad	
			17.8	Upper Lagarto	
		Middle		Middle Lagarto	BURKEVILLE
		Early		Lower Lagarto	JASPER AQUIFER
			24.2	Oakville	
	Oligocene		32	Frio	CATAHOULA
			34	Vicksburg	

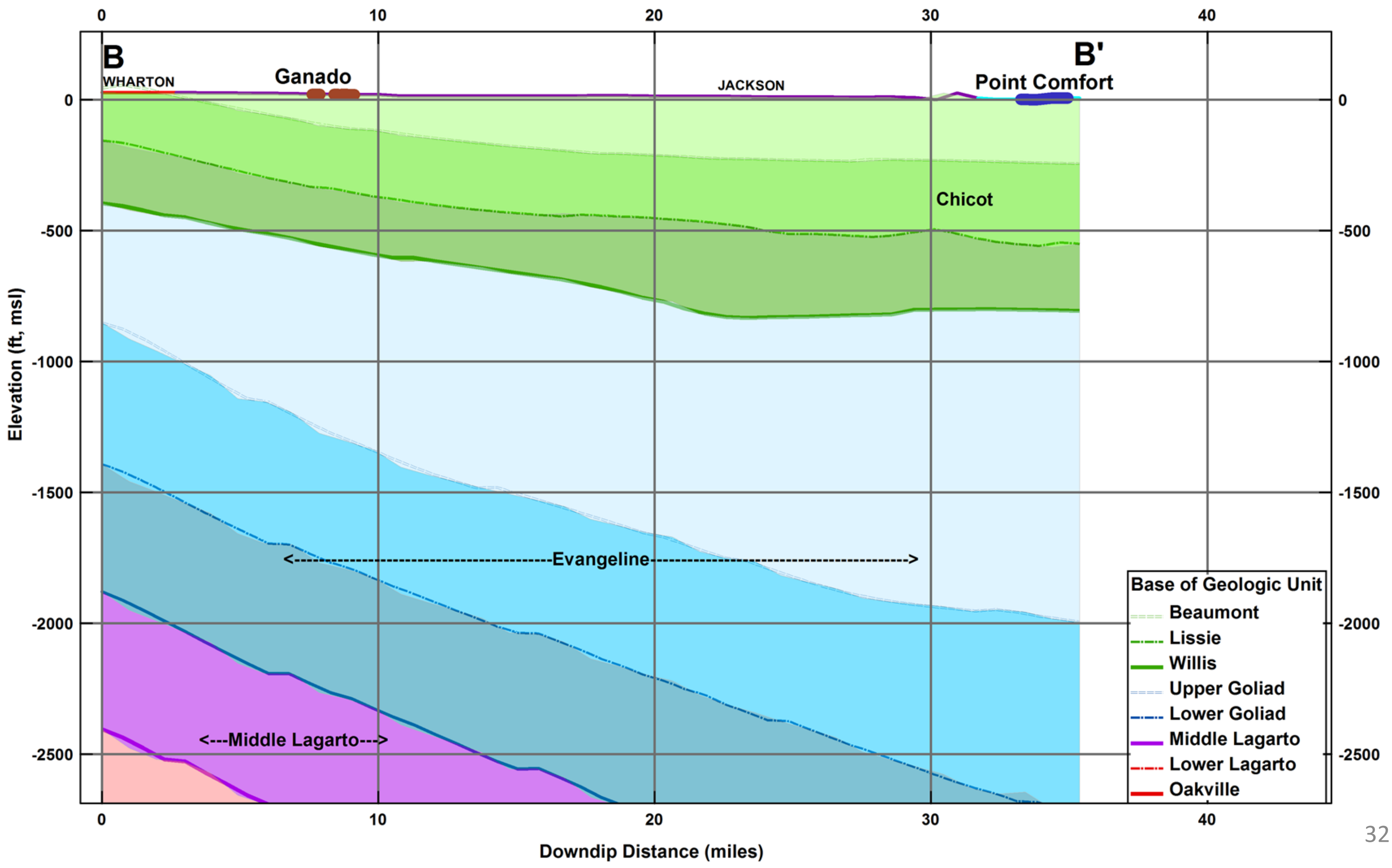
TWDB Water Quality and Lithology Data



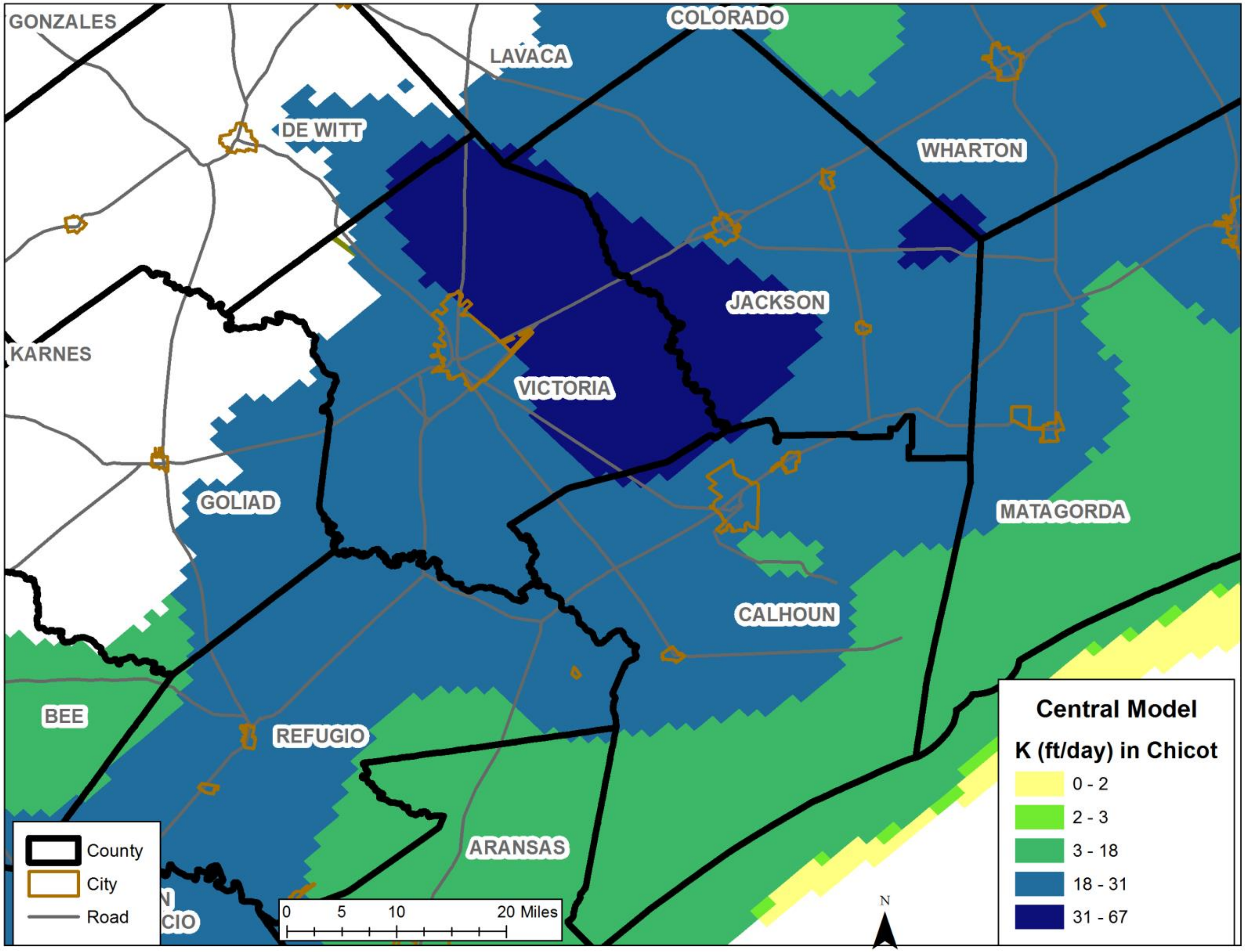
Geological Cross-Section A-A’



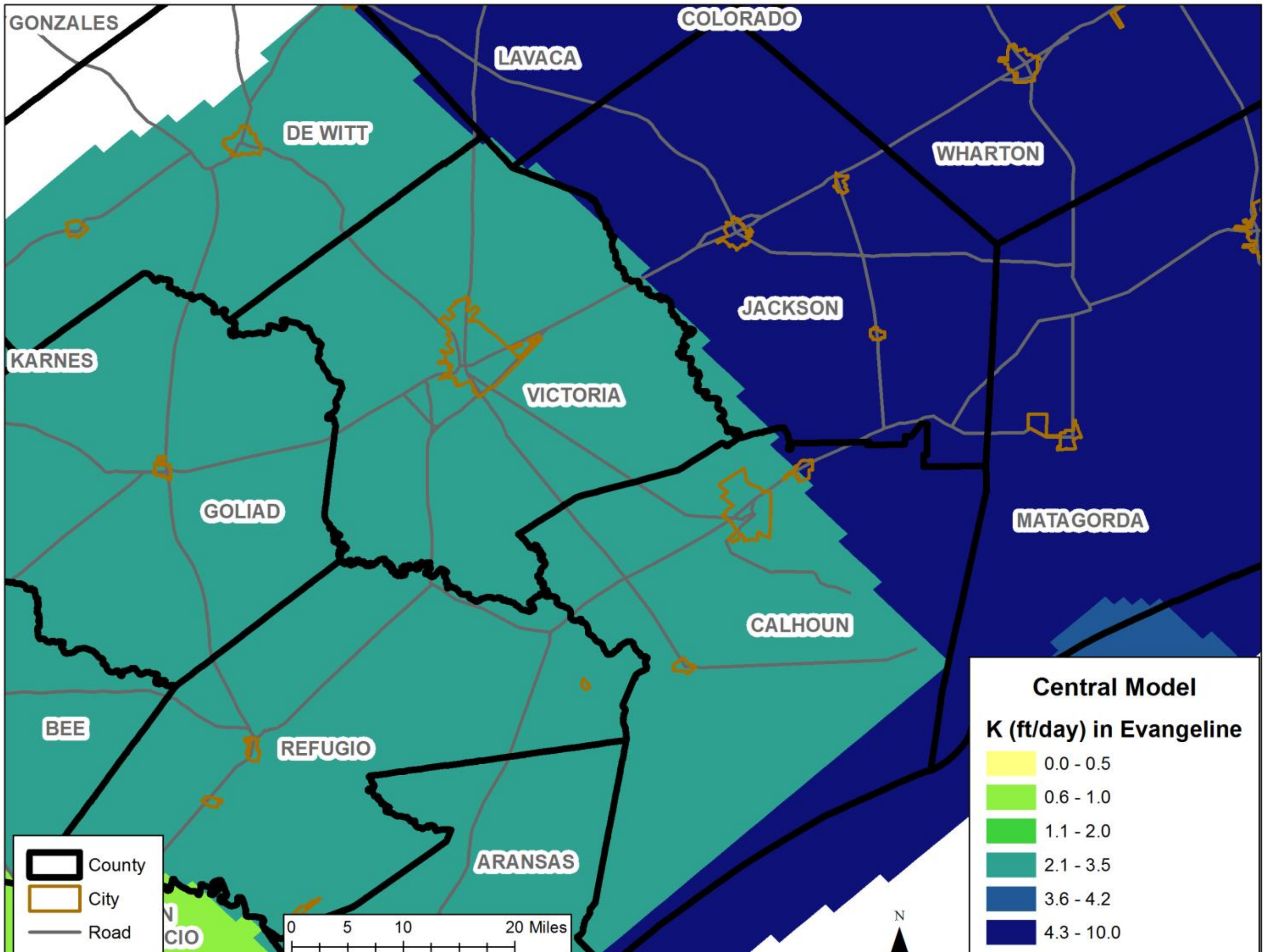
Geological Cross-Section B-B’



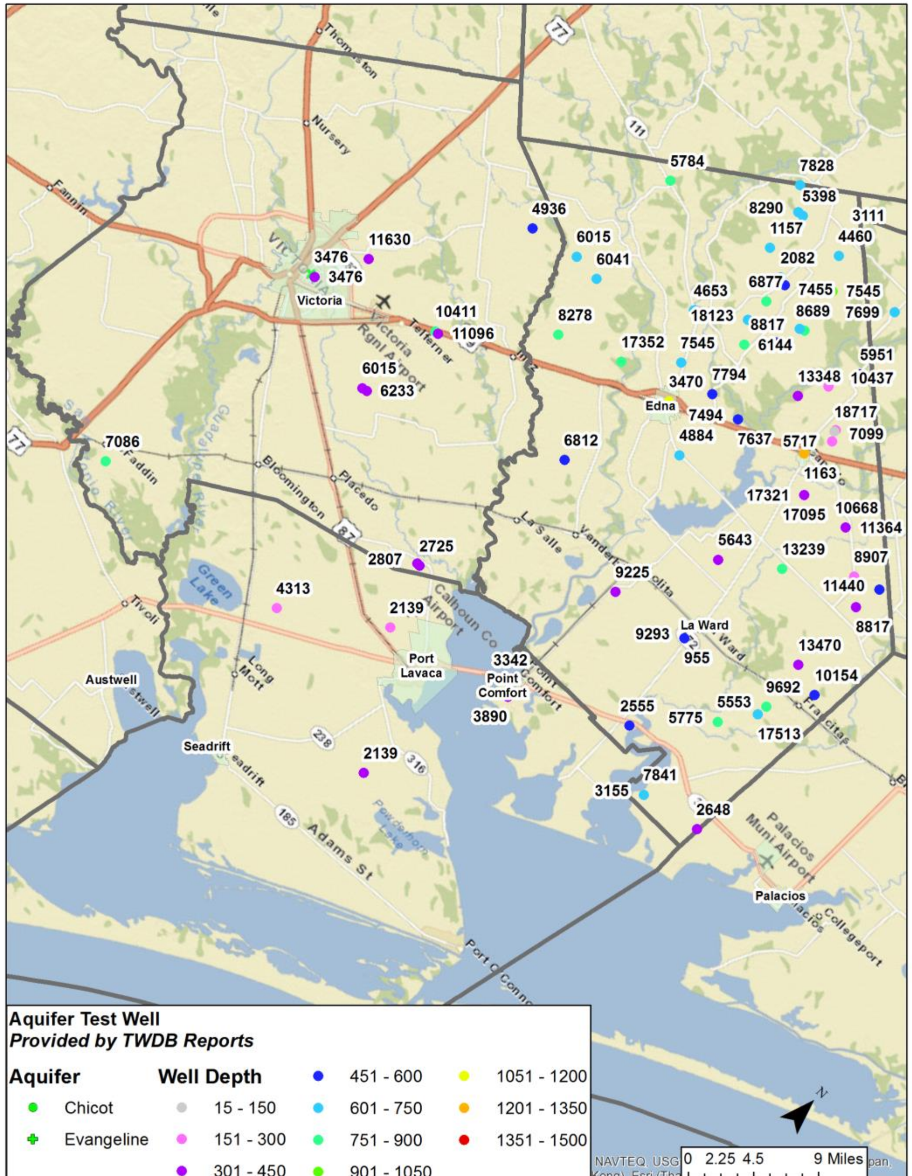
GMA 15 GAM Hydraulic Conductivity (K)- Chicot Aquifer



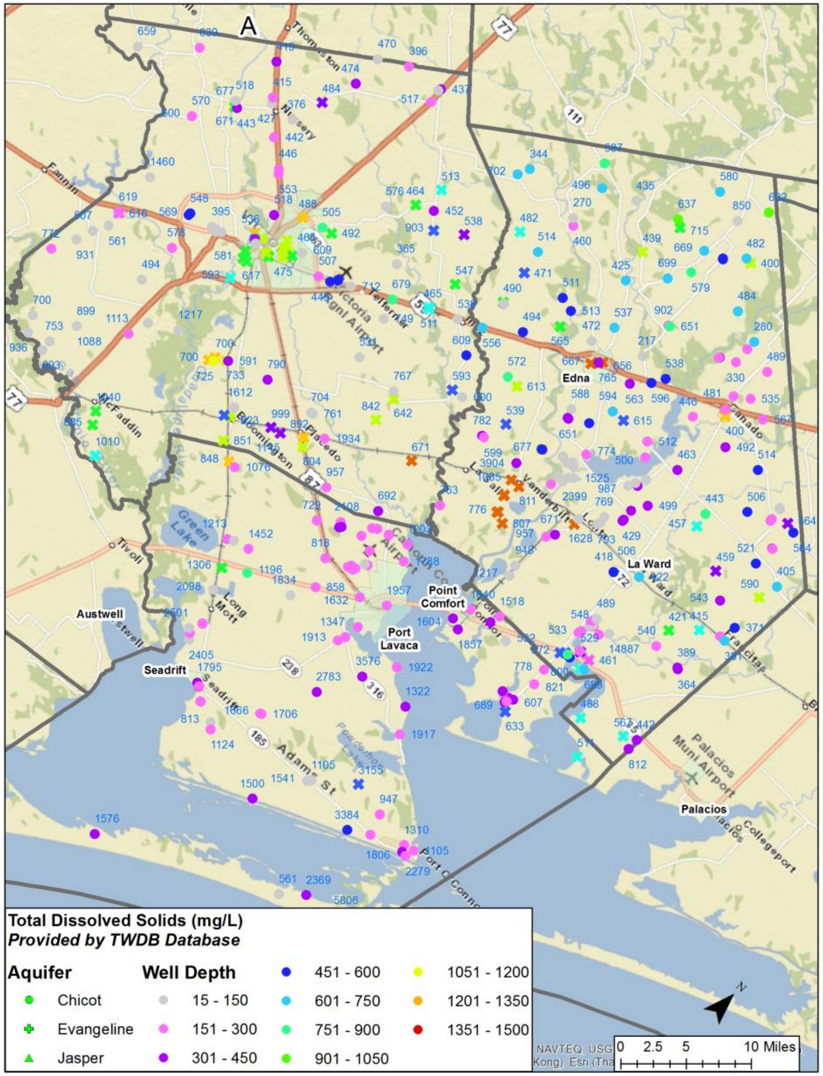
GMA 15 GAM Hydraulic Conductivity (K)-Evangeline Aquifer

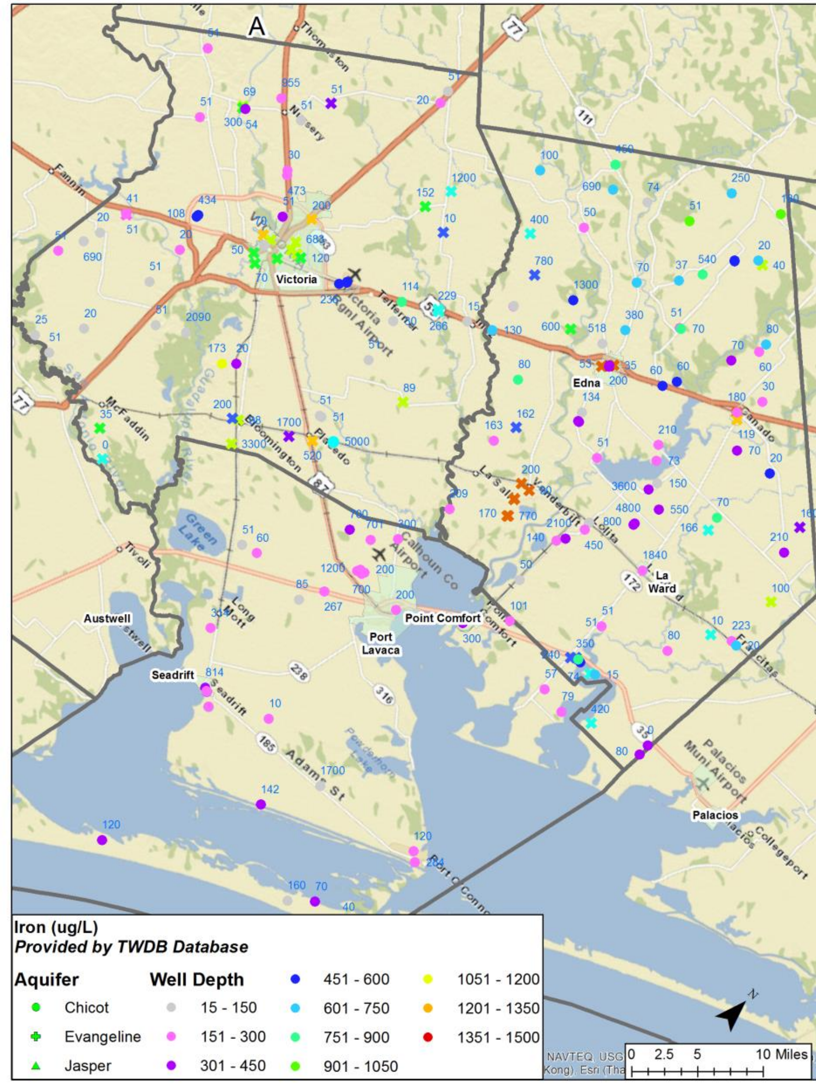


Aquifer Pumping Tests



TDS and Iron Distributions (mg/L)





Injection Wells and Public Water Supply Wells

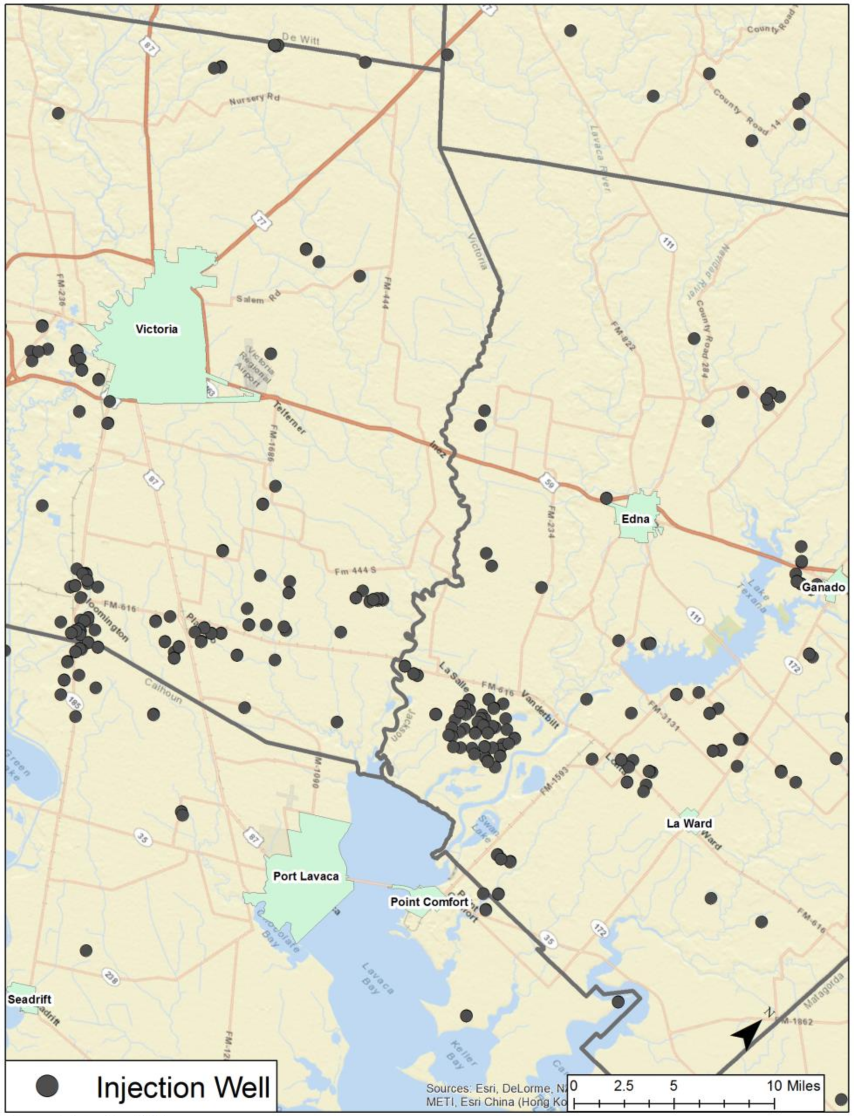
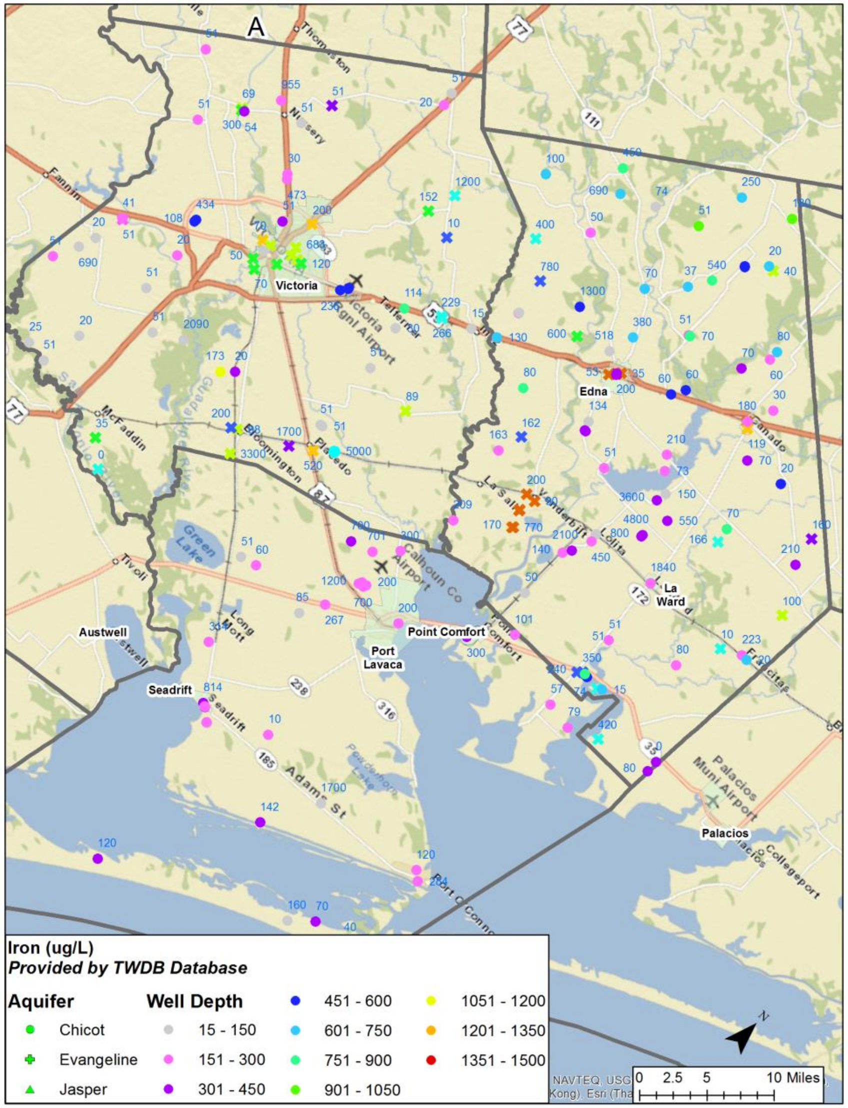
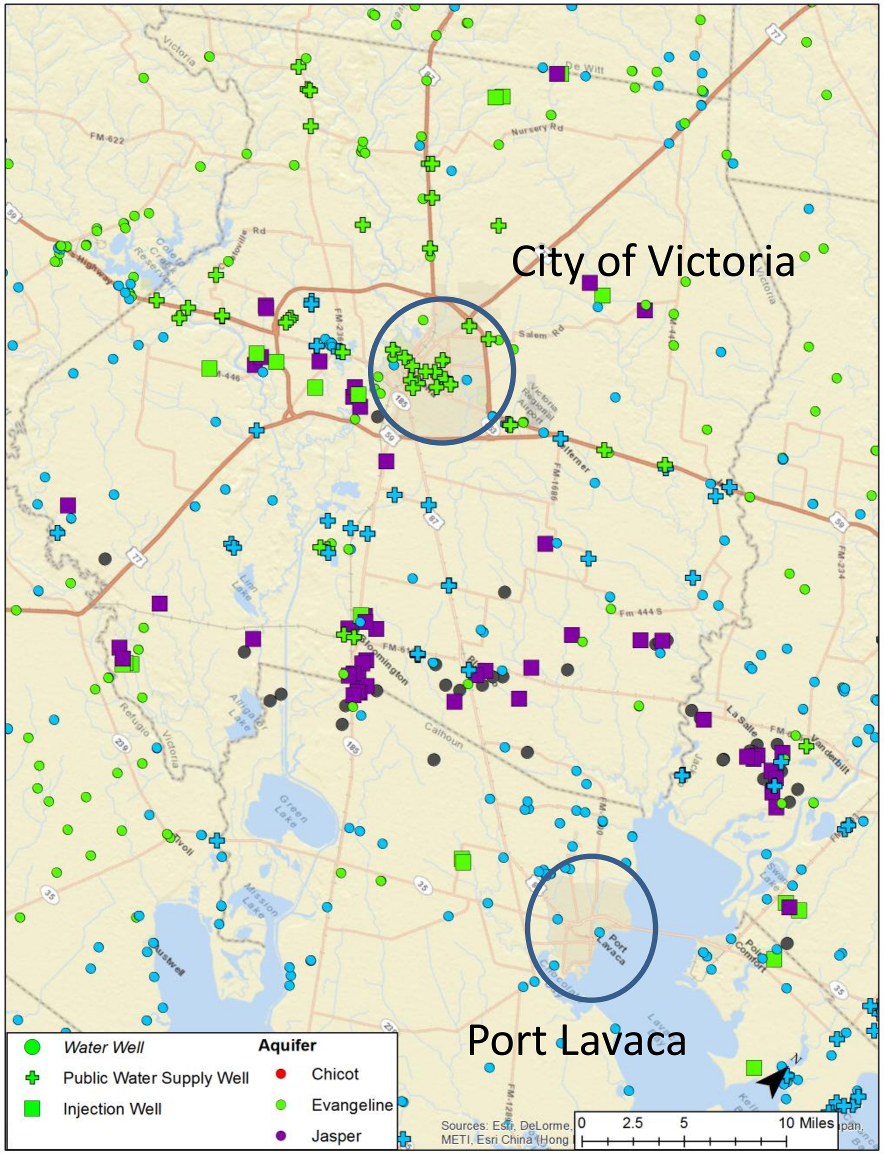
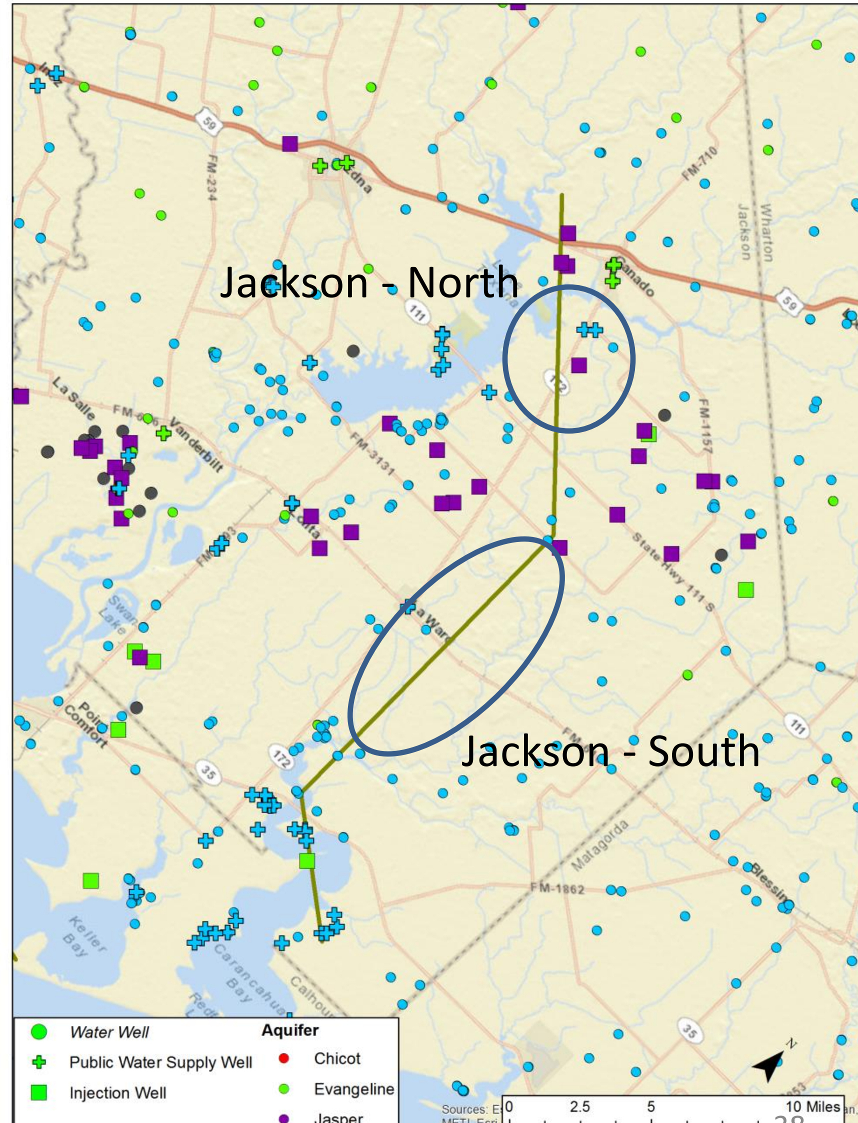


Figure 3_Injection Wells

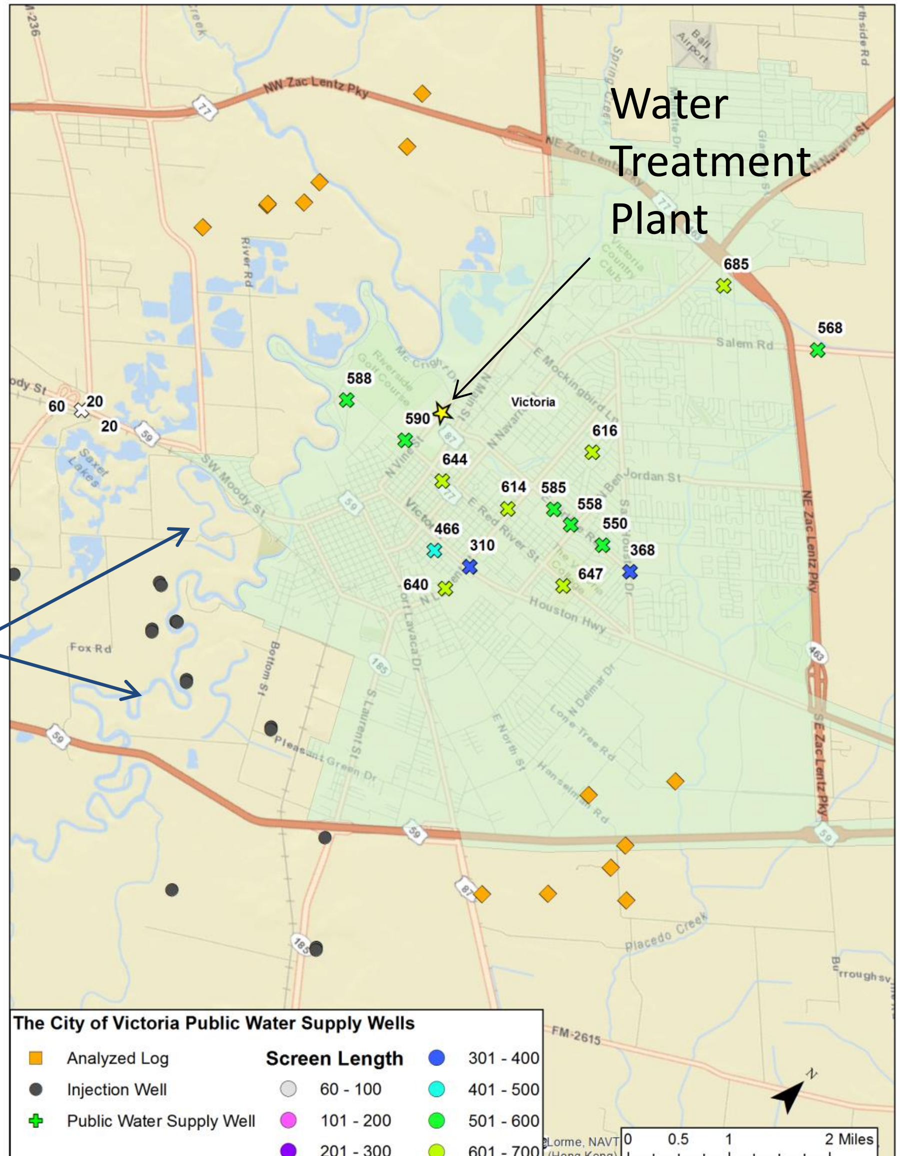


Potential Aquifer Storage and Recovery Sites



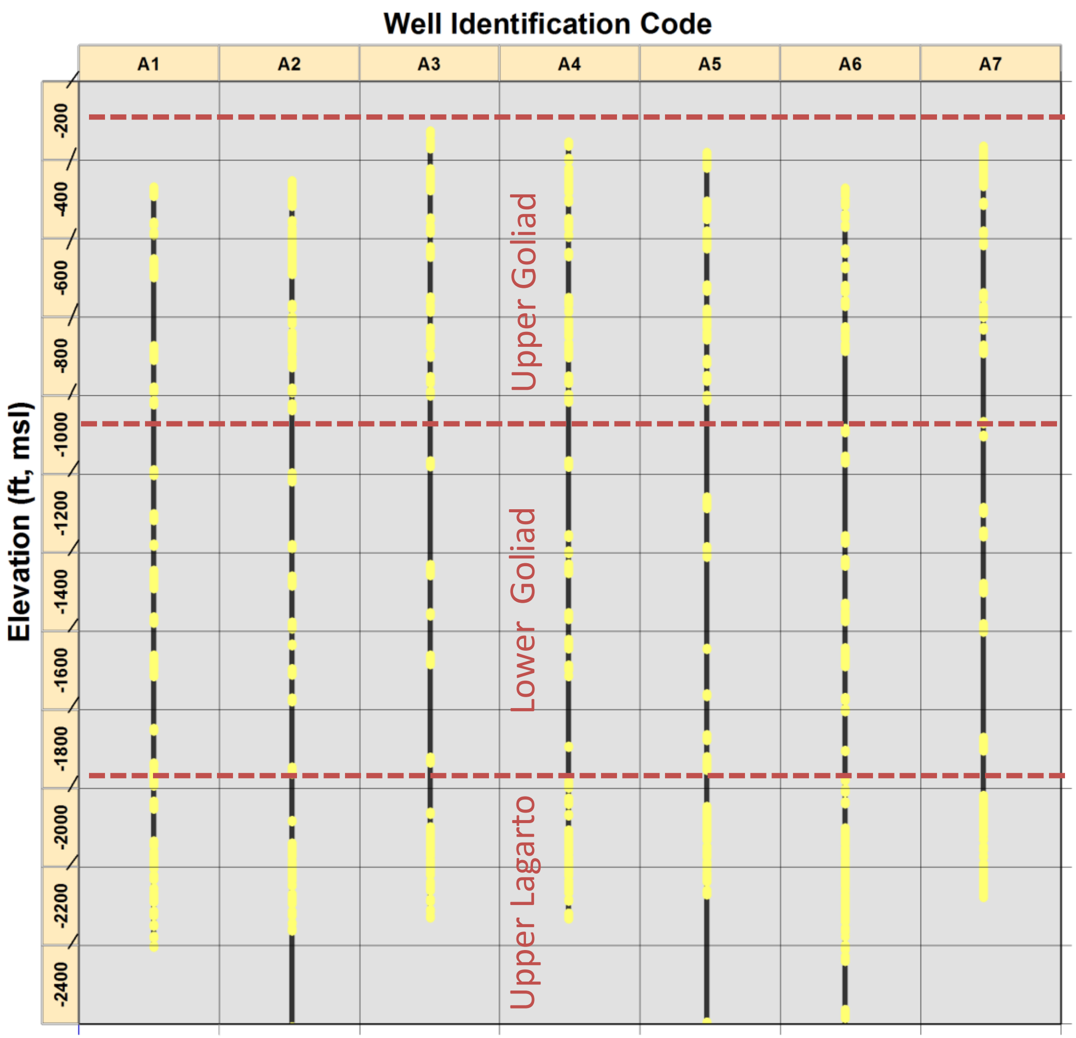


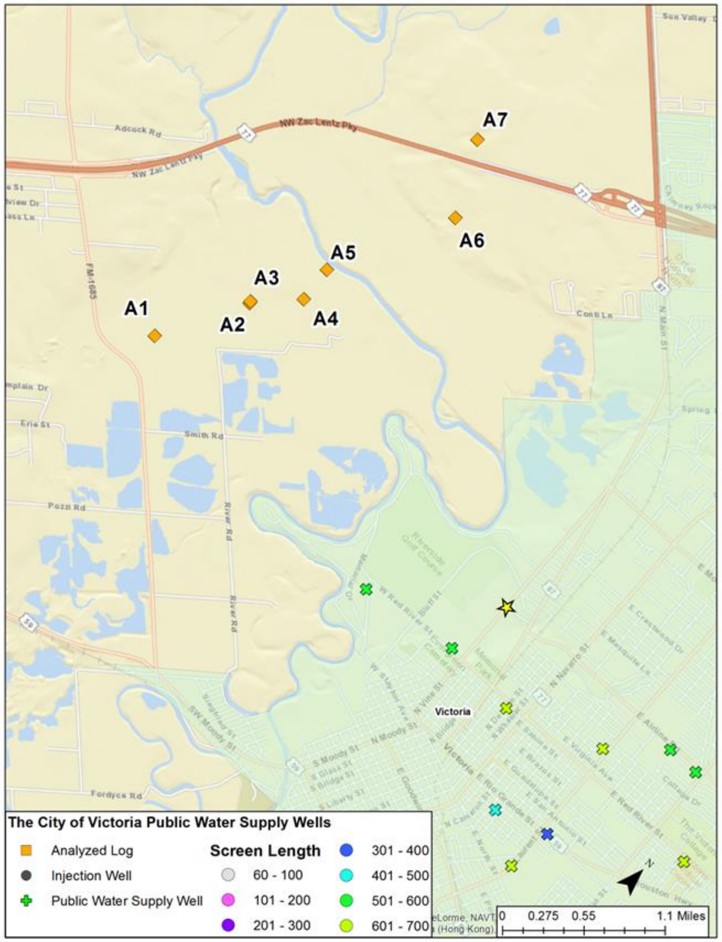
Victoria: Two Sets of Geophysical Logs



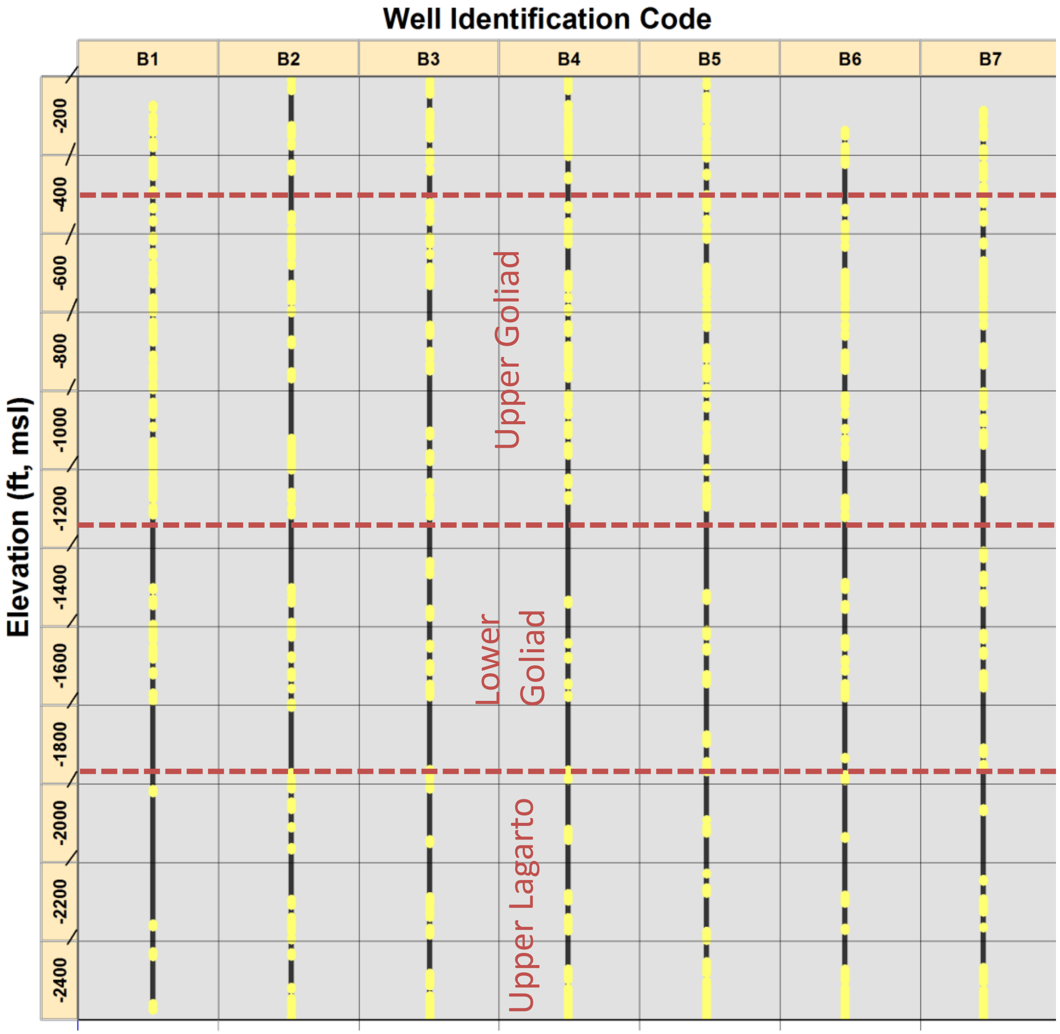
Guadalupe River

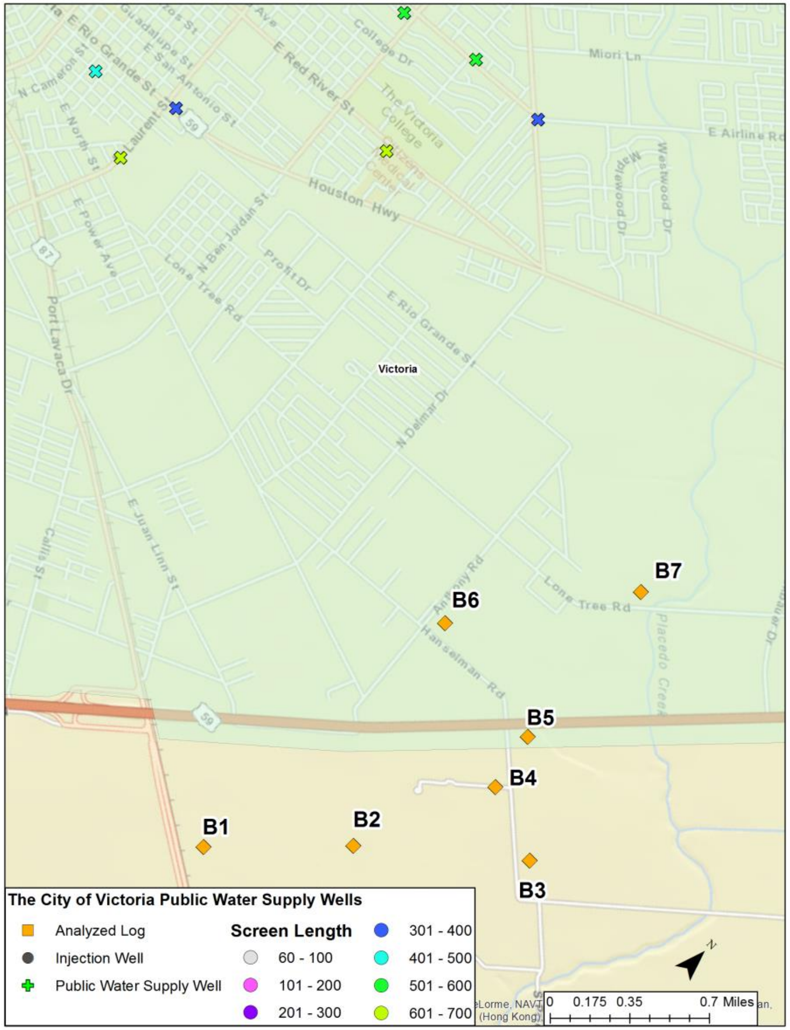
Sand Bed Thicknesses: North Region





Sand Bed Thicknesses: South Region





Victoria Area ASR Site Characteristics

- Upper Goliad in Evangeline Aquifer is the Target Zone
  - ~300 ft bgs to ~1000 ft bgs
  - Same zone as City of Victoria Public Water Supply Wells
- Preferable Site in North Region
  - Away from Injection Wells in southern portion of City
  - Away from Public Water Supply Wells in central portion of the City
  - 2 to 5 miles from Water Treatment Plant
- TDS is estimated between 450 mg/L and 600 mg/L
- Dissolved Iron is estimated between 50 ug/L and 500 ug/L
- Hydraulic Conductivity (K) Value
  - GAM 15 GAM indicates average Evangeline K is about 3 ft/dy
  - GAM 16 GAM indicates average Evangeline K is about 0.5 ft/day
  - No aquifer test results in Evangeline but Chicot/Evangeline Well is about 12 ft/day
    - Screen interval from 135 to 450 ft bgs
    - No aquifer test data available to review
- Several Sand Bed Thicknesses of 20 to 40 feet throughout Upper Goliad

