Corpus Christi Aquifer Storage and Recovery Feasibility Project

TWDB Contract No. 1600011956

Prepared for: Texas Water Development Board
Prepared by: HDR Engineering Inc., INTERA Inc, Geochemical Solutions LLC, and Wellspec
Project Partners: Corpus Christi Aquifer Storage and Recovery Conservation District and City of Corpus Christi

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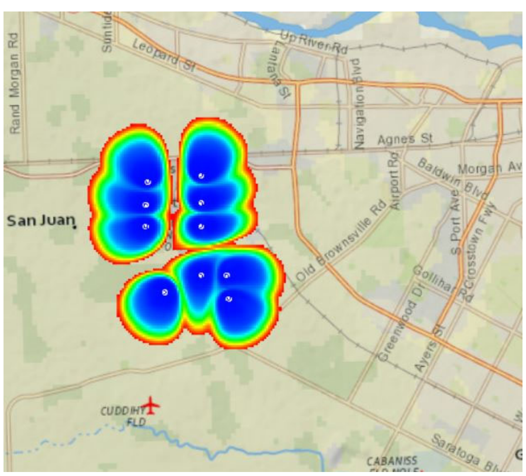
August 2019 **Final Report**



Draft Final Report
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Corpus Christi Aquifer Storage and Recovery Feasibility Project

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Acknowledgements

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HDR appreciates the continual and ongoing support of the leadership and staff of the City of Corpus Christi and the Corpus Christi Aquifer Storage and Recovery Conservation District board of directors. We appreciate Felder Water Well and Pump Service LLC's expertise and their long hours and commitment to the success of the Corpus Christi exploratory testing program.

For the City of Corpus Christi, specific acknowledgement and appreciation to: Bill Green PE for initiating the ASR Program and feasibility project; Larijai Francis for coordination within City Departments, review, guidance, and administrative support with the District; Alex Barabanov for contracting and engineering support; Marisa Juarez and Crystal Ybanez for sample bottles, analyzing samples, and extensive coordination with supporting laboratories for water quality analysis during the exploratory testing program; and Jim Boyle for construction inspection during the field program.

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At the TWDB, we particularly appreciate Erika Mancha and Matt Webb for administrative and contracting support.

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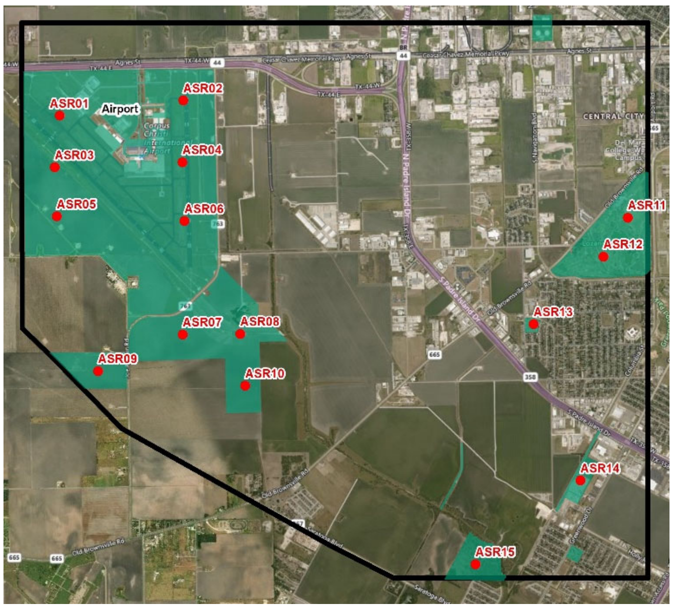
Acronyms and Abbreviations

Al	aluminum
amsl	above mean sea level
As	arsenic
ASR	aquifer storage and recovery
AWWA	American Water Works Association
bgs	below ground surface
BOD	biochemical oxygen demand
CCASR	Corpus Christi Aquifer Storage and Recovery
CEC	cation exchange capacity
CFR	Code of Federal Regulations
City	City of Corpus Christi
CO2	carbon dioxide
COC	constituent of concern
Cr	Chromium
Cu	Copper
District	Corpus Christi Aquifer Storage and Recovery Conservation District
DO	dissolved oxygen
DOC	dissolved organic carbon
EPA	Environmental Protection Agency
Fe	iron
Felder	Felder Water Well & Pump Service, LLC
ft bls	feet below land surface

Geo Cam	Geo Cam, Inc
Geochemical Solutions	Geochemical Solutions, LLC
GHB	General Head Boundary
gpm	gallons per minute
HFO	hydrous ferric oxide
MCL	maximum contaminant levels
MGD	million gallons per day
MIEX	magnetic ion exchange resin
mm	millimeter
Mn	manganese
MW	Monitoring Well
NGW	Native groundwater
NMR	Nuclear Magnetic Resonance
ORP	Oxidation-reduction potential
Pb	lead
PCBs	polychlorinated biphenyls
PPE	personal protective equipment
QA/QC	Quality Assurance/Quality Control
RRC	Railroad Commission of Texas
Se	Selenium
SEE/SEP	Sequential selective extraction (also called sequential extraction procedure)
SP	spontaneous potential
SVOCs	Semivolatile Organic Compounds
TAC	Texas Administrative Code

TCEQ	Texas Commission on Environmental Quality
TDS	total dissolved solids
TPDES	Texas Pollution Discharge Elimination System
TW	Test Well
TWC	Texas Water Code
TWDB	Texas Water Development Board
BRACS	Brackish Resources Aquifer Characterization System database
U	uranium
UIC	Underground Injection Control
USACE	United States Army Corps of Engineers
USDW	underground source of drinking water
USGS	United States Geological Survey
VOCs	Volatile Organic Compounds
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant
XRD	Rietveld X-Ray Diffraction
XRF	X-Ray Fluorescence



Executive Summary

Corpus Christi Aquifer Storage and Recovery Feasibility Study (E16265)

Corpus Christi, Texas
August 30, 2019

CITY OF CORPUS CHRISTI TEXAS
INCORPORATED 1852

CCASRCD
Corpus Christi Aquifer Storage & Recovery Conservation District

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Executive Summary

1 Introduction

The Corpus Christi Aquifer Storage and Recovery Feasibility Project (Project) was performed from August 2016 to May 2019 on behalf of the Corpus Christi Aquifer Storage and Recovery Conservation District (District), with support from the Texas Water Development (TWDB) and City of Corpus Christi (City) through an inter-local agreement with the District. The District and City are actively studying ASR feasibility to provide a long term, cost-effective water supply for future growth. The work associated with this Project focused on the following primary tasks, as described in the scope of work in Exhibit A:

- Formulating field testing approach, test drilling plan, and preparing design and technical specifications for test drilling program;
- Conducting exploratory test drilling and sampling;
- Performing a geochemical analysis to identify source and groundwater compatibilities related to storing source water in ASR storage zones;
- Developing a groundwater model and simulating potential ASR operations; and
- Evaluating ASR operating policies affecting project implementation.

Primary goals and objectives of the project were confirmed at the kick-off meeting on October 17, 2016. A brief analysis of field drilling techniques was then performed (Exhibit B) resulting in a two-phased field testing approach, core barrel method for collecting core samples, and goal to complete at least one borehole as a permanent monitoring well. The two-phased field approach consisted of drilling a smaller, initial Phase I test hole to evaluate drill cuttings and geophysics and using this information to identify preferred test sites and storage intervals for Phase II aquifer pump tests and sampling. The test drilling, sampling, and field construction work plan summarized the field drilling and testing approach and Gulf Coast aquifer considerations (Exhibit C). After discussions with the City and District, up to six sites were identified for potential testing to a depth of up to 1,200 feet.

The exploratory test drilling program had the following objectives:

- Evaluate the geology and hydrogeology of the Gulf Coast aquifer system for potential ASR locations; and
- Collect and analyze hydrogeological, geochemical, and water quality data that will be used to model ASR operations and evaluate ASR feasibility.

The City of Corpus Christi issued contract bidding documents for the exploratory test drilling program on March 24, 2017 which included technical specifications and well construction diagrams. Felder Water Well & Pump Service LLC was issued notice to proceed on September 26, 2017 for drilling, testing, and well construction services. Exploratory test drilling was conducted at four City-owned sites located within the District from October 9, 2017 to May 15, 2018. Based on Phase I results for the four sites, two sites were recommended for pump testing, collecting of core samples, and water quality testing. These Phase II tests were performed on a total of three intervals ranging from 410 ft to 769 ft below land surface. Three permanent monitoring wells were installed for future monitoring and testing, with two of the monitoring wells completed in desired ASR storage intervals. Favorability of ASR well development, ranking of investigated areas, and optimal depths of storage intervals are discussed in Section 2, with a more detailed discussion along with additional exploratory testing program results in Exhibit D.

A geochemical analysis was conducted to determine the compatibility of storing treated effluent from Greenwood Wastewater Treatment Plant (WWTP) or potable water from O.N. Stevens Water Treatment Plant (WTP) within the potential storage zones tested during Phase II of the exploratory testing program. Mineralogy results from cores collected from the potential storage zones and water quality data from the exploratory testing program were used to develop a conceptual site model and PHREEQC model to identify geochemical processes that are expected to play a significant role in conditions during recharge and storage. Based on additional conversations with the City, it was deemed that the most likely recharge source would be Greenwood WWTP effluent if preliminary geochemical compatibility proved favorable due to less competing needs for its use, native groundwater quality considerations, and more frequent availability for recharge than O.N. Stevens WTP water. Although the geochemical analyses did not identify any fatal-flaws, tertiary treatment of WWTP will likely be needed prior to aquifer recharge and monitoring during pilot testing will be critical in proving up geochemical desk-top analyses prior to full scale project implementation. Considerations regarding geochemical compatibility and treatment needs are discussed in Section 3. Details of the geochemical analysis and modeling, operational approaches, and anticipated tertiary water treatment needs prior to recharge are discussed in Exhibit E.

A field-scale groundwater model was constructed using MODFLOW-NWT with site-specific data that was collected during the exploratory test drilling program. The 13-layer model included three most likely storage zones (S1, S2, and S3) based on the exploratory testing program results. Due to lower hydraulic aquifer properties and poorer water quality in the deeper storage interval, ASR operations were simulated in S1 and S2 but not S3. S1 and S2 correspond to Layers 4 and 8, respectively. MT3DMS was used to simulate changes in total dissolved solids and chlorides with ASR operation.

The model was then used to simulate most likely ASR operational scenarios based on source water availability and future water demands in the vicinity of the project site, as identified through conversations with City Staff and stakeholders. During scenario development, it was determined that industrial water users in the vicinity of the ASR wellfield would be the most likely customers for recovered water. This determination is based on projected future growth and non-potable needs that could be met with ASR supplies with minimal to no treatment anticipated after recovery.

Based on information gathered from City Staff on Greenwood WWTP treated effluent capacity constraints, a future ASR project was evaluated to consist of two phases. Phase I is focused on 10 wells at the Corpus Christi International Airport site and Phase II would add an additional 5 wells to the east of Phase I. Phase I limits recharge to 5 MGD, which is based on current Greenwood WWTP capacity and would be capable of providing up to 8 MGD through recovery at ASR wells. If tertiary treated Greenwood WWTP effluent by-passes ASR and is delivered concurrent with ASR recovery, then the combined water supply would be 13 MGD for Phase I. Phase I and II operated conjunctively would be capable of providing about 10 MGD from ASR well operation, or up to 18 MGD with Greenwood WWTP expansion[1]. A map showing proposed ASR well layout for Phase I and II and associated recharge and recovery rates are discussed in Section 4. A discussion of field scale groundwater model development and results of the ASR operating scenario simulations is provided in Exhibit F.

The state rules governing most facets of ASR project implementation in Texas are administered by the Texas Commission on Environmental Quality (TCEQ) and are contained in Title 30 of the Texas Administrative Code (30 TAC), Chapter 331, Underground Injection Control (UIC). The TCEQ has primacy from the US EPA to regulate most injection wells through the Texas UIC Program. Since the proposed ASR project does not currently contemplate recovery of water directly to a public water system, rules related to public supply wells and groundwater sources and development, as contained in 30 TAC §290.41 (c), do not apply. Of particular relevance to the proposed ASR project are the requirements in 30 TAC§331.186 (a), which outlines the criteria to be consider by TCEQ in authorizing ASR operations. The effluent from the Greenwood WWTP does not currently meet drinking water standards for chloride, TDS, manganese, and nitrate concentration, or pathogen removal. While it is anticipated that nitrate and manganese will likely be below the drinking water maximum contaminant limit after tertiary treatment, the other parameters will not be significantly altered prior to recharge. As such, the City will need to demonstrate to the TCEQ that proposed ASR well operations will not: 1) render the groundwater produced from the receiving formation harmful or detrimental to people, animals, vegetation, or property, or 2) require an unreasonably higher level of treatment of the groundwater produced from the receiving geologic formation than is necessary for the native groundwater in order to render the groundwater suitable for beneficial use.

Additional ASR operating policy considerations are included in Section 5, with more detailed discussion in Exhibit G. Subsidence is not expected, however risk may increase with longer recovery cycles and higher recovery rates. Prior to implementation of an ASR program, it is recommended that extensometers are installed to monitor subsidence.

There are several existing wells identified within the ASR study area that will likely be impacted by ASR implementation. Additional efforts to survey unregistered wells in the vicinity of the proposed ASR well field area would be helpful to identify wells to monitor and/or mitigate in advance of commencing ASR operations. Supply protection is within the jurisdictional authority of the District as detailed in the District's Groundwater Management Plan developed during this Project (Appendix B in Exhibit G). The District's Five Year Plan which leverages the results of this Project towards implementation of an ASR project is included in the Groundwater Management Plan adopted April 18, 2019.

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[1] Based on City staff feedback, Greenwood WWTP expansion to 12 MGD by Year 2025-2030 would result in about 8 MGD treated effluent available for potential ASR use.

2 Exploratory Drilling Program Findings

2.1 Favorability of ASR Well Development

Four locations (Sites 1, 2, 3, and 6) were drilled and downhole geophysics surveys conducted to a nominal depth of 1,200 feet below ground surface (bgs) during Phase I. A review of Phase I boring logs and geophysics results indicated the geology consists of alternating lenses of clay and fine sand and likely brackish to saline groundwater. Only two depth intervals (410-450 feet bgs and 570-650 feet bgs) at Site 1 and one depth interval (609-769 feet bgs) at Site 3 contained a reasonable total thickness of fine sand that would be recommended for Phase II testing. Site 2 and Site 6 were not selected for Phase II testing based on a review of geophysical logs in the area and Phase I results indicating that Site 2 and Site 6 conditions were unlikely to provide new information beyond that provided by the Phase II program of Sites 1 and 3. Figure 2-1 shows the locations of sites tested during the exploratory testing program.

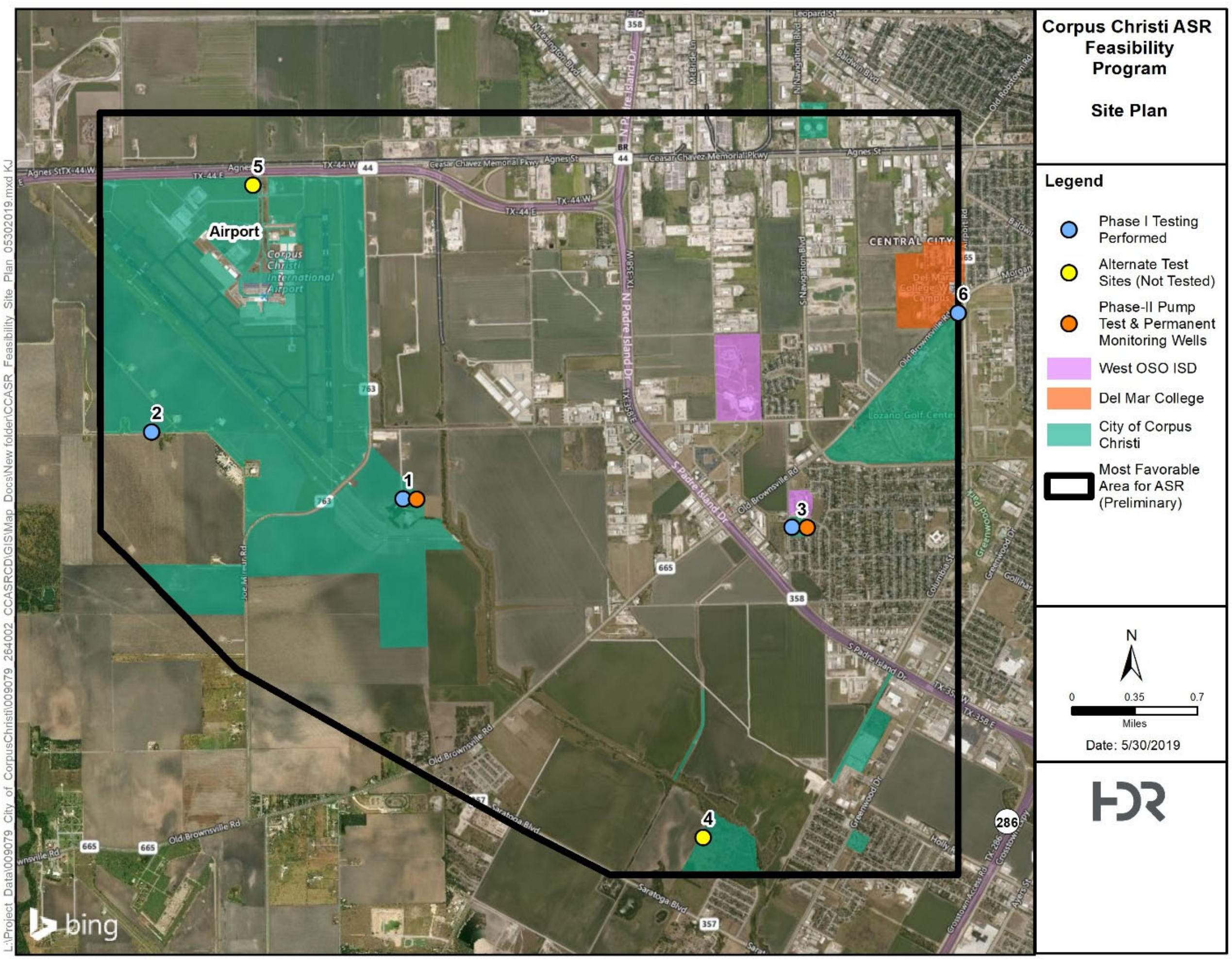

Figure 2-1. Sites Tested During the Exploratory Test Drilling Program

Permanent monitoring wells (MW-1S and MW-1D) were installed at Site 1 and MW-3 at Site 3. Phase II activities at Sites 1 and 3 consisted of collection of aquifer core, construction of temporary test wells, performance of pumping tests, and collection of water quality samples. Field water quality parameters measured during the pumping tests indicate brackish to saline groundwater and anaerobic conditions. Hydrogen sulfide odor was observed at Sites 1 and 3. Groundwater samples were collected from MW-1S (not considered a candidate for ASR) and from the three test wells during pumping tests for laboratory analysis. Laboratory results show native groundwater levels exceed maximum contaminant levels (MCL) or secondary MCLs for iron, manganese, chlorides, sulfates, total coliforms, and total dissolved soils.

Based on cross sections developed by Intera (Exhibit F) which included geophysical logs from the four Project sites and other well logs in the area, four potential storage intervals were identified. The first interval is about 400 feet to 450 feet bgs. The second and third intervals run between 525 feet and 700 feet bgs. The fourth interval starts at about 1,000 feet bgs and runs to about 1,050 feet bgs. The sand layers are referred to as S1 (shallowest) through S4 (deepest).

Pumping tests were performed on temporary test wells at pumping rates ranging from around 200-300 gpm. The pumping tests showed the aquifers to be confined. Aquifer transmissivity is estimated to be 475-676 ft^2/day. At Site 1 transmissivities were estimated for S1 and S2, while at Site 3, transmissivities were estimated for layers S2 and S3 combined. Based on a transmissivity of 676 ft^2/d and a thickness of 40 feet, the hydraulic conductivity of S1 at Site 1 was estimated to be 17 ft/d. Based on a transmissivity of 475 ft^2/d and a thickness of 80 feet, the hydraulic conductivity of S2 at Site 1 was estimated to be 6 ft/d. The combined transmissivity of S2 and S3 at Site 3 was estimated to be 665 ft^2/d. Assuming a hydraulic conductivity of S2 from Site 1 (6 ft/d) and the thickness 80 feet to estimate a transmissivity of 480 ft^2/d, then the contribution of S3 to the composite transmissivity is the remaining 185 ft^2/d. Dividing by the S3 thickness of 45 feet results in an estimated hydraulic conductivity of 4 ft/d for S3. These hydraulic conductivity results corresponds to a fine or silty sand. However, due to the inter-bedded and alternating sand and clay lenses the aquifer capacity may be slightly more. It is anticipated that wells in this area would be capable of producing at least 300-400 gpm with multi-interval operation, which is considered favorable and consistent with previous study estimates.

2.2 Ranking of Investigated Areas

Of the four sites tested during Phase I, Site 1 and 3 showed more favorable geology for ASR than Sites 2 and 6 based on localized clay lenses encountered during Phase I. However, for the purposes of modeling, the entire area was considered for ASR operations based on the stratified Gulf Coast alternating sand and clay layering structure and hydraulic interconnection observed between 450 and 650 feet at Site 1 in spite of alternating clay lenses. Based on cross sections developed by Intera (Exhibit F) during development for the groundwater model, it appears there is good continuity over the area within the depth intervals at 410-450 feet bgs and 570-770 feet bgs. It is anticipated that the geology at the airport and about 2 miles to the east is more favorable, than areas further east (i.e. Site 6).

2.3 Optimal Depths and Storage Intervals for ASR

Based on the exploratory test drilling program results, the most favorable ASR storage intervals are located between 350 and 800 feet below ground surface. This information was used to identify potential ASR well locations (Figure 2-2) and assign preferable storage zones for ASR operation by area (Table 2-1). Figure 2-2 shows proposed ASR well locations and Table 2-1 designates preferable zones for ASR operation. S1 is about 400 feet to 450 feet bgs. S2 is about 525 feet to 700 feet bgs.

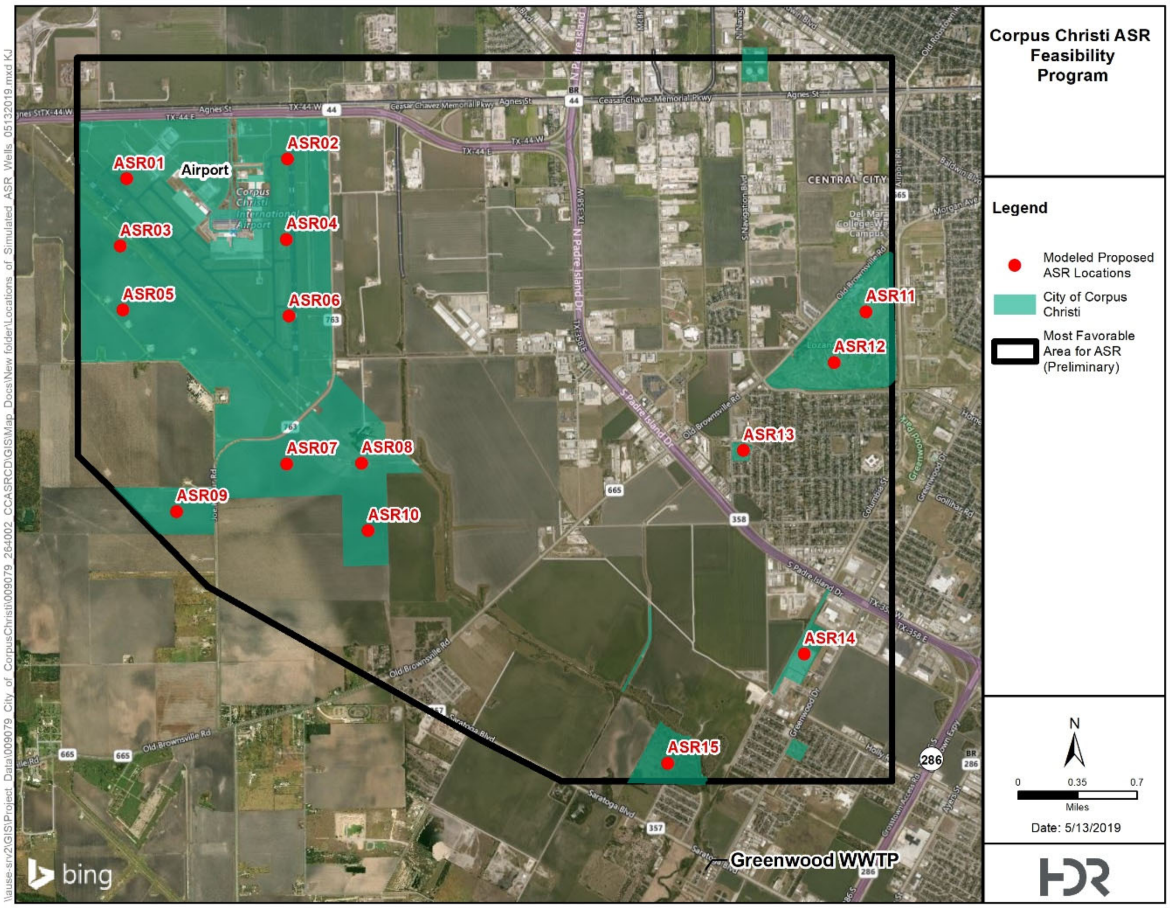

Figure 2-2. Modeled ASR Wells and City Owned Properties

Table 2-1. Recharge Intervals for each of the ASR Well Locations

Well ID	Intervals
ASR01	S1, S2
ASR02	S1, S2
ASR03	S1, S2
ASR04	S1, S2
ASR05	S1, S2
ASR06	S1, S2
ASR07	S1, S2
ASR08	S1, S2
ASR09	S1, S2
ASR10	S1, S2
ASR11	S1
ASR12	S1
ASR13	S1, S2
ASR14	S1
ASR15	S1

3 Considerations Regarding Geochemical Compatibility and Pretreatment Needs

This phase is critical to understanding potential reactions that may lead to clogging of the near-well pore space or mobilization of undesirable constituents from the aquifer matrix resulting in increased concentration of these constituents in the recovered water, with a goal of avoiding these impacts through additional treatment and/or operations.

Geochemical Solutions, LLC prepared a geochemical conceptual site model to describe the expected geochemical processes that are expected to play a significant role in conditions during recharge and storage. Theoretical model calculations were performed to evaluate the extent to which metals[2] held in aquifer solids could be released into recharged water within the storage zone, and mixtures of native groundwater with recharge water. Based on the high dissolved oxygen and slightly alkaline pH of the potential recharge water from WWTP, primary metals of concern are not conceptually expected to be released in significant quantities.

PHREEQC (Parkhurst and Appelo, 2013) geochemical modeling was then performed using the water quality results obtained for potential recharge water sources, native groundwater, and mixtures of source and native groundwater relative to the aquifer matrix for potential storage and recovery zones at Sites 1 and 3 based on aquifer solids testing results. The dominant processes

[2] The primary constituents considered in the geochemical analysis include: aluminum (Al), arsenic (As), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), selenium (Se), and uranium (U) measured in the laboratory by Sequential Extraction Procedure (SEP) characterization, although bulk water characteristics, such as major anions and cations, redox potential, pH and dissolved oxygen were also evaluated in modeling calculations.

evaluated by PHREEQC include: mixing of recharge water and native groundwater, precipitation of saturated solids from solution, aquifer solid dissolution, and adsorption/desorption. Intentional bias was included in model calculations to provide for a "conservative, worst case" scenario by assuming that the constituents of concern are surface adsorbed, which increases the potential for their release to contacting recharge water and provides an upper bound estimate for potential constituent concentrations in the contacting recharge water. Modeled results showed that, anticipated maximum dissolved concentrations were below applicable maximum contaminant levels (MCLs).

Although the native groundwater is more saline, the redox and pH conditions that drive aquifer solid stability are very similar to that of the recharge water based on geochemical analyses. In some cases, however, lowering the salinity of the native groundwater during recharge could lead to release of cations to solution which has the potential to damage clays and impact operation of groundwater recharge. In this case, the geochemical evaluation provides an indicator that potential recharge water is geochemically compatible with the native groundwater aquifer solids. At this field-scale level, no critical issues are identified. Pilot testing is necessary to confirm prior to constructing and ASR project.

Although the geochemical analyses does not identify any fatal-flaws, the following parameters need to be monitored during a groundwater recharge program:

- Total Dissolved Solids- Ionic strength of source water for recharge does not meet the ionic strength goals3 to prevent fragmentation and native groundwater could damage clays. Clay fragmentation issues can lead to issues with dispersion or swelling of clay particles which can irreversibly diminish recharge capacity.
- Potassium- Greenwood WWTP effluent has similar calcium and magnesium levels to aquifer storage zones, however potassium is two to three times higher in concentration. There is a cation/anion disparity between the source water for recharge and the native groundwater, which has the potential to damage clays and impact operation of groundwater recharge.
- Temperature- Avoid recharge of low temperature water. Low recharge temperatures (less than 10 deg C) can dramatically increase the viscosity of water, reducing permeability through the storage aquifer.
- Nutrients- Organics, phosphates, and inorganic nitrogen species (ammonia, nitrate, and nitrite) in the Greenwood WWTP treated effluent can be problematic for biological fouling of the well during recharge where the dissolved oxygen and nutrient concentrations are the highest.
- Total Suspended Solids- In addition, even low amounts of total suspended solids (<2 mg/L) can contribute to particle accumulation in the recharge well and the aquifer storage zone. The current levels of total suspended solids in the Greenwood WWTP effluent may contribute to physical plugging, so reduction of TSS is necessary to reduce back-flushing needs during recharge operations.

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[3] Ionic strength should be within a one-half order of magnitude of aquifer quality to prevent swelling, repulsion, and migration of clay minerals (Bott, 2017).

- Pathogens- Pathogen removal could be attained within the soil matrix by a process known as soil aquifer treatment. However, pathogen decay can be used as a food source for microbes that occur in the native groundwater which can lead to ASR operational issues such as clogging.
- Organic Carbon- Organic carbon in the source water for recharge could produce microbial growth that changes the redox conditions from oxidative to reductive. That change could produce mineral scale and possible release of constituents of concern like manganese, iron, and other major cations. For this reason, organic carbon reduction of source water is likely necessary.
- Color- Color issues associated with the presence of iron are typically observed at concentrations of 0.3 mg/L or higher. Native groundwater in potential storage zones exceeds this level. A significant portion of the iron is ferrous, but color issues may occur at these locations during withdrawal as dissolved oxygen concentrations increase. Iron concentrations in the aquifer should be monitored for potential oxidation of iron.
- Sulfate- Sulfate is a parameter that is frequently monitored and causes a salty taste. Sulfate is present in the groundwater above secondary drinking water standards. While sulfate is odorless, sulfate-reducing bacteria are capable of converting sulfate to hydrogen sulfide, which has a rotten egg smell. These organisms are typically present in anaerobic soils. Maintaining a residual dissolved oxygen concentration greater than 0.15 mg/L can assist with reducing hydrogen sulfide production.
- Arsenic, cyanide, and radionuclides- Although potential recharge sources detected levels for arsenic, cyanide, radionuclides (gross alpha and gross beta) and uranium lower than the drinking water MCLs, recharge water should be monitored for these constituents due to the lack of presence in native groundwater in the tested storage zones.

For most previous ASR applications, TCEQ has required treatment to drinking water standards prior to recharge but newer rules passed in 2015 and described in Section 5 of Exhibit G may give some flexibility since both the quality of the effluent relative to drinking water is considered along with the potential to degrade the native groundwater. This project would improve the native groundwater for constituents more relevant to Safe Drinking Water Act with tertiary treatment prior to injection that address the constituents above MCL included in the bulleted list above. Although the storage aquifer is considered brackish is would still be classified as an underground source of drinking water (USDW) per Title 40, Code of Federal Regulations (40 CFR) Section 144.3, and it is likely that additional treatment at the WWTP may be required by TCEQ to meet MCLs, and could be necessary to maintain ASR operations and water compatibility. Treatment may include modifications to the WWTP's treatment process to promote de-nitrification, reduce turbidity, and improve the disinfection system to further inactivate bacteria.

A step by step process for completing a TCEQ Experimental ASR permit application and estimated timeframe for permit authorization to conduct a pilot scale testing program, and subsequent Phase I and II construction project, is included in Section 6 of Exhibit G.

4 ASR Simulations

4.1 Recommended Injection and Recovery Rates

Six operating scenarios were simulated for proposed wells shown in Figure 2-2 to investigate the impact of changes to recharge and recovery duration on the simulated maximum TDS and chloride concentrations at end of recovery cycles. Recharge rates and durations were limited to a maximum of 90 psi based on the depth to the top of the upper most sand interval (Railroad Commission of Texas, 2016), which is the assumed fracture limit of the strata. The ratio of recharge to recovery were no more than 80 percent and estimated pumping levels at the end of recovery cycles were at least 80 feet above the top of S1 to account for the telescoped well design which would limit the pump setting depth. Scenarios were run assuming both 10 well Phase I and 15 well Phase I and II system configurations. Well locations were consistent for each system configuration across all scenarios. With the exception of the baseline scenario, which had one recharge and one recovery cycle, all operating scenarios had storage and recovery cycles which were repeated six times during the model simulation to simulate long-term operation.

The operational scenarios represented a range of potential operating conditions for drought-protection and seasonal operations for industrial water use (Table 4-1). For the drought-protection scenarios based on historical drought conditions, the extent of storage influence after six cycles of recharge for 5 years and recovery from 10 ASR wells for 1.5 years (Scenario A) or 15 ASR wells for 2 years (Scenario B). Seasonal operations were simulated with recharge for 2 years and recovery for 6 or 9 months in four scenarios (Scenario C1, C2, D1, and D2) based on phased operations and to illustrate changes in stored water quality with longer recovery cycle (Scenario C2 and D2). Scenarios C1 and D1, having a shorter recovery cycle of 6 months for Phase I and Phase I and II, respectively, resulted in more water remaining in storage at the end of six cycles.

For all scenarios, anticipated chloride and TDS concentrations were based on the measured concentrations from native groundwater and were loaded into model layers. S1 and S2 at Site 1 reported TDS levels of 11,600 mg/L and 8,800 mg/L, respectively. The composite measurement for S2 and S3 in Site 3 is 15,000 mg/L. Source water quality of 1,711 mg/L TDS and 579 mg/L chloride measured at the Greenwood WWTP on December 13, 2017 was used to simulate aquifer recharge water quality. Water quality impacts at ASR wells resulting from simulated ASR operations were then evaluated for recovered water during the ASR recharge and recovery cycles while keeping in mind the water quality needs for non-potable industrial use.

Table 4-1 provides a summary of the results from Scenarios A through D. The baseline scenario was not summarized as it used a different methodology to determine water quality of recovered water and was mainly used to test the model and evaluate the sensitivity of model parameters.

Table 4-1. Summary of Model Scenario Results

	Scenario	A[1]	B[2]	C1[3]	C2[3]	D1[4]	D2[4]
	Number of ASR Wells	10	15	10	10	15	15
	Recharge Cycle Length (Years)	5	5	2	2	2	2
	Recovery Cycle Length (Years)	1.50	2.00	0.50	0.75	0.50	0.75
	Total Recharge (MGD)	4.8	6.6	4.8	4.8	7.3	7.3
	Total Recovery (MGD)	7.9	8.2	7.9	7.9	9.1	9.1
	Greatest Individual Wellhead Pressure (Ft of Water Above Land Surface)	205	211[5]	175	175	205	205
After 1st Recharge / Recovery Cycle	Total Storage Volume (MG)	4,500	6,000	2,050	1,500	3,660	2,830
	TDS (mg/L) of Recovered Water	3,500	3,700	3,450	4,550	3,000	3,900
	Chloride (mg/L) of Recovered Water	1,400	1,550	1,400	1,900	1,200	1,600
After 6 Recharge / Recovery Cycles	Total Storage Volume (MG)	30,500	36,000	12,300	8,000	22,000	17,000
	TDS (mg/L) of Recovered Water	2,100	2,120	1,975	2,450	1,885	2,135
	Chloride (mg/L) of Recovered Water	750	760	705	900	660	775

[1]Constrained to 5 MGD Recharge and 8.4 MGD Recovery or a wellhead pressure (in feet above land surface) of 209 feet

[2]Constrained to 8 MGD Recharge and 10 MGD Recovery or a wellhead pressure (in feet above land surface) of 209 feet

[3]Constrained to 5 MGD Recharge and 9 MGD Recovery or a wellhead pressure (in feet above land surface) of 209 feet

[4]Constrained to 8 MGD Recharge and 10 MGD Recovery or a wellhead pressure (in feet above land surface) of 209 feet

[5]211 feet is acceptable because the top of the storage zone is 400 feet below surface, which allows for a pressure of 100 psi (230 feet)

Results of the operation simulations indicated the following:

- At the initial project recharge capacity of 4.8 MGD, continuous recharge is limited to approximately 5 years due to well pressures approaching the assumed fracture limit; recharge rates would need to be reduced or recovery rates increased thereafter.
- At the future Phase II project recharge capacity of 7.3 MGD, continuous recharge is limited to approximately 2 years due to well pressures approaching the assumed fracture limit, with a 6.6 MGD recharge rate slightly exceeding the 90 psi limit at 5 years. Recovery rates may need to be increased during actual operation.
- The 10 well configuration sustained 7.9 MGD of recovery for 1.5 years to overcome needs during a severe, regional drought comparable to a severe drought event from February 1996- June 1997 when the local reservoir system dropped below 30% storage for 474 days.
- The 15 well configuration sustained a 9.1 MGD supply for up to 0.75 years and 8.2 MGD for 2 years.
- For the Phase II scenario with a 31 percent volumetric recovery per cycle (Scenario D1), the TDS concentrations at the end of the first cycle was 3,000 mg/L and 1,885 mg/L after the sixth cycle.
- For scenarios with volumetric recovery between 40 and 50 percent (Scenarios C1 and D2), the TDS concentrations at the end of the first cycle was between 3,450 and 3,900 mg/L and the final cycle was between 1,975 and 2,135 mg/L.

- For the Phase I scenario with a volumetric recovery of 62 percent (Scenario C2), the TDS concentrations at the end of the first cycle was 4,550 mg/L and the final cycle was 2,450 mg/L.
- The operating scenarios explored thus far prioritizes end user water quality. If future industrial customers have water needs that can use higher TDS/chloride levels, than the model can be used to simulate higher recovery rates or longer recovery cycles to maintain new water quality goals. Thus, the yields provided in this report are considered a conservative estimate.

In summary, all modeled scenarios show maximum TDS and chlorides in the recovered water to be below 5,000 mg/L and 2,000 mg/L, respectively, within during the timeframes simulated. Results of the operations modeling suggests that volumetric recovery of at least 61 percent can be achieved on the initial recovery cycle with a maximum TDS concentration less than 5,000 mg/L. Results also suggest that reduced TDS concentration is more strongly related to the number of cycles than the total amount of water stored, for a given volumetric recovery target. However, increasing the volume of water recharged relative to the volume recovered has the greatest impact on reducing the contribution of native groundwater (NGW).

Assuming no supply constraints, recharge rates can be limited by the allowable maximum well pressure and the target recovery rate. Excessive recharge pressure can result in hydraulic fracturing in the recharge interval and, potentially, the vertically adjacent confining units. Following fracturing, stored water can exit the storage zone through vertical flow paths when recharge zone pressures are elevated during recharge operations. These same flow paths close as recovery is initiated and storage zone pressures decline, trapping stored water in the adjacent zone and negatively affecting recovery efficiency. The fracture pressure tends to increase with the depth to the top of the storage zone and the degree of cementation in the recharge zone.

4.2 Project Size to Meet Desired Objectives

Based on the results of this ASR study, it is estimated that a project yield of 13-18 MGD is attainable it tertiary treated Greenwood WWTP effluent by-passes ASR and is delivered concurrent with ASR recovery. The operating scenarios showed that ASR operations could be configured to meet uninterruptible industrial demands during severe drought conditions or used seasonally to respond to peak demands or higher usage months.

5 ASR Policy Considerations and Next Steps for ASR Permit Application

The TCEQ has primacy from the US EPA to regulate most injection wells (and ASR) through the Texas UIC Program.

Prior to passage of House Bill (HB) 655 in June 2015, water injected into ASR wells was required to meet public drinking water standards (30 TAC §§290.101 - 290.119, 290.121, 290.122), regardless of the intended use of the recovered water. Similarly, construction, operation, reporting requirements related to public supply wells were also referenced in the ASR rules. HB 655 amended the ASR regulations to establish requirements for ASR injection wells by including provisions to require injected water to be at a water quality as to not degrade native groundwater in the proposed storage interval.

A successful ASR well application for a CCASR project will need to provide evidence in the permit application that the City has sufficient surface control to prevent access to stored water that does not meeting drinking standards, or at a minimum, to water that is harmful to people. The data needed to support such an application will likely require completion of pilot ASR well using the actual treated effluent proposed for the project. The pilot ASR well would likely be authorized under a short-term, experimental Class V authorization. Since any use of the NGW from the proposed storage zone for consumption by people or animals would require desalination, a case can be made that introduction of the treated effluent would reduce the salinity of the NGW and treatment requirements.

Because it is anticipated that the recharge water will not meet drinking water standards at the wellhead, it is likely an individual Class V permit would be required from TCEQ before operations could commence. The individual permit process requires the applicant to issue a Notice of Application and Intent to Obtain a Permit and a Notice of Application and Preliminary Decision. Persons potentially affected by the proposed injection well may request a public meeting and hearing prior to a decision being made by TCEQ. If the application is contested, the administrative hearing and appeals process can add one to three years to the permitting process.

The District's Five Year Plan (Appendix B of Exhibit G) includes steps to complete a TCEQ Experimental Permit Application as follows:

- Prepare pilot and cycle testing plan including additional treatment for piloting to address turbidity, nutrients, pathogens, organics, and other parameters relevant to ASR operations (discussed above in Section 3)
- Meet with TCEQ to discuss and adapt plan and proposed permitting approach
- Prepare experimental well design
- Complete experimental permit application

Following receipt of permit application, ASR pilot program would be designed and implemented to include water conditioning system and surface facilities design to test Greenwood WWTP source water in potential ASR storage zones identified in this study.

6 Preliminary Costs for Tertiary Treatment and Wellfield Infrastructure for Pilot, Phase I and Phase II Programs

Preliminary costs of treatment strategies were evaluated to successfully produce a reuse wastewater stream at the Greenwood Wastewater Treatment Plant (WWTP) suitable for indirect non-potable reuse through ASR. The cost opinion includes infrastructure, wells, and well field piping to operate a phased ASR project for 13 (Phase I) to 18 MGD (Phase II) future supply.

Prior to implementing Phase I and II, a piloting program will be conducted at Greenwood WWTP to verify field tests and confirm water treatment processes necessary to obtain a TCEQ permit for ASR injection, which requires that the source water for recharge to be treated to a sufficient quality so as to not impact or impair the aquifer formation or groundwater as well as avoid excessive clogging that would affect operations and maintenance. To meet this requirement, the Greenwood WWTP will need to be improved with additional treatment processes. The following constituents in the existing effluent could affect the groundwater environment or well operations and thereby are currently limiting the injection potential:

- Total Suspended Solids (TSS)
- Nitrate (NO_3)
- Total Organic Carbon (TOC)
- Manganese (Mn)
- Bacteria

Exhibit H discusses potential treatment configurations for piloting and provides a range of costs for implementation of the Phase I and II ASR program based on these treatment configurations. The treatment processes that are considered include: a Modified Ludzack-Ettinger (MLE) process, microfiltration, ozone and biologically active filters (BAF). By piloting these systems as stand-alone and in series, a preferable treatment strategy can be identified for Phase I and II. Upon receipt of pilot test results, the Phase I and II costs will need to be revisited based on actual treatment needs. It is anticipated that the ASR supplies would be used for industrial purposes and would not need to be treated to potable standards. If this condition changes or potable supplies are sought, additional treatment may be required.

7 Conclusions and Recommendations

Based on the results of this Project, it is estimated that a yield of 13 MGD is attainable based on current WWTP capacity and up to 18 MGD is possible with Phase II expansion. The operating scenarios showed that ASR operations could be configured to meet uninterruptible industrial demands during severe drought conditions or used seasonally to respond to peak demands or higher usage months. Results of the operations modeling suggests that volumetric recovery of at least 61 percent can be achieved on the initial recovery cycle with a maximum TDS concentration less than 5,000 mg/L. Both ASR operating approaches to meet severe drought conditions or with seasonal operation to respond to peak demands or higher usage months achieve recovered water quality between 1,975 to 2,450 mg/L after a few cycles.

The most likely use of recovered water from ASR is for non-potable, industrial demands. The geochemical analysis did not present any fatal flaws, however tertiary treatment of Greenwood WWTP treated effluent would be needed to reduce nutrient, pathogen, and organic concentrations prior to recharge to meet regulatory needs and facilitate a successful ASR program.

There are several ASR operating policy aspects to consider to mitigate risk and uncertainty, which include:

- Protecting stored water, including confirming existing wells that may be impacted with ASR operations and enforcing District rules that prohibit drilling in ASR protection area;
- Compliance with TCEQ regulations, including achieving any exemptions as may be required based on site-specific conditions including water quality;

- Consistent recharge water quality that is treated according to TCEQ standards at levels to minimize well clogging and/or clay fragmentation
- Continuous monitoring by the District after implementing ASR Phase I or II programs to (a) reduce influence of existing wells on or resulting from ASR operations (b) record subsidence data prior to ASR construction and during ASR operation and (c) record water levels and water quality.

Based on the exploratory test drilling program results, the most favorable ASR storage intervals are located between 350 and 800 feet below ground surface. Although the modeled ASR wells are operated during recharge to limit wellhead pressures to a maximum safe operating condition (Railroad Commission of Texas, 2016), water level rises are expected during recharge events. If an existing well is screened in the target zone or has unsealed or leaking casings in deeper wells, then the well will flow and cause the area to become water logged. To provide a conservative estimate for planning purposes, there were six wells in the study area identified with depths between 300 and 1000 feet below ground surface that are likely impacted with Phase I and II ASR operation. There may be additional wells outside the study area below that could be affected during long-term ASR operation that would need to be monitored. If artesian conditions occur after construction and implementation of the ASR program, ASR operations should be revisited and/or wells plugged depending on condition and owner use. It is recommended that oil and gas well locations in the vicinity of ASR site are monitored during ASR operations to verify information reported by the RRC regarding surface casing depths and that inactive wells have been plugged appropriately.

The field scale groundwater model was constructed based on the best information available and collected during the exploratory well testing program, however the results should only be used as a guide. Field ASR cycle testing will need to confirm actual wellhead pressures as the analysis includes a twenty percent head increase due to inefficiencies within each ASR well that may be a conservative value. Additionally, the model shows that the storage buffer zone does not substantially drift in any one direction away from each ASR well due to the relatively low hydraulic conductivity and lack of a strong water level gradient. However, likely heterogeneity of the aquifer hydraulic conductivity may yield a storage buffer zone that migrates to one direction away from the ASR well that may result in more mixing of higher salinity ambient groundwater and reduce the quality of recovered water.

The Phase I project cost to deliver up to 13 MGD at an industrial delivery point, including treatment, ASR operations, and conveyance is expected to range from $68,632,000 to $90,199,000 depending on the treatment process to be refined during pilot program. This results in a capacity cost of $5.28 to $6.94 per gallon per day (gpd). The unit cost of water is estimated to be $479 to $606 per ac-ft <u>during recovery</u>, which is the firm yield expected during drought conditions. Due to the range of ASR operating conditions that are possible based on industrial needs and water quality desires including the lack of piloting results to refine the treatment strategy required, a full unit cost for the project to account for both recovery and recharge conditions cannot be assessed at this time.

The Phase II project cost to deliver up to 18 MGD at an industrial delivery point, including treatment, ASR operations, and conveyance ranges from $123,253,000 to $174,668,000 based on treatment process to be refined with pilot test results. This results in a capacity cost of $6.84 to $9.70 gpd. The unit cost of water is estimated to be $604 to $812 per ac-ft <u>during recovery</u>, which is the firm yield expected during drought conditions. Again, due to the range of ASR operating conditions that are possible based on industrial needs and water quality desires including the lack of piloting results to refine the treatment strategy required, a full unit cost for the project to account for both recovery and recharge conditions cannot be assessed at this time.

Details of the cost analysis and assumptions for the pilot testing, Phase I and Phase II programs are included in Exhibit H.

The pilot well test program is needed to confirm aquifer response, operations, prove up geochemical interactions, and identify criteria for appropriate design and operations of a full scale ASR program. TWDB comments on the Draft Report and proposed responses are included in Exhibit I.

8 References

Parkhurst, D.L., and Appelo, C.A.J., 2013, Description of input and examples for PHREEQC version 3— A computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations: U.S. Geological Survey Techniques and Methods, book 6, chap. A43, 497 p., available only at https://pubs.usgs.gov/tm/06/a43/.

Railroad Commission of Texas, 2016. Injection/Disposal Well Permitting, Testing, and Monitoring Manual, Technical Review section.

Exhibit A Scope of Work

ATTACHMENT I
EXHIBIT B

SCOPE OF WORK - REVISED

Task 1. Formulate Program

Task 1.1- Prepare and meet with the CONTRACTOR to identify goals, objectives, and preferred source water for ASR. Submit water quality data request to the City of Corpus Christi including list of constituents of study interest.

Task 1.2- Confirm drilling and sampling techniques to accomplish project objectives.

Task 1.3- Develop preliminary test drilling, sampling, and well construction plan.

Task 1.4- Submit a pdf version to the TWDB summarizing program approach.

Task 2. Exploratory Test Drilling Program

Task 2.1- Confirm test program approach including location, depth and number of test boreholes. Review of nearby logs to gain insight on local aquifer structure and stratigraphy.

Task 2.2- Prepare design and specifications for test drilling program and contract documents. Pre-bid process and selection of driller.

Task 2.3- Design, supervise, and execute a test drilling program of up to three boreholes.

Task 2.4- Collect and classify lithology at discrete depth intervals or perceived formation changes to characterize permeable sand zones and impermeable clay intervals.

Task 2.5- Collect core samples while drilling through permeable and confining areas of the borehole. Cores will be collected for hydraulic testing and sent to the laboratory for geochemical analysis.

Task 2.6- Collect water quality samples and specific capacity testing at intervals beginning in the lower Chicot to determine salinity and relative specific capacity of the encountered formations. Obtain field measurements and water quality samples for laboratory analysis.

Task 2.7- Analyze geophysical logs and identify sand intervals for isolation and pump testing. Develop well screen interval recommendations.

Task 2.8- Perform isolated interval testing (pump tests), while collecting continuous water levels to calculate hydraulic conductivity. Collect water quality samples for laboratory analysis.

Task 3. Geochemical Analysis and Modeling

Task 3.1- Collect and analyze water quality data from potential recharge water sources as determined in kick-off meeting with CONTRACTOR staff. Collect one sample for analysis of a full suite of chemical constituents, including regulated organic, inorganic and radionuclide constituents, and parameters needed for geochemical modeling at a minimum.

Task 3.2- Perform geochemical modeling of representative potential recharge water sources, native groundwater from individual developed ASR wells and mixtures of source and native groundwater using PhreeqC or The Geochemical Workbench thermodynamic modeling software.

Task 3.3- Submit a pdf version of Technical Memorandum provided to the District/City to the TWDB summarizing results of exploratory test drilling program and geochemical analysis.

Task 4. Field Scale Groundwater Model to Simulate Storage and Recovery Operations

Task 4.1- Select grid and layering of model based on Task 1- drilling program and previous studies.

Task 4.2- Construct a local, field scale model and assign aquifer model parameters.

Task 4.3- Meet with the CONTRACTOR to identify ASR operational scenarios for modeling, to include recharge, production schedule, and rates in accordance with CONTRACTOR goals.

Task 4.4- Prepare model simulations for up to four scenarios to evaluate the aquifer response of recharge and recovery for different schedules and rates, including likelihood of stratification within storage and movement during injection/idle/recovery periods. These simulations would span seasonal operations (recharge in the winter and recovery in the summer) and long-term water banking.

Task 4.5- Evaluate impact of native brackish groundwater on ASR recovery.

Task 4.6- In advance of performing Tasks 4.4 and 4.5 above, develop model scenarios based on WWTP effluent source water constraints and future industrial growth in the vicinity of the proposed ASR site. Obtain information on water quantity and quality needs from industry representatives. Develop monthly industrial water demand projections for Year 2020 and 2060, assuming historical seasonal use patterns and TWDB decadal projections used in the 2021 Region N Plan.

Task 5. ASR Operating Policy Considerations

Task 5.1- Using results from Tasks 1.3, identify considerations for ASR operating policy to mitigate risk and uncertainty. TCEQ regulations, water quality standards, subsidence, and supply protection measures will be considered.

Task 5.2- Submit a pdf version of the Technical Memorandum provided to the District/City to the TWDB summarizing field scale modeling and ASR operating policy considerations.

Task 5.3- Update CCASRCD Groundwater Management Plan to include TWDB information. Develop District goals based on findings from the Corpus Christi Aquifer Storage and Recovery Feasibility Project (Tasks 1-4).

Task 5.4- Submit approved CCASRCD Groundwater Management Plan to the TWDB in accordance with 31 TAC 356 and TWC Chapter 36 provisions.

Task 6. Meetings and Deliverables

Task 6.1- Prepare for and participate in up to three (3) meetings with representatives of the CONTRACTOR, PARTICIPANTS, TWDB and other stakeholders to provide status reports and present interim results of the studies.

Task 6.2- Prepare quarterly status reports to the TWDB to present information and findings developed within the reporting period.

Task 6.3- Prepare and submit a draft report and electronic presentation to the TWDB, not later than the STUDY COMPLETION DATE. The report will include the following items to assess ASR feasibility:

- Favorability of ASR well development for each area tested in the exploratory drilling program,
- Ranking of investigated areas based on ASR well feasibility,
- Optimal depths and storage intervals of planned ASR wells,
- Recommended injection and recovery rates per well for optimal performance,
- Considerations regarding geochemical compatibility and pre-treatment needs, if applicable
- Number of wells to meet available flow volumes and desired objectives,
- ASR policy considerations, and
- Next steps to complete an EPA Class V ASR well permit application.

Task 6.4- Prepare and submit final reports and electronic presentation to the TWDB within 120 days of the STUDY COMPLETION DATE. Data generated during Task 1 through 5 will be provided to TWDB as appendices to the final report. This data will include, as applicable, but may not be limited to: well lithology, sieve analysis, hydraulic testing, geochemical analysis, laboratory measurements, water quality including both field and laboratory results, specific capacities, density measurements, geophysical logs with identified sand intervals, and geochemical and numerical modeling.

Task 7. TCEQ Experimental Permit Support

Task 7.1- Consider suitable ASR pilot sites near existing infrastructure. Prepare pilot/testing cycle information including additional treatment to address constituents of interest based on Task 3 findings. Prepare experimental well design for permit application. NOTE: This information, including engineering schematics and diagrams will not be included in draft and final reports for security reasons consistent with TWDB policies.

Task 7.2 Summarize TCEQ Experimental Permit Application process to include in draft and final report (Task 6).

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Exhibit B Memo- Trade Off in Methods

Memo

Date:	January 11, 2017
Project:	Corpus Christi ASR Feasibility Study- E16265
To:	Larijai Francis
Cc:	Steve Ramos and Dan McGinn
From:	Kristi Shaw
Subject:	Trade-offs in Drilling Methodology and Approach - Drilling and Testing Program

HDR is in the process of developing the drilling and testing program for the project. In accordance with Task 0.4 of the Scope of Work, we have developed a list of trade-offs in drilling methodology and approach to the project. This list was not meant to be a review of possible drilling methods, but rather outline major decisions that will affect project quality and cost and provide HDR recommendations.

1. Single borehole for coring/geophysics/interval testing vs. a two-phased approach whereby a smaller borehole would be drilled for geophysics and then a second hole nearby for coring/interval testing zones and layers of interest for up to three locations based on geophysics results.

   Single Borehole Approach:

   Benefits: Drilling costs would be limited to a single borehole and reaming of that borehole.

   Drawbacks: All decisions regarding coring depths would need to be made somewhat blindly on the first pass, without previous knowledge of how deep and thick the zones of interest are, since coring needs to be performed in an undisturbed borehole. Coring would be reactionary based on the drill cuttings, and zones of interest could be missed. If a borehole ends up having no suitable sand for ASR, the additional money spent on coring an interval that is anticipated but not identified through geophysics to have suitable sands would be a waste.

   Two-Phased Approach:

   Benefits: Zones of interest for coring and interval testing are more accurately determined from a small-diameter, relatively quickly-drilled, less expensive borehole. This becomes particularly beneficial if a borehole does not exhibit suitable sand for ASR; no money would be wasted coring a borehole that has poor geology.

   Drawbacks: General higher cost of drilling two boreholes if suitable sands are discovered.

   Recommendation #1: Two-phased Approach

2. Core barrel coring vs. sidewall coring for geochemical lab analysis.

   Core Barrel Coring:

Benefits: Larger sample size; greater sample recovery with use of core catchers; less-disturbed samples since core barrel cores are taken ahead of the drill bit; mud cake on the borehole wall is not collected, so it will not contaminate the sample; and higher quality data than sidewall coring.

Drawbacks: Core barrel coring is more costly and time-consuming than sidewall coring.

Sidewall Coring:

Benefits: Can be completed after the entire borehole is drilled. Lower cost. Quicker than core barrel method.

Drawbacks: Small sample size (e.g., 1-inch by 3-inch "plugs"). Unconsolidated samples can mix within sample chamber. Mud cake from the borehole is collected with the sample. Sample contains relatively large percentage of disturbed material. Sample recovery can be problematic.

Recommendation #2: Core barrel coring.

3. Plug each borehole after data collection vs. developing as a monitoring well.

Plug Each Borehole:

Benefits: Quick and low-cost way of finishing a borehole.

Drawbacks: No monitoring well data would be available for future use.

Complete Monitoring Wells in Boreholes:

Benefits: Monitoring wells provide a location from which groundwater levels and water quality can be measured. Long-term data collection option for the District, City, and TWDB. Monitoring wells would be useful during the design, installation, and ongoing monitoring of a full-scale ASR system.

Drawbacks: Completing a borehole as a monitoring well is more expensive and time-consuming than plugging with grout.

Recommendation #3: Complete at least one monitoring well screened in an interval that appears suitable for ASR. Make a decision after the borehole drilling is complete whether to complete a monitoring well in the geophysics borehole or in the second borehole (following interval testing). Multiple locations for monitoring well completion is preferable but may be limited by budget and bids.

Exhibit C Exploratory Test Drilling Program Work Plan

Exploratory Test Drilling Program Work Plan

Corpus Christi Aquifer Storage and Recovery Feasibility Project (E16265)

Corpus Christi, Texas

January 12, 2017

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Contents

Tables

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1 Introduction

The Corpus Christi Aquifer Storage and Recovery Conservation District (District), with support from the City of Corpus Christi (City), is actively studying aquifer storage and recovery (ASR) to promote water supply resiliency for industrial customers and for a cost-effective long term regional water supply management strategy. The District developed a 5-year plan in 2009 which included a schedule of major elements of an ASR feasibility plan. In support of the 5-year plan, the Texas Water Development Board (TWDB) conducted a geologic characterization of the District and surrounding counties in 2012. In 2015, the District performed a desktop aquifer characterization study at three specific areas within the District boundaries which was delivered in a 2016 report entitled "Aquifer Characterization Study for ASR Feasibility". The study identified a preferred ASR test area (Figure 1) based on interpretation of nearby geophysical logs that showed favorable permeable zones comprised of sand or mostly sand spanning a few hundred feet within the lower Chicot and/or upper Evangeline Aquifers, in either continuous unit or at multiple intervals considered most desirable for ASR development. The results of the 2016 study serve as a basis for this exploratory test drilling program work plan. This work plan was developed based on feedback received from the stakeholders during the project kick-off meeting on October 17, 2016. Meeting notes are included in Attachment 1. HDR will provide technical and support services, and supervise field data collection activities during the execution of this work plan.

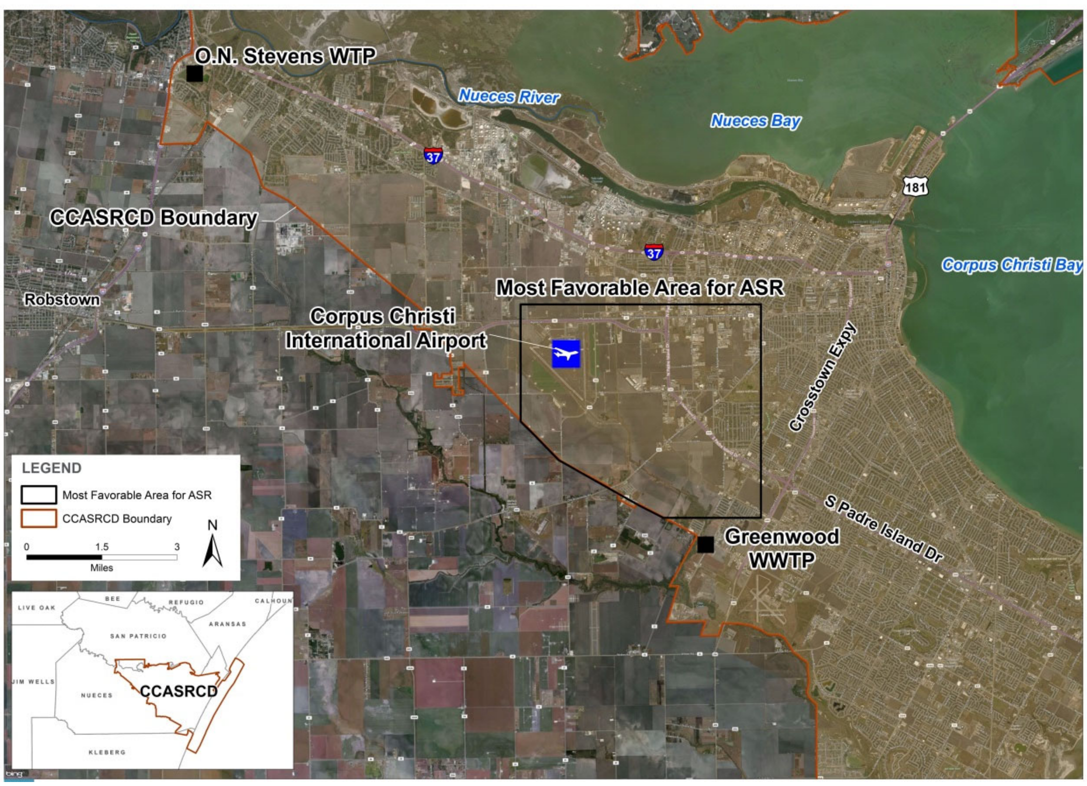

Figure 1. Most Favorable Area for ASR Development
(from City of Corpus Christi Aquifer Characterization Study, 2016)

2 Project Objectives

The exploratory test drilling program has the following objectives:

- Evaluate the geology and hydrogeology of the Gulf Coast aquifer system for potential ASR locations; and
- Gather hydrogeological, geochemical, and water quality data that will be used to model ASR operations and evaluate ASR feasibility.

3 Local Hydrogeology

The project will be completed in the unconsolidated Gulf Coast aquifer system. The major stratigraphic units of the Gulf Coast Aquifer are shown in Figure 2. The Gulf Coast aquifer system is highly stratified with discontinuous layers of sand and clay alluvium. Specific units that are expected to contain a greater percentage of sand include the lower portion of the Chicot Aquifer and the upper portion of the underlying Evangeline Aquifer. Target depths for these aquifers range from 400-1,200 feet below land surface (bls).

Based on 254 TWDB well records within the vicinity of the District, the average hydraulic conductivity of the Chicot and Evangeline aquifers is 10.7 feet/day. Individual well yields range from 10-3,000 gallons per minute (gpm). The potentiometric surface may range from 30-70 feet bls based on sparse water level data in wells, and artesian conditions are anticipated.

Groundwater quality can range from fresh to moderately saline, and quality is not necessarily related to depth. It is expected, however, that water quality degrades below approximately 1,000 feet bls.

System	Series	Stratigraphic Units (TWDB, 2012)	Hydrogeologic Units Galloway (1991)	Estimated Thickness near Study Area (USGS, 1968)	Rock Characteristics	Water-bearing Property Columns	
Quaternary	Pleistocene	Alluvium/ Beaumont Clay	Chicot Aquifer	100-200	Clay, interbedded with layers of medium to fine sand.	Yields small to moderate quantities of fresh to moderately saline water.	Gulf Coast Aquifer
		Lissie Formation		200-300	Clay, sandy clay, sand and gravel.	Yields small to large quantities of fresh to slightly saline water.	
Tertiary	Pliocene	Willis		200-400	Sand, gravel, sandy clay, and clay.		
		Goliad Sand	Evangeline Aquifer	600-2,400(?)	Sand and sandstone interbedded with gravel and clay.	Capable of yielding moderate to large quantities of fresh, slightly saline , and saline water.	
	Miocene	Fleming/ Lagarto	Burkeville Confining System	3,600+(?)	Clay, silty calcareous clay, and interbedded sand and gravel. Caliche in the outcrop.	Yields small to large quantities of slightly saline to saline water.	
		Oakville Sandstone	Jasper Aquifer	3,000+(?)	Fine to coarse sand, sand-stone and clay.	Capable of yielding moderate to large quantities of slightly saline to saline water.	
	Oligocene	Catahoula Tuff	Catahoula Confining System	3,000+(?)	Predominantly tuffaceous clay and tuff, locally sandy clay, bentonitic clay, and thin beds of sand and conglomerate.	Yields small to moderate quantities of saline water.	

Figure 2 . Gulf Coast Aquifer Water Bearing Stratigraphy in the Study Area

4 Exploratory Test Drilling Program

4.1 Description

The approach for the exploratory test drilling program will be to perform an initial evaluation which includes drilling a borehole and completing downhole geophysics at multiple locations, followed by an expanded evaluation which includes soil coring and interval pumping tests at select locations where the observed geology appears most favorable for an ASR project. Review of drill cuttings and geophysical logs during the initial evaluation will be used to select locations for expanded evaluation. Locations that have one or more layers of sand and gravel that are greater than approximately 70 feet[1] in thickness will be considered for expanded evaluation. The preliminary goal is to perform the initial evaluation at a minimum of three (3) and up to six (6) locations depending on site logistics and driller bids, and an expanded evaluation at three (3) locations. Drilling locations will be located on City-owned property or where the City has been granted permission for testing, as shown on Figure 3. Descriptions of the drilling locations are provided in

Table 4-1.

The six (6) locations were identified based on several factors including:

- Review of nearby existing geophysical logs which indicated favorable aquifer conditions;
- Road access and site logistics, including maintaining a minimum distance of at least ½ mile from Corpus Christi International Airport runway;
- Land ownership. Note: Five (5) of the proposed locations are on City of Corpus Christi-owned land with one (1) location on land owned by West Oso ISD;
- Access to water for drilling; and
- Ease of ability to “map” the geologic data collected during the program to have a better understanding of local hydrogeologic variability and support City’s interest in characterizing a broader area for ASR feasibility[2].

A review of nearby logs, included in Attachment 2, indicates that the most-suitable intervals for ASR that is expected to be fairly continuous over the study area will likely be encountered at 400 – 500 feet bls and 980 – 1100 feet bls. The site-specific geophysics gathered during the initial evaluation will confirm target intervals for advanced testing including coring, pump tests, water quality analysis.

Depending on the geology observed in the field at the first three drilling locations, a decision may be made in the field whether to continue the initial evaluation at other locations or to begin the expanded evaluation.

Public utilities will be located by the driller using the local one-call service prior to drilling. All drilling will be performed in accordance with 16 TAC Chapter 76. An HDR field geologist will be present during drilling and testing, and will log the borehole and provide monitoring of drilling operations.

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[1] This minimum thickness will be revisited during the field review of the cuttings and geophysical logs.

[2] Previous studies estimated up to 5 mgd can be developed within the most favorable ASR area with a 10 well- ASR system. At the kick-off meeting, the City expressed interest in seeking water supplies up to 20,000 – 30,000 ac-ft/yr (or 18 to 26 mgd) providing geology is favorable.

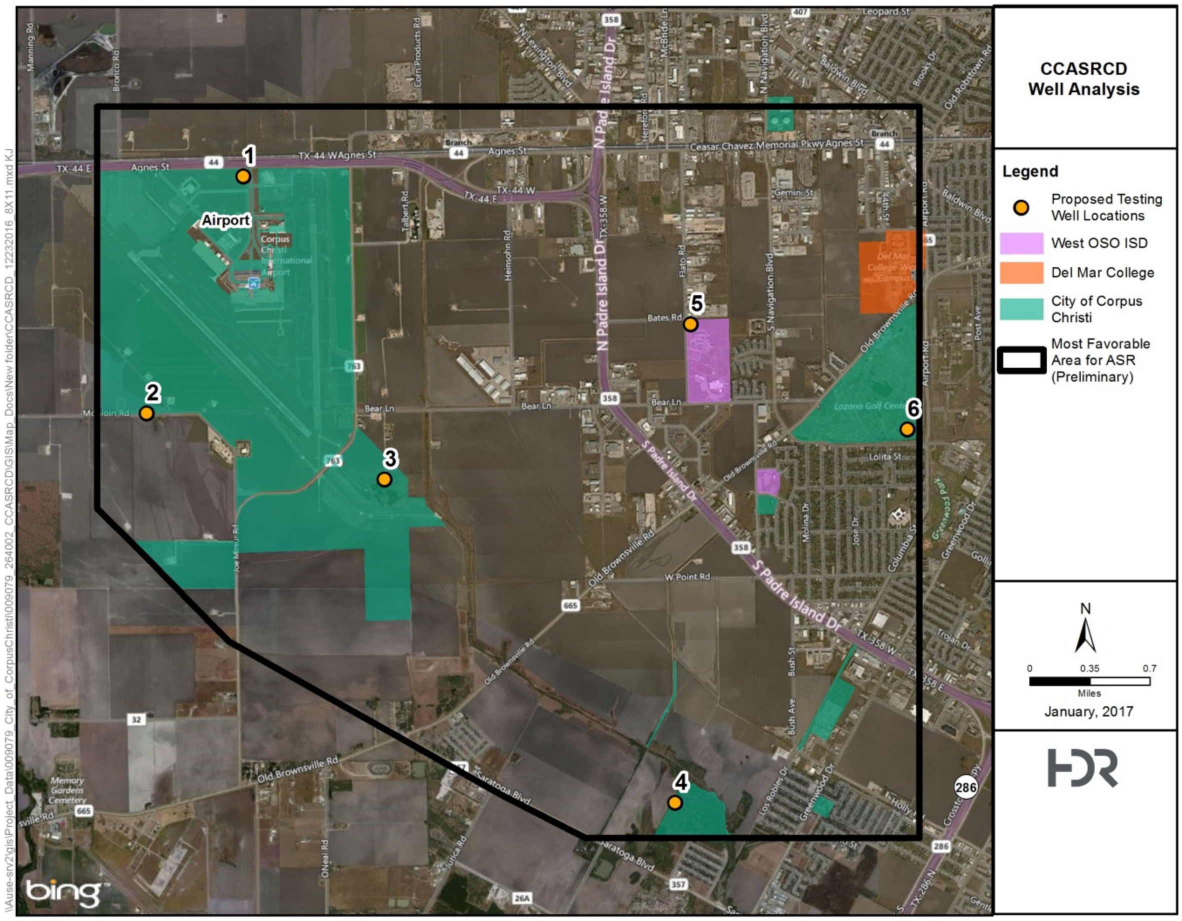

Figure 3. Draft Well Locations for Exploratory Testing Program

Table 4-1. Drilling Location Summary

Location ID	Lat	Long	Land Surface Elevation (ft-msl), estimated	Address Description
#1	-97.502907	27.783776	42.2	Off International Drive, near Corpus Christi International Airport entrance. Near hydrant
#2	-97.512277	27.763828	41.1	Inside airport fencing, adjacent to County Road 34. Near hydrant.
#3	-97.489707	27.758061	31.1	Rural area. No hydrant. Water needed will be trucked in.
#4	-97.462356	27.730585	27.5	Rural area about 1/4 mile NE of residential area. Brush removal may be required.
#5	-97.460503	27.770961	41.2	Near intersection of Bases Rd and Flato Road by Oso HS administration building.
#6	-97.439935	27.761954	38.1	In native area, Gabe Lozano Golf Course.

4.2 Initial Evaluation

During the initial evaluation a minimum of three (3) and up to six (6) boreholes will be drilled to an approximate maximum depth of 1,200 feet bls. Drilling will be performed using mud rotary techniques, which is appropriate for the depth and unconsolidated materials that are expected. Drill cuttings will be collected and logged every 10 feet during drilling. Within the ASR target zone of 400-1,200 feet bls, cuttings samples from significant sand layers will be bagged and submitted to a laboratory for sieve analysis. Up to fifteen (15) sieve samples will be submitted for each borehole. Grain size results will be used as a qualitative estimation of hydraulic conductivity and for design of temporary test wells during the expanded evaluation.

Borehole geophysical logging will be performed on the mud-filled hole after the maximum depth has been reached. The geophysical suite will consist of the following:

- Natural Gamma Ray;
- Electrical Resistivity (long and short normal);
- Spontaneous Potential;
- Sonic[3]; and
- Caliper.

The driller will use a small-diameter drill bit as appropriate to minimize drilling costs and to maximize the effectiveness of the borehole geophysical logging. Expected borehole diameter is 9-7/8 inches. Driller will be responsible for providing an open borehole for the geophysics subcontractor. The geophysics subcontractor will provide hard copy printouts of logging runs for review by HDR, and professional opinion on locations of the best water-bearing layers. HDR will recommend whether to abandon the borehole after geophysical logging is complete, or to complete a monitoring well in the borehole.

Results of each borehole drilled during the initial evaluation will inform the selection of locations for coring and interval testing. The decision process for selecting locations for expanded evaluation includes the following inputs:

- Number of locations with at least 70-ft+ thick sand layers. (Note: thickness criteria may be modified based on overall results of the initial evaluation.) Preference will be given to locations with the most sand that might support ASR. Complete absence of significant sand layers would indicate an unsuitable location for ASR, and expanded evaluation would not be recommended.
- Correlation of sand layers between locations. Laterally continuous sand layers would be beneficial for ASR. Preference will be given to locations where potentially continuous sand layers are indicated over locations that do not correlate.

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[3] Nuclear Magnetic Resonance (NMR) has been considered to assist in estimating hydraulic conductivity and permeability during the initial evaluation. This method will be considered in bid requests, but at this time it appears that the cost of this procedure outweighs the benefits.

- Presence of upper and lower clay confining layers. Preference will be given to locations where sand interval(s) are confined by clay lenses on the top and bottom, which would help bound an ASR system and improve recovery efficiency during operation.
- The remaining drilling budget will be reviewed throughout the initial evaluation. In the event that more than one location qualifies for expanded evaluation, the initial evaluation of other wells may be terminated after drilling the third location in favor of beginning the expanded evaluation.

By the end of the initial evaluation, the locations and target depths of sand layers for the expanded evaluation will have been determined.

4.3 Expanded Evaluation

An expanded evaluation will be completed at locations where the initial evaluation indicates good potential for ASR, using the decision process detailed in Section 4.2. During the expanded evaluation, a separate borehole will be drilled adjacent to the initial location to facilitate core sample collection, interval testing, and water quality sampling at pre-determined target depths based results of the initial evaluation. Drilling will be performed using mud rotary techniques. Borehole diameter will be approximately 12-1/4 inches to accommodate temporary well construction for interval testing. Drill cuttings will be collected and logged every 10 feet during drilling. A top-down approach will be used, where coring and interval testing is completed on the shallowest target sand layer first, followed by coring and interval testing of lower target sand layers.

4.3.1 Core Sampling

Prior to reaching the target depth of the first ASR zone for testing, the standard drill string will be removed from the borehole and switched over to core barrel coring tooling. Beginning at the confining layer above the first target sand layer, core barrel samples of approximately 10 feet in length will be collected from the following intervals:

- One (1) core barrel sample collected from the contact between the upper confining layer and the target sand layer;
- Two (2) core barrel samples collected from within target sand layer, evenly distributed across the target sand layer;
- One (1) core barrel sample collected from the contact between the lower confining layer and the target sand interval.

The driller may choose to alternate between drilling and coring within the target sand layer.

Core samples will be packaged and sent to an approved laboratory for: photograph, grain-size, x-ray diffraction (mineralogy), x-ray fluorescence (chemistry), cation exchange capacity with individual exchangeable cation concentrations, thin section petrology, scanning electron microscopy photomicrographs, and acid insoluble residue analysis. Cores will be wrapped with saran wrap and butchers paper, labeled, and packed in coolers with dry ice so that the cores freeze and remain frozen during delivery to the laboratory. Laboratory analytical results will be used in future geochemical modeling for the project.

Following coring of the first target sand layer, interval testing will be conducted as described in Section 4.3.2 below. Once interval testing is complete, drilling will continue down to the top of the second target sand interval and the coring and interval testing process repeated. This process would be repeated for a third target sand interval, if necessary.

4.3.2 Interval Testing

Interval testing will consist of pumping tests conducted in constructed temporary wells after core sampling is completed to the base of the first target sand layer, and will be repeated in lower target sand layers after coring is completed in each layer.

Temporary Well Construction

A temporary 6-inch diameter steel well will be constructed in the approximately 12-1/4-inch diameter borehole, screened across the entire target sand layer for each interval. The driller will complete the temporary well with sand filter pack around the screen and bentonite seal above the filter pack. Filter pack gradation will be based on the formation samples collected during the initial evaluation, and selected by the driller with approval by HDR. The screen slot size will be selected by the driller to withhold the filter pack. Bentonite seal will have a thickness of 10 feet to seal off the interval from shallower groundwater. The temporary well will be developed via airlifting until the discharge is relatively clear and free of sediment.

Pumping Test

After the temporary well is constructed and developed, a pumping test will be completed in the temporary well consisting of a 2-hour step-drawdown test, 24-hr constant-rate pumping test, and a recovery test. A pump capable of pumping 200 gpm will be installed. During the step-drawdown test, the temporary well will be pumped for 30 minutes each at four successively greater pumping rates (e.g., 40, 60, 80, and 100% of the maximum yield of the pump). The step length may be increased if the pumping water level is not relatively stable at the end of the step, as determined by HDR, and all steps will be run for the same duration. The 24-hr constant-rate test will begin after water levels have recovered at least 95% from the step-drawdown test. The recovery test will begin immediately after the constant-rate test is terminated. Near the conclusion of the constant-rate test a water quality sample will be collected by HDR and analyzed for the following parameters:

- Field parameters: temperature, conductivity, pH, oxidation reduction potential (closed cell), dissolved oxygen, and turbidity.
- Water quality samples will be collected for each interval and testing location and shipped for laboratory analysis for the following parameters, at a minimum: aluminum, arsenic, both dissolved and total iron and manganese, calcium, coliform/e. coli, sodium, total alkalinity, sulfate, chloride, copper, fluoride, nitrate, nitrite, ammonia, phosphate, lead, total organic carbon, total dissolved solids, total suspended solids, specific conductance, and pH, and zinc.

- At a minimum, one sample for each testing interval will be analyzed by a laboratory for a full suite of TCEQ primary and secondary drinking water standards, which includes regulated organics, inorganics, synthetic organic compounds, and radionuclides.

The driller will provide a flow meter, or orifice and potentiometer tube, and a flow control valve. Discharge rates will be maintained at the target rate +/- 5% during testing. During the step-drawdown test, the flow rate will be measured every 5 minutes. During the constant-rate test the flow rate will be measured every 5 minutes during the first 30 minutes, every 30 minutes for the first 6 hours, and once every 6 hours thereafter. Discharge water will be piped at least 400 feet from the temporary well. Discharge will be to the land surface preferably towards stormwater sewer or swale, unless specified by the City for containment. Erosion at the pipe outlet will be minimized by discharging onto plywood or plastic sheeting.

A 1.25-inch diameter PVC pipe will be installed to the top of the pump to facilitate water level measurement in the temporary well. The lower 10 feet of the PVC pipe will be perforated, and a bottom cap installed. Drawdown and recovery will be observed in the temporary well using an electronic pressure transducer and data logger, and also using a hand-held water level meter with data recorded manually. HDR will program the transducer to record pressure measurements at time intervals determined in the field, depending on the options available for the transducer. Early test measurements should be made at approximately 1-sec intervals in order to capture the rapid drawdown in the well. A separate transducer will be programmed to record linear (e.g., every 30 minutes) measurements of barometric pressure. Data from this transducer will be used to correct the pressure readings in the other transducer and remove the barometric effects on the water levels. Background (static) manual water level measurements will be collected prior to and at the end of the step-drawdown and constant-rate tests. Additional manual water level measurements will be collected at the following frequencies: every 30 minutes during the first 6 hours of the constant-rate test and once every 6 hours thereafter, and every 6 hours during the recovery test.

The upper portion of the borehole above the well screen and seal would remain mud-filled during the pumping test. Following the interval pumping test the temporary well casing and screen will be jacked out of the borehole. The driller will remove collapsed material from the borehole and continue drilling down to the top of the next test interval, and the coring and interval testing repeated. All target sand layers would be tested using the same borehole.

HDR will serve as the client representative and will be on-site for field check of the above procedures during drilling, sampling, and testing program.

4.4 Optional Monitoring Well Installation

There are opportunities to install permanent monitoring wells in the geophysical boreholes and/or in the interval testing boreholes after testing is complete. Permanent monitoring wells would be useful for monitoring groundwater levels and collecting water quality samples during the design, installation, and testing of a full-scale ASR well field. Monitoring wells would continue to provide value during ASR operation when evaluating system effectiveness.

The decision of where to install a monitoring well and for how many locations will be made with input from the District and City prior to mobilization of the field crew. Prior to installing a monitoring well the borehole may need to be cleaned out if material collapses into the borehole during interval testing and removal of the temporary well casing and screen. Monitoring wells are expected to be constructed from 2-inch diameter Schedule 80 PVC with 2-inch diameter stainless steel screens. Larger diameter (e.g., 4-inches) wells are not likely necessary since groundwater levels are relatively shallow and the need for larger sampling pumps is not anticipated. Monitoring well screens would intersect the entire target sand layer and have 0.020-inch slot openings. The driller would select an appropriate filter pack gradation that will withhold the formation and be withheld by a 0.020-inch slot screen, for approval by HDR. The annular space of the monitoring well would be sealed in accordance with 16 TAC Chapter 76. Monitoring wells would be developed via airlifting until the discharge is relatively clear and free of sediment. Surface completions for monitoring wells would be performed by the driller. Typical surface completions would include an above-grade steel protective casing with locking cap, concrete pad, and protective bollards.

4.5 Field Program Needs and Considerations

Lay-down Area

A lay-down area will be available for drillers at each site for the duration of the exploratory testing program to stage equipment, drilling and well construction materials, and receive cement and bentonite for drilling. A 200 ft x 200 ft graded area is assumed to be available and sufficient for the driller's purposes.

Access Roads

All-weather road access will be available for drilling rig use. Existing roads are being considered for drilling locations and will be used when practicable so as to not compromise the discovery phase of the program. If additional access roads need to be constructed, the driller will construct and maintain access roads for the duration of the exploratory test program. This is estimated to only be needed for one or two locations, at a maximum. The driller will be required to clean public access roads of dirt and debris at each site resulting from their construction, equipment and activities.

Drilling Pads and Access Roads

The driller will provide basic site preparation, including clearing/mowing of vegetation and earth work or grading to construct a shallow excavated flat area for driller as may be needed. Approximate anticipated pad size is 150 ft x 150 ft.

Drilling Water Supply

An approved water source will be provided by the City for drilling. It is anticipated that fire hydrants or a water truck station will be available. The driller is responsible for getting water to the drilling locations.

Mud and Cuttings Handling

The City authorizes the driller to construct temporary mud pits at each drilling site. Typical pit size ranges up to 6 ft deep and 20 ft long. If construction of above ground pits is required of the driller, the City will notify HDR prior to finalizing the Request for Bid documents. Temporary fencing for safety will be arranged and provided by the City. The driller will be responsible for hauling mud, cuttings and other produced waste to an approved facility. The landfill fee for disposal will be paid by the City. A typical size for mud tank is estimated at 2,000 barrels or more.

Disposal of Water from Well Development and Interval Testing

Each drilling location is within approximately 400 feet of a ditch or natural drainage which can be used for disposal of water pumped from the temporary wells. The City will be responsible for identifying any required discharge permits needed. The driller will provide erosion control measures at the discharge point. Drilling mud and cuttings cannot be discharged.

Site Restoration

The driller will restore drilling locations after all drilling and testing activities are complete.

Site Security

Drilling locations are on City-owned public property; interaction with the public is possible. The driller is responsible for maintaining a working perimeter around the equipment to limit exposure to the public. The working perimeter will be marked with temporary fencing and caution tape as needed.

Noise Ordinances

Local noise ordinances are in effect from 10 pm to 8 am and may apply to one or more drilling locations. HDR will work with the City to determine noise ordinances that apply to the drilling, and develop the appropriate mitigation.

4.6 Selection of Drilling Techniques

Mud rotary is commonly used when drilling in unconsolidated formations and is considered to be the preferred drilling technique for the project. The primary benefits of mud rotary drilling over other methods include:

- Not depth-limited; 1,200 feet is typically easily obtainable.
- Provides an open, mud-filled borehole for conducting a full suite of geophysical testing.
- Relatively fast and inexpensive.

No casing is advanced during mud rotary drilling. Instead, a mud cake is created on the wall of the borehole during drilling which prevents the borehole from collapsing by maintaining a positive head against the artesian pressures of the formation. The mud cake is also the primary drawback of the method, as the mud cake must be broken down through a development process before hydraulic well testing or sampling can occur. However, HDR has observed the installation of successful pumping wells up to 4,000 gpm using mud rotary drilling in deep, stratified sediments.

Other drilling techniques that were considered for the project are listed below, along with a brief description of benefits and drawbacks of each technique.

- Sonic drilling. Benefits: provides a cased borehole and collection of depth-specific soil samples for logging and analysis; no mud cake; can set temporary screens for hydraulic testing. Drawbacks: Depth-limited to ~600 feet; casing prevents full geophysical suite; slower than mud rotary, especially at greater depths.
- Dual rotary. Benefits: provides a cased borehole; no mud cake; can set temporary screens for hydraulic testing. Drawbacks: Depth-limited to ~800 feet with a 10-14-inch diameter borehole; casing prevents full geophysical suite; slower than mud rotary; expensive.

5 Reporting

HDR will report to the City on a weekly basis by email and phone regarding progress of field work. One project meeting with the District is also proposed to communicate project results. It is expected that the field program will be completed within three months.

Following completion of the exploratory test drilling program, HDR will prepare a technical memorandum that describes the methods and results.

6 Project Management

6.1 Roles and Responsibilities

Contact information has been redacted for security reasons.

6.2 Data Management

Project field data will be contained in field notebooks, boring logs, and daily reports. Daily reports will be completed electronically in Microsoft Word format after each shift. File naming for daily reports will be as follows:

Daily Report_CCASR_yyyymmdd_initials_shift (day or night).docx

Example: Daily Report_CCASR_20170715_ASK_day.docx

Boring logs will be transcribed to Microsoft Excel spreadsheets. The field notebooks will be scanned and placed in the project electronic database. Electronic data will be archived in HDR's ProjectWise data system.

6.3 Health and Safety

All field staff will comply with their company's health and safety program. Field staff must wear personal protective equipment (PPE), which at a minimum must include steel toed boots, hard hat, and orange safety vest while on a drilling site. Drilling staff shall at a minimum also wear eye protection, hearing protection and work gloves. Other specialized safety equipment required for drilling shall be utilized by drilling contractor's staff.

Safety briefings will be held at the beginning of the project and upon encountering any change in condition or at the request of any project personnel.

6.4 Quality Assurance/Quality Control

All work will be completed according to the standard of practice for that specific project task. The completed work products will be reviewed by a designated QA/QC reviewer (Doug Haney) following the HDR QA/QC protocol.

7 Meeting Notes

7.1 Attachment 1 – Kick-Off Meeting Minutes

Meeting Notes from Kick-off Meeting on October 17, 2016

Meeting Notes

Project:	Corpus Christi Aquifer Storage and Recovery Feasibility Study
Subject:	Kick-off Meeting
Date:	October 17, 2016 2:30 PM – 4:30 PM
Location:	ACM Conference Room, City Hall 5th Floor
Attendees:	Fred Segundo, Dan McGinn, Tom Tagliabue, Mark Van Vleck, Itzel Ojeda, Larijai Francis, Lisa Aguilar, Daniel Deng (City and/or District) Matt Webb (TWDB) Kristi Shaw and Troy St. Tours (HDR)

Discussion regarding City Project E 16265 (Corpus Christi Aquifer Storage and Recovery Feasibility)

a. Background and Findings. HDR presented summary of previous work and results leading up to the feasibility study.

b. Key Questions that the District and City would like this ASR project to answer. Primary questions that the City and District would like this study to answer include: (1) What is an appropriate injection rate? (2) What is an appropriate withdrawal rate? and (3) How much storage can be achieved?

A successful ASR project would be one that provides needed water during times when demand exceeds supply at a lesser cost than other options. Success should not be tied to recovery efficiencies.

c. Primary Goals and Objectives. The City and District would like to consider ASR to meet seasonal peak demands as well as storage of excess water when available to use for back-up supply during drought intervals.

d. Drilling Program Preference. The City and District desire to maintain flexibility in the drilling program and avoid costly expenditures and collection of detailed information at sites that may be unsuitable for ASR. The City and District prefer to conduct preliminary tests with smaller boreholes to collect lithology and geophysical data, and if conditions are favorable, proceeding forward with collecting samples for laboratory analysis and aquifer testing.

e. RFI/RFQ Process to Procure Driller. The City's standard for issuing Request for Competitively Sealed Bids will be used to procure the driller. City of Corpus Christi contract guidelines will need to be followed. TWDB contracting requirements and provisions that need to be included in the solicitation will be verified.

f. Water quantity goal/target for ASR storage and recovery. Previous studies estimated up to 5 mgd can be developed within the most favorable ASR area with a 10 well- ASR system. The City is interested in seeking water supplies up to 20,000 – 30,000 ac-ft/yr (or 18 to 26 mgd). Providing geology is favorable, the City would like to consider diverting water from reservoir system storage for pre-treatment and ASR storage rather than subjecting to 60% evaporative losses.

g. Estimated operations- seasonal for summer peaking and/or long term for water banking. Both types of operations are possible and will need to be considered as part of the study.

h. Anticipated end use. ASR stored water could be used by local industries or potable water customers. Depending on end water use and quality needs, ASR stored water may need additional treatment after recovery to treat to potable standards for drinking water distribution.

i. **Confirm source water.** The City and District would like the study to consider treated effluent from a North WWTP (potential) and/or water from the potable, distribution system as the source water for ASR. Water quality data from Greenwood WWTP will serve as a proxy for treated effluent.

j. **TCEQ information re: permits, source water treatment requirements, and exploratory testing program.** TCEQ staff reported that no TCEQ permission or authorization is required for an exploratory well program as long as water is not being injected into the aquifer. TCEQ rules do not require injected water to be treated to potable standard prior to injection as previous rules required, but rather that the injected water does not degrade the native groundwater or affect water chemistry downgradient of the ASR project. TCEQ Chapter 331 Class V injection well construction and closure standards specify that "ASR injection and production wells associated with a project must be under common ownership, lease, joint operating agreement, or contract." HDR will set up a meeting with TCEQ staff to determine how rules will be interpreted, and if it requires that a City have a controlling interest in all land above ASR storage zone, or just where wells exist.

k. **Key steps and using data gathered for mid-course adjustments.** HDR described the five major work tasks associated with the study: program formulation, exploratory test drilling program, geochemical analysis/modeling, field scale groundwater model, ASR operating procedures, and meetings/reports. Key factors affecting the successful implementation of an ASR project include regulatory, infrastructure, and hydrogeologic compatibilities. This project focuses on the hydrogeologic component, but will also consider regulatory issues associated with water quality standards. HDR will seek to identify ASR opportunities that are compatible with new infrastructure or other ongoing projects, where practicable based on information provided by the City.

l. **Project schedule.** An updated schedule was presented in response to contracting set-backs and kick-off meeting scheduling. A draft report is due to the TWDB by March 29, 2019; and final report is due by July 29, 2019. Interim technical memorandums will be provided to City Staff and the District upon completion of each of the major tasks, and prior to status update meetings with the TWDB. The schedule estimates 45-60 days to review drillers bid proposals, with notice to proceed by the City/District by June 13, 2017.

m. **Next District meeting:** January 26, 2017

n. **Action Items/ Follow-up.**

   a. HDR to follow up with City of Corpus Christi staff to obtain the following:
      i. Industrial water quality criteria and needs;
      ii. GIS shapefiles or maps showing:
         1. City owned or authorized land for ASR test wells;
         2. New floodplain maps;
         3. Treated water distribution; wastewater collection and power lines.

   b. City of Corpus Christi staff to send Request for Bid template and required contract documents and specifications. City of Corpus Christi and HDR to follow up with the TWDB to obtain TWDB contracting requirements.

   c. HDR to set up meeting with TCEQ to identify land requirements and confirm water quality standards for injection.

7.2 Attachment 2 – Review of Nearby Geophysical Logs

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CCASRCD
Well Analysis
Legend
Existing Wells
Proposed Testing Well Locations
Cross Sections
Most Favorable Area for ASR (Preliminary)
NS - 1
NS - 2
W-E
1
2
3
4
5
6
Corpus Christi International Airport
N
0
0.25
0.5
Miles
January, 2017
HDR

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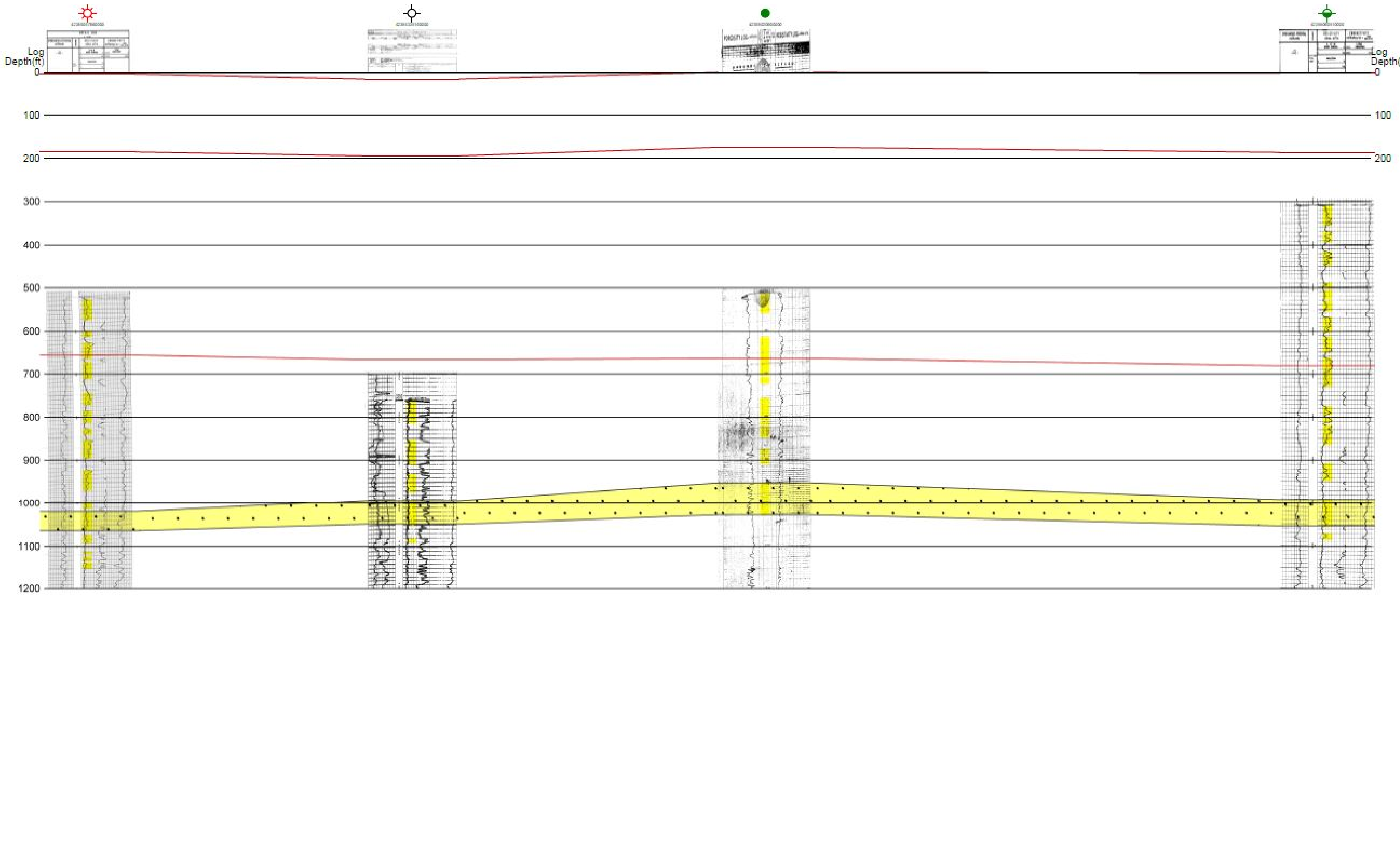
NS1 (wells presented in order North to South)



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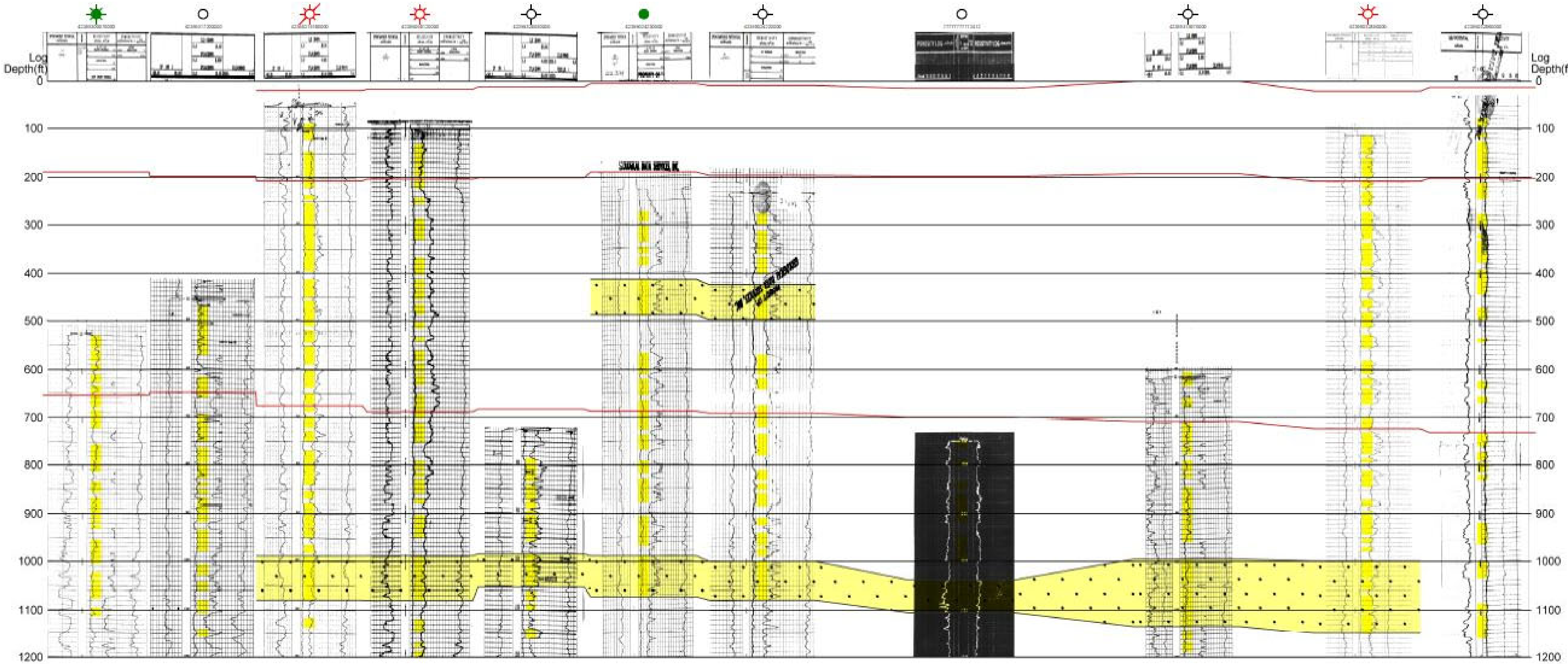
NS2 (wells presented in order from North to South)



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W-E (wells presented in order from West to East)

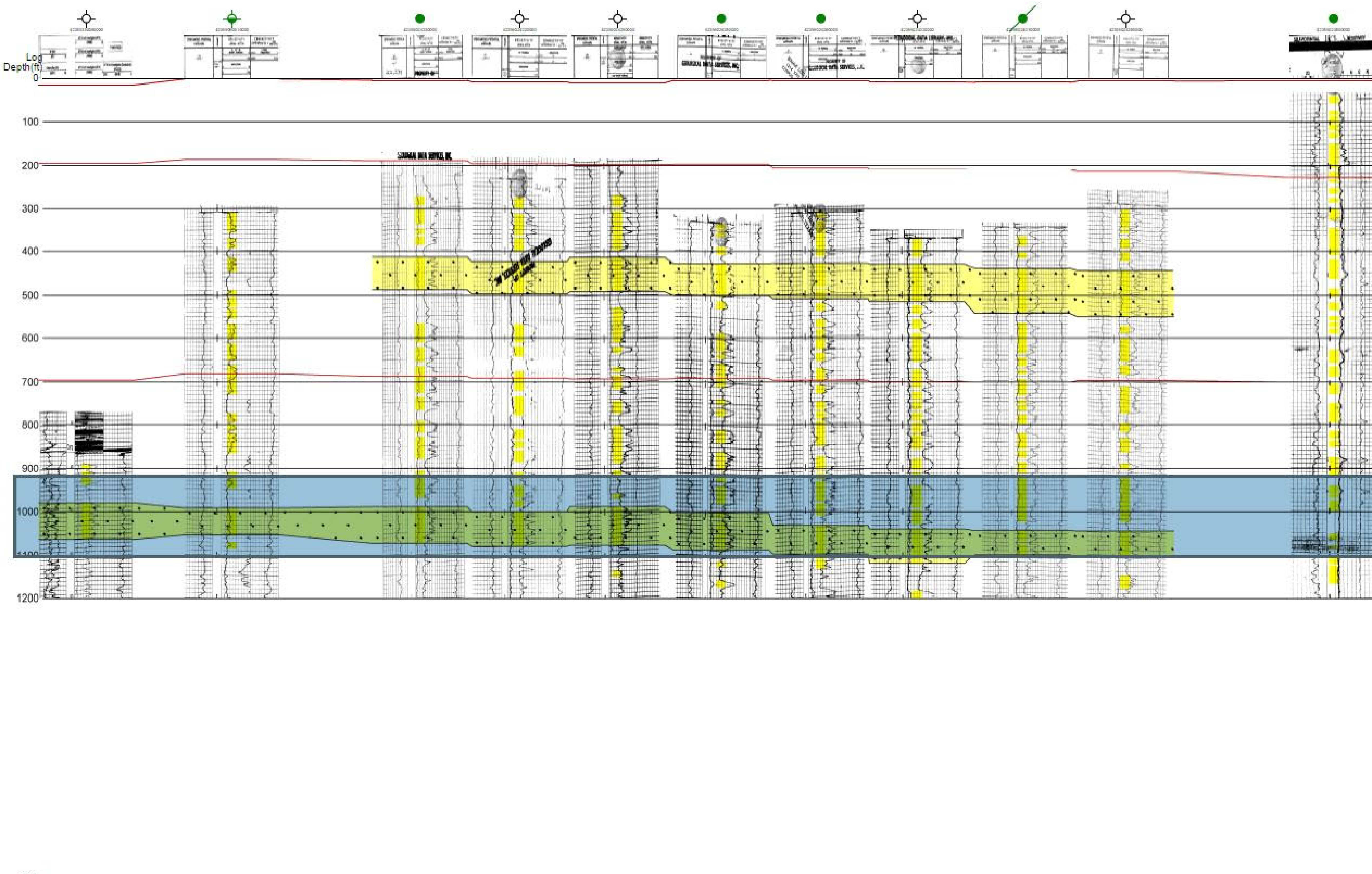

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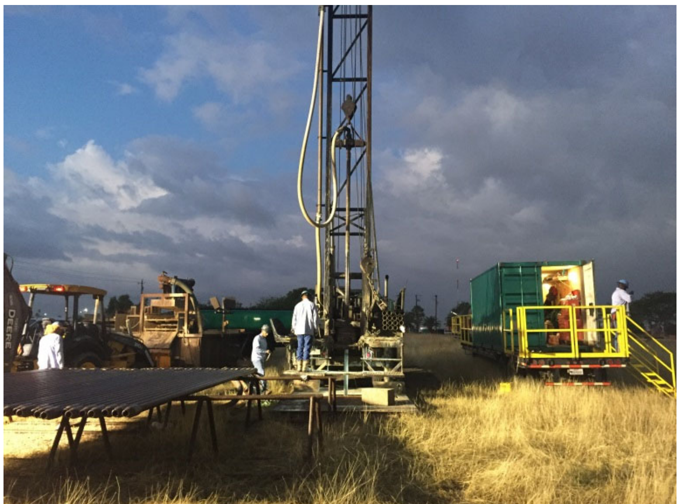
Exhibit D Memo- Exploratory Test Drilling Program



Exploratory Test Drilling Program- Technical Memorandum

Corpus Christi Aquifer Storage and Recovery Feasibility Study (E16265)

Corpus Christi, Texas

October 4, 2018

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Contents

Tables

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Appendices

1 Introduction

The Corpus Christi Aquifer Storage and Recovery District (District), with contracting authority through the City of Corpus Christi (City), hired HDR to conduct an investigation of aquifer storage and recovery (ASR) feasibility within the District. The investigation includes exploratory test hole and test well drilling, geochemical analysis, and groundwater modeling to develop recommendations for ASR operations. Exploratory test drilling was conducted at four City-owned sites located within the District from October 9, 2017 to May 15, 2018. This technical memorandum summarizes the process and results of the exploratory test drilling program, including construction of permanent monitoring wells for future use.

1.1 Background

The District, with support from the City, is actively studying ASR to promote water supply resiliency for industrial customer growth, to improve regional system operations, and for cost-effective long term regional water supply. The District developed a 5-year plan in 2009 which included a schedule of major elements of an ASR feasibility plan. In support of the 5-year plan, the Texas Water Development Board (TWDB) conducted a geologic characterization of the District and surrounding counties in 2012[1]. A few years later, HDR performed a desktop aquifer characterization study[2] on behalf of the District at three specific areas within the District boundaries. The study identified the most favorable ASR test drilling area of three sites considered (Figure 1) based on interpretation of nearby geophysical logs that showed favorable permeable zones comprised of sand or mostly sand within the lower Chicot and/or upper Evangeline Aquifers. Existing well logs suggested sand zones that spanned a few hundred feet in either a continuous unit or at multiple intervals considered desirable for ASR development. The results of the 2016 study serve as a basis for this feasibility project. This project is a continuation of the 5-year plan through site-specific hydrogeological and geochemical testing and modeling to determine the optimal intervals within the subsurface aquifer system for ASR development and operation.

1.2 Purpose

The purpose of this report is to summarize drilling and sampling procedures, as well as information gathered during the exploratory testing phase of the Corpus Christi Aquifer Storage and Recovery (CCASR) Feasibility Project. Other project tasks, including geochemical/source water compatibility analysis, groundwater modeling, and development of recommendations for ASR operations will be discussed in future reports.

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[1] Meyer, John E., Texas Water Development Board, “Geologic Characterization of and Data Collection in the Corpus Christi Aquifer Storage and Recovery Conservation District and Surrounding Counties”, Open File Report 12-01, September 2012.

[2] HDR, “Aquifer Characterization Study for ASR Feasibility”, January 20, 2016.

2 Study Area

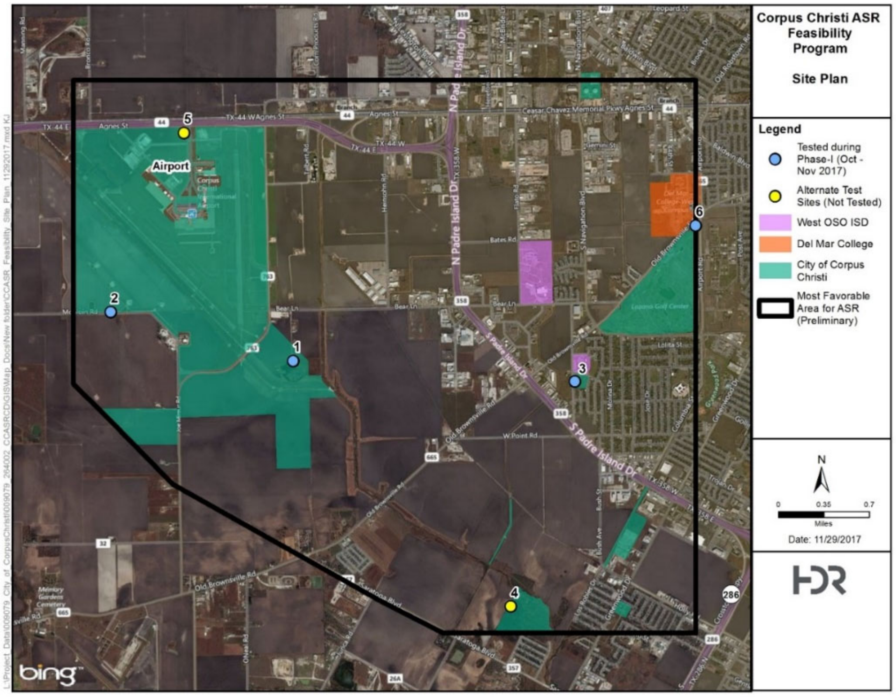
The study area under investigation is the most favorable area for ASR identified in the 2016 report. Six potential exploratory testing sites within the study area were selected through discussions with District and City personnel, with four sites[3] selected for testing as shown on Figure 1. Site selection criteria included the following: sites are on land owned by the City; sites are accessible for drilling; sites provide spatial coverage of the study area; and a source of water for drilling is reasonably close.

3 Exploratory Testing

Exploratory testing was performed using a two-phased approach to obtain subsurface data. The first phase (Phase I) involved drilling a relatively small-diameter (6.75-inch) borehole for obtaining soil cuttings and completing a downhole geophysics survey. Together, these Phase I activities provided a preliminary understanding of the geology at a site, after which a decision was made whether to cease investigation at a site or to continue onto Phase II of the exploratory testing to gather additional information to further characterize site geology where conditions appeared favorable for ASR. Phase II involved drilling a larger-diameter (12.25-inch) borehole for obtaining soil core samples, installing a temporary test well at one or more target depth intervals, conducting pumping tests, and collecting groundwater samples for water quality analysis. Permanent monitoring wells were installed at select locations and in intervals of interest. Phase I and Phase II testing activities, and the decision-making process involved at each site, are described in detail in the following sections.

[3] It should be noted that the original scope included preliminary testing at up to three locations, but based on findings in the field, the District and City opted to test an additional (fourth) location.

Figure 1. Site Plan for ASR Exploratory Drilling Testing Program



3.1 Exploratory Testing – Phase I

3.1.1 Drilling

Drilling rig at Site 1 during Phase I

Phase I drilling was performed by Felder Water Well & Pump Service, LLC (Felder) of Angleton, Texas using a Midway 1500 drill rig and direct mud rotary methods. HDR provided a geologist or engineer to conduct part-time observation of drilling activities. A 6.75-inch diameter borehole was drilled to the target depth of approximately 1,200 feet below ground surface (bgs). Water for drilling was supplied from a City fire hydrant located near drilling sites. Drilling mud consisted of a mixture of bentonite (Quik-Gel), dispersant (Quik-Trol Gold LV), soda ash to control pH, and potable water. Drilling mud was pumped through a mud cleaner tank where soil cuttings were removed from the drilling mud using vibrating screens, and then circulated back to the borehole. Samples of soil cuttings were collected into sample bags at 10-foot depth intervals and logged by the driller. Boring logs are contained in Appendix A. Site geology is described in Section 4.

Final drilled depths are shown in Table 3-1. The locations of Phase I boreholes at Site #1, Site #2, Site #3, and Site #6 are shown on Figures 3-2 through 3-5, respectively.

Table 3-1. Drilled Depths – Phase I

Location	Date of Drilling	Drilled Depth (feet bgs)
Site #1	10/9/17-10/12/17	1,197
Site #2	10/16/17-10/19/17	1,197
Site #3	10/24/17-10/25/17	1,197
Site #6	10/31/17-11/1/17	1,197

bgs = below ground surface

Figure 2. Site 1 Locations of Phase I borehole (P1), Phase II test well (TW 1) and Monitoring Wells (MW 1S and MW 1D)

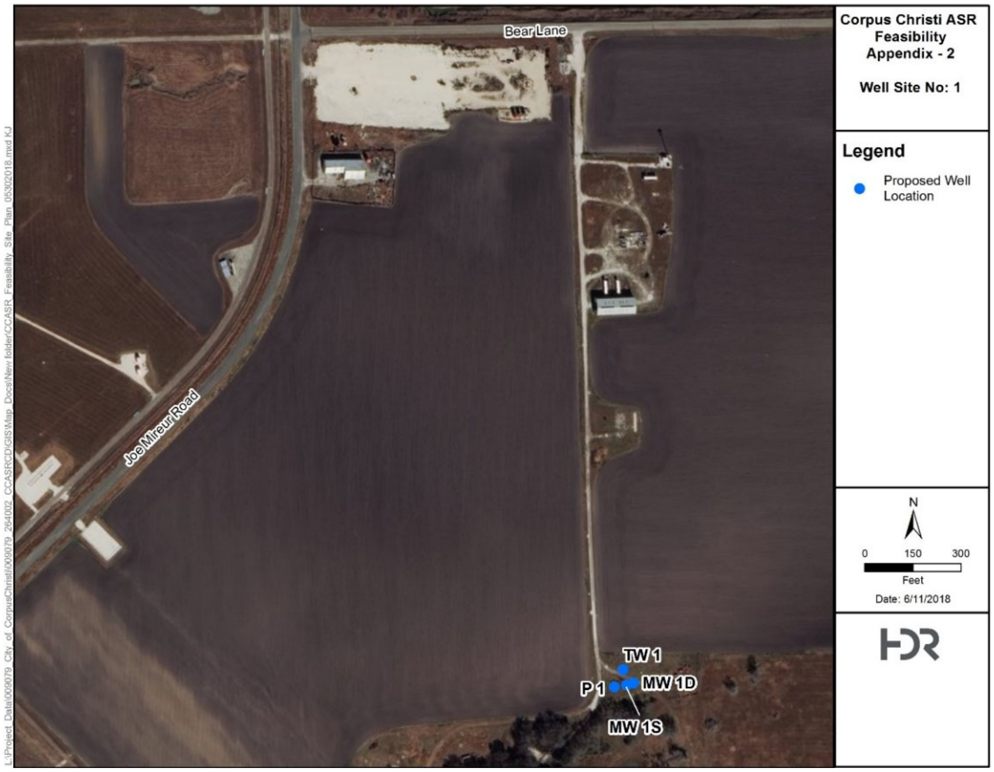


Figure 3. Site 2 Location of Phase I borehole (P2). This site was not selected for Phase II testing.

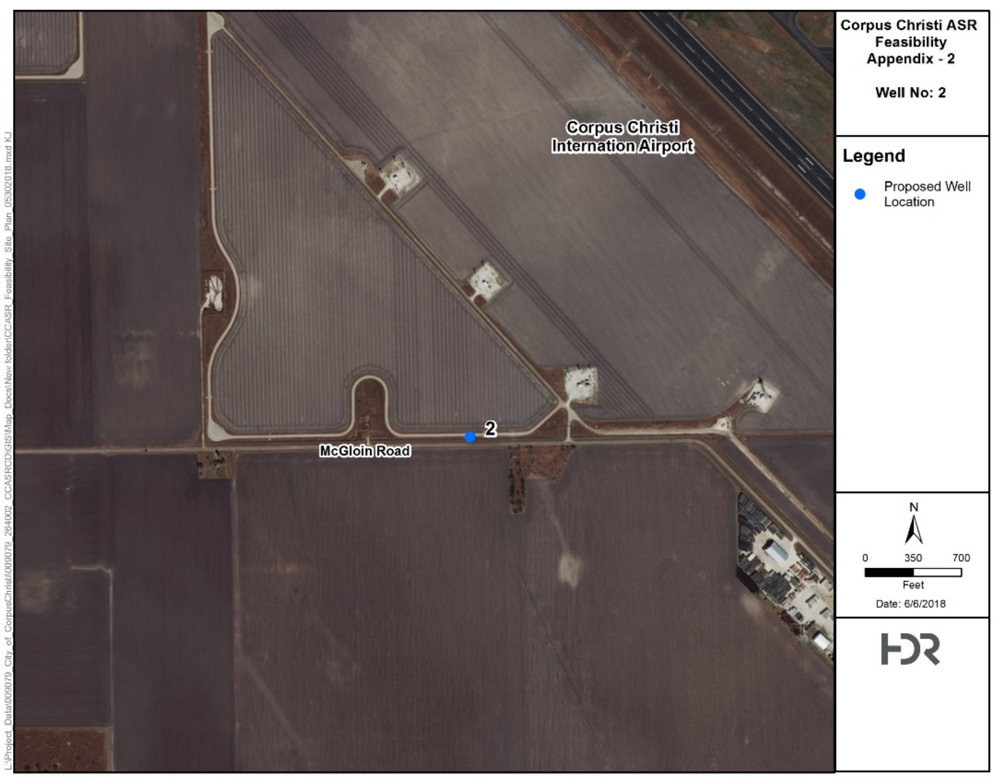
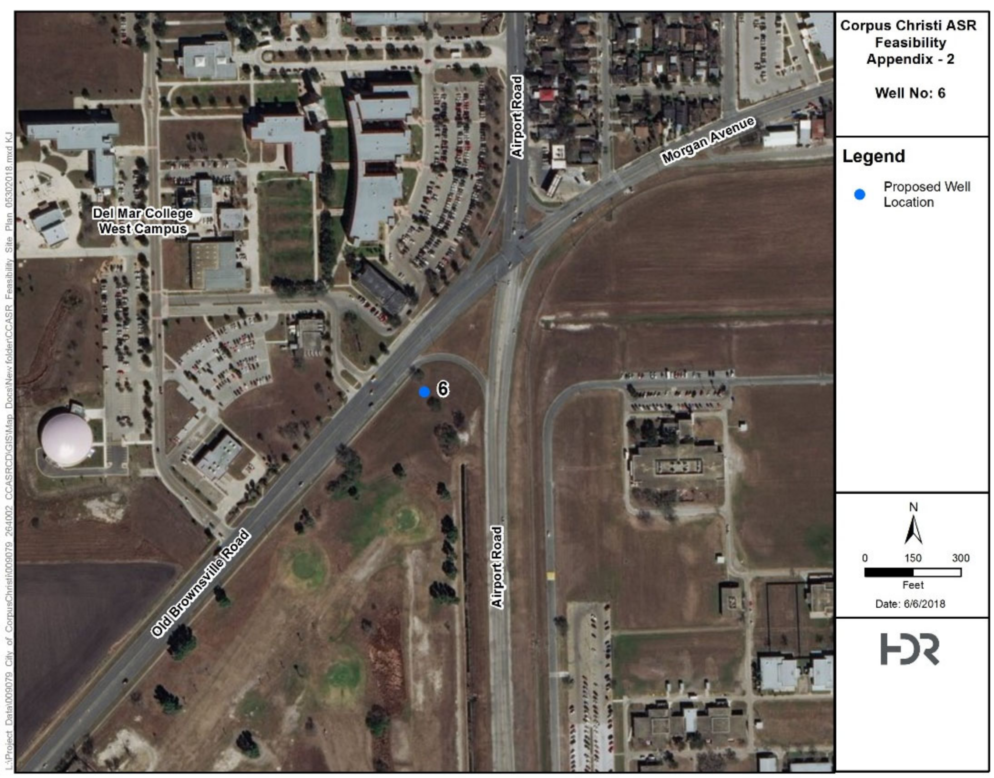


Figure 4. Site 3 Location of Phase I borehole (P3), Phase II test well (TW 3) and Monitoring Well (MW 3)

Figure 5. Site 6 Location of Phase I borehole (P6). This site was not selected for Phase II testing.



At Sites #1, #2, and #6, drill cuttings and drilling mud were discharged to the land surface and thin-spread and allowed to dry. At Site #3 (Westhaven Park), drill cuttings and drilling mud were collected into a frac tank and transported to Site #1 for thin-spreading and drying.

3.1.2 Downhole Geophysics Survey

After the 6.75-inch diameter borehole was drilled to the desired depth and prior to conducting the borehole geophysics survey, the driller reconditioned the drilling mud by removing additional soil cuttings and setting the specific gravity and viscosity of the drilling mud as needed to maximize the effectiveness of the geophysics instruments. The drill stem was then removed from the borehole and the downhole geophysics survey performed.

Felder retained a geophysics subconsultant, Geo Cam, Inc. (Geo Cam) of San Antonio, Texas to conduct the downhole geophysics surveys. Geophysics surveys were completed in open boreholes filled with bentonite drilling mud. A total of four separate geophysics tools were placed down the borehole. The following geophysics analyses were performed:

- Tool 1: gamma ray, spontaneous potential (SP), normal resistivity (8-inch, 16-inch, 32-inch, and 64-inch)
- Tool 2: caliper (3-arm)
- Tool 3: fluid temperature and conductivity
- Tool 4: full waveform sonic

The caliper tool was calibrated in the field prior to each use. Geo Cam indicated that the other tools do not receive calibration. Occasionally geophysics tools would not reach the bottom of the 1,197-foot borehole. The reasoning for this offered by Felder and Geo Cam is the presence of swelling clays which sealed off a portion of the borehole. This reasoning was supported by visible clay on the bottom of some tools after the tool was tripped out of the borehole. Field-time decisions were made whether to re-drill the borehole in order to clean out the swelling clays and complete the geophysics analyses to the target depth. It was decided not to re-drill the borehole at Site #1, Site #2, and Site #3 since the logging had been completed to acceptable depths. The Site #6 borehole was re-drilled due to the caliper tool only reaching a depth of 680 feet bgs on the first attempt (a depth of 1,116 feet bgs was reached on the second attempt). Table 2 describes the maximum depths reached by the geophysics tools at each site. Copies of geophysical logs are included in Appendix B. Geophysics results are described in Section 4.

Table 3-2. Downhole Geophysics Survey Depths

Location	Date of Survey	Analysis	Maximum Depth Surveyed (feet bgs)
Site #1	10/12/17	Gamma, SP, Resistivity	1,193 nominal
		Caliper	1,050
		Fluid Temperature, Conductivity	1,046
		Full Waveform Sonic	1,048
Site #2	10/19/17	Gamma, SP, Resistivity	1,194 nominal
		Caliper	1,192
		Fluid Temperature, Conductivity	907
		Full Waveform Sonic	924
Site #3	10/28/17	Gamma, SP, Resistivity	1,188 nominal
		Caliper	1,191
		Fluid Temperature, Conductivity	1,184
		Full Waveform Sonic	1,184
Site #6	11/1/17	Gamma, SP, Resistivity	1,193 nominal
		Caliper	1,116
		Fluid Temperature, Conductivity	1,136
		Full Waveform Sonic	1,119

bgs = below ground surface

3.1.3 Field-Informed Decisions and Approach – Post-Phase I

After four Phase I boreholes (Sites #1, #2, #3, and #6) were drilled and downhole geophysics survey completed, the geology was assessed and preliminary decisions were made as to whether a site was suitable for proceeding to Phase II of the CCASR Feasibility Project. HDR examined the boring logs and geophysical logs and developed recommendations for Phase II test intervals. In general, the geology consists of thin (2-35 feet) lenses of fine sand separated by clay. Site geology is described in more detail in Section 4. It was decided that the minimum depth for ASR in this area should be about 400 feet in order to prevent interference with existing domestic wells. None of the four sites drilled exhibited multiple, thick (e.g., 70-100 feet) layers of sand. Due to the heterogeneous character of the Gulf Coast aquifer, this was not particularly surprising, but deviated slightly from the geophysical interpretations based on limited geophysical logs available for use during the 2016 study. Thinner sand lenses (less than 40 feet) were observed below a depth of 400 feet bgs, and no site had considerably more sand than the other sites. It was therefore decided that the two remaining Phase I sites (#4 and #5) would not be drilled due to the unlikelihood of encountering different sands from those identified at previous locations. Phase II testing was selected for Site #1 and Site #3 since those sites had the most sand present within reasonable test intervals, and zones exhibiting high gamma spikes could be avoided which could be attributed to potassium-40 or potential radioactive mineralogy. A chronological summary of the decision – making process for each site is shown in Table 3-3.

Table 3-3. Phase I Decision-Making Process

Location	Decision
Site #1	1. Site #1 did not exhibit multiple, thick (e.g., 70-100 feet) continuous layers of sand, however four sand lenses that were each 20-30 feet thick were observed between 410 and 650 feet bgs. A shallow monitoring well (MW-1S, screened 154-164 feet bgs) was installed for future use by the City and TWDB for monitoring regional water levels and water quality. Any existing wells that might exist in the area for local domestic or livestock use are anticipated to be screened at a comparable interval as MW-1S. No registered wells have been confirmed in the vicinity.
	2. After drilling the remaining sites (#2, #3, and #6), it was deemed that Site #1 has the best geology of all four sites and it would be prudent to perform Phase II testing to characterize the collective behavior of sand units identified during Phase I. Two depth intervals, 410-450 feet bgs and 570-650 feet bgs, were selected for Phase II testing based on the presence and higher thickness of sand lenses within these intervals. The gamma spike observed at 667 feet bgs, about 20 feet beneath the deep interval, is avoided.
	3. A second, deeper monitoring well (MW-1D, screened 570-590, 598-608, 622-642 feet bgs) was installed for monitoring during multiple-well pumping tests and future use by the City and TWDB for monitoring regional water levels and water quality.
Site #2	1. Sand lenses observed deeper than 400 feet bgs at Site #2 are not significantly thick and composed of sands with inter-bedded clay layers.
	2. Abandon Phase I borehole and move on to Site #3.
	3. Do not perform Phase II exploratory testing.
Site #3	1. Site #3 did not exhibit multiple, thick (e.g., 70-100 feet) continuous layers of sand. Sand lenses observed deeper than 400 feet bgs are 20-40 feet thick and composed of very fine sand, the most appreciable of these occurring from 610- 770 feet bgs.
	2. Abandon Phase I borehole and move on to Site #6.
	3. After drilling Site #6, it was deemed that Site #3 has the second-best geology of all four sites and it would be prudent to perform Phase II testing to characterize the collective behavior of sand units. One depth interval, 610-765 feet bgs, was selected for Phase II testing based on the presence of appreciable sand lenses within this interval.
Site #6	1. Site #6 does not have favorable geologic conditions for ASR. Sand lenses observed deeper than 400 feet bgs were not significantly thick and composed of very fine sand with inter-bedded clay layers.
	2. Abandon Phase I borehole.
	3. Do not perform Phase II exploratory testing.
Site #4, Site #5	1. After drilling Sites #1, #2, #3, and #6, it was decided not to drill Site #4 or Site #5 due to unlikelihood of finding thicker sand lenses than the sand lenses observed at the other sites.

3.2 Monitoring Well Installation

The CCASR Feasibility Project scope accounted for contingency items, such as installation of permanent monitoring wells, in order to have infrastructure in place for monitoring future ASR activities. This plan was recommended based on the results of Phase I exploratory testing, leading to the installation of three permanent monitoring wells for various purposes. This section describes the rationale for installing the permanent monitoring wells and provides details of well construction.

3.2.1 Monitoring Well Installation Approach

The rationale for the installation of permanent monitoring wells is described below.

MW-1S: Monitoring well MW-1S was installed at Site #1 during Phase I. At the time that MW-1S was installed, the geology at Site #1 was still being evaluated for future testing and the remaining Phase I sites (#2, #3, and #6) had not yet been drilled. A decision was made to install a shallow monitoring well that the City or TWDB could use for future monitoring of water levels and water quality. MW-1S is screened in an interval thought to be representative of screened intervals of most current domestic and livestock wells in the area, so that impacts of ASR operations could be monitored in the future should results prove favorable for piloting or ASR construction.

Monitoring Well at Site 1 (MW-1D)

MW-1D: Monitoring well MW-1D was installed at Site #1 after Phase I boreholes had been drilled at Sites #1, #2, #3, and #6. Site #1 had the most favorable geology of all four sites, and Phase II testing was planned for Site #1. After discussion with the District and City, it was decided that a deep monitoring well would be appropriate at Site #1, as it would allow for an observation well during Phase II pumping tests as well as provide a future monitoring point for ASR activities.

MW-3: Monitoring well MW-3 was installed at Site #3 after Phase II testing was complete at Site #1 and Site #3. Although it was recommended for installation prior to Phase II testing, due to weather conditions and material delays, it was installed after testing. The monitoring well at Site #3 provides a future monitoring point for ASR activities.

Monitoring Well at Site 3 (MW-3)

Monitoring well locations for Site #1 and Site #3 are shown on Figure 2 and Figure 4, respectively.

3.2.2 Monitoring Well Construction

Felder drilled monitoring well borings using direct mud rotary methods. Prior to installing the monitoring well, Felder reconditioned the drilling mud in the borehole to remove fine-grained sediments. Monitoring well construction is described below.

MW-1S: MW-1S was installed on October 13, 2017 in a new 7.5-inch diameter borehole drilled approximately 25 feet from the Phase I borehole. The borehole was drilled to 166 feet bgs. Well screen consists of 2-inch diameter Type 304 stainless steel with 0.020-inch continuous wire-wrap slot openings from 154-164 feet bgs. Stainless steel centralizers were installed on the well screen. Well casing consists of 2-inch diameter Schedule 80 PVC from approximately 2.5 feet above grade to 154 feet bgs. A filter pack consisting of gradation #12-20 silica sand was installed around the well screen from 149-166 feet bgs. The borehole annular space above the filter pack was filled with 3/8-inch diameter bentonite chips from 6-149 feet bgs, and concrete grout from 0-6 feet bgs. Above-grade locking casing, concrete pad, and protective bollards were installed.

Installation of Monitoring Well at Site 1

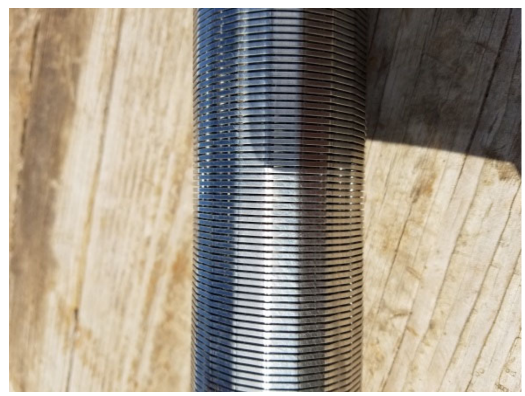
MW-1D: MW-1D was installed on November 14, 2017 in a new 6.75-inch diameter borehole drilled 25.6 feet from MW-1S. The borehole was drilled to 642 feet bgs. Well screen consists of 2-inch diameter Type 304 stainless steel with 0.020-inch continuous wire-wrap slot openings from 570-590, 598-608, and 622-642 feet bgs. Stainless steel centralizers were installed on the well screen. Well casing consists of 2-inch diameter Schedule 10 stainless steel from approximately 2.5 feet above grade to 570 feet bgs and between each well screen. A filter pack consisting of gradation #12-20 silica sand was installed around the well screen from 556-642 feet bgs. The borehole annular space above the filter pack was filled with 3/8-inch diameter bentonite chips from 549-556 feet bgs, and cement grout from 0-549 feet bgs. Above-grade locking casing, concrete pad, and protective bollards were installed.

MW-3: MW-3 was installed on March 6, 2018 in the same 12.25-inch diameter borehole used for Phase II testing. The borehole was drilled to 768 feet bgs. Well screen consists of 2-inch diameter Type 304 stainless steel with 0.020-inch continuous wire-wrap slot openings from 610-765 feet bgs. Stainless steel centralizers were installed on the well screen. Well casing consists of 2-inch diameter Schedule 10 stainless steel from just below ground surface to 610 feet bgs. A filter pack consisting of gradation #12-20 silica sand was installed around the well screen from 610-767 feet bgs. The borehole annular space above the filter pack was filled with 3/8-inch diameter bentonite chips from 600-610 feet bgs, and cement grout from 0-600 feet bgs. A monument flush with the ground surface, locking well plug, and concrete pad were installed. Monitoring well construction details are summarized in Table 3-4 below. State of Texas monitoring well reports submitted by Felder are contained in Appendix C.

Table 3-4. Monitoring Well Construction Details

Well	Installation Date	Well Diameter (inches)	Screen Interval (feet bgs)	Screen Type	Surface Completion Type
MW-1S	10/13/17	2	154-164	Stainless steel wire-wrap, 0.020-inch slot	Above-grade
MW-1D	11/14/17	2	570-590, 598-608, 622-642	Stainless steel wire-wrap, 0.020-inch slot	Above-grade
MW-3	3/6/18	2	610-765	Stainless steel wire-wrap, 0.020-inch slot	Flush

3.2.3 Monitoring Well Development



Well screen

After monitoring wells were installed, the drilling mud remaining in the well casing was removed and well development began as soon as possible, typically within 24 hours of installation. Monitoring wells were developed using airlift methods. The airline was lowered to approximately five feet above the bottom of the well and compressed air applied until the water discharge became relatively clear. The compressor was then turned off for five minutes, and then back on for five minutes, and this process repeated until each discharge cycle produced relatively clear water. Early cycles produced highly turbid water at the beginning of each discharge cycle. By the end of development, the discharged water at the beginning of each cycle had been reduced to cloudy, and was clear by the end of each cycle. Development efforts totaled 3 to 5 hours per monitoring well.

The following airlift discharge rates were maintained during monitoring well development:

- MW-1S: 32 GPM
- MW-1D: 43 GPM
- MW-3: 60 GPM

3.3 Exploratory Testing – Phase II

Phase II testing was performed at sites that exhibited one or more reasonably thick intervals of sand lenses that might be considered desirable for ASR. Two sites, Site #1 and Site #3, were further tested during Phase II. Site #1 was recommended for two Phase II test intervals: 410-450 feet bgs and 568-648 feet bgs. Site #3 was recommended for one Phase II test interval: 609-769 feet bgs. Phase II testing began on December 11, 2017, and consisted of soil coring, temporary well installation, pumping tests, and water quality testing. This section describes the Phase II exploratory testing completed at Site #1 and Site #3.

3.3.1 Drilling

Phase II drilling was performed by Felder using a Midway 3500 drill rig and direct mud rotary methods. HDR provided a geologist or engineer to conduct part-time observation of drilling activities. Phase II boreholes were located at least 25 feet and less than 60 feet from any previous boreholes or monitoring wells constructed during this program. A 9.875-inch diameter borehole was drilled for purposes of soil coring, and the borehole was reamed out to 12.25-inch diameter to accommodate the installation of a 6-inch diameter temporary well. Water for drilling was supplied from a City fire hydrant located in close proximity to the testing location, and if necessary, delivered by truck to the drilling site. Drilling mud consisted of a mixture of bentonite (Quik-Gel), dispersant (Quik-Trol Gold LV), soda ash to control pH, and potable water. Drilling mud was pumped through a mud cleaner tank where soil cuttings were removed from the drilling mud using vibrating screens, and then circulated back to the borehole.

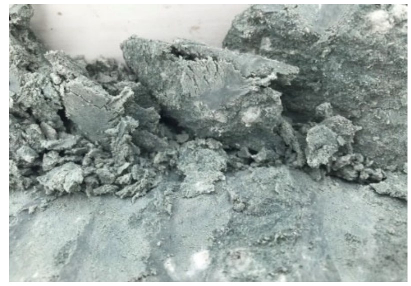
3.3.2 Soil Coring

Holders for inspecting and preserving cores during inspection and sampling

Once a new Phase II borehole was drilled to the top of the target test interval, continuous wireline soil coring was conducted in order to retrieve undisturbed soil samples for mineralogical and geochemical analysis. An HDR geologist observed the soil coring and logged the cores. The coring tool consists of a 6-inch diameter, 20-foot long outer barrel with 9.875-inch diameter rotary cutting bit that is connected to standard 4.5-inch diameter drill stem. An inner barrel is used to collect 1.5-inch diameter soil cores, and is retrieved by wireline through the drill stem. A latching mechanism keeps the inner barrel in place inside the outer barrel during coring, and is released with a special mechanism (by wireline) prior to removing the inner barrel. The coring tool can also be used for drilling by equipping the inner barrel with a cutting bit and locking the inner barrel into the outer barrel. Soil samples for laboratory analysis were collected by HDR using clean, stainless steel implements. Filled sample containers were placed into a cooler with ice. Soil samples were shipped to Test America for analysis of metals, and to Mineralogy, Inc. for x-ray fluorescence, cation exchange capacity, x-ray diffraction, and particle size distribution analysis. Soil sample analytical results will be included in a separate report. Soil coring conducted at Site #1 and Site #3 is described below.

Core sample collection device

Site #1, Intermediate Interval: Soil cores were collected from 405-456 feet bgs on December 14, 2017. Only stiff clay was recovered (approximately 19 feet total); no sand was recovered. The driller offered two explanations for the lack of sand recovery: the sand was being washed away by drilling mud before entering the inner barrel; or, once stiff clays entered the inner barrel, they would immediately swell and prevent sand from entering. One composite soil sample was collected for analysis.



Core portion- example of silt/clay

On December 21, 2017, Felder demobilized and modified the coring tool so that sand would be recoverable at the remaining sites.