On-going Characterization Work

- Mapping Sand Beds
  - Port Lavaca Area
  - Jackson County
- Hydraulic Conductivity Values
  - Averages from GAM and aquifer pumping tests
  - Estimates for large sand beds
- Scoping calculations using groundwater models
  - Groundwater migration rates
  - Injection rates

Sources of Supply

- City of Victoria
  - 3860A (Lipscomb)
  - 3858A (Murphy)
  - 4117A (Ruschhaupt)
  - 3844A (Schmidt)
  - 3862A
  - 3606A
  - 5466B
- GBRA
  - 5178 (Permit 1614)

Daily Timestep Water Availability Analysis Victoria and GBRA

Model Assumptions

- Full exercise of surface water rights
- Daily Average USGS Gauged Flows
    - #08176500 Guadalupe River at Victoria
        1 day travel time to confluence with San Antonio River
    - #08188500 San Antonio River at Goliad
        2 day travel time to confluence with Guadalupe River
    - Corrected for priority order usage
        Assumed 100% water needs met for upstream **senior** water right holders
- Channel losses as included in the GSA WAM model
- Daily water demands calculated from monthly demands in GSA WAM Run 3
- Permit special provisions included

Water Demand and Demand Centers

- Demand to Year 2040:
  - Victoria: 8% increase per decade
  - GBRA: Peak day of 10.2 mgd
  - Applied to current demand patterns

- Demand Centers:
  - Victoria: City's service area
  - GBRA: PLWTP or closest feasible location

Remaining Work

- Data collection
- Completion of hydrogeologic analyses
- Completion of ASR model based prioritized ASR applications
  - Recharge and recovery rates
  - Target storage volumes
  - Treatment facility requirements
- Water quality analysis
- Development of conceptual plan and cost estimates
- Evaluation of permitting/environmental issues
- Economic analysis
- Draft and final reports

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Appendix B

Infrastructure Assessment for the Victoria Area Regional Plan for Aquifer Storage and Recovery (ASR) Final Report

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Infrastructure Assessment for the Victoria Area Regional Plan for Aquifer Storage and Recovery (ASR) Final Report

Submitted by:

THE CITY OF VICTORIA TEXAS

LAVACA - NAVIDAD RIVER AUTHORITY

GBRA

VICTORIA COUNTY GROUNDWATER CONSERVATION DISTRICT

Port of Victoria, Texas

Submitted to

Texas Water Development Board

Prepared by:

NEI Naismith Engineering, Inc

STATE OF TEXAS
DAVID B. FUSILIER
87710
LICENSED PROFESSIONAL ENGINEER
10/08/2014

October 2014

NEI Project No. 8806/TWDB Contract No. 1348321576

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Executive Summary

1.0 Infrastructure Assessment for Victoria Area ASR Feasibility

1.1 City of Victoria – Public Water System Infrastructure Assessment

An ASR system serving the City of Victoria would be located in areas to allow for easy integration into the City's distribution system and would require minimal infrastructure improvements with respect to the distribution system. Location of the ASR system at the City of Victoria's Surface Water Treatment Plan (SWTP), WTP No. 3, and WTP No. 4 would permit the utilization of existing storage tanks and service pumps already in place. **Figure 1.1** shows the City of Victoria water distribution system and the general location of potential areas for ASR wells.

The City's SWTP is located on the west side of the city near the Guadalupe River. Under normal operating conditions the River Water Pump Station transfers river water from the Guadalupe River to the Off Channel Storage (OCS) ponds located on the southwest side of the City. The River Water Pump Station also has the capability of pumping directly to the surface water treatment plant. A schematic of the City's treatment and pumping system is shown in **Figure 1.2**.

The High Service Pump Station feeds Elevated Storage Tank #4 (EST #4) and EST #6 in the High Pressure Zone of the distribution system. The Medium Service Pump Station pumps to Water Plant #3 (WP #3) located in the Low Pressure Zone of the distribution system. Service pump stations are also located in the distribution system at WP #3 that serves the low pressure zone of the distribution system and WP #4 that serves the high pressure zone of the distribution system.

As described in Section 3.0, the ASR system was modeled for both the base year conditions (represented by the year 2008) and dry year conditions (represented by the year 2011). The simulations were carried out through the year 2040 and assumed a demand increase of 8% per decade. Based on these demands a comparison between the dry year conditions of 2011 and 2040 and the City's existing treatment and pumping capabilities was performed. Pump stations were compared based on their firm pumping capacity (i.e., pumping capacity with the largest unit out of service). **Table 1-2**, on the following page, shows these comparisons.

Based on a comparison of the water demands and pumping and treatment capacities the main areas of concern are the firm pumping capacities of the Raw Water Pump Station and the combined firm pumping capacities of WP #3 and WP #4 that serve the distribution system. When compared to the 2040 maximum day demand of 24.888 MGD these facilities firm pumping capabilities fall just below the maximum day demand. At some point in the future, and prior to 2040, it is recommended that the City increase the Raw Water Pump Station firm pumping capacity and the combined WP #3 and WP #4 service pump firm pumping capacity beyond the 2040 maximum day demand of 24.888 MGD.

Table 1-2: City of Victoria - Comparison of System Demands vs. Pumping & Treatment Capacities.

	DEMANDS				PUMPING/TREATMENT CAPACITIES				
	2040 MAX DAY	2040 AVG DAY	2011 MAX DAY	2011 AVG DAY	RIVER WATER PUMP STATION[A]	RAW WATER PUMP STATION[A]	SWTP	HIGH SVC + MED SVC PUMPS @ SWTP	SVC PUMPS @ WP #3 + WP #4
gpm	17,283	10,432	13,717	8,279	22,900	16,200	17,500	18,400	15,700
MGD	24.888	15.022	19.752	11.922	32.98	23.33	25.20	26.50	22.61
AFY	27,880	16,828	22,127	13,355	36,940	26,132	28,230	29,681	25,326

Notes:

A. Pump rates based on estimated pump capacities received from City of Victoria staff; as noted by staff these rates may vary depending on river level and the OCS pond levels.

1. Values in MGD for 2011 Max Day and Avg Day are from Table 3-1 in Final Report.
2. 2040 values = 2011 values * 1.26 (as described in the Final Report).
3. Pumping capacities shown are Firm Capacities (pumping with largest pump out of service).
4. Cells in yellow are below 2040 Max Day values.

1.2 City of Victoria – Off-Channel Storage (OCS) Infrastructure Assessment

The City of Victoria's water system includes an Off Channel Storage (OCS) area. The OCS system includes a total of eleven old, abandoned gravel pits that are located on the southwest side of the City. These gravel pits are now an integral part of the City's water treatment system providing for the storage and settling of raw water pumped from the Guadalupe River by the River Water Pump Station. The existing OCS pond system is shown on **Figures 1.3** and **1.4.**

In 2011 the City commissioned an evaluation of the existing off channel storage ponds. For the infrastructure assessment, the original CDM study was reviewed and its recommendations were evaluated as part of this planning study.

CDM's study concluded that there was a large storage volume in the existing OCS ponds that was currently not useful. Much of the existing volume determined to be unusable was due to surface connection channels or connecting pipes that were constructed elevations too high to allow for the pumping of the entire volume of water stored in some of the OCS ponds.

At the present time the City's Raw Water Pump station pumps water from OCS Pond 8 to the City's Surface Water Treatment Plant. OCS Pond 8 is connected by a 48 inch diameter pipe to OCS Pond 4. In turn, OCS Pond 4 is connected by a surface channel to OCS Pond 3. Together, OCS Ponds 3, 4, and 8 provide a total of approximately 775 AF of "useful" storage, while their total volume is approximately 1,336 AF.

The existing OCS system includes ponds that are not directly connected to OCS Ponds 3, 4, or 8. At the present time, when additional raw water is needed, it is necessary for the City to use a portable pump to transfer water from these ponds. The City most commonly uses OCS Ponds 5, 6, and 7 for this purpose. These three ponds provide approximately 1,311 AF of "useful" raw water storage volume.

This ASR Feasibility Report includes several different design scenarios, with many of the scenarios assuming a minimum available OCS storage volume of at least 2,000 AF. It is recommended that improvements be made to the OCS pond system so it will provide a minimum of 2,000 AF of raw water storage that is accessible to the existing Raw Water Pump Station located at OCS Pond 8.

To meet the goal of 2,000 AF of accessible raw water storage in the OCS ponds the following recommendations from the CDM, Inc. study should be implemented as part of any ASR system improvements:

1. The channel connection between OCS Pond 3 and OCS Pond 4 should be lowered. The connecting pipe between OCS Pond 4 and OCS Pond 8 should be replaced with a similar size pipe installed at the lowest possible elevation between the ponds.
2. Connect OCS Ponds 5, 6, and 7 to the existing system to eliminate the need for use of a portable pump. The connection can be accomplished by the installation of a pipe between OCS Ponds 7 and 8, and the construction of connection channels between OCS Pond 5 and 6, and OCS Pond 6 and 7.

Based on the above recommended improvements the OCS system would include storage volumes in OCS Ponds 3, 4, 5, 6, 7, and 8 that could be directly pumped by the Raw Water Pump Station located in OCS Pond 8. Following the above recommendations would result in the OCS ponds having a total volume of 2,527 AF of accessible, “useful” storage (see **Table 11-3** for details).

Table 11-3. Off-Channel Storage (OCS) System “Useful” Volumes.

Recommendation #		Storage (AF = acre-feet)
	Existing “Useful” Storage (in OCS Ponds 3, 4, and 8)	775
1.	“Useful” Storage Added to OCS Ponds 3, 4, and 8	441
2.	“Useful” Storage Added to OCS Ponds 5, 6, and 7	1,311
	Total “Useful” Raw Water Storage in OCS System	**2,527**

The CDM study estimated that the connection improvements in OCS Ponds 3, 4, and 8 could be constructed for approximately $0.6 million. The study estimated that the connection of OCS Ponds 5, 6, and 7 could be constructed for approximately $1.6 million. The total construction cost for these recommended improvements would be approximately $2.2 million.

1.3 Victoria County Navigation District/Port of Victoria - Infrastructure Assessment

The Victoria County Navigation District (“Navigation District”) has a water rights permit that allows for the diversion of up to 5,000 AFY for non-consumptive industrial purposes. The permit also includes the use of a 132 AF reservoir to store the diverted water, however at the time this report was finalized the reservoir had not been constructed. The permit requires that all diverted water be returned to the Victoria Barge Canal. A special condition of the permit includes a requirement that the Navigation District operate and maintain an alternative source of water supply that has sufficient capacity to compensate for any consumptive use of water.

At the present time the Navigation District operates a public water supply system (TCEQ PWS 2350051). The system is classified by the TCEQ as a non-transient, non-community public water system and consists of two groundwater wells that have a combined rated capacity of 170 gpm (274 AFY). For the calendar year 2009 the system pumped at an average rate of 5.43 gpm (8.75 AF). Any consumptive use approaching the system's rated capacity would place the Navigation District in a position of potentially not meeting their obligations under the terms of their water rights permit that requires them to compensate for any consumptive use.

An ASR system could serve as the Navigation District's alternative source of water supply to meet the stipulations of the TCEQ water rights permit. At the present time the Navigation District does not hold surface water rights that would allow for the use of water in an ASR system.

However, instead of operating an ASR system at the Port of Victoria site, another option would be for the Navigation District to be obtain any needed consumptive use water from the City of Victoria. An ASR system installed for the City would help to firm up the City's water supply and create the opportunity for the Navigation District to purchase water directly from the City.

In order to allow for the purchase of water from the City of Victoria an interconnecting water line from the Port of Victoria facility to a point of interconnection with the City of Victoria's existing water distribution system would need to be constructed. This interconnecting line would be approximately 8.7 miles long and would connect to the City's system near the intersection of Port Lavaca Drive and US Highway 59 North. A 16 inch diameter pipeline should allow the interconnection to be installed without the need of a booster pump station. The interconnecting line is estimated to cost approximately $4,665,000.

2.0 Financing Options for Plan Implementation

Financing options for this project can involve both open market as well as state and federally subsidized programs. The following is a discussion of identified options to fund the proposed ASR project. This discussion will focus on the general terms and conditions of the financing because there are several factors that can enter into the final terms and conditions of a loan.

2.1 Open Market

The City of Victoria has financed most of its water improvements using money that is included in its annual budget or through long term bond financing. The rates and terms of the loans are typically negotiated or sold on a competitive basis. The typical term for a loan is 20-25 years and interest rates are based on the prevailing market interest rates for similar types of securities. For the City of Victoria, the loans can be secured through a pledge of ad valorem taxes, utility revenues, or a combination of both taxes and revenues. For the river authorities, the loans must be secured through a pledge of utility revenues.

2.2 Texas Water Development Board

The Texas Water Development Board (TWDB) offers several financing programs for water infrastructure. The TWDB programs include both federally subsidized interest rate programs as well as state supported programs. The federally subsidized programs include the Drinking Water State Revolving Fund. State supported programs include the Texas Water Development Fund (DFund) the State Participation Program (SP), the Water Infrastructure Fund (WIF), and the State Water Implementation Fund for Texas (SWIFT).

2.2.1 Drinking Water State Revolving Fund (DWSRF)

The Drinking Water State Revolving Fund (DWSRF) is a federally subsidized program that reduces interest rates to borrowers who qualify for assistance. Additional loan forgiveness can also be approved for specific "green" initiatives which include energy conservation and water conservation. The interest rate subsidy will reduce the borrowing costs by lowering the interest rates below market rates. Typical loans are for a 20 year term.

Financial assistance from the DWSRF can be utilized for: water treatment facilities, distribution systems, upgrade or replace water infrastructure, address standards from the Safe Drinking Water Act, consolidation of systems, purchasing additional capacity, source water protect projects, and eligible green project reserve components.

2.2.2 Texas Water Development Fund (DFund)

The Texas Water Development Fund (DFund) is a state backed program that offers local borrowers the same interest rate as that of the State of Texas. This term of the loan is typically 20-30 years with interest rates based on the cost of borrowing by the TWDB. The DFund offers the advantage of being able to fund projects with multiple, eligible water and wastewater related purposes in one loan. This program offers the most flexible eligibility requirements and can be used for multiple purposes including: water supply, water transmission and distribution systems, water conservation, water quality, flood control, and municipal solid waste.

2.2.3 State Participation Program

The State Participate Program allows the TWDB to become a temporary partner in a regional project when the local sponsors are unable to assume the total debt for an optimally sized facility. The TWDB may acquire an ownership interest in both the facilities as well as water rights. The project sponsor is required to repurchase the TWDB interest under a repayment schedule that allows for the deferral of principal and interest payments. The amount of funding available is dependent on appropriations be the Texas Legislature. Principal and interest payment deferrals are typically for 10 years with repayment based on simple interest accrued during the deferral period.

2.2.4 Water Infrastructure Fund

The Water Infrastructure Fund offers state loans for up to 20 years at a subsidized interest rate below the TWDB cost of funds. Loans can be used for the planning, design and construction of projects identified in the State Water Plan. Projects funded by the WIF must be identified strategies in the most recent Regional and State Water Plans. The amount of available funding is dependent on appropriations from the Texas Legislature.

2.2.5 State Water Implementation Fund for Texas

The State Water Implementation Fund for Texas was established by the Legislature and approved by the voters in November of 2013 and is designed to help fund projects in the State Water Plan. Available funding will be allocated based on a point system and will be used as part of an overall funding strategy to implement projects. Eligible projects include conservation and reuse, desalination of groundwater and seawater, building new pipelines and developing new reservoirs and well fields as well as other water related projects. By legislative mandate 20% of the SWIFT funds must be used for conservation and reuse, 10% for rural communities and agricultural conservation projects.

1.0 Infrastructure Assessment for Victoria Area ASR Feasibility

1.1 City of Victoria – Public Water System Infrastructure Assessment

As previously discussed in Section 8.2.2, an ASR system serving the City of Victoria would be located in areas to allow for easy integration into the City's distribution system and would require minimal infrastructure improvements with respect to the distribution system. Location of the ASR system at the City of Victoria's Surface Water Treatment Plan (SWTP), WTP No. 3, and WTP No. 4 would permit the utilization of existing storage tanks and service pumps already in place. **Figure 1.1** shows the City of Victoria water distribution system and the general location of potential areas for ASR wells.

The City's SWTP is located on the west side of the city near the Guadalupe River. Under normal operating conditions the River Water Pump Station transfers river water from the Guadalupe River to the Off Channel Storage (OCS) ponds located on the southwest side of the City. The River Water Pump Station also has the capability of pumping directly to the surface water treatment plant. These OCS ponds are a series of former gravel pits that allow for the storage and settling of the raw river water prior to treatment. The Raw Water Pump Station located in OCS Pond #8 pumps the raw water in the OCS ponds to the SWTP for processing through a conventional treatment train. Once the raw water is treated by the SWTP it is stored in two 2.25 MG on-site clearwells prior to pumping the treated water into the City's distribution system. A schematic of the City's treatment and pumping system is shown in **Figure 1.2**.

The City's SWTP has a maximum treatment capacity of 25.2 MGD (28,230 AFY). The treated water stored in the SWTP's on-site clearwells is pumped into the distribution system by a High Service Pump Station and a Medium Service Pump Station, that pump to the distribution system's high pressure zone and low pressure zone, respectively. Each service pump station pumps to 24 inch diameter lines that feed the distribution system.

The High Service Pump Station feeds Elevated Storage Tank #4 (EST #4) and EST #6 in the High Pressure Zone of the distribution system. The Medium Service Pump Station pumps to Water Plant #3 (WP #3) located in the Low Pressure Zone of the distribution system.

Service pump stations are also located in the distribution system at WP #3 that serves the low pressure zone of the distribution system and WP #4 that serves the high pressure zone of the distribution system.

The City's water system includes five elevated storage tanks that have a combined capacity of 4.0 MG. The system also includes a total of 6.5 MG of ground storage in additional to the 4.5 MG of clearwell storage located at the SWTP.

A summary of the City's treatment, storage, and pumping capacities can be found in **Table 1-1**.

Table 1-1. City of Victoria Public Water System Water Treatment, Pumping & Storage Facilities.

	Firm Pumping Capacity (gpm)	Firm Pumping Capacity (MGD)	Firm Pumping Capacity (AFY)
River Water Pump Station			
2 pumps @ 6,700 gpm each	22,900	32.98	36,940
2 pumps @ 9,500 gpm each			
Raw Water Pump Station			
3 pumps @ 8,100 gpm each	16,200	23.33	26,133
Surface Water Treatment Plant (SWTP)			
Treatment Capacity	17,500	25.20	28,230
TREATED WATER PUMPING FACILITIES			
SWTP High Service Pumps (pumps to EST #4 & EST #6 in High Pressure Plane)			
3 pumps@ 4,000 gpm each	8,000	11.52	12,095
WP #4 (pumps to EST #4 & EST #6 in High Pressure Plane)			
3 pumps @ 2,250 gpm each	4,500	6.48	7,259
SWTP Medium Service Pumps (pumps to WP #3 in Low Pressure Plane)			
3 pumps @ 5,200 gpm each	10,400	14.98	16,776
WP #3 (pumps to EST #3 & EST #5 in Low Pressure Plane)			
3 pumps @ 4,200 gpm each	10,200	14.69	16,454
2 pumps @ 3,000 gpm each			

WATER STORAGE

GROUND STORAGE			ELEVATED STORAGE		
Clearwell @ SWTP	2.25		EST #1	1.0	
Clearwell @ SWTP	2.25		EST #3	0.5	
	4.5	**MG**	EST #4	0.5	
			EST #5	1.0	
GST @ WP #3	2.0		EST #6	1.0	
GST @ WP #3	1.0			**4.0**	**MG**
GST @ WP #3	1.0				
GST @ WP #3	1.5		**TOTAL EST =**	**4.0**	**MG**
	5.5	**MG**			
GST @ WP #4	1.0				
	1.0	**MG**			
TOTAL GROUND STORAGE =	**11.0**	**MG**			

Notes: 1. **Firm capacity** is defined as the pumping or treatment rate with the largest unit out of service.

2. All storage volumes are in millions of gallons (MG).

As described in Section 3.0, the ASR system was modeled for both the base year conditions (represented by the year 2008) and dry year conditions (represented by the year 2011). The simulations were carried out through the year 2040 and assumed a demand increase of 8% per decade. Based on these demands a comparison between the dry year conditions of 2011 and 2040 and the City's existing treatment and pumping capabilities was performed. Pump stations were compared based on their firm pumping capacity (i.e., pumping capacity with the largest unit out of service). **Table 1-2** shows these comparisons.

Table 1-2: City of Victoria - Comparison of System Demands vs. Pumping & Treatment Capacities.

	DEMANDS				PUMPING/TREATMENT CAPACITIES				
	2040 MAX DAY	2040 AVG DAY	2011 MAX DAY	2011 AVG DAY	RIVER WATER PUMP STATION[A]	RAW WATER PUMP STATION[A]	SWTP	HIGH SVC + MED SVC PUMPS @ SWTP	SVC PUMPS @ WP #3 + WP #4
gpm	17,283	10,432	13,717	8,279	22,900	16,200	17,500	18,400	15,700
MGD	24.888	15.022	19.752	11.922	32.98	23.33	25.20	26.50	22.61
AFY	27,880	16,828	22,127	13,355	36,940	26,132	28,230	29,681	25,326

Notes:

A. Pump rates based on estimated pump capacities received from City of Victoria staff; as noted by staff these rates may vary depending on river level and the OCS pond levels.

1. Values in MGD for 2011 Max Day and Avg Day are from Table 3-1 in Final Report.
2. 2040 values = 2011 values * 1.26 (as described in the Final Report).
3. Pumping capacities shown are Firm Capacities (pumping with largest pump out of service).
4. Cells in yellow are below 2040 Max Day values.

Based on a comparison of the water demands and pumping and treatment capacities the main areas of concern are the firm pumping capacities of the Raw Water Pump Station and the combined firm pumping capacities of WP #3 and WP #4 that serve the distribution system. When compared to the 2040 maximum day demand of 24.888 MGD these facilities firm pumping capabilities fall just below the maximum day demand. It should be noted that both the Raw Water Pump Station and the combined WP #3 and WP #4 firm pumping capacities are greater than the 2011 Maximum Day demand of 19.752 MGD. At some point in the future, and prior to 2040, it is recommended that the City increase the River Water Pump Station firm pumping capacity and the combined WP #3 and WP #4 service pump firm pumping capacity beyond the 2040 maximum day demand of 24.888 MGD.

1.2 City of Victoria – Off-Channel Storage (OCS) Infrastructure Assessment

As previously discussed Section 3.0 and 7.1.1, the City of Victoria's water system includes an Off Channel Storage (OCS) area. The OCS system includes a total of eleven old, abandoned gravel pits that are located on the southwest side of the City. These gravel pits are now an integral part of the City's water treatment system providing for the storage and settling of raw water pumped from the Guadalupe River by the River Water Pump Station. The existing OCS pond system is shown on **Figures 1.3** and **1.4.**

In 2011 the City commissioned an evaluation of the existing off channel storage ponds. This report by CDM, Inc. (CDM) was finalized in October 2011 and included bathymetric surveys of the off channels storage ponds, detailed descriptions of the existing OCS system, recommendations on improvements to the existing system, and cost estimates for the recommended projects. The CDM study has been included as **Appendix A**. For the infrastructure assessment, the original CDM study was reviewed and its recommendations were evaluated as part of this planning study.

CDM's study concluded that there was a large storage volume in the existing OCS ponds that was currently not useful. Much of the existing volume determined to be unusable was due to surface connection channels or connecting pipes that were constructed elevations too high to allow for the pumping of the entire volume of water stored in some of the OCS ponds.

At the present time the City's Raw Water Pump station pumps water from OCS Pond 8 to the City's Surface Water Treatment Plant. OCS Pond 8 is connected by a 48 inch diameter pipe to OCS Pond 4. In turn, OCS Pond 4 is connected by a surface channel to OCS Pond 3. Together, OCS Ponds 3, 4, and 8 provide a total of approximately 775 AF of "useful" storage, while their total volume is approximately 1,336 AF. The difference between "useful" storage and total volume is the amount of water stored below the elevation of the ponds' connecting pipe or channel, which in effect is never available for pumping by the Raw Water Pump Station.

The existing OCS system includes ponds that are not directly connected to OCS Ponds 3, 4, or 8. At the present time, when additional raw water is needed, it is necessary for the City to use a portable pump to transfer water from these ponds. The City most commonly uses OCS Ponds 5, 6, and 7 for this purpose. These three ponds provide approximately 1,311 AF of "useful" raw water storage volume.

The ASR Feasibility Report includes several different design scenarios which are summarized in Table 7.2 of the report. Many of the design scenarios assume a minimum available OCS storage volume of at least 2,000 AF. It is recommended that improvements be made to the OCS pond system so it will provide a minimum of 2,000 AF of raw water storage that is accessible to the existing Raw Water Pump Station located at OCS Pond 8.

To meet the goal of 2,000 AF of accessible raw water storage in the OCS ponds the following recommendations from the CDM, Inc. study should be implemented as part of any ASR system improvements:

1. The channel connection between OCS Pond 3 and OCS Pond 4 should be lowered. The connecting pipe between OCS Pond 4 and OCS Pond 8 should be replaced with a similar size pipe installed at the lowest possible elevation between the ponds. CDM's study indicates that these improvements would provide access to an additional 441 AF of raw water;
2. Connect OCS Ponds 5, 6, and 7 to the existing system to eliminate the need for use of a portable pump. The connection can be accomplished by the installation of a pipe between OCS Ponds 7 and 8, and the construction of connection channels between OCS Pond 5 and 6, and OCS Pond 6 and 7. These interconnects would add approximately 1,311 AF to the existing storage system and would allow the Raw Water Pump Station at OCS Pond 8 to access this additional water directly, without the use of portable pumps.

Based on the above recommended improvements the OCS system would include storage volumes in OCS Ponds 3, 4, 5, 6, 7, and 8 that could be directly pumped by the Raw Water Pump Station located in OCS Pond 8. Following the above recommendations would result in the OCS ponds having a total volume of 2,527 AF of accessible, "useful" storage (see **Table 1-3** for details).

Table 1-3. Off-Channel Storage (OCS) System "Useful" Volumes.

Recommendation #		Storage (AF = acre-feet)
	Existing "Useful" Storage (in OCS Ponds 3, 4, and 8)	775
1.	"Useful" Storage Added to OCS Ponds 3, 4, and 8	441
2.	"Useful" Storage Added to OCS Ponds 5, 6, and 7	1,311
	Total "Useful" Raw Water Storage in OCS System	**2,527**

NOTES:

- "Useful" storage is raw water volume that can be accessed by the existing Raw Water Pump Station located in OCS Pond 8.
- Recommendation 1: "Useful" storage increased by lowering existing connections between OCS Ponds 3 and 4 (channel) and OCS Ponds 4 and 8 (pipe).
- Recommendation 2: "Useful" storage increased by installation of a connecting pipe between OCS Ponds 7 and 8 (pipe) and by channel connections between OCS Ponds 7 and 5 and OCS Ponds 5 and 6.

The CDM study estimated that the connection improvements in OCS Ponds 3, 4, and 8 could be constructed for approximately $0.6 million. The study estimated that the connection of OCS Ponds 5, 6, and 7 could be constructed for approximately $1.6 million. The total construction cost for these recommended improvements would be approximately $2.2 million. These improvements would add an additional 1,752 AF of "useful" raw water storage at a cost of approximately $1,260/AF. As a comparison, both Options A and D listed in Table 7.1 of the ASR Feasibility Report included total recoverable ASR volumes of 83,030 AF. Based on the estimated total ASR system cost of $ 21.1 million and an estimated $136/AF for treatment of the storage water the cost for storage in the ASR system is approximately $390/AF.

1.3 Victoria County Navigation District/Port of Victoria - Infrastructure Assessment

As discussed previously in Section 5.0 of the ASR Feasibility Report, the Victoria County Navigation District ("Navigation District") has a water rights permit that allows for the diversion of up to 5,000 AFY for non-consumptive industrial purposes. The permit also includes the use of a 132 AF reservoir to store the diverted water, however at the time this report was finalized the reservoir had not been constructed. The permit requires that all diverted water be returned to the Victoria Barge Canal. A special condition of the permit includes a requirement that the Navigation District operate and maintain an alternative source of water supply that has sufficient capacity to compensate for any consumptive use of water.

At the present time the Navigation District operates a public water supply system (TCEQ PWS 2350051). The system is classified by the TCEQ as a non-transient, non-community public water system and consists of two groundwater wells that have a combined rated capacity of 170 gpm (274 AFY). For the calendar year 2009 the system pumped at an average rate of 5.43 gpm (8.75 AF). Any consumptive use approaching the system's rated capacity would place the Navigation District in a position of potentially not meeting their obligations under the terms of their water rights permit that requires them to compensate for any consumptive use.

An ASR system could serve as the Navigation District's alternative source of water supply to meet the stipulations of the TCEQ water rights permit. As described in Section 6.6.4 of the ASR Feasibility Report, the area surrounding the Port of Victoria has attractive hydrogeological conditions that would be suitable for an ASR system. However, at the present time the Navigation District does not hold surface water rights that would allow for the use of water in an ASR system.

However, instead of operating an ASR system at the Port of Victoria site, another option would be for the Navigation District to be obtain any needed consumptive use water from the City of Victoria. An ASR system installed for the City would help to firm up the City's water supply and create the opportunity for the Navigation District to purchase water directly from the City.

In order to allow for the purchase of water from the City of Victoria an interconnecting water line from the Port of Victoria facility to a point of interconnection with the City of Victoria's existing water distribution system would need to be constructed. This interconnecting line would be approximately 8.7 miles long and would connect to the City's system near the intersection of Port Lavaca Drive and US Highway 59 North. A 16 inch diameter pipeline should allow the interconnection to be installed without the need of a booster pump station. The interconnecting line is estimated to cost approximately $4,665,000. A summary of the interconnection cost estimate is outlined in **Table 1-4.**

Table 1-4. Cost Estimate Summary – Port of Victoria Connection to City of Victoria PWS

Cost Estimate Summary
Water Supply Project Option
March 2014 Prices
Port of Victoria Connection to City of Victory PWS

Item		*Estimated Costs for Facilities*
Capital Costs		
Connecting Pipeline – 8.7 mile, 16" Dia.	$	3 ,000,000
Pump Station(s)		-
SCADA		100,000
Total Capital Cost	**$**	**3,100,000**
Engineering, Legal Costs and Contingencies	$	1,085,000
Environmental & Archaeology Studies		
Land Acquisition and Access		
Interest During Construction (1 year)		180,000
Total Project Cost	**$**	**4,665,000**
Annual Costs*		
Debt Service (5 percent, 30 years)	$	305,000
* - annual cost do not include operation and maintenance costs or water costs		

2.0 Financing Options for Plan Implementation

Financing options for this project can involve both open market as well as state and federally subsidized programs. The following is a discussion of identified options to fund the proposed ASR project. This discussion will focus on the general terms and conditions of the financing because there are several factors that can enter into the final terms and conditions of a loan.

2.1 Open Market

The City of Victoria has financed most of its water improvements using money that is included in its annual budget or through long term bond financing. The rates and terms of the loans are typically negotiated or sold on a competitive basis. The typical term for a loan is 20-25 years and interest rates are based on the prevailing market interest rates for similar types of securities. For the City of Victoria, the loans can be secured through a pledge of ad valorem taxes, utility revenues, or a combination of both taxes and revenues. For the river authorities, the loans must be secured through a pledge of utility revenues.

2.2 Texas Water Development Board

The Texas Water Development Board (TWDB) offers several financing programs for water infrastructure. The TWDB programs include both federally subsidized interest rate programs as well as state supported programs. The federally subsidized programs include the Drinking Water State Revolving Fund. State supported programs include the Texas Water Development Fund (DFund) the State Participation Program (SP), the Water Infrastructure Fund (WIF), and the State Water Implementation Fund for Texas (SWIFT).

2.2.1 Drinking Water State Revolving Fund (DWSRF)

The Drinking Water State Revolving Fund (DWSRF) is a federally subsidized program that reduces interest rates to borrowers who qualify for assistance. Additional loan forgiveness can also be approved for specific "green" initiatives which include energy conservation and water conservation. The interest rate subsidy will reduce the borrowing costs by lowering the interest rates below market rates. Typical loans are for a 20 year term.

Financial assistance from the DWSRF can be utilized for:

- water treatment facilities,
- distribution systems,
- upgrade or replace water infrastructure,
- address standards from the Safe Drinking Water Act,
- consolidation of systems,
- purchasing additional capacity,
- source water protect projects, and
- eligible green project reserve components

The TWDB accepts projects for the DWSRF program annually, beginning on December 1 and ending on March 1. Following adoption of the IUP by the Board, the TWDB may reopen the program for additional projects that meet certain criteria such as eligible green projects, emergency, and construction-ready projects or if funds are available after the initial application submission deadline.

2.2.2 Texas Water Development Fund (DFund)

The Texas Water Development Fund (DFund) is a state backed program that offers local borrowers the same interest rate as that of the State of Texas. This program offers the most flexible eligibility requirements and can be used for multiple purposes including:

- Water supply
- Water transmission and distribution systems
- Water conservation
- Water quality
- Flood control
- Municipal solid waste

This term of the loan is typically 20-30 years with interest rates based on the cost of borrowing by the TWDB. The DFund offers the advantage of being able to fund projects with multiple, eligible water and wastewater related purposes in one loan.

2.2.3 State Participation Program

The State Participate Program allows the TWDB to become a temporary partner in a regional project when the local sponsors are unable to assume the total debt for an optimally sized facility. The TWDB may acquire an ownership interest in both the facilities as well as water rights. The project sponsor is required to repurchase the TWDB interest under a repayment schedule that allows for the deferral of principal and interest payments. The amount of funding available is dependent on appropriations be the Texas Legislature. Principal and interest payment deferrals are typically for 10 years with repayment based on simple interest accrued during the deferral period.

2.2.4 Water Infrastructure Fund

The Water Infrastructure Fund offers state loans for up to 20 years at a subsidized interest rate below the TWDB cost of funds. Loans can be used for the planning, design and construction of projects identified in the State Water Plan. Projects funded by the WIF must be identified strategies in the most recent Regional and State Water Plans. The amount of available funding is dependent on appropriations from the Texas Legislature.

2.2.5 State Water Implementation Fund for Texas

The State Water Implementation Fund for Texas was established by the Legislature and approved by the voters in November of 2013 and is designed to help fund projects in the State Water Plan. Available funding will be allocated based on a point system and will be used as part of an overall funding strategy to implement projects. Eligible projects include conservation and reuse, desalination of groundwater and seawater, building new pipelines and developing new reservoirs and well fields as well as other water related projects. By legislative mandate 20% of the SWIFT funds must be used for conservation and reuse, 10% for rural communities and agricultural conservation projects.

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FIGURES

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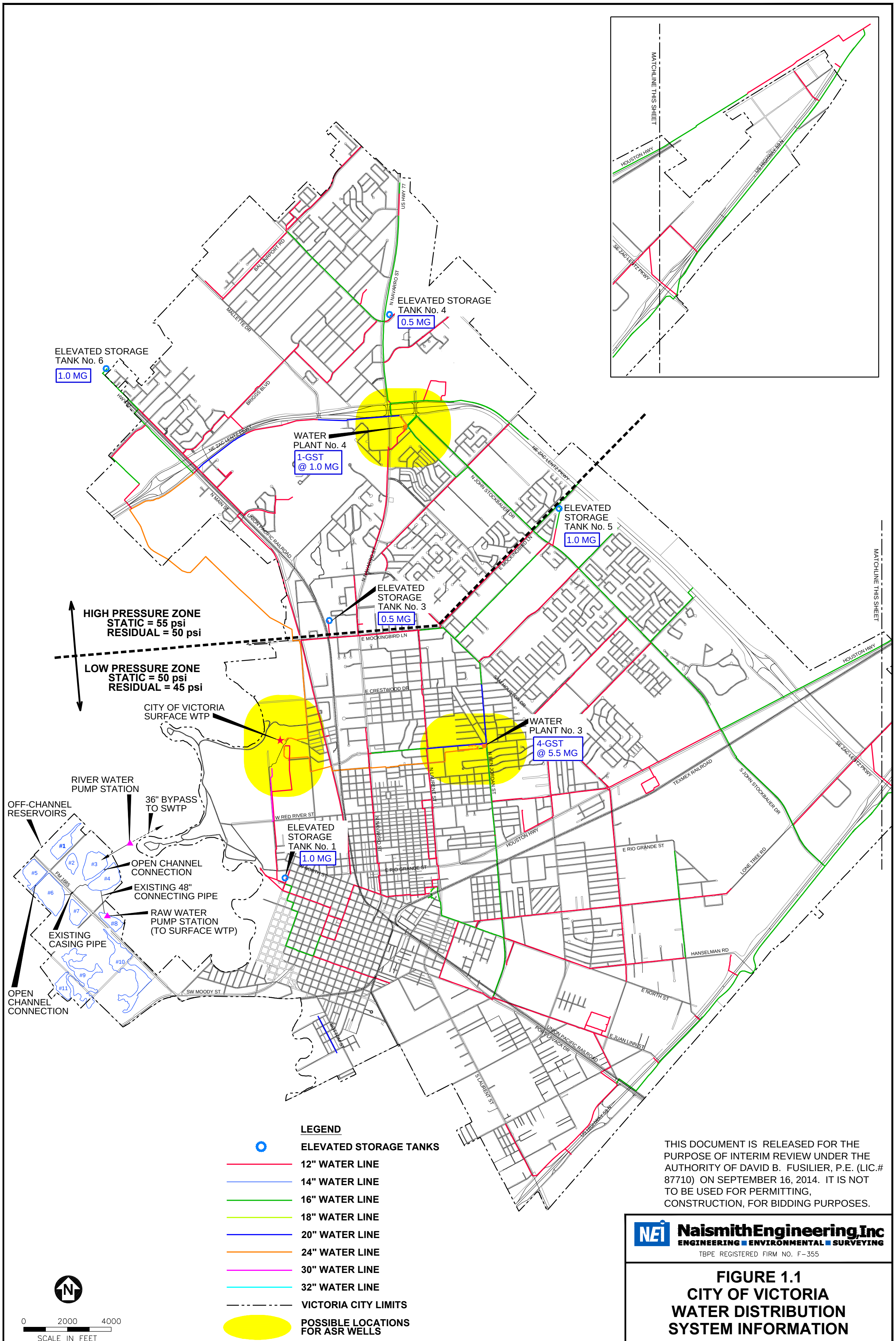

FIGURE 1.1
CITY OF VICTORIA
WATER DISTRIBUTION
SYSTEM INFORMATION

Base Map Source: This Map is Created from GIS Shape Files Provided from the City of Victoria, Texas.

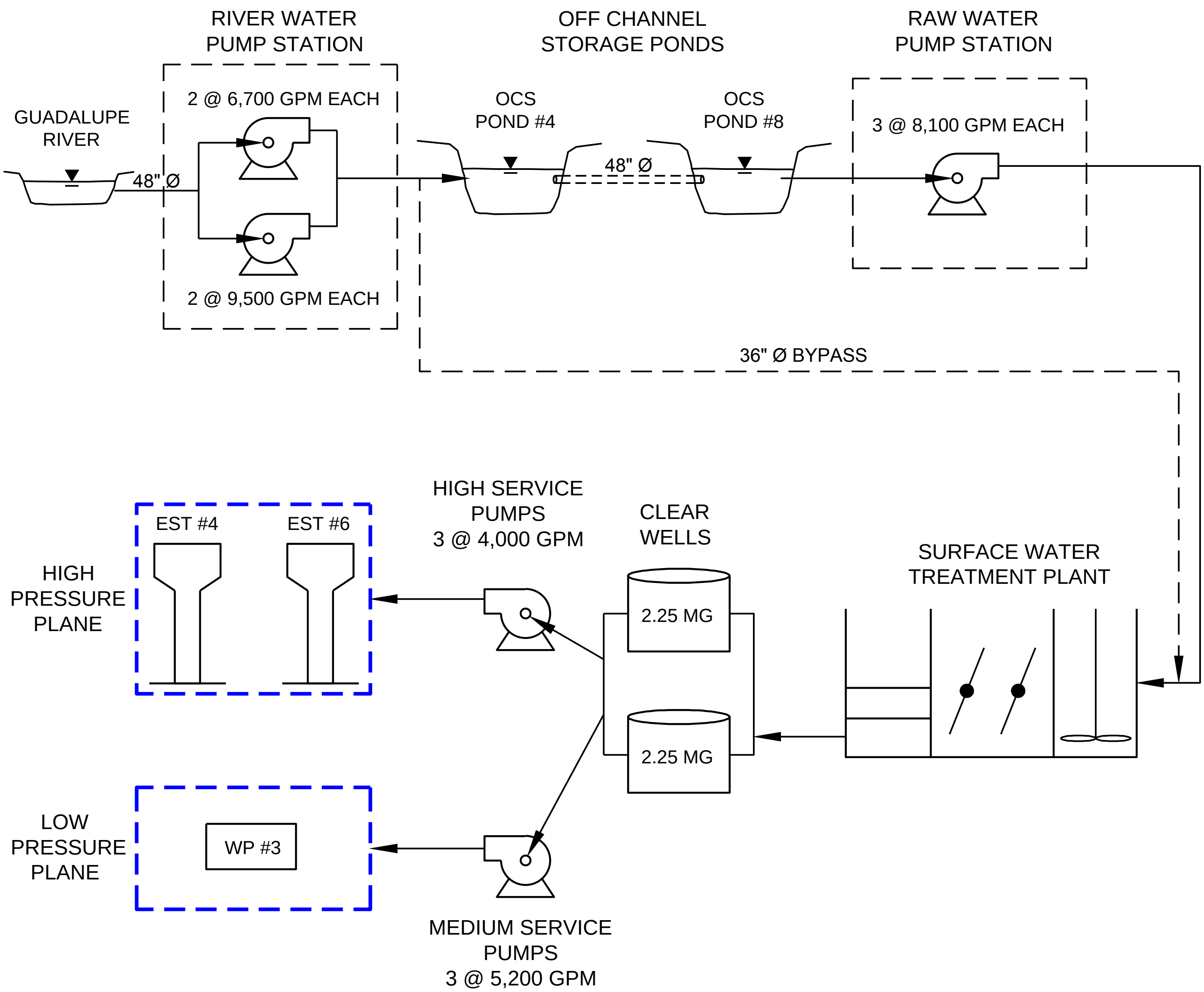

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FIGURE 1.2
CITY OF VICTORIA
SCHEMATIC OF
PUBLIC WATER SYSTEM

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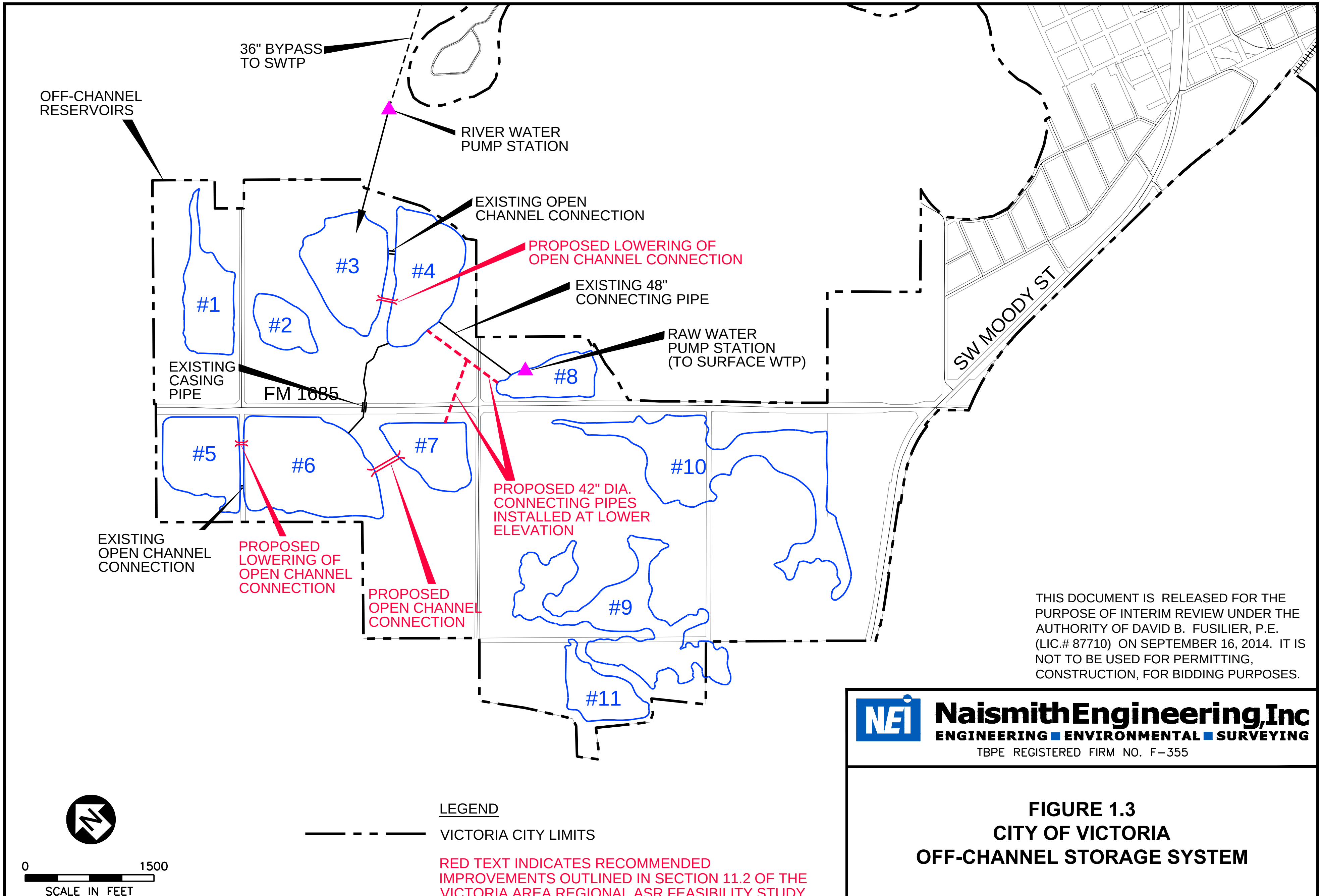
Checked By: DBF	Project No.: 8806	Date: 09/16/14	Rev.: 09/16/14	Of



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LEGEND

VICTORIA CITY LIMITS

RED TEXT INDICATES RECOMMENDED IMPROVEMENTS OUTLINED IN SECTION 11.2 OF THE VICTORIA AREA REGIONAL ASR FEASIBILITY STUDY

Base Map Source: This Map is Created from GIS Shape Files Provided from the City of Victoria, Texas.

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FIGURE 1.3
CITY OF VICTORIA
OFF-CHANNEL STORAGE SYSTEM

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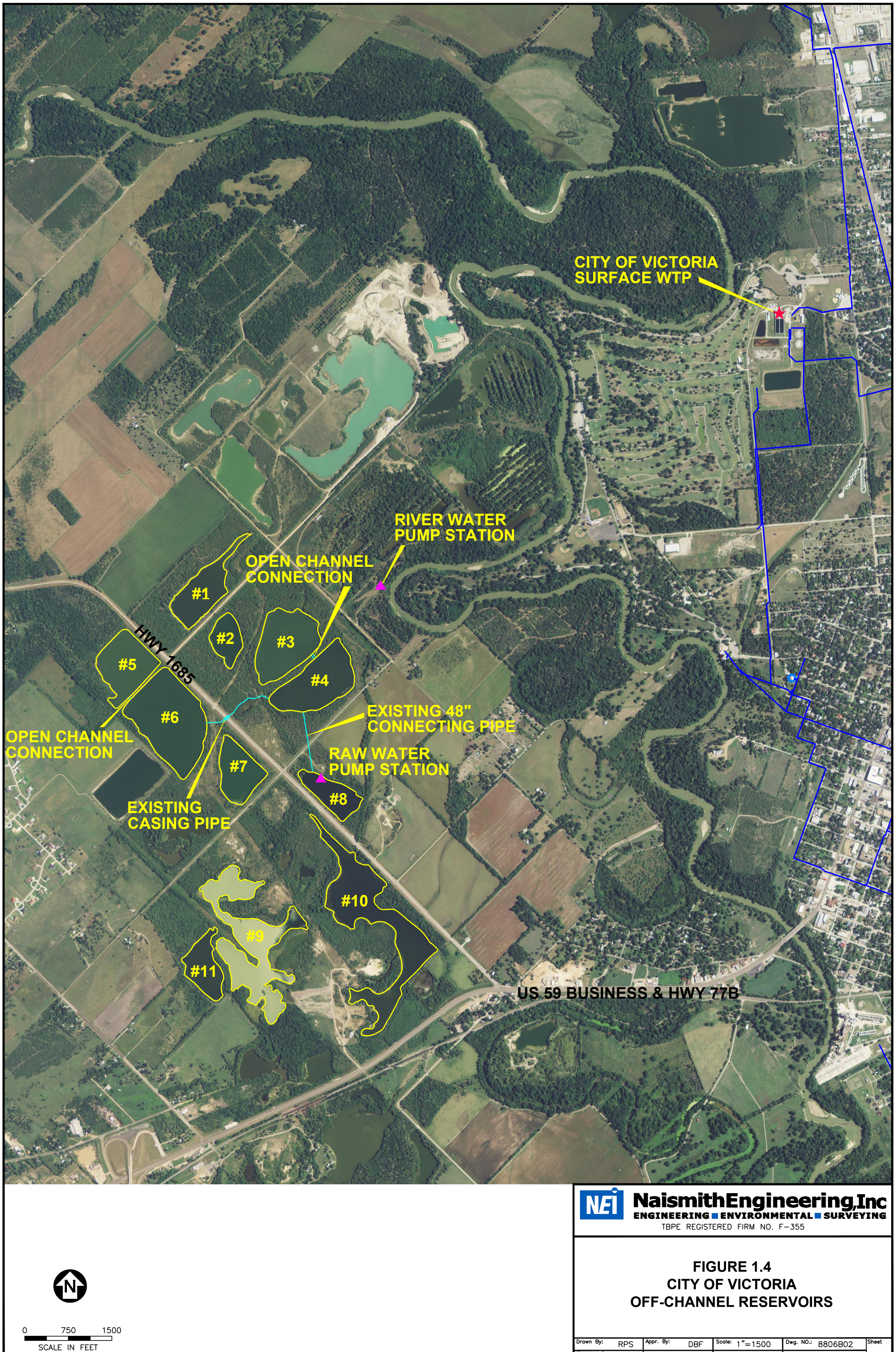

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FIGURE 1.4
CITY OF VICTORIA
OFF-CHANNEL RESERVOIRS

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Checked By:	DBF	Project No.:	8806	Date:	09/16/14	Rev.:	09/16/14	of	

Appendix A

Preliminary Engineering Report
City of Victoria - Off Channel Reservoir
Additional Volume Evaluation
by CDM, Inc., October 2011

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PRELIMINARY ENGINEERING REPORT

OFF CHANNEL RESERVOIR ADDITIONAL VOLUME EVALUATION

Prepared for
City of Victoria

October 2011

STATE OF TEXAS
ALLEN D. WOELKE, P.E.
54386
REGISTERED PROFESSIONAL ENGINEER
10/26/11

CDM

Texas TBPE Firm Registration No. F-3043

CITY OF VICTORIA
OFF CHANNEL RESERVOIR ADDITIONAL VOLUME

PRELIMINARY ENGINEERING REPORT

As part of the surface water project that introduced treated surface water from the Guadalupe River into the City of Victoria, several off channel reservoirs (OCRs), which were previously gravel quarries, were acquired to provide storage of surface water for use when it was not possible to divert from the Guadalupe River. **Figure 1** shows the location and numbering of the OCRs along with the 100-year flood plain and floodway boundary. Figure 1 also shows the limit of the City's property in the OCR area.

When the treated surface water system was first constructed, the diversion scheme and the use of the OCRs were as follows:

- Surface water is diverted from the Guadalupe River at Fox's Bend using the River Intake and Pump Station
- Surface water is pumped to OCR-4
- OCR-4 and OCR-3 are connected near the surface with an open channel
- OCR-4 is connected to OCR-8 with a 48-in pipe
- A raw water pump station pumps water from OCR-8 to the surface water treatment plant
- A shallow casing runs beneath FM 1685 to allow pumping of water from OCR-6 to OCR-4.

The City wanted to determine how much volume was in each of the OCRs, connected and not connected, and to determine the cost to connect them by gravity to the system.

The scope of work for this preliminary engineering evaluation consists of bathymetric surveys of all 11 OCRs to allow the volume in the OCRs to be determined. Based on initial volumes and costs to connect the OCRs, final potential connection locations were surveyed to aid in the preparation of construction cost estimates for the connections. The connections would be made with open channels if possible and with pipe connections if open channel connections were not feasible.

This report presents the results of the preliminary engineering study, including the volumes of the OCRs, the cost to connect the OCRs and recommendations for additional storage to further firm up the surface water supply.

Index

CDM

Texas TBPE Firm Registration No. F-3043

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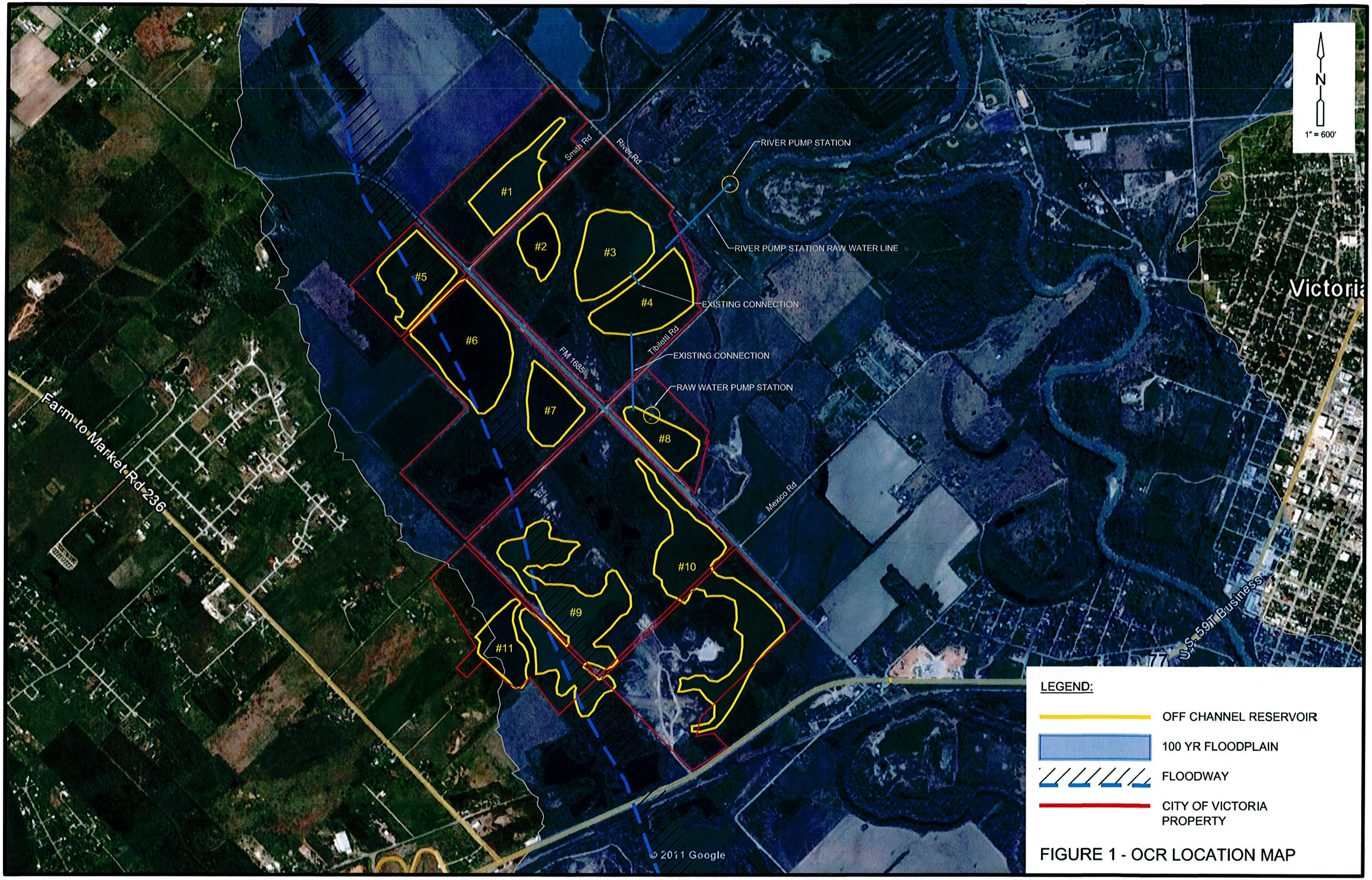


FIGURE 1 - OCR LOCATION MAP

Bathymetric Survey

Urban Surveying, Inc. (USI) performed the bathymetric survey of all 11 OCRs. The bathymetric survey was conducted using a Sonarmite depth sounder integrated with a Trimble R8 Real Time Kinematic survey system. The OCR contours were provided to CDM in an electronic format. Autodesk Civil 3D was used to determine the volume of the OCRs based on the contours provided by USI. The volume information was used to develop stage-storage relationships for all 11 OCRs.

Based on this information, it was determined that the total volume of OCR-3, OCR-4 and OCR-8 is 1,319.4 Ac-Ft. The volumes of all the OCRs are shown graphically in **Figure 2**. Details on the top and bottom elevations of each OCR are shown graphically in **Figure 3**. In Figure 3, the volume of the OCR is shown diagrammatically by the width of the rectangle. The wider the rectangle, the more volume contained in the OCR. In general, the following conclusions can be drawn from the information provided in Figures 2 and 3.

1. OCR-6 is the largest of the OCRs, with OCR3 and OCR-4 the next largest.
2. OCR-9 and OCR-10 have large surface areas but are shallower than the other OCRs and hence have relatively small volumes compared to their surface area.
3. OCR-9, OCR-10 and OCR-11 have a lower top elevation than the remaining OCRs. Connecting these three OCRs by gravity to the remainder of the system would have a negative impact on the available storage in the remaining OCRs. Raising the elevation of OCR-9 and OCR-10 is not possible because of their location within the Guadalupe River Floodway.

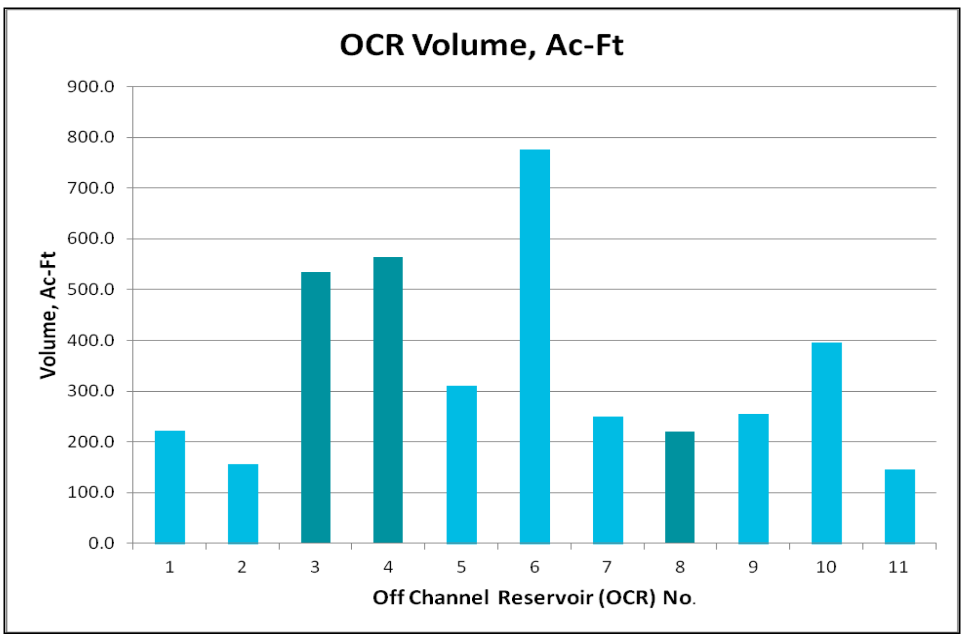
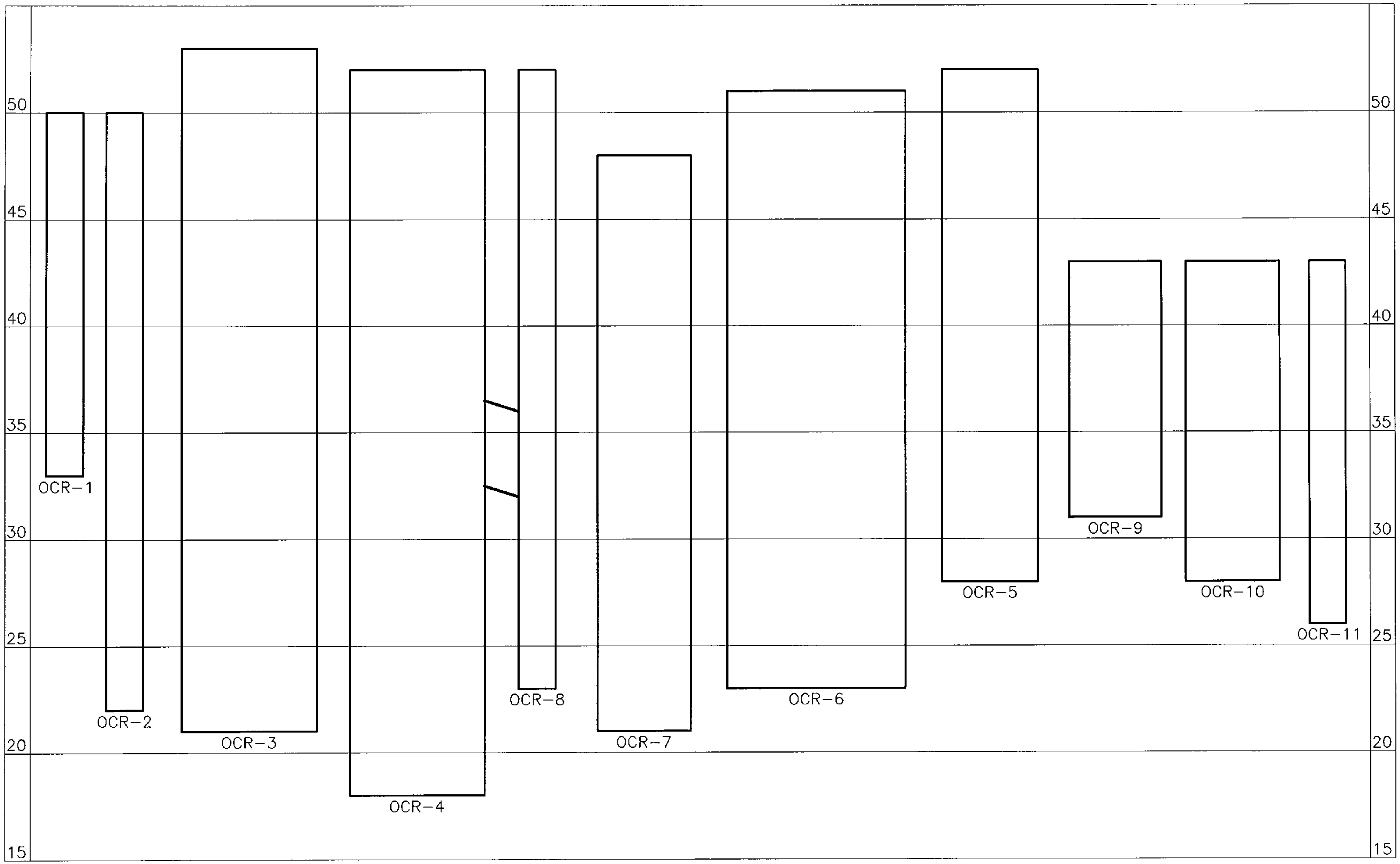


Figure 2. Individual OCR Volumes



CDM

CITY OF VICTORIA, TEXAS

OCR PROFILE

FIGURE No 3

Existing Raw Water System

Water from the currently connected OCRs is pumped to the City's Water Treatment Plant using a Raw Water Pump Station in OCR-8. A section view of the pump station is shown in **Figure 4**. The section in Figure 4 was taken from the construction plans for the Raw Water Pump Station. When the pump station was constructed in the late 1990's, the bottom elevation of the pump was set as 30.50 as shown in Figure 4, which was based on limited cross section data available at that time for OCR-8.

Based on the current bathymetric survey, the bottom of OCR-8 is elevation 23; however, the OCR bottom at the pump station is at an elevation of 26 based upon soundings recently made by City staff. It is possible to lengthen the column and shaft on the existing pumps to take advantage of more storage in OCR-8 and the other connected OCRs. It is recommended that the pump columns and shafts be extended to take advantage of the maximum feasible amount of available storage. Moreover, it may be advantageous to dredge OCR-8 so that it is as deep as OCR-7 so that more of the total volume in the OCRs could be utilized.

Likewise, in the late 1990's, a 48-inch pipe connection between OCR-4 and OCR-8 was constructed to allow gravity flow from OCR-4 to OCR-8. This connection is shown in Figure 3. This gravity connection was constructed to work with the pump elevation shown in Figure 4, but does not allow the entire volume of OCR-4 to drain to OCR-8. The existing gravity connection was constructed with an elevation of 32.5 in OCR-4. The bottom of OCR-4 based on the bathymetric survey is lower than an elevation of 20. OCR-3 is connected to OCR-4 by a shallow channel at an elevation of 44.

The OCR volume information presented in Figure 2 is the total volume in each OCR. The useful storage in the OCR is dependent on how much of the water in the OCR can reach the raw water pump station and be pumped to the water treatment plant. The total volume of OCR-3, OCR-4 and OCR-8 based on the bathymetric survey and the useful volume, the volume that can reach the existing raw water pumps by gravity, is shown below.

	Total Volume	Useful Volume
OCR-3	534.6	182.8
OCR-4	565.0	408.3
OCR-8	219.9	184.4
Total	1,319.5	775.5

Approximately 40% of the total volume in OCR-3, ORC-4 and OCR-8 is not useful because it is not connected by gravity to the raw water pumps.

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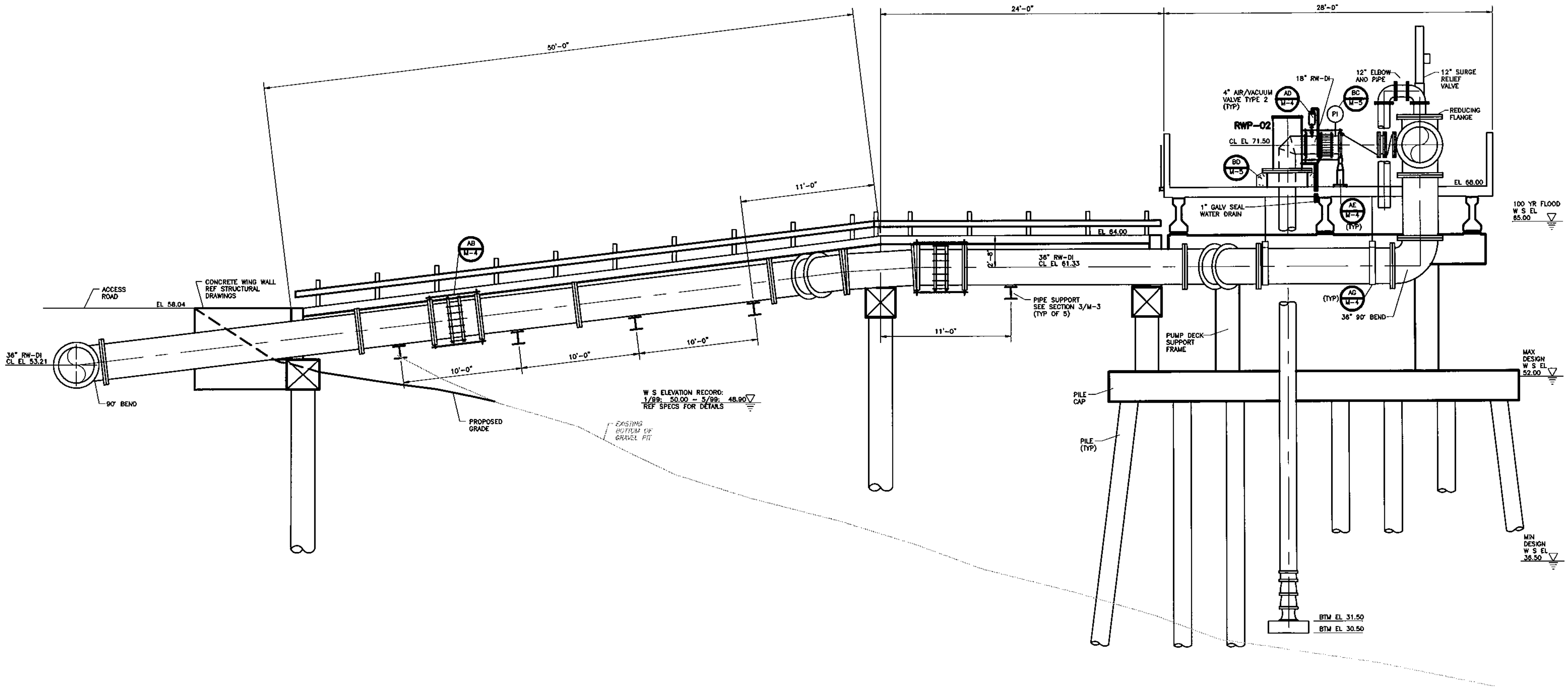

SECTION 1/M-1
NTS

CITY OF VICTORIA, TEXAS

RAW WATER PUMP STATION MECHANICAL SECTION

CDM

FIGURE No 4

To maximize the useful volume in the OCRs, the connections between OCRs should be at the lowest possible elevation. OCR-8 is the controlling elevation based on how low the raw water pumps can be set and the bottom elevation in OCR-8. If the pumps are lowered in OCR-8, then the connection from OCR-4 to OCR-8 and connection between OCR-3 and OCR-4 should be lowered to take advantage of additional volume in OCR-3 and OCR-4. The new, lower connection from OCR-4 to OCR-8 would be constructed in conjunction with other improvements to connect other OCRs to OCR-8 and is discussed below.

Increasing Connected OCR Volume

The City desires to increase the OCR volume connected by gravity to its raw water pump station. In evaluating the OCRs, the largest OCR by volume is OCR-6, and connecting it to the OCRs already connected to the raw water pump station would add 775.5 Ac-Ft of total volume, a 59% increase in the total volume. OCR-5 is extremely close to OCR-6 and could be connected relatively easily. OCR-7 is in proximate location of a connection between OCR-6 and OCR-8 and it should be included if OCR-6 is connected to the raw water pump station in OCR-8. The total volume of OCR-5, OCR-6 and OCR-7 is 1,336.2 Ac-Ft. Connecting OCR-5, OCR-6 and OCR-7 to OCR-8 doubles the total volume of OCRs connected to the raw water pump station.

The total volume in all 11 OCRs is 3,830 Ac-Ft. Connecting OCR-3, OCR-4, OCR-5, OCR-6, OCR-7 and OCR-8 connects 69% of the total volume. The total volume in the remaining five OCRs, OCR-1, OCR-2, OCR-9, OCR-10 and OCR-11, is 1,175.2 Ac-Ft. The largest of the remaining OCRs is OCR-10 and it has a total volume of 400 Ac-Ft; however, because of a stream running into OCR-10 the use of water from this OCR is complicated by water rights considerations. Also, as can be seen on Figure 3, the top of ground elevation of OCR-10 is eight ft lower than the top of ground elevation in OCR-3 through OCR-8 and connecting this OCR with the others by gravity would actually lower the useful volume available to the City. The lower water surface elevation is also an issue for OCR-9 and OCR-11. None of the remaining OCRs has an individual volume of more than 255 Ac-Ft.

OCR-1 and OCR-2 are close to OCR-3 and could be connected relatively easily. Together they have a total volume of 379 Ac-Ft. Adding OCR-1 and OCR-2 to OCR-3 through OCR-8 would increase the total volume by 14%.

Cost of Adding Existing OCR Storage

Preliminary costs for adding the storage was determined and then evaluated on a cost per Ac-Ft basis to determine which of the OCRs was the most economical to connect to the existing system. A plan of the improvements is shown in **Figure 5**, and profiles of the proposed channels and pipelines are shown in **Figure 6** and **Figure 7**.

Connecting OCR-5, OCR-6 and OCR-7 to the system adds 1,336.2 Ac-Ft total volume and 1,311 Ac-Ft of useful volume to the system. The cost to add the 1,311 Ac-Ft of useful storage in OCR-5, OCR-6 and OCR-7 to the system is $1,559,000. This added useful volume has a unit cost of $1,189/Ac-Ft. The cost of adding a deeper channel between OCR-3 and OCR-4 and a connection between OCR-4 and OCR-8 at a lower elevation to take advantage of more volume in OCR-3 and OCR-4 is $560,040. The

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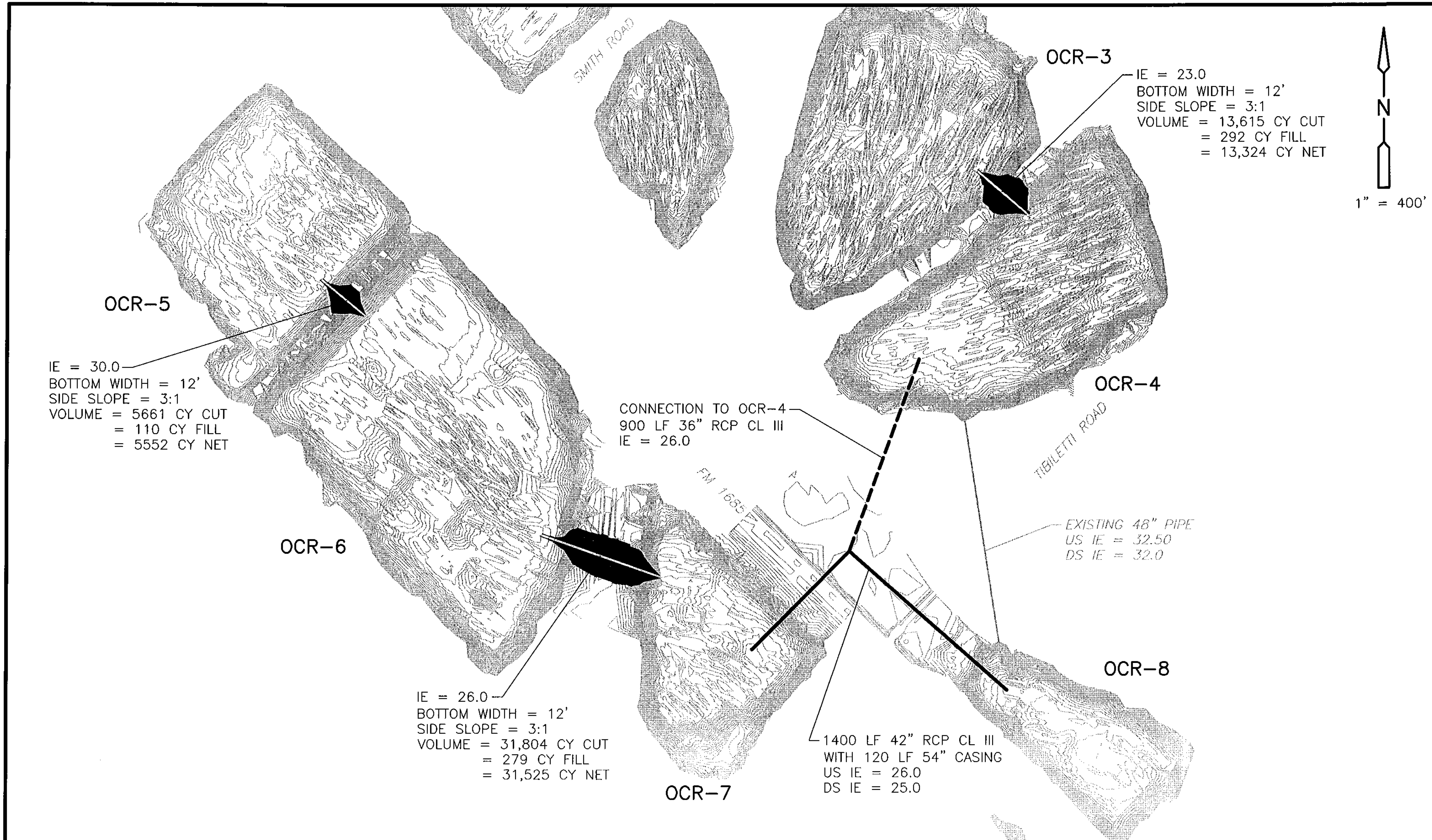

CITY OF VICTORIA, TEXAS

OCR CONNECTION PLAN

CDM

FIGURE No 5

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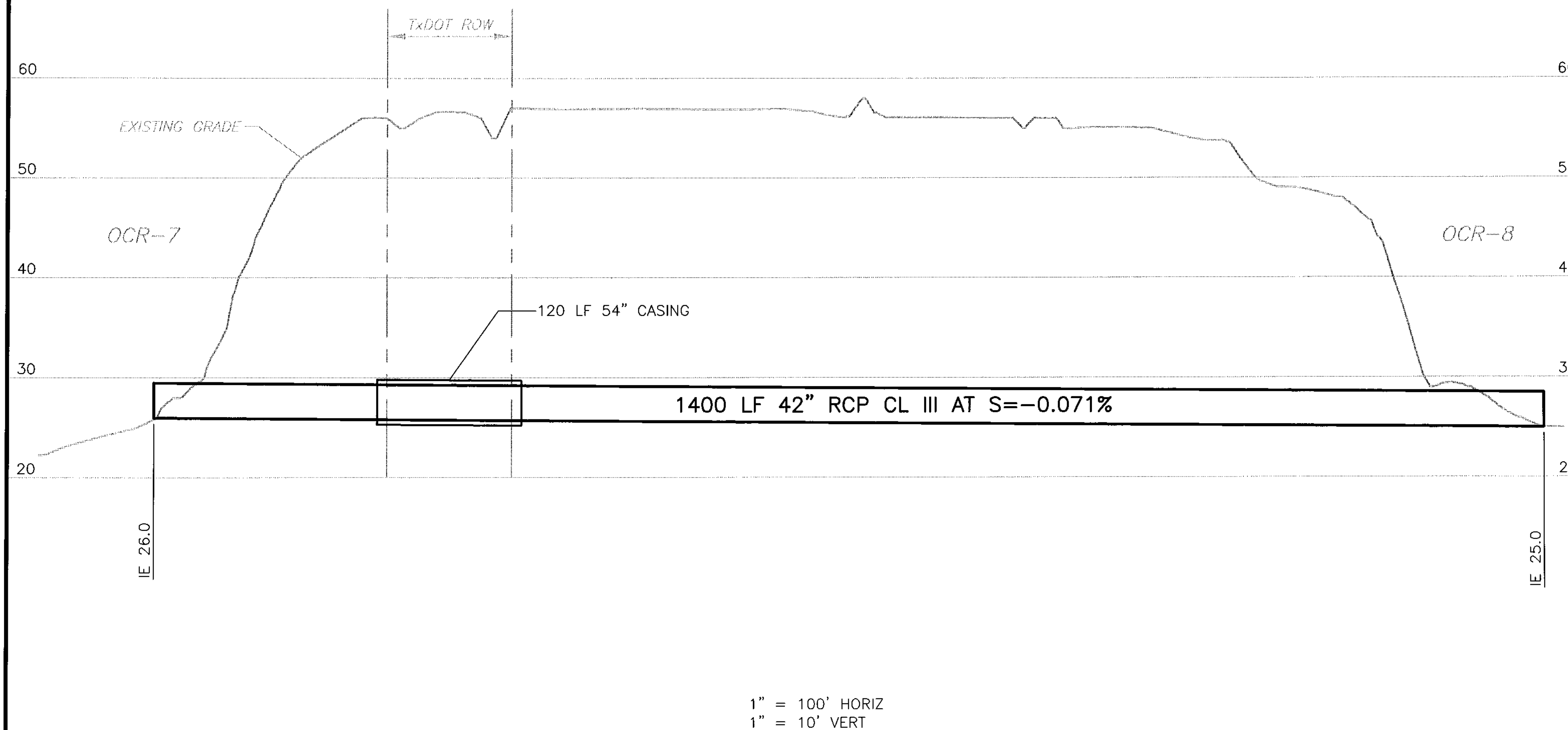

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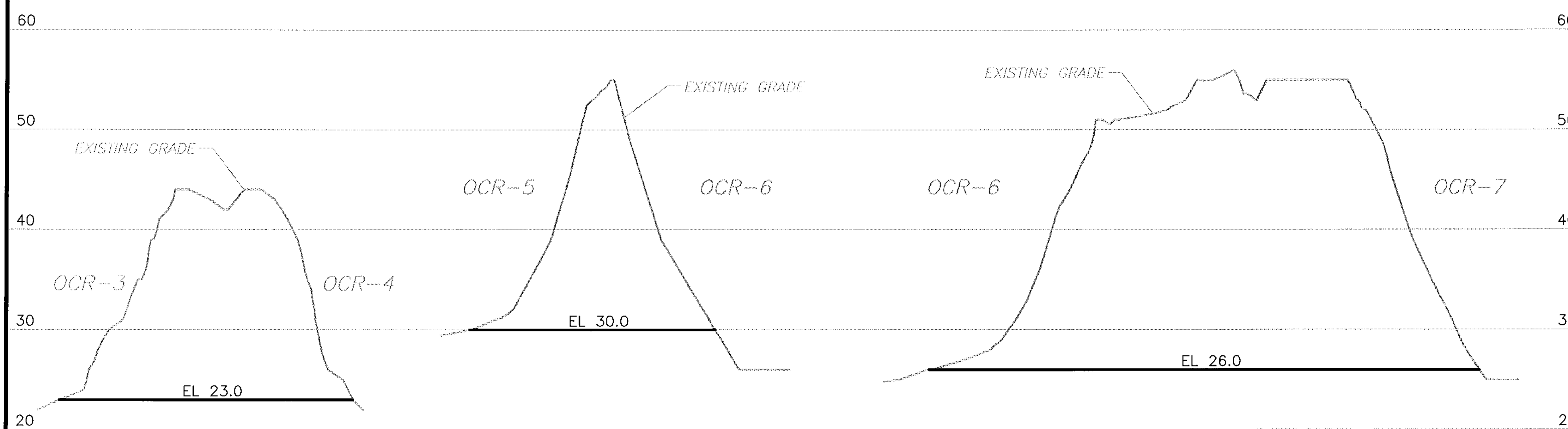
CITY OF VICTORIA, TEXAS

PROFILE FROM
OCR-7 TO OCR-8

FIGURE No 6



1" = 100' HORIZ
1" = 10' VERT

CDM

CITY OF VICTORIA, TEXAS

PROFILE FROM OCR-3 TO OCR-4
& FROM OCR-5 TO OCR-6 &
FROM OCR-6 TO OCR-7

FIGURE No 7

volume in OCR-3 and OCR-4 that can be utilized by adding this lower connection is 336 Ac-Ft in OCR-3 and 105 Ac-Ft in OCR-4. The cost per Ac-Ft for accessing the additional volume in OCR-3 and OCR-4 is $1,270/Ac-Ft. The cost to add the 379 Ac-Ft of useful volume in OCR-1 and OCR-2 to the system is $561,000. This added useful volume has a unit cost of $1,480/Ac-Ft. The cost information for these improvements is detailed in **Table 1**.

It is recommended that the City's first priority in adding OCR volume is to increase the useful volume of OCR-3 and OCR-4. The next addition should be to connect OCR-5, OCR-6 and OCR-7 to the raw water pump station in OCR-8. The additional volume at OCR-1 and OCR-2 would be the last volume connected due to the small additional volume and higher unit cost to add the volume to the system.

Required Storage

The City's surface water right is approximately 94% reliable based on the hydrologic studies conducted for the water rights application. The gap in the surface water reliability is filled by using the storage in the OCRs, using the existing groundwater wells, and calling on water in Canyon Lake under contract with GBRA. Although an exhaustive water availability analysis is beyond the scope of this study, a simple analysis of the water needed in storage to meet potential deficits is presented below.

In 2009 and 2011, the City was prevented from diverting water from the Guadalupe River because the flow in the Guadalupe River was less than the minimum flow restrictions in its water rights permit. This period when diversions were not allowed were in the months of July, August and September. During these months the water treated at the surface water treatment plant averaged 15 mgd. The City's goal is to have six months of storage in the OCRs. During the other three months, the amount of treated water needed is assumed to average 12 mgd. The City has two wells connected directly to the raw water line entering the surface water treatment plant. These two wells have a combined capacity of 4 mgd. Therefore, the OCR storage goal would provide three months of 11 mgd and three months of 8 mgd. The volume of storage to provide this amount of water in the OCRs is 5,365 Ac-Ft.