Site #1, Deep Interval: Soil cores were collected from 568-650 feet bgs from January 4-5, 2018. Recovery of sand and clay was successful using the modified coring tool. Felder turned the coring tool into the undisturbed formation 'dry', rather than washing with drilling mud, in order to increase the chance of recovering sand. A drawback to this method was that only a 2-foot length of soil core could be collected at a time due to difficulty in removing the tight, relatively dry soil from the inner barrel. One composite soil sample was collected for analysis.

Site #3: Soil cores were collected from 616-770 feet bgs from January 27-30, 2018. Recovery of sand and clay was successful using the modified coring tool. Felder turned the coring tool into the undisturbed formation 'dry', rather than washing with drilling mud, in order to increase the chance of recovering sand. A drawback to this method was that only a 2-foot length of soil core could be collected at a time due to difficulty in removing the tight, relatively dry soil from the inner barrel. One composite soil sample and a sample duplicate was collected for analysis.

Core portion- example of fine sands

3.3.3 Temporary Test Well Installation and Development

After soil coring was completed on the desired test interval, the borehole was reamed out using a 12.25-inch diameter drill bit and direct mud rotary methods, and a temporary 6-inch diameter test well installed. Test wells were constructed from the following components common to each of the test wells:

- Well Screen: 6-inch diameter stainless steel wire-wrap (0.025-inch slot openings) over pipe-based carbon steel pipe with 3/8-inch diameter drilled openings, 40-foot sections;
- Well Casing: 6-inch diameter carbon steel with threaded collar joints;
- Filter Pack: #12-20 gradation silica sand; and

Temporary well casing

- Bentonite Seal: 3/8-inch bentonite chips.

All screen and casing joints consist of threaded collars designed to aid in future removal of the temporary well using a pipe clamp. A 1-inch diameter steel pipe was used to pump filter pack sand into the annulus around the well screen, and also served to displace drilling mud from the borehole using potable water prior to filter packing. This practice makes for a cleaner well and reduces well development time. Clean water was pumped into the annulus until the discharge was cloudy water with most of the drilling mud removed. After the filter pack was installed, a bentonite chip seal was placed on top of the filter pack. The remaining annulus was left open, with fresh drilling mud placed in the annulus and periodically circulated through the 1-inch diameter steel pipe in order to keep the borehole open. Specific temporary test well construction details are shown below.

Site #1, TW-450 (Intermediate Interval):

Test well TW-450 was installed on December 15, 2017. Well screen was installed from 410-450 feet bgs, and filter pack sand from 405-452 feet bgs. A bentonite chip seal was installed from 398-405 feet bgs. Well was developed at a rate of 125-150 gpm.

Site #1, TW-650 (Deep Interval):

Test well TW-650 was installed on January 6, 2018. Well screen was installed from 570-650 feet bgs, and filter pack sand from 565-650 feet bgs. A bentonite chip seal was installed from 560-565 feet bgs. Well was developed at a rate of approximately 300 gpm.

Site #3:

The test well at Site #3 was installed on February 14, 2018. Well screen was installed from 609-769 feet bgs, and filter pack sand from 604-770 feet bgs. A bentonite chip seal was installed from 599-604 feet bgs. Well was developed at a rate of approximately 320 gpm.

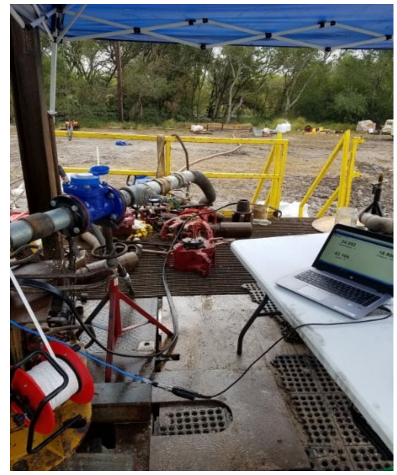
Test wells were developed using airlift methods until the discharge was relatively clear, although the presence of clay in the formation prevented the discharge from becoming clear. Approximately 3 hours of development efforts were performed on each test well. Following airlift development, a submersible test pump was installed and tested for operation, which further cleared up the discharge and served as the final step in well development.

3.3.4 Pumping Tests

An aquifer pumping test was performed on each test well in order to estimate hydraulic properties. Pumping tests were operated by Felder and monitored by HDR. Pumping tests consisted of a step-drawdown test, constant rate test, and recovery test. Water levels were monitored during the pumping tests using In-Situ© Level TROLL© 700 pressure transducers with vented cables. Manual water level measurements were taken with an electronic water level indicator. Two 1-inch diameter PVC pipes were installed to a depth of 10 feet above the pump in order to house the pressure transducer and collect manual water level measurements. Pumping test logistics are described below.

Site #1, TW-450 (Intermediate Interval):

The TW-450 pumping test was conducted from December 17-19, 2017. A Goulds 160L15 submersible pump with check valve was set at 250 feet bgs. The step-drawdown test was completed at successively increasing pumping rates of 62 gpm, 100 gpm, 156 gpm, and 200 gpm, with 40-minute step durations. Following recovery from the step-drawdown test, the constant rate was conducted at a rate of 196 gpm for 24 hours. Total drawdown in the test well during the constant rate test was 146.09 feet, for a specific capacity of 1.3 gpm/ft. MW-1D is 51.3 feet from the test well and showed 0.65 feet of drawdown during the constant rate test. MW-1S was monitored periodically and had no measureable drawdown.



Constant rate test set-up at Site 1

Site #1, TW-650 (Deep Interval):

The TW-650 pumping test was conducted from January 8-11, 2018. A Goulds 250L20 submersible pump with check valve was set at 231 feet bgs. The step-drawdown test was completed at successively increasing pumping rates of 101 gpm, 148 gpm, 200 gpm, and 278 gpm, with 30-minute step durations. Following recovery from the step-drawdown test, the constant rate was conducted at a rate of 255 gpm for 72 hours. Total drawdown in the test well during the constant rate test was 145.5 feet, for a specific capacity of 1.7 gpm/ft. MW-1D is 51.3 feet from the test well and showed 74.75 feet of drawdown during the constant rate test. MW-1S was monitored periodically and had no measureable drawdown.

Site #3:

The Site #3 pumping test was conducted from February 16-20, 2018. A Goulds 320L30 submersible pump with check valve was set at 252 feet bgs. The step-drawdown test was completed at successively increasing pumping rates of 192 gpm, 242 gpm, 285 gpm, and 318 gpm, with 30-45-minute step durations. Following recovery from the step-drawdown test, the constant rate was conducted at a rate of 305 gpm for 72 hours. Total drawdown in the test well during the constant rate test was 128.06 feet, for a specific capacity of 2.4 gpm/ft. Monitoring wells at Site #1 (approximately 2.2 miles from Site #3) had no measureable drawdown.

Plots of water level measurements recorded during the pumping tests are included in Appendix D. Upon completion of each pumping test, Felder removed the pump and 1-inch diameter PVC stilling pipes from the well, and then pulled the temporary 6-inch diameter well and 1-inch diameter steel pipe from the borehole. Test well casings and screens were cleaned and re-used.

3.3.5 Water Quality Sample Collection

Groundwater samples were collected during Phase II activities in order to analyze native aquifer water quality and aid in the assessment of ASR feasibility in the study area. HDR collected the samples. Sample collection is described below:

- Monitoring well MW-1S was sampled on December 12, 2017 after purging the well for 100 minutes at 12 gpm using a pump with intake set at 40 feet bgs. Aquifer interval sampled: 154-164 feet bgs.
- Site #1, test well TW-450 was sampled on December 19, 2017 at the end of the 24-hr constant rate pumping test. Sample was collected from a sample tap installed on the discharge line near the well head. Aquifer interval sampled: 410-450 feet bgs.
- Site #1, test well TW-650 was sampled on January 11, 2018 at the end of the 72-hr constant rate pumping test. Sample was collected from a sample tap installed on the discharge line near the well head. Aquifer interval sampled: 570-650 feet bgs.
- Site #3 test well was sampled on February 20, 2018 at the end of the 72-hr constant rate pumping test. Sample was collected from a sample tap installed on the discharge line near the well head. Aquifer interval sampled: 609-769 feet bgs.

HDR delivered the samples in person to the City of Corpus Christi O.N. Stevens Water Treatment Plant within two hours of collection. The City of Corpus Christi performed some analyses and shipped the remaining sample containers to ALS Environmental in Houston, Texas under contract for additional analyses. Samples were analyzed for the analytes listed in Table 3-5. Analytical results are described in Section 5.

Table 3-5. Groundwater Quality Analyses

Analyte or Analyte Group	Analysis Method
Ammonia	EPA 350.1
Asbestos	ENV 005
Biological Oxygen Demand	SM 5210B
Bromide	EPA 300.0
Calcium	SM 3500 Ca B
Chloride	EPA 300.0
Color	SM 2120B
Cyanide, free	EPA OIA 1667
Dioxin (2,3,7,8-TCDD)	1613B
Dissolved Organic Carbon	SM 5310C
E. Coli and Total Coliform	SM 9223B
Fecal Coliform	SM 9222D
Fluoride	SM 4500-F-C
Herbicides, chlorinated (2,4,5-TP and 2,4 D)	SW8151A
Iron, ferric and ferrous	SM 3500FED
Metals, total and dissolved	EPA 200.8, EPA 245.1
pH	SM 4500H+B

Table 3-5. Groundwater Quality Analyses

Analyte or Analyte Group	Analysis Method
Nitrate and Nitrite	EPA 353.2
Odor (Threshold Odor Number)	SM 2150B
Pesticides, chlorinated	EPA 608
Polychlorinated Biphenyls (PCBs)	EPA 608
Radium 226, Radium 228, Gross Alpha, Gross Beta	EPA 904.0, EPA 903.1, EPA 900.0,
Semivolatile Organic Compounds (SVOCs)	EPA 625
SVOCs, low-level	SW8270
Silicon	SW6010
Sulfate	EPA 300.0
Surfactants	SM 5540C
Total Alkalinity, Bicarbonate	SM 2320B
Total Dissolved Solids	SM 2540C
Total Phosphorus	EPA 365.1
Uranium	SW6020
Volatile Organic Compounds (VOCs)	EPA 624

Field water quality readings were collected during constant rate pumping tests in order to track changes in groundwater quality over time as pumping occurs. A Horiba U-52 water quality meter equipped with a flow cell was attached to a sample tap on the discharge line near the well head. The Horiba U-52 was programmed to collect and store readings every 30 minutes during the constant rate test. Field water quality results are described in Section 5.

3.4 Borehole Abandonment

Felder abandoned completed boreholes using cement grout emplaced through a tremie pipe. Phase I boreholes (6.75-inch diameter) at Sites #1, #2, #3, and #6 were abandoned after the downhole geophysics surveys were completed. The Phase II borehole (12.25-inch diameter) at Site #1 was abandoned after the pumping test was complete and the temporary test well was removed from the borehole. The Phase II borehole at Site #3 was not abandoned, and instead was used to complete monitoring well MW-3.

4 Site Geology and Hydrogeology

The primary goal of the CCASR Feasibility Project was to develop an understanding of the geology and hydrogeology in the study area. Mud rotary drill cuttings collected during Phase I exploration provided the first direct look at the geologic materials. Boring logs are presented in Appendix A. The materials described on the boring logs were validated by the downhole geophysics surveys (included in Appendix B), and further defined through soil coring during Phase II exploration. A summary report of the downhole geophysics surveys was produced by Robert E. Crowder (RECC), and is included in Appendix B. Site hydrogeology was assessed during Phase II exploration.

4.1 Geology

The geology at each of the four Phase I exploration sites consists of unconsolidated alluvium in alternating lenses of clay and fine sand. These alternating lenses continue to at least 1,197 feet bgs, which is the maximum depth drilled during the project. Occasional shell fragments were observed. A description of the clay and sand lenses is given below.

Clay: Clay lenses comprise approximately one-half to two-thirds of the total lithology, with individual clay lenses generally ranging from 0.5-20 feet in thickness and occasionally reaching 80 feet thick. Clay is blue, gray, grayish brown, or red in color. Consistency of the clay varies from soft to hard. Clay observed in undisturbed soil cores and on the bottom of drill bits exhibits medium to high plasticity.

Silt/ clay

Sand: Fine sand lenses generally range in thickness from 0.5-25 feet and occasionally reach 35-40 feet thick. Total sand thickness is 410-450 feet. The fine sand lenses have a grain size ranging from approximately 0.1-0.4 millimeter (mm) (0.004-0.015 inch). Sand is light gray to tan in color. Density of the sand varies from loose to very dense, at times drilling as a consolidated material.

The coarsest material occurs in a zone between approximately 110-240 feet bgs, and varies by site as follows: Site #1 from 139-197 feet bgs (0.30-0.35 mm fine sand); Site #2 from 112-182 feet bgs (0.25-0.35 mm fine sand to fine gravel); and Site #3 from 133-234 feet bgs (0.15-0.25 mm fine sand to fine gravel). Site #6 did not exhibit a significant thickness of coarse material at any depth.

Fine sands

Resistivity logging confirms the presence of sand lenses (higher resistivity) in relation to clay lenses (lower resistivity). Gamma logging also indicates alternating sands and clays, with higher gamma readings in the clay and lower gamma readings in the sand. Several high gamma readings were noted in geophysical logs over the four sites, predominantly in clay layers as expected. Clay zones are not considered desirable storage zone for ASR. High gamma can be due to the presence of potassium, phosphate minerals, or radioactive mineralization. Gamma spikes were observed at 667 and 874 feet bgs at Site #1, from 145-185 feet bgs at Site #2, and at 464 and 818 feet bgs at Site #6.

4.1.1 Geology of Phase II Test Intervals

Phase II test intervals were chosen based on depth, lithology, and gamma readings. Test intervals needed to be at least 400 feet bgs, which is considered the minimum depth for ASR in order to minimize potential interference with wells in the area. Sand-dominated lithology, such as zones with frequent sand lenses, is required. Test intervals were also selected to avoid zones with gamma spikes. The geology of intervals selected for Phase II testing are as follows:

- Site #1, Intermediate Interval: Fine sand comprises approximately 31 feet of the 40-foot test interval from 410-450 feet bgs (clay comprises the remaining 9 feet of the interval). Individual sand lenses within the test interval are 3-10 feet thick.
- Site #1, Deep Interval: Fine sand comprises approximately 40 feet of the 80-foot test interval from 570-650 feet bgs (clay comprises the remaining 40 feet of the interval). Individual sand lenses within the test interval are 0.5-11 feet thick. The zone associated with the gamma spike at 667 feet bgs is avoided.
- Site #3: Fine sand comprises approximately 92 feet of the 160-foot test interval from 607-767 feet bgs (clay comprises the remaining 63 feet of the interval). Individual sand lenses within the test interval are 11-34 feet thick.

Mineralogy analyses were performed on soil core samples from the Phase II test intervals, and are described in a separate report. Based on drill logs, it appears that a dominant, continuous sand interval may exist at approximate depth of 570 to 760 feet from Site 1 to Site 3 and a secondary zone at approximate depth of 410 to 520 feet. The dominant and secondary zone appears to show sands beginning slightly deeper at Site 3, as compared to Site 1, with frequent inter-bedded clay layers in the secondary zone at Site 3. For this reason, the secondary zone was tested at Site 1, but not at Site 3. Due to the lack of City-owned properties to the east of Site 1, it is inconclusive whether or not sands are continuous for these two intervals throughout the study area between Sites 1 and 3.

4.2 Hydrogeology

The conceptual hydrogeology in the study area includes shallow sand lenses and clay lenses under unconfined conditions, underlain by clay confining layers and confined sand lens aquifers. Depth of first groundwater was documented by the driller between 14 ft and 18 ft bgs during Phase I exploratory testing. Sand lenses targeted for construction of monitoring wells and test wells during the project are confined aquifers. The interconnected nature of the sand lenses was evidenced during the Site #1 Intermediate Interval pumping test, when MW-1D (screened 120 feet deeper than the pumping well) had 0.65 feet of measureable drawdown. Static water levels were 12.98 feet bgs in MW-1S and 12.07 feet bgs in MW-1D on December 14, 2017. A land elevation survey should be performed and water levels monitored at monitoring wells to confirm static hydraulic gradient with certainty. The static water level in the temporary test well at Site #3 was approximately 20 feet bgs on February 16, 2018.

Aquifer properties were estimated at Site #1 and Site #3 through pumping tests performed on test wells. A total of three pumping tests were performed: Site #1 Intermediate Interval, Site #1 Deep Interval, and Site #3. Constant rate pumping tests were analyzed by Intera using the AQTESOLV® computer program and the Papadopulos-Cooper (1967) method for confined aquifer analysis. Plots of the analyses are included in Appendix E. Pumping test curves are indicative of a confined aquifer. Estimates of aquifer transmissivity are 475-676 ft^2/day with an average of 605 ft^2/day for the three pumping tests. Hydraulic conductivity is 12-22 ft/day based on the estimated transmissivity and assuming the saturated thickness of the sand lenses within the test interval. These hydraulic conductivity values are typical of fine sand or silty sand. It should be noted that for Site #1-Intermediate and Site #3, the time-drawdown analysis was performed on data collected in the pumped well (no nearby monitoring well), which could result in a lower transmissivity in actuality since it could include excess drawdown from pumped well inefficiency. Additional Theis recovery analysis using the time-recovery data from pump tests[4], which does not have well inefficiency, was performed to evaluate the presence of boundary conditions, recharge effects, or variations in storage which may affect anticipated aquifer performance. The transmissivity estimates using this alternate method were comparable to the estimates from the Papadopulos-Cooper method. Based on analysis of recovery data, it appears that the pump test results indicate little to no recharge or barrier boundaries for the sites and aquifers tested and therefore the transmissivity values are considered appropriate. Storativity is estimated at 0.00013 (unitless), which indicates a confined aquifer. Storativity was only calculated for Site #1 Deep Interval using MW-1D as a monitoring well; storativity results for the other pumping tests are not available since they only involved a pumped well. Estimates of aquifer transmissivity, hydraulic conductivity, and storativity are presented in Table 4-1. It is anticipated that wells in this area would be capable of producing at rates of 300-400 gpm with multi-interval operation, consistent with 2016 study estimates.

Table 4-1. Aquifer Hydraulic Properties

Parameter	Units	Site #1 Intermediate Interval (410-450 feet bgs)	Site #1 Deep Interval (570-650 feet bgs)	Site #3 (607-767 feet bgs)
Transmissivity	ft^2/day	676	475	665
Hydraulic Conductivity	ft/day	22[1]	12[2]	12[3]
Storativity	unitless	N/A[4]	0.00013	N/A[4]

Notes:

1. Based on saturated thickness of sand lenses within test interval (31 feet).
2. Based on saturated thickness of sand lenses within test interval (40 feet).
3. Based on saturated thickness of sand lenses within test interval (~92 feet).
4. Storativity not available (no monitoring well available during testing).

5 Groundwater Quality

Groundwater quality was assessed during downhole geophysics surveys, well development, and pumping tests. Indicators of groundwater quality include field observations and laboratory analysis of groundwater samples. The following sections describe the field observations and laboratory results.

5.1 Field Observations of Water Quality

Downhole geophysics provided an initial assessment of groundwater quality. Each borehole exhibited resistivity of approximately 5 ohm-m or less, which is considered low (high conductivity) and is an indicator of brackish water. Formation water was more conductive than the drilling mud in the

[4] Recovery was measured by the In-Situ© Level TROLL© 700 pressure transducers data logger after pump tests ended.

borehole, generally indicating poor groundwater quality. Decreasing resistivity with depth indicates worsening groundwater quality with depth, but this may be partially attributable to finer-grained materials present at greater depths. In the case of Site 1, better water quality (lower salinity) was reported in the deeper interval than intermediate interval. Temperature increases of 2-4 degrees Celsius with depth were observed. Gamma spikes were observed at certain locations and depths. While not a direct indicator of groundwater quality, high gamma readings could be an indicator of potential radioactive mineralization as discussed previously. Zones exhibiting high gamma readings were intentionally avoided during Phase II and therefore no groundwater samples were analyzed from high-gamma zones. Groundwater samples representative of Phase II tested intervals described further in Section 4.1.1 showed non-detection levels of gross alpha, gross beta, and uranium. Radium levels were below maximum contaminant levels (MCL).

Groundwater quality field parameters were measured during pumping tests using a Horiba U-52 meter and flow cell. Parameters measured include the following: temperature, pH, conductivity, dissolved oxygen, oxidation-reduction potential (ORP), and turbidity. The following additional parameters were calculated by the instrument: total dissolved solids, salinity, and specific gravity. Field groundwater quality parameters are summarized in Table 5-1. Small, clear gas bubbles were noted in the flow cell during pumping tests.

Table 5-1. Field Groundwater Quality Parameters

Parameter	Units	Site #1 Intermediate Interval (410-450 feet bgs)	Site #1 Deep Interval (570-650 feet bgs)	Site #3 (607-767 feet bgs)	
Temperature	degrees C	23.13	26.21	27.9	min
		24.03	28.26	28.2	max
		23.73	26.95	28.1	avg
pH	standard units	7.86	8.51	7.7	min
		7.88	8.85	7.8	max
		7.87	8.75	7.7	avg
Conductivity	mS/cm	18.6	13.8	23.8	min
		18.8	14.5	24.4	max
		18.71	14.12	24.3	avg
Dissolved Oxygen	mg/L	0.00	0.20	0.00	min
		0.00	1.61	0.22	max
		0.00	0.36	0.13	avg
ORP	mV	-336	-194	-180.0	min
		-333	-160	-173.0	max
		-334.04	-182.78	-176.3	avg
Turbidity	NTU	3.80	0.10	8.1	min
		10.10	7.00	48.0	max

Table 5-1. Field Groundwater Quality Parameters

Parameter	Units	Site #1 Intermediate Interval (410-450 feet bgs)	Site #1 Deep Interval (570-650 feet bgs)	Site #3 (607-767 feet bgs)	
		5.58	3.47	23.5	avg
Total Dissolved Solids	mg/L	11,500	8,540	14,700	min
		11,600	8,990	15,100	max
		11,590	8,750	15,000	avg
Salinity	ppm	11,000	8,000	14,400	min
		11,100	8,300	14,800	max
		11,080	8,150	14,700	avg
Specific Gravity	sigma t	5.70	2.40	7.1	min
		6.00	2.90	7.4	max
		5.86	2.74	7.4	avg

Field readings indicate highly conductive groundwater with total dissolved solids of 8,540-15,100 mg/L, which corresponds to brackish to saline water. There were no discernable water quality trends observed during pumping and water quality stabilized readily during step testing. Specific gravity calculations indicate a groundwater density of 1.0024-1.0074, typical of brackish to saline water. The groundwater is slightly alkaline with pH between 7.5 and 9. Low dissolved oxygen indicates anaerobic, or reducing, conditions amenable for generation of sulfide. Hydrogen sulfide odors were noted during the development of MW-1S, and during the pumping tests for the Site #1 Intermediate Interval, Site #1 Deep Interval, and at Site #3. A petroleum odor was also noted in addition to hydrogen sulfide when developing the test well for the Site #1 Intermediate Interval. Small bubbles were observed in production water at Site #1 Deep Interval and Site #3.

5.2 Laboratory Groundwater Quality Parameters

Laboratory analytical results for groundwater samples collected and submitted during exploratory drilling activities are summarized in Table 5-2. MW-1S was tested and reported in the table, however, it represents an interval that is not considered a candidate for ASR nor does it appear to be hydraulically connected to the ASR intervals of interest discussed previously in Sections 4.1 and 4.2.

Analytical results indicate concentrations of chloride, total dissolved solids, sulfate, iron, and manganese above the Maximum Contaminant Level (MCL) or Secondary MCL. Sodium is present in relatively high (parts-per-thousand) concentrations. The high sodium, chloride, and total dissolved solids concentrations are typical of brackish to saline water. Sulfates are likely reducing to sulfide in the low-dissolved oxygen conditions. Synthetic chemicals including VOCs, SVOCs, pesticides, herbicides, PCBs, and surfactants were generally not detected, with only a few analytes detected at concentrations below the MCL. The potential source of the petroleum odor in the Site #1

Intermediate Interval (410-450 feet bgs) was not indicated in laboratory data. These groundwater quality results will be analyzed in greater detail, in addition to source water data in a future memorandum on geochemical/source water compatibility.

Table 5-2. Laboratory Groundwater Quality Results

Analyte	Analyte Group	Method	Maximum Contaminant Level (mg/L or pCi/L for radionuclides)	Maximum Contaminant Level (µg/L)	Secondary Maximum Contaminant Level (mg/L)	Secondary Maximum Contaminant Level (µg/L)	Unit	MW-1S* (12/12/17)	Site #1 TW-450 (12/19/17)	Site #1 TW-650 (1/11/18)	Site 3 (2/20/18)
E. Coli	Bacteria	SM 9223B	positive detection					absent	absent	absent	absent
Fecal Coliforms	Bacteria	SM 9222D	positive detection				cfu	<1	<1	1	<1
Total Coliforms	Bacteria	SM 9223B	positive detection					absent	present	present	present
2,3,7,8-TCDD (Dioxin)	Dioxin	1613B	0.00000003	0.00003			pg/L	ND	ND	ND	ND
Alkalinity	General	SM 2540C					mg/L	172	122	108	91
Alkalinity, Total (As CaCO3)	General	SM 2320B					mg/L	188	129	124	102
Ammonia	General	EPA 350.1					mg/L	<0.2	<0.2	0.3	0.3
Asbestos (million fibers/liters, fibers longer than 10 µm)	General	ENV 005	7				MFL	<AS	<AS	<AS	NA
Bicarbonate (alkalinity, CaCO3)	General	SM 2320B					mg/L	188	129	124	102
Biochemical Oxygen Demand	General	SM 5210B					mg/L	<3	<3	<3	<3
Bromide	General	EPA 300.0					mg/l	57	<20	14.7	21
Chloride	General	EPA 300.0			300		mg/L	13,143	4270	3262	5738
Color (color units)	General	SM 2120B			15		PtCo	2	2	8	21
Cyanide (as free Cyanide)	General	EPA OIA 1677	0.2	200			µg/L	ND	ND	ND	ND
Dissolved organic carbon	General	SM 5310C					mg/L	<0.3	0.96	<0.3	<0.3
Fluoride	General	SM 4500-F-C	4	4000	2	2000	mg/L	0.5	1.11	74.1	171
Nitrate	General	EPA 353.2	10	10000			mg/L	<0.02	<0.02	9.9	5.4
Nitrite	General	EPA 353.2	1	1000			mg/L	<0.02	<0.02	<0.02	<10
Odor (TON)	General	SM 2150B			3			100	200	1.1	1
pH	General	SM 4500H+B			6.5-8.5			7.07	7.61	7.88	
Phosphorous total	General	EPA 365.1					mg/L	<0.2	<0.2	<0.03	<0.2
Silica (reported as silicon)	General	SW6010					mg/L	15	7.4	6.6	8.2
Sulfate	General	EPA 300.0			300		mg/L	2338	2306	1693.3	2979
Total Dissolved Solids	General	SM 2540C			1000		mg/L	22544	9545	8253	14085
2,4,5-TP	Herbicides	SW8151A	0.05	50			µg/L	<0.0500	<0.0505	<0.0500	<0.0505
2,4-D	Herbicides	SW8151A	0.07	70			µg/L	<0.0600	<0.0606	<0.0600	<0.0606
Dalapon	Herbicides	SW8151A	0.2	200			µg/L	0.744	<0.0707	0.54	0.213
Dinoseb	Herbicides	SW8151A	0.007	7			µg/L	<0.0500	<0.0505	<0.0500	<0.0505
Aluminum dissolved	Metals	EPA 200.8			0.2	200	µg/L	<20.0	<20.0	<20.0	<20.0
Aluminum total	Metals	EPA 200.8			0.2	200	µg/L	9.59	45.1	106	252
Antimony dissolved	Metals	EPA 200.8	0.006	6			µg/L	1.7	<4.00	<0.800	<4.00
Antimony total	Metals	EPA 200.8	0.006	6			µg/L	1.79	<0.265	0.066	<0.600
Arsenic dissolved	Metals	EPA 200.8	0.01	10			µg/L	3.98	<5.00	<1.00	<5.00
Arsenic total	Metals	EPA 200.8	0.01	10			µg/L	3.82	<1.25	0.619	<1.00
Barium dissolved	Metals	EPA 200.8	2	2000			µg/L	40.2	15.7	15.6	15.6
Barium total	Metals	EPA 200.8	2	2000			µg/L	39.6	15.1	16.2	18.3
Beryllium dissolved	Metals	EPA 200.8	0.004	4			µg/L	<3.50	<3.50	<3.50	<3.50
Beryllium total	Metals	EPA 200.8	0.004	4			µg/L	<0.455	<0.455	<0.0910	<0.500
Cadmium dissolved	Metals	EPA 200.8	0.005	5			µg/L	<0.800	<4.00	<0.800	<4.00
Cadmium total	Metals	EPA 200.8	0.005	5			µg/L	<0.385	<0.385	0.153	<0.600
Calcium	Metals	SM 3500 Ca B					mg/L	1723	240	197	317**

Chromium dissolved	Metals	EPA 200.8	0.1	100			µg/L	<1.00	<5.00	<1.00	<5.00
Chromium total	Metals	EPA 200.8	0.1	100			µg/L	<1.26	<1.26	<0.251	<1.00
Cobalt dissolved	Metals	EPA 200.8					µg/L	<0.800	<4.00	<0.800	<4.00
Cobalt total	Metals	EPA 200.8					µg/L	<0.200	<0.200	0.047	<0.800
Copper dissolved	Metals	EPA 200.8	1.3	1300	1	1000	µg/L	<1.00	<5.00	<1.00	16.1
Copper total	Metals	EPA 200.8	1.3	1300	1	1000	µg/L	<0.850	<0.850	1.64	35.5
Ferric Iron	Metals	SM 3500 Fe D					mg/L	<0.200	<0.200	<0.200	<0.200
Ferrous Iron	Metals	SM 3500 Fe D					mg/L	0.359	0.062	0.71	0.939
Iron dissolved	Metals	EPA 200.8			0.3	300	µg/L	184	<390	<78.0	<390
Iron total	Metals	EPA 200.8			0.3	300	µg/L	367	<250	370	673
Lead dissolved	Metals	EPA 200.8	0.015	15			µg/L	<0.700	<3.50	<0.700	<3.50
Lead total	Metals	EPA 200.8	0.015	15			µg/L	<0.600	<0.600	0.144	<2.50
Magnesium total	Metals	EPA 200.8					µg/L	475000	52800	35600	78100
Manganese dissolved	Metals	EPA 200.8			0.05	50	µg/L	616	50.4	48.5	106
Manganese total	Metals	EPA 200.8			0.05	50	µg/L	611	48.5	56	113
Mercury	Metals	EPA 245.1	0.002	2			µg/L	0.09	<0.0300	0.039	<0.0300
Mercury dissolved	Metals	EPA 245.1	0.002	2			µg/L	<0.0300	<0.0300	<0.0300	<0.0300
Molybdenum dissolved	Metals	EPA 200.8					µg/L	<7.50	<7.50	98.8	192
Molybdenum total	Metals	EPA 200.8					µg/L	<2.45	<2.45	102	207
Nickel dissolved	Metals	EPA 200.8					µg/L	29.2	<5.00	<1.00	<5.00
Nickel total	Metals	EPA 200.8					µg/L	<0.550	<0.550	<0.110	5.78
Potassium total	Metals	EPA 200.8					µg/L	26200	6600	5540	8240
Selenium dissolved	Metals	EPA 200.8	0.05	50			µg/L	28.8	14.7	8.66	13.4
Selenium total	Metals	EPA 200.8	0.05	50			µg/L	30.7	<4.30	6.34	15.4
Silver dissolved	Metals	EPA 200.8			0.1	100	µg/L	<0.800	<4.00	<0.800	<4.00
Silver total	Metals	EPA 200.8			0.1	100	µg/L	<0.220	0.59	0.06	<0.500
Sodium total	Metals	EPA 200.8					µg/L	5850000	3150000	2780000	4280000
Strontium dissolved	Metals	EPA 200.8					µg/L	44800	11800	9610	13500
Strontium total	Metals	EPA 200.8					µg/L	39800	11800	7850	13900
Thallium dissolved	Metals	EPA 200.8	0.002	2	0.005	5	µg/L	<1.00	<5.00	<1.00	<5.00
Thallium total	Metals	EPA 200.8	0.002	2	0.005	5	µg/L	<1.25	1.88	0.462	<0.800
Zinc dissolved	Metals	EPA 200.8			5	5000	µg/L	146	<12.5	65.9	150
Zinc total	Metals	EPA 200.8			5	5000	µg/L	144	138	81.4	187
Aroclor 1016, 1221, 1232,1242,1248,1254,1260 (PCBs)	PCBs	EPA 608	0.0005	0.5			µg/L	<0.0125 each	<0.0126 each	<0.0125 each	<0.0125 each
Chlordane	Pesticides	EPA 608	0.002	2			µg/L	<0.0250	<0.0253	<0.0250	<0.0250
Endrin	Pesticides	EPA 608	0.002	2			µg/L	<0.0000830	<0.0000838	<0.0000830	<0.0000830
Heptachlor	Pesticides	EPA 608	0.0004	0.4			µg/L	<0.0000450	<0.0000455	<0.0000450	<0.0000450
Heptachlor epoxide	Pesticides	EPA 608	0.0002	0.2			µg/L	<0.0000270	<0.0000273	<0.0000270	<0.0000270
Methoxychlor	Pesticides	EPA 608	0.04	40			µg/L	<0.000573	<0.000579	<0.000573	<0.000573
Toxaphene	Pesticides	EPA 608	0.003	3			µg/L	<0.0250	<0.0253	<0.0250	<0.0250
Gross Alpha (pCi/L)	Radionuclides	GFPC	15				pCi/L	ND (+/- 30)	ND (+/- 16)	ND (+/- 18)	ND (+/- 27)
Gross Beta (pCi/L)	Radionuclides	GFPC	50				pCi/L	61 (+/- 28)	ND (+/- 12)	ND (+/- 26)	ND (+/- 15)
Radium-226 (pCi/L)	Radionuclides	EPA 903.1	5				pCi/L	3.4 (+/- 1)	0.75 (+/- 0.25)	0.57 (+/- 0.34)	1.7 (+/- 0.6)
Radium-228 (pCi/L)	Radionuclides	GFPC	5				pCi/L	4.9 (+/- 1.4)	1.5 (+/- 0.49)	2.12 (+/- 0.63)	3.6 (+/- 1.1)
Uranium	Radionuclides	SW6020	0.03	30			µg/L	0.32	ND	ND	ND
Surfactants MBAS (foaming agents)	Surfactants	SM 5540C			0.5	500	mg/L	<0.0250	<0.0250	<0.0250	<0.0250
Alachlor	SVOC	SW8270	0.0002	0.2			µg/L	<0.20	<0.20	<0.20	<0.20
Atrazine	SVOC	EPA 625	0.003	3			µg/L	<0.612	<0.612	<0.600	<0.600

Benzo(a)pyrene	SVOC	EPA 625	0.0002	0.2			µg/L	<0.408	<0.408	<0.400	<0.400
Bis (2-ethylhexyl) phthalate	SVOC	EPA 625	0.006	6			µg/L	<0.816	<0.816	<0.800	<0.800
Di(2-ethylhexyl)adipate	SVOC	SW8270	0.4	400			µg/L	ND		ND	ND
Hexachlorobenzene	SVOC	EPA 625	0.001	1			µg/L	<0.306	<0.306	<0.300	<0.300
Hexachlorocyclopentadiene	SVOC	EPA 625	0.05	50			µg/L	<0.408	<0.408	<0.400	<0.400
Pentachlorophenol	SVOC	EPA 625	0.001	1			µg/L	<0.816	<0.816	<0.800	<0.800
Simazine	SVOC	SW8270	0.004	4			µg/L	<0.20	<0.20	<0.20	<0.20
1,1,1-Trichloroethane	VOCs	EPA 624	0.2	200			µg/L	<0.500	<0.500	<0.500	<0.500
1,1,2-Trichloroethane	VOCs	EPA 624	0.005	5			µg/L	<0.500	<0.500	<0.500	<0.500
1,1-Dichloroethylene	VOCs	EPA 624	0.007	7			µg/L	<0.500	<0.500	<0.500	<0.500
1,2- Dibromo-3-chloropropane	VOCs	EPA 624	0.0002	0.2			µg/L	<0.500	<0.500	<0.500	<0.500
1,2,4-Trichlorobenzene	VOCs	EPA 624	0.07	70			µg/L	<0.600	1.94	<0.600	<0.600
1,2-Dibromoethane	VOCs	EPA 624					µg/L	<0.400	<0.400	<0.400	<0.400
1,2-Dichloroethane	VOCs	EPA 624	0.005	5			µg/L	<0.500	<0.500	<0.500	<0.500
1,2-Dichloropropane	VOCs	EPA 624	0.005	5			µg/L	<0.700	<0.700	<0.700	<0.700
1,3-Dichlorobenzene	VOCs	EPA 624	0.6	600			µg/L	<0.500	<0.500	<0.500	<0.500
1,4-Dichlorobenzene	VOCs	EPA 624	0.075	75			µg/L	<0.600	<0.600	<0.600	<0.600
Benzene	VOCs	EPA 624	0.005	5			µg/L	<0.600	<0.600	<0.600	<0.600
Carbon tetrachloride	VOCs	EPA 624	0.005	5			µg/L	<0.600	<0.600	<0.600	<0.600
Chlorobenzene	VOCs	EPA 624	0.1	100			µg/L	<0.400	<0.400	<0.400	<0.400
cis- 1,2-dichloroethene	VOCs	EPA 624	0.07	70			µg/L	<0.600	<0.600	<0.600	<0.600
Ethylbenzene	VOCs	EPA 624	0.7	700			µg/L	<0.500	<0.500	<0.500	<0.500
Methylene Chloride	VOCs	EPA 624	0.005	5			µg/L	<1.00	<1.00	<1.00	<1.00
Styrene	VOCs	EPA 624	0.1	100			µg/L	<0.500	<0.500	<0.500	<0.500
Tetrachloroethene	VOCs	EPA 624	0.005	5			µg/L	<0.600	<0.600	<0.600	<0.600
Toluene	VOCs	EPA 624	1	1000			µg/L	<0.500	<0.500	<0.500	<0.500
trans-1,2-Dichloroethene	VOCs	EPA 624	0.1	100			µg/L	<0.400	<0.400	<0.400	<0.400
Trichloroethene	VOCs	EPA 624	0.005	5			µg/L	<0.500	<0.500	<0.500	<0.500
Vinyl chloride	VOCs	EPA 624	0.002	2			µg/L	<0.400	<0.400	<0.400	<0.400
Xylenes (total)	VOCs	EPA 624	10	10000			µg/L	<0.500	<0.500	<0.500	<0.500

Notes: Orange shading denotes exceedance of Federal Maximum Contaminant Level or Secondary Maximum Contaminant Level.

*MW-1S is included in table for data completion, however, it is NOT considered a candidate for ASR nor does it appear to be hydraulically connected. **Calcium was also evaluated with Method EPA 200.8 and detected at 266 mg/L.

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6 Summary and Conclusions

Phase I and Phase II exploratory testing was performed from October 2017 to May 2018. Four locations (Sites #1, #2, #3, and #6) were drilled and downhole geophysics surveys conducted to a nominal depth of 1,200 feet bgs during Phase I. A review of Phase I boring logs and geophysics results indicated the geology consists of alternating lenses of clay and fine sand and likely brackish to saline groundwater. Only two depth intervals (410-450 feet bgs and 570-650 feet bgs) at Site #1 and one depth interval (609-769 feet bgs) at Site #3 contained a reasonable total thickness of fine sand that would be recommended for Phase II testing. Site #2 and Site #6 were not selected for Phase II testing.

Permanent monitoring wells MW-1S and MW-1D were installed at Site #1 and MW-3 at Site #3. Phase II activities at Sites #1 and #3 consisted of soil core collection, construction of temporary test wells, performance of pumping tests, and collection of water quality samples. Soil samples were collected for mineralogical and geochemical analysis, the results of which will be included in a future geochemical analysis report. Pumping tests were performed on temporary test wells at pumping rates ranging from around 200-300 gpm. The pumping tests showed the aquifers to be confined. Aquifer transmissivity is estimated to be 475-676 ft^2/day and the calculated hydraulic conductivity is 12-22 ft/day, which corresponds to a fine sand or silty sand. Aquifer storativity is estimated at 0.00013. For Site #1-Intermediate and Site #3, the time-drawdown analysis was performed on data collected in the pumped well (no nearby monitoring well) using a Papadopulos-Cooper method in AQTESOLV. Additional recovery analysis was performed to verify the model-calculated transmissivity estimates and reported comparable values with those calculated using the Papadopulos-Cooper method. It is anticipated that wells in this area would be capable of producing at 300-400 gpm with multi-interval operation, consistent with 2016 study estimates.

Field water quality parameters measured during the pumping tests indicate brackish to saline groundwater and anaerobic conditions. Hydrogen sulfide odor was observed at Sites #1 and #3. Groundwater samples were collected from MW-1S (not considered a candidate for ASR) and from the three test wells during pumping tests for laboratory analysis. Laboratory results show levels that exceed MCL or secondary MCLs for iron, manganese, chlorides, sulfates, total coliforms, and total dissolved soils. These groundwater quality results will be analyzed in greater detail, in addition to source water data in a future memorandum on geochemical/source water compatibility.

HDR will use these results of Phase I and Phase II exploratory testing in geochemical compatibility analyses, development of a field-scale groundwater model, and generation of ASR operating conditions and policy recommendations. These will be described in interim technical memorandums and a final project report.

7 References

Papadopulos, I.S. and H.H. Cooper, 1967. Drawdown in a well of large diameter, Water Resources Research, vol. 3, no. 1, pp. 241-244.

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A

Boring Logs

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A-1

Exploratory Testing
Phase I

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Felder Water Well & Pump Service, LLC

Daily Driller Report

Customer:	City of Corpus Christi
Project:	Corpus Christi Aquifer Storage and Recovery Feasibility Study
Project #:	E16265
Date:	10/12/2017
Reference Statement:	Pilot Hole 1

Driller Name:	Eric Branch
Bit Size:	6.75 bit 2-7/8" drill pipe
Average ROP/Hour:	75'/hr day 1 40'/hr day 2
Depth Interval:	surf-743' day1 743'-1103' day 2 1103-1203 and log day 3

From	To	Formation Encountered
surf	14	clay/black gumbo
14	31	sand .006
31	80	clay soft blue sand streaks
80	88	sand and large shell
88	90	clay
90	97	sand .010
97	139	clay soft blue
139	184	sand .012-.014
184	187	clay
187	197	sand .012
197	291	clay w/sand streaks and small gravel
291	299	sand .006
299	315	clay hard blue
315	320	sand .006
320	340	clay hard blue
340	353	sand .006
353	390	clay hard blue
390	400	sand .006
400	432	clay hard blue
432	454	sand .006-.008-.010
454	455	clay
455	467	sand .006-.008-.012
467	472	clay soft w/sand streaks
472	576	clay hard blue turning softer
576	592	sand .006
592	602	clay hard blue
602	622	sand .006
622	629	clay hard

629	651	sand .006-.008
From	To	Formation Encountered
651	667	clay hard blue
667	670	sand
670	675	clay hard sand streaks
675	685	sand .006
685	687	clay
687	708	sand .006-.008 clay streaks
708	808	clay hard blue to red
808	814	soft clay sand streaks
814	826	sand .006
826	829	clay soft
829	860	sand .006
860	883	clay hard blue
883	890	sand .006
890	910	clay hard blue
910	921	sand .006
921	922	clay
922	930	sand .005
930	962	clay hard blue
962	964	sand
964	990	clay hard blue
990	1013	sand .005 .006
1013	1032	clay with sand streaks
1032	1062	sand .005
1062	1086	clay hard blue
1086	1088	sand
1088	1124	clay hard
1124	1135	sand .006 w/clay streaks
1135	1142	clay w/ sand streaks
1142	1147	sand .005
1147	1151	clay hard
1151	1169	sand .005 w/soft clay streaks
1169	1172	clay hard
1172	1174	sand
1174	1182	clay hard blue
1182	1190	sand .005
1190	1204	clay hard blue

Felder Water Well & Pump Service, LLC

Daily Driller Report

Customer:	City of Corpus Christi
Project:	Corpus Christi Aquifer Storage and Recovery Feasibility Study
Project #:	E16265
Date:	10/17/2017
Reference Statement:	Test Hole 2 Airport

Driller Name:	Eric Branch
Bit Size:	6.75 2-7/8" drill pipe
Average ROP/Hour:	85' per hr
Depth Interval:	10/17 surf-803

From	To	Formation Encountered
0	72	clay black brown white
72	83	sand .006
83	91	clay sand mix soft
91	112	clay soft blue
112	148	sand .010-.012
148	150	clay
150	182	sand .012-.014 small gravel
182	193	clay hard blue
193	205	sand .005-.006
205	276	clay soft blue
276	302	sand .005-.006
302	320	clay blue sand streaks
320	331	sand .005-.006
331	338	clay soft blue
338	340	sand
340	368	clay blue with sand streaks
368	375	sand .005-.006
375	408	clay hard blue
408	425	sand .006
425	447	clay
447	452	sand fine
452	536	clay sand streaks
536	542	fine
542	557	clay hard blue
557	560	sand
560	561	clay hard blue
561	568	sand
568	597	clay sand streaks

From	To	Formation Encountered
597	609	sand .005
609	616	clay hard blue sand streaks
616	642	sand .006
642	652	clay hard
652	663	sand .005
663	668	clay soft blue
668	680	sand .005
680	687	clay hard blue
687	688	sand
688	689	clay hard
689	708	sand .005-.006
708	764	clay hard red/brown
764	770	sand .005
770	799	clay hard brown
799	805	sand fine-.005
805	815	clay hard blue
815	838	sand .005-.006
838	839	clay soft blue
839	843	sand .006
843	894	clay hard with fine sand streaks
894	909	sand fine with clay streaks
909	911	sand
911	925	clay hadr blue
925	933	sand fine-.005
933	940	clay hard blue
940	948	sand fine-.005
948	966	clay with sand streaks
966	972	sand fine
972	986	sand fine .005
986	997	clay hard
997	1001	sand fine-.005
1001	1020	sand fine-.005
1020	1022	sand stone hard
1022	1026	sand fine-.005
1026	1028	clay hard
1028	1034	sand fine
1034	1054	silty clay and fine sand
1054	1056	sandstone hard
1056	1102	clay hard sticky blue

From	To	Formation Encountered
1102	1110	sand fine

1110	1116	clay hard
1116	1128	clay and silty sand
1128	1144	sand fine-.005
1144	1145	sandstone hard
1145	1164	clay hrd blue sticky
1164	1186	fine silty sand
1186	1197	clayhard blue sticky
1197	1201	sand
1201	1203	clay hard sticky blue

Felder Water Well & Pump Service, LLC

Daily Driller Report

Customer:	City of Corpus Christi
Project:	Corpus Christi Aquifer Storage and Recovery Feasibility Study
Project #:	E16265
Date:	10/24/2017-10/25/2017
Reference Statement:	Test Hole 3 Westhaven Park

Driller Name:	Eric Branch
Bit Size:	6.75 2-7/8" drill pipe
Average ROP/Hour:	75' per hr on 10/24 55' per hr on 10/25
Depth Interval:	10/24/17 surface-883' 10/25/17 883'-1203'

From	To	Formation Encountered
0	117	clay black/grey
117	119	sand
119	133	clay blue
133	178	sand .006-.008-.010 small gravel
178	180	clay
180	234	large sand and small gravel
234	238	clay
238	241	sand .006
241	242	clay
242	249	sand .006
249	250	clay
250	265	sand .006-.005-fine
265	280	clay blue
280	281	sand stone
281	310	clay blue soft to hard
310	313	sand fine
313	348	clay hard blue
348	372	sand .006-.008-.006
372	374	clay
374	375	sand stone
375	376	sand
376	379	clay hard blue
379	380	sand stone
380	397	sand hard
397	417	clay hard blue
417	420	sand hard
420	456	clay hard to soft
456	462	sand fine

From	To	Formation Encountered
462	478	clay hard
478	483	sand fine
483	485	clay soft
485	511	sand .005-.006
511	528	clay hard blue
528	530	sand
530	532	clay soft blue
532	537	sand fine-.005
537	546	clay
546	551	sand
551	569	clay hard blue
569	571	sand stone
571	623	clay hard swelling blue
623	648	sand .005-.006
648	650	clay soft
650	661	sand .005-.006
661	676	clay hard
676	710	sand fine .005-.006
710	742	clay hard
742	756	sand .005-.006
756	759	clay
759	774	sand .005 with clay streaks
774	780	clay with sand streaks
780	860	clay hard blue to brown
860	874	silty brown clay
874	893	sand fine .005
893	896	clay
896	902	sand fine
902	917	clay hard blue
917	930	fine sand and silty clay
930	942	clay hard blue
942	974	silty sand and clay mix
974	988	clay hard blue
988	992	silty clay and sand
992	1019	sand hard fine-.005 with sand stone streaks
1019	1061	clay hard blue to brown with sand streaks
1061	1070	sand fine

From	To	Formation Encountered
1070	1074	clay hard

1074	1086	silty brown clay with sand streaks
1086	1115	sand fine
1115	1119	clay hard
1119	1135	sand fine
1135	1137	clay hard
1137	1144	silty clay
1144	1166	clay hard
1166	1171	sand fine soft
1171	1172	clay soft
1172	1178	sand fine
1178	1203	clay hard

Felder Water Well & Pump Service, LLC

Daily Driller Report

Customer:	City of Corpus Christi
Project:	Corpus Christi Aquifer Storage and Recovery Feasibility Study
Project #:	E16265
Date:	10/31/2017
Reference Statement:	Test Hole 6 Golf Course

Driller Name:	Eric Branch
Bit Size:	6.75 2-7/8 drill pipe
Average ROP/Hour:	10/31/2017 87'/hr 11/1/2017 65'/hr
Depth Interval:	10/31/2017 0-903' 10/31/2017 903-1204'

From	To	Formation Encountered
0	18	clay black brown
18	26	sand fine
26	28	clay
28	34	sand and clay mix
34	88	clay brown /tan/red
88	100	sand fine-.005
100	126	clay soft blue
126	128	sand
128	153	clay blue soft
153	163	sand .008-.010-.012
163	168	clay blue
168	172	sand
172	176	clay blue soft
176	191	sand .008-.010-.012
191	206	clay blue
206	225	sand .008-.010
225	232	clay blue
232	238	sand .006
238	251	clay
251	261	sand .006
261	268	clay blue
268	277	sand .006
277	321	clay hard
321	330	sand fine-.005 clay streaks
330	344	clay
344	345	sand stone
345	347	sand fine
347	349	clay

349	359	sand .005-.006
From	To	Formation Encountered
359	443	clay soft blue
443	446	sand fine
446	447	clay
447	467	sand .006-.008 clay streaks
467	474	clay
474	483	sand .008-.010 drills loose
483	489	clay
489	500	sand .006-.008 drills loose
500	512	clay blue
512	518	sand .006-.008 drills loose
518	519	clay
519	525	sand .006-.008 clay streaks
525	537	clay sand streaks with sand stone
537	546	sand .006 drills loose
546	554	clay and sand mix
554	556	sand stone hard
556	598	clay blue
598	605	sand fine
605	615	clay blue
615	626	sand .005 clay streaks
626	635	sand .005
635	649	clay sand streaks
649	652	sand
652	668	clay blue
668	674	sand .005-.006
674	682	clay blue sand streaks
682	686	sand fine
686	721	clay blue hard
721	727	sand fine
727	733	clay blue soft
733	737	sand fine
737	748	clay blue soft
748	756	clay sand streaks
756	769	sand fine-.005 with clay streaks
769	778	clay blue soft
778	783	sand fine
783	806	clay blue hard
806	810	sand silty/fine
From	To	Formation Encountered
810	840	clay hard

840	851	silty clay
851	881	sand fine silty/fine
881	883	clay hard
883	884	rock
884	890	clay hard
890	897	sand fine
897	913	clay blue
913	927	silty sand and clay
927	934	sand fine
934	966	clay hard brown sticky swelling
966	982	sand hard fine
982	986	clay
986	1009	sand fine
1009	1015	silty blue clay
1015	1040	clay brown hard sticky swelling
1040	1061	silty blue clay
1061	1112	silty fine sand
1112	1129	clay hard blue
1129	1132	silt
1132	1171	clay and silt mix
1171	1190	clay hard brown swelling
1190	1196	silty clay
1196	1204	silt

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Monitoring Wells

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Felder Water Well & Pump Service, LLC

Daily Driller Report

Customer:	City of Corpus Christi
Project:	Corpus Christi Aquifer Storage and Recovery Feasibility Study
Project #:	E16265
Date:	10/13/2017
Reference Statement:	MW - 1S

Driller Name:	Eric Branch
Bit Size:	7.5" drill bit 2 7/8" drill pipe
Average ROP/Hour:	
Depth Interval:	

From	To	Formation Encountered
surf	8	clay/black gumbo
8	25	sand .006
25	74	clay soft blue sand streaks
74	82	sand and large shell
82	84	clay
84	91	sand .010
91	133	clay soft blue
133	172	sand .012-.014

Felder Water Well & Pump Service, LLC

Daily Driller Report

Customer:	City of Corpus Christi
Project:	Corpus Christi Aquifer Storage and Recovery Feasibility Study
Project #:	E16265
Date:	11/13/2017
Reference Statement:	MW - 1D

Driller Name:	Eric Branch
Bit Size:	6.75" drill bit 2 7/8" drill pipe
Average ROP/Hour:	
Depth Interval:	

From	To	Formation Encountered
surf	8	clay/black gumbo
8	25	sand .006
25	74	clay soft blue sand streaks
74	82	sand and large shell
82	84	clay
84	91	sand .010
91	133	clay soft blue
133	178	sand .012-.014
178	181	clay
181	191	sand .012
191	285	clay w/sand streaks and small gravel
285	293	sand .006
293	309	clay hard blue
309	314	sand .006
314	334	clay hard blue
334	347	sand .006
347	384	clay hard blue
384	396	sand .006
396	426	clay hard blue
426	448	sand .006-.008-.010
448	449	clay
449	461	sand .006-.008-.012
461	466	clay soft w/sand streaks
466	570	clay hard blue turning softer
570	586	sand .006
586	596	clay hard blue
596	616	sand .006
616	623	clay hard
623	650	sand .006-.008

Felder Water Well & Pump Service, LLC

Daily Driller Report

Customer:	City of Corpus Christi
Project:	Corpus Christi Aquifer Storage and Recovery Feasibility Study
Project #:	E16265
Date:	2/13/2018
Reference Statement:	MW - 3

Driller Name:	Eric Branch
Bit Size:	12.25" drill bit 4.5" drill pipe
Average ROP/Hour:	
Depth Interval:	

From	To	Formation Encountered
0	111	clay black/grey
111	113	sand
113	127	clay blue
127	172	sand .006-.008-.010 small gravel
172	174	clay
174	228	large sand and small gravel
228	238	clay
232	235	sand .006
235	236	clay
236	243	sand .006
243	244	clay
244	259	sand .006-.005-fine
259	274	clay blue
274	275	sand stone
275	304	clay blue soft to hard
304	307	sand fine
307	342	clay hard blue
342	366	sand .006-.008-.006
366	368	clay
368	369	sand stone
369	370	sand
370	373	clay hard blue
373	374	sand stone
374	391	sand hard
391	411	clay hard blue
411	414	sand hard
414	450	clay hard to soft
450	456	sand fine

From	To	Formation Encountered
456	472	clay hard
472	477	sand fine
477	479	clay soft
479	505	sand .005-.006
505	522	clay hard blue
522	524	sand
524	526	clay soft blue
526	531	sand fine-.005
531	540	clay
540	545	sand
545	563	clay hard blue
563	565	sand stone
565	617	clay hard swelling blue
617	642	sand .005-.006
642	644	clay soft
644	655	sand .005-.006
655	670	clay hard
670	704	sand fine .005-.006
704	736	clay hard
736	750	sand .005-.006
750	753	clay
753	770	sand .005 with clay streaks

A-3

Exploratory Testing
Phase II

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Felder Water Well & Pump Service, LLC

Daily Driller Report

Customer:	City of Corpus Christi
Project:	Corpus Christi Aquifer Storage and Recovery Feasibility Study
Project #:	E16265
Date:	12/15/2017
Reference Statement:	TW - 1 Site #1, Intermediate Interval. Screen 410-450 ft bgs

Driller Name:	Eric Branch
Bit Size:	12.25" bit size 4.5" drill pipe
Average ROP/Hour:	
Depth Interval:	

From	To	Formation Encountered
surf	8	clay/black gumbo
8	25	sand .006
25	74	clay soft blue sand streaks
74	82	sand and large shell
82	84	clay
84	91	sand .010
91	133	clay soft blue
133	178	sand .012-.014
178	181	clay
181	191	sand .012
191	285	clay w/sand streaks and small gravel
285	293	sand .006
293	309	clay hard blue
309	314	sand .006
314	334	clay hard blue
334	347	sand .006
347	384	clay hard blue
384	396	sand .006
396	426	clay hard blue
426	450	sand .006-.008-.010

Felder Water Well & Pump Service, LLC

Daily Driller Report

Customer:	City of Corpus Christi
Project:	Corpus Christi Aquifer Storage and Recovery Feasibility Study
Project #:	E16265
Date:	1/4/2018
Reference Statement:	TW - 2 Site #1, Deep Interval. Screen 570-650 ft bgs

Driller Name:	Eric Branch
Bit Size:	12.25" drill bit 4.5" drill pipe
Average ROP/Hour:	
Depth Interval:	

From	To	Formation Encountered
surf	8	clay/black gumbo
8	25	sand .006
25	74	clay soft blue sand streaks
74	82	sand and large shell
82	84	clay
84	91	sand .010
91	133	clay soft blue
133	178	sand .012-.014
178	181	clay
181	191	sand .012
191	285	clay w/sand streaks and small gravel
285	293	sand .006
293	309	clay hard blue
309	314	sand .006
314	334	clay hard blue
334	347	sand .006
347	384	clay hard blue
384	396	sand .006
396	426	clay hard blue
426	448	sand .006-.008-.010
448	449	clay
449	461	sand .006-.008-.012
461	466	clay soft w/sand streaks
466	570	clay hard blue turning softer
570	586	sand .006
586	596	clay hard blue
596	616	sand .006
616	623	clay hard
623	650	sand .006-.008

Felder Water Well & Pump Service, LLC

Daily Driller Report

Customer:	City of Corpus Christi
Project:	Corpus Christi Aquifer Storage and Recovery Feasibility Study
Project #:	E16265
Date:	1/26/2018
Reference Statement:	TW - 3 Site #3. Screen 609-769 ft bgs

Driller Name:	Eric Branch
Bit Size:	12.25" drill bit 4.5" drill pipe
Average ROP/Hour:	
Depth Interval:	

From	To	Formation Encountered
0	111	clay black/grey
111	113	sand
113	127	clay blue
127	172	sand .006-.008-.010 small gravel
172	174	clay
174	228	large sand and small gravel
228	238	clay
232	235	sand .006
235	236	clay
236	243	sand .006
243	244	clay
244	259	sand .006-.005-fine
259	274	clay blue
274	275	sand stone
275	304	clay blue soft to hard
304	307	sand fine
307	342	clay hard blue
342	366	sand .006-.008-.006
366	368	clay
368	369	sand stone
369	370	sand
370	373	clay hard blue
373	374	sand stone
374	391	sand hard
391	411	clay hard blue
411	414	sand hard
414	450	clay hard to soft
450	456	sand fine

From	To	Formation Encountered
456	472	clay hard
472	477	sand fine
477	479	clay soft
479	505	sand .005-.006
505	522	clay hard blue
522	524	sand
524	526	clay soft blue
526	531	sand fine-.005
531	540	clay
540	545	sand
545	563	clay hard blue
563	565	sand stone
565	617	clay hard swelling blue
617	642	sand .005-.006
642	644	clay soft
644	655	sand .005-.006
655	670	clay hard
670	704	sand fine .005-.006
704	736	clay hard
736	750	sand .005-.006
750	753	clay
753	770	sand .005 with clay streaks

B

Downhole Geophysics

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GEO CAM

Water Well Logging & Video Recording Services

Geo Cam, Inc. 17118 Classen Rd. San Antonio, TX 78217 210-495-9121

Borehole: **CC-ASR-WELL NO. 1**

Logs: **GAMMA, RESISTIVITY, CALIPER, SP, TEMP. FLRES**

Project: **CC-ASR-WELL NO. 1** Date: 10-12-2017

Client: **FELDER WATER WELLS** County:

Location: **N 27* 45' 29.6" W 97* 29' 22.0"** State: TX

BOREHOLE DATA

Drilling Contractor: FELDER WATER WELLS **Driller T.D. (ft) : 1203'**

Elevation: 0' GPS Logger T.D. (ft) : 1201.5'

Depth Ref: R.T. + 6' Date Drilled: 10-12-2017

BIT RECORD				CASING RECORD		
RUN	BIT SIZE (in)	FROM (ft)	TO (ft)	SIZE/WGT/THK	FROM (ft)	TO (ft)
1	6 3/4"	0'	1203'	NA		
2						
3						

Drill Method: MUD ROTARY Weight: **Fluid Level (ft) :**

Hole Medium: Mud Type: Time Since Circ:

Viscosity: Rm: at: Deg C

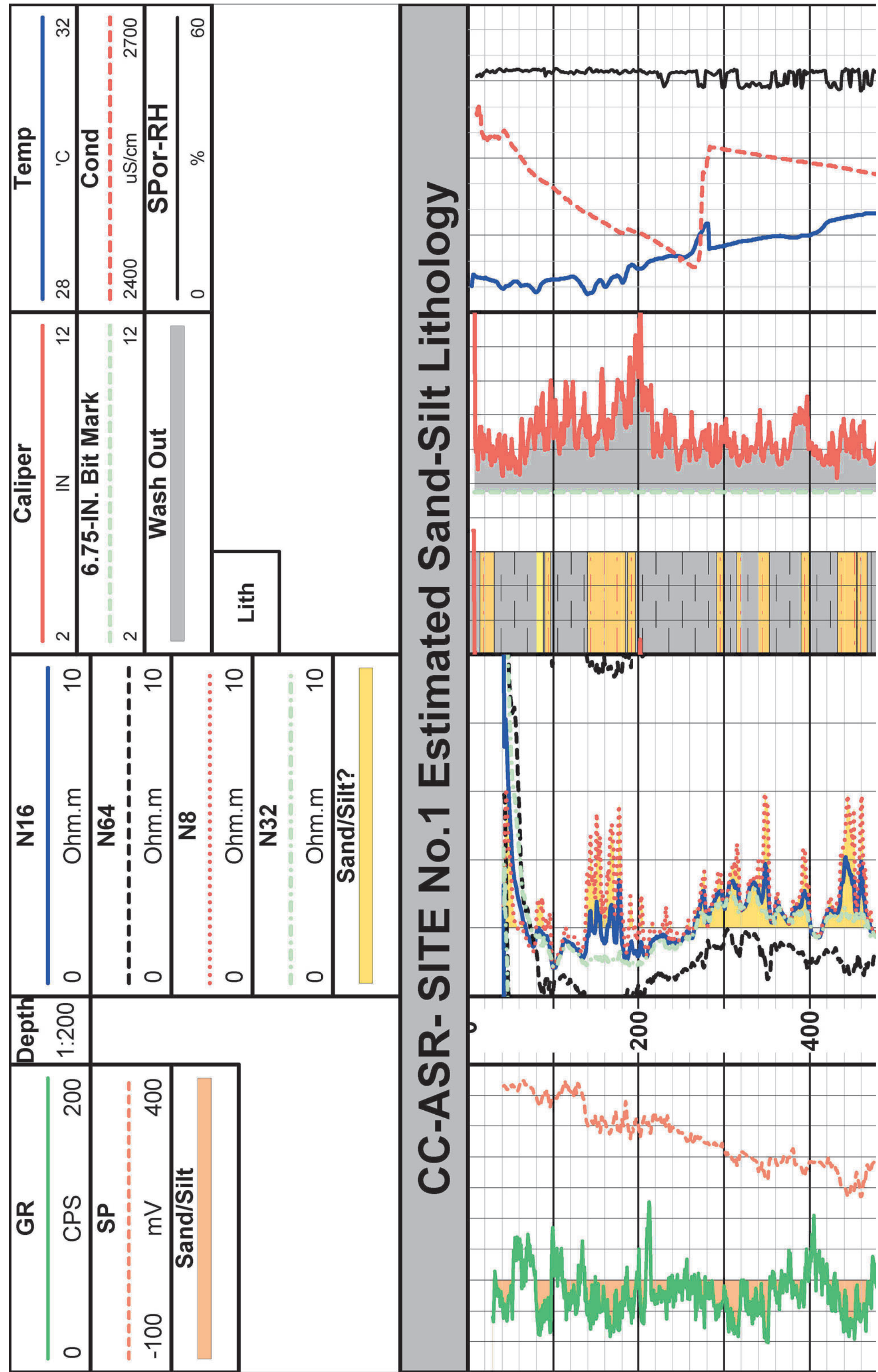
GENERAL DATA

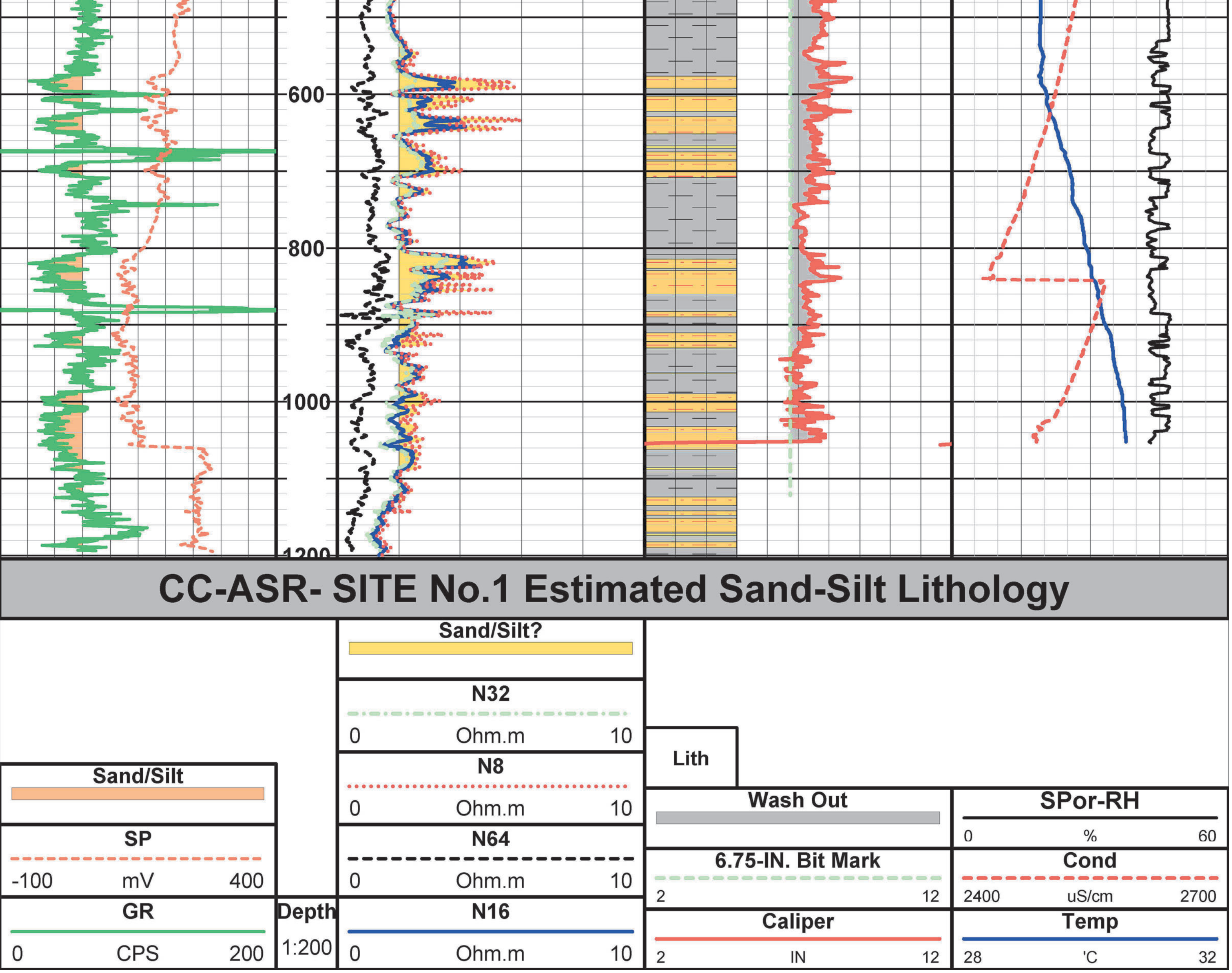
Logged by: Kelly Tuten Unit/Truck: 09

Witness:

LOG TYPE	RUN NO	SPEED (ft/min)	FROM (ft)	TO (ft)	FT./ IN.
GAMMA	2	35	1194	29	20
RESISTIVITY, SP	2	35	1199	42	20
CALIPER	1	45	1056	6	20

Comments:




600
800
1000
1200
CC-ASR- SITE No.1 Estimated Sand-Silt Lithology
Sand/Silt
SP
-100 mV 400
GR
0 CPS 200
Depth
1:200
Sand/Silt?
N32
0 Ohm.m 10
N8
0 Ohm.m 10
N64
0 Ohm.m 10
N16
0 Ohm.m 10
Lith
Wash Out
6.75-IN. Bit Mark
2 12
Caliper
2 IN 12
SPor-RH
0 % 60
Cond
2400 uS/cm 2700
Temp
28 'C 32

GEO CAM

Water Well Logging & Video Recording Services

Borehole: CC-ASR-WELL NO.2

Logs: GAMMA, RESISTIVITY, SP FTC, CALIPER, FWS

Geo Cam, Inc. 17118 Classen Rd. San Antonio, TX 78217 210-495-9121

Project: CC-ASR-WELL NO.2 | Date: 10/19/2017

Client: **FELDER** | County: NUECES

Location: **N 27* 45' 49.77" W 97* 30' 44.82"** | State: TX

BOREHOLE DATA

Drilling Contractor: FELDER | **Driller T.D. (ft) : 1203**

Elevation: -33' GPS | Logger T.D. (ft) : 1200

Depth Ref: RT | Date Drilled: 10/19/17

BIT RECORD				CASING RECORD		
RUN	BIT SIZE (in)	FROM (ft)	TO (ft)	SIZE/WGT/THK	FROM (ft)	TO (ft)
1	6.75"	GL	TD	NONE		
2						
3						

Drill Method: MUD ROTARY | Weight: | **Fluid Level (ft) :** FULL

Hole Medium: | Mud Type: NATIVE, GEL | Time Since Circ: NA

Viscosity: | Rm: | at: | Deg C

GENERAL DATA

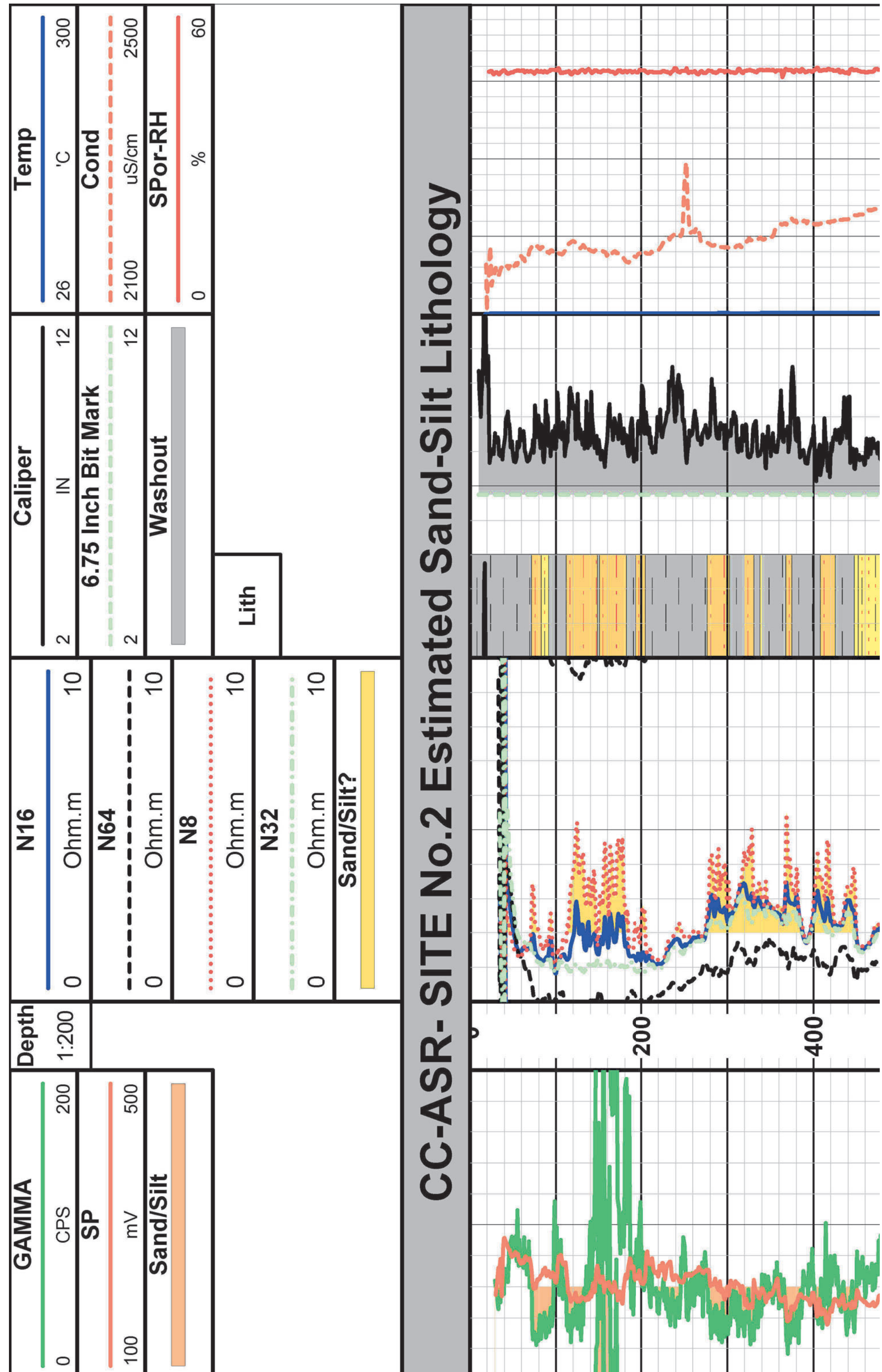
Logged by: ADAM ROBERTS | Unit/Truck: 09

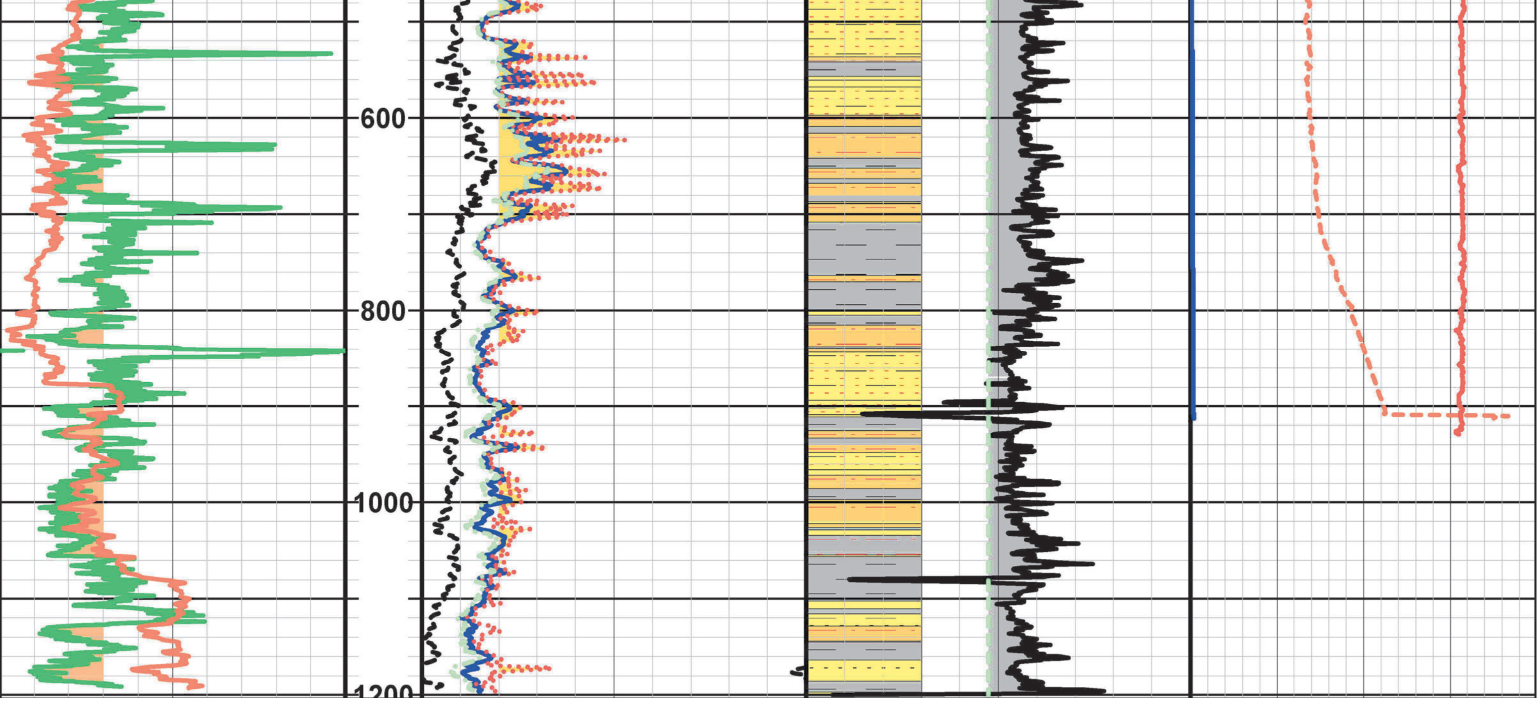
Witness: ERIC

LOG TYPE	RUN NO	SPEED (ft/min)	FROM (ft)	TO (ft)	FT./ IN.
GAMMA	2	45	1191.6'	29'	20
RESISTIVITY, SP	2	45	1200'	35.3'	20
CALIPER	4	45	1197.9'	9.9'	20

Comments: ALL MEASUREMENTS TAKEN FROM ROTARY TABLE DEPTH.

FLUID TEMP. COND. TOOL WAS RAN ONLY DOWN TO 913FT WHERE IT WAS HELD UP IN THE BOREHOLE DUE TO POSSIBLE SWELLING OF CLAYS




600
800
1000
1200

GEO CAM

Water Well Logging & Video Recording Services

Geo Cam, Inc. 17118 Classen Rd. San Antonio, TX 78217 210-495-9121

Borehole: **CC-ASR-WELL NO. 3**

Logs: **GAMMA, RESISTIVITY, CALIPER, SP, TEMP. FLUID CONDUCTIVITY**

Project: **CC-ASR-WELL NO. 3** Date: 10-28-2017

Client: **FELDER WATER WELLS** County: NUECES

Location: **N 27* 45' 21.4" W 97* 27' 14.6"** State: TX

BOREHOLE DATA

Drilling Contractor: FELDER WATER WELLS **Driller T.D. (ft) : 1203'**

Elevation: 19' GPS Logger T.D. (ft) : 1198'

Depth Ref: R.T. + 5.6' Date Drilled: 10-28-2017

BIT RECORD				CASING RECORD		
RUN	BIT SIZE (in)	FROM (ft)	TO (ft)	SIZE/WGT/THK	FROM (ft)	TO (ft)
1	6 3/4"	0'	1203'	NA		
2						
3						

Drill Method: MUD ROTARY Weight: **Fluid Level (ft) :** 40'

Hole Medium: Mud Type: Time Since Circ:

Viscosity: Rm: at: Deg C

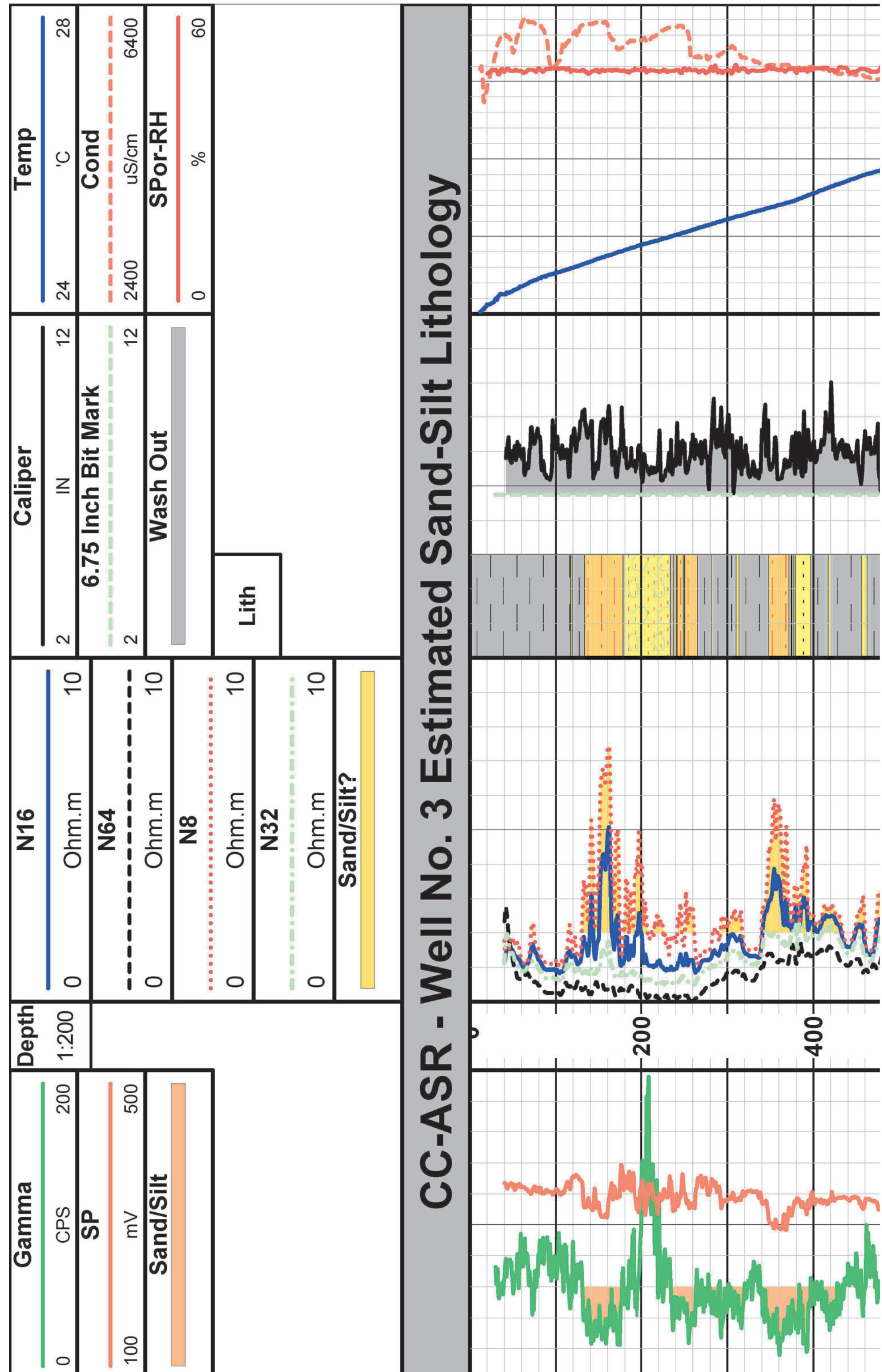
GENERAL DATA

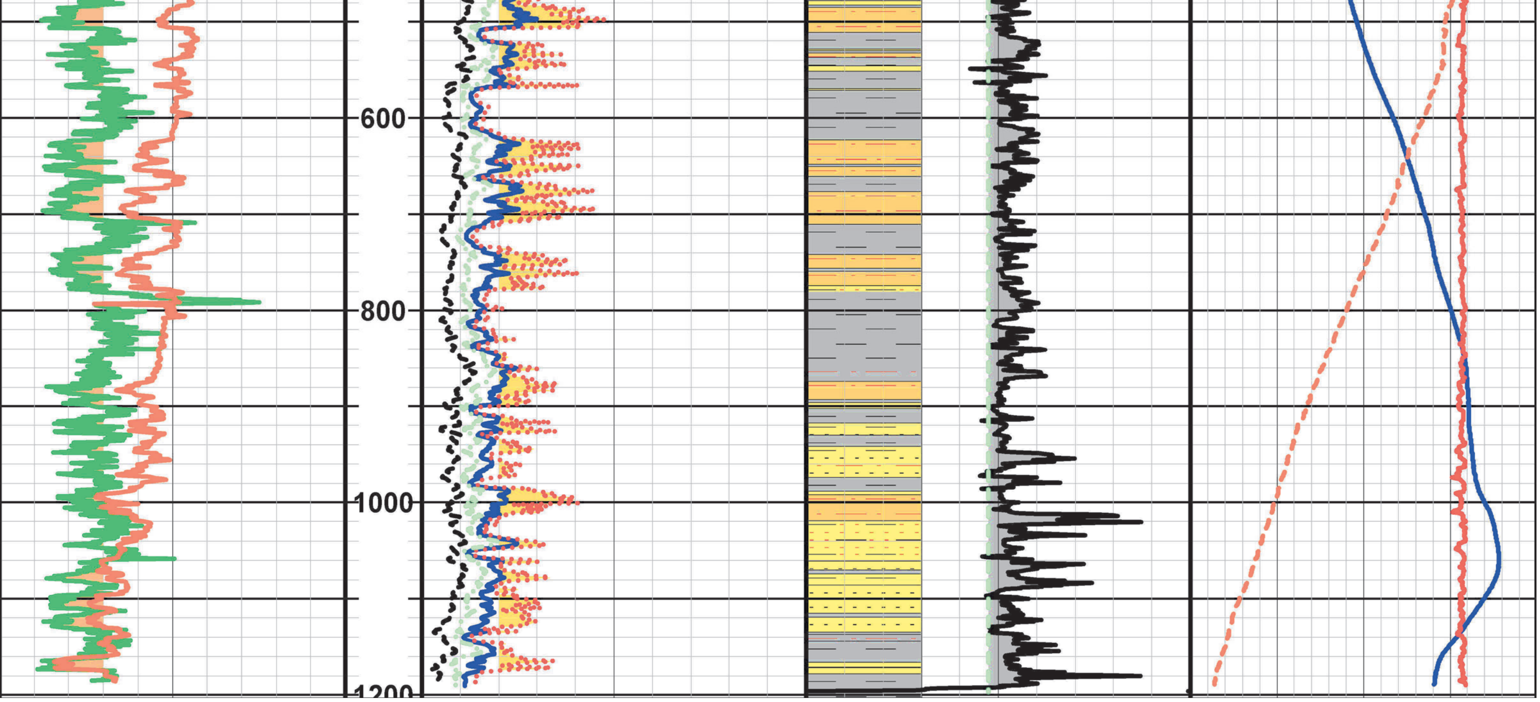
Logged by: Kelly Tuten Unit/Truck: 09

Witness:

LOG TYPE	RUN NO	SPEED (ft/min)	FROM (ft)	TO (ft)	FT./ IN.
GAMMA	2	35	1193	30	20
RESISTIVITY, SP	2	35	1194	40	20
CALIPER	1	35	1197	42	20

Comments:




600
800
1000
1200

GEO CAM

Water Well Logging & Video Recording Services

Geo Cam, Inc. 17118 Classen Rd. San Antonio, TX 78217 210-495-9121

Borehole: CC-ASR WELL NO. 6

Logs: GAMMA, RESISTIVITY, CALIPER, SPR, TEMP., FLRES

Project: CC-ASR WELL NO. 6 | Date: 11-01-2017
Client: FELDER W.W. | County: NUECES
Location: N 27* 46' 23.4" W 97* 26' 19.6" | State: TX

BOREHOLE DATA

Drilling Contractor: FELDER W.W. | **Driller T.D. (ft) : 1204'**
Elevation: 57' GPS | Logger T.D. (ft) : 1201'
Depth Ref: R.T. +5.7' | Date Drilled: 11-01-2017

BIT RECORD				CASING RECORD		
RUN	BIT SIZE (in)	FROM (ft)	TO (ft)	SIZE/WGT/THK	FROM (ft)	TO (ft)
1	6 3/4"	0	1203	NONE		
2						
3						

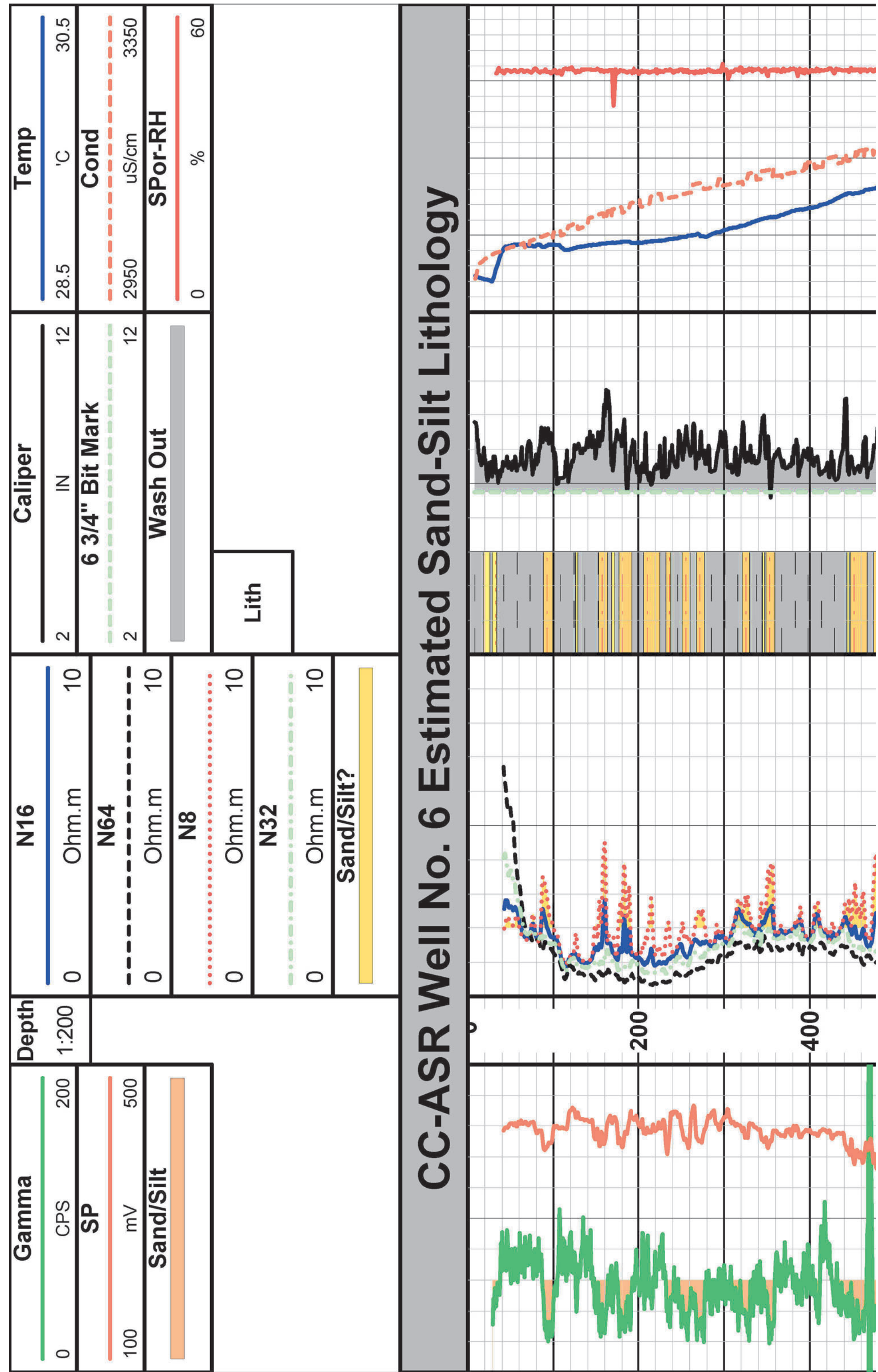
Drill Method: MUD ROTARY | Weight: | **Fluid Level (ft) :** 10'
Hole Medium: | Mud Type: | Time Since Circ:
Viscosity: | Rm: | at: | Deg C

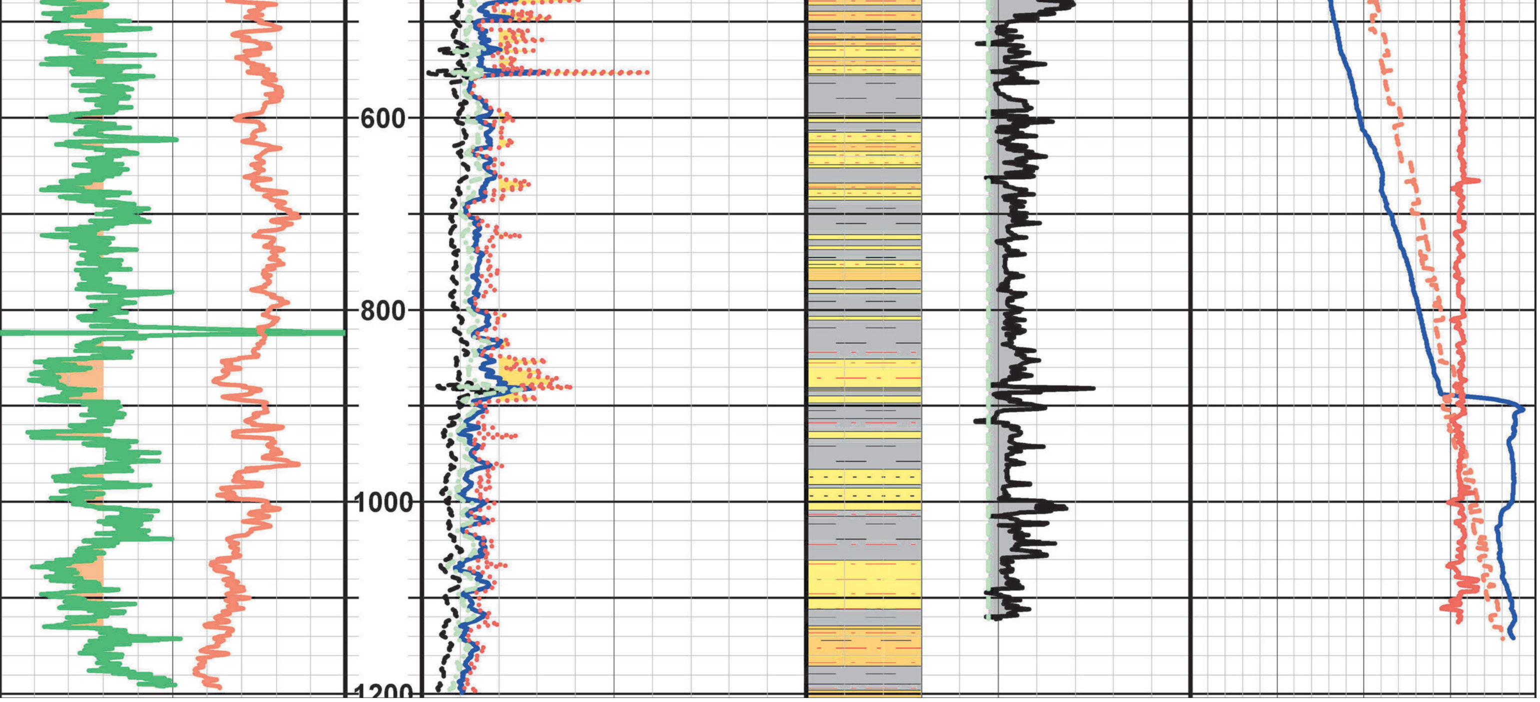
GENERAL DATA

Logged by: Kelly Tuten | Unit/Truck: 09
Witness:

LOG TYPE	RUN NO	SPEED (ft/min)	FROM (ft)	TO (ft)	FT./ IN.
GAMMA	2	30	1193	29	20
RESISTIVITY, SP	2	30	1199	42	20
CALIPER	1	30	1122	8	20

Comments:





600
800
1000
1200

C

State of Texas Wells Logs

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C-1

MW-1S

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STATE OF TEXAS WELL REPORT for Tracking #479848

Owner:	City of Corpus Christi	Owner Well #:	1
Address:	1201 Leopard St Corpus Christi, TX 78401	Grid #:	83-13-7
Well Location:	6801 FM 763 Corpus Christi, TX 78417 #1 - Monitor Well	Latitude:	27° 45' 29.58" N
		Longitude:	097° 29' 21.3" W
		Elevation:	28 ft. above sea level
Well County:	Nueces		
Number of Wells Drilled:	3		

Type of Work: **New Well** Proposed Use: **Monitor**

Drilling Start Date: **10/13/2017** Drilling End Date: **10/14/2017**

Borehole:

Diameter (in.)	*Top Depth (ft.)*	*Bottom Depth (ft.)*
7.5	0	172

Drilling Method: **Mud (Hydraulic) Rotary**

Borehole Completion: **Filter Packed; Straight Wall**

Filter Pack Intervals:

Top Depth (ft.)	*Bottom Depth (ft.)*	*Filter Material*	*Size*
155	172	Gravel	

Annular Seal Data:

Top Depth (ft.)	*Bottom Depth (ft.)*	*Description (number of sacks & material)*
0	12	Cement 10 Bags/Sacks
12	155	Hole Plug 25 Bags/Sacks

Seal Method: **Tremie**

Sealed By: **Driller**

Distance to Property Line (ft.): **No Data**

Distance to Septic Field or other concentrated contamination (ft.): **No Data**

Distance to Septic Tank (ft.): **No Data**

Method of Verification: **No Data**

Surface Completion: **Alternative Procedure Used** **Surface Completion by Driller**

Water Level: **No Data**

Packers: **No Data**

Type of Pump: **No Data**

Well Tests: **Jetted** **Yield: 30 GPM**

Water Quality:

Strata Depth (ft.)	Water Type
No Data	**No Data**

Chemical Analysis Made: **No**

Did the driller knowingly penetrate any strata which contained injurious constituents?: **No**

Certification Data: The driller certified that the driller drilled this well (or the well was drilled under the driller's direct supervision) and that each and all of the statements herein are true and correct. The driller understood that failure to complete the required items will result in the report(s) being returned for completion and resubmittal.

Company Information: **Felder Water Well & Pump Service, LLC**

P.O.Box 1033
Angleton, TX 77516

Driller Name: **David Eric Branch** License Number: **56029**

Apprentice Name: **Dale Felder** Apprentice Number: **2440**

Comments: **No Data**

Report Amended on 6/1/2018 by Request #25172

Report Amended on 6/6/2018 by Request #25249

Lithology:
DESCRIPTION & COLOR OF FORMATION MATERIAL

Top (ft.)	Bottom (ft.)	Description
0	14	Clay/black gumbo
14	31	Sand .006
31	80	Clay soft blue sand streaks
80	88	Sand and large shell
88	90	Clay
90	97	Sand .010
97	139	Clay soft blue
139	172	Sand .012-.014

Casing:
BLANK PIPE & WELL SCREEN DATA

Dia (in.)	Type	Material	Sch./Gage	Top (ft.)	Bottom (ft.)
2	Blank	New Plastic (PVC)	80	+3	155
2	Screen	New Stainless Steel	0.025	155	172

IMPORTANT NOTICE FOR PERSONS HAVING WELLS DRILLED CONCERNING CONFIDENTIALITY

TEX. OCC. CODE Title 12, Chapter 1901.251, authorizes the owner (owner or the person for whom the well was drilled) to keep information in Well Reports confidential. The Department shall hold the contents of the well log confidential and not a matter of public record if it receives, by certified mail, a written request to do so from the owner.

Please include the report's Tracking Number on your written request.

Texas Department of Licensing and Regulation
P.O. Box 12157
Austin, TX 78711
(512) 334-5540

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C-2

MW-1D

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STATE OF TEXAS WELL REPORT for Tracking #479856

Owner: **City of Corpus Christi**

Owner Well #: **2**

Address: **1201 Leopard St**
Corpus Christi, TX 78417

Grid #: **83-13-7**

Latitude: **27° 45' 29.64" N**

Well Location: **6801 FM 763**
Corpus Christi, TX 78417

Longitude: **097° 29' 21.06" W**

#2 - Monitor Well

Elevation: **28 ft. above sea level**

Well County: **Nueces**

Number of Wells Drilled: **3**

Type of Work: **New Well**

Proposed Use: **Monitor**

Drilling Start Date: **11/13/2017** Drilling End Date: **11/14/2017**

Borehole:

Diameter (in.)	Top Depth (ft.)	Bottom Depth (ft.)
6.75	0	648

Drilling Method: **Mud (Hydraulic) Rotary**

Borehole Completion: **Filter Packed; Straight Wall**

Filter Pack Intervals:

Top Depth (ft.)	Bottom Depth (ft.)	Filter Material	Size
562	648	Gravel	

Annular Seal Data:

Top Depth (ft.)	Bottom Depth (ft.)	Description (number of sacks & material)
0	555	Cement 90 Bags/Sacks
555	562	Hole Plug 5 Bags/Sacks

Seal Method: **Tremie**

Sealed By: **Driller**

Distance to Property Line (ft.): **No Data**

Distance to Septic Field or other concentrated contamination (ft.): **No Data**

Distance to Septic Tank (ft.): **No Data**

Method of Verification: **No Data**

Surface Completion: **Alternative Procedure Used** **Surface Completion by Driller**

Water Level: **No Data**

Packers: **No Data**

Type of Pump: **No Data**

Well Tests: **Jetted** **Yield: 43 GPM**

Water Quality:

Strata Depth (ft.)	Water Type
No Data	**No Data**

Chemical Analysis Made: **No**

Did the driller knowingly penetrate any strata which contained injurious constituents?: **No**

Certification Data: The driller certified that the driller drilled this well (or the well was drilled under the driller's direct supervision) and that each and all of the statements herein are true and correct. The driller understood that failure to complete the required items will result in the report(s) being returned for completion and resubmittal.

Company Information: **Felder Water Well & Pump Service, LLC**

P.O.Box 1033
Angleton, TX 77516

Driller Name: **David Eric Branch** License Number: **56029**

Apprentice Name: **Dale Felder** Apprentice Number: **2440**

Comments: **No Data**

Report Amended on 6/1/2018 by Request #25173

Report Amended on 6/6/2018 by Request #25244

Lithology:
DESCRIPTION & COLOR OF FORMATION MATERIAL

Top (ft.)	Bottom (ft.)	Description
0	14	Clay/black gumbo
14	31	Sand .006
31	80	Clay soft blue sand streaks
80	88	Sand and large shell
88	90	Clay
90	97	Sand .010
97	139	Clay soft blue
139	184	Sand .012-.014
184	187	Clay
187	197	Sand .012
197	291	Clay w/sand streaks & small gravel
291	299	Sand .006
299	315	Clay hard blue
315	320	Sand .006
320	340	Clay hard blue

Casing:
BLANK PIPE & WELL SCREEN DATA

Dia (in.)	Type	Material	Sch./Gage	Top (ft.)	Bottom (ft.)
2	Blank	New Stainless Steel	10	+3	576
2	Screen	New Rod Base Stainless Steel	0.020	576	596
2	Blank	New Stainless Steel	10	596	604
2	Screen	New Rod Base Stainless Steel	0.020	604	614
2	Blank	New Stainless Steel	10	614	628
2	Screen	New Rod Base Stainless Steel	0.020	628	648

340	353	Sand .006
353	390	Clay hard blue
390	400	Sand .006
400	432	Clay hard blue
432	454	Sand .006-.008-.010
454	455	Clay
455	467	Sand .006-.008-.012
467	472	Clay soft w/sand streaks
472	576	Clay hard blue turning softer
576	592	Sand .006
592	602	Clay hard blue
602	622	Sand .006
622	629	Clay hard
629	648	Sand .006-.008

IMPORTANT NOTICE FOR PERSONS HAVING WELLS DRILLED CONCERNING CONFIDENTIALITY

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Texas Department of Licensing and Regulation
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Austin, TX 78711
(512) 334-5540

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C-3

MW-3

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STATE OF TEXAS WELL REPORT for Tracking #479863

Owner:	**City of Corpus Christi**	Owner Well #:	**3**
Address:	**1201 Leopard St Corpus Christi, TX 78401**	Grid #:	**83-13-8**
Well Location:	**1716 Cliff Maus Dr Corpus Christi, TX 78401 #3 - Monitor Well**	Latitude:	**27° 45' 21" N**
		Longitude:	**097° 27' 14.82" W**
		Elevation:	**32 ft. above sea level**
Well County:	**Nueces**		
Number of Wells Drilled:	**3**		

Type of Work: **New Well** — Proposed Use: **Monitor**

Drilling Start Date: **3/5/2018** Drilling End Date: **3/6/2018**

Borehole:

Diameter (in.)	Top Depth (ft.)	Bottom Depth (ft.)
12.25	**0**	**767**

Drilling Method: **Mud (Hydraulic) Rotary**

Borehole Completion: **Filter Packed; Straight Wall**

Filter Pack Intervals:

Top Depth (ft.)	Bottom Depth (ft.)	Filter Material	Size
610	**767**	**Gravel**	

Annular Seal Data: **No Data**

Seal Method: **Tremie**

Sealed By: **Driller**

Distance to Property Line (ft.): **No Data**

Distance to Septic Field or other concentrated contamination (ft.): **No Data**

Distance to Septic Tank (ft.): **No Data**

Method of Verification: **No Data**

Surface Completion: **Alternative Procedure Used** **Surface Completion by Driller**

Water Level: **No Data**

Packers: **No Data**

Type of Pump: **No Data**

Well Tests: **Jetted** **Yield: 60 GPM**

Water Quality:

Strata Depth (ft.)	Water Type
No Data	**No Data**

Chemical Analysis Made: **No**

Did the driller knowingly penetrate any strata which contained injurious constituents?: **No**

Certification Data: The driller certified that the driller drilled this well (or the well was drilled under the driller's direct supervision) and that each and all of the statements herein are true and correct. The driller understood that failure to complete the required items will result in the report(s) being returned for completion and resubmittal.

Company Information: **Felder Water Well & Pump Service, LLC**

P.O.Box 1033
Angleton, TX 77516

Driller Name: **David Eric Branch** License Number: **56029**

Apprentice Name: **Dale Felder** Apprentice Number: **2440**

Comments: **No Data**

Report Amended on 6/1/2018 by Request #25174

Report Amended on 6/6/2018 by Request #25241

Report Amended on 8/1/2018 by Request #25674

Report Amended on 8/2/2018 by Request #25678

Lithology:
DESCRIPTION & COLOR OF FORMATION MATERIAL

Top (ft.)	Bottom (ft.)	Description
0	117	Clay black/grey
117	119	Sand
119	133	Clay blue
133	178	Sand .006-.008-.010 small gravel
178	180	Clay
180	234	Large sand and small gravel
234	238	Clay
238	241	Sand .006
241	242	Clay
242	249	Sand .006
249	250	Clay
250	265	Sand .006-.005-fine
265	280	Clay blue

Casing:
BLANK PIPE & WELL SCREEN DATA

Dia (in.)	Type	Material	Sch./Gage	Top (ft.)	Bottom (ft.)
2	Blank	New Stainless Steel	10	-0.05	610
2	Screen	New Pipe Base Stainless Steel	0.025	610	765

280	281	Sand stone
281	310	Clay blue soft to hard
310	313	Sand fine
313	348	Clay hard blue
348	372	Sand .006-.008-.006
372	374	Clay
374	375	Sand stone
375	376	Sand
376	379	Clay hard blue
379	380	Sand stone
380	397	Sand hard
397	417	Clay hard blue
417	420	Sand hard
420	456	Clay hard to soft
456	462	Sand fine
462	478	Clay hard
478	483	Sand fine
483	485	Clay soft
485	511	Sand .005-.006
511	528	Clay hard blue
528	530	Sand
530	532	Clay soft blue
532	537	Sand fine .005
537	546	Clay
546	551	Sand
551	569	Clay hard blue
569	571	Sand stone
571	623	Clay hard swelling blue
623	648	Sand .005-.006
648	650	Clay soft
650	661	Sand .005-.006
661	676	Clay hard
676	710	Sand fine .005-.006
710	742	Clay hard
742	756	Sand .005-.006
756	759	Clay
759	767	Sand .005 w/clay streaks

IMPORTANT NOTICE FOR PERSONS HAVING WELLS DRILLED CONCERNING CONFIDENTIALITY

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Austin, TX 78711
(512) 334-5540

D

Pumping Test Water Level Measurements

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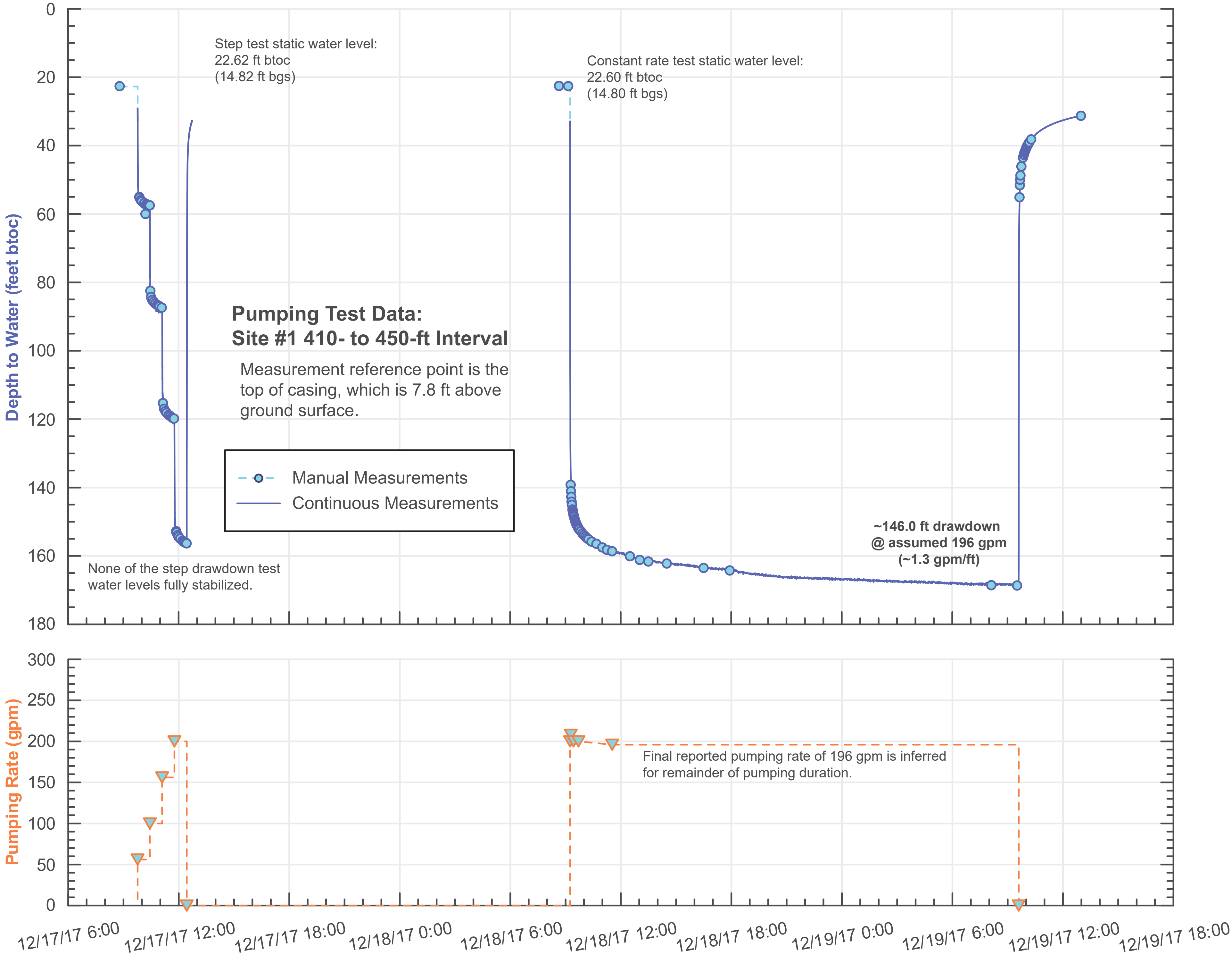
Pumping Test Data:
Site #1 410- to 450-ft Interval
Measurement reference point is the top of casing, which is 7.8 ft above ground surface.
Step test static water level:
22.62 ft btoc
(14.82 ft bgs)
Constant rate test static water level:
22.60 ft btoc
(14.80 ft bgs)
Manual Measurements
Continuous Measurements
None of the step drawdown test water levels fully stabilized.
~146.0 ft drawdown
@ assumed 196 gpm
(~1.3 gpm/ft)
Final reported pumping rate of 196 gpm is inferred for remainder of pumping duration.
Depth to Water (feet btoc)
Pumping Rate (gpm)
0
20
40
60
80
100
120
140
160
180
300
250
200
150
100
50
0
12/17/17 6:00
12/17/17 12:00
12/17/17 18:00
12/18/17 0:00
12/18/17 6:00
12/18/17 12:00
12/18/17 18:00
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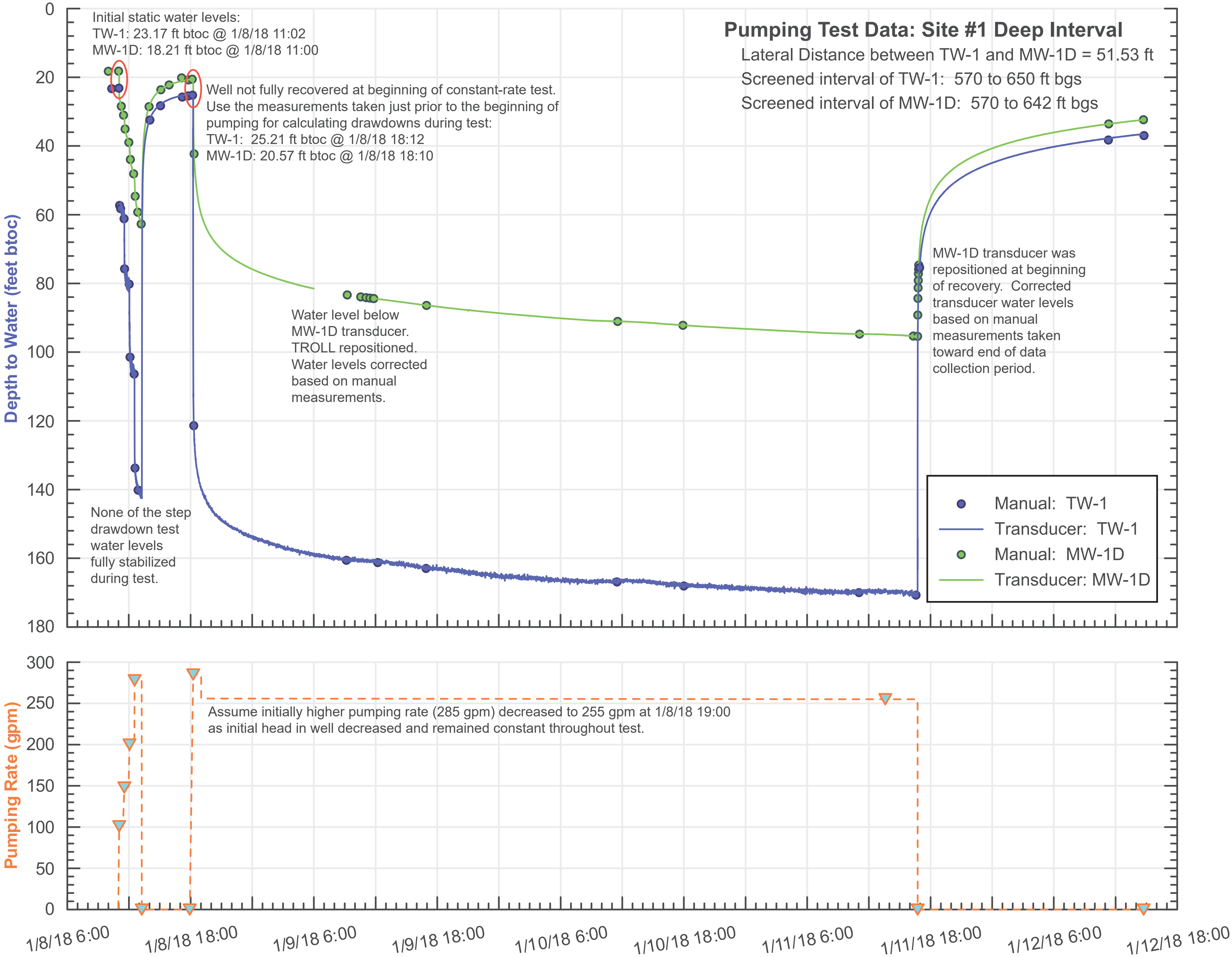
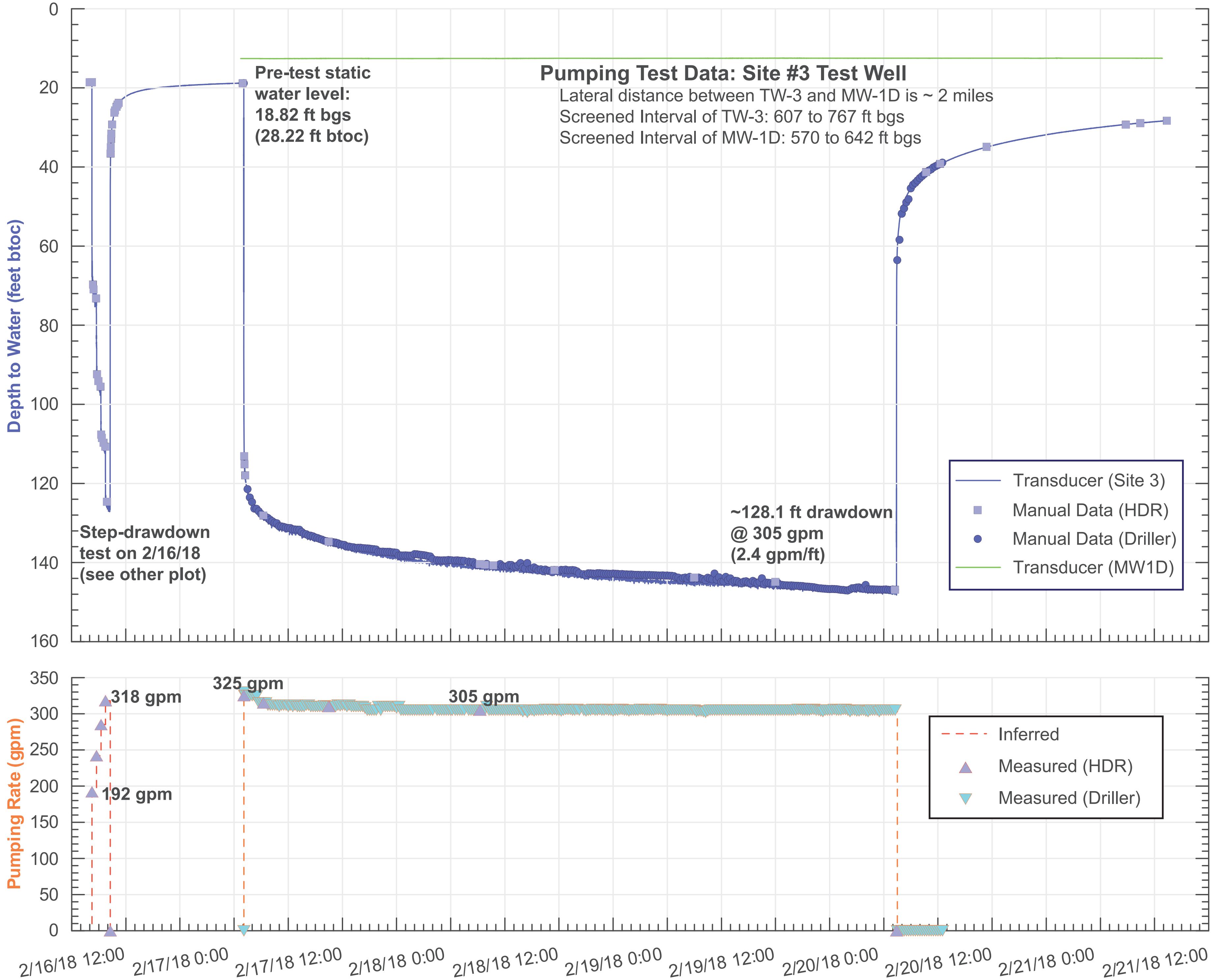
12/19/17 18:00



Pumping Test Data: Site #1 Deep Interval
Lateral Distance between TW-1 and MW-1D = 51.53 ft
Screened interval of TW-1: 570 to 650 ft bgs
Screened interval of MW-1D: 570 to 642 ft bgs
Initial static water levels:
TW-1: 23.17 ft btoc @ 1/8/18 11:02
MW-1D: 18.21 ft btoc @ 1/8/18 11:00
Well not fully recovered at beginning of constant-rate test.
Use the measurements taken just prior to the beginning of
pumping for calculating drawdowns during test:
TW-1: 25.21 ft btoc @ 1/8/18 18:12
MW-1D: 20.57 ft btoc @ 1/8/18 18:10
Water level below
MW-1D transducer.
TROLL repositioned.
Water levels corrected
based on manual
measurements.
MW-1D transducer was
repositioned at beginning
of recovery. Corrected
transducer water levels
based on manual
measurements taken
toward end of data
collection period.
None of the step
drawdown test
water levels
fully stabilized
during test.
Manual: TW-1
Transducer: TW-1
Manual: MW-1D
Transducer: MW-1D
Depth to Water (feet btoc)
0
20
40
60
80
100
120
140
160
180
Assume initially higher pumping rate (285 gpm) decreased to 255 gpm at 1/8/18 19:00
as initial head in well decreased and remained constant throughout test.
Pumping Rate (gpm)
300
250
200
150
100
50
0
1/8/18 6:00
1/8/18 18:00
1/9/18 6:00
1/9/18 18:00
1/10/18 6:00
1/10/18 18:00
1/11/18 6:00
1/11/18 18:00
1/12/18 6:00
1/12/18 18:00


Pumping Test Data: Site #3 Test Well
Lateral distance between TW-3 and MW-1D is ~ 2 miles
Screened Interval of TW-3: 607 to 767 ft bgs
Screened Interval of MW-1D: 570 to 642 ft bgs
Pre-test static water level: 18.82 ft bgs (28.22 ft btoc)
Step-drawdown test on 2/16/18 (see other plot)
~128.1 ft drawdown @ 305 gpm (2.4 gpm/ft)
Depth to Water (feet btoc)
0
20
40
60
80
100
120
140
160
Transducer (Site 3)
Manual Data (HDR)
Manual Data (Driller)
Transducer (MW1D)
Pumping Rate (gpm)
350
300
250
200
150
100
50
0
318 gpm
192 gpm
325 gpm
305 gpm
Inferred
Measured (HDR)
Measured (Driller)
2/16/18 12:00
2/17/18 0:00
2/17/18 12:00
2/18/18 0:00
2/18/18 12:00
2/19/18 0:00
2/19/18 12:00
2/20/18 0:00
2/20/18 12:00
2/21/18 0:00
2/21/18 12:00

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E

Pumping Test Analytical Plots

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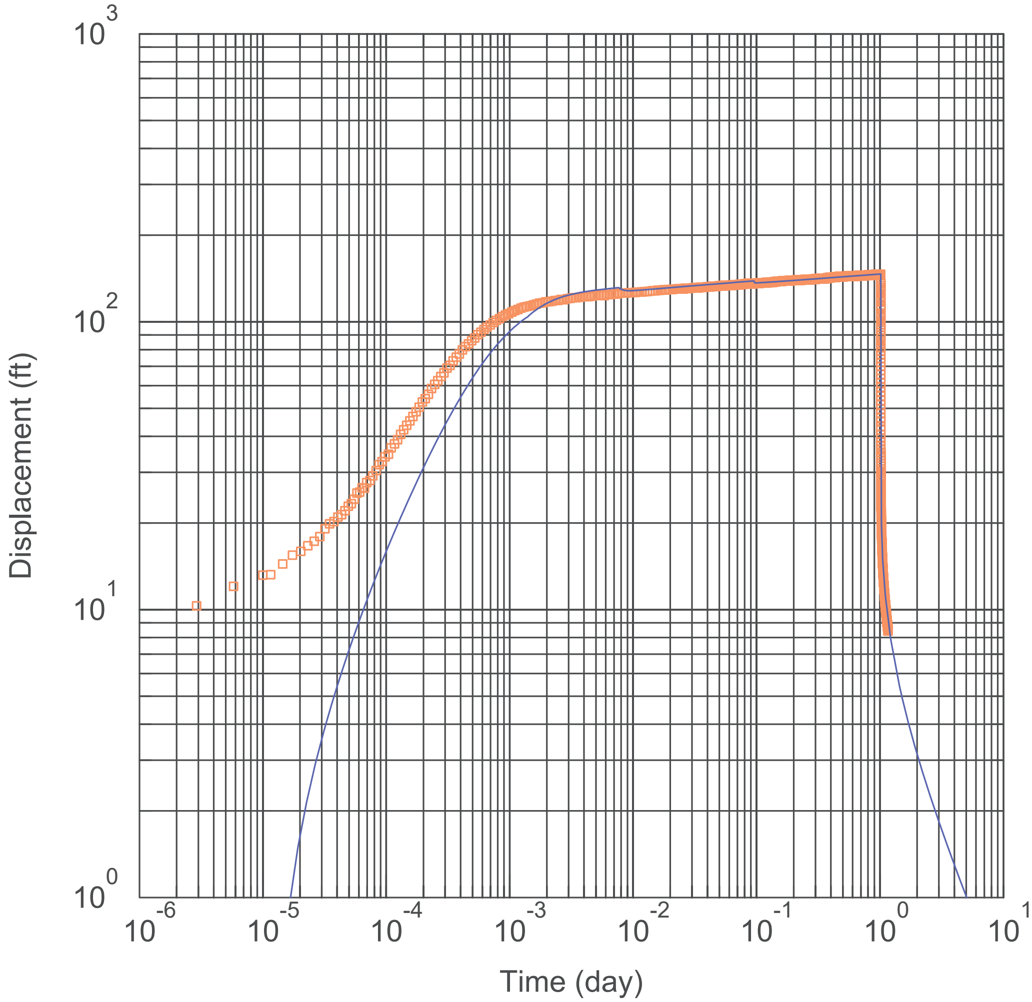


WELL TEST ANALYSIS

Data Set: S:\...\HDR_Corpus_TW_singlewell_03_PapadopolousCooper_Rev1_040918.aqt
Date: 04/09/18 Time: 17:02:49

PROJECT INFORMATION

Company: INTERA
Client: HDR
Location: Corpus area
Test Well: TW
Test Date: Dec 18-19, 2017

Assumed well dimensions:
Casing radius = 0.25 ft (6-in diameter)
Gravel pack radius = 0.417 ft (10-in diameter)

Assume well is fully penetrating into 40-ft aquifer.
Fit is insensitive to aquifer thickness.

AQUIFER DATA

Saturated Thickness: 40. ft

Anisotropy Ratio (Kz/Kr): ~~1.~~

Fit is insensitive to anisotropy (assumes isotropic)

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
TW: 410-450 ft	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
TW: 410-450 ft	0	0

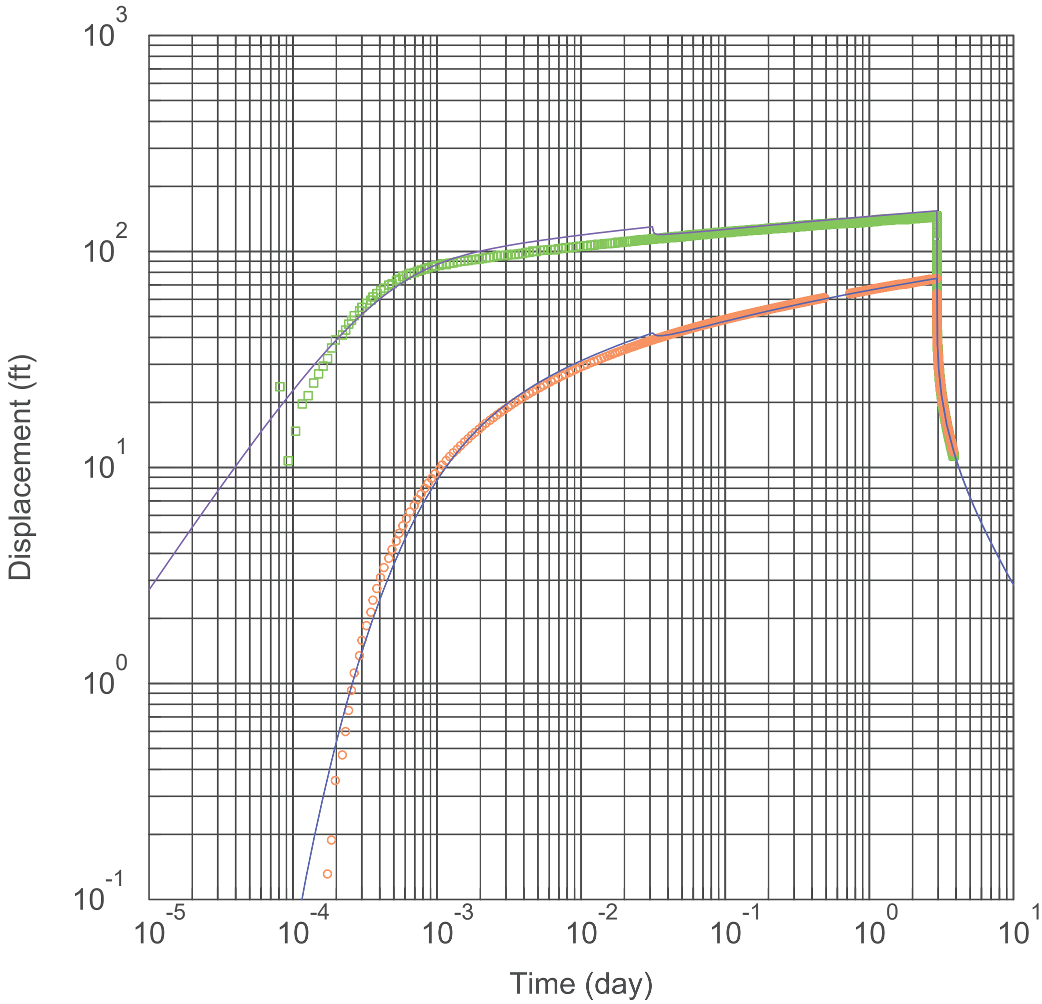
SOLUTION

Aquifer Model: Confined

Solution Method: Papadopulos-Cooper

T = 676. ft^2/day
r(w) = 0.417 ft

~~S = 4.281E-11~~
Storage estimate not valid for single-well analysis.
r(c) = 0.25 ft



Assume pumping well is fully penetrating into 80-ft thick aquifer.

Monitor well is screened 72 ft into aquifer, but solution method assumes wells are fully penetrating.

Fit is insensitive to aquifer thickness.

SITE #1 DEEP INTERVAL

Data Set: S:\AUS\HDR_Corpus\pumping_tests\aqtesolv\HDR_Corpus_Jan2018_Deep_00_013118.aqt
Date: 01/31/18 Time: 15:58:26

PROJECT INFORMATION

Company: INTERA
Client: HDR
Location: Corpus Christi area
Test Well: TW-1
Test Date: Jan 8-11, 2018

Assumed well dimensions:
TW-1 Casing radius = 0.25 ft (6-in diameter)
TW-1 Gravel pack radius = 0.417 ft (10-in diameter)
MW-1D Casing radius = 0.083 ft (2-in diameter)
MW-1D Gravel pack radius = 0.1888 (4.5-in diameter)

AQUIFER DATA

Saturated Thickness: 80. ft Anisotropy Ratio (Kz/Kr): ~~1.~~

Fit is insensitive to anisotropy (assumes isotropic)

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
TW-1	0	0

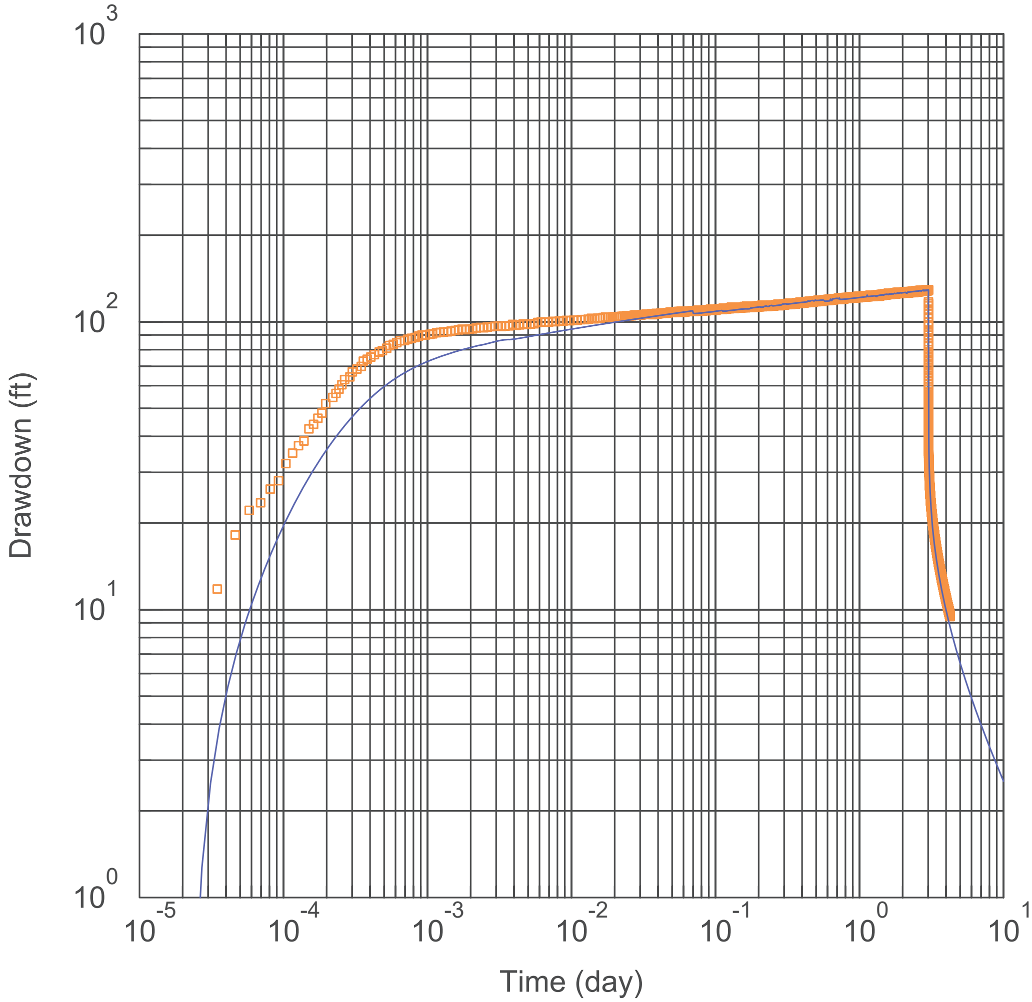
Observation Wells

Well Name	X (ft)	Y (ft)
TW-1	0	0
MW-1D	51.5	0

SOLUTION

Aquifer Model: Confined Solution Method: Papadopulos-Cooper

T = 475. ft^2/day S = 0.00013
r(w) = 0.42 ft r(c) = 0.25 ft



CORPUS ASR SITE 3

Data Set: S:\...\HDR_Corpus_Mar2018_Site3_singlewell_02_PapadopolousCooper_031418.aqt
Date: 03/14/18 Time: 12:01:49

PROJECT INFORMATION

Company: INTERA
Client: HDR
Location: Corpus Christi, TX
Test Well: TW Site 3
Test Date: Feb 17-21, 2018

Assumed well dimensions:
Casing radius = 0.25 ft (6-in diameter)
Gravel pack radius = 0.417 ft (10-in diameter)

AQUIFER DATA

Assume well is fully penetrating into 160-ft aquifer.
Fit is insensitive to aquifer thickness.

Saturated Thickness: 160. ft

Anisotropy Ratio (Kz/Kr): ~~1.~~

Fit is insensitive to anisotropy (assumes isotropic)

WELL DATA

Pumping well and observation well are the same.
No additional monitoring well.

Pumping Wells

Well Name	X (ft)	Y (ft)
TW Site 3	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ TW Site 3	0	0

SOLUTION

Aquifer Model: Confined

Solution Method: Papadopulos-Cooper

T = 665. ft^2/day
r(w) = 0.417 ft

~~S = 0.0002763~~
r(c) = 0.25 ft

Storage estimate not valid for single-well analyses.

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Exhibit E Memo- Geochemical Analysis and Modeling

Geochemical Analysis and Modeling- Technical Memorandum

Corpus Christi Aquifer Storage and Recovery Feasibility Study (E16265)

Corpus Christi, Texas

February 6, 2019

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Contents

Tables

Figures

Appendices

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1 Introduction

The Corpus Christi Aquifer Storage and Recovery District (District), with contracting authority through the City of Corpus Christi (City), hired HDR to conduct an investigation of aquifer storage and recovery (ASR) feasibility within the District area. The feasibility study includes exploratory test well drilling, geochemical analysis, and groundwater modeling to evaluate the suitability of local aquifers for ASR operations. An exploratory test drilling program was conducted at four City-owned sites located near the Corpus Christi International Airport from October 9, 2017 to May 15, 2018. The results of the exploratory test drilling program is summarized in a technical memorandum issued October 4, 2018.