If OCR-3 through OCR-8 are connected by gravity, the combined surface area of these OCRs is 131.9 acres. The design net lake surface evaporation in Victoria County during the period May through October is 2.97 ft. The design net lake surface evaporation was computed using the 90 percentile gross lake surface evaporation and the 10 percentile rainfall for Victoria County. This design net lake surface evaporation would be a worst case scenario. The volume of water lost from the OCRs to evaporation during the six month design period is 392 Ac-Ft. Therefore, the total volume the City needs in storage to meet a six month design period is 5,757 Ac-Ft.

If OCR-3 through OCR-8 are connected, the total useful volume available to the City is 2,546 Ac-Ft. The City should actively pursue acquiring an additional 3,211 Ac-Ft of storage to firm up its water rights using stored water only. The additional storage could be added by dredging more volume in the existing OCRs or by constructing a new off channel pond near the existing OCRs.

Table 1

Off Channel Reservoir (OCR) Phase 2 Connections Connect OSR-5, OCR-6, OCR-7							
Connection Identification	**Crossing Type**	**Dia.**	**Length**	**Bottom Width**	**Depth**	**Excavation Volume (cy)**	**Cost**
Connect OCR-5 to OCR-6	Open Channel		245	12	25	5,661	$ 84,915
Connect OCR-6 to OCR-7	Open Channel		550	12	29	31,804	$ 477,060
Connect OCR-7 to OCR-8	TXDOT Bore	54	120				$ 97,200
Connect OCR-7 to OCR-8	Pipe Connection	42	1400				$ 470,400
						Subtotal	$ 1,129,575
						Contingency (20%)	$ 225,915
						Construction Subtotal	$ 1,355,490
						Professional Services (15%)	$ 203,300
						Total	$ 1,558,790

Off Channel Reservoir (OCR) Phase 2 Connections Connect OCR-4 and OCR-8						
Connection Identification	**Crossing Type**	**Dia.**	**Length**	**Bottom Width**	**Depth**	**Cost**
Connect OCR-4 to OCR-8	Pipe Connection	36	700	na	na	$ 201,600
Connect OCR-3 to OCR-4	Open Cannel	na	295	12	21	$ 204,225
					Subtotal	$ 405,825
					Contingency (20%)	$ 81,165
					Construction Subtotal	$ 486,990
					Professional Services (15%)	$ 73,050
					Total	$ 560,040

Off Channel Reservoir (OCR) Phase 3 Connections Connect OCR-1 and OCR-2						
Connection Identification	**Crossing Type**	**Dia.**	**Length**	**Bottom Width**	**Depth**	**Cost**
Connect OCR-1 to OCR-2	Open Cut Pipe Crossing	48	200	na	na	$ 144,000
Connect OCR-2 to OCR-3	Open Channel		350	12	20	$ 262,500
					Subtotal	$ 406,500
					Contingency (20%)	$ 81,300
					Construction Subtotal	$ 487,800
					Professional Services (15%)	$ 73,200
					Total	$ 561,000

The estimated cost to dredge and dispose of the material from the OCRs is $2.50/cy if the spoil can be disposed of near the dredge area. The unit cost for dredging could be much higher if the spoil has to be trucked off site for disposal. At a unit cost of $2.50/cy, the unit cost for additional storage is $4,033/Ac-ft. To dredge a volume of 3,211 Ac-Ft from the existing OCRs would cost in excess of $17 million, including contingencies and professional services.

Construction of an off channel pond would require the purchase of additional property since there is limited space outside of the floodway on the City owned property. If the off channel pond was constructed 20-ft deep, the area of the pond and levees required to construct the pond would total 200 acres. A planning level estimate for the land and the construction of the off channel pond is $7.2 million. The unit cost for storage in this constructed off channel pond is $2,323/Ac-Ft.

Conclusion and Recommendation

Based on the evaluation of the OCRs and the City's needs for useful volume in the OCR system, we recommend making the following improvements.

1. Add a new lower connection from OCR-4 to OCR-8 and a deeper channel from OCR-3 to OCR-4. These improvements provide access to an additional 441 Ac-Ft of useful volume for a construction cost of $560,040. The unit cost of this additional useful volume is $1,270/Ac Ft.

2. Connect OCR-5, OCR-6 and OCR-7 to the existing system. These improvements add 1,311 Ac-Ft of useful volume the existing to OCR connected storage. The cost to connect OCR-5, OCR-6 and OCR-7 to the existing system is $1,558,709 for a unit cost of $1,189/Ac-Ft.

3. Finally, connect OCR-1 and OCR-2 to the system. These improvements add an additional 379 Ac-Ft of useful volume and costs $561,000 for a unit cost of $1,480/Ac-Ft of useful volume and is less expensive than adding additional storage by constructing a new off channel pond or dredging material from the existing OCRs.

4. To add enough storage to meet six months of water demand without diverting from the Guadalupe River, the City would have to construct 3,211 Ac-Ft of additional storage near the existing OCRs at a unit cost of $2,323/Ac-Ft and will total $7.2 million in capital costs.

Appendix B

Public Meetings Documentation

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Public Meeting
June 26, 2013

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Regional Plan for ASR/OCS in the Golden Crescent Region of Texas

Kickoff Meeting Agenda

Date:	**Wednesday, June 26, 2013**
Time:	**10: 00AM**
Location:	**Victoria Community Center Annex**
	2905 E. North Street, Victoria, TX 77901
Meeting Purpose:	**Project Kickoff**

1. Introductions and Sign In
2. Confirm the scope of work, and verify communication protocols, roles and responsibilities
3. Confirm the area to be evaluated for potential well fields, and potential sources of supply
4. Discuss and confirm analysis of surface water availability
5. Discuss participant issues and concerns
6. Confirm participant preferences and report standards
7. Confirm and document participant goals and objectives for the study
8. Confirm the existing OCS sites to be evaluated
9. Review the fundamental aspects of ASR and its various applications
10. Discuss and document any stakeholder and public involvement requirements and the study team's responsibilities
11. Confirm the schedule.
12. Other Items for Discussion
13. Action Items

KICKOFF MEETING – REGIONAL PLAN FOR ASR/OCS IN THE GOLDEN CRESCENT REGION OF TEXAS
Victoria Community Center Annex
Wednesday, June 26, 2013
10:00 a.m.

Name	Address	Phone Number	E-mail
JERRY JAMES	COV	361-648-0340	
Lynn Short	COV	361-550-2489	
Billy Settles	Port of Victoria (Civilcorp)	361-550-0560	bsettles@civilcorp.us
Randy Bena	Port of Victoria (Civil Corp)	361-550-8866	rbena@civilcorp.us
JAMES ROACH	COV	361-550-1890	jroach@victoriatx.org
Donald Reese	COV	361-550-1829	dreese@victoriatx.org
TIM ANDRUSS	VCGCD	361 579 6863	tim.andruss@vcgcd.org
Herb Wittliff	GBRA	" 552-9751	hwittliff@gbra.org

KICKOFF MEETING – REGIONAL PLAN FOR ASR/OCS IN THE GOLDEN CRESCENT REGION OF TEXAS

Victoria Community Center Annex
Wednesday, June 26, 2013
10:00 a.m.

Name	Address	Phone Number	E-mail
Stephanie Shelly	GBRA	361-552-9751	sshelly@gbra.org
Don Koble	GBRA	361-552-9751	dkoble@gbra.org
FRED BLUMBERG	MP/ARCADIS	(512) 584-4242	fred.blumberg@arcadis-us.com
Charlie Hickman	GBRA	830-379-5822	chickman@gbra.org
Pat Brzozowski	lnra	361 782 5229	pbrzozowski@lnra.org
Doug Anders	LNRA	361-782-5229	danders@LNRA.org
TOM BROWN	NEI	512-708-9322	tbrown@naismith-ENGINEERING.COM

Kickoff Meeting

Victoria Regional Plan for ASR and Off Channel Storage

Naismith Engineering Team
Malcolm Pirnie/ARCADIS-US, Inc.
ASR Systems, LLC
INTERA, Inc.
June 26, 2013

Meeting Agenda
Interactive Discussion

- Introductions
- Scope of work; communication protocols; roles and responsibilities
- Participant issues and concerns
- Participant preferences and report standards
- Participant goals and objectives
- Existing OCS sites to be evaluated
- Public involvement requirements: study team’s responsibilities
- Well field locations and sources of supply
- Analysis of surface water availability
- Fundamental aspects of ASR and its various applications
- Schedule.
- Other Items for Discussion
- Action Items

Scope of Work

- Task 1—Kickoff Meeting and Public Meeting No. 1
- Task 2—Initial Data Collection & Analysis
- Task 3—Advanced Data Collection, ASR Workshop and Public Meeting No. 2
- Task 4—Alternatives Assessment
  - *Analysis of OCS*
  - *Analysis of ASR sources of supply and storage requirements*
  - *Evaluation of ASR storage locations*
  - *Conceptual plan and cost estimates*
  - *Evaluation of permitting, environmental and institutional issues*
  - *Economic analysis of storage costs*
  - *Milestone Report*
- Final Reports and Public Meeting No. 3

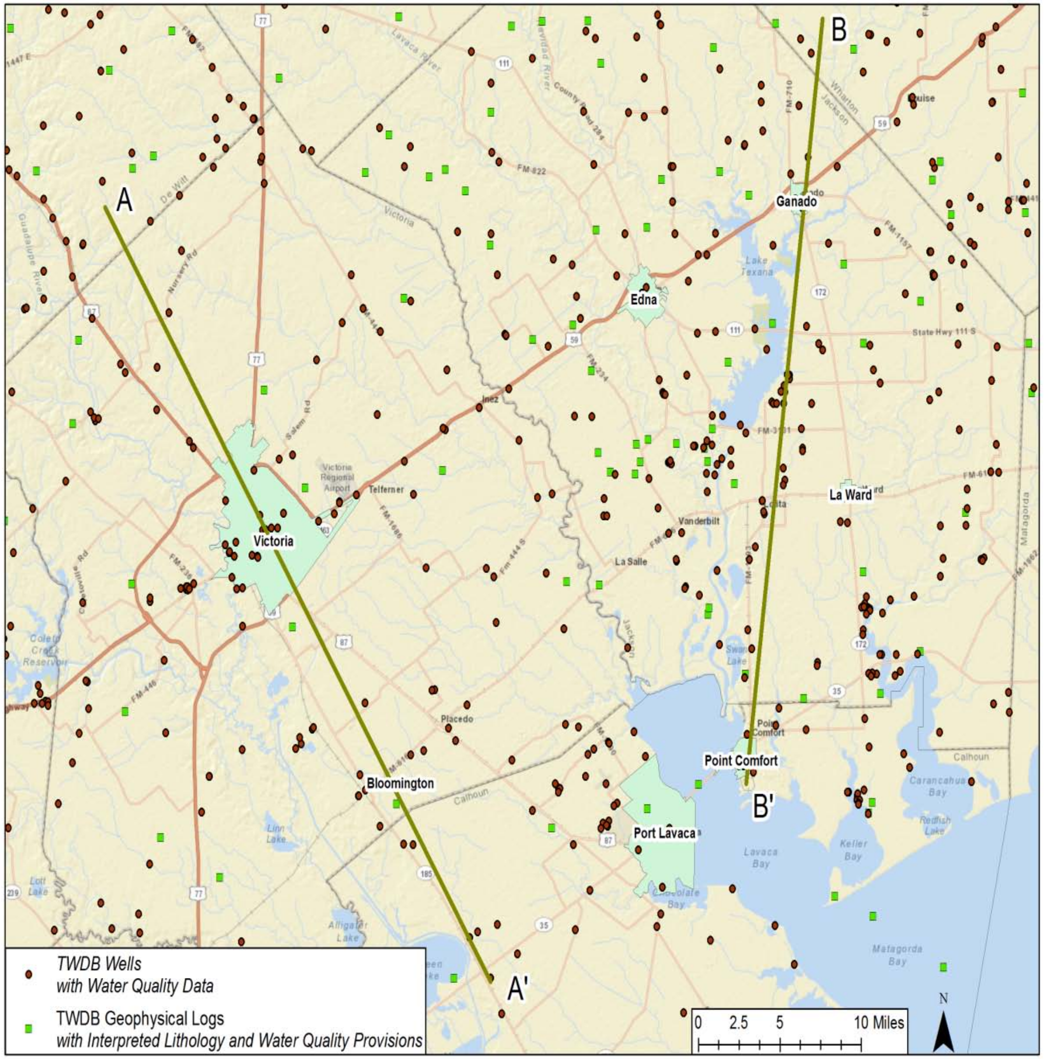
Meeting Agenda
Interactive Discussion

- ✓ Introductions
- ✓ Scope of work; communication protocols; roles and responsibilities
- ❖ Participant issues and concerns
- ❖ Participant preferences and report standards
- ❖ Participant goals and objectives
- ❖ Existing OCS sites to be evaluated
- ❖ Public involvement requirements: study team’s responsibilities
- Well field locations and sources of supply
- Analysis of surface water availability
- Fundamental aspects of ASR and its various applications
- Schedule.
- Other Items for Discussion
- Action Items

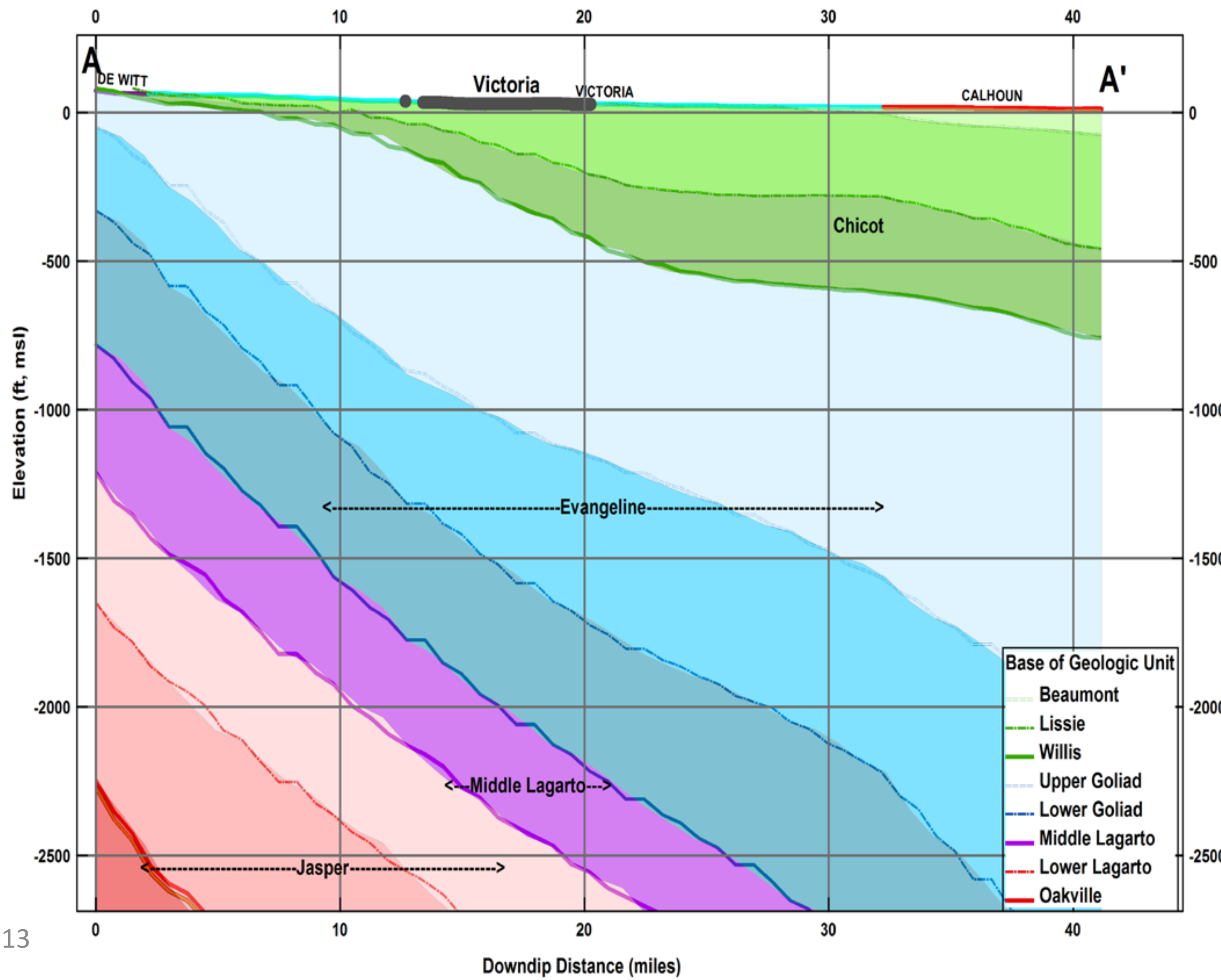
Well Field Locations and Sources of Supply

- Well Field Locations
  - City of Victoria
  - Bloomington vicinity
  - Selected portion of Jackson County
- Sources of Supply
  - City of Victoria existing water rights—for treatment at Victoria's WTP
  - GBRA's COA 18-5178—for treatment at PLWTP

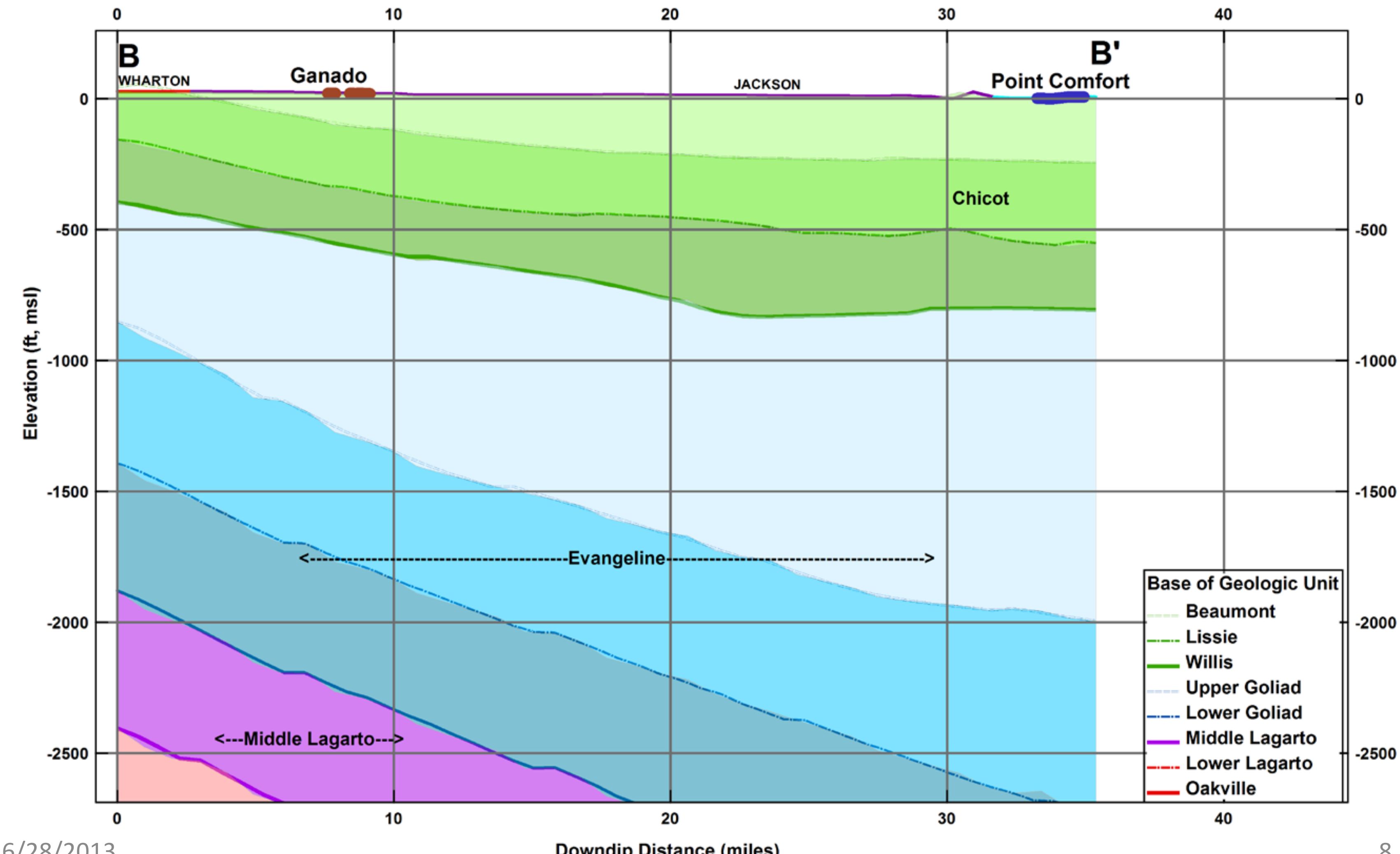
Potential Wellfield Locations



Cross Section A-A’

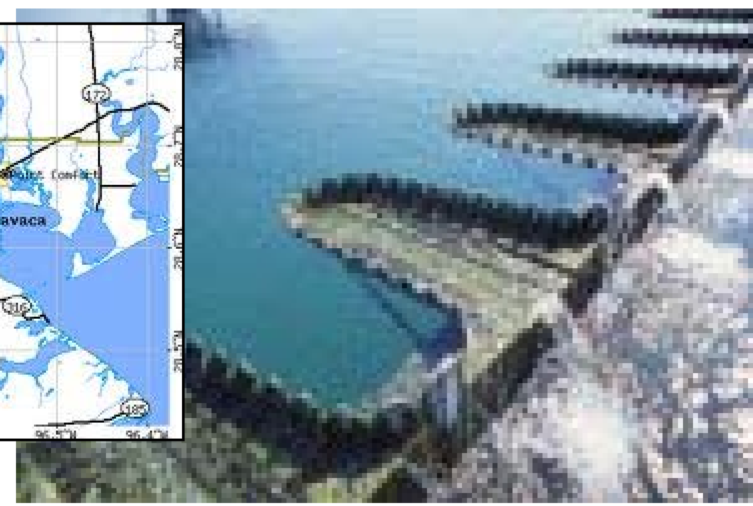


Cross Section B-B’

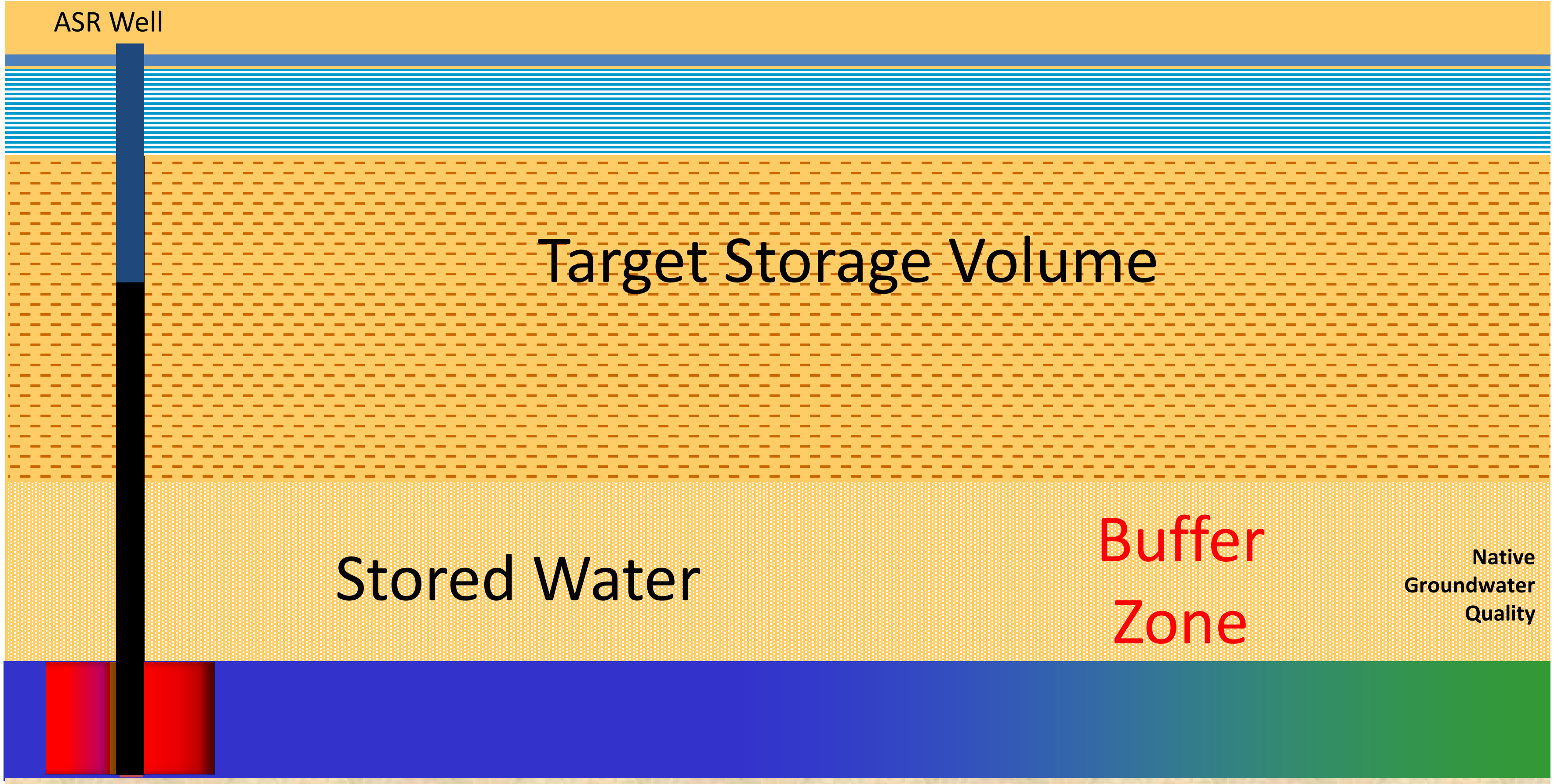


Sources of Supply

- City of Victoria
  - 3860A (Lipscomb)
  - 3858A (Murphy)
  - 4117A (Ruschhaupt)
  - 3844A (Schmidt)
  - 3862A
  - 3606A
  - 5466B
- GBRA
  - 5178 (Permit 1614)



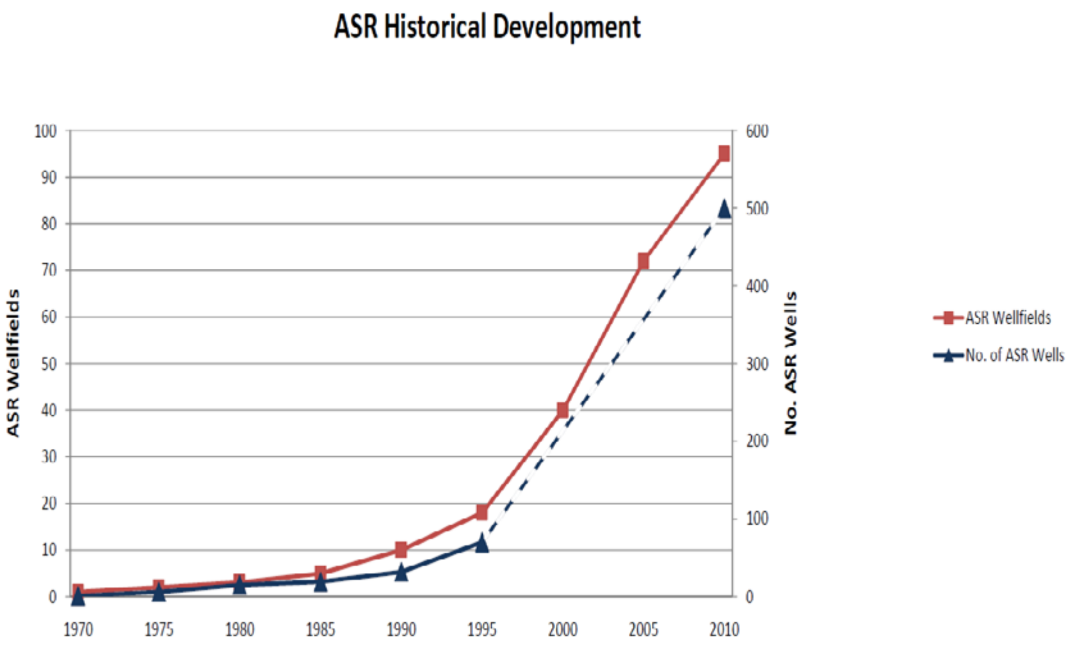
ASR Well Concept and Terminology



TSV is the sum of the stored water volume and the buffer zone volume,typically expressed in MG/MGD of recovery capacity, or in "days"

Fundamental Aspects of ASR

- Rapid growth of ASR in US and other countries since 1969
- 26 different types of ASR applications
- Many different types of water sources for aquifer recharge
- Storage in many different types of aquifers and lithologic settings



Contributing Factors

- **Economics**
  - Typically less than half the capital cost of alternatives
  - Phased implementation
  - Marginal cost pricing
- **Proven Success in US**
  - About 100 well fields in 22 states
  - Over 500 operating ASR wells
- **Environmental and Water Quality Benefits**
  - Small footprint
  - Improvement in stored water quality
- **Adaptability to Different Situations**
  - Storage: fresh, brackish or saline aquifers
  - Sources: drinking water, reclaimed water, stormwater and groundwater
  - Over 26 different applications

ASR Operating Ranges

- Well depths
  - 30 to 2700 feet
- Storage interval thickness
  - 20 to 400 feet
- Storage zone TDS
  - 30 mg/l to 39,000 mg/l
- Storage Volumes
  - 100 AF to 270,000 AF
- Bubble radius
  - Typically less than 1000 ft.
- Individual wells up to 8 MGD capacity
- Wellfield capacity up to 157 MGD

Calleguas MWD, California

ASR Well

ASR Applications

Seasonal storage and peaking

Long term storage for water supply

Emergency supply storage

DBP reduction

Deferral of water facility expansions

Maintenance of distribution system
    pressure/ flow

Improvement of water quality

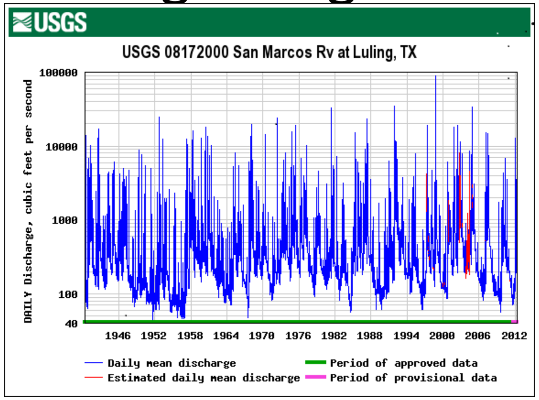
Prevention of saltwater intrusion

Approximately 13 other applications worldwide

Kerrville ASR Well

Seasonal Storage

- Store water in wet months for recovery during dry months
- Source water typically available even during drought



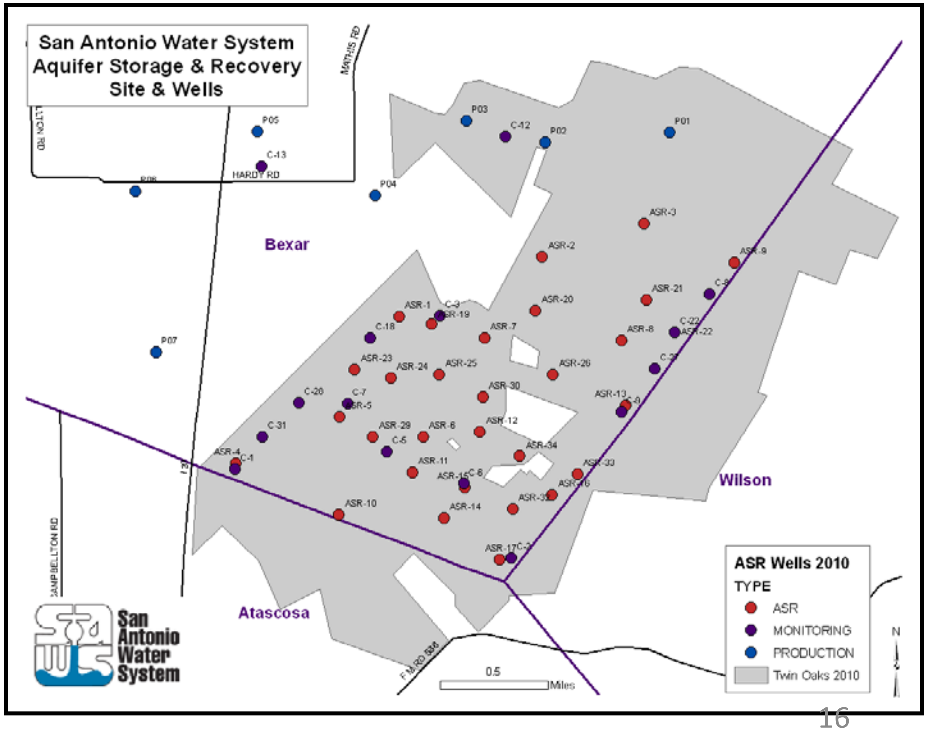
- Store best quality water for recovery when needed
- Storage duration: days to months

West Palm Beach, Florida
ASR Well – 8 MGD Capacity
Largest ASR Well in the World

Long-Term Storage or “Water Banking” and Diurnal Storage

- Water Banking
  - Store water in wet years for recovery during extended droughts
  - Store water when spare capacity is available
  - Recover during later years, deferring the need for expansion.
  - Principal reason for ASR in western states

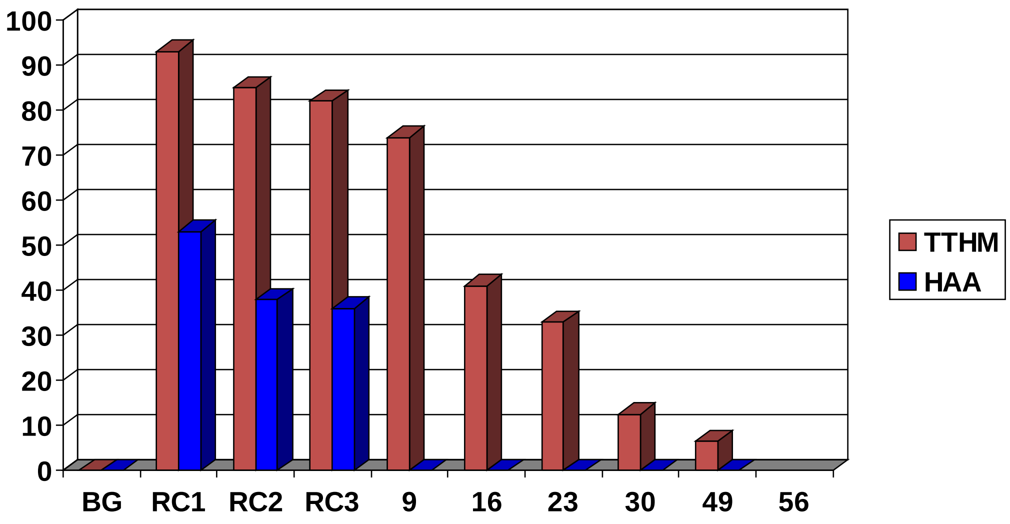
- Diurnal Storage
  - Store water during nights and weekends for recovery during the day



Disinfection Byproduct Reduction

- Elimination of Haloacetic Acids and their formation potential

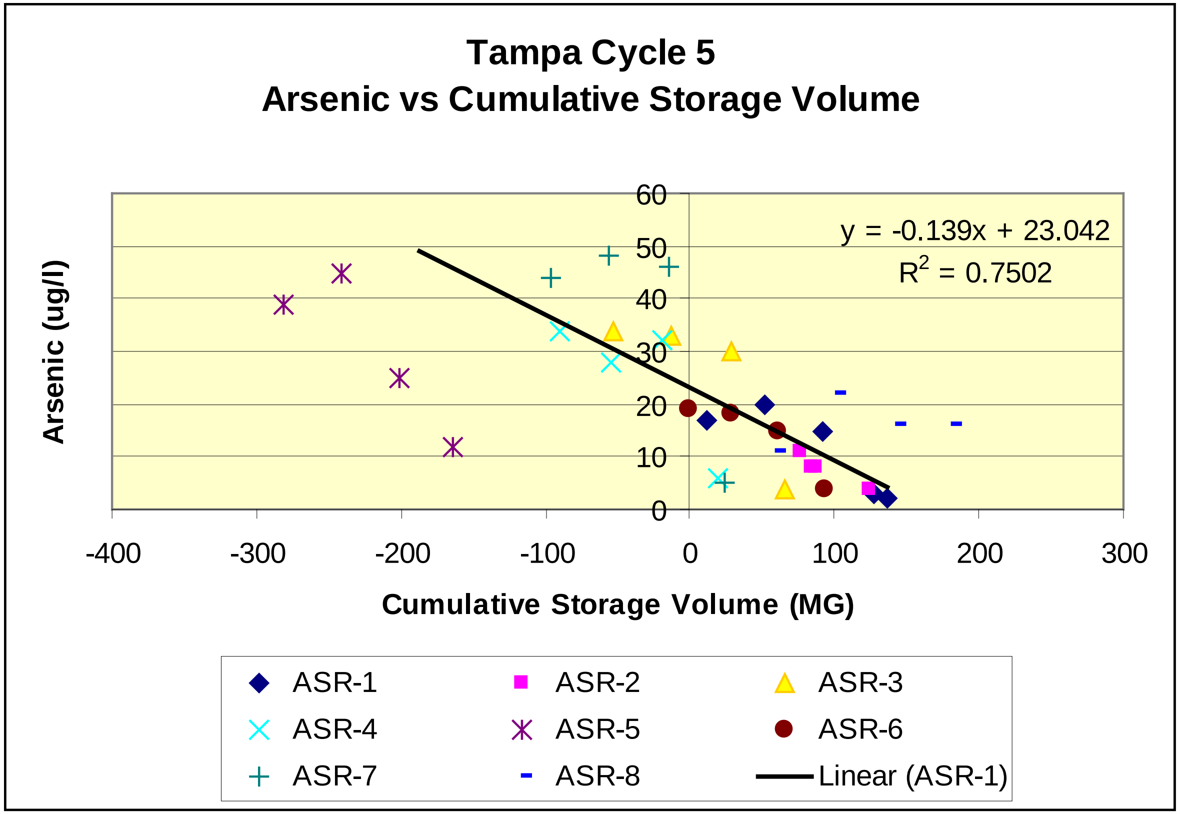
- Reduction of Trihalomethanes and reduction of their formation potential



Disinfection Byproduct Attenuation – Centennial WSD, Highlands Ranch, CO

Improve Water Quality

- Arsenic
- Fluoride
- Salinity
- THM and HAA
- Fe and Mn
- H_2S
- N & P
- TOC (carbon sequestration)
- Microbiota
- pH stabilization



Arsenic Decreases as the Cumulative Storage Volume Increases

Meeting Agenda
Interactive Discussion

- ✓ Introductions
- ✓ Scope of work; communication protocols; roles and responsibilities
- ✓ Participant issues and concerns
- ✓ Participant preferences and report standards
- ✓ Participant goals and objectives
- ✓ Existing OCS sites to be evaluated
- ✓ Public involvement requirements: study team’s responsibilities
- ✓ Well field locations and sources of supply
- ✓ Analysis of surface water availability
- ✓ Fundamental aspects of ASR and its various applications
- ❖ Schedule.
- ❖ Other Items for Discussion
- ❖ Action Items

Agenda

For a
Public Meeting
on:

The Development of a Regional Plan for Aquifer Storage and Recovery and/or Off Channel Storage Projects in the Golden Crescent Region of Texas

Date: Wednesday, June 26, 2013
Time: 4 to 5 p.m.
Location: Victoria Community Center Annex, 2905 E. North St., Victoria, TX 77901

I. **Welcome and Introductions** (Jerry James, City of Victoria)

II. **Project Background** (Jerry James, City of Victoria)

III. **Overview of Aquifer Storage and Recovery (ASR) Methodology and Applications** (Fred Blumberg, Arcadis/Malcom Pirnie)

IV. **Project Approach, Scope of Work and Schedule** (Tom Brown, Naismith Engineering, Inc.)

V. **Public Participation Opportunities** (James Dodson, Naismith Engineering, Inc.)

VI. **Questions/Comments**

P.O. BOX 1758 • VICTORIA, TEXAS 77902-1758 • (361) 485-3230 • FAX (361) 485-3226

PUBLIC MEETING – REGIONAL PLAN FOR ASR/OCS IN THE GOLDEN CRESCENT REGION OF TEXAS
Victoria Community Center Annex
Wednesday, June 26, 2013
4:00-5:00 p.m.