As part of determining ASR feasibility, this geochemical analysis was conducted to determine the compatibility of storing treated effluent from Greenwood Wastewater Treatment Plant (WWTP) or potable water from O.N. Stevens Water Treatment Plant (WTP) within the native aquifer setting. This phase is critical to avoid reactions that may lead to clogging of the near-well pore space or mobilization of undesirable constituents from the aquifer matrix resulting in increased concentration of these constituents in the recovered water. This technical memorandum summarizes the results of the geochemical analysis and modeling, including whether either of these situations is likely to occur, and what operational approaches, recharge water treatment, and/or aquifer conditioning might be necessary to avoid potential adverse effects.

2 Study Area

The project area was identified in a preliminary 2016 study[1] as the most favorable area for ASR of three sites evaluated across the District. Building upon these study results, six potential exploratory testing sites were identified from discussions with District and City personnel with four sites selected for Phase I and II testing, as shown in Figure 1. As summarized in the exploratory testing program report[2], Phase II testing was performed at sites that exhibited one or more reasonably thick sand intervals that tend to be desirable for ASR based on Phase I findings and field geologist recommendation. Phase II field activities consisted of soil coring, temporary well installation, pumping tests, and water quality testing.

Two sites, Site #1 and Site #3, showed favorable sand thicknesses based on Phase I findings and were tested as part of Phase II. For sites where multiple, thicker sand intervals were observed, as in the case of Site #1, different intervals were tested. Aquifer cores and water samples representative of potential storage zones were collected and

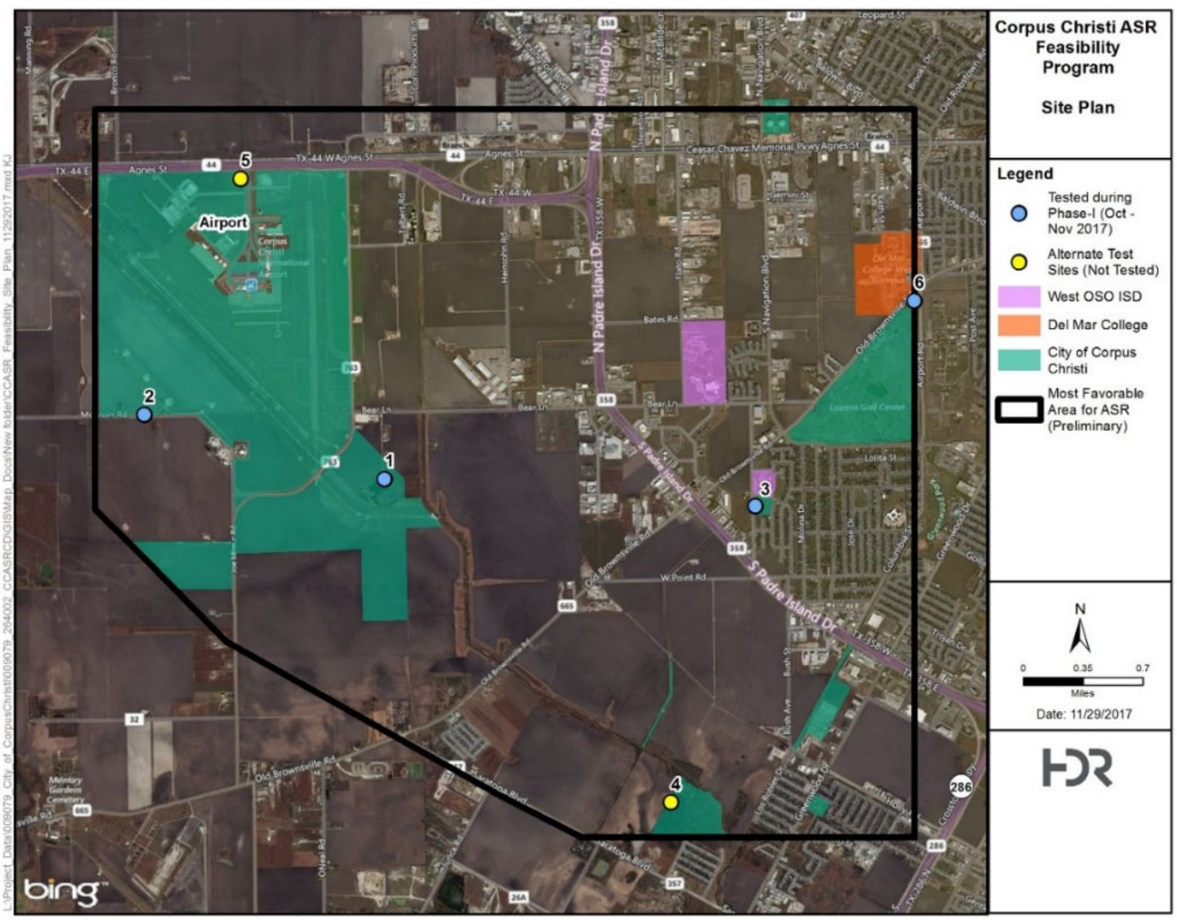
[1] HDR, “Aquifer Characterization Study for ASR Feasibility”, January 20, 2016.
[2] HDR, “Exploratory Test Drilling Program- Technical Memorandum”, October 4, 2018.

tested for geochemical compatibility analysis. At Site #1, two aquifer intervals were tested; 410-450 feet below ground surface (bgs) and 568-648 feet bgs. One thicker aquifer interval was tested at Site #3: 609-769 feet bgs. Phase II testing was conducted from December 11, 2017 to January 12, 2018 at Site #1 and January 26 to February 22, 2018 at Site #3.

Two potential source waters identified by the City for ASR were considered as part of this study. Samples were collected from the Parshall flume after treatment at the Greenwood WWTP. Water from the O.N. Stevens WTP was collected from the distribution system. Analyses from these samples were used in evaluating source water and native groundwater compatibility. Water quality data is presented in Appendix A.

Based on additional conversations with the City, it was deemed that the most likely recharge source would be Greenwood WWTP effluent if preliminary geochemical compatibility proved favorable due to less competing needs for its use, native groundwater quality considerations, and more frequent availability for recharge than O.N. Stevens WTP water. However, for purposes of this report both sources are evaluated and considered.

Figure 1. Site Plan for ASR Exploratory Drilling Testing Program



3 Sample Collection and Methods of Analysis

Geochemical Solutions, LLC (Geochemical Solutions) teamed with HDR to provide geochemical analysis and modeling. Geochemical Solutions reviewed project objectives, performed a broad-scale literature review of Gulf Coast aquifer studies, and contacted laboratories to discuss objectives and confirm laboratory testing methods. Based on this information, Geochemical Solutions developed a field sample collection method for preparing soil core samples and identified testing methods to provide the data needed for geochemical analysis and modeling as shown in Table 3-1, and described in further detail in Appendix B.

Composite cores were collected in the field using the following procedure:

- A coring tool was developed and used by the driller to collect an intact core through the aquifer interval of interest.
- Representative core samples were prepared by collecting materials from the center of the core to minimize contact with drilling fluids.
- Materials from cores corresponding to a storage interval of interest were homogenized, with a sample extracted for laboratory analysis. For example, for a 10 foot long 6 inch diameter core, a one inch diameter core along the entire 10 feet from the center of the core was placed in a clean container and mixed thoroughly. Care was taken in the field to minimize the time the material was exposed to air.
- A glass jar provided by the soils laboratory was filled to the top with the homogenized material. This produced a lab sample representative of the bulk composition of the original core.
- Samples were placed in a refrigerator according to laboratory directives and shipped to the laboratory in a cooler with ice.

Table 3-1. Aquifer Solid Testing: Corpus Christi ASR

Informational Need	Recommended Tests	Notes
1. Visual character	Photograph	None.
2. Surface area of particles in aquifer solid matrix	Grain size analysis	None.
3. Minerals present and relative percentage in aquifer solid mix	Rietveld X-Ray Diffraction (XRD)	Rietveld XRD is a quantitative XRD and reports percentages of minerals in an analyzed sample. This information, with sequential extraction (discussed below) provides more robust information for unconsolidated sediments than grain mount thin section petrology, scanning electron microscopy, and acid insoluble residue analysis.
4. Minerals present and relative percentage in aquifer solid mix	X-Ray Fluorescence (XRF)	XRF is used to determine the elemental composition of aquifer materials.

Table 3-1. Aquifer Solid Testing: Corpus Christi ASR

Informational Need	Recommended Tests	Notes
5. Total constituents of concern (COCs) concentrations per mass of aquifer solid	EPA Method (3050/6010)	3050 digestion is a standard EPS protocol that provides near-total concentrations dissolving only elements that may become soluble in water.
6. COCs in geochemically reactive aquifer solid phases	Sequential, selective extraction (SEE).	SEE is more specific and discreet than acid extractable analysis and provides more useful information for feasibility evaluation. Partition constituents of concern among electrostatic exchangeable sites, carbonate minerals (sensitive to pH) and ferric iron solids (sensitive to pH and redox state). SEM/EDAX is a suitable alternative, but is more time consuming, costly, and may not be sufficiently sensitive for all trace constituents.
7. Capacity to adsorb cations from solution	Cation exchange capacity (CEC)	None.

Source: Geochemical Solutions, LLC

Groundwater samples from aquifer storage zones of interest at Sites #1 and #3, discussed previously in Section 2, were collected during pump testing. Samples were submitted for laboratory analysis for a select suite of chemical constituents, including regulated organic, inorganic and radionuclide constituents, as listed in Table 3-2. Analytical results for both potential source waters and the three groundwater zones tested are discussed in Section 5. A table of laboratory results is provided in Appendix A.

Field water quality readings collected during constant rate pumping tests are presented in Table 3-3. These measurements were recorded to track changes in groundwater quality as pumping occurred. A Horiba U-52 water quality meter equipped with a flow cell was attached to a sample tap on the discharge line near the well head. The Horiba U-52 was programmed to collect and store readings every 30 minutes during the constant rate test. Field parameters measured include the following: temperature, pH, conductivity, dissolved oxygen (DO), oxidation-reduction potential (ORP), and turbidity. The following additional parameters were calculated by the instrument; total dissolved solids, salinity, and specific gravity. These results were discussed in the previous technical memorandum[3] and were used for geochemical analysis and modeling, as described in Appendix B.

Table 3-2. Water Quality Analyses

Analyte or Analyte Group	Analysis Method
Ammonia	EPA 350.1
Asbestos	ENV 005

[3] HDR, "Exploratory Test Drilling Program- Technical Memorandum", October 4, 2018.

Table 3-2. Water Quality Analyses

Analyte or Analyte Group	Analysis Method
Biological Oxygen Demand	SM 5210B
Bromide	EPA 300.0
Calcium	SM 3500 Ca B
Chloride	EPA 300.0
Color	SM 2120B
Cyanide, free	EPA OIA 1667
Dioxin (2,3,7,8-TCDD)	1613B
Dissolved Organic Carbon (DOC)	SM 5310C
E. Coli and Total Coliform	SM 9223B
Fecal Coliform	SM 9222D
Fluoride	SM 4500-F-C
Herbicides, chlorinated (2,4,5-TP and 2,4 D)	SW8151A
Iron, ferric and ferrous	SM 3500FED
Metals, total and dissolved	EPA 200.8, EPA 245.1
pH	SM 4500H+B
Nitrate and Nitrite	EPA 353.2
Odor (Threshold Odor Number)	SM 2150B
Pesticides, chlorinated	EPA 608
Polychlorinated Biphenyls (PCBs)	EPA 608
Radium 226, Radium 228, Gross Alpha, Gross Beta	EPA 904.0, EPA 903.1, EPA 900.0,
Semivolatile Organic Compounds (SVOCs)	EPA 625
SVOCs, low-level	SW8270
Silicon	SW6010
Sulfate	EPA 300.0
Surfactants	SM 5540C
Total Alkalinity, Bicarbonate	SM 2320B
Total Dissolved Solids	SM 2540C
Total Phosphorus	EPA 365.1
Uranium	SW6020
Volatile Organic Compounds (VOCs)	EPA 624

Table 3-3. Field Groundwater Quality Parameters

Parameter	Units	Site #1 Intermediate Interval (410-450 feet bgs)	Site #1 Deep Interval (570-650 feet bgs)	Site #3 (607-767 feet bgs)	
Temperature	degrees C	23.13	26.21	27.9	min
		24.03	28.26	28.2	max
		23.73	26.95	28.10	avg
pH	standard units	7.86	8.51	7.7	min
		7.88	8.85	7.8	max
		7.87	8.75	7.7	avg
Conductivity	mS/cm	18.6	13.8	23.8	min
		18.8	14.5	24.4	max
		18.71	14.12	24.30	avg
Dissolved Oxygen	mg/L	0.00	0.20	0.00	min
		0.00	1.61	0.22	max
		0.00	0.36	0.13	avg
ORP	mV	-336	-194	-180.0	min
		-333	-160	-173.0	max
		-334.0	-182.8	-176.3	avg
Turbidity	NTU	3.80	0.10	8.1	min
		10.10	7.00	48.0	max
		5.58	3.47	23.5	avg
Total Dissolved Solids	mg/L	11,500	8,540	14,700	min
		11,600	8,990	15,100	max
		11,590	8,750	15,000	avg
Salinity	ppm	11,000	8,000	14,400	min
		11,100	8,300	14,800	max
		11,080	8,150	14,700	avg
Specific Gravity	g/cm^3	1.0057	1.0024	1.0071	min
		1.006	1.0029	1.0074	max
		1.00586	1.00274	1.0074	avg

4 Water Quality Compatibility Considerations

The water quality results were evaluated to identify source water compatibility issues for storing two different types of recharge water, Greenwood WWTP treated effluent or O.N. Stevens WTP potable supplies from the City's distribution system, in three different storage zones; Site #1 at 410-450 feet bgs (CCASR-1-TW450), and 568-648 feet bgs (CCASR-1-TW650), and Site #3: 609-769 feet bgs (Site #3). Recharge water is anticipated to come in contact with the groundwater in these storage zones. This contact interface where blending of recharge water and native groundwater is likely to occur is referred to as the buffer zone. An additional groundwater sample at Site #1 was collected and analyzed for an upper zone located about 150 feet bgs, corresponding to the screened interval for a new shallow monitoring well installed during this project, but is not reported in this memo since the interval was found to have no hydraulic connection to the lower 450 feet or 650 feet bgs zones.

Based on initial water quality results for the Greenwood WWTP treated effluent sample, a second sample was collected at the same location on July 11, 2018 and analyzed for bacteria, nutrients, radionuclides, and metals. All water quality results from laboratory analyses are included in Appendix A. The results from the verification sample were not significantly different from the original Greenwood WWTP effluent sample results.

The primary impact of recharge water quality incompatibility includes physical plugging, mobilization of metals, mineral precipitation, biofouling, and/or aquifer formation damage.

Physical Plugging - The tendency for a storage zone to plug during recharge is a function of the quality of the recharge, especially the total suspended solids concentration, and the size of the storage zone matrix pores. Monitoring mounding and drawdown during recharge and recovery, respectively, can provide data needed to predict the potential for physical plugging.

Mobilization of Metals – Leaching of arsenic and metals is a result of chemical disequilibrium caused by the introduction of dissimilar fresh water into the aquifer storage zone. As a result of fluid-rock interaction, the concentration of metals in stored water may exceed the concentrations in both the source and native groundwater conditions. A difference in redox state between injected and native groundwater appears to be the main cause of leaching (Maliva and Missimer, 2010).

Mineral Precipitation - Chemical reactions with native groundwater, recharge water, and aquifer matrix can precipitate metal-bearing oxides. Dissolved oxygen can play a key role in how minerals can clog aquifer pore space and reduce water quality. If dissolved oxygen concentrations exceed 1 mg/L, conditions are favorable for metal bearing-mineral precipitation.

Biofouling - Dissolved oxygen and nutrients such as phosphate, inorganic nitrogen, and organics can promote biological growth, reducing pore space in the aquifer. Biofilm growth can also interplay with mineral precipitation and cause further aquifer plugging. These issues may extend to the well and significantly reduce well efficiency if not managed with disinfection periodically. Biofilm growth can be mitigated with disinfection prior to recharge or periodic disinfection of the ASR well. Standards for disinfection are outlined in the American Water Works Association (AWWA) Standard 654-13.

Formation Damage and Dissolution - Additional concerns include damage to clay particles and mineral dissolution. If mineral compositions of recharge and native groundwater are different, it may be possible to introduce a salt solution to the wells to stabilize clays. If the ionic strength of the recharge water exceeds that of the native groundwater, clays may be strengthened in the interstitial spaces.

5 Water Quality Evaluation

Table 5-1 provides an overview of water quality data for potential source waters for storage and native groundwater in the preferred storage zones. A full list of all laboratory water quality measurements is presented in Appendix A.

Table 5-1. Laboratory Water Quality Data for Potential Source Water and Native Groundwater Storage Zones Tested During the Exploratory Program

Repeat List	MCL (mg/L)	SMCL (mg/L)	Unit	Greenwood WWTP (12/13/17)	O.N. Stevens WTP (3/8/18)	CCASR-1-TW450 (12/19/17)	CCASR-1-TW650 (1/11/18)	Site #3 (2/20/18)
Alkalinity			mg/L	187	157	122	108	91
Alkalinity, Total (As CaCO3)			mg/L	190		129	124	102
Ammonia			mg/L	0.5	0.5	<0.2	0.3	0.3
Arsenic, total	0.01		µg/L	3.08	<1.00	<1.25	0.619	<1.00
Arsenic, dissolved	0.01		µg/L	2.92	1.63	<5.00	<1.00	<5.00
Bromide			mg/l	1.66	0.36	<20	14.7	21
Calcium			mg/L	159	65.9	240	197	317
Chloride		300	mg/L	579	169	4,270	3,262	5,738
Chromium total	0.1		µg/L	0.542	<1.00	<1.26	<0.251	<1.00
Color (color units)		15	PtCo	19	1	2	8	21
Cyanide (as free Cyanide)	0.2		µg/L	2.5	ND	ND	ND	ND
Dissolved organic carbon			mg/L	6	4.42	0.96	<0.3	<0.3
E. Coli	positive detection			present	absent	absent	absent	absent

Table 5-1. Laboratory Water Quality Data for Potential Source Water and Native Groundwater Storage Zones Tested During the Exploratory Program

Repeat List	MCL (mg/L)	SMCL (mg/L)	Unit	Greenwood WWTP (12/13/17)	O.N. Stevens WTP (3/8/18)	CCASR-1-TW450 (12/19/17)	CCASR-1-TW650 (1/11/18)	Site #3 (2/20/18)
Fecal Coliforms	positive detection		cfu	10	<1	<1	1	<1
Ferric Iron			mg/L	<0.200	<0.200	<0.200	<0.200	<0.200
Ferrous Iron			mg/L	0.034	<0.0200	0.062	0.71	0.939
Ionic Strength			mol/L	0.0428	0.0156	0.2386	0.2063	0.3521
Iron (total and dissolved and Fe^{2+}/Fe^{3+}) total		0.3	µg/L	125	<50.0	<250	370	673
Iron (total and dissolved and Fe^{2+}/Fe^{3+}) dissolved		0.3	µg/L	<78.0	<78.0	<390	<78.0	<390
Lead total	0.015		µg/L	0.175	<0.500	<0.600	0.144	<2.50
Lead dissolved	0.015		µg/L	<0.700	<0.700	<3.50	<0.700	<3.50
Magnesium (laboratory reported only total, est.)			µg/L	25,000	12,400	52,800	35,600	78,100
Manganese, total		0.05	µg/L	127	<2.20	48.5	56	113
Manganese, dissolved		0.05	µg/L	114	<2.50	50.4	48.5	106
Nitrate	10		mg/L	16.4	1.6	<0.02	9.9	5.4
Odor (TON)		3		40	1	200	1.1	1
pH, minimum		7		7.85	8.05	7.61	7.88	
Phosphate (shown as Total Phosphorous on City WUL report per email 3/19/18)			mg/L	3.5	<0.2	<0.2	<0.03	<0.2
Potassium (laboratory reported only total, est.)			µg/L	17,600	8,340	6,600	5,540	8,240
Selenium, total	0.05		µg/L	<0.860	<0.500	<4.30	6.34	15.4
Selenium, dissolved	0.05		µg/L	1.12	<1.00	14.7	8.66	13.4
Silica (reported as silicon)			mg/L	10	8.9	7.4	6.6	8.2
Sulfate		300	mg/L	254	104	2306	1693.3	2979
Sulfide, total dissolved								
Total Coliforms	positive detection			present	absent	present	present	present
Total Dissolved Solids		1,000	mg/L	1,711	622	9,545	8,253	14,085
Uranium	0.03		µg/L	6.8	1.1	ND	ND	ND
Biochemical Oxygen Demand			mg/L	2	<4	<3	<3	<3
Phosphorous			mg/L	3.5	<0.2	<0.2	<0.03	<0.2
Ca+Mg/(Na+K)			-	0.537	0.543	0.093	0.083	0.092

5.1 Total Dissolved Solids (TDS)

Total dissolved solids (TDS) plays a critical role in aquifer compatibility. Although the native groundwater is more saline, the redox and pH conditions that drive aquifer solid stability are very similar to that of the recharge water according to the geochemical analysis performed (Appendix B). Under ASR operations, a gradient of salinity will exist between the native groundwater and the recharge water. The magnitude of that gradient is driven by physical mixing of the two waters. Geochemical modeling of the potential for release of constituents within the aquifer formation that might compromise the chemical nature of recharged water indicates that the effect will be small to negligible. Lowering the salinity of the native groundwater could lead to release of cations to solution. Consideration of salinity differences would primarily impact the buffer zones between the native brackish groundwater and the stored freshwater.

Ionic strength should be within a one-half order of magnitude of aquifer quality to prevent swelling, repulsion, and migration of clay minerals (Bott, 2017). The native groundwater at the test sites has relatively high TDS concentrations and considered brackish (3,000 to 10,000 mg/L) or saline (>10,000 mg/L). Greenwood WWTP effluent and O.N. Stevens WTP finished water quality do not meet the ionic strength goals to prevent clay fragmentation at the storage sites, as shown in Table 5-2, although the geochemical analysis describes this phenomena to be unlikely to occur. Clay fragmentation issues can lead to issues with dispersion or swelling of clay particles which can irreversibly diminish recharge capacity.

Further compatibility testing and conditioning of wells through pilot testing could assist with developing protocol to keep clay minerals stable.

Table 5-2. Salinity data for all sampling points

Lab Data	SMCL	Unit	Greenwood WWTP (12/13/17)	O.N. Stevens WTP (3/8/18)	CCASR-1-TW450 (12/19/17)	CCASR-1-TW650 (1/11/18)	Site #3 (2/20/18)
Ionic Strength	-	mol/L	0.0428	0.0156	0.2386	0.2063	0.3521
½ Order of Magnitude Ionic Strength	-	mol/L	-	-	0.0477	0.0413	0.070
Total Dissolved Solids	1000	mg/L	1,711	622	9,545	8,253	14,085

5.2 Cation/Anion Chemistry

A summary of the cation/anion ratio is provided in Table 5-3. Greenwood WWTP effluent has similar calcium and magnesium levels to aquifer storage zones, however potassium is two to three times higher in concentration. The catio/anion ratio for the O.N. Stevens WTP plant water is very similar to the Greenwood WWTP effluent, however the raw cation/anion concentrations are nearly half of what is found in WWTP effluent. Aquifer samples are sodium dominant, as would be expected with brackish/saline water. There is a cation/anion disparity between the source water for recharge and the native groundwater, which has the potential to damage clays and impact operation of groundwater recharge. Since scaling and clogging are not expected in mixed waters, monitoring of aquifer clay quality is recommended during a groundwater recharge program.

Table 5-3. Cation/anion ratio for all sampling points

Lab Data	Unit	Greenwood WWTP (12/13/17)	ON Stevens WTP (3/8/18)	CCASR-1-TW450 (12/19/17)	CCASR-1-TW650 (1/11/18)	Site #3 (2/20/18)
Ca+Mg/(Na+K)	-	0.537	0.543	0.093	0.083	0.092

5.3 Temperature

Low recharge temperatures (less than 10 deg C) can dramatically increase the viscosity of water, reducing permeability through the storage aquifer. Since the average temperature of the source waters is close to 20 to 25 deg C, cycle testing using water less than 10 deg C could reduce exposure of recharge water to lower permeability portions of the storage zones, skewing the test results. Considerations should be made to limit short-term cycle testing to annual periods when recharge would typically occur.

5.4 Nutrients and Total Suspended Solids

Organics, phosphates, and inorganic nitrogen species (ammonia, nitrate, and nitrite) in the Greenwood WWTP treated effluent can be problematic for biological fouling of the well during recharge where the dissolved oxygen and nutrient concentrations are the highest. Biological fouling can lead to increased back-flushing of the well and the need for higher disinfectant residual concentrations. Typical signs of biofouling include decreased water quality, reduced specific capacity (gpm per foot of mounding or drawdown), changes in iron or manganese concentrations (from the recharge water), and increased occurrence of slime in the recharge and recovery well.

Nutrient concentrations from the O.N. Stevens WTP are not expected to cause consistent biofouling issues. Seasonal management of biofouling should be monitored and a disinfectant could be fed periodically when signs of biofouling are detected.

An examination of the Greenwood WWTP effluent nutrients is provided in Table 5-4. The dominant nutrients likely to cause biological growth are BOD_5 (the five day biochemical oxygen demand), DO, nitrate, and phosphate. The concentrations of nutrients found in Greenwood WWTP effluent are favorable for biofouling.

In addition, even low amounts of total suspended solids (<2 mg/L) can contribute to particle accumulation in the recharge well and the aquifer storage zone. The current levels of total suspended solids in the Greenwood WWTP effluent may contribute to physical plugging, so if recharge is pursued, backflushing could be triggered by decreased specific capacity during recharge.

Table 5-4. Biological water quality parameters

Parameter	Units	Average (2010-2016)
BOD_5	mg/L	2.63
pH	S.U.	7.67
Dissolved Oxygen	mg/L	7.84
Ammonia	mg/L	0.66
Nitrate	mg/L	15.9
Nitrite	mg/L	0.36
Total Suspended Solids	mg/L	5.2

5.5 Pathogens

Beyond the vicinity of the actual well, aquifers may act as nutrient and pathogen removal systems through a processes known as soil aquifer treatment (Pyne, 2016; Velasquez, 2016). The soil aquifer treatment acts as a polishing step for WWTP effluent where organics, pathogens, and nutrients may be partially removed. Dissolved oxygen uptake by microbial communities can take hours to days and generates carbon dioxide (CO_2). Ammonia reduction and denitrification processes are a slower reaction but can occur in a few days to weeks.

According to Velasuez et al. (2016), soil aquifer treatment may be able to achieve 50-75% removal of dissolved organic carbon, 75% removal of ammonia, and up to 99% removal of phosphate. Pathogen removal may occur by predation or adsorption. Removal efficiencies vary by physical/chemical structure of the aquifer, but some studies have shown up to 99% removal of fecal coliform, depending on the duration of storage. Additional removal of pharmaceuticals and personal care products and other micro-contaminants routinely found in treated wastewater effluent may also be achievable in the soil aquifer treatment.

5.6 Redox conditions

Oxidation and reduction (redox) reactions play an important role in geochemical processes. To estimate the redox conditions that may develop in the groundwater during recharge, a redox framework described in Jurgens et al. (2009) was utilized to characterize the potential for dominant redox processes. Criteria and threshold concentration for redox processes associated with nitrate, manganese, and iron can be predictive of redox chemistry. At average conditions, all sites demonstrated anoxic chemistry (average DO <0.36 mg/L), however a wide range of DO was measured (0.00 to 1.61 mg/L). When the average field water quality data was compared to the redox process criteria from Jurgens et al. (2009), groundwater from CCASR-1-TW450 indicated potential for sulfate, iron, and manganese redox processes. Groundwater from CCASR-1-TW650 and Site #3 indicated strong nitrate redox processes, with the potential for sulfate, iron, and manganese redox processes.

Geochemical Solutions, LLC provided a geochemical analysis and model (using USGS computational codes – PHREEQC) to anticipate the changes to geochemical stability by introducing recharge water from Greenwood WWTP or O.N Stevens WTP to the aquifer. PHREEQC is a computer program developed by the United States Geologic Survey (USGS) that is designed to perform a wide variety of aqueous geochemical calculations to identify geochemical incompatibilities (Parkhurst and Appelo, 2013). A summary of the PHREEQC modeling and conceptual geochemical evaluation is summarized in Section 6, and discussed in more detail in Appendix B. Further investigation of the mineralogy and water quality demonstrated that the of the aquifer environment is generally oxic, and therefore the criteria exceedences described in Jurgen et al. (2009) may not be representative of redox conditions that are highly dependent on dissolved oxygen distribution in the aquifer. Results from the geochemical analysis indicated that the redox conditions of native groundwater, aquifer solids, and potential recharge waters are similar. It was noted, however, that organic carbon in the source water for recharge could produce microbial growth that changes the redox conditions from oxidative to reductive. That change could produce mineral scale and possible release of constituents of concern like manganese, iron, and other major cations. For this reason, organic carbon reduction of source water prior to recharge may be necessary.

Organic carbon can be successfully removed by either biological or physical-chemical methods as a polishing step. Biological processes, such as a membrane bioreactor or biological filter, are capable of reducing organic carbon through biological degradation. While these processes tend to be more cost effective than physical-chemical methods, they do require consistent monitoring and fine-tuning to ensure that the biological community maintains effective carbon removal. Physical-chemical methods, such as enhanced coagulation, granular activated carbon, and magnetic ion exchange resin (MIEX), have also been implemented for enhanced carbon removal. These systems require additional operations and maintenance costs associated with chemical addition, and carbon/resin replacement.

5.7 Additional Considerations

Color issues associated with the presence of iron are typically observed at concentrations of 0.3 mg/L or higher. When iron is found in anoxic conditions, dissolved (ferrous) iron is the dominant form (colorless). As dissolved oxygen increases during withdrawal from the well, there is the potential for dissolved iron to precipitate as iron hydroxide solids, which contribute to a reddish brown water color. Both the Greenwood WWTP treated effluent and O.N. Stevens WTP finished water total iron concentrations are below 0.3

mg/L. The highest iron concentrations were measured in CCASR-1-TW650 and Site 3, both greater than 0.3 mg/L. A significant portion of the iron is ferrous, but color issues may occur at these locations during withdrawal as dissolved oxygen concentrations increase. Iron concentrations in the aquifer should be monitored for potential oxidation of iron.

Sulfate is a parameter that is frequently monitored and causes a salty taste. The Greenwood WWTP treated effluent concentration slightly exceeds the EPA's Secondary Drinking Water Standards for nuisance chemicals (250 mg/L), while water in the potential recharge zones greatly exceed the secondary standards. While sulfate is odorless, sulfate-reducing bacteria are capable of converting sulfate to hydrogen sulfide, which has a rotten egg smell. These organisms are typically present in anaerobic soils. Maintaining a residual dissolved oxygen concentration greater than 0.15 mg/L can assist with reducing hydrogen sulfide production.

6 Summary of Geochemical Analysis and Modeling Findings

Geochemical Solutions, LLC prepared a geochemical conceptual site model to describe the expected geochemical processes that are expected to play a significant role in equilibrium conditions achieved, or a lack thereof, during recharge and storage. Theoretical model calculations were performed to evaluate the extent to which constituents held in aquifer solids could be released into recharged water within the storage zone, and mixtures of native groundwater with recharge water. The primary constituents considered in the geochemical analysis include: aluminum (Al), arsenic (As), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), selenium (Se), and uranium (U) measured in the laboratory by Sequential Extraction Procedure (SEP) characterization, although bulk water characteristics, such as major anions and cations, redox potential, pH and dissolved oxygen were also evaluated in modeling calculations. Cadmium is often a constituent of concern during evaluations such as this one, but was detected in only one groundwater sample, far below water quality standards. Thus, cadmium was not included in the geochemical assessment.

The SEP process evaluates the presence of metals in the aquifer matrix and adsorption or desorption potential. The native groundwater has high salinity and inhibits adsorption of primary constituents of concern identified above to exchangeable sites on aquifer solids. Thus, the low concentrations of these constituents can only be released if the aquifer solids host is dissolved. Given that the recharge (WWTP and WTP) water is saturated with dissolved oxygen and has slightly alkaline pH, the carbonate minerals, hydrous ferric oxide (HFO), and crystalline iron oxides embedded in the mineral surfaces are expected to remain stable. Thus, the primary constituents of concern are not conceptually expected to be released in significant quantities.

Geochemical Solutions, LLC performed PHREEQC (Parkhurst and Appelo, 2013) geochemical modeling using the water quality results obtained for potential recharge water sources, native groundwater, and mixtures of source and native groundwater relative to the aquifer matrix expected to be encountered in the potential storage and recovery zones at Sites #1 and #3 based on aquifer solids testing results. The present computational evaluation is based on the conceptual model that describes dominant processes that are expected to control water quality upon injection of recharge water. Owing to the relatively long residence times for recharge water and the relatively fast reactions anticipated, the approach used is thermodynamic and not kinetic. That is to say the approach describes ultimate end points of processes and not the specific time required to reach that end point. The dominant processes include: mixing of recharge water and native groundwater, precipitation of saturated solids from solution, aquifer solid dissolution, and adsorption/desorption. Intentional bias was included in model calculations to provide for a “worst case” scenario by assuming that the constituents of concern are surface adsorbed, which increases the potential for their release to contacting recharge water. This approach provides an upper bound estimate for potential concentrations of constituents in the contacting recharge water. Modeled results showed that, ultimate maximum anticipated (modeled) dissolved concentrations were below applicable maximum contaminant levels (MCLs). The results of the geochemical compatibility analysis is included in Appendix B. Laboratory test reports associated with the aquifer core analyses described in Table 3-1 are included at the end of Appendix B.

Mixing of native groundwater with recharge water does not appear to have the potential to lead to scaling or clogging, however special considerations of water quality parameters discussed in Section 5 should still be kept in mind. Major minerals that can commonly form to produce scale (calcite, gypsum, HFO) are either under-saturated or at equilibrium with the mixed waters and therefore should not precipitate. Care should be taken to avoid introduction of organic carbon into the groundwater system that could lead to microbial processes that can change the oxic character of the groundwater environment to a more chemically reducing one, consistent with the Section 5.6 discussion.

The present evaluation provides an indicator that potential recharge water is geochemically compatible with the native groundwater aquifer solids. At this field-scale level, no critical issues are identified. However, the present solids data should not be interpreted as rigorously representative as there is some uncertainty due to compositing of aquifer solids over relatively long intervals, field challenges in collecting representative sands and clay in the 410-450’ intermediate interval at Site #1, and heterogeneity of the Gulf Coast Aquifer. Prediction and assuredness of part per billion concentrations is impractical at this level, driven by limited data for aquifer solids described above, uncertainty in stability in Greenwood WWTP treated effluent quality in the future including climatological impacts and seasonal fluctuations, and standard model errors introduced and compounded by combining model calculation components. The study presents an assessment that suggests the aquifer solids and Greenwood WWTP treated effluent water are geochemically compatible and should yield a positive outcome, barring any unknown factors that could not be included in calculations. Additional analysis and recharge testing would add confidence, but the present evaluation does not identify any specific fatal flaws. Further modeling is probably not necessary if aquifer solids encountered in the storage and recovery zone have a mineralogy and chemical character that is consistent with the present evaluation.

7 Water Treatment Considerations

The O.N. Stevens WTP is a potable water supply with no constituents identified that exceed MCL or secondary MCLs. Several constituents measured in the Greenwood WWTP treated effluent exceed MCL or secondary MCL levels and will likely warrant pre-treatment levels prior to recharge to comply with Texas Commission on Environmental Quality (TCEQ) provisions and avoid plugging or biofouling, including; bacteria, nutrient removal (nitrate), and manganese. Additionally, recharge water with high turbidity water and/or organic carbon water should be avoided. For most ASR applications, TCEQ has required treatment to drinking water standards prior to recharge. Although the storage aquifer is considered brackish is would still be classified as an underground source of drinking water (USDW) per Title 40, Code of Federal Regulations (40 CFR) Section 144.3, and it is likely that additional treatment at the WWTP may be required by TCEQ to meet MCLs, and could be necessary to maintain ASR operations and water compatibility. Treatment may include modifications to the WWTP's treatment process to promote de-nitrification, reduce turbidity, and improve the disinfection system to further inactivate bacteria.

Although Greenwood WWTP treated effluent detected levels for arsenic, cyanide, radionuclides (gross alpha and gross beta) and uranium are lower than MCLs, TCEQ may require monitoring of Greenwood WWTP treated effluent for these constituents due to the lack of presence in native groundwater in the tested storage zones. These treatment considerations will be discussed further in a future technical memorandum focused on ASR operating policies and conditions.

8 Bibliography

Bott, C., 2017. HRSD's Vision for Managed Aquifer Recharge in Eastern Virginia.

Jurgens, B., Mcmahon, P., Chapelle, F., 2009. An Excel® Workbook for Identifying Redox Processes in Ground Water.

Maliva, R.G. and Missimer, Thomas M., 2010, Aquifer Storage and Recovery and Managed Aquifer Recharge Using Wells: Planning, Hydrogeology, Design, and Operation.

Parkhurst, D.L., and Appelo, C.A.J., 2013, Description of input and examples for PHREEQC version 3— A computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations: U.S. Geological Survey Techniques and Methods, book 6, chap. A43, 497 p., available only at https://pubs.usgs.gov/tm/06/a43/.

Pyne, R.D.G., 2016. Approximately 175 Operational ASR Wellfields in the United States (2016) in at least 25 States, plus many other countries 11.

Velasquez, D.J., 2016. Soil Aquifer Treatment for wastewater reclamation in a high water demand society 149.

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Appendix A – Water Quality Laboratory Test Results

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Appendix A- Water Quality Laboratory Results

Analyte	Analyte Group	Method	Maximum Contaminant Level (mg/L or pCi/L for radionuclides)	Maximum Contaminant Level (µg/L)	Secondary Maximum Contaminant Level (mg/L) (MCL)	Secondary Maximum Contaminant Level (µg/L)	Unit	Greenwood WWTP (12/13/17) AND Results for analytes re-tested on 7/11/18 shown in (###[a])	ON Stevens WTP (3/8/18)	CCASR-1-TW450 (12/19/17)	CCASR-1-TW650 (1/11/18)	Site 3 (2/20/18)
E. Coli	Bacteria	SM 9223B	positive detection					present (absent[a])	absent	absent	absent	absent
Fecal Coliforms	Bacteria	SM9222D	positive detection				cfu	10 (TNTC[a])	<1	<1	1	<1
Total Coliforms	Bacteria	SM 9223B	positive detection					present (present[a])	absent	present	present	present
2,3,7,8-TCDD (Dioxin)	Dioxin	1613B	0.00000003	0.00003000			pg/L	ND	ND	ND	ND	ND
Alkalinity	General	SM2540C					mg/L	187	157	122	108	91
Alkalinity, Total (As CaCO3)	General	SM2320B					mg/L	190		129	124	102
Ammonia	General	EPA 350.1					mg/L	0.5	0.5	<0.2	0.3	0.3
Asbestos	General	ENV 005	7				MFL	<AS	0	<AS	<AS	NA
Bicarbonate (alkalinity, bicarbonate as CaCO3)	General	SM2320B					mg/L	190		129	124	102
Bromide	General	EPA 300.0					mg/l	1.66	0.36	<20	14.7	21
Chloride	General	EPA 300.0			300	300,000	mg/L	579	169	4270	3262	5738
Color (color units)	General	SM2120B			15		PtCo	19	1	2	8	21
Cyanide (as free Cyanide)	General	OIA 1677	0.2	200			µg/L	2.5	ND	ND	ND	ND
Dissolved organic carbon	General	SM 5310C					mg/L	6	4.42	0.96	<0.3	<0.3
Fluoride	General	SM 4500-F-C	4	4,000	2	2,000	mg/L	1.03	0.69	1.11	74.1	171
Odor (TON)	General	SM2150B			3			40	1	200	1.1	1
pH, minimum	General	SM 4500H+B			7			7.85	8.05	7.61	7.88	
Silica (reported as silicon)	General	SW6010					mg/L	10	8.9	7.4	6.6	8.2
Sulfate	General	EPA 300.0			300	300,000	mg/L	254	104	2306	1693.3	2979
Total Dissolved Solids	General	SM 2540C			1,000		mg/L	1711	622	9545	8253	14085
Biological Oxygen Demand	General	SM 5210B					mg/L	2	<4	<3	<3	<3
Phosphorous	General	EPA 365.1					mg/L	3.5	<0.2	<0.2	<0.03	<0.2
2,4,5-TP	Herbicides	SW8151A	0.05	50			µg/L	<0.0500	<0.0510	<0.0505	<0.0500	<0.0505
2,4-D	Herbicides	SW8151A	0.07	70			µg/L	<0.0600	<0.0612	<0.0606	<0.0600	<0.0606
Dalapon	Herbicides	SW8151A	0.20	200			µg/L	0.197	<0.0714	<0.0707	0.54	0.213
Dinoseb	Herbicides	SW8151A	0.01	7			µg/L	<0.0500	<0.0510	<0.0505	<0.0500	<0.0505
Aluminum total	Metals	EPA 200.8			0.20	200	µg/L	20.7	147	45.1	106	252
Aluminum dissolved	Metals	EPA 200.8			0.20	200	µg/L	7.75	146	<20.0	<20.0	<20.0
Antimony total	Metals	EPA 200.8	0.01	6			µg/L	1.53	<0.600	<0.265	0.066	<0.600
Antimony dissolved	Metals	EPA 200.8	0.01	6			µg/L	0.854	<0.800	<4.00	<0.800	<4.00
Arsenic total	Metals	EPA 200.8	0.01	10			µg/L	3.08 (5.56[a])	<1.00	<1.25	0.619	<1.00
Arsenic dissolved	Metals	EPA 200.8	0.01	10			µg/L	2.92 (4.37[a])	1.63[b]	<5.00	<1.00	<5.00
Barium total	Metals	EPA 200.8	2.00	2,000			µg/L	56.1	99.2	15.1	16.2	18.3
Barium dissolved	Metals	EPA 200.8	2.00	2,000			µg/L	51.1	105	15.7	15.6	15.6
Beryllium total	Metals	EPA 200.8	0.00	4			µg/L	<0.0910	<0.500	<0.455	<0.0910	<0.500
Beryllium dissolved	Metals	EPA 200.8	0.00	4			µg/L	<0.700	<0.700	<3.50	<3.50	<3.50
Boron	Metals	EPA 200.8					µg/L		307			12400
Cadmium total	Metals	EPA 200.8	0.01	5			µg/L	<0.0770	<0.600	<0.385	0.153	<0.600
Cadmium dissolved	Metals	EPA 200.8	0.01	5			µg/L	<0.800	<0.800	<4.00	<0.800	<4.00
Calcium	Metals	SM 3500CaB					mg/L	159	65.9	240	197	317[c]
Chromium total	Metals	EPA 200.8	0.10	100			µg/L	0.542	<1.00	<1.26	<0.251	<1.00
Chromium dissolved	Metals	EPA 200.8	0.10	100			µg/L	<1.00	<1.00	<5.00	<1.00	<5.00
Cobalt total	Metals	EPA 200.8					µg/L	0.663	<0.800	<0.200	0.047	<0.800

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Analyte	Analyte Group	Method	Maximum Contaminant Level (mg/L or pCi/L for radionuclides)	Maximum Contaminant Level (µg/L)	Secondary Maximum Contaminant Level (mg/L) (MCL)	Secondary Maximum Contaminant Level (µg/L)	Unit	Greenwood WWTP (12/13/17) AND Results for analytes re-tested on 7/11/18 shown in (###[a])	ON Stevens WTP (3/8/18)	CCASR-1-TW450 (12/19/17)	CCASR-1-TW650 (1/11/18)	Site 3 (2/20/18)
Cobalt dissolved	Metals	EPA 200.8					µg/L	<0.800	<0.800	<4.00	<0.800	<4.00
Copper total	Metals	EPA 200.8	1.30	1,300	1.00	1,000	µg/L	0.734	1.07	<0.850	1.64	35.5
Copper dissolved	Metals	EPA 200.8	1.30	1,300	1.00	1,000	µg/L	1.21	1.45	<5.00	<1.00	16.1
Iron (total and dissolved and Fe2+/Fe3+) total	Metals	EPA 200.8			0.30	300	µg/L	125	<50.0	<250	370	673
Iron (total and dissolved and Fe2+/Fe3+)dissolved	Metals	EPA 200.8			0.30	300	µg/L	<78.0	<78.0	<390	<78.0	<390
Lead total	Metals	EPA 200.8	0.02	15			µg/L	0.175	<0.500	<0.600	0.144	<2.50
Lead dissolved	Metals	EPA 200.8	0.02	15			µg/L	<0.700	<0.700	<3.50	<0.700	<3.50
Magnesium (laboratory reported only total, est.)	Metals	EPA 200.8					µg/L	25000	12400	52800	35600	78100
Manganese total	Metals	EPA 200.8			0.05	50	µg/L	127	<2.20	48.5	56	113
Manganese dissolved	Metals	EPA 200.8			0.05	50	µg/L	114	<2.50	50.4	48.5	106
Molybdenum total	Metals	EPA 200.8					µg/L	2.19	2	<2.45	102	207
Molybdenum dissolved	Metals	EPA 200.8					µg/L	1.92	1.68	<7.50	98.8	192
Nickel total	Metals	EPA 200.8					µg/L	2.97	1.41[b]	<0.550	<0.110	5.78
Nickel dissolved	Metals	EPA 200.8					µg/L	2.95	1.2[b]	<5.00	<1.00	<5.00
Potassium (laboratory reported only total, est.)	Metals	EPA 200.8					µg/L	17600	8340	6600	5540	8240
Selenium total	Metals	EPA 200.8	0.05	50			µg/L	<0.860	<0.500	<4.30	6.34	15.4
Selenium dissolved	Metals	EPA 200.8	0.05	50			µg/L	1.12	<1.00	14.7	8.66	13.4
Silver total	Metals	EPA 200.8			0.10	100	µg/L	0.093	<0.500	0.59	0.06	<0.500
Silver dissolved	Metals	EPA 200.8			0.10	100	µg/L	<0.800	<0.800	<4.00	<0.800	<4.00
Sodium (laboratory reported only total, est.)	Metals	EPA 200.8					µg/L	334,000	118,000	3,150,000	2,780,000	4,280,000
Strontium total	Metals	EPA 200.8					µg/L	1,150	646	11,800	7,850	13,900
Strontium dissolved	Metals	EPA 200.8					µg/L	1,080	575	11,800	9,610	13,500
Thallium (not requested) total	Metals	EPA 200.8	0.002	2	0.01		µg/L	<0.250	<0.800	1.88	0.462	<0.800
Thallium (not requested) dissolved	Metals	EPA 200.8	0.00	2	0.01		µg/L	<1.00	<1	<5.00	<1.00	<5.00
Tin (not requested)	Metals	EPA 200.8					µg/L		<0.900			<0.900
Titanium	Metals	EPA 200.8					µg/L		<0.800			3.46
Vanadium (not requested)	Metals	EPA 200.8					µg/L		4.52			<1.00
Zinc total	Metals	EPA 200.8			5.00	5,000	µg/L	34	<2.00	138	81.4	187
Zinc dissolved	Metals	EPA 200.8			5.00	5,000	µg/L	33.4	<2.50	<12.5	65.9	150
Ferric Iron	Metals	SM3500FED					mg/L	<0.200	<0.200	<0.200	<0.200	<0.200
Ferrous Iron	Metals	SM3500FED					mg/L	0.034	<0.0200	0.062	0.71	0.939
Mercury	Metals	E245.1	0.00	2			mg/L	0.000104[b]	<0.0000300	<0.0000300	0.000039	<0.0000300
Mercury dissolved	Metals	E245.1	0.00	2			mg/L		<0.0000300	<0.0000300	<0.0000300	<0.0000300
Nitrate	Nutrients	EPA 353.2 (EPA 300.0)	10.00	10,000			mg/L	16.4	1.6	<0.02	9.9	5.4
Nitrite	Nutrients	EPA 353.2 (EPA 300.0)	1.00	1,000			mg/L	<0.02	<0.02	<0.02	<0.02	<10
Aroclor 1016, 1221, 1232,1242,1248,1254,1260 (previously listed as Polychlorinated biphenyls (PCB))	PCBs	E608	0.001	1			mg/L	<0.0000125 each	<0.0000126 each	<0.0000126 each	<0.0000125 each	<0.0000125 each
Chlordane	Pesticides	E608	0.002	2			mg/L	<0.0000250	<0.0000253	<0.0000253	<0.0000250	<0.0000250
Endrin	Pesticides	E608	0.002	2			mg/L	<0.0000000830	<0.0000000838	<0.0000000838	<0.0000000830	<0.0000000830
Heptachlor	Pesticides	E608	0.0004	0.4			mg/L	0.00000161	<0.0000000455	<0.0000000455	<0.0000000450	<0.0000000450
Heptachlor epoxide	Pesticides	E608	0.0002	0.2			mg/L	<0.0000000270	<0.0000000273	<0.0000000273	<0.0000000270	<0.0000000270

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Analyte	Analyte Group	Method	Maximum Contaminant Level (mg/L or pCi/L for radionuclides)	Maximum Contaminant Level (µg/L)	Secondary Maximum Contaminant Level (mg/L) (MCL)	Secondary Maximum Contaminant Level (µg/L)	Unit	Greenwood WWTP (12/13/17) AND Results for analytes re-tested on 7/11/18 shown in (###[a])	ON Stevens WTP (3/8/18)	CCASR-1-TW450 (12/19/17)	CCASR-1-TW650 (1/11/18)	Site 3 (2/20/18)
Methoxychlor	Pesticides	E608	0.04	40			mg/L	<0.000000573	<0.000000579	<0.000000579	<0.000000573	<0.000000573
Toxaphene	Pesticides	E608	0.003	3			mg/L	<0.0000250	<0.0000253	<0.0000253	<0.0000250	<0.0000250
Radium-226 (pCi/L)	Radionuclides	903.1	5				pCi/L	0.23 (+/- 0.14)	ND (+/- 0.16)	0.75 (+/- 0.25)	0.57 (+/- 0.34)	1.7 (+/- 0.6)
Radium-228 (pCi/L)	Radionuclides	GFPC					pCi/L	ND (+/- 0.3)	ND (+/- 0.44)	1.5 (+/- 0.49)	2.12 (+/- 0.63)	3.6 (+/- 1.1)
Gross Alpha (pCi/L)	Radionuclides	900	15				pCi/L	9.2 +/- 5.5; (2.29 +/-4.41[a])	ND (+/- 1.1)	ND (+/- 16)	ND (+/- 18)	ND (+/- 27)
Gross Beta (pCi/L)	Radionuclides	900	50				pCi/L	59 +/- 12; (13.2 +/- 5.19[a])	8.3 (+/- 2.1)	ND (+/- 12)	ND (+/- 26)	ND (+/- 15)
Uranium	Radionuclides	SW6020	0.03	30			µg/L	6.8 (5.36 +/- 0.195[a])	1.1	ND	ND	ND
Surfactants MBAS (previously listed as foaming agents)	Surfactants	SM5540C			0.50	500	mg/L	0.061	0.034	<0.0250	<0.0250	<0.0250
Alachlor	SVOC	SW 8270	0.0002	0			µg/L	<0.20	<0.21	<0.20	<0.20	<0.20
Simazine	SVOC	SW 8270	0.0040	4			µg/L	<0.20	<0.21	<0.20	<0.20	<0.20
Atrazine	SVOC	EPA 625	0.0030	3			µg/L	<0.606	<0.606	<0.612	<0.600	<0.600
Benzo(a)pyrene (previously listed as Benzopyrene)	SVOC	EPA 625	0.0002	0			µg/L	<0.404	<0.404	<0.408	<0.400	<0.400
Bis (2-ethylhexyl) phthalate (previously listed as Di(2-ethylhexyl)phthalate)	SVOC	EPA 625	0.01	6			µg/L	<0.808	<0.808	<0.816	<0.800	<0.800
Hexachlorobenzene	SVOC	EPA 625	0.00	1			µg/L	<0.303	<0.303	<0.306	<0.300	<0.300
Hexachlorocyclopentadiene	SVOC	EPA 625	0.05	50			µg/L	<0.404	<0.404	<0.408	<0.400	<0.400
Pentachlorophenol	SVOC	EPA 625	0.00	1			µg/L	<0.808	<0.808	<0.816	<0.800	<0.800
Di(2-ethylhexyl)adipate	SVOC	SW 8270D	0.40	400			µg/L	ND	ND		ND	ND
1,1,1-Trichloroethane	VOCs	EPA 624	0.20	200			µg/L	<0.500	<0.500	<0.500	<0.500	<0.500
1,1,2-Trichloroethane	VOCs	EPA 624	0.01	5			µg/L	<0.500	<0.500	<0.500	<0.500	<0.500
1,1-Dichloroethylene	VOCs	EPA 624	0.01	7			µg/L	<0.500	<0.500	<0.500	<0.500	<0.500
1,2,4-Trichlorobenzene	VOCs	EPA 624	0.07	70			µg/L	<0.600	<0.600	1.94	<0.600	<0.600
1,2-Dichloroethane	VOCs	EPA 624	0.01	5			µg/L	<0.500	<0.500	<0.500	<0.500	<0.500
1,2-Dichloropropane	VOCs	EPA 624	0.01	5			µg/L	<0.700	<0.700	<0.700	<0.700	<0.700
Benzene	VOCs	EPA 624	0.01	5			µg/L	<0.600	<0.600	<0.600	<0.600	<0.600
Carbon tetrachloride	VOCs	EPA 624	0.01	5			µg/L	<0.600	<0.600	<0.600	<0.600	<0.600
cis- 1,2-dichloroethene (previous cis-1,2-Dichloroethylene)	VOCs	EPA 624	0.07	70			µg/L	<0.600	<0.600	<0.600	<0.600	<0.600
1,2- Dibromo-3-chloropropane (previously listed as Dibromochloropropane)	VOCs	EPA 624	0.0002	0.2			µg/L	<0.500	<0.500	<0.500	<0.500	<0.500
Methylene Chloride (previously as Dichloromethane)	VOCs	EPA 624	0.01	5			µg/L	<1.00	<1.00	<1.00	<1.00	<1.00
Ethylbenzene	VOCs	EPA 624	0.70	700			µg/L	<0.500	<0.500	<0.500	<0.500	<0.500
1,2-Dibromoethane (previously listed as ethylene dibromide)	VOCs	EPA 624					µg/L	<0.400	<0.400	<0.400	<0.400	<0.400
Chlorobenzene (previously listed) Monochlorobenzene	VOCs	EPA 624	0.10	100			µg/L	<0.400	<0.400	<0.400	<0.400	<0.400
1,3-Dichlorobenzene (previous identified o-Dichlorobenzene)	VOCs	EPA 624	0.60	600			µg/L	<0.500	<0.500	<0.500	<0.500	<0.500
1,4-Dichlorobenzene (previously para-Dichlorobenzene)	VOCs	EPA 624	0.08	75			µg/L	<0.600	<0.600	<0.600	<0.600	<0.600

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Analyte	Analyte Group	Method	Maximum Contaminant Level (mg/L or pCi/L for radionuclides)	Maximum Contaminant Level (µg/L)	Secondary Maximum Contaminant Level (mg/L) (MCL)	Secondary Maximum Contaminant Level (µg/L)	Unit	Greenwood WWTP (12/13/17) AND Results for analytes re-tested on 7/11/18 shown in (###[a])	ON Stevens WTP (3/8/18)	CCASR-1-TW450 (12/19/17)	CCASR-1-TW650 (1/11/18)	Site 3 (2/20/18)
Styrene	VOCs	EPA 624	0.10	100			µg/L	<0.500	<0.500	<0.500	<0.500	<0.500
Tetrachloroethene (previous Tetrachloroethylene)	VOCs	EPA 624	0.01	5			µg/L	<0.600	<0.600	<0.600	<0.600	<0.600
Toluene	VOCs	EPA 624	1.00	1,000			µg/L	<0.500	<0.500	<0.500	<0.500	<0.500
trans-1,2-Dichloroethene (previous trans-1,2-Dichloroethylene)	VOCs	EPA 624	0.10	100			µg/L	<0.400	<0.400	<0.400	<0.400	<0.400
Trichloroethene (previous Trichloroethylene)	VOCs	EPA 624	0.01	5			µg/L	<0.500	<0.500	<0.500	<0.500	<0.500
Vinyl chloride	VOCs	EPA 624	0.00	2			µg/L	<0.400	<0.400	<0.400	<0.400	<0.400
Xylenes (total)	VOCs	EPA 624	10	10,000			µg/L	<0.500	<0.500	<0.500	<0.500	<0.500

[a] Results for re-tested Greenwood sample on 7/11/18

[b] J flag.

[c] Calcium was also evaluated with Method EPA 200.8 and detected at 266 mg/L.

exceeds MCL/SMCL

TNTC- Too many colonies present to provide a result.

MFL- Million fibers/liters, fibers longer than 10 µm

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Appendix B – Geochemical Analysis and Core Laboratory Results

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MEMORANDUM

TO:	Kristi Shaw	**FROM:**	Mark A. Williamson, PhD Jason Nolan, PhD
ORGANIZATION:	HDR	**DATE:**	January 31, 2019
CC:	File	**PROJECT:**	1060.1
SUBJECT:	Geochemical Analysis and Modeling for Corpus Christi Aquifer Storage and Recovery Feasibility Project (E16265)		

1.0 Purpose and Need

The Corpus Christi Aquifer Storage and Recovery Conservation District (District) was formed in 2005 to facilitate aquifer storage and recovery (ASR) project(s) by the City of Corpus Christi to enhance its water supply, treatment, and distribution operations for the benefit of its retail and wholesale customers (CCASRCD, 2014). The District contracted with HDR to perform an initial aquifer characterization study beneath the District to evaluate ASR feasibility in accordance with District goals and objectives at three locations within the District's boundaries (HDR, 2016). The initial aquifer characterization identified an area near the Corpus Christi International Airport and north of the Greenwood wastewater treatment plant (WWTP) as a preferable site for ASR development. Based on a Phase I exploratory testing program of Sites 1, 2, 3, and 6, which included borehole log and geophysics interpretations down to 1,200 feet, Sites 1 and 3 were determined to contain sand intervals that may be suitable for ASR storage and recovery and therefore were evaluated more closely in a Phase II program that included collection of additional field data that was used to perform geochemical analysis and modeling, the results of which are presented in this technical memo. This document presents an evaluation of the geochemical characteristics of the aquifer at three proposed sites, two City-owned locations located within approximately a ten-square mile area inclusive of the Corpus Christi International Airport. This memo addresses the possible changes in water quality on the recharge of two potential source waters (potable water from the O.N. Stevens water treatment plant (WTP) or treated recovered water from the Greenwood WWTP) at these sites.

2.0 Approach

Aquifer storage and recovery is a long-term water supply strategy and thus sites must be evaluated using geochemical models to assist in evaluating future water quality relative to chemical constituents of concern (COC). The following objectives were developed to characterize the potential of geochemical impacts with recharge from a new source water into the Gulf Coast aquifer and native groundwater system, including:

- Evaluate current aquifer groundwater geochemistry and mineralogy that may influence groundwater stored water with recharge from WTP or WWTP sources.
- Develop a conceptual model for the drilled Sites 1 and 3 that include anticipated geochemical processes that may affect water quality by altering native aquifer conditions with recharge of WTP or WWTP source water.

- Perform geochemical modeling calculations for injection of representative potential recharge water that includes effects related to mixing with native groundwater, dissolution/precipitation of solids and adsorption/desorption of COCs.

The present assessment considers two potential recharge sites, one at two specific depth intervals and another at a single depth interval, based on anticipated sand thicknesses identified during Phase I borehole geophysics. They are labeled as: Site 1-450; Site 1-650; and Site 3-750 with the site ID denoting the bottom depth of the aquifer strata studied. Two distinct water sources for recharge are considered: Greenwood WWTP treated effluent and O.N. Stevens WTP potable water. Potential impacts associated with the regionally relevant COCs that are of concern in drinking water are assessed. Specific methods for sample collection and presentation of analytical results are presented elsewhere (Exploratory Test Program Summary for Corpus Christi Aquifer Storage and Recovery Feasibility Project- Task 2 (E16265)). The COCs considered in this report are: aluminum (Al), arsenic (As), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), selenium (Se), and uranium (U), although bulk water characteristics, such as major anions and cations, redox potential, pH and dissolved oxygen are also used to conduct modeling calculations. Cadmium is often a COC during evaluations such as this one, but was detected in only one groundwater sample, far below water quality standards. Thus, cadmium was not included in the present evalution.

Sediment cores were collected from potential sites and aliquots from those cores were homogenized and stored under cool temperatures prior to analysis via chemical and physical methods. For aquifer solids, several characterization procedures provide important information for modeling potential future water quality.

<u>Aquifer Solids:</u>

Bulk X-Ray Fluorescence Analysis provides a rough assessment of the concentration of COCs. This measurement is most useful to compare with acid digestible COCs (see below) to evaluate what proportion of each COC is environmentally available and which are chemically resilient.

X-Ray Diffraction with Rietveld Refinement provides a quantitative assessment of minerals present in the aquifer solids matrix, and their abundance. A more typical XRD analysis only identifies minerals present, not their abundance. Rietveld XRD characterization identifies potentially reactive minerals that may (or may not) contain COCs. It also aids in understanding the oxidation state of the aquifer solids, which plays a key role in sequestering or releasing COCs, as recharge water (sourced from the WTP or WWTP) water is recharged. This type of data can also be key in understanding the potential of the aquifer to resist changes in the pH of the recharged water.

Total concentrations of COCs in solids is measured by digesting the sample in acid and then analyzing the resulting solution. Technically speaking, the procedure used is USEPA Method 3050 for digestion coupled with USEPA Method 6020A to analyze the solution. This procedure is often called "total" concentration, but is, in fact, only a partial digestion. Very unreactive silica-based minerals are not dissolved in this procedure. Method 3050 extracts COCs that have a possibility of being released to the environment. The use of USEPA Method 3050/6020A does not discriminate between the types of minerals from which COCs are extracted.

Sequential Extraction Procedure (SEP) determines the concentrations of COCs in several categories of mineral reactivity. The procedure provides important insight into what bulk materials the trace COCs are associated with. SEP can also identify potential COC-containing materials in aquifer solids that are structurally amorphous and, therefore, not identified with XRD. For example, arsenic associated with adsorption sites on mineral surfaces is of greater concern than arsenic held within crystalline iron oxides.

Sequential extraction provides useful insight into the distribution of COCs in sediment matrices that helps to constrain reactions that could be associated with injection of recharge water. Sequential extraction is conducted using a multi-step process that leaches a single sediment sample with increasingly stronger solutions. Each extraction is designed to dissolve specific mineral classes, releasing the COCs associated with that fraction. As steps progress, the likelihood for COC release from sediment under typical aquifer conditions decreases. The overall result partitions COCs among mineral classes and provides meaningful insight into potential release of COCs to recharge water. The seven fractions included in the SEP analysis procedure (see Appendix C for method specifics) used to evaluate core composite samples collected during the field drilling program are:

1. *Exchangeable Fraction:* Measures COCs that are weakly, and reversibly, sorbed to soil minerals, amorphous solids, and/or organic material by electrostatic forces.
2. *Carbonate Phase:* This extraction targets COCs that are held in carbonate minerals.
3. *Non-Crystalline Iron and Aluminum Oxides Phase (described as Non-crystalline Materials Phase in lab report methods, Appendix C):* This extraction targets COCs that are complexed by amorphous hydrous ferric hydroxide (HFO) and hydrous aluminum oxide (HAO).
4. *Crystalline Iron Oxide Phase (described as Metal Hydroxide Phase in lab report methods, Appendix C):* COCs held in more crystalline ferric iron oxides (more stable and resistant than HFO).
5. *Organic Phase:* This extraction targets trace elements strongly bound to organic material.
6. *Sulfide Minerals:* The extraction is used to characterize COCs associated with sulfide minerals.
7. *Residual Fraction:* Trace elements remaining in the soil after the previous extractions, which are distributed among silicates, phosphates, and unreactive oxides.

The cation exchange capacity (CEC) of aquifer solids is a measure of the capacity to adsorb COC from contacting solution. CEC was collected prior to having sequential extraction data and served as a potential backup parameter for modeling should (1) HFO/HAO not be present in the sediments and (2) there was sufficient COC concentrations in injection water (above MCLs) to address potential attenuation. However, sequential extraction data and chemical analysis of injection water showed that HFO/HAO was present to potentially release COCs and that nothing was held by exchangeable sites to release. In addition, injection water COC concentrations are not high enough to require assessment of potential attenuation. Hence, CEC was ultimately not needed, or used.

<u>Native Groundwater and Potential Recharge Water</u>

Analysis of the chemical characteristics of native groundwater contributes to establishing a basis for the current geochemical conditions. A specific goal is to constrain equilibrium water-rock interactions. Similar characterization of recharge water provides the information required to understand the extent to which recharge water will disrupt current equilibrium conditions and potentially degrade the quality of the recharge water by dissolving some portions of the aquifer solids or causing COCs in the recharge water to precipitate after interacting with the aquifer solids.

3.0 Conceptual Site Model

A geochemical conceptual site model (CSM) describes the expected geochemical processes at a site (Merkel, 2008) that are expected to play a significant role. A conceptual model is necessary as it guides computational work by defining specific conditions, and ensures that all relevant processes are included, while ignoring any irrelevant processes. For ASR assessments, there are numerous processes that may occur as water is recharged into an aquifer and displaces the already established steady equilibrium state. To the extent that the recharge water is substantially different in terms of pH, redox (Eh) and salinity conditions, as well as overall chemical composition, aquifer solids may become chemically unstable. Subsequently, COCs may be released into the recharge water, restricting its potential uses. The conceptual model is thus used as a self-check to ensure that computations consider the appropriate processes for this specific type of project, but avoids unnecessary complications.

Injection of recharge water will create a bubble of fresh water in the aquifer. At the margins of the bubble, there will be substantial mixing, while in the middle, virtually no mixing will occur. For the various degrees of mixing, the solution in the groundwater system will develop a new chemical equilibrium with the contacted aquifer solids. Possible reactions can include precipitation or dissolution of solids, adsorption of COCs from mixed solutions onto aquifer solids, or release of adsorbed COCs originally present in the aquifer. The extent of these processes is regulated most by substantial changes in pH, redox, and salinity. On a comparative basis, native groundwater has a similar pH, but more salinity and less dissolved oxygen. The lower salinity of the recharge water can be conceptually expected to lead to some release of COCs to solution from aquifer solids onto which they may be adsorbed.

Site characterization data provides original aquifer conditions. Native groundwater chemistry clearly defines the water that will mix with the chemistry of the recharge water, while characterization of solids defines potentially reactive materials and the presence of potential COCs. Previously introduced site characterization techniques yielded the following findings that define the CSM and guide computation modeling:

<u>Bulk X-Ray Fluorescence Analysis (Appendix A):</u> The aquifer solids are dominated by silica, aluminum, calcium, sodium, and iron. This bulk chemistry is consistent with the presence of common minerals in sandy environments like quartz, feldspar, and clays, as noted in the drilling logs.

<u>X-Ray Diffraction (XRD) with Rietveld Refinement (Appendix A):</u> Quartz (unreactive) is dominant across all sites (51.5 – 77%), with much lower amounts of feldspars (e.g. oligoclase, orthoclase; 3.5-6.5%; unreactive). The presence of calcite (calcium carbonate; 4.6 – 18.7%) is important and documents a high pH buffering capacity for the contact water. Recharge water will equilibrate with the calcite in the aquifer very rapidly to buffer the pH at slightly alkaline conditions, and is an important reaction. Dolomite (calcium-magnesium carbonate), occurring at some sites at low levels (0 - 0.3%), will have a similar effect as calcite. The presence of solid phase iron minerals is also noted at each site (0.1 – 0.8%), as either hematite, goethite, or magnetite, representing potential reactive minerals and potential release of COCs across sites, pending changes in pH and redox state. Hydrous ferric oxide (HFO) is also likely present, but is generally an amorphous, microcrystalline-crystalline solid and is not detected by XRD. These iron phases are stable only under oxic (oxygen containing) conditions and their presence is indicative of oxic conditions in the aquifer. HFO contains both strong and weak binding sites and plays a significant role in binding COCs (e.g. arsenic) (Dzombak and Morel, 1990). More importantly, these iron-containing phases are often responsible for regulating these COCs and their presence at the site provides a basis for understanding potential future changes in water quality following injection of the WWTP water.

<u>Total COCs in Sediment (Appendix B):</u> Samples from all of the sites showed expected concentrations of iron (5000 – 6300 mg/kg), aluminum (4100 – 7800 mg/kg), and manganese (120 – 250 mg/kg). With respect to more environmentally significant COCs, concentrations of arsenic (2.6 – 6 mg/kg), copper (4.8 – 11 mg/kg), chromium (4.4 – 10 mg/kg), lead (4.4 – 11 mg/kg), selenium (1.1 – 1.9 mg/kg), and uranium (0.48 – 2.1 mg/kg) were lower. All of the COCs are below global averages except for arsenic and selenium, which are higher (Mason and Moore, 1982). Site 1 sediment from both depth intervals

consistently contained lower concentrations of COCs than the other study locations. This aspect (the documented occurrence of COCs) is potentially important.

Sequential Extraction Procedure (Appendix C): Sequential Extraction Procedure (SEP) characterization reveals a lack of environmentally significant COCs associated with highly reactive exchangeable sites (SEP Step 1) and carbonate minerals (SEP Step 2). The native groundwater has a high salinity, which does not favor adsorption of COCs on exchangeable mineral surfaces, hence none would be expected to be detected in fraction 1 of the SEP. Indeed, in fraction 1 (exchangeable fraction), only manganese is present above detection limits, ranging from 1.6 – 3.3 mg/kg. No other COC's are held in easily exchangeable sites; hence, simple ion exchange (adsorption/desorption) would not be expected to have a significant impact on the quality of the recharge water. Thus, the groundwater conditions are consistent with the results of the SEP.

Environmentally sensitive COCs were observed to be associated with the amorphous and crystalline iron oxides (SEP Steps 3-4). However, the COCs appear to be present within these materials and not adsorbed onto their surfaces. Hence, for the COCs associated with these iron minerals to be released, the iron minerals would have to dissolve.

The sum of the SEP steps (1-4) represents the most geochemically reactive COC-containing phases. These phases are considered the most likely potential source of COCs from sediment if the recharge water destabilizes those solid phases. SEP steps 5 and beyond correspond to less reactive classes of material. Moreover, XRD indicates that mineral sulfides are not present and the presence of ferric iron solids indicate an oxic environment, in which sulfide phases are unstable and do not occur. In addition, as discussed in the report, the recharge water is quite consistent with the native groundwater in terms of Eh and pH, differing primarily in TDS. As such, it would not be expected to appreciably destabilize organically bound COCs.

As noted above, the relatively high salinity of the current groundwater inhibits adsorption of COCs. Thus, the low concentrations of COCs associated with these phases can only be released if the host is dissolved. Given that the recharge (WWTP and WTP) water is saturated with DO (dissolved oxygen), and has a slightly alkaline pH, carbonate minerals, HFO, and crystalline iron oxides are expected to remain stable. Thus, the COCs associated with these phases are not conceptually expected to be released in significant quantities. However, intentional bias is included in model calculations (see below) to provide for a "worst case" scenario by assuming that the COC's are surface adsorbed, which increases the potential for their release to contacting recharge water. This approach provides an upper bound estimate for potential concentrations of COCs in the contacting recharge water and is described below.

Groundwater Composition (see HDR document Exploratory Test Program Summary for Corpus Christi Aquifer Storage and Recovery Feasibility Project- Task 2 (E16265)): Generally speaking, the dissolved COC concentrations in the aquifer are consistently low across the sites. No COC values measured in native groundwater exceeded EPA maximum contaminant limits, with numerous COCs being non-detectable.

The aquifer is generally oxic, based on the mineralogy and presence of COCs in the sediment rather than dissolved[1]. The pH is slightly alkaline and appears to be buffered by the presence of Calcite. The aquifer is fairly saline (total dissolved solids content ranges from 8223 – 14,085 mg/L, with the sodium levels up to 4,280 mg/L and chloride up to 5,740 mg/L. Calcium is present, at 197-317 mg/L (average

[1] The presence of DO in native groundwater, and ferric iron minerals in the solids is inconsistent with a negative Eh. Further, as described by Lindberg and Runnells (1984), Eh measurements are fundamentally inconclusive in natural waters lacking sufficient electrochemical buffering (which is basically all natural waters except that with high iron, 10's of ppm and mostly higher). Thus, laboratory characterizations were the basis for establishing oxic conditions.

251 mg/L), with accompanying magnesium and sulfate concentrations ranging to 71.6 mg/L and 1,693-2,979 mg/L, respectively.

Saturation indices (SI) were calculated at all sites to assess the state of equilibrium between aquifer solid phases and native groundwater water. The saturation index (Langmuir, 1997) is calculated based on the following formula:

$$SI = \log \frac{IAP}{Ksp}$$

Where: IAP= Ion-activity product

K_{sp}= Solubility product

The SI of a solid phase can range from negative (undersaturated) to positive (supersaturated). An SI of zero (or nearly so) would indicate the solid/mineral is in equilibrium with the aqueous phases in solution. An SI value for a given mineral of less than zero (negative values) indicates that the mineral is unstable in the groundwater environment. SI values greater than zero suggest that the given mineral could be forming. For the present evaluation, understanding the stability of minerals already present in the aquifer solids is key. Unless the minerals are placed in an unstable condition through the injection of recharge water, COCs of environmental concern will remain in the aquifer solids and not compromise recharge water quality.

In summary, given the characterization data for the aquifer solids at the study site and the associated chemistry of the native groundwater and recharge water, we have a conceptual site model (CSM) to guide subsequent computational evaluation. Geochemical characterization of aquifer solids and associated groundwater informs us that COCs of environmental concern are present in the aquifer solids of the study site and that the native groundwater is quite saline, with a slightly alkaline pH and oxic character. The chemical quality of the recharge WWTP water can be degraded only to the extent that COC-containing aquifer solids become unstable on contact with relatively fresh WWTP or WWTP water mixes with native groundwater and its higher salinity. The principle focus of the present evaluation is COCs of environmental concern, and not mixing of fresh and saline water.

The SEP characterization provides the most critical information. It indicates that COCs are not present in exchangeable sites (Appendix C), which is consistent with the saline nature of the native groundwater. High salinity inhibits adsorption onto exchangeable sites on aquifer solids. COCs are also not really present in carbonate minerals (e.g. Calcite). However, iron and aluminum oxide phases (ranging from the relatively amorphous to crystalline) contain measureable concentrations of COCs. Changes in groundwater chemistry could lead to these COC-containing phases becoming unstable and releasing associated COCs.

The chemical stability of COC-containing iron and aluminum oxide phases is reliant on pH and oxidation-reduction potential. Alkaline pH and oxic conditions favor their stability, which is consistent with mineralogy that documents their presence in aquifer solids in contact with alkaline pH groundwater. The chemistry of recharge water is, therefore, of prime importance to understanding the potential for degradation of its quality upon contact with aquifer solids.

Recharge water appears to offer little to no mechanism for release of environmentally sensitive COCs from the aquifer solids. The pH of the recharge water is alkaline and typically quite similar (within 0.2 pH units) to the native groundwater. The recharge water is also saturated with DO. Hence, the recharge water will not significantly alter the pH or redox potential in a way that would cause iron oxide phases to dissolve. It is possible for the recharge water to produce a chemically reducing condition, which could lead to the instability of iron oxides and the release of COCs. However, this would require an appreciable increase in the dissolved organic carbon content of the recharge water. So, to the extent that the recharge water chemistry does not significantly change, the stability of the aquifer solids will be largely preserved.

4.0 Computational Geochemical Modeling

The goal of computational geochemical modeling for the project site is to clarify the present geochemical conditions and subsequently impose likely (or possible) conditions on the injection of WWTP water to gauge potential water quality changes. The overall effort provides an assessment of a likely outcome, but also provides the perspective of a bounding analysis to constrain the range of possible outcomes. Calculations are largely conducted using PHREEQC.

PHREEQC is a geochemical computational code developed by the US Geological Survey (Parkhurst and Appelo, 2013) and available freely for public use. It is used to speciate aqueous solutions, calculate equilibrium, evaluate saturation indices, model mechanistic adsorption, and simulate mixing of waters, in addition to other modules not utilized in this study. PHREEQC is script based, requiring a manually entered computer code. PHREEQC simulations typically results in large output files of results, which are post-processed by the modeler to extract only the specific data that is relevant to the study's objective for illustration and interpretation.

The present computational evaluation is based on the conceptual model that describes dominant processes that are expected to control water quality upon injection of recharge water. Owing to the relatively long residence times for recharge water and the relatively fast reactions anticipated, the approach used is thermodynamic and not kinetic. That is to say the approach describes ultimate end points of processes and not the specific time required to reach that end point. The dominant processes include: mixing of recharge water and native groundwater, precipitation of saturated solids from solution, aquifer solid dissolution, and adsorption/desorption.

Within the framework of the conceptual model, several computational assessments and calculations illustrate and constrain the potential geochemical stability of the groundwater system upon injection of recharge water and bound reasonably foreseeable potential changes in water quality.

Pourbaix (Eh-pH) Diagrams.
As noted above, COCs of environmental concern are present in iron and aluminum (HFO and HAO) oxide minerals that can be affected by changes in pH or redox state (Eh). Pourbaix diagrams provide the perspective to understand the extent to which the stability of these oxides might be compromised, or preserved.

Dissolution of Iron and Aluminum Oxides.
The dissolution of COC-containing iron and aluminum oxides can, as noted above, be promoted by changing pH or Eh conditions. The pH and Eh condition of recharge water appears to support the stability of iron oxides and not promote their dissolution. Hence, these iron oxides can only be expected to dissolve if they come into contact with water that is unsaturated with respect to iron and aluminum oxides. This can occur without changes in pH or Eh. Therefore, the present evaluation makes calculations based on mixing recharge water and native groundwater in a range of proportions to represent the recharge bubble, and simulate any oxide mass dissolving into that water. Mixing ratio calculations are made for a 5%:95% recharge water to GW ratio to 100%:0% recharge water: GW, at 5% step intervals size to cover the entire injection region of created recharge bubble. Associated proportional release of COCs (mass of COC per mass of iron oxide) is determined, and the resulting change in water quality is the result. This represents the expected case response for injection of recharge

water. This analysis represents a worst-case conservative assessment that maximizes the mass of COC release.

Hypothetical Release of COCs from Adsorption Sites.
The characterization of available aquifer solids, groundwater and recharge water suggest that simple dissolution of iron oxides appears to be the most likely mechanism for release of COCs to recharge WWTP water. However, to provide additional perspective and a bounding calculation, simulations were conducted assuming that COCs were, alternatively, held in exchangeable surface position on iron and aluminum oxides. This simply assumes a different geochemical mechanism for interaction of water with solids and limits the mass of COCs released to solution, resulting in lower concentrations than the expected case above.

Potential for Scaling and Clogging.
In addition to evaluating concerns related to the potential for compromising the chemical quality of recharged water via release of regulated COCs from the aquifer solids, the present evaluation made an initial assessment of the potential for scaling and clogging of either injection well screens or nearby aquifer solids through the formation of geochemical solid precipitates. To the extent that mixing of native groundwater with recharge water leads to a condition of significant oversaturation for any solids, solid precipites may form, leading toscaling of injection wells or clogging of aquifer porosity may occur. This assessment was made by mixing both potential recharge waters with native ground water associated with potential ASR target intervals. Unlike other calculations which used PHREEQC, this evaluation utilized the Geochemist's Workbench (commercially available program from Aqueous Solutions, LLC and is a world-wide standard geochemical calculation tool that relies on the same theory and mathematical basis as PHREEQC). The evaluation was made by mixing native groundwater with each potential recharge water, at ten percent increments, and calculating the state of saturation for all potential solid phases that might form.

4.1 Pourbaix Diagrams

Pourbaix diagrams display forms of solids and dissolved species for a given element that would be expected in groundwater or sediment. Hence, they are commonly referred to as stability diagrams and show the most stable species for the given solution conditions. Pourbaix diagrams are thermodynamic tools and do not account for kinetics. They illustrate energetically favored conditions.

Horizontal lines on Pourbaix diagrams represent transitions that depend on reduction-oxidation (redox) conditions but which are independent of pH. Vertical lines represent transitions that depend on pH but which are independent of redox conditions (Eh). Sloping lines represent transitions that depend both on pH and Eh.

Iron

As noted above, Goethite (a generally crystalline iron oxide mineral) was observed to occur in groundwater (at about 0.5%). Saturation index calculations indicate that the native groundwater is at equilibrium with amorphous HFO, while the SEP characterization indicates that COCs are present in each. So, below, are Pourbaix diagrams that illustrate the stability fields of HFO and Goethite, respectively, with native groundwater.

Figure 4.1.1 is a Pourbaix diagram highlighting HFO (shown in the figure as $Fe(OH)_3$; ppd[2]). The figure shows the position of the average site native groundwater conditions (of pH and Eh). Although several things are shown in the figure, the focus is the position of the native groundwater relative to HFO. Note that the groundwater is very nearly on the line separating dissolved iron ($FeSO_4$ in figure) and HFO. The groundwater is only just at/near equilibrium with HFO. With any decrease in Eh (more chemically reducing) or in pH (more acidic), the HFO would become unstable and start to dissolve, releasing COCs.

Recharge water is virtually the same pH as native groundwater, and with the presence of Calcite in the sediments as a buffer, no change in pH is expected. The recharge water also has a higher DO content and is expected, therefore, to potentially raise the Eh level slightly. In terms of both pH and Eh, the recharge water should not destabilize the HFO, and release associated COCs.

Figure 4.1.2 is a Pourbaix diagram for iron that highlights the stability of Goethite. Although similar to Figure 4.1.1, the native groundwater is even more solidly within the stability field for Goethite and the slight to no change in groundwater pH and Eh on injection of recharge water means that Goethite (and associated COCs) is expected to remain stable.

It is worth noting here that the ubiquitous occurrence of microbes can result in altered aquifer redox. If substantial dissolved organic carbon (DOC) is introduced to the aquifer, it could potentially stimulate microbial activity, which is likely to lead to more chemically reducing condition (lower Eh). Such a change could easily destabilize iron oxide phases, releasing COCs, and result in a degradation of water quality. Analysis of the recharge water indicates that DOC is present, but at very low and limited concentrations and is not deemed to represent a concern. This can be viewed as a risk and a caution to manage the chemical quality of recharged WWTP water to limit DOC.

Taken together, these Pourbaix diagrams illustrate that COC-containing iron oxides in the aquifer solids are stable under native conditions, and are anticipated to remain stable on injection of recharge water. This view does, of course, require that recharge water not vary appreciably in the future, particularly with respect to dissolved organic carbon.

[2] ppd indicates precipitated

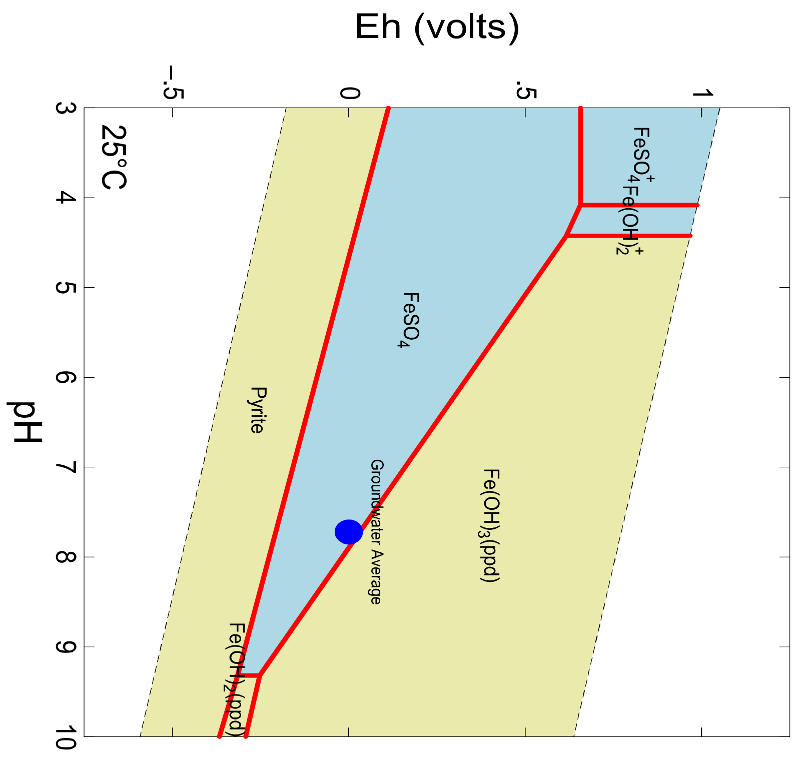

Figure 4.1.1Pourbaix diagram for iron, highlighting HFO.

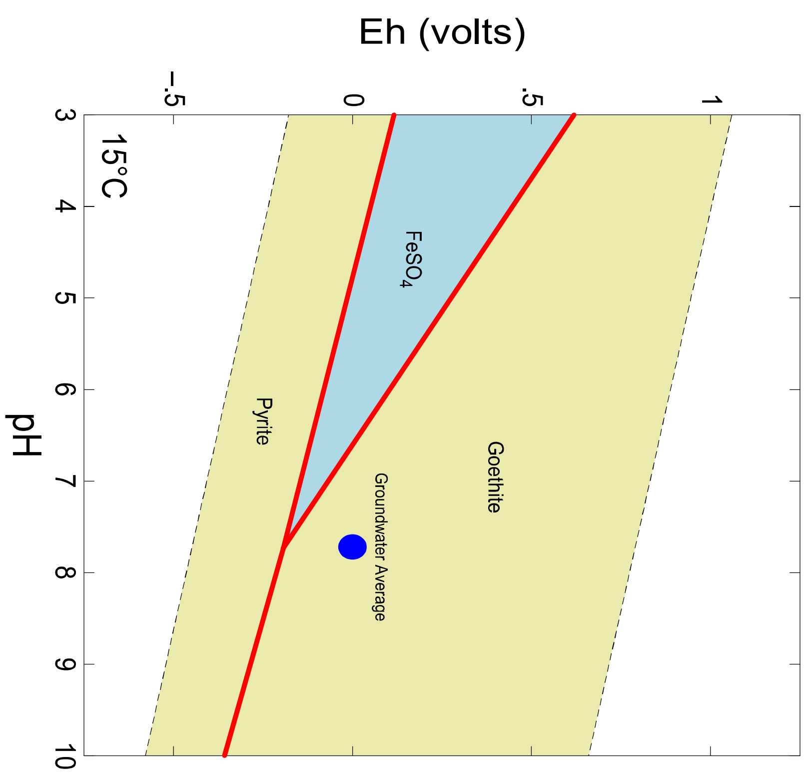

Figure 4.1.2 Pourbaix diagram for iron, highlighting Goethite.

Aluminum

Although hydrous aluminum oxides (HAO) were not detected by XRD, SEP characterization demonstrates their presence in the aquifer solids in a non- or micro-crystalline form. HAO can be an important phase for regulating trace COCs. Like iron oxides, COCs can be either incorporated into the structure of HAO, and released only by dissolution of the HAO, or held on exchangeable surface sites. As described elsewhere, adsorbed COCs were not observed with SEP characterization and so, like iron oxides, the basic geochemical stability of HAO is important.

Figure 4.1.3 is a Pourbaix diagram for aluminum, highlighting Gibbsite (equivalent to HAO). Also shown are native groundwater conditions. Even more than iron oxides, the groundwater environment is very much within the stability field of Gibbsite, and any modest changes in Eh and pH on injection of the recharge water will not result in the destabilization of Gibbsite. Any COCs associated with the aluminum oxides are unlikely to be released to solution.

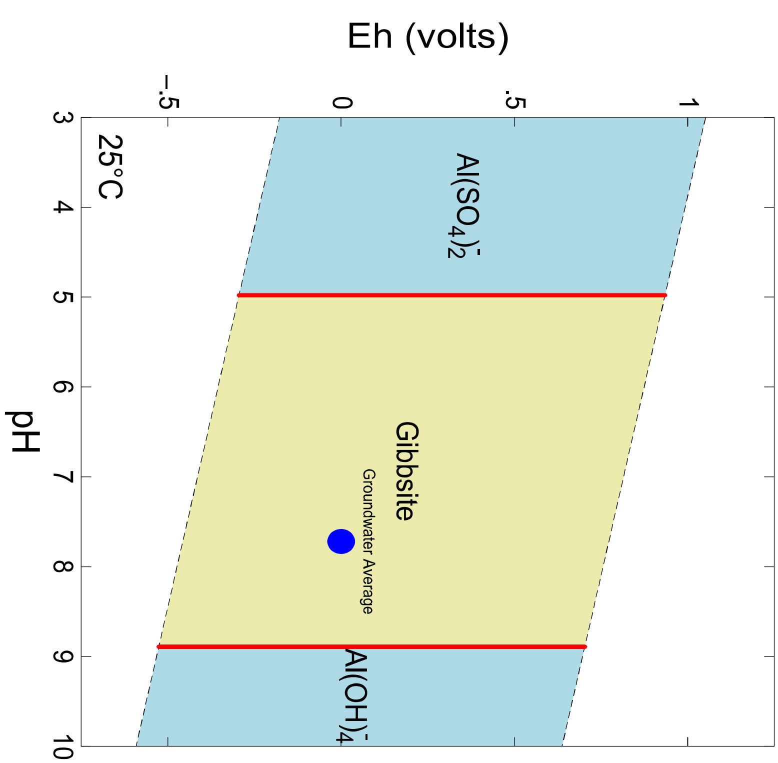

Figure 4.1.3. Pourbaix diagram for aluminum highlighting Gibbsite (HAO equivalent).

4.2 Groundwater Predictive Modeling of Iron Oxide Dissolution

The dissolution of HFO and the accompanying release of COCs within them represents, given the data available to date, the most probable mechanism for degrading the chemical quality of recharge WWTP water. As illustrated above, there are essentially no changes in master variables (pH and Eh) associated with injection of recharge water that would create a destabilizing environment for the HFO. However, the recharge water is very low in dissolved iron. This means that although overall conditions favor the stability of iron oxides, the low iron in the recharge water could lead to an unsaturated condition, causing the HFO to dissolve. This is not, technically, a case of being destabilized, but could lead to partial dissolution of the HFO and release of COCs to contacting water in the storage zone. The amount that could dissolve is limited to the amount required to raise the iron concentration to the saturated state. PHREEQC performs this calculation.

PHREEQC modeling mixed the recharge water and native groundwater in 20 different proportions, from 0% native groundwater to 95%, in 5% increments, and allowed that water to dissolve iron oxides. The increase in iron concentration was attributed to dissolution of HFO. This mass of iron was used to calculate an associated mass of COCs of environmental concern (mg COC per mg Fe in SEP analyses) released to solution.

Table 4.2.1 reports the PHREEQC-modeled increase in iron concentrations, which were used to calculate the associated increase in COC concentrations. Table 4.2.2 reports the *maximum* concentration determined for each COC, from all of the mixing proportions. As the table shows, the maximum anticipated (modeled) dissolved COC concentrations are all well below the MCL values.

Table 4.2.1. Increase in iron in solution during recharge injection, maximum from mixing ratios.

Site	**Increase in iron in solution (µg/L)**
Site 1 450ft bgs & Greenwood WWTP	9.57E-05*
Site 1 450ft bgs & Stevens WTP	9.62E-05
Site 1 650ft bgs & Greenwood WWTP	3.06E-05
Site 1 650ft bgs & Stevens WTP	3.11E-05
Site 3 750ft bgs & Greenwood WWTP	5.40E-03
Site 3 750ft bgs & Stevens WTP	5.40E-03

Note: 9.57E-05 notation is equal to alternative scientific notation 9.57×10^{-5}. A similar equivalency applies to all tabulated results.

Table 4.2.2. Maximum COC in WWTP injection water (mg/L) for 20 proportions of native groundwater and injection water (as new equilibrium occurs).

Site	**As**	**Cr**	**Cu**	**Mn**	**Pb**	**Se**	**U**
MCL	0.01	0.1	1.3	0.05*	0.015	0.05	0.03
Site 1 450ft bgs & Greenwood WWTP	3.26E-05	3.13E-05	4.03E-05	2.10E-03	1.45E-05	4.66E-05	1.26E-05
Site 1 450ft bgs & Stevens WTP	3.28E-05	3.15E-05	4.05E-05	2.11E-03	1.45E-05	4.68E-05	1.27E-05
Site 1 650ft bgs & Greenwood WWTP	9.54E-06	7.59E-06	1.57E-05	1.20E-03	2.70E-05	1.83E-05	1.32E-05
Site 1 650ft bgs & Stevens WTP	9.67E-06	7.70E-06	1.59E-05	1.22E-03	2.74E-05	1.86E-05	1.34E-05
Site 3 750ft bgs & Greenwood WWTP	1.55E-03	9.41E-04	2.52E-03	8.47E-02	2.45E-03	2.44E-03	4.67E-04
Site 3 750ft bgs & Stevens WTP	1.55E-03	9.41E-04	2.52E-03	8.47E-02	2.45E-03	2.44E-03	4.67E-04

*secondary standard

4.3 Groundwater Predictive Modeling with Surface Complexation

Although straightforward dissolution of iron oxides represents the expected response after injection of recharge water, alternative modeling of a release of COCs via a sorption/desorption mechanism represents an additional perspective and bounding calculation. This calculation is more hypothetical and more complicated.

Mechanistic surface complexation models (SCM) typically rely on oxides (iron and aluminum here) on sediment surfaces to account for the phenomenon of surface complexation (COCs adsorbed onto solid surface). The diffuse double layer model describing ion adsorption to HFO and HAO (gibbsite) by Dzombak and Morel (1990), and Karamalidis and Dzombak (2010), was selected for this effort and is well developed in literature. These proxy minerals are determined by quantifying oxides of these metals in field collected sediment, thus accounting for the bulk of reactive surfaces with which a species can interact. In doing so, these models excel over simple K_d approaches in accounting for variable Eh, pH, TDS, COC concentration, and surface site competition (Bethke 2008; Stoliker et al. 2011).

Some SCM reactions for COCs considered in the present evaluation are included in the stock PHREEQC database. Additionally, others were obtained from the USGS WATEQ4F database. This database contains the reactions for most elements of interest, except for As and Cr. The constants utilized were all verified from external sources for consistency with data included in WATEQ4F incorporation into the revised database (Martell, 2001). Values for Al do not exist in databases or from either source listed above (Karamalidis and Morel, 2010). Thus, adsorption of dissolved aluminum onto iron or onto solid aluminum is not considered in models and an accurate depiction of aluminum release from sediment cannot be modeled using SCM.

For purposes of this ASR feasibility assessment, results of SEP steps 1-4 are combined in these SCM calculations to represent the COC mass held on aquifer solids by adsorptive forces. Recall that although adsorptive processes are not deemed to be dominant or important in the system, hypothetically simulating them provides an analysis of a worst-case scenario, for perspective.

4.3.1 Preparation of Hypothetical Solids:

SEP characterization of the aquifer solids indicates that COCs are not retained on exchangeable sorption sites of minerals. Hence, some preparatory calculations are required to mathematically produce what amounts to a synthetic aquifer solid that best represents the aquifer based on mineralogical results of cores to use in the COC release modeling. This corresponds to using the mass of iron and aluminum oxide minerals indicated by solid characterization, and mathematically loading them with a mass of COCs that corresponds to the same total mass of SEP steps 1-4.

The mass of HFO and HAO used in the models were determined based on extractable aluminum and iron content from sediment samples collected from each site. These values were compared to aluminum and iron values from SEP steps 1-4. The lowest value for each site between the two methods was used to provide the least adsorptive media in model calculations, providing a "less adsorption, worst case model." The extractable aluminum and iron concentrations measured are shown in Table 4.3.1. For site density calculated from total iron or aluminum, the approach described by Dzombak and Morel (1990) and Karamalidis and Dzombak (2010) was used. Sorption site densities were calculated as 0.2 moles of sorption sites per mole of extractable iron and 0.41 moles of sorption sites per mole of extractable aluminum. This uses 0.05 assumed fraction of extractable iron available for sorption sites (consistent with Dzombak and Morel [1990]) and 0.12 of aluminum (Karamalidis and Dzombak [2010]). The extractable aluminum and iron concentrations in the solids were variable. Therefore, a sorption site conditions was calculated in Table 4.2.1. A comparison to values calculated from SEP steps 1-4 is also provided[3].

[3] The following conversion is utilized for calculated site density:

Table 4.3.1 Extractable iron and aluminum content of sediment measured by sediment "total" acid extractions and SEP Steps 1-4 from the Corpus Christi sites 1-450,1-650, 3-750.

Sample Name	**Iron**	**Al**	**HFO**	**HAO**	**HFO**	**HAO**
	mg/Kg	mg/Kg	mol/kg	mol/kg	mol(sites)/kg	mol(sites)/kg
Site 1_450 SEP 1-4	482	1360	4.51E-03	1.74E-02	4.51E-03	1.74E-02
Site 1_450 Total*	5200	4100	4.87E-02	5.26E-02	9.73E-03	2.16E-02
Site 1_650 SEP 1-4	647	807.7	6.05E-03	1.04E-02	6.05E-03	1.04E-02
Site 1_650 Total*	6300	7800	5.90E-02	1.00E-01	1.18E-02	4.10E-02
Site 3_750 SEP 1-4	966	1200	9.04E-03	1.54E-02	9.04E-03	1.54E-02
Site 3_750 Total*	5000	5500	4.68E-02	7.05E-02	9.36E-03	2.89E-02

Note: Total refers acid digestion and analysis by ICPMS via method 3050/6020.

Surface adsorbed COCs were loaded in the model onto the sediment prior to mixing, as no sediment typically exists as a clean slate. This was done during initial geochemical model executions. During the pre-loading step, COC surfaces were artificially loaded to be consistent with SEP data. To do this, dissolved concentrations in the base runs were adjusted, maintaining measured HFO/HAO values (determined with SEP data for amorphous iron and aluminum oxide extraction, SEP Step 3), to adequately load surfaces with COCs[4]. Thus, by adjusting these starting values, we are ensuring that adequate COC is on the sediment, to match SEP values, and allow for the most possible COC to be released into groundwater when simulating injection of recharge water. This approach provides a "worst probable" case for the dissolved COC concentrations one might expect, and allows for further sensitivity analyses as ASR suitability studies progress.

4.3.3 Model Results: Tables 4.3.2 – 4.3.10 represent the effect of introducing recharge water into the aquifer at a specific mixing ratio with native aquifer water. The ratios, from 5% to 100% reflect the

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$$[\equiv FeOH/\equiv AlOH^0] = [(s)] * [Hf(a)o] * \frac{1g}{1000} * \frac{mol\ Hf(a)O}{55.845g\ (26.98g)} * \frac{0.2\ mol \equiv FeOH (0.41\ mol \equiv AlOH^0)}{mol\ Hf(a)o}$$

[≡FeOH/≡AlOH^0] is the concentration of iron adsorption sites in mol/L for model input,

[Solid] is the concentration of solid in g/L,

[HF(A)O] is the amount of extractable Fe or Al in mg per kg of solid,

Mol HF(A)O is the moles of extractable Fe or Al, and

0.02 or 0.41 is the estimated fraction of extractable Fe or Al adsorption sites.

[4] Dissolved values for all COCs had to be increased or remain the same as measured in order to add adequate COCs on sites to match SEP measurements. In most cases the value of this change is lower than analytical detection limits. This would allow the maximum possible desorption potential to exist in calculations, but would not change measured surface site potential. In many cases (ie. As, Cu, Cr, Pb, Se, U), initial dissolved values in solution were measured as non-detects. In those cases, while values may not be detectable, some dissolved concentrations do likely exist. For instance, at Site 1-450, arsenic was non-detectable by analytical instrumentation. But to match the surface adsorbed values on HFO/HAO to SEP steps 1-4, dissolved arsenic was adjusted to $7x10^{-5}$ mg/L. This value set in PHREEQC in the base run to adequately preload the surfaces for reversible adsorption in SCM, would still be non-detectable by instrumentation. However, this value allows us to add 1.25mg/kg of As in the system, on sediment, that could desorb if equilibrium conditions indicate.

stratification of injection water both vertically and horizontally across the recharge water bubble. This water is then mathematically placed into equilibrium with Calcite, as saturation indices for native groundwater indicated equilibrium for all of the sampling locations. Subsequently, the modeled groundwater is then placed into equilibrium with the pre-loaded adsorption surfaces of the HFO and HAO, allowing desorption of COC's into the mix of recharge water and native groundwater. Remember, this involved intentionally ignoring the results of the SEP analysis to produce a worst-case analysis. Also, the extent of desorption is dictated by the chemical composition of the recharge-native groundwater mixtures. Not all of the COC loaded onto the HFO and HAO will desorb into solution.

Calculation results in tables 4.3.2 – 4.3.10 report values for the nine COCs across the three injection intervals, using two different recharge sources (Greenwood WWTP and Stevens WTP water). Values in the first column indicate the total concentration measured in the native groundwater. The highest value from PHREEQC-modeling predicted from the mix steps (5:95 % recharge: GW to 100:0 % recharge:GW) is shown in column two. The modeled change in dissolved COC concentration is shown in column three. A negative value indicates that dissolved COCs are predicted to decrease. A positive number demonstrates that desorption of the COC from sediment is possible, and that dissolved concentrations are predicted to increase, although only slightly. Table entries of "na" indicate that either the COC is initially non-detect in groundwater or there is a lack of SEP data (SEP is not a viable measurement method for U), and a comparison cannot be made. Columns four and five contain data from sediment SEP and total metal acid extractions for perspective relative to dissolved values. The model results indicate that even with a worst-case analysis, the COC concentrations should be well below the MCL requirements.

Table 4.3.2 Aluminum*

	Measured Native GW (mg/L)	Modeled Highest Recharged GW Value (mg/L)	Modeled change	Sediment SEP 1-4 (mg/kg)	Total* in Sediment (mg/kg)
Site 1 450ft bgs & Greenwood WWTP	4.51E-02	4.51E-02	-7.78E-04	1360	4100
Site 1 450ft bgs & Stevens WTP	4.51E-02	1.47E-01	1.02E-01	1360	4100
Site 1 650ft bgs & Greenwood WWTP	1.06E-01	1.03E-01	-3.43E-03	807.7	7800
Site 1 650ft bgs & Stevens WTP	1.06E-01	1.47E-01	4.11E-02	807.7	7800
Site 3 750ft bgs & Greenwood WWTP	2.52E-01	2.53E-02	-2.27E-01	1200	5450
Site 3 750ft bgs & Stevens WTP	2.52E-01	1.47E-01	-1.05E-01	1200	5450

Note: *Aluminum does not have SCM adsorption values. Changes are dependent purely on mixing of dissolved GW values and those in recharge waters, as aluminum was measured in all of the waters tested.

Table 4.3.3 Arsenic

	Measured Native GW (mg/L)	Modeled Highest Recharged GW Value (mg/L)	Modeled change	Sediment SEP 1-4 (mg/kg)	Total* in Sediment (mg/kg)
Site 1 450ft bgs & Greenwood WWTP	ND	8.23E-05	na	1.24	2.6
Site 1 450ft bgs & Stevens WTP	ND	7.51E-05	na	1.24	2.6
Site 1 650ft bgs & Greenwood WWTP	6.19E-04	4.72E-05	-5.72E-04	1.52	6
Site 1 650ft bgs & Stevens WTP	6.19E-04	4.64E-05	-5.73E-04	1.52	6
Site 3 750ft bgs & Greenwood WWTP	ND	3.62E-05	na	2.09	2.9
Site 3 750ft bgs & Stevens WTP	ND	3.58E-05	na	2.09	2.9

Table 4.3.4 Chromium

	Measured Native GW (mg/L)	Modeled Highest Recharged GW Value (mg/L)	Modeled change	Sediment SEP 1-4 (mg/kg)	Total* in Sediment (mg/kg)
Site 1 450ft bgs & Greenwood WWTP	ND	7.66E-02	na	1.19	4.4
Site 1 450ft bgs & Stevens WTP	ND	7.61E-02	na	1.19	4.4
Site 1 650ft bgs & Greenwood WWTP	ND	7.58E-05	na	1.21	6.0
Site 1 650ft bgs & Stevens WTP	ND	7.36E-05	na	1.21	6.0
Site 3 750ft bgs & Greenwood WWTP	ND	8.73E-02	na	1.27	6.4
Site 3 750ft bgs & Stevens WTP	ND	8.71E-02	na	1.27	6.4

Table 4.3.5 Copper

	Measured Native GW (mg/L)	Modeled Highest Recharged GW Value (mg/L)	Modeled change	Sediment SEP 1-4 (mg/kg)	Total* in Sediment (mg/kg)
Site 1 450ft bgs & Greenwood WWTP	ND	3.06E-04	na	1.53	4.8
Site 1 450ft bgs & Stevens WTP	ND	3.45E-04	na	1.53	4.8
Site 1 650ft bgs & Greenwood WWTP	1.63E-03	5.22E-04	-1.11E-03	2.5	5.3
Site 1 650ft bgs & Stevens WTP	1.63E-03	6.27E-04	-1.00E-03	2.5	5.3
Site 3 750ft bgs & Greenwood WWTP	3.55E-02	5.16E-04	-3.50E-02	3.4	10.1
Site 3 750ft bgs & Stevens WTP	3.55E-02	5.92E-04	-3.49E-02	3.4	10.1

Table 4.3.6 Iron

	Measured Native GW (mg/L)	Modeled Highest Recharged GW Value (mg/L)	Modeled change	Sediment SEP 1-4 (mg/kg)	Total* in Sediment (mg/kg)
Site 1 450ft bgs & Greenwood WWTP	ND	1.25E-01	na	482	5200
Site 1 450ft bgs & Stevens WTP	ND	9.61E-05	na	482	5200
Site 1 650ft bgs & Greenwood WWTP	3.70E-01	3.61E-01	-9.33E-03	647	6300
Site 1 650ft bgs & Stevens WTP	3.70E-01	3.54E-01	-1.56E-02	647	6300
Site 3 750ft bgs & Greenwood WWTP	6.73E-01	6.54E-01	-1.85E-02	966	4900
Site 3 750ft bgs & Stevens WTP	6.73E-01	6.48E-01	-2.48E-02	966	4900

Table 4.3.7 Lead

	Measured Native GW (mg/L)	Modeled Highest Recharged GW Value (mg/L)	Modeled change	Sediment SEP 1-4 (mg/kg)	Total* in Sediment (mg/kg)
Site 1 450ft bgs & Greenwood WWTP	ND	1.52E-04	na	0.55	4.4
Site 1 450ft bgs & Stevens WTP	ND	1.58E-04	na	0.55	4.4
Site 1 650ft bgs & Greenwood WWTP	1.44E-04	1.09E-03	9.49E-04	4.3	6.0
Site 1 650ft bgs & Stevens WTP	1.44E-04	1.15E-03	1.00E-03	4.3	7.3
Site 3 750ft bgs & Greenwood WWTP	ND	6.25E-04	na	3.3	8.4
Site 3 750ft bgs & Stevens WTP	ND	6.46E-04	na	3.3	8.4

Table 4.3.8 Manganese

	Measured Native GW (mg/L)	Modeled Highest Recharged GW Value (mg/L)	Modeled change	Sediment SEP 1-4 (mg/kg)	Total* in Sediment (mg/kg)
Site 1 450ft bgs & Greenwood WWTP	4.85E-02	7.32E-02	2.47E-02	79.9	120
Site 1 450ft bgs & Stevens WTP	4.85E-02	4.91E-02	5.61E-04	79.9	120
Site 1 650ft bgs & Greenwood WWTP	5.60E-02	8.65E-02	3.05E-02	191.3	250
Site 1 650ft bgs & Stevens WTP	5.60E-02	6.93E-02	1.33E-02	191.3	250
Site 3 750ft bgs & Greenwood WWTP	1.13E-01	1.22E-01	8.85E-03	114.3	165
Site 3 750ft bgs & Stevens WTP	1.13E-01	1.20E-01	6.68E-03	114.3	165

Table 4.3.9 Selenium

	Measured Native GW (mg/L)	Modeled Highest Recharged GW Value (mg/L)	Modeled change	Sediment SEP 1-4 (mg/kg)	Total in Sediment (mg/kg)
Site 1 450ft bgs & Greenwood WWTP	ND	4.00E-03	na	1.77	1.1
Site 1 450ft bgs & Stevens WTP	ND	4.00E-03	na	1.77	1.1
Site 1 650ft bgs & Greenwood WWTP	6.34E-03	8.99E-03	2.65E-03	2.92	ND
Site 1 650ft bgs & Stevens WTP	6.34E-03	8.98E-03	2.64E-03	2.92	ND
Site 3 750ft bgs & Greenwood WWTP	1.54E-02	9.74E-03	-5.66E-03	3.29	ND
Site 3 750ft bgs & Stevens WTP	1.54E-02	9.74E-03	-5.66E-03	3.29	ND

Table 4.3.10 Uranium

	Measured Native GW (mg/L)	Modeled Highest Recharged GW Value (mg/L)	Modeled change	Sediment SEP 1-4 (mg/kg)	Total* in Sediment (mg/kg)
Site 1 450ft bgs & Greenwood WWTP	ND	6.38E-03	na	na	0.48
Site 1 450ft bgs & Stevens WTP	ND	9.44E-04	na	na	0.48
Site 1 650ft bgs & Greenwood WWTP	ND	8.67E-03	na	na	2.1
Site 1 650ft bgs & Stevens WTP	ND	8.38E-03	na	na	2.1
Site 3 750ft bgs & Greenwood WWTP	ND	1.74E-02	na	na	0.64
Site 3 750ft bgs & Stevens WTP	ND	1.71E-02	na	na	0.64

NOTES:
1. ND: None detection based on analytical detection limits (variable by analyte)
2. na: Not applicable or unable to be calculated due to non-detect or missing data.
3. *Total Values from 3050 Method independent of SEP total to alleviate HF bound metals from consideration. For Site 1 450 ft bgs values represent average of two samples.

4.4 Potential for Scaling and Clogging

Conceptually, calcite (calcium carbonate), HFO (discussed throughout this report) and gypsum (calcium sulfate) are candidates for potential scaling and clogging effects. Of course, these effects can only be experienced if the solubility of these phases is exceeded and a solid precipitate forms. Native groundwater is either undersaturated with these phases, or at near equilibrium (calcite). Potential recharge waters are also at near equilibrium with calcite, and undersaturated with gypsum and HFO (iron not detected in recharge water).

On mixing, in all proportions, neither calcite nor gypsum is identified as oversaturated and should not precipitate, removing concern about scaling or clogging from these phases. Iron is not detected in the recharge water, and is present at very low concentrations in native groundwater. Formation of HFO is not indicated at this time. A sensitivity check to use iron at analytical method detection limits for recharge water indicated that the HFO was oversaturated and could form. However, at the very low detection limits, the potential volume of HFO formation was on the order of 0.00001 cubic centimeters per liter (1000 cubic centimeters). This small quantity represents a highly biased worst case assessment, and does not appear be a concern. This finding should not be considered sufficient for engineering decisions, and should receive consideration from licensed engineering professionals for certification.

5.0 Conclusion

Overall, the native groundwater, aquifer solids, and potential recharge waters are geochemically compatible. The native groundwater is more saline, but the redox and pH conditions that drive aquifer solid stability are very similar to that of the recharge water. With injection, a gradient of salinity will exist between the native groundwater and the recharge water bubble. The magnitude of that gradient is driven by physical mixing of the two and is not a geochemical process. Modeling the release of regulated COCs that might compromise the chemical quality of recharged water indicates that the effect will be small to negligible.

Mixing of native groundwater with recharge water does not appear to have the potential to lead to scaling or clogging. Major minerals that can commonly form to produce scale (calcite, gypsum, HFO) are either undersaturated or at equilibrium with the mixed waters.

From the perspective of an initial fatal flaw assessment, using the identified recharge waters should be compatible with the native groundwater environment. However, it should be noted that the introduction of organic carbon into the groundwater system has the potential to lead to microbial processes that can change the oxic character of the groundwater environment to a more chemically reducing one. Such a change can produce conditions that might destabilize HFO, causing it to dissolve and release all of its COC load. This could lead to elevated concentrations of COC above regulatory thresholds and limit potential uses of the freshwater bubble as a resource. Therefore, it is important to ensure that recharged recharge water has suitably low levels of organic carbon, such as currently exist in the two candidate water sources.

The present evaluation provides some assurance that potential recharge water is geochemically compatible with the native groundwater aquifer solids. However, owing to compositing of aquifer solids over relatively long intervals, approximating the proportion of sand and clay horizons at only two locations, the present solids data should not be interpreted as rigorously representative. Hydrologic interpretations and identification of most desirable target ASR zones/volumes could be used to delineate the volume of material that could be sampled and analyzed to amend the data presented in this report. Such an analysis would add confidence, but the present evaluation does not identify any specific fatal flaws beyond the potential injection of organic carbon, which can, and should, be guarded against. Further modeling is probably not necessary since the aquifer solids in the final ASR target zone have a mineralogy and SEP character that is consistent with the present evaluation.

6.0 References

Bethke, C. Geochemical and Biogeochemical Reaction Modeling, 2008 Cambridge University Press.

CCASRCD, Groundwater Management Plan, 2014.

Ground Water Management Plan. Corpus Christi Aquifer Storage And Recovery Conservation District.

Dzombak, D.A. and F.M.M. Morel, *Surface complexation modeling: hydrous ferric oxide*. 1990, New York: Wiley. xvii, 393.

HDR. Aquifer Characterization Study for ASR Feasibility. HDR. 2016.

Karamalidis, A.K. and D.A. Dzombak, *Surface Complexation Modeling: Gibbsite*. 2010, Hoboken, NJ: John Wiley and Sons, Inc.

Langmuir, D. (1997) Aqueous Environmental Geochemistry. Prentice Hall.

Lindberg, R. D. and D.D. Runnells (1984) Ground Water Redox Reactions: An Analysis of Equilibrium State Applied to Eh Measurements and Geochemical Modeling. *Science*, New Series, Vol. 225, No. 4665 (Aug. 31, 1984), pp. 925-927

Martell, A.E. and R.K. Smith, *Critical Stability Constants, Standard Reference Database 46, Version 6.30*. 2001, National Institute of Standards, Gaithersburg, MD.

Mason, B. and C.B. Moore (1982) Principles of Geochemistry, 4th ed., John Wiley and Sons.

Merkel, B., Planer-Friedrich, B., and Nordstrom, D. K., 2008, Groundwater Geochemistry: A Practical Guide to Modeling of Natural and Contaminated Aquatic Systems, 2005 Springer-Verlag Berlin Heidelberg.

Parkhurst, D. L., and Appelo, C. A. J., 2013, Description of input and examples for PHREEQC version 3: a computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations: US Geological Survey, 2328-7055.

Stoliker, D. L., Kent, D. B., and Zachara, J. M., 2011, Quantifying Differences in the Impact of Variable Chemistry on Equilibrium Uranium(VI) Adsorption Properties of Aquifer Sediments: Environmental Science & Technology, v. 45, no. 20, p. 8733-8740.

APPENDIX A

Final Test Report

Client:	HDR, Inc.	MI#:	18026
Project:	CCASR-10031312	Sample Type:	N/A
Location:	Corpus Christi, TX	Date:	03/26/18

Contact	Kristi Shaw
Address	HDR, Inc.
	4401 West Gate Blvd
	Suite 400
	Austin, TX 787-1469
E-mail	kristi.shaw@hdrinc.com
Phone	N/A
Project ID:	CCASR-10031312
Test Methods	XRD / XRF / CEC / LPSA / Macro Imaging
MI Lab Supervisor	
	Timothy B. Murphy

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TABLE I

X-RAY DIFFRACTION with Rietveld Refinement

Client:	HDR	MI#:	18026
Well ID:	CCASR-10031312	Location:	Corpus Christi, TX

Reitvelt Results

	CCASR-01-U	CCASR-01-L	CCASR-03-A	CCASR-03-T
	18026-01	18026-02	18026-03	18026-04
Mineral Constituents	**Relative Abundance (%)**			
Quartz	77	51.5	57.9	59.3
Oligoclase	6.5	6.2	5.9	6.4
Orthoclase	3.6	3.9	4.3	4.3
Calcite	4.6	18.7	11.1	12.5
Dolomite		0.2	0.2	0.3
Magnetite	0.1			
Hematite	0.2			
Goethite		0.4	0.5	0.8
Kaolinite	0.5			
Clinochlore		0.3		0.2
Illite / Mica	3.9	12.6	13.5	11.1
Montmorillonite (1 H2O layer)	1.9	3.6	3.6	2.7
Montmorillonite (2 H2O layer)	0.8	0.9	1	0.9
Mixed-Layered Illite/Smectite	0.8	1.7	2	1.5
TOTAL	99.9	100	100	100
% Illite layers in ML Illite/Smectite	60%	60%	60%	60%

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TABLE II

X-RAY FLUORESCENCE ANALYSIS

Client:	HDR	MI#:	18026
Project:	CCASR-10031312	Location:	Corpus Christi, TX

Sample ID	CCASR-01-U	CCASR-01-L	CCASR-03-A	CCASR-03-T	CCASR-01-U
M.I. Sample ID	18026-01	18026-02	18026-03	18026-04	18026-01R*
Chemical Formula	Results (mass %)				
Na2O	1.0497	1.3635	1.4843	1.4321	1.0669
MgO	0.9008	1.9252	1.5661	1.3354	0.9533
Al2O3	7.6398	12.0323	11.1605	10.1699	7.6226
SiO2	78.7618	62.6689	67.9157	70.1434	78.7165
P2O5	0.108	0.1483	0.1307	0.1113	0.0886
S	0.3146	0.1777	0.0887	0.152	0.3322
Cl	0.0533	0.086	0.148	0.1184	0.0503
K2O	1.7898	2.1822	2.0584	1.9701	1.7651
CaO	6.5571	14.9435	11.9113	11.0377	6.5443
TiO2	0.3737	0.6267	0.5656	0.5182	0.3987
MnO	0.0249	0.0613	0.0406	0.0391	0.0256
Fe2O3	1.7431	3.2966	2.6043	2.5339	1.7514
Zn	ND	0.0078	ND	ND	ND
Rb	ND	0.0093	0.0104	0.0079	0.0096
Sr	0.0204	0.0389	0.0324	0.0303	0.022
Zr	0.0382	0.0444	0.0468	0.0402	0.0375
BaO	0.1159	0.0961	0.0801	0.1123	0.1

18026-01R = Quality Control Duplicate

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TABLE III

CATION EXCHANGE CAPACITY ANALYSIS

Client:	HDR	MI#:	18026
Project:	CCASR-10031312	Location:	Corpus Christi, TX

		Calcium		Magnesium		Potassium		Sodium		
		Results	PQL**	Results	PQL**	Results	PQL**	Results	PQL**	Cumulative
		(meg/100g)		(meg/100g)		(meg/100g)		(meg/100g)		CEC
CCASR-01-U	18026-01	20.5	0.010	1.58	0.010	0.772	0.010	4.16	0.010	27.012
CCASR-01-L	18026-02	17.6	0.010	2.32	0.010	1.08	0.010	7.27	0.010	28.270
CCASR-03-A	18026-03	21.0	0.010	2.19	0.010	0.995	0.010	10.4	0.010	34.585
CCASR-03-T	18026-04	21.5	0.010	2.38	0.010	1.25	0.010	10.3	0.010	35.430

Method Reference: 40 CFR 136, 261, Method for Chemical Analysis of Water and Waste EPA-600/4-79-020 March 1983
CEC Method Reference: Method of Soil Analysis, Chemical and Microbiological Properties, 2nd Ed.; American Society of Agronomy, Iinc.
Soil Science Society of America, Inc. page 160.
**CEC analysis provided by Accurate Laboratories & Training Center; Stillwater, OK*
***PQL= Practical Quantitation Limit*

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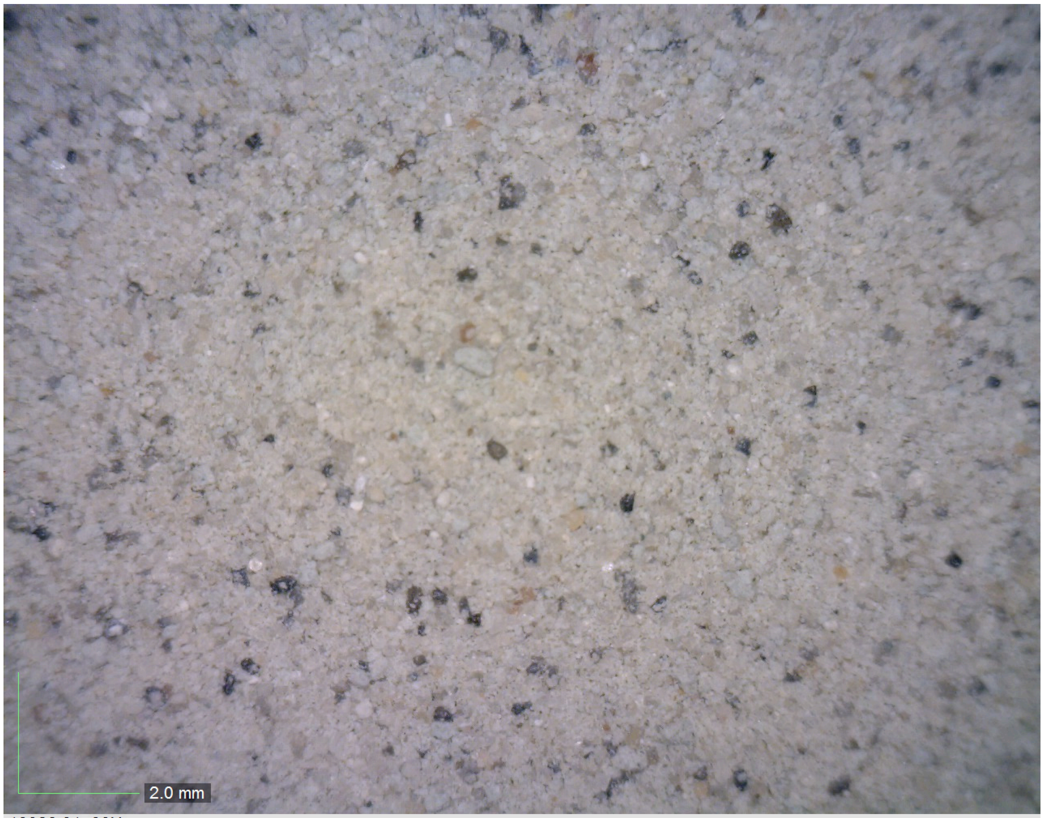
CCASR-01-U; MI#18026-01



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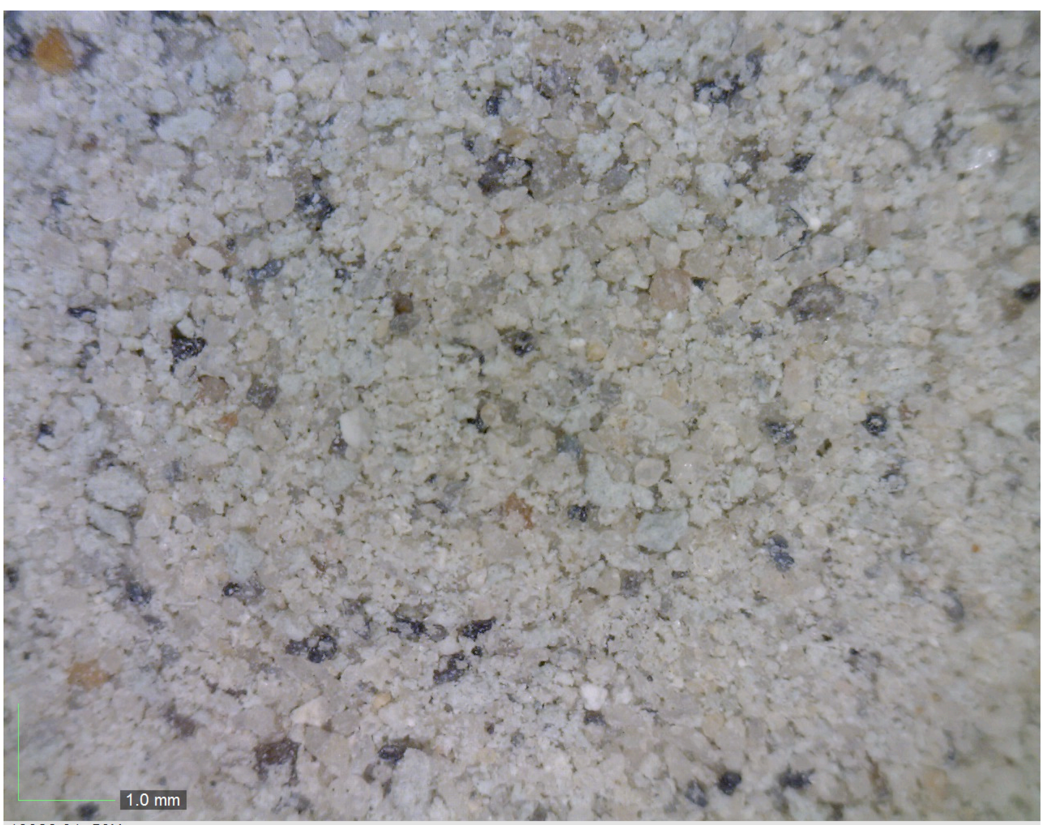
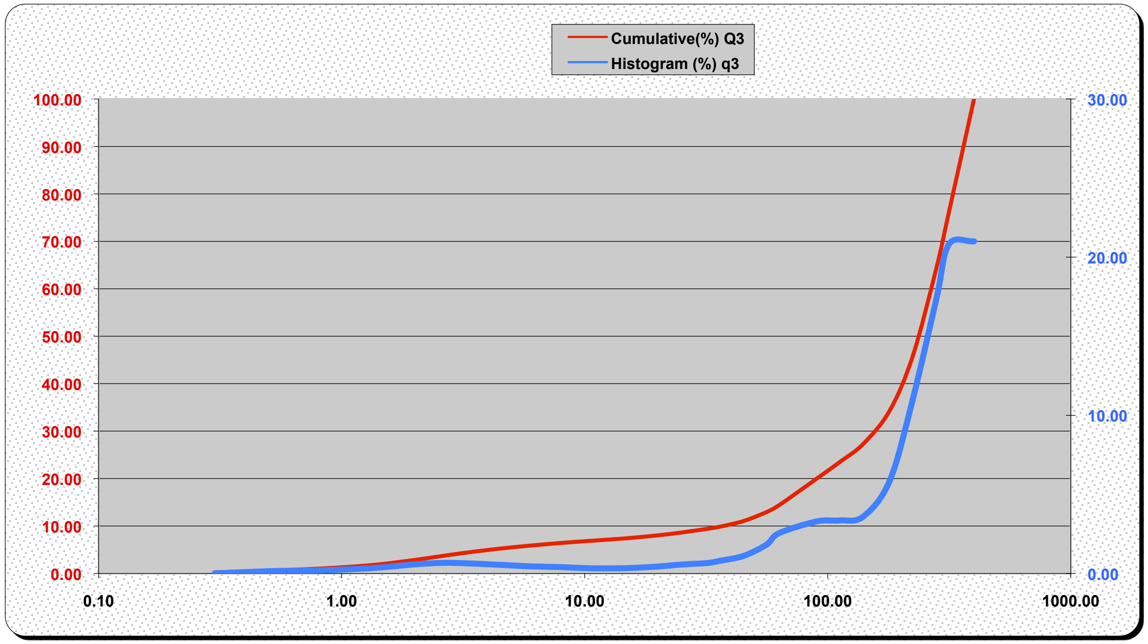


18026.01; 50X

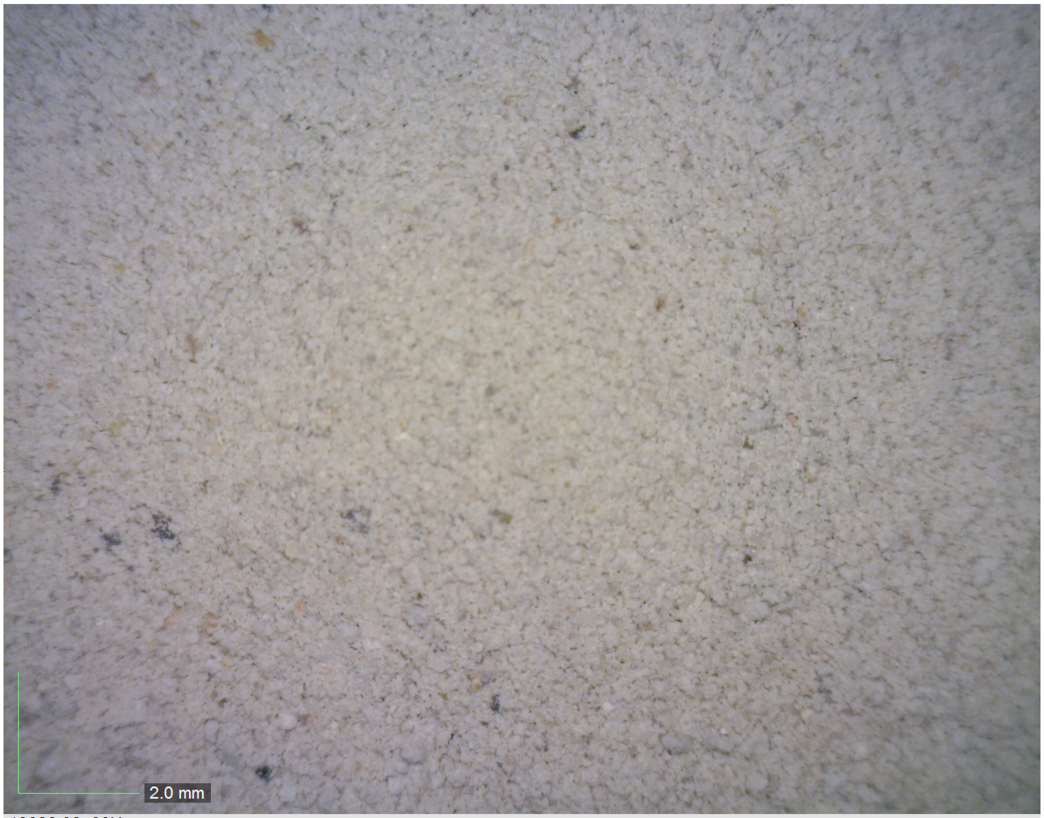
Figure I
Particle Size Distribution Analysis
Sample ID: CCASR-01-U
Mineralogy, Inc. Job No.: 18026-01

Size(µm)	From DATA.mes	Cumulative(%) Q3	Histogram (%) q3
0.30	0.0023	**0.23**	0.00
0.50	0.0058	**0.58**	0.14
0.70	0.0087	**0.87**	0.18
1.00	0.0129	**1.29**	0.25
1.40	0.0187	**1.87**	0.36
2.00	0.0285	**2.85**	0.58
2.60	0.0369	**3.69**	0.67
3.20	0.0433	**4.33**	0.65
4.00	0.0495	**4.95**	0.58
5.00	0.0549	**5.49**	0.51
6.00	0.0588	**5.88**	0.45
8.00	0.0643	**6.43**	0.40
10.00	0.0679	**6.79**	0.34
12.00	0.0707	**7.07**	0.32
15.00	0.0743	**7.43**	0.34
20.00	0.0803	**8.03**	0.44
25.00	0.0863	**8.63**	0.56
32.00	0.0941	**9.41**	0.66
36.00	0.0986	**9.86**	0.80
45.00	0.1104	**11.04**	1.11
56.00	0.1294	**12.94**	1.82
63.00	0.1437	**14.37**	2.54
90.00	0.1997	**19.97**	3.29
112.00	0.2347	**23.47**	3.35
140.00	0.273	**27.30**	3.60
180.00	0.3434	**34.34**	5.87
224.00	0.4585	**45.85**	11.03
280.00	0.6435	**64.35**	17.37
315.00	0.7605	**76.05**	20.81
400.00	1	**100.00**	21.00
		TOTAL:	**100.00**

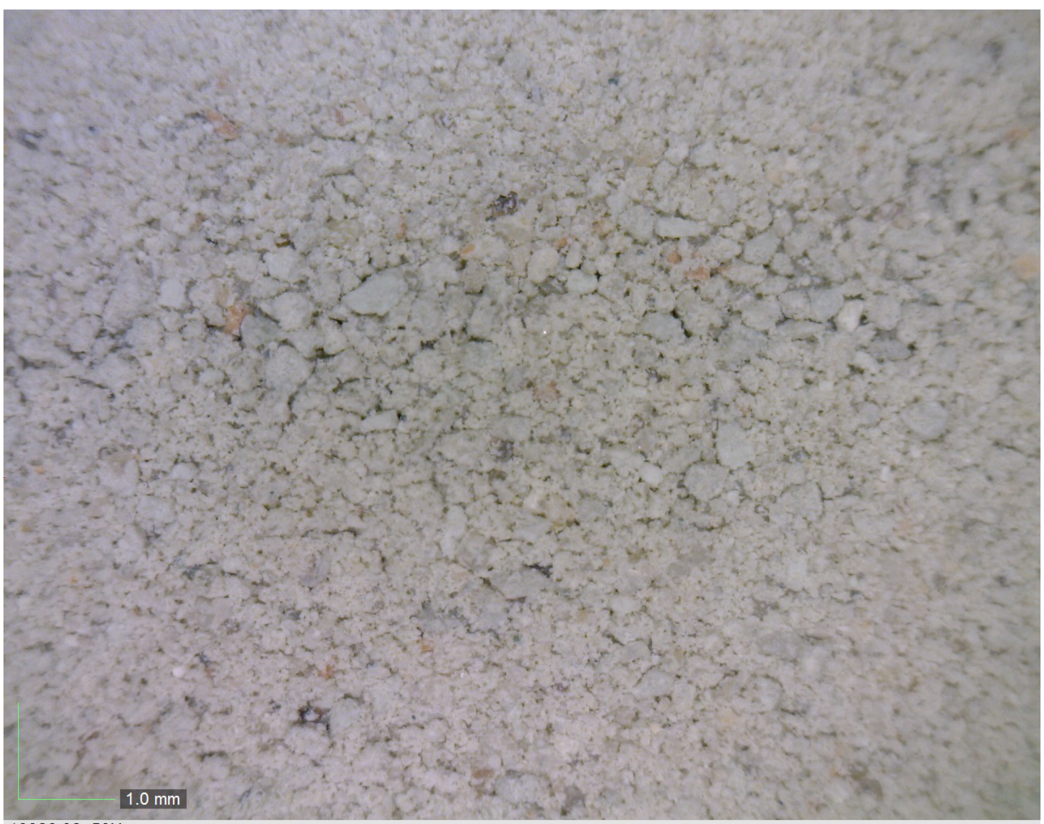


	Diameter at 10%	Diameter at 50%	Diameter at 90%	Cumulative at 100 µm
Min.	35.725	234.275	361.692	21.329
Max	38.286	236.39	362.252	22.123
Mean	36.978	235.502	362.026	21.667
Std deviation	1.156	0.864	0.227	0.364

CCASR-01-L; MI#18026-02



18026.02; 30X



18026.02; 50X

Figure II
Particle Size Distribution Analysis
Sample ID: CCASR-01-L
Mineralogy, Inc. Job No.: 18026-02

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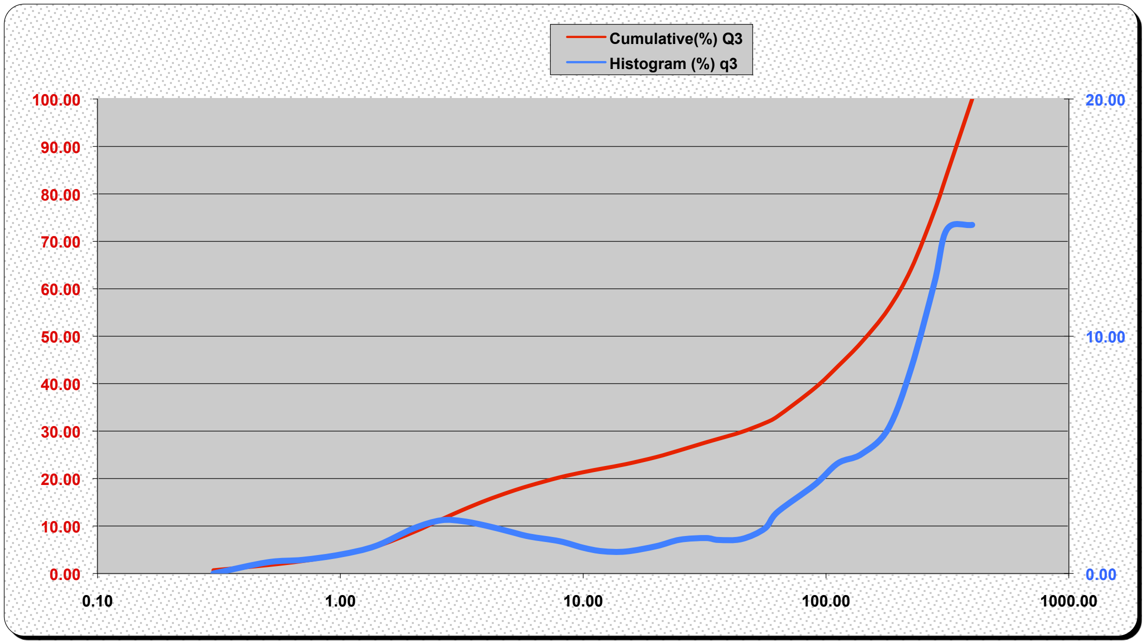
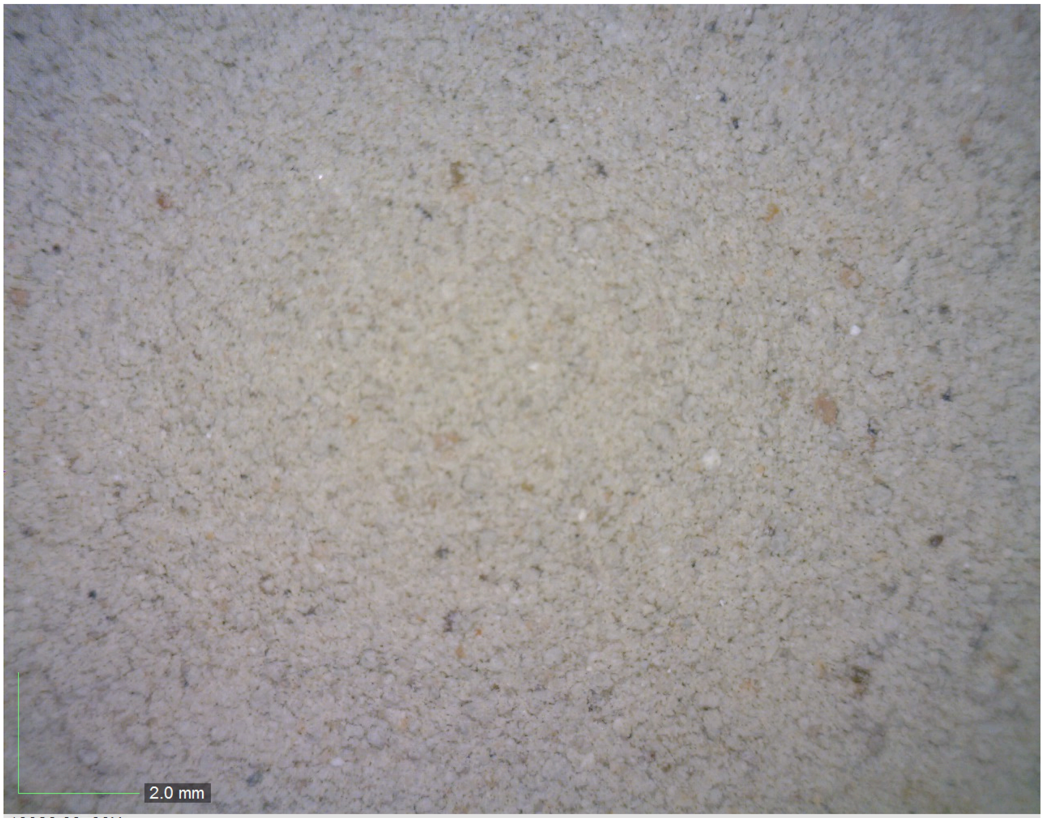
Size(µm)	From DATA.mes	Cumulative(%) Q3	Histogram (%) q3
0.30	0.0067	**0.67**	0.00
0.50	0.0175	**1.75**	0.47
0.70	0.0262	**2.62**	0.57
1.00	0.039	**3.90**	0.80
1.40	0.0566	**5.66**	1.16
2.00	0.0871	**8.71**	1.90
2.60	0.1136	**11.36**	2.24
3.20	0.1342	**13.42**	2.20
4.00	0.1544	**15.44**	2.01
5.00	0.1721	**17.21**	1.76
6.00	0.1849	**18.49**	1.56
8.00	0.2025	**20.25**	1.36
10.00	0.2134	**21.34**	1.08
12.00	0.2211	**22.11**	0.94
15.00	0.2304	**23.04**	0.92
20.00	0.2453	**24.53**	1.15
25.00	0.2596	**25.96**	1.42
32.00	0.2762	**27.62**	1.49
36.00	0.2837	**28.37**	1.41
45.00	0.2983	**29.83**	1.45
56.00	0.317	**31.70**	1.90
63.00	0.3307	**33.07**	2.58
90.00	0.3909	**39.09**	3.75
112.00	0.4367	**43.67**	4.65
140.00	0.4873	**48.73**	5.03
180.00	0.5562	**55.62**	6.08
224.00	0.6413	**64.13**	8.63
280.00	0.7648	**76.48**	12.28
315.00	0.8418	**84.18**	14.51
400.00	1	**100.00**	14.69
		TOTAL:	**100.00**



	Diameter at 10%	Diameter at 50%	Diameter at 90%	Cumulative at 100 µm
Min.	2.243	145.277	343.64	40.734
Max	2.349	148.851	344.328	41.676
Mean	2.273	146.621	343.922	41.244
Std deviation	0.044	1.514	0.308	0.383

CCASR-03-A; MI#18026-03

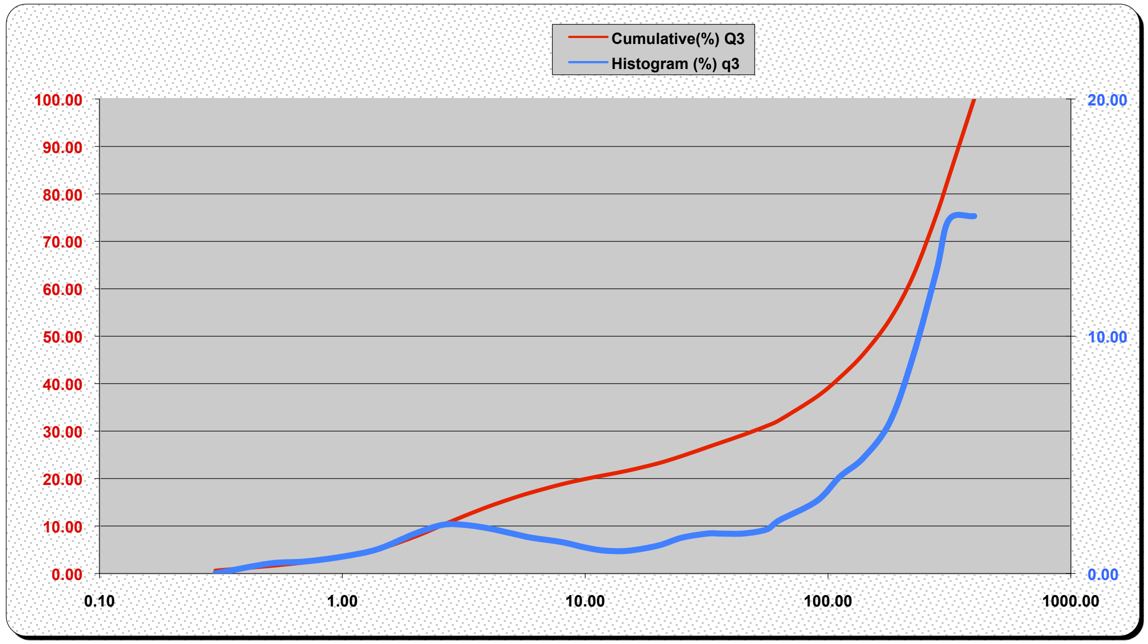


18026.03; 30X

18026.03; 50X

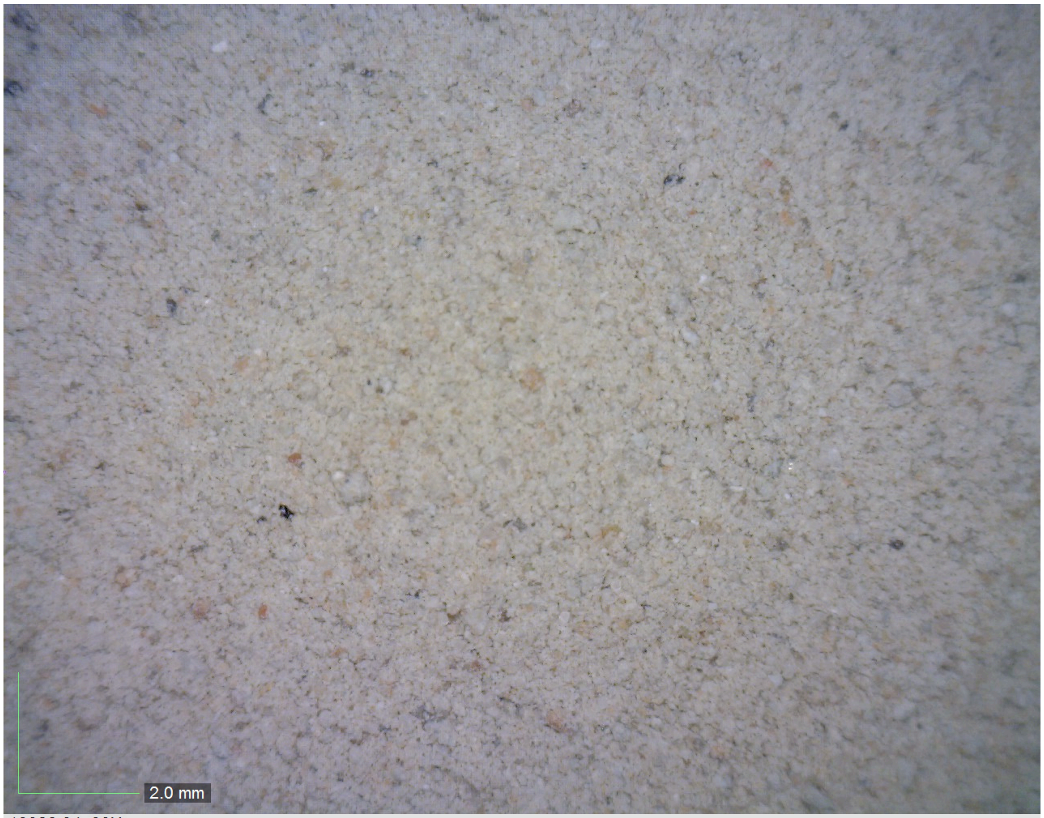
Figure III
Particle Size Distribution Analysis
Sample ID: CCASR-03-A
Mineralogy, Inc. Job No.: 18026-03

Size(µm)	From DATA.mes	Cumulative(%) Q3	Histogram (%) q3
0.30	0.006	**0.60**	0.00
0.50	0.0157	**1.57**	0.42
0.70	0.0234	**2.34**	0.50
1.00	0.0349	**3.49**	0.71
1.40	0.0506	**5.06**	1.03
2.00	0.078	**7.80**	1.69
2.60	0.1025	**10.25**	2.05
3.20	0.1218	**12.18**	2.04
4.00	0.1411	**14.11**	1.90
5.00	0.1582	**15.82**	1.68
6.00	0.1707	**17.07**	1.51
8.00	0.188	**18.80**	1.32
10.00	0.1991	**19.91**	1.09
12.00	0.2071	**20.71**	0.96
15.00	0.2168	**21.68**	0.96
20.00	0.2322	**23.22**	1.18
25.00	0.2475	**24.75**	1.51
32.00	0.2664	**26.64**	1.68
36.00	0.2754	**27.54**	1.68
45.00	0.2925	**29.25**	1.68
56.00	0.311	**31.10**	1.86
63.00	0.323	**32.30**	2.24
90.00	0.3726	**37.26**	3.06
112.00	0.4132	**41.32**	4.08
140.00	0.4627	**46.27**	4.88
180.00	0.5358	**53.58**	6.39
224.00	0.6268	**62.68**	9.15
280.00	0.7564	**75.64**	12.77
315.00	0.8363	**83.63**	14.91
400.00	1	**100.00**	15.06
		TOTAL:	**100.00**



	Diameter at 10%	Diameter at 50%	Diameter at 90%	Cumulative at 100 µm
Min.	2.49	154.117	344.457	38.131
Max	2.592	163.985	346.714	40.209
Mean	2.533	159.175	345.666	39.127
Std deviation	0.04	4.172	0.972	0.875

CCASR-03-T; MI#18026-04



18026.04; 30X

18026.04; 50X

Figure IV
Particle Size Distribution Analysis
Sample ID: CCASR-03-T
Mineralogy, Inc. Job No.: 18026-04

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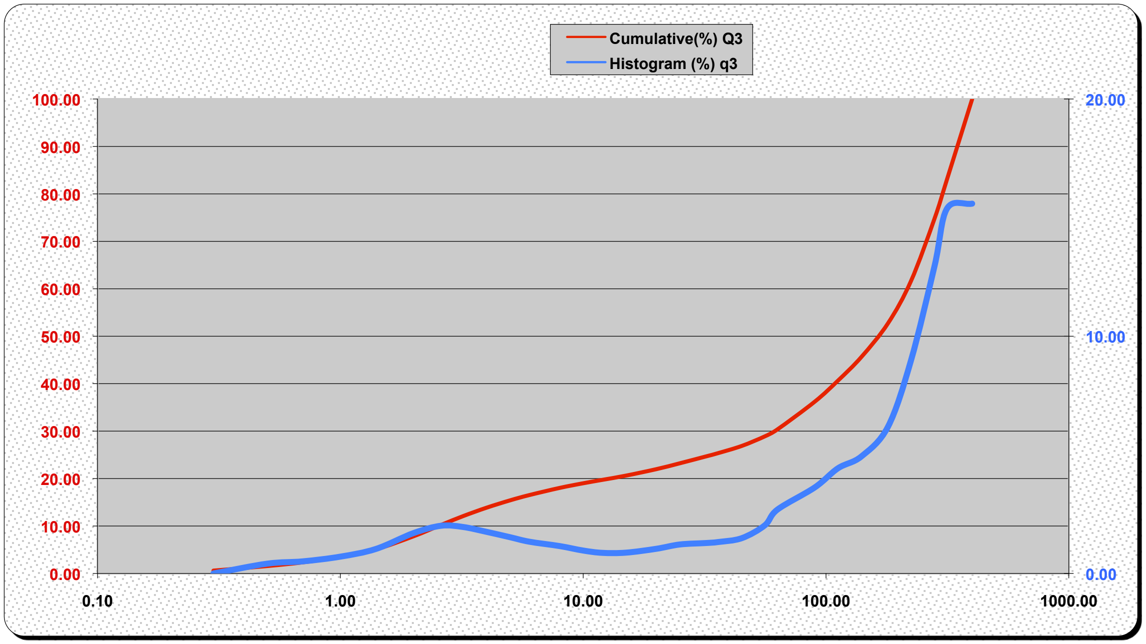
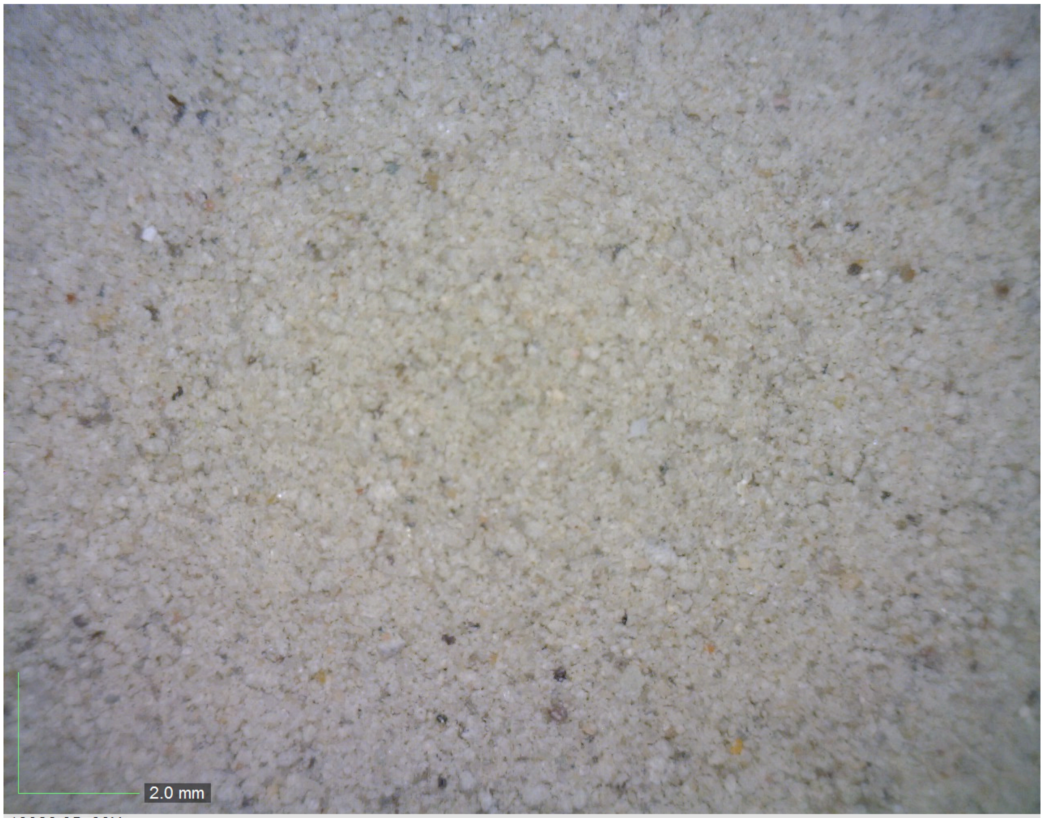
Size(µm)	From DATA.mes	Cumulative(%) Q3	Histogram (%) q3
0.30	0.006	**0.60**	0.00
0.50	0.0156	**1.56**	0.41
0.70	0.0234	**2.34**	0.51
1.00	0.0349	**3.49**	0.71
1.40	0.0507	**5.07**	1.03
2.00	0.0783	**7.83**	1.70
2.60	0.1023	**10.23**	2.01
3.20	0.1208	**12.08**	1.96
4.00	0.1386	**13.86**	1.75
5.00	0.1541	**15.41**	1.53
6.00	0.1652	**16.52**	1.34
8.00	0.1803	**18.03**	1.15
10.00	0.1901	**19.01**	0.97
12.00	0.1973	**19.73**	0.87
15.00	0.2062	**20.62**	0.88
20.00	0.2198	**21.98**	1.04
25.00	0.2322	**23.22**	1.22
32.00	0.2466	**24.66**	1.28
36.00	0.2537	**25.37**	1.33
45.00	0.2688	**26.88**	1.49
56.00	0.289	**28.90**	2.03
63.00	0.3034	**30.34**	2.69
90.00	0.3623	**36.23**	3.63
112.00	0.4064	**40.64**	4.43
140.00	0.4565	**45.65**	4.94
180.00	0.5272	**52.72**	6.18
224.00	0.6166	**61.66**	8.99
280.00	0.7482	**74.82**	12.97
315.00	0.8306	**83.06**	15.38
400.00	1	**100.00**	15.59
		TOTAL:	**100.00**

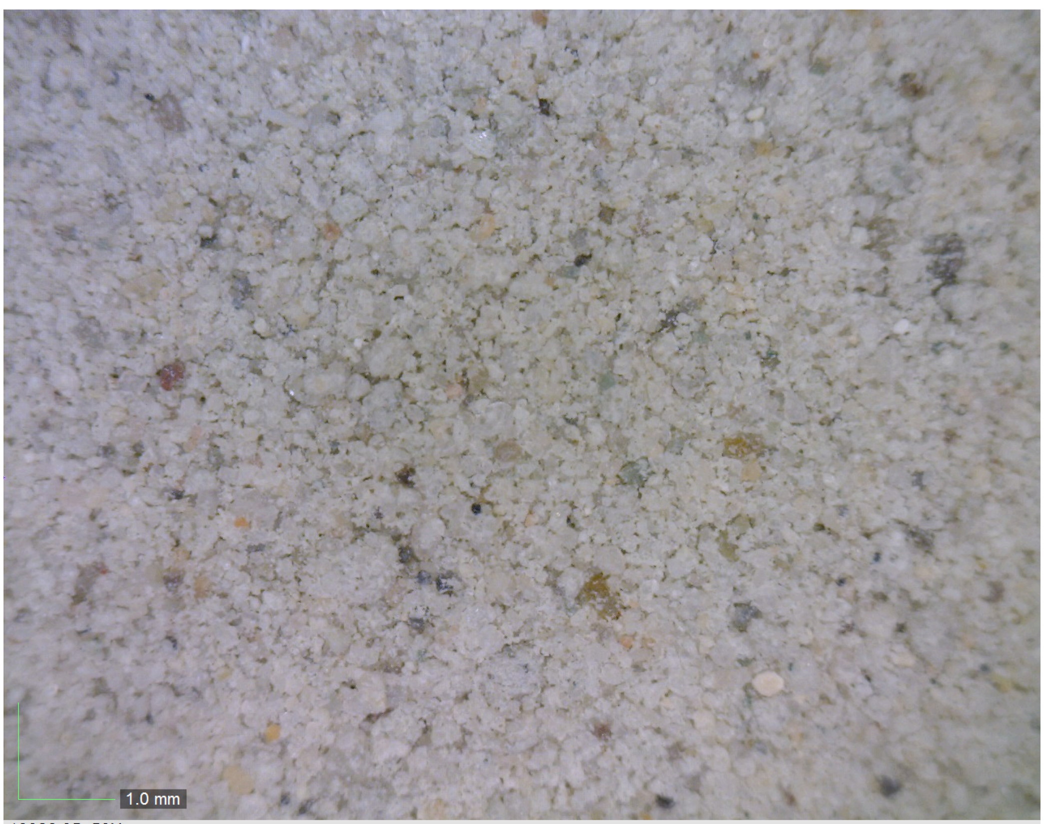


	Diameter at 10%	Diameter at 50%	Diameter at 90%	Cumulative at 100 µm
Min.	2.477	155.492	345.594	36.825
Max	2.613	172.249	349.149	39.673
Mean	2.537	163.512	347.346	38.293
Std deviation	0.056	6.64	1.421	1.11

CCASR-01-F; MI#18026-05



18026.05; 30X

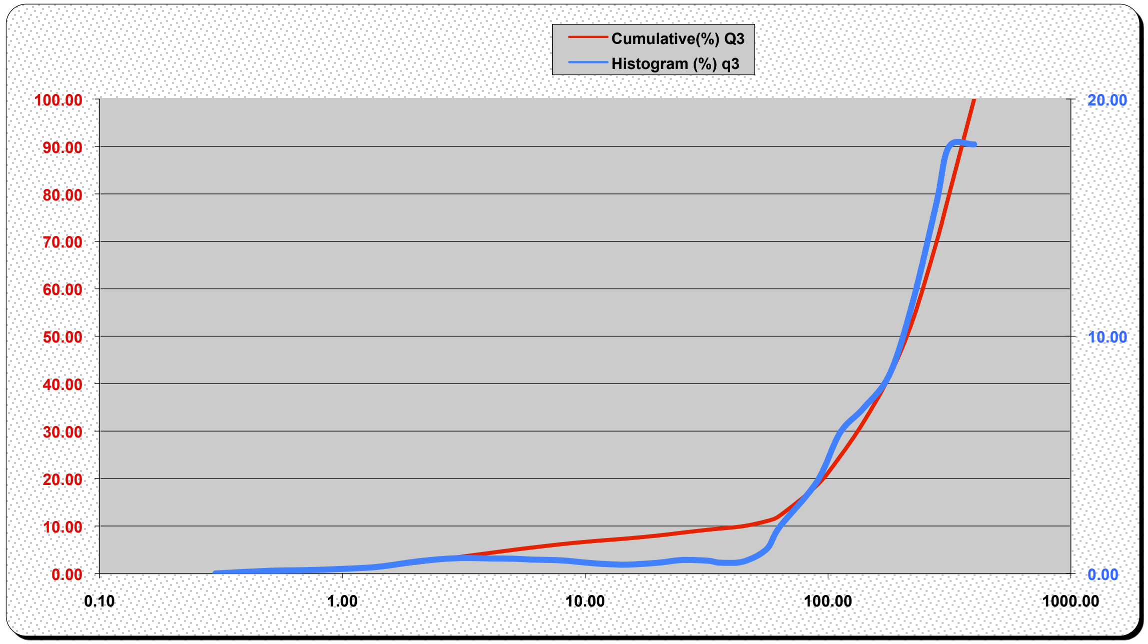


18026.05; 50X

Figure V
Particle Size Distribution Analysis
Sample ID: CCASR-01-F
Mineralogy, Inc. Job No.: 18026-05

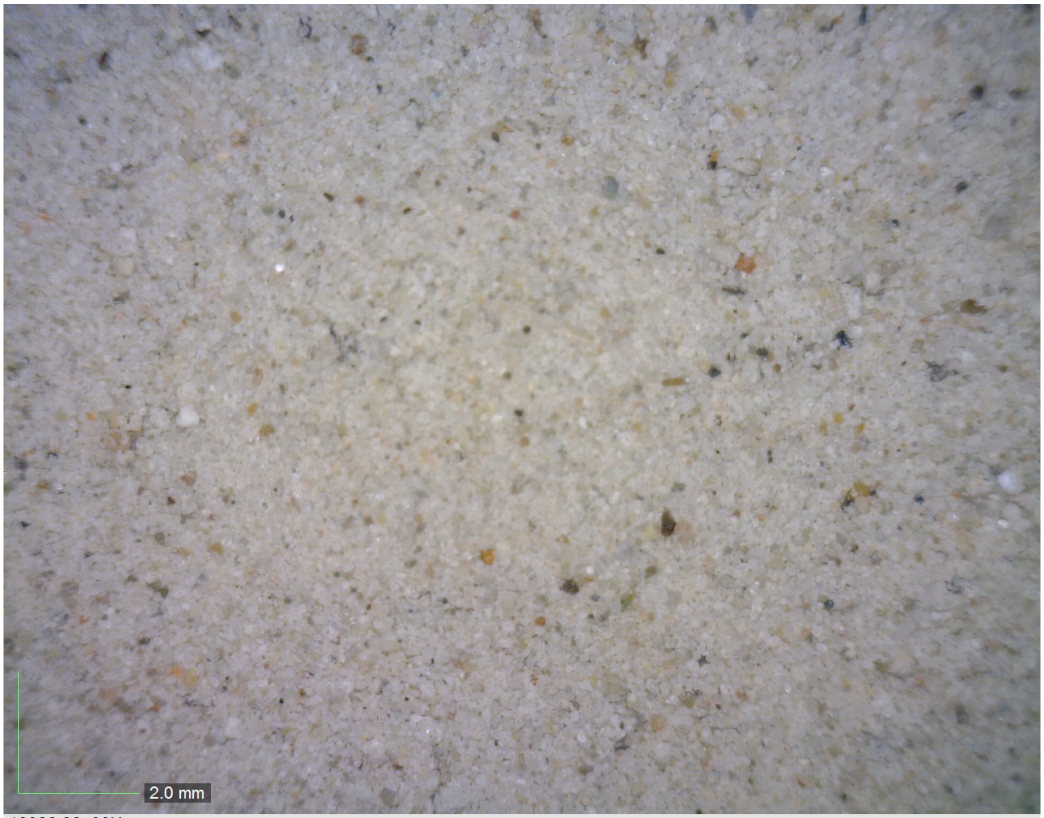
MINERALOGY-INC
WHERE SCIENCE GETS DOWN TO EARTH!

Size(µm)	From DATA.mes	Cumulative(%) Q3	Histogram (%) q3
0.30	0.0017	**0.17**	0.00
0.50	0.0044	**0.44**	0.11
0.70	0.0066	**0.66**	0.14
1.00	0.0098	**0.98**	0.19
1.40	0.0142	**1.42**	0.28
2.00	0.0225	**2.25**	0.50
2.60	0.03	**3.00**	0.61
3.20	0.0363	**3.63**	0.65
4.00	0.0429	**4.29**	0.63
5.00	0.0494	**4.94**	0.62
6.00	0.0544	**5.44**	0.59
8.00	0.0618	**6.18**	0.55
10.00	0.0666	**6.66**	0.46
12.00	0.07	**7.00**	0.40
15.00	0.0739	**7.39**	0.37
20.00	0.08	**8.00**	0.45
25.00	0.0859	**8.59**	0.57
32.00	0.0921	**9.21**	0.54
36.00	0.0946	**9.46**	0.45
45.00	0.0999	**9.99**	0.51
56.00	0.1105	**11.05**	1.04
63.00	0.1212	**12.12**	1.94
90.00	0.1857	**18.57**	3.87
112.00	0.2463	**24.63**	5.93
140.00	0.319	**31.90**	6.97
180.00	0.4181	**41.81**	8.43
224.00	0.5356	**53.56**	11.49
280.00	0.6988	**69.88**	15.64
315.00	0.7979	**79.79**	17.99
400.00	1	**100.00**	18.09
		TOTAL:	**100.00**

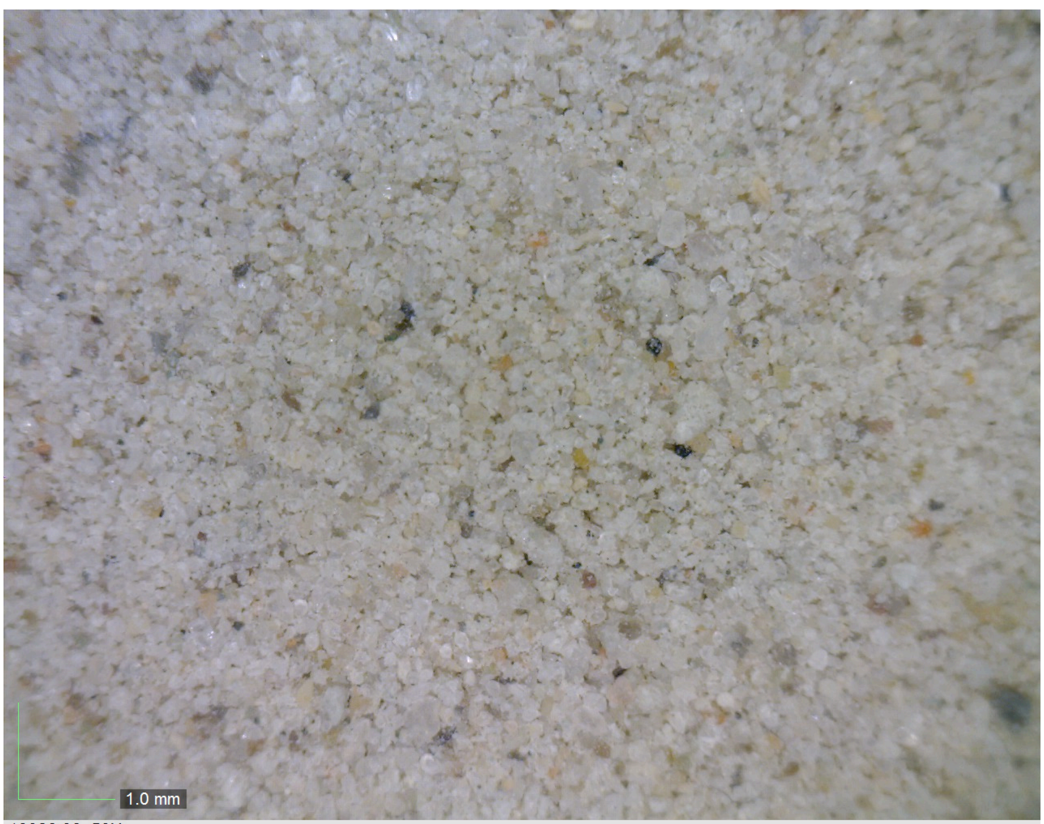


	Diameter at 10%	Diameter at 50%	Diameter at 90%	Cumulative at 100 µm
Min.	41.157	208.019	354.965	20.947
Max	47.429	211.531	355.899	21.75
Mean	44.559	209.632	355.399	21.333
Std deviation	2.567	1.443	0.393	0.314

CCASR-03-F; MI#18026-06



18026.06; 30X

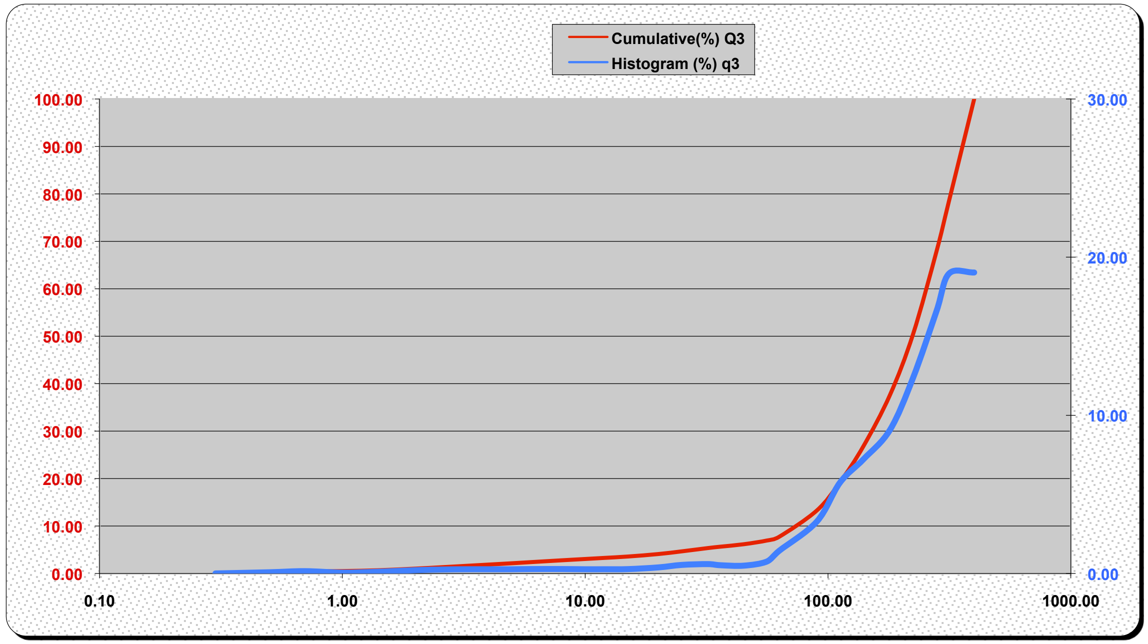


18026.06; 50X

Figure VI
Particle Size Distribution Analysis
Sample ID: CCASR-03-F
Mineralogy, Inc. Job No.: 18026-06

MINERALOGY-INC
WHERE SCIENCE GETS DOWN TO EARTH!

Size(µm)	From DATA.mes	Cumulative(%) Q3	Histogram (%) q3
0.30	0	**0.00**	0.00
0.50	0.0018	**0.18**	0.07
0.70	0.0041	**0.41**	0.14
1.00	0.005	**0.50**	0.05
1.40	0.0067	**0.67**	0.11
2.00	0.0102	**1.02**	0.21
2.60	0.0133	**1.33**	0.25
3.20	0.0159	**1.59**	0.26
4.00	0.0187	**1.87**	0.27
5.00	0.0215	**2.15**	0.27
6.00	0.0239	**2.39**	0.28
8.00	0.0277	**2.77**	0.28
10.00	0.0305	**3.05**	0.27
12.00	0.0328	**3.28**	0.27
15.00	0.0357	**3.57**	0.27
20.00	0.0409	**4.09**	0.38
25.00	0.0466	**4.66**	0.54
32.00	0.0535	**5.35**	0.59
36.00	0.0564	**5.64**	0.52
45.00	0.0616	**6.16**	0.49
56.00	0.0694	**6.94**	0.75
63.00	0.0774	**7.74**	1.44
90.00	0.1328	**13.28**	3.28
112.00	0.1922	**19.22**	5.74
140.00	0.2684	**26.84**	7.22
180.00	0.3763	**37.63**	9.08
224.00	0.5042	**50.42**	12.37
280.00	0.6794	**67.94**	16.60
315.00	0.785	**78.50**	18.96
400.00	1	**100.00**	19.03
		TOTAL:	**100.00**



	Diameter at 10%	Diameter at 50%	Diameter at 90%	Cumulative at 100 µm
Min.	72.34	221.719	357.731	15.802
Max	73.889	222.924	358.119	15.982
Mean	72.881	222.414	357.927	15.924
Std deviation	0.592	0.479	0.155	0.072

APPENDIX B

TestAmerica

THE LEADER IN ENVIRONMENTAL TESTING

ANALYTICAL REPORT

TestAmerica Laboratories, Inc.
TestAmerica St. Louis
13715 Rider Trail North
Earth City, MO 63045
Tel: (314)298-8566

TestAmerica Job ID: 160-26616-1
Client Project/Site: Metals - Sediment Matrix

For:
HDR Inc
4401 West Gate Blvd
Ste 400
Austin, Texas 78745

Attn: Kristi Shaw

Authorized for release by:
2/23/2018 4:02:03 PM

Ivan Vania, Project Manager II
(314)298-8566
ivan.vania@testamericainc.com

This report has been electronically signed and authorized by the signatory. Electronic signature is intended to be the legally binding equivalent of a traditionally handwritten signature.

Results relate only to the items tested and the sample(s) as received by the laboratory.

1 2 3 4 5 6 7 8 9 10 11

Table of Contents

Job ID: 160-26616-1

Laboratory: TestAmerica St. Louis

Narrative

waiting for pre-payment

CASE NARRATIVE

Client: Geochemical Solutions, LLC

Project: Metals - Sediment Matrix

Report Number: 160-26616-1

With the exceptions noted as flags or footnotes, standard analytical protocols were followed in the analysis of the samples and no problems were encountered or anomalies observed. In addition all laboratory quality control samples were within established control limits, with any exceptions noted below. Each sample was analyzed to achieve the lowest possible reporting limit within the constraints of the method. In some cases, due to interference or analytes present at high concentrations, samples were diluted. For diluted samples, the reporting limits are adjusted relative to the dilution required.

TestAmerica St. Louis attests to the validity of the laboratory data generated by TestAmerica facilities reported herein. All analyses performed by TestAmerica facilities were done using established laboratory SOPs that incorporate QA/QC procedures described in the application methods. TestAmerica's operations groups have reviewed the data for compliance with the laboratory QA/QC plan, and data have been found to be compliant with laboratory protocols unless otherwise noted below.

The test results in this report meet all NELAP requirements for parameters for which accreditation is required or available. Any exceptions to NELAP requirements are noted in this report. Pursuant to NELAP, this report may not be reproduced, except in full, without the written approval of the laboratory.

Calculations are performed before rounding to avoid round-off errors in calculated results.

All holding times were met and proper preservation noted for the methods performed on these samples, unless otherwise detailed in the individual sections below.

All solid sample results for Chemistry analyses are reported on an ""as received"" basis unless otherwise indicated by the presence of a % solids value in the method header. All soil/sediment sample results for radiochemistry analyses are based upon sample as dried and disaggregated with the exception of tritium, carbon-14, and iodine-129 by gamma spectroscopy unless requested as wet weight by the client."

Any minimum detectable concentration (MDC), critical value (DLC), or Safe Drinking Water Act detection limit (SDWA DL) is sample-specific unless otherwise stated elsewhere in this narrative.

Reference the chain of custody and condition upon receipt report for any variations on receipt conditions and temperature of samples on receipt.

Manual Integrations were performed only when necessary and are in compliance with the laboratory's standard operating procedure. Detailed information can be found in the raw data section of the level IV report.

This laboratory report is confidential and is intended for the sole use of TestAmerica and its client.

RECEIPT

The samples were received on 2/2/2018 9:20 AM; the samples arrived in good condition, properly preserved and, where required, on ice. The temperatures of the 2 coolers at receipt time were 1.3º C and 1.8º C.

Receipt Exceptions

The Chain-of-Custody (COC) was not relinquished.

Job ID: 160-26616-1 (Continued)

Laboratory: TestAmerica St. Louis (Continued)

METALS (ICP/MS)
Samples CCASR-01-V (160-26616-1), CCASR-01-L (160-26616-2), CCASR-03-A (160-26616-3), CCASR-03-T (160-26616-4) and CCASR-01-L DRILLING MUD (160-26616-5) were analyzed for Metals (ICP/MS) in accordance with EPA SW-846 Method 6020A. The samples were leached on 02/02/2018, prepared on 02/06/2018 and analyzed on 02/16/2018.

The presence of the '4' qualifier indicates analytes where the concentration in the unspiked sample exceeded four times the spiking amount.

Due to the high concentration of Iron, the matrix spike / matrix spike duplicate (MS/MSD) for preparation batch 160-349361 and 160-349911 and analytical batch 160-351826 could not be evaluated for accuracy and precision. The associated laboratory control sample (LCS) met acceptance criteria: (160-26616-A-1-C MS) and (160-26616-A-1-D MSD).

The matrix spike / matrix spike duplicate (MS/MSD) recoveries for preparation batch 160-349361 and 160-349911 and analytical batch 160-351826 were outside control limits for Aluminum and Magnesium. Sample matrix interference is suspected because the associated laboratory control sample (LCS) recovery was within acceptance limits: (160-26616-A-1-C MS) and (160-26616-A-1-D MSD).

The following samples in preparation batches 160-349361 and 160-349911, and analytical batch 160-351826, were diluted due to the abundance of non-target analytes. The samples contain high concentrations of salts which can cause instrument and QC failures when analyzed at a lesser dilution: CCASR-01-V (160-26616-1), CCASR-01-L (160-26616-2), CCASR-03-A (160-26616-3), CCASR-03-T (160-26616-4), CCASR-01-L DRILLING MUD (160-26616-5), (160-26616-A-1-C MS), (160-26616-A-1-D MSD), and (160-26616-A-1-B SD). Elevated reporting limits (RLs) are provided.

The low level check (CCVL) in analytical batch 160-351826 was outside upper QC limits for Manganese and Iron. The concentration of these analytes in the sample was at such a high level as to make the CCVL unnecessary: (CCVL 160-351826/38).

Aluminum and Manganese were detected in method blank MB 160-349911/1-A at levels that were above the method detection limit but below the reporting limit. The values should be considered estimates, and have been flagged. If the associated sample reported a result above the MDL and/or RL, the result has been flagged.

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

PERCENT SOLIDS
Samples CCASR-01-V (160-26616-1), CCASR-01-L (160-26616-2), CCASR-03-A (160-26616-3), CCASR-03-T (160-26616-4) and CCASR-01-L DRILLING MUD (160-26616-5) were analyzed for percent solids in accordance with EPA Method 160.3 MOD. The samples were analyzed on 02/06/2018.

No analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

TestAmerica St. Louis
13715 Rider Trail North

Earth City, MO 63045
Phone: 314.298.8566 Fax: 314.298.8757

Chain of Custody Record

200184

TestAmerica
THE LEADER IN ENVIRONMENTAL TESTING
TestAmerica Laboratories, Inc.
TAL-8210 (0713)

Regulatory Program: ☐ DW ☐ NPDES ☐ RCRA ☑ Other: Core sampling

Client Contact	Project Manager: Kristi Shaw	Site Contact: Ivan Vania	Date: 1/31/18	COC No:
Company Name: HDR Engineering Inc.	Tel/Fax: 512-912-5118	Lab Contact: 314-298-8566	Carrier:	1 of 1 COCs
Address: 4401 West Gate Blvd., Suite 400	Analysis Turnaround Time			Sampler: JSK
City/State/Zip: Austin, TX 78722	☐ CALENDAR DAYS ☐ WORKING DAYS			For Lab Use Only:
Phone: 512-912-5118	TAT if different from Below ______			Walk-in Client:
Fax: 512-912-5158	☐ 2 weeks			Lab Sampling:
Project Name: Corpus Christi ASR Program	☐ 1 week			
Site: Site 1 + Site 3	☐ 2 days			Job / SDG No.:
P O #	☐ 1 day			

160-26616 Chain of Custody

	Sample Identification	Sample Date	Sample Time	Sample Type (C=Comp, G=Grab)	Matrix	# of Cont.	Filtered Sample (Y / N)	Perform MS / MSD (Y / N)	6020A(3050/6010)	6108 SEP	Sample Specific Notes:
✗	CCASR-01-V	12/14/17	16:28	C	soil/core	2	N	N	✓	✓	* For Ivan Vania *
✗	CCASR-01-L	1/5/18	13:00	C	soil/core	2	N	N	✓	✓	* Sample Methods:
✗	CCASR-03-A	1/31/18	13:00	C	soil/core	2	N	N	✓	✓	
✗	CCASR-03-T	1/31/18	13:00	C	soil/core	2	N	N	✓	✓	• SEP/6010:
	CCASR-01-L Drilling Mud (only Ivan)	1/5/18	13:00	C	mud	1	N	N	✓		As, ~~U~~, Pb, Cu, Cr, Se Fe, Al, Mn, Mg
											•3050/6010: As, U, Pb, Co, Cr, Se, Al, Fe, Mg, Mn

Preservation Used: 1= Ice, 2= HCl; 3= H2SO4; 4=HNO3; 5=NaOH; 6= Other ______

Possible Hazard Identification:
Are any samples from a listed EPA Hazardous Waste? Please List any EPA Waste Codes for the sample in the Comments Section if the lab is to dispose of the sample.
☐ Non-Hazard ☐ Flammable ☐ Skin Irritant ☐ Poison B ☐ Unknown

Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
☑ Return to Client ☐ Disposal by Lab ☐ Archive for ______ Months

Special Instructions/QC Requirements & Comments:
Please call with any questions. Ship 1 bottle per sample to John Reynolds - TA Knoxville per 1/2/18 email.

Custody Seals Intact: ☐ Yes ☐ No | Custody Seal No.: | Cooler Temp. (°C): Obs'd: ______ Corr'd: ______ | Therm ID No.: ______

Relinquished by:	Company:	Date/Time:	Received by: BT	Company: TA	Date/Time: 2/2/18 0920
Relinquished by: ✗ BT	Company: TA	Date/Time: 2/2/18 1700	Received by:	Company:	Date/Time:
Relinquished by:	Company:	Date/Time:	Received in Laboratory by:	Company:	Date/Time:

✗ Shipped 1-250h to Knoxville Lab

Login Sample Receipt Checklist

Client: HDR Inc　　Job Number: 160-26616-1

Login Number: 26616　　**List Source: TestAmerica St. Louis**
List Number: 1
Creator: Daniels, Brian J

Question	Answer	Comment
Radioactivity wasn't checked or is </= background as measured by a survey meter.	True	
The cooler's custody seal, if present, is intact.	N/A	
Sample custody seals, if present, are intact.	True	
The cooler or samples do not appear to have been compromised or tampered with.	True	
Samples were received on ice.	True	
Cooler Temperature is acceptable.	True	
Cooler Temperature is recorded.	True	
COC is present.	True	
COC is filled out in ink and legible.	True	
COC is filled out with all pertinent information.	False	COC was not relinquished.
Is the Field Sampler's name present on COC?	True	
There are no discrepancies between the containers received and the COC.	True	
Samples are received within Holding Time (excluding tests with immediate HTs)	True	
Sample containers have legible labels.	True	
Containers are not broken or leaking.	True	
Sample collection date/times are provided.	True	
Appropriate sample containers are used.	True	
Sample bottles are completely filled.	True	
Sample Preservation Verified.	True	
There is sufficient vol. for all requested analyses, incl. any requested MS/MSDs	True	
Containers requiring zero headspace have no headspace or bubble is <6mm (1/4").	N/A	
Multiphasic samples are not present.	True	
Samples do not require splitting or compositing.	True	
Residual Chlorine Checked.	N/A	

Definitions/Glossary

Client: HDR Inc
Project/Site: Metals - Sediment Matrix

TestAmerica Job ID: 160-26616-1

Qualifiers

Metals

Qualifier	Qualifier Description
B	Compound was found in the blank and sample.
F1	MS and/or MSD Recovery is outside acceptance limits.
J	Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.
4	MS, MSD: The analyte present in the original sample is greater than 4 times the matrix spike concentration; therefore, control limits are not applicable.
^	ICV,CCV,ICB,CCB, ISA, ISB, CRI, CRA, DLCK or MRL standard: Instrument related QC is outside acceptance limits.

Glossary

Abbreviation	These commonly used abbreviations may or may not be present in this report.
¤	Listed under the "D" column to designate that the result is reported on a dry weight basis
%R	Percent Recovery
CFL	Contains Free Liquid
CNF	Contains No Free Liquid
DER	Duplicate Error Ratio (normalized absolute difference)
Dil Fac	Dilution Factor
DL	Detection Limit (DoD/DOE)
DL, RA, RE, IN	Indicates a Dilution, Re-analysis, Re-extraction, or additional Initial metals/anion analysis of the sample
DLC	Decision Level Concentration (Radiochemistry)
EDL	Estimated Detection Limit (Dioxin)
LOD	Limit of Detection (DoD/DOE)
LOQ	Limit of Quantitation (DoD/DOE)
MDA	Minimum Detectable Activity (Radiochemistry)
MDC	Minimum Detectable Concentration (Radiochemistry)
MDL	Method Detection Limit
ML	Minimum Level (Dioxin)
NC	Not Calculated
ND	Not Detected at the reporting limit (or MDL or EDL if shown)
PQL	Practical Quantitation Limit
QC	Quality Control
RER	Relative Error Ratio (Radiochemistry)
RL	Reporting Limit or Requested Limit (Radiochemistry)
RPD	Relative Percent Difference, a measure of the relative difference between two points
TEF	Toxicity Equivalent Factor (Dioxin)
TEQ	Toxicity Equivalent Quotient (Dioxin)

Method Summary

Client: HDR Inc
Project/Site: Metals - Sediment Matrix

TestAmerica Job ID: 160-26616-1

Method	Method Description	Protocol	Laboratory
6020A	Metals (ICP/MS)	SW846	TAL SL
Moisture	Percent Moisture	EPA	TAL SL

Protocol References:

EPA = US Environmental Protection Agency

SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

Laboratory References:

TAL SL = TestAmerica St. Louis, 13715 Rider Trail North, Earth City, MO 63045, TEL (314)298-8566

Sample Summary

Client: HDR Inc
Project/Site: Metals - Sediment Matrix

TestAmerica Job ID: 160-26616-1

Lab Sample ID	Client Sample ID	Matrix	Collected	Received
160-26616-1	CCASR-01-V	Solid	12/14/17 16:28	02/02/18 09:20
160-26616-2	CCASR-01-L	Solid	01/05/18 13:00	02/02/18 09:20
160-26616-3	CCASR-03-A	Solid	01/31/18 13:00	02/02/18 09:20
160-26616-4	CCASR-03-T	Solid	01/31/18 13:00	02/02/18 09:20
160-26616-5	CCASR-01-L DRILLING MUD	Solid	01/05/18 13:00	02/02/18 09:20

Client Sample ID: CCASR-01-V

Lab Sample ID: 160-26616-1
Date Collected: 12/14/17 16:28
Matrix: Solid
Date Received: 02/02/18 09:20
Percent Solids: 89.0

Method: 6020A - Metals (ICP/MS)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	4100	F1 B	13	5.4	mg/Kg	☼	02/06/18 14:49	02/16/18 17:02	5
Arsenic	2.6	J	2.7	1.1	mg/Kg	☼	02/06/18 14:49	02/16/18 17:02	5
Chromium	4.4		2.7	1.2	mg/Kg	☼	02/06/18 14:49	02/16/18 17:02	5
Copper	4.8		2.7	1.1	mg/Kg	☼	02/06/18 14:49	02/16/18 17:02	5
Iron	5200		13	5.4	mg/Kg	☼	02/06/18 14:49	02/16/18 17:02	5
Lead	4.4		0.81	0.34	mg/Kg	☼	02/06/18 14:49	02/16/18 17:02	5
Magnesium	1300	F1	130	67	mg/Kg	☼	02/06/18 14:49	02/16/18 17:02	5
Manganese	120	B	1.3	0.54	mg/Kg	☼	02/06/18 14:49	02/16/18 17:02	5
Selenium	1.1	J	1.3	0.86	mg/Kg	☼	02/06/18 14:49	02/16/18 17:02	5
Uranium	0.48		0.27	0.11	mg/Kg	☼	02/06/18 14:49	02/16/18 17:02	5

Client Sample ID: CCASR-01-L

Lab Sample ID: 160-26616-2
Date Collected: 01/05/18 13:00
Matrix: Solid
Date Received: 02/02/18 09:20
Percent Solids: 81.5

Method: 6020A - Metals (ICP/MS)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	7800	B	29	12	mg/Kg	☼	02/06/18 14:49	02/16/18 17:49	10
Arsenic	6.0		5.9	2.4	mg/Kg	☼	02/06/18 14:49	02/16/18 17:49	10
Chromium	10		5.9	2.6	mg/Kg	☼	02/06/18 14:49	02/16/18 17:49	10
Copper	5.3	J	5.9	2.4	mg/Kg	☼	02/06/18 14:49	02/16/18 17:49	10
Iron	6300	^	29	12	mg/Kg	☼	02/06/18 14:49	02/16/18 17:49	10
Lead	7.3		1.8	0.74	mg/Kg	☼	02/06/18 14:49	02/16/18 17:49	10
Magnesium	2800		290	150	mg/Kg	☼	02/06/18 14:49	02/16/18 17:49	10
Manganese	250	^ B	2.9	1.2	mg/Kg	☼	02/06/18 14:49	02/16/18 17:49	10
Selenium	ND		2.9	1.9	mg/Kg	☼	02/06/18 14:49	02/16/18 17:49	10
Uranium	2.1		0.59	0.24	mg/Kg	☼	02/06/18 14:49	02/16/18 17:49	10

Client Sample ID: CCASR-03-A

Lab Sample ID: 160-26616-3
Date Collected: 01/31/18 13:00
Matrix: Solid
Date Received: 02/02/18 09:20
Percent Solids: 85.2

Method: 6020A - Metals (ICP/MS)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	5500	B	29	11	mg/Kg	☼	02/06/18 14:49	02/16/18 17:56	10
Arsenic	2.9	J	5.7	2.3	mg/Kg	☼	02/06/18 14:49	02/16/18 17:56	10
Chromium	6.5		5.7	2.6	mg/Kg	☼	02/06/18 14:49	02/16/18 17:56	10
Copper	11		5.7	2.3	mg/Kg	☼	02/06/18 14:49	02/16/18 17:56	10
Iron	5000	^	29	11	mg/Kg	☼	02/06/18 14:49	02/16/18 17:56	10
Lead	11		1.7	0.71	mg/Kg	☼	02/06/18 14:49	02/16/18 17:56	10
Magnesium	1900		290	140	mg/Kg	☼	02/06/18 14:49	02/16/18 17:56	10
Manganese	160	^ B	2.9	1.1	mg/Kg	☼	02/06/18 14:49	02/16/18 17:56	10
Selenium	ND		2.9	1.8	mg/Kg	☼	02/06/18 14:49	02/16/18 17:56	10
Uranium	0.63		0.57	0.23	mg/Kg	☼	02/06/18 14:49	02/16/18 17:56	10

Client Sample ID: CCASR-03-T
Lab Sample ID: 160-26616-4
Date Collected: 01/31/18 13:00
Matrix: Solid
Date Received: 02/02/18 09:20
Percent Solids: 85.5

Method: 6020A - Metals (ICP/MS)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	5400	B	26	10	mg/Kg	☼	02/06/18 14:49	02/16/18 18:03	10
Arsenic	2.9	J	5.2	2.1	mg/Kg	☼	02/06/18 14:49	02/16/18 18:03	10
Chromium	6.3		5.2	2.3	mg/Kg	☼	02/06/18 14:49	02/16/18 18:03	10
Copper	9.1		5.2	2.1	mg/Kg	☼	02/06/18 14:49	02/16/18 18:03	10
Iron	4800	^	26	10	mg/Kg	☼	02/06/18 14:49	02/16/18 18:03	10
Lead	5.8		1.6	0.65	mg/Kg	☼	02/06/18 14:49	02/16/18 18:03	10
Magnesium	2000		260	130	mg/Kg	☼	02/06/18 14:49	02/16/18 18:03	10
Manganese	170	^ B	2.6	1.0	mg/Kg	☼	02/06/18 14:49	02/16/18 18:03	10
Selenium	ND		2.6	1.7	mg/Kg	☼	02/06/18 14:49	02/16/18 18:03	10
Uranium	0.64		0.52	0.21	mg/Kg	☼	02/06/18 14:49	02/16/18 18:03	10

Client Sample ID: CCASR-01-L DRILLING MUD
Lab Sample ID: 160-26616-5
Date Collected: 01/05/18 13:00
Matrix: Solid
Date Received: 02/02/18 09:20
Percent Solids: 15.7

Method: 6020A - Metals (ICP/MS)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	100000	B	140	55	mg/Kg	☼	02/06/18 14:49	02/16/18 18:10	10
Arsenic	45		27	11	mg/Kg	☼	02/06/18 14:49	02/16/18 18:10	10
Chromium	110		27	12	mg/Kg	☼	02/06/18 14:49	02/16/18 18:10	10
Copper	120		27	11	mg/Kg	☼	02/06/18 14:49	02/16/18 18:10	10
Iron	82000	^	140	55	mg/Kg	☼	02/06/18 14:49	02/16/18 18:10	10
Lead	94		8.2	3.4	mg/Kg	☼	02/06/18 14:49	02/16/18 18:10	10
Magnesium	35000		1400	680	mg/Kg	☼	02/06/18 14:49	02/16/18 18:10	10
Manganese	2200	^ B	14	5.5	mg/Kg	☼	02/06/18 14:49	02/16/18 18:10	10
Selenium	10	J	14	8.8	mg/Kg	☼	02/06/18 14:49	02/16/18 18:10	10
Uranium	17		2.7	1.1	mg/Kg	☼	02/06/18 14:49	02/16/18 18:10	10

QC Sample Results

Client: HDR Inc
Project/Site: Metals - Sediment Matrix

TestAmerica Job ID: 160-26616-1

Method: 6020A - Metals (ICP/MS)

Lab Sample ID: MB 160-349911/1-A
Matrix: Solid
Analysis Batch: 351826

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 349911

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	1.71	J	4.2	1.7	mg/Kg		02/06/18 14:49	02/16/18 16:42	2
Arsenic	ND		0.84	0.34	mg/Kg		02/06/18 14:49	02/16/18 16:42	2
Chromium	ND		0.84	0.38	mg/Kg		02/06/18 14:49	02/16/18 16:42	2
Copper	ND		0.84	0.34	mg/Kg		02/06/18 14:49	02/16/18 16:42	2
Iron	ND		4.2	1.7	mg/Kg		02/06/18 14:49	02/16/18 16:42	2
Lead	ND		0.25	0.11	mg/Kg		02/06/18 14:49	02/16/18 16:42	2
Magnesium	ND		42	21	mg/Kg		02/06/18 14:49	02/16/18 16:42	2
Manganese	0.179	J	0.42	0.17	mg/Kg		02/06/18 14:49	02/16/18 16:42	2
Selenium	ND		0.42	0.27	mg/Kg		02/06/18 14:49	02/16/18 16:42	2
Uranium	ND		0.084	0.034	mg/Kg		02/06/18 14:49	02/16/18 16:42	2

Lab Sample ID: LCS 160-349911/2-A
Matrix: Solid
Analysis Batch: 351826

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 349911

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Uranium	89.3	88.6		mg/Kg		99	80 - 120

Lab Sample ID: LCSSRM 160-349911/3-A
Matrix: Solid
Analysis Batch: 351826

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 349911

Analyte	Spike Added	LCSSRM Result	LCSSRM Qualifier	Unit	D	%Rec	%Rec. Limits
Aluminum	8090	6830		mg/Kg		84.4	39.6 - 160.7
Arsenic	100	105		mg/Kg		104.9	69.6 - 131.0
Chromium	107	104		mg/Kg		96.9	69.4 - 134.6
Copper	166	177		mg/Kg		106.6	75.3 - 128.3
Iron	14600	14000		mg/Kg		95.7	36.1 - 163.7
Lead	88.4	95.2		mg/Kg		107.7	69.9 - 130.1
Magnesium	2930	2770		mg/Kg		94.5	65.9 - 134.5
Manganese	311	318		mg/Kg		102.2	74.9 - 125.4
Selenium	87.7	97.3		mg/Kg		111.0	64.1 - 135.7

Lab Sample ID: 160-26616-1 MS
Matrix: Solid
Analysis Batch: 351826

Client Sample ID: CCASR-01-V
Prep Type: Total/NA
Prep Batch: 349911

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits
Aluminum	4100	F1 B	1090	11600	F1	mg/Kg	☼	692	75 - 125
Arsenic	2.6	J	109	110		mg/Kg	☼	98	75 - 125
Chromium	4.4		109	113		mg/Kg	☼	100	75 - 125
Copper	4.8		109	114		mg/Kg	☼	100	75 - 125

Client: HDR Inc
Project/Site: Metals - Sediment Matrix

TestAmerica Job ID: 160-26616-1

Method: 6020A - Metals (ICP/MS) (Continued)

Lab Sample ID: 160-26616-1 MS
Matrix: Solid
Analysis Batch: 351826

Client Sample ID: CCASR-01-V
Prep Type: Total/NA
Prep Batch: 349911

Analyte	Sample Result	Sample Qualifier	Spike Added	MS Result	MS Qualifier	Unit	D	%Rec	%Rec. Limits
Iron	5200		1090	9200	4	mg/Kg	☼	365	75 - 125
Lead	4.4		109	110		mg/Kg	☼	97	75 - 125
Magnesium	1300	F1	1090	3300	F1	mg/Kg	☼	179	75 - 125
Manganese	120	B	109	252		mg/Kg	☼	117	75 - 125
Selenium	1.1	J	54.6	53.6		mg/Kg	☼	96	75 - 125
Uranium	0.48		109	110		mg/Kg	☼	100	75 - 125

Lab Sample ID: 160-26616-1 MSD
Matrix: Solid
Analysis Batch: 351826

Client Sample ID: CCASR-01-V
Prep Type: Total/NA
Prep Batch: 349911

Analyte	Sample Result	Sample Qualifier	Spike Added	MSD Result	MSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Aluminum	4100	F1 B	1040	11300	F1	mg/Kg	☼	693	75 - 125	3	30
Arsenic	2.6	J	104	106		mg/Kg	☼	99	75 - 125	4	30
Chromium	4.4		104	108		mg/Kg	☼	100	75 - 125	5	30
Copper	4.8		104	110		mg/Kg	☼	102	75 - 125	3	30
Iron	5200		1040	9310	4	mg/Kg	☼	394	75 - 125	1	30
Lead	4.4		104	105		mg/Kg	☼	97	75 - 125	5	30
Magnesium	1300	F1	1040	3160	F1	mg/Kg	☼	176	75 - 125	4	30
Manganese	120	B	104	246		mg/Kg	☼	117	75 - 125	3	30
Selenium	1.1	J	51.8	52.3		mg/Kg	☼	99	75 - 125	3	30
Uranium	0.48		104	104		mg/Kg	☼	100	75 - 125	5	30

1 2 3 4 5 6 7 8 9 10 11

Metals

Leach Batch: 349361

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
160-26616-1	CCASR-01-V	Total/NA	Solid	Dry and Grind	
160-26616-2	CCASR-01-L	Total/NA	Solid	Dry and Grind	
160-26616-3	CCASR-03-A	Total/NA	Solid	Dry and Grind	
160-26616-4	CCASR-03-T	Total/NA	Solid	Dry and Grind	
160-26616-5	CCASR-01-L DRILLING MUD	Total/NA	Solid	Dry and Grind	
160-26616-1 MS	CCASR-01-V	Total/NA	Solid	Dry and Grind	
160-26616-1 MSD	CCASR-01-V	Total/NA	Solid	Dry and Grind	

Prep Batch: 349911

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
160-26616-1	CCASR-01-V	Total/NA	Solid	3050B	349361
160-26616-2	CCASR-01-L	Total/NA	Solid	3050B	349361
160-26616-3	CCASR-03-A	Total/NA	Solid	3050B	349361
160-26616-4	CCASR-03-T	Total/NA	Solid	3050B	349361
160-26616-5	CCASR-01-L DRILLING MUD	Total/NA	Solid	3050B	349361
MB 160-349911/1-A	Method Blank	Total/NA	Solid	3050B	
LCS 160-349911/2-A	Lab Control Sample	Total/NA	Solid	3050B	
LCSSRM 160-349911/3-A	Lab Control Sample	Total/NA	Solid	3050B	
160-26616-1 MS	CCASR-01-V	Total/NA	Solid	3050B	349361
160-26616-1 MSD	CCASR-01-V	Total/NA	Solid	3050B	349361

Analysis Batch: 351826

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
160-26616-1	CCASR-01-V	Total/NA	Solid	6020A	349911
160-26616-2	CCASR-01-L	Total/NA	Solid	6020A	349911
160-26616-3	CCASR-03-A	Total/NA	Solid	6020A	349911
160-26616-4	CCASR-03-T	Total/NA	Solid	6020A	349911
160-26616-5	CCASR-01-L DRILLING MUD	Total/NA	Solid	6020A	349911
MB 160-349911/1-A	Method Blank	Total/NA	Solid	6020A	349911
LCS 160-349911/2-A	Lab Control Sample	Total/NA	Solid	6020A	349911
LCSSRM 160-349911/3-A	Lab Control Sample	Total/NA	Solid	6020A	349911
160-26616-1 MS	CCASR-01-V	Total/NA	Solid	6020A	349911
160-26616-1 MSD	CCASR-01-V	Total/NA	Solid	6020A	349911

General Chemistry

Analysis Batch: 349922

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
160-26616-1	CCASR-01-V	Total/NA	Solid	Moisture	
160-26616-2	CCASR-01-L	Total/NA	Solid	Moisture	
160-26616-3	CCASR-03-A	Total/NA	Solid	Moisture	
160-26616-4	CCASR-03-T	Total/NA	Solid	Moisture	
160-26616-5	CCASR-01-L DRILLING MUD	Total/NA	Solid	Moisture	
160-26616-5 DU	CCASR-01-L DRILLING MUD	Total/NA	Solid	Moisture	

APPENDIX C

TestAmerica

THE LEADER IN ENVIRONMENTAL TESTING

ANALYTICAL REPORT

TestAmerica Laboratories, Inc.
TestAmerica Knoxville
5815 Middlebrook Pike
Knoxville, TN 37921
Tel: (865)291-3000

TestAmerica Job ID: 140-10636-1
Client Project/Site: Corpus Christi ASR Program (SEP)

For:
HDR Inc
4401 West Gate Blvd
Ste 400
Austin, Texas 78745

Attn: Kristi Shaw

Ryan Henry

Authorized for release by:
2/28/2018 11:27:49 AM

Ryan Henry, Project Manager I
(865)291-3000
william.henry@testamericainc.com

The test results in this report meet all 2003 NELAC and 2009 TNI requirements for accredited parameters, exceptions are noted in this report. This report may not be reproduced except in full, and with written approval from the laboratory. For questions please contact the Project Manager at the e-mail address or telephone number listed on this page.

This report has been electronically signed and authorized by the signatory. Electronic signature is intended to be the legally binding equivalent of a traditionally handwritten signature.

Results relate only to the items tested and the sample(s) as received by the laboratory.

Table of Contents

Definitions/Glossary

Client: HDR Inc
Project/Site: Corpus Christi ASR Program (SEP)

TestAmerica Job ID: 140-10636-1

Qualifiers

Metals

Qualifier	Qualifier Description
J	Result is less than the RL but greater than or equal to the MDL and the concentration is an approximate value.
*	LCS or LCSD is outside acceptance limits.
*	RPD of the LCS and LCSD exceeds the control limits
B	Compound was found in the blank and sample.
F5	Duplicate RPD exceeds limit, and one or both sample results are less than 5 times RL. The data are considered valid because the absolute difference is less than the RL.
F3	Duplicate RPD exceeds the control limit

Glossary

Abbreviation	These commonly used abbreviations may or may not be present in this report.
¤	Listed under the "D" column to designate that the result is reported on a dry weight basis
%R	Percent Recovery
CFL	Contains Free Liquid
CNF	Contains No Free Liquid
DER	Duplicate Error Ratio (normalized absolute difference)
Dil Fac	Dilution Factor
DL	Detection Limit (DoD/DOE)
DL, RA, RE, IN	Indicates a Dilution, Re-analysis, Re-extraction, or additional Initial metals/anion analysis of the sample
DLC	Decision Level Concentration (Radiochemistry)
EDL	Estimated Detection Limit (Dioxin)
LOD	Limit of Detection (DoD/DOE)
LOQ	Limit of Quantitation (DoD/DOE)
MDA	Minimum Detectable Activity (Radiochemistry)
MDC	Minimum Detectable Concentration (Radiochemistry)
MDL	Method Detection Limit
ML	Minimum Level (Dioxin)
NC	Not Calculated
ND	Not Detected at the reporting limit (or MDL or EDL if shown)
PQL	Practical Quantitation Limit
QC	Quality Control
RER	Relative Error Ratio (Radiochemistry)
RL	Reporting Limit or Requested Limit (Radiochemistry)
RPD	Relative Percent Difference, a measure of the relative difference between two points
TEF	Toxicity Equivalent Factor (Dioxin)
TEQ	Toxicity Equivalent Quotient (Dioxin)

Job ID: 140-10636-1

Laboratory: TestAmerica Knoxville

Narrative

Job Narrative
140-10636-1

Receipt
The samples were received on 2/3/2018 at 8:45am and arrived in good condition, properly preserved and, where required, on ice. The temperature of the cooler at receipt was 0.0º C.

Receipt Exceptions
The following sample was listed on the Chain of Custody (COC); however, no sample was received: CCASR-01-L Drilling Mud

Metals
7 Step Sequential Extraction Procedure

These soil samples were prepared and analyzed using TestAmerica Knoxville standard operating procedure KNOX-MT-0008, "7 Step Sequential Extraction Procedure". SW-846 Method 6010B as incorporated in TestAmerica Knoxville standard operating procedure KNOX-MT-0007 was used to perform the final instrument analyses.

An aliquot of each sample was sequentially extracted using the steps listed below:

· Step 1 - Exchangeable Fraction: A 5 gram aliquot of sample was extracted with 25 mL of 1M magnesium sulfate ($MgSO_4$), centrifuged and filtered. 5 mL of the resulting leachate was digested using method 3010A and analyzed by method 6010B. Results are reported in mg/kg on a dry weight basis.
· Step 2 - Carbonate Fraction: The sample residue from step 1 was extracted with 25 mL of 1M sodium acetate/acetic acid (NaOAc/HOAc) at pH 5, centrifuged and filtered. 5 mL of the resulting leachate was digested using method 3010A and analyzed by method 6010B. Results are reported in mg/kg on a dry weight basis.
· Step 3 - Non-crystalline Materials Fraction: The sample residue from step 2 was extracted with 25 mL of 0.2M ammonium oxalate (pH 3), centrifuged and filtered. 5 mL of the resulting leachate was digested using method 3010A and analyzed by method 6010B. Results are reported in mg/kg on a dry weight basis.
· Step 4 - Metal Hydroxide Fraction: The sample residue from step 3 was extracted with 25 mL of 1M hydroxylamine hydrochloride solution in 25% v/v acetic acid, centrifuged and filtered. 5 mL of the resulting leachate was digested using method 3010A and analyzed by method 6010B. Results are reported in mg/kg on a dry weight basis.
· Step 5 - Organic-bound Fraction: The sample residue from step 4 was extracted three times with 25 mL of 5% sodium hypochlorite (NaClO) at pH 9.5, centrifuged and filtered. The resulting leachates were combined and 5 mL were digested using method 3010A and analyzed by method 6010B. Results are reported in mg/kg on a dry weight basis.
· Step 6 - Acid/Sulfide Fraction: The sample residue from step 5 was extracted with 25 mL of a 3:1:2 v/v solution of HCl-HNO_3-H_2O, centrifuged and filtered. 5 mL of the resulting leachate was diluted to 50 mL with reagent water and analyzed by method 6010B. Results are reported in mg/kg on a dry weight basis.
· Step 7 - Residual Fraction: A 1.0 g aliquot of the sample residue from step 6 was digested using HF, HNO_3, HCl and H_3BO_3. The digestate was analyzed by ICP using method 6010B. Results are reported in mg/kg on a dry weight basis.

In addition, a 1.0 g aliquot of the original sample was digested using HF, HNO_3, HCl and H_3BO_3. The digestate was analyzed by ICP using method 6010B. Total metal results are reported in mg/kg on a dry weight basis.

Results were calculated using the following equation:

Result, µg/g or mg/Kg, dry weight = $(C \times V \times V1 \times D) / (W \times S \times V2)$

Where:
C = Concentration from instrument readout, µg/mL
V = Final volume of digestate, mL
D = Instrument dilution factor
V1 = Total volume of leachate, mL
V2 = Volume of leachate digested, mL
W = Wet weight of sample, g

1 2 3 4 5 6 7 8 9 10 11 12 13

Job ID: 140-10636-1 (Continued)

Laboratory: TestAmerica Knoxville (Continued)

S = Percent solids/100

A method blank, laboratory control sample and laboratory control sample duplicate were prepared and analyzed with each SEP step in order to provide information about both the presence of elements of interest in the extraction solutions, and the recovery of elements of interest from the extraction solutions. Results outside of laboratory QC limits do not reflect out of control performance, but rather the effect of the extraction solution upon the analyte.

A laboratory sample duplicate was prepared and analyzed with each batch of samples in order to provide information regarding the reproducibility of the procedure.

SEP Report Notes:

The final report lists the results for each step, the result for the total digestion of the sample, and a sum of the results of steps 1 through 7 by element.

Magnesium was not reported for step 1 because the extraction solution for this step (magnesium sulfate) contains high levels of magnesium. The sum of steps 1 through 7 is much higher than the total result for magnesium due to the magnesium introduced by the extraction solutions.

The digestates for steps 1, 2 and 5 were analyzed at a dilution due to instrument problems caused by the high solids content of the digestates. The reporting limits were adjusted accordingly.

Method(s) 6010B: The serial dilution performed for the following samples associated with batch 140-18463 was outside control limits: (140-10636-A-1-A SD ^)

Method(s) 6010B, 6010B SEP: The following samples were diluted due to the presence of Titanium which interferes with Lead: CCASR-01-L (140-10636-2), CCASR-03-A (140-10636-3) and CCASR-03-T (140-10636-4). Elevated reporting limits (RLs) are provided.

Method(s) 6010B, 6010B SEP: The following samples were diluted 1:10 for Aluminum and Magnesium due to the nature of the sample matrix: CCASR-01-U (140-10636-1), CCASR-01-L (140-10636-2), CCASR-03-A (140-10636-3), CCASR-03-T (140-10636-4), (140-10636-A-1-B DU) and (140-10636-A-1-Z DU). Elevated reporting limits (RLs) are provided.

No additional analytical or quality issues were noted, other than those described above or in the Definitions/Glossary page.

General Chemistry
No analytical or quality issues were noted, other than those described in the Definitions/Glossary page.

Sample Summary

Client: HDR Inc
Project/Site: Corpus Christi ASR Program (SEP)

TestAmerica Job ID: 140-10636-1

Lab Sample ID	Client Sample ID	Matrix	Collected	Received
140-10636-1	CCASR-01-U	Solid	12/14/17 16:28	02/03/18 08:45
140-10636-2	CCASR-01-L	Solid	01/05/18 13:00	02/03/18 08:45
140-10636-3	CCASR-03-A	Solid	01/31/18 13:00	02/03/18 08:45
140-10636-4	CCASR-03-T	Solid	01/31/18 13:00	02/03/18 08:45

Client Sample ID: CCASR-01-U

Date Collected: 12/14/17 16:28
Date Received: 02/03/18 08:45

Lab Sample ID: 140-10636-1
Matrix: Solid
Percent Solids: 92.5

Method: 6010B SEP - SEP Metals (ICP) - Step 1

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	ND		43	6.9	mg/Kg	☼	02/16/18 08:00	02/22/18 11:39	4
Arsenic	ND		2.2	0.56	mg/Kg	☼	02/16/18 08:00	02/22/18 11:39	4
Chromium	ND		2.2	0.30	mg/Kg	☼	02/16/18 08:00	02/22/18 11:39	4
Copper	ND		5.4	0.35	mg/Kg	☼	02/16/18 08:00	02/22/18 11:39	4
Iron	ND		22	13	mg/Kg	☼	02/16/18 08:00	02/22/18 11:39	4
Lead	ND		2.2	0.48	mg/Kg	☼	02/16/18 08:00	02/22/18 11:39	4
Manganese	**1.6**	**J**	3.2	0.13	mg/Kg	☼	02/16/18 08:00	02/22/18 11:39	4
Selenium	ND		2.2	0.74	mg/Kg	☼	02/16/18 08:00	02/22/18 11:39	4

Method: 6010B SEP - SEP Metals (ICP) - Step 2

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	ND	*	32	5.2	mg/Kg	☼	02/19/18 08:00	02/22/18 12:35	3
Arsenic	**0.46**	**J**	1.6	0.42	mg/Kg	☼	02/19/18 08:00	02/22/18 12:35	3
Chromium	ND	*	1.6	0.23	mg/Kg	☼	02/19/18 08:00	02/22/18 12:35	3
Copper	**0.55**	**J**	4.1	0.52	mg/Kg	☼	02/19/18 08:00	02/22/18 12:35	3
Iron	**24**	*****	16	9.4	mg/Kg	☼	02/19/18 08:00	02/22/18 12:35	3
Lead	ND		1.6	0.36	mg/Kg	☼	02/19/18 08:00	02/22/18 12:35	3
Magnesium	**10000**		810	5.5	mg/Kg	☼	02/19/18 08:00	02/22/18 12:35	3
Manganese	**59**		2.4	0.91	mg/Kg	☼	02/19/18 08:00	02/22/18 12:35	3
Selenium	**0.86**	**J B**	1.6	0.55	mg/Kg	☼	02/19/18 08:00	02/22/18 12:35	3

Method: 6010B SEP - SEP Metals (ICP) - Step 3

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**60**		11	2.3	mg/Kg	☼	02/20/18 08:00	02/22/18 13:31	1
Arsenic	**0.27**	**J**	0.54	0.14	mg/Kg	☼	02/20/18 08:00	02/22/18 13:31	1
Chromium	**0.094**	**J**	0.54	0.076	mg/Kg	☼	02/20/18 08:00	02/22/18 13:31	1
Copper	**0.63**	**J**	1.4	0.28	mg/Kg	☼	02/20/18 08:00	02/22/18 13:31	1
Iron	**68**		5.4	3.1	mg/Kg	☼	02/20/18 08:00	02/22/18 13:31	1
Lead	ND	*	0.54	0.12	mg/Kg	☼	02/20/18 08:00	02/22/18 13:31	1
Magnesium	**1200**	**B**	270	1.8	mg/Kg	☼	02/20/18 08:00	02/22/18 13:31	1
Manganese	**9.4**	**B**	0.81	0.029	mg/Kg	☼	02/20/18 08:00	02/22/18 13:31	1
Selenium	**0.26**	**J B**	0.54	0.18	mg/Kg	☼	02/20/18 08:00	02/22/18 13:31	1

Method: 6010B SEP - SEP Metals (ICP) - Step 4

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**1300**		11	1.7	mg/Kg	☼	02/21/18 08:00	02/22/18 14:26	1
Arsenic	**0.51**	**J B**	0.54	0.24	mg/Kg	☼	02/21/18 08:00	02/22/18 14:26	1
Chromium	**1.1**	**B**	0.54	0.076	mg/Kg	☼	02/21/18 08:00	02/22/18 14:26	1
Copper	**0.35**	**J**	1.4	0.24	mg/Kg	☼	02/21/18 08:00	02/22/18 14:26	1
Iron	**390**		5.4	3.1	mg/Kg	☼	02/21/18 08:00	02/22/18 14:26	1
Lead	**0.55**		0.54	0.12	mg/Kg	☼	02/21/18 08:00	02/22/18 14:26	1
Magnesium	**600**		270	1.8	mg/Kg	☼	02/21/18 08:00	02/22/18 14:26	1
Manganese	**9.9**		0.81	0.14	mg/Kg	☼	02/21/18 08:00	02/22/18 14:26	1
Selenium	**0.65**	**B ***	0.54	0.51	mg/Kg	☼	02/21/18 08:00	02/22/18 14:26	1

Method: 6010B SEP - SEP Metals (ICP) - Step 5

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	ND	*	160	25	mg/Kg	☼	02/22/18 08:00	02/26/18 11:21	5
Arsenic	ND		8.1	2.1	mg/Kg	☼	02/22/18 08:00	02/26/18 11:21	5
Chromium	**1.2**	**J**	8.1	1.1	mg/Kg	☼	02/22/18 08:00	02/26/18 11:21	5

Client Sample ID: CCASR-01-U

Lab Sample ID: 140-10636-1

Date Collected: 12/14/17 16:28 **Matrix: Solid**

Date Received: 02/03/18 08:45 **Percent Solids: 92.5**

Method: 6010B SEP - SEP Metals (ICP) - Step 5 (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Copper	ND		20	1.3	mg/Kg	☼	02/22/18 08:00	02/26/18 11:21	5
Iron	ND	*	81	48	mg/Kg	☼	02/22/18 08:00	02/26/18 11:21	5
Lead	ND	*	8.1	1.8	mg/Kg	☼	02/22/18 08:00	02/26/18 11:21	5
Magnesium	**100**	**J B**	4100	33	mg/Kg	☼	02/22/18 08:00	02/26/18 11:21	5
Manganese	**2.6**	**J ***	12	2.0	mg/Kg	☼	02/22/18 08:00	02/26/18 11:21	5
Selenium	ND		8.1	2.8	mg/Kg	☼	02/22/18 08:00	02/26/18 11:21	5

Method: 6010B SEP - SEP Metals (ICP) - Step 6

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**3400**		11	1.7	mg/Kg	☼	02/22/18 08:00	02/26/18 12:16	1
Arsenic	**1.8**		0.54	0.16	mg/Kg	☼	02/22/18 08:00	02/26/18 12:16	1
Chromium	**2.2**		0.54	0.076	mg/Kg	☼	02/22/18 08:00	02/26/18 12:16	1
Copper	**2.4**		1.4	0.087	mg/Kg	☼	02/22/18 08:00	02/26/18 12:16	1
Iron	**4400**		5.4	3.1	mg/Kg	☼	02/22/18 08:00	02/26/18 12:16	1
Lead	**3.1**		0.54	0.12	mg/Kg	☼	02/22/18 08:00	02/26/18 12:16	1
Magnesium	**780**		270	1.8	mg/Kg	☼	02/22/18 08:00	02/26/18 12:16	1
Manganese	**29**		0.81	0.27	mg/Kg	☼	02/22/18 08:00	02/26/18 12:16	1
Selenium	ND		0.54	0.18	mg/Kg	☼	02/22/18 08:00	02/26/18 12:16	1

Method: 6010B SEP - SEP Metals (ICP) - Step 7

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**15000**		110	17	mg/Kg	☼	02/23/18 08:00	02/26/18 14:59	10
Arsenic	**0.33**	**J**	0.54	0.14	mg/Kg	☼	02/23/18 08:00	02/26/18 13:11	1
Chromium	**6.0**		0.54	0.076	mg/Kg	☼	02/23/18 08:00	02/26/18 13:11	1
Copper	**1.7**		1.4	0.087	mg/Kg	☼	02/23/18 08:00	02/26/18 13:11	1
Iron	**3300**		5.4	4.4	mg/Kg	☼	02/23/18 08:00	02/26/18 13:11	1
Lead	**3.0**		0.54	0.12	mg/Kg	☼	02/23/18 08:00	02/26/18 13:11	1
Magnesium	**680**	**J**	2700	18	mg/Kg	☼	02/23/18 08:00	02/26/18 14:59	10
Manganese	**22**		0.81	0.056	mg/Kg	☼	02/23/18 08:00	02/26/18 13:11	1
Selenium	ND		0.54	0.18	mg/Kg	☼	02/23/18 08:00	02/26/18 13:11	1

Method: 6010B SEP - SEP Metals (ICP) - Sum of Steps 1-7

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**20000**		10	1.6	mg/Kg			02/27/18 13:33	1
Arsenic	**3.3**		0.50	0.13	mg/Kg			02/27/18 13:33	1
Chromium	**11**		0.50	0.070	mg/Kg			02/27/18 13:33	1
Copper	**5.6**		1.3	0.080	mg/Kg			02/27/18 13:33	1
Iron	**8100**		5.0	4.1	mg/Kg			02/27/18 13:33	1
Lead	**6.7**		0.50	0.11	mg/Kg			02/27/18 13:33	1
Magnesium	**14000**		250	1.7	mg/Kg			02/27/18 13:33	1
Manganese	**130**		0.75	0.052	mg/Kg			02/27/18 13:33	1
Selenium	**1.8**		0.50	0.17	mg/Kg			02/27/18 13:33	1

Method: 6010B - SEP Metals (ICP) - Total

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**22000**		110	17	mg/Kg	☼	02/15/18 08:00	02/26/18 15:44	10
Arsenic	**3.5**		0.54	0.14	mg/Kg	☼	02/15/18 08:00	02/26/18 14:12	1
Chromium	**6.6**		0.54	0.076	mg/Kg	☼	02/15/18 08:00	02/26/18 14:12	1
Copper	**5.1**		1.4	0.087	mg/Kg	☼	02/15/18 08:00	02/26/18 14:12	1
Iron	**5700**		5.4	4.4	mg/Kg	☼	02/15/18 08:00	02/26/18 14:12	1

Client Sample ID: CCASR-01-U

Lab Sample ID: 140-10636-1

Date Collected: 12/14/17 16:28 **Matrix: Solid**

Date Received: 02/03/18 08:45 **Percent Solids: 92.5**

Method: 6010B - SEP Metals (ICP) - Total (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Lead	**7.2**		0.54	0.12	mg/Kg	☼	02/15/18 08:00	02/26/18 14:12	1
Magnesium	**1400**	**J**	2700	18	mg/Kg	☼	02/15/18 08:00	02/26/18 15:44	10
Manganese	**100**		0.81	0.056	mg/Kg	☼	02/15/18 08:00	02/26/18 14:12	1
Selenium	ND		0.54	0.18	mg/Kg	☼	02/15/18 08:00	02/26/18 14:12	1

1 2 3 4 5 6 7 8 9 10 11 12 13

Client Sample ID: CCASR-01-L Lab Sample ID: 140-10636-2

Date Collected: 01/05/18 13:00 **Matrix: Solid**
Date Received: 02/03/18 08:45 **Percent Solids: 80.0**

Method: 6010B SEP - SEP Metals (ICP) - Step 1

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	ND		50	8.0	mg/Kg	☼	02/16/18 08:00	02/22/18 11:49	4
Arsenic	ND		2.5	0.65	mg/Kg	☼	02/16/18 08:00	02/22/18 11:49	4
Chromium	ND		2.5	0.35	mg/Kg	☼	02/16/18 08:00	02/22/18 11:49	4
Copper	ND		6.3	0.40	mg/Kg	☼	02/16/18 08:00	02/22/18 11:49	4
Iron	ND		25	15	mg/Kg	☼	02/16/18 08:00	02/22/18 11:49	4
Lead	ND		2.5	0.55	mg/Kg	☼	02/16/18 08:00	02/22/18 11:49	4
Manganese	**3.3**	**J**	3.8	0.16	mg/Kg	☼	02/16/18 08:00	02/22/18 11:49	4
Selenium	ND		2.5	0.85	mg/Kg	☼	02/16/18 08:00	02/22/18 11:49	4

Method: 6010B SEP - SEP Metals (ICP) - Step 2

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**7.7**	**J ***	38	6.0	mg/Kg	☼	02/19/18 08:00	02/22/18 12:45	3
Arsenic	ND		1.9	0.49	mg/Kg	☼	02/19/18 08:00	02/22/18 12:45	3
Chromium	ND	*	1.9	0.26	mg/Kg	☼	02/19/18 08:00	02/22/18 12:45	3
Copper	ND		4.7	0.60	mg/Kg	☼	02/19/18 08:00	02/22/18 12:45	3
Iron	**47**	*****	19	11	mg/Kg	☼	02/19/18 08:00	02/22/18 12:45	3
Lead	**1.6**	**J**	1.9	0.41	mg/Kg	☼	02/19/18 08:00	02/22/18 12:45	3
Magnesium	**12000**		940	6.4	mg/Kg	☼	02/19/18 08:00	02/22/18 12:45	3
Manganese	**120**		2.8	1.1	mg/Kg	☼	02/19/18 08:00	02/22/18 12:45	3
Selenium	**1.5**	**J B**	1.9	0.64	mg/Kg	☼	02/19/18 08:00	02/22/18 12:45	3

Method: 6010B SEP - SEP Metals (ICP) - Step 3

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**120**		13	2.6	mg/Kg	☼	02/20/18 08:00	02/22/18 13:41	1
Arsenic	**0.66**		0.63	0.16	mg/Kg	☼	02/20/18 08:00	02/22/18 13:41	1
Chromium	**0.25**	**J**	0.63	0.088	mg/Kg	☼	02/20/18 08:00	02/22/18 13:41	1
Copper	**0.50**	**J**	1.6	0.33	mg/Kg	☼	02/20/18 08:00	02/22/18 13:41	1
Iron	**190**		6.3	3.6	mg/Kg	☼	02/20/18 08:00	02/22/18 13:41	1
Lead	ND	*	0.63	0.14	mg/Kg	☼	02/20/18 08:00	02/22/18 13:41	1
Magnesium	**1400**	**B**	310	2.1	mg/Kg	☼	02/20/18 08:00	02/22/18 13:41	1
Manganese	**15**	**B**	0.94	0.034	mg/Kg	☼	02/20/18 08:00	02/22/18 13:41	1
Selenium	**0.32**	**J B**	0.63	0.21	mg/Kg	☼	02/20/18 08:00	02/22/18 13:41	1

Method: 6010B SEP - SEP Metals (ICP) - Step 4

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**680**		13	2.0	mg/Kg	☼	02/21/18 08:00	02/22/18 14:36	1
Arsenic	**0.86**	**B**	0.63	0.28	mg/Kg	☼	02/21/18 08:00	02/22/18 14:36	1
Chromium	**0.96**	**B**	0.63	0.088	mg/Kg	☼	02/21/18 08:00	02/22/18 14:36	1
Copper	**2.0**		1.6	0.28	mg/Kg	☼	02/21/18 08:00	02/22/18 14:36	1
Iron	**410**		6.3	3.6	mg/Kg	☼	02/21/18 08:00	02/22/18 14:36	1
Lead	**2.7**		0.63	0.14	mg/Kg	☼	02/21/18 08:00	02/22/18 14:36	1
Magnesium	**690**		310	2.1	mg/Kg	☼	02/21/18 08:00	02/22/18 14:36	1
Manganese	**53**		0.94	0.16	mg/Kg	☼	02/21/18 08:00	02/22/18 14:36	1
Selenium	**1.1**	**B ***	0.63	0.59	mg/Kg	☼	02/21/18 08:00	02/22/18 14:36	1

Method: 6010B SEP - SEP Metals (ICP) - Step 5

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**32**	**J B ***	190	29	mg/Kg	☼	02/22/18 08:00	02/26/18 11:31	5
Arsenic	ND		9.4	2.4	mg/Kg	☼	02/22/18 08:00	02/26/18 11:31	5
Chromium	**1.9**	**J**	9.4	1.3	mg/Kg	☼	02/22/18 08:00	02/26/18 11:31	5

Client Sample ID: CCASR-01-L
Date Collected: 01/05/18 13:00
Date Received: 02/03/18 08:45

Lab Sample ID: 140-10636-2
Matrix: Solid
Percent Solids: 80.0

Method: 6010B SEP - SEP Metals (ICP) - Step 5 (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Copper	ND		23	1.5	mg/Kg	☼	02/22/18 08:00	02/26/18 11:31	5
Iron	ND	*	94	55	mg/Kg	☼	02/22/18 08:00	02/26/18 11:31	5
Lead	ND	*	9.4	2.1	mg/Kg	☼	02/22/18 08:00	02/26/18 11:31	5
Magnesium	**130**	**J B**	4700	38	mg/Kg	☼	02/22/18 08:00	02/26/18 11:31	5
Manganese	**5.9**	**J ***	14	2.3	mg/Kg	☼	02/22/18 08:00	02/26/18 11:31	5
Selenium	**3.4**	**J**	9.4	3.3	mg/Kg	☼	02/22/18 08:00	02/26/18 11:31	5

Method: 6010B SEP - SEP Metals (ICP) - Step 6

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**5000**		13	2.0	mg/Kg	☼	02/22/18 08:00	02/26/18 12:26	1
Arsenic	**2.8**		0.63	0.19	mg/Kg	☼	02/22/18 08:00	02/26/18 12:26	1
Chromium	**5.3**		0.63	0.088	mg/Kg	☼	02/22/18 08:00	02/26/18 12:26	1
Copper	**1.3**	**J**	1.6	0.10	mg/Kg	☼	02/22/18 08:00	02/26/18 12:26	1
Iron	**4100**		6.3	3.6	mg/Kg	☼	02/22/18 08:00	02/26/18 12:26	1
Lead	**1.4**		0.63	0.14	mg/Kg	☼	02/22/18 08:00	02/26/18 12:26	1
Magnesium	**1200**		310	2.1	mg/Kg	☼	02/22/18 08:00	02/26/18 12:26	1
Manganese	**22**		0.94	0.31	mg/Kg	☼	02/22/18 08:00	02/26/18 12:26	1
Selenium	ND		0.63	0.21	mg/Kg	☼	02/22/18 08:00	02/26/18 12:26	1

Method: 6010B SEP - SEP Metals (ICP) - Step 7

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**22000**		130	20	mg/Kg	☼	02/23/18 08:00	02/26/18 15:09	10
Arsenic	**0.86**		0.63	0.16	mg/Kg	☼	02/23/18 08:00	02/26/18 13:21	1
Chromium	**10**		0.63	0.088	mg/Kg	☼	02/23/18 08:00	02/26/18 13:21	1
Copper	**1.9**		1.6	0.10	mg/Kg	☼	02/23/18 08:00	02/26/18 13:21	1
Iron	**6000**		6.3	5.1	mg/Kg	☼	02/23/18 08:00	02/26/18 13:21	1
Lead	**2.4**		1.3	0.28	mg/Kg	☼	02/23/18 08:00	02/26/18 16:24	2
Magnesium	**2200**	**J**	3100	21	mg/Kg	☼	02/23/18 08:00	02/26/18 15:09	10
Manganese	**35**		0.94	0.065	mg/Kg	☼	02/23/18 08:00	02/26/18 13:21	1
Selenium	ND		0.63	0.21	mg/Kg	☼	02/23/18 08:00	02/26/18 13:21	1

Method: 6010B SEP - SEP Metals (ICP) - Sum of Steps 1-7

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**28000**		10	1.6	mg/Kg			02/27/18 13:33	1
Arsenic	**5.2**		0.50	0.13	mg/Kg			02/27/18 13:33	1
Chromium	**18**		0.50	0.070	mg/Kg			02/27/18 13:33	1
Copper	**5.7**		1.3	0.080	mg/Kg			02/27/18 13:33	1
Iron	**11000**		5.0	4.1	mg/Kg			02/27/18 13:33	1
Lead	**8.2**		0.50	0.11	mg/Kg			02/27/18 13:33	1
Magnesium	**17000**		250	1.7	mg/Kg			02/27/18 13:33	1
Manganese	**250**		0.75	0.052	mg/Kg			02/27/18 13:33	1
Selenium	**6.3**		0.50	0.17	mg/Kg			02/27/18 13:33	1

Method: 6010B - SEP Metals (ICP) - Total

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**35000**		130	20	mg/Kg	☼	02/15/18 08:00	02/26/18 15:54	10
Arsenic	**6.2**		0.63	0.16	mg/Kg	☼	02/15/18 08:00	02/26/18 14:23	1
Chromium	**23**		0.63	0.088	mg/Kg	☼	02/15/18 08:00	02/26/18 14:23	1
Copper	**6.2**		1.6	0.10	mg/Kg	☼	02/15/18 08:00	02/26/18 14:23	1
Iron	**10000**		6.3	5.1	mg/Kg	☼	02/15/18 08:00	02/26/18 14:23	1

Client Sample ID: CCASR-01-L

Lab Sample ID: 140-10636-2

Date Collected: 01/05/18 13:00
Matrix: Solid
Date Received: 02/03/18 08:45
Percent Solids: 80.0

Method: 6010B - SEP Metals (ICP) - Total (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Lead	**8.4**		1.3	0.28	mg/Kg	☼	02/15/18 08:00	02/26/18 16:39	2
Magnesium	**5100**		3100	21	mg/Kg	☼	02/15/18 08:00	02/26/18 15:54	10
Manganese	**200**		0.94	0.065	mg/Kg	☼	02/15/18 08:00	02/26/18 14:23	1
Selenium	ND		0.63	0.21	mg/Kg	☼	02/15/18 08:00	02/26/18 14:23	1

Client Sample ID: CCASR-03-A | Lab Sample ID: 140-10636-3

Date Collected: 01/31/18 13:00 | **Matrix: Solid**
Date Received: 02/03/18 08:45 | **Percent Solids: 86.2**

Method: 6010B SEP - SEP Metals (ICP) - Step 1

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	ND		46	7.4	mg/Kg	☼	02/16/18 08:00	02/22/18 11:54	4
Arsenic	ND		2.3	0.60	mg/Kg	☼	02/16/18 08:00	02/22/18 11:54	4
Chromium	ND		2.3	0.32	mg/Kg	☼	02/16/18 08:00	02/22/18 11:54	4
Copper	ND		5.8	0.37	mg/Kg	☼	02/16/18 08:00	02/22/18 11:54	4
Iron	ND		23	13	mg/Kg	☼	02/16/18 08:00	02/22/18 11:54	4
Lead	ND		2.3	0.51	mg/Kg	☼	02/16/18 08:00	02/22/18 11:54	4
Manganese	**2.3**	**J**	3.5	0.14	mg/Kg	☼	02/16/18 08:00	02/22/18 11:54	4
Selenium	ND		2.3	0.79	mg/Kg	☼	02/16/18 08:00	02/22/18 11:54	4

Method: 6010B SEP - SEP Metals (ICP) - Step 2

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	ND	*	35	5.6	mg/Kg	☼	02/19/18 08:00	02/22/18 12:51	3
Arsenic	**0.50**	**J**	1.7	0.45	mg/Kg	☼	02/19/18 08:00	02/22/18 12:51	3
Chromium	ND	*	1.7	0.24	mg/Kg	☼	02/19/18 08:00	02/22/18 12:51	3
Copper	ND		4.4	0.56	mg/Kg	☼	02/19/18 08:00	02/22/18 12:51	3
Iron	**46**	*****	17	10	mg/Kg	☼	02/19/18 08:00	02/22/18 12:51	3
Lead	**1.3**	**J**	1.7	0.38	mg/Kg	☼	02/19/18 08:00	02/22/18 12:51	3
Magnesium	**10000**		870	5.9	mg/Kg	☼	02/19/18 08:00	02/22/18 12:51	3
Manganese	**80**		2.6	0.97	mg/Kg	☼	02/19/18 08:00	02/22/18 12:51	3
Selenium	**1.4**	**J B**	1.7	0.59	mg/Kg	☼	02/19/18 08:00	02/22/18 12:51	3

Method: 6010B SEP - SEP Metals (ICP) - Step 3

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**100**		12	2.4	mg/Kg	☼	02/20/18 08:00	02/22/18 13:46	1
Arsenic	**0.39**	**J**	0.58	0.15	mg/Kg	☼	02/20/18 08:00	02/22/18 13:46	1
Chromium	**0.28**	**J**	0.58	0.081	mg/Kg	☼	02/20/18 08:00	02/22/18 13:46	1
Copper	**1.1**	**J**	1.5	0.30	mg/Kg	☼	02/20/18 08:00	02/22/18 13:46	1
Iron	**180**		5.8	3.4	mg/Kg	☼	02/20/18 08:00	02/22/18 13:46	1
Lead	ND	*	0.58	0.13	mg/Kg	☼	02/20/18 08:00	02/22/18 13:46	1
Magnesium	**1100**	**B**	290	2.0	mg/Kg	☼	02/20/18 08:00	02/22/18 13:46	1
Manganese	**12**	**B**	0.87	0.031	mg/Kg	☼	02/20/18 08:00	02/22/18 13:46	1
Selenium	**0.39**	**J B**	0.58	0.20	mg/Kg	☼	02/20/18 08:00	02/22/18 13:46	1

Method: 6010B SEP - SEP Metals (ICP) - Step 4

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**1100**		12	1.9	mg/Kg	☼	02/21/18 08:00	02/22/18 14:41	1
Arsenic	**1.2**	**B**	0.58	0.26	mg/Kg	☼	02/21/18 08:00	02/22/18 14:41	1
Chromium	**0.99**	**B**	0.58	0.081	mg/Kg	☼	02/21/18 08:00	02/22/18 14:41	1
Copper	**2.3**		1.5	0.26	mg/Kg	☼	02/21/18 08:00	02/22/18 14:41	1
Iron	**740**		5.8	3.4	mg/Kg	☼	02/21/18 08:00	02/22/18 14:41	1
Lead	**2.0**		0.58	0.13	mg/Kg	☼	02/21/18 08:00	02/22/18 14:41	1
Magnesium	**540**		290	2.0	mg/Kg	☼	02/21/18 08:00	02/22/18 14:41	1
Manganese	**20**		0.87	0.15	mg/Kg	☼	02/21/18 08:00	02/22/18 14:41	1
Selenium	**1.5**	**B ***	0.58	0.55	mg/Kg	☼	02/21/18 08:00	02/22/18 14:41	1

Method: 6010B SEP - SEP Metals (ICP) - Step 5

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	ND	*	170	27	mg/Kg	☼	02/22/18 08:00	02/26/18 11:36	5
Arsenic	ND		8.7	2.2	mg/Kg	☼	02/22/18 08:00	02/26/18 11:36	5
Chromium	**1.2**	**J**	8.7	1.2	mg/Kg	☼	02/22/18 08:00	02/26/18 11:36	5

Client Sample ID: CCASR-03-A
Date Collected: 01/31/18 13:00
Date Received: 02/03/18 08:45

Lab Sample ID: 140-10636-3
Matrix: Solid
Percent Solids: 86.2

Method: 6010B SEP - SEP Metals (ICP) - Step 5 (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Copper	**1.4**	**J**	22	1.4	mg/Kg	☼	02/22/18 08:00	02/26/18 11:36	5
Iron	ND	*	87	51	mg/Kg	☼	02/22/18 08:00	02/26/18 11:36	5
Lead	ND	*	8.7	1.9	mg/Kg	☼	02/22/18 08:00	02/26/18 11:36	5
Magnesium	**80**	**J B**	4400	35	mg/Kg	☼	02/22/18 08:00	02/26/18 11:36	5
Manganese	ND	*	13	2.1	mg/Kg	☼	02/22/18 08:00	02/26/18 11:36	5
Selenium	ND		8.7	3.0	mg/Kg	☼	02/22/18 08:00	02/26/18 11:36	5

Method: 6010B SEP - SEP Metals (ICP) - Step 6

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**3600**		12	1.9	mg/Kg	☼	02/22/18 08:00	02/26/18 12:31	1
Arsenic	**1.2**		0.58	0.17	mg/Kg	☼	02/22/18 08:00	02/26/18 12:31	1
Chromium	**2.6**		0.58	0.081	mg/Kg	☼	02/22/18 08:00	02/26/18 12:31	1
Copper	**0.86**	**J**	1.5	0.093	mg/Kg	☼	02/22/18 08:00	02/26/18 12:31	1
Iron	**2900**		5.8	3.4	mg/Kg	☼	02/22/18 08:00	02/26/18 12:31	1
Lead	**1.5**		0.58	0.13	mg/Kg	☼	02/22/18 08:00	02/26/18 12:31	1
Magnesium	**820**		290	2.0	mg/Kg	☼	02/22/18 08:00	02/26/18 12:31	1
Manganese	**16**		0.87	0.29	mg/Kg	☼	02/22/18 08:00	02/26/18 12:31	1
Selenium	ND		0.58	0.20	mg/Kg	☼	02/22/18 08:00	02/26/18 12:31	1

Method: 6010B SEP - SEP Metals (ICP) - Step 7

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**18000**		120	19	mg/Kg	☼	02/23/18 08:00	02/26/18 15:14	10
Arsenic	**0.74**		0.58	0.15	mg/Kg	☼	02/23/18 08:00	02/26/18 13:27	1
Chromium	**8.4**		0.58	0.081	mg/Kg	☼	02/23/18 08:00	02/26/18 13:27	1
Copper	**1.8**		1.5	0.093	mg/Kg	☼	02/23/18 08:00	02/26/18 13:27	1
Iron	**5000**		5.8	4.8	mg/Kg	☼	02/23/18 08:00	02/26/18 13:27	1
Lead	**2.8**		1.2	0.26	mg/Kg	☼	02/23/18 08:00	02/26/18 16:29	2
Magnesium	**930**	**J**	2900	20	mg/Kg	☼	02/23/18 08:00	02/26/18 15:14	10
Manganese	**34**		0.87	0.060	mg/Kg	☼	02/23/18 08:00	02/26/18 13:27	1
Selenium	ND		0.58	0.20	mg/Kg	☼	02/23/18 08:00	02/26/18 13:27	1

Method: 6010B SEP - SEP Metals (ICP) - Sum of Steps 1-7

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**23000**		10	1.6	mg/Kg			02/27/18 13:33	1
Arsenic	**4.0**		0.50	0.13	mg/Kg			02/27/18 13:33	1
Chromium	**14**		0.50	0.070	mg/Kg			02/27/18 13:33	1
Copper	**7.5**		1.3	0.080	mg/Kg			02/27/18 13:33	1
Iron	**8800**		5.0	4.1	mg/Kg			02/27/18 13:33	1
Lead	**7.5**		0.50	0.11	mg/Kg			02/27/18 13:33	1
Magnesium	**14000**		250	1.7	mg/Kg			02/27/18 13:33	1
Manganese	**170**		0.75	0.052	mg/Kg			02/27/18 13:33	1
Selenium	**3.3**		0.50	0.17	mg/Kg			02/27/18 13:33	1

Method: 6010B - SEP Metals (ICP) - Total

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**30000**		120	19	mg/Kg	☼	02/15/18 08:00	02/26/18 15:59	10
Arsenic	**2.8**		0.58	0.15	mg/Kg	☼	02/15/18 08:00	02/26/18 14:28	1
Chromium	**16**		0.58	0.081	mg/Kg	☼	02/15/18 08:00	02/26/18 14:28	1
Copper	**9.5**		1.5	0.093	mg/Kg	☼	02/15/18 08:00	02/26/18 14:28	1
Iron	**9500**		5.8	4.8	mg/Kg	☼	02/15/18 08:00	02/26/18 14:28	1

Client Sample ID: CCASR-03-A
Lab Sample ID: 140-10636-3

Date Collected: 01/31/18 13:00 — **Matrix: Solid**
Date Received: 02/03/18 08:45 — **Percent Solids: 86.2**

Method: 6010B - SEP Metals (ICP) - Total (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Lead	**8.5**		1.2	0.26	mg/Kg	☼	02/15/18 08:00	02/26/18 16:44	2
Magnesium	**3300**		2900	20	mg/Kg	☼	02/15/18 08:00	02/26/18 15:59	10
Manganese	**170**		0.87	0.060	mg/Kg	☼	02/15/18 08:00	02/26/18 14:28	1
Selenium	ND		0.58	0.20	mg/Kg	☼	02/15/18 08:00	02/26/18 14:28	1

1 2 3 4 5 6 7 8 9 10 11 12 13

Client Sample ID: CCASR-03-T **Lab Sample ID: 140-10636-4**
Date Collected: 01/31/18 13:00 **Matrix: Solid**
Date Received: 02/03/18 08:45 **Percent Solids: 86.7**

Method: 6010B SEP - SEP Metals (ICP) - Step 1

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	ND		46	7.4	mg/Kg	☼	02/16/18 08:00	02/22/18 11:59	4
Arsenic	ND		2.3	0.60	mg/Kg	☼	02/16/18 08:00	02/22/18 11:59	4
Chromium	ND		2.3	0.32	mg/Kg	☼	02/16/18 08:00	02/22/18 11:59	4
Copper	ND		5.8	0.37	mg/Kg	☼	02/16/18 08:00	02/22/18 11:59	4
Iron	ND		23	13	mg/Kg	☼	02/16/18 08:00	02/22/18 11:59	4
Lead	ND		2.3	0.51	mg/Kg	☼	02/16/18 08:00	02/22/18 11:59	4
Manganese	**2.7**	**J**	3.5	0.14	mg/Kg	☼	02/16/18 08:00	02/22/18 11:59	4
Selenium	ND		2.3	0.78	mg/Kg	☼	02/16/18 08:00	02/22/18 11:59	4

Method: 6010B SEP - SEP Metals (ICP) - Step 2

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**6.4**	**J ***	35	5.5	mg/Kg	☼	02/19/18 08:00	02/22/18 12:56	3
Arsenic	ND		1.7	0.45	mg/Kg	☼	02/19/18 08:00	02/22/18 12:56	3
Chromium	ND	*	1.7	0.24	mg/Kg	☼	02/19/18 08:00	02/22/18 12:56	3
Copper	ND		4.3	0.55	mg/Kg	☼	02/19/18 08:00	02/22/18 12:56	3
Iron	**45**	*****	17	10	mg/Kg	☼	02/19/18 08:00	02/22/18 12:56	3
Lead	**0.98**	**J**	1.7	0.38	mg/Kg	☼	02/19/18 08:00	02/22/18 12:56	3
Magnesium	**10000**		870	5.9	mg/Kg	☼	02/19/18 08:00	02/22/18 12:56	3
Manganese	**83**		2.6	0.97	mg/Kg	☼	02/19/18 08:00	02/22/18 12:56	3
Selenium	**1.2**	**J B**	1.7	0.59	mg/Kg	☼	02/19/18 08:00	02/22/18 12:56	3

Method: 6010B SEP - SEP Metals (ICP) - Step 3

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**110**		12	2.4	mg/Kg	☼	02/20/18 08:00	02/22/18 13:51	1
Arsenic	**0.39**	**J**	0.58	0.15	mg/Kg	☼	02/20/18 08:00	02/22/18 13:51	1
Chromium	**0.49**	**J**	0.58	0.081	mg/Kg	☼	02/20/18 08:00	02/22/18 13:51	1
Copper	**1.5**		1.4	0.30	mg/Kg	☼	02/20/18 08:00	02/22/18 13:51	1
Iron	**220**		5.8	3.3	mg/Kg	☼	02/20/18 08:00	02/22/18 13:51	1
Lead	ND	*	0.58	0.13	mg/Kg	☼	02/20/18 08:00	02/22/18 13:51	1
Magnesium	**1100**	**B**	290	2.0	mg/Kg	☼	02/20/18 08:00	02/22/18 13:51	1
Manganese	**11**	**B**	0.87	0.031	mg/Kg	☼	02/20/18 08:00	02/22/18 13:51	1
Selenium	**0.31**	**J B**	0.58	0.20	mg/Kg	☼	02/20/18 08:00	02/22/18 13:51	1

Method: 6010B SEP - SEP Metals (ICP) - Step 4

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	**1100**		12	1.8	mg/Kg	☼	02/21/18 08:00	02/22/18 14:46	1
Arsenic	**1.0**	**B**	0.58	0.25	mg/Kg	☼	02/21/18 08:00	02/22/18 14:46	1
Chromium	**1.0**	**B**	0.58	0.081	mg/Kg	☼	02/21/18 08:00	02/22/18 14:46	1
Copper	**2.6**		1.4	0.25	mg/Kg	☼	02/21/18 08:00	02/22/18 14:46	1
Iron	**780**		5.8	3.3	mg/Kg	☼	02/21/18 08:00	02/22/18 14:46	1
Lead	**2.2**		0.58	0.13	mg/Kg	☼	02/21/18 08:00	02/22/18 14:46	1
Magnesium	**550**		290	2.0	mg/Kg	☼	02/21/18 08:00	02/22/18 14:46	1
Manganese	**23**		0.87	0.15	mg/Kg	☼	02/21/18 08:00	02/22/18 14:46	1
Selenium	**1.2**	**B ***	0.58	0.54	mg/Kg	☼	02/21/18 08:00	02/22/18 14:46	1

Method: 6010B SEP - SEP Metals (ICP) - Step 5

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	ND	*	170	27	mg/Kg	☼	02/22/18 08:00	02/26/18 11:41	5
Arsenic	ND		8.7	2.2	mg/Kg	☼	02/22/18 08:00	02/26/18 11:41	5
Chromium	**2.0**	**J**	8.7	1.2	mg/Kg	☼	02/22/18 08:00	02/26/18 11:41	5

Client Sample ID: CCASR-03-T — Lab Sample ID: 140-10636-4

Date Collected: 01/31/18 13:00 — **Matrix: Solid**
Date Received: 02/03/18 08:45 — **Percent Solids: 86.7**

Method: 6010B SEP - SEP Metals (ICP) - Step 5 (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Copper	2.1	J	22	1.4	mg/Kg	☼	02/22/18 08:00	02/26/18 11:41	5
Iron	ND	*	87	51	mg/Kg	☼	02/22/18 08:00	02/26/18 11:41	5
Lead	ND	*	8.7	1.9	mg/Kg	☼	02/22/18 08:00	02/26/18 11:41	5
Magnesium	90	J B	4300	35	mg/Kg	☼	02/22/18 08:00	02/26/18 11:41	5
Manganese	ND	*	13	2.1	mg/Kg	☼	02/22/18 08:00	02/26/18 11:41	5
Selenium	ND		8.7	3.0	mg/Kg	☼	02/22/18 08:00	02/26/18 11:41	5

Method: 6010B SEP - SEP Metals (ICP) - Step 6

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	4200		12	1.8	mg/Kg	☼	02/22/18 08:00	02/26/18 12:36	1
Arsenic	1.2		0.58	0.17	mg/Kg	☼	02/22/18 08:00	02/26/18 12:36	1
Chromium	3.4		0.58	0.081	mg/Kg	☼	02/22/18 08:00	02/26/18 12:36	1
Copper	0.94	J	1.4	0.092	mg/Kg	☼	02/22/18 08:00	02/26/18 12:36	1
Iron	3300		5.8	3.3	mg/Kg	☼	02/22/18 08:00	02/26/18 12:36	1
Lead	1.4		0.58	0.13	mg/Kg	☼	02/22/18 08:00	02/26/18 12:36	1
Magnesium	960		290	2.0	mg/Kg	☼	02/22/18 08:00	02/26/18 12:36	1
Manganese	18		0.87	0.29	mg/Kg	☼	02/22/18 08:00	02/26/18 12:36	1
Selenium	ND		0.58	0.20	mg/Kg	☼	02/22/18 08:00	02/26/18 12:36	1

Method: 6010B SEP - SEP Metals (ICP) - Step 7

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	19000		120	18	mg/Kg	☼	02/23/18 08:00	02/26/18 15:19	10
Arsenic	0.46	J	0.58	0.15	mg/Kg	☼	02/23/18 08:00	02/26/18 13:32	1
Chromium	8.4		0.58	0.081	mg/Kg	☼	02/23/18 08:00	02/26/18 13:32	1
Copper	1.8		1.4	0.092	mg/Kg	☼	02/23/18 08:00	02/26/18 13:32	1
Iron	4800		5.8	4.7	mg/Kg	☼	02/23/18 08:00	02/26/18 13:32	1
Lead	2.7		1.2	0.25	mg/Kg	☼	02/23/18 08:00	02/26/18 16:34	2
Magnesium	1300	J	2900	20	mg/Kg	☼	02/23/18 08:00	02/26/18 15:19	10
Manganese	31		0.87	0.060	mg/Kg	☼	02/23/18 08:00	02/26/18 13:32	1
Selenium	ND		0.58	0.20	mg/Kg	☼	02/23/18 08:00	02/26/18 13:32	1

Method: 6010B SEP - SEP Metals (ICP) - Sum of Steps 1-7

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	24000		10	1.6	mg/Kg			02/27/18 13:33	1
Arsenic	3.0		0.50	0.13	mg/Kg			02/27/18 13:33	1
Chromium	15		0.50	0.070	mg/Kg			02/27/18 13:33	1
Copper	8.9		1.3	0.080	mg/Kg			02/27/18 13:33	1
Iron	9200		5.0	4.1	mg/Kg			02/27/18 13:33	1
Lead	7.2		0.50	0.11	mg/Kg			02/27/18 13:33	1
Magnesium	14000		250	1.7	mg/Kg			02/27/18 13:33	1
Manganese	170		0.75	0.052	mg/Kg			02/27/18 13:33	1
Selenium	2.7		0.50	0.17	mg/Kg			02/27/18 13:33	1

Method: 6010B - SEP Metals (ICP) - Total

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	27000		120	18	mg/Kg	☼	02/15/18 08:00	02/26/18 16:04	10
Arsenic	2.4		0.58	0.15	mg/Kg	☼	02/15/18 08:00	02/26/18 14:34	1
Chromium	17		0.58	0.081	mg/Kg	☼	02/15/18 08:00	02/26/18 14:34	1
Copper	5.6		1.4	0.092	mg/Kg	☼	02/15/18 08:00	02/26/18 14:34	1
Iron	7500		5.8	4.7	mg/Kg	☼	02/15/18 08:00	02/26/18 14:34	1

Client Sample ID: CCASR-03-T | **Lab Sample ID: 140-10636-4**
Date Collected: 01/31/18 13:00 | **Matrix: Solid**
Date Received: 02/03/18 08:45 | **Percent Solids: 86.7**

Method: 6010B - SEP Metals (ICP) - Total (Continued)

Analyte	Result	Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Lead	**7.5**		1.2	0.25	mg/Kg	☼	02/15/18 08:00	02/26/18 16:49	2
Magnesium	**2900**		2900	20	mg/Kg	☼	02/15/18 08:00	02/26/18 16:04	10
Manganese	**150**		0.87	0.060	mg/Kg	☼	02/15/18 08:00	02/26/18 14:34	1
Selenium	ND		0.58	0.20	mg/Kg	☼	02/15/18 08:00	02/26/18 14:34	1

Default Detection Limits

Client: HDR Inc
Project/Site: Corpus Christi ASR Program (SEP)

TestAmerica Job ID: 140-10636-1

Method: 6010B SEP - SEP Metals (ICP) - Step 1

Prep: 3010A
SEP: Exchangeable

Analyte	RL	MDL	Units	Method
Aluminum	10	1.6	mg/Kg	6010B SEP
Arsenic	0.50	0.13	mg/Kg	6010B SEP
Chromium	0.50	0.070	mg/Kg	6010B SEP
Copper	1.3	0.080	mg/Kg	6010B SEP
Iron	5.0	2.9	mg/Kg	6010B SEP
Lead	0.50	0.11	mg/Kg	6010B SEP
Manganese	0.75	0.031	mg/Kg	6010B SEP
Selenium	0.50	0.17	mg/Kg	6010B SEP

Method: 6010B SEP - SEP Metals (ICP) - Step 2

Prep: 3010A
SEP: Carbonate

Analyte	RL	MDL	Units	Method
Aluminum	10	1.6	mg/Kg	6010B SEP
Arsenic	0.50	0.13	mg/Kg	6010B SEP
Chromium	0.50	0.070	mg/Kg	6010B SEP
Copper	1.3	0.16	mg/Kg	6010B SEP
Iron	5.0	2.9	mg/Kg	6010B SEP
Lead	0.50	0.11	mg/Kg	6010B SEP
Magnesium	250	1.7	mg/Kg	6010B SEP
Manganese	0.75	0.28	mg/Kg	6010B SEP
Selenium	0.50	0.17	mg/Kg	6010B SEP

Method: 6010B SEP - SEP Metals (ICP) - Step 3

Prep: 3010A
SEP: Non-Crystalline

Analyte	RL	MDL	Units	Method
Aluminum	10	2.1	mg/Kg	6010B SEP
Arsenic	0.50	0.13	mg/Kg	6010B SEP
Chromium	0.50	0.070	mg/Kg	6010B SEP
Copper	1.3	0.26	mg/Kg	6010B SEP
Iron	5.0	2.9	mg/Kg	6010B SEP
Lead	0.50	0.11	mg/Kg	6010B SEP
Magnesium	250	1.7	mg/Kg	6010B SEP
Manganese	0.75	0.027	mg/Kg	6010B SEP
Selenium	0.50	0.17	mg/Kg	6010B SEP

Method: 6010B SEP - SEP Metals (ICP) - Step 4

Prep: 3010A
SEP: Metal Hydroxide

Analyte	RL	MDL	Units	Method
Aluminum	10	1.6	mg/Kg	6010B SEP
Arsenic	0.50	0.22	mg/Kg	6010B SEP
Chromium	0.50	0.070	mg/Kg	6010B SEP
Copper	1.3	0.22	mg/Kg	6010B SEP
Iron	5.0	2.9	mg/Kg	6010B SEP
Lead	0.50	0.11	mg/Kg	6010B SEP
Magnesium	250	1.7	mg/Kg	6010B SEP

Method: 6010B SEP - SEP Metals (ICP) - Step 4 (Continued)
Prep: 3010A
SEP: Metal Hydroxide

Analyte	RL	MDL	Units	Method
Manganese	0.75	0.13	mg/Kg	6010B SEP
Selenium	0.50	0.47	mg/Kg	6010B SEP

Method: 6010B SEP - SEP Metals (ICP) - Step 5
Prep: 3010A
SEP: Organic-Bound

Analyte	RL	MDL	Units	Method
Aluminum	30	4.7	mg/Kg	6010B SEP
Arsenic	1.5	0.38	mg/Kg	6010B SEP
Chromium	1.5	0.21	mg/Kg	6010B SEP
Copper	3.8	0.24	mg/Kg	6010B SEP
Iron	15	8.8	mg/Kg	6010B SEP
Lead	1.5	0.33	mg/Kg	6010B SEP
Magnesium	750	6.1	mg/Kg	6010B SEP
Manganese	2.3	0.37	mg/Kg	6010B SEP
Selenium	1.5	0.52	mg/Kg	6010B SEP

Method: 6010B SEP - SEP Metals (ICP) - Step 6
SEP: Acid/Sulfide

Analyte	RL	MDL	Units	Method
Aluminum	10	1.6	mg/Kg	6010B SEP
Arsenic	0.50	0.15	mg/Kg	6010B SEP
Chromium	0.50	0.070	mg/Kg	6010B SEP
Copper	1.3	0.080	mg/Kg	6010B SEP
Iron	5.0	2.9	mg/Kg	6010B SEP
Lead	0.50	0.11	mg/Kg	6010B SEP
Magnesium	250	1.7	mg/Kg	6010B SEP
Manganese	0.75	0.25	mg/Kg	6010B SEP
Selenium	0.50	0.17	mg/Kg	6010B SEP

Method: 6010B SEP - SEP Metals (ICP) - Step 7
Prep: Residual

Analyte	RL	MDL	Units	Method
Aluminum	10	1.6	mg/Kg	6010B SEP
Arsenic	0.50	0.13	mg/Kg	6010B SEP
Chromium	0.50	0.070	mg/Kg	6010B SEP
Copper	1.3	0.080	mg/Kg	6010B SEP
Iron	5.0	4.1	mg/Kg	6010B SEP
Lead	0.50	0.11	mg/Kg	6010B SEP
Magnesium	250	1.7	mg/Kg	6010B SEP
Manganese	0.75	0.052	mg/Kg	6010B SEP
Selenium	0.50	0.17	mg/Kg	6010B SEP

Method: 6010B SEP - SEP Metals (ICP) - Sum of Steps 1-7

Analyte	RL	MDL	Units	Method
Aluminum	10	1.6	mg/Kg	6010B SEP
Arsenic	0.50	0.13	mg/Kg	6010B SEP

Method: 6010B SEP - SEP Metals (ICP) - Sum of Steps 1-7 (Continued)

Analyte	RL	MDL	Units	Method
Chromium	0.50	0.070	mg/Kg	6010B SEP
Copper	1.3	0.080	mg/Kg	6010B SEP
Iron	5.0	4.1	mg/Kg	6010B SEP
Lead	0.50	0.11	mg/Kg	6010B SEP
Magnesium	250	1.7	mg/Kg	6010B SEP
Manganese	0.75	0.052	mg/Kg	6010B SEP
Selenium	0.50	0.17	mg/Kg	6010B SEP

Method: 6010B - SEP Metals (ICP) - Total

Prep: Total

Analyte	RL	MDL	Units	Method
Aluminum	10	1.6	mg/Kg	6010B
Arsenic	0.50	0.13	mg/Kg	6010B
Chromium	0.50	0.070	mg/Kg	6010B
Copper	1.3	0.080	mg/Kg	6010B
Iron	5.0	4.1	mg/Kg	6010B
Lead	0.50	0.11	mg/Kg	6010B
Magnesium	250	1.7	mg/Kg	6010B
Manganese	0.75	0.052	mg/Kg	6010B
Selenium	0.50	0.17	mg/Kg	6010B

Client: HDR Inc
Project/Site: Corpus Christi ASR Program (SEP)

TestAmerica Job ID: 140-10636-1

Method: 6010B - SEP Metals (ICP) - Total

Lab Sample ID: MB 140-18118/7-A
Matrix: Solid
Analysis Batch: 18463

Client Sample ID: Method Blank
Prep Type: Total/NA
Prep Batch: 18118

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	ND		10	1.6	mg/Kg		02/15/18 08:00	02/26/18 13:52	1
Arsenic	ND		0.50	0.13	mg/Kg		02/15/18 08:00	02/26/18 13:52	1
Chromium	ND		0.50	0.070	mg/Kg		02/15/18 08:00	02/26/18 13:52	1
Copper	ND		1.3	0.080	mg/Kg		02/15/18 08:00	02/26/18 13:52	1
Iron	ND		5.0	4.1	mg/Kg		02/15/18 08:00	02/26/18 13:52	1
Lead	ND		0.50	0.11	mg/Kg		02/15/18 08:00	02/26/18 13:52	1
Magnesium	ND		250	1.7	mg/Kg		02/15/18 08:00	02/26/18 13:52	1
Manganese	ND		0.75	0.052	mg/Kg		02/15/18 08:00	02/26/18 13:52	1
Selenium	ND		0.50	0.17	mg/Kg		02/15/18 08:00	02/26/18 13:52	1

Lab Sample ID: LCS 140-18118/8-A
Matrix: Solid
Analysis Batch: 18463

Client Sample ID: Lab Control Sample
Prep Type: Total/NA
Prep Batch: 18118

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Aluminum	100	101		mg/Kg		101	75 - 125
Arsenic	5.00	5.12		mg/Kg		102	75 - 125
Chromium	10.0	10.6		mg/Kg		106	75 - 125
Copper	12.5	13.2		mg/Kg		106	75 - 125
Iron	50.0	53.5		mg/Kg		107	75 - 125
Lead	5.00	5.08		mg/Kg		102	75 - 125
Magnesium	500	496		mg/Kg		99	75 - 125
Manganese	5.00	5.40		mg/Kg		108	75 - 125
Selenium	7.50	7.82		mg/Kg		104	75 - 125

Lab Sample ID: LCSD 140-18118/9-A
Matrix: Solid
Analysis Batch: 18463

Client Sample ID: Lab Control Sample Dup
Prep Type: Total/NA
Prep Batch: 18118

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Aluminum	100	100		mg/Kg		100	75 - 125	0	30
Arsenic	5.00	5.06		mg/Kg		101	75 - 125	1	30
Chromium	10.0	10.7		mg/Kg		107	75 - 125	1	30
Copper	12.5	13.2		mg/Kg		106	75 - 125	0	30
Iron	50.0	53.5		mg/Kg		107	75 - 125	0	30
Lead	5.00	5.10		mg/Kg		102	75 - 125	0	30
Magnesium	500	505		mg/Kg		101	75 - 125	2	30
Manganese	5.00	5.42		mg/Kg		108	75 - 125	0	30
Selenium	7.50	7.79		mg/Kg		104	75 - 125	0	30

Lab Sample ID: 140-10636-1 DU
Matrix: Solid
Analysis Batch: 18463

Client Sample ID: CCASR-01-U
Prep Type: Total/NA
Prep Batch: 18118

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Arsenic	3.5		3.06		mg/Kg	☼	14	30
Chromium	6.6		9.37	F3	mg/Kg	☼	34	30
Copper	5.1		5.58		mg/Kg	☼	10	30
Iron	5700		7070		mg/Kg	☼	21	30

Method: 6010B - SEP Metals (ICP) - Total (Continued)

Lab Sample ID: 140-10636-1 DU
Matrix: Solid
Analysis Batch: 18463

Client Sample ID: CCASR-01-U
Prep Type: Total/NA
Prep Batch: 18118

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Lead	7.2		7.04		mg/Kg	☼	2	30
Manganese	100		118		mg/Kg	☼	13	30
Selenium	ND		ND		mg/Kg	☼	NC	30

Lab Sample ID: 140-10636-1 DU
Matrix: Solid
Analysis Batch: 18463

Client Sample ID: CCASR-01-U
Prep Type: Total/NA
Prep Batch: 18118

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Aluminum	22000		22500		mg/Kg	☼	3	30
Magnesium	1400	J	2270	J F5	mg/Kg	☼	46	30

Method: 6010B SEP - SEP Metals (ICP)

Lab Sample ID: MB 140-18119/6-B ^4
Matrix: Solid
Analysis Batch: 18398

Client Sample ID: Method Blank
Prep Type: Step 1
Prep Batch: 18208

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	ND		40	6.4	mg/Kg		02/16/18 08:00	02/22/18 11:24	4
Arsenic	ND		2.0	0.52	mg/Kg		02/16/18 08:00	02/22/18 11:24	4
Chromium	ND		2.0	0.28	mg/Kg		02/16/18 08:00	02/22/18 11:24	4
Copper	ND		5.0	0.32	mg/Kg		02/16/18 08:00	02/22/18 11:24	4
Iron	ND		20	12	mg/Kg		02/16/18 08:00	02/22/18 11:24	4
Lead	ND		2.0	0.44	mg/Kg		02/16/18 08:00	02/22/18 11:24	4
Manganese	ND		3.0	0.12	mg/Kg		02/16/18 08:00	02/22/18 11:24	4
Selenium	1.14	J	2.0	0.68	mg/Kg		02/16/18 08:00	02/22/18 11:24	4

Lab Sample ID: LCS 140-18119/7-B ^5
Matrix: Solid
Analysis Batch: 18398

Client Sample ID: Lab Control Sample
Prep Type: Step 1
Prep Batch: 18208

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Aluminum	100	103		mg/Kg		103	75 - 125
Arsenic	5.00	5.24		mg/Kg		105	75 - 125
Chromium	10.0	10.2		mg/Kg		102	75 - 125
Copper	12.5	12.4		mg/Kg		99	75 - 125
Iron	50.0	51.2		mg/Kg		102	75 - 125
Lead	5.00	4.80		mg/Kg		96	75 - 125
Manganese	5.00	4.71		mg/Kg		94	75 - 125
Selenium	7.50	8.27		mg/Kg		110	75 - 125

Lab Sample ID: LCSD 140-18119/8-B ^5
Matrix: Solid
Analysis Batch: 18398

Client Sample ID: Lab Control Sample Dup
Prep Type: Step 1
Prep Batch: 18208

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Aluminum	100	99.5		mg/Kg		100	75 - 125	4	30
Arsenic	5.00	5.08		mg/Kg		102	75 - 125	3	30

Method: 6010B SEP - SEP Metals (ICP) (Continued)

Lab Sample ID: LCSD 140-18119/8-B ^5
Matrix: Solid
Analysis Batch: 18398

Client Sample ID: Lab Control Sample Dup
Prep Type: Step 1
Prep Batch: 18208

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Chromium	10.0	9.99		mg/Kg		100	75 - 125	2	30
Copper	12.5	12.0		mg/Kg		96	75 - 125	3	30
Iron	50.0	49.9		mg/Kg		100	75 - 125	3	30
Lead	5.00	4.52		mg/Kg		90	75 - 125	6	30
Manganese	5.00	4.55		mg/Kg		91	75 - 125	4	30
Selenium	7.50	7.47		mg/Kg		100	75 - 125	10	30

Lab Sample ID: 140-10636-1 DU
Matrix: Solid
Analysis Batch: 18398

Client Sample ID: CCASR-01-U
Prep Type: Step 1
Prep Batch: 18208

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Aluminum	ND		ND		mg/Kg	☼	NC	30
Arsenic	ND		ND		mg/Kg	☼	NC	30
Chromium	ND		ND		mg/Kg	☼	NC	30
Copper	ND		ND		mg/Kg	☼	NC	30
Iron	ND		ND		mg/Kg	☼	NC	30
Lead	ND		ND		mg/Kg	☼	NC	30
Manganese	1.6	J	1.38	J	mg/Kg	☼	12	30
Selenium	ND		ND		mg/Kg	☼	NC	30

Lab Sample ID: MB 140-18209/6-B ^3
Matrix: Solid
Analysis Batch: 18398

Client Sample ID: Method Blank
Prep Type: Step 2
Prep Batch: 18242

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	ND		30	4.8	mg/Kg		02/19/18 08:00	02/22/18 12:19	3
Arsenic	ND		1.5	0.39	mg/Kg		02/19/18 08:00	02/22/18 12:19	3
Chromium	ND		1.5	0.21	mg/Kg		02/19/18 08:00	02/22/18 12:19	3
Copper	ND		3.8	0.48	mg/Kg		02/19/18 08:00	02/22/18 12:19	3
Iron	ND		15	8.7	mg/Kg		02/19/18 08:00	02/22/18 12:19	3
Lead	ND		1.5	0.33	mg/Kg		02/19/18 08:00	02/22/18 12:19	3
Magnesium	ND		750	5.1	mg/Kg		02/19/18 08:00	02/22/18 12:19	3
Manganese	ND		2.3	0.84	mg/Kg		02/19/18 08:00	02/22/18 12:19	3
Selenium	1.06	J	1.5	0.51	mg/Kg		02/19/18 08:00	02/22/18 12:19	3

Lab Sample ID: LCS 140-18209/7-B ^5
Matrix: Solid
Analysis Batch: 18398

Client Sample ID: Lab Control Sample
Prep Type: Step 2
Prep Batch: 18242

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Aluminum	100	ND	*	mg/Kg		0.8	75 - 125
Arsenic	5.00	4.59		mg/Kg		92	75 - 125
Chromium	10.0	7.89		mg/Kg		79	75 - 125
Copper	12.5	11.5		mg/Kg		92	75 - 125
Iron	50.0	ND	*	mg/Kg		7	75 - 125
Lead	5.00	4.18		mg/Kg		84	75 - 125
Magnesium	500	428	J	mg/Kg		86	75 - 125
Manganese	5.00	4.97		mg/Kg		99	75 - 125

QC Sample Results

Method: 6010B SEP - SEP Metals (ICP) (Continued)

Lab Sample ID: LCS 140-18209/7-B ^5 | **Client Sample ID: Lab Control Sample**
Matrix: Solid | **Prep Type: Step 2**
Analysis Batch: 18398 | **Prep Batch: 18242**

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Selenium	7.50	7.17		mg/Kg		96	75 - 125

Lab Sample ID: LCSD 140-18209/8-B ^5 | **Client Sample ID: Lab Control Sample Dup**
Matrix: Solid | **Prep Type: Step 2**
Analysis Batch: 18398 | **Prep Batch: 18242**

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Aluminum	100	ND	*	mg/Kg		2	75 - 125	95	30
Arsenic	5.00	4.38		mg/Kg		88	75 - 125	5	30
Chromium	10.0	6.94	*	mg/Kg		69	75 - 125	13	30
Copper	12.5	10.8		mg/Kg		86	75 - 125	7	30
Iron	50.0	ND	*	mg/Kg		3	75 - 125	84	30
Lead	5.00	4.49		mg/Kg		90	75 - 125	7	30
Magnesium	500	411	J	mg/Kg		82	75 - 125	4	30
Manganese	5.00	4.57		mg/Kg		91	75 - 125	8	30
Selenium	7.50	6.98		mg/Kg		93	75 - 125	3	30

Lab Sample ID: 140-10636-1 DU | **Client Sample ID: CCASR-01-U**
Matrix: Solid | **Prep Type: Step 2**
Analysis Batch: 18398 | **Prep Batch: 18242**

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Aluminum	ND	*	5.73	J *	mg/Kg	☼	NC	30
Arsenic	0.46	J	0.448	J	mg/Kg	☼	3	30
Chromium	ND	*	ND	*	mg/Kg	☼	NC	30
Copper	0.55	J	0.673	J	mg/Kg	☼	21	30
Iron	24	*	20.6	*	mg/Kg	☼	15	30
Lead	ND		0.482	J	mg/Kg	☼	NC	30
Magnesium	10000		10200		mg/Kg	☼	1	30
Manganese	59		56.7		mg/Kg	☼	4	30
Selenium	0.86	J B	1.16	J	mg/Kg	☼	30	30

Lab Sample ID: MB 140-18243/6-B | **Client Sample ID: Method Blank**
Matrix: Solid | **Prep Type: Step 3**
Analysis Batch: 18398 | **Prep Batch: 18290**

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	ND		10	2.1	mg/Kg		02/20/18 08:00	02/22/18 13:16	1
Arsenic	ND		0.50	0.13	mg/Kg		02/20/18 08:00	02/22/18 13:16	1
Chromium	ND		0.50	0.070	mg/Kg		02/20/18 08:00	02/22/18 13:16	1
Copper	ND		1.3	0.26	mg/Kg		02/20/18 08:00	02/22/18 13:16	1
Iron	ND		5.0	2.9	mg/Kg		02/20/18 08:00	02/22/18 13:16	1
Lead	ND		0.50	0.11	mg/Kg		02/20/18 08:00	02/22/18 13:16	1
Magnesium	5.96	J	250	1.7	mg/Kg		02/20/18 08:00	02/22/18 13:16	1
Manganese	0.102	J	0.75	0.027	mg/Kg		02/20/18 08:00	02/22/18 13:16	1
Selenium	0.222	J	0.50	0.17	mg/Kg		02/20/18 08:00	02/22/18 13:16	1

QC Sample Results

Client: HDR Inc
Project/Site: Corpus Christi ASR Program (SEP)

TestAmerica Job ID: 140-10636-1

Method: 6010B SEP - SEP Metals (ICP) (Continued)

Lab Sample ID: LCS 140-18243/7-B
Matrix: Solid
Analysis Batch: 18398

Client Sample ID: Lab Control Sample
Prep Type: Step 3
Prep Batch: 18290

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Aluminum	100	99.3		mg/Kg		99	75 - 125
Arsenic	5.00	5.10		mg/Kg		102	75 - 125
Chromium	10.0	10.5		mg/Kg		105	75 - 125
Copper	12.5	12.7		mg/Kg		101	75 - 125
Iron	50.0	52.9		mg/Kg		106	75 - 125
Lead	5.00	ND	*	mg/Kg		2	75 - 125
Magnesium	500	504		mg/Kg		101	75 - 125
Manganese	5.00	5.33		mg/Kg		107	75 - 125
Selenium	7.50	7.85		mg/Kg		105	75 - 125

Lab Sample ID: LCSD 140-18243/8-B
Matrix: Solid
Analysis Batch: 18398

Client Sample ID: Lab Control Sample Dup
Prep Type: Step 3
Prep Batch: 18290

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Aluminum	100	98.3		mg/Kg		98	75 - 125	1	30
Arsenic	5.00	4.97		mg/Kg		99	75 - 125	3	30
Chromium	10.0	10.3		mg/Kg		103	75 - 125	1	30
Copper	12.5	12.6		mg/Kg		101	75 - 125	0	30
Iron	50.0	52.6		mg/Kg		105	75 - 125	0	30
Lead	5.00	0.252	J *	mg/Kg		5	75 - 125	88	30
Magnesium	500	499		mg/Kg		100	75 - 125	1	30
Manganese	5.00	5.26		mg/Kg		105	75 - 125	1	30
Selenium	7.50	7.67		mg/Kg		102	75 - 125	2	30