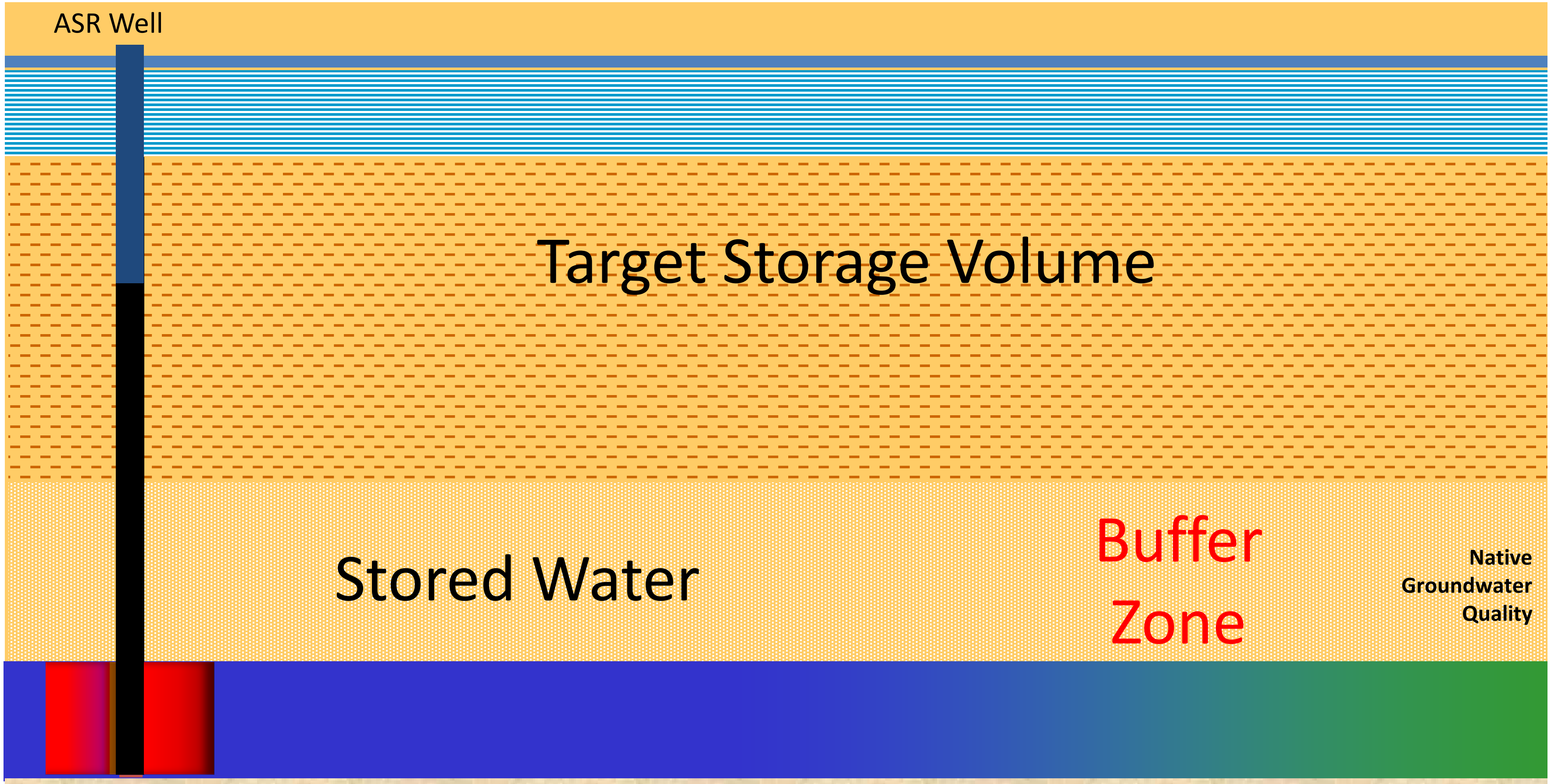
Name	Address	Phone Number	E-mail
RONALD KUBECKA LNRA BOARD	330 C.R. 464 PALACIOS, TEX. 77465	361-550-1517	R.KUBECKA @ LNRA.ORG ~~RANGELANDSEED@HOTMAIL.COM~~
PATRICK MURFEE	P.O. BOX 10313 LUBBOCK, TX 79408	806-765-8015	PATRICKMURFEE@GMAIL.COM
Charlie Hickman	933 E Court St. Seguin, TX 78155	830-379-5822	chickman@gbra.org
Tommy SCHULTE	101 W. GOODWIN, SUITE 902 VICTORIA, TX 77901	361-578-5778	tschulte@gbra.org
JERRY JAMES	COV		
Doug Anders	P.O. Box 429 Edna, TX 77957	361-782-5229	danders@lnra.org

Public Meeting

Opportunities for ASR and Off Channel Storage in Golden Crescent Region

Naismith Engineering Team
Malcolm Pirnie/ARCADIS-US, Inc.
ASR Systems, LLC
INTERA, Inc.
June 26, 2013

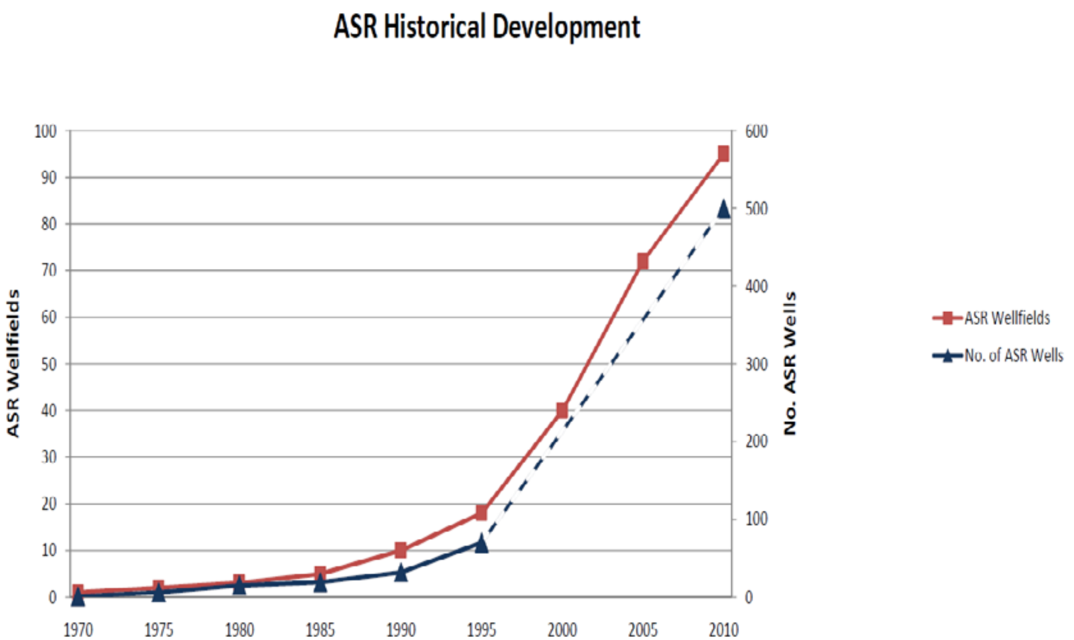
ASR Well Concept and Terminology



TSV is the sum of the stored water volume and the buffer zone volume,typically expressed in MG/MGD of recovery capacity, or in "days"

Fundamental Aspects of ASR

- Rapid growth of ASR in US and other countries since 1969
- 26 different types of ASR applications
- Many different types of water sources for aquifer recharge
- Storage in many different types of aquifers and lithologic settings



Contributing Factors

- **Economics**
  - Typically less than half the capital cost of alternatives
  - Phased implementation
  - Marginal cost pricing
- **Proven Success in US**
  - About 100 well fields in 22 states
  - Over 500 operating ASR wells
- **Environmental and Water Quality Benefits**
  - Small footprint
  - Improvement in WQ
- **Adaptability to Different Situations**
  - Storage: fresh, brackish or saline aquifers
  - Sources: drinking water, reclaimed water, stormwater and groundwater
  - Over 26 different applications

ASR Operating Ranges

- Well depths
  - 30 to 2700 feet
- Storage interval thickness
  - 20 to 400 feet
- Storage zone TDS
  - 30 mg/l to 39,000 mg/l
- Storage Volumes
  - 100 AF to 270,000 AF
- Bubble radius
  - Typically less than 1000 ft.
- Individual wells up to 8 MGD capacity
- Wellfield capacity up to 157 MGD

ASR Applications

Seasonal storage and peaking

Long term storage for water supply

Emergency supply storage

DBP reduction

Deferral of water facility expansions

Maintenance of distribution system pressure/ flow

Improvement of water quality

Prevention of saltwater intrusion

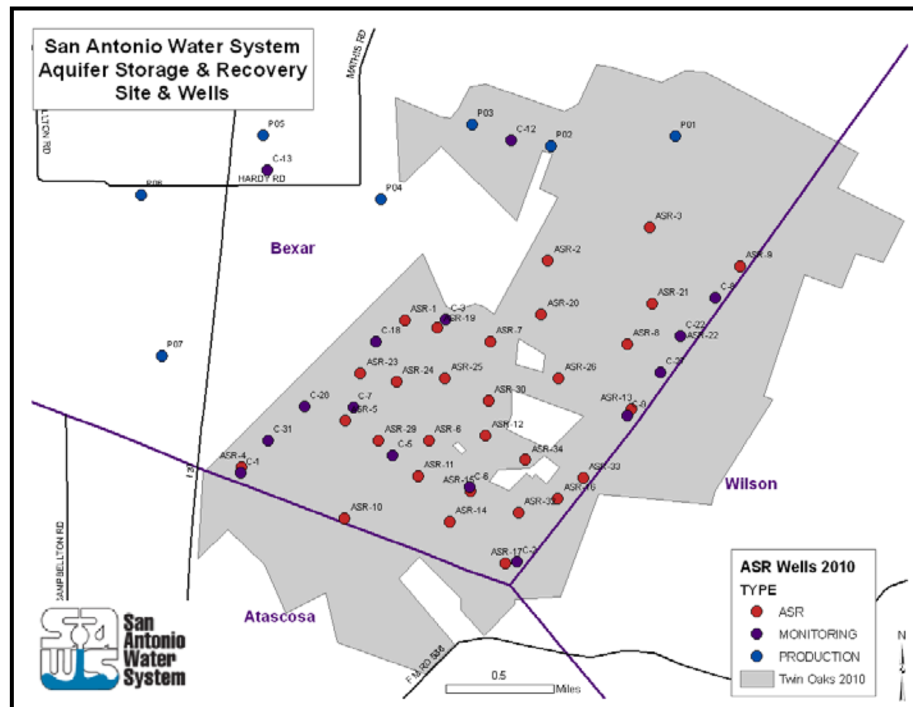
Approximately 13 other applications worldwide

Seasonal Storage

- Store water in wet months for recovery during dry months
- Store best quality water for recovery when needed
- Storage duration: days to months

Long-Term Storage or "Water Banking" and Diurnal Storage

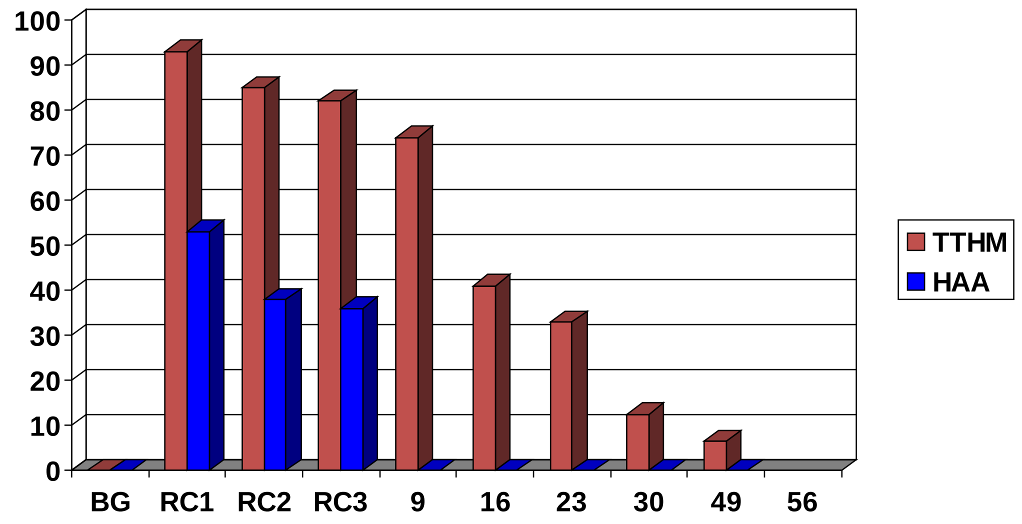
- Water Banking
  - Store water in wet years for recovery during extended droughts
  - Store water when spare capacity is available
  - Recover during later years, deferring the need for expansion.
  - Principal reason for ASR in western states
- Diurnal Storage
  - Store water during nights and weekends for recovery during the day



Disinfection Byproduct Reduction

- Elimination of Haloacetic Acids and their formation potential

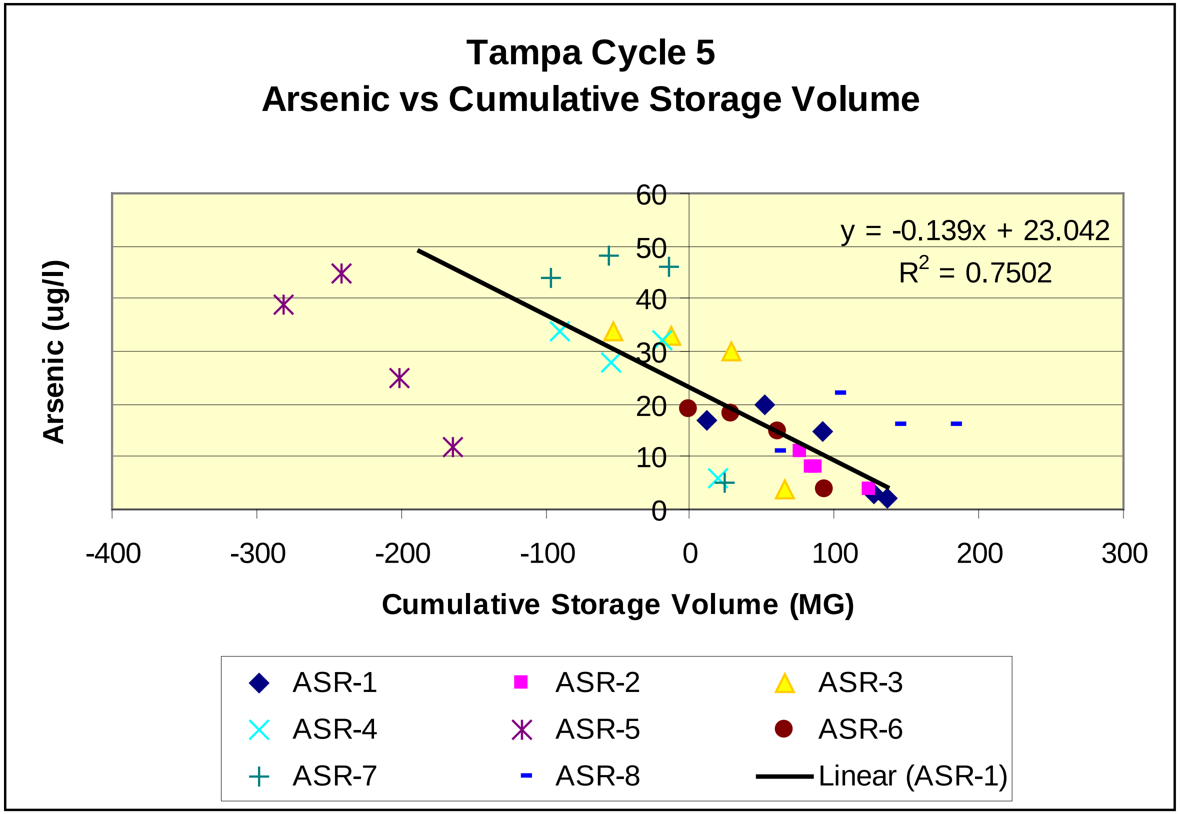
- Reduction of Trihalomethanes and reduction of their formation potential



Disinfection Byproduct Attenuation – Centennial WSD, Highlands Ranch, CO

Improve Water Quality

- Arsenic
- Fluoride
- Salinity
- THM and HAA
- Fe and Mn
- H_2S
- N & P
- TOC (carbon sequestration)
- Microbiota
- pH stabilization



Arsenic Decreases as the Cumulative Storage Volume Increases

ASR Projects in Texas

Summary

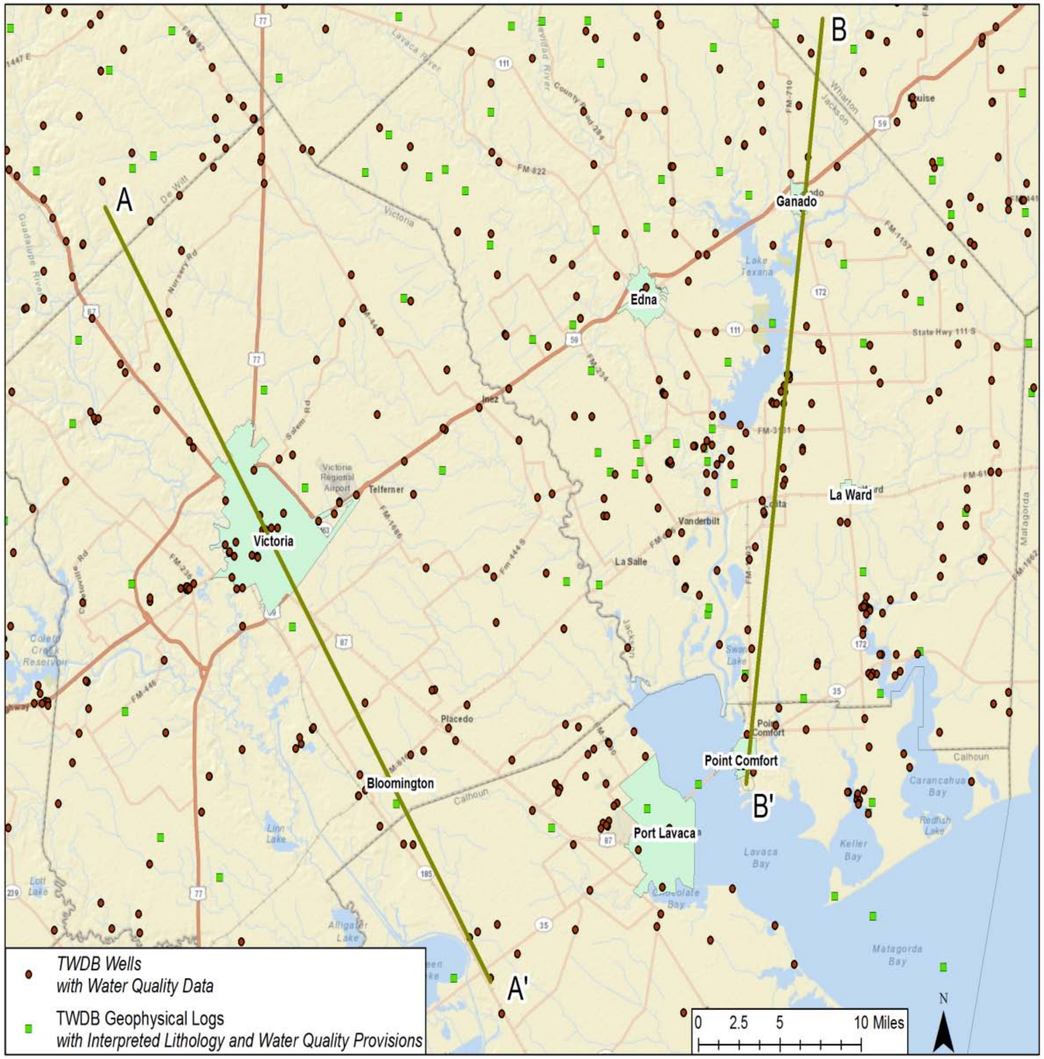
Component	EPWU (10 mgd)	Kerrville (2.65 mgd)	SAWS (60 mgd)
Date	1985	1995	2004
Source Water	Treated Wastewater	Treated River Water	Groundwater
Storage	300-835 feet Hueco Bolson	495-613 feet Lower Trinity	400-600 feet Carrizo
Issues	• Original well design • Customers for reclaimed water	• Litigation during permitting • Lack of source water	• Single pipeline • Distribution system limitations
Expansion Plans	Expanding FHWRP Constructing 4th spreading basin	Adding 3rd ASR well WTP expansion in Regional Plan	Part of 50-year Management Plan Evaluating TSV

MALCOLM PIRNIE

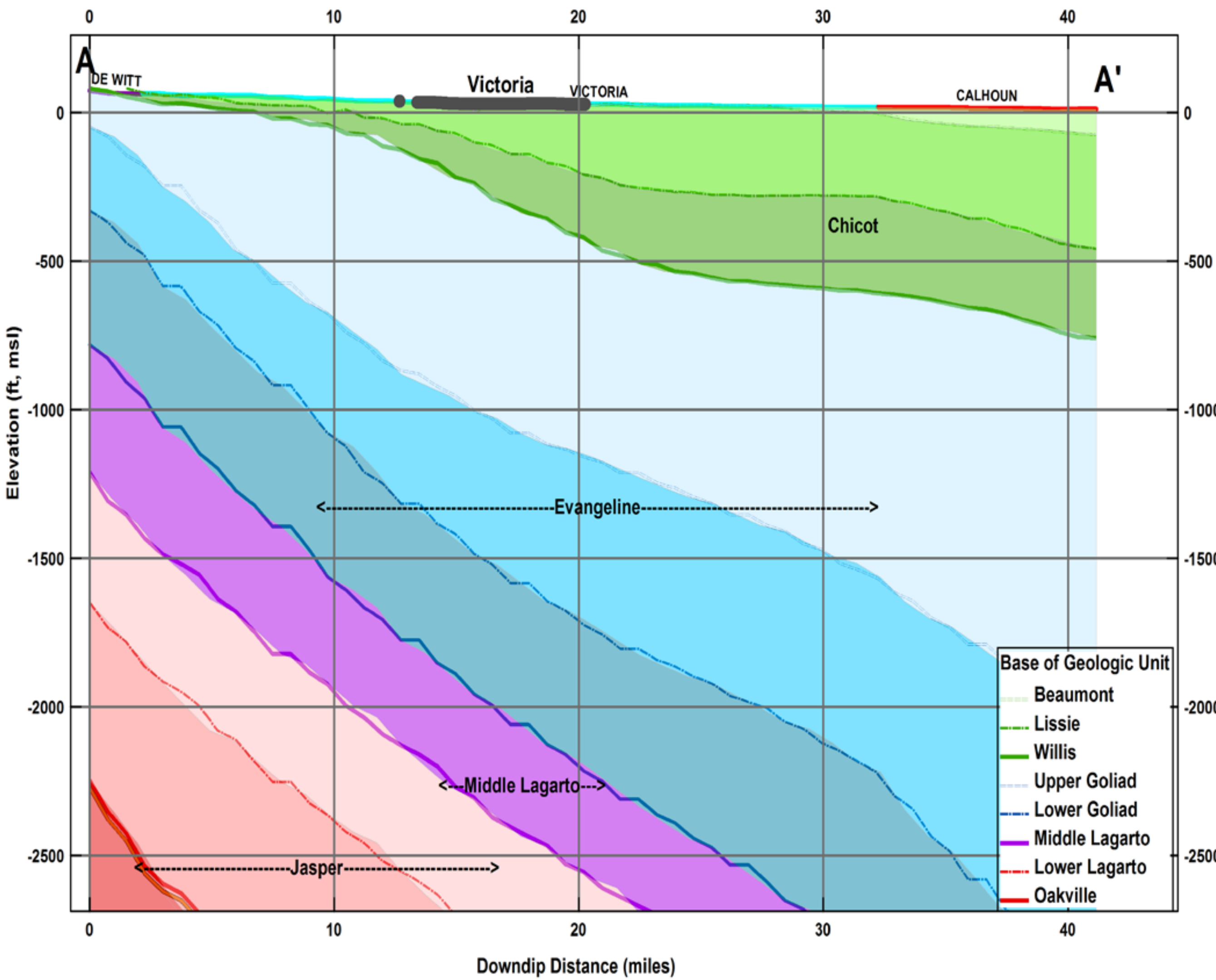
Well Field Locations and Sources of Supply

- Well Field Locations
  - City of Victoria
  - Bloomington vicinity
  - Selected portion of Jackson County
- Sources of Supply
  - City of Victoria existing water rights—for treatment at Victoria's WTP
  - GBRA's COA 18-5178—for treatment at PLWTP

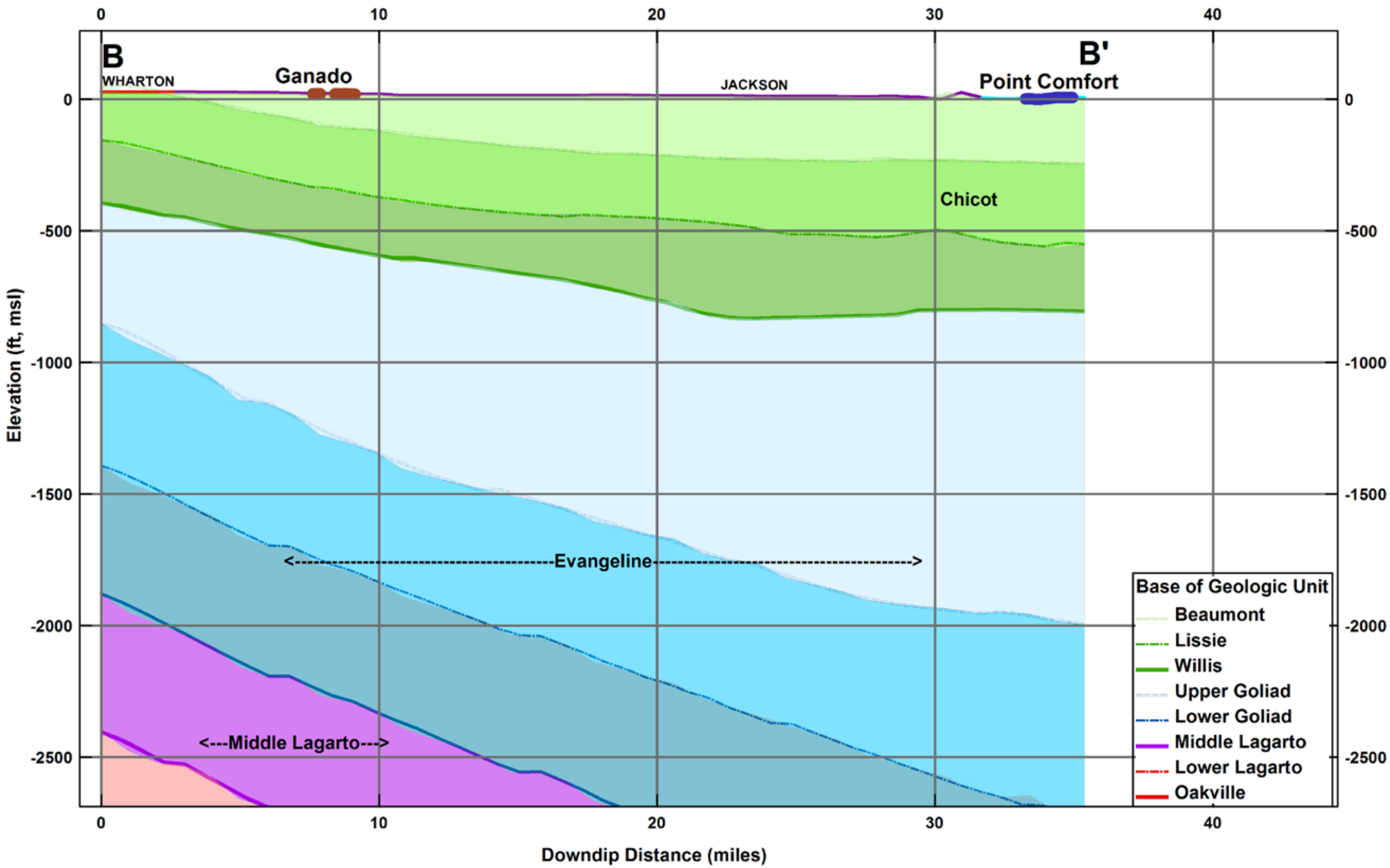
Potential Wellfield Locations



Cross Section A-A’

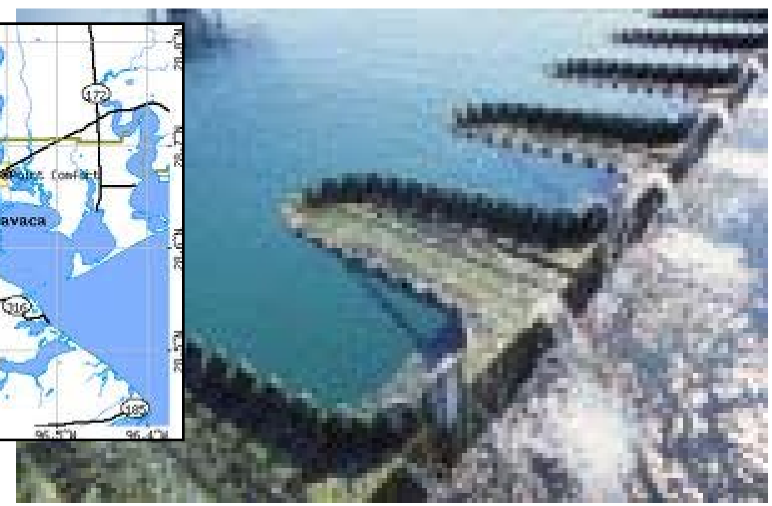


Cross Section B-B’



Sources of Supply

- City of Victoria
  - 3860A (Lipscomb)
  - 3858A (Murphy)
  - 4117A (Ruschhaupt)
  - 3844A (Schmidt)
  - 3862A
  - 3606A
  - 5466B
- GBRA
  - 5178 (Permit 1614)



Imagine the result

Questions?

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Public Meeting
September 12, 2013

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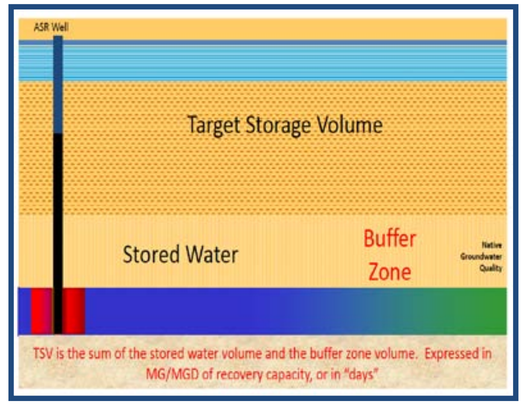
Project Meeting on:

The Development of a Regional Plan for Aquifer Storage and Recovery and/or Off Channel Storage Projects in the Golden Crescent Region of Texas



Agenda

Date: Thursday, September 12, 2013
Time: 9 am to 4 p.m.
Location: 700 N. Main Center, Rm. 204; 700 N Main St., Victoria, TX 77901

I. **Welcome and Introductions** (Jerry James, City of Victoria)

II. **Discussion of ASR concepts and applications** (David Pyne)

III. **Agreement by Sponsors on priority of ASR applications for Victoria Area study** (Fred Blumberg & David Pyne)

IV. **Discussion of hydrogeologic data collection and opinions to date** (Steve Young)

V. **Discussion of future water demands and confirmation of demand centers for Victoria and GBRA** (Fred Blumberg)

VI. **Schedule for remainder of project**

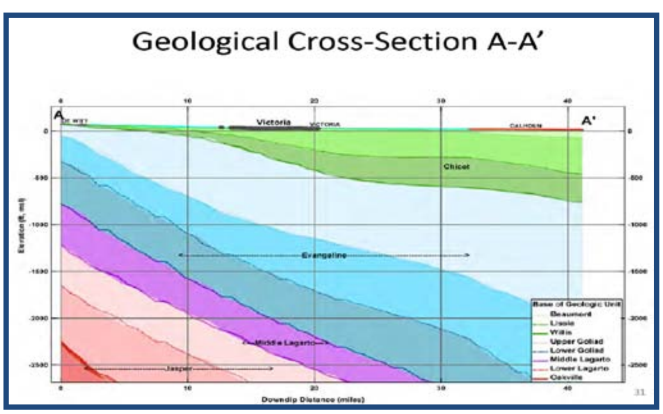
VII. **Action Items**

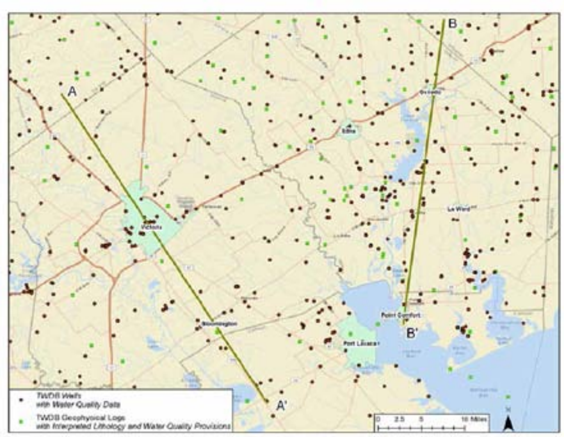
VIII. **Presentation on USGS research on issues related to ASR** (George Ozuna & Mark Null)

IX. **Questions/Comments**

X. **Lunch (**on your own**)**

XI. **Site visit.**





Naismith Engineering, Inc

JOB NO.

SHEET NO.

DESCRIPTION Regional ASR Planning Study Workshop

DATE 9-12-13

BY

Name	Affiliation	E-mail
JERRY JAMES	COV	jjames@victoriatx.org
Doug Anders	LNRA	danders@lnra.org
James Dodson	NEI	
DAVID MEESEY	TWDB	david.meesey@twdb.texas.gov
Patrick Brzozowski	lnra	pbrzozowski@lnra.org
DAVID FUSILIER	NEI	dfusilier@naismith-engineering.com
Donald Reese	COV	dreese@victoriatx.org
Lynn Short	COV	lshort@victoriatx.org
Jimmy Roach	COV	jroach@victoriatx.org
MARK NULL	USGS	jmnull@usgs.gov
Billy Settles	POV	bsettles@civilcorp.us
John Bumgarner	USGS	jbumgarner@usgs.gov
DAVID PYNE	ASR SYSTEMS	dpyne@asrsystems.ws
STEVEN Young	INTERA	syoung@intera.com
FRED BLUMBERG	ARCADIS	fred.blumberg@arcadis-us.com
Thomas D Hill	GBRA	thill@gbra.org
Tim Andruss	VCGCD	tim.andruss@vcgcd.org
Charlie Hickman	GBRA	chickman@gbra.org
Stephanie Shelly	GBRA	sshelly@gbra.org
GARY MIDDLETON	SCTWAC	gary.middleton@suddenlink.net
Herb Wittliff	"	hwittliff@gbra.org

ASR Workshop

Victoria Regional Plan for ASR and Off Channel Storage

Naismith Engineering Team

Malcolm Pirnie/ARCADIS-US, Inc.

ASR Systems, LLC

INTERA, Inc.

September 12, 2013

INTERA

ASR SYSTEMS

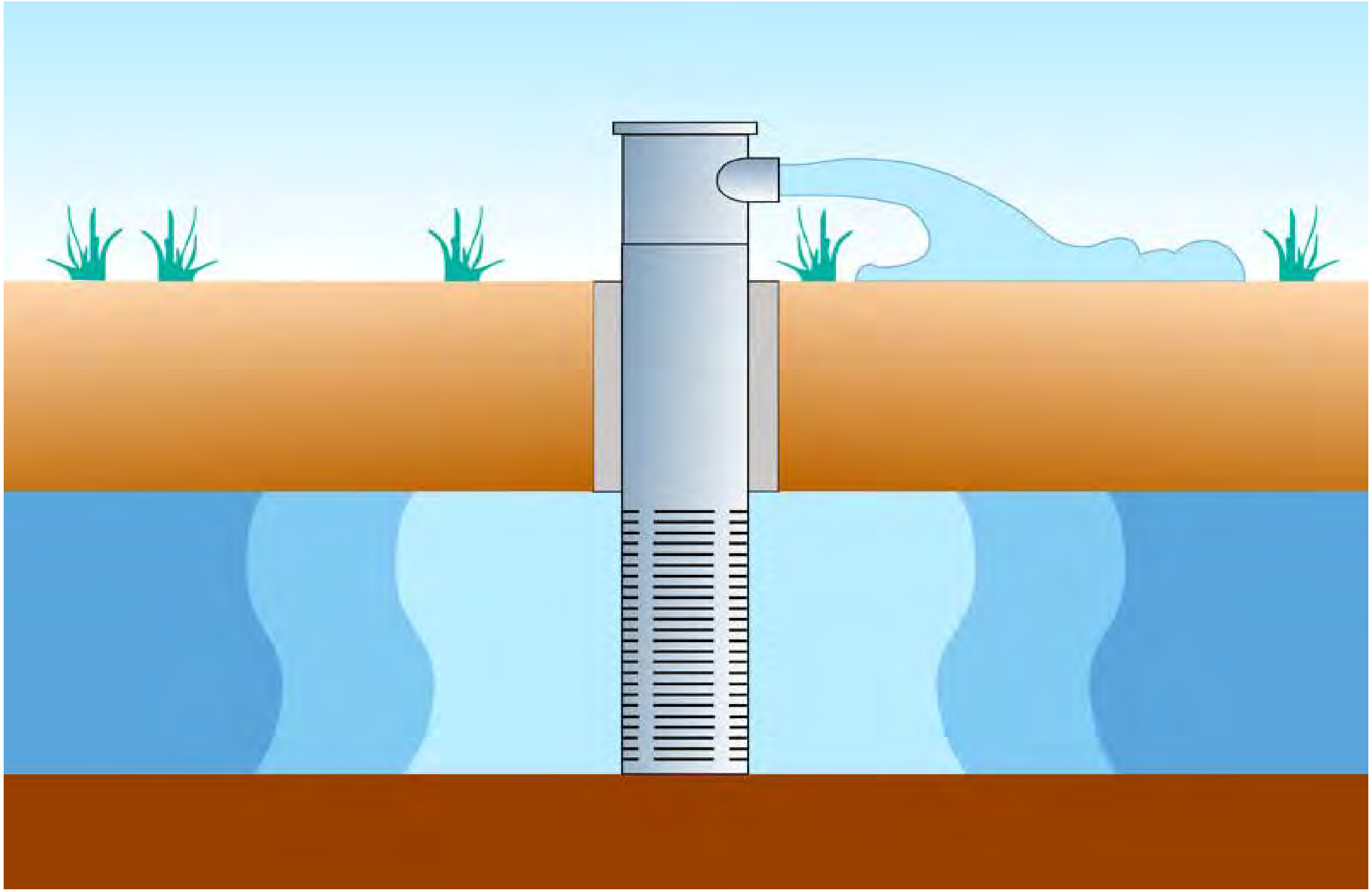
MALCOLM PIRNIE

ARCADIS

Workshop Agenda

- Introductions
- ASR concepts and applications
- Prioritization of applications for this Project
- Hydrogeologic data collection to date
- Confirmation of storage locations for this Project
- Sources of supply and water availability
- Future water demand and demand centers
- Remaining work
- USGS Presentation

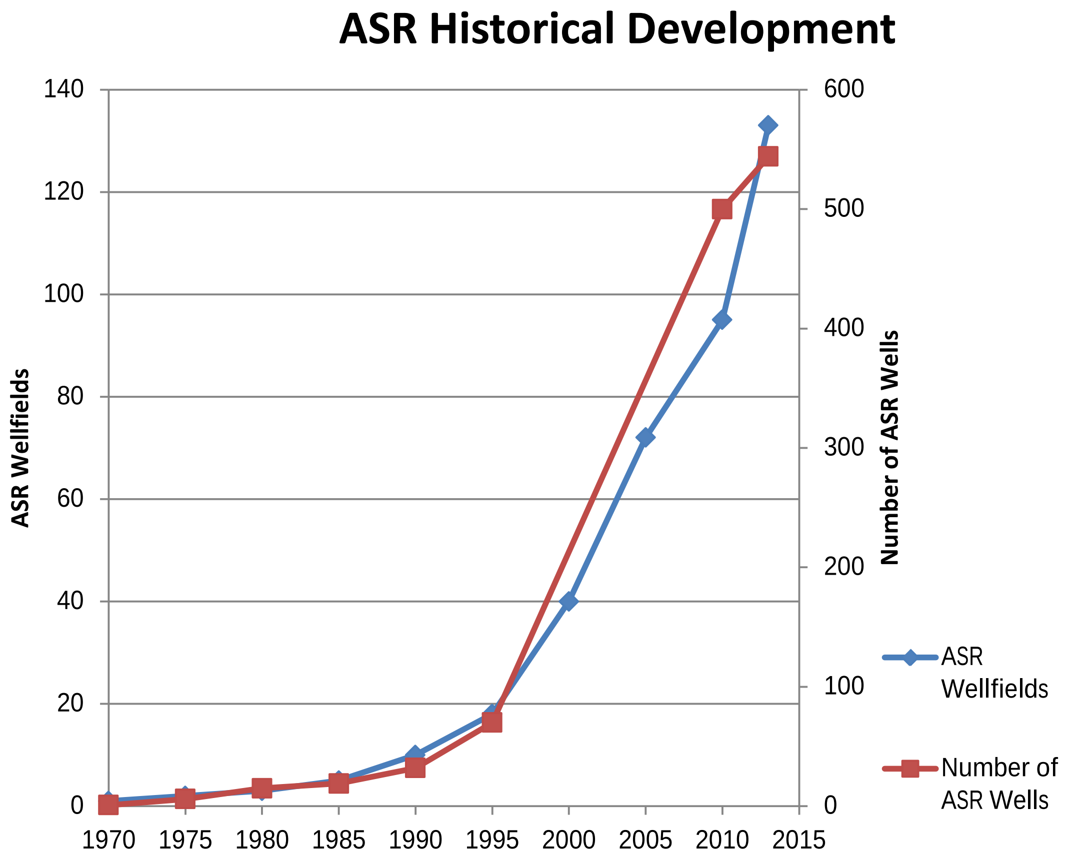
Aquifer Storage Recovery



Storage of water through a well in a suitable aquifer during times when the water is available, and recovery of the stored water from the same well when needed

ASR Development in the U.S.

- Currently (2013) at least 544 ASR wells in at least 133 ASR wellfields in about 22 states*
- Many other countries as well
- 27 different types of ASR applications
- Many different types of water sources for aquifer recharge
- Storage in many different types of aquifers and lithologic settings



*2013 inventory update by Dr Frederick Bloetscher, Florida Atlantic University

Factors Contributing to Global ASR Implementation

- Economics
  - Typically less than half the capital cost of alternative water supply sources
  - Phased implementation
  - Marginal cost pricing
- Proven Success
  - About 133 wellfields in 22 states with over 544 operating, fully permitted ASR wells
- Environmental and Water Quality Benefits
  - Maintain minimum flows
  - Small storage footprint compared to surface reservoirs
- Adaptability to Different Situations
  - Fresh, brackish or saline storage aquifers
  - Drinking water, reclaimed water, stormwater or groundwater storage
  - Over 27 different applications

Mt Pleasant, SC – Well ASR-2

Broad Range: Water Sources and Storage Zones

Kerrville ASR Well

- Water sources for ASR storage
  - Drinking water
  - Reclaimed water (AZ, TX, FL, NJ, CA)
  - Seasonally-available stormwater
  - Groundwater from overlying, underlying or nearby aquifers
- Storage zones
  - Fresh, brackish and saline aquifers
  - Confined, semi-confined and unconfined aquifers
  - Sand, clayey sand, gravel, sandstone, limestone, dolomite, basalt, conglomerates, glacial deposits
  - Vertical “stacking” of storage zones

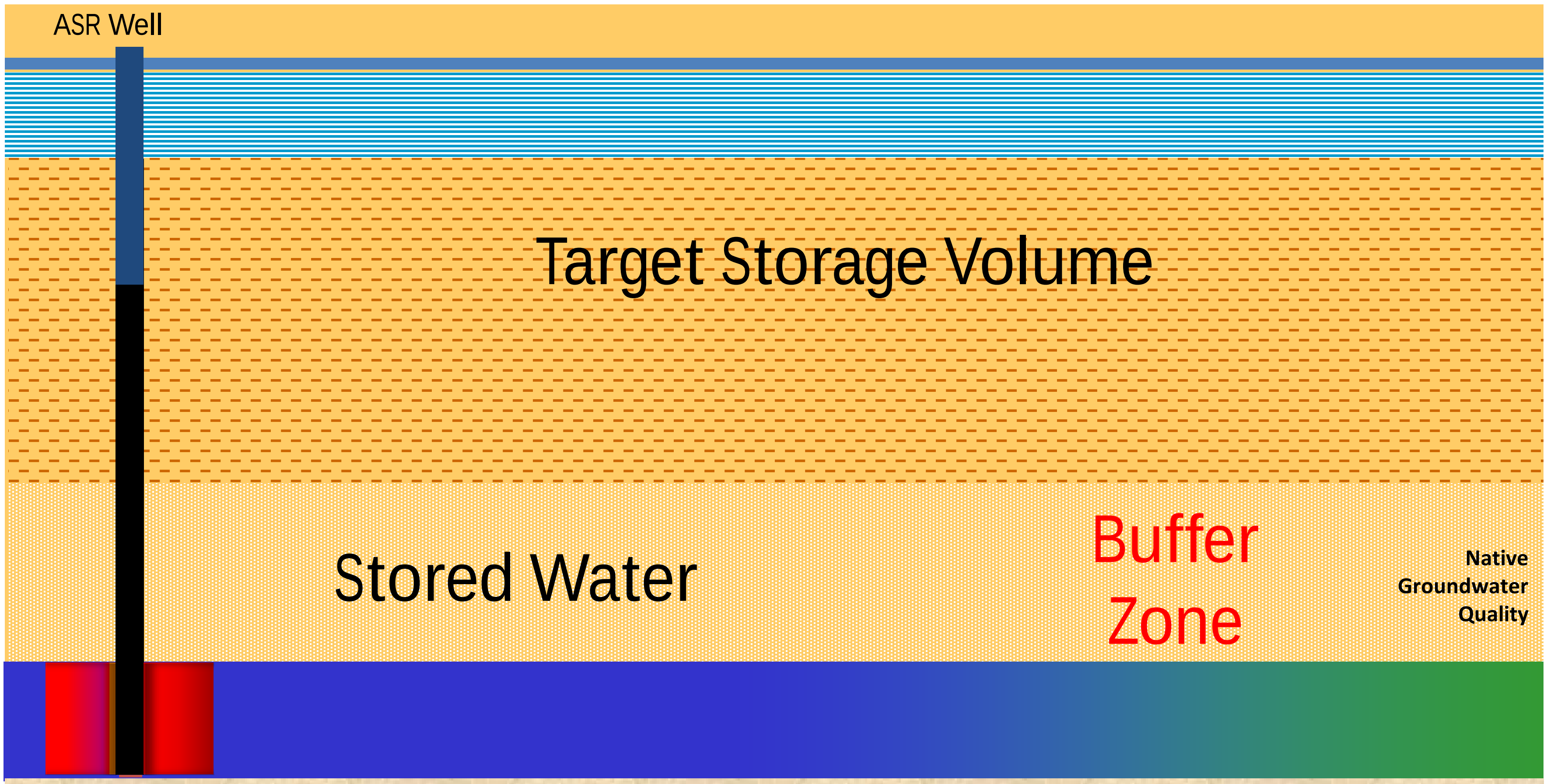
ASR Operating Ranges

- Well depths
  - 30 to 2,700 feet
- Storage interval thickness
  - 20 to 400 feet
- Storage zone Total Dissolved Solids
  - 30 mg/l to 39,000 mg/l
- Storage Volumes
  - 100 AF to 270,000 AF
- Bubble radius less than 1,000 ft
- Individual wells up to 8 MGD capacity
- Wellfield capacity up to 157 MGD

Calleguas MWD, California

ASR Well

Formation and Maintenance of TSV: Achieves Recovered Water Quality Goals



TSV is the sum of the stored water volume and the buffer zone volume. Expressed in MG/MGD of recovery capacity, or in "days"

Phase 1 Feasibility Assessment Discussion Items

- Objectives
- Historic and projected water demands and variability
- Water supply availability
- Water quality variability and treatment requirements
- Storage volume requirements
- Hydrogeology
- ASR conceptual plans
- Economics
- Legal, regulatory, institutional considerations

Beaufort-Jasper WSA, SC

Well ASR-1

Victoria Area
Potential ASR Objectives

Select and Prioritize One or More Pertinent ASR Applications:

- **Seasonal storage**
- **Long-term storage (“water banking”)**
- **Emergency storage (“strategic water reserve”)**
- **Diurnal storage**
- **Disinfection byproduct reduction**
- Restore groundwater levels
- Control subsidence
- **Maintain distribution system pressures**
- **Maintain distribution system flow**
- Aquifer thermal energy storage (ATES)

Kiawah Island, SC

Denver, CO

Victoria Area
Potential ASR Objectives Cont'd

- Reduce environmental effects of streamflow diversions
- Agricultural water supply
- Nutrient reduction in agricultural runoff
- Enhance wellfield production
- **Defer expansion of water facilities**
- Reclaimed water storage for reuse
- Stabilize aggressive water
- **Hydraulic control of contaminant plumes**
- Maintenance or restoration of aquatic ecosystems

Manatee County, FL – ASR Well, 1983

ACEC Grand Award, 1984

Long-term storage:
"Water Banking for the Drought of Record"

- How to estimate the Target Storage Volume (TSV)
- ASR facilities capacity determined by the greater of required recharge capacity or required recovery capacity to provide 100% reliability
- Buffer zone volume as a percentage of the TSV
- "Will the stored water still be there when we need it?"
- Lateral velocity of groundwater in the storage aquifer(s)?
- Proximity of other groundwater users?
- Measures available to protect availability of the stored water

Seasonal Storage

- May be an important secondary benefit of ASR in Texas (in addition to providing storage for DOR)
- Annual benefit, not just once in a lifetime
- Facilitates more efficient use of existing infrastructure, meeting peaks from ASR instead of from water treatment plants and transmission pipelines

Orangeburg SC

Total 6.5 MGD

Two ASR wells in two different aquifers within a single wellhouse

Strategic Storage for Emergencies

- Water systems dependent upon a single source and/or a long transmission pipeline

- Accidental loss, contamination, warfare, terrorism, natural disaster

- Build a strategic water reserve deep underground

Des Moines Water Works, Iowa – 100 MGD WTP
Before and After 1993 Flood

Emergency Storage: Des Moines ASR Objectives

Deepest ASR well in the world – 2700 ft in Jordan Sandstone Aquifer

Retrofit of Existing Abandoned Production Well

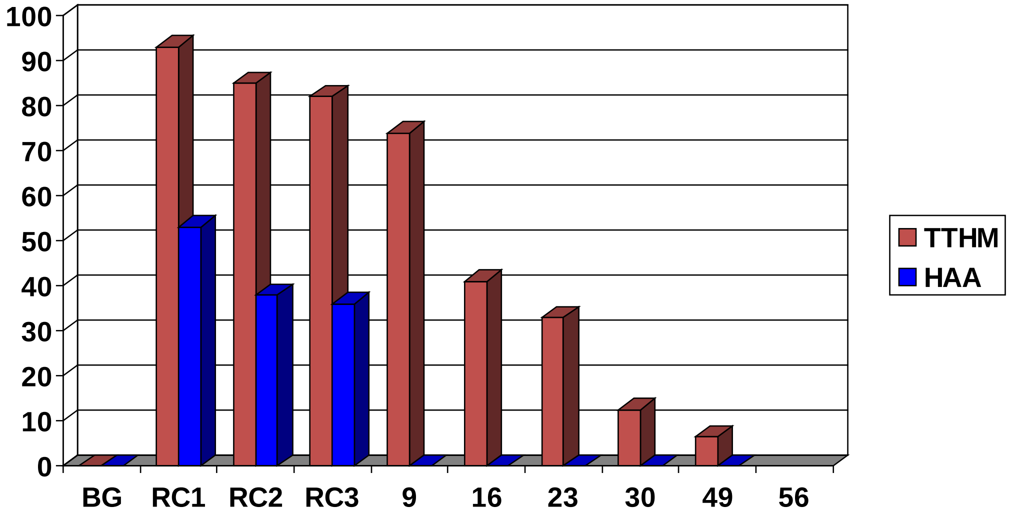
Primary ASR Objective
- Emergency Water Supply
- 30 MGD for 90 days – 2.7 BG

Secondary ASR Objective
- Seasonal Water Storage
- 10 MGD for 90 days – 0.9 BG

Tertiary ASR Objective
- Eliminate need for nitrate removal during spring thaw

Disinfection Byproduct Reduction

- Elimination of Haloacetic Acids and their formation potential in a few days due to aerobic subsurface microbial activity
- Reduction of Trihalomethanes and reduction of their formation potential in a few weeks due to anaerobic subsurface microbial activity



Disinfection Byproduct Attenuation – Centennial WSD, Highlands Ranch, CO

Maintain Pressure, Flow and WQ In Distribution Systems

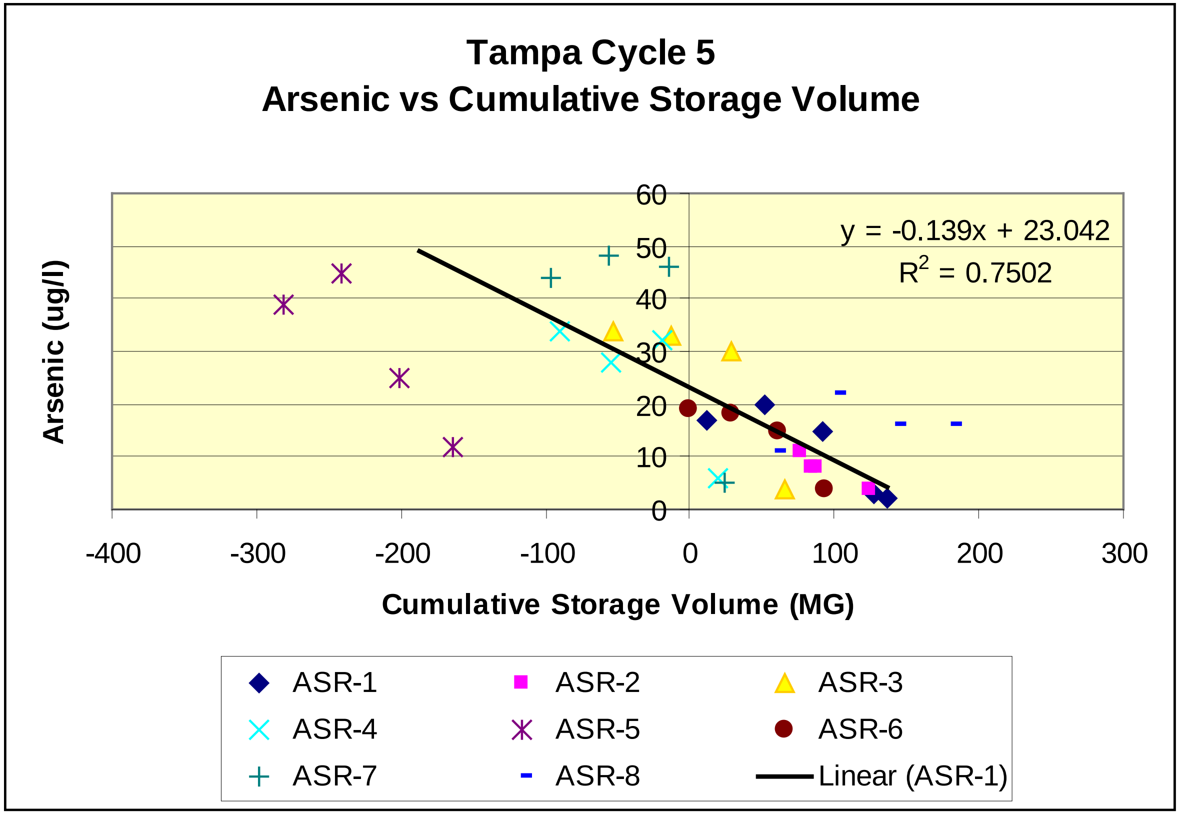
- Locate ASR wells in seasonal low pressure areas:
  - Top of a hill
  - End of a long pipelines
  - Summer beach resort

- Avoid the need for flushing pipelines to waste to maintain water quality in distant portions of a water distribution system

Murray Avenue ASR Well
Cherry Hill, New Jersey

Improve Water Quality

- Arsenic
- Fluoride
- Salinity
- THM and HAA
- Fe and Mn
- H_2S
- N & P
- TOC (carbon sequestration)
- Microbiota
- pH stabilization



Arsenic Decreases as the Cumulative Storage Volume Increases

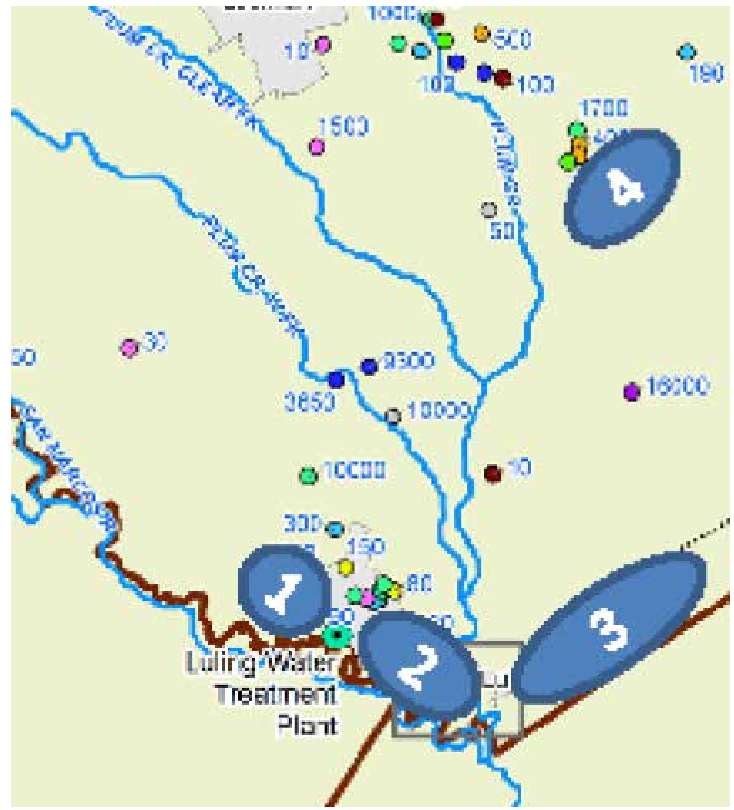
Defer Expansion of Water Facilities

- Operate treatment facilities to meet slightly more than average demands, providing for maintenance periods and times of inadequate supply
- Meet maximum day demands from ASR wells; peak hour demands from elevated and ground storage tanks
- Typically reduce capital costs by >50%

Highlands Ranch, CO
One of 26 ASR wells underground in vaults

Hydraulic Control of Contaminant Plumes

- Oilfield injection wells:
  - Disposal of produced brine water
  - Old, corroded carbon-steel cased wells
- Other contamination sources (nitrates, chlorides, etc)



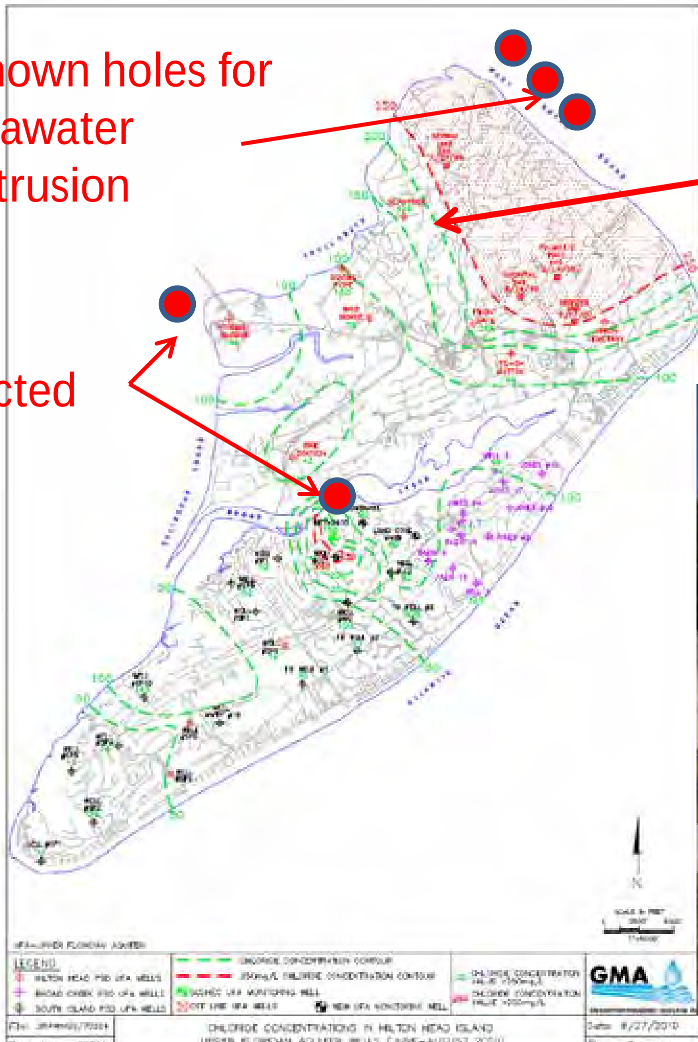
Hilton Head Island
Upper Floridan Aquifer Seawater Intrusion

Known holes for seawater intrusion

HILTON HEAD PSD WELL ASR-1

OPERATIONAL WITHIN 23 MONTHS

Suspected holes



ASR is Cost-Effective

- June 2006 Survey of Florida ASR Costs
  - Based on 11 ASR wellfields in Florida
  - Capital cost includes construction and engineering
  - Unit capital cost: $1.00 per gpd of recovery capacity, within range of $0.50 to $2.00
  - Approximately one-sixth the unit capital cost of surface reservoir storage, within range of 1/3 to 1/30
- San Antonio Water System, TX (2004 to 2006)
  - $1.10 per gpd recovery capacity for 60 MGD ASR wellfield
- NC and SC four ASR wellfields (2012 to 2013)
  - Average: $1.02 per gpd recovery capacity
  - Range: $0.77 to $1.55 per gpd

Capital Cost Comparisons

Source/Storage Option	Typical $/GPD Capacity
Conventional Supply	0.50 – 5.00
ASR	0.50 - 2.00
Brackish Desalination	2.00 – 5.00
Seawater Desalination	7.00 – 12.00
Surface Reservoirs	3.00 – 30.00
Indirect Potable Reuse	7.00 – 25.00

ASR is complementary to other sources, increasing total yield and reliability. With adequate ASR capacity, 100% reliability can be achieved at reasonable capital cost.

ASR Operational Considerations

- Availability and suitability of well sites
- Retrofit of existing wells vs new wells
- Proximity of transmission/distribution pipelines and their conveyance capacity during recharge/recovery
- Disposal of water during testing and operations
- Recharge water quality and variability
- Geochemistry, pre- and post-treatment requirements
- Inventory of nearby wells, owners, depths, uses
- Instrumentation and control system capabilities

Potential ASR Well Locations

- Water treatment plant
- Elevated storage tanks
- Ground storage reservoirs
- Fringes of the distribution system
- Other locations in the service area
- Outlying areas with preferred hydrogeologic suitability

Other Considerations Affecting ASR Feasibility

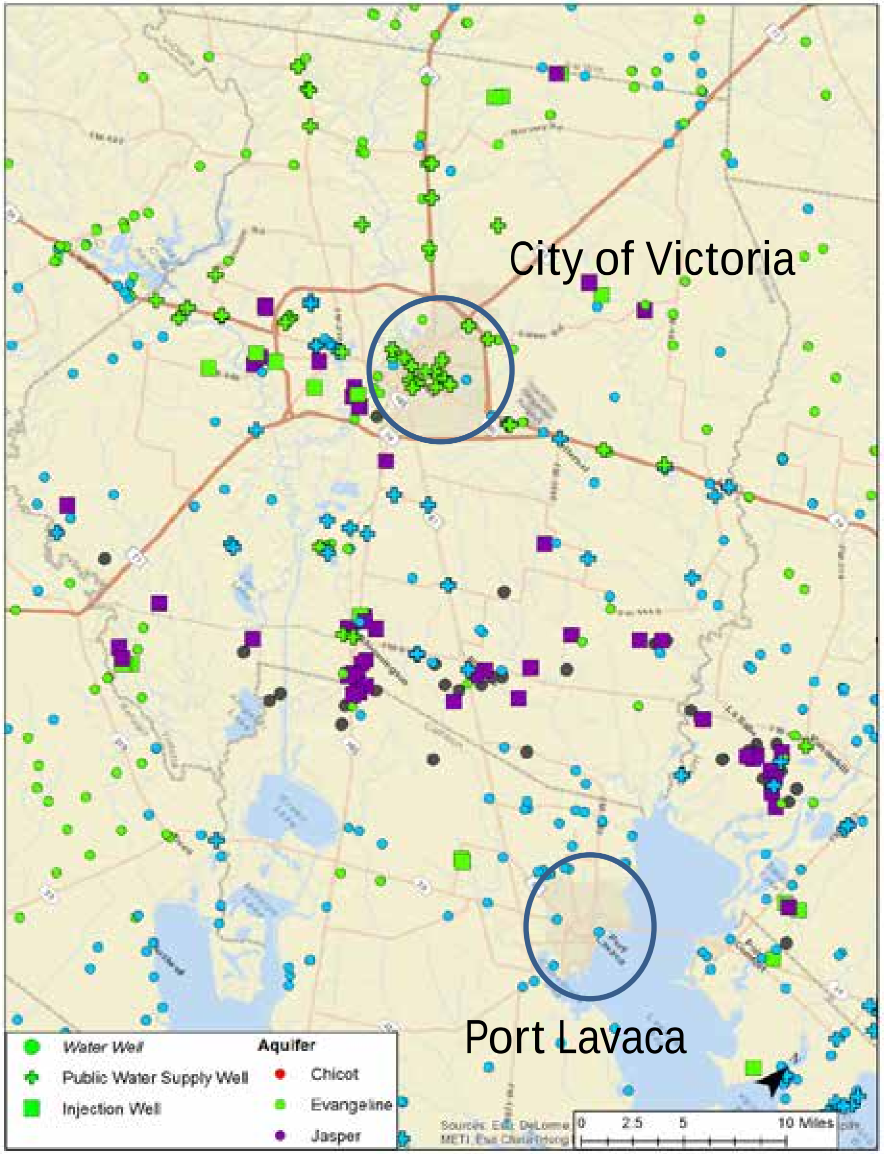
- Water rights
- Legal constraints
- Regulatory constraints
- Institutional constraints
- Funding
- Priority relative to other needs
- Others

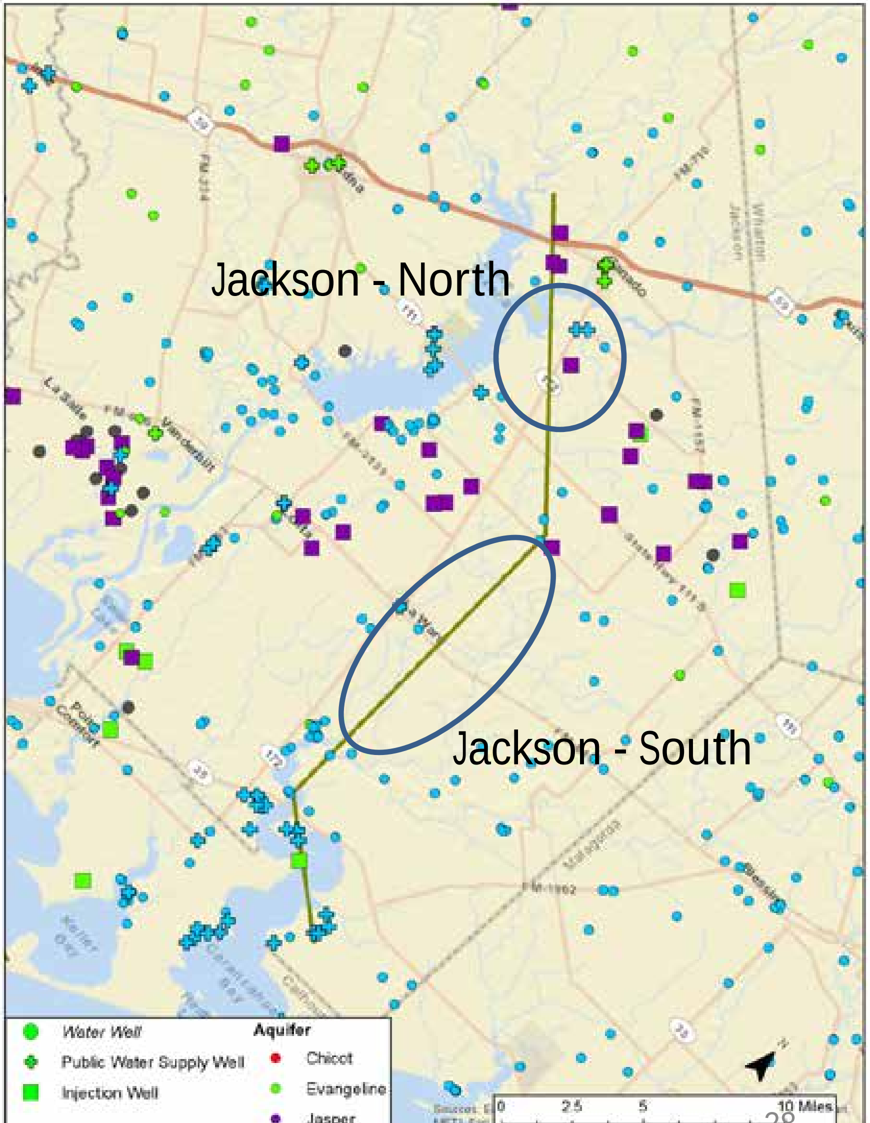
Cocoa, Florida
1 of 10 ASR wells
Operating since 1987

Hydrogeologic Data Collection

- Potential ASR Sites
- Gulf Coast Geology
- Aquifer Hydraulic Properties
- Water Quality Measurements
- Injection Wells and Public Water Supply Wells
- Sand Bed Thickness (Example: City of Victoria)
- Characterization Summary (Example: City of Victoria)
- On-going Work

Potential Aquifer Storage and Recovery Sites

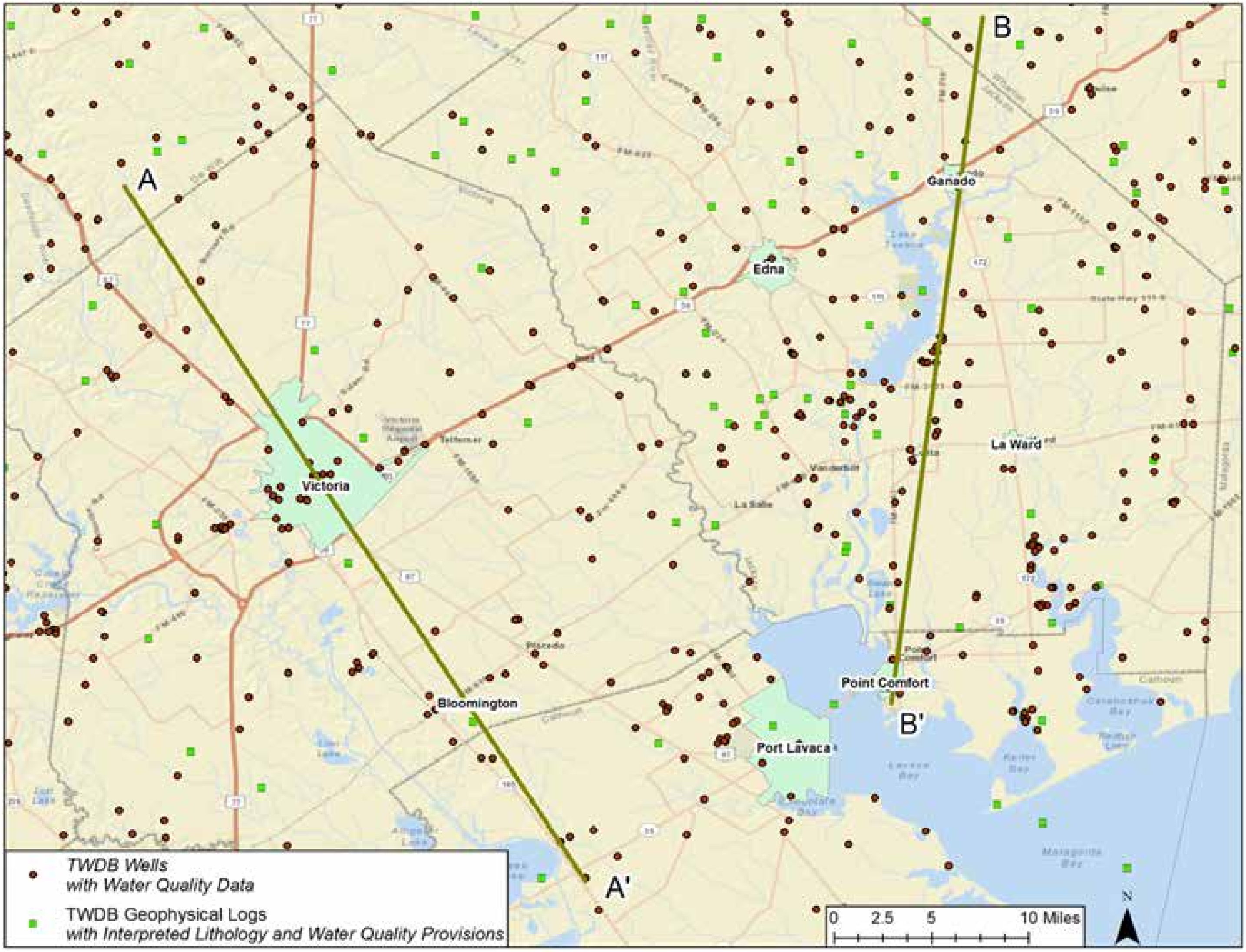




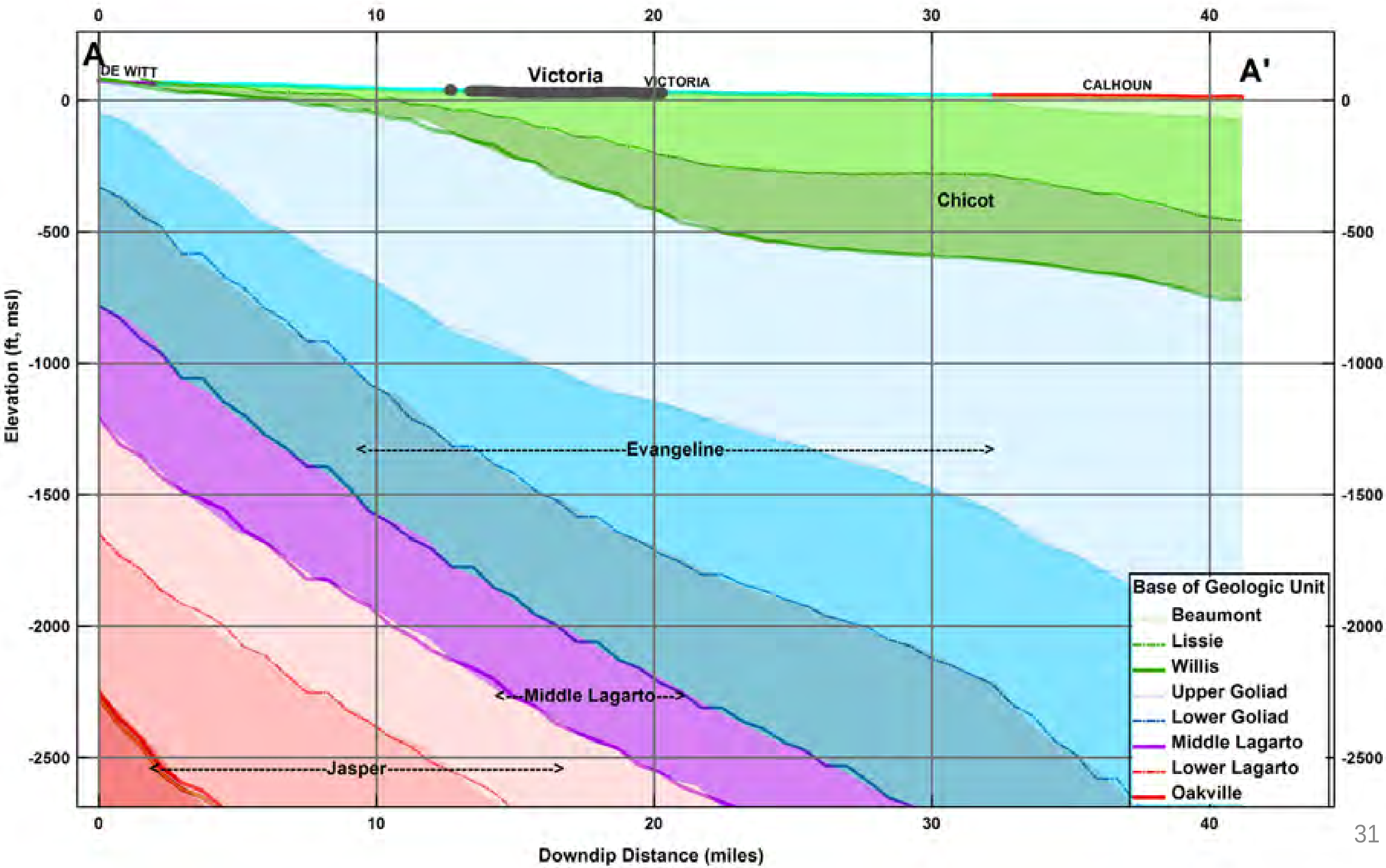
Geological Column

ERA	Epoch		Est. Age (M.Y)	Geologic Unit	Hydrogeologic Unit
Cenozoic	Pleistocene		0.7	Beaumont	CHICOT AQUIFER
			1.6	Lissie	
	Pliocene		3.8	Willis	
	Miocene	Late	11.2	Upper Goliad	EVANGELINE AQUIFER
			14.5	Lower Goliad	
		Middle	17.8	Upper Lagarto	
				Middle Lagarto	BURKEVILLE
		Early		Lower Lagarto	JASPER AQUIFER
			24.2	Oakville	
	Oligocene		32	Frio	CATAHOULA
			34	Vicksburg	

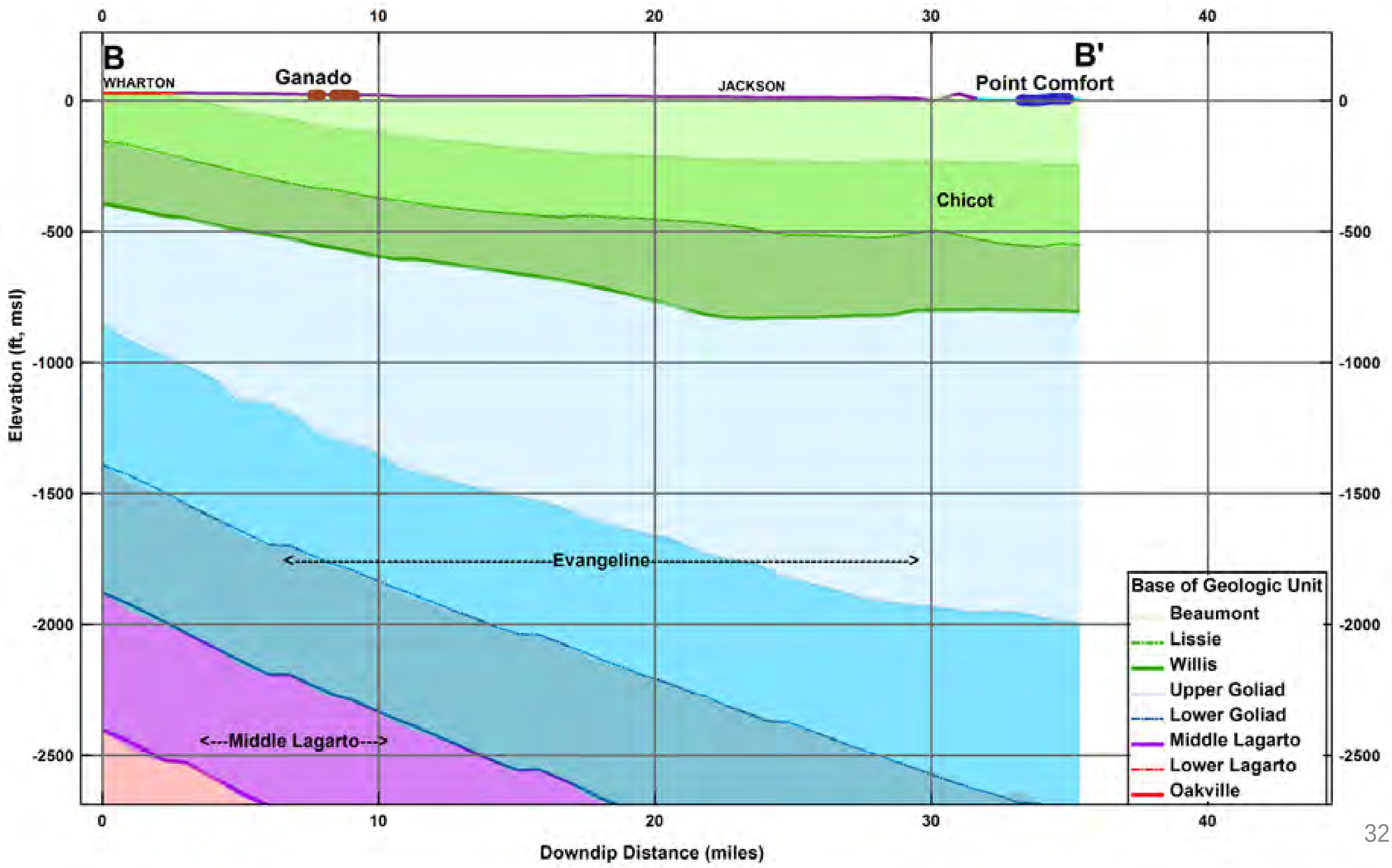
TWDB Water Quality and Lithology Data



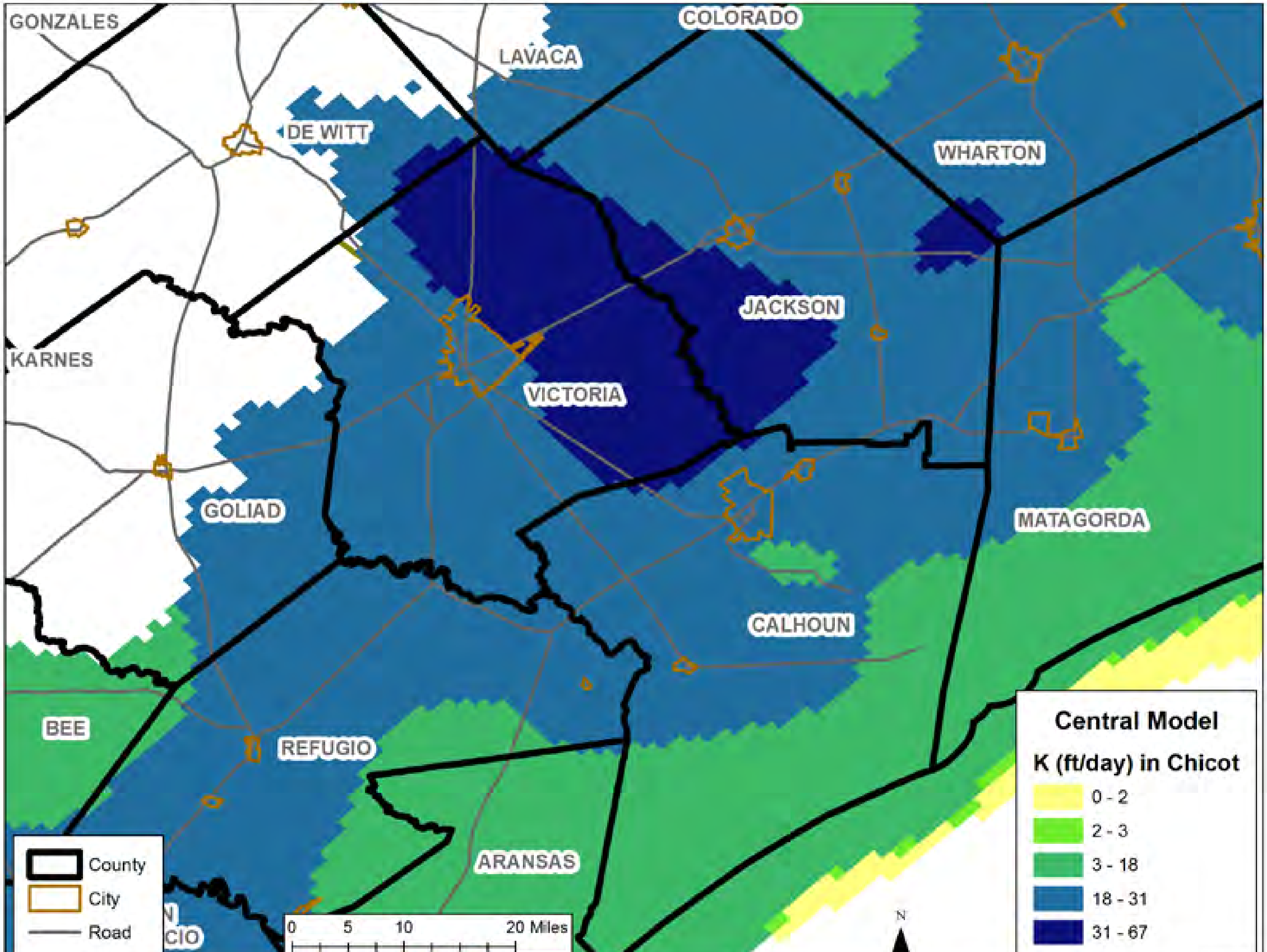
Geological Cross-Section A-A’



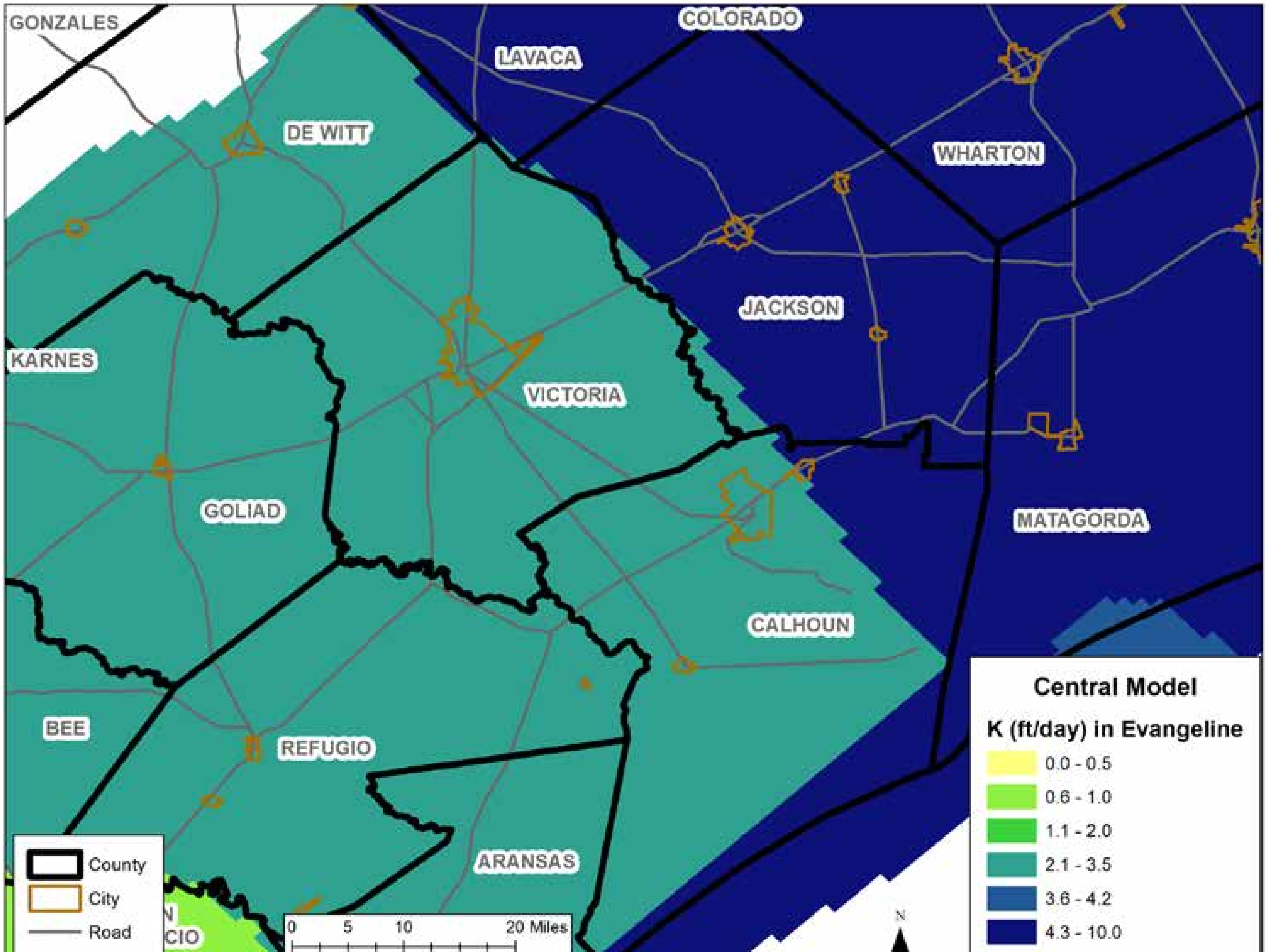
Geological Cross-Section B-B'



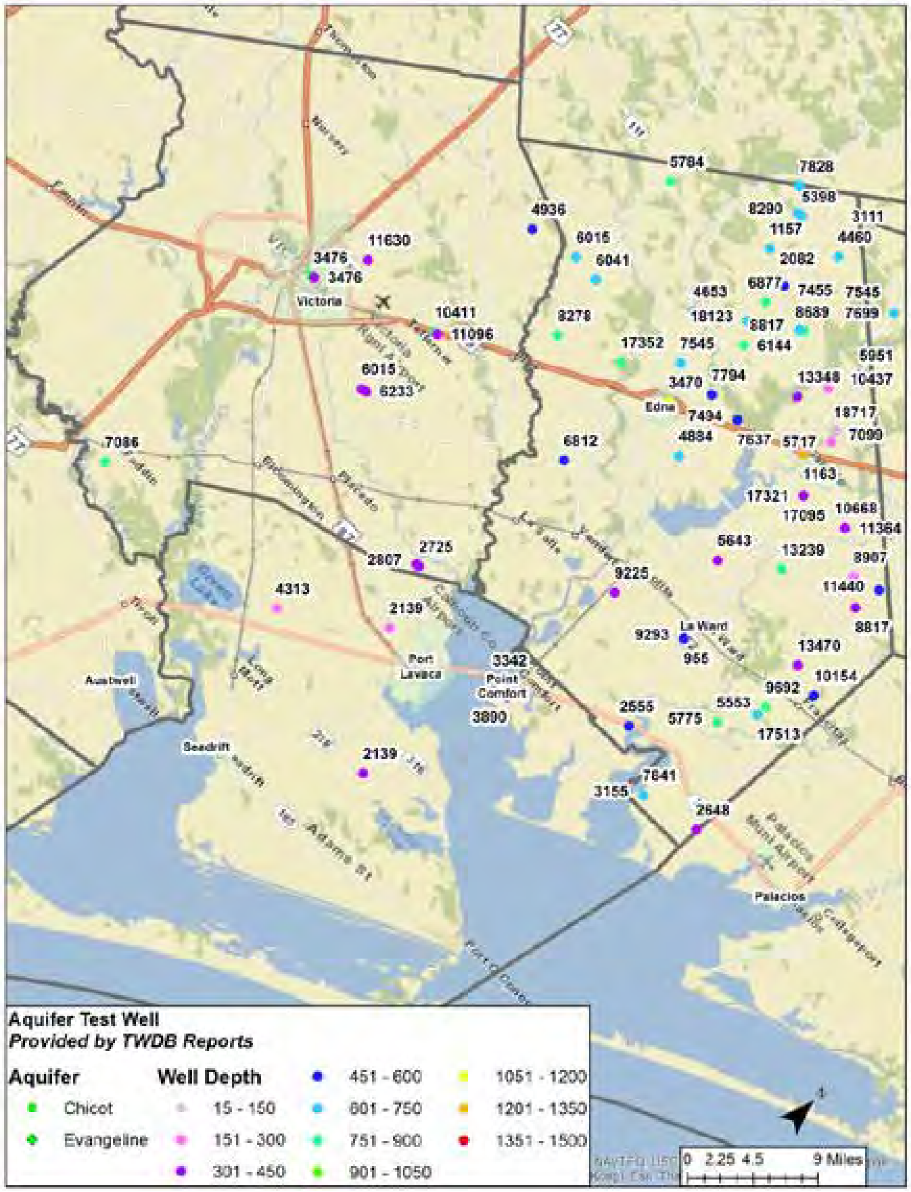
GMA 15 GAM Hydraulic Conductivity (K)- Chicot Aquifer