Lab Sample ID: 140-10636-1 DU
Matrix: Solid
Analysis Batch: 18398

Client Sample ID: CCASR-01-U
Prep Type: Step 3
Prep Batch: 18290

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Aluminum	60		46.1		mg/Kg	☼	26	30
Arsenic	0.27	J	0.281	J	mg/Kg	☼	3	30
Chromium	0.094	J	0.0963	J	mg/Kg	☼	2	30
Copper	0.63	J	0.690	J	mg/Kg	☼	9	30
Iron	68		71.5		mg/Kg	☼	4	30
Lead	ND	*	0.167	J *	mg/Kg	☼	NC	30
Magnesium	1200	B	1050		mg/Kg	☼	14	30
Manganese	9.4	B	8.50		mg/Kg	☼	10	30
Selenium	0.26	J B	0.328	J	mg/Kg	☼	21	30

Lab Sample ID: MB 140-18291/6-B
Matrix: Solid
Analysis Batch: 18398

Client Sample ID: Method Blank
Prep Type: Step 4
Prep Batch: 18328

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	ND		10	1.6	mg/Kg		02/21/18 08:00	02/22/18 14:11	1
Arsenic	0.456	J	0.50	0.22	mg/Kg		02/21/18 08:00	02/22/18 14:11	1
Chromium	0.0835	J	0.50	0.070	mg/Kg		02/21/18 08:00	02/22/18 14:11	1
Copper	ND		1.3	0.22	mg/Kg		02/21/18 08:00	02/22/18 14:11	1

Client: HDR Inc
Project/Site: Corpus Christi ASR Program (SEP)

TestAmerica Job ID: 140-10636-1

Method: 6010B SEP - SEP Metals (ICP) (Continued)

Lab Sample ID: MB 140-18291/6-B
Matrix: Solid
Analysis Batch: 18398

Client Sample ID: Method Blank
Prep Type: Step 4
Prep Batch: 18328

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Iron	ND		5.0	2.9	mg/Kg		02/21/18 08:00	02/22/18 14:11	1
Lead	ND		0.50	0.11	mg/Kg		02/21/18 08:00	02/22/18 14:11	1
Magnesium	ND		250	1.7	mg/Kg		02/21/18 08:00	02/22/18 14:11	1
Manganese	ND		0.75	0.13	mg/Kg		02/21/18 08:00	02/22/18 14:11	1
Selenium	0.724		0.50	0.47	mg/Kg		02/21/18 08:00	02/22/18 14:11	1

Lab Sample ID: LCS 140-18291/7-B
Matrix: Solid
Analysis Batch: 18398

Client Sample ID: Lab Control Sample
Prep Type: Step 4
Prep Batch: 18328

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Aluminum	100	100		mg/Kg		100	75 - 125
Arsenic	5.00	5.54		mg/Kg		111	75 - 125
Chromium	10.0	10.3		mg/Kg		103	75 - 125
Copper	12.5	12.7		mg/Kg		102	75 - 125
Iron	50.0	52.0		mg/Kg		104	75 - 125
Lead	5.00	5.11		mg/Kg		102	75 - 125
Magnesium	500	482		mg/Kg		96	75 - 125
Manganese	5.00	5.21		mg/Kg		104	75 - 125
Selenium	7.50	0.919	*	mg/Kg		12	75 - 125

Lab Sample ID: LCSD 140-18291/8-B
Matrix: Solid
Analysis Batch: 18398

Client Sample ID: Lab Control Sample Dup
Prep Type: Step 4
Prep Batch: 18328

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Aluminum	100	97.7		mg/Kg		98	75 - 125	2	30
Arsenic	5.00	5.46		mg/Kg		109	75 - 125	2	30
Chromium	10.0	10.0		mg/Kg		100	75 - 125	3	30
Copper	12.5	12.4		mg/Kg		100	75 - 125	2	30
Iron	50.0	50.7		mg/Kg		101	75 - 125	3	30
Lead	5.00	4.87		mg/Kg		97	75 - 125	5	30
Magnesium	500	479		mg/Kg		96	75 - 125	1	30
Manganese	5.00	5.10		mg/Kg		102	75 - 125	2	30
Selenium	7.50	0.828	*	mg/Kg		11	75 - 125	10	30

Lab Sample ID: 140-10636-1 DU
Matrix: Solid
Analysis Batch: 18398

Client Sample ID: CCASR-01-U
Prep Type: Step 4
Prep Batch: 18328

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Aluminum	1300		1150		mg/Kg	☼	8	30
Arsenic	0.51	J B	0.569		mg/Kg	☼	11	30
Chromium	1.1	B	1.09		mg/Kg	☼	0.1	30
Copper	0.35	J	0.341	J	mg/Kg	☼	2	30
Iron	390		437		mg/Kg	☼	11	30
Lead	0.55		0.546		mg/Kg	☼	0.5	30
Magnesium	600		495		mg/Kg	☼	19	30
Manganese	9.9		8.58		mg/Kg	☼	15	30

Method: 6010B SEP - SEP Metals (ICP) (Continued)

Lab Sample ID: 140-10636-1 DU
Matrix: Solid
Analysis Batch: 18398

Client Sample ID: CCASR-01-U
Prep Type: Step 4
Prep Batch: 18328

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Selenium	0.65	B *	0.594	*	mg/Kg	☼	9	30

Lab Sample ID: MB 140-18329/6-B ^5
Matrix: Solid
Analysis Batch: 18463

Client Sample ID: Method Blank
Prep Type: Step 5
Prep Batch: 18370

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	24.3	J	150	24	mg/Kg		02/22/18 08:00	02/26/18 11:05	5
Arsenic	ND		7.5	1.9	mg/Kg		02/22/18 08:00	02/26/18 11:05	5
Chromium	ND		7.5	1.1	mg/Kg		02/22/18 08:00	02/26/18 11:05	5
Copper	ND		19	1.2	mg/Kg		02/22/18 08:00	02/26/18 11:05	5
Iron	ND		75	44	mg/Kg		02/22/18 08:00	02/26/18 11:05	5
Lead	ND		7.5	1.7	mg/Kg		02/22/18 08:00	02/26/18 11:05	5
Magnesium	33.3	J	3800	31	mg/Kg		02/22/18 08:00	02/26/18 11:05	5
Manganese	ND		11	1.9	mg/Kg		02/22/18 08:00	02/26/18 11:05	5
Selenium	ND		7.5	2.6	mg/Kg		02/22/18 08:00	02/26/18 11:05	5

Lab Sample ID: LCS 140-18329/7-B ^5
Matrix: Solid
Analysis Batch: 18463

Client Sample ID: Lab Control Sample
Prep Type: Step 5
Prep Batch: 18370

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Aluminum	300	ND	*	mg/Kg		7	75 - 125
Arsenic	15.0	12.5		mg/Kg		83	75 - 125
Chromium	30.0	33.3		mg/Kg		111	75 - 125
Copper	37.5	37.6		mg/Kg		100	75 - 125
Iron	150	ND	*	mg/Kg		3	75 - 125
Lead	15.0	6.19	J *	mg/Kg		41	75 - 125
Magnesium	1500	1400	J	mg/Kg		93	75 - 125
Manganese	15.0	2.02	J *	mg/Kg		13	75 - 125
Selenium	22.5	22.5		mg/Kg		100	75 - 125

Lab Sample ID: LCSD 140-18329/8-B ^5
Matrix: Solid
Analysis Batch: 18463

Client Sample ID: Lab Control Sample Dup
Prep Type: Step 5
Prep Batch: 18370

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Aluminum	300	ND	*	mg/Kg		7	75 - 125	0	30
Arsenic	15.0	11.5		mg/Kg		77	75 - 125	8	30
Chromium	30.0	33.2		mg/Kg		111	75 - 125	0	30
Copper	37.5	36.1		mg/Kg		96	75 - 125	4	30
Iron	150	ND	*	mg/Kg		4	75 - 125	19	30
Lead	15.0	6.74	J *	mg/Kg		45	75 - 125	8	30
Magnesium	1500	1390	J	mg/Kg		92	75 - 125	1	30
Manganese	15.0	3.78	J *	mg/Kg		25	75 - 125	61	30
Selenium	22.5	26.0		mg/Kg		116	75 - 125	14	30

Method: 6010B SEP - SEP Metals (ICP) (Continued)

Lab Sample ID: 140-10636-1 DU **Client Sample ID: CCASR-01-U**
Matrix: Solid **Prep Type: Step 5**
Analysis Batch: 18463 **Prep Batch: 18370**

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Aluminum	ND	*	ND	*	mg/Kg	☼	NC	30
Arsenic	ND		ND		mg/Kg	☼	NC	30
Chromium	1.2	J	ND		mg/Kg	☼	NC	30
Copper	ND		ND		mg/Kg	☼	NC	30
Iron	ND	*	ND	*	mg/Kg	☼	NC	30
Lead	ND	*	ND	*	mg/Kg	☼	NC	30
Magnesium	100	J B	78.2	J	mg/Kg	☼	26	30
Manganese	2.6	J *	2.64	J *	mg/Kg	☼	3	30
Selenium	ND		ND		mg/Kg	☼	NC	30

Lab Sample ID: MB 140-18371/6-A **Client Sample ID: Method Blank**
Matrix: Solid **Prep Type: Step 6**
Analysis Batch: 18463 **Prep Batch: 18371**

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	ND		10	1.6	mg/Kg		02/22/18 08:00	02/26/18 12:01	1
Arsenic	ND		0.50	0.15	mg/Kg		02/22/18 08:00	02/26/18 12:01	1
Chromium	ND		0.50	0.070	mg/Kg		02/22/18 08:00	02/26/18 12:01	1
Copper	ND		1.3	0.080	mg/Kg		02/22/18 08:00	02/26/18 12:01	1
Iron	ND		5.0	2.9	mg/Kg		02/22/18 08:00	02/26/18 12:01	1
Lead	ND		0.50	0.11	mg/Kg		02/22/18 08:00	02/26/18 12:01	1
Magnesium	ND		250	1.7	mg/Kg		02/22/18 08:00	02/26/18 12:01	1
Manganese	ND		0.75	0.25	mg/Kg		02/22/18 08:00	02/26/18 12:01	1
Selenium	ND		0.50	0.17	mg/Kg		02/22/18 08:00	02/26/18 12:01	1

Lab Sample ID: LCS 140-18371/7-A **Client Sample ID: Lab Control Sample**
Matrix: Solid **Prep Type: Step 6**
Analysis Batch: 18463 **Prep Batch: 18371**

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Aluminum	100	92.8		mg/Kg		93	75 - 125
Arsenic	5.00	4.97		mg/Kg		99	75 - 125
Chromium	10.0	9.90		mg/Kg		99	75 - 125
Copper	12.5	12.0		mg/Kg		96	75 - 125
Iron	50.0	48.2		mg/Kg		96	75 - 125
Lead	5.00	5.00		mg/Kg		100	75 - 125
Magnesium	500	476		mg/Kg		95	75 - 125
Manganese	5.00	5.04		mg/Kg		101	75 - 125
Selenium	7.50	7.46		mg/Kg		100	75 - 125

Lab Sample ID: LCSD 140-18371/8-A **Client Sample ID: Lab Control Sample Dup**
Matrix: Solid **Prep Type: Step 6**
Analysis Batch: 18463 **Prep Batch: 18371**

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Aluminum	100	95.7		mg/Kg		96	75 - 125	3	30
Arsenic	5.00	5.01		mg/Kg		100	75 - 125	1	30
Chromium	10.0	10.0		mg/Kg		100	75 - 125	1	30
Copper	12.5	12.1		mg/Kg		97	75 - 125	1	30

Method: 6010B SEP - SEP Metals (ICP) (Continued)

Lab Sample ID: LCSD 140-18371/8-A
Client Sample ID: Lab Control Sample Dup
Matrix: Solid
Prep Type: Step 6
Analysis Batch: 18463
Prep Batch: 18371

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Iron	50.0	49.1		mg/Kg		98	75 - 125	2	30
Lead	5.00	5.00		mg/Kg		100	75 - 125	0	30
Magnesium	500	484		mg/Kg		97	75 - 125	2	30
Manganese	5.00	5.09		mg/Kg		102	75 - 125	1	30
Selenium	7.50	7.57		mg/Kg		101	75 - 125	1	30

Lab Sample ID: 140-10636-1 DU
Client Sample ID: CCASR-01-U
Matrix: Solid
Prep Type: Step 6
Analysis Batch: 18463
Prep Batch: 18371

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Aluminum	3400		2290	F3	mg/Kg	☼	39	30
Arsenic	1.8		1.76		mg/Kg	☼	0.5	30
Chromium	2.2		1.61	F3	mg/Kg	☼	32	30
Copper	2.4		1.82		mg/Kg	☼	29	30
Iron	4400		3670		mg/Kg	☼	17	30
Lead	3.1		2.76		mg/Kg	☼	13	30
Magnesium	780		525	F5	mg/Kg	☼	39	30
Manganese	29		26.7		mg/Kg	☼	8	30
Selenium	ND		ND		mg/Kg	☼	NC	30

Lab Sample ID: MB 140-18392/6-A
Client Sample ID: Method Blank
Matrix: Solid
Prep Type: Step 7
Analysis Batch: 18463
Prep Batch: 18392

Analyte	MB Result	MB Qualifier	RL	MDL	Unit	D	Prepared	Analyzed	Dil Fac
Aluminum	ND		10	1.6	mg/Kg		02/23/18 08:00	02/26/18 12:56	1
Arsenic	ND		0.50	0.13	mg/Kg		02/23/18 08:00	02/26/18 12:56	1
Chromium	ND		0.50	0.070	mg/Kg		02/23/18 08:00	02/26/18 12:56	1
Copper	ND		1.3	0.080	mg/Kg		02/23/18 08:00	02/26/18 12:56	1
Iron	ND		5.0	4.1	mg/Kg		02/23/18 08:00	02/26/18 12:56	1
Lead	ND		0.50	0.11	mg/Kg		02/23/18 08:00	02/26/18 12:56	1
Magnesium	ND		250	1.7	mg/Kg		02/23/18 08:00	02/26/18 12:56	1
Manganese	ND		0.75	0.052	mg/Kg		02/23/18 08:00	02/26/18 12:56	1
Selenium	ND		0.50	0.17	mg/Kg		02/23/18 08:00	02/26/18 12:56	1

Lab Sample ID: LCS 140-18392/7-A
Client Sample ID: Lab Control Sample
Matrix: Solid
Prep Type: Step 7
Analysis Batch: 18463
Prep Batch: 18392

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Aluminum	100	99.7		mg/Kg		100	75 - 125
Arsenic	5.00	4.98		mg/Kg		100	75 - 125
Chromium	10.0	10.5		mg/Kg		105	75 - 125
Copper	12.5	12.9		mg/Kg		103	75 - 125
Iron	50.0	51.9		mg/Kg		104	75 - 125
Lead	5.00	5.00		mg/Kg		100	75 - 125
Magnesium	500	491		mg/Kg		98	75 - 125
Manganese	5.00	5.34		mg/Kg		107	75 - 125

Method: 6010B SEP - SEP Metals (ICP) (Continued)

Lab Sample ID: LCS 140-18392/7-A — **Client Sample ID: Lab Control Sample**
Matrix: Solid — **Prep Type: Step 7**
Analysis Batch: 18463 — **Prep Batch: 18392**

Analyte	Spike Added	LCS Result	LCS Qualifier	Unit	D	%Rec	%Rec. Limits
Selenium	7.50	7.71		mg/Kg		103	75 - 125

Lab Sample ID: LCSD 140-18392/8-A — **Client Sample ID: Lab Control Sample Dup**
Matrix: Solid — **Prep Type: Step 7**
Analysis Batch: 18463 — **Prep Batch: 18392**

Analyte	Spike Added	LCSD Result	LCSD Qualifier	Unit	D	%Rec	%Rec. Limits	RPD	RPD Limit
Aluminum	100	101		mg/Kg		101	75 - 125	1	30
Arsenic	5.00	5.04		mg/Kg		101	75 - 125	1	30
Chromium	10.0	10.7		mg/Kg		107	75 - 125	2	30
Copper	12.5	13.2		mg/Kg		106	75 - 125	2	30
Iron	50.0	53.2		mg/Kg		106	75 - 125	2	30
Lead	5.00	5.13		mg/Kg		103	75 - 125	3	30
Magnesium	500	503		mg/Kg		101	75 - 125	2	30
Manganese	5.00	5.40		mg/Kg		108	75 - 125	1	30
Selenium	7.50	7.77		mg/Kg		104	75 - 125	1	30

Lab Sample ID: 140-10636-1 DU — **Client Sample ID: CCASR-01-U**
Matrix: Solid — **Prep Type: Step 7**
Analysis Batch: 18463 — **Prep Batch: 18392**

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Arsenic	0.33	J	0.649	F5	mg/Kg	☼	64	30
Chromium	6.0		4.43		mg/Kg	☼	30	30
Copper	1.7		1.42		mg/Kg	☼	16	30
Iron	3300		2320	F3	mg/Kg	☼	34	30
Lead	3.0		2.83		mg/Kg	☼	5	30
Manganese	22		18.1		mg/Kg	☼	18	30
Selenium	ND		ND		mg/Kg	☼	NC	30

Lab Sample ID: 140-10636-1 DU — **Client Sample ID: CCASR-01-U**
Matrix: Solid — **Prep Type: Step 7**
Analysis Batch: 18463 — **Prep Batch: 18392**

Analyte	Sample Result	Sample Qualifier	DU Result	DU Qualifier	Unit	D	RPD	RPD Limit
Aluminum	15000		13300		mg/Kg	☼	12	30
Magnesium	680	J	731	J	mg/Kg	☼	7	30

Metals

Prep Batch: 18118

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
140-10636-1	CCASR-01-U	Total/NA	Solid	Total	
140-10636-2	CCASR-01-L	Total/NA	Solid	Total	
140-10636-3	CCASR-03-A	Total/NA	Solid	Total	
140-10636-4	CCASR-03-T	Total/NA	Solid	Total	
MB 140-18118/7-A	Method Blank	Total/NA	Solid	Total	
LCS 140-18118/8-A	Lab Control Sample	Total/NA	Solid	Total	
LCSD 140-18118/9-A	Lab Control Sample Dup	Total/NA	Solid	Total	
140-10636-1 DU	CCASR-01-U	Total/NA	Solid	Total	

SEP Batch: 18119

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
140-10636-1	CCASR-01-U	Step 1	Solid	Exchangeable	
140-10636-2	CCASR-01-L	Step 1	Solid	Exchangeable	
140-10636-3	CCASR-03-A	Step 1	Solid	Exchangeable	
140-10636-4	CCASR-03-T	Step 1	Solid	Exchangeable	
MB 140-18119/6-B ^4	Method Blank	Step 1	Solid	Exchangeable	
LCS 140-18119/7-B ^5	Lab Control Sample	Step 1	Solid	Exchangeable	
LCSD 140-18119/8-B ^5	Lab Control Sample Dup	Step 1	Solid	Exchangeable	
140-10636-1 DU	CCASR-01-U	Step 1	Solid	Exchangeable	

Prep Batch: 18208

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
140-10636-1	CCASR-01-U	Step 1	Solid	3010A	18119
140-10636-2	CCASR-01-L	Step 1	Solid	3010A	18119
140-10636-3	CCASR-03-A	Step 1	Solid	3010A	18119
140-10636-4	CCASR-03-T	Step 1	Solid	3010A	18119
MB 140-18119/6-B ^4	Method Blank	Step 1	Solid	3010A	18119
LCS 140-18119/7-B ^5	Lab Control Sample	Step 1	Solid	3010A	18119
LCSD 140-18119/8-B ^5	Lab Control Sample Dup	Step 1	Solid	3010A	18119
140-10636-1 DU	CCASR-01-U	Step 1	Solid	3010A	18119

SEP Batch: 18209

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
140-10636-1	CCASR-01-U	Step 2	Solid	Carbonate	
140-10636-2	CCASR-01-L	Step 2	Solid	Carbonate	
140-10636-3	CCASR-03-A	Step 2	Solid	Carbonate	
140-10636-4	CCASR-03-T	Step 2	Solid	Carbonate	
MB 140-18209/6-B ^3	Method Blank	Step 2	Solid	Carbonate	
LCS 140-18209/7-B ^5	Lab Control Sample	Step 2	Solid	Carbonate	
LCSD 140-18209/8-B ^5	Lab Control Sample Dup	Step 2	Solid	Carbonate	
140-10636-1 DU	CCASR-01-U	Step 2	Solid	Carbonate	

Prep Batch: 18242

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
140-10636-1	CCASR-01-U	Step 2	Solid	3010A	18209
140-10636-2	CCASR-01-L	Step 2	Solid	3010A	18209
140-10636-3	CCASR-03-A	Step 2	Solid	3010A	18209
140-10636-4	CCASR-03-T	Step 2	Solid	3010A	18209
MB 140-18209/6-B ^3	Method Blank	Step 2	Solid	3010A	18209
LCS 140-18209/7-B ^5	Lab Control Sample	Step 2	Solid	3010A	18209
LCSD 140-18209/8-B ^5	Lab Control Sample Dup	Step 2	Solid	3010A	18209

1 2 3 4 5 6 7 8 9 10 11 12 13

Metals (Continued)

Prep Batch: 18242 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
140-10636-1 DU	CCASR-01-U	Step 2	Solid	3010A	18209

SEP Batch: 18243

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
140-10636-1	CCASR-01-U	Step 3	Solid	Non-Crystalline	
140-10636-2	CCASR-01-L	Step 3	Solid	Non-Crystalline	
140-10636-3	CCASR-03-A	Step 3	Solid	Non-Crystalline	
140-10636-4	CCASR-03-T	Step 3	Solid	Non-Crystalline	
MB 140-18243/6-B	Method Blank	Step 3	Solid	Non-Crystalline	
LCS 140-18243/7-B	Lab Control Sample	Step 3	Solid	Non-Crystalline	
LCSD 140-18243/8-B	Lab Control Sample Dup	Step 3	Solid	Non-Crystalline	
140-10636-1 DU	CCASR-01-U	Step 3	Solid	Non-Crystalline	

Prep Batch: 18290

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
140-10636-1	CCASR-01-U	Step 3	Solid	3010A	18243
140-10636-2	CCASR-01-L	Step 3	Solid	3010A	18243
140-10636-3	CCASR-03-A	Step 3	Solid	3010A	18243
140-10636-4	CCASR-03-T	Step 3	Solid	3010A	18243
MB 140-18243/6-B	Method Blank	Step 3	Solid	3010A	18243
LCS 140-18243/7-B	Lab Control Sample	Step 3	Solid	3010A	18243
LCSD 140-18243/8-B	Lab Control Sample Dup	Step 3	Solid	3010A	18243
140-10636-1 DU	CCASR-01-U	Step 3	Solid	3010A	18243

SEP Batch: 18291

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
140-10636-1	CCASR-01-U	Step 4	Solid	Metal Hydroxide	
140-10636-2	CCASR-01-L	Step 4	Solid	Metal Hydroxide	
140-10636-3	CCASR-03-A	Step 4	Solid	Metal Hydroxide	
140-10636-4	CCASR-03-T	Step 4	Solid	Metal Hydroxide	
MB 140-18291/6-B	Method Blank	Step 4	Solid	Metal Hydroxide	
LCS 140-18291/7-B	Lab Control Sample	Step 4	Solid	Metal Hydroxide	
LCSD 140-18291/8-B	Lab Control Sample Dup	Step 4	Solid	Metal Hydroxide	
140-10636-1 DU	CCASR-01-U	Step 4	Solid	Metal Hydroxide	

Prep Batch: 18328

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
140-10636-1	CCASR-01-U	Step 4	Solid	3010A	18291
140-10636-2	CCASR-01-L	Step 4	Solid	3010A	18291
140-10636-3	CCASR-03-A	Step 4	Solid	3010A	18291
140-10636-4	CCASR-03-T	Step 4	Solid	3010A	18291
MB 140-18291/6-B	Method Blank	Step 4	Solid	3010A	18291
LCS 140-18291/7-B	Lab Control Sample	Step 4	Solid	3010A	18291
LCSD 140-18291/8-B	Lab Control Sample Dup	Step 4	Solid	3010A	18291
140-10636-1 DU	CCASR-01-U	Step 4	Solid	3010A	18291

SEP Batch: 18329

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
140-10636-1	CCASR-01-U	Step 5	Solid	Organic-Bound	
140-10636-2	CCASR-01-L	Step 5	Solid	Organic-Bound	
140-10636-3	CCASR-03-A	Step 5	Solid	Organic-Bound	

Metals (Continued)

SEP Batch: 18329 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
140-10636-4	CCASR-03-T	Step 5	Solid	Organic-Bound	
MB 140-18329/6-B ^5	Method Blank	Step 5	Solid	Organic-Bound	
LCS 140-18329/7-B ^5	Lab Control Sample	Step 5	Solid	Organic-Bound	
LCSD 140-18329/8-B ^5	Lab Control Sample Dup	Step 5	Solid	Organic-Bound	
140-10636-1 DU	CCASR-01-U	Step 5	Solid	Organic-Bound	

Prep Batch: 18370

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
140-10636-1	CCASR-01-U	Step 5	Solid	3010A	18329
140-10636-2	CCASR-01-L	Step 5	Solid	3010A	18329
140-10636-3	CCASR-03-A	Step 5	Solid	3010A	18329
140-10636-4	CCASR-03-T	Step 5	Solid	3010A	18329
MB 140-18329/6-B ^5	Method Blank	Step 5	Solid	3010A	18329
LCS 140-18329/7-B ^5	Lab Control Sample	Step 5	Solid	3010A	18329
LCSD 140-18329/8-B ^5	Lab Control Sample Dup	Step 5	Solid	3010A	18329
140-10636-1 DU	CCASR-01-U	Step 5	Solid	3010A	18329

SEP Batch: 18371

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
140-10636-1	CCASR-01-U	Step 6	Solid	Acid/Sulfide	
140-10636-2	CCASR-01-L	Step 6	Solid	Acid/Sulfide	
140-10636-3	CCASR-03-A	Step 6	Solid	Acid/Sulfide	
140-10636-4	CCASR-03-T	Step 6	Solid	Acid/Sulfide	
MB 140-18371/6-A	Method Blank	Step 6	Solid	Acid/Sulfide	
LCS 140-18371/7-A	Lab Control Sample	Step 6	Solid	Acid/Sulfide	
LCSD 140-18371/8-A	Lab Control Sample Dup	Step 6	Solid	Acid/Sulfide	
140-10636-1 DU	CCASR-01-U	Step 6	Solid	Acid/Sulfide	

Prep Batch: 18392

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
140-10636-1	CCASR-01-U	Step 7	Solid	Residual	
140-10636-2	CCASR-01-L	Step 7	Solid	Residual	
140-10636-3	CCASR-03-A	Step 7	Solid	Residual	
140-10636-4	CCASR-03-T	Step 7	Solid	Residual	
MB 140-18392/6-A	Method Blank	Step 7	Solid	Residual	
LCS 140-18392/7-A	Lab Control Sample	Step 7	Solid	Residual	
LCSD 140-18392/8-A	Lab Control Sample Dup	Step 7	Solid	Residual	
140-10636-1 DU	CCASR-01-U	Step 7	Solid	Residual	

Analysis Batch: 18398

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
140-10636-1	CCASR-01-U	Step 1	Solid	6010B SEP	18208
140-10636-1	CCASR-01-U	Step 2	Solid	6010B SEP	18242
140-10636-1	CCASR-01-U	Step 3	Solid	6010B SEP	18290
140-10636-1	CCASR-01-U	Step 4	Solid	6010B SEP	18328
140-10636-2	CCASR-01-L	Step 1	Solid	6010B SEP	18208
140-10636-2	CCASR-01-L	Step 2	Solid	6010B SEP	18242
140-10636-2	CCASR-01-L	Step 3	Solid	6010B SEP	18290
140-10636-2	CCASR-01-L	Step 4	Solid	6010B SEP	18328
140-10636-3	CCASR-03-A	Step 1	Solid	6010B SEP	18208
140-10636-3	CCASR-03-A	Step 2	Solid	6010B SEP	18242

Metals (Continued)

Analysis Batch: 18398 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
140-10636-3	CCASR-03-A	Step 3	Solid	6010B SEP	18290
140-10636-3	CCASR-03-A	Step 4	Solid	6010B SEP	18328
140-10636-4	CCASR-03-T	Step 1	Solid	6010B SEP	18208
140-10636-4	CCASR-03-T	Step 2	Solid	6010B SEP	18242
140-10636-4	CCASR-03-T	Step 3	Solid	6010B SEP	18290
140-10636-4	CCASR-03-T	Step 4	Solid	6010B SEP	18328
MB 140-18119/6-B ^4	Method Blank	Step 1	Solid	6010B SEP	18208
MB 140-18209/6-B ^3	Method Blank	Step 2	Solid	6010B SEP	18242
MB 140-18243/6-B	Method Blank	Step 3	Solid	6010B SEP	18290
MB 140-18291/6-B	Method Blank	Step 4	Solid	6010B SEP	18328
LCS 140-18119/7-B ^5	Lab Control Sample	Step 1	Solid	6010B SEP	18208
LCS 140-18209/7-B ^5	Lab Control Sample	Step 2	Solid	6010B SEP	18242
LCS 140-18243/7-B	Lab Control Sample	Step 3	Solid	6010B SEP	18290
LCS 140-18291/7-B	Lab Control Sample	Step 4	Solid	6010B SEP	18328
LCSD 140-18119/8-B ^5	Lab Control Sample Dup	Step 1	Solid	6010B SEP	18208
LCSD 140-18209/8-B ^5	Lab Control Sample Dup	Step 2	Solid	6010B SEP	18242
LCSD 140-18243/8-B	Lab Control Sample Dup	Step 3	Solid	6010B SEP	18290
LCSD 140-18291/8-B	Lab Control Sample Dup	Step 4	Solid	6010B SEP	18328
140-10636-1 DU	CCASR-01-U	Step 1	Solid	6010B SEP	18208
140-10636-1 DU	CCASR-01-U	Step 2	Solid	6010B SEP	18242
140-10636-1 DU	CCASR-01-U	Step 3	Solid	6010B SEP	18290
140-10636-1 DU	CCASR-01-U	Step 4	Solid	6010B SEP	18328

Analysis Batch: 18463

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
140-10636-1	CCASR-01-U	Step 5	Solid	6010B SEP	18370
140-10636-1	CCASR-01-U	Step 6	Solid	6010B SEP	18371
140-10636-1	CCASR-01-U	Step 7	Solid	6010B SEP	18392
140-10636-1	CCASR-01-U	Step 7	Solid	6010B SEP	18392
140-10636-1	CCASR-01-U	Total/NA	Solid	6010B	18118
140-10636-1	CCASR-01-U	Total/NA	Solid	6010B	18118
140-10636-2	CCASR-01-L	Step 5	Solid	6010B SEP	18370
140-10636-2	CCASR-01-L	Step 6	Solid	6010B SEP	18371
140-10636-2	CCASR-01-L	Step 7	Solid	6010B SEP	18392
140-10636-2	CCASR-01-L	Step 7	Solid	6010B SEP	18392
140-10636-2	CCASR-01-L	Step 7	Solid	6010B SEP	18392
140-10636-2	CCASR-01-L	Total/NA	Solid	6010B	18118
140-10636-2	CCASR-01-L	Total/NA	Solid	6010B	18118
140-10636-2	CCASR-01-L	Total/NA	Solid	6010B	18118
140-10636-3	CCASR-03-A	Step 5	Solid	6010B SEP	18370
140-10636-3	CCASR-03-A	Step 6	Solid	6010B SEP	18371
140-10636-3	CCASR-03-A	Step 7	Solid	6010B SEP	18392
140-10636-3	CCASR-03-A	Step 7	Solid	6010B SEP	18392
140-10636-3	CCASR-03-A	Step 7	Solid	6010B SEP	18392
140-10636-3	CCASR-03-A	Total/NA	Solid	6010B	18118
140-10636-3	CCASR-03-A	Total/NA	Solid	6010B	18118
140-10636-3	CCASR-03-A	Total/NA	Solid	6010B	18118
140-10636-4	CCASR-03-T	Step 5	Solid	6010B SEP	18370
140-10636-4	CCASR-03-T	Step 6	Solid	6010B SEP	18371
140-10636-4	CCASR-03-T	Step 7	Solid	6010B SEP	18392
140-10636-4	CCASR-03-T	Step 7	Solid	6010B SEP	18392

Metals (Continued)

Analysis Batch: 18463 (Continued)

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
140-10636-4	CCASR-03-T	Step 7	Solid	6010B SEP	18392
140-10636-4	CCASR-03-T	Total/NA	Solid	6010B	18118
140-10636-4	CCASR-03-T	Total/NA	Solid	6010B	18118
140-10636-4	CCASR-03-T	Total/NA	Solid	6010B	18118
MB 140-18118/7-A	Method Blank	Total/NA	Solid	6010B	18118
MB 140-18329/6-B ^5	Method Blank	Step 5	Solid	6010B SEP	18370
MB 140-18371/6-A	Method Blank	Step 6	Solid	6010B SEP	18371
MB 140-18392/6-A	Method Blank	Step 7	Solid	6010B SEP	18392
LCS 140-18118/8-A	Lab Control Sample	Total/NA	Solid	6010B	18118
LCS 140-18329/7-B ^5	Lab Control Sample	Step 5	Solid	6010B SEP	18370
LCS 140-18371/7-A	Lab Control Sample	Step 6	Solid	6010B SEP	18371
LCS 140-18392/7-A	Lab Control Sample	Step 7	Solid	6010B SEP	18392
LCSD 140-18118/9-A	Lab Control Sample Dup	Total/NA	Solid	6010B	18118
LCSD 140-18329/8-B ^5	Lab Control Sample Dup	Step 5	Solid	6010B SEP	18370
LCSD 140-18371/8-A	Lab Control Sample Dup	Step 6	Solid	6010B SEP	18371
LCSD 140-18392/8-A	Lab Control Sample Dup	Step 7	Solid	6010B SEP	18392
140-10636-1 DU	CCASR-01-U	Step 5	Solid	6010B SEP	18370
140-10636-1 DU	CCASR-01-U	Step 6	Solid	6010B SEP	18371
140-10636-1 DU	CCASR-01-U	Step 7	Solid	6010B SEP	18392
140-10636-1 DU	CCASR-01-U	Step 7	Solid	6010B SEP	18392
140-10636-1 DU	CCASR-01-U	Total/NA	Solid	6010B	18118
140-10636-1 DU	CCASR-01-U	Total/NA	Solid	6010B	18118

Analysis Batch: 18491

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
140-10636-1	CCASR-01-U	Sum of Steps 1-7	Solid	6010B SEP	
140-10636-2	CCASR-01-L	Sum of Steps 1-7	Solid	6010B SEP	
140-10636-3	CCASR-03-A	Sum of Steps 1-7	Solid	6010B SEP	
140-10636-4	CCASR-03-T	Sum of Steps 1-7	Solid	6010B SEP	

General Chemistry

Analysis Batch: 17912

Lab Sample ID	Client Sample ID	Prep Type	Matrix	Method	Prep Batch
140-10636-1	CCASR-01-U	Total/NA	Solid	Moisture	
140-10636-2	CCASR-01-L	Total/NA	Solid	Moisture	
140-10636-3	CCASR-03-A	Total/NA	Solid	Moisture	
140-10636-4	CCASR-03-T	Total/NA	Solid	Moisture	
140-10636-1 DU	CCASR-01-U	Total/NA	Solid	Moisture	

Lab Chronicle

Client: HDR Inc
Project/Site: Corpus Christi ASR Program (SEP)

TestAmerica Job ID: 140-10636-1

Client Sample ID: CCASR-01-U
Date Collected: 12/14/17 16:28
Date Received: 02/03/18 08:45

Lab Sample ID: 140-10636-1
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Sum of Steps 1-7	Analysis	6010B SEP		1			18491	02/27/18 13:33	KNC	TAL KNX
	Instrument ID: NOEQUIP									
Total/NA	Analysis	Moisture		1			17912	02/05/18 15:21	BKD	TAL KNX
	Instrument ID: NOEQUIP									

Client Sample ID: CCASR-01-U
Date Collected: 12/14/17 16:28
Date Received: 02/03/18 08:45

Lab Sample ID: 140-10636-1
Matrix: Solid
Percent Solids: 92.5

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	Total			1.000 g	50 mL	18118	02/15/18 08:00	KNC	TAL KNX
Total/NA	Analysis	6010B		1			18463	02/26/18 14:12	KNC	TAL KNX
	Instrument ID: DUO									
Total/NA	Prep	Total			1.000 g	50 mL	18118	02/15/18 08:00	KNC	TAL KNX
Total/NA	Analysis	6010B		10			18463	02/26/18 15:44	KNC	TAL KNX
	Instrument ID: DUO									
Step 1	SEP	Exchangeable			5.000 g	25 mL	18119	02/15/18 08:00	KNC	TAL KNX
Step 1	Prep	3010A			5 mL	50 mL	18208	02/16/18 08:00	KNC	TAL KNX
Step 1	Analysis	6010B SEP		4			18398	02/22/18 11:39	KNC	TAL KNX
	Instrument ID: DUO									
Step 2	SEP	Carbonate			5.000 g	25 mL	18209	02/16/18 08:00	KNC	TAL KNX
Step 2	Prep	3010A			5 mL	50 mL	18242	02/19/18 08:00	KNC	TAL KNX
Step 2	Analysis	6010B SEP		3			18398	02/22/18 12:35	KNC	TAL KNX
	Instrument ID: DUO									
Step 3	SEP	Non-Crystalline			5.000 g	25 mL	18243	02/19/18 08:00	KNC	TAL KNX
Step 3	Prep	3010A			5 mL	50 mL	18290	02/20/18 08:00	KNC	TAL KNX
Step 3	Analysis	6010B SEP		1			18398	02/22/18 13:31	KNC	TAL KNX
	Instrument ID: DUO									
Step 4	SEP	Metal Hydroxide			5.000 g	25 mL	18291	02/20/18 08:00	KNC	TAL KNX
Step 4	Prep	3010A			5 mL	50 mL	18328	02/21/18 08:00	KNC	TAL KNX
Step 4	Analysis	6010B SEP		1			18398	02/22/18 14:26	KNC	TAL KNX
	Instrument ID: DUO									
Step 5	SEP	Organic-Bound			5.000 g	75 mL	18329	02/21/18 08:00	KNC	TAL KNX
Step 5	Prep	3010A			5 mL	50 mL	18370	02/22/18 08:00	KNC	TAL KNX
Step 5	Analysis	6010B SEP		5			18463	02/26/18 11:21	KNC	TAL KNX
	Instrument ID: DUO									
Step 6	SEP	Acid/Sulfide			5.000 g	250 mL	18371	02/22/18 08:00	KNC	TAL KNX
Step 6	Analysis	6010B SEP		1			18463	02/26/18 12:16	KNC	TAL KNX
	Instrument ID: DUO									
Step 7	Prep	Residual			1.000 g	50 mL	18392	02/23/18 08:00	KNC	TAL KNX
Step 7	Analysis	6010B SEP		1			18463	02/26/18 13:11	KNC	TAL KNX
	Instrument ID: DUO									
Step 7	Prep	Residual			1.000 g	50 mL	18392	02/23/18 08:00	KNC	TAL KNX
Step 7	Analysis	6010B SEP		10			18463	02/26/18 14:59	KNC	TAL KNX
	Instrument ID: DUO									

TestAmerica Knoxville

Client Sample ID: CCASR-01-L **Lab Sample ID: 140-10636-2**
Date Collected: 01/05/18 13:00 **Matrix: Solid**
Date Received: 02/03/18 08:45

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Sum of Steps 1-7	Analysis	6010B SEP		1			18491	02/27/18 13:33	KNC	TAL KNX
	Instrument ID: NOEQUIP									
Total/NA	Analysis	Moisture		1			17912	02/05/18 15:21	BKD	TAL KNX
	Instrument ID: NOEQUIP									

Client Sample ID: CCASR-01-L **Lab Sample ID: 140-10636-2**
Date Collected: 01/05/18 13:00 **Matrix: Solid**
Date Received: 02/03/18 08:45 **Percent Solids: 80.0**

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	Total			1.000 g	50 mL	18118	02/15/18 08:00	KNC	TAL KNX
Total/NA	Analysis	6010B		1			18463	02/26/18 14:23	KNC	TAL KNX
	Instrument ID: DUO									
Total/NA	Prep	Total			1.000 g	50 mL	18118	02/15/18 08:00	KNC	TAL KNX
Total/NA	Analysis	6010B		10			18463	02/26/18 15:54	KNC	TAL KNX
	Instrument ID: DUO									
Total/NA	Prep	Total			1.000 g	50 mL	18118	02/15/18 08:00	KNC	TAL KNX
Total/NA	Analysis	6010B		2			18463	02/26/18 16:39	KNC	TAL KNX
	Instrument ID: DUO									
Step 1	SEP	Exchangeable			5.000 g	25 mL	18119	02/15/18 08:00	KNC	TAL KNX
Step 1	Prep	3010A			5 mL	50 mL	18208	02/16/18 08:00	KNC	TAL KNX
Step 1	Analysis	6010B SEP		4			18398	02/22/18 11:49	KNC	TAL KNX
	Instrument ID: DUO									
Step 2	SEP	Carbonate			5.000 g	25 mL	18209	02/16/18 08:00	KNC	TAL KNX
Step 2	Prep	3010A			5 mL	50 mL	18242	02/19/18 08:00	KNC	TAL KNX
Step 2	Analysis	6010B SEP		3			18398	02/22/18 12:45	KNC	TAL KNX
	Instrument ID: DUO									
Step 3	SEP	Non-Crystalline			5.000 g	25 mL	18243	02/19/18 08:00	KNC	TAL KNX
Step 3	Prep	3010A			5 mL	50 mL	18290	02/20/18 08:00	KNC	TAL KNX
Step 3	Analysis	6010B SEP		1			18398	02/22/18 13:41	KNC	TAL KNX
	Instrument ID: DUO									
Step 4	SEP	Metal Hydroxide			5.000 g	25 mL	18291	02/20/18 08:00	KNC	TAL KNX
Step 4	Prep	3010A			5 mL	50 mL	18328	02/21/18 08:00	KNC	TAL KNX
Step 4	Analysis	6010B SEP		1			18398	02/22/18 14:36	KNC	TAL KNX
	Instrument ID: DUO									
Step 5	SEP	Organic-Bound			5.000 g	75 mL	18329	02/21/18 08:00	KNC	TAL KNX
Step 5	Prep	3010A			5 mL	50 mL	18370	02/22/18 08:00	KNC	TAL KNX
Step 5	Analysis	6010B SEP		5			18463	02/26/18 11:31	KNC	TAL KNX
	Instrument ID: DUO									
Step 6	SEP	Acid/Sulfide			5.000 g	250 mL	18371	02/22/18 08:00	KNC	TAL KNX
Step 6	Analysis	6010B SEP		1			18463	02/26/18 12:26	KNC	TAL KNX
	Instrument ID: DUO									
Step 7	Prep	Residual			1.000 g	50 mL	18392	02/23/18 08:00	KNC	TAL KNX
Step 7	Analysis	6010B SEP		1			18463	02/26/18 13:21	KNC	TAL KNX
	Instrument ID: DUO									

Lab Chronicle

Client: HDR Inc — TestAmerica Job ID: 140-10636-1

Project/Site: Corpus Christi ASR Program (SEP)

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 7	Prep	Residual			1.000 g	50 mL	18392	02/23/18 08:00	KNC	TAL KNX
Step 7	Analysis	6010B SEP		10			18463	02/26/18 15:09	KNC	TAL KNX
	Instrument ID: DUO									
Step 7	Prep	Residual			1.000 g	50 mL	18392	02/23/18 08:00	KNC	TAL KNX
Step 7	Analysis	6010B SEP		2			18463	02/26/18 16:24	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: CCASR-03-A

Lab Sample ID: 140-10636-3

Date Collected: 01/31/18 13:00

Matrix: Solid

Date Received: 02/03/18 08:45

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Sum of Steps 1-7	Analysis	6010B SEP		1			18491	02/27/18 13:33	KNC	TAL KNX
	Instrument ID: NOEQUIP									
Total/NA	Analysis	Moisture		1			17912	02/05/18 15:21	BKD	TAL KNX
	Instrument ID: NOEQUIP									

Client Sample ID: CCASR-03-A

Lab Sample ID: 140-10636-3

Date Collected: 01/31/18 13:00

Matrix: Solid

Date Received: 02/03/18 08:45

Percent Solids: 86.2

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	Total			1.000 g	50 mL	18118	02/15/18 08:00	KNC	TAL KNX
Total/NA	Analysis	6010B		1			18463	02/26/18 14:28	KNC	TAL KNX
	Instrument ID: DUO									
Total/NA	Prep	Total			1.000 g	50 mL	18118	02/15/18 08:00	KNC	TAL KNX
Total/NA	Analysis	6010B		10			18463	02/26/18 15:59	KNC	TAL KNX
	Instrument ID: DUO									
Total/NA	Prep	Total			1.000 g	50 mL	18118	02/15/18 08:00	KNC	TAL KNX
Total/NA	Analysis	6010B		2			18463	02/26/18 16:44	KNC	TAL KNX
	Instrument ID: DUO									
Step 1	SEP	Exchangeable			5.000 g	25 mL	18119	02/15/18 08:00	KNC	TAL KNX
Step 1	Prep	3010A			5 mL	50 mL	18208	02/16/18 08:00	KNC	TAL KNX
Step 1	Analysis	6010B SEP		4			18398	02/22/18 11:54	KNC	TAL KNX
	Instrument ID: DUO									
Step 2	SEP	Carbonate			5.000 g	25 mL	18209	02/16/18 08:00	KNC	TAL KNX
Step 2	Prep	3010A			5 mL	50 mL	18242	02/19/18 08:00	KNC	TAL KNX
Step 2	Analysis	6010B SEP		3			18398	02/22/18 12:51	KNC	TAL KNX
	Instrument ID: DUO									
Step 3	SEP	Non-Crystalline			5.000 g	25 mL	18243	02/19/18 08:00	KNC	TAL KNX
Step 3	Prep	3010A			5 mL	50 mL	18290	02/20/18 08:00	KNC	TAL KNX
Step 3	Analysis	6010B SEP		1			18398	02/22/18 13:46	KNC	TAL KNX
	Instrument ID: DUO									
Step 4	SEP	Metal Hydroxide			5.000 g	25 mL	18291	02/20/18 08:00	KNC	TAL KNX
Step 4	Prep	3010A			5 mL	50 mL	18328	02/21/18 08:00	KNC	TAL KNX
Step 4	Analysis	6010B SEP		1			18398	02/22/18 14:41	KNC	TAL KNX
	Instrument ID: DUO									
Step 5	SEP	Organic-Bound			5.000 g	75 mL	18329	02/21/18 08:00	KNC	TAL KNX
Step 5	Prep	3010A			5 mL	50 mL	18370	02/22/18 08:00	KNC	TAL KNX

Client Sample ID: CCASR-03-A

Date Collected: 01/31/18 13:00
Date Received: 02/03/18 08:45

Lab Sample ID: 140-10636-3
Matrix: Solid
Percent Solids: 86.2

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 5	Analysis	6010B SEP		5			18463	02/26/18 11:36	KNC	TAL KNX
	Instrument ID: DUO									
Step 6	SEP	Acid/Sulfide			5.000 g	250 mL	18371	02/22/18 08:00	KNC	TAL KNX
Step 6	Analysis	6010B SEP		1			18463	02/26/18 12:31	KNC	TAL KNX
	Instrument ID: DUO									
Step 7	Prep	Residual			1.000 g	50 mL	18392	02/23/18 08:00	KNC	TAL KNX
Step 7	Analysis	6010B SEP		1			18463	02/26/18 13:27	KNC	TAL KNX
	Instrument ID: DUO									
Step 7	Prep	Residual			1.000 g	50 mL	18392	02/23/18 08:00	KNC	TAL KNX
Step 7	Analysis	6010B SEP		10			18463	02/26/18 15:14	KNC	TAL KNX
	Instrument ID: DUO									
Step 7	Prep	Residual			1.000 g	50 mL	18392	02/23/18 08:00	KNC	TAL KNX
Step 7	Analysis	6010B SEP		2			18463	02/26/18 16:29	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: CCASR-03-T

Date Collected: 01/31/18 13:00
Date Received: 02/03/18 08:45

Lab Sample ID: 140-10636-4
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Sum of Steps 1-7	Analysis	6010B SEP		1			18491	02/27/18 13:33	KNC	TAL KNX
	Instrument ID: NOEQUIP									
Total/NA	Analysis	Moisture		1			17912	02/05/18 15:21	BKD	TAL KNX
	Instrument ID: NOEQUIP									

Client Sample ID: CCASR-03-T

Date Collected: 01/31/18 13:00
Date Received: 02/03/18 08:45

Lab Sample ID: 140-10636-4
Matrix: Solid
Percent Solids: 86.7

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	Total			1.000 g	50 mL	18118	02/15/18 08:00	KNC	TAL KNX
Total/NA	Analysis	6010B		1			18463	02/26/18 14:34	KNC	TAL KNX
	Instrument ID: DUO									
Total/NA	Prep	Total			1.000 g	50 mL	18118	02/15/18 08:00	KNC	TAL KNX
Total/NA	Analysis	6010B		10			18463	02/26/18 16:04	KNC	TAL KNX
	Instrument ID: DUO									
Total/NA	Prep	Total			1.000 g	50 mL	18118	02/15/18 08:00	KNC	TAL KNX
Total/NA	Analysis	6010B		2			18463	02/26/18 16:49	KNC	TAL KNX
	Instrument ID: DUO									
Step 1	SEP	Exchangeable			5.000 g	25 mL	18119	02/15/18 08:00	KNC	TAL KNX
Step 1	Prep	3010A			5 mL	50 mL	18208	02/16/18 08:00	KNC	TAL KNX
Step 1	Analysis	6010B SEP		4			18398	02/22/18 11:59	KNC	TAL KNX
	Instrument ID: DUO									
Step 2	SEP	Carbonate			5.000 g	25 mL	18209	02/16/18 08:00	KNC	TAL KNX

Client Sample ID: CCASR-03-T

Date Collected: 01/31/18 13:00
Date Received: 02/03/18 08:45

Lab Sample ID: 140-10636-4
Matrix: Solid
Percent Solids: 86.7

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 2	Prep	3010A			5 mL	50 mL	18242	02/19/18 08:00	KNC	TAL KNX
Step 2	Analysis	6010B SEP		3			18398	02/22/18 12:56	KNC	TAL KNX
	Instrument ID: DUO									
Step 3	SEP	Non-Crystalline			5.000 g	25 mL	18243	02/19/18 08:00	KNC	TAL KNX
Step 3	Prep	3010A			5 mL	50 mL	18290	02/20/18 08:00	KNC	TAL KNX
Step 3	Analysis	6010B SEP		1			18398	02/22/18 13:51	KNC	TAL KNX
	Instrument ID: DUO									
Step 4	SEP	Metal Hydroxide			5.000 g	25 mL	18291	02/20/18 08:00	KNC	TAL KNX
Step 4	Prep	3010A			5 mL	50 mL	18328	02/21/18 08:00	KNC	TAL KNX
Step 4	Analysis	6010B SEP		1			18398	02/22/18 14:46	KNC	TAL KNX
	Instrument ID: DUO									
Step 5	SEP	Organic-Bound			5.000 g	75 mL	18329	02/21/18 08:00	KNC	TAL KNX
Step 5	Prep	3010A			5 mL	50 mL	18370	02/22/18 08:00	KNC	TAL KNX
Step 5	Analysis	6010B SEP		5			18463	02/26/18 11:41	KNC	TAL KNX
	Instrument ID: DUO									
Step 6	SEP	Acid/Sulfide			5.000 g	250 mL	18371	02/22/18 08:00	KNC	TAL KNX
Step 6	Analysis	6010B SEP		1			18463	02/26/18 12:36	KNC	TAL KNX
	Instrument ID: DUO									
Step 7	Prep	Residual			1.000 g	50 mL	18392	02/23/18 08:00	KNC	TAL KNX
Step 7	Analysis	6010B SEP		1			18463	02/26/18 13:32	KNC	TAL KNX
	Instrument ID: DUO									
Step 7	Prep	Residual			1.000 g	50 mL	18392	02/23/18 08:00	KNC	TAL KNX
Step 7	Analysis	6010B SEP		10			18463	02/26/18 15:19	KNC	TAL KNX
	Instrument ID: DUO									
Step 7	Prep	Residual			1.000 g	50 mL	18392	02/23/18 08:00	KNC	TAL KNX
Step 7	Analysis	6010B SEP		2			18463	02/26/18 16:34	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Method Blank

Date Collected: N/A
Date Received: N/A

Lab Sample ID: MB 140-18118/7-A
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	Total			1.000 g	50 mL	18118	02/15/18 08:00	KNC	TAL KNX
Total/NA	Analysis	6010B		1			18463	02/26/18 13:52	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Method Blank

Date Collected: N/A
Date Received: N/A

Lab Sample ID: MB 140-18119/6-B ^4
Matrix: Solid

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 1	SEP	Exchangeable			5.000 g	25 mL	18119	02/15/18 08:00	KNC	TAL KNX
Step 1	Prep	3010A			5 mL	50 mL	18208	02/16/18 08:00	KNC	TAL KNX

Client Sample ID: Method Blank
Lab Sample ID: MB 140-18119/6-B ^4
Date Collected: N/A
Matrix: Solid
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 1	Analysis	6010B SEP		4			18398	02/22/18 11:24	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Method Blank
Lab Sample ID: MB 140-18209/6-B ^3
Date Collected: N/A
Matrix: Solid
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 2	SEP	Carbonate			5.000 g	25 mL	18209	02/16/18 08:00	KNC	TAL KNX
Step 2	Prep	3010A			5 mL	50 mL	18242	02/19/18 08:00	KNC	TAL KNX
Step 2	Analysis	6010B SEP		3			18398	02/22/18 12:19	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Method Blank
Lab Sample ID: MB 140-18243/6-B
Date Collected: N/A
Matrix: Solid
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 3	SEP	Non-Crystalline			5.000 g	25 mL	18243	02/19/18 08:00	KNC	TAL KNX
Step 3	Prep	3010A			5 mL	50 mL	18290	02/20/18 08:00	KNC	TAL KNX
Step 3	Analysis	6010B SEP		1			18398	02/22/18 13:16	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Method Blank
Lab Sample ID: MB 140-18291/6-B
Date Collected: N/A
Matrix: Solid
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 4	SEP	Metal Hydroxide			5.000 g	25 mL	18291	02/20/18 08:00	KNC	TAL KNX
Step 4	Prep	3010A			5 mL	50 mL	18328	02/21/18 08:00	KNC	TAL KNX
Step 4	Analysis	6010B SEP		1			18398	02/22/18 14:11	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Method Blank
Lab Sample ID: MB 140-18329/6-B ^5
Date Collected: N/A
Matrix: Solid
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 5	SEP	Organic-Bound			5.000 g	75 mL	18329	02/21/18 08:00	KNC	TAL KNX
Step 5	Prep	3010A			5 mL	50 mL	18370	02/22/18 08:00	KNC	TAL KNX
Step 5	Analysis	6010B SEP		5			18463	02/26/18 11:05	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Method Blank
Lab Sample ID: MB 140-18371/6-A
Date Collected: N/A
Matrix: Solid
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 6	SEP	Acid/Sulfide			5.000 g	250 mL	18371	02/22/18 08:00	KNC	TAL KNX
Step 6	Analysis	6010B SEP		1			18463	02/26/18 12:01	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Method Blank
Lab Sample ID: MB 140-18392/6-A
Date Collected: N/A
Matrix: Solid
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 7	Prep	Residual			1.000 g	50 mL	18392	02/23/18 08:00	KNC	TAL KNX
Step 7	Analysis	6010B SEP		1			18463	02/26/18 12:56	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Lab Control Sample
Lab Sample ID: LCS 140-18118/8-A
Date Collected: N/A
Matrix: Solid
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	Total			1.000 g	50 mL	18118	02/15/18 08:00	KNC	TAL KNX
Total/NA	Analysis	6010B		1			18463	02/26/18 13:57	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Lab Control Sample
Lab Sample ID: LCS 140-18119/7-B ^5
Date Collected: N/A
Matrix: Solid
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 1	SEP	Exchangeable			5.000 g	25 mL	18119	02/15/18 08:00	KNC	TAL KNX
Step 1	Prep	3010A			5 mL	50 mL	18208	02/16/18 08:00	KNC	TAL KNX
Step 1	Analysis	6010B SEP		5			18398	02/22/18 11:30	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Lab Control Sample
Lab Sample ID: LCS 140-18209/7-B ^5
Date Collected: N/A
Matrix: Solid
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 2	SEP	Carbonate			5.000 g	25 mL	18209	02/16/18 08:00	KNC	TAL KNX
Step 2	Prep	3010A			5 mL	50 mL	18242	02/19/18 08:00	KNC	TAL KNX
Step 2	Analysis	6010B SEP		5			18398	02/22/18 12:25	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Lab Control Sample **Lab Sample ID: LCS 140-18243/7-B**
Date Collected: N/A **Matrix: Solid**
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 3	SEP	Non-Crystalline			5.000 g	25 mL	18243	02/19/18 08:00	KNC	TAL KNX
Step 3	Prep	3010A			5 mL	50 mL	18290	02/20/18 08:00	KNC	TAL KNX
Step 3	Analysis	6010B SEP		1			18398	02/22/18 13:21	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Lab Control Sample **Lab Sample ID: LCS 140-18291/7-B**
Date Collected: N/A **Matrix: Solid**
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 4	SEP	Metal Hydroxide			5.000 g	25 mL	18291	02/20/18 08:00	KNC	TAL KNX
Step 4	Prep	3010A			5 mL	50 mL	18328	02/21/18 08:00	KNC	TAL KNX
Step 4	Analysis	6010B SEP		1			18398	02/22/18 14:16	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Lab Control Sample **Lab Sample ID: LCS 140-18329/7-B ^5**
Date Collected: N/A **Matrix: Solid**
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 5	SEP	Organic-Bound			5.000 g	75 mL	18329	02/21/18 08:00	KNC	TAL KNX
Step 5	Prep	3010A			5 mL	50 mL	18370	02/22/18 08:00	KNC	TAL KNX
Step 5	Analysis	6010B SEP		5			18463	02/26/18 11:10	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Lab Control Sample **Lab Sample ID: LCS 140-18371/7-A**
Date Collected: N/A **Matrix: Solid**
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 6	SEP	Acid/Sulfide			5.000 g	250 mL	18371	02/22/18 08:00	KNC	TAL KNX
Step 6	Analysis	6010B SEP		1			18463	02/26/18 12:06	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Lab Control Sample **Lab Sample ID: LCS 140-18392/7-A**
Date Collected: N/A **Matrix: Solid**
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 7	Prep	Residual			1.000 g	50 mL	18392	02/23/18 08:00	KNC	TAL KNX
Step 7	Analysis	6010B SEP		1			18463	02/26/18 13:01	KNC	TAL KNX
	Instrument ID: DUO									

Lab Chronicle

Client: HDR Inc
Project/Site: Corpus Christi ASR Program (SEP)

TestAmerica Job ID: 140-10636-1

Client Sample ID: Lab Control Sample Dup
Lab Sample ID: LCSD 140-18118/9-A
Date Collected: N/A
Matrix: Solid
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	Total			1.000 g	50 mL	18118	02/15/18 08:00	KNC	TAL KNX
Total/NA	Analysis	6010B		1			18463	02/26/18 14:02	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Lab Control Sample Dup
Lab Sample ID: LCSD 140-18119/8-B ^5
Date Collected: N/A
Matrix: Solid
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 1	SEP	Exchangeable			5.000 g	25 mL	18119	02/15/18 08:00	KNC	TAL KNX
Step 1	Prep	3010A			5 mL	50 mL	18208	02/16/18 08:00	KNC	TAL KNX
Step 1	Analysis	6010B SEP		5			18398	02/22/18 11:35	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Lab Control Sample Dup
Lab Sample ID: LCSD 140-18209/8-B ^5
Date Collected: N/A
Matrix: Solid
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 2	SEP	Carbonate			5.000 g	25 mL	18209	02/16/18 08:00	KNC	TAL KNX
Step 2	Prep	3010A			5 mL	50 mL	18242	02/19/18 08:00	KNC	TAL KNX
Step 2	Analysis	6010B SEP		5			18398	02/22/18 12:30	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Lab Control Sample Dup
Lab Sample ID: LCSD 140-18243/8-B
Date Collected: N/A
Matrix: Solid
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 3	SEP	Non-Crystalline			5.000 g	25 mL	18243	02/19/18 08:00	KNC	TAL KNX
Step 3	Prep	3010A			5 mL	50 mL	18290	02/20/18 08:00	KNC	TAL KNX
Step 3	Analysis	6010B SEP		1			18398	02/22/18 13:26	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Lab Control Sample Dup
Lab Sample ID: LCSD 140-18291/8-B
Date Collected: N/A
Matrix: Solid
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 4	SEP	Metal Hydroxide			5.000 g	25 mL	18291	02/20/18 08:00	KNC	TAL KNX
Step 4	Prep	3010A			5 mL	50 mL	18328	02/21/18 08:00	KNC	TAL KNX
Step 4	Analysis	6010B SEP		1			18398	02/22/18 14:21	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Lab Control Sample Dup
Lab Sample ID: LCSD 140-18329/8-B ^5
Date Collected: N/A
Matrix: Solid
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 5	SEP	Organic-Bound			5.000 g	75 mL	18329	02/21/18 08:00	KNC	TAL KNX
Step 5	Prep	3010A			5 mL	50 mL	18370	02/22/18 08:00	KNC	TAL KNX
Step 5	Analysis	6010B SEP		5			18463	02/26/18 11:16	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Lab Control Sample Dup
Lab Sample ID: LCSD 140-18371/8-A
Date Collected: N/A
Matrix: Solid
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 6	SEP	Acid/Sulfide			5.000 g	250 mL	18371	02/22/18 08:00	KNC	TAL KNX
Step 6	Analysis	6010B SEP		1			18463	02/26/18 12:11	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: Lab Control Sample Dup
Lab Sample ID: LCSD 140-18392/8-A
Date Collected: N/A
Matrix: Solid
Date Received: N/A

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 7	Prep	Residual			1.000 g	50 mL	18392	02/23/18 08:00	KNC	TAL KNX
Step 7	Analysis	6010B SEP		1			18463	02/26/18 13:06	KNC	TAL KNX
	Instrument ID: DUO									

Client Sample ID: CCASR-01-U
Lab Sample ID: 140-10636-1 DU
Date Collected: 12/14/17 16:28
Matrix: Solid
Date Received: 02/03/18 08:45

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Analysis	Moisture		1			17912	02/05/18 15:21	BKD	TAL KNX
	Instrument ID: NOEQUIP									

Client Sample ID: CCASR-01-U
Lab Sample ID: 140-10636-1 DU
Date Collected: 12/14/17 16:28
Matrix: Solid
Date Received: 02/03/18 08:45
Percent Solids: 92.5

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Total/NA	Prep	Total			1.000 g	50 mL	18118	02/15/18 08:00	KNC	TAL KNX
Total/NA	Analysis	6010B		1			18463	02/26/18 14:18	KNC	TAL KNX
	Instrument ID: DUO									
Total/NA	Prep	Total			1.000 g	50 mL	18118	02/15/18 08:00	KNC	TAL KNX
Total/NA	Analysis	6010B		10			18463	02/26/18 15:49	KNC	TAL KNX
	Instrument ID: DUO									
Step 1	SEP	Exchangeable			5.000 g	25 mL	18119	02/15/18 08:00	KNC	TAL KNX

Client Sample ID: CCASR-01-U
Lab Sample ID: 140-10636-1 DU
Date Collected: 12/14/17 16:28
Matrix: Solid
Date Received: 02/03/18 08:45
Percent Solids: 92.5

Prep Type	Batch Type	Batch Method	Run	Dil Factor	Initial Amount	Final Amount	Batch Number	Prepared or Analyzed	Analyst	Lab
Step 1	Prep	3010A			5 mL	50 mL	18208	02/16/18 08:00	KNC	TAL KNX
Step 1	Analysis	6010B SEP		4			18398	02/22/18 11:44	KNC	TAL KNX
	Instrument ID: DUO									
Step 2	SEP	Carbonate			5.000 g	25 mL	18209	02/16/18 08:00	KNC	TAL KNX
Step 2	Prep	3010A			5 mL	50 mL	18242	02/19/18 08:00	KNC	TAL KNX
Step 2	Analysis	6010B SEP		3			18398	02/22/18 12:40	KNC	TAL KNX
	Instrument ID: DUO									
Step 3	SEP	Non-Crystalline			5.000 g	25 mL	18243	02/19/18 08:00	KNC	TAL KNX
Step 3	Prep	3010A			5 mL	50 mL	18290	02/20/18 08:00	KNC	TAL KNX
Step 3	Analysis	6010B SEP		1			18398	02/22/18 13:36	KNC	TAL KNX
	Instrument ID: DUO									
Step 4	SEP	Metal Hydroxide			5.000 g	25 mL	18291	02/20/18 08:00	KNC	TAL KNX
Step 4	Prep	3010A			5 mL	50 mL	18328	02/21/18 08:00	KNC	TAL KNX
Step 4	Analysis	6010B SEP		1			18398	02/22/18 14:31	KNC	TAL KNX
	Instrument ID: DUO									
Step 5	SEP	Organic-Bound			5.000 g	75 mL	18329	02/21/18 08:00	KNC	TAL KNX
Step 5	Prep	3010A			5 mL	50 mL	18370	02/22/18 08:00	KNC	TAL KNX
Step 5	Analysis	6010B SEP		5			18463	02/26/18 11:26	KNC	TAL KNX
	Instrument ID: DUO									
Step 6	SEP	Acid/Sulfide			5.000 g	250 mL	18371	02/22/18 08:00	KNC	TAL KNX
Step 6	Analysis	6010B SEP		1			18463	02/26/18 12:21	KNC	TAL KNX
	Instrument ID: DUO									
Step 7	Prep	Residual			1.000 g	50 mL	18392	02/23/18 08:00	KNC	TAL KNX
Step 7	Analysis	6010B SEP		1			18463	02/26/18 13:16	KNC	TAL KNX
	Instrument ID: DUO									
Step 7	Prep	Residual			1.000 g	50 mL	18392	02/23/18 08:00	KNC	TAL KNX
Step 7	Analysis	6010B SEP		10			18463	02/26/18 15:04	KNC	TAL KNX
	Instrument ID: DUO									

Laboratory References:

TAL KNX = TestAmerica Knoxville, 5815 Middlebrook Pike, Knoxville, TN 37921, TEL (865)291-3000

Laboratory: TestAmerica Knoxville

All accreditations/certifications held by this laboratory are listed. Not all accreditations/certifications are applicable to this report.

Authority	Program	EPA Region	Identification Number	Expiration Date
	AFCEE		N/A	
ANAB	DoD ELAP		L2311	02-13-19
Arkansas DEQ	State Program	6	88-0688	06-16-18
California	State Program	9	2423	06-30-18
Colorado	State Program	8	TN00009	02-28-19
Connecticut	State Program	1	PH-0223	09-30-19
Florida	NELAP	4	E87177	06-30-18
Georgia	State Program	4	906	04-13-20
Hawaii	State Program	9	N/A	04-13-18
Kansas	NELAP	7	E-10349	10-31-18
Kentucky (DW)	State Program	4	90101	12-31-18
Louisiana	NELAP	6	83979	06-30-18
Louisiana (DW)	NELAP	6	LA160005	12-31-18
Maryland	State Program	3	277	03-31-19
Michigan	State Program	5	9933	04-13-20
Nevada	State Program	9	TN00009	07-31-18
New Jersey	NELAP	2	TN001	06-30-18
New York	NELAP	2	10781	03-31-18
North Carolina (DW)	State Program	4	21705	07-31-18
North Carolina (WW/SW)	State Program	4	64	12-31-18
Ohio VAP	State Program	5	CL0059	11-22-18
Oklahoma	State Program	6	9415	08-31-18
Oregon	NELAP	10	TNI0189	01-01-19
Pennsylvania	NELAP	3	68-00576	12-31-18
Tennessee	State Program	4	2014	04-13-20
Texas	NELAP	6	T104704380-16-9	08-31-18
US Fish & Wildlife	Federal		LE-058448-0	07-31-18
USDA	Federal		P330-13-00262	08-20-19
Utah	NELAP	8	TN00009	07-31-18
Virginia	NELAP	3	460176	09-14-18
Washington	State Program	10	C593	01-19-19
West Virginia (DW)	State Program	3	9955C	12-31-18
West Virginia DEP	State Program	3	345	04-30-18
Wisconsin	State Program	5	998044300	08-31-18

Method Summary

Client: HDR Inc
Project/Site: Corpus Christi ASR Program (SEP)

TestAmerica Job ID: 140-10636-1

Method	Method Description	Protocol	Laboratory
6010B	SEP Metals (ICP) - Total	SW846	TAL KNX
6010B SEP	SEP Metals (ICP)	SW846	TAL KNX
Moisture	Percent Moisture	EPA	TAL KNX

Protocol References:

EPA = US Environmental Protection Agency

SW846 = "Test Methods For Evaluating Solid Waste, Physical/Chemical Methods", Third Edition, November 1986 And Its Updates.

Laboratory References:

TAL KNX = TestAmerica Knoxville, 5815 Middlebrook Pike, Knoxville, TN 37921, TEL (865)291-3000

TestAmerica St. Louis
13715 Rider Trail North
Earth City, MO 63045
Phone: 314.298.8566 Fax: 314.298.8757

Chain of Custody Record

200184

TestAmerica
THE LEADER IN ENVIRONMENTAL TESTING
TestAmerica Laboratories, Inc.
TAL-8210 (0713)

Regulatory Program: ☐ DW ☐ NPDES ☐ RCRA ☑ Other: Core Sampling

Client Contact			
Company Name: HDR Engineering Inc.	Project Manager: Kristi Shaw	Site Contact: Ivan Vania	Date: 1/31/18
Address: 4401 West Gate Blvd, Suite 400	Tel/Fax: 512-912-5118	Lab Contact: 314-298-8566	Carrier:
City/State/Zip: Austin, TX 78722	Analysis Turnaround Time: ☐ CALENDAR DAYS ☐ WORKING DAYS		
Phone: 512-912-5118	TAT if different from Below ______		
Fax: 512-912-5158	☐ 2 weeks		
Project Name: Corpus Christi ASR Program	☐ 1 week		
Site: Site 1 + Site 3	☐ 2 days		
P O #	☐ 1 day		

COC No: 1 of 1 COCs
Sampler: JSK
For Lab Use Only:
Walk-in Client:
Lab Sampling:
Job / SDG No.:

Sample Identification	Sample Date	Sample Time	Sample Type (C=Comp, G=Grab)	Matrix	# of Cont.	Filtered Sample (Y / N)	Perform MS / MSD (Y / N)	6020A(3050/6010)	6108 SEP	Sample Specific Notes:
CCASR-01-V	12/14/17	16:28	C	soil/core	2	N	N	✓	✓	*For Ivan Vania*
CCASR-01-L	1/5/18	13:00	C	soil/core	2	N	N	✓	✓	*Sample Methods:
CCASR-03-A	1/31/18	13:00	C	soil/core	2	N	N	✓	✓	•SEP/6010:
CCASR-03-T	1/31/18	13:00	C	soil/core	2	N	N	✓	✓	As, ~~U~~, Pb, Cu, Cr, Se
CCASR-01-L Drilling Mud (only Ivan)	1/5/18	13:00	C	mud	1	N	N	✓		Fe, Al, Mn, Mg
										•3050/6010:
Custody seals intact										As, U, Pb, Cu, Cr,
Received at AT 0.1/CT 0.0°C										Se, Al, Fe, Mg, Mn
BKD 2-3-18										
1 cooler FedEx# 7048632353818 SAT										

140-10636 Chain of Custody

Preservation Used: 1= Ice, 2= HCl; 3= H2SO4; 4=HNO3; 5=NaOH; 6= Other

Possible Hazard Identification:
Are any samples from a listed EPA Hazardous Waste? Please List any EPA Waste Codes for the sample in the Comments Section if the lab is to dispose of the sample.
☐ Non-Hazard ☐ Flammable ☐ Skin Irritant ☐ Poison B ☐ Unknown

Sample Disposal (A fee may be assessed if samples are retained longer than 1 month)
☑ Return to Client ☐ Disposal by Lab ☐ Archive for ______ Months

Special Instructions/QC Requirements & Comments:
Please call with any questions. Ship 1 bottle per sample to John Reynolds - TA Knoxville per 1/2/18 email.

Custody Seals Intact: ☐ Yes ☐ No | Custody Seal No.: | Cooler Temp. (°C): Obs'd: ____ Corr'd: ____ Therm ID No.: ____

Relinquished by:	Company:	Date/Time:	Received by:	Company:	Date/Time:
			B	TA	2/2/18 0920
B	TA	2/2/18 1700	[signature]	TA-KNX	2-3-18 08:45
			Received in Laboratory by:		

* Shipped 1-250h to Knoxville Lab

Loc: 140
10636

TESTAMERICA KNOXVILLE SAMPLE RECEIPT/CONDITION UPON RECEIPT ANOMALY CHECKLIST

Log In Number:

Review Items	Yes	No	NA	If No, what was the problem?	Comments/Actions Taken
1. Are the shipping containers intact?	✓			☐ Containers, Broken	8, CCASR-01-L DRILLING MUD
2. Were ambient air containers received intact?			✓	☐ Checked in lab	
3. The coolers/containers custody seal if present, is it intact?	✓			☐ Yes ☐ NA	
4. Is the cooler temperature within limits? (> freezing temp. of water to 6 °C, VOST: 10°C) Thermometer ID : 5665 Correction factor: -0.1°c	✓			☐ Cooler Out of Temp, Client Contacted, Proceed/Cancel ☐ Cooler Out of Temp, Same Day Receipt	
5. Were all of the sample containers received intact?	✓			☐ Containers, Broken	
6. Were samples received in appropriate containers?	✓			☐ Containers, Improper; Client Contacted; Proceed/Cancel	
7. Do sample container labels match COC? (IDs, Dates, Times)	✓			☐ COC & Samples Do Not Match ☐ COC Incorrect/Incomplete ☐ COC Not Received	
8. Were all of the samples listed on the COC received?		✓		☐ Sample Received, Not on COC ☑ Sample on COC, Not Received	
9. Is the date/time of sample collection noted?	✓			☐ COC; No Date/Time; Client Contacted	**Labeling Verified by:** **Date:**
10. Was the sampler identified on the COC?	✓			☐ Sampler Not Listed on COC	
11. Is the client and project name/# identified?	✓			☐ COC Incorrect/Incomplete	**pH test strip lot number:**
12. Are tests/parameters listed for each sample?	✓			☐ COC No tests on COC	
13. Is the matrix of the samples noted?	✓			☐ COC Incorrect/Incomplete	
14. Was COC relinquished? (Signed/Dated/Timed)	✓			☐ COC Incorrect/Incomplete	
15. Were samples received within holding time?	✓			☐ Holding Time - Receipt	
16. Were samples received with correct chemical preservative (excluding Encore)?			✓	☐ pH Adjusted, pH Included (See box 16A) ☐ Incorrect Preservative	
17. Were VOA samples received without headspace?			✓	☐ Headspace (VOA only)	
18. Did you check for residual chlorine, if necessary? (e.g. 1613B, 1668) Chlorine test strip lot number:			✓	☐ Residual Chlorine	
19. For 1613B water samples is pH<9?			✓	☐ If no, lab will adjust	
20. For rad samples was sample activity info. Provided?			✓	☐ Project missing info	

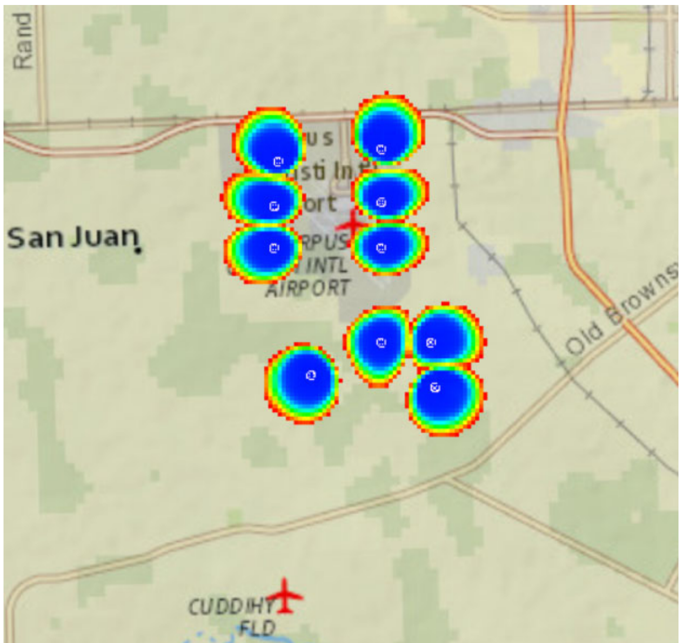
	Box 16A: pH Preservation	Box 18A: Residual Chlorine
Preservative:		
Lot Number:		
Exp Date:		
Analyst:		
Date:		
Time:		

Project #: PM Instructions:

Sample Receiving Associate: [signature] Date: 2-3-18

QA026R30.doc, 080916

Exhibit F Memo- Field Scale Groundwater Model and Results of ASR Operating Scenario Simulations



Field Scale Groundwater Model and Results of ASR Operating Scenario Simulations- Technical Memorandum

Corpus Christi Aquifer Storage and Recovery Feasibility Study (E16265)

Corpus Christi, Texas

August 29, 2019

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Contents

Tables

Figures

Appendix

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1 Executive Summary

As part of determining ASR feasibility, a field-scale groundwater model was constructed with site-specific data that was collected during the exploratory test drilling program. The model was then used to simulate most likely ASR operational scenarios based on source water availability and future water demands in the vicinity of the project site, as identified through conversations with City Staff and industrial stakeholders. Background on the selected scenarios is summarized in the Appendix.

Six operational usage scenarios were simulated using the groundwater model. The Baseline Scenario was used to establish wellfield configurations with acceptable interference between wells, and to set the recharge intervals based on this assessment. In addition, the overall recharge capacity of the system was assessed based on the constraints in water levels that limited the wellhead pressures to a maximum safe operating condition.

For all scenarios, anticipated chloride and TDS concentrations were based on the measured concentrations from native groundwater and were loaded into model layers. Source water quality of 1,711 mg/L TDS and 579 mg/L chloride measured at the Greenwood WWTP on December 13, 2017 was used to simulate aquifer recharge water quality. Water quality impacts at ASR wells resulting from simulated ASR operations were then evaluated for recovered water during the ASR recharge and recovery cycles while keeping in mind the water quality needs for non-potable industrial use.

All scenarios used the well field configuration and the recharge capacity rates of each well that were established during the baseline scenario. The scenarios identified ASR phases to grow the program more cost effectively according to water need. Phase 1, included in 3 scenarios, consisted of 10 ASR wells located on the airport property. Phase 2 represented a build-out, future condition with an additional 5 ASR wells located on City-owned properties to the east and southeast (for 15 wells total). Each scenario alternated water recharge and recovery cycles using a combined well recharge rate that limited the wellhead pressures to a maximum of approximately 90 psi and also limited the increase of TDS or chloride concentrations within the recovered water. There may be additional opportunities to develop a third ASR wellfield between Phase 1 and Phase 2 sites, however this was not evaluated in this report because the City does not currently own or lease land in this area.

The recharge and recovery scenarios were configured as such:

Baseline Scenario – Recharge occurs for 5 years, then recovery for 5 months alternating with recharge for 7 months for the next five years for a total simulation period of 10 years and encompassed 5 recharge and recovery cycles.

Scenario A – Recharge occurs for 5 years in the 10- Phase I ASR wells. After the fifth year, the recharged water is recovered for 1.5 years. This cycle is then repeated for a total simulation period of 39 years, which encompasses 6 recharge and recovery cycles.

Scenario B – Recharge occurs for 5 years in the 10- Phase I ASR wells and 5- Phase 2 ASR wells, concurrently. After the fifth year, the recharged water is recovered for 2 years. This cycle is then repeated for a total simulation period of 42 years, which encompasses 6 recharge and recovery cycles.

Scenario C1 – Recharge occurs for 2 years in the 10- Phase I ASR wells. After the second year, the recharged water is recovered for 6 months. This cycle is then repeated for a total simulation period of 15 years, which encompasses 6 recharge and recovery cycles.

Scenario C2 – Recharge occurs for 2 years in the 10- Phase I ASR wells. After the second year, the recharged water is recovered for 9 months. The difference between Scenario C1 and C2 is a longer recovery period for Scenario C2 to determine if recovered water degrades substantially with a slightly longer recovery period when using identical recharge periods. This cycle is then repeated for a total simulation period of 16.5 years, which encompasses 6 recharge and recovery cycles.

Scenario D1 – Recharge occurs for 2 years in the 10- Phase I ASR wells and 5- Phase 2 ASR wells. After the second year, the recharged water is recovered for 6 months. This cycle is then repeated for a total simulation period of 15 years, which encompasses 6 recharge and recovery cycles.

Scenario D2 – Recharge occurs for 2 years in the 10- Phase I ASR wells and 5- Phase 2 ASR wells. After the second year, the recharged water is recovered for 9 months. The difference between Scenario D1 and D2 is a longer recovery period for Scenario D2 to determine if recovered water degrades substantially with a slightly longer recovery period when using identical recharge periods. This cycle is then repeated for a total simulation period of 16.5 years, which encompasses 6 recharge and recovery cycles.

Table 1-1 provides a summary of the results from Scenarios A through D. The baseline scenario was not summarized as it used a different methodology to determine water quality of recovered water and was mainly used to test the model and evaluate the sensitivity of model parameters.

Table 1-1. Summary of Model Scenario Results

	Scenario	A[1]	B[2]	C1[3]	C2[3]	D1[4]	D2[4]
	Number of ASR Wells	10	15	10	10	15	15
	Recharge Cycle Length (Years)	5	5	2	2	2	2
	Recovery Cycle Length (Years)	1.50	2.00	0.50	0.75	0.50	0.75
	Total Recharge (MGD)	4.8	6.6	4.8	4.8	7.3	7.3
	Total Recovery (MGD)	7.9	8.2	7.9	7.9	9.1	9.1
	Greatest Individual Wellhead Pressure (Ft of Water Above Land Surface)	205	211[5]	175	175	205	205
After 1st Recharge / Recovery Cycle	Total Storage Volume (MG)	4,500	6,000	2,050	1,500	3,660	2,830
	TDS (mg/L) of Recovered Water	3,500	3,700	3,450	4,550	3,000	3,900
	Chloride (mg/L) of Recovered Water	1,400	1,550	1,400	1,900	1,200	1,600
After 6 Recharge / Recovery Cycles	Total Storage Volume (MG)	30,500	36,000	12,300	8,000	22,000	17,000
	TDS (mg/L) of Recovered Water	2,100	2,120	1,975	2,450	1,885	2,135
	Chloride (mg/L) of Recovered Water	750	760	705	900	660	775

[1]Constrained to 5 MGD Recharge and 8.4 MGD Recovery or a wellhead pressure (in feet above land surface) of 209 feet

[2]Constrained to 8 MGD Recharge and 10 MGD Recovery or a wellhead pressure (in feet above land surface) of 209 feet

[3]Constrained to 5 MGD Recharge and 9 MGD Recovery or a wellhead pressure (in feet above land surface) of 209 feet

[4]Constrained to 8 MGD Recharge and 10 MGD Recovery or a wellhead pressure (in feet above land surface) of 209 feet

[5]211 feet is acceptable because the top of the storage zone is 400 feet below surface, which allows for a pressure of 100 psi (230 feet)

The key findings from the recharge and recovery scenarios are as follows:

The recharge rate for Scenarios A and B (4.8 MGD and 6.6 MGD, respectively) are near the maximum allowable to maintain wellhead pressures under 90 psi (slightly over for Scenario B). At the end of the first recovery cycle, maximum TDS and chloride values near 4,000 mg/L and 1,600 mg/L, respectively and decrease by nearly half by the last recovery cycle.

Scenario C1 and C2 use the same recharge rate of 4.8 MGD for 2 years (10 wells), but use different length recovery cycles of 6 and 9 months, respectively. Wellhead pressures remain well below the maximum allowable pressures by limiting the recharge below 5 MGD, so recharge rates could be increased if the water is available. At the end of the first recovery cycle, maximum TDS values near 3,500 mg/L at the end of the 6 month recovery cycle and 4,600 mg/L at the end of the 9 month recovery cycle, indicating that the 9 month recovery cycle duration may be too great with only 2 years of aquifer recharge. At the end of the last recovery cycle, the maximum TDS values of the 6 month recovery cycle are about 2,000 mg/L and 2,500 mg/L at the end of the 9 month recovery cycle, indicating that enough water has been put into storage to substantially reduce mixing with higher salinity ambient groundwater. Chloride concentrations show the same trends.

Scenario D1 and D2 use the same recharge rate of 7.3 MGD for 2 years (15 wells), but use different length recovery cycles of 6 and 9 months, respectively. Wellhead pressures remain slightly below the maximum allowable pressures, but are near the maximum allowable. At the end of the first recovery cycle, maximum TDS values near 3,000 mg/L at the end of the 6 month recovery cycle and 4,000 mg/L at the end of the 9 month recovery cycle, indicating that the 9 month recovery cycle duration may be too great with only 2 years of aquifer recharge. At the end of the last recovery cycle, the TDS values of the 6 month and 9 month recovery cycle are about 2,000 mg/L, indicating that enough water has been put into storage to substantially reduce mixing with higher salinity ambient groundwater. Chloride concentrations show the same trends.

In summary, all model simulations show maximum TDS and chlorides in the recovered water to be below 5,000 mg/L and 2,000 mg/L, respectively, within during the timeframes simulated. However, scenario C2 was closest to the maximum concentrations considered and likely would have exceeded the maximum concentrations if the recovery period was a couple of months longer. Generally, wellhead pressure will likely be a bigger limiting factor than TDS and chloride increasing during recovery cycles, unless the concentration threshold is lowered to meet more stringent industrial use standards.

2 Introduction

The Corpus Christi Aquifer Storage and Recovery District (District), with contracting authority through the City of Corpus Christi (City), hired HDR to conduct an investigation of aquifer storage and recovery (ASR) feasibility within the District area. The feasibility study includes exploratory test drilling, geochemical analysis, and groundwater modeling to evaluate the suitability of local aquifers for ASR operations. An exploratory test drilling program was conducted at four City-owned sites located near the Corpus Christi International Airport from October 9, 2017 to May 15, 2018. A geochemical analysis was then performed using data collected during the exploratory test drilling program to determine the compatibility of storing treated effluent from Greenwood Wastewater Treatment Plant (WWTP) or potable water from O.N. Stevens Water Treatment Plant (WTP) within the native aquifer setting. The results of the exploratory test drilling program and geochemical analysis are summarized in technical memorandums issued October 4, 2018 and February 6, 2019, respectively.

As part of determining ASR feasibility, a field-scale groundwater model was constructed using site-specific data collected during the exploratory test drilling program. The model was then used to simulate probable ASR operational scenarios based on source water availability and future water demand needs in the vicinity of the project site, as identified through conversations with City Staff and industrial stakeholders.

This technical memorandum summarizes the conceptual model approach which served as the basis for field-scale groundwater model development, key features of the groundwater model, modeling assumptions, and results of ASR operational scenarios including recovery efficiencies based on native water quality and likely ASR operations.

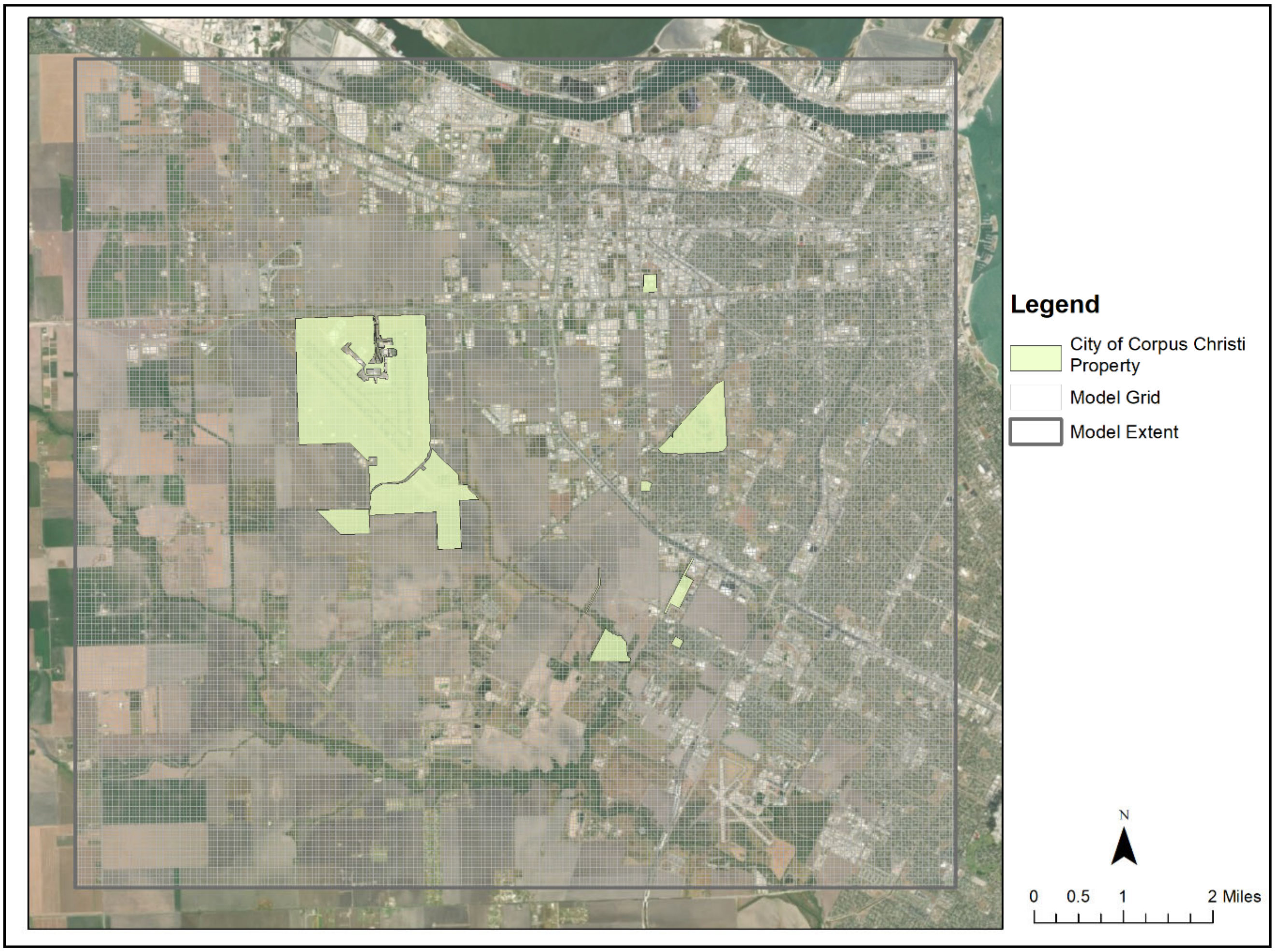
2.1 Model Objectives

The purpose of constructing a groundwater model was to simulate the operation of an ASR well field in the study area based on aquifer parameters determined during the exploratory test drilling program. A groundwater model allows exploration of different wellfield configurations, recharge and production rates, and operational strategies. Key modeling objectives were to determine the maximum overall recharge and recovery rates that could be achieved, and the recoverability and estimated water quality of the recovered water under different operational strategies.

2.2 Study Area

The study area included in the model is located within the boundaries of the Corpus Christi Aquifer Storage and Recovery Conservation District (District) near the center of the City of Corpus Christi city limits in Nueces County. Although the model extends beyond the active ASR study area to address boundary conditions, the ASR wells simulated in the model are located on City-owned properties, at the Corpus Christi international airport and adjoining area, Westhaven Park, and Lozano Golf Course based on findings from the exploratory test drilling program. Figure 2-1 shows the model extent and the City-owned properties.

Figure 2-1. Study Area and Groundwater Model Extent



3 Conceptual Model Development

A conceptual model was developed to summarize major hydrogeologic components of the study area relevant to the development of the groundwater model. The conceptual model focused on hydrostratigraphy, hydraulic properties, and water levels. Hydrostratigraphy includes the location of contiguous sand layers that could form the target storage intervals, and clay layers that could serve to provide vertical confinement. Hydraulic properties of the sand layers (primarily horizontal hydraulic conductivity) control the recharge and production capacity of an ASR well, and the pressure response at a given flow rate. Water levels define the magnitude and direction of the natural groundwater gradient, which can affect recoverability if stored water drifts away from the recharge/production well. Water levels also determine how much recharge pressure can be applied relative to wellhead pressure, and how much drawdown is available for a well during recovery.

3.1 Stratigraphy

A conceptual understanding of the local stratigraphy in the study area was prepared by interpreting geophysical logs from the exploratory test drilling program and additional wells in the vicinity reported in the Texas Water Development Board Brackish Resources Aquifer Characterization System (TWDB BRACS) database to develop cross sections for the area and correlate this information to prepare a hydrostratigraphic surface area for the model to develop model layering.

3.1.1 Geophysical log data and Interpretation

Two primary sources of geophysical log data were available: first, the logs taken as part of the District's exploratory test drilling program and second, other existing logs in or near the study area, primarily from oil and gas exploration.

3.1.1.1 Logs from the Corpus Christi Drilling Program

The four logs that were obtained from the exploratory test drilling program are located in the study area, as described below.

CCASR Well No 1 is located to the southeast of the Corpus Christi International Airport, off of Bear Lane, at coordinates 27°45'29.6"N, 97°29'22.0"W. The borehole was drilled to a total depth of 1203 ft bgs with the sand beds of interest found between 430 ft and 740 ft bgs. A permanent monitoring well was installed at this location.

CCASR Well No 2 is located to the southwest of the Corpus Christi International Airport, off of County Road 34, at coordinates 27°45'49.77"N, 97°30'44.82"W. The borehole was drilled to a total depth of 1203 ft bgs with the sand beds of interest found between 400 ft and 720 ft bgs.

CCASR Well No 3 at the southwest corner of Westhaven Park, off of Cliff Maus Drive, at coordinates 27°45'21.4"N, 97°27'14.6"W. The borehole was drilled to a total depth of 1203 ft bgs with the sand beds of interest found between 450 ft and 780 ft bgs.

CCASR Well No 4 is located to the south of Del Mar College West Campus adjacent to the Gabe Lozano Golf Course, near the intersection of Old Brownsville Rd and Airport Rd, at coordinates 27°46'23.4"N, 97°26'19.6"W. The borehole was drilled to a total depth of 1204 feet with sand beds of interest found between 440 ft and 850 ft bgs.

CCASR Wells 1-3 geophysical logs contained the following geophysical log curves: Gamma, Spontaneous Potential, Resistivity, Caliper, Temperature, and Conductance. CCASR Well No 4 was limited to Gamma, Spontaneous Potential, and Resistivity curves.

3.1.1.2 Logs from Other Sources

Interpretation of the four logs obtained as part of the drilling program formed the basis for identifying potential target storage intervals. However, because the study area extends outside the locations of the exploratory test wells (due to the model grid extent, Section 3.2) it was desirable to find additional logs throughout the study area that could be used to laterally extend stratigraphic interpretations.

Existing geophysical logs in the Gulf Coast are primarily derived from oil and gas exploration. These logs typically start below ground surface (called the top logging interval) and may extend 1,000s of feet below (bottom logging interval). Because we were primarily interested in the first 1,000 feet of geology, those existing logs with a top logging interval at or less than about 900 feet below ground surface (bgs) were not considered for inclusion in the dataset. In addition, logs needed to have two key geophysical log curves, spontaneous potential and resistivity, to allow lithologic interpretation (identification of sand and clay layers) to occur.

Logs from the TWDB BRACS database, and the Bureau of Economic geology that were in the study area were filtered based on top logging interval and geophysical log curve availability. Of those available, 34 logs were selected based on these criteria.

Each geophysical log contains a varying set of geophysical curves, but resistivity curves were common to all the geophysical logs in the study. In total, there are 34 resistivity curves, 30 spontaneous potential curves, 21 conductance curves, 4 gamma ray curves, 3 porosity curves, 1 caliper, and 1 acoustic curve contained in the set. Of the 34 logs, 11 logs had their top logging interval above 100 ft bgs, 15 had their top logging interval between 250 and 500 feet bgs, and the remaining logs had their top logging interval below 500 feet bgs. For those logs with a deep top logging interval, only the deeper portion of the target horizons could be interpreted.

3.1.2 Cross Section Development

A lithostratigraphic approach was taken to characterizing stratigraphy, where sand and clay layers were identified, and correlated between logs. Characterizing stratigraphy in this fashion generally requires the development of cross sections, whereby geophysical logs are lined up side by side with a common vertical datum, and examined to determine whether the sand or clay layers on one log appear to extend to neighboring wells. Correlating sand layers on cross sections in this way allows an assessment of the occurrence and extent of the potential recharge intervals in the study area. Similarly, correlation of the clays provides information about the potential for confinement of those storage intervals above and below.

Identification of sands and clays on geophysical logs required interpretation of resistivity curves. To identify clays, we observed a baseline of resistivity characterized by overlapping resistivity curves and relatively shallow kicks to the right. To identify sands, we marked the tops and bottoms where the resistivity curve appears to move to the right, increasing in resistivity, away from the clay baseline. When a gamma curve was available, such as on the logs obtained from the drilling program, we used the gamma curve to confirm the interpretation of the resistivity curve. Gamma curves generally move to the right in the presence of clay intervals, and to the left in the presence of sand intervals.

Initial interpretation of the sand intervals during the drilling program, based on both drill cuttings and geophysical log interpretation, identified three to four sand intervals that might be suitable for storage. These intervals generally correspond with depths between 400 feet and 1,000 feet bgs. Figure 3-1 shows the location of the four wells drilled during the Phase I exploratory test drilling program and well locations where geophysical logs were available from other sources to form a cross sectional view of the major sand and clay intervals impacting groundwater flow and storage potential in a west to east manner for the study area.

Figure 3-1. Locations of Geophysical Logs and Cross Sections in the Study Area

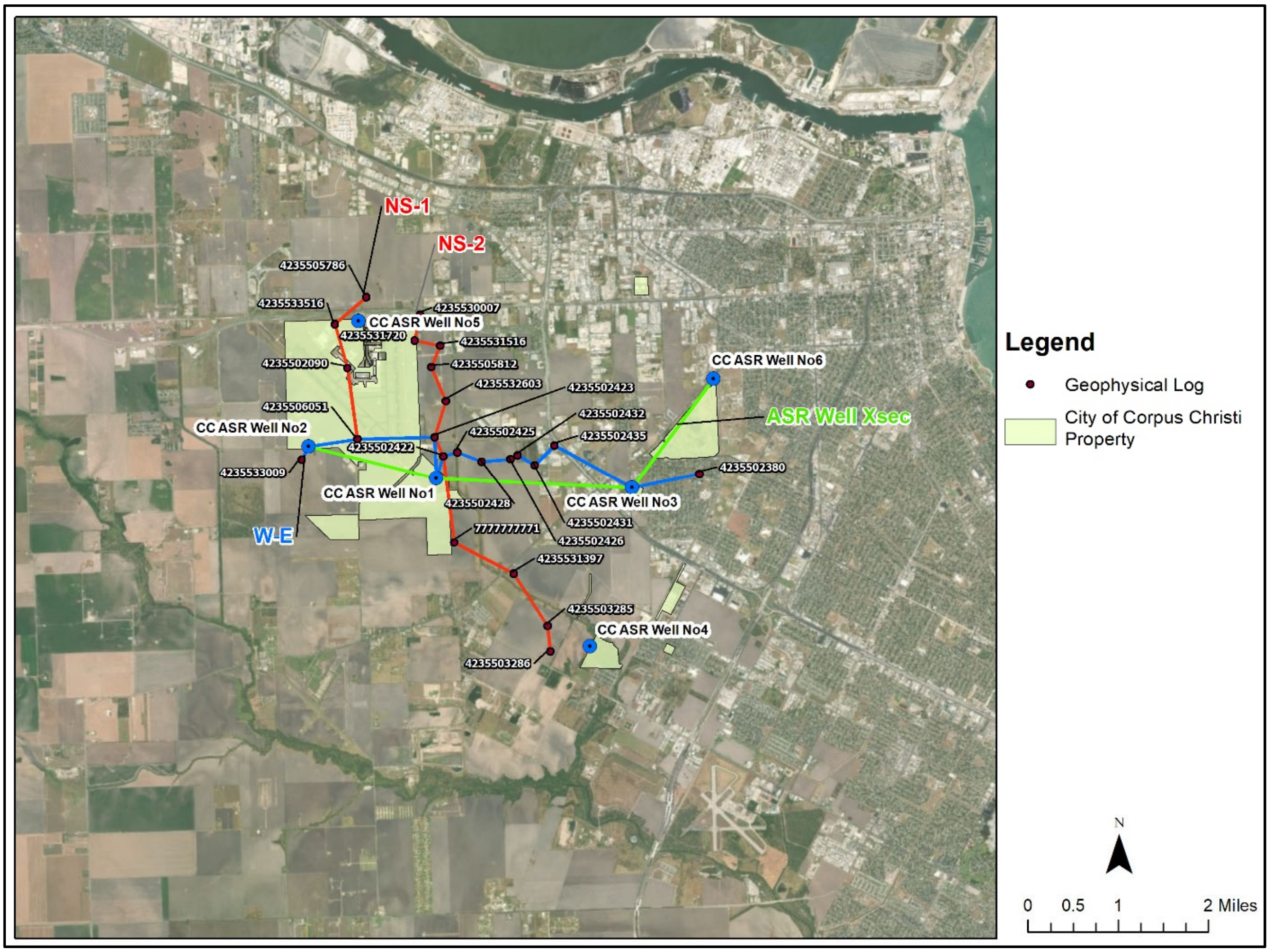


Figure 3-2 shows the ASR Well cross section focused on the four locations evaluated during the exploratory test drilling program from west to east with interpreted sand intervals identified in yellow. The four potential storage intervals are identified in the figure. The first interval is about 400 feet to 450 feet bgs. The second and third intervals run between 525 feet and 700 feet bgs. The fourth interval starts at about 1,000 feet bgs and runs to about 1,050 feet bgs. The sand layers are labeled S1 (shallowest) through S4 (deepest) on the cross section.

In order to develop a model of the full study area, additional existing logs were identified and correlated with the logs from the exploratory test drilling program. The second cross section developed, W-E, included two of the drilling program well logs, and added 11 logs positioned generally from west to east. This cross section is shown in Figure 3-3. Intervals S1 through S3 correlate relatively well across the W-E section. Interval S4, the deepest interval, has poor correlation.

Two additional cross sections (N-S-1 and N-S-2) running north to south were created to help tie together the sand intervals along that axis. These cross sections are shown in Figures 3-4 and 3-5. Because of the relatively deep top logging intervals for some logs on those cross sections, the correlation for N-S-1 was not as robust as for the N-S-2 section. As with the W-E section, S4 does not show strong correlation across logs on the N-S sections.

When considering potential recharge zones, depth is a key factor. Depth typically increases both the cost of construction and the cost of operation for an ASR well. In addition, in the Gulf Coast Aquifer, water quality typically degrades with depth which was confirmed by water quality measurements collected during the field program. These reasons combined with the poor correlation for S4 on the extended cross sections.

Figure 3-2. Cross Section ASR Well Developed Using Logs from the City's Exploratory Test Drilling Program

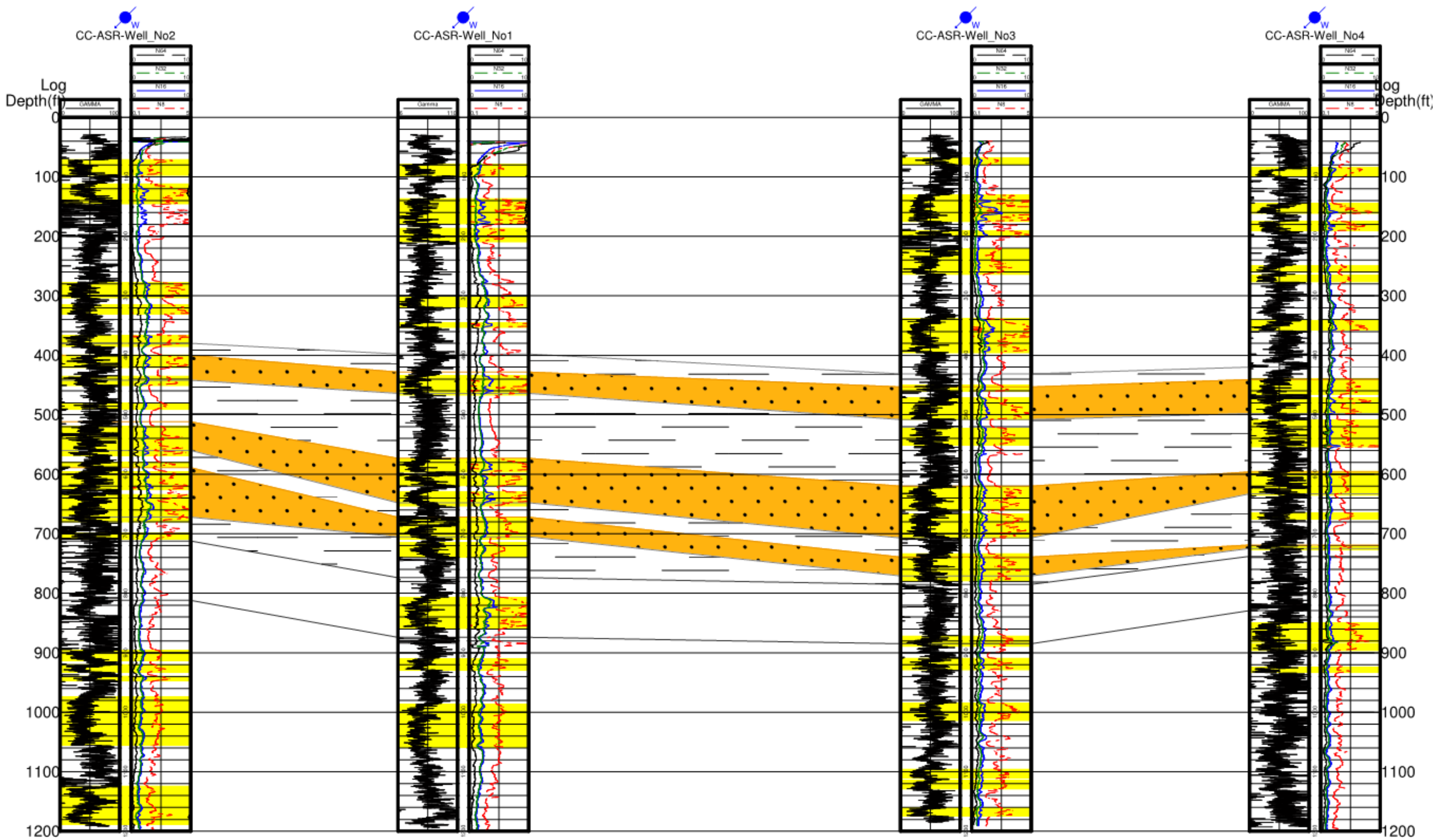


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Figure 3-3. Cross Section W-E-2

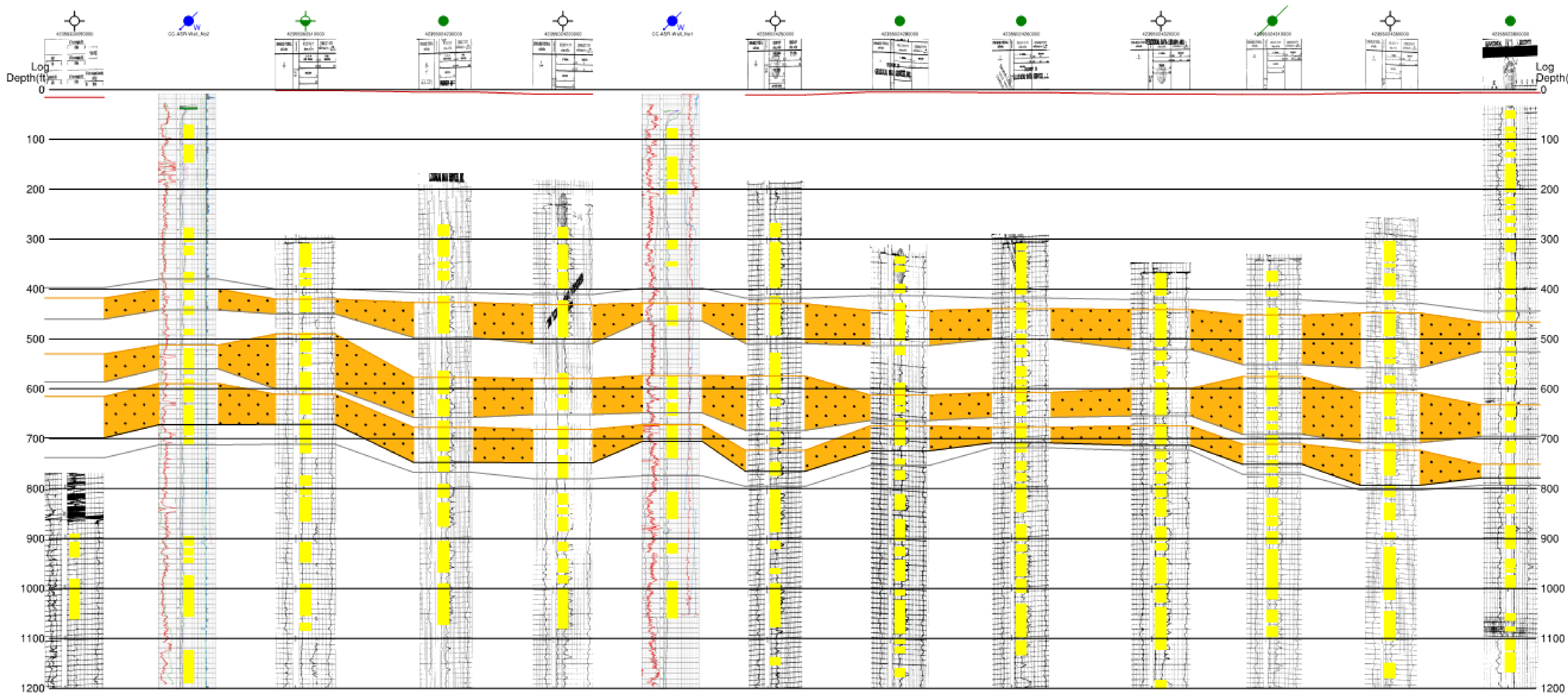

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Figure 3-4. Cross Section N-S-1

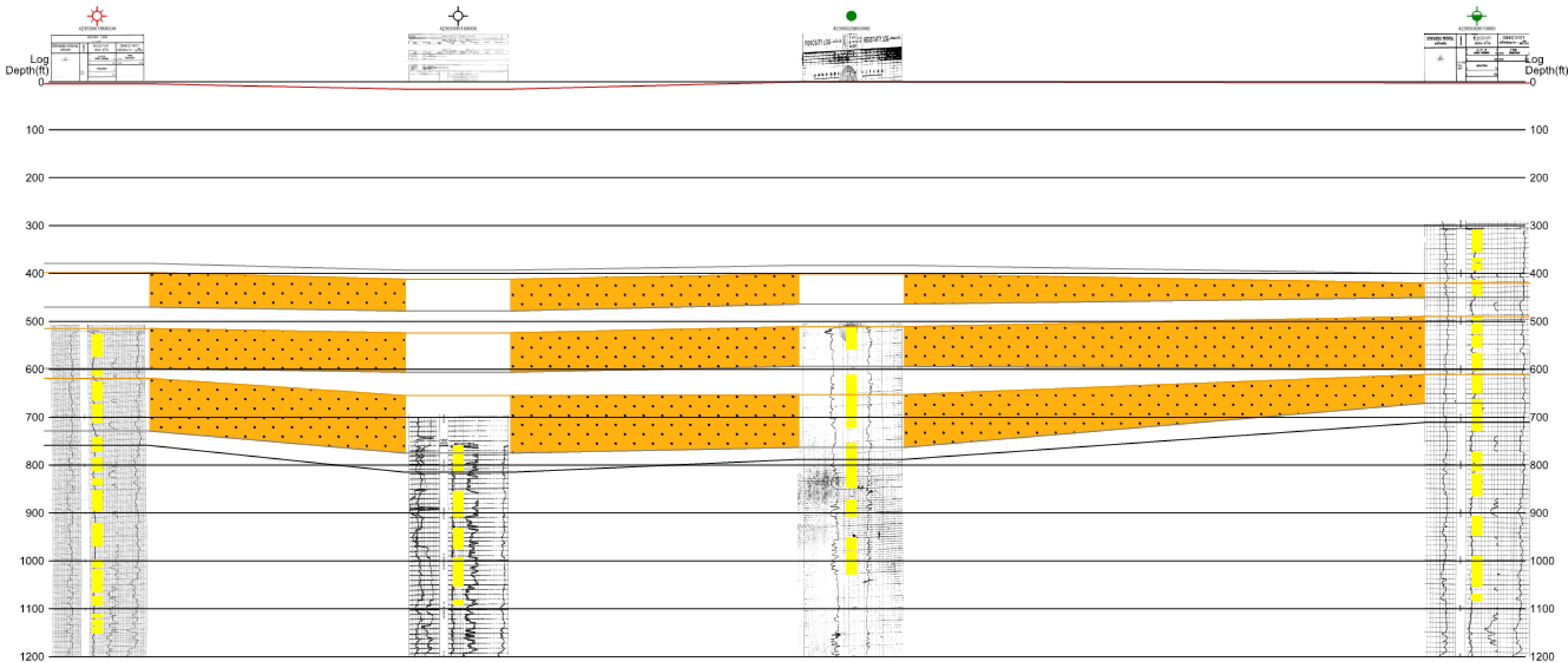

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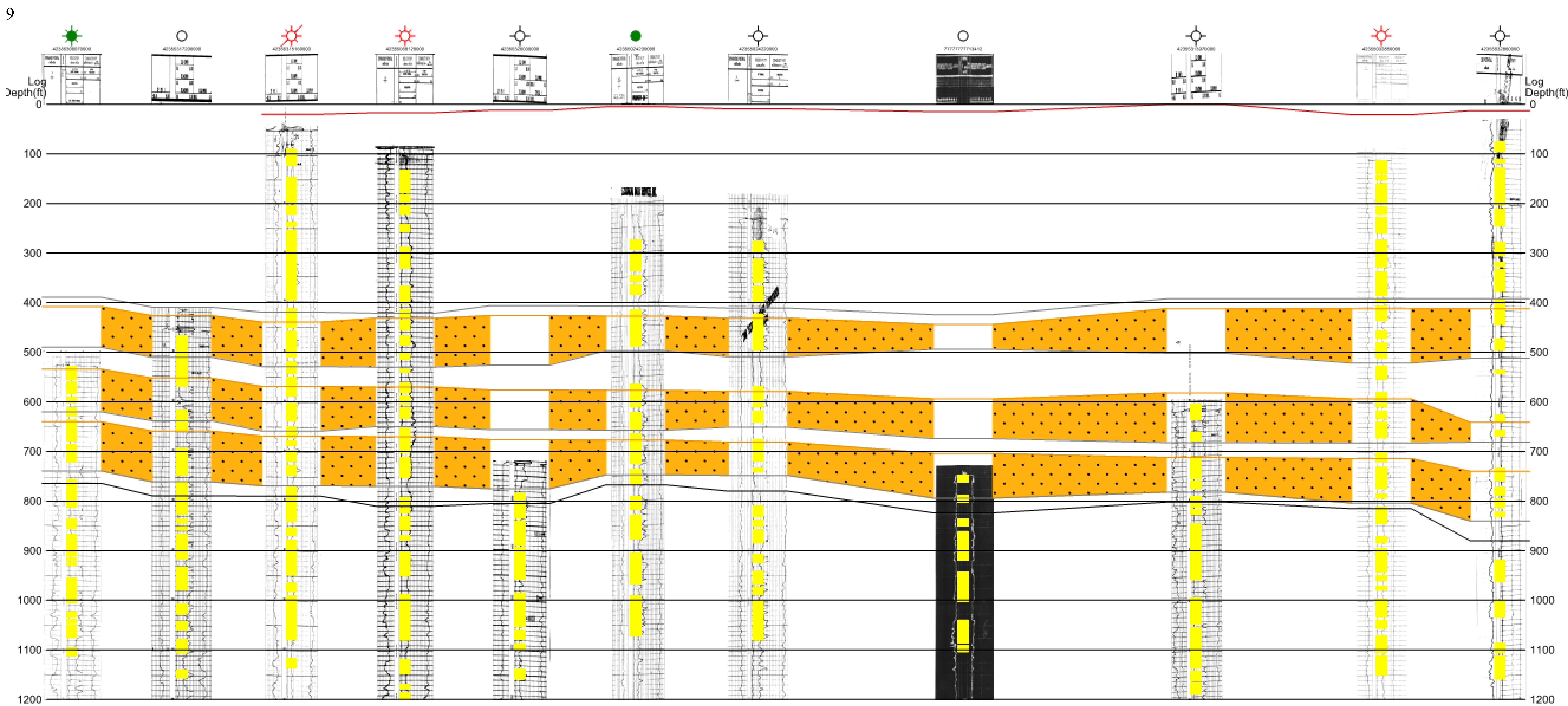
Figure 3-5. Cross Section N-S-2



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3.1.3 Creation of Hydrostratigraphic Surfaces

The results of the cross section correlation was the identification of the top and bottom of S1 – S3 on the 27 logs included in the four cross sections shown in Figures 3-2 to 3-5. In addition, the thickness of the clay intervals above S1 and below S3 were marked on each log.

The top of S1 was interpolated across the study area to form a surface that served as the datum for extending the other intervals. The thickness of each of the intervals was then interpolated across the study area. These thicknesses were then stacked below the top of S1 surface to create continuous surfaces for the tops and bottoms of the other intervals. The surfaces were created based on thickness rather than elevation to allow enforcement of a minimum thickness and avoid inversions. The bottom of S3 was compared to the elevation at each log as QA check for the strategy.

On each cross section (Figures 3-2 to 3-5) the elevation of the top and bottom of the S1 through S3 surfaces is shown overlain on the log signatures. The surface elevations and thicknesses compare favorably with the elevations and thicknesses of the sand packages identified on the logs. This favorable comparison adds confidence that the surfaces can be used as the basis for development of layer structure in the groundwater model, and that the layer structure will be consistent with the intervals S1 through S3 originally identified during the exploratory test drilling program.

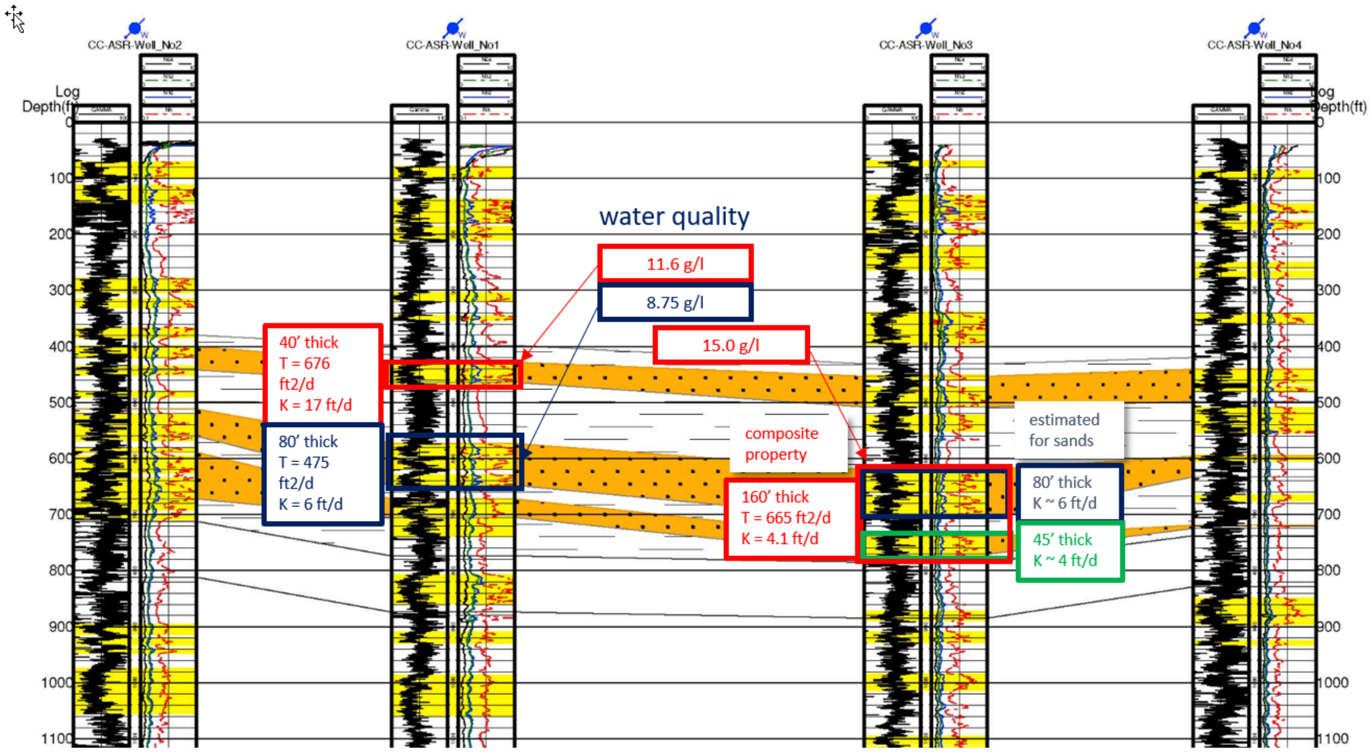
3.2 Hydraulic Properties

3.2.1 Horizontal Hydraulic Conductivity

During the drilling program, three pump tests were performed which provides the basis for estimating hydraulic conductivity for sand intervals S1 – S3. Figure 3-6 shows a summary of the estimated transmissivities and measured TDS concentrations for each of the layers. At CCASR Well No 1 transmissivities were estimated for S1 and S2, while at CCASR Well No 3, transmissivities were estimated for layers S2 and S3 combined. Based on a transmissivity of 676 ft2/d and a thickness of 40 feet, the hydraulic conductivity of S1 at CCASR Well No 1 was estimated to be 17 ft/d. Based on a transmissivity of 475 ft2/d and a thickness of 80 feet, the transmissivity of S2 at CCASR Well No 1 was estimated to be 6 ft/d. The combined transmissivity of S2 and S3 at CCASR Well No 3 was estimated to be 665 ft2/d. If we use the hydraulic conductivity of S2 from CCASR Well No 1 (6 ft/d) and the thickness 80 feet to estimate a transmissivity of 480 ft2/d, then the contribution of S3 to the composite transmissivity is the remaining 185 ft2/d. Dividing by the S3 thickness of 45 feet results in an estimated hydraulic conductivity of 4 ft/d for S3.

The hydraulic conductivity of the clay layers cannot be easily estimated from field tests, because clays are difficult to isolate and produce little water under pumping conditions. The TWDB groundwater availability model that contains the study area (Chowdhury and others, 2004) does not provide an estimate of the horizontal hydraulic conductivity of the clays, because clay layers are not explicitly characterized or simulated. Because clays provide such a small contribution to the horizontal transmissivity, the horizontal hydraulic conductivity of the clays is not typically considered important to the hydraulic response in an aquifer.

Figure 3-6. Summary of Hydraulic Testing and Calculated Hydraulic Conductivities, Along with Interval Water Quality Results



3.2.2 Vertical Hydraulic Conductivity

The vertical hydraulic conductivity of the combined sand-clay bed system was not estimated during the drilling program. Estimating vertical conductivity from a pump test requires nested wells completed in two sand intervals isolated by one or more intervening clay layers, and this configuration was not available. The vertical hydraulic conductivity of the clay layers is important because it is a factor in determining the hydraulic isolation of the sand intervals.

Typical vertical hydraulic conductivities in groundwater models of the Gulf Coast Aquifer range from 0.001 to 0.0001 feet per day in clay-rich units (Young and others, 2016). While the estimated regional composite vertical conductivity in the Chicot Aquifer is typically higher than 0.001 feet/day, this is due to the clay beds not being regionally extensive. Studies have shown the importance of scale in parameterizing groundwater models (e.g. Fogg and others, 1986) because the apparent interconnectedness of the sands or clays changes depending on the representative volume over which they are averaged.

At the ASR project scale (100s to 1000s of feet, rather than 10s of miles), we would expect that identified clay confining beds would act more competently, and have conductivities reflective of clay-rich sediment, rather than mixed sand-clay. Because there is uncertainty in the vertical hydraulic conductivity of the clay beds, we explored the sensitivity of the performance of the ASR to clay vertical conductivity during the predictive modeling (Section 5).

3.2.3 Storage Properties

Because the target ASR storage intervals are in the confined portion of the aquifer at a minimum of 400 feet bls, the confined storage is the most important storage parameter. The specific storage for the Gulf Coast Aquifer is typically simulated as 1.7×10^{-5} at 500 feet of depth (Young and others, 2016). For the S2 unit tested at CCASR Well No 1, storage of 1.3×10^{-4} was calculated at depth of 570 to 600 feet. The unconfined shallow portion of the Chicot Aquifer typically has an estimated specific yield of about 0.05 (Young and others, 2016).

3.3 Water Levels

Water levels were measured during the exploratory test drilling program. At the site of CCASR Well No 1, water levels ranged between 16.4 and 18.9 feet amsl, while water levels at the site of CCASR Well No 3 were just over 20 feet amsl. These corresponded to depths below ground surface of between 12 and 19 feet. A summary of the water level measurements is shown in Table 3.1.

In an attempt to establish a more regional trend in water levels, we extracted and analyzed all measurements in the study area from the TWDB groundwater database. Most of the water level measurements from the TWDB groundwater database were 50 or more years old. In addition, the measurements had few discernable spatial trends, potentially due to effects of pumping during the time the measurements were taken. Give these characteristics, these measurements did not contribute to the assessment.

In general, we would expect water levels to decrease to an elevation close to sea level near the inlet opening to the north. The effect of the canal to the east is unknown. Because in the Gulf Coast Aquifer, water levels generally increase with depth, the ground water levels beneath the free water surface in the inlet may be a few feet more than zero; however, the actual value is unknown.

Given the uncertainties in the data in the study area, we conceptualized water levels to be between 15 and 20 feet amsl west to east across the study area along the line formed between drilling sites 1 and 3. To the north, along the shoreline, we expect water levels to have decreased to between zero and five feet, based on the vertical gradient observed between MW-1S (18.0 feet) and MW-1D (19.0 feet). The distance from the wells to the shorelines to the north is about five miles. So the natural gradient is estimated at about 0.0005 ft/ft in the middle and northern part of the study area, given about 15 feet of decrease over five miles. The gradient in the southern portion of the study area is unknown, but assumed to be similar in magnitude.

Given a gradient of about 0.0005 ft/ft, and the highest measured hydraulic conductivity of 17 ft/d, the darcy velocity of the natural system would be about

0.0085 ft/d, with an interstitial velocity (assuming an effective porosity of about 0.15) of 0.057 ft/d or about 20 feet per year. While this drift distance is small over the course of a year, the natural gradient does have the potential to have some effect on recoverability of long term storage (i.e. 5 years or more).

Table 3-1. Summary of Water Level Measurements from the City's Exploratory Test Drilling Program

Well/Borehole	Date	Below Casing Top (ft)	Below Ground Surface (ft)	Top of Casing (ft amsl)	Land Surface (ft amsl)	Water Level (ft amsl)	Note
TW-1	1/8/18	23.2	15.4	7.8	31.8	16.4	Deep step test
TW-1	12/17/17	22.6	14.8	7.8	31.8	17.0	just prior to intermediate step test
TW-1	12/18/17	22.6	14.8	7.8	31.8	17.0	just prior to intermediate CR test
MW-1S	10/18/17	16.0	13.0	3.0	31.0	18.0	
MW-1S	12/14/17	15.9	13.0	3.0	31.0	18.0	
MW-1D	12/14/17	17.2	12.1	5.1	31.0	18.9	
TW-3/MW-3	2/16/18	28.0	18.6	9.4	39.0	20.4	step test
TW-3/MW-3	2/17/18	28.2	18.8	9.4	39.0	20.2	CR test

3.4 Native Groundwater Quality

Groundwater in the area is generally thought to be brackish. Water quality samples taken during the exploratory test drilling program are consistent with this observation. Figure 3.6 shows a summary of the intervals measured and the total dissolved solids (TDS) values for the intervals. S1 and S2 in CCASR Well No 1 reported TDS levels of 11,600 mg/L and 8,800 mg/L, respectively. The composite measurement for S2 and S3 in CCASR Well No 3 is 15,000 mg/L. The higher composite TDS at CCASR Well No 3 may be due to spatial variation in water quality, or indicate that S3 is of poorer water quality than S2.

4 Numerical Model Construction

Based on the conceptual model parameters described above, a local, field scale numerical model was constructed to simulate aquifer storage and recovery operations and evaluate aquifer response of recharge and recovery for different schedules and rates.

4.1 Code Selection

To simulate recoverability for an ASR project, both flow and transport must be simulated, so codes were required for both processes.

4.1.1 Flow

The industry standard code for simulating groundwater flow is MODFLOW, which was developed and is maintained by the United States Geological Survey. MODFLOW has several variants in general use, but the most commonly used version at this time is MODFLOW-NWT (Niswonger and others, 2011). This is a version that uses regular grids, but has an improved Newton-Raphson solver. MODFLOW-6, which is the newest version of MODFLOW, was still in beta testing at the time of model construction. MODFLOW-USG, which allows unstructured grids, was not selected because the complexity of an unstructured grid was not required for this application.

4.1.2 Transport

Transport is typically simulated either as advective-only, which considers only the movement of constituents due to the average interstitial velocity or “full transport”, which will typically consider dispersion and potentially diffusion. Because of the potential for dispersion to have an effect on recoverability, due to the mixing that occurs at the edge of the recharge “bubble”, we chose to simulate full transport. The code that is available to simulate full transport using MODFLOW flow fields is MT3DMS (Zheng and Wang, 1999).

4.1.3 Variable Density

Variable density effects can occur during aquifer recharge, at the edge of the buffer zone, where the recharge water is in contact with the brackish native groundwater (Ward and others, 2008). If the native groundwater is significantly denser than the recharge water, then a wedge of native groundwater theoretically may intrude below the recharge water, causing an increase in the size of the mixing zone. In a given storage interval, this effect is difficult to distinguish from the mechanical dispersion that occurs at the leading edge of the recharge water, as native water is displaced. Given the high vertical resolution that would be required to simulated density effects during transport, and the likely masking of these effects by mechanical dispersion, we chose to not explicitly simulate variable density flow in the groundwater model. Additionally, the contrast in densities between ambient brackish groundwater and the slightly brackish recharge water is not great enough to affect water levels significantly to warrant the simulation of variable density flow. We did explore the sensitivity of recoverability to dispersion in the predictive simulations (Section 5).

4.2 Model Grid

4.2.1 Horizontal Extent and Discretization

The extent of the model grid was chosen such that the boundaries would not have a significant effect on the simulation of the ASR wellfield. In order to estimate the required distance, we used an analytic element model to estimate how hydraulic impacts at an ASR well propagated to various distances, assuming the hydraulic properties of S1, which is the most productive sand, and thus the sand where the most extensive cone of depression would form, relative to drawdown at the well. Simulations showed that for 300 feet of drawdown at the well, about 15 feet (5%) of drawdown occurred at a distance 13,000 feet away after the model simulation reached steady-state conditions.

Based on these simulations, we chose 13,000 feet as the "distance boundary" for the model grid. Figure 2-1 shows the model grid extent relative to the study area. The distance from the outer edges of the City of Corpus Christi properties to the edges of the grid is a minimum distance of 13,000 feet.

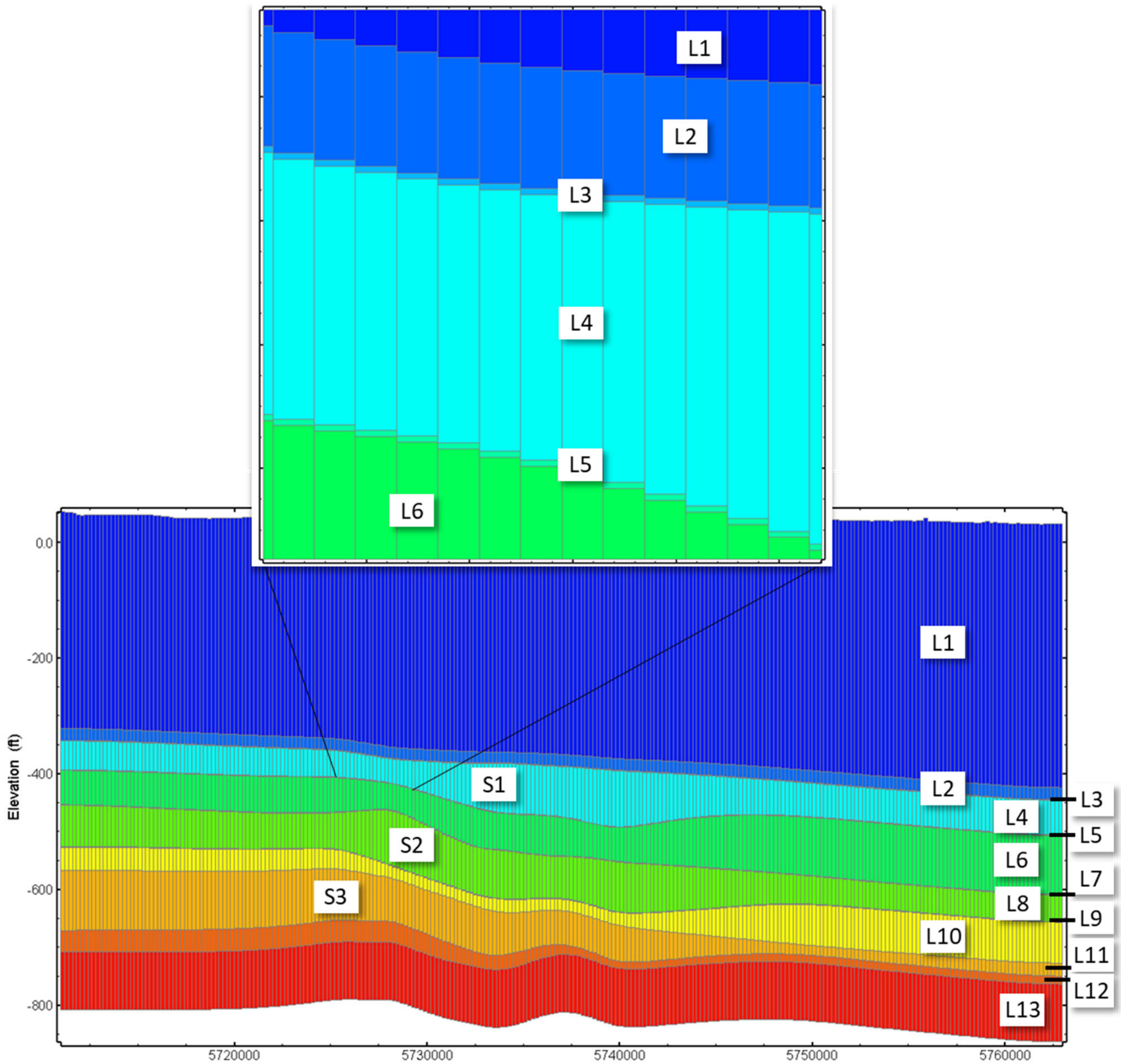
The horizontal grid was discretized using regular 200 foot intervals, so all gridblocks in the model were 200 foot by 200 foot square. We tested a grid with 100 foot square grid cells, but the increased computational burden caused run times to reach several hours, which was not desirable for this application. We further discuss the effect of gridblock size on simulation of mechanical dispersion in Section 4.4.2.

4.2.2 Vertical Extent and Discretization

The vertical extent of the grid started at ground surface, and continued to the deepest clay, occurring below S3, with an additional 100 feet of material below that clay unit. This additional material was added to prevent the bottom of C3 from acting as a no-flow boundary, i.e. it acted as a bottom "distance boundary". In between the top and bottom model layers, seven layers were used to represent the three sand intervals, and four clay units adjacent to those intervals. In addition, one foot thick layers were added between the confining clay layers and the sand intervals. These refined layers have no effect on the hydraulic response of the model, but act to reduce vertical numerical dispersion from the sand intervals to the adjacent layers and vice versa.

The model layering is shown in Figure 4-1, on an example cross section for row 119. The inset shows the refinement adjacent to S1 for the overlying and underlying clay units.

Figure 4-1. Example Cross Section Showing the Vertical Discretization of the Model Grid, Along with Layer Numbering



4.3 Model Boundaries

The model had three types of boundaries: no-flow, general head, and wells (fixed flux). The no-flow boundaries occurred at the top and bottom of the model. Because of the hundreds of feet of sediment between the uppermost recharge interval and land surface, land surface as a no-flow boundary is not expected to impact the results of the ASR simulation. Similarly, the thickness of Layer 13 prevents the no-flow boundary at the bottom from affecting hydraulic response in the recharge intervals.

4.3.1 General Head Boundaries

General head boundaries were used on the perimeter of the model to simulate a continuing aquifer beyond the active model extent. They were implemented using the MODFLOW General Head Boundary (GHB) package. Because the model extent was designed so that hydraulic impacts on the wellfield would not propagate significantly to the boundaries, the general head boundaries do not have much effect at the wellfield during transient simulation. Their importance is in establishing the natural gradient at the start of the simulation, which from Section 3.3 is estimated to be about 0.0005 ft/ft. The natural groundwater gradient effects recoverability because it can cause bubble drift, where the center of mass of the recharge water moves along the natural gradient and away from the ASR well.