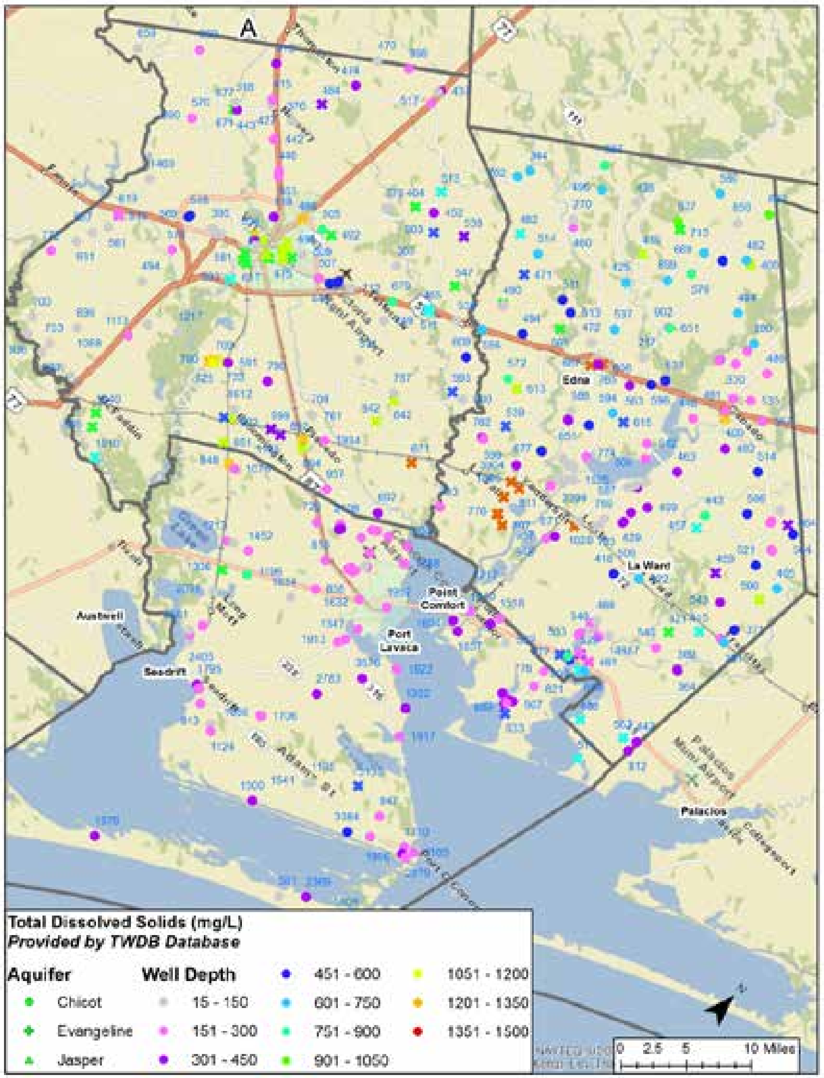
GMA 15 GAM Hydraulic Conductivity (K)- Evangeline Aquifer

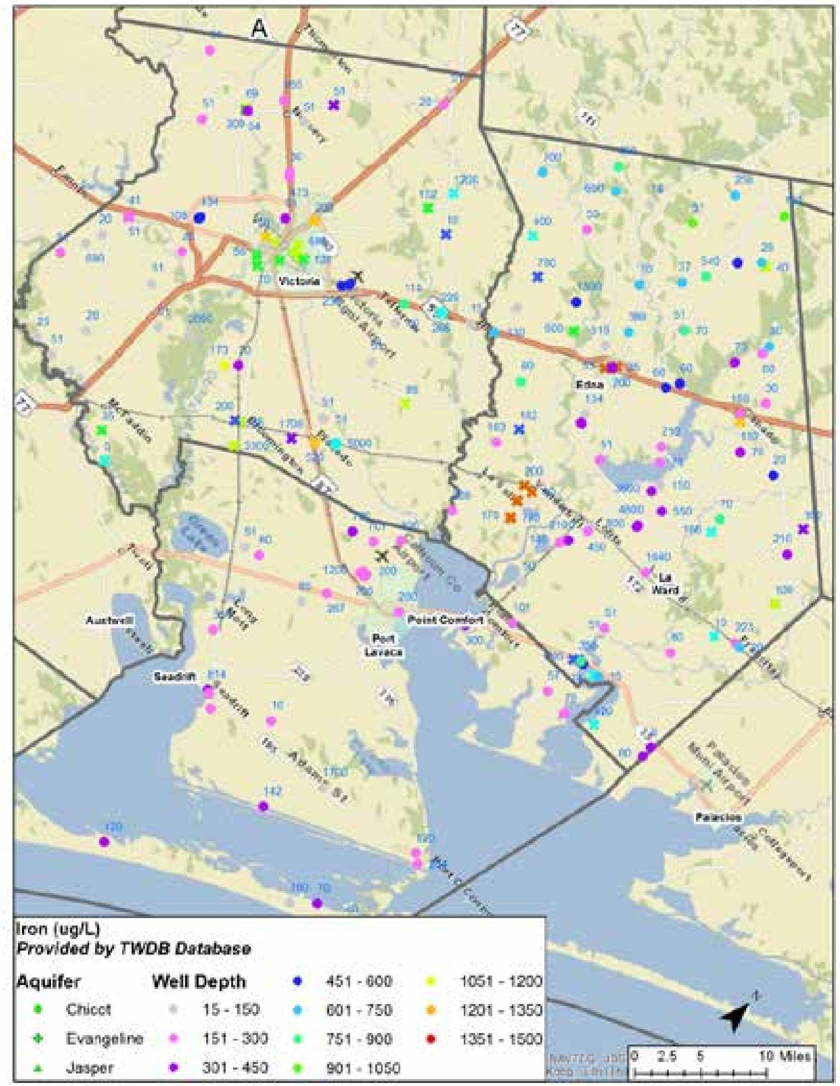


Aquifer Pumping Tests



TDS and Iron Distributions (mg/L)





Injection Wells and Public Water Supply Wells

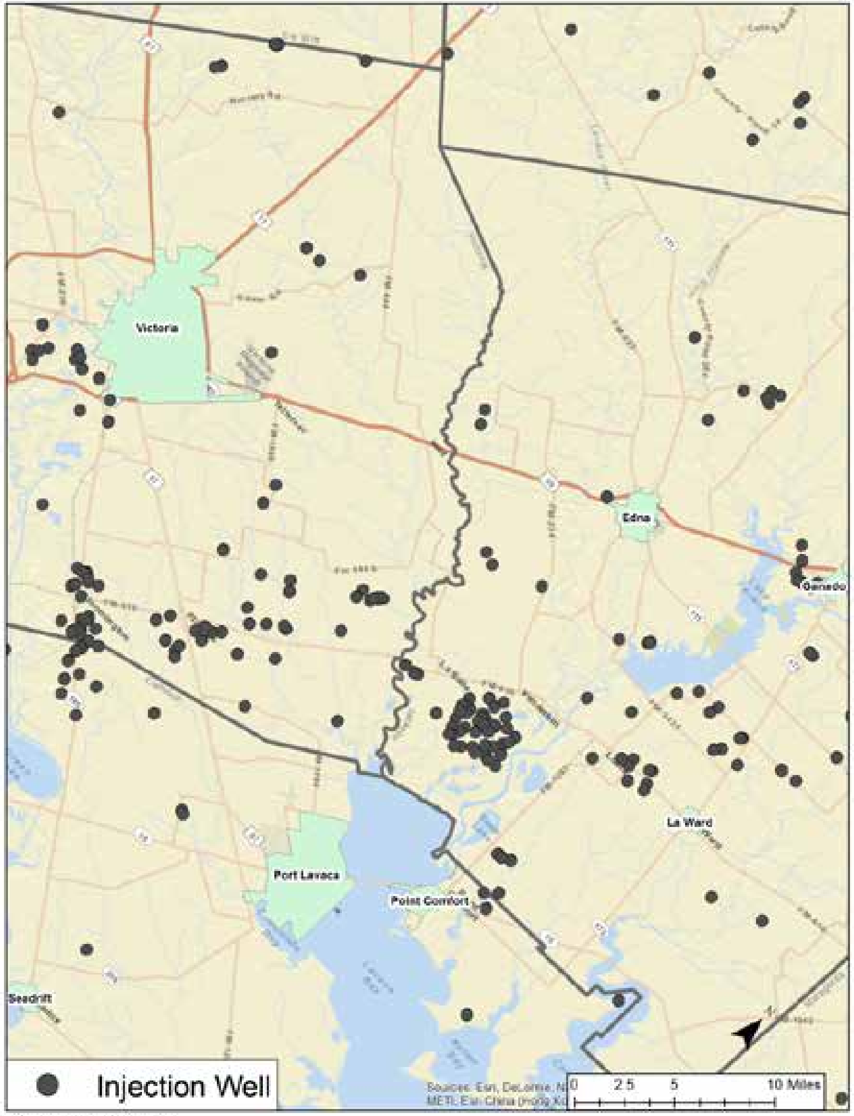
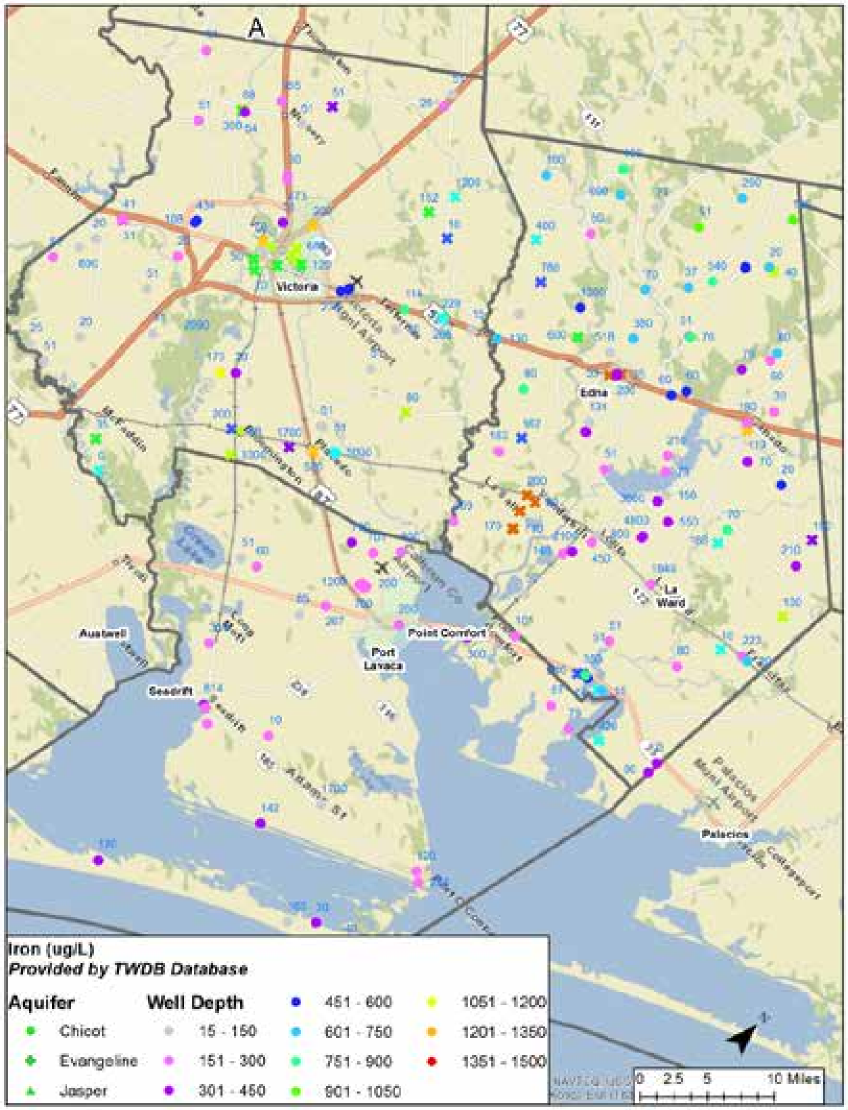
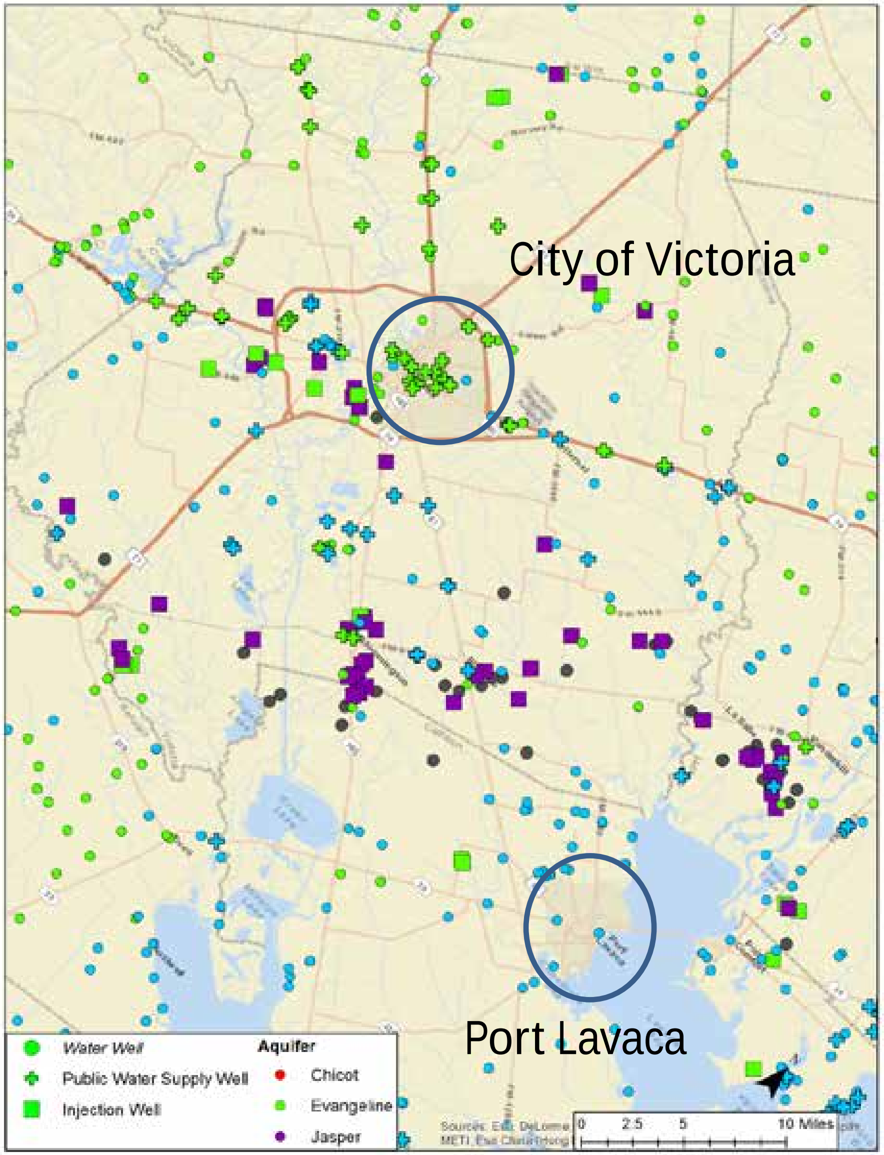
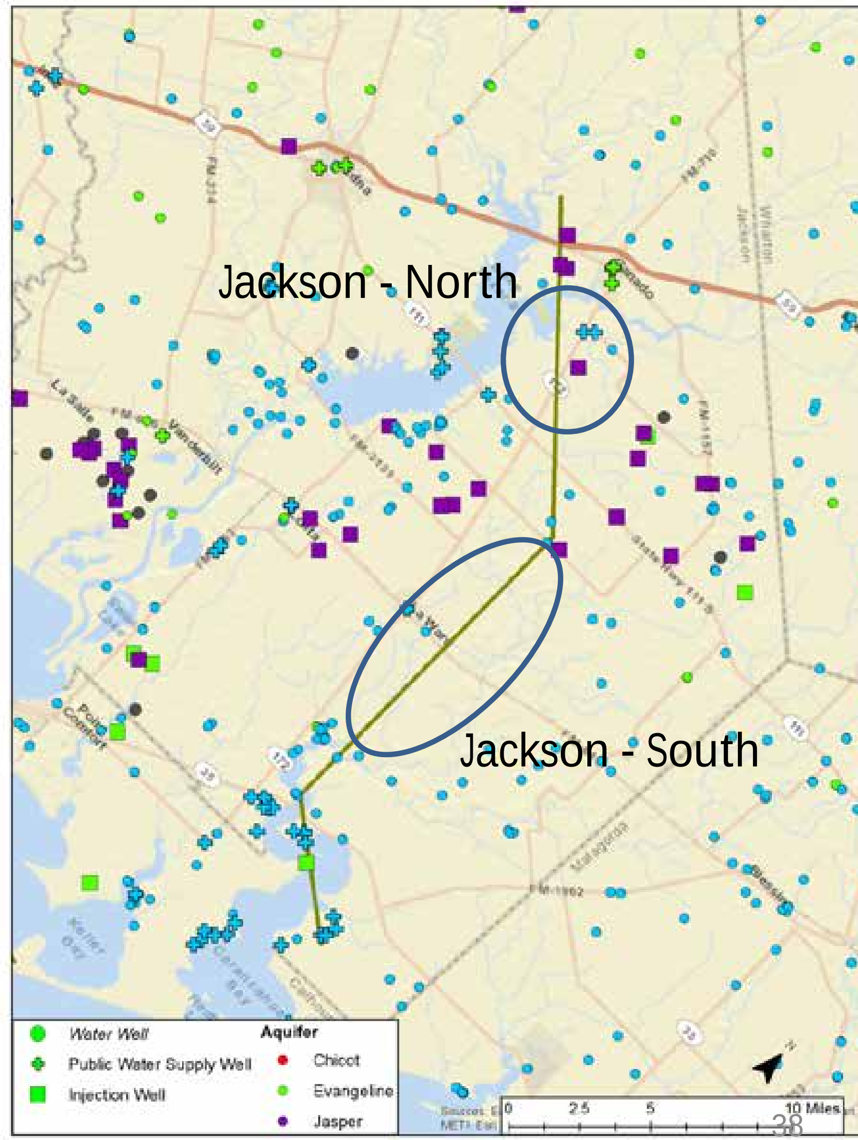


Figure 3_Injection Wells

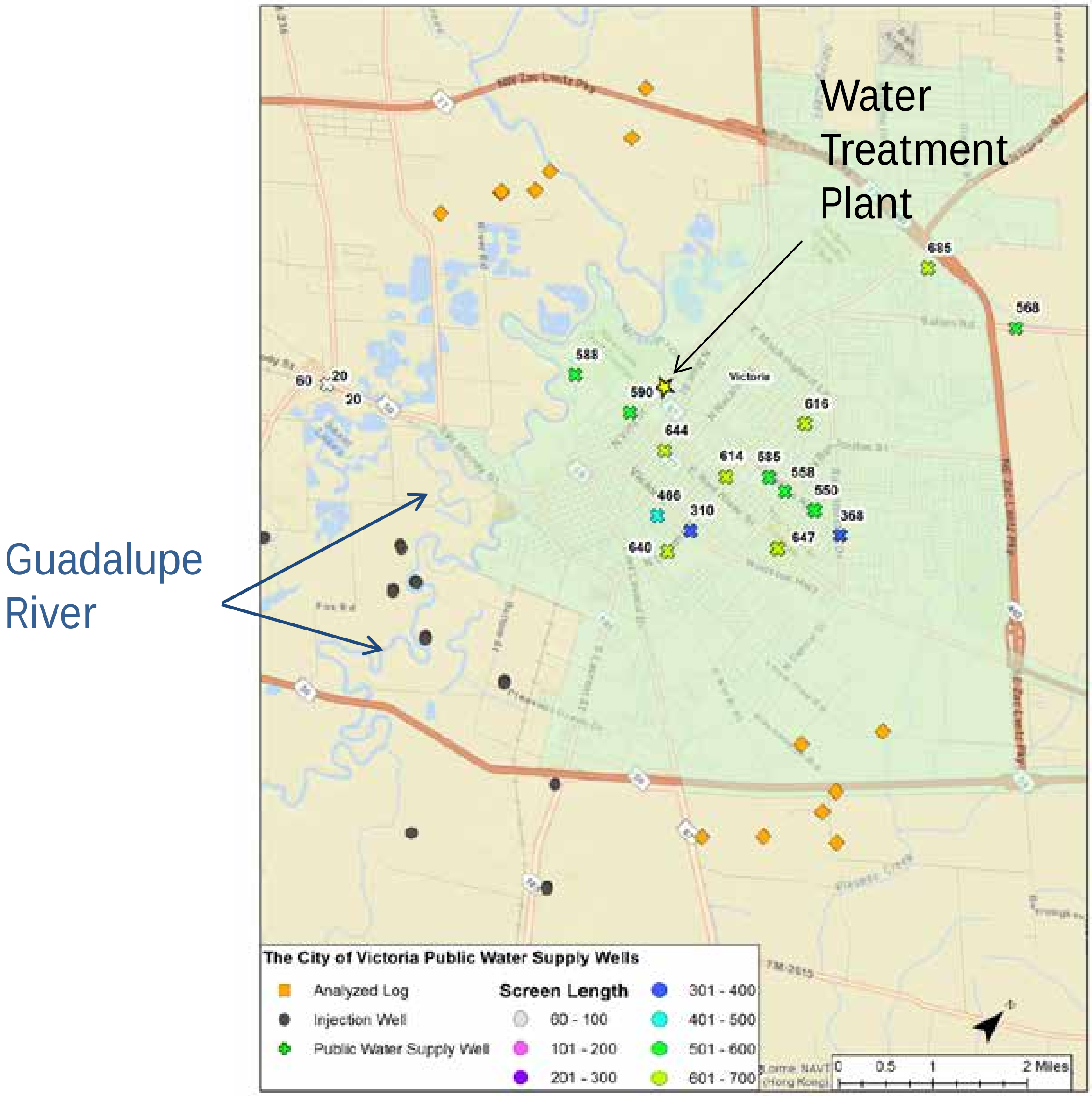


Potential Aquifer Storage and Recovery Sites

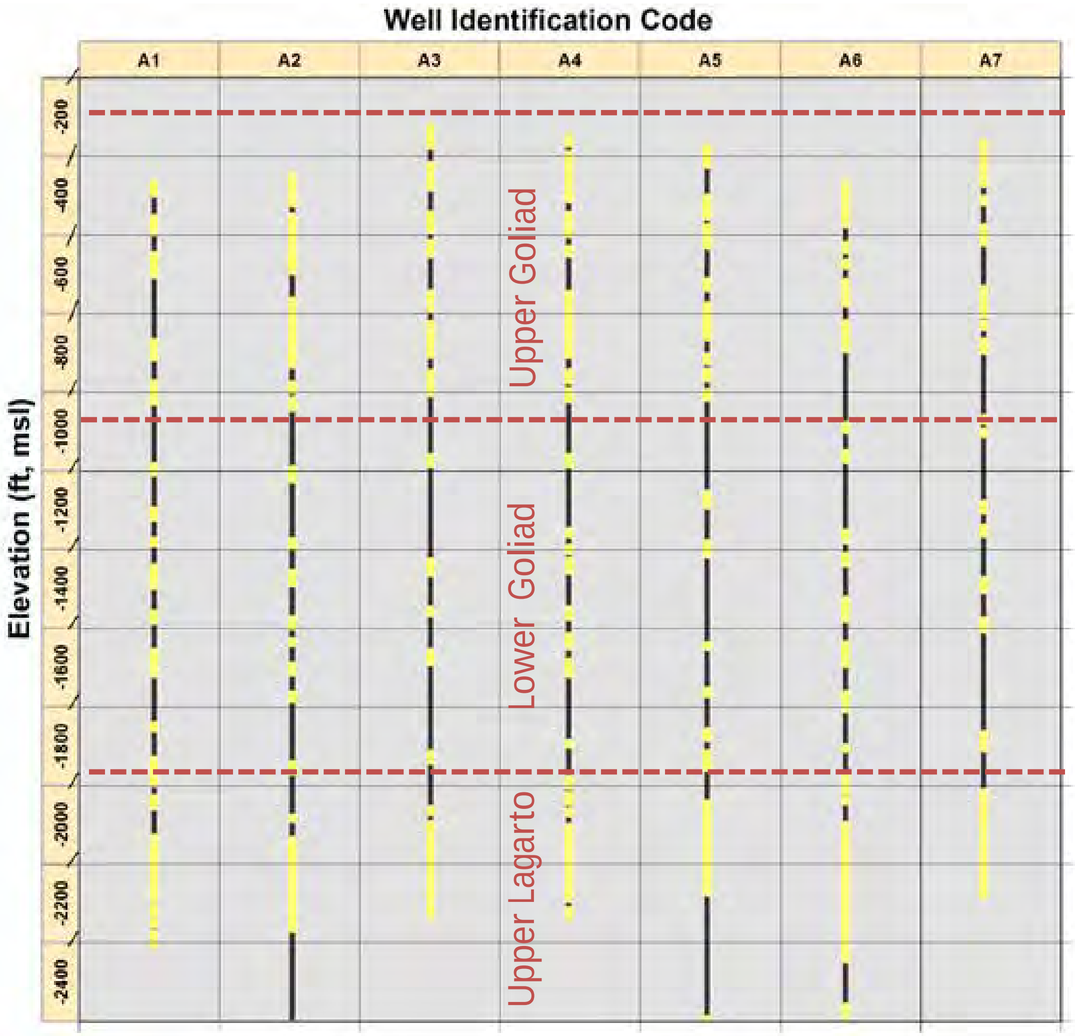


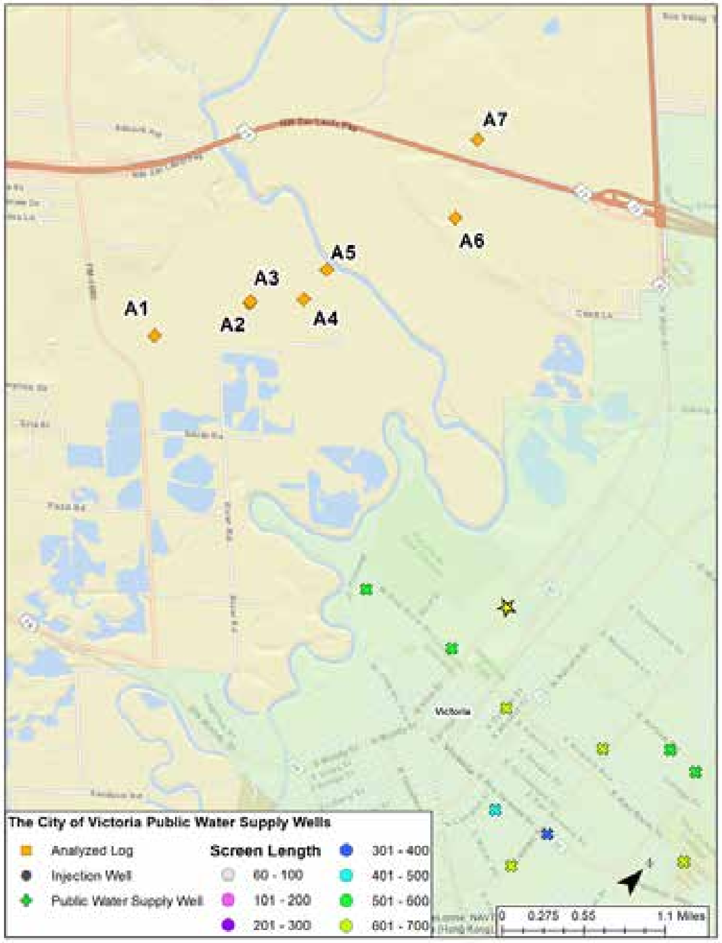


Victoria: Two Sets of Geophysical Logs

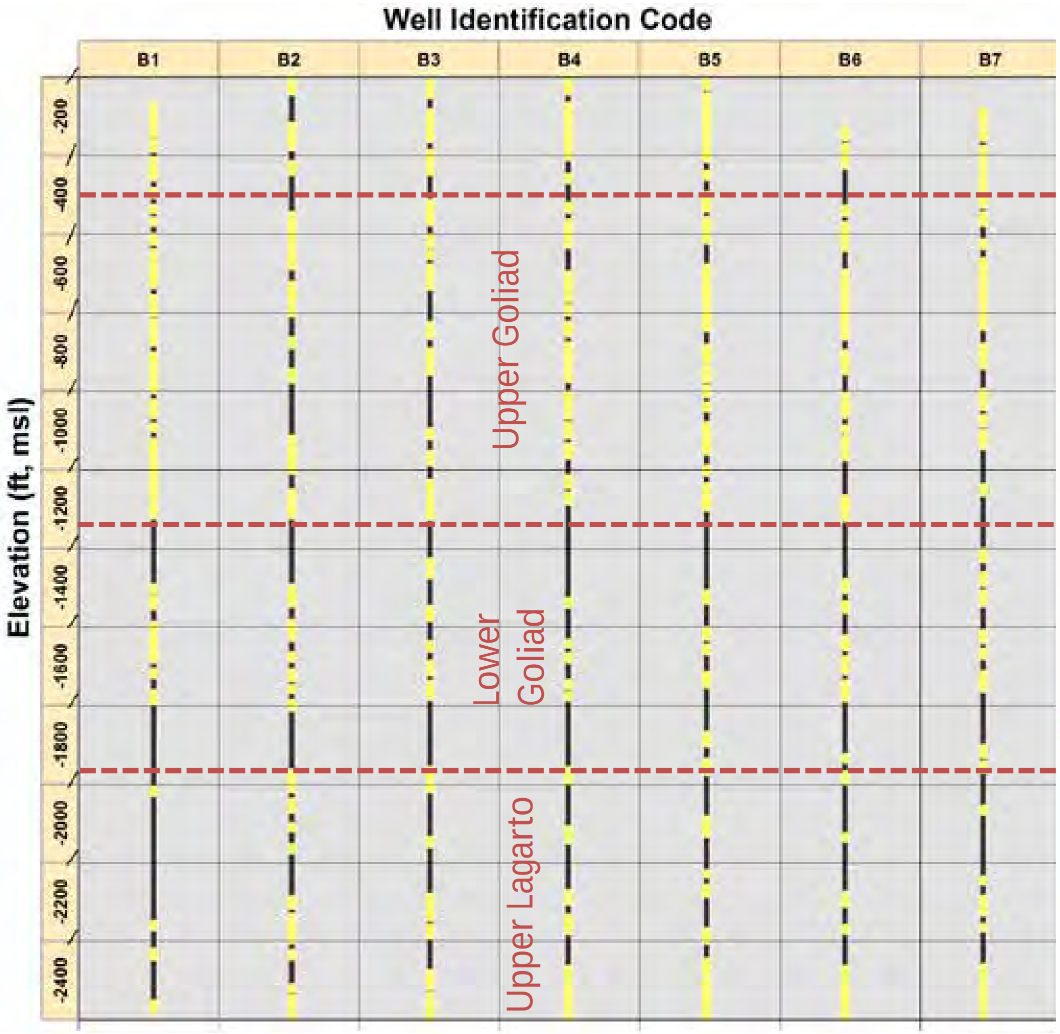


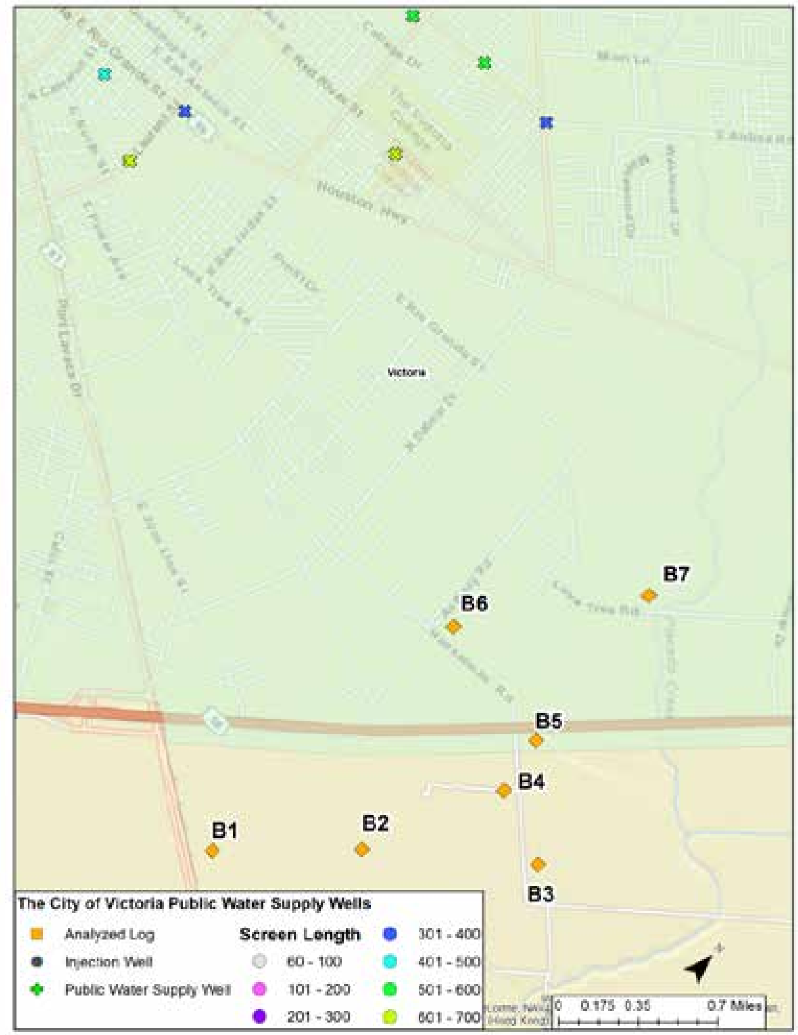
Sand Bed Thicknesses: North Region





Sand Bed Thicknesses: South Region





Victoria Area ASR Site Characteristics

- Upper Goliad in Evangeline Aquifer is the Target Zone
  - ~300 ft bgs to ~1000 ft bgs
  - Same zone as City of Victoria Public Water Supply Wells
- Preferable Site in North Region
  - Away from Injection Wells in southern portion of City
  - Away from Public Water Supply Wells in central portion of the City
  - 2 to 5 miles from Water Treatment Plant
- TDS is estimated between 450 mg/L and 600 mg/L
- Dissolved Iron is estimated between 50 ug/L and 500 ug/L
- Hydraulic Conductivity (K) Value
  - GAM 15 GAM indicates average Evangeline K is about 3 ft/dy
  - GAM 16 GAM indicates average Evangeline K is about 0.5 ft/day
  - No aquifer test results in Evangeline but Chicot/Evangeline Well is about 12 ft/day
    - Screen interval from 135 to 450 ft bgs
    - No aquifer test data available to review
- Several Sand Bed Thicknesses of 20 to 40 feet throughout Upper Goliad

On-going Characterization Work

- Mapping Sand Beds
  - Port Lavaca Area
  - Jackson County
- Hydraulic Conductivity Values
  - Averages from GAM and aquifer pumping tests
  - Estimates for large sand beds
- Scoping calculations using groundwater models
  - Groundwater migration rates
  - Injection rates

Sources of Supply

- City of Victoria
  - 3860A (Lipscomb)
  - 3858A (Murphy)
  - 4117A (Ruschhaupt)
  - 3844A (Schmidt)
  - 3862A
  - 3606A
  - 5466B
- GBRA
  - 5178 (Permit 1614)

Daily Timestep Water Availability Analysis Victoria and GBRA

Model Assumptions

- Full exercise of surface water rights
- Daily Average USGS Gauged Flows
  - #08176500 Guadalupe River at Victoria
    1 day travel time to confluence with San Antonio River
  - #08188500 San Antonio River at Goliad
    2 day travel time to confluence with Guadalupe River
  - Corrected for priority order usage
    Assumed 100% water needs met for upstream **senior** water right holders
- Channel losses as included in the GSA WAM model
- Daily water demands calculated from monthly demands in GSA WAM Run 3
- Permit special provisions included

Water Demand and Demand Centers

- Demand to Year 2040:
  - – Victoria: 8% increase per decade
  - – GBRA: Peak day of 10.2 mgd
  - – Applied to current demand patterns

- Demand Centers:
  - – Victoria: City's service area
  - – GBRA: PLWTP or closest feasible location

Remaining Work

- Data collection
- Completion of hydrogeologic analyses
- Completion of ASR model based prioritized ASR applications
  - Recharge and recovery rates
  - Target storage volumes
  - Treatment facility requirements
- Water quality analysis
- Development of conceptual plan and cost estimates
- Evaluation of permitting/environmental issues
- Economic analysis
- Draft and final reports

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Public Meeting
April 28, 2014

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NOTICE OF PUBLIC MEETING

The City of Victoria will host a
Public Meeting on

The Development of a Regional Plan for Aquifer Storage and Recovery and/or Off Channel Storage Projects in the Golden Crescent Region of Texas

Date: Monday, ~~May~~ April 28, 2014
Time: 10a.m to 12:00p.m.
Planning Department Conference Room
First Floor, City of Victoria 700 N. Main Center

700 N. Main St.
Victoria, TX 77901

AGENDA

- **I. Introductions**
- **II. Review of Scope of Work and Schedule (Tom Brown, NEI)**
- **III. Presentation of Draft Report**
  - **Fred Blumberg, Arcadis, Inc.**
  - **David Fusilier, Naismith Engineering, Inc.**
- **IV. Questions from participants**
- **V. Next Steps**
- **VI. Public Comment**
- **VII. Adjournment**

Naismith Engineering, Inc

JOB NO. 8806 – Victoria Regional ASR Planning Study

SHEET NO.

DESCRIPTION Sign-In Sheet

DATE 4-28-14

BY

Name	Organization
Tom Brown	NEI
David Fusilier	NEI
James Dodson	NEI
Steve Young	INTERA
Fred Blumberg	ARCADIS
Randy Bena	Port of Victoria
David Meesey	TWDB
Donald Reese	COV
Jerry James	COV
Lynn Short	COV
Matt Webb	TWDB
Tim Andruss	VCGCD
Thomas D. Hill	GBRA
Charlie Hickman	GBRA
Stephanie Shelly	GBRA
Don Koble	GBRA

Infrastructure and Off Channel Storage Assessment for the Victoria Area Feasibility Study

For The Golden Crescent Region of Texas

Public Meeting

April 28, 2014

Infrastructure Assessment

- **Based on available information from project participants**

- **Infrastructure needs assessed:**
  - **City of Victoria**
  - **City of Victoria Off Channel Storage Ponds**
  - **Victoria County Navigation District/Port of Victoria**
  - **GBRA/Calhoun County**

How Can an ASR Project be Developed to Help Minimize Infrastructure Improvements?