The heads in the GHBs were set to simulate the approximate 15 to 20 feet amsl head in the area where the between Sites 1 and 3, as discussed in Section 3.3. The GHBs along the shorelines of the inlet to the north were set to just above 0 feet amsl. The overall gradient achieved in the steady-state heads used to initialize the model is similar to the 0.0005 ft/ft estimated from the water levels taken during the drilling program.

4.3.2 Wells

The ASR wells were simulated using the MODFLOW WEL package. At each ASR well location, wells were simulated in one or more of the recharge intervals. Where multiple recharge intervals were utilized at the same well location, the model represents the multiple ASR wells as co-located but completed in different intervals. Figure 4-2 shows the locations of the simulated ASR wells.

The recharge intervals at each well location were determined based on trial and error, by simulating ASR operations and looking at interference between wells. The final completion intervals are shown in Table 4-1. The recharge and production rates were weighted according to transmissivity for each interval to help balance the hydraulic effects (i.e. the drawdown and uplift) at the wells.

Figure 4-2. Locations of the Simulated ASR Wells

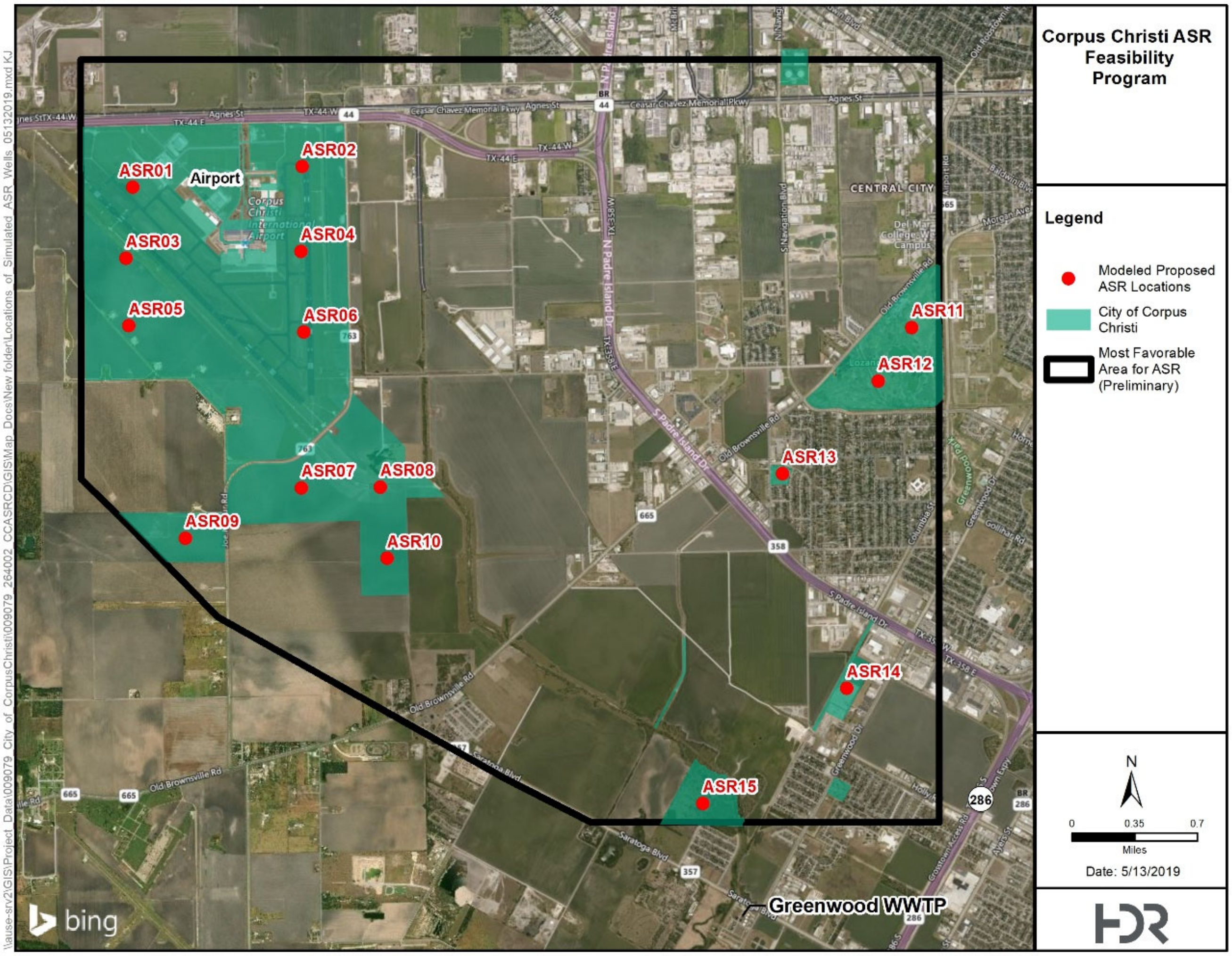


Table 4-1. Recharge Intervals for each of the ASR Well Locations

Well ID	Intervals
ASR01	S1, S2
ASR02	S1, S2
ASR03	S1, S2
ASR04	S1, S2
ASR05	S1, S2
ASR06	S1, S2
ASR07	S1, S2
ASR08	S1, S2
ASR09	S1, S2
ASR10	S1, S2
ASR11	S1
ASR12	S1
ASR13	S1, S2
ASR14	S1
ASR15	S1

4.4 Aquifer Parameters

4.4.1 Hydraulic Properties

Table 4-2 shows the hydraulic parameters assigned to each model layer. Hydraulic conductivity for the recharge intervals were set from the pump test estimates described in Section 3.2. For the composite layers, 1 and 9, a composite hydraulic conductivity was used; this composite hydraulic conductivity did not affect the hydraulic response in the recharge intervals. For the shallowest layer, the specific storage is parameterized using a value representing a semi-confined layer, since a portion of the layer is near surface and could be considered unconfined. The hydraulic response was not sensitive to this storage parameter.

Table 4-2. Summary of Hydraulic Properties by Layer for the Groundwater Model

Layer	Kh (ft/d)	Kv (ft/d)	Ss (1/ft)	Type
1	1	0.1	1.30E-04	Composite
2	0.1	0.001	1.70E-05	Clay
3	0.1	0.001	1.70E-05	Clay (1 ft)
4	17	0.1	1.30E-04	Sand
5	0.1	0.001	1.70E-05	Clay (1 ft)
6	0.1	0.001	1.70E-05	Clay
7	0.1	0.001	1.70E-05	Clay (1 ft)

Layer	Kh (ft/d)	Kv (ft/d)	Ss (1/ft)	Type
8	6	0.1	1.30E-04	Sand
9	0.1	0.001	1.70E-05	Clay (1 ft)
10	0.1	0.001	1.70E-05	Clay
11	4	0.1	1.70E-05	Sand
12	0.1	0.001	1.70E-05	Clay
13	1	0.1	1.70E-05	Composite

4.4.2 Transport Parameters

The key transport parameters for simulating ASR are porosity and dispersivity. The effective porosity was estimated to be 0.25 based on literature values (Young and others, 2016). While this porosity is at the lower end of the range (e.g. Figure 11-18 in Young and others, 2016), the effective porosity (the porosity that governs interstitial flow velocities) is typically lower than bulk porosities estimated from geophysical logs. Using a lower porosity would be considered conservative from an ASR perspective, since it increases both interstitial velocity (and thus mechanical dispersivity) and the lateral footprint of the stored water.

Dispersivity is commonly conceptualized as a scale-dependent parameter. That is, the larger the distance traveled by a solute plume, the high the apparent dispersivity. Results presented in Gelhar and others (1992) indicate that while longitudinal dispersivity is highly variable, it typically averages about 1/10 of the scale of the transport problem, for transport over distances of 100s or 1000s of feet. For a typical storage period, the recharge bubble radii are likely to range in the hundreds of feet to approaching 1000 feet. The initial estimate for longitudinal dispersivity was 30 feet, which is an order of magnitude less than the typical range of the bubble radii. Transverse dispersivity was assumed to be 1/10 of longitudinal dispersivity, and vertical dispersivity was assumed to be 1/100th of the longitudinal dispersivity.

When simulating transport with a finite difference model, the grid Peclet number is considered. This number compares the grid dimension to the value of longitudinal dispersivity. Grid Peclet numbers of 10 or less are can provide acceptable numerical dispersion for problems that are mostly advection dominated. For highly advection dominated problems, grid Peclet numbers should typically be in the range of 2-4. For the base case scenario, the grid Peclet number is the ratio of the grid dimension (200 feet) to the dispersivity (30 feet), resulting in 6.7, which is less than 10, but greater than the 2-4 range. We explore the sensitivity of the simulated dispersivity to grid dimension in Section 6.

After initial analysis after model calibration, for scenarios after the base case scenario, the longitudinal dispersivity was increased to 60 feet. This resulted is a grid Peclet number of 3.3, which is within the optimal range for advection dominated problems. Base case scenario results are still valid as the dispersivity number may change again after analyzing the results of ASR pilot testing.

4.4.3 Water Quality Parameters

Chloride and TDS concentrations based on the measured concentrations from the exploratory test wells was added to model layers. Measured concentrations were added to the model layers corresponding to tested borehole intervals. Interpolation of concentrations from model layers with measured concentrations was used to populate model layers without measured concentrations including clay layers. Concentrations of chloride and TDS increase with depth and is reflected in the concentration input in model layers. Table 4-3 includes the Chloride and TDS concentrations used in the transport model.

The source water quality used to simulate aquifer recharge is 1,711 mg/L TDS and 579 chloride. These values were measured at the Greenwood WWTP on December 13, 2017.

Table 4-3. Chloride and TDS Concentrations used in the Transport Model

Model Layer	Chloride (mg/l)	TDS (mg/l)
1	1,000	4,000
2	2,000	6,000
3	3,000	8,000
4	4,270*	9,545*
5	4,330	9,655
6	4,390	9,765
7	4,450	9,875
8	4,500*	10,000*
9	4,900	11,350
10	5,300	12,700
11	5,738*	14,085*
12	7,000	17,000
13	9,000	20,000

*Concentrations represent values measured in the lab from Test Well samples.

5 Simulation of ASR Operations

5.1 Operational Constraints

5.1.1 Drawdown and Uplift

ASR systems are typically designed so that a minimum recovery rate can occur over some period when demand exceeds conventional supplies. The amount of water that is to be produced during a recovery cycle, plus some amount of additional water that initially provides a buffer on the edge of the stored water in the recharge zone, is called the target storage volume. The system recovery capacity may be constrained by per-well recovery rates and the number of wells, or it may be constrained by recharge capacity, i.e. the amount of water that can be stored prior to recovery.

On a per-well basis, the recovery rate is limited by the specific capacity of the well and the available drawdown. In the current case, the available drawdown is the distance from the initial static water level to the top of the first recharge interval (S1), plus some offset that accounts for a factor of safety and the pump being set above the top of the screen. For the purposes of these simulations the offset was targeted to be a minimum of 80 feet, so the minimum distance between the water level and top of interval S1 during any point in ASR operation was 80 feet to avoid dewatering the storage zone.

The per-well recharge rate is limited by the amount of positive pressure (uplift) that can be put on a wellhead and the specific capacity of the well. For the base case scenario, wellhead pressures did not exceed 60 psi, or about 140 feet of head above ground surface. The Texas Commission on Environmental Quality (TCEQ) regulates and permits injection wells (which includes ASR wells) and advises that wellhead pressures shall not exceed 0.25 psi per foot of depth from surface. Generally, the top of the first recharge interval (S1) is 350 to 400 feet below ground surface, which limits the recharge pressure to 87.5 to 100 psi. For the model scenarios completed after the base case scenario, the psi at the wellhead was limited to approximately 90 psi. In general, ASR operations avoid recharging at a higher rate than recovery, to prevent mobilization of fines into the interval near the well.

5.1.2 Correction Factors for Simulated Heads

In MODFLOW, the amount of drawdown or uplift that is simulated in a grid cell containing a well represents a radial composite of the head over the area of the grid cell. That composite value will differ based on the size of the grid cell. To estimate the actual head that would occur in a wellbore, the simulated head should be adjusted to correct for this effect.

The Peaceman correction factor is a common strategy used to account for these inaccuracies associated with simulating radial flow to a pumping well (Trescott and others, 1976; Peaceman, 1983). The Peaceman correction factor is defined by Equation 5.1. The value of *d*s is subtracted from the simulated water level in the grid cell to produce a water level that is lower than that in the grid cell. The corrected head is theoretically appropriate to compare to a water level measured in a pumping well that is centered in the grid cell.

$$ds = \frac{Q}{2\pi T} \ln\left(\frac{0.2\Delta x}{r_w}\right) \quad \text{(Equation 5.1)}$$

where;

*d*s – correction that lowers the predicted water level for a grid cell
Q – the total discharge rate of the pumping from the grid cell
T – the transmissivity of the cell element
Δx – the side length of the cell element (grid)
rw – the actual radius of the pumping well

To estimate a simulated drawdown at each well, initial steady-state water level was compared to the maximum drawdown at a well to calculate *ds*. The side length of a grid cell was 200 feet.

An additional correction that is sometimes applied to simulated drawdown or uplift is well efficiency. The well efficiency characterizes the difference between the water level in the aquifer just outside the screen and gravel pack and the water level in the wellbore. If a well is 100% efficient, then these two water levels are the same, i.e. there is no energy loss due to the water moving through the gravel pack and screen. If a well is 90% efficient, then 90 feet of drawdown in the aquifer just outside the gravel pack corresponds to 100 feet of drawdown in the wellbore.

Because the simulated drawdown does not account for inefficiencies in the well, the simulated drawdown is divided by the well efficiency in order to estimate the actual drawdown in the wellbore. For the current simulations, an efficiency of 80% was assumed. The efficiency of a well is mostly dependent on the quality of the well construction, and minimum efficiencies are often a contractual requirement during drilling of ASR wells.

5.2 Modeled ASR Operating Scenario(s)

Seven scenarios were simulated using the groundwater model based on an evaluation of future industrial demand needs in the vicinity of the ASR study area and/or supply volume needed to overcome potential reductions during historical drought conditions (Appendix). The baseline scenario was used to establish wellfield configurations with acceptable interference between wells, and to set the recharge intervals based on this assessment. In addition, the overall recharge capacity of the system was assessed based on the constraints in water levels discussed in Section 5.1.

Scenarios A through D are operational scenarios and the well field configuration and recharge rates were established during the baseline scenario. The scenarios separated ASR operations in two phases. Phase 1 consisted of 10 ASR wells located on the airport property. Phase 2, included in 3 scenarios, represented a build-out, future condition with up to 15 wells operating to include 5 ASR wells located on City-owned properties to the east and southeast. Each scenario alternated water recharge and recovery cycles, specified with monthly stress periods, using a combined well recharge rate that limited the wellhead pressures to a maximum of approximately 90 psi and also limiting the increase of TDS or chloride within the recovered water. A general description of Scenarios A through D are provided along with detailed descriptions and analysis of results in the following sections.

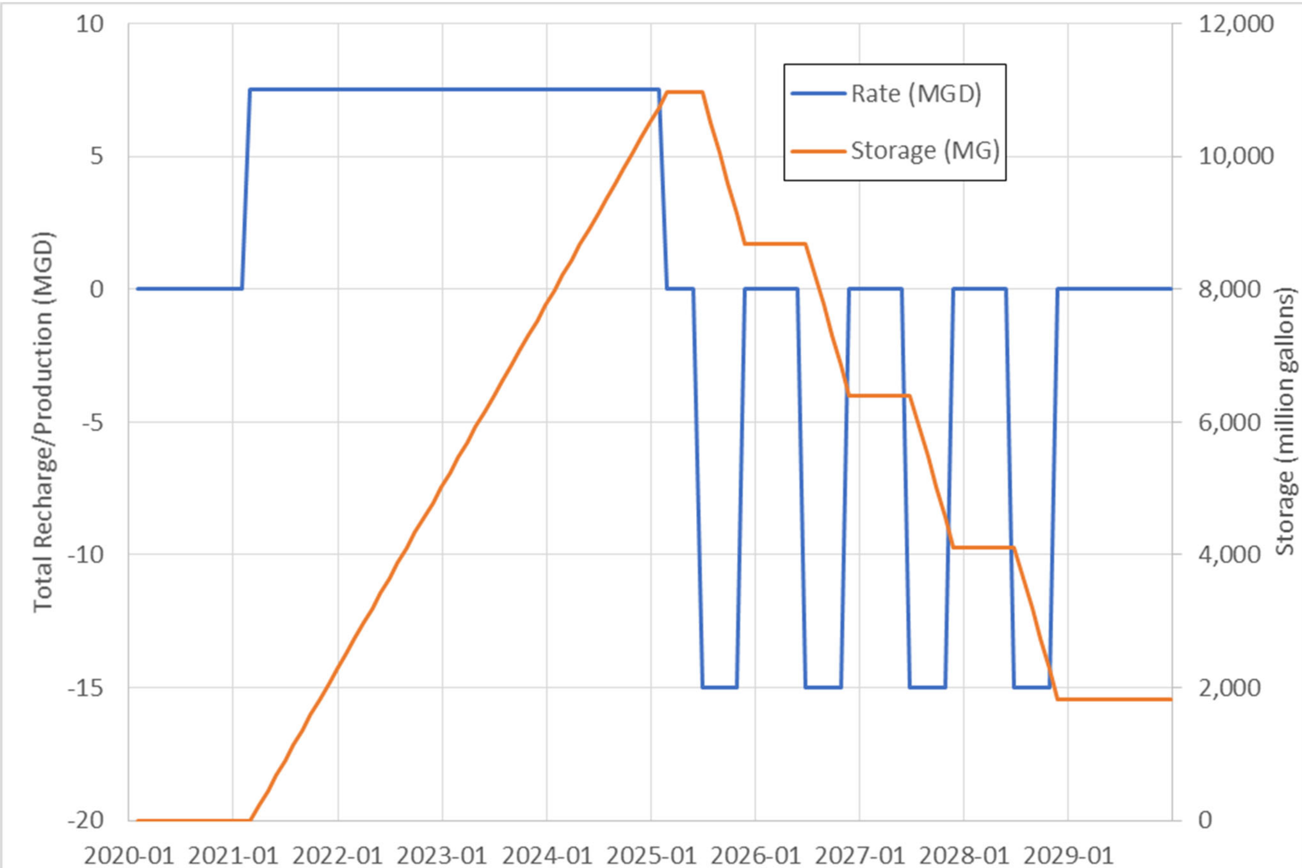
Additionally, water quality impacts of ASR operations for scenarios A through D were evaluated based on the TDS and chloride concentrations for native groundwater discussed in Section 3.4.

5.2.1 Baseline Testing Scenario

The baseline scenario simulates a series of basic drought event or water banking operations. In this concept, water is stored over several years and recovered later during droughts or peak demands. In this scenario, recharge occurs for five years when excess capacity is available. After the fifth year, the excess capacity is no longer available and summer demand exceeds conventional supplies, so water is produced from the ASR system June through October for the next five years. The event triggering the need for recovery could be increased demand due to growth or decrease in conventional supplies due to drought. The recharge and recovery cycles are shown in Figure 5-1.

This first scenario was used to explore wellfield configurations, assess interference between wells, and to set the recharge intervals based on this assessment. In addition, the overall capacity of the system was assessed based on the constraints in water levels discussed in Section 5.1.

Figure 5-1. Total Recharge and Recovery Rates and Cumulative Storage for Baseline Scenario



5.2.2 Scenario A- Drought Supply Application (based on historical drought)

Scenario A simulated drought supply application based on historical drought conditions. In this scenario, recharge occurs for five years in the ten Phase I ASR wells. After the fifth year, the recharged water is recovered for one and a half years. This cycle is then repeated for a total simulation period of thirty-nine years, which encompasses six recharge and recovery cycles.

5.2.3 Scenario B- Drought Supply Application + Contingency for Future Uncertainty

Scenario B simulated drought supply application plus contingency for future uncertainty. In this scenario, recharge occurs for five years in the ten Phase I ASR wells and five Phase 2 ASR wells, concurrently. After the fifth year, the recharged water is recovered for two years. This cycle is then repeated for a total simulation period of forty-two years, which encompasses six recharge and recovery cycles.

5.2.4 Scenario C1- Future Demands

Scenario C1 simulated future demands. In this scenario, recharge occurs for two years in the ten Phase I ASR wells. After the second year, the recharged water is recovered for 6 months. This cycle is then repeated for a total simulation period of fifteen years, which encompasses six recharge and recovery cycles.

5.2.5 Scenario C2- Future Demands

Scenario C2 simulated future demands. In this scenario, recharge occurs for two years in the ten Phase I ASR wells. After the second year, the recharged water is recovered for 9 months. The difference between Scenario C1 and C2 is a longer recovery period for Scenario C2 to determine if recovered water degrades substantially with a slightly longer recovery period when using identical recharge periods. This cycle is then repeated for a total simulation period of sixteen and a half years, which encompasses six recharge and recovery cycles.

5.2.6 Scenario D1- Future Demands + ASR Build-out

Scenario D1 simulated future demands at ASR well build-out. In this scenario, recharge occurs for two years in the ten Phase I ASR wells and five Phase 2 ASR wells. After the second year, the recharged water is recovered for six months. This cycle is then repeated for a total simulation period of fifteen years, which encompasses six recharge and recovery cycles.

5.2.7 Scenario D2- Future Demands + ASR Build-out

Scenario D2 simulated future demands at ASR well build-out. In this scenario, recharge occurs for two years in the ten Phase I ASR wells and five Phase 2 ASR wells. After the second year, the recharged water is recovered for nine months. The difference between Scenario D1 and D2 is a longer recovery period for Scenario D2 to determine if recovered water degrades substantially with a slightly longer recovery period when using identical recharge periods. This cycle is then repeated for a total simulation period of sixteen and a half years, which encompasses six recharge and recovery cycles.

5.3 Simulation Results

The simulation results will be discussed in terms of recharge and recovery rates, water levels and system recoverability.

5.3.1 Recharge and Recovery Rates

As discussed in Section 4.3.2, recharge and recovery rates were apportioned by the transmissivity of each injection interval, using transmissivity as a surrogate for well productivity. In addition, after an initial simulation, heads at each well were examined to determine which wells experienced the most interference from other wells in the wellfield. Rates at those wells were adjusted in order to generally balance the amount of uplift or drawdown that was occurring, and maintain the heads inside the constraints discussed in Section 5.1.

The maximum recharge and recovery rates for the scenarios described below are summarized in Table 5-1.

Baseline Testing Scenario

The recharge rates for the Baseline Testing Scenario for most wells range between 250 to 350 gpm, with a range for all ASR wells between 249 gpm and 517 gpm. The recovery rates for most simulated wells are between 500 and 600 gpm, with a range for all ASR wells between 499 and 1034 gpm. The recovery rates are basically twice the recharge rates.

Scenario A- Drought Supply Application (based on historical drought)- 10 wells

The recharge rates for Scenario A for most simulated wells range between 260 to 350 gpm, with a range from 262 gpm to 439 gpm. The recovery rates for most simulated wells are between 430 and 550 gpm, with a range between about 432 and 725 gpm. The total recharge rate for all wells is 4.8 million gallons per day (MGD) over 5 years and the total recovery rate for all wells is 7.9 MGD over 1.5 years. The recovery rates are sixty percent greater than the recharge rates.

Scenario B- Drought Supply Application + Contingency for Future Uncertainty- 15 wells

The recharge rates for Scenario B for most simulated wells range between 240 to 340 gpm, with a range from 237 gpm to 398 gpm. The recovery rates for most simulated wells are between 300 and 400 gpm, with a range between about 296 and 497 gpm. The total recharge rate for all wells is 6.6 MGD over 5 years and the total recovery rate for all wells is 8.2 MGD over 2 years. The recovery rates are twenty to seventy-five percent greater than the recharge rates.

Scenario C1- Future Demands- 10 wells

The recharge rates for Scenario C1 for most simulated wells range between 260 to 360 gpm, with a range from 262 gpm to 439 gpm. The recovery rates for most simulated wells are between 450 and 550 gpm, with a range between about 432 and 725 gpm. The total recharge rate for all wells is 4.8 million gallons per day (MGD) over 2 years and the total recovery rate for all wells is 7.9 MGD over 6 months. The recovery rates are sixty percent greater than the recharge rates.

Scenario C2- Future Demands- 10 wells

The difference between Scenario C1 and C2 is a longer recovery period for Scenario C2 to determine if recovered water degrades substantially with a slightly longer recovery period when using identical recharge periods. The recharge and recovery rates for Scenario C2 is the same as Scenario C1. The total recharge rate for all wells is 4.8 million gallons per day (MGD) over 2 years and the total recovery rate for all wells is 7.9 MGD over 9 months. The recovery rates are sixty percent greater than the recharge rates.

Scenario D1- Future Demands + ASR Build-out- 15 wells

The recharge rates for Scenario D1 for most simulated wells range between 280 to 380 gpm, with a range from 274 gpm to 460 gpm. The recovery rates for most simulated wells are between 350 and 450 gpm, with a range between about 343 and 575 gpm. The total recharge rate for all wells is 7.3 MGD over 2 years and the total recovery rate for all wells is 9.1 MGD over 6 months. The recovery rates are fifteen to thirty-five percent greater than the recharge rates.

Scenario D2- Future Demands + ASR Build-out

The difference between Scenario D1 and D2 is a longer recovery period for Scenario D2 to determine if recovered water degrades substantially with a slightly longer recovery period when using identical recharge periods. The recharge and recovery rates for Scenario D2 is the same as Scenario D1. The total recharge rate for all wells is 7.3 MGD over 2 years and the total recovery rate for all wells is 9.1 MGD over 9 months. The recovery rates are fifteen to thirty-five percent greater than the recharge rates.

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Table 5-1. Maximum Recharge and Recovery Rates (gpm)

Well	Baseline		Scenario A		Scenarios B		Scenarios C1		Scenarios C2		Scenarios D1		Scenarios D2	
	Recharge	Recovery	Recharge	Recovery	Recharge	Recovery	Recharge	Recovery	Recharge	Recovery	Recharge	Recovery	Recharge	Recovery
ASR01	329	658	346	570	346	432	346	570	346	570	362	453	362	453
ASR02	419	837	439	725	398	497	439	725	439	725	460	575	460	575
ASR03	267	535	281	463	281	351	281	463	281	463	294	367	294	367
ASR04	340	680	357	589	357	446	357	589	357	589	374	467	374	467
ASR05	249	499	262	432	262	327	262	432	262	432	274	343	274	343
ASR06	308	616	323	534	323	404	323	534	323	534	339	423	339	423
ASR07	277	553	290	479	290	363	290	479	290	479	304	380	304	380
ASR08	301	602	316	521	286	357	316	521	316	521	331	414	331	414
ASR09	322	643	338	557	338	422	338	557	338	557	354	442	354	442
ASR10	354	708	372	614	354	443	372	614	372	614	389	487	389	487
ASR11	318	636	NA	NA	239	298	NA	NA	NA	NA	286	358	286	358
ASR12	316	632	NA	NA	237	296	NA	NA	NA	NA	285	356	285	356
ASR13	458	916	NA	NA	344	430	NA	NA	NA	NA	412	516	412	516
ASR14	433	866	NA	NA	260	325	NA	NA	NA	NA	300	375	300	375
ASR15	517	1034	NA	NA	258	323	NA	NA	NA	NA	300	375	300	375

NA= Not applicable.

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5.3.2 Water Levels

The simulated water levels were corrected for grid size and well efficiency as described in Section 5.1.2. The maximum and minimum water levels, during recharge and recovery respectively, were assessed for the simulation. The maximum water levels were compared to ground surface to estimate the maximum wellhead pressures. The minimum water levels were compared to the top of S1 to assess whether the target 80 foot offset was being maintained as described in Section 5.1.1.

The maximum well pressures during recharge for the scenarios described below are summarized in Table 5-2.

The minimum distance between the water level and top of the storage layer during recovery for the scenarios described below are summarized in Table 5-3.

Baseline Testing Scenario

The maximum wellhead pressures range fairly evenly between 110 and 150 feet of head, with one wells exceeding 150 feet of head. All of the minimum water levels are at least 85 feet above the top of S1, with most between 150 and 180 feet above top of S1.

Scenario A- Drought Supply Application (based on historical drought)

The maximum wellhead pressures range fairly evenly between 180 and 200 feet of head, with one well at 203 feet of head. Because the approximate constraint is 209 feet (90 psi), the wells may have the ability to be operated at slightly higher recharge rates in the field (if additional recharge water is available), depending on the results of field testing. All of the minimum water levels are at least 85 feet above the top of S1, with most between 85 and 100 feet above top of S1. All of the minimum water levels are at least 85 feet above the top of S1, with most between 190 and 200 feet above top of S1.

Scenario B- Drought Supply Application + Contingency for Future Uncertainty

The maximum wellhead pressures range between 170 and 210 feet of head, with one well experiencing 211 feet of head. 211 feet of head equates to 91 psi, which is acceptable as the thickness of the sediments overlying the recharge zone is about 400 feet (which allows a pressure of 100 psi). The wells that are at 205 feet of head or below may be operated at slightly higher recharge rates in the field, depending on the results of field testing. All of the minimum water levels are at least 85 feet above the top of S1, with most between 105 and 150 feet above top of S1.

Scenarios C1 and C2- Future Demands

The maximum wellhead pressures range between 140 and 174 feet of head, with no wells exceeding 175 feet of head. All wells may be operated at slightly higher recharge rates in the field (if additional recharge water is available), depending on the results of field testing. However, this scenario was constrained by a maximum combined recharge rate of 5 MGD, which is why the recharge rates were not set higher. All of the minimum water levels are at least 85 feet above the top of S1, with most between 140 and 180 feet above top of S1.

Scenarios D1 and D2- Future Demands + ASR Build-out

The maximum wellhead pressures range between 160 and 203 feet of head. Because the approximate constraint is 209 feet (90 psi), the wells may be operated at slightly higher recharge rates in the field (if additional recharge water is available), depending on the results of field testing. The minimum water levels is about 84 feet above the top of S1, with most between 90 and 120 feet above top of S1.

Table 5-2. Maximum Positive Wellhead Pressures (in feet of water)

Well	Baseline	Scenario A	Scenario B	Scenario C1	Scenario C2	Scenario D1	Scenario D2
ASR01	111	188	199	157	149	177	170
ASR02	118	203	207	173	165	197	190
ASR03	115	182	194	152	144	173	165
ASR04	123	193	208	163	155	188	180
ASR05	118	181	192	151	143	172	164
ASR06	130	190	205	161	152	186	178
ASR07	138	186	202	160	152	186	178
ASR08	154	200	211	174	166	203	195
ASR09	129	188	202	162	155	185	177
ASR10	143	193	209	169	162	199	191
ASR11	134	NA	177	NA	NA	176	170
ASR12	141	NA	182	NA	NA	183	176
ASR13	142	NA	179	NA	NA	178	171
ASR14	141	NA	173	NA	NA	168	162
ASR15	144	NA	173	NA	NA	167	161

NA= Not applicable.

Table 5-3. Distance between Minimum Water Level and Top of Layer S1 (feet)

Well	Baseline	Scenario A	Scenario B	Scenario C1	Scenario C2	Scenario D1	Scenario D2
ASR01	156	205	156	164	187	113	134
ASR02	165	226	157	184	208	125	148
ASR03	157	194	147	148	173	99	123
ASR04	167	212	160	162	189	106	132
ASR05	161	189	143	141	167	93	117
ASR06	171	198	149	145	173	90	118
ASR07	171	195	147	146	173	91	117
ASR08	175	188	129	143	167	84	110
ASR09	173	195	146	154	177	101	123
ASR10	179	204	148	167	188	106	128
ASR11	155	NA	141	NA	NA	135	150
ASR12	150	NA	142	NA	NA	131	148
ASR13	199	NA	128	NA	NA	107	126
ASR14	180	NA	126	NA	NA	112	126
ASR15	179	NA	105	NA	NA	94	106

NA= Not applicable.

6 Recoverability Sensitivity

The baseline testing scenario was used to test the sensitivity of recoverability to several characteristics of the modeling approach that had been discussed previously. This recoverability was calculated by examining the simulated concentration of recharge water through time at the grid cells containing the wells. Recharge water was given a concentration of 1.0; and, native groundwater was given a concentration of 0.0. So, concentrations less than 1.0 indicate that some fraction of native water is being recovered. Because native water has a higher TDS than the recharge water, this would have the effect of increasing the TDS of the recovered water.

Figure 6-1 shows the simulated recovery of stored water through time for the four recovery cycles, as shown in Figure 5.1. The increases in recovered volume occur during summer production over the 4 year recovery period. The total volume of water in storage at the beginning of the four recovery events was 11,000 MG. The total recovery volume for the four recovery events is just over 9,000 MG, of which about 8,000 MG is stored water. The fraction of recovered water that is recharge water is plotted on the same Figure 6-1. During the first two recovery cycles, the recovery fraction is over 0.98. During the third recovery cycle, the fraction drops below 0.98, but still stays at about 0.95. During the fourth and final recovery cycle, the fraction drops more significantly to below 0.90 as the produced water starts to encounter the mixing zone.

Because vertical confinement may be important to recoverability, a sensitivity case was run where the vertical conductivity of the clay layers was decreased by an order of magnitude to 0.0001 ft/d. If significant native water were moving into the production interval during recovery, then this tightening of the clay layers is expected to reduce that movement. A comparison between the recovery fraction with Kv_{clay} = 0.001 ft/d and Kv_{clay} = 0.0001 ft/d is shown in Figure 6-2. The decrease in vertical conductivity has only a small effect on the fraction, with a difference of about 0.01 at the end of simulation.

Dispersivity can have a strong effect on how much mixing occurs at the leading edge of the bubble as it is forming. The size of the mixing zone can determine how much recharge water can be recovered before significant native water begins to be produced. To determine the effect of dispersivity, two simulations were run where the longitudinal dispersivity was varied from the base value of 30 feet to 15 feet and 5 feet. Five feet is a low estimate for dispersivity if the bubble extends 100s of feet from the well. Figure 6-3 shows a comparison of the three cases. As expected, decreasing dispersivity increases the fraction of recharge water recovered through time, since the size of the mixing zone decreases.

In Section 4.4.2, we discussed the potential impact of grid block size relative to simulated dispersivity on numerical dispersion. To determine whether the grid block size had a significant effect on the predicted fraction of recharge water recovered through time, we performed a simulation with the grid block size reduced from 200 feet to 100 feet, so the grid peclet number was reduced from 6.7 to 3.3. A comparison is shown in Figure 6-4. While the smaller grid does show a minor difference between the recovery fractions through time, it does not justify the increased computational burden for the smaller grid.

Figure 6-1. Recovery of Stored Water through Time versus Total Produced Water for the Baseline Scenario

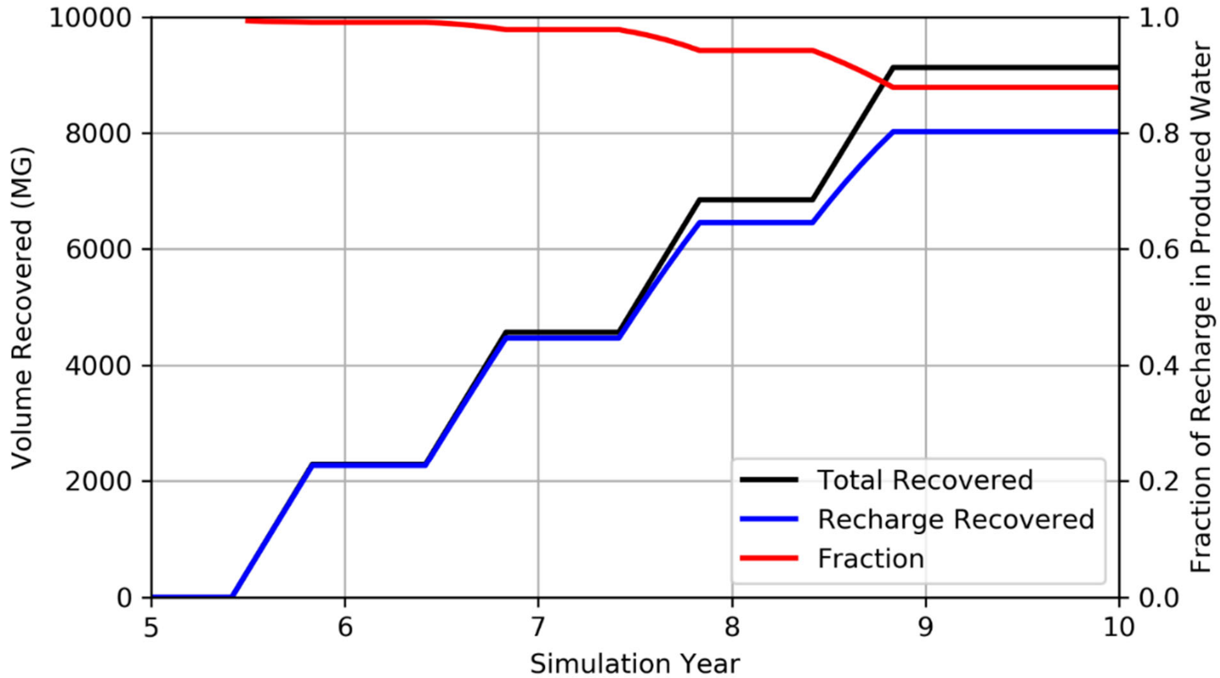


Figure 6-2. Sensitivity of Recovery Fraction to Vertical Hydraulic Conductivity of the Clay Layers for the Baseline Scenario

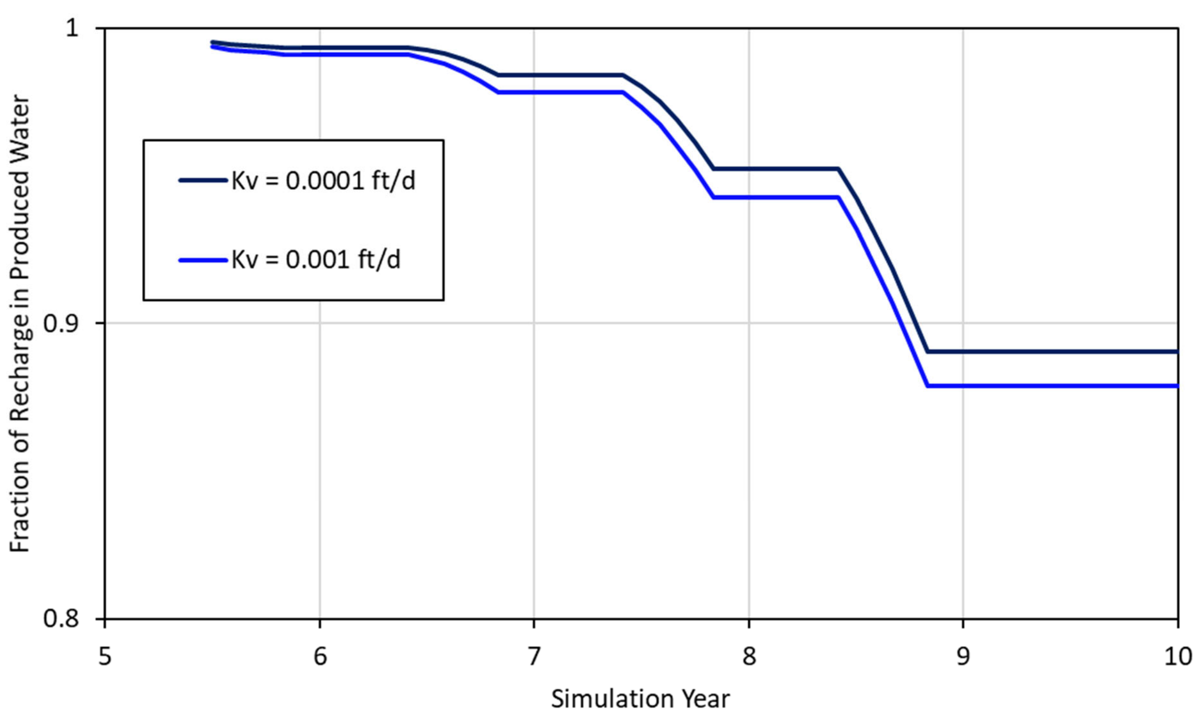


Figure 6-3. Sensitivity of Recovery Fraction to Longitudinal Dispersivity

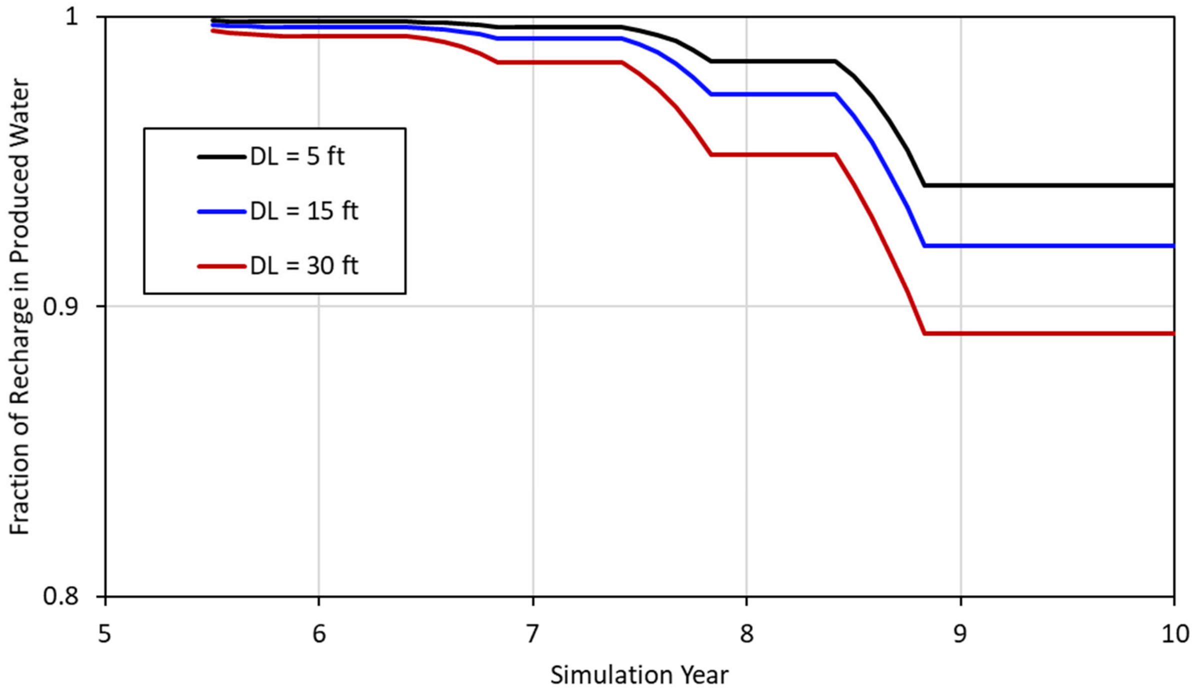
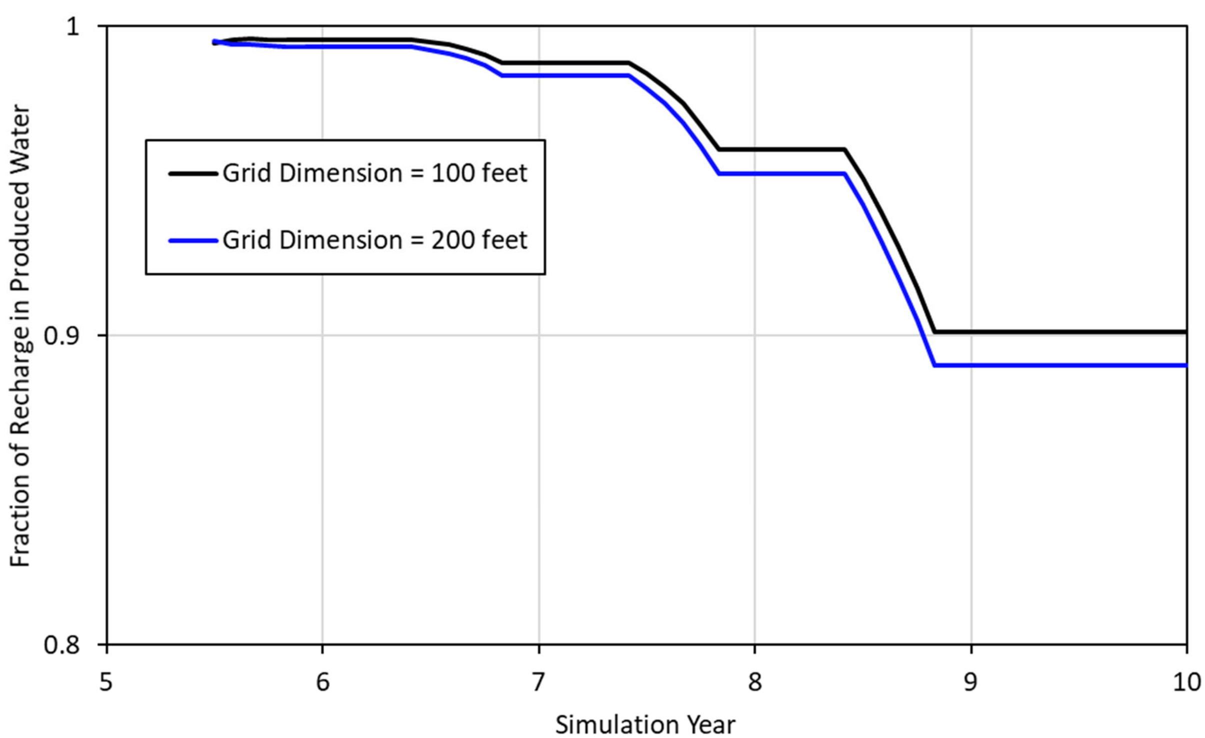


Figure 6-4. Sensitivity of Recovery Fraction to Grid Dimension



At the request of the Texas Water Development Board (TWDB) in the Draft Final report comments, a recovery sensitivity analysis was conducted to evaluate the impact of lowering the effective porosity values for both sand (such as 0.1 to 0.15) and clay (such as 0.05 to 0.1). For this analysis, Scenario B and D1 were analyzed, representative of drought and seasonal operations respectively. See Table 1-1 for scenario descriptions and parameters. The porosity values that were tested for model sensitivity are shown in Table 6-1.

A summary of the porosity sensitivity results is shown in Table 6-2. For Scenario B, decreasing the porosity of the sand to 15% and leaving the porosity of the clay at 25% (Scenario Bn3) resulted in the greatest increase of the recovered water TDS and specific conductivity of 30 mg/L, each at the end of the first recovery cycle. A reduction in the porosity of clay to 10% and sand to 15% (Scenario Bn4) resulted in a decrease of the recovered TDS and specific conductivity of 890 mg/L and 35 mg/L, respectively, at the end of the first recovery cycle. Changes in porosity resulted in minimal changes to salinity at the end of six recovery cycles.

For Scenario D1, changes to porosity in the clay and sand units had very minimal impact to recovered water salinity, which is likely due to the shorter recharge and recovery cycles when compared to Scenario B. Maximum changes in the recovered water TDS and specific conductance was about 50 to 65 mg/L.

Overall, the recovered water salinity is not very sensitive to minor changes in porosity of the sand and clay units.

Table 6-1. Porosity Values that were Tested for Model Sensitivity

Sensitivity Run	Sand Porosity	Clay Porosity
Bn1	0.2	0.05
Bn2	0.1	0.05
Bn3	0.15	0.25
Bn4	0.15	0.1
D1n1	0.2	0.05
D1n2	0.1	0.05
D1n3	0.15	0.25
D1n4	0.15	0.1

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Table 6-2. Summary of Impact of Porosity on Recoverability for Scenarios B and D1

	Scenario	B[1]	Bn1	Bn2	Bn3	Bn4	D1[2]	D1n1	D1n2	D1n3	D1n4
	Number of ASR Wells	15	15	15	15	15	15	15	15	15	15
	Recharge Cycle Length (Years)	5	5	5	5	5	2	2	2	2	2
	Recovery Cycle Length (Years)	2.00	2.00	2.00	2.00	2.00	0.50	0.50	0.50	0.50	0.50
	Total Recharge (MGD)	6.6	6.6	6.6	6.6	6.6	7.3	7.3	7.3	7.3	7.3
	Total Recovery (MGD)	8.2	8.2	8.2	8.2	8.2	9.1	9.1	9.1	9.1	9.1
	Greatest Individual Wellhead Pressure (Ft of Water Above Land Surface)	211[3]	211	211	211	211	205	205	205	205	205
After 1st Recharge / Recovery Cycle	Total Storage Volume (MG)	6,000	6,000	6,000	6,000	6,000	3,660	3,660	3,660	3,660	3,660
	TDS (mg/L) of Recovered Water	3,700	3,670	3,720	3,730	2,810	3,000	2,840	2,920	2,965	2,950
	Chloride (mg/L) of Recovered Water	1,550	1,495	1,515	1,520	1,515	1,200	1,185	1,215	1,170	1,160
After 6 Recharge / Recovery Cycles	Total Storage Volume (MG)	36,000	36,000	36,000	36,000	36,000	22,000	22,000	22,000	22,000	22,000
	TDS (mg/L) of Recovered Water	2,120	1,950	1,970	2,150	2,150	1,885	2,135	1,835	1,895	1,895
	Chloride (mg/L) of Recovered Water	760	670	695	775	715	660	645	655	665	660

[1]Constrained to 8 MGD Recharge and 10 MGD Recovery or a wellhead pressure (in feet above land surface) of 209 feet

[2]Constrained to 8 MGD Recharge and 10 MGD Recovery or a wellhead pressure (in feet above land surface) of 209 feet

[3]211 feet is acceptable because the top of the storage zone is 400 feet below surface, which allows for a pressure of 100 psi (230 feet)

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7 Water Quality Impacts for Each Scenario

The recoverability for scenarios A through D was estimated by measuring the simulated TDS and chloride concentrations of recovered water on a well-by-well basis. Water quality impacts to the recovered water for Scenarios A through D are estimated by evaluating the simulated changes in TDS and chloride concentrations during the recharge and recovery cycles. The TDS and chloride concentrations for each scenario were monitored in each simulated ASR well and plotted to determine if concentrations exceeded approximately 5,000 mg/L TDS or 2,000 mg/L chloride, which are slight to moderate brackish water quality. These concentrations are likely the maximum values acceptable for industrial, non-potable use. When the recovered water quality exceeds the concentrations of the recharged water quality (1,711 mg/L TDS or 579 chloride), this indicates that greater salinity native groundwater is mixing with the recharged water buffer zone.

The methodology used to determine recoverability in the baseline testing scenario differs from Scenarios A through D in that the baseline testing scenario simulated the ratio of recovered water versus native groundwater using a fraction of 1.0, while Scenarios A through D simulated the actual measured TDS and chloride concentrations recovered to determine the ability of recovered water to remain within the desired salinity range. The presented concentrations are the average from all wells during model simulations. The simulated concentrations provides a better understanding of the quality of recovered water and the ability of the recovered water to satisfy the water quality demands of customers.

7.1 Scenario A- Drought Supply Application (based on historical drought)

Figure 7-1 and 7-2 shows the simulated volume of stored water through time for Scenario A- Drought Supply Application with 10 ASR wells. Water storage in the aquifer increased over the first 5 year recharge cycle to about 8,750 MG, which decreased to about 4,500 MG at the end of the first year and a half recovery cycle. Water storage increased to about 30,500 MG by the end of the sixth recharge/recovery cycle after 37.5 years.

Figure 7-1 shows that TDS stabilized below 1,750 mg/L after about one year during the first recharge cycle and increased to about 3,300 mg/L and 3,700 mg/L in model layers 4 and 8 (storage intervals in Figure 4.1), respectively at the end of the first recovery cycle, with an anticipated blended TDS concentration of slightly over 3,500 mg/L. It took about six months for TDS to stabilize below 1,750 mg/L after the second recharge cycle and increased to about 2,500 mg/L and 2,800 mg/L in model layers 4 and 8, respectively at the end of the second recovery cycle, with an anticipated blended TDS concentration of slightly over 2,600 mg/L. The TDS concentration in the recovered water decreases during the second recovery cycle due to the increase of the recharge water storage volume in the aquifer. By the end of the sixth recovery cycle, the TDS concentration only increased to approximately 2,000 mg/L and 2,200 mg/L in model layers 4 and 8, respectively, with an anticipated blended TDS concentration of 2,100 mg/L. This decreasing TDS trend shows that as storage of recharged water increases over successive cycles, thus creating an expanding storage volume, the amount of mixing of native higher salinity water decreases, which results in recovered water that more closely reflects the salinity of the recharged water.

Figure 7-2 shows that chloride stabilized below 600 mg/L after about one year during the first recharge cycle and increased to about 1,300 mg/L and 1,500 mg/L in model layers 4 and 8, respectively at the end of the first recovery cycle, with an anticipated blended chloride concentration of about 1,400 mg/L. By the end of the sixth recovery cycle, the chloride concentration only increased to approximately 700 mg/L and 800 mg/L in model layers 4 and 8, respectively, with an anticipated blended chloride concentration of 750 mg/L. Similar to TDS, the decreasing chloride concentration trend shows that as storage of recharged water increases over successive cycles, thus creating an expanding storage volume, the amount of mixing of native higher salinity water decreases, which results in recovered water that more closely reflects the salinity of the recharged water.

Under this scenario, five years is more than adequate for the recharged water to stabilize at low concentrations and suggests that two years of recharge is the minimum amount of time to develop an adequate storage volume and that as the storage reserve is carried over between cycles with additional recharge water added, recovered water quality shows lower TDS and chloride concentrations with subsequent cycles.

Figure 7-1. Scenario A- Aquifer Storage Volume and Produced Water TDS Concentrations (mg/L)

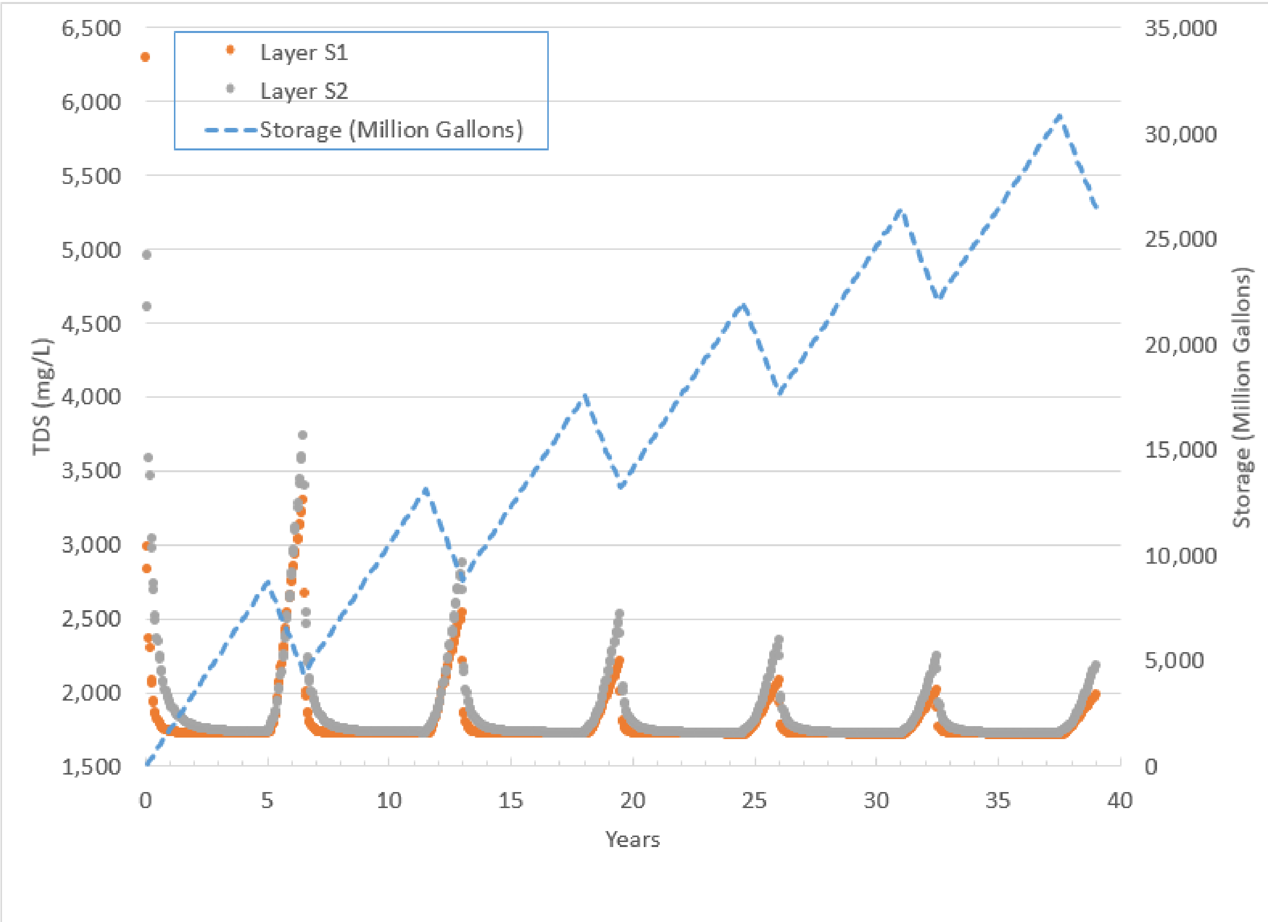
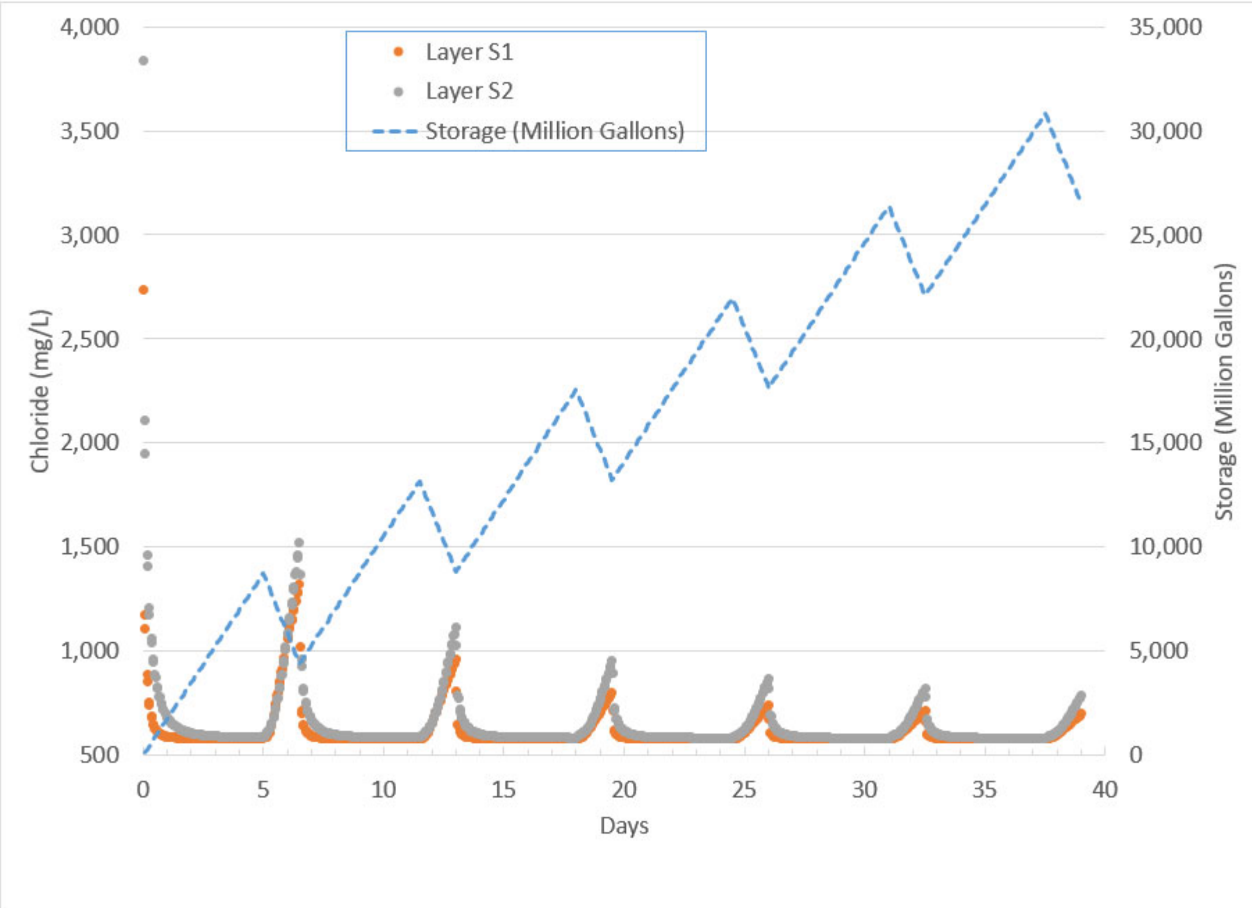


Figure 7-2. Scenario A- Aquifer Storage Volume and Produced Water Chloride Concentrations (mg/L)



7.2 Scenario B- Drought Supply Application + Contingency for Future Uncertainty

Figure 7-3 and 7-4 shows the simulated volume of stored water through time for Scenario B- Drought Supply Application+ Contingency for Future Uncertainty with 15 ASR wells. Water storage in the aquifer increased over the first 5 year recharge cycle to about 12,000 MG, which decreased to about 6,000 MG at the end of the first two year recovery cycle. Water storage increased to about 36,000 MG by the end of the sixth recharge/recovery cycle after 42 years.

Figure 7-3 shows that TDS stabilized below 1,750 mg/L after about one year during the first recharge cycle and increased to about 3,550 mg/L and 3,900 mg/L in model layers 4 and 8 (storage intervals in Figure 4.1), respectively at the end of the first recovery cycle, with an anticipated blended TDS concentration of about 3,700 mg/L. It took about six months for TDS to stabilize below 1,750 mg/L after the second recharge cycle and increased to about 2,650 mg/L and 2,950 mg/L in model layers 4 and 8, respectively at the end of the second recovery cycle, with an anticipated blended TDS concentration of about 2,800 mg/L. The TDS concentration in the recovered water decreases during the second recovery cycle due to the increase of the recharge water storage volume in the aquifer. By the end of the sixth recovery cycle, the TDS concentration only increased to approximately 2,020 mg/L and 2,220 mg/L in model layers 4 and 8, respectively, with an anticipated blended TDS concentration of about 2,120 mg/L. This decreasing TDS trend shows that as storage of recharged water increases over successive cycles, thus creating an expanding storage volume, the amount of mixing of native higher salinity water decreases, which results in recovered water that more closely reflects the salinity of the recharged water.

Figure 7-4 shows that chloride stabilized below 600 mg/L after about one year during the first recharge cycle and increased to about 1,450 mg/L and 1,600 mg/L in model layers 4 and 8, respectively at the end of the first recovery cycle, with an anticipated blended chloride concentration of about 1,550 mg/L. By the end of the sixth recovery cycle, the chloride concentration only increased to approximately 710 mg/L and 810 mg/L in model layers 4 and 8, respectively, with an anticipated blended chloride concentration of 760 mg/L. Similar to TDS, the decreasing chloride concentration trend shows that as storage of recharged water increases over successive cycles, thus creating an expanding storage volume, the amount of mixing of native higher salinity water decreases, which results in recovered water that more closely reflects the salinity of the recharged water.

Under this scenario, five years is more than adequate for the recharged water to stabilize at low concentrations and suggests that two years of recharge is the minimum amount of time to develop an adequate storage volume and that as the storage reserve is carried over between cycles with additional recharge water added, recovered water quality shows lower TDS and chloride concentrations with subsequent cycles.

Figure 7-3. Scenario B- Aquifer Storage Volume and Produced Water TDS Concentrations (mg/L)

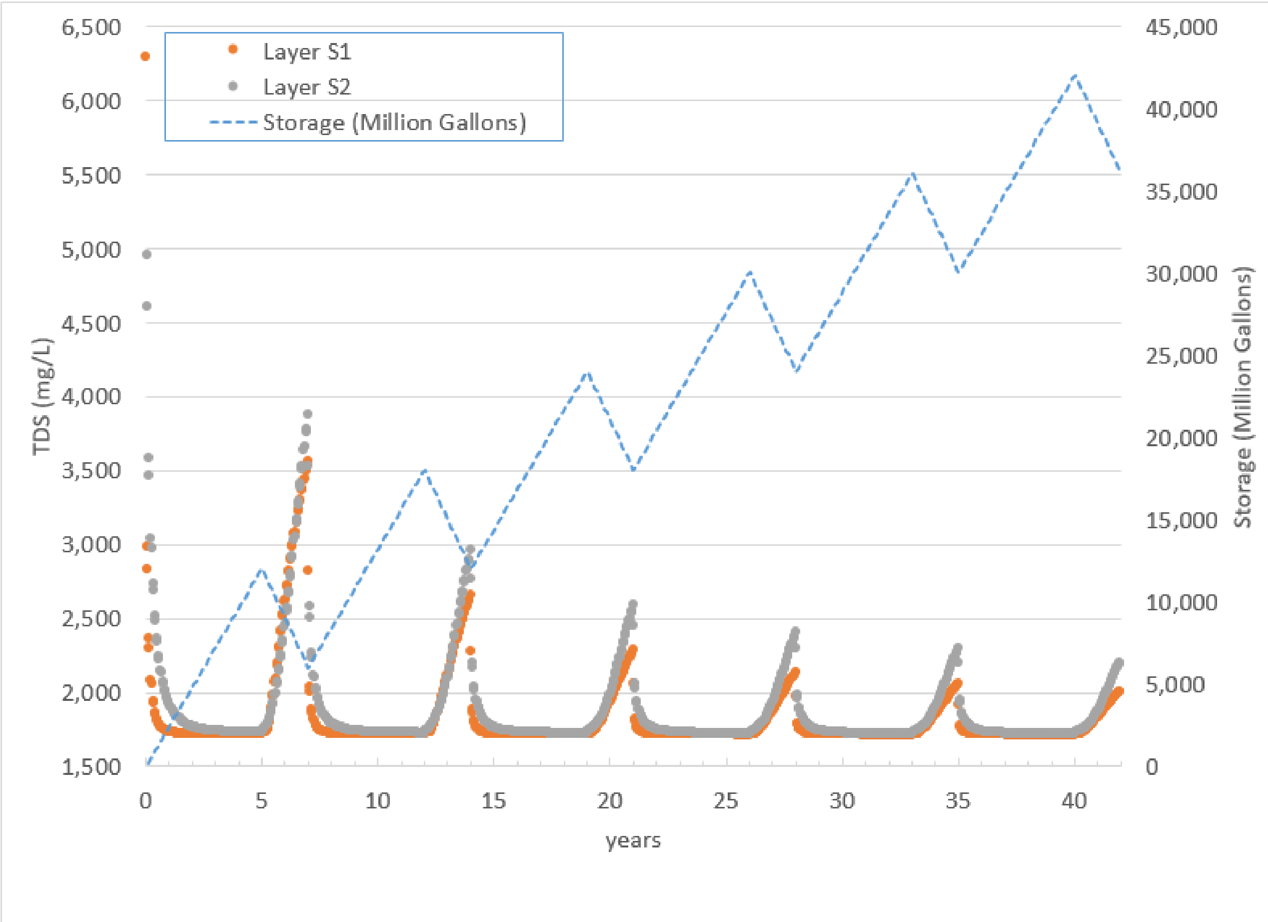
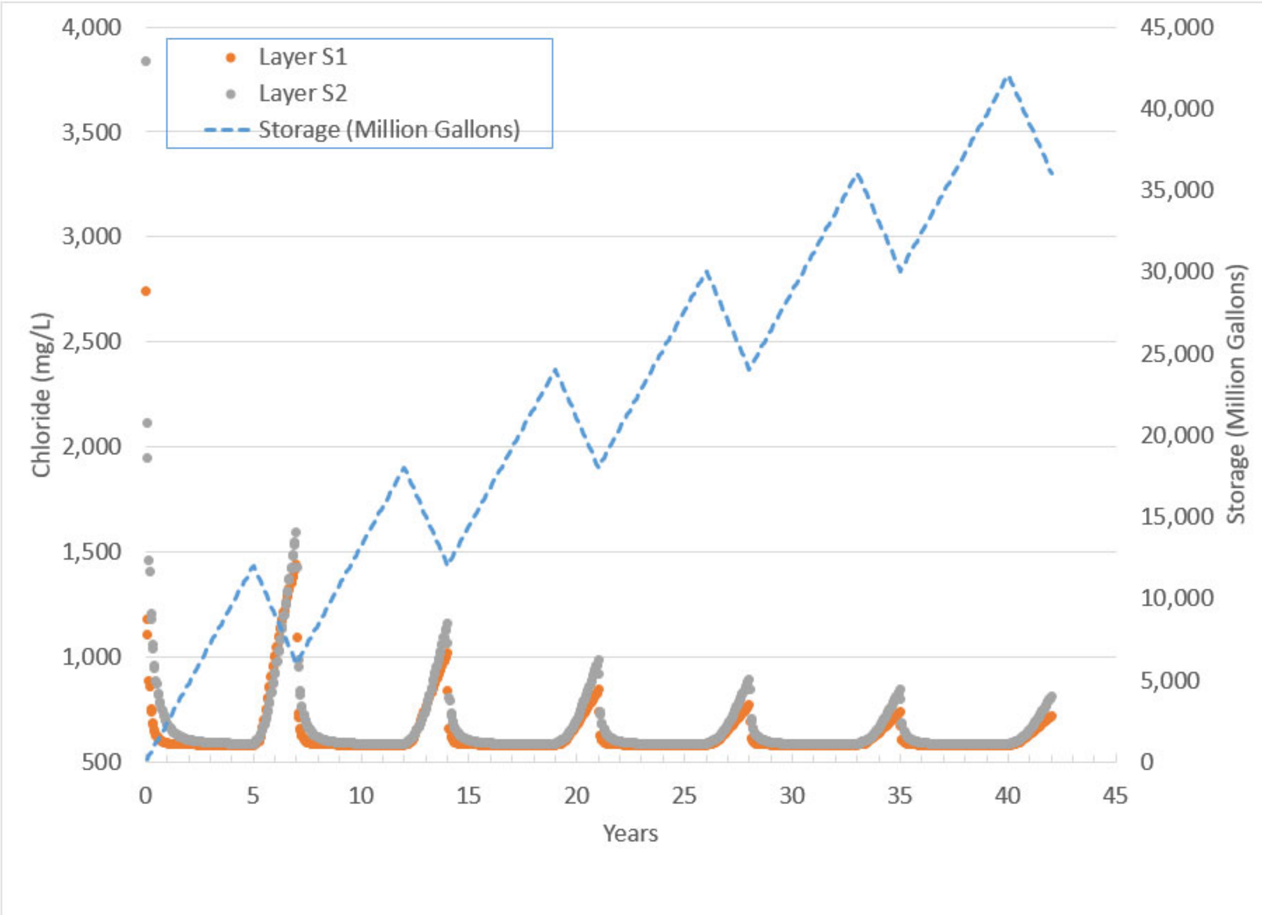


Figure 7-4. Scenario B- Aquifer Storage Volume and Produced Water Chloride Concentrations (mg/L)



7.3 Scenario C1- Future Demands

Figure 7-5 and 7-6 shows the simulated volume of stored water through time for Scenario C1- Future Demands with 10 ASR wells having a 2 year recharge cycle followed by a six month recovery cycle. Water storage in the aquifer increased over the first 2 year recharge cycle to about 3,500 MG, which decreased to about 2,050 MG at the end of the first six month recovery cycle. Water storage increased to about 12,300 MG by the end of the sixth recharge/recovery cycle after 15 years.

Figure 7-5 shows that TDS stabilized below 1,750 mg/L after about one year during the first recharge cycle and increased to about 3,100 mg/L and 3,750 mg/L in model layers 4 and 8 (storage intervals in Figure 4.1), respectively at the end of the first recovery cycle, with an anticipated blended TDS concentration of about 3,450 mg/L. It took about six months for TDS to stabilize below 1,750 mg/L after the second recharge cycle and increased to about 2,450 mg/L and 2,700 mg/L in model layers 4 and 8, respectively at the end of the second recovery cycle, with an anticipated blended TDS concentration of about 2,550 mg/L. The TDS concentration in the recovered water decreases during the second recovery cycle due to the increase of the recharge water storage volume in the aquifer. By the end of the sixth recovery cycle, the TDS concentration only increased to approximately 1,950 mg/L and 2,000 mg/L in model layers 4 and 8, respectively, with an anticipated blended TDS concentration of about 1,975 mg/L. This decreasing TDS trend shows that as storage of recharged water increases over successive cycles, thus creating an expanding storage volume, the amount of mixing of native higher salinity water decreases, which results in recovered water that more closely reflects the salinity of the recharged water.

Figure 7-6 shows that chloride stabilized below 600 mg/L after about one year during the first recharge cycle and increased to about 1,250 mg/L and 1,550 mg/L in model layers 4 and 8, respectively at the end of the first recovery cycle, with an anticipated blended chloride concentration of about 1,400 mg/L. By the end of the sixth recovery cycle, the chloride concentration only increased to approximately 700 mg/L and 710 mg/L in model layers 4 and 8, respectively, with an anticipated blended chloride concentration of 705 mg/L. Similar to TDS, the decreasing chloride concentration trend shows that as storage of recharged water increases over successive cycles, thus creating an expanding storage volume, the amount of mixing of native higher salinity water decreases, which results in recovered water that more closely reflects the salinity of the recharged water.

Under this scenario, two years is more than adequate for the recharged water to stabilize at low concentrations and suggests that two years of recharge is the minimum amount of time to develop an adequate storage volume and that as the storage reserve is carried over between cycles with additional recharge water added, recovered water quality shows lower TDS and chloride concentrations with subsequent cycles.

Figure 7-5. Scenario C1- Aquifer Storage Volume and Produced Water TDS Concentrations (mg/L)

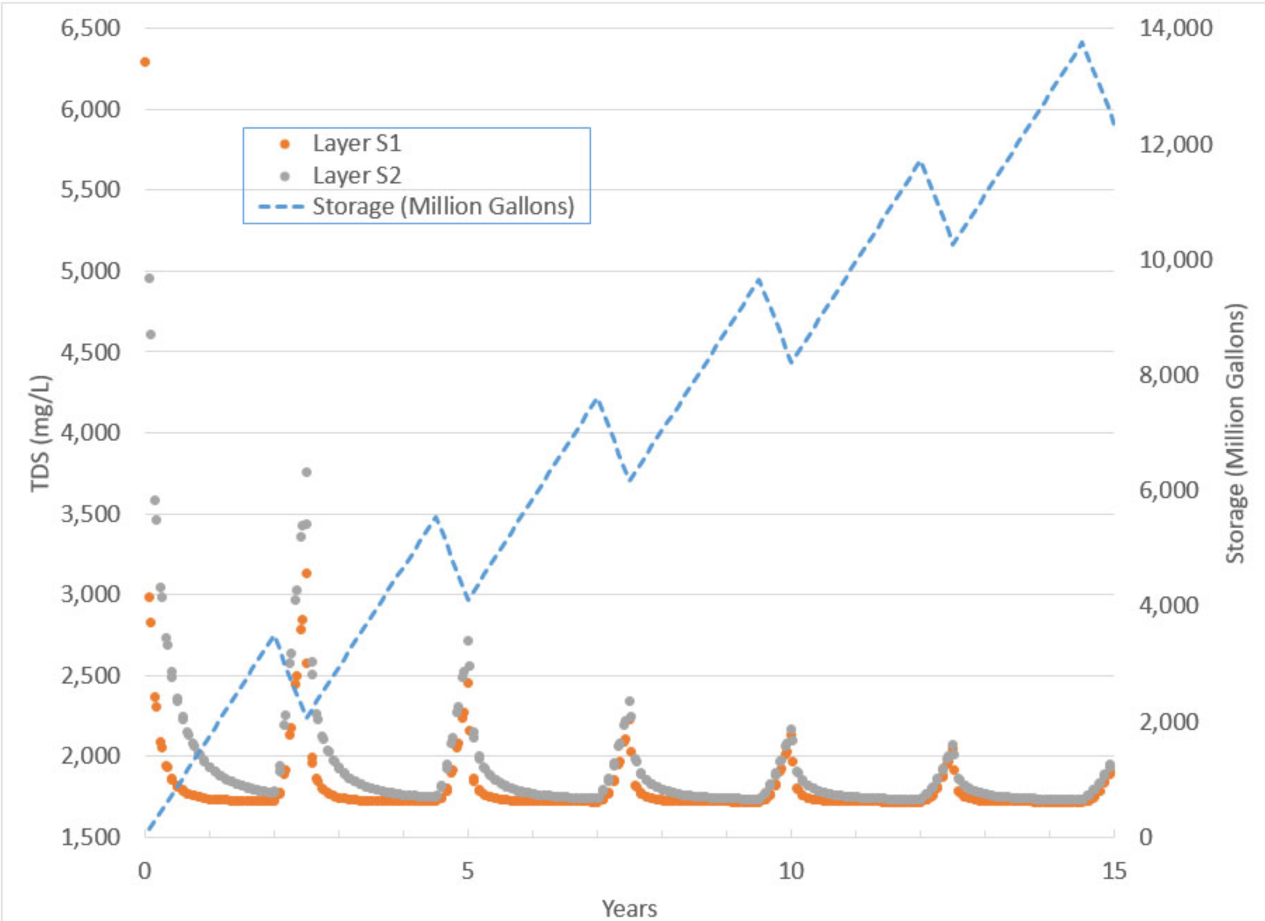
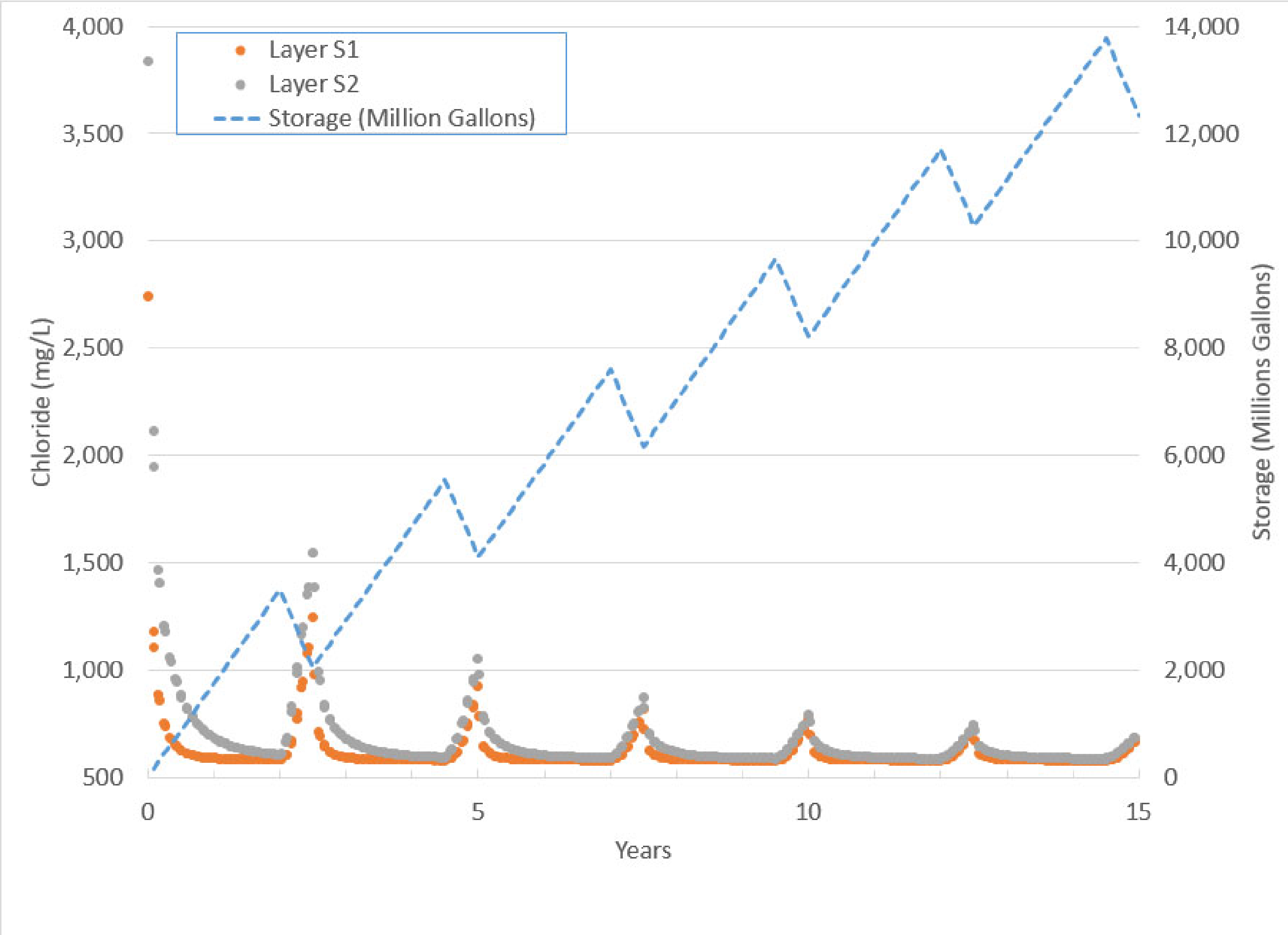


Figure 7-6. Scenario C1- Aquifer Storage Volume and Produced Water Chloride Concentrations (mg/L)



7.4 Scenario C2- Future Demands

Figure 7-7 and 7-8 shows the simulated volume of stored water through time for Scenario C2- Future Demands with 10 ASR wells having a 2 year recharge cycle followed by a nine month recovery cycle. Water storage in the aquifer increased over the first 2 year recharge cycle to about 3,500 MG, which decreased to about 1,500 MG at the end of the first nine month recovery cycle. Water storage increased to about 8,000 MG by the end of the sixth recharge/recovery cycle after 16.5 years (4,300 MG less than the six month recovery cycle under Scenario C1).

Figure 7-7 shows that TDS stabilized below 1,750 mg/L after about one year during the first recharge cycle and increased to about 4,150 mg/L and 4,900 mg/L in model layers 4 and 8 (storage intervals in Figure 4.1), respectively at the end of the first recovery cycle, with an anticipated blended TDS concentration of about 4,550 mg/L (Approximately 1,000 mg/L greater than the shorter first 6 month recovery cycle in Scenario C1). It took about seven months for TDS to stabilize below 1,750 mg/L after the second recharge cycle and increased to about 3,200 mg/L and 3,700 mg/L in model layers 4 and 8, respectively at the end of the second recovery cycle, with an anticipated blended TDS concentration of about 3,500 mg/L (Approximately 1,000 mg/L greater than the second 6 month recovery cycle in Scenario C1). The TDS concentration in the recovered water decreases during the second recovery cycle due to the increase of the recharge water storage volume in the aquifer. By the end of the sixth recovery cycle, the TDS concentration only increased to approximately 2,300 mg/L and 2,550 mg/L in model layers 4 and 8, respectively, with an anticipated blended TDS concentration of about 2,450 mg/L (about 500 mg/L greater than Scenario C1 with the 6 month recovery cycles). This decreasing TDS trend shows that as storage of recharged water increases over successive cycles, thus creating an expanding storage volume, the amount of mixing of native higher salinity water decreases, which results in recovered water that more closely reflects the salinity of the recharged water.

Figure 7-8 shows that chloride stabilized below 600 mg/L after about one year during the first recharge cycle and increased to about 1,700 mg/L and 2,100 mg/L in model layers 4 and 8, respectively at the end of the first recovery cycle, with an anticipated blended chloride concentration of about 1,900 mg/L (Approximately 500 mg/L greater than the shorter first 6 month recovery cycle in Scenario C1). By the end of the sixth recovery cycle, the chloride concentration only increased to approximately 850 mg/L and 950 mg/L in model layers 4 and 8, respectively, with an anticipated blended chloride concentration of 900 mg/L (about 200 mg/L greater than Scenario C1 with the 6 month recovery cycles). Similar to TDS, the decreasing chloride concentration trend shows that as storage of recharged water increases over successive cycles, thus creating an expanding storage volume, the amount of mixing of native higher salinity water decreases, which results in recovered water that more closely reflects the salinity of the recharged water.

Under this scenario, two years is more than adequate for the recharged water to stabilize at low concentrations and suggests that two years of recharge is the minimum amount of time to develop an adequate storage volume and that as the storage reserve is carried over between cycles with additional recharge water added, recovered water quality shows lower TDS and chloride concentrations with subsequent cycles. Furthermore, a nine month recovery cycle leads to greater salinity in the recovered water than the six month recovery cycle.

Figure 7-7. Scenario C2- Aquifer Storage Volume and Produced Water TDS Concentrations (mg/L)

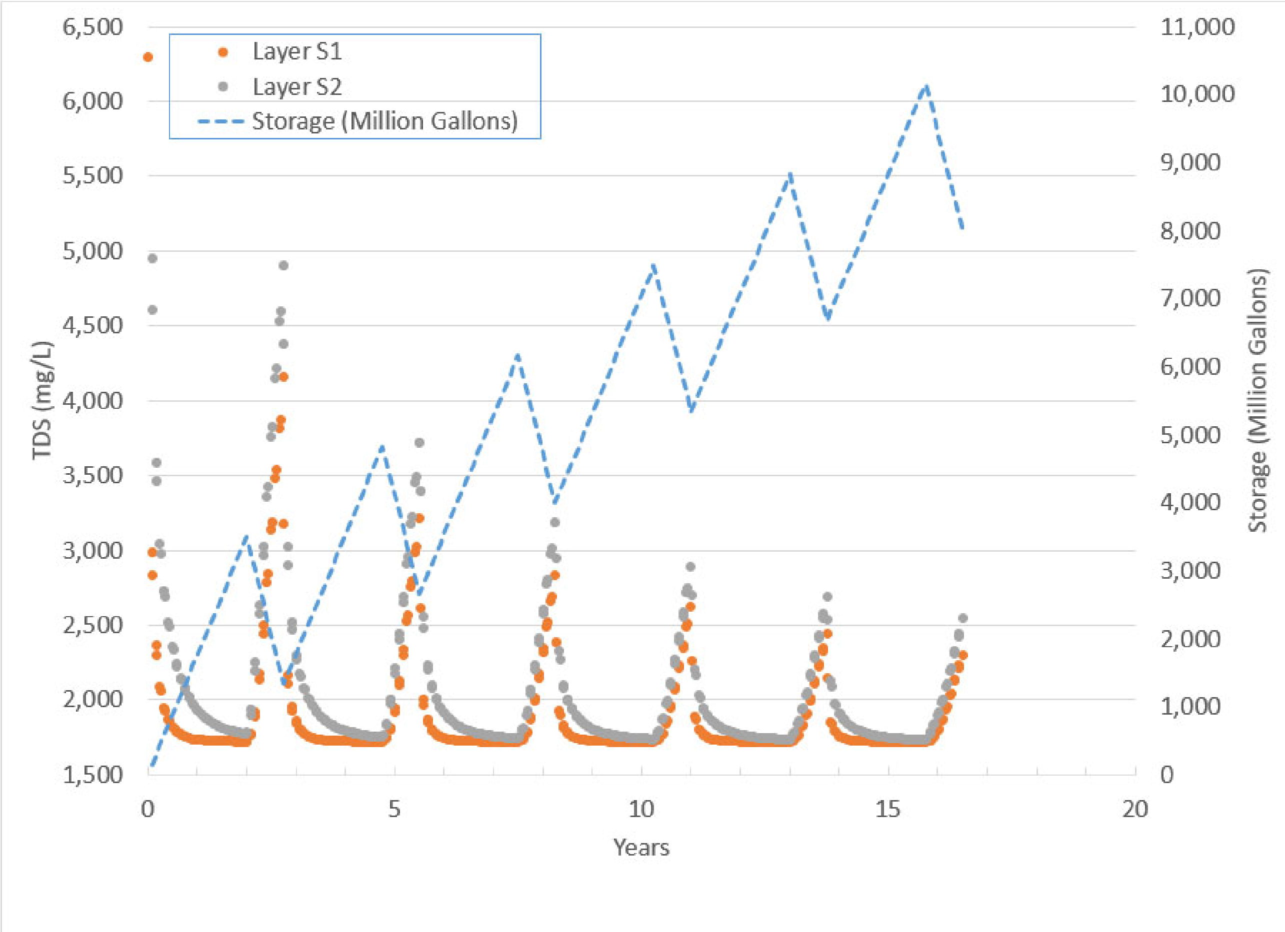
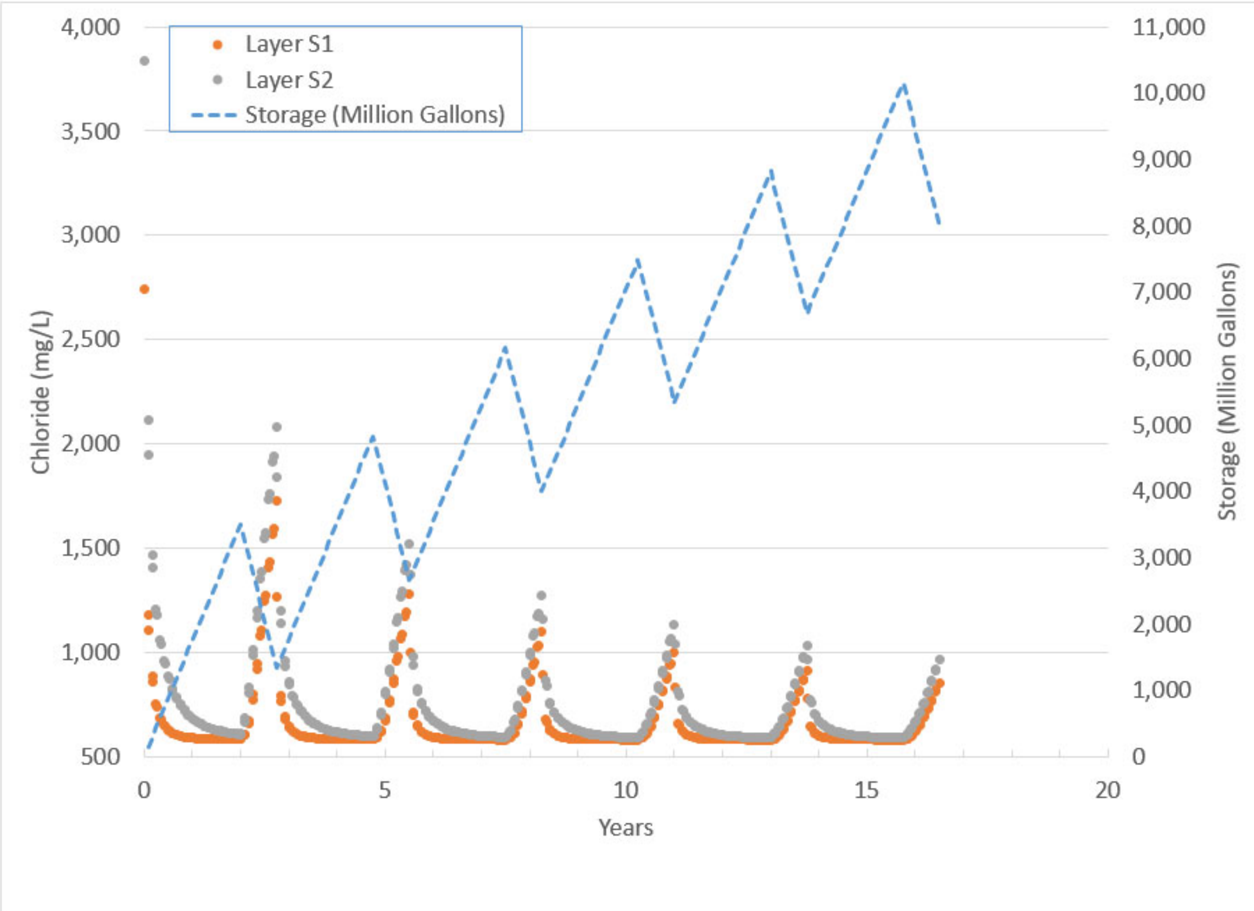


Figure 7-8. Scenario C2- Aquifer Storage Volume and Produced Water Chloride Concentrations (mg/L)



7.5 Scenario D1- Future Demands+ ASR Build-out

Figure 7-9 and 7-10 shows the simulated volume of stored water through time for Scenario D1- Future Demands + Build-out with 15 ASR wells having a 2 year recharge cycle followed by a six month recovery cycle. Water storage in the aquifer increased over the first 2 year recharge cycle to about 5,300 MG, which decreased to about 3,660 MG at the end of the first six month recovery cycle. Water storage increased to about 22,000 MG by the end of the sixth recharge/recovery cycle after 15 years.

Figure 7-9 shows that TDS stabilized below 1,750 mg/L after about one year during the first recharge cycle and increased to about 2,800 mg/L and 3,200 mg/L in model layers 4 and 8 (storage intervals in Figure 4.1), respectively at the end of the first recovery cycle, with an anticipated blended TDS concentration of about 3,000 mg/L. It took about six months for TDS to stabilize below 1,750 mg/L after the second recharge cycle and increased to about 2,250 mg/L and 2,350 mg/L in model layers 4 and 8, respectively at the end of the second recovery cycle, with an anticipated blended TDS concentration of about 2,300 mg/L. The TDS concentration in the recovered water decreases during the second recovery cycle due to the increase of the recharge water storage volume in the aquifer. By the end of the sixth recovery cycle, the TDS concentration only increased to approximately 1,890 mg/L and 1,880 mg/L in model layers 4 and 8, respectively, with an anticipated blended TDS concentration of about 1,885 mg/L. This decreasing TDS trend shows that as storage of recharged water increases over successive cycles, thus creating an expanding storage volume, the amount of mixing of native higher salinity water decreases, which results in recovered water that more closely reflects the salinity of the recharged water.

Figure 7-10 shows that chloride stabilized below 600 mg/L after about one year during the first recharge cycle and increased to about 1,100 mg/L and 1,280 mg/L in model layers 4 and 8, respectively at the end of the first recovery cycle, with an anticipated blended chloride concentration of about 1,200 mg/L. By the end of the sixth recovery cycle, the chloride concentration only increased to approximately 660 mg/L and 660 mg/L in model layers 4 and 8, respectively, with an anticipated blended chloride concentration of 660 mg/L. Similar to TDS, the decreasing chloride concentration trend shows that as storage of recharged water increases over successive cycles, thus creating an expanding storage volume, the amount of mixing of native higher salinity water decreases, which results in recovered water that more closely reflects the salinity of the recharged water.

Under this scenario, two years is more than adequate for the recharged water to stabilize at low concentrations and suggests that two years of recharge is the minimum amount of time to develop an adequate storage volume and that as the storage reserve is carried over between cycles with additional recharge water added, recovered water quality shows lower TDS and chloride concentrations with subsequent cycles.

Figure 7-9. Scenario D1- Aquifer Storage Volume and Produced Water TDS Concentrations (mg/L)

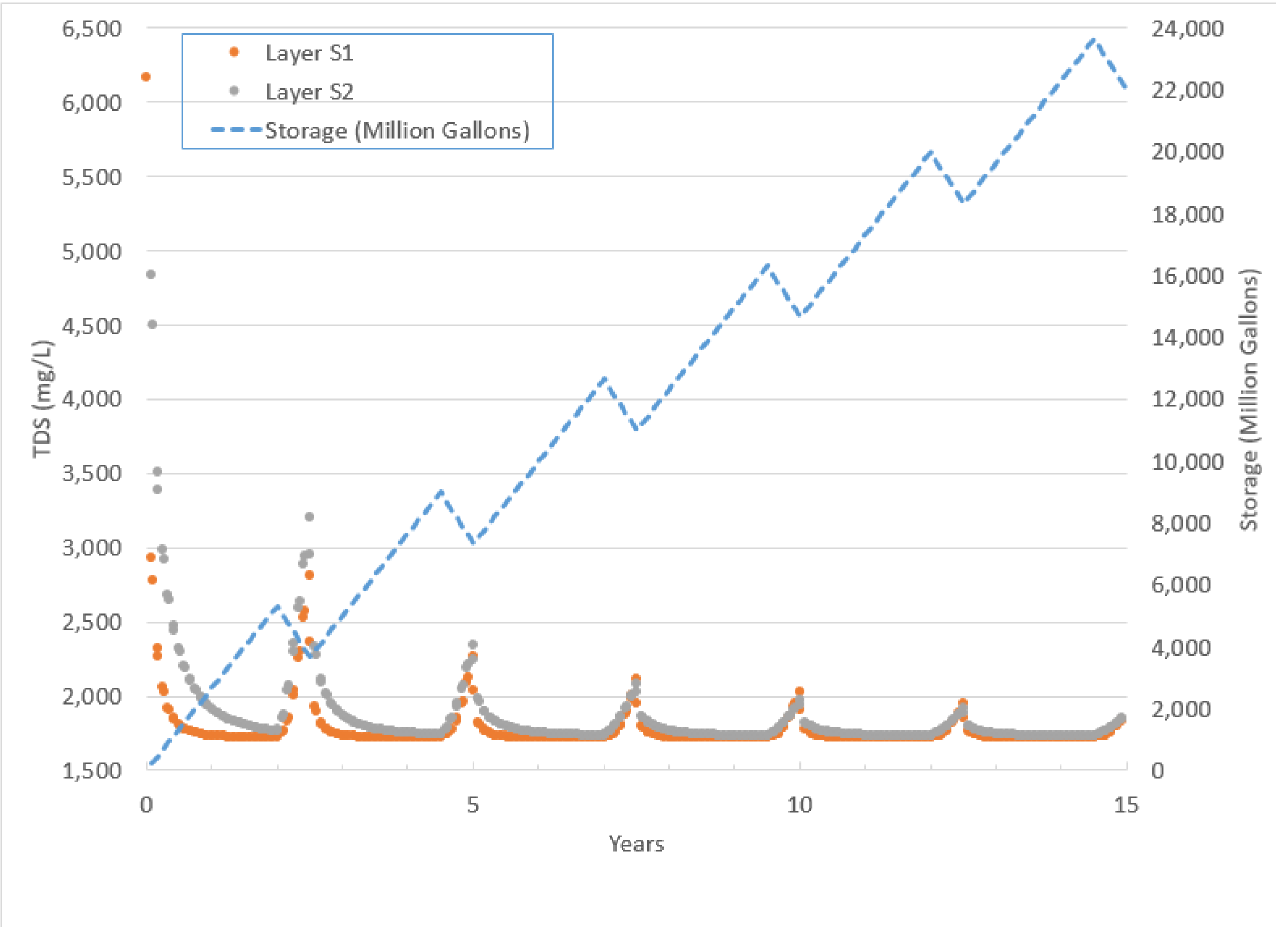
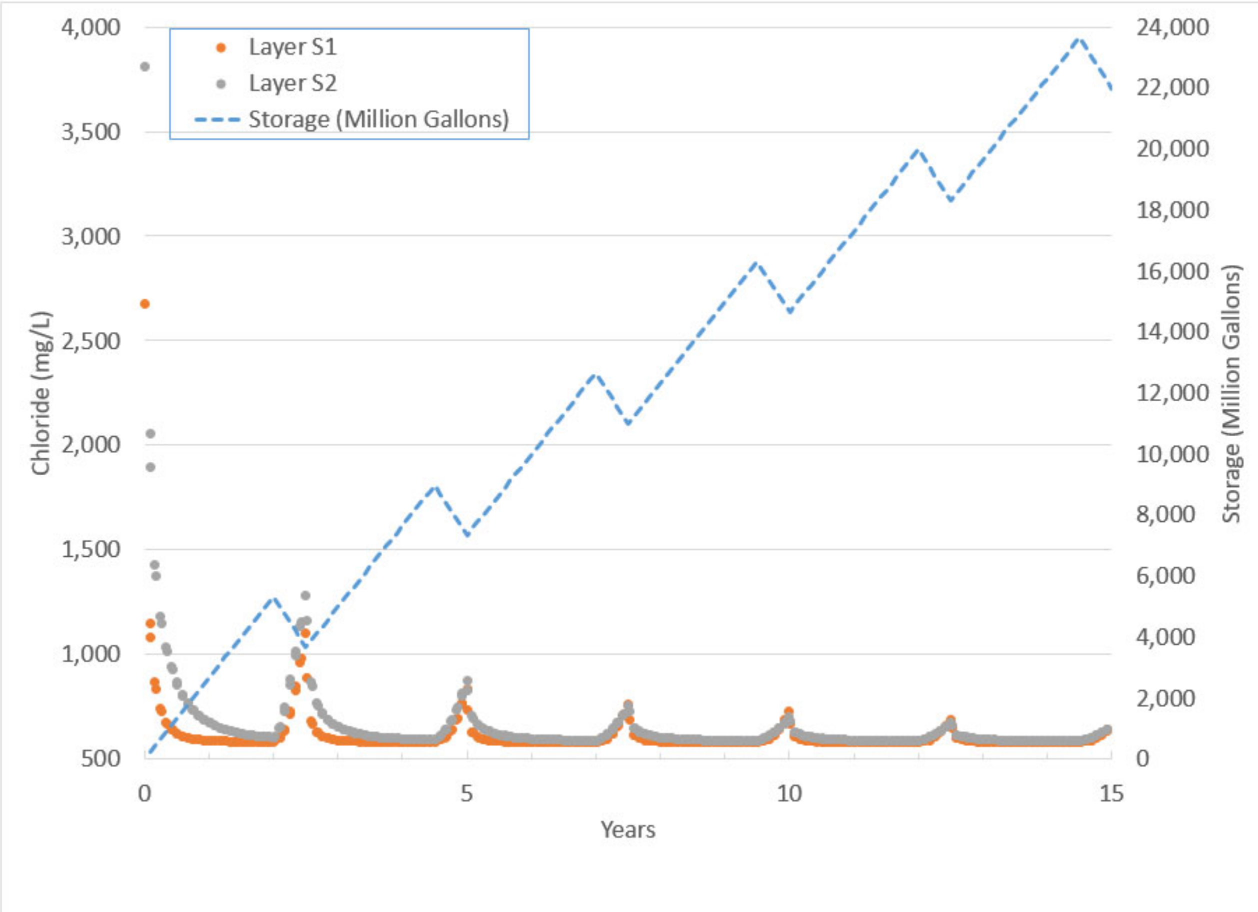


Figure 7-10. Scenario D1- Aquifer Storage Volume and Produced Water Chloride Concentrations (mg/L)



7.6 Scenario D2- Future Demands+ ASR Build-out

Figure 7-11 and 7-12 shows the simulated volume of stored water through time for Scenario D2- Future Demands + Build-out with 15 ASR wells having a 2 year recharge cycle followed by a nine month recovery cycle. Water storage in the aquifer increased over the first 2 year recharge cycle to about 5,300 MG, which decreased to about 2,830 MG at the end of the first nine month recovery cycle. Water storage increased to about 17,000 MG by the end of the sixth recharge/recovery cycle after 16.5 years (5,000 MG less than the six month recovery cycle under Scenario D1).

Figure 7-11 shows that TDS stabilized below 1,750 mg/L after about one year during the first recharge cycle and increased to about 3,630 mg/L and 4,120 mg/L in model layers 4 and 8 (storage intervals in Figure 4.1), respectively at the end of the first recovery cycle, with an anticipated blended TDS concentration of about 3,900 mg/L (Approximately 900 mg/L greater than the shorter first 6 month recovery cycle in Scenario D1). It took about six months for TDS to stabilize below 1,750 mg/L after the second recharge cycle and increased to about 2,830 mg/L and 3,020 mg/L in model layers 4 and 8, respectively at the end of the second recovery cycle, with an anticipated blended TDS concentration of about 2,950 mg/L (approximately 650 mg/L greater than the second 6 month recovery cycle in Scenario D1). The TDS concentration in the recovered water decreases during the second recovery cycle due to the increase of the recharge water storage volume in the aquifer. By the end of the sixth recharge-recovery cycle, the TDS concentration only increased to approximately 2,120 mg/L and 2,150 mg/L in model layers 4 and 8, respectively, with an anticipated blended TDS concentration of about 2,135 mg/L (about 250 mg/L greater than Scenario D1 with the 6 month recovery cycles). This decreasing TDS trend shows that as storage of recharged water increases over successive cycles, thus creating an expanding storage volume, the amount of mixing of native higher salinity water decreases, which results in recovered water that more closely reflects the salinity of the recharged water.

Figure 7-12 shows that chloride stabilized below 600 mg/L after about one year during the first recharge cycle and increased to about 1,475 mg/L and 1,715 mg/L in model layers 4 and 8, respectively at the end of the first recovery cycle, with an anticipated blended chloride concentration of about 1,600 mg/L (Approximately 400 mg/L greater than the shorter first 6 month recovery cycle in Scenario D1). By the end of the sixth recovery cycle, the chloride concentration only increased to approximately 770 mg/L and 780 mg/L in model layers 4 and 8, respectively, with an anticipated blended chloride concentration of 775 mg/L (about 115 mg/L greater than Scenario D1 with the 6 month recovery cycles). Similar to TDS, the decreasing chloride concentration trend shows that as storage of recharged water increases over successive cycles, thus creating an expanding storage volume, the amount of mixing of native higher salinity water decreases, which results in recovered water that more closely reflects the salinity of the recharged water.

Under this scenario, two years is more than adequate for the recharged water to stabilize at low concentrations and suggests that two years of recharge is the minimum amount of time to develop an adequate storage volume and that as the storage reserve is carried over between cycles with additional recharge water added, recovered water quality shows lower TDS and chloride concentrations with subsequent cycles. Furthermore, a nine month recovery cycle leads to greater salinity in the recovered water than the six month recovery cycle.

Figure 7-11. Scenario D2- Aquifer Storage Volume and Produced Water TDS Concentrations (mg/L)

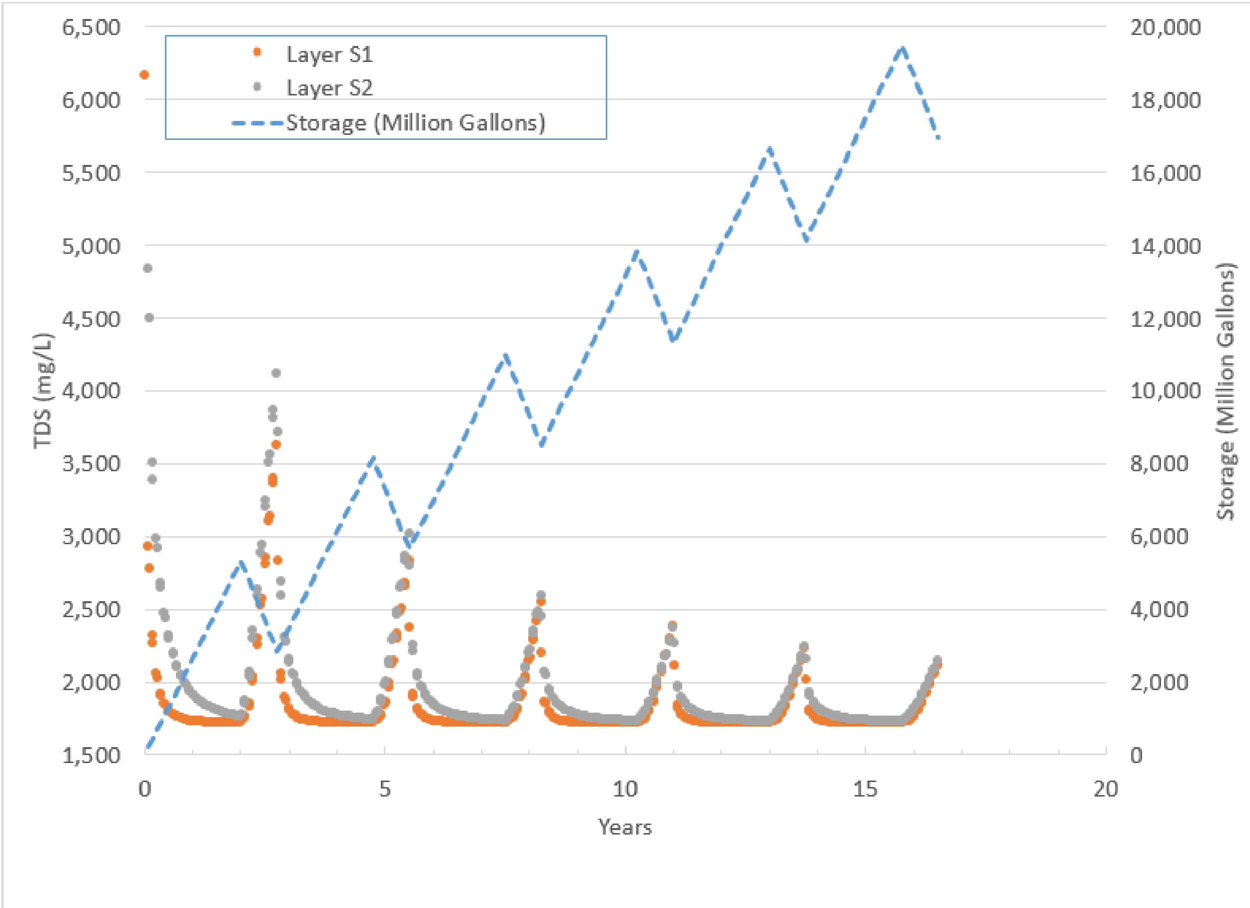
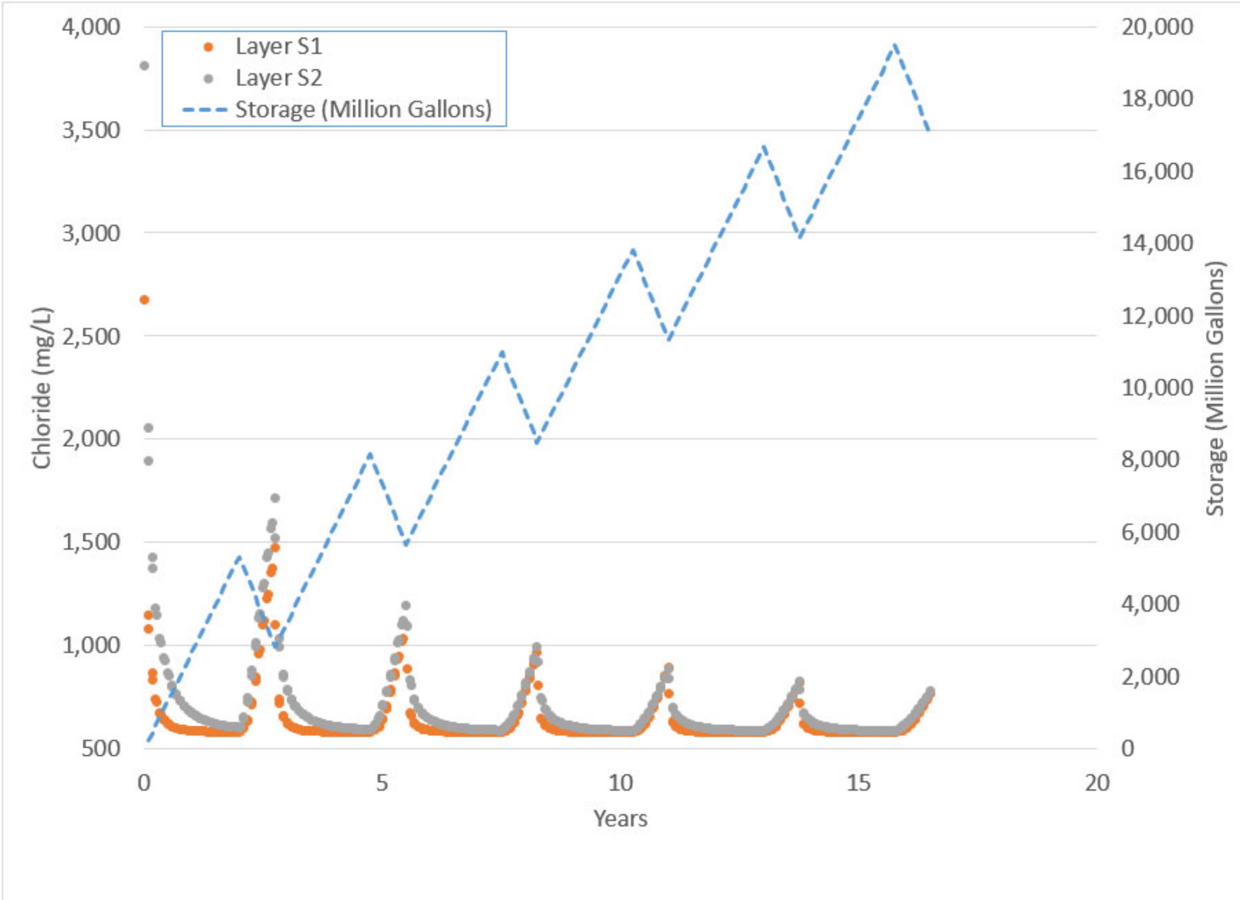


Figure 7-12. Scenario D2- Aquifer Storage Volume and Produced Water Chloride Concentrations (mg/L)



8 Model Scenarios Summary

Table 8-1 provides a summary of the results from Scenarios A through D. The baseline scenario was not summarized as it used a different methodology to determine water quality of recovered water and was mainly used to test the model and evaluate the sensitivity of model parameters.

Scenarios A through D simulated potential operating scenarios and evaluated the wellhead pressure (measured in feet above land surface) and the changes in TDS and chloride during successive recharge and recovery cycles. Scenarios A and B simulated operation during drought conditions using 10 ASR wells and 15 ASR wells, respectively. Scenarios C and D simulated future demands with 10 ASR wells and 15 ASR wells, respectively. All scenarios recharged water with a constant concentration of 1,711 mg/L TDS and 579 chloride.

Table 8-1 shows that the recharge rate for Scenarios A and B (4.8 MGD and 6.6 MGD, respectively) are near the maximum allowable to maintain wellhead pressures under 90 psi (slightly over for Scenario B). At the end of the first recovery cycle, TDS and chloride values near 4,000 mg/L and 1,600 mg/L, respectively and decrease by nearly half by the last recovery cycle.

Scenario C1 and C2 use the same recharge rate of 4.8 MGD for 2 years (10 wells), but use different length recovery cycles of 6 and 9 months, respectively. Wellhead pressures remain well below the maximum allowable pressures by limiting the recharge below 5 MGD, so recharge rates could be increased if the water is available. At the end of the first recovery cycle, TDS values near 3,500 mg/L at the end of the 6 month recovery cycle and 4,600 mg/L at the end of the 9 month recovery cycle, indicating that the 9 month recovery cycle duration may be too great with only 2 years of aquifer recharge. At the end of the last recovery cycle, the TDS values of the 6 month recovery cycle are about 2,000 mg/L and 2,500 mg/L at the end of the 9 month recovery cycle, indicating that enough water has been put into storage to substantially reduce mixing with higher salinity ambient groundwater. Chloride concentrations show the same trends.

Scenario D1 and D2 use the same recharge rate of 7.3 MGD for 2 years (15 wells), but use different length recovery cycles of 6 and 9 months, respectively. Wellhead pressures remain slightly below the maximum allowable pressures, but are near the maximum allowable. At the end of the first recovery cycle, TDS values near 3,000 mg/L at the end of the 6 month recovery cycle and 4,000 mg/L at the end of the 9 month recovery cycle, indicating that the 9 month recovery cycle duration may be too great with only 2 years of aquifer recharge. At the end of the last recovery cycle, the TDS values of the 6 month and 9 month recovery cycle are about 2,000 mg/L, indicating that enough water has been put into storage to substantially reduce mixing with higher salinity ambient groundwater. Chloride concentrations show the same trends.

All model simulations met the criteria of a maximum 5,000 mg/L TDS or 2,000 mg/L chloride within the recovered water during the timeframes simulated. However, scenario C2 nearly exceeded the maximum concentrations considered and likely would have exceeded the maximum concentrations if the recovery period was a couple of months longer. Generally, wellhead pressure will likely be a bigger limiting factor than TDS and chloride increasing during recovery cycles, unless the concentration threshold is lowered to meet more stringent industrial use standards.

Field ASR cycle testing will need to confirm actual wellhead pressures as the analysis includes a twenty percent head increase due to inefficiencies within each ASR well that may be a conservative value. Additionally, the model shows that the storage buffer zone does not substantially drift in any one direction away from each ASR well due to the relatively low hydraulic conductivity and lack of a strong water level gradient. However, likely heterogeneity of the aquifer hydraulic conductivity may yield a storage buffer zone that migrates to one direction away from the ASR well that may result in more mixing of higher salinity ambient groundwater and reduce the quality of recovered water.

Table 8-1. Summary of Model Scenario Results

	Scenario	A[1]	B[2]	C1[3]	C2[3]	D1[4]	D2[4]
	Number of ASR Wells	10	15	10	10	15	15
	Recharge Cycle Length (Years)	5	5	2	2	2	2
	Recovery Cycle Length (Years)	1.50	2.00	0.50	0.75	0.50	0.75
	Total Recharge (MGD)	4.8	6.6	4.8	4.8	7.3	7.3
	Total Recovery (MGD)	7.9	8.2	7.9	7.9	9.1	9.1
	Greatest Individual Wellhead Pressure (Ft of Water Above Land Surface)	205	211[5]	175	175	205	205
After 1st Recharge / Recovery Cycle	Total Storage Volume (MG)	4,500	6,000	2,050	1,500	3,660	2,830
	TDS (mg/L) of Recovered Water	3,500	3,700	3,450	4,550	3,000	3,900
	Chloride (mg/L) of Recovered Water	1,400	1,550	1,400	1,900	1,200	1,600
After 6 Recharge / Recovery Cycles	Total Storage Volume (MG)	30,500	36,000	12,300	8,000	22,000	17,000
	TDS (mg/L) of Recovered Water	2,100	2,120	1,975	2,450	1,885	2,135
	Chloride (mg/L) of Recovered Water	750	760	705	900	660	775

[1]Constrained to 5 MGD Recharge and 8.4 MGD Recovery or a wellhead pressure (in feet above land surface) of 209 feet

[2]Constrained to 8 MGD Recharge and 10 MGD Recovery or a wellhead pressure (in feet above land surface) of 209 feet

[3]Constrained to 5 MGD Recharge and 9 MGD Recovery or a wellhead pressure (in feet above land surface) of 209 feet

[4]Constrained to 8 MGD Recharge and 10 MGD Recovery or a wellhead pressure (in feet above land surface) of 209 feet

[5]211 feet is acceptable because the top of the storage zone is 400 feet below surface, which allows for a pressure of 100 psi (230 feet)

9 Model Assumptions and Limitations

The groundwater model was developed to represent the conceptual model of the Gulf Coast Aquifer system within the District's jurisdiction near the Corpus Christi International Airport. The model design relied upon data from the exploratory test drilling program and other sources. Key model assumptions and limitations are discussed below, including how they might affect the predictions made using the model.

9.1 Stratigraphy

The conceptualization of stratigraphy was based on correlating sand intervals between locations where geophysical logs were available. There is an inherent assumption that the sand intervals are continuous and connected between the logging sites. The Gulf Coast aquifer is heterogeneous, and we did not have enough data density to calculate a correlation length for the sands. If the sands are not continuous, then instead of the recharge water moving horizontally along an interval out to the target storage volume radius, the water may encounter pinchouts or other obstructions that deflect it vertically up or down. This effect of heterogeneity is likely to decrease the recoverability of the recharge water.

Similarly, the confining units separating the sands were assumed to be continuous between the logs. If the confining units are missing in areas, the recharge water may tend to migrate vertically in these missing areas. This also has the potential to affect the recoverability of the recharge water.

Similarly, the confining units separating the sands were assumed to be continuous between the logs. If the confining units are missing in areas, the recharge water may tend to migrate vertically in these missing areas. This also has the potential to affect the recoverability of the recharge water. Cycle testing of test ASR wells and/or additional boreholes and testing in the areas of ASR sites would aid in the elimination of uncertainty concerning the continuity of confining units and the heterogeneity of the aquifer units.

9.2 Hydraulic Properties

The horizontal hydraulic conductivities used to parameterize the model were based on a limited number (two) pump tests. We assumed that the properties extended throughout the model grid, beyond the radius of influence of the pump tests. If the hydraulic conductivities are higher or lower in areas away from the test wells, then productivity of the wells will vary accordingly.

The vertical hydraulic conductivity of the clay beds was estimated based on values from models of the Gulf Coast Aquifer. Because there are so few estimates of vertical conductivity at the required scale, this is a common approach to parameterization. If the vertical conductivity of the clays is much higher or lower than assumed, then the confinement will correspondingly be worse or better, respectively.

9.3 Transport Properties

The key transport properties, porosity and dispersivity, were estimated from literature values. While porosity should not have a large effect on recoverability, if dispersivity is much higher than simulated, then the recoverability may decrease due to the increased size of the mixing zone. An increased mixing zone size would increase the mixing of recharged water with ambient groundwater that have greater salinity values.

10 Summary of Modeling Findings and Operational Considerations for Long-Term Water Supply Program

- The optimal recharge rate of all ASR wells combined is approximately 5 MGD for 10 Phase 1 ASR wells and 7.3 MGD for a combined Phase 1 and Phase 2 ASR 15 well program to maintain wellhead pressures below 90 psi. Combined rates higher than 5 MGD for Phase 1 and 7.3 MGD for Phase 1 + 2 may exceed 90 psi wellhead pressures in some ASR wells.

- The possibility exists that water levels may rise above land surface in existing and/or abandoned wells within the immediate area of ASR wellfield if the well is screened or has leaking or unsealed casing within the ASR storage interval.
- Model simulations indicate that, initially, it will require at least two years of aquifer recharge to develop a sufficient volume of storage to facilitate six months of recovery of water without significant increases to salinity. Subsequent recharge cycles could be shorter and allow for slightly longer recovery cycles, as evidenced by the continual decrease in recovered water salinity during successive recovery cycles.
- Developing the target storage volume may require recharge rates nearing 5 MGD for Phase 1 ASR wells or 7.3 MGD for Phase 1 + Phase 2 ASR wells for at least two years, which would establish a storage volume of about 3,500 MG and 5,300 MG, respectively. This would allow a recovery volume of about 1,500 MG over six months at a rate of 8 MGD for 10 wells and 9 MGD for 15 wells and still maintain relatively low salinity of the recovered water. Withdrawing for more than 6 months after 2 years of recharge may induce unacceptable salinity levels until a greater volume of water is recharged into storage.
- For drought protection, if water is recharged into aquifer storage for up to 5 years at a rate of 5 MGD in Phase 1 ASR wells, water could be recovered for up 1.5 years at a rate of 8 MGD. Repeating this cycle shows that water storage continues to increase and salinity of the recovered water continues to decrease.
- Cycle testing of a pilot ASR well would be needed to validate the model findings and establish long-term operating procedures. If the cycle testing mimicked the schedule simulated during modeling, the findings could either validate the results of the model or be used to calibrate the model to actual site conditions that would allow for more precise model results.

11 Recommendations for Future Work and Model Updates

ASR cycle testing in a pilot test well would provide the data to confirm model simulation results or update the model parameters. Data collected from cycle testing could be used to calibrate the model water levels and salinity with ASR operation, to provide more accurate values for transport parameters, such as porosity and dispersivity, and identify variability of hydraulic conductivity measurements affecting the design and implementation of full-scale ASR project in accordance with the District's Five Year Plan.

12 References

Fogg, G.E., 1986. Groundwater flow and sand body interconnectedness in a thick, multiple-aquifer system. Water Resources Research, 22(5), pp.679-694.

Gelhar, L.W., Welty, C. and Rehfeldt, K.R., 1992. A critical review of data on field-scale dispersion in aquifers. Water resources research, 28(7), pp.1955-1974.

Niswonger, R.G., Panday, Sorab, and Ibaraki, Motomu, 2011. MODFLOW-NWT, A Newton formulation for MODFLOW-2005: U.S. Geological Survey Techniques and Methods 6–A37, 44 p.

Peaceman, D.W., 1983. Interpretation of Well-Block Pressures in Numerical Reservoir Simulation With Nonsquare Grid Blocks and Anisotropic Permeability, paper SPE 10528, SPE Journal (June 1983), 531-543.

Trescott, P.C., Pinder, G.F. and Larson, S.P., 1976. Finite-difference model for aquifer simulation in two dimensions with results of numerical experiments (p. 116). US Government Printing Office.

Young, S.C., Jigmond, M., Deeds, N.E, Blainey and J. Ewing, T.E., 2016. Identification of Potential Brackish Groundwater Production Areas – Gulf Coast Aquifer System. TWDB Contract Number 1600011947. 664 pp.

Ward, J.D., Simmons, C.T. and Dillon, P.J., 2008. Variable-density modelling of multiple-cycle aquifer storage and recovery (ASR): Importance of anisotropy and layered heterogeneity in brackish aquifers. Journal of hydrology, 356(1-2), pp.93-105.

Zheng, Chunmiao and Wang, P. Patrick, 1999. MT3DMS: A Modular Three-Dimensional Multispecies Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems; Documentation and User's Guide; prepared for U.S. Army Corp of Engineers: Contract report SERDP; 99-1.

Appendix

Background Development of Modeling Scenarios

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Greenwood WWTP effluent availability (i.e. ASR recharge potential)
Based on conversations with John Byrum, 1/29/19 and 2/4/2019

- **Current Supply-** Assume 4.5-5 MGD effluent available from Greenwood WWTP for potential ASR use. Currently, there is a plan to divert 2 MGD to Broadway WWTP. A reasonable assumption for ASR potential is 63% of total plant capacity.
- **Future Expansion-** Anticipate expanding Greenwood WWTP capacity to 12 MGD by Year 2025-2030. In next 10 years, likely up to 7.5-8 MGD treated effluent available for potential ASR use.
- **Reuse Contracts-** Negligible amount of treated effluent delivered to Lozano Golf Course and Champions Ball Park
- **Water Quality-** Greenwood WWTP effluent generally has minimal fluctuations in water quality. No violations in TSS. Limited opportunities for Broadway reuse due to high chlorides.

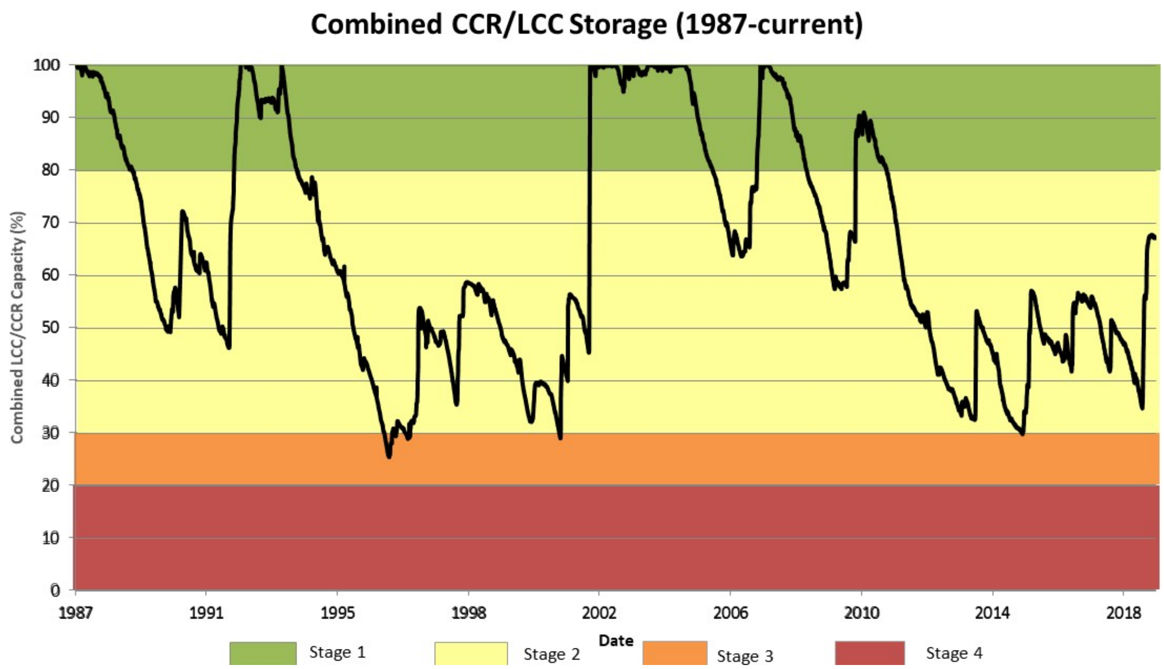
Local Industrial Demands/Water Quality Needs (i.e. ASR recovery potential)
Based on conversations with Industrial Representatives and Corpus Christi Regional EDC, 1/23/19-1/24/19 and 2/4/19-2/5/19

- **Future Projected Demands-** Recent growth of about 5.2 MGD in past 3 years Nueces County-industrial growth. Additional 10.3 to 12 MGD anticipated with LyondellBasell expansions, Noble Energy, Epic, Permico, and others.
- **ASR Potential to Meet Industrial Demands-** "If 7-9 MGD water supply was available in the next few years, the industrial demand would eagerly purchase it from the City" (M. Culbertson, EDC)
- **Water Quality-** No specific water quality standards, generally plants will accept raw and/or drinking water quality. Some facilities has RO treatment facilities on site, however higher TDS (>1000 mg/L) and calcium would increase O&M costs. Less stringent water quality needs for cooling (fewer cycles as TDS increases). Boiler processes are sensitive to TDS.
- **Minimal Seasonal Use Fluctuations-** Generally there are minimal fluctuations in use patterns. In general each plant tries to operate at maximum capacity, requiring full water demand.

Source of Base Map: City of Corpus Christi, 2014. ASR study site location added by HDR.

Drought Mitigation (i.e. ASR recovery potential)

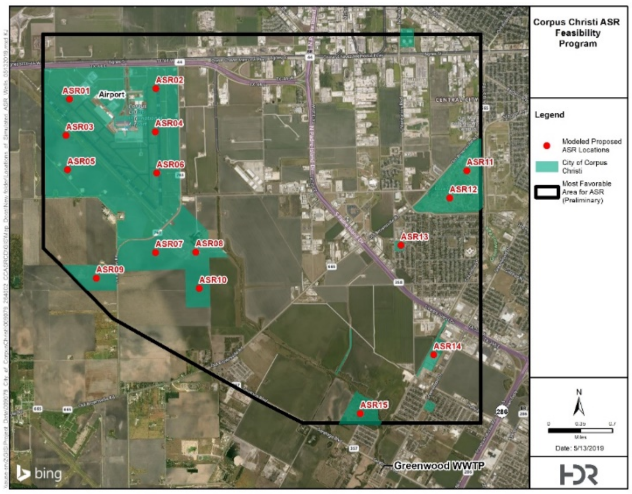
- **Past Events when CCR/LCC Combined Storage was <40% (since initial fill of CCR in 1987)**
    - Feb 22, 1996 to June 23, 1997 (474 days)- Most Severe
        - Below 30%- July 3 to Sept 24, 1996 (84 days); Oct 26 to Nov 5 (11 days); Feb 18 to Apr 4, 1997 (46 days). Total time- 141 days
    - July 16, 2000 to Sept 5, 2001 (417 days)
        - Below 30%- Aug 18 to Aug 31, 2001 (14 days)
    - Dec 7, 2012 to Oct 23, 2013 (321 days)
    - July 8, 2014 to May 12, 2015 (307 days)
    - July 16, 2018 to Sept 15, 2018 (62 days)
- **Longest Period of Time CCR/LCC Combined Storage <40%- 474 days**
- **Total ASR recovery needed to overcome reductions for 2020-2060 Demands-** 7.5 MGD – 8.4 MGD for 1.3 years (474 days)



Anticipated Water Supply Reductions for Repeat of Feb 1996-June 1997 Drought Conditions for Year 2020-2070 Manufacturing Demands
(474 days < 40% CCR/LCC capacity)

Water Demand (ac-ft/yr)		2020	2030	2040	2050	2060	2070
NUECES	MANUFACTURING	45,411	50,363	50,363	50,363	50,363	50,363
SAN PATRICIO	MANUFACTURING	38841	43223	43223	43223	43223	43223
Based on repeat of 2/22/96 to 6/23/97 drought (474 days total) Relative to Year 2020-2070 demands per 2021 Region N Plan	**Anticipated Water Supply Reductions for Severe Drought Conditions (ac-ft/yr)**						
	DCP reduction- For Nueces County assumes 15% for <30% CCR/LCC storage; For San Patricio County assumes 10% for 30-40% CCR/LCC storage; 15% <30% CCR/LCC storage (over 474 day period)						
		2020	*2030*	*2040*	*2050*	*2060*	*2070*
	Nueces- Industry (15% <30 only)	2,631	2,918	2,918	2,918	2,918	2,918
	San Patricio- Industry	5,794	6,448	6,448	6,448	6,448	6,448
	Nueces- MGD	2.3	2.6	2.6	2.6	2.6	2.6
	San Patricio- MGD	5.2	5.8	5.8	5.8	5.8	5.8
	Total- MGD	**7.5**	**8.4**	**8.4**	**8.4**	**8.4**	**8.4**

Exhibit G Memo- ASR Operating Policy Considerations



ASR Operating Policy Considerations- Technical Memorandum

Corpus Christi Aquifer Storage and Recovery Feasibility Study (E16265)

Corpus Christi, Texas

August 29, 2019

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Appendix

1 Executive Summary

This memorandum discusses ASR operating policy considerations to mitigate risk and uncertainty based on results gathered during previous ASR feasibility study tasks, including exploratory test program, geochemical analysis, and groundwater modeling of ASR operating scenarios.

Based on the results of this ASR study, it is estimated that a project yield of 13-18 MGD is attainable. The operating scenarios showed that ASR operations could be configured to meet uninterruptible industrial demands during severe drought conditions or used seasonally to respond to peak demands or higher usage months. Results of the operations modeling suggests that volumetric recovery of at least 61 percent can be achieved on the initial recovery cycle with a maximum TDS concentration less than 5,000 mg/L. Both ASR operating approaches to meet severe drought conditions or with seasonal operation to respond to peak demands or higher usage months achieve recovered water quality between 1,975 to 2,450 mg/L after a few cycles.

The proposed ASR project is located within the jurisdiction of the Corpus Christi Aquifer Storage and Recovery Conservation District (District). The District and City have an interlocal agreement, that when exercised, allows them to collaboratively manage and operate the proposed ASR project for beneficial water supply purposes.

Rules governing most facets of ASR project implementation in Texas are administered by the TCEQ and are contained in Title 30 of the Texas Administrative Code (30 TAC), Chapter 331, Underground Injection Control (UIC). The requirements in 30 TAC§331.186 (a) outlines the criteria to be consider by TCEQ in authorizing ASR operations. The effluent from the Greenwood WWTP does not currently meet drinking water standards for chloride, TDS, manganese, and nitrate concentration, or pathogen removal. While it is anticipated that nitrate and manganese will likely be below the drinking water maximum contaminant limit after tertiary treatment, the other parameters will not be significantly altered prior to injection. As such, the City will need to demonstrate to the TCEQ that proposed ASR well operations will not: 1) render the groundwater produced from the receiving formation harmful or detrimental to people, animals, vegetation, or property, or 2) require an unreasonably higher level of treatment of the groundwater produced from the receiving geologic formation than is necessary for the native groundwater in order to render the groundwater suitable for beneficial use. A successful ASR well application for the CCASR project will need to provide evidence in the permit application that the City has sufficient surface control to prevent access to stored water that does not meet drinking standards, or at a minimum, to water that is harmful to people.

There are several ASR operating policy aspects to consider to mitigate risk and uncertainty, which include:

- Protecting stored water, including confirming existing wells that may be impacted with ASR operations and enforcing District rules that prohibit drilling in ASR protection area;

- Compliance with TCEQ regulations, including achieving any exemptions as may be required based on site-specific conditions including water quality;
- Consistent recharge water quality that is treated according to TCEQ standards at levels to minimize well clogging and/or clay fragmentation
- Continuous monitoring by the District after implementing ASR Phase I or II programs to (a) reduce influence of existing wells on or resulting from ASR operations (b) record subsidence data prior to ASR construction and during ASR operation and (c) record water levels and water quality.

The most likely use of recovered water from ASR is for non-potable, industrial demands. The geochemical analysis did not present any fatal flaws, however tertiary treatment of Greenwood WWTP treated effluent would be needed to reduce nutrient, pathogen, and organic concentrations prior to recharge to meet regulatory needs and facilitate a successful ASR program. If the City's needs change in the future then advanced treatment after ASR recovery could treat to potable standards for integration in the potable distribution system near the project site.

Based on the exploratory test drilling program results, the most favorable ASR storage intervals are located between 350 and 800 feet below ground surface. Although the modeled ASR wells are operated during recharge to limit wellhead pressures to a maximum safe operating condition (Railroad Commission of Texas, 2016), water level rises are expected during recharge events. If an existing well is screened in the target zone or has unsealed or leaking casings in deeper wells, then the well will flow and cause the area to become water logged. To provide a conservative estimate for planning purposes, there were six wells in the study area identified with depths between 300 and 1000 feet below ground surface that are likely impacted with Phase I and II ASR operation. There may be additional wells outside the study area below that could be affected during long-term ASR operation that would need to be monitored. If artesian conditions occur after construction and implementation of the ASR program, ASR operations should be revisited and/or wells plugged depending on condition and owner use. It is recommended that oil and gas well locations in the vicinity of ASR site are monitored during ASR operations to verify information reported by the RRC regarding surface casing depths and that inactive wells have been plugged appropriately.

The pilot well test program is needed to confirm aquifer response, operations, prove up geochemical interactions, and identify criteria for appropriate design and operations of a full scale ASR program.