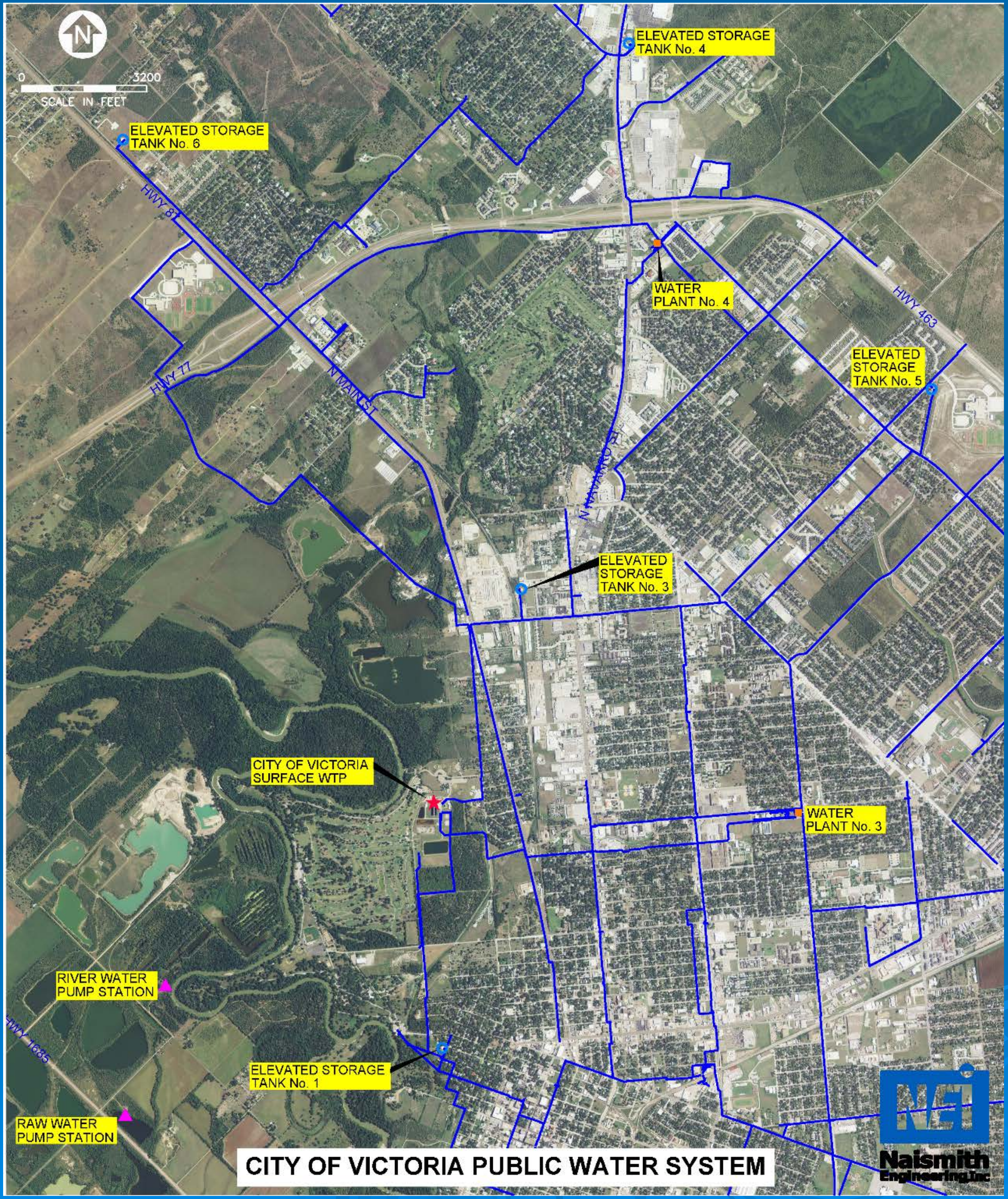
- **Locate ASR wells near existing facilities**
  (i.e., disinfection facilities, storage tanks, booster pumps, etc…)

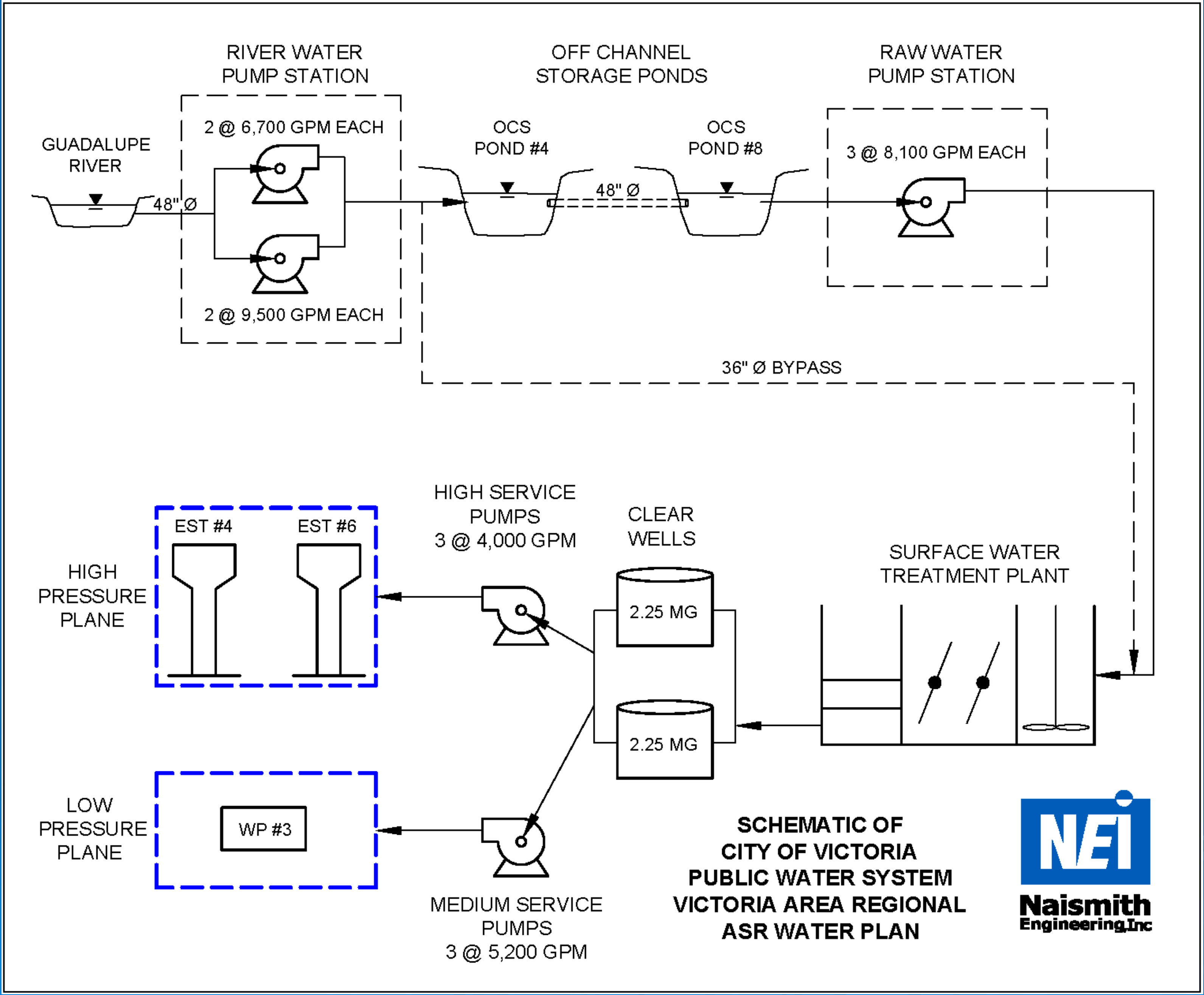
- **Stored ASR water is treated water**
  (disinfection is all that is needed prior to use by customer)

- **Use ASR water to help with peak flows**
  (instead of increasing treatment capacity)

- **Use of ASR water does not increase demand**

CITY OF VICTORIA
PUBLIC WATER SYSTEM


N
0
3200
SCALE IN FEET
ELEVATED STORAGE TANK No. 4
ELEVATED STORAGE TANK No. 6
HWY 87
WATER PLANT No. 4
HWY 463
ELEVATED STORAGE TANK No. 5
HWY 77
N MAIN ST
ELEVATED STORAGE TANK No. 3
CITY OF VICTORIA SURFACE WTP
WATER PLANT No. 3
RIVER WATER PUMP STATION
ELEVATED STORAGE TANK No. 1
RAW WATER PUMP STATION
CITY OF VICTORIA PUBLIC WATER SYSTEM
Naismith Engineering Inc


RIVER WATER
PUMP STATION
OFF CHANNEL
STORAGE PONDS
RAW WATER
PUMP STATION
GUADALUPE
RIVER
2 @ 6,700 GPM EACH
OCS
POND #4
OCS
POND #8
3 @ 8,100 GPM EACH
48" Ø
48" Ø
2 @ 9,500 GPM EACH
36" Ø BYPASS
HIGH SERVICE
PUMPS
3 @ 4,000 GPM
CLEAR
WELLS
EST #4
EST #6
HIGH
PRESSURE
PLANE
SURFACE WATER
TREATMENT PLANT
2.25 MG
2.25 MG
LOW
PRESSURE
PLANE
WP #3
MEDIUM SERVICE
PUMPS
3 @ 5,200 GPM
SCHEMATIC OF
CITY OF VICTORIA
PUBLIC WATER SYSTEM
VICTORIA AREA REGIONAL
ASR WATER PLAN
Naismith
Engineering, Inc

Demand vs. Capacity

- **Demand**
  - **Year 2011 Demand [represents "dry" year]**
  - **Year 2040 [= Year 2011 Demand x 1.26 (8% increase per decade)]**

- **Capacity**
  - **Includes Surface WTP Capacities**
  - **Includes Pumping Capacities**
  - **Firm Pumping Capacity = largest unit out of service**

Table 1-2. System Demands vs. Pumping & Treatment Capacities

	DEMANDS				PUMPING/TREATMENT CAPACITIES				
	2040 MAX DAY	2040 AVG DAY	2011 MAX DAY	2011 AVG DAY	RIVER WATER PUMP STATION[A]	RAW WATER PUMP STATION[A]	SWTP	HIGH SVC + MED SVC PUMPS @ SWTP	SVC PUMPS @ WP #3 + WP #4
gpm	17,283	10,432	13,717	8,279	22,900	**16,200**	17,500	18,400	**15,700**
MGD	24.888	15.022	19.752	11.922	32.98	**23.33**	25.20	26.50	**22.61**
AFY	27,880	16,828	22,127	13,355	36,940	**26,132**	28,230	29,681	**25,326**

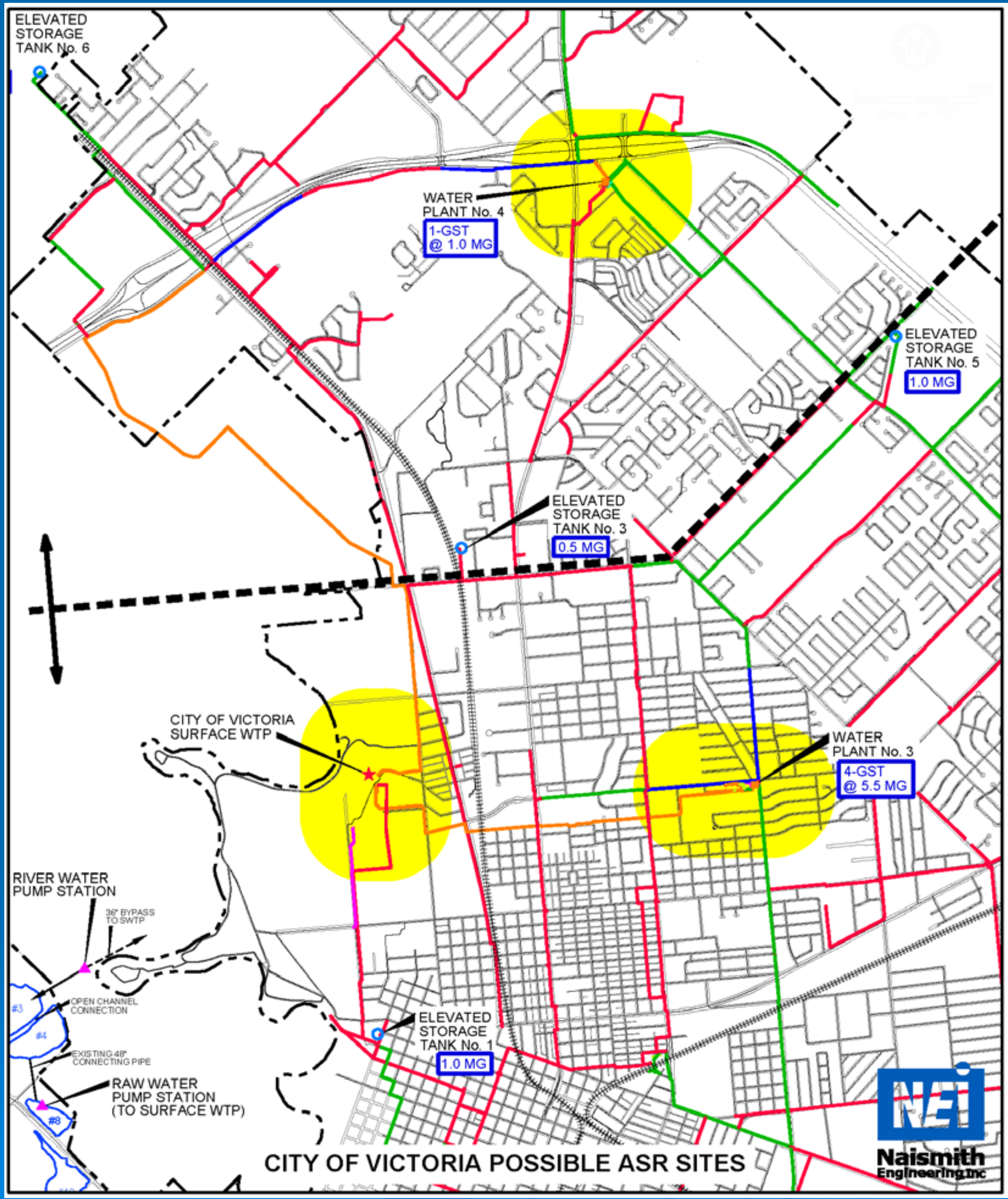
Notes:

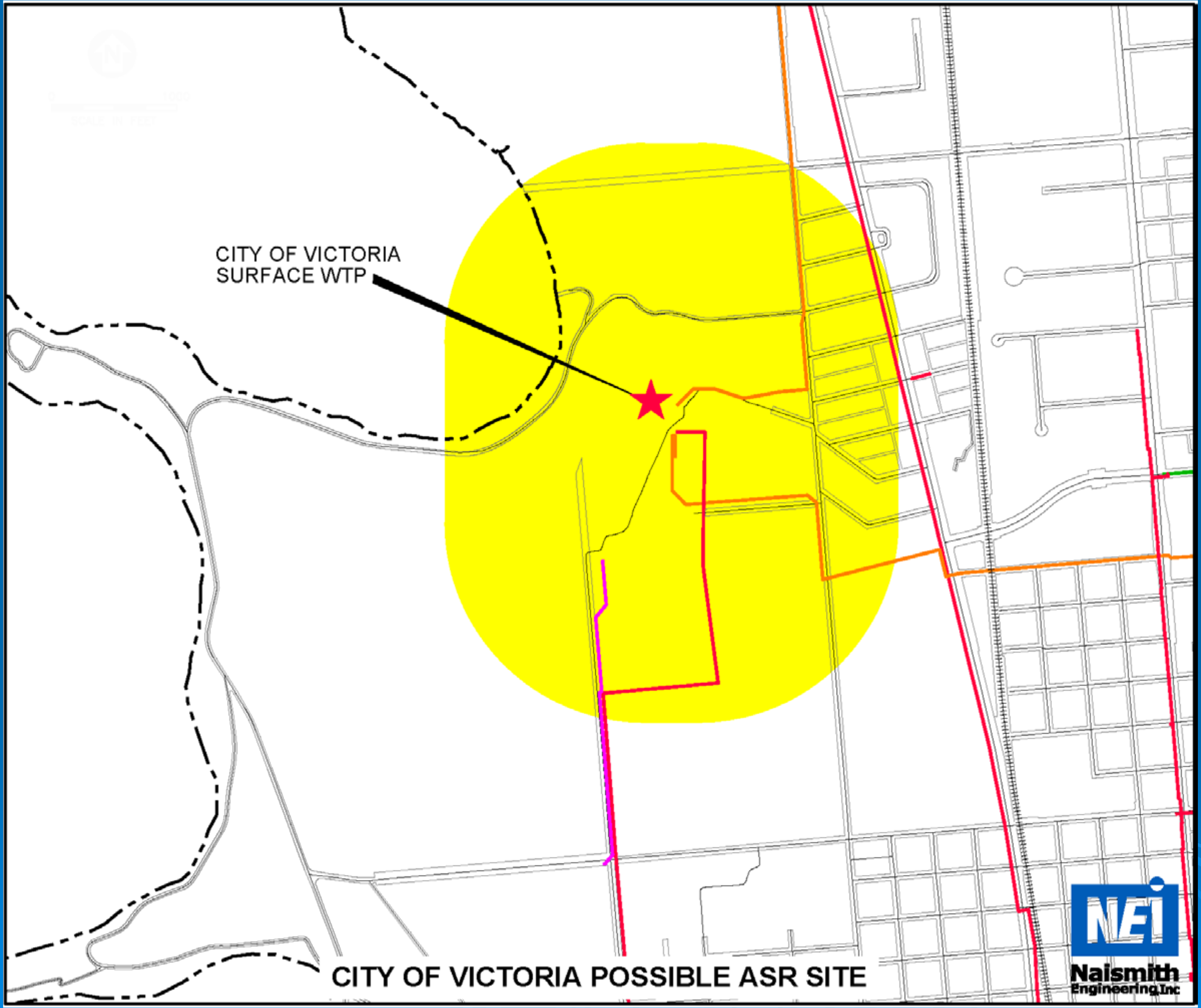
1. Values in MGD for 2011 Max Day & Avg Day are from Table 3-1 in DRAFT ASR Feasibility Study Final Report.
2. 2040 values = 2011 Values x 1.26 (as described in DRAFT ASR Feasibility Study Final Report.
3. Pumping capacities shown are firm pumping capacities (assumed largest unit out of service).
4. **Cells with yellow text are below 2040 Max Day values.**

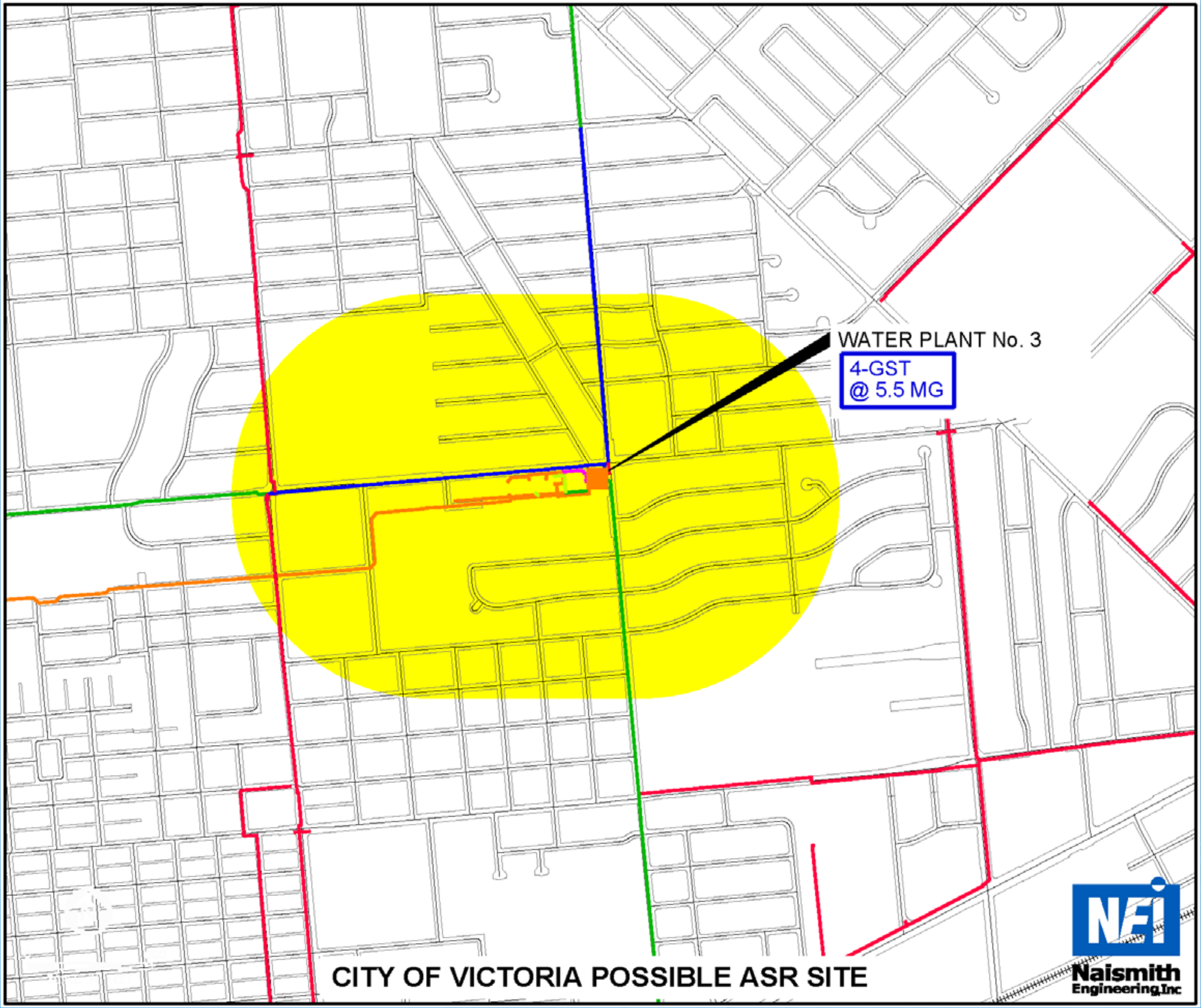
A. Pumping rates from City of Victoria staff members; as noted by staff these rates vary based on river/OCS levels

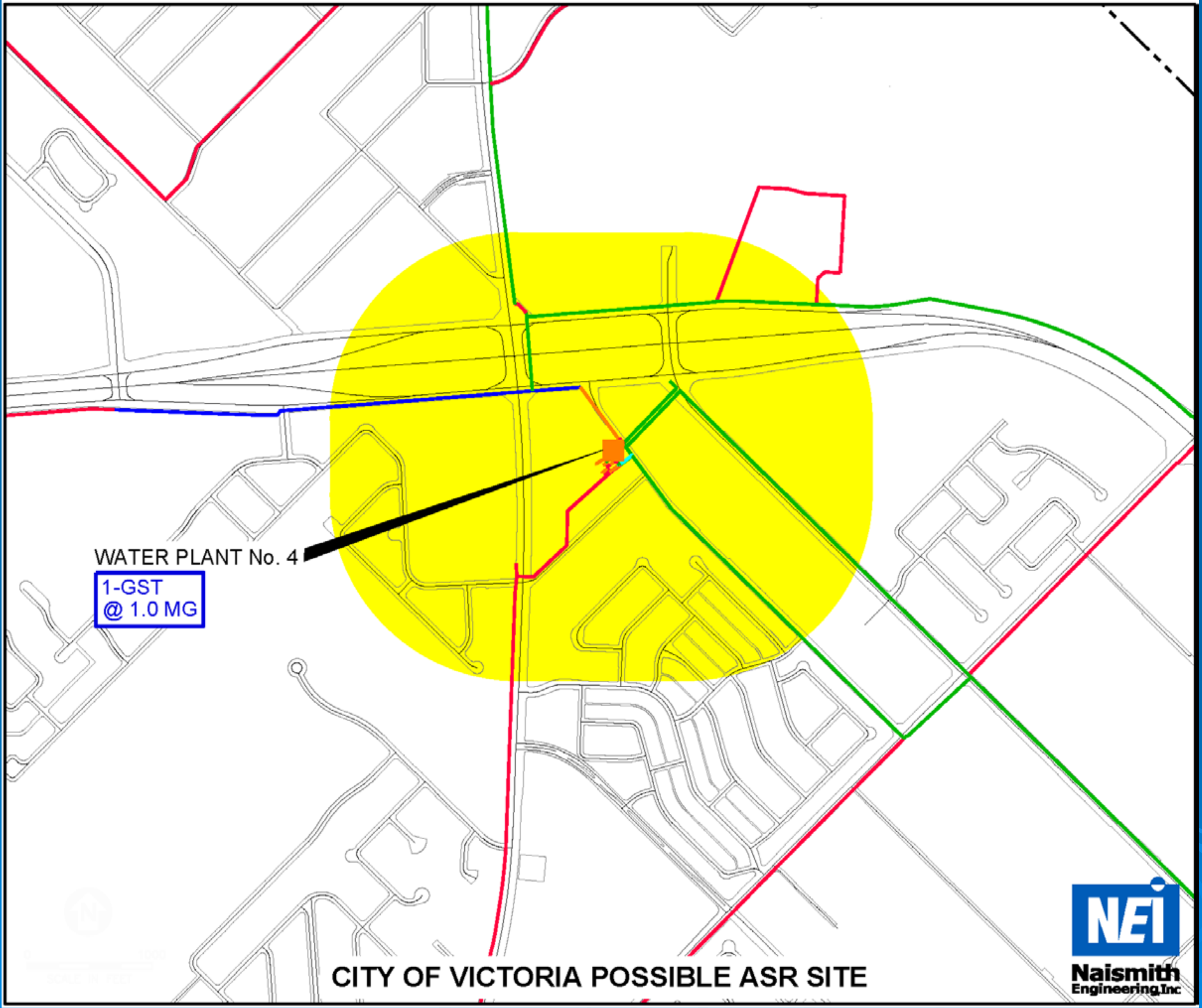
CITY OF VICTORIA
POTENTIAL ASR SITE LOCATIONS

- **Surface Water Treatment Plant (SWTP)**
- **Water Plant #3 (WP #3)**
- **Water Plant #4 (WP #4)**

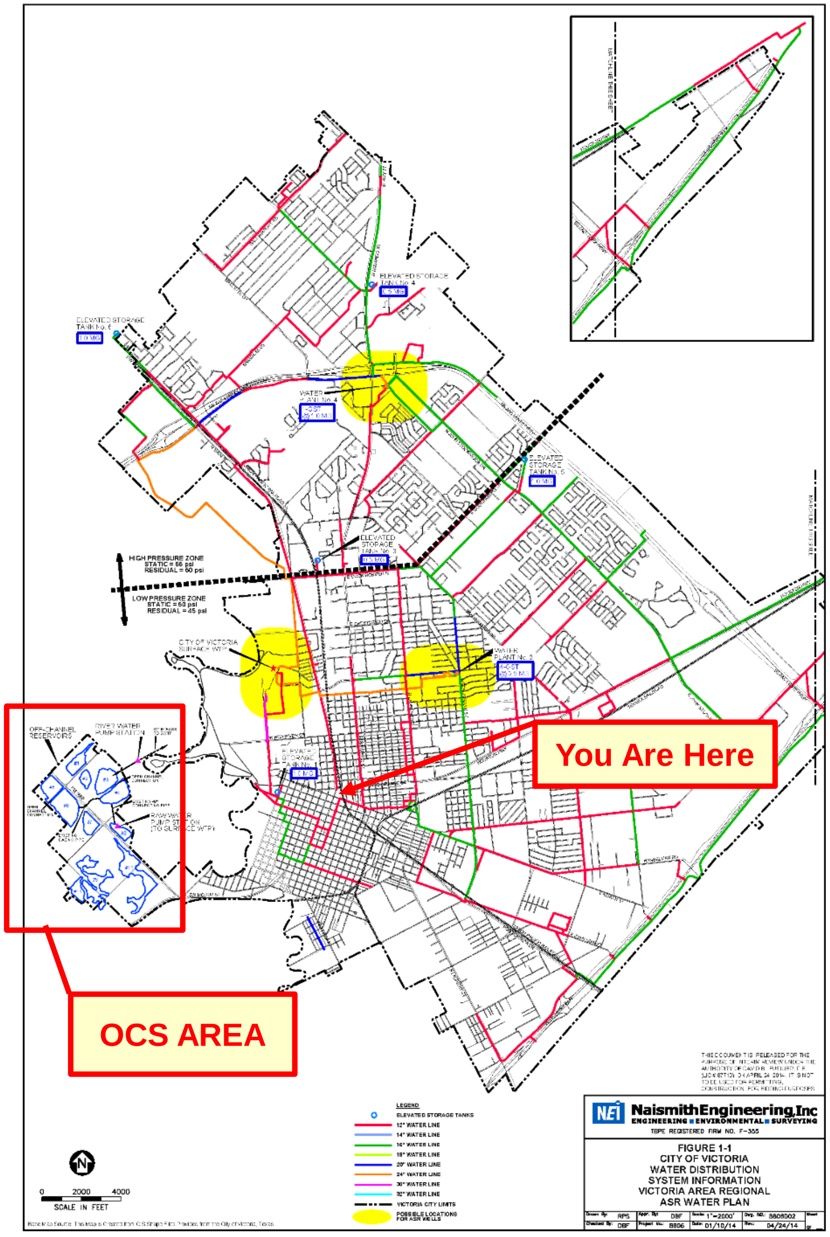

ELEVATED STORAGE TANK No. 6
WATER PLANT No. 4
1-GST @ 1.0 MG
ELEVATED STORAGE TANK No. 5
1.0 MG
ELEVATED STORAGE TANK No. 3
0.5 MG
CITY OF VICTORIA SURFACE WTP
WATER PLANT No. 3
4-GST @ 5.5 MG
RIVER WATER PUMP STATION
36" BYPASS TO SWTP
OPEN CHANNEL CONNECTION
EXISTING 48" CONNECTING PIPE
RAW WATER PUMP STATION (TO SURFACE WTP)
ELEVATED STORAGE TANK No. 1
1.0 MG
CITY OF VICTORIA POSSIBLE ASR SITES
Naismith Engineering Inc


CITY OF VICTORIA
SURFACE WTP
CITY OF VICTORIA POSSIBLE ASR SITE
NEI
Naismith
Engineering Inc

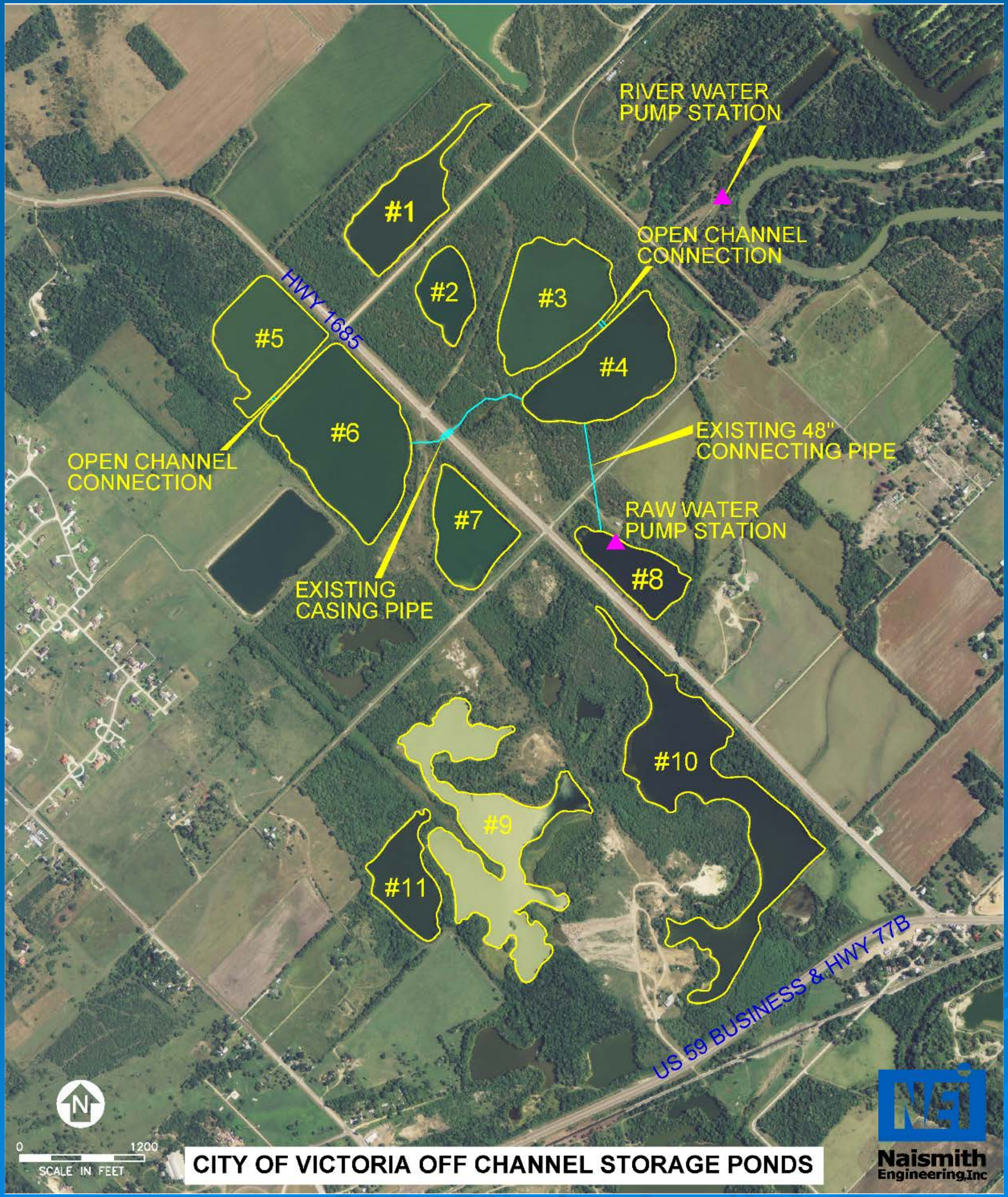

WATER PLANT No. 3
4-GST
@ 5.5 MG
CITY OF VICTORIA POSSIBLE ASR SITE
NEI
Naismith
Engineering,Inc


WATER PLANT No. 4
1-GST
@ 1.0 MG
CITY OF VICTORIA POSSIBLE ASR SITE
NEI
Naismith Engineering, Inc.

CITY OF VICTORIA
OFF CHANNEL STORAGE (OCS) ASSESSMENT



ELEVATED STORAGE TANK No. 4
ELEVATED STORAGE TANK No. 6
HIGH PRESSURE ZONE
LOW PRESSURE ZONE
OFF-CHANNEL RESERVOIRS
RIVER WATER PUMP STATION
You Are Here
OCS AREA
LEGEND
ELEVATED STORAGE TANKS
12" WATER LINE
14" WATER LINE
16" WATER LINE
18" WATER LINE
20" WATER LINE
24" WATER LINE
30" WATER LINE
32" WATER LINE
VICTORIA CITY LIMITS
POSSIBLE LOCATIONS FOR ASR WELLS
0 2000 4000
SCALE IN FEET
NaismithEngineering,Inc
FIGURE 1-1
CITY OF VICTORIA
WATER DISTRIBUTION
SYSTEM INFORMATION
VICTORIA AREA REGIONAL
ASR WATER PLAN


RIVER WATER
PUMP STATION
OPEN CHANNEL
CONNECTION
#1
#2
#3
#4
#5
#6
#7
#8
#9
#10
#11
HWY 1685
OPEN CHANNEL
CONNECTION
EXISTING 48"
CONNECTING PIPE
RAW WATER
PUMP STATION
EXISTING
CASING PIPE
US 59 BUSINESS & HWY 77B
N
0
1200
SCALE IN FEET
CITY OF VICTORIA OFF CHANNEL STORAGE PONDS
Naismith
Engineering,Inc

OCS Assessment

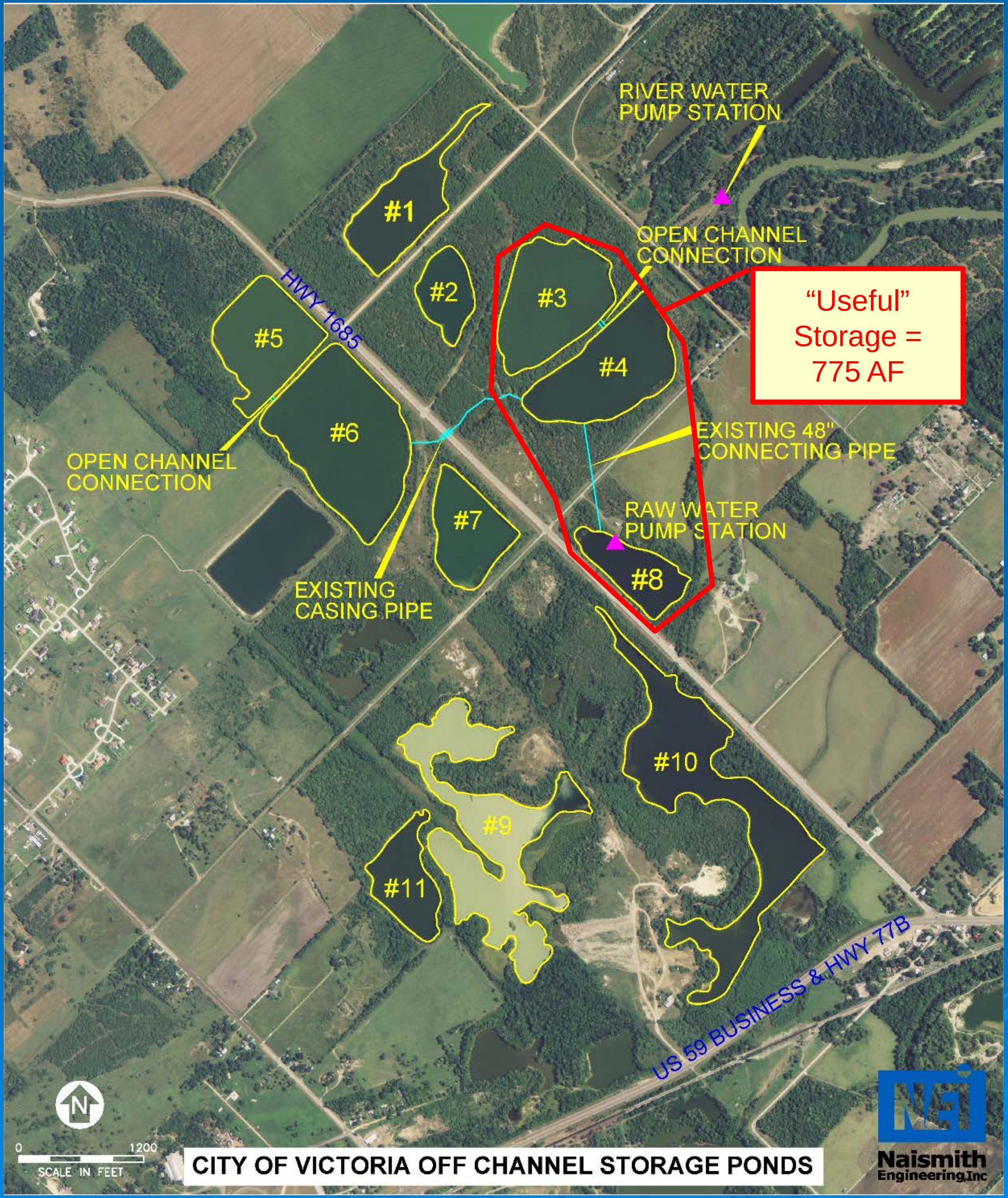
- Reviewed City of Victoria commissioned study "Preliminary Engineering Report – Off Channel Reservoir Additional Volume Evaluation" by CDM, Inc. dated October 26, 2011.
- Pond capacities and elevations in CDM, Inc. report are assumed to be accurate.
- Cost estimates in CDM, Inc. study used for comparisons purposes.
- Our recommendations are based on existing City of Victoria PWS capacities and the DRAFT ASR Feasibility Study.

OCS Assessment

- ASR Feasibility Study options modeled with an assumed OCS Storage Volume of 2,000 AF.
- Goal – provide a minimum “Useful” Storage Volume of 2,000 AF.
- “Useful” Storage is defined as raw water that can be pumped directly by Raw Water Pump Station.

OCS System

- Raw Water Pump Station located at OCS Pond 8 (can only pump directly from Ponds 3, 4 and 8).
- City has portable pump that can be used to pump raw water from Ponds 5, 6 and 7 to Pond 8.
- Total Volume of All Ponds = 3,801 AF
- Existing “Useful” Volume = 775 AF (only in Ponds 3, 4 and 8)


RIVER WATER
PUMP STATION
OPEN CHANNEL
CONNECTION
"Useful" Storage = 775 AF
#1
#2
#3
#4
#5
#6
#7
#8
#9
#10
#11
HWY 1685
OPEN CHANNEL
CONNECTION
EXISTING 48"
CONNECTING PIPE
RAW WATER
PUMP STATION
EXISTING
CASING PIPE
US 59 BUSINESS & HWY 77B
N
0
1200
SCALE IN FEET
CITY OF VICTORIA OFF CHANNEL STORAGE PONDS
Naismith
Engineering,Inc

OCS SYSTEM
TOTAL VOLUMES vs. "USEFUL" VOLUME

OCS POND	TOTAL VOLUME (AF)	"USEFUL" VOLUME (AF)
1	179	--
2	200	--
3	535	183
4	565	408
5	305	--
6	776	--
7	255	--
8	220	184
9	255	--
10	400	--
11	141	--
TOTAL	**3,831**	**775**

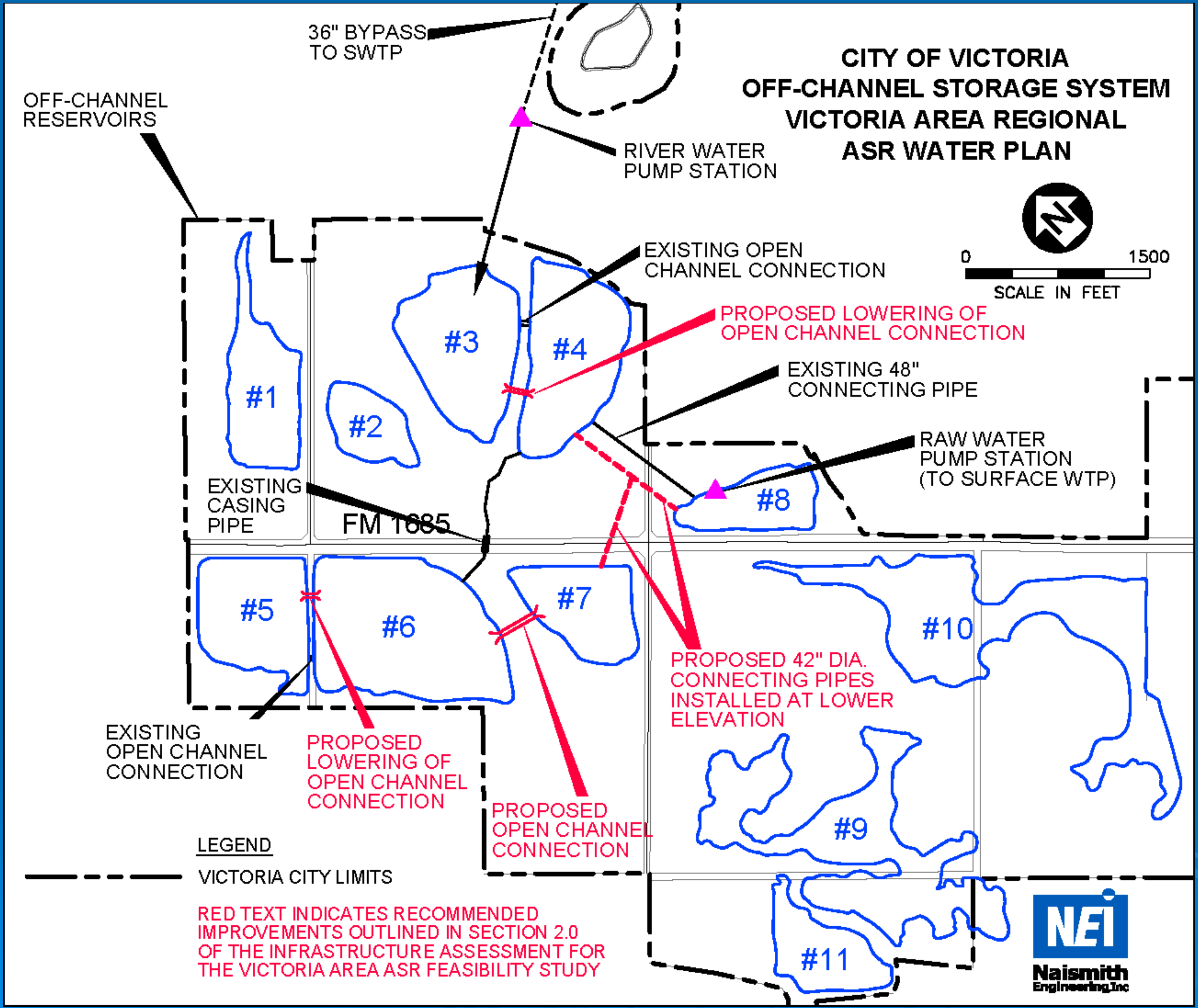
1. "Useful" storage is defined as stored raw water that can be pumped directly by the Raw Water Pump Station located at OCS Pond 8.
2. All storage volumes and "useful" storage volumes from "Preliminary Engineering Report – Off Channel Reservoir Additional Volume Evaluation" by CDM, Inc., signed October 26, 2011

OCS SYSTEM RECOMMENDED IMPROVEMENTS

Recommendation #		Storage (AF = acre-feet)
	Existing "Useful" Storage (in Ponds 3, 4 and 8)	775
1.	**"Useful" Storage Added to Ponds 3, 4 and 8**	441
2.	**"Useful" Storage Added to Ponds 5, 6, and 7**	1,311
	TOTAL "USEFUL" RAW WATER STORAGE in OCS SYSTEM	2,527

Total "Useful" Storage Added = 1,752 AF.

Note: "Useful" storage is defined as stored raw water that can be pumped directly by the Raw Water Pump Station located at OCS Pond 8.


CITY OF VICTORIA
OFF-CHANNEL STORAGE SYSTEM
VICTORIA AREA REGIONAL
ASR WATER PLAN
36" BYPASS
TO SWTP
OFF-CHANNEL
RESERVOIRS
RIVER WATER
PUMP STATION
EXISTING OPEN
CHANNEL CONNECTION
0
1500
SCALE IN FEET
PROPOSED LOWERING OF
OPEN CHANNEL CONNECTION
EXISTING 48"
CONNECTING PIPE
RAW WATER
PUMP STATION
(TO SURFACE WTP)
#1
#2
#3
#4
#5
#6
#7
#8
#9
#10
#11
EXISTING
CASING
PIPE
FM 1685
PROPOSED 42" DIA.
CONNECTING PIPES
INSTALLED AT LOWER
ELEVATION
EXISTING
OPEN CHANNEL
CONNECTION
PROPOSED
LOWERING OF
OPEN CHANNEL
CONNECTION
PROPOSED
OPEN CHANNEL
CONNECTION
LEGEND
VICTORIA CITY LIMITS
RED TEXT INDICATES RECOMMENDED
IMPROVEMENTS OUTLINED IN SECTION 2.0
OF THE INFRASTRUCTURE ASSESSMENT FOR
THE VICTORIA AREA ASR FEASIBILITY STUDY
Naismith
Engineering, Inc

OCS SYSTEM RECOMMENDED IMPROVEMENTS

- **Total Raw Water Storage Proposed = 2,527 AF**
- **Total "Useful" Raw Water Storage Added = 1,752 AF.**
- **Cost of Adding 1,752 AF of Raw Water Storage = $1,260/AF**
- **Overall Cost of ASR Water Storage = $390/AF***
- **Ponds 1 & 2 can be tied in to add 379 AF of additional storage [cost is $1,480/AF].**

* - Cost of ASR Water Storage based on Option A from Feasibility Study (see Table 7-1) which stores 83,030 AF for total project cost of $21.1 million + $136/AF to treat water prior to storage.

OCS SYSTEM
RECOMMENDED IMPROVEMENTS

What does 2,527 AF of Raw Water Storage Provide?

42 days @ 2011 Max Day

69 days @ 2011 Avg Day

33 days @ 2040 Max Day

55 days @ 2040 Avg Day

VICTORIA COUNTY NAVIGATION DISTRICT / PORT OF VICTORIA

VICTORIA COUNTY NAVIGATION DISTRICT / PORT OF VICTORIA

- EXISTING WATER RIGHTS PERMIT FOR NON-CONSUMPTIVE INDUSTRIAL USE.
- EXISTING WATER RIGHTS PERMIT = 5,000 AFY.
- WATER RIGHTS PERMIT ALLOWS STORAGE IN A 132 AF RESERVOIR (not yet constructed).
- ALL DIVERTED WATER MUST BE RETURNED TO VICTORIA BARGE CANAL.

VICTORIA COUNTY NAVIGATION DISTRICT / PORT OF VICTORIA

- **SITE IS SUITABLE FOR ASR*.**
- **CURRENTLY NO READILY AVAILABLE "CONSUMABLE" WATER FOR USE IN ASR SYSTEM.**
- **CONSUMPTIVE USE COULD BE MET BY PURCHASE OF WATER FROM CITY OF VICTORIA.**
- **CITY OF VICTORIA ASR SYSTEM COULD CREATE OPPORTUNITY FOR WATER PURCHASE.**

* - from DRAFT Victoria Area ASR Feasibility Study.

VICTORIA COUNTY NAVIGATION DISTRICT / PORT OF VICTORIA

- **PIPELINE CONNECTION WITH CITY OF VICTORIA COULD SUPPLY PURCHASED WATER.**
- **TIE-IN POINT WOULD BE NEAR PORT LAVACA DRIVE & US HWY 59.**
- **16" DIAMETER WATER LINE COULD ELIMINATE NEED FOR BOOSTER PUMP STATION.**
- **TOTAL PROJECT COST OF APPROX. $4,665,000.**

GBRA/Calhoun County

GBRA/Calhoun County

- **Locate ASR wells at or near Port Lavaca WTP**
- **Utilize existing facilities**
  (i.e., disinfection facilities, storage tanks, booster pumps, etc…)

Questions & Comments

- Naismith Engineering:
  - Tom Brown
  - David B. Fusilier, P.E.

NEI – Austin Office: (512) 708-9322