2 Introduction

The Corpus Christi Aquifer Storage and Recovery District (District), with contracting authority through the City of Corpus Christi (City), hired HDR to conduct an investigation of aquifer storage and recovery (ASR) feasibility within the District area. The feasibility study included exploratory test drilling, geochemical analysis, and groundwater modeling to evaluate the suitability of local aquifers for ASR operations and to identify ASR operating policy considerations summarized in this technical memorandum. The exploratory test drilling program was conducted at four City-owned sites located near the Corpus Christi International Airport from October 9, 2017 to May 15, 2018. A geochemical analysis was then performed using data collected during the exploratory test drilling program to determine the compatibility of storing treated effluent from Greenwood Wastewater Treatment Plant (WWTP) or potable water from O.N. Stevens Water Treatment Plant (WTP) within the native aquifer setting. Based on native groundwater quality and growing industrial water demand needs, the City suggested that treated effluent from Greenwood WWTP would likely be the best source for ASR. Information gathered was then used to develop a Field Scale Groundwater Model to evaluate potential ASR operating scenarios for various recharge and recovery rates, schedule, and the resulting impact on water quality of recovered water from storage. The results of the exploratory test drilling program, geochemical analysis, and field scale groundwater model operating scenarios are summarized in technical memorandums issued October 4, 2018, February 6, 2019, and May 9, 2019 respectively.

This technical memorandum presents ASR operating policy considerations to mitigate risk and uncertainty based on results gathered during this ASR feasibility study tasks described above. The topics described in this memorandum include: Texas Commission on Environmental Quality (TCEQ) regulatory framework, water quality standards, subsidence, and groundwater management considerations for ASR supply protection.

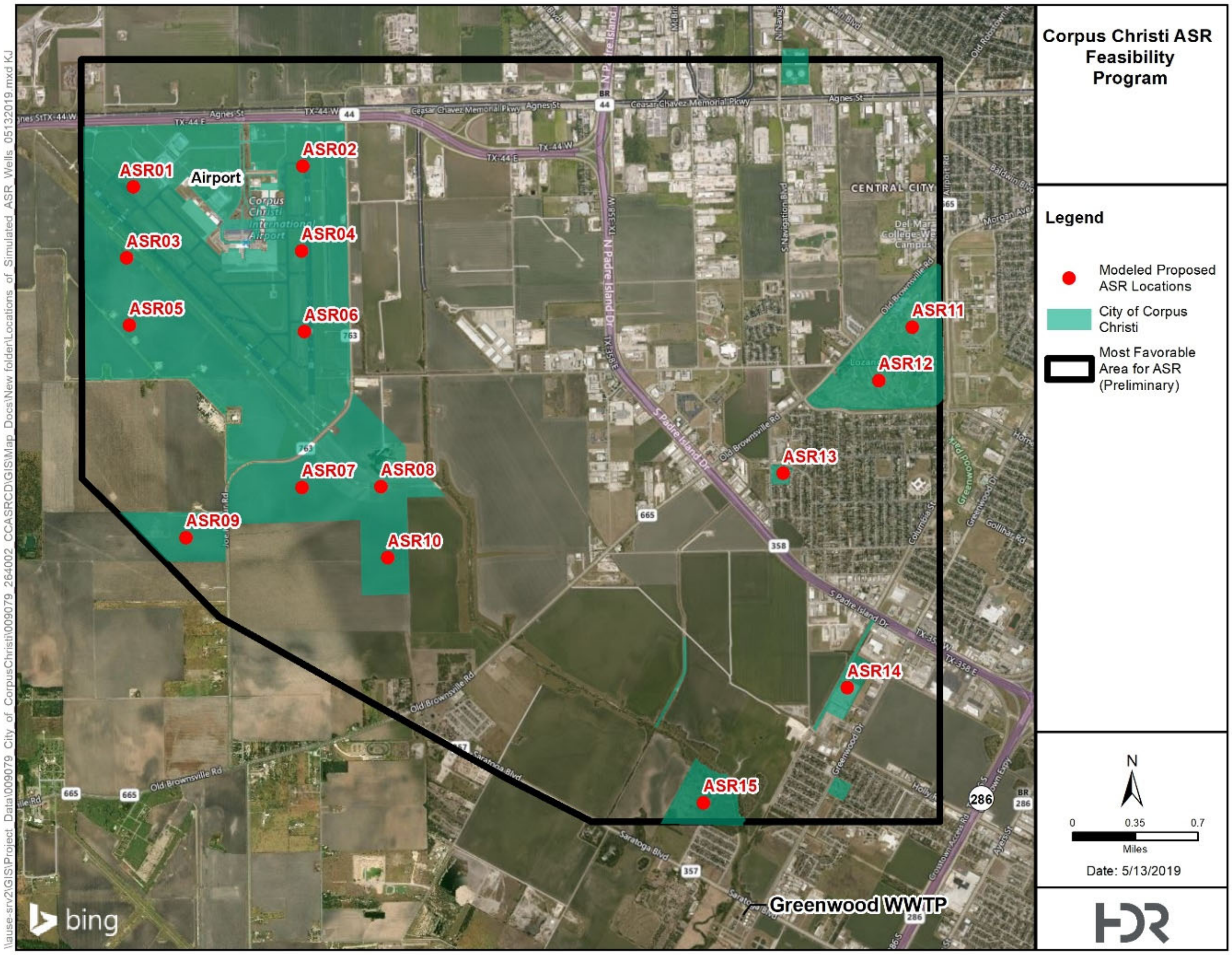
3 Estimated Project Supply

3.1 Study Area

The study area included in the model is located within the boundaries of the District, which is within the City of Corpus Christi city limits in Nueces County. Although the model extends beyond the active ASR study area to address boundary conditions, the ASR wells simulated in the model are located at the Corpus Christi International Airport, Westhaven Park, and Lozano Golf Course. Site selections were based on findings from the exploratory test drilling program. Figure 3-1 shows proposed locations of ASR wells, with all being located on City-owned properties.

Based on information gathered from City Staff on Greenwood WWTP effluent volume available for storage and stakeholder feedback on likely industrial water demands and future growth, the ASR project was evaluated to consist of two phases. Phase I is focused on 10 wells at the Corpus Christi International Airport site and Phase II would add an additional 5 wells to the east of Phase I. Phase I limits recharge to 5 MGD, which isbased on Greenwood WWTP capacity constraints and would be capable of providing up to 8 MGD through recovery at ASR wells. If treated, Greenwood WWTP treatment effluent is delivered concurrent with ASR recovery, then the combined water supply would be 13 MGD. Phase I and II operated conjunctively would be capable of providing about 10 MGD from ASR well operation, or up to 18 MGD with Greenwood WWTP expansion[1].

Figure 3-1. Modeled ASR Wells and City Owned Properties



3.2 Well Yield and Recovery Efficiencies

The effective yield for an ASR system can be limited by the sustainable recovery rate of the ASR wells or, if the native groundwater (NGW) is of a lesser quality than the water being stored, the quality of the recovered water relative to the intended use. For the ASR project, both recovery rate and water quality have the potential to limit project yield. Based on information gathered during the Exploratory Test Drilling Program, all 10 Phase I ASR wells would be completed in sand intervals S1 and S2

[1] Based on City staff feedback, Greenwood WWTP expansion to 12 MGD by Year 2025-2030 would result in about 8 MGD treated effluent available for potential ASR use.

for storage, with 4 of the 5 Phase II wells being completed exclusively in S1 (HDR, May 2019). The top of the upper most sand interval (S1), which varies between 350 and 450 feet below land surface (ft bls) in the study area, represents one potential limitation on the maximum recovery rate.

Water quality samples collected during test drilling indicated that S1 and S2 have TDS concentrations of approximately 9,545 mg/L and 14,085 mg/L, respectively (HDR, May 2019). NGW TDS levels are significantly above the 2,000 to 5,000 mg/L target level identified as having the greatest applicability to potential industrial users. With the TDS concentration of treated effluent from the Greenwood WWTP estimated at approximately 1,711 mg/L, as the concentration of NGW approaches 40 percent in the recovered water, the TDS concentration exceeds 5,000 mg/L, significantly reducing potential uses for the recovered blend.

Several factors influence the NGW content in the recovered water. Some important factors include:

- volume of recharge water in storage at the end of the recovery period;
- duration of recharge (and storage) periods preceding recovery relative to the regional migration rate of NGW in the storage interval; and
- proximity of adjacent recharge extent associated with other ASR wells.

In general, the usable volume of recovered water improves as the total volume of water in storage increases and the relative age of the water in storage decreases. The proximity of adjacent wells is only a significant factor if there is a significant regional gradient or if recharge and recovery volumes and rates are substantially out of balance between adjacent ASR wells.

Assuming no supply constraints, recharge rates can be limited by the allowable maximum well pressure and the target recovery rate. Excessive recharge pressure can result in hydraulic fracturing in the recharge interval and, potentially, the vertically adjacent confining units. Following fracturing, stored water can exit the storage zone through vertical flow paths when recharge zone pressures are elevated (during recharge operations). These same flow paths close as recovery is initiated and storage zone pressures decline, trapping stored water in the adjacent zone and negatively affecting recovery efficiency. The fracture pressure tends to increase with the depth to the top of the storage zone and the degree of cementation in the recharge zone. The impact of well pressures associated with recharge is further discussed as it relates to nearby wells in Section 4.3.

The most common limitation on recharge rate is the target recovery rate and the associated ability to effectively remove accumulated solids in the ASR well using the well pump. Standard practice dictates that recharge rates should be limited to no more than 80 percent of the short-term pumping capacity. Typically, the maximum pumping rate is established based on physical limits, such as the available drawdown. However, regulatory limits on drawdown may also limit pumping rates.

Various operation scenarios were developed based on source water (recharge) availability and future water demand needs in the vicinity of the project site, as identified through conversations with City Staff and industrial stakeholders (HDR, May 2019). A Baseline Scenario was used to establish wellfield configurations with acceptable interference between wells, and to set the recharge intervals in the field-scale groundwater model constructed with site-specific data collected during the exploratory test drilling program. Six l operating scenarios were simulated to investigate the impact of changes to recharge and recovery duration on the simulated maximum TDS and chloride concentrations at end of recovery cycles. Recharge rates and durations were limited to a maximum of 90 psi based on the depth to the top of the upper most sand interval (Railroad Commission of Texas, 2016). The ratio of recharge to recovery were no more than 80 percent and estimated pumping levels at the end of recovery cycles were at least 80 feet above the top of S1 to account for the telescoped well design which would limit the pump setting depth. Scenarios were run assuming both 10 well (Phase I) and 15 well Phase I and II system configurations. Well locations were consistent for each system configuration across all scenarios. With the exception of the baseline scenario, which had one recharge and one recovery cycle, all operating scenarios had storage and recovery cycles which were repeated six times during the model simulation to simulate long-term operation.

Results of the operation simulations indicated the following:

- At the initial project recharge capacity of 4.8 MGD, continuous recharge is limited to approximately 5 years due to well pressures approaching the assumed fracture limit; recharge rates would need to be reduced or recovery rates increased thereafter.
- At the future Phase II project recharge capacity of 7.3 MGD, continuous recharge is limited to approximately 2 years due to well pressures approaching the assumed fracture limit, with a 6.6 MGD recharge rate slightly exceeding the 90 psi limit at 5 years. Recovery rates may need to be increased during actual operation.
- The 10 well configuration sustained 7.9 MGD of recovery for 1.5 years to overcome needs during a severe, regional drought.
- The 15 well configuration sustained 9.1 MGD for up to 0.75 years and 8.2 MGD for 2 years.
- For the Phase II scenario with a 31 percent volumetric recovery per cycle (Scenario D1), the TDS concentrations at the end of the first cycle was 3,000 mg/L and 1,885 mg/L after the sixth cycle.
- For scenarios with volumetric recovery between 40 and 50 percent (Scenarios C1 and D2), the TDS concentrations at the end of the first cycle was between 3,450 and 3,900 mg/L and the final cycle was between 1,975 and 2,135 mg/L.
- For the Phase I scenario with a volumetric recovery of 62 percent (Scenario C2), the TDS concentrations at the end of the first cycle was 4,550 and the final cycle was 2,450 mg/L.

Results of the operations modeling suggests that volumetric recovery of at least 61 percent can be achieved on the initial recovery cycle with a maximum TDS concentration less than 5,000 mg/L. Results also suggest that reduced TDS concentration is more strongly related to the number of cycles than the total amount of water stored, for a given volumetric recovery target. However, increasing the volume of water recharged relative to the volume recovered has the greatest impact on reducing the contribution of NGW.

Storage of fresh water in brackish to saline NGW can cause the fresh water to rise in the storage interval due to density differences between the two waters, especially near the extent of storage water where lateral velocities can be relatively small. Since the density difference between the NGW at approximately 10,000 mg/L, and the proposed treated effluent from the Greenwood WWTP at approximately 1,700 mg/L, is about 0.6 percent, we do not anticipate increased mixing related to density differential. The nature of the sand packages, with intervening layers of clayey strata common, further reduces the potential for stratification of stored water due to density differences.

4 Protection of Stored Water

For a project owner to pursue ASR for water supply responsibly, it is essential that the project owner possess a right to the appropriated water that will be managed in the proposed ASR project and has the authority to manage and operate the ASR in a way necessary to protect the storage zone for future recovery.

The proposed ASR project is located within the jurisdiction of the Corpus Christi Aquifer Storage and Recovery Conservation District (District). The District was formed as a result of enabling legislation through Senate Bill No. 1831 and authorized to regulate groundwater within its boundaries coextensive with the City of Corpus Christi city limits and to develop and protect municipal aquifer storage areas created by the City of Corpus Christi, as codified in Special District Local Laws Code Chapter 8811. The primary purposes of the District are to: (1) provide for conservation, preservation, protection, and recharge, (2) prevent waste, and (3) control land surface subsidence. A key goal of the District is to enhance the City of Corpus Christi's (City) water supply, treatment and distribution system through management of projects within the District's purview and jurisdictional authority. The City delivers return flows to meet 2001 TCEQ Agreed Order provisions for bay and estuary health, with treated wastewater effluent produced by the City's six wastewater treatment plants in excess of this amount being available for recovery and reuse. City Staff have confirmed that Greenwood WWTP treated effluent at the rate simulated is available for this ASR project, after accounting for return flow provisions. The District and City have an interlocal agreement, that when exercised, allows them to collaboratively manage and operate the proposed ASR project for beneficial water supply purposes.

4.1 Corpus Christi Aquifer Storage and Recovery Conservation District Rules and Management Plan

The District's Management Plan identifies the protection of aquifer storage zones within its jurisdictional area as a goal for the District amongst others. Furthermore, a 5 Year Plan included proposed elements and ASR-related tasks is included in the Management Plan to provide guidance to the City on the District's operations and future projects. More specifically, operational elements of the plan are to identify ASR operational considerations and gain confidence in developing a successful ASR program compliant with TCEQ regulations. The District's Management Plan, which includes the Five-Year Plan and District Rules, is included in Appendix B.

4.2 Anticipated Extent of Stored Water

A key operational consideration for determining ASR feasibility is understanding the extent of stored water influence. The field scale groundwater model developed for this project was used to evaluate six operational usage scenarios for a 10 well and 15 well configuration system discussed previously (HDR, May 2019). The operational scenarios represented a range of potential operating conditions for drought-protection and seasonal operations for industrial water use. For the drought-protection scenarios based on historical drought conditions, the extent of storage influence after six cycles of recharge for 5 years and recovery from 10 ASR wells for 1.5 years (Scenario A) or 15 ASR wells for 2 years (Scenario B) is shown in Figure 4-1 and Figure 4-2, respectively. Seasonal operations were simulated with recharge for 2 years and recovery for 6 or 9 months in four scenarios (Scenario C1, C2, D1, and D2) based on phased operations and to illustrate changes in stored water quality with longer recovery cycle (Scenario C2 and D2). Scenarios C1 and D1, having a shorter recovery cycle of 6 months for Phase I and Phase I and II, respectively, resulted in more water remaining in storage at the end of six cycles. The extent of which is summarized in Figures 4-3 and 4-4.

The scenarios with the largest storage area extent is associated with Scenario A and B operations (Figure 4-1 and Figure 4-2), because the scenario requires a larger stored volume to meet recovery needs over a 1.5 to 2 year drought period at a sustained recovery rate. The color variation in the figures illustrates the extent of stored water most representative of source water and lower TDS/chloride (blue) as it transitions into the buffer zone adjacent to NGW with higher TDS/chloride levels (red).

Although the scenarios show the storage area extending slightly beyond current City-owned lands, the storage extent is fully located within the District's groundwater management jurisdiction.

Figure 4-1. Modeled Recharge Extent for Scenario A-Drought Response after Six Cycles of 5 year Recharge and 1.5 Year Recovery Pattern with 10 Phase I wells

Figure 4-2. Modeled Recharge Extent for Scenario B-Drought Response after Six Cycles of 5 year Recharge and 2 Year Recovery Pattern with 15 Phase I and II wells

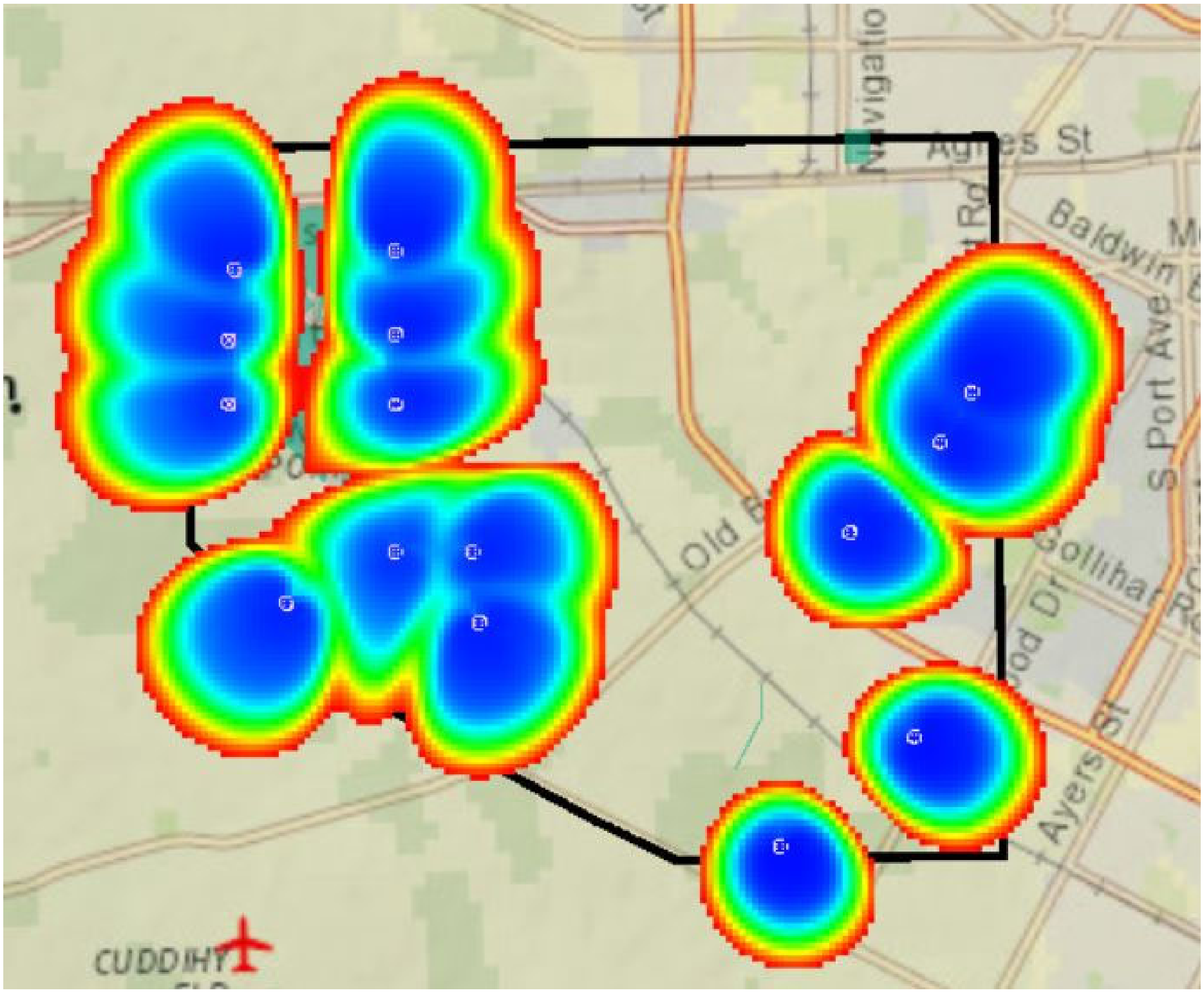
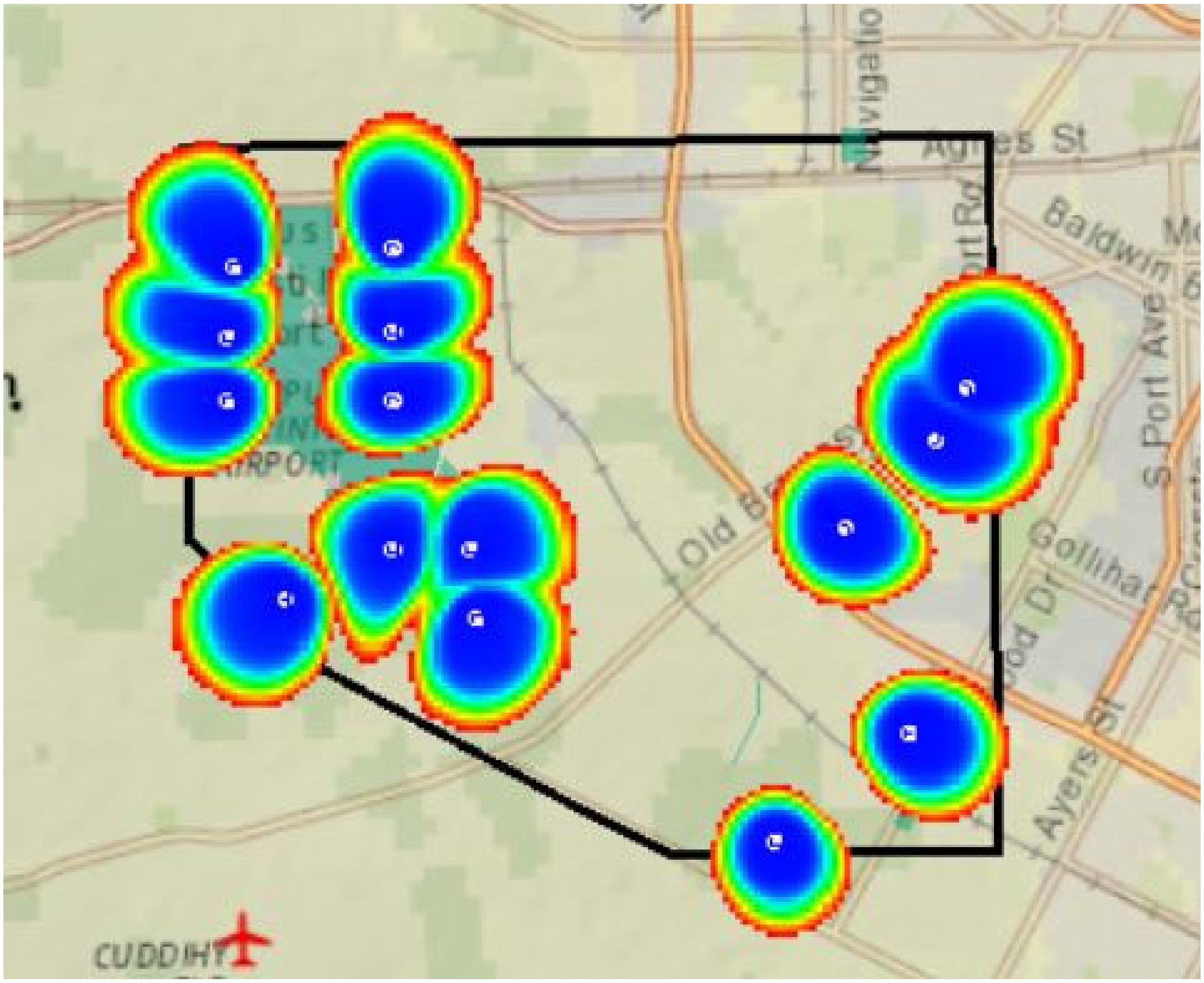


Figure 4-3. Modeled Recharge Extent for Scenario C1-Seasonal Usage after Six Cycles of 2 Year Recharge and 6 Month Recovery (7.9 MGD) Pattern with 10 Phase I wells

Figure 4-4. Modeled Recharge Extent for Scenario D1-Seasonal Usage after Six Cycles of 2 Year Recharge and 6 Month Recovery (9.1 MGD) Pattern with 15 Phase I and II wells



4.3 Management of Existing Wells in the Vicinity of ASR Wellfield Area

Based on the exploratory test drilling program results, the most desired ASR storage intervals are located between 350 and 800 feet below ground surface. Although the modeled ASR wells are operated during recharge to limit wellhead pressures to a maximum safe operating condition (Railroad Commission of Texas, 2016), water level rises are expected during recharge events. If an existing well is screened in the target zone or if deeper wells, have unsealed or leaking casings, then the well will flow and cause the area to become water logged.

4.3.1 Existing Wells

The following databases were accessed to identify existing wells and associated depths:

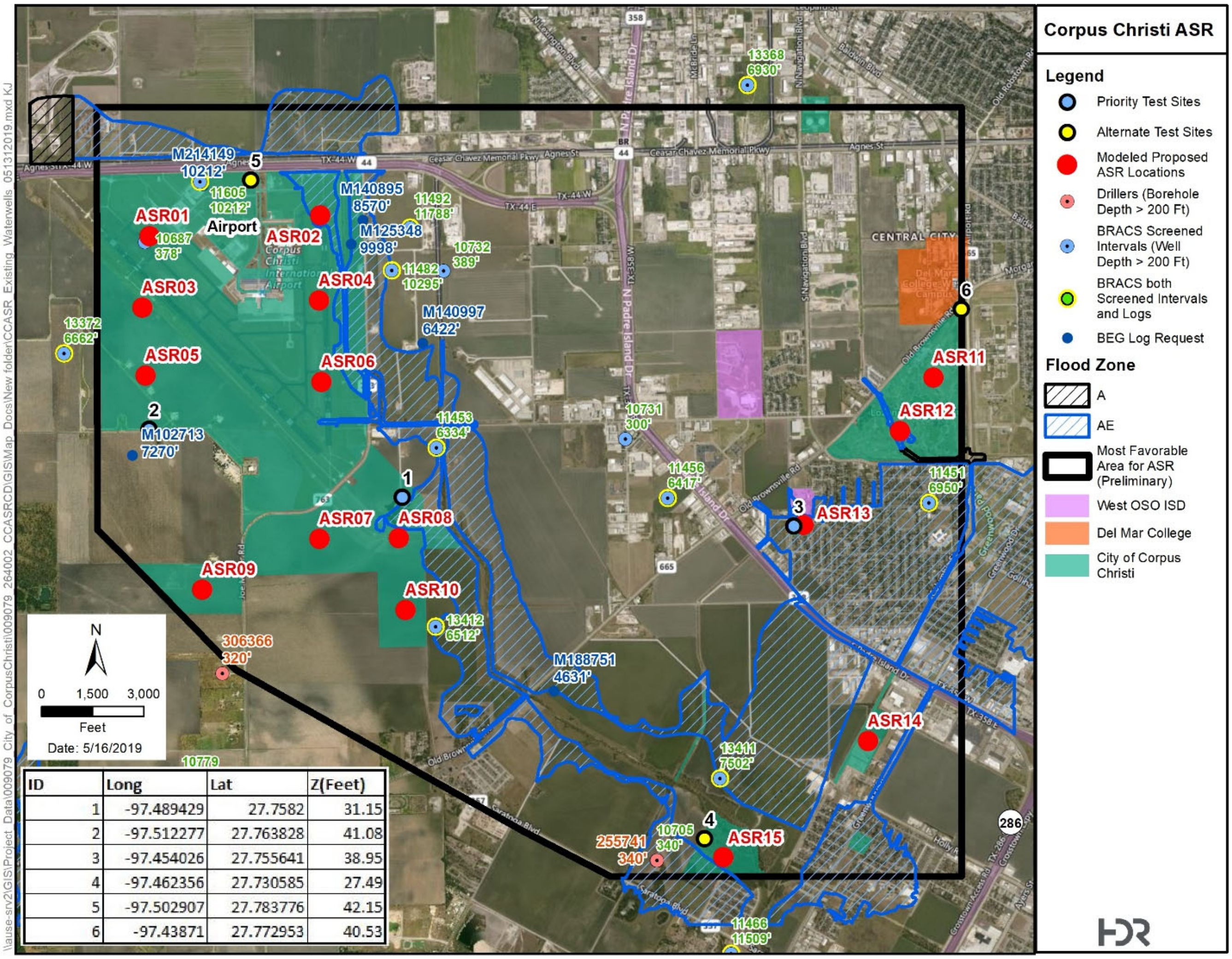
- Texas Water Development Board well inventory,

- Brackish Resources Aquifer Characterization System- Corpus Christi Aquifer Storage and Recovery Conservation District and Surrounding Counties (TWDB, 2012)
- Bureau of Economic Geology logs in study area
- Drillers Database, maintained by the TWDB.
- Railroad Commission of Texas (RRC)

To provide a conservative estimate for planning purposes, wells in the study area identified with depths between 300 and 1000 feet below ground surface were flagged to be potentially impacted by ASR operation. There may be additional wells outside the study area below that could be affected during long-term ASR operation that would need to be monitored. If artesian conditions occur after construction and implementation of the ASR program, ASR operations should be revisited and/or wells plugged depending on condition and owner use.

Figure 4-5 shows existing water wells in the study area from TWDB databases. Six possible water wells were identified from BRACS and drillers databases at depths of 300 to 369 ft that may be relevant to ASR storage zones, to include: 10687, 10705, 10731, 10732, 255741, and 306366. The condition of these wells is unknown, however owner data are available.

Figure 4-5. Existing Water Wells in the Vicinity of Proposed ASR Wells

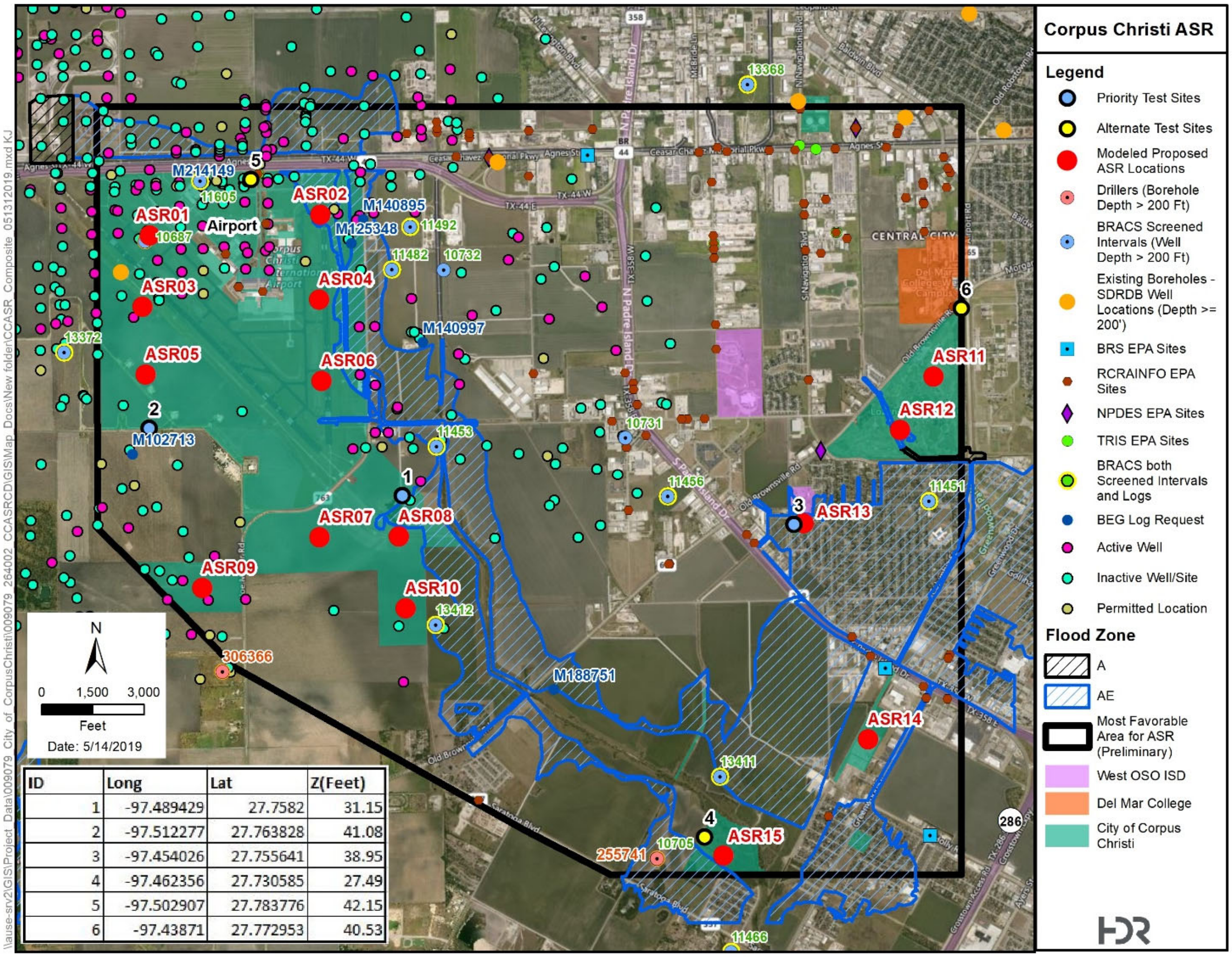


ID	Long	Lat	Z(Feet)
1	-97.489429	27.7582	31.15
2	-97.512277	27.763828	41.08
3	-97.454026	27.755641	38.95
4	-97.462356	27.730585	27.49
5	-97.502907	27.783776	42.15
6	-97.43871	27.772953	40.53

Oil and gas wells were added to the water well maps to include all known wells in the area (Figure 4-6). There are some wells that show as being active near the airport, however many are shown as being plugged and the RRC thought some of these reported active wells may actually be plugged. The RRC- District 04 Corpus Christi division reported that oil and gas wells in Nueces County have surface casings to minimum depths of 1,000 to 1,500 feet because of useable water in the area.[2] Based on this information, it is not anticipated that ASR operations will impact oil and gas wells in the vicinity unless inactive wells were improperly abandoned or plugged.

[2] Conversation with Shane Cameron at Texas Railroad Commission-District 04 Corpus Christi on May 13, 2019,

Figure 4-6. All Known Wells (Water and Oil/Gas Wells) in the Vicinity of Proposed ASR Wells



4.3.2 Suggested Approach for Existing Wells

It is recommended that the six water wells identified above are further evaluated to confirm well depth and condition. If it is determined these wells might be affected by ASR operations, it is recommended that these wells are considered for plugging and/or abandonment, or at very minimum that these wells are monitored in the future after wellfield construction and during ASR operations.

Other than the six potential wells with unknown status that have depths comparable to the storage zone, there is no indication of existing wells within the study area that rely on the storage zones targeted by ASR. Furthermore, since NGW in the storage zones report TDS levels between 8,253 and 14,085 mg/L and chloride levels between 3,262 and 5,738 mg/L, it is highly unlikely that existing wells that may be completed in the ASR storage intervals would be pumping water for human or livestock consumption purposes as it would require reverse osmosis or other advanced water treatment processes prior to consumption.

It is recommended that the oil and gas well locations are monitored during ASR operations to verify information reported by the RRC. Additional, unregistered wells may be located in the vicinity of the ASR study area that are unaccounted for in public databases. In accordance with the District groundwater management plan, public awareness and communication campaigns in collaboration with the City should be undertaken prior to implementing an ASR program.

5 ASR Regulations

5.1 Class V ASR Well Rules

Rules governing most facets of ASR project implementation in Texas are administered by the TCEQ and are contained in Title 30 of the Texas Administrative Code (30 TAC), Chapter 331, Underground Injection Control (UIC). The TCEQ has primacy from the US EPA to regulate most injection wells through the Texas UIC Program. Table 5.1 summarizes the rules specific to developing an ASR project in the CCASR District. Since the proposed ASR project does not currently contemplate recovery of water directly to a public water system, rules related to public supply wells, as contained in 30 TAC §290.41 (c), groundwater sources and development, do not apply and are not included in Table 5.1.

Prior to passage of House Bill (HB) 655 in June 2015, water injected into ASR wells was required to meet public drinking water standards (30 TAC §§290.101 - 290.119, 290.121, 290.122), regardless of the intended use of the recovered water. Similarly, construction, operation, reporting requirements related to public supply wells were also referenced in the ASR rules. HB 655 amended the ASR regulations to establish requirements for ASR injection wells by including provisions to require injected water to be at a water quality as to not degrade native groundwater in the proposed storage interval.

Table 5.1 Texas ASR Rules

Authorization	Class V injection wells associated with an ASR project may be authorized by individual permit, general permit, or by rule.	§331.7 (h)
Authorization	Area of review is defined by a radius of 1/2 mile from a single well or a radius of 1/2 mile from the centroid of the injection well field for more than one well. If the extent of the underground stored water of the ASR project will exceed the area determined by the 1/2 mile radius (as described above), the area of review is the area determined by the projected extent of the underground stored water as calculated by using site-specific hydrogeologic information and projected operational characteristics.	§331.182

Authorization	Within the area of review, the following factors must be defined: (1) location of all artificial penetrations that penetrate the interval to be used for aquifer storage and recovery, including but not limited to: water wells and abandoned water wells from commission well files or ground water district files; oil and gas wells and saltwater injection wells from the Railroad Commission of Texas files; and waste disposal wells/other injection wells from the commission disposal well files; (2) completion and construction information, where available, for identified artificial penetrations; (3) site specific, significant geologic features, such as faults and fractures; and (4) all information required for the consideration of an aquifer storage and recovery injection well under §331.186(a) of this title (relating to Additional Requirements).	§331.182 (1) - (4)
Authorization	a) The executive director or commission shall consider the following before issuing an individual permit, a general permit, or an authorization by rule for an aquifer storage and recovery (ASR) injection well: (1) whether the injection of water will comply with the standards set forth under the federal Safe Drinking Water Act (42 United States Code, §§300f, et seq); (2) the extent to which the cumulative volume of water injected for storage in the receiving geologic formation can be successfully recovered from the geologic formation for beneficial use, taking into account that the injected water may be comingled to some degree with native groundwater; (3) the effect of the ASR project on existing water wells; and (4) whether the introduction of water into the receiving geologic formation will alter the physical, chemical, or biological quality of the native groundwater to a degree that would: (A) render the groundwater produced from the receiving formation harmful or detrimental to people, animals, vegetation, or property; or (B) require an unreasonably higher level of treatment of the groundwater produced from the receiving geologic formation than is necessary for the native groundwater in order to render the groundwater suitable for beneficial use.	§331.186 (a)

Closure Standards	The well must be closed in a manner that complies with §331.5 of this title (relating to Prevention of Pollution) and 40 Code of Federal Regulations (CFR) §144.12 ("prohibition of movement of fluid into underground sources of drinking water," effective June 2, 1987 at 48 FR 20676). Any contaminated soil, gravel, sludge, liquids, or other materials removed from or adjacent to the well must be managed in accordance with Chapter 350 of this title (relating to Texas Risk Reduction Program), and all other applicable federal, state, and local regulations and requirements.	§331.133 (a)
Closure Standards	(b) Closure shall be accomplished by removing all of the removable casing and the entire well shall be pressure filled via a tremie pipe with cement from bottom to the land surface. (c) As an alternative to the procedure in subsection (b) of this section, if a Class V well is not completed through zones containing undesirable groundwater, water that is injurious to human health and the environment or water that can cause pollution to land or other waters, the well may be filled with fine sand, clay, or heavy mud followed by a cement plug extending from land surface to a depth of not less than ten feet below the land surface. (d) As an alternative to the procedure in subsection (b) of this section, if a Class V well is completed through zones containing undesirable groundwater, water that is injurious to human health and the environment or water that can cause pollution to land or other waters, either the zone(s) containing undesirable groundwater or the fresh groundwater zone(s) shall be isolated with cement plugs and the remainder of the wellbore filled with bentonite grout (9.1 pounds per gallon mud or more) followed by a cement plug extending from land surface to a depth of not less than ten feet below the land surface.	§331.133 (b) - (d)
Design standards (general)	All Class V aquifer storage and recovery (ASR) injection wells shall be designed, constructed, completed, and closed to prevent commingling, through the wellbore and casing, of injection waters with other fluids outside of the authorized injection zone; mixing through the wellbore and casing of fluids from aquifers of substantively different water quality; and infiltration through the wellbore and casing of water from the surface into ground water zones. (1) Plans and specifications. Except as specifically required in the terms of the Class V injection well authorization, the drilling and completion of a Class V ASR injection well shall be done in accordance with the requirements of §331.132 of this title (relating to Construction Standards)	§331.183

	(A) If the project operator proposes to change the injection interval to one not reviewed during the authorization process, the project operator shall notify the executive director immediately. The project operator may not inject into any unauthorized zone. (B) The executive director shall be notified immediately of any other changes, including but not limited to, changes in the completion of the well, changes in the setting of screens, and changes in the injection intervals within the authorized injection zone. (2) Construction materials. Casing materials for Class V ASR injection wells shall be constructed of materials resistant to corrosion. (3) Construction and workover supervision. All phases of any ASR injection well construction, workover or closure shall be supervised by qualified individuals who are knowledgeable and experienced in practical drilling engineering and who are familiar with the special conditions and requirements of injection well and water well construction. (4) An ASR production well, or an ASR injection well that is also serving as an ASR production well, and is providing water to a public water system must comply with the applicable requirements for groundwater sources in §290.41 of this title (relating to Water Sources). (5) All ASR injection wells and all ASR production wells associated with a single ASR project must be located: (A) within a continuous perimeter boundary of one parcel of land; or (B) within two or more adjacent parcels of land under the common ownership, lease, joint operating agreement, or contract.	
Individual ASR Permit Notice	Applicant must publish Notice of Application and Preliminary Decision issued by TCEQ. The notice required by §39.419 of this title must be published by the applicant once in a newspaper of general circulation in the county in which the injection well will be located.	RULE §39.419 (b)

Monitoring and Reporting Requirements	(a) An aquifer storage and recovery (ASR) project operator shall monitor each ASR injection well and each ASR production well associated with an ASR project. Each calendar month the project operator shall provide the executive director either a written or electronic report of the following information for the previous month: (1) the volume of water injected for storage; (2) the volume of water recovered for beneficial use; (3) monthly average injection pressures; and (4) other information as determined by the executive director as necessary for the protection of underground sources of drinking water. (b) On an annual basis, an ASR project operator shall perform water quality testing on water to be injected at an ASR project and on water that is recovered from that project. The ASR project operator shall provide the executive director either a written or electronic report of the results of this testing. The report shall include the test results for all water quality parameters identified in the individual permit, general permit, or authorization by rule.	§331.185
Operating Requirements	(a) All Class V aquifer storage and recovery (ASR) injection wells shall be operated in such a manner that injection will not endanger drinking water sources. Underground injection endangers drinking water sources if such injection may result in the presence in underground water which supplies or can reasonably be expected to supply any public water system of any contaminant, and if the presence of such contaminant may result in such system's not complying with any national primary drinking water regulation or may otherwise adversely affect the health of persons. (b) Injection pressure at the wellhead shall not exceed a maximum which shall be calculated so as to assure the pressure in the injection zone does not cause movement of fluid out of the injection zone. (c) The owner or operator of an ASR injection well that has ceased operations for more than two years shall notify the executive director 30 days prior to resuming operation of the well. (d) The owner or operator shall maintain the mechanical integrity of all wells operated under this section. (e) The quality of the water injected at an ASR project must meet the requirements in §331.186(a)(1) of this title (relating to Additional Requirements). Water recovered from an ASR project that is provided to a public water system is subject to all applicable requirements, maximum contaminant levels, and treatment techniques under Chapter 290 of this title (relating to Public Drinking Water). (f) All ASR injection and ASR production wells must be installed with a flow meter for measuring the volume of water injected and the volume of the water recovered.	§331.184

	(g) This subsection only applies to an ASR project that is located within the jurisdiction of a groundwater conservation district or other special-purpose district with the authority to regulate the withdrawal of groundwater. (1) An authorization or permit issued under this chapter may not authorize a volume of water to be recovered that exceeds the volume of water that is injected or the volume of injected water that the commission determines can be recovered, whichever is less; and (2) The requirements of Texas Water Code, Chapter 36, Subchapter N apply to the volume of water recovered from an ASR project that exceeds the volume of water the commission determines can be recovered, and otherwise as applicable.	
Post-construction Submittals	Upon completion of an ASR injection well, the following information shall be submitted to the executive director within 30 days of receipt of the results of all analyses and test results: (1) as-built drilling and completion data on the well; (2) all logging and testing data on the well; (3) formation fluid analyses; (4) injection fluid analyses; (5) injectivity and pumping tests determining well capacity and reservoir characteristics; (6) hydrogeologic modeling, with supporting data, predicting mixing zone characteristics and injection fluid movement and quality; and (7) other information as determined by the executive director as necessary for the protection of underground sources of drinking water.	§331.186 (b)
Surface Water Rights	While a holder of a water right (or contract) that does not prohibit the use of the water in an ASR project may undertake an ASR project without obtaining any additional authorization under Texas Water Code (TWC), Chapter 11, the water right holder must: (1) obtain any required authorizations under TWC, Chapter 27, Subchapter G, and TWC, Chapter 36, Subchapter N; and (2) comply with the terms of the applicable water right.	§295.21 (a)
Well Driller	Class V injection wells shall be installed by a water well driller licensed by the Texas Department of Licensing and Regulation.	§331.133 (a)

Of particular relevance to the proposed ASR project are the requirements in 30 TAC§331.186 (a), which outlines the criteria to be consider by TCEQ in authorizing ASR operations. The effluent from the Greenwood WWTP does not currently meet drinking water standards for chloride, TDS, manganese, and nitrate concentration, or pathogen removal. While it is anticipated that nitrate and manganese will likely be below the drinking water maximum contaminant limit after tertiary treatment, the other parameters will not be significantly altered prior injection. As such, the City will need to demonstrate to the TCEQ that proposed ASR well operations will not: 1) render the groundwater produced from the receiving formation harmful or detrimental to people, animals, vegetation, or property, or 2) require an unreasonably higher level of treatment of the groundwater produced from the receiving geologic formation than is necessary for the NGW in order to render the groundwater suitable for beneficial use.

A successful ASR well application for the CCASR project will need to provide evidence in the permit application that the City has sufficient surface control to prevent access to stored water that does not meeting drinking standards, or at a minimum, to water that is harmful to people. The data needed to support such an application will likely require completion of pilot ASR well using the actual treated effluent proposed for the project. The pilot ASR well would likely be authorized under a short-term, experimental Class V authorization described in more detail in Section 6. Since any use of the NGW from the proposed storage zone involve ingesting the water by people or animals would require desalination, a case can be made that introduction of the treated effluent would only reduce the salinity of the NGW and reduce the treatment requirements.

Because it is anticipated that the recharge water will not meet drinking water standards at the wellhead, it is likely an individual Class V permit would be required from TCEQ before operations could commence. The individual permit process requires the applicant to issue a Notice of Application and Intent to Obtain a Permit and a Notice of Application and Preliminary Decision. Persons potentially affected by the proposed injection well may request a public meeting and hearing prior to a decision being made by TCEQ. If the application is contested, the administrative hearing and appeals process can add one to three years to the permitting process.

5.2 Storage Zone Native Groundwater Quality Issues

As presented in Section 3.2, the TDS concentration in the NGW is expected to be around 10,000 mg/L. Recharge into or below an aquifer with greater than 10,000 mg/L TDS will likely have additional requirements related to preventing migration of fluid from the storage zone into an overlying aquifer with a TDS concentration less than or equal to 10,000 mg/l. Aquifers with a TDS concentration less than or equal to 10,000 mg/l are defined by TCEQ as an underground source of drinking water (USDW), per 30 TAC §331.2(a)(115). Due to the unique situations in the Gulf Coast aquifer system in the ASR study area, including TDS results reported in a shallow monitoring well screened between 154-164 ft below ground surface and recharge source having fresher water quality, it is likely that this project would qualify for an aquifer exemption. The final determination to be made by TCEQ.

ASR wells that inject below the USDW require installation of a fully cemented intermediate well casing referred to as a surface casing. The casing is installed prior to penetrating a significant section of the deeper strata so that the typically high salinity NGW does not migrate up the open hole causing degradation of the overlying USDW. The surface casing also provides an additional barrier between water injected through the USDW to the storage zone. A second casing, the long string, is required to be installed from the top of the target storage zone to land surface. As with the surface casing, annular space must be completely cemented through the entire length of the casing. Inside the long string is installed a removable injection tubing that serves as the primary barrier between the formations penetrated by the long string and the injected fluid. Seal (packers) are installed between the injection tubing and the long string casing, at the bottom and the top of the casing. The pressure in the sealed annulus must be maintained above the maximum anticipated pressure in the injection tubing so that if the tubing leaks, monitoring fluid outside the tubing will enter the tubing and the annular monitoring system will indicate a tubing failure. Since ASR wells completed into a USDW do not require injection tubing or a supplemental surface casing, ASR wells completed below the USDW have higher construction costs. In Florida, EPA exemptions to these additional casing standards have been granted for municipal effluent projects. This project is a good candidate for receiving such an exemption, as could be promulgated by TCEQ.

The proposed ASR wells presented in Figure 3-1 are completed in, at most, two sand intervals separated by more than 100 feet of clayey strata at most well sites. The potential exists that one of the target zones would be classified as a USDW and other may not. If this is the case, separate wells would need to be completed into each of the sand interval to avoid connecting the two and potentially causing contamination of a USDW. Constructing two wells at such sites would more than double the assumed well costs for these sites. Additional conversations with TCEQ are needed to verify interpretation of the standards relevant to this project, especially since the TDS and chloride levels of recharge water are significantly lower than the NGW in storage zones.

6 TCEQ Class V Experimental ASR Authorization and Permit

The pilot ASR will test the recharge and recovery of highly treated wastewater that generally meets drinking water standards. The NGW in the proposed storage zone is anticipated to be between 8,000 and 12,000 mg/L TDS, so injection would require a Class V injection well authorization or permit. Because the water to be stored would likely not reliably meet requirements of the Safe Drinking Water Act (42 U.S.C. §300f et seq.), the executive director of the TCEQ, may require an individual permit to allow ASR testing per 30 TAC § 331.186(a)(1). However, because the City is seeking permission to perform limited testing and not an operating permit, and the storage zone TDS is approaching the 10,000 mg/L TDS threshold for being designated as an underground source of drinking water, TCEQ may allow the testing under a temporary authorization as an Experimental ASR well. The process for obtaining an experimental ASR well authorization or an individual permit is outline herein.

6.1 Experimental ASR Well Authorization Application

The first step in obtaining an authorization is to complete the Class V Injection Well Inventory/ Authorization form (TCEQ 10338, revised June 15, 2018). This is a general application for all Class V well type, including ASR pilot wells. TCEQ prepared a draft application specific to ASR pilot wells in 2018 but the form was never finalized.

The form is arranged in five sections. The content of each section is outlined below:

- Section I, General Information – includes information about the owner, operator, location, introduction method, and purpose of the proposed project;
- Section II, Proposed Down Hole Design – a signed and sealed well diagram indicated proposed hole diameters, planned size, depth, and material of all well tubulars, and the volume and type of cement grout to be used are included here;
- Section III, Proposed Trench System, Subsurface Fluid Distribution System, or Infiltration Gallery – This section would be left blank for the Corpus Christi application;
- Section IV, Site Hydrogeological and Injection Zone Data – includes information on the injection geologic and hydraulic characteristic, NGW and injectate quality, hydraulic properties of any confining strata, horizontal and vertical extent of the injected water during testing period, maximum expected injection rate, duration and pressure, and an inventory of existing wells within ¼ of the proposed ASR well; and
- Section V Site History – the nature and extent of any anthropological groundwater contamination, and any associate remediation, are documented here.

In addition to the information required in the Class V Injection Well Inventory/ Authorization form, the TCEQ will likely require details of the proposed advanced water treatment pilot plant that will produce the recharged water to be used in the ASR pilot testing. Proposed treatment processes currently being considered for the pilot, include the following: Modified Ludzack-Ettinger (MLE) process to reduce nitrates, microfiltration for removal of TSS and bacteria, and/or ozone and biologically active filters (BAF) to remove organics, manganese, and bacteria. The pilot program would test these different treatment processes as stand-alone or combined series to determine the preferred treatment configuration for Phase I and II implementation. TCEQ will consider the reliability of the proposed process train and associated monitoring and controls to ensure that injected water meets the minimum standards proposed in the application. This information would likely be separated from the submittal and reviewed by the TCEQ Public Water System plan review team.

6.2 TCEQ Review and Actions

The TCEQ's Underground Injection Control (UIC) Program staff will review the permit application and may request additional information to make a determination whether the project is can be authorized by rule or would need an individual permit. If the application is compliant with current Class V rules, and approval will be send to allow construction and testing within the parameters outlined in the application. Based on recent experience with an ASR project author by rule, the TCEQ review and approval process should take 4 to 6 months. Issues related to the origin of the recharge water may extend the review and approval process.

If the application is deemed to be unsuitable for authorization by rule due to failure to demonstrate that the recharge quality meets standards or other inconsistency, TCEQ may require the applicant to pursue an individual permit. In addition to the potential for several rounds of requests for additional information and evaluation by UIC Program staff, TCEQ may prepare and require the applicant to publish a Notice of Application and Intent to Obtain a Permit and a Notice of Application and Preliminary Decision in local new paper or other approved media outlet. If requested by persons potentially affected by the project, a public meeting must be held to solicit comments on the draft application. If changes are made to the draft permit as a result of comments received by TCEC, the publishing and comment process must be repeated.

If the draft permit is uncontested, the TCEQ Executive Director will issue the permit. If the permit is contested by persons potentially affected by the project, the Executive Director will either issue or deny the permit after legal appeals are complete. The Executive Director's decision can be appealed to the Commission and a hearing process will be conducted to either confirm or reverse the Executive Director's decision. The minimum time between submittal of an application and issuance of a final individual permit would be 9 months.

6.3 ASR Well Application for Phase I and II Implementation

After completion of the pilot ASR testing program, a Class V ASR well permit application would be prepared[3]. The Class V ASR well application requires information regarding the well owner, well location, anticipated design, well site and storage zone characteristics, and maximum injection rate, volume, and pressure must be submitted to the TCEQ Underground Injection Control Permits Section of the Radioactive Materials Division. If this information provided demonstrates consistency with the rules, TCEQ staff will issue a permit for construction and operation of the ASR well.

Significant effort may be required to prepare the well inventory and demonstration of recoverability content in the application. The area of review for the well inventory is defined as the projected extent of the underground stored water or 1/2 mile radius from the proposed centroid of the ASR wellfield, whichever is greater. Groundwater modeling is usually required to develop required information on the expected volume of water to be stored and the amount that can be recovered for beneficial use. Because the proposed storage zones have TDS concentrations greater than 3,000 mg/L, the Texas Railroad Commission will need to review the project and issue a determination that the project would have no adverse impact on mineral resources in the area.

Within 30 days of completing well construction and testing, the owner/applicant must submit the following information to the Underground Injection Control Permits Section of TCEQ:

- as-built drilling and completion data on the well
- all logging and testing data on the well

[3] TCEQ staff have suggested that the pilot ASR testing permit can be applied to the Phase I and II projects without requiring additional permits, based on pilot results.

- formation fluid analyses
- injection fluid analyses
- injectivity and pumping tests determining well capacity and reservoir characteristics
- hydrogeologic modeling, with supporting data, predicting mixing zone characteristics and injection fluid movement and quality
- other information as determined by the executive director as necessary for the protection of underground sources of drinking water.

There is currently no form available from TCEQ to list the required post-construction information so any transmittal letter should reference the Class V project permit number assigned by TCEQ.

6.4 Other Permits and Authorizations

Although projects no longer require an amendment to a water right (for appropriated surface water), there are numerous permits or approvals which may be required for development of ASR infrastructure. Federal and State of Texas permits and approvals include:

- Section 404 permit administered by the United States Army Corps of Engineers (USACE)
- Texas Historical Commission cultural resources review (approval only)
- Texas Pollution Discharge Elimination System (TPDES) Construction General Permit TXR150000 (approval only)

Permits and reviews for development of water transmission other surface infrastructure may include:

- Site development permit
- Right-of-way use permit
- Building permit (chemical feed equipment)
- Driveway permit.

7 Water Quality Needs for ASR Operation

As part of the geochemical analysis performed to evaluate ASR feasibility, both treated potable water from O.N. Stevens WTP and treated wastewater effluent from Greenwood WWTP were considered as potential source water supplies for recharge (HDR, February 2019). After receiving City staff feedback, Greenwood WWTP treated effluent was anticipated to be the most probable source water for ASR based on several factors, including but not limited to: location and consistent supply from Greenwood WWTP, competing water demands for potable supplies, NGW quality, future industrial growth, drought-proof needs, and more flexible water quality criteria for non-potable industrial water demands. The source water availability is increased with use of Greenwood WWTP effluent during periods of peak demand and promotes year round use even during drought-conditions.

The geochemical analysis did not present any fatal flaws using the recharged water for ASR storage and recovery. However, several constituents measured in the Greenwood WWTP treated effluent exceed MCL or secondary MCL levels and will likely warrant tertiary treatment prior to recharge to comply with TCEQ provisions and avoid plugging or biofouling, including: bacteria, nutrient removal (nitrate), and manganese (HDR, February 2019). Tertiary treatment to condition treated effluent prior to aquifer recharge, may include modifications to the WWTP's treatment to promote de-nitrification, reduce turbidity, and improve the disinfection system to further inactivate bacteria. There are several studies conducted by others that have concluded that introduction of pathogens into ASR systems that store treated effluent is not a major issue if the natural groundwater microorganisms are active enough to reduce viral survival (Gordon, 2002; Toze and Hanna, 2002). The activity of NGW microorganisms is the major influence on the survival of microbial pathogens in groundwater (Bekele, 2006). At this time, it is unknown what impact the bacteria in treated effluent will have on the storage zone and interaction with NGW microorganisms. Data collected during pilot testing can be used to refine (and possibly reduce) treatment requirements for Phase I system build-out. Reclaimed wastewater may contain unregulated chemicals and microorganisms for which there are no promulgated standards, but yet may still impact public health and environment (e.g., prescription drugs and personal care products) (Maliva and Missimer, 2010).

7.1 Well Clogging

Well clogging can occur as a result of several operational factors. Clogging tends to reduce recharge and recovery rate and increase the frequency of backflushing or mechanical/chemical well rehabilitation if plugging is persistent. The following processes can result in well plugging:

- Mechanical plugging related to accumulation of suspended solids in the recharge water at the aquifer face
- Chemical plugging related to deposition of insoluble precipitates formed during mixing of the recharge and NGW near the well bore
- Biological fouling by bacteria growth near the borehole
- Clay fragmentation due to ion exchange and associated accumulation in pore spaces near the borehole

The clogging risk at the proposed ASR well is increased by relative small grain size of the sand and silt in the target storage zones (HDR February 2019). Table 6-1 summarizes the particle size at which 10 percent (D_{10}), and 60 percent (D_{60}), of the sample (by weight), is smaller. Also included in the table is the Coefficient of Uniformity (Cu), which is calculated as the ratio of D_{60} to D_{10}.

Table 6-1. Recharge Zone Sample Gradation

Sample	D10 (µm)	D60 (µm)	Cu	% Passing #200	USCS Designation
01-F	45.1	246.1	5.5	15	Silty Sand
01-L	2.29	202.6	88	36	Silty Sand
01-U	37.1	266.8	7.2	17	Silty Sand

03-A	2.54	211.0	83	35	Silty Sand
03-F	74.0	254.6	3.4	10	Poorly Graded Sand with Silt
03-T	2.54	215.8	85	33	Silty Sand

Based on the Unified Soil Classification System (ASTM D2487 – 17), five of the six sand samples were classified as silty sand. The coarsest sand (03-F), is poorly graded sand with silt since the fines fraction (percent passing No. 200 sieve), less than 12 percent and the Cu is less than 6.Using a common cutoff for fine sand at 425 µm, all the samples would be classified as fine. Compared to rapid sand filters on convention municipal water treatment plants, the gradation of the storage zone sediments are much finer. Therefore, the target storage zones will tend to filter and accumulate almost all suspended solids on the aquifer surface causing a rapid increase in well pressure to maintain a given recharge rate.

Similarly, even minor precipitation of solids in the aquifer would immediately reduce recharge and recovery capacities due to the relatively low porosity values, as indicated by the significant fine fraction in all samples. Fortunately, the geochemical assessment (HDR, February 2019), indicated mixing of the proposed recharge water and NGW would not tend to be scale forming.

As present in the geochemical assessment, high BOD, inorganic nitrogen, and dissolved oxygen levels in the Greenwood WWTP effluent indicated a tendency for significant biofilm formation in the vicinity of the well bore. Any biofilm formation will result in an immediate increase in recharge pressure. Unlike accumulated solids in the recharge water, backflushing may not effectively remove the biomass. Instead, chemical treatment and mechanical agitation may be required to restore recharge and recovery capacity. These rehabilitation activities require the well pump to be removed.

7.2 Clay Dissolution in the Aquifer Formation

Sand aquifers may experience a local reduction in permeability around wells when salinity is altered (Maliva and Missimer, 2010). For an ASR system using brackish aquifer for storage, clay minerals can disassociate, swell, or fragment when fresher water is introduced and contract when stored water is pumped out and original salinity conditions are restored. The two possible causes of reduction in permeability is in situ swelling and dispersion (Brown and Silvey, 1977). Swelling clays like montmorillonite are most apt to expand, dependent on exchangeable cations contained in the clay. This condition may lead to clay dispersion, which results in mobilizing clay particles that reduces permeability, sometimes irreversibly (Maliva and Missimer, 2010). Montmorillonite, a swelling clay, is a relatively small amount of the overall mineral composition in the storage zones comprising about 2.7-3.6% based on core analyses (HDR, February 2019). The operating conditions in the modeled scenarios have included provisions to maintain and accumulate stored water in excess of recovery amount to help mitigate and reduce water quality fluctuations during recharge and recovery cycles.

Based on an analysis of the ionic strength of the Greenwood WWTP water compared to the NGW in the proposed storage zones, there is potential for clay minerals to become mobile during recharge and cluster in pore openings between the sand grains, reducing formation permeability (HDR, February 2019). Tertiary treatment processes of the Greenwood effluent would not significantly alter the ionic strength of the effluent so the initial recharge cycle should be very short (less than 1 day at the design recharge rate) and evidence of clogging (deviation of the mounding from predicted value over time), should be closely monitored. Recovered water turbidity levels should also be monitored during the entire recovery cycle. If there is evidence that clays are mobilizing due to ion exchange, consideration should be given to conditioning the storage zone with a calcium chloride solution to fix the clays before proceeding with addition recharge testing.

8 Subsidence Potential

When a confined aquifer is pumped, compression of the aquifer matrix allows groundwater to be released from storage. When present, fine-grained materials such as clays, have the greatest potential for compression under these conditions. If the change in pressure from pumping is large enough and these layers of fine-grained materials are under-consolidated, then irreversible compaction of the materials can occur.

When compaction occurs in the subsurface, the reduction in thickness of the clay layers may propagate upwards and result in a lowering of land surface elevation, which is called “land subsidence”. The Gulf Coast Aquifer, with the prevalence of these clay layers, has potential for compaction and subsidence throughout its footprint in Texas. Subsidence is a growing concern in the Texas Gulf Coast even in areas outside those with historical evidence of compaction (e.g. the greater Houston area). In this section we discuss the potential for subsidence for ASR projects in the Gulf Coast Aquifer.

8.1 Previous Subsidence Studies in the Gulf Coast Aquifer

HDR Team member INTERA recently completed a two-year study assessing potential subsidence for ASR operations in the Gulf Coast Aquifer (Kelley and Deeds, 2019). Our current discussion of subsidence relies primarily on the findings of this study. Other relevant literature include the assessment of subsidence for seven Central Gulf Coast groundwater conservation districts southwest of the Houston-Galveston area (Young, 2016), and the TWDB state-wide assessment of the potential for subsidence (Furnans and others, 2017). The Young (2016) report indicates that subsidence has not occurred in neighboring Refugio County. Furnans and others (2017) reports that estimated subsidence risk in neighboring San Patricio County is between “Medium” and “High”.

We divide our discussion of ASR subsidence potential into two categories: intrinsic and design/operational factors. Intrinsic factors are specific to the hydrogeology that exists at a proposed ASR site, such as aquifer lithology or hydraulic properties. Design/operational factors are those that can be controlled within the limits of cost, such as target storage intervals and recharge/production schedules. A carefully considered design and operational approach may be able to overcome some sub-optimal intrinsic factors, resulting in a successful ASR system.

8.2 Intrinsic Aquifer Parameters Governing Compaction and Subsidence

8.2.1 Maximum Compaction: Overall Interbed Thickness and Compressibility

The maximum compaction that can occur for a given aquifer is dependent on three factors. These include the total thickness of clay layers, the compressibility of those clays (quantified by their specific storage), and the overall change in pressure due to drawdown. In equation form:

$$\Delta b = \Delta h b S_s$$

where:

Δb = change in thickness of clay layer (compaction)

b = overall thickness of clay layer

S_s = specific storage

Δh = change in hydraulic head

The compressibility of clays should generally decrease with depth due to overburden stresses, so generally shallow clay layers are thought to be prone to greater maximum compaction than deeply buried clay layers.

8.2.2 Rate of Compaction: Individual Clay Bed Thickness and Vertical Conductivity

In order for compaction to occur in a clay bed, the change in pressure from drawdown that occurs from groundwater production in the sands must propagate into the clays, which takes time. The rate of this pressure propagation is dependent on the vertical conductivity of the clays. For a clay to reach maximum compaction, the pressure change must propagate all the way to the center of the clay bed. So both the vertical conductivity of the clay, and the clay bed thickness (the distance to the center of the clay bed) are factors affecting the timing of compaction. Lower vertical conductivities mean slower compaction rates, and thicker clay beds reach maximum compaction more slowly than thinner clay beds. In general, vertical conductivities of clays should decrease with depth, due to consolidation from overburden pressure.

8.2.3 Stress at Which Compaction Begins: Drawdown at Preconsolidation Stress

Since initial deposition, an aquifer has typically undergone many different stress states, due to changing overburden pressure and changing water levels. If an aquifer is currently experiencing the maximum historical effective stress, it is considered "normally consolidated". If the current effective stress is less than the maximum historical stress (called the preconsolidation stress), then the aquifer is considered "overconsolidated". An overconsolidated aquifer can undergo additional stress without resulting compaction, since the clays in the aquifer had previously been compacted under a higher stress condition (assuming there was sufficient time for the clay layers to near ultimate compaction at that condition).

If the current effective stress is less than the preconsolidation stress, then additional stress will result in elastic compression both the sands and clay beds in the aquifer. Elastic compression is reversible. Once the current effect stress reaches the preconsolidation stress, then irreversible compaction will occur in the clay beds, which may then result in subsidence at land surface. Preconsolidation stress cannot be measured in situ; estimates in the literature have been based on comparing drawdowns to the onset of observed compaction. The safest assumption is that an aquifer is normally consolidated and that some compaction will occur under any change in effective stress (i.e. drawdown).

8.2.4 Compaction and Subsidence: The Effect of Depth

In the previous three sections, we noted that increasing depth generally decreases the potential for compaction, since increasing depth generally correlates with decreasing clay compressibility and decreasing clay vertical conductivity. Increasing depth also has the general effect of reducing the likelihood of compaction in the subsurface creating subsidence at land surface. This is because subsurface compaction does not propagate in one dimension vertically towards the surface, but rather propagates radially, or at least has some horizontal as well as vertical components. The deeper the compaction occurs, the more area over which the effects are spread, reducing the impact at any one location. This "dilution" of impact does not apply when compaction occurs over a large area, so if drawdown impacts are regional, then compaction is more likely to result in observable subsidence at surface.

8.3 Design and Operational Factors that Govern Subsidence

In this section, we discuss design and operational factors that should be considered for an ASR system to minimize potential for subsidence.

8.3.1 Occurrence of Clay Beds in the Storage Interval

One of the most critical design factors is the number and thickness of clay beds in the proposed storage interval. The "cleaner" (higher percent sand) the storage interval, the less clay bed thickness is available for potential compaction. Cleaner sands are also typically more transmissive; a more transmissive interval will reduce drawdown compared to a less transmissive interval for a given production rate. Whenever possible, high percent sand intervals should be targeted for storage. Both S1 and S2 are considered to have high percent sand content. We have noted previously that in the Gulf Coast Aquifer, a high percent sand interval at one location may not correlate over a large distance laterally away from the well location. However, because drawdown is greatest at the location of the well, this increase in clay percent at some distance away from the well will be offset by a reduced change in effective stress as drawdown decreases radially away from the well.

8.3.2 Depth of the Storage Interval

The intrinsic factors of compressibility and clay vertical conductivity both generally decrease with depth. So deeper storage intervals should have less potential for compaction than shallow intervals. However, cost generally increases with depth for any ASR operation, and water quality and transmissivity may also degrade with increasing depth. Any reduced compaction benefit of increasing the depth of the storage interval will often be offset by these other factors.

8.3.3 Location of ASR Wells

The wellfield design that was proposed and simulated in the groundwater model, as shown in Figure 4-5, had several locations where sand intervals S1 and S2 were both targeted for storage at the same well location. "Stacking" two wells at the same location has the effect of increasing storage and recovery potential without having to build out the additional supporting infrastructure that would be required if the second well were located some distance away.

Simulations performed by Kelley and Deeds (2019) showed that targeting multiple storage intervals at one location made sense from a compaction perspective, only if the best interval (in terms of sand percent and transmissivity) was fully utilized before considering the next interval with less favorable intrinsic properties. So increasing recharge and recovery rates in a single favorable interval (within the limits of drawdown and wellhead pressure) is better from a compaction perspective than spreading the same recharge and recovery over the favorable and less favorable intervals.

Well spacing is another design consideration, since drawdown interference between wells will increase the overall drawdown and the potential for compaction. Increased well spacing must be balanced by land ownership and infrastructure cost, but in general greater spacing will result in less compaction potential. The proposed wells are located about ¼ mile apart, which was established to minimize drawdown interference.

8.3.4 Operational Factors

Compaction and subsidence during operation of an ASR system is best achieved by limiting the magnitude and duration of drawdown. When the ASR is recharging, heads are increased at and around the ASR well, so no compaction will occur. If recovery begins immediately after a recharge cycle, then drawdown compared to static water levels will not occur immediately, since the cone of impression (increased heads) results in a starting water level that is higher than static. However, very little time elapses under recovery conditions before drawdown below static conditions begins to occur at the well. This means that if recovery is occurring over a long period (for instance, during an extended drought) the ASR system will begin to behave similarly to a standard wellfield, i.e. little to no reduced compaction benefit occurs due to recharge. If recovery is shorter in duration, where recovery occurs only for a few months per year to meet peak demands in the summer, or seasonally as modeled in Scenarios C and D, then the compaction benefit of the recharge is increased significantly. Thus in compaction-prone areas, a cyclic ASR operation will have less potential for subsidence than an operation with more extended recovery periods.

Prior to implementation of an ASR program, it is recommended that extensometers are installed to monitor subsidence over time. The United States Geological Survey (USGS)[4] installed 13 extensometers in the Houston-Galveston region between 1973 and 1980 to collect compaction data and has used this information to measure subsidence in the Gulf Coast Aquifer near the Houston area. The District and City may want to consider this USGS subsidence program when developing a program for the ASR area.

9 Long Term Operations and Maintenance Considerations

The pilot testing program results will confirm and help define long term operations and maintenance considerations. A few likely maintenance considerations are identified as follows:

- Well rechargivity, computed as the ratio of recharge rate (gpm) to the rise in well level, will need to be closely monitored at each ASR well. On a weekly basis during recharge, following a back flush cycle, the well would need to be allowed to stabilize and recharge rate recorded. Given the fine gradation of the target storage zone, and potential for biological growth, frequent back flushing may be required to dislodge and remove biofilms before pores become clogged. While the optimal backflush frequency will be investigated during cycle testing, it is likely that twice daily backflushing may be beneficial. Operators would need to closely monitor the filter pack level to ensure pack levels are maintained above the uppermost screen at all times. If needed, an elevated chlorine residual may be needed to control biological growth near the well bore. Clogging nearest the well bore has a greater impact on pressure increase than further out in the storage zone. A concentration of between 3 mg/L to 5 mg/L free chlorine may be required to control growth around the well bore.

[4] In cooperation with Harris Galveston Subsidence District, the City of Houston, Fort Bend County Subsidence District, Lone Star Groundwater Conservation District, and Brazoria County Groundwater Conservation District

- A more aggressive backflush rate than is normally used may be beneficial for the project. ASR wells storing potable water in sand and gravel storage zone would typically limit recharge to 80 percent of the peak recharge rate. However, given the potential for biofilm formation, biofilm removal may be more effective and complete by limiting recharge to 50-67 percent of the peak recharge. Only the Scenario D simulations exceed this range recharge/recovery rate ratio, but the others are within this range. Operators would need to closely monitor the filter pack level in the lap section of the production liner to be sure pack levels are maintained above the uppermost screen at all times.
- To limit the extent of biofilm development beyond the radius effectively controlled by backflushing and disinfectant residual, semi-annual to annual shut-in periods may be required to promote die-off of biological communities. Intermittent backflush cycle may be associated with the shut-in period to remove accumulated biomass, before recharge operations are reinitiated. These shut-in periods would only be required after long period without recovery operations.

10 Conclusions, Assumptions and Uncertainty

Based on the results of this ASR study, it is estimated that a project yield of 13-18 MGD is attainable. The operating scenarios showed that ASR operations could be configured to meet uninterruptible industrial demands during severe drought conditions or used seasonally to respond to peak demands or higher usage months. The most likely use of recovered water from ASR is for non-potable, industrial demands. The geochemical analysis did not present any fatal flaws, however tertiary treatment of Greenwood WWTP treated effluent would be needed to reduce nutrient, pathogen, and organic concentrations prior to recharge to meet regulatory needs and facilitate a successful ASR program. If the City’s needs change in the future then advanced treatment after ASR recovery could treat this water to potable standards for integration in the potable distribution system near the project site.

There are several ASR operating policy aspects to consider to mitigate risk and uncertainty, which include:

- Protecting stored water, including confirming existing wells that may be impacted with ASR operations and enforcing District rules that prohibit drilling in ASR protection area;
- Compliance with TCEQ regulations, including achieving any exemptions as may be required based on site-specific conditions including water quality;
- Consistent recharge water quality that is treated according to TCEQ standards at levels to minimize well clogging and/or clay fragmentation
- Continuous monitoring by the District after implementing ASR Phase I or II programs to (a) reduce influence of existing wells on or resulting from ASR

operations (b) record subsidence data prior to ASR construction and during ASR operation and (c) record water levels and water quality.

The field scale groundwater model was constructed based on the best information available and collected during the exploratory well testing program, however the results should only be used as a guide. The pilot well test program is needed to confirm aquifer response, operations, prove up geochemical interactions, and identify criteria for appropriate design and operations of a full scale ASR program.

11 References

ASTM Standard D2487, 2017. "Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)", ASTM International.

Bekele, E.B., Toze, S., Sidhu, Jl, and Hanna, J., 2006, Development of a microbial model to aid management of aquifer recharge systems in recharge systems in protecting and enhancing groundwater resources. Proceedings, 5th International Symposium on Management of Aquifer Recharge, Berlin, Germany, June 11-16, 2005: Paris, UNESCO.

Brown, D.L, and Silvey, W.D., 1977, Artificial recharge to a freshwater-sensitive brackish-water sand aquifer, Norfolk, Virginia: U.S. Geological Survey Professional Paper 939.

Furnans, J., M. Keester, D. Colvin, J. Bauer, J. Barber, G. Gin, V. Danielson, L. Erickson, R. Ryan, K. Khorzad, A. Worsley, G. Snyder, 2017. Final Report: Identification of the Vulnerability of the Major and Minor Aquifers of Texas to Subsidence with Regard to Groundwater Pumping. TWDB Contract Number 1648302062. 434 pp.

Gordon, G., Wall, K., and Toze, S., 2002. Influence of conditions on the survival of enteric viruses and indicator organisms in groundwater.

12 HDR, February 2019. Geochemical Analysis and Modeling- Technical Memorandum, Corpus Christi Aquifer Storage and Recovery Feasibility Study (E16265).

HDR, May 2019. Field Scale Groundwater Model and Results of ASR Operating Scenario Simulations- Technical Memorandum, Corpus Christi Aquifer Storage and Recovery Feasibility Study (E16265).

Kelly, V. and N. Deeds, 2019. Final Report - Assessment of Subsidence and Regulatory Considerations for Aquifer Storage and Recovery in the Evangeline and Chicot Aquifers. Prepared for the Harris Galveston Subsidence District. 190pp.

Maliva and Missimer, 2010. Aquifer Storage and Recovery and Managed Aquifer Recharge Using Wells: Planning, Hydrogeology, Design and Operation.

Railroad Commission of Texas, 2016. Injection/Disposal Well Permitting, Testing, and Monitoring Manual, Technical Review section.

Young, S., 2016. Estimates of Land Subsidence in GMA 15 Based on Ground Surface Elevation Data and Model Results. Prepared for Groundwater Conservation Districts of GMA-15. 144pp.

A

Appendix A- Greenwood WWTP Supply and Future Industrial Water Demands

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Background Information- ASR Operating Scenarios
Draft- February 6, 2019

Greenwood WWTP effluent availability (i.e. ASR recharge potential)

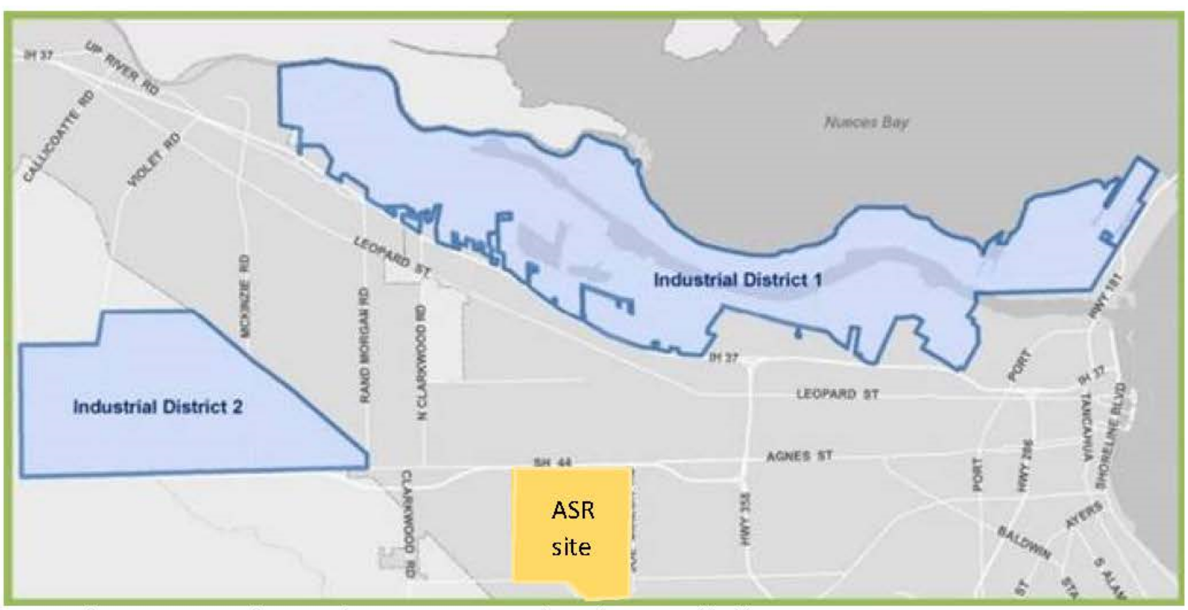
Based on conversations with John Byrum, 1/29/19 and 2/4/2019

- **Current Supply**- Assume 4.5-5 MGD effluent available from Greenwood WWTP for potential ASR use. Currently, there is a plan to divert 2 MGD to Broadway WWTP. A reasonable assumption for ASR potential is 63% of total plant capacity.
- **Future Expansion**- Anticipate expanding Greenwood WWTP capacity to 12 MGD by Year 2025-2030. In next 10 years, likely up to 7.5-8 MGD treated effluent available for potential ASR use.
- **Reuse Contracts**- Negligible amount of treated effluent delivered to Lozano Golf Course and Champions Ball Park
- **Water Quality**- Greenwood WWTP effluent generally has minimal fluctuations in water quality. No violations in TSS. Limited opportunities for Broadway reuse due to high chlorides.

Local Industrial Demands/Water Quality Needs (i.e. ASR recovery potential)

Based on conversations with Industrial Representatives and Corpus Christi Regional EDC, 1/23/19-1/24/19 and 2/4/19-2/5/19

- **Future Projected Demands**- Recent growth of about 5.2 MGD in past 3 years Nueces County-industrial growth. Additional 10.3 to 12 MGD anticipated with LyondellBasell expansions, Noble Energy, Epic ,Permico, and others.
- **ASR Potential to Meet Industrial Demands**- "If 7-9 MGD water supply was available in the next few years, the industrial demand would eagerly purchase it from the City" (M. Culbertson, EDC)
- **Water Quality**- No specific water quality standards, generally plants will accept raw and/or drinking water quality. Some facilities has RO treatment facilities on site, however higher TDS (>1000 mg/L) and calcium would increase O&M costs. Less stringent water quality needs for cooling (fewer cycles as TDS increases). Boiler processes are sensitive to TDS.
- **Minimal Seasonal Use Fluctuations**- Generally there are minimal fluctuations in use patterns. In general each plant tries to operate at maximum capacity, requiring full water demand.

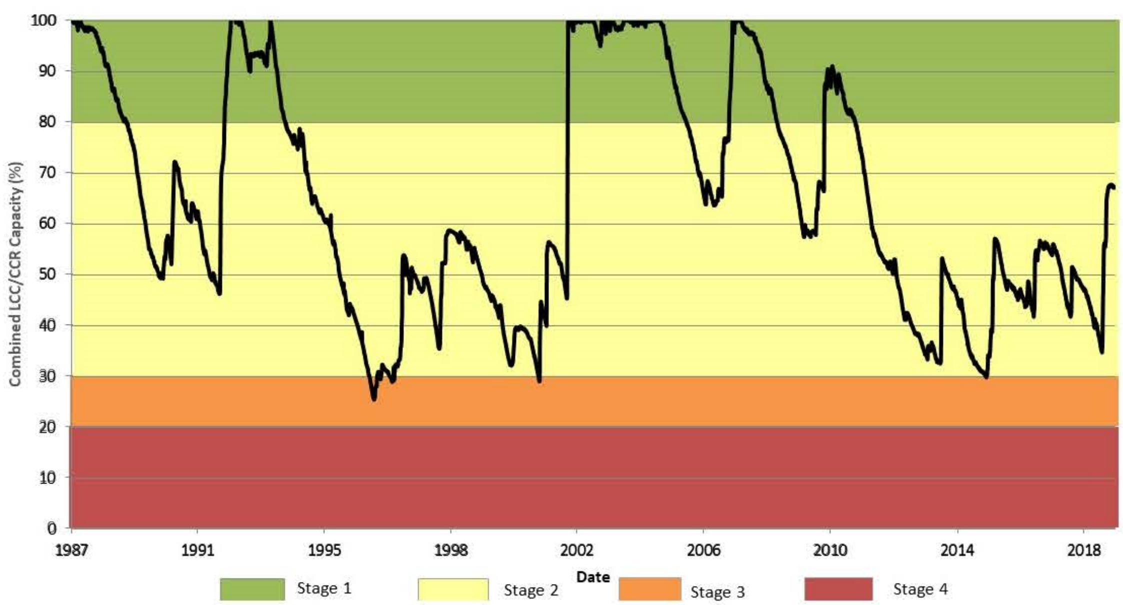


Source of Base Map: City of Corpus Christi, 2014. ASR study site location added by HDR.

Drought Mitigation (i.e. ASR recovery potential)

- **Past Events when CCR/LCC Combined Storage was <40% (since initial fill of CCR in 1987)**
  - Feb 22, 1996 to June 23, 1997 (474 days)- Most Severe
    - Below 30%- July 3 to Sept 24, 1996 (84 days); Oct 26 to Nov 5 (11 days); Feb 18 to Apr 4, 1997 (46 days). Total time- 141 days
  - July 16, 2000 to Sept 5, 2001 (417 days)
    - Below 30%- Aug 18 to Aug 31, 2001 (14 days)
  - Dec 7, 2012 to Oct 23, 2013 (321 days)
  - July 8, 2014 to May 12, 2015 (307 days)
  - July 16, 2018 to Sept 15, 2018 (62 days)
- **Longest Period of Time CCR/LCC Combined Storage <40%- 474 days**
- **Total ASR recovery needed to overcome reductions for 2020-2060 Demands-** 7.5 MGD – 8.4 MGD for 1.3 years (474 days)

Combined CCR/LCC Storage (1987-current)



Anticipated Water Supply Reductions for Repeat of Feb 1996-June 1997 Drought Conditions for Year 2020-2070 Manufacturing Demands
(474 days < 40% CCR/LCC capacity)

Water Demand (ac-ft/yr)		2020	2030	2040	2050	2060	2070
NUECES	MANUFACTURING	45,411	50,363	50,363	50,363	50,363	50,363
SAN PATRICIO	MANUFACTURING	38841	43223	43223	43223	43223	43223
Based on repeat of 2/22/96 to 6/23/97 drought (474 days total) Relative to Year 2020-2070 demands per 2021 Region N Plan	**Anticipated Water Supply Reductions for Severe Drought Conditions (ac-ft/yr)**						
	DCP reduction- For Nueces County assumes 15% for <30% CCR/LCC storage; For San Patricio County assumes 10% for 30-40% CCR/LCC storage; 15% <30% CCR/LCC storage (over 474 day period)						
		2020	*2030*	*2040*	*2050*	*2060*	*2070*
	Nueces- Industry (15% <30 only)	2,631	2,918	2,918	2,918	2,918	2,918
	San Patricio- Industry	5,794	6,448	6,448	6,448	6,448	6,448
	Nueces- MGD	2.3	2.6	2.6	2.6	2.6	2.6
	San Patricio- MGD	5.2	5.8	5.8	5.8	5.8	5.8
	Total- MGD	**7.5**	**8.4**	**8.4**	**8.4**	**8.4**	**8.4**

B

Appendix B – Corpus Christi Aquifer Storage and Recovery Conservation District Groundwater Management Plan

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Groundwater Management Plan

for the Corpus Christi Aquifer Storage and Recovery Conservation District (CCASRCD)

Updated from 2014 Groundwater Management Plan to include Five-Year Plan

April 18, 2019

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Contents

Tables

Figures

Appendices

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1 Groundwater Management Plan

This groundwater management plan was developed in accordance with 31 Texas Administrative Code (TAC) 356.51— 356.53 and Texas Water Code (TWC) 36.1071 requirements. The Corpus Christi Aquifer Storage and Recovery Conservation District (District) was formed as a result of enabling legislation through Senate Bill No. 1831 (Appendix A).

1.1 District Mission

The District is a groundwater conservation district (GCD) created in accordance with Texas Water Code (TWC) Chapter 36. The primary purposes of the District are to: (1) provide for conservation, preservation, protection, and recharge, (2) prevent waste, and (3) control land surface subsidence. In accordance with GCD requirements, the District prepared a Groundwater Management Plan in 2008 that was subsequently updated in 2013 and 2014. The previous groundwater management plans were approved by the Texas Water Development Board (TWDB). In accordance with TWC 36 and TAC 356.52, this groundwater management plan is developed as a five-year update that meets statutory requirements and includes goals that are both time-based and quantifiable.

The primary goal of the District is to enhance the City of Corpus Christi's (City) water supply, treatment and distribution system through management of an Aquifer Storage and Recovery District, the boundaries of which were described in Senate Bill No. 1831 to be coextensive with the City of Corpus Christi city limits (Appendix A). Through an interlocal agreement, the City and District cooperatively manage, operate, and administer activities of the District (Appendix B). A major consideration when forming the District was to ensure that water stored in an aquifer storage and recovery (ASR) facility could not be diverted by nearby wells.

The District's mission, as presented in the Rules and Regulations of the District (Appendix C), is as follows— The District is committed to the management and protection of groundwater resources of the District, including those injected into the ground for storage and later use. As a basic tenant of this commitment, the District seeks to maintain a sustainable, adequate, reliable, cost effective, and high quality water source to promote the vitality, economy, and environment of the District and greater Corpus Christi area. The District will work with and for the citizens of the District and cooperate with other local, regional, and state agencies involved in the study and management of groundwater resources. The District shall take no action without a full consideration of the groundwater needs of the citizens of the District.

The District's objectives include:

- Seasonal, long-term, and emergency (strategic reserve) storage
- Augmentation of peak storage capacity
- Improving system water quality by maintaining minimum flows during seasons of low demand

- Deferring expansion of some of the water system infrastructure
- Mitigation of streamflow requirements
- Management of stormwater flow and estuary salinity
- Helping to meet large retail customer demands

The location of the District is shown in Figure 1-1. As illustrated on the map, most of the District is located in Nueces County; however, the District also includes very limited parts of Kleberg and San Patricio Counties.

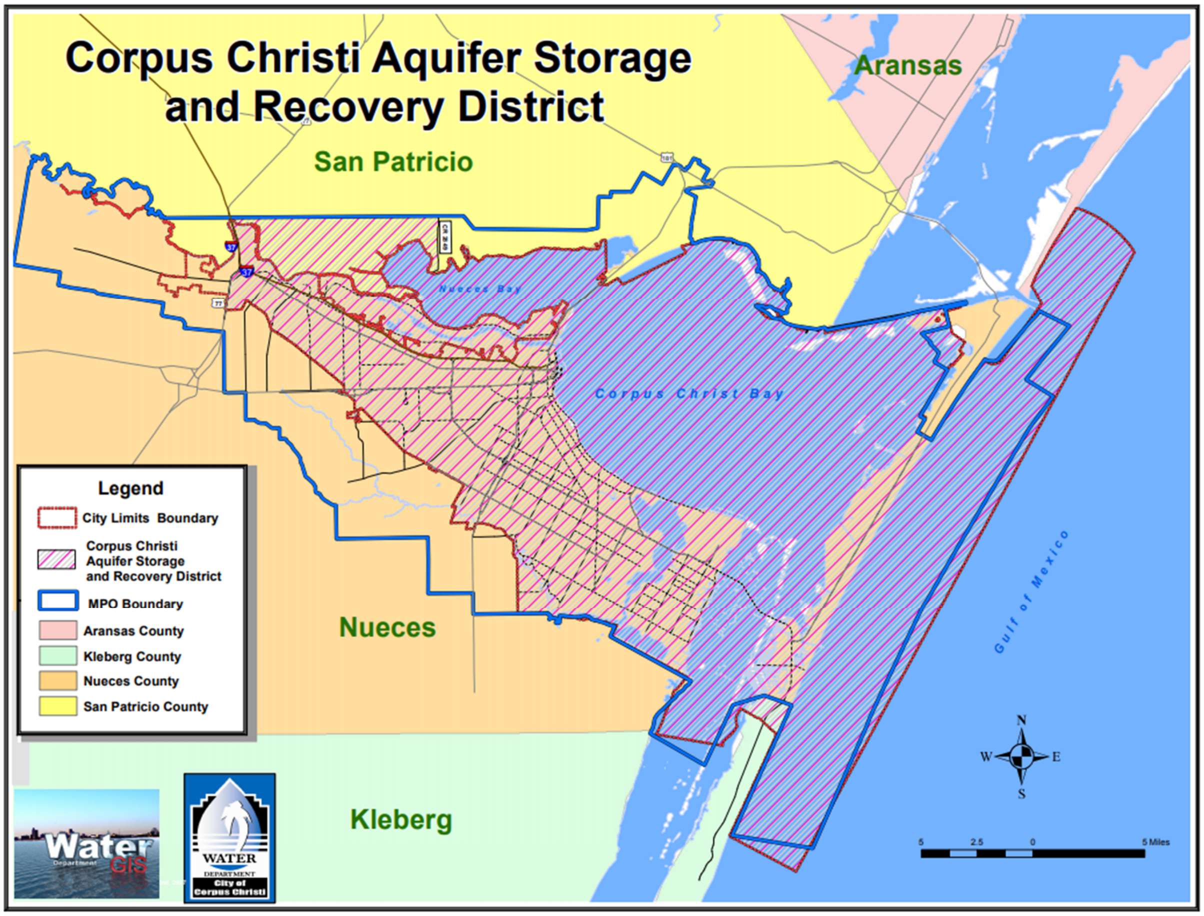

Figure 1-1. Corpus Christi Aquifer Storage and Recovery District

1.2 Purpose and Time Period of the Management Plan

The purpose of the management plan is to specify planning tools and development policies to manage and protect the groundwater resources of the District. The groundwater management plan (GMP) contains estimates of groundwater availability within the District, major groundwater water budget components summarizing water entering and leaving the District's groundwater system, details of how the District manages groundwater, and management goals for the District. The management plan is supported by technical information provided by the TWDB and other site-specific information available for the District.

The GMP allows the District to act and provide jurisdictional authority and protection in accordance with the requests of the state law. The 75th Texas Legislature (1997) established a statewide comprehensive regional water planning initiative with the enactment of Senate Bill 1 (SB1). SB1 included amendments to Chapter 36 of the Texas Water Code that require groundwater conservation districts to develop a groundwater management plan that shall be submitted to the TWDB for approval as administratively complete. SB1 provides for review and approval of the GMPs by the TWDB. In 2001, the 77th Texas Legislature further clarified the water planning and management provisions of SB1 with the enactment of Senate Bill 2 (SB2) and House Bill (HB) 1763. The administrative requirements of Chapter 36 of the Texas Water Code related to groundwater management plan development are specified in 31 Texas Administrative Code, Chapter 356. This plan has been prepared to fulfill all requirements for groundwater management plans required by SB1, SB2, Chapter 36 Texas Water Code, and 31 Texas Administrative Code Chapter 356.

This plan shall be in effect for a period of five years from the date of approval by the TWDB, unless a new or amended management plan is adopted by the District Board of Directors and certified by the TWDB.

1.3 District Administration

The District is governed by a Board of Directors, comprised of 6 members elected to staggering 2 and 4-year terms. The Board elects officers annually and the officers must be confirmed by the Corpus Christi City Council. If a vacancy occurs, then the Board may appoint a Director to serve the remainder of the term. The District's Board of Directors and Management Staff are listed in Tables 1-1 and 1-2, respectively.

This GMP was considered and adopted at an open meeting on April 18, 2019. Appendix D includes public notice and meeting minutes from the District Board meeting where the GMP was adopted.

The District participates in Region N Regional Water Planning Group meetings, local groundwater management area (GMA) meetings, and with county clerks in counties for which the District has jurisdictional land. Appendix E includes evidence of coordination with regional surface water entities.

Table 1-1. Corpus Christi Aquifer Storage and Recovery Conservation District Board of Directors

Director	Role
Fred Segundo	Chairman/ President
Daniel McGinn	Vice Chairman/ Vice- President
Jeff Edmonds	Secretary
Mark Van Vleck	Director
Sharon Lewis	Director

Table 1-2. Corpus Christi Aquifer Storage and Recovery Conservation District Management Staff

Management Staff	Role
Larijai Francis	Administrator/ General Manager
Lisa Aguilar	Legal Counsel
Itzel Ojeda	Executive Assistant

1.4 Aquifer Setting

1.4.1 Geologic Setting

The Gulf Coast Aquifer system is the primary water-bearing geologic formation beneath the District, with the main hydrogeologic units consisting of the Chicot and Evangeline aquifers. The Beaumont Clay, Lissie Formation, and Goliad Sands are the major stratigraphic units of the Gulf Coast Aquifer, as shown in Figures 1-2 and 1-3. These units are hydrologically interconnected to yield small to moderate supplies of fresh and slightly saline water (Shafer and USGS, 1968). Geologic units of the Gulf Coast Aquifer system dip east toward the coast at a direction roughly perpendicular to the local shoreline and the strike of geologic units is approximately parallel to the shoreline (TWDB, 2010). The source of recharge to groundwater in Nueces County is primarily through precipitation on the outcrop in counties to the northwest and west. The heterogeneous character of the stratigraphic units makes correlation and distinction of individual beds difficult even within short distances, however, it is most important to note that the units are in hydrologic continuity (Shafer and USGS, 1968) as shown in Figure 1-4 and therefore recharge and recovery of an ASR program are likely to impact not only the direct storage zone but adjacent units. This hydrogeologic framework provides a desirable structure for multiple interval well screening to optimize well production performance. The rate of movement of groundwater ranges from tens to hundreds of feet per year, depending on the hydraulic gradient, permeability of sediments, and other factors (Shafer and USGS, 1968). Groundwater flow is in a southeasterly manner towards the Gulf of Mexico.

Water levels in the Gulf Coast Aquifer in Nueces County fluctuate as a result of changes in rates of recharge, pumping, and barometric pressure. As shown in Figure 1-5, there are only a few TWDB-registered wells within the District area. For this reason, it is difficult to determine the current water level and historical water level fluctuations within the study area, but it is estimated to be 10 to 40 feet below land surface.

The Evangeline Aquifer is the most productive water-bearing hydrogeologic unit in the Gulf Coast Aquifer, with well yields of around 800 gallons per minute (gpm) reported in the Nueces and San Patricio County vicinity as compared to 430 gpm reported for Chicot wells (Meyer, 2012). In the study area, the top of the Evangeline Aquifer is roughly 400 to 700 feet below land surface. The Chicot Aquifer overlies the Evangeline Aquifer, and while it provides suitable supplies for domestic and livestock purposes, from a long-term perspective the Chicot Aquifer does not present the most desirable long-term storage opportunity for an ASR system. The general characteristics of major interest are sand water-bearing zones, which provide the largest opportunity for aquifer storage and recovery and the locations of confining beds of silts and clays. Well logs have been used to assist in characterizing the aquifer and the recent on-going Corpus Christi Aquifer Storage and Recovery Feasibility Project conducted by the District with support from the TWDB has collected additional data, described in Section 2.2, to further characterize the ASR resources of the District.

System	Series	Stratigraphic Units (TWDB, 2012)	Hydrogeologic Units Galloway (1991)	Estimated Thickness near Study Area (USGS, 1968)	Rock Characteristics	Water-bearing Property Columns	
Quaternary	Pleistocene	Alluvium/ Beaumont Clay	Chicot Aquifer	100-200	Clay, interbedded with layers of medium to fine sand.	Yields small to moderate quantities of fresh to moderately saline water.	Gulf Coast Aquifer
		Lissie Formation		200-300	Clay, sandy clay, sand and gravel.	Yields small to large quantities of fresh to slightly saline water.	
Tertiary	Pliocene	Willis		200-400	Sand, gravel, sandy clay, and clay.		
		Goliad Sand	Evangeline Aquifer	600-2,400(?)	Sand and sandstone interbedded with gravel and clay.	Capable of yielding moderate to large quantities of fresh, slightly saline , and saline water.	
	Miocene	Fleming/ Lagarto	Burkeville Confining System	3,600+(?)	Clay, silty calcareous clay, and interbedded sand and gravel. Caliche in the outcrop.	Yields small to large quantities of slightly saline to saline water.	
		Oakville Sandstone	Jasper Aquifer	3,000+(?)	Fine to coarse sand, sand-stone and clay.	Capable of yielding moderate to large quantities of slightly saline to saline water.	
	Oligocene	Catahoula Tuff	Catahoula Confining System	3,000+(?)	Predominantly tuffaceous clay and tuff, locally sandy clay, bentonitic clay, and thin beds of sand and conglomerate.	Yields small to moderate quantities of saline water.	

Figure 1-2. Geologic and Hydrologic Units of the District (HDR, 2016. Adapted from Baker and USGS, 1979)

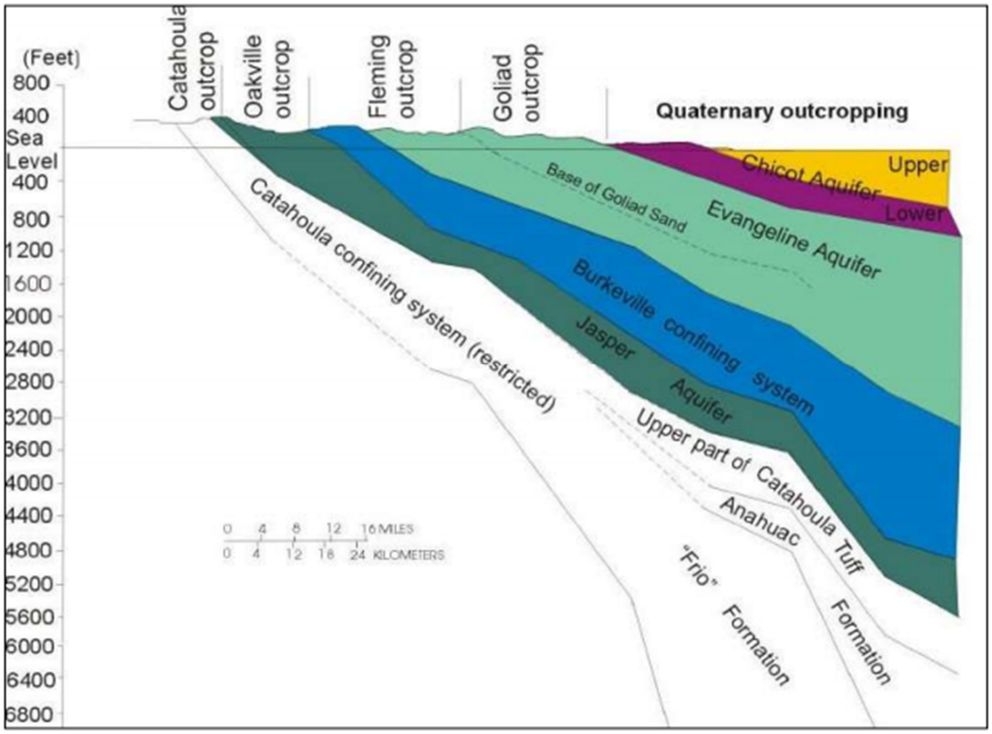

Figure 1-3. Cross-Section of the Gulf Coast Aquifer (CCASRCD, 2014)

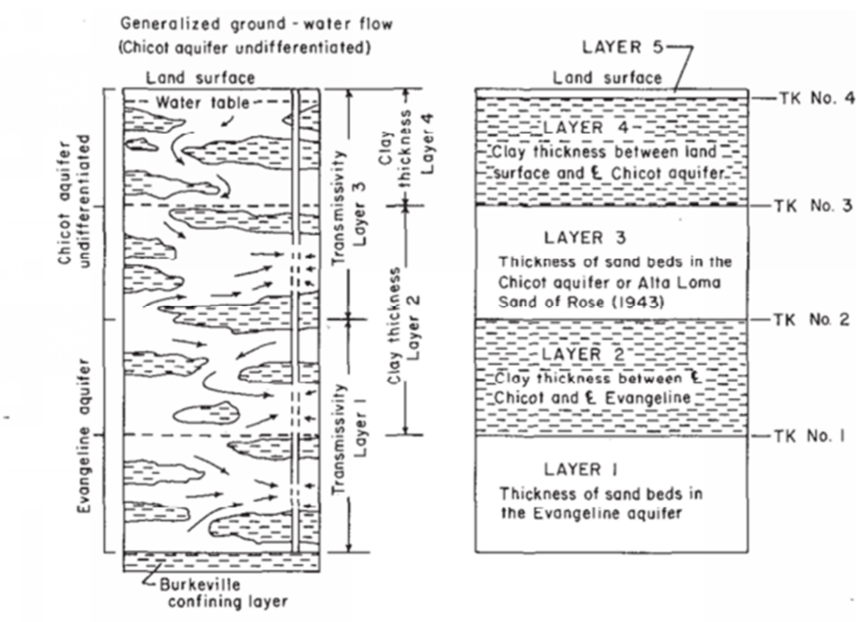

Figure 1-4. Inter-Connectedness in the Gulf Coast Aquifer Structure (USGS, 1985)

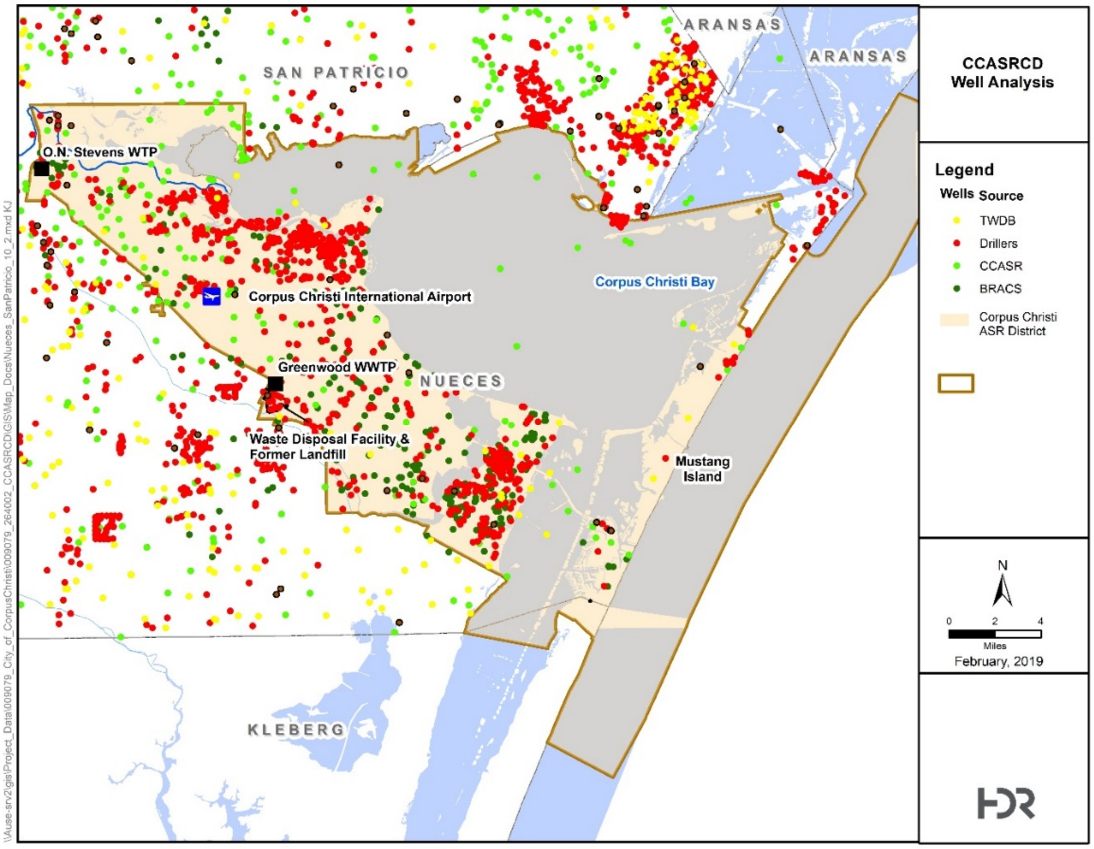

Figure 1-5. Location of Wells (Water Supply Oil and Gas) Located in the District

1.5 District Information

1.5.1 Modeled Available Groundwater (MAG) in the District

(31 TAC 356.52(a)(5)(A) and TWC 36.1071(e)(3)(A))

The Texas Water Code (TWC§36.108) defines "modeled available groundwater" (MAG) as the amount of water that the executive administrator (TWDB) determines may be produced on an average annual basis to achieve a desired future condition (DFC) set forth by local GCDs and GMAs. Based on these DFCs, the TWDB uses the appropriate groundwater availability model (GAM) to develop MAG quantities, which represent the annual availability from regional aquifers based on submitted DFCs.

One of the key coordination goals within each GMA is the development of DFCs for the aquifers within their area, as required by the Texas Administrative Code:

"The desired, quantified condition of groundwater resources (such as water levels, water quality, spring flows, or volumes) at a specified time or times in the future or in perpetuity, as defined by participating groundwater conservation districts within a groundwater management area as part of the joint planning process." Desired future conditions have to be physically possible, individually and collectively, if different desired future conditions are stated for different geographic areas overlying an aquifer or subdivision of an aquifer." [TAC§356.2(8)]

The District participates in development of DFCs with GMA 16, which includes the area within the District boundaries and jurisdictional authority. The groundwater availability model (GAM) run that calculated the MAG for purposes of this management plan is GAM Run 17-025 MAG (TWDB, 2017b), which is attached as Appendix F of this plan. The GAM Run 17-025 MAG, dated May 19, 2017, used an alternative groundwater availability model developed specifically for GMA 16 (Hutchison and others, 2011) to calculate the difference in water levels at the beginning of 2010 and end of 2060 for the Gulf Coast Aquifer System. The MAG values were determined by extracting pumping rates by decade from the model results using ZONEBUDGET Version 3.01 (Harbaugh, 2009). Drawdown averages were calculated by county and GCD for the entire GMA. Details on methods, assumptions, and results for the GAM Run 17-025 MAG analysis for the portion of the Gulf Coast Aquifer system located in GMA 16 is located in Appendix F.

The DFCs for the Gulf Coast Aquifer System described in Resolution No. 2017-01 and adopted January 17, 2017 by GMA 16 specified that the GMA-wide drawdown from the Gulf Coast Aquifer System shall not exceed an average of 62 feet in December 2060 from estimated year 2010 conditions.

The amount of MAG for the Gulf Coast Aquifer system to meet but not exceed the DFC increases from about 233,000 acre-feet per year in 2020 to 312,000 acre-feet per year in 2060. For the District area, the MAG increases from 328 acre-feet per year in 2010 to 398 acre-feet per year in 2060, as shown in Table 1-3. The MAG for Nueces and San Patricio counties where the District is predominantly located, is shown by river basin in Table 1-4.

Table 1-3. Modeled Available Groundwater for the Gulf Coast Aquifer System in Groundwater Management Area 16 within the Corpus Christi Aquifer Storage and Recovery Conservation District for Each Decade between 2010 and 2060. Values are in Acre-Feet per Year

Groundwater Conservation District (GCD)	County	Aquifer	2010	2020	2030	2040	2050	2060
Corpus Christi ASRCD	Nueces	Gulf Coast Aquifer System	328	342	356	370	384	398

Source: TWDB, 2017b.

Table 1-4. Modeled Available Groundwater by Decade for the Gulf Coast Aquifer System in Groundwater Management Area 16 for Nueces and San Patricio counties. Results are in Acre-Feet per Year

County	RWPA	River Basin	Aquifer	2020	2030	2040	2050	2060
Nueces	N	Nueces-Rio Grande	Gulf Coast Aquifer System	5,862	6,191	6,522	6,851	7,079
Nueces	N	Nueces	Gulf Coast Aquifer System	727	756	787	816	845
Nueces	N	San Antonio-Nueces	Gulf Coast Aquifer System	0	0	0	0	0
San Patricio	N	Nueces	Gulf Coast Aquifer System	4,130	4,502	4,874	5,247	5,619
San Patricio	N	San Antonio-Nueces	Gulf Coast Aquifer System	39,481	40,514	41,548	42,581	43,615

Source: TWDB, 2017b.

1.5.2 Groundwater Budget Components

(31 TAC 356.52(a)(5)(C-E) and TWC 36.1071(e)(3)(C-E))

In June 2018, the TWDB prepared GAM Run 18-012 to discuss methods, assumptions, and groundwater budget components of the GAM Run for the central portion of the Gulf Coast Aquifer System for use by the District in preparing this GMP (TWDB, 2018a). TWDB GAM Run 18-012 is included in Appendix G. The groundwater budgets summarize the amount of water entering and leaving the aquifers, which were extracted from the GAM for the Gulf Coast Aquifer System located within the District and averaged over the historical calibration period.

- Precipitation recharge—the aerially distributed recharge sourced from precipitation falling on the outcrop areas of the aquifers (where the aquifer is exposed at land surface) within the district.
- Surface-water outflow—the total water discharging from the aquifer (outflow) to surface-water features such as streams, reservoirs, and springs. Additionally, GAM Run 18-012 estimated the outflow to the bays.
- Flow into and out of district—the lateral flow within the aquifer between the district and adjacent counties.
- Flow between aquifers—the net vertical flow between the aquifer and adjacent aquifers or confining units. This flow is controlled by the relative water levels in each aquifer and aquifer properties of each aquifer or confining unit that define the amount of leakage that occurs.

A graphical depiction of these water budget components along with the modeled results are summarized in Figure 1-6 and in Table 1-5.

Recharge in the Gulf Coast Aquifer occurs predominantly through the infiltration of rainfall. Researchers have estimated the rate of recharge for the area of the Gulf Coast Aquifer that is proximate to or includes the District. Ryder (1988) estimated that the rate of recharge was less than 2 inches per year and Dutton and Richter (1990) estimated a range of 0.1 to 0.4 inches per year.

The majority of the rain that falls on the land surface runs off and is not available for recharge to the aquifer. A significant portion of the water that infiltrates the soil is lost through evapotranspiration. Some water that infiltrates the soil recharges the aquifer but is not held in storage because it is discharged through springs or bank seepage in creeks and rivers. Vertical recharge to the aquifer is the fraction of the rainfall that originally infiltrated the soil and reached the aquifer to augment the amount of water in storage or available for use.

According to GAM Run 18-012, the volume of recharge for the District area is estimated to be 7 acre-feet per year. The amount of water flowing into the District is estimated to be 202 acre-feet per year with 89 acre-feet per year estimated to be flowing out of the District, as shown in Table 1-5. The estimated net annual volume of flow between each aquifer in the District from brackish units to the Gulf Coast Aquifer is 396 acre-feet per year. The amount of water discharged from the Gulf Coast Aquifer to surface water bodies is estimated to be 482 acre-feet/year, which includes 417 acre-feet per year to rivers and 65 acre-feet per year to bays.

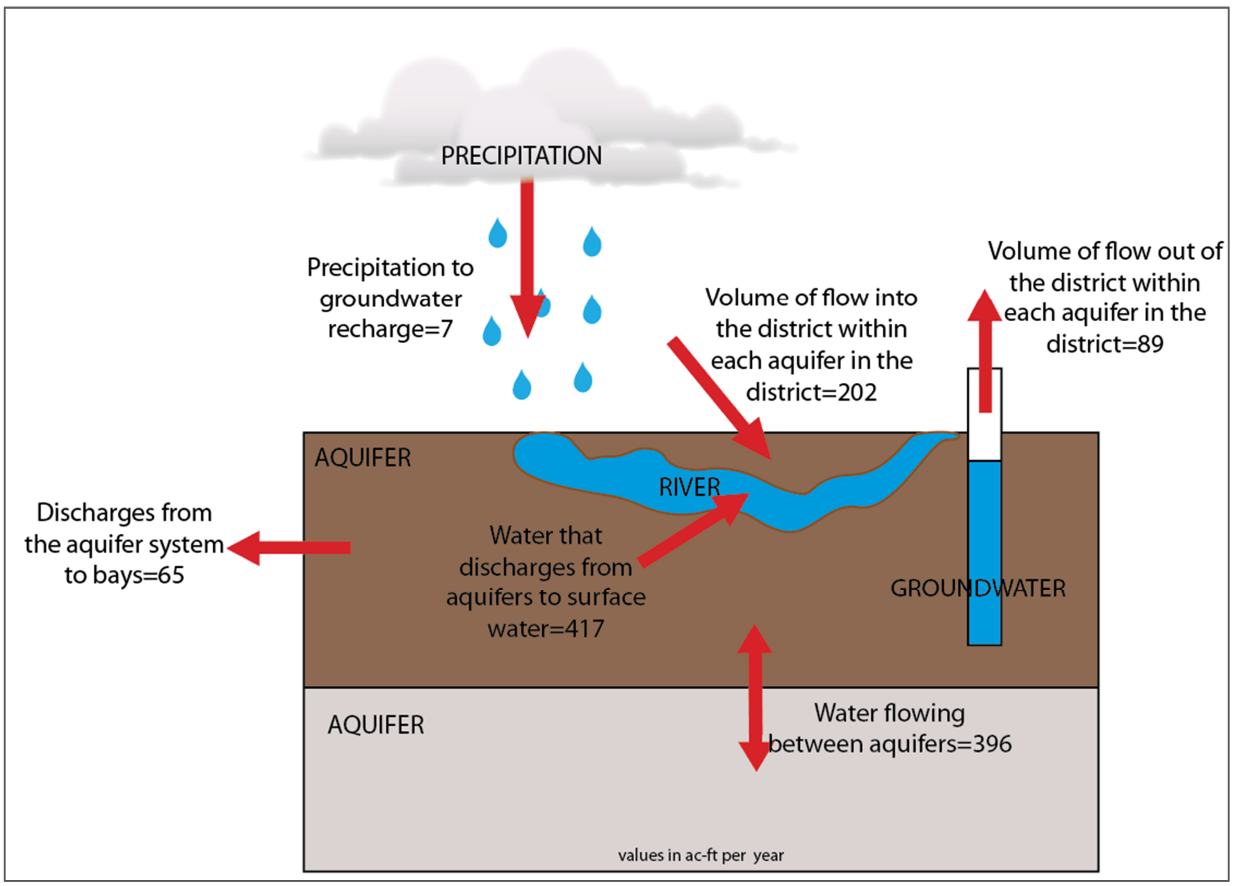

Figure 1-6. Mass Balance in the Corpus Christi Aquifer Storage and Recovery Conservation District (CCASR) based on GAM Run 18-012 and summarized in Table 1.5. Units are in Acre-Feet per Year

Table 1-5. Summarized Information for the Gulf Coast Aquifer System for the Corpus Christi Aquifer Storage and Recovery Conservation District's Groundwater Management Plan. All Values Are Reported In Acre-Feet per Year and Rounded to the Nearest 1 Acre-Foot

Management Plan Requirement	Aquifer or Confining Unit	Results
Estimated annual amount of recharge from precipitation to the district	Gulf Coast Aquifer System	7
Estimated annual volume of water that discharges from the aquifer to springs and any surface-water body including lakes, streams, and rivers	Gulf Coast Aquifer System	417
Estimated annual volume of water that discharges from the aquifer to bays	Gulf Coast Aquifer System	65
Estimated annual volume of flow into the district within each aquifer in the district	Gulf Coast Aquifer System	202
Estimated annual volume of flow out of the district within each aquifer in the district	Gulf Coast Aquifer System	89
Estimated net annual volume of flow between each aquifer in the district	Gulf Coast Aquifer System	396

1.5.3 Historical Groundwater Use and 2017 State Water Plan Data

In December 2018, the TWDB prepared a report for the District that included estimated historical groundwater use and information from the 2017 State Water Plan Datasets (TWDB, 2018b). The report, included in Appendix H, included the following information from the 2017 State Water Plan (TWDB, 2017a): estimated historical groundwater use, projected surface water supplies, projected water demands, projected water supply needs, and projected water management strategies. The projected surface water supplies and projected water demands within the District were pro-rated for the District's consideration and use in developing the GMP. Since the District only covers a portion of Nueces and San Patricio counties, the data values were modified with an apportioning multiplier (19.76% for Nueces County and 2.88% for San Patricio County) to create new values that more accurately represent conditions within district boundaries. The TWDB report included data for Nueces and San Patricio counties only, although a small portion of the District boundaries extend into Kleberg County. For projected surface water supplies the county-wide water user group (WUG) data values (county other, steam electric power, manufacturing, irrigation, mining and livestock) are modified using the multiplier. WUG values for municipalities, water supply corporations, and utility districts are not apportioned; instead, their full values are retained when they are located within the district, and eliminated when they are located outside based on District feedback.

1.5.4 Projected Surface Water Supply

(31 TAC 356.52(a)(5)(F) and TWC 36.1071(e)(3)(F))

The TWDB report indicated a projected surface water supply in Nueces County of 81,654 acre-feet per year in 2020 and increasing to 94,713 acre-feet per year in the 2070 projection. In the San Patricio County, the sum of the projected surface water supplies is 8,041 acre-feet per year for the District in 2020 and 8,513 acre-feet per year for 2070 (Appendix H). Surface water supplies by county are summarized in Table 1-6 for Nueces and San Patricio counties.

Table 1-6. Projected Surface Water Supplies by County. Values Are in Acre-Feet per Year (TWDB, 2018b)

County	2020	2030	2040	2050	2060	2070
Nueces County	81,654	87,176	90,909	93,320	94,182	94,713
San Patricio County	8,041	8,184	8,229	8,311	8,418	8,513

1.5.5 Groundwater Usage and Availability

(31 TAC 356.52(a)(5)(B) and TWC 36.1071(e)(3)(B))

The TWDB gathered estimated historical groundwater use for Nueces and San Patricio counties through its annual Water User Survey (TWDB, 2018b). Groundwater use in Nueces County has increased from 347 acre-feet per year in 2001 to 1,135 acre-feet per year in 2016 (average of 993 acre-feet per year). Groundwater use in San Patricio County ranged from 197 acre-feet per year in 2001 to 497 acre-feet per year in 2011 before declining from 2012 to 2016 (average of 311 acre-feet per year). Average groundwater use in Nueces and San Patricio Counties during from 2001 to 2016 is shown in Table 1-7. The most recent water use survey estimates annual groundwater use of 1,135 acre-feet per year in Nueces County and 209 acre-feet per year in San Patricio County for the year 2016 (Appendix H).

Table 1-7. Estimated Historic Groundwater Usage in Nueces and San Patricio Counties. Values Are in Acre-Feet per Year (TWDB, 2018b)

Year	Source	Municipal	Manufacturing	Mining	Steam Electric	Irrigation	Livestock	Total
Nueces County								
2001-2016	GW	235	448	181	0	83	46	993
San Patricio County								
2001-2016	GW	65	0	1	0	241	4	311

1.5.6 Projected Water Demand

(31 TAC 356.52(a)(5)(G) and TWC 36.1071(e)(3)(G))

The projected water demand within the District in 2020 according to the most recently adopted 2017 State Water Plan is 85,121 acre-feet per year in Nueces County and

10,092 acre-feet per year for San Patricio County. These water demands within the District are projected to increase to 103,478 acre-feet per year and 11,234 acre-feet per year for Nueces and San Patricio counties respectively, by year 2070 (Appendix H). Summaries of the 2017 State Water Plan water demand projections are in Tables 1-8 through 1-10. Currently, the Coastal Bend Regional Water Group is in the process of developing the 2021 Coastal Bend (Region N) Regional Water Plan, which will be assimilated into the 2022 State Water Plan. The county-wide projected water demands from the 2021 Region N Plan and 2022 State Water Plan have been adopted by the TWDB, but have not been apportioned to the District area and therefore are not included in this GMP.

Table 1-8. Total Projected Water Demand in the District. Values Are in Acre-Feet per Year

County	2020	2030	2040	2050	2060	2070
NUECES	85,121	90,652	94,375	97,181	100,423	103,478
SAN PATRICIO	10,092	10,379	10,543	10,739	10,985	11,234

Table 1-9. Water Demands by WUG Type for Nueces County from the 2017 State Water Plan. Values Are in Acre-Feet per Year

County	WUG Type	2020	2030	2040	2050	2060	2070
NUECES	IRRIGATION	86	91	95	100	106	110
NUECES	LIVESTOCK	63	63	63	63	63	63
NUECES	MANUFACTURING	9,934	10,557	11,165	11,688	12,511	13,391
NUECES	MINING	143	169	188	202	224	249
NUECES	MUNICIPAL	71,924	76,297	78,778	80,295	81,776	82,840
NUECES	STEAM ELECTRIC POWER	2,971	3,475	4,086	4,833	5,743	6,825
NUECES Total		**85,121**	**90,652**	**94,375**	**97,181**	**100,423**	**103,478**

Source: TWDB, 2017a.

Table 1-10. Water Demands by WUG Type for San Patricio County from the 2017 State Water Plan. Values Are in Acre-Feet per Year

County	WUG Type	2020	2030	2040	2050	2060	2070
SAN PATRICIO	IRRIGATION	319	352	390	430	476	537
SAN PATRICIO	LIVESTOCK	12	12	12	12	12	12
SAN PATRICIO	MANUFACTURING	1,144	1,241	1,337	1,421	1,527	1,641
SAN PATRICIO	MINING	10	13	13	13	14	15
SAN PATRICIO	MUNICIPAL	8,607	8,761	8,791	8,863	8,956	9,029
SAN PATRICIO	STEAM ELECTRIC POWER	0	0	0	0	0	0
SAN PATRICIO Total		**10,092**	**10,379**	**10,543**	**10,739**	**10,985**	**11,234**

1.5.7 Water Supply Needs and Water Management Strategies

(TWC 36.1071(e)(4))

The 2017 State Water Plan projected that there would be water supply needs for Nueces and San Patricio counties (Appendix H). Current water supplies were prioritized to meet municipal demands first limited by infrastructure constraints, which resulted in supply deficits related to future projected water demands being assigned to non-municipal water user groups (i.e. manufacturing). The projected water supply needs in Nueces County are estimated at -1,583 acre-feet per year for Year 2020 and -28,021 acre-feet per year for Year 2070. In San Patricio County, the projected water need deficiency is greater than Nueces County. The 2017 State Water Plan estimates the projected water supply needs in San Patricio County at -6,451 acre-feet per year for year 2020 and -22,720 acre-feet per year for 2070. The water supply needs are summarized in Tables 1-11 through 1-13 below.

Water management strategies recommended for Nueces and San Patricio Counties, including specific WUGs for which they are recommended and those relevant to District area are shown in provided in Appendix H. The projected supply by implementing water management strategies in Nueces County, according to the most recently adopted 2017 State Water Plan, amounts to 32,764 acre-feet per year for the year 2020 and 58,096 acre-feet per year in the in 2070 if all water management strategies are developed. For San Patricio County, the projected supply attributed to water management strategies in the 2017 State Water Plan is 10,384 acre-feet per year in the District for Year 2020 and 25,707 acre-feet per year for Year 2070.

Table 1-11. Projected Total Water Supply Needs in the TWDB 2017 State Water Plan. Values Are in Acre-Feet per Year

County	2020	2030	2040	2050	2060	2070
NUECES	-1,583	-1,547	-1,511	-3,418	-15,345	-28,021
SAN PATRICIO	-6,451	-8,804	-11,126	-13,671	-17,817	-22,720

Table 1-12. Nueces County Needs from the 2017 State Water Plan. Values Are in Acre-Feet per Year

WUG Type	2020	2030	2040	2050	2060	2070
Mining	0	0	0	0	0	0
Livestock	0	0	0	0	0	0
Steam Electric Power	0	0	0	0	-2,846	-6,893
Manufacturing	0	0	0	-1,905	-10,981	-19,603
Municipal	-1,095	-1,255	-1,335	-1,405	-1,471	-1,522
Irrigation	262	240	217	193	167	141
Total	-1,583	-1,547	-1,511	-3,418	-15,345	-28,021

Table 1-13. San Patricio County Needs from the 2017 State Water Plan. Values Are in Acre-Feet per Year

WUG Type	2020	2030	2040	2050	2060	2070
Mining	193	144	125	105	73	32
Livestock	0	0	0	0	0	0
Steam Electric Power	0	0	0	0	0	0
Manufacturing	-6,451	-8,804	-11,126	-13,172	-15,754	-18,529
Municipal	566	526	512	497	479	466
Irrigation	3,356	2,197	916	-499	-2,063	-4,191
Total	-6,451	-8,804	-11,126	-13,671	-17,817	-22,720

1.6 District Management Goals

(31 TAC 356.51; 356.52(a)(2-4) and TWC 36.1071(e)(1)

Pursuant to the purpose for which the District was created in 2005 and the District's mission described earlier in this document, the District has developed management goals that will be measured by specific and time-based actions during the five years following adoption of this management plan and consistent with the established DFCs in the District's groundwater management area in accordance with 31 TAC 356.52, TWC 36.1071, and TWC 36.1085. Each goal to be addressed, according to 31 TAC 356.52(a)(1), is outlined below and includes management objectives and performance standards to evaluate the effectiveness and efficiency of District activities. Additional details on how the District will manage groundwater supplies and track progress in achieving its goals are also described, including goals that will be tracked on an annual basis.

1.6.1 Develop and Protect Municipal Aquifer Storage Areas

(Special District Local Laws Code Chapter 8811.002)

Objective: Protect Municipal Aquifer Storage Areas within the boundaries of the District for which jurisdictional authority has been granted to develop and protect municipal aquifer storage areas created by the City of Corpus Christi.

Performance Standard: The District will compile information in a database of known water wells located within the District including status, pumping rate, and water quality data. The District with support from the City of Corpus Christi will mail-out educational information at least once a year to residents and businesses located in ASR areas actively being studied including disseminating maps of areas protected for City's ASR projects. Well owners likely impacted by the City's ASR activities will be notified. If unregistered wells are found to be operating in the area in such a way as to impact District and City projects, the District will discuss remedies with the City of Corpus Christi which may result in enforcement of mitigation procedures which may include well owner suspending pumping operations and/or well abandonment. The District will enforce District Rules. The District will provide for security monitoring, including fencing and other measures, to protect monitoring wells, production and recharge wells owned within the District jurisdiction. The District will continue to maintain and develop the ASR program, including actions necessary to enforce its 5 Year Plan.

1.6.2 Providing the Most Efficient Use of Groundwater

(31 TAC 356.52(a)(1)(A) and TWC 36.1071(a)(1))

Objective: Continue to manage and enforce District Rules and Regulations including, but not limited to: well drilling application requirements, distance and spacing requirements for permits, monitoring well requirements, ownership of stored water, production limits, and transfer of produced groundwater outside District limits.

Performance Standard: District is able to limit permit authorizations to assure no harm or negative impact will occur to the aquifer storage area and landowners holding adjacent properties. Maximum allowable production in operating permit for non-exempt well limited to 0.04 acre-feet per contiguous surface area owned unless exemption is granted. In consideration of maximum allowable production limits, the District will consider service needs and area of the retail utility in lieu of surface area owned or operated by the retail public water utility. The District will periodically review filed State Well Reports and TWDB databases to confirm permitted and/or registered water wells within District jurisdiction. Additionally, the District will periodically review monitored water level reports provided by permit holders to the District.

Objective: Each year, the District will require all new exempt or permitted wells that are constructed within the boundaries of the district to be registered with the District in accordance with the District rules. The District will continue to gather information on all exempt and non-exempt wells located within the District, including encouraging owners of existing, exempt wells to register with the District.

Performance Standard: The District shall, in each of its annual reports, provide the number of exempt and permitted wells registered by the District for the prior year.

Objective: The District requires permits prior to construction for all new non-exempt wells within the limits of the District as outlined in the District Rules and Regulations.

Performance Standard: The District shall in each annual report, provide a summary of the number and type of applications made for the permitted use of groundwater in the District and the number and type of permits issued, and the total number of wells currently permitted within the District.

Objective: The District will establish a monitoring well network within the District over the next two years to monitor water levels and water quality. It is the District's intent to identify existing wells suitable for use as monitoring wells.

Performance Standard: The District and City of Corpus Christi, with support from a TWDB grant, constructed three monitoring wells as part of the ongoing Corpus Christi Aquifer Storage and Recovery Feasibility project. These wells will be monitored by the District. The District shall establish a monitoring well program and shall report on the status of the monitoring well network in each annual report.

1.6.3 Controlling and Preventing Waste of Groundwater

(31 TAC 356.52(a)(1)(B) and TWC 36.1071(a)(2))

Objective: The District will annually monitor water levels and production rates consistent with permits within the District area.

Performance Standard: The District will receive and record water level measurements as required by permit holders for wells drilled and rehabilitation of existing wells that pump more than 200 acre-feet per year in accordance with District Rules and Regulations. The District will periodically review monitored water level reports provided by permit holders to the District, and verify production is limited to maximum authorized recharge and withdrawals and instantaneous rate of withdrawal subject to permit and consistent with conditions set forth in the District's Rules and Regulations.

Objective: Each year, the District will meet with the City of Corpus Christi to identify opportunities to send information to the public regarding eliminating and reducing wasteful practices in the use of groundwater.

Performance Standard: The District will seek opportunities to collaborate with the City of Corpus Christi on communication and public awareness programs. Following each meeting with the City, District staff will document topics of discussion with the City including a summary of opportunities for cooperation with the City to promote efficient use of the District's groundwater. The District will include a summary in each annual report of Board's decisions regarding cooperative public information activities with the City including the number of cooperative activities participated in by the District and summary description of each activity, where applicable.

Objective: Each year, the District will review and evaluate District Rules and Regulations to determine whether any amendments are needed to decrease the amount of waste of groundwater within the District. The District's review of its rules will take place during a properly noticed meeting, and any decisions regarding amendments to the District Rules will be through formal District Board action and documented in the minutes of the Board.

Performance Standard: The District will, in each annual report, include a summary discussion of the District Board's review and decisions regarding amendments to the District's Rules and Regulations. Documentation in the annual report will include at minimum, the date, time and location of the District Board meeting, and approved meeting minutes of the Board's review and actions taken regarding rule amendments.

1.6.4 Controlling and Preventing Subsidence

(31 TAC 356.52(a)(1)(C) and TWC 36.1071(a)(3))

Objective: Continue to manage and enforce the District's Rules and Regulations, particularly those relevant to managing groundwater resources to control subsidence and prevent degradation of water quality.

Performance Standard: The District will review permit application materials for non-exempt wells (as needed) related to projected effects of proposed injection or withdrawal on subsidence and effects on existing permit holders or other groundwater users in the District.

Objective: Within two years following adoption of this management plan and approval by the TWDB, the District will consider a subsidence monitoring plan to monitor potential subsidence in the District. The subsidence monitoring plan will include an overall assessment of subsidence potential within the District based on projected groundwater usage and/or ASR operations, protocols for monitoring subsidence, and coordination efforts with USGS, adjacent GCDs and other stakeholders.

Performance Standard: The District will include a summary of subsidence monitoring plan activities in its annual reports, and as data becomes available, will develop a subsidence report to aggregate data gathered for the City of Corpus Christi and other local stakeholders that may be affected. If subsidence monitoring is deemed necessary, the District will take measures to install a subsidence monitoring network and will tabulate and report results in the annual report. If practicable, the District shall coordinate with USGS to implement subsidence monitoring gages. In accordance with District Rules, execute changes in groundwater operation to respond to evidence of regional subsidence.

1.6.5 Conjunctive Surface Water Management Issues

(31 TAC 356.52(a)(1)(D) and TWC 36.1071(a)(4))

Objective: Each year, the District will participate in the regional water planning process by attending Region N Regional Water Planning Group meetings to encourage the development of surface water supplies to meet the needs of water users in the District.

Performance Standard: A representative of the District will attend a minimum of 50% of the Region N Regional Water Planning Group meetings, and a minimum of 10% of the adjacent Region L Regional Water Planning Group meetings to stay abreast of conditions that may impact the District jurisdiction. The District will document attendance and participation of District representatives in Region N and Region L meetings in each annual report. Documentation will include a table of Region N and L meetings scheduled during the preceding 12 months, attendance status of District staff, and name of District staff attending.

1.6.6 Natural Resource Issues that are Impacted by the Use and Availability of Groundwater

(31 TAC 356.52(a)(1)(E) and TWC 36.1071(a)(5))

Objective: The District will continue to investigate and document the location, depth, and uses of existing water wells within the District including groundwater production on non-exempt wells in addition to pumping reports.

Performance Standard: The District will prepare a database that includes a listing of each water well and pertinent data located within the District's jurisdiction. A map will be prepared showing locations of registered and/or permitted wells within the District. Additional information from TWDB well databases will be evaluated periodically and database updated, accordingly. A summary table of each water well and pertinent characteristic of the well, including map showing well locations will be included in the Annual Report.

1.6.7 Drought Conditions

(31 TAC 356.52(a)(1)(F) and TWC 36.1071(a)(6))

Objective: The District will monitor City of Corpus Christi drought triggers on a weekly basis during dry events and respond to District-declared droughts according to the City's Drought Contingency Plan.

Performance Standard: Enforce District's authority if needed to pro-rate groundwater use, place special requirements on, modify, delay, or deny a permit for a new well during a District-declared drought (CCASRCD, 2016). A brief summary of drought conditions, responses, and actions taken during the year will be summarized in the District's Annual Report.

1.6.8 Conservation

(31 TAC 356.52(a)(1)(G) and TWC 36.1071(a)(7))

Objective: The District will promote water conservation by working with the City of Corpus Christi Water Conservation Team to actively support water conservation and prudent use of water and will report these activities on an annual basis. The District will encourage conservation in accordance with the City's Water Conservation Plan.

Performance Standard: The District will review water conservation plans required to be filed with applicant's permit application. The District will include in each annual report a summary of water conservation efforts, including educational or public awareness efforts in conjunction with City of Corpus Christi outreach.

Objective: Each year, the District will promote water conservation by working with the City of Corpus Christi Water Conservation Team. At least once a year, the District will distribute, through the City, information to the public by means of brochures, public presentations, classroom presentations, displays at local events, and newspaper articles.

Performance Standard: The District will, in each annual report, include a summary of the educational efforts taken, success and outreach details, and copies of the information distributed.

1.6.9 Recharge Enhancement

(31 TAC 356.52(a)(1)(G) and TWC 36.1071(a)(7))

Objective: The District will continue to work collaboratively with the City to evaluate aquifer storage and recovery opportunities to mitigate future drought impacts on water supplies and to support and bolster the City's long-term regional water supply program, including but not limited to implementation of ASR activities set forth in the Five-Year Plan.

Performance Standard: The District will, in each annual report, include a summary of ongoing and completed aquifer storage and feasibility tasks associated with recharge enhancement through well recharge of water into the subsurface aquifer systems.

Objective: Continue to update, manage and enforce the District's Rules and Regulations, particularly those relevant to aquifer storage and recovery operations.

Performance Standard: Pursuant to District Rules, production of water in areas with municipal setting designations is prohibited. The District will address any potential violations during regularly scheduled District meetings held on an estimated quarterly basis. On an annual basis, or more frequently if needed, the District will work with the City to heighten public awareness for protection of aquifer storage and recovery projects by sending mailers or issuing a public information announcement to stakeholders and interested parties likely to be impacted by District-approved projects consistent with ASR management, including rising water levels during recharge and water level declines during recovery.

1.6.10 Rainwater Harvesting

(31 TAC 356.52(a)(1)(G) and TWC 36.1071(a)(7))

Objective: Each year, the District will promote rainwater harvesting consistent with the City of Corpus Christi's Water Conservation by working with the City of Corpus Christi Water Conservation Team. At least once a year, the District will distribute, through the City, information to the public by means of brochures, public presentations, classroom presentations, displays at local events and newspaper articles.

Performance Standard: The District will, in each annual report, include a summary of the educational efforts taken, success and outreach details, and copies of the information distributed.

1.6.11 Precipitation Enhancement

(31 TAC 356.52(a)(1)(G) and TWC 36.1071(a)(7))

At this time, the District is not located in an area with an ongoing, publicly available precipitation enhancement program. The District has determined that this goal is not appropriate or cost-effective. Since this goal is deemed not to be applicable, the District has not developed objectives or performance standards at this time.

1.6.12 Brush Control

(31 TAC 356.52(a)(1)(G) and TWC 36.1071(a)(7))

At this time, the District has determined that this goal is not appropriate or cost-effective. Since this goal is deemed not to be applicable, the District has not developed objectives or performance standards at this time.

1.6.13 Desired Future Conditions

(31 TAC 356.52(a)(1)(H) and TWC 36.1071(a)(8))

Objective: Consider all current and future permits on an annual basis, within a context of managing total groundwater production on a long-term basis to achieve DFCs consistent with the District's Rules and Regulations.

Performance Standard: The District will continue to participate in developing DFCs through the GMA process. Review information provided by the TWDB including: modeled available groundwater (MAG) values, estimates of current and projected amount of groundwater produced within the District, and other data. Continue to monitor amount of groundwater authorized under permits previously issued by the District, yearly precipitation and production patterns, and provide reasonable estimate of the amount of groundwater actually produced from permits issued by the District.

Objective: Monitor existing pumping and resulting water levels on an annual level, where practicable, as to not exceed desired future conditions.

Performance Standard: District Board is authorized to adjust downward the maximum allowable production upon permit renewal to achieve the desired future conditions. Maximum allowable production in operating permit for non-exempt well limited to 0.04 acre-feet per contiguous surface area owned unless exemption is granted.

Objective: Each year, the District will sample water levels of at least three wells within the District. These results will be monitored over five years and used to calculate a five-year average water level.

Performance Standard: The District will, in each annual report, include the monitoring results of the sampled wells and use this information in assessing any changes that may be needed on the District or GMA level.

2 Five-Year Plan for ASR

2.1 Objective

The primary purpose of the District's Five-Year Plan is to provide guidance to the City of Corpus Christi (City) and District on (1) District's day-to-day operations, (2) studies that are needed to identify potential operational issues and gain confidence in developing a successful ASR program, and (3) compliance with TCEQ regulations. The District developed Five Year Plans in 2009 and 2015 as stand-alone documents. In an attempt to stream-line program management and documentation, the Five-Year Plan is combined and added here to the District's Groundwater Management Plan and updated accordingly to reflect findings of site-specific ASR feasibility programs conducted since 2015. In addition to pursing the District management goals described above and enforcing the District's Rules and Regulations, the District will also take deliberate measures to leverage previous and ongoing results from local, aquifer storage and recovery studies conducted within the District jurisdiction to enhance the City's water supply, treatment, and distribution system.

2.2 Background

The District developed an initial 5-year plan in 2009, which included a schedule of major elements of an ASR feasibility plan (HDR, 2009). In support of the five-year plan, the TWDB conducted a geologic characterization of the District and surrounding counties in 2012 (Meyer, 2012). This information was then used by the District to provide an update to the five-year plan (CCASRCD, 2015). The District, with support from the City, has been studying ASR since 2015 to promote water supply resiliency for industrial customer growth, to improve regional system operations, and for cost-effective long-term regional water supply. In 2015 and 2016, HDR performed a desktop aquifer characterization study on behalf of the District at three specific areas within the District boundaries considering the TWDB study findings (HDR, 2016). The study identified a favorable ASR test drilling area located near the Corpus Christi International Airport based on interpretation of nearby geophysical logs that showed favorable permeable zones comprised of sand or mostly sand within the lower Chicot and/or upper Evangeline Aquifers. Existing well logs suggested sand zones that spanned a few hundred feet in either a continuous unit or at multiple intervals considered desirable for ASR development.

In October 2016, the District began a three-year ASR feasibility program with a generous $433,000 grant from the TWDB to collect and evaluate site-specific data to refine the results of the 2016 Study. This project implements the District's Five-Year Plan (CCASRCD, 2015) through site-specific hydrogeological and geochemical testing and modeling to determine the optimal intervals within the subsurface aquifer system for ASR development and operation. The on-going ASR program is scheduled for completion in August 2019. Key tasks include; conducting an exploratory test drilling program, performing geochemical analysis of the subsurface environment focusing on aquifer storage and recovery suitability, developing a field-scale groundwater model to simulate storage and recovery operations, evaluating ASR operating policy considerations, and preparing ASR policy and operation recommendations. The exploratory drilling program consisted of testing four sites (as shown in Figure 2-1) to depths of 1,200 feet; performing geophysical logging and evaluating cuttings from Phase I wells; drilling Phase II wells and conducting step and constant rate pump tests up to about 400 gpm per interval; and collecting core and water quality samples for laboratory analysis at favorable intervals identified during Phase I. Preliminary results estimate ASR wells drilled to a maximum depth of 800 ft-msl can produce an overall recovery capacity ranging from 7 to 15 MGD with project-phasing. Three permanent monitoring wells were installed during the program to be used by the District and TWDB for future monitoring and testing.

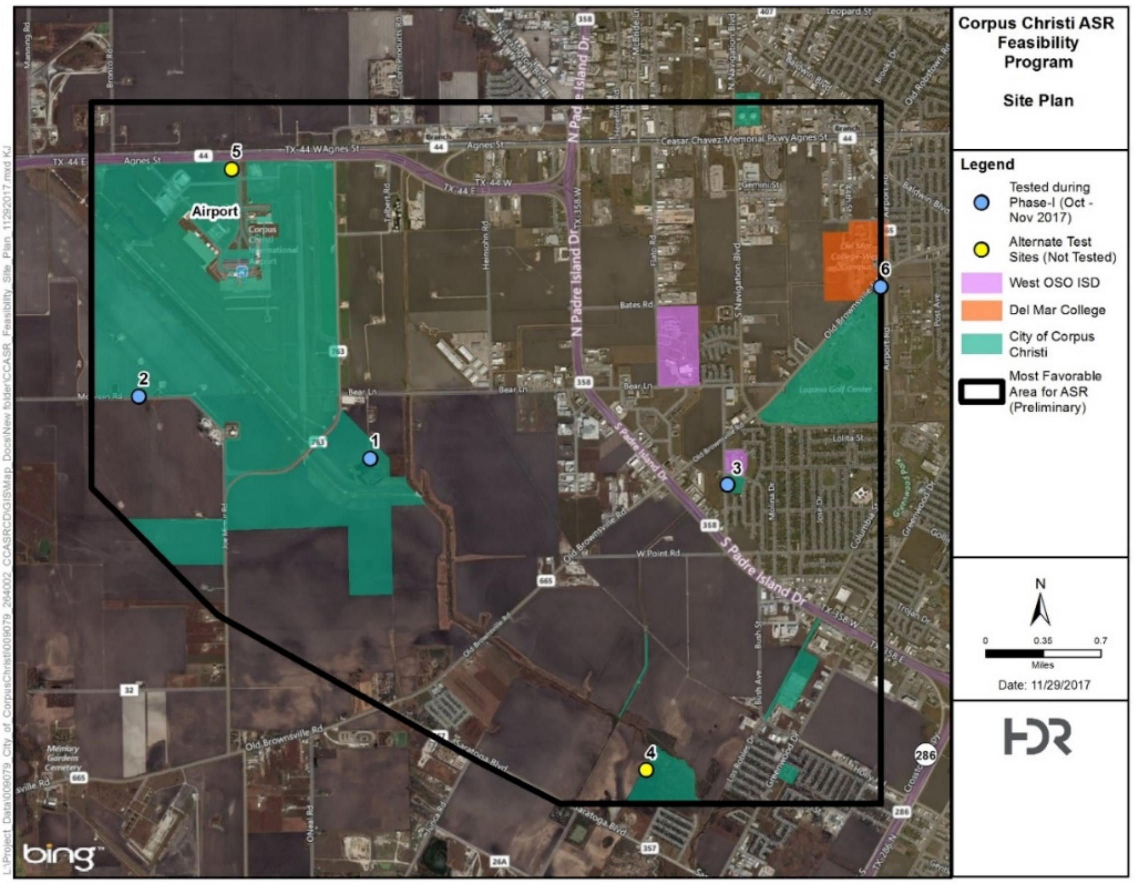

Figure 2-1. Sites Tested during the District's ASR Feasibility Study

2.3 Summary of Proposed Elements and Tasks in the Five-Year Plan

The proposed Five-Year Plan acknowledges the progress made since 2015 and leverages the results from the District's ASR Feasibility program towards project implementation. The primary elements of the proposed Five-Year Plan include:

- Administration and District Operations
  - Rulemaking
  - Well inventory
  - Well registration and permitting
  - Record keeping, including documenting District-wide historic and current water levels and water quality
  - Communications and outreach
  - Review collected data and update District operations if necessary
  - Participation with other water regulatory, management, and planning agencies and groups, including but not limited to:
    - GMA 16
    - Region N Regional Water Planning Group
    - Joint planning with San Patricio County GCD, especially in overlap area with District
    - TWDB
    - Texas Commission on Environmental Quality (TCEQ)
    - Coastal Bend Bays & Estuaries Program/Nueces Estuary Advisory Council
    - Aransas, San Patricio, Nueces, and Kleberg County clerks
    - Local industrial stakeholders
- TCEQ Experimental Permit Application based on Corpus Christi ASR Feasibility Study findings
  - Prepare pilot/cycle testing plan, including additional treatment for piloting to address turbidity, nutrients, pathogens, organics, and other parameters relevant to ASR operations.
  - Meet with TCEQ to discuss and adapt plan and proposed permitting approach
  - Prepare experimental well design
  - Complete experiment permit application
- Coordinate with resource agencies and seek partnership opportunities
  - USGS for subsidence monitoring stations
  - EPA for water quality testing during piloting
  - TWDB for routine monitoring program
- Design and Implement ASR Piloting Program
  - Greenwood WWTP source for potential storage
  - Permitting
  - Water Conditioning System and Surface Facilities Design

- Pilot Well Design
- Prepare Bidding Documents and Selection of Contractor
- ASR Pilot Testing Construction Services
- Cycle Testing

- Design and Implement ASR Project (near Corpus Christi International Airport; 10 wells (est.))
  - Update ASR Program based on cycle testing findings
  - Consider operational approach to optimize and effectively integration ASR project into the City's regional water supply system; update ASR operational scenarios as needed
  - Verify existing wells located in the vicinity likely impacted by ASR operations
  - Prepare communication plan, including mitigation (if needed)
  - Prepare permitting and monitoring program
  - Design, permit, construct, and implement ASR well field, water conditioning, ASR wells, and surface facilities in accordance with regulatory requirements including 30 TAC 331.181-186 statutes for aquifer storage and recovery projects
  - Prepare operations and maintenance plan

2.4 Proposed Schedule

The overall approach in the preparation of the proposed schedule for the Five-Year Plan is based on:

- Identifying the sequence of data and information needed for later tasks
- Leveraging previous District and City ASR study results. Proceed thoughtfully towards performing next steps to allow the District to develop a comfort and confidence with implementation of the Five-Year Plan
- Addressing important issues or fatal flaws early in the development of an ASR program to mitigate risk and uncertainty
- Deferring some of the less critical tasks and/or more expensive tasks to later stages

Table 2-1 presents an outline of the proposed schedule for major elements in the plan.

Table 2-1. Proposed Schedule for Major Elements of the Five-Year Plan

Element	2019	2020	2021	2022	2023	2024
Administration and District Operations						
TCEQ Experimental Permit Application						

Coordination with resource agencies/partnership opportunities						
Design and Implement ASR Piloting Program						
Construct and Implement ASR Project						

2.5 Estimated Cost

A summary of the estimated costs for the major elements and tasks in the plan are provided in Table 2-2.

Table 2-2 Cost Estimate for Major Elements of the Five-Year Plan

Element	2019	2020	2021	2022	2023	2024	Total
Administration and District Operations	$10,000	$25,000	$25,000	$25,000	$25,000	$25,000	$135,000
TCEQ Experimental Permit Application	$121,600						$121,600
Coordination with resource agencies/partnership opportunities	$8,000						$8,000
ASR Piloting Program		$400,000-$500,000	$400,000-$500,000				$800,000 - $1M
Construct and Implement ASR Project (near CCI Airport)				$2M	$5M	$5M	$12M

3 References

Baker and USGS, 1979, Stratigraphic and Hydrogeologic Framework of Part of the Coastal Plain of Texas.

Corpus Christi Aquifer Storage and Recovery Conservation District (CCASRCD), 2014, Groundwater Management Plan.

Corpus Christi Aquifer Storage and Recovery Conservation District (CCASRCD), 2015, 5 Year Plan Update.

Corpus Christi Aquifer Storage and Recovery Conservation District (CCASRCD), 2016, Rules and Regulations of the Corpus Christi Aquifer Storage and Recovery Conservation District.

Dutton, A. R, and B. C. Richter, 1990. Regional geohydrology of the Gulf Coast Aquifer in Matagorda and Wharton Counties, Texas: Development of a numerical model to estimate the impact of water management strategies, Bureau of Economic Geology, University of Texas at Austin, Final Technical Report prepared for the Lower Colorado River Authority.

Harbaugh, A. W., 2009, Zonebudget Version 3.01, A computer program for computing subregional water budgets for MODFLOW ground-water flow models: U.S. Geological Survey Groundwater Software.

HDR, 2009, A Proposed Five-Year Plan for Corpus Christi Aquifer Storage and Recovery Groundwater Conservation District.

HDR, 2016, Aquifer Characterization Study for ASR Feasibility.

Hutchison, W.R., Hill, M.E., Anaya, R., Hassan, M.M., Oliver, W., Jigmond, M., Wade, S., and Aschenbach, E., 2011, Groundwater Management Area 16 Groundwater Flow Model, Texas Water Development Board, unpublished report.

Meyer, John E., 2012, Geologic Characterization of and Data Collection in the Corpus Christi Aquifer Storage and Recovery Conservation District and Surrounding Counties, TWDB Open File Report 12-01.

Ryder, P., 1988, Hydrogeology and predevelopment flow in the Texas Gulf Coast Aquifer systems.

Shafer, G. and United States Geological Survey, 1968, Groundwater Resources of Nueces and San Patricio Counties.

Texas Water Development Board (TWDB), 2010, Hydrostratigraphy of the Gulf Coast Aquifer from the Brazos River to the Rio Grande.

Texas Water Development Board (TWDB), 2017a, TWDB 2017 State Water Plan (SWP). https://www.twdb.texas.gov/waterplanning/swp/2017/doc/SWP17-Water-for-Texas.pdf

Texas Water Development Board (TWDB), 2017b, GAM Run 17-025 MAG: Modeled Available Groundwater for the Gulf Coast Aquifer System in Groundwater Management Area 16.

Texas Water Development Board (TWDB), 2018a, GAM Run 18-012: Corpus Christi Aquifer Storage and Recovery Conservation District Groundwater Management Plan.

Texas Water Development Board (TWDB), 2018b, Estimated Historical Groundwater Use and 2017 State Water Plan Datasets: Corpus Christi Aquifer Storage and Recovery Conservation District.

United States Geological Survey (USGS), 1985, Digital Models for Simulation of Ground-Water Hydrology of the Chicot and Evangeline Aquifers along the Gulf Coast of Texas.

A

Appendix A – Enabling Legislation SB 1831

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AN ACT

relating to the creation of the Corpus Christi Aquifer Storage and Recovery Conservation District.

BE IT ENACTED BY THE LEGISLATURE OF THE STATE OF TEXAS:

SECTION 1. Subtitle H, Title 6, Special District Local Laws Code, is amended by adding Chapter 8811 to read as follows:

CHAPTER 8811. CORPUS CHRISTI AQUIFER STORAGE AND RECOVERY CONSERVATION DISTRICT

SUBCHAPTER A. GENERAL PROVISIONS

Sec. 8811.001. DEFINITIONS. In this chapter:

(1) "Board" means the board of directors of the district.

(2) "Director" means a member of the board.

(3) "District" means the Corpus Christi Aquifer Storage and Recovery Conservation District.

Sec. 8811.002. NATURE OF DISTRICT. The district is a conservation and reclamation district in Kleberg, Nueces, and San Patricio Counties created under and essential to accomplish the purposes of Section 59, Article XVI, Texas Constitution. The district is created to develop and protect municipal aquifer storage areas created by the City of Corpus Christi.

Sec. 8811.003. CONFIRMATION ELECTION NOT REQUIRED. An election to confirm the creation of the district is not required.

Sec. 8811.004. INITIAL DISTRICT TERRITORY. The initial boundaries of the district are coextensive with the city limits of the City of Corpus Christi and include:

(1) property owned by or under contract to the City of Corpus Christi in Nueces and Kleberg Counties; and

(2) in San Patricio County, property owned by or under contract to the City of Corpus Christi and bounded on the west by Interstate Highway 37 and U.S. Highway 77, on the north by the metropolitan planning organization boundary, on the east by County Road 2849, and on the south by the city limits of the City of Corpus Christi.

Sec. 8811.005. APPLICABILITY OF OTHER LAW. Except as otherwise provided by this chapter, Chapter 36, Water Code, applies to the district.

Sec. 8811.006. CREATION OF GROUNDWATER CONSERVATION DISTRICTS IN SAN PATRICIO COUNTY. (a) This chapter does not preclude the creation of a groundwater conservation district in San Patricio County.

(b) A groundwater conservation district created in San Patricio County may not limit or restrict the district from recovering water stored by the district in a municipal aquifer storage area in the district, even if the municipal aquifer storage area is also located in the groundwater conservation district.

(c) To the extent that the boundaries of the district and a groundwater conservation district in San Patricio County overlap, the power and authority of the two districts are joint and coextensive.

(d) The district and land in the district are exempt from taxes and fees imposed by a groundwater conservation district created in San Patricio County.

[Sections 8811.007-8811.020 reserved for expansion]

SUBCHAPTER B. BOARD OF DIRECTORS

Sec. 8811.021. DIRECTORS; TERMS. (a) The district is governed by a board of five directors.

(b) Except as provided by Subsection (c), directors serve staggered four-year terms.

(c) The initial directors shall draw lots to determine which three directors shall serve four-year terms that expire at the end of the calendar year four years after the effective date of the Act creating this chapter, and which two directors shall serve two-year terms that expire at the end of the calendar year two years after the effective date of the Act creating this chapter.

Sec. 8811.022. APPOINTMENT OF DIRECTORS. The Corpus Christi City Council shall appoint the directors.

Sec. 8811.023. VACANCY. If a vacancy occurs on the board, the board may appoint a director to serve the remainder of the term.

Sec. 8811.024. OFFICERS. The board shall annually elect officers. The officers must be confirmed by the Corpus Christi City Council.

[Sections 8811.025-8811.050 reserved for expansion]

SUBCHAPTER C. POWERS AND DUTIES

Sec. 8811.051. AQUIFER STORAGE AND RECOVERY PROJECTS. The district may implement and develop aquifer storage and recovery projects.

Sec. 8811.052. MUNICIPAL AQUIFER STORAGE AREAS IN SAN

PATRICIO COUNTY. The district may not allow more water to be recovered from a municipal aquifer storage area in San Patricio County than the amount of water stored by the district at the municipal aquifer storage area.

Sec. 8811.053. TAXES AND BONDS PROHIBITED. The district may not impose a tax or issue bonds.

Sec. 8811.054. EMINENT DOMAIN. The district may not exercise the power of eminent domain.

SECTION 2. (a) The legal notice of the intention to introduce this Act, setting forth the general substance of this Act, has been published as provided by law, and the notice and a copy of this Act have been furnished to all persons, agencies, officials, or entities to which they are required to be furnished under Section 59, Article XVI, Texas Constitution, and Chapter 313, Government Code.

(b) The governor has submitted the notice and Act to the Texas Commission on Environmental Quality.

(c) The Texas Commission on Environmental Quality has filed its recommendations relating to this Act with the governor, lieutenant governor, and speaker of the house of representatives within the required time.

(d) All requirements of the constitution and laws of this state and the rules and procedures of the legislature with respect to the notice, introduction, and passage of this Act are fulfilled and accomplished.

SECTION 3. This Act takes effect immediately if it receives a vote of two-thirds of all the members elected to each house, as provided by Section 39, Article III, Texas Constitution. If this Act does not receive the vote necessary for immediate effect, this Act takes effect September 1, 2005.

David Dewhurst
President of the Senate

Speaker of the House

I hereby certify that S.B. No. 1831 passed the Senate on April 28, 2005, by the following vote: Yeas 31, Nays 0; and that the Senate concurred in House amendment on May 28, 2005, by the following vote: Yeas 31, Nays 0.

Secretary of the Senate

I hereby certify that S.B. No. 1831 passed the House, with amendment, on May 25, 2005, by the following vote: Yeas 144, Nays 0, two present not voting.

Chief Clerk of the House

Approved:

17 JUNE 05
Date

RICK PERRY
Governor

FILED IN THE OFFICE OF THE
SECRETARY OF STATE
2:10 PM O'CLOCK

JUN 17 2005

Secretary of State

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B

Appendix B – Interlocal Agreement between the City of Corpus Christi and the Corpus Christi Aquifer Storage and Recovery Conservation District for Groundwater Management within District Boundaries

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INTERLOCAL AGREEMENT
FOR MANAGEMENT OF GROUNDWATER WITHIN
THE BOUNDARIES OF THE
CORPUS CHRISTI AQUIFER STORAGE AND
RECOVERY CONSERVATION DISTRICT

This Interlocal Agreement is entered into by and between the City of Corpus Christi, Texas ("City") and the Corpus Christi Aquifer Storage and Recovery Conservation District ("CCASRCD").

Recitals

WHEREAS, CCASRCD was established by the Texas Legislature, as an independent political subdivision of the State of Texas, with its own authority and duties established by State law, to develop and protect municipal aquifer storage areas created by the City of Corpus Christi,

WHEREAS, the City appoints the CCASRCD's board of directors,

WHEREAS, CCASRCD does not have the authority to tax, issue bonds, or use the power of eminent domain, but does have the authority to raise revenue through permit fees and fees for service,

WHEREAS, the activities of the CCASRCD are intended to support the City's potable water storage and distribution system, the activities of the CCASRCD need to be closely coordinated between the two entities, and

WHEREAS, the purpose of this Agreement is to clarify the roles of the City and CCASRCD relating to the development and protection of municipal aquifer storage areas created by the City of Corpus Christi,

NOW, THEREFORE in consideration of the mutual covenants in this Agreement, the participating local governments (the "Parties"), authorized by appropriate actions of their governing bodies, hereby agree as follows:

1. Scope of Services.

a. The City will perform the following services for CCASRCD:

(1) Authorize City employees to serve as directors of the CCASRCD, without compensation from CCASRCD.

(2) Allow the City Manager, or the City Manager's designee, to serve as the General Manager of the CCASRCD, without compensation from CCASRCD.

(3) Allow the Assistant City Manager to designate other City employees to perform services for the CCASRCD, without compensation from CCASRCD.

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Res. 027606

CC Aquifer Stor. & Recov. Distr.

(4) As the agent of the CCASRCD, solicit, negotiate, and contract with consultants to assist with CCASRCD functions.

> (a) The City employees involved shall follow normal City procurement policies.
>
> (b) The Assistant City Manager, as CCASRCD General Manager, is authorized to execute contracts for consulting services that do not exceed the limit at which competitive bids are required under the Texas Local Government Code, as amended (which will be referred to in this Agreement as the "procurement limit"), without the approval of the CCASRCD Board of Directors.
>
> (c) Contracts for consulting services over the procurement limit must be approved by the CCASRCD Board of Directors before it is executed.
>
> (d) The City shall reimburse the CCASRCD for the costs of any contracts for consulting services.
>
> (e) Before any contract for consulting services that will involve an expenditure over the procurement limit is executed, the CCASRCD shall obtain the concurrence of the City Council.

(5) All City employees acting as agents for the CCASRCD shall comply with both the City's and CCASRCD's codes of ethics. Acting for both the CCASRCD and City in the same or related matter is not considered a conflict of interest under either code of ethics.

(6) Authorize City employees to travel on CCASRCD business, and reimburse the City employees for any travel expenses under applicable City travel policies and procedures.

(7) Maintain the financial records of the CCASRCD. The records must be maintained as separate funds, and shall be maintained under applicable City policies and procedures as applied to other City funds.

(8) Invest any CCASRCD funds. The CCASRCD funds must be invested under applicable City policies and procedures in the same manner as the City invest its own funds.

(9) Maintain and manage the records of and information acquired by the CCASRCD.

> (a) The CCASRCD's Records Management Program and Records Retention Schedule are modeled on the City's Records Management Program and Records Retention Schedule.

(b) The CCASRCD General Manager is the CCASRCD Records Management Officer. The City Secretary will assist the CCASRCD Records Management Officer.

(c) The CCASRCD board designates the City Secretary, or his/her designee, as the Public Information Coordinator to satisfy the training requirement of Texas Government Code, Section 552.012.

(10) As agent for the CCASRCD, build, acquire, or obtain property and install improvements and facilities.

(a) The City shall reimburse the CCASRCD for 100% of the costs incurred to acquire or obtain property and to install or construct improvements and facilities.

(b) Before any property is acquired, capital improvements made, or facilities constructed or installed, which costs more than procurement limit, the CCASRCD shall obtain the concurrence of the City Council.

(11) Develop groundwater management plans, including:

(a) Regional comprehensive management plan with other groundwater and surface water management entities and

(b) CCASRCD management plan.

(12) Provide insurance coverage within the City's insurance plan for CCARSCD, its officers and City staff performing duties for CCARSCD.

b. The CCASRCD will perform the following services for the City:

(1) Adopt rules relating to the following, if necessary to protect the City's aquifer storage and recovery wells and system, before the wells and system are placed into operation:

(a) Limits on groundwater production,

(b) Spacing of wells,

(c) Conservation, preservation, protection, and recharge of groundwater,

(d) Subsidence control,

(e) Prevention of degradation of water quality, and

(f) Prevention of waste of groundwater.

(2) Enforce the CCASRCD rules by injunction, civil penalties, and other remedies.

(3) Build, acquire, or obtain property and install improvements and facilities.

(4) Purchase, sell, transport, and distribute surface water and groundwater, in consultation with the City. All contracts for the purchase, sale, transport, or distribution of surface or groundwater must be approved the City's City Council before it is executed.

(5) Conduct surveys of groundwater.

(6) Conduct research.

(7) Require submission of accurate well driller logs for wells within the CCASRCD boundaries.

(8) Require permits for drilling, equipping, operating, completing, or substantially altering wells and well pumps within the CCASRCD boundaries.

(9) Regulate well spacing and production.

(10) Require the closing or capping of open and uncovered wells.

(11) Regulate the transfer of groundwater outside CCASRCD.

(12) Adopt appropriate permit fees and fees for service to provide revenue for CCASRD activities.

(13) Provide reimbursement to the City for expenses incurred under this Agreement, when sufficient revenue exists in CCASRCD accounts for such reimbursement.

2. Budgets.

a. CCASRCD shall prepare and submit to the City's budget office a budget for its activities that includes projections of expenditures that the City is required to reimburse during the City's next fiscal year.

b. The City Council shall review and approve the portion of the CCASRCD budget that is funded by the City, as part of its approval of the City budget.

c. The expenditure for any items that are specifically identified in the CCASRCD budget that was approved by the City Council is considered to have been approved by the City Council.

d. Amendments to the budget may be made during a fiscal year with the approval of the City Council.

3. Other Agreements, Supplementary Agreements and Protocols. The Parties are encouraged to enter into additional agreements and protocols as convenient or necessary.

4. Implementation. The City Manager and CCASRCD General Manager are authorized and directed to take all steps necessary or convenient to implement this Agreement, and shall cooperate in developing a plan for the implementation of the activities provided for in this Agreement.

5. Participation Notice. Each Party shall notify the other Parties of its participation in this Agreement by furnishing an executed original of the attached Participation Notice.

6. Warranty. The Agreement has been officially authorized by the governing body of each Party, and each signatory to this Agreement guarantees and warrants that the signatory has full authority to execute this Agreement and to legally bind their respective Party to this Agreement.

7. Administrative Services. The City agrees to provide administrative services necessary to coordinate this Agreement, including providing Parties with a current list of contact information for each Party.

8. Federal and State Participation. Federal and state entities and other local governments may participate in this Agreement, to the extent of any limitations of their authority, by furnishing an executed original of the attached Participation Notice to the City.

9. Expending Funds. Each Party, which performs services under this Agreement, will do so with funds available from current revenues of the Party. No Party shall have any liability for the failure to expend funds to provide aid under this Agreement.

10. Term of Agreement.

a. This Agreement shall become effective as to each Party when approved and executed by that Party.

b. Once approved by all Parties, this Agreement shall be for a term of one year, and shall be automatically renewed annually, unless any party its participation by giving written notice to the other parties at least sixty days before the end of each annual term.

c. Termination of participation in this Agreement by any Party does not affect the continued operation of this Agreement between and among the remaining Parties, and this Agreement shall continue in force and remain binding on the remaining Parties.

11. Oral and Written Agreements. All oral or written agreements between the parties relating to the subject matter of this Agreement, which were developed prior to the execution of this Agreement, have been reduced to writing and are contained in this Agreement.

12. Entire Agreement. This Agreement, including Attachments, represents the entire Agreement between the Parties and supersedes any and all prior agreements between the parties, whether written or oral, relating to the subject of this agreement.

13. Interlocal Cooperation Act. The Parties agree that activities contemplated by this Agreement are "governmental functions and services" and that the Parties are "local governments" as that term is defined in the Interlocal Cooperation Act.

14. Severability. If any provision of this Agreement is held invalid for any reason, the invalidity does not affect other provisions of the Agreement, which can be given effect without the invalid provision. To this end the remaining provisions of this Agreement are severable and continue in full force and effect.

15. Validity and Enforceability. If any current or future legal limitations affect the validity or enforceability of a provision of this Agreement, then the legal limitations are made a part of this Agreement and shall operate to amend this Agreement to the minimum extent necessary to bring this Agreement into conformity with the requirements of the limitations, and so modified, this Agreement continue in full force and effect.

16. Not for Benefit of Third Parties. This Agreement and all activities under this Agreement are solely for the benefit of the Parties and not the benefit of any third party.

17. Exercise of Police Power. This Agreement and all activities under this Agreement are undertaken solely as an exercise of the police power of the Parties, exercised for the health, safety, and welfare of the public generally, and not for the benefit of any particular person or persons and the Parties shall not have nor be deemed to have any duty to any particular person or persons.

18. City policies and procedures to control. In activities conducted or performed by City staff under the terms of this Agreement, City staff shall conform to applicable City policies and procedures, as though the staff member was performing a City task or duty.

19. Immunity not Waived. Nothing in this Agreement is intended, nor may it be deemed, to waive any governmental, official, or other immunity or defense of any of the Parties or their officers, employees, representatives, and agents as a result of the execution of this Agreement and the performance of the covenants contained in this Agreement.

20. Civil Liability to Third Parties. Each Responding Party will be responsible for any civil liability for its own actions under this Agreement, and will determine what level, if any, of insurance or self-insurance it should maintain for such situations.

21. No Liability of Parties to One Another. One Party may not be responsible and is not civilly liable to another for not responding, or for responding at a particular level of resources or in a particular manner. Each Party to this Agreement waives all claims against the other Parties to this Agreement for compensation for any loss, damage, personal injury, or death occurring as a consequence of the performance of this Agreement, except those caused in whole or in part by the negligence of an officer, employee, or agent of another Party.

22. Notices.

a. Notices under this agreement may be delivered by mail as follows:

City:

City of Corpus Christi
Attn: City Manager
P.O. Box 9277
Corpus Christi, Texas 78469-9277

CCASRCD:

Corpus Christi Aquifer Storage and Recovery Conservation District
Attn: General Manager
P.O. Box 9277
Corpus Christi, Texas 78469-927

b. The parties to this agreement may specify to the other party in writing another address for notice.

23. Amendments to Agreement.

a. This Agreement may not be amended except by written agreement approved by the governing bodies of the Parties.

b. No officer or employee of any of the Parties may waive or otherwise modify the limitations in this Agreement, without the express action of the governing body of the Party.

24. Captions. Captions to provisions of this Agreement are for convenience and shall not be considered in the interpretation of the provisions.

25. Governing Law and Venue. This Agreement shall be governed by the laws of the State of Texas. Venue for an action arising under this Agreement shall be in accordance with the Texas Rules of Civil Procedure.

CORPUS CHRISTI AQUIFER STORAGE AND RECOVERY CONSERVATION DISTRICT

By: Oscar M. Martinez
Oscar Martinez, President

Date: 3-3-08

ATTEST:

By:
Fred Segundo, Secretary

Date: 3-3-08

CITY OF CORPUS CHRISTI

ATTEST

Armando Chapa
City Secretary

By:

George K. Noe
City Manager

APPROVED AS TO FORM:

This 29th day of February, 2008

Gary W. Smith
Assistant City Attorney
For City Attorney

Res. 027606 AUTHORIZED
BY COUNCIL 03/11/08
A.C.
SECRETARY

PARTICIPATION NOTICE

I hereby notify the Parties that Corpus Christi Aquifer Storage and Recovery Conservation District has approved participation in the Interlocal Agreement for Management of Groundwater within the Boundaries of the Corpus Christi Aquifer Storage and Recovery Conservation District, by lawful action of its governing body, a true copy of which is attached and incorporated in this Agreement.

Fred Segundo
Secretary

3-3-08
Date

PARTICIPATION NOTICE

I hereby notify the Parties that the City of Corpus Christi has approved participation in the Interlocal Agreement for Management of Groundwater within the Boundaries of the Corpus Christi Aquifer Storage and Recovery Conservation District, by lawful action of its governing body, a true copy of which is attached and incorporated in this Agreement.

Armando Chapa
City Secretary

3/14/08
Date

C

Appendix C – Corpus Christi ASR Conservation District Rules

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Rules and Regulations of the Corpus Christi Aquifer Storage and Recovery Conservation District

Original: April 18, 2013

Amended: December 1, 2016

CORPUS CHRISTI AQUIFER STORAGE AND RECOVERY CONSERVATION DISTRICT
RULES AND REGULATIONS
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CORPUS CHRISTI AQUIFER STORAGE AND RECOVERY CONSERVATION DISTRICT
RULES AND REGULATIONS

INTRODUCTION

Groundwater conservation Districts (GCDs) are the state's preferred method of groundwater management in order to protect property rights, balance the conservation and development of groundwater to meet the needs of the state, and use the best available science in the conservation and development of groundwater through rules developed, adopted, and promulgated by a District in accordance with the provisions of The Texas Water Code, Title 2: Water Administration, Subtitle E: Groundwater Management, Chapter 36: Groundwater Conservation Districts. As with other GCDs, the major purposes of the District are to:

1) Provide for conservation, preservation, protection, and recharge;
2) Prevent waste; and,
3) Control land surface subsidence.

The Corpus Christi Aquifer Storage and Recovery Conservation District (District) was created in 2005 by the 79th Texas Legislature enactment of SB 1831, Section 1, Subtitle H, Title 6. Special District Local Laws Code was amended by adding Chapter 8811 to include the District. The District is located in Aransas, Kleberg, Nueces, and San Patricio Counties, Texas. The initial boundaries of the District (also known as CCASRCD) are coextensive with the city limits of the City of Corpus Christi and are bound:

1) To the north, by the metropolitan planning organization (i.e., Corpus Christi Metropolitan Planning Organization) boundary;
2) To the east, by the Gulf of Mexico and the city limits of Corpus Christi;
3) To the south, by the city limits of Corpus Christi; and,
4) To the west, by property owned by, or under contract to, the City of Corpus Christi.

The District's jurisdictional boundary covers four counties, including Aransas, Kleberg, Nueces, and San Patricio counties. The total land surface area of the District and the surface area of the District within each of these counties was calculated using a spatial analysis tool within GIS. The total area of the District is distributed in percentage of land in each county as follows: Aransas County: 0.01 %, Nueces County: 48.92 %, Kleberg County: 5.67 %, and San Patricio County: 45.40 %. The surface area of the District within each of these counties are as follows: Aransas County: 2.32%, Nueces County 35.43 %, Kleberg County: 2.38 %, and San Patricio County 2.92%.

Neighboring Districts include Kenedy County Groundwater District and San Patricio County Groundwater District, both Districts formed via legislation passed during the 2007 legislative session.

The District is committed to the management and protection of the groundwater resources of the District, including those injected into the ground for storage and later use. The District is committed to maintaining a sustainable, adequate, reliable, cost effective, and high quality source of groundwater to promote the vitality, economy, and environment of the District. The District will work with and for the citizens of the District and cooperate with other local, regional, and state agencies involved in the study and management of groundwater resources. The District shall take no action without a full consideration of the groundwater needs of the citizens of the District.

The District's objectives are to enhance the City of Corpus Christi's (City) water supply, treatment, and distribution. A major concern when forming the District was to ensure that water stored in an aquifer storage and recovery (ASR) facility could not by diverted by nearby wells. According to the District's Groundwater Management Plan, the District's objectives include:

1) Seasonal, long-term, and emergency (strategic reserve) storage;
2) Augmentation of peak storage capacity;
3) Improving system water quality by maintaining minimum flows during seasons of low demand;
4) Deferring expansion of some of the water system infrastructure;
5) Mitigation of streamflow requirements;
6) Management of stormwater flow and estuary salinity; and,
7) Helping to meet large retail customer demands.

This document outlines the rules and regulations set forth by the Corpus Christi Aquifer Storage and Recovery Conservation District, as they apply to their District.

SECTION 1. DEFINITIONS AND MATTERS OF GENERAL APPLICABILITY

Rule 1.1 Definitions

In the administration of its duties, the Corpus Christi Aquifer Storage and Recovery Conservation District (District) follows the definitions of terms set forth in Chapter 36, Texas Water Code, with modifications. The definitions are as follows:

1. "Acre-foot" means the amount of water necessary to cover one acre of land to the depth of one foot, or 325,851 U.S. gallons of water.

2. "Act" means the Corpus Christi Aquifer Storage and Recovery Conservation District's enabling legislation, the 79th Texas Legislature enactment of SB 1831, Section 1, Subtitle H, Title 6. Special District Local Laws Code was amended by adding Chapter 8811 to include the District.

3. "Additional production" means the amount of water produced from an excluded well in excess of that amount produced under permit by the Railroad Commission of Texas.

4. "Affected person" means, for any matter before the District, a person who has a personal justifiable interest related to a legal right, duty, privilege, power, or economic interest that is within the District's regulatory authority and affected by the matter before the District, not including a person who has an interest common to members of the public.

5. "Agricultural crop" means food or fiber commodities grown for resale or commercial purposes that provide food, clothing, animal feed, or other products.

6. "Agricultural use" or purposes means the use of groundwater for irrigation to produce an agricultural crop.

7. "Aquifer" means a geologic formation, group of formations, or part of a formation that is capable of yielding a significant amount of water to a well or spring, and also includes subdivision(s) of an aquifer.

8. "Aquifer storage area" means an area demarcated and agreed upon by the District and permittee for the purpose of groundwater storage, which must abide by applicable rules outlined herein.

9. "Aquifer storage and recovery project" means a project involving the injection of water into a geologic formation for the purpose of subsequent recovery and beneficial use by the project operator.

10. "Beneficial use" or "beneficial purpose" means use of groundwater for:
    a. Agricultural, gardening, domestic, stock raising, municipal, mining, manufacturing, industrial, commercial, or recreational purposes;
    b. Exploring for, producing, handling, or treating oil, gas, sulfur, lignite, or other minerals; or,
    c. Any other purpose that is nonspeculative, useful, and beneficial to the user that does not commit or result in waste as that term is defined in these rules.

11. "Best available science" means conclusions that are logically and reasonably derived using statistical or quantitative data, techniques, analyses, and studies that are publicly available to reviewing scientists and can be employed to address a specific scientific question.

12. "Board" means the Board of Directors of the Corpus Christi Aquifer Storage and Recovery Conservation District.

13. "Casing" means a tubular, water tight structure installed in the excavated or drilled hole to maintain the well opening and, along with cementing, to confine the groundwater to their zones of origin and to prevent the entrance of surface pollutants.

14. "Cement" means a neat Portland or construction cement mixture of not more than seven gallons of water per ninety-four (94) pound sack of dry cement, creating a cement slurry in which bentonite, gypsum, or other additives may be included.

15. "Desired future condition" means a quantitative description, adopted in accordance with Texas Water Code Section 36.108, of desired condition of the groundwater resources in a management area at one or more specified future times.

16. "Deteriorated well" means a well, the condition of which will cause, or is potentially likely to cause, pollution of any water in the District.

17. "Director" means a person appointed by the City Council of the City of Corpus Christi (City Council), or by the Board in the case of a resignation, and who is qualified and has taken the Constitutional oath of office.
18. "District" means the Corpus Christi Aquifer Storage and Recovery Conservation District as authorized under Acts 2005, 79th Legis., R.S., ch. 897, p. 3088. The legislation is codified as Chapter 8811, Vernon's Texas Codes Annotated, Special District Local Laws Code.
19. "District office" means the office of the District, which may be changed from time to time by resolution of the Board.
20. "Domestic use" means the use of groundwater by an individual or a household to support essential domestic activity.
21. "Drilling permit" means a permit for a water well to be drilled, including test wells, or an existing well that is to be re-drilled.
22. "Drilling registration" means the registration required for an exempt well that is to be drilled.
23. "Essential domestic activity" includes water for use inside the home, watering domestic animals, protecting foundations, and recreation only for swimming pools. The term does not include water use activities for which consideration is given or for which the product is to be sold, irrigation of lawns and landscaped areas, filling or refilling ponds, lakes, tanks, reservoirs, or other confinements that have a capacity greater than 25,000 gallons, or non-closed system geothermal heating/cooling systems.
24. "GPM" means gallons per minute.
25. "Groundwater" means water percolating below the surface of the earth.
26. "Groundwater reservoir" means a specific subsurface water-bearing stratum.
27. "Hearing body" means the Board, any committee of the Board, or a hearing examiner at any hearing held under the authority of law.
28. "Hearing examiner" means the person appointed by the Board of directors to conduct a hearing or other proceeding.
29. "Landowner" means the person who holds possessory rights to the land surface or the groundwater.
30. "Modeled available groundwater" means the amount of water that the executive administrator determines may be produced on an average annual basis to achieve a desired future condition established under Texas Water Code Section 36.108.

31. "Municipal setting designation" means an area designated by the City Council under the authority of Section 551.005, Texas Local Government Code and Subchapter W, Chapter 361, Texas Health and Safety Code.
32. "Municipal use" means the use of groundwater through public water supply systems authorized by the State of Texas and includes individual wells supplying water for irrigation for non-agricultural purposes.

33. "New well application" means an application for a permit for a water well that has not been drilled or an injection well permit to inject water into a groundwater aquifer.

34. "Open Meetings law" means Chapter 551, Texas Government Code, as it may be amended from time to time.

35. "Operating permit" means any type of permit issued by the District that relates to the operation of or production from a water well, which may include authorization to drill or complete a water well if the District does not require a separate permit for drilling or completing a water well.

36. "Party" means a person who is an automatic participant in a proceeding before the District or a person who is an affected person as defined under these rules and who has been designated as a participant in the proceeding before the District.

37. "Person" means an individual, corporation, Limited Liability Company, organization, government or governmental subdivision or agency, business trust, estate, trust, partnership, association, or any other legal entity.

38. "Pollution" means the alteration of the physical, thermal, chemical, or biological quality of, or the contamination of, any water in the District, that renders the water harmful, detrimental, or injurious to humans, animal life, vegetation, or property or to public health, safety, or welfare, or impairs the usefulness or public enjoyment of the water for any lawful or reasonable use.

39. “Project Operator” means a person holding an authorization under Section 15 to undertake an aquifer storage and recovery project.

40. "Presiding officer" means the president, vice-president, secretary or other Board member presiding at any hearing or other proceeding or a hearing examiner conducting any hearing or other proceeding.

41. “Production limit” means a numerical limitation of the annual amount of Groundwater authorized to be produced under an operating permit. The production limit is generally expressed in acre-feet per year or gallons per year.

42. "Public Information Act" means Chapter 552, Texas Government Code, also called the "Open Records law," as it may be amended from time to time.

43. "Quorum" means a majority of the members of the Board of Directors.

44. "Registration" means the recordation of a certificate issued by the District for a well that is exempt from an operating permit.

45. "Rule" or "rules" mean the rules and regulations of the District.

46. “Subsidence” means the lowering in elevation of the land surface caused by withdrawal of groundwater.

47. "Texas Rules of Civil Procedure" and "Texas Rules of Evidence" mean the civil procedure and evidence rules, as adopted by the Supreme Court of Texas, as amended, and in effect at the time of the action or proceeding. Except as modified by these District rules, the rights, duties and responsibilities of the presiding officer acting under the Texas Rules of Civil Procedure and the Texas Rules of Evidence are the same as a court acting under those rules, without a jury.

48. “Transfer Permit” means a permit issued by the District allowing the transfer of groundwater outside of the District’s boundaries.

49. "Waste" means any one or more of the following:
    a. Withdrawal of groundwater from a groundwater reservoir at a rate and in an amount that causes or threatens to cause intrusion into the reservoir of water unsuitable for agricultural purposes, gardening, domestic use, stock raising purposes, or other beneficial purposes;
    b. The flowing or producing of wells from a groundwater reservoir if the water produced is not used for a beneficial purpose;
    c. Escape of groundwater from a groundwater reservoir to any other reservoir or geologic stratum that does not contain groundwater;
    d. Pollution or harmful alteration of groundwater in a groundwater reservoir by saltwater or by other deleterious matter admitted from another stratum or from the surface of the ground;
    e. Willfully or negligently causing, suffering, or allowing groundwater to escape into any river, creek, natural watercourse, depression, lake, reservoir, drain, sewer, street, highway, road, or road ditch, or onto any land other than that of the owner of the well unless such discharge is authorized by permit, rule, or other order issued by the Texas Commission on Environmental Quality, its predecessors or successors, under Chapter 26, Texas Water Code;
    f. Groundwater pumped for irrigation that escapes as irrigation tailwater onto land other than that of the owner of the well unless permission has been granted by the occupant of the land receiving the discharge;
    g. For water produced from an artesian well, "waste" has the meaning assigned by Section 11.205, Texas Water Code;
        i. Section 11.205. Wasting Water from Artesian Well: Unless the water from an artesian well is used for a purpose and in a manner in which it may be lawfully

used on the owner’s land, it is waste and unlawful to willfully cause or knowingly permit the water to run off the owner’s land or to percolate through the stratum above which the water is found.

h. Groundwater that is discharged into a watercourse for transit to another location when the losses in transit exceed 20%; or,
i. Operating a deteriorated well.

50. "Water meter" or "water measuring device" for large volume users means a water flow measuring device that can within +/- 10% accurately record the amount of groundwater produced during a measured time.

51. "Well" means any facility, device, or method used to withdraw or sample groundwater from, or observe the water level in, a groundwater reservoir in the District.
    a. Types of wells:
        i. "Additional production well" means a well that is otherwise excluded by law from regulation by the District that is also used for additional purposes regulated by the District.
        ii. "Artesian well" means a water well completed in the confined portion of an aquifer such that, when properly cased, water will rise in the well by natural pressure above the base of the overlying impermeable stratum.
        iii. "ASR well" means either an ASR Injection well, ASR Monitoring well, or ASR Recovery well."
        iv. "ASR Injection well" means a well drilled to inject water into an aquifer for storage.
        v. "ASR Monitoring well" means a well drilled to measure the level of stored water within an aquifer.
        vi. "ASR Recovery well" means a well drilled to recover water from aquifer storage.
        vii. "De-watering well" or "depressurizing well" means a well-used to remove water from a construction site or an excavation, or to relieve hydrostatic uplift on permanent structures. De-watering wells may include exempt, non-exempt, and excluded wells.
        viii. "Exempt well" means a well that is:
            1. Drilled or equipped to produce no more than 25,000 gallons per day; or,
            2. Drilled or equipped to produce water for watering livestock and poultry connected with farming, ranching, or dairy enterprises.
        ix. "Existing well" means a well that is in existence or for which drilling has commenced on the day of adoption of these rules.
        x. "Excluded well" means a well drilled for oil, gas, sulfur, uranium, or brine, or for core tests, or for injection of gas, saltwater, or other fluid or for any purpose, under permits issued by the Railroad Commission of Texas.
        xi. "Injection well" means a well into which fluids are injected.
        xii. "Monitoring well" means a well installed to measure some property of the groundwater or the aquifer that it penetrates.

xiii. "New well" means a well not in existence or for which drilling has not commenced on the day of adoption of these rules.
xiv. "Non-exempt well" means either an existing or a new well subject to these rules.

52. "Well operator" means the person who operates a well or a water distribution system supplied by a well.

53. "Well owner" means the person who owns a possessory interest in a well, the land upon which a well is located or to be located, or the beneficial user of the groundwater.

54. "Well system" means a well or group of wells tied to the same distribution system.

55. "Withdraw" means the act of extracting or producing groundwater by pumping or some other method.

Rule 1.2 Purpose of Rules and Mission Statement

The purpose of these rules and regulations is to accomplish the intent of the creation of the District by the Act and to facilitate the purposes of Chapter 36 of the Texas Water Code.

The District's mission statement is as follows: The Corpus Christi Aquifer Storage and Recovery Conservation District (District) is committed to manage and protect the groundwater resources of the District, including those injected into the ground for storage and later use. The District is committed to maintaining a sustainable, adequate, reliable, cost effective, and high quality source of groundwater to promote the vitality, economy, and environment of the District. The District will work with and for the citizens of the District and cooperate with other local, regional, and state agencies involved in the study and management of groundwater resources. The District shall take no action without a full consideration of the groundwater needs of the citizens of the District.

Rule 1.3 Use and Effect of Rules

These rules and regulations are used by the District as guidelines to facilitate the duties assigned to the District by law, the Act, and Chapter 36 of the Texas Water Code. They shall not be construed as a limitation or restriction on the exercise of any discretion, where it exists; nor shall they be construed to deprive the District of the exercise of any powers, duties, or jurisdiction conferred by law; nor shall they be construed to limit or restrict the amount and character of data or information which may be required to be collected for the proper administration of the Act.

Rule 1.4 Amending Rules

The Board may, following notice and public hearing, amend these rules or adopt new rules from time to time.

Rule 1.5 Headings and Captions

The section and other headings and captions contained in these rules are for reference purposes only and do not affect in any way the meaning or interpretation of these rules.

Rule 1.6 Construction

A reference to a title, chapter, or section without further identification is a reference to a title, chapter or section of the Texas Water Code. Construction of words and phrases are governed by the Code Construction Act, Chapter 311, Subchapter B, Texas Government Code. Whenever a singular noun is used, it may refer to a plural; whenever a plural noun is used, it may refer to a singular.

Rule 1.7 Methods of Service under the Rules

Except as otherwise provided in these rules, any notice or document required by these rules to be served or delivered may be delivered to the recipient, or the recipient's authorized representative, in person, by agent, by courier receipted delivery, by certified or registered mail sent to recipient's last known address, or by fax to the recipient's current fax number and shall be accomplished by 5:00 o'clock p.m. of the date on which it is due. Service by mail is complete upon deposit in a post office or other official depository of the United States Postal Service. Service by fax is complete upon transfer, except that any transfer commencing after 5:00 o'clock p.m. shall be deemed complete the following business day. If service or delivery is by mail, and the recipient has the right, or is required, to do some act within a prescribed period of time after service, three days will be added to the prescribed period. Where service by other methods has proved unsuccessful, the service may be complete upon publication of the notice in a newspaper of general circulation in the District, or by such method as the hearing body may provide.

Rule 1.8 Severability

If any one or more of the provisions contained in these rules is for any reason held to be invalid, to be illegal, or to be unenforceable in any respect, the invalidity, illegality, or unenforceability may not affect any other rule or provision of these rules and these rules will be construed as if such invalid, illegal, or unenforceable rule or provision had never been contained in these rules.

SECTION 2. BOARD OF DIRECTORS

Rule 2.1 Purpose of the Board

The purpose of the Board is to facilitate the implementation of these rules and regulations, to accomplish the intent of the creation of the District by the Act, and to facilitate the purposes of Chapter 36 of the Texas Water Code.

Rule 2.2 Board Structure and Officers

The District Board of Directors is composed of 5 members initially elected to staggered 2- and 4-year terms. All directors are appointed by the Corpus Christi City Council. The Board shall elect officers annually and the officers must be confirmed by the City Council. If a vacancy occurs on the Board, then the Board may appoint a Director to serve the remainder of the term.

The District's Board of Directors is comprised of a Chairman, Vice Chairman, Secretary, General Manager, and Member(s). The Board of Directors holds regular meetings at City Hall located at 1201 Leopard Street, Corpus Christi, Texas on a quarterly basis, unless otherwise posted. All meetings of the District's Board of Directors are public meetings noticed and held in accordance with all public meeting requirements. The District Board of Directors meetings are posted in each county along with other items of interest by the District.

Rule 2.3 Meetings

The Board will hold a regular meeting at least quarterly on a day and place that the Board may establish from time to time by resolution. At the request of the Chairman, or by written request of at least three members, the Board may hold special meetings. All Board meetings will be held in accordance with the Open Meetings law.

Rule 2.4 Committees

The Chairman may establish committees for formulation of policy recommendations to the Board, and appoint the chair and membership of the committees, which may be derived from the Board or outside of the Board. Committee members serve at the pleasure of the Chairman.

Rule 2.5 Ex Parte Communications

A Board member may communicate ex parte with other members of the Board and staff.

SECTION 3. GENERAL MANAGER

Rule 3.1 General Manager

The person employed by the Board as General Manager shall be the chief operating officer of the District and shall have full authority to manage, operate, and execute the affairs of the District, subject only to decisions made by the Board. The General Manager is responsible for employing all persons necessary to conduct the function, operation, and business of the District and for determining their compensation.

The General Manager is empowered to obtain official or legal status in matters of concern or interest to the District in public hearing processes or other proceedings. This will only occur when Board action cannot be obtained in a timely manner to establish an official Board or District position or when the opportunity to obtain such status presents itself. Such matters will be brought to the Board for action at the earliest possible convenience.

Rule 3.2 Delegation of Authority

The General Manager may delegate his/her administrative duties in order to effectively and expeditiously execute his/her duties, providing that no such delegation shall ever relieve him/her of responsibilities which are ultimately his/hers under the Act, Rules and Regulations, or Board Orders.

SECTION 4. DISTRICT

Rule 4.1 Minutes and Records of the District

All documents, reports, records, and minutes of the District are available for public inspection and copying in accordance with the Public Information Act. Persons who are furnished copies may be assessed a copying charge, pursuant to policies established by the Board. A list of charges for copies will be furnished by the District.

Rule 4.2 Certified Copies

Requests for certified copies must be in writing. Certified copies may be made by the Secretary, Assistant Secretary, or the General Manager and will be affixed with the seal of the District. Persons furnished with certified copies may be assessed a certification charge, in addition to the copying charge, pursuant to policies established by the Board.

Rule 4.3 Official Office and Office Hours

The Board, by resolution, shall establish an official office for the District, and the office will maintain regular business hours.

SECTION 5. DISTANCE AND SPACING REQUIREMENTS

Rule 5.1 Required Distance from Aquifer Boundary

An applicant proposing to develop an aquifer storage area shall provide to the District the location of the storage area described by metes and bounds and the District shall enter an order demarcating the boundaries of the aquifer storage area. The order shall be recorded in the real property records of the affected county and, thereafter, no well shall be permitted to be drilled within one mile of the boundaries of the demarcated aquifer storage area except by the person who developed the storage area, but the Board may, if good cause is shown by clear and convincing evidence, that no harm or negative impact will occur to the aquifer storage area, allow drilling activity by others upon entering special orders or adding special permit conditions and requirements.

Rule 5.2 Required Distance from Property Lines

Except as provided in Rule 5.3, a new well may not be drilled within 50 feet from the property line of any adjoining landowner or an area designated with a municipal setting designation. This spacing may be reduced or increased by the Board upon demonstration either that such spacing is overly protective of neighboring wells or is insufficiently protective of neighboring wells. All other non-excluded wells completed in other aquifers in the District will be considered on a case by case basis.

Rule 5.3 Exceptions to Spacing Requirements

(a) Provided that an applicant presents waivers signed by the adjoining landowner(s) or the developer of the demarcated aquifer storage area, stating that they have no objection to the proposed location of the well site, the minimum distance from the property line requirements will not apply to the new proposed well location, subject to the right of the Board to limit production of the well to prevent or minimize injury to adjoining landowners or the aquifer.

(b) Provided that an applicant shows good cause why a new well should be allowed to be drilled closer than the required minimum distance of 50 feet from the property line of the adjoining landowner(s), or closer than the distances stated in Rules 5.1 and 5.2, the issue of distance requirements will be considered during the technical review process and/or the contested case process. If the Board chooses to grant a permit to drill a well that does not meet the distance requirements, the Board may limit the production of the well to prevent or to minimize injury to adjoining landowners or the aquifer.

(c) In addition, the Board may, if good cause is shown by clear and convincing evidence, enter special orders or add special permit conditions increasing or decreasing the distance requirements.

(d) ASR wells that are a part of an ASR project authorized by the Texas Commission on Environmental Quality are subject to the rules stated in Section 15.

Rule 5.4 Requirement of Monitor Well(s)

Applications for wells drilled and existing wells when reworked, equipped to pump more than 200 acre-feet per year, or the equivalent on a daily basis, shall include provisions for monitoring, on as frequent a basis as reasonably possible, water levels in the aquifer from which withdrawals are to be made using one or more existing wells, subject to more detailed orders of the Board as set forth in the permit and all applicable rules, including but not limited to Rules 7.3 and 8.3(b)(2)(D). The Board may, upon application, exempt an applicant from this rule.

Rule 5.5 Ownership of Water Stored in an Aquifer Storage Area

Water injected into an aquifer storage area is owned by the person who injected the water and is not percolating groundwater.

SECTION 6. PRODUCTION LIMITATIONS

Rule 6.1 Maximum Allowable Production from Aquifers in District

(a) The amount of annual maximum production specified in the operating permit for a non-exempt well may be up to 0.04 acre-feet per contiguous surface acre[1] owned or operated by the applicant, unless a small amount is requested. Applicants may request that greater amounts of production per surface acre be authorized provided the applicant can demonstrate to the District's satisfaction that local hydrogeologic conditions will allow the withdrawal of a greater amount of groundwater per annum without negatively affecting water levels of adjoining properties or otherwise interfering with an adjacent landowner's ability to withdraw and use groundwater. If necessary, the Board may adjust downward the maximum allowable production upon permit renewal to achieve the desired future conditions under Section (b) below. In establishing the maximum allowable production for a retail public water utility, the District will consider the service needs and service area of the retail public water utility in addition to or in lieu of surface area owned or operated by the retail public water utility.

(b) In issuing permits, the District shall manage total groundwater production on a long-term basis to achieve the desired future condition and the District will also consider:

1. The modeled available groundwater determined by the executive administrator of the Texas Water Development Board;
2. The executive administrator's estimate of the current and projected amount of groundwater produced under exemptions granted by District rules;
3. The amount of groundwater authorized under permits previously issued by the District;
4. A reasonable estimate of the amount of groundwater that is actually produced under permits issued by the District; and,
5. Yearly precipitation and production patterns.

Rule 6.2 Areas of Depletion and Proration Orders

In order to protect public health and welfare and to conserve and manage the groundwater resources in the District during times of drought or depletion, the District may pro-rate groundwater use, place special requirements on, modify, delay, or deny a permit for a new well during a District-declared drought.

Rule 6.3 Additional Production Wells

An applicant must follow the rules and regulations outlined in this Section and Section 5 concerning the addition of production wells.

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[1] Calculated by dividing the Gulf Coast Aquifer System (central portion) Groundwater Availability Model derived amount of water that flows through the system (620,000 acre-feet) by the total area of the GCAS (central portion; approximately 15,000,000 acres), providing amount of water available (in acre-feet) by area (acre). This is an estimation that requires further study.

Rule 6.4 Storage and Recovery Aquifers

Certain demarcated aquifer storage areas are to be designated for the specific purpose of aquifer storage and later recovery. These aquifers are to be deliberately injected with fresh water which are likely to cause the water levels to rise and, during withdrawal, cause the water levels to drop. In these areas, the rise and drop of water is normal and to be expected. Section 6 is not applicable to these demarcated areas.

Rule 6.5 Municipal Setting Designations

Production of water in areas with municipal setting designations is prohibited.

Rule 6.6 Subsidence

(a) Permittees will follow the rules and regulations set forth in order to provide for the conservation, preservation, protection, recharge, and prevention of waste of groundwater, and of groundwater reservoirs or their subdivisions, to control subsidence caused by withdrawal of water from those groundwater reservoirs or their subdivisions, and to prevent degradation of water quality.

(b) Permittees will drill for and produce the groundwater below the surface of real property without causing waste or malicious drainage of other property or negligently causing subsidence.

(c) The District reserves the right to amend these rules and regulations, following notice and public hearing, to reflect changes caused by regional subsidence.

SECTION 7. DEPOSITS AND FEES FOR OPERATING PERMITS, FEES, and FILING REPORTS

Rule 7.1 Initial Application Fee and Filing of State Well Reports and Plugging Reports

(a) Each application for an operating permit of any type issued by the District or drilling registration must be accompanied by a one-time non-refundable application fee of $250.00, which will be accepted and deposited in the District account by the General Manager. The purpose of the application fee is to cover the cost of reviewing an application and processing an operating permit and to ensure receipt by the District of the information set out herein. Such administrative deposit or fee shall not unreasonably exceed the cost to the District for such administrative acts. The applicant may be required by the Board to deposit with the District additional funds if the amount of the original deposit is expended prior to the Board's final action on the operating permit.

(b) In the event that neither the driller's logs or completion logs of the well nor the operating permit marked "abandoned" is returned to the District office within 180 calendar days after the issuance date of the operating drilling permit or operating drilling registration, the deposit becomes the property of the District and the operating drilling permit or operating drilling registration is deemed cancelled without further action by the Board, unless an extension has been granted. Extensions may be granted by the Board to the extent of 180 days or less, as the Board determines is appropriate.

(c) As an additional fee for administrative acts of the District, after an application for any operating permit issued by the District has been determined to be administratively complete by the Board, the applicant shall deposit with the District an amount of money determined by the Board to cover the cost associated with an uncontested or contested hearing regarding the operating permit application. The amount of the deposit shall be sufficient to pay legal fees, expert fees, court reporter fees, hearing facility rental fees, and other expenses. The remaining deposit balance, if any, is refundable following approval of the operating permit, disposal of any motions for rehearing, and receipt of anticipated expenses. The applicant may be required by the Board to deposit with the District additional funds if the amount of the original deposit is expended prior to the Board's final action on the permit.

Rule 7.2 Regulatory Fees

(a) Regulatory fees shall be paid to the District on a monthly basis for the amount of water actually produced from non-exempt wells under operating permits and transfer permits, which fees shall be established by resolution of the Board and paid to the District within 15 days after the end of the reporting month.

(b) An exempt or excluded well is not excused from regulatory pumping fees if the groundwater is exported from the District. The owner of the well shall identify to the District the amount of water exported from the District on a monthly basis and pay a regulatory pumping fee to the District in an amount equal to the pumping fee of a non-exempt well plus the surcharge, as defined in Rule 7.2(e), which shall be paid to the District within 15 days after the end of the reporting month. Groundwater that is discharged pursuant to a permit issued by the Texas Commission on Environmental Quality or its predecessors and not sold is not considered to have been transferred from the District unless the discharge is part of an overall water transfer and sale.

(c) The owner of all wells exporting water out of the District shall report the amount of water actually produced on a monthly basis under operating permits and transfer permits, which fees shall be established by resolution of the Board and paid to the District within 15 days after the end of the reporting month.

(d) Regulatory fees not paid by 25 days after the end of the reporting month are considered delinquent and the fee payer shall be assessed a late fee of 5 percent of the amount due.

(e) The District may impose a surcharge equivalent of up to 50 percent of the District's production fee for water transported out of the District.

Rule 7.3 Filing Reports

(a) The driller's log and completion log, referred to by the Texas Department of Licensing and Regulation State Water Well Driller's Board as a "State Well Report," shall be filed with the

District within 30 days from the preparation of the report pertaining to groundwater production, groundwater quality, or aquifer testing. In the event a well is plugged, the person who plugs the well shall within 30 days after plugging and abandonment is complete, submit a plugging report to the District in accordance with the Rules of the Texas Department of Licensing and Regulation, unless an extension has been granted.

(b) Water levels in monitoring wells designated under these rules shall be reported to the District at the same time as regulatory fees are paid to the District unless provided otherwise in the permit or in a written agreement with the District.

SECTION 8. OPERATING PERMITS, REGISTRATIONS, AND AMENDMENTS

Rule 8.1 Drilling Registrations and Drilling Permits

(a) After the effective date of these rules, no person shall drill an exempt water well before filing an application for a drilling registration and receiving the registration or drill a non-exempt water well before filing an application for a drilling permit and receiving the drilling permit. Each original application for a water well drilling registration or drilling permit requires a separate application. Application forms will be provided by the District and furnished to the applicant upon request.

(b) Contents of an application: An application for a drilling registration or drilling permit shall be in writing and sworn, and shall contain:

1. The name and mailing address of the applicant and the name and address of the owner of the land, if different from the applicant, on which the well is to be located;
2. If the applicant is other than the owner of the property, documentation establishing the applicable authority to construct and operate a well on the owner's property for the proposed use;
3. For exempt wells, a statement regarding the basis for asserting that the well will be exempt under Rule 8.6;
4. A statement of the nature and purpose of the proposed well, its use and the amount of water to be used for each purpose;
5. Except for exempt wells, availability of feasible and practicable alternative supplies to the applicant;
6. Except for exempt wells, the projected effect of the proposed injection or withdrawal on the aquifer or any other aquifer conditions, depletion, subsidence, or effects on existing permit holders or other groundwater users in the District;
7. Except for exempt and injection wells, the applicant's water conservation plan and, if any subsequent user of the water is a municipality or entity providing retail water services, the water conservation plan of that municipality or entity shall also be provided and a declaration that the applicant will comply with the District's Groundwater Management Plan;
8. The location of the well and the estimated or proposed rate at which water will be injected and/or withdrawn and where the water is proposed to be used; and,

9. A well closure plan or a declaration that the applicant will comply with well plugging guidelines and report closure to the applicable authorities, including the District.

(c) The General Manager will assist the applicant for a voluntary registration for a well exempt under these rules and for a monitoring well and issue the registration.

(d) A drilling registration or drilling permit application may be changed by the applicant by submitting a written, sworn amendment to the application, calling the attention of the District to the proposed changes. For drilling permit applications, if an amendment is filed, new notice may be required to be given if significant changes are requested. All amendments must be approved by the District and appropriate fees may be assessed to review the amendment. Such administrative deposit or fee shall not unreasonably exceed the cost to the District for such administrative acts.

(e) An individual or entity may mitigate or make emergency repairs to an existing well provided that the mitigation or repair is required by the Railroad Commission of Texas and the mitigation or repair does not violate Rule 10.1.

Rule 8.2 Registrations

(a) This subsection concerns wells which are exempt pursuant to Rule 8.6 and in existence on the effective date of these rules or which are no longer subject to the rules of the Railroad Commission of Texas, but will continue to be used, provided they will be exempt wells according to these rules. All existing water wells exempt under these rules from the requirement of an operating permit may be registered with the District by the well owner or the well operator. If the exempt well is in existence on the effective date of these rules, the well owner or operator may file with the District an application for a certificate of registration. After review and the determination by the General Manager that the well is exempt, the owner or operator shall be issued a certificate of registration by the General Manager. A registration may be amended by following the procedures for a new registration and identifying the changes requested.

(b) For proposed, exempt wells, not in existence on the effective date of these rules, the owner shall apply for a drilling registration and request that the well be registered. The application shall include the information set out in Rule 8.1(b). The General Manager shall review the drilling registration application and make a preliminary determination on whether the well meets the exemptions provided in Rule 8.6. If it is concluded that the applicant seeks a drilling registration for a well that will be exempt under these rules, the General Manager shall issue the drilling registration to the applicant. After the well is drilled and upon the filing of the driller's log and completion report with the District, the General Manager shall issue to the owner or operator a certificate of registration.

(c) The driller's log and completion report (and on abandonment, if drilled, the plugging and abandonment report) shall be filed with the District as provided in Rule 7.3.

Rule 8.3 General Permitting Policies and Procedures

(a) Operating Permit Requirement: The well owner or well operator must file a written, sworn application for an operating permit prior to operating any well for either injection of water or the withdrawal of water, not otherwise exempt under Rule 8.6 or excluded, unless additional production is obtained from the well. The connection of a water well to any means of distributing the water, whether temporary or permanent, shall be deemed as operating the well. Pumping tests of a well are not deemed operating the well. The operating permit may be approved by the General Manager under such terms and conditions as the Board shall direct, and the well shall remain permitted until an operating permit term has expired and is no longer required for the well/well system. For non-exempt wells in existence on the effective date of the creation of the District, an application for an operating permit or, after the District's Groundwater Management Plan is approved, an operating permit must be filed on or before August 31, 2007.

(b) Operating Permit Applications: Every well shall have a separate application for an operating permit, unless it is an exempt well or an excluded well having no additional production. Every well requires a separate application for an operating permit. Application forms will be provided by the District and furnished to the applicant upon request. The application shall be in writing, sworn, and provide the following information:

1. For non-exempt wells in existence on the effective date of these rules, the information provided for drilling permits stated in Rule 8.1, and any additional information requested by the General Manager.
2. For non-exempt wells not in existence on the effective date of these rules:
    a. Any corrections to the information supplied in the drilling permit application;
    b. The date the well was drilled and its location;
    c. The instantaneous (gallons per minute; gpm), daily, and annual rate at which the applicant seeks to inject into the well or pump the well and/or withdraw from the well;
    d. For wells to be drilled and equipped to produce more than 200 acre-feet per year, or the equivalent on a daily basis, excluding irrigation wells, such information must include, to the extent practical, the transmissivity and storativity of the aquifer from which groundwater is to be withdrawn and also shall include an assessment of the impact on the aquifer of the proposed pumpage. It is expected that these aquifer parameters be determined based on a pumping test of at least twenty-four hours duration. Any observation well used for determining transmissivity and storativity of an aquifer must be sufficiently close to the well being pumped to discern the effects of the pumping well on water levels in the aquifer in accordance with the anticipated transmissivity and storativity of the aquifer and duration of the pumping test. All testing is to be performed under the direction and control of a licensed professional engineer or a licensed professional geoscientist in the State of Texas, who shall affix his or her signature and seal to the test results and assessment

of aquifer impact. For recognized well fields, defined as two or more wells operated by the same entity at or within plus thirty percent of the minimum spacing prescribed in Section 5 of these rules, a single aquifer test will be sufficient.; and,

e. Any additional information requested by the Board or the General Manager.

(c) Notice of Permit Hearing: Once the District has received an original application for a drilling permit to withdraw water or to inject water or an operating permit for a non-exempt water well and the application is deemed administratively complete, the General Manager, with Board orders, will prepare a written notice of the application and public hearing as provided in Rule 13.2.

(d) Decision and Issuance of Permit: In deciding whether or not to grant a permit or permit amendment, and in setting the terms of the permit, the Board shall consider the Texas Water Code and the District rules, including:

1. The application conforms to the requirements prescribed by Chapter 36, Water Code, and is accompanied by the prescribed fees;
2. The proposed injection or use of water unreasonably affects existing groundwater and surface water resources or existing permit holders;
3. The proposed use of water is dedicated to any beneficial use;
4. The proposed use of water is consistent with the District's approved Groundwater Management Plan;
5. The applicant has agreed to avoid waste and achieve water conservation;
6. The applicant has agreed that reasonable diligence will be used to protect groundwater quality and that the applicant will follow well plugging guidelines at the time of well closure; and,
7. The terms and conditions that shall be attached to the permit or permit amendment to protect the groundwater resources of the District and the users within the District.

(e) Operating Permit Provisions: The operating permit will contain the name and address of the well owner or operator, the location of the well, the maximum rate at which water may be injected, where the water will be used and the purpose of use of the water, other criteria deemed necessary by the Board for the protection of the public health, safety, welfare, conservation, and management of the groundwater resources in the District, and the standard provisions listed in Rule 8.4. The operating permit may also contain provisions relating to the means and methods of transportation of water produced within the District, and any other provisions that the Board may direct.

(f) Aggregation of Withdrawal: In issuing a permit, the authorized withdrawal for a given well may be aggregated, at the discretion of the District, with the authorized withdrawal from other permitted wells designated by the District. Geographic location of wells, operational or legal control of the wells, ownership or legal control of the property where the wells are located, and use of the wells for a common purpose will be considered in determining whether or not to allow aggregation of withdrawal. For the purpose of categorizing wells by the amount of groundwater production, where wells are permitted with an aggregate withdrawal, the total authorized withdrawal shall be assigned to wells in aggregate, rather than allocating to each well a pro-rata share or estimated production.

(g) Effect of Acceptance of Permit: Acceptance of the permit by the person to whom it is issued constitutes acknowledgment by that person and agreement to comply with all of the terms, provisions, conditions, limitations, and restrictions stated in the permit and in these rules.

Rule 8.4 Operating Permit Provisions

All operating permits are granted subject to these rules, orders of the Board, and the laws of the State of Texas. An operating permit may be modified at any time by the Board in accordance with the District's Groundwater Management Plan. In addition to any special provisions or other requirements incorporated into the permit, each permit issued shall contain the following standard permit provisions:

1. This operating permit is granted in accordance with the provisions of the rules of the District, and acceptance of this permit constitutes an acknowledgment and agreement that the permittee accepts the terms and conditions of the permit and will comply with the rules and Groundwater Management Plan of the District.

2. This permit confers only the right to operate the well described in this permit under these rules, and its terms may be amended pursuant to the provisions of these rules. To protect the permit holder from illegal use by a new landowner, within 10 days after the date of sale, the operating permit holder must notify the District in writing of the name and address of the new owner. Any person who becomes the owner of a currently permitted well must, within 20 calendar days from the date of the change in ownership, file an application for a permit amendment to effect a transfer of the permit.

3. The operation of the well for the authorized withdrawal must be conducted in a non-wasteful manner.

4. Injections or withdrawals from all non-exempt wells must be measured by a water meter or estimated by the owner or operator using a water measuring device or method that is within plus or minus 10% of accuracy. Measured or estimated water use shall be reported to the District monthly and the applicable fee paid. Permittees shall keep accurate records of the groundwater injected or withdrawn and the purposes of the withdrawal. Such records shall be available for inspection by District representatives.

5. The well site must be accessible to District representatives for inspection, and the permittee agrees to cooperate fully in any reasonable inspection of the well and well site.

6. The application for which this operating permit has been issued is incorporated by reference in this permit, and this operating permit is granted on the basis of and contingent upon the

accuracy of the information provided in that application. A finding that false or inaccurate information has been provided is grounds for immediate revocation of the operating permit. Operating permits are subject to the imposition of additional provisions in accordance with the District's approved Groundwater Management Plan.

7. The maximum authorized withdrawal is limited to the amount stated in the permit on an annualized basis and the instantaneous rate of withdrawal can be no more than 1.25 times the amount authorized on an annual basis, except when groundwater production from wells is aggregated in accordance with Rule 8.3(g), unless otherwise authorized by the permit.

8. Violation of this permit's terms, conditions, requirements, or special provisions, including pumping amounts in excess of authorized withdrawal, is grounds for revocation of the permit and/or punishable by civil penalties as provided by the District Rule 14.4.

9. Wherever special provisions in this permit are inconsistent with other provisions or rules of the District, the special provisions of the permit shall prevail.

Rule 8.5 Operating Permit Limitations

(a) Maximum Authorized Withdrawal: No operating permittee shall inject, pump or withdraw any groundwater on an annual basis in excess of the amount of groundwater authorized in the operating permit and no rate of pumping shall be in excess of 1.25 times the instantaneous rate necessary to produce the authorized withdrawal on an annual basis, except when groundwater production from wells is aggregated in accordance with Rule 8.3(g) or unless otherwise authorized by the operating permit.

(b) Operating Permit Required: Unless otherwise exempt or excluded, no person shall operate a well without an operating permit issued by the District. However, if there is additional production from an exempt or excluded well, the operating permit requirement of these rules do apply.

(c) When an operating permit is granted, the permittee shall begin and complete construction of the permitted well diligently and, if the permit is for withdrawal, produce water from the well for the purpose(s) authorized within 24 months from the date the permit is issued. Failure of a permittee to begin and complete construction, and pump water from the permitted well for the authorized purpose(s) within the time period specified shall cause the permit to terminate and the permittee shall lose all rights thereunder without further action by the District; however, permittees may, upon a showing that it is not technically or economically feasible to connect the well to existing infrastructure or to a reasonably necessary extension of existing infrastructure within the 24 month period, be granted the full five year term of the operating permit to complete construction, and pump water from the permitted well for the authorized purpose(s). The permittee who has been granted an operating permit pursuant to this subsection must record a copy of the operating permit and the applicable spacing rule in effect at the time the operating permit is granted in the county real property records.

Rule 8.6 Exemptions

(a) Except as otherwise provided in these rules, the operating permit requirements of this Section 8 do not apply to exempt wells, however, the drilling registration requirements of Rule 8.1 and the registration requirements of Rule 8.2 do apply to a well-used solely for domestic use or for providing water for livestock or poultry on a tract of land larger than ten (10) acres that is either drilled, completed, or equipped so that it is incapable of producing more than 25,000 gallons of groundwater per day.

(b) New and existing exempt wells may be registered with the District.

Rule 8.7 Registration or Operating Permit Not Required

Wells drilled for oil, gas, sulfur, uranium, lignite, or brine or core tests, or for injection of gas, saltwater, or other fluids, or for any other purpose under permits issued by the Railroad Commission of Texas, other than additional production, are excluded under these rules. The District may not require a drilling permit for a well to supply water for drilling any wells permitted by the Railroad Commission of Texas, except as allowed by the Texas Water Code. Any well that ceases to be used for these purposes and is then used or additionally used as an ordinary water well, is subject to the rules of the District to the extent of the non-excluded purposes.

Any water well drilled and operated under the authority of the Railroad Commission of Texas that produces water in excess of that quantity necessary and for purposes other than the Railroad Commission permitted activity shall be subject to the rules and fees of the District to the extent excess water is produced and the purposes of use that are different than the Railroad Commission permitted activity.

Water wells drilled to supply water for hydrocarbon production activities, including lignite, must meet the spacing requirements of the District, including the limitations imposed by the designation of an aquifer storage area, unless no space is available within 300 feet of the production well or central injection station, in which event the applicant must demonstrate to the Board that the storage aquifer will not be impacted.

Rule 8.8 Change in Operating Permits

(a) If the holder of an operating permit, in connection with the renewal of a permit or otherwise, requests a change that requires an amendment to the permit under District rules, the permit as it existed before the permit amendment process remains in effect until the later of:
   1. The conclusion of the permit amendment or renewal process, as applicable; or,
   2. Final settlement or adjudication on the matter of whether the change to permit requires a permit amendment.

(b) If the permit amendment process results in the denial of an amendment, the permit as it existed before the permit amendment process shall be renewed under Rule 8.9 without penalty, unless Subsection (b) of that section applies to the applicant.

(c) The District may initiate an amendment to an operating permit, in connection with the renewal of a permit or otherwise, in accordance with the District's rules. If the District initiates an amendment to an operating permit, the permit as it existed before the permit amendment process shall remain in effect until the conclusion of the permit amendment process, as applicable.

Rule 8.9 Operating Permit Renewal

(a) Except as provided by Subsection (b), the District shall, without a hearing, renew or approve an application to renew an operating permit before the date on which the permit expires, provided that:

1. The application, if required by the District, is submitted in a timely manner and accompanied by any required fees in accordance with District rules; and,
2. The permit holder is not requesting a change related to the renewal that would require a permit amendment under District rules.

(b) The District is not required to renew a permit under this section if the applicant:

1. Is delinquent in paying a fee required by the District;
2. Is subject to a pending enforcement action for a substantive violation of a District permit, order, or rule that has not been settled by agreement with the District or a final adjudication; or,
3. Has not paid a civil penalty or has otherwise failed to comply with an order resulting from a final adjudication of a violation of a District permit, order, or rule.

(c) If the District is not required to renew a permit under Subsection (b)(2) above, the permit remains in effect until the final settlement or adjudication on the matter of the substantive violation.

SECTION 9. PERMITS FOR TRANSFER OF GROUNDWATER OUT OF THE DISTRICT

Rule 9.1 Permit Required

Groundwater produced from within the District may not be transferred outside the District's boundaries unless the Board has issued the well owner/operator a transfer permit. The requirements of this rule are applicable without regard to the manner in which the water is transferred out of the District and specifically includes discharges into watercourses to convey water, as well as pipelines and aqueducts.

Rule 9.2 Applicability

A groundwater transfer permit is not required for transportation of groundwater that is part of a manufactured product, or if the groundwater is to be used on contiguous property with the same property ownership, that straddles the District boundary line or within the City of Corpus Christi.

Rule 9.3 Application

(a) An application for a transfer permit must be filed in the District office, be in writing and sworn, and include the following information:

1. The name and mailing address of the applicant and the name and address of the owner of the land from which the transfer is to be made, if different from the applicant, on which the well is to be located;
2. If the applicant is other than the owner of the property, documentation establishing the applicable authority to construct and operate a well on the owner's property for the proposed transfer;
3. A statement of the nature and purpose of the proposed use and the amount of water to be used for each purpose and the period of time each purpose is expected to continue;
4. Availability of water in the District and in the proposed receiving area during the period for which the water supply is requested;
5. Availability of feasible and practicable alternative supplies to the applicant, municipality or entity;
6. The amount and purposes of use for which water is needed in the proposed receiving area for which water is needed;
7. The projected effect of the proposed withdrawal on the aquifer or any other aquifer conditions, depletion, subsidence, or effects on existing permit holders or other groundwater users within the District as determined by a licensed professional engineer or a licensed professional geoscientist in the State of Texas;
8. The indirect costs and economic and social impacts associated with the proposed transfer of water from the District;
9. The approved regional and state water plan, if one has been approved, and the approved District Groundwater Management Plan;
10. Other facts and considerations deemed necessary by the District's Board or General Manager for protection of the public health and welfare and conservation and management of natural resources in the District;
11. The applicant's water conservation plan and, if any subsequent user of the water is a municipality or entity providing retail water services, the water conservation plan of that municipality or entity shall also be provided;
12. The location of the well; and,
13. The period of time for which the permit is sought.

(b) The Board, at its discretion, may combine permit applications.

Rule 9.4 Hearing and Permit Issuance

(a) Applications for transfer permits are subject to the hearing procedures provided by these rules.

(b) In determining whether to issue a permit to transfer groundwater out of the District, the Board shall consider the information provided in Rule 9.3, the Texas Water Code, the District's Groundwater Management Plan, the District's mission statement and such other information the Board deems relevant.

Rule 9.5 Transfer Permit Amendments

Amendment to a Transfer Permit: It is a violation of these rules to transfer any amount of water in excess of the amount, withdrawal rate, or by any means or route not authorized by a transfer permit. A written, sworn application for an amendment to a transfer permit must be filed and the amendment granted before any deviation in the transfer permit occurs. The applicant must demonstrate that the originally authorized terms and conditions in the transfer permit have proven inadequate and why there is a need to change the authorization.

(1) Submission of application: The applicant for an amendment to modify the transfer permit shall provide sufficient documentation that the original authorizations have proven inadequate and the reasons for the need to make the change(s).

(2) Action on Amendment: The General Manager shall prepare a notice to be given of the amendment, which shall be given as in the original application, and a public hearing conducted in the manner prescribed for permit issuance.

Rule 9.6 Duration of Transfer Permit

The period for which water may be transferred under a transfer permit shall be at least three (3) years if construction of a conveyance system has not been initiated within the period specified in the permit or at least thirty years if construction of a conveyance system has been initiated prior to the issuance of the permit. Initiation of construction means letting of contracts for construction of facilities from the point of the well to at least the District boundary and the commencement of actual construction under the contract.

Rule 9.7 Transfer Permit Assessments

The fees for the transfer of water out of the District will be set forth by resolution of the Board.

SECTION 10. REWORKING AND REPLACING A WELL

Rule 10.1 Procedures

(a) An existing, permitted or exempt well may not be reworked or re-equipped in a manner that will change the authorizations contained in the operating permit or registration without a written, sworn application for an amendment that is approved by the Board in the case of an operating permit, or the General Manager in the case of a registration. Re-drilling a well requires a new permit.

(b) An operating permit must be applied for, if a party wishes to increase the rate of production of an exempt well to the point of increasing the size of the column pipe and gallon per minute rate by reworking or re-equipping the well such that the well is no longer exempt.

(c) A drilling permit or a drilling registration must be applied for and granted if a party wishes to replace an existing well with a new, replacement well.

(d) A replacement well, in order to be considered such, must be drilled within 30 feet of the existing well and shall not be drilled nearer the property line, provided the original well was not "grandfathered," if it meets distance requirements (Rule 5), production (Rule 6), when production rules are adopted, and completion (Rule 11) requirements. The Board may grant such application without further notice and/or variances to this rule on a case by case basis.

(e) After the effective date of these rules, upon commencing reworking or replacing permitted wells drilled and equipped to produce more than 200 acre-feet of water per year, the reworked or replacement well also shall be equipped to allow measurement of water levels in the well, and such water levels shall be measured on as frequent a basis as reasonably possible, preferably on a daily, but no greater than weekly, basis between the time the water level in the well first can be measured after the pump fails or is turned off to just before the pump is restarted for production. Reporting of water levels measured in accordance with this rule shall be coincident with payment of regulatory fees.

Rule 10.2 Emergency Reworking or Replacing of a Well

An emergency replacement or reworking of a well under the auspices of the Railroad Commission of Texas may be performed with notice to the District so long as there is no change to the rate or amount of withdrawal. New driller's logs and completion logs must be filed with the District within the same period of time as the logs are required to be filed with the Texas Water Development Board.

SECTION 11. WELL LOCATION AND COMPLETION

Rule 11.1 Responsibility

After an application for a well drilling permit or drilling registration has been granted, the well, if drilled, must be drilled within 30 feet of the location specified in the permit or registration application, and not elsewhere; however, the well shall not be drilled within 50 feet of the property line of the adjoining landowner, except as provided in Rule 5.3 or within an aquifer storage demarcated area. If the well should be commenced or drilled at a different location, the drilling or operation of such well is contrary to the authorizations contained in the permit and may be enjoined by the Board pursuant to Chapter 36, Texas Water Code and these rules. As described in the Rules of Texas Department of Licensing and Regulation, all well drillers and persons having a well drilled, deepened, or otherwise altered shall adhere to the provisions of the rule prescribing the location of wells and proper completion and these rules.

Rule 11.2 Location of Domestic, Industrial, Injection, and Irrigation Wells

(a) A new well must be located a minimum horizontal distance of 50 feet from any water- tight sewage facility and liquid-waste collection facility.

(b) A new well may not be located closer than a minimum horizontal distance of 150 feet from any potential source of contamination, such as existing or proposed livestock or poultry yards, privies, and septic systems, including tanks, piping, any evapo-transpiration pits, and pressure-dose distribution systems.

(c) A new well must not be located at a site generally subject to flooding; provided, however, that if a well must be placed in a flood prone area, it must be completed with a watertight sanitary well seal and steel casing extending a minimum of 24 inches above the known flood level, unless the well is approved by the Texas Commission on Environmental Quality.

(d) No new well may be located within five-hundred (500) feet of a sewage treatment plant, solid waste disposal site, or land irrigated by sewage plant effluent, or within three hundred (300) feet of a sewage wet well, sewage pumping station, or a drainage ditch that contains industrial waste discharges or wastes from sewage treatment systems.

Rule 11.3 Standards of Completion for Domestic, Industrial, Injection, and Irrigation Wells

Water well drillers must indicate the method of completion on the Well Report filed through the Texas Water Development Board's Texas Well Report Submission and Retrieval System. Domestic, industrial, Class V injection, and irrigation wells must be completed in accordance with the stricter of the following specifications or Texas Department of Licensing and Regulation rules set forth at 16 Texas Administrative Code, Chapter 76, local county or incorporated city ordinances:

(a) The annular space between the borehole and the casing shall be filled with cement slurry from the ground level to a depth of not less than 10 feet below the land surface or well head.

(b) All wells shall have a concrete slab or sealing block above the cement slurry around the well at the ground surface.

(c) The slab or block shall extend at least two (2) feet from the well in all directions and have a minimum thickness of four inches and shall be separated from the well casing by a plastic or mastic coating or sleeve to prevent bonding of the slab to the casing.

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

(e) In all wells:
   1. the casing shall extend a minimum of one foot above the original ground surface; and
   2. A slab or block as described in Rule 11.3(b) is required above the cement slurry except when a pitless adapter is used. Pitless adapters may be used in such wells provided that:
      a. Pitless adapter is welded to the casing or fitted with another suitably effective seal; and,
      b. The annular space between the borehole and the casing is filled with cement to a depth not less than 15 feet below the adapter connection.

(f) All wells, especially those that are gravel packed, shall be completed so aquifers or zones containing waters that differ are not allowed to commingle through the borehole-casing annulus or the gravel pack so as to result in pollution as defined in these rules.

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

(h) The mix of cement shall conform to the definition contained in these rules.

(i) In addition, all new wells permitted after the effective date of these rules that are drilled and equipped to produce more than 200 acre-feet of water per year also shall be equipped to allow measurement of water levels in the well.

Rule 11.4. Re-Completions

(a) The landowner shall have the continuing responsibility of insuring that a well does not allow commingling of undesirable water and fresh water or the unwanted loss of water through the wellbore to other porous strata.

(b) If a well is allowing the commingling of undesirable water and fresh water or the unwanted loss of water, and the casing in the well cannot be removed and the well re- completed within the applicable rules, the casing in the well shall be perforated and cemented in a manner that will prevent the commingling or loss of water. If such a well has no casing, then the well shall be cased and cemented, or plugged in a manner that will prevent such commingling or loss of water.

(c) The Board may direct the landowner to take steps to prevent the commingling of undesirable water and fresh water, or the unwanted loss of water.

(d) In an aquifer storage unit, some commingling of undesirable water and fresh water will occur and is authorized by an injection permit.

SECTION 12. WASTE AND BENEFICIAL USE

Rule 12.1 Waste Defined

Waste has the meaning as defined in Rule 1.1.

Rule 12.2 Waste Prevention

(a) Groundwater shall not be produced in or used within or without the District, in such a manner as to constitute waste as defined in Rule 1.1.

(b) No person shall cause pollution of the groundwater reservoir or aquifer in the District as defined in Rule 1.1.

(c) No person shall allow, cause, suffer, or permit waste as that term is defined herein.

(d) No person shall allow the continued existence of a deteriorated well.

Rule 12.3 Use for a Beneficial Purpose

Groundwater produced in the District shall be used for a beneficial purpose as defined in Rule 1.1.

SECTION 13. HEARINGS

Rule 13.1 Types of Hearings

The District conducts two general types of public hearings: (1) Permit hearings involving permit matters, in which the rights, duties, or privileges of a party are determined after an opportunity for an adjudicative hearing, and (2) Rulemaking hearings involving matters of general applicability that implement, interpret, or prescribe the law or District policy, or that describe the procedure or practice requirements of the District. Any matter designated for hearing before the Board may be referred by the Board for hearing before a hearing examiner. The general list of public hearings includes:

(a) Permit Hearings.

1. Permit Applications, Amendments, and Revocations: The District will hold hearings on water well drilling permits, operating permits, transfer permits or amendments and permit revocations or suspensions. Hearings involving permit matters may be scheduled before a hearing examiner. A permit application or an amendment to a permit is considered contested when a person with a personal justiciable interest files a protest and seeks a contested case hearing, unless the Board determines otherwise.
2. Hearings on Motions for Rehearing: Motions for rehearing will be heard by the Board pursuant to Rule 13.8(b).

(b) Rule-making Hearings.

(c) District Groundwater Management Plan: At its discretion, when authorized by law, after giving notice, the Board shall hold a public hearing to adopt or revise the Groundwater Management Plan.

(d) District Rules: The District shall hold a public hearing in accordance with these rules to adopt or revise these rules.

(e) Other Matters: A public hearing may be held on any matter within the jurisdiction of the duties and responsibilities of the Board, if the Board deems a hearing to be in the public interest, or necessary to effectively carry out the duties and responsibilities of the Board.

RULE 13.2 Notice and Scheduling of Public Hearings

(a) Notices of all public hearings of the District shall be prepared by the General Manager.

1. For all applications, except drilling registrations and registrations, the notice will be provided to the applicant, who has the responsibility for giving the notice. At a minimum, the notice shall state the following information:
    a. The name and address of the applicant;
    b. The name or names of the owner or owners of the land, if different from the applicant;
    c. The date the application was filed and the number assigned to it;
    d. The time and date when and place where the hearing will be held;
    e. The address or approximate location of the proposed well;
    f. A brief summary of the information included in the application;
    g. A brief explanation of the proposed permit or permit amendment, including any requested amount of groundwater, the purpose of the proposed use and any change in use;

h. The time, date and location of the hearing; and,
i. Any other information requested by the Board.

2. For rule-making hearings, the General Manager is responsible for giving the notice. The notice shall be given not less than 20 days before the rule-making hearing. The notice shall be posted in a place readily accessible to the public at the District office, be provided to the county clerks of Nueces, San Patricio, Aransas, and Kleberg Counties, published in one or more newspapers of general circulation in each county, provide notice by mail, facsimile, or electronic mail to any person who has requested notice, and a copy of the proposed rule shall be made available at the District office. The notice shall include the time, date and place of the rule-making hearing, a brief explanation of the subject of the rule-making hearing, and a location or internet site at which a copy of the proposed rule(s) may be reviewed or copied.

(b) The applicant shall give the notification to adjacent property owners and landowners as shown in the county tax rolls as of the date the application is filed and, in addition, to all existing registered and permitted well owners within 3,000 feet of the proposed well as shown in the records of the District on the day the application is filed not less than 10 days before the public hearing and provide the District with proof of service. The applicant shall also publish the notice once in a newspaper(s) in general circulation in each county in the District not be less than 10 calendar days before the date set for the hearing. A publisher's affidavit and tear sheet of the notice shall be provided to the District. Proof of service and the publisher's affidavit and tear sheet of the notice shall be filed with the District prior to the commencement of the hearing. In considering whether notice has been given, the Board may evaluate the good faith effort of the applicant to give the notice. The General Manager shall also post notice in a publicly accessible place at the District's office, provide notice to the county clerk of the county in which the proposed well is located, give regular mail, facsimile, or electronic mail notice to any person who has requested notice and regular mail notice to any other person entitled to receive notice under these rules. An officer or employee of the District shall make an affidavit establishing attempted service of the notice by first class mail, facsimile or electronic mail in accordance with the information provided by the person as proof that the notice was provided. However, the failure to provide the notice to persons requesting the notice does not invalidate an action taken by the District.

(c) Notice will be given to each person who requests in writing copies of public hearing notices pursuant to the procedures set forth in this rule, and any other person the Board deems appropriate. The date of delivery or mailing of notice may not be less than 10 calendar days before the date set for the hearing.

(d) Requests for notices:

1. Any person having an interest in the subject matter of a permit application or amendment hearing or hearings may receive written notice of such hearing or hearings by submitting a request in writing. The request must identify with as much specificity as possible the hearing or hearings for which written notice is

requested. The request remains valid for a period of one year from the date of the request, after which time a new request must be submitted. Failure to provide written notice under this subsection does not invalidate any action taken by the Board.

2. Any person may submit a written request for notice of a rule-making hearing. The request is effective for the remainder of the calendar year in which the request is received. The request for a rule-making notice must be renewed by making a new request each year. An affidavit of an officer or employee establishing the attempted service of notice by first class mail, facsimile, or electronic mail is proof that notice was provided by the District. However, the failure to provide the notice shall not invalidate an action taken by the District at a rule-making hearing.

(e) Public hearings may be scheduled during the District's regular business hours, Monday through Friday of each week, except District holidays. All permit hearings will be held at the District office, unless the Board directs otherwise. However, the Board may from time to time change or schedule additional dates, times, and places for permit hearings. Other hearings will be scheduled at the dates, times and locations set at a regular Board meeting, unless an emergency meeting becomes necessary, which shall be publicized and held as required by law. The District may schedule as many applications for consideration at one hearing as deemed desirable. Hearings may be continued from time to time and date to date without additional mailed or published notice.

Rule 13.3 Board Action, Contested Case Hearing Requests, and Preliminary Hearing

(a) The Board may take action on any uncontested application at a properly noticed public meeting held at any time after the public hearing at which the application is scheduled to be heard. The Board may issue a written order to:

1. Grant the application;
2. Grant the application with special conditions; or,
3. Deny the application.

(b) The Board shall schedule a preliminary hearing to hear a request for a contested case hearing filed in accordance with rules adopted under Texas Water Code Section 36.415. The preliminary hearing may be conducted by:

1. A quorum of the Board;
2. An individual to whom the Board has delegated in writing the responsibility to preside as a hearing examiner over the hearing or matters related to the hearing; or,
3. The State Office of Administrative Hearings under Texas Water Code Section 36.416.

(c) Following a preliminary hearing, the Board shall determine whether any person requesting the contested case hearing has standing to make that request and whether a justiciable issue related to the application has been raised. If the Board determines that no person who requested a contested case hearing had standing or that no justiciable issues were raised, the Board may take any action authorized in Subsection (a) above.

(d) An applicant may, not later than the 20th day after the date the Board issues an order granting the application, demand a contested case hearing if the order:

1. Includes special conditions that were not part of the application as finally submitted; or,
2. Grants a maximum amount of groundwater production that is less than the amount requested in the application.

<u>Rule 13.4 General Procedures</u>

(a) Authority of the Presiding Officer: The presiding officer may conduct the hearing or other proceeding in the manner the presiding officer deems most appropriate for the particular proceeding. In permit or amendment application hearings, the presiding officer shall designate parties to the proceedings. The applicant shall always be designated a party.

(b) The presiding officer has the authority to:

1. Set hearing dates, other than the initial hearing date for permit matters in accordance with Rule 13.2;
2. Convene the hearing at the time and place specified in the notice for public hearing;
3. Set any necessary additional hearing dates;
4. Establish the jurisdiction of the District concerning the subject matter under consideration;
5. Rule on motions and on the admissibility of evidence and amendments to pleadings;
6. Designate and align parties and establish the order for presentation of evidence;
7. Administer oaths to all persons presenting testimony;
8. Examine witnesses;
9. Issue subpoenas when required to compel the attendance of witnesses or the production of papers and documents;
10. Require the taking of depositions and compel other forms of discovery under these rules;
11. Ensure that information and testimony are introduced as conveniently and expeditiously as possible, without prejudicing the rights of any party to the proceeding;
12. Conduct public hearings in an orderly manner in accordance with these rules;
13. Recess any hearing from time to time and place to place;
14. Reopen the record of a hearing for additional evidence when necessary to make the record more complete;
15. Exercise any other appropriate powers necessary or convenient to effectively carry out the responsibilities of presiding officer; and,
16. Determine how to apportion among the parties the costs related to:
    a. Contract for the services of a presiding officer; and,

b. The preparation of the official hearing record.

(c) Hearing Registration Forms: Each individual who participates in a hearing or other proceeding of the District must submit a form providing the following information: name; address; whether the person plans to testify; who the person represents if the person is not there in the person's individual capacity; and any other information relevant to the hearing or other proceeding.

(d) Appearance and Representative Capacity: Any interested person may appear in person or may be represented by counsel, engineer, or other representative provided the representative is fully authorized to speak and act for the principal. Such person or representative may present evidence, exhibits, or testimony, or make an oral presentation in accordance with the procedures applicable to the particular proceeding. Any partner may appear on behalf of the partnership. A duly authorized officer or agent of a public or private corporation, Limited Liability Company, political subdivision, governmental agency, municipality, association, firm, or other entity may appear for the entity. A fiduciary may appear for a ward, trust, or estate. A person appearing in a representative capacity may be required to prove proper authority.

(e) Alignment of Parties and Number of Representatives Heard: Participants in a proceeding may be aligned according to the nature of the proceeding and their relationship to it. The presiding officer may require the participants of an aligned class to select one or more persons to represent them in the proceeding or on any particular matter or ruling and may limit the number of representatives heard, but must allow at least one representative of an aligned class to be heard in the proceeding or on any particular matter or ruling.

(f) Appearance by Applicant or Movant: The applicant, movant or party requesting the hearing or other proceeding or their representative should be present at the hearing or other proceeding. Failure to so appear may be grounds for withholding consideration of a matter and dismissal without prejudice or may require the rescheduling or continuance of the hearing or other proceeding if the presiding officer deems it necessary in order to fully develop the record.

(g) Reporting: Public hearings and other proceedings will be recorded on audio cassette tape or, at the discretion of the presiding officer, may be recorded by a certified shorthand reporter. The District does not prepare transcripts for the public of hearings or other proceedings recorded on audio cassette tape on District equipment, but the District will arrange access to the recording. Subject to availability of space, any party may, at their own expense, arrange for a reporter to report the hearing or other proceeding or for recording of the hearing or other proceeding. The cost of reporting or transcribing a permit hearing may be assessed in accordance with Rule 13.5(b). In all District matters, if a proceeding is recorded by a reporter, and a copy of the transcript of testimony is ordered by any person, the testimony will be transcribed and the original transcript filed with the papers of the proceeding at the expense of the person requesting the transcript of testimony. Copies of the transcript of testimony of any hearing or other proceeding thus reported may be purchased from the reporter.

(h) Continuance: The presiding officer may continue hearings or other proceedings from time to time and from place to place without the necessity of publishing, serving, mailing or otherwise issuing a new notice. If a public hearing or other proceeding is continued and a time and place (other than the District office) for the public hearing or other proceeding to reconvene are not publicly announced at the hearing or other proceeding by the presiding officer before it is recessed, the presiding officer must provide a notice giving the time, date, and location of the continued public hearing by regular mail to the parties. It is not necessary to post at the county courthouses or publish a newspaper notice of the new setting.

(i) Filing of Documents and Time Limit: Applications, motions, exceptions, communications, requests, briefs or other papers and documents required to be filed under these rules or by law must be received in hand at the District's office within the time limit, if any, set by these rules or by the presiding officer for filing. Mailing within the time period is insufficient if the submissions are not actually received by the District within the time limit.

(j) Computing Time: In computing any period of time specified by these rules, by a presiding officer, by Board orders, or by law, the day of the act, event, or default after which the designated period of time begins to run is not included, but the last day of the period computed is included, unless the last day is a Saturday, Sunday or legal holiday as determined by the Board, in which case the period runs until the end of the next day which is neither a Saturday, Sunday nor a legal holiday.

(k) Affidavit: Whenever the making of an affidavit by a party to a public hearing or other proceeding is necessary, it may be made by the party or the party's representative or counsel. This rule does not dispense with the necessity of an affidavit being made by a party when expressly required by statute.

(l) Broadening the Issues: No person will be allowed to appear in any public hearing or other proceeding that in the opinion of the presiding officer is for the sole purpose of unduly broadening the issues to be considered in the public hearing or other proceeding.

(m) Conduct and Decorum: Every person, party, representative, witness, and other participant in a proceeding must conform to ethical standards of conduct and must exhibit courtesy and respect for all other participants. No person may engage in any activity during a proceeding that interferes with the orderly conduct of District business. If in the judgment of the presiding officer, a person is acting in violation of this provision, the presiding officer will first warn the person to refrain from engaging in such conduct. Upon further violation by the same person, the presiding officer may exclude that person from the proceeding for such time and under such conditions as the presiding officer deems necessary.

Rule 13.5 Uncontested Permit Hearing Procedures

(a) Written Notice of Intent to Contest: Any person who intends to contest a permit application must provide written notice of that intent to the District office and the applicant at least five calendar days prior to the date of the public hearing. If the General Manager intends to contest a permit application, the General Manager must provide the applicant written notice of that intent at least five calendar days prior to the date of the public hearing. If no notice of intent to contest is received five calendar days prior to the public hearing, the General Manager, as instructed by the Board of Directors, will cancel the public hearing and the Board will consider the permit at the next regular Board meeting.

(b) Informal Hearings: Permit hearings may be conducted informally when, in the judgment of the hearing body, the conduct of a proceeding under informal procedures will save time or cost to the parties, lead to a negotiated or agreed settlement of facts or issues in controversy, and not prejudice the rights of any party.

(c) Agreement of Parties: If, during an informal proceeding, all parties reach a negotiated or agreed settlement which, in the judgment of the hearing body, settles the facts or issues in controversy, the proceeding will be considered an uncontested case. The hearing body will summarize the evidence, make findings of fact and conclusions of law based on the existing record and any other evidence submitted by the parties at the hearing.

(d) Decision to Proceed as Uncontested or Contested Case: If the parties do not reach a negotiated or agreed settlement of the facts and issues in controversy or if any party contests a staff recommendation, and the hearing body determines these issues will require extensive discovery proceedings, the hearing body will declare the case to be contested and convene a prehearing conference as set forth in Rule 13.5. The hearing body may also recommend issuance of a temporary permit for a period not to exceed 4 months, with any special provisions the hearing body deems necessary, for the purpose of completing the contested case process. Any case not declared a contested case under this provision is an uncontested case and the hearing body will summarize the evidence, make findings of fact and conclusions of law, and make appropriate recommendations to the Board.

(e) Recordation of the Hearing: In an uncontested case, the presiding officer may substitute minutes or the report required under Texas Water Code 36.410 for the method of recording the hearing.

Rule 13.6 Contested Permit Hearing Procedures

(a) Pre-Hearing Conference: A pre-hearing conference shall be held to consider any matter which may expedite the hearing or otherwise facilitate the hearing process.

1. Matters Considered: Matters which may be considered at a preheating conference include, but are not limited to;
    a. The designation of parties;
    b. The formulation and simplification of issues;
    c. The necessity or desirability of amending applications or other pleadings;

d. The possibility of making admissions or stipulations;
e. The scheduling of discovery;
f. The identification of and specification of the number of witnesses;
g. The filing and exchange of prepared testimony and exhibits; and,
h. The procedure at the hearing.

2. Notice: A prehearing conference may be held at a date, time, and place stated in a separate notice given in accordance with Rule 13.2, or at the date, time, and place for hearing stated in the notice of public hearing, and may be continued from time to time and place to place, at the discretion of the presiding officer.
3. Conference Action: Action taken at a prehearing conference may be reduced to writing and made a part of the record or may be stated on the record at the close of the conference.

(b) Assessing Reporting and Transcription Costs: Upon the timely request of any party, or at the discretion of the hearing body, the hearing body may make a recommendation to the Board regarding the assessment of reporting and transcription costs to one or more of the parties. If the Board is the hearing body, a hearing report with recommendations need not be filed. The hearing examiner must consider the following factors in assessing reporting and transcription costs:

1. The party who requested the transcript;
2. The financial ability of the party to pay the costs;
3. The extent to which the party participated in the hearing;
4. The relative benefits to the various parties of having a transcript;
5. The budgetary constraints of a governmental entity participating in the proceeding; and,
6. Any other factor that is relevant to a just and reasonable assessment of costs.

(c) In any proceeding where the assessment of reporting or transcription costs is an issue, the hearing body must provide the parties an opportunity to present evidence and argument on the issue. A recommendation regarding the assessment of costs must be included in the hearing body's report to the Board.

(d) Designation of Parties: Parties to a hearing will be designated on the first day of hearing or at such other time as the hearing body determines. The General Manager and any person specifically named in a matter are automatically designated parties. Persons other than the automatic parties must, in order to be admitted as a party, appear at the proceeding in person or by representative and seek to be designated. To be designated as a party, the person must be an affected person as defined in Rule 1.1. After parties are designated, no other person may be admitted as a party unless, in the judgment of the hearing body, there exists good cause and the hearing will not be unreasonably delayed.

(e) Rights of Designated Parties: Subject to the direction and orders of the hearing body, parties have the right to conduct discovery, present a direct case, cross-examine witnesses, make oral and written arguments, obtain copies of all documents filed in the proceeding, receive copies of all notices issued by the District concerning the proceeding, and otherwise fully participate in the proceeding.

(f) Persons Not Designated Parties: At the discretion of the hearing body, persons not designated as parties to a proceeding may submit comments or statements, orally or in writing. Comments or statements submitted by non-parties may be included in the record, but may not be considered by the hearing body as evidence.

(g) Furnishing Copies of Pleadings: After parties have been designated, a copy of every pleading, request, motion, or reply filed in the proceeding must be provided by the author to every other party or the party's representative. A certification of this fact must accompany the original instrument when filed with the District. Failure to provide copies may be grounds for withholding consideration of the pleading or the matters set forth therein.

(h) Disabled Parties and Witnesses: Persons who have special requests concerning their need for reasonable accommodation, as defined by the Americans With Disabilities Act, 42 U.S.C. 12111(9), during a Board meeting or a hearing, shall make advance arrangements with the General Manager of the District. Reasonable accommodation shall be made unless undue hardship, as defined in 42 U.S.C. 12111(10), would befall the District.

(i) Agreements to be in Writing: No agreement between parties or their representatives affecting any pending matter will be considered by the hearing examiner unless it is in writing, signed, and filed as part of the record, or unless it is announced at the hearing and entered into the record.

(j) Discovery: Discovery will be conducted upon such terms and conditions, and at such times and places, as directed by the hearing body. Unless specifically modified by these rules or by order of the hearing body, discovery will be governed by, and subject to the limitations set forth in, the Texas Administrative Procedures Act. In addition to the forms of discovery authorized under the Texas Administrative Procedures Act, the parties may exchange informal requests for information by agreement.

(k) Discovery Sanctions: If the hearing body finds a party is abusing the discovery process in seeking, responding to, or resisting discovery, the hearing body may:

1. Suspend processing of the application for a permit if the applicant is the offending party;
2. Disallow any further discovery of any kind or a particular kind by the offending party;
3. Rule that particular facts be regarded as established against the offending party for the purposes of the proceeding, in accordance with the claim of the party obtaining the discovery ruling;
4. Limit the offending party's participation in the proceeding;
5. Disallow the offending party's presentation of evidence on issues that were the subject of the discovery request; and/or,

6. Recommend to the Board that the hearing be dismissed with or without prejudice.

(l) Compelling Testimony, Swearing Witnesses, and Subpoena Power: The hearing body may compel the testimony of any person which is necessary, helpful, or appropriate to the hearing. The hearing body will administer the oath in a manner calculated to impress the witness with the importance and solemnity of the promise to adhere to the truth. The hearing body may issue subpoenas to compel the testimony of any person and the production of books, papers, documents, or tangible things, in the manner provided in the Texas Rules of Civil Procedure.

(m) Evidence: Except as modified by these rules, the Texas Administrative Procedures Act govern the admissibility and introduction of evidence; however, evidence not admissible under the Texas Administrative Procedures Act may be admitted if it is of the type commonly relied upon by reasonably prudent persons in the conduct of their affairs. In addition, evidence may be stipulated by agreement of all parties.

(n) Written Testimony: When a proceeding will be expedited and the interest of the parties will not be prejudiced substantially, testimony may be received in written form. The written testimony of a witness, either in narrative or question and answer form, may be admitted into evidence upon the witness being sworn and identifying the testimony as a true and accurate record of what the testimony would be if given orally. The witness will be subject to clarifying questions and to cross-examination, and the prepared testimony will be subject to objection.

(o) Requirements for Exhibits: Exhibits of a documentary character must be sized to not unduly encumber the files and records of the District. All exhibits must be numbered and, except for maps and drawings, may not exceed 8-1/2 by 11 inches in size.

(p) Abstracts of Documents: When documents are numerous, the hearing body may receive in evidence only those that are representative and the hearing body may require the abstracting of relevant data from the documents and the presentation of the abstracts in the form of an exhibit. Parties have the right to examine the documents from which abstracts are made.

(q) Introduction and Copies of Exhibits: Each exhibit offered must be tendered for identification and placed in the record. Copies must be furnished to the hearing body and to each of the parties, unless the hearing body rules otherwise.

(r) Excluding Exhibits: In the event an exhibit has been identified, objected to, and excluded, it may be withdrawn by the offering party. If withdrawn, the exhibit will be returned and the offering party waives all objections to the exclusion of the exhibit. If not withdrawn, the exhibit will be included in the record for the purpose of preserving the objection to excluding the exhibit.

(s) Official Notice: The hearing body may take official notice of all facts judicially cognizable. In addition, official notice may be taken of generally recognized facts within the area of the District's specialized knowledge.

(t) Documents in District Files: Extrinsic evidence of authenticity is not required as a condition precedent to admissibility of documents maintained in the files and records of the District.

(u) Oral Argument: At the discretion of the hearing body, oral arguments may be heard at the conclusion of the presentation of evidence. Reasonable time limits may be prescribed. The hearing body may require or accept written briefs in lieu of, or in addition to, oral arguments. When the matter is presented to the Board for final decision, further oral arguments may be heard by the Board, if the Board is not the hearing body.

(v) If a hearing is uncontested, or becomes uncontested during the course of the hearing, the presiding officer may substitute minutes or the report required by law for a method of recording the hearing.

<u>Rule 13.7 Conclusion of the Public Hearing and Report</u>

(a) Closing the Record and Proposal for Decision: At the conclusion of the presentation of evidence and any oral argument, the hearing body may either close the record or keep it open and allow the submission of additional evidence, exhibits, briefs, or proposed findings and conclusions from one or more of the parties. No additional evidence, exhibits, briefs, or proposed findings and conclusions may be filed unless permitted or requested by the hearing body. After the record is closed, the hearing body will prepare a proposal for decision to the Board, and submit the proposal for decision to the Board not later than the 30th day after the date the evidentiary hearing is concluded, if the Board is not the hearing body. The proposal for decision must include a summary of the subject matter of the hearing and evidence, together with the hearing body's findings and conclusions and recommendations for action. Upon completion and issuance of the hearing body's proposal for decision, a copy must be submitted to the Board, delivered to each party to the proceeding and to each party who provided comments. In a contested case, delivery to the parties must be by certified mail.

(b) Exceptions to the Hearing Body's Proposal for Decision and Reopening the Record: Prior to Board action, any party in a contested case or a party who provided comments may file written exceptions to the hearing body's proposal for decision, and any party in an uncontested case may request an opportunity to make an oral presentation of exceptions to the Board. Upon review of the proposal for decisions and exceptions, the hearing body may reopen the record for the purpose of developing additional evidence, or may deny the exceptions and submit the proposal for decision and exceptions to the Board. The Board may, at any time and in any case, remand the matter to the hearing body for further proceedings.

(c) Time for Board Action on Certain Permit Matters: In the case of hearings involving new permit applications, original applications for existing wells, or applications for permit renewals or amendments, the hearing body's proposal for decision should be submitted, and the Board shall act, within 60 calendar days after the close of the hearing record.

(d) The Board shall consider the proposal for decision at a final hearing. Additional evidence may not be presented during a final hearing. The parties may present oral argument at a final hearing to summarize the evidence, present legal argument, or argue an exception to the proposal for decision. A final hearing may be continued as provided by Rule 13.3 (h).

(e) The Board may change a finding of fact or conclusion of law made by the administrative law judge, or may vacate or modify an order issued by the administrative judge, only if the Board determines:

1. That the administrative law judge did not properly apply or interpret applicable law, District rules, written policies provided under Texas Water Code Section 36.416(e), or prior administrative decisions:
2. That a prior administrative decision on which the administrative law judge relied is incorrect or should be changed; or,
3. That a technical error in finding of fact should be changed.

(f) The Board may take action on uncontested application at a properly noticed public meeting held at any time after the public hearing at which the application is scheduled to be heard. The public hearing may be held in conjunction with a regularly scheduled or special called Board meeting. The Board action may occur at the same Board meeting as the public meeting. The Board may issue a written order to grant an application, grant an application with special conditions, or deny the application.

(g) Following an uncontested hearing, an applicant may, no later than the 20th day after the date the Board issues an order granting the application, demand in writing a contested case hearing if the order:

1. Includes special conditions that were not a part of the application as finally submitted; or,
2. Grants a maximum amount of groundwater production that is less than the amount requested in the application.

<u>Rule 13.8 Rule-Making Public Hearing Procedures</u>

(a) General Procedures: The presiding officer will conduct the rule-making public hearing in the manner the presiding officer deems most appropriate to obtain all relevant information pertaining to the subject of the hearing as conveniently, inexpensively, and expeditiously as possible. The presiding officer may follow the guidelines of Robert's Rules of Order, Newly Revised.

(b) Submission of Documents: Any interested Person may submit written statements, protests or comments, briefs, affidavits, exhibits, technical reports, or other documents relating to the subject of the hearing. Such documents must be submitted no later than the time of the hearing, as stated in the notice of hearing given in accordance with Rule 13.2; provided, however, that the presiding officer may grant additional time for the submission of documents.

(c) Oral Presentations: Any person desiring to speak on the subject of the hearing must so indicate on the registration form provided at the hearing. The presiding officer establishes the order of testimony and may limit the number of times a person may speak, the time period for oral presentations, and the time period for raising questions. In addition, the presiding officer may limit or exclude cumulative, irrelevant, or unduly repetitious presentations.

(d) Conclusion of the Hearing, Closing the Record, and Hearing Body's Report: At the conclusion of the testimony, and after the receipt of all documents, the presiding officer may either close the record, or keep it open to allow the submission of additional information. If the presiding officer is a hearing examiner or chairman of a committee, the presiding officer must, after the record is closed, prepare a report to the Board. The report must include a summary of the subject of the hearing and the public comments received, together with the hearing body's recommendations for action. Upon completion and issuance of the hearing body's report, a copy must be submitted to the Board. Any interested person who so requests in writing will be notified when the report is completed, and furnished a copy of the report.

(e) Exceptions to the Hearing Body's Report and Reopening the Record: Any interested person may make exceptions to the hearing body's report, and the Board may reopen the record, in the manner prescribed in Rule 13.6(b).

Rule 13.9 Final Decision and Appeals

(a) Board action: After the record is closed and the matter is submitted to the Board, the Board may then take the matter under advisement, continue it from day to day, reopen or rest the matter, refuse the action sought or grant the same in whole or part, or take any other appropriate action but the Board shall act on an application for any type of permit or permit amendment not less than 60 days after the date the final hearing is concluded. The Board action takes effect at the conclusion of the meeting and is not affected by a motion for rehearing.

(b) Requests for Rehearing or Findings and Conclusions: Any decision of the Board on a matter may be appealed by requesting a rehearing before the Board within 20 calendar days of the date of the Board's decision, in the case of a contested or uncontested hearing on an application, the applicant, or a party to a contested hearing, may administratively appeal. Such a rehearing request must be filed at the District office in writing and must state clear and concise grounds for the request. Such a rehearing request is mandatory with respect to any decision or action of the Board before any appeal may be brought. The Board's decision is final if no request for rehearing is made within the specified time, or upon the Board's denial of the request for rehearing, or upon rendering a decision after rehearing. If the rehearing request is granted by the Board, the date of the rehearing will be within 45 calendar days thereafter, unless otherwise agreed to by the parties to the proceeding. The failure of the

Board to grant or deny the request for rehearing within 90 calendar days of submission will be deemed to be a denial of the request.

Rule 13.10 Appeal of Desired Future Conditions and Judicial Appeal of Desired Future Conditions

(a) An affected person may file a petition with the District requiring that the District contract with the State Office of Administrative Hearings (SOAH) to conduct a hearing appealing the reasonableness of the desired future condition. The petition must be filed not later than the 120th day after the date on which the District adopts a desired future condition under Texas Water Code Section 36.108(d-4). The petition must provide evidence that the District did not establish a reasonable desired future condition of the groundwater resources in the management area.

(b) In this Rule, "Affected person" means:

1. An owner of land in Groundwater Management Areas 15 and 16;
2. A groundwater conservation District or subsidence District in or adjacent to Groundwater Management Areas 15 and 16;
3. A regional water planning group with a water management strategy in Groundwater Management Areas 15 and 16;
4. A person who holds or is applying for a permit from a District in Groundwater Management Areas 15 and 16;
5. A person with legally defined interest in groundwater in Groundwater Management Areas 15 and 16; or,
6. Any other person defined as affected by the Texas Commission on Environmental Quality rule.

(c) Not later than the 10th day after receiving a petition, the District shall submit a copy of the petition to the Texas Water Development Board. The Texas Water Development Board shall conduct an administrative review and study required by Texas Water Code Section 36.1083(e), which must be completed and delivered to SOAH not later than 120 days after the Texas Water Development Board receives the petition. SOAH shall consider the study described and the desired future conditions explanatory report submitted to the development Board under Texas Water Code Section 36.108(dd)(3) to be part of the administrative record in the SOAH hearing. The Texas Water Development Board shall make available relevant staff as expert witnesses if requested by SOAH or a party to the hearing.

(d) Not later than 60 days after receiving a petition appealing the reasonableness of the desired future conditions filed under Texas Water Code Section 36.1083(b), the District shall submit to SOAH a copy of the petition and contract with SOAF to conduct a contested case hearing.

(e) The petitioner shall pay the costs associated with the contract with SOAH and shall deposit with the District an amount determined by the District, after consultation with SOAH, that is sufficient to pay the contract amount. The deposit must be received within 15 days of written notification by the District to the petitioner specifying the amount of the deposit. Failure to timely pay the deposit may result in dismissal of the petition. After the hearing is completed and all costs paid to SOAH, the District shall refund any excess money to the petitioner.

(f) Unless provided by SOAH, the District shall provide notice of a hearing appealing the reasonableness of the desired future conditions. Not later than the 10th day before the date of a hearing, the General Manager or Board shall provide notice as follows (unless notice provided by SOAH):

1. General Notice:
    a. Post notice in a place readily accessible to the public at the District office; and,
    b. Provide notice to the county clerk of each county in the District.
2. Individual Notice by Regular Mail, Facsimile, or Electronic Mail to:
    a. The petitioner;
    b. Any person who has requested notice;
    c. Each nonparty District and regional water planning group located in Groundwater Management Areas 15 and 16;
    d. The Texas Water Development Board; and,
    e. The Texas Commission on Environmental Quality.

(g) After the hearing and within 60 days of the receipt of the administrative law judge's findings of fact and conclusions of law in a proposal for decision, including a dismissal of a petition, the District shall issue a final order stating the District's decision on the contested matter and the District's findings of fact and conclusions of law. The District may change a finding of fact or conclusion of law made by the administrative law judge, or may vacate or modify an order issued by the administrative law judge, as provided by Texas Government Code Section 2001.058(e).

(h) If the District vacates or modifies the proposal for decision, the District shall issue a report describing in detail the District's reasons for disagreement with the administrative law judge's findings of fact and conclusions of law. The report shall provide the policy, scientific, and technical justifications for the District's decision

(i) If the District in its final order finds that a desired future condition is unreasonable, not later than the 60th day after the date of the final order, the District shall reconvene in a joint planning meeting with the other Districts in Groundwater Management Areas 15 and 16 for the purpose of revising the desired future condition. The District and other Districts in Groundwater Management Areas 15 and 16 shall follow the procedures in Texas Water Code Section 36.108 to adopt new desired future conditions applicable to the District.

(j) A final order by the District finding that a desired future condition is unreasonable does not invalidate the adoption of a desired future condition by a District that did not participate as a party in the hearing conducted under this Rule.

(k) A final District order issued under this Rule may be appealed to a District court with jurisdiction over any part of the territory of the District that issued the order. An appeal under this subsection must be filled with the District court not later than the 45th day after the date the District issued the final order. The case shall be decided under the substantial evidence standard of review as provided by Texas Government Code Section 2001.174. If the court finds that a desired future condition is unreasonable, the court shall strike the desired future condition and order the Districts in Groundwater Management Areas 15 and 16 to reconvene not later than the 60th day after the date of the court order in a joint planning meeting for the purpose of revising the desired future condition. The District and other Districts in the management area shall follow the procedures in Texas Water Code Section 36.108 to adopt new desired future conditions applicable to the District. A court's finding under this Rule does not apply to a desired future condition that is not a matter before the court.

SECTION 14. INVESTIGATIONS AND ENFORCEMENT

Rule 14.1 Notice and Access to Property

Board members and District agents and employees are entitled to access to all property within the District to carry out technical and other investigations necessary to the implementation of the District rules. Prior to entering upon property for the purpose of conducting an investigation, the person seeking access must give notice in writing or in person or by telephone to the owner, lessee, or operator, agent, or employee of the well owner or lessee, as determined by information contained in the application or other information on file with the District. Notice is not required if prior permission is granted to enter without notice. Inhibiting or prohibiting access to any Board member or District agents or employees who are attempting to conduct an investigation under the District rules constitutes a violation and subjects the person who is inhibiting or prohibiting access, as well as any other person who authorizes or allows such action, to the penalties set forth in the Texas Water Code, Section 36.102, 36.122, or 36.205.

Rule 14.2 Conduction of Investigation

Investigations or inspections that require entrance upon property must be conducted at reasonable times, and must be consistent with the establishment's rules and regulations concerning safety, internal security, and fire protection. The persons conducting such investigations must identify themselves and present credentials upon request of the owner, lessee, operator, or person in charge of the well.

Rule 14.3 Rule Enforcement

If it appears that a person has violated, is violating, or is threatening to violate any provision of the District rules the Board of Directors may institute and conduct a suit in the name of the District for enforcement of rules through the provisions of Section 36.102, Texas Water Code.

Rule 14.4 Penalty for Violating Rules, Permit Condition, or Board Orders

The penalty for violating a rule, permit term or condition, or order of the Board is up to $5,000 per violation per day for each day the violation continues.

Rule 14.5 Sealing of Wells

(a) Following due process, the District may, upon orders from a court of competent jurisdiction, seal wells that are prohibited from withdrawing groundwater within the District by the District rules to ensure that a well is not operated in violation of the District rules. A well may be sealed when:

1. No application has been made for a permit to drill or to register a new well;
2. No application has been made for an operating permit to withdraw groundwater from an existing or new well that is not registered, excluded or exempted from the requirement that a permit be obtained in order to lawfully withdraw groundwater; or,
3. The Board has denied, canceled or revoked a drilling permit or an operating permit.

(b) The well may be sealed by physical means, and tagged to indicate that the well has been sealed by the District, and other appropriate action may be taken as necessary to preclude operation of the well or to identify unauthorized operation of the well.

(c) Tampering with, altering, damaging, or removing the seal of a sealed well, or in any other way violating the integrity of the seal, or pumping of groundwater from a well that has been sealed constitutes a violation of these rules and subjects the person performing that action, as well as any well owner or primary operator who authorizes or allows that action, to such penalties as provided by the District rules.

SECTION 15. AQUIFER STORAGE AND RECOVERY PROJECTS

Rule 15.1 Definitions

In this Rule, “aquifer storage and recovery project”, “ASR injection well”, and “ASR recovery well” have the meanings previously identified.

Rule 15.2 Registration and Reporting of Wells

(a) A project operator shall:

1. Register the ASR injection wells and ASR recovery wells associated with the aquifer storage and recovery project with the District;
2. Each calendar month by deadline established by the Texas Commission on Environmental Quality (TCEQ) for reporting to the TCEQ, provide the District with a copy of the written or electronic report required to be provided to the TCEQ under Texas Water Code Section 27.155; and,
3. Annually by deadline established by the TCEQ for reporting to the TCEQ, provide the District with a copy of the written or electronic report required to be provided to the TCEQ under Section 27.156.

(b) If an aquifer storage and recovery project recovers an amount of groundwater that exceeds the volume authorized by the TCEQ to be revered under the project, the project operator shall report to the District the volume of groundwater recovered that exceeds the volume authorized to be recovered in addition to providing the report required above in Rule 15.2(a)2.

Rule 15.3 Permitting, Spacing, and Production Requirements

(a) Except as provided by Subsection(b) below, the District may not require a permit for the drilling, equipping, operation, or completion of an ASR injection well or an ASR recovery well that is authorized by the TCEQ.

(b) The ASR recovery wells that are associated with an aquifer storage and recovery project are subject to the permitting, spacing, and production requirements of the District if the amount of groundwater recovered from the wells exceeds the volume authorized by the TCEQ to be recovered under the project. The requirements of the District apply only to the portion of the volume of groundwater recovered from the ASR recovery wells that exceeds the volume authorized by TCEQ to be recovered.

(c) A project operator may not recover groundwater by an aquifer storage and recovery project in an amount that exceeds the volume authorized by the TCEQ to be recovered under the project unless the project operator complies with the applicable requirements of the District as described by this section.

Rule 15.4 Fees and Surcharges

(a) The District may not assess a production fee, transportation or export fee, or surcharge for groundwater recovered from an ASR recovery well, except to the extent that the amount of groundwater recovered under the aquifer storage and recovery project exceeds the volume authorized by the commission to be recovered.

(b) The District may assess a well registration fee or other administrative fee for an ASR recovery well in the same manner that the District assesses such a fee for other wells registered with the District.

Rule 15.5 Consideration of Desired Future Conditions

The District may consider hydrogeologic conditions related to the injection and recovery of groundwater as part of an aquifer storage and recovery project in the planning for and monitoring of the achievement of a desired future condition for the aquifer in which the wells associated with the projects are located.

D

Appendix D – Evidence of Public Notice and Adoption by District Board

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E

Appendix E – Evidence of Coordination with Regional Surface Water Entities *(to be inserted after adoption)*

NOTE: This section has been redacted at TWDB request for security reasons.

F

Appendix F – GAM Run 17-025 MAG: Modeled Available Groundwater for the Gulf Coast Aquifer System in GMA 16 (May 19, 2017)

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GAM RUN 17-025 MAG: MODELED AVAILABLE GROUNDWATER FOR THE GULF COAST AQUIFER SYSTEM IN GROUNDWATER MANAGEMENT AREA 16

Rohit Raj Goswami, Ph.D., P.E.
Texas Water Development Board
Groundwater Division
Groundwater Availability Modeling Section
(512) 463-0495
May 19, 2017

STATE OF TEXAS
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05/19/2017

GAM Run 17-025 MAG: Modeled Available Groundwater for the Gulf Coast Aquifer System in Groundwater Management Area 16

Rohit Raj Goswami, Ph.D., P.E.
Texas Water Development Board
Groundwater Division
Groundwater Availability Modeling Section
(512) 463-0495
May 19, 2017

EXECUTIVE SUMMARY:

The modeled available groundwater for Groundwater Management Area 16 (Figure 1) for the Gulf Coast Aquifer System is summarized by decade for the groundwater conservation districts and counties (Table 1) and for use in the regional water planning process (Table 2). The modeled available groundwater estimates range from approximately 233,000 acre-feet per year in 2020 to 312,000 acre-feet per year in 2060 (Tables 1 and 2). The estimates were extracted from results of a model run using the alternative groundwater availability model for Groundwater Management Area 16 (version 1.01). The model run files, which meet the desired future conditions of Groundwater Management Area 16, were submitted to the Texas Water Development Board (TWDB) as part of the Desired Future Conditions Explanatory Report for Groundwater Management Area 16. The explanatory report and other materials submitted to the TWDB were determined to be administratively complete on April 19, 2017.

REQUESTOR:

Mr. David O'Rourke, consultant for Groundwater Management Area 16.

DESCRIPTION OF REQUEST:

In a letter dated January 25, 2017, Mr. David O'Rourke, consultant for Groundwater Management Area 16, provided the TWDB with the desired future conditions of the Gulf Coast Aquifer System adopted by the groundwater conservation district representatives in Groundwater Management Area 16. All other aquifers in Groundwater Management Area 16 (Carrizo-Wilcox and Yegua-Jackson) were declared non-relevant for joint planning purposes. The Gulf Coast Aquifer System includes the Chicot Aquifer, Evangeline Aquifer, and the Jasper Aquifer. Clarifications to the submitted materials were received by TWDB on April 4, 2017. The desired future conditions for the Gulf Coast Aquifer System, as described in Resolution No. 2017-01 and adopted January 17, 2017, by the groundwater conservation districts within Groundwater Management Area 16, are described below:

Groundwater Management Area 16 [all counties]

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 62 feet in December 2060 from estimated year 2010 conditions.

Bee Groundwater Conservation District

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 76 feet in December 2060 from estimated year 2010 conditions.

Live Oak Underground Water Conservation District

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 34 feet in December 2060 from estimated year 2010 conditions.

McMullen Groundwater Conservation District

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 9 feet in December 2060 from estimated year 2010 conditions.

Red Sands Groundwater Conservation District

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 40 feet in December 2060 from estimated year 2010 conditions.

Kenedy County Groundwater Conservation District

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 40 feet in December 2060 from estimated year 2010 conditions.

Brush Country Groundwater Conservation District

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 69 feet in December 2060 from estimated year 2010 conditions.

Duval County Groundwater Conservation District

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 104 feet in December 2060 from estimated year 2010 conditions.

San Patricio County Groundwater Conservation District

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 48 feet in December 2060 from estimated year 2010 conditions.

Starr County Groundwater Conservation District

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 69 feet in December 2060 from estimated year 2010 conditions.

No District - Cameron County

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 70 feet in December 2060 from estimated year 2010 conditions.

No District - Hidalgo County

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 118 feet in December 2060 from estimated year 2010 conditions.

No District - Kleberg County

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 28 feet in December 2060 from estimated year 2010 conditions.

No District - Nueces County

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 21 feet in December 2060 from estimated year 2010 conditions.

No District - Webb County

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 113 feet in December 2060 from estimated year 2010 conditions.

No District - Willacy County

Drawdown of the Gulf Coast Aquifer System shall not exceed an average of 40 feet in December 2060 from estimated year 2010 conditions.

METHODS:

The alternative groundwater availability model for Groundwater Management Area 16 (Hutchison and others, 2011) was run using the model files submitted with the explanatory report (O’Rourke, 2017). Model-calculated water levels were extracted for the years 2010 and 2060, and drawdown was calculated as the difference between water levels at the beginning of 2010 and water levels at the end of 2060. Drawdown averages were calculated for the Gulf Coast Aquifer System by county, groundwater conservation districts, and the entire groundwater management area. As specified in the explanatory report (O'Rourke, 2017), drawdown for model cells that became dry during the simulation (water level dropped below the base of the cell) were excluded from the averaging. The calculated drawdown averages were compared with the desired future conditions to verify that the pumping scenario specified by the district representatives achieved the desired future conditions within a one-foot variance.

The modeled available groundwater values were determined by extracting pumping rates by decade from the model results using ZONEBUDGET Version 3.01 (Harbaugh, 2009). Table 1 presents the annual pumping rates by county and groundwater conservation district, subtotaled by groundwater conservation district, and then summed for Groundwater Management Area 16. Table 2 presents the annual pumping rates by county, river basin, regional water planning area, and groundwater conservation district within Groundwater Management Area 16.

Modeled Available Groundwater and Permitting

As defined in Chapter 36 of the Texas Water Code, "modeled available groundwater" is the estimated average amount of water that may be produced annually to achieve a desired future condition. Groundwater conservation districts must consider modeled available groundwater when issuing permits in order to manage groundwater production to achieve the desired future condition(s). Districts must also consider annual precipitation and production patterns, the estimated amount of pumping exempt from permitting, existing permits, and a reasonable estimate of actual groundwater production under existing permits.

PARAMETERS AND ASSUMPTIONS:

The parameters and assumptions for the groundwater availability are described below:

- The analysis used version 1.01 of the alternate groundwater availability model for Groundwater Management Area 16. See Hutchison and others (2011) for assumptions and limitations of the model.

- The model has six layers that represent the Chicot Aquifer (Layer 1), the Evangeline Aquifer (Layer 2), the Burkeville Confining Unit (Layer 3), the Jasper Aquifer (Layer 4), the Yegua-Jackson Aquifer (Layer 5), and the Queen-City, Sparta and Carrizo-Wilcox Aquifer System (Layer 6).

- The model was run with MODFLOW-2000 (Harbaugh and others, 2000).

- Groundwater Division checked the validity of the assertion that starting water levels in the model were comparable to the measured water-level conditions at the end of year 2010. Water-level values were averaged over the entire area of Groundwater Management Area 16 for the measured and modeled conditions between the years 2000 and 2010. These averaged water-level values are reported in Table 3. As presented in Table 3, the average water-levels indicate that conditions in the field did not change significantly, however, model estimated values differ significantly (by over 12 feet). Such a difference in the model estimates can be explained by the difference in values of pumping and recharge used in the model and those occurring in the field for the period between the years 2000 and 2010. It is important to note here that the groundwater availability model for Groundwater Management Area 16 was constructed using the confined aquifer assumption (and LAYCON=0 option) available within MODFLOW-96. Such an assumption leads to an almost linear response between pumping and drawdown. The Groundwater Division checked and verified the validity of the assumption by taking out the pumping input in the model from the years 2000 to 2010 and obtaining equivalent drawdown values in the year 2060. Based on the analysis, we conclude that the submitted model files are acceptable for developing estimates of modeled available groundwater. Please note that the confined aquifer assumption may also lead to physically unrealistic conditions with pumping in a model cell continuing even when water levels have dropped below the base of the model cell.

- Drawdown averages and modeled available groundwater values are based on official aquifer boundaries (Figures 1 and 2).

- Drawdown values for cells with water levels below the base elevation of the cell ("dry" cells) were excluded from the averaging. However, pumping values from those cells were included in the calculation of modeled available groundwater.

- Estimates of modeled available groundwater from the model simulation were rounded to whole numbers.

- Average drawdown per county may include some model cells that represent portions of surface water such as bays, reservoirs, and the Gulf of Mexico.

RESULTS:

The modeled available groundwater for the Gulf Coast Aquifer System that achieves the desired future conditions adopted by Groundwater Management Area 16 increases from approximately 233,000 acre-feet per year in 2020 to 312,000 acre-feet per year in 2060 (Tables 1 and 2). The modeled available groundwater is summarized by groundwater conservation district and county (Table 1) and by county, river basin, and regional water planning area for use in the regional water planning process (Table 2). Small differences of values between table summaries are due to rounding errors.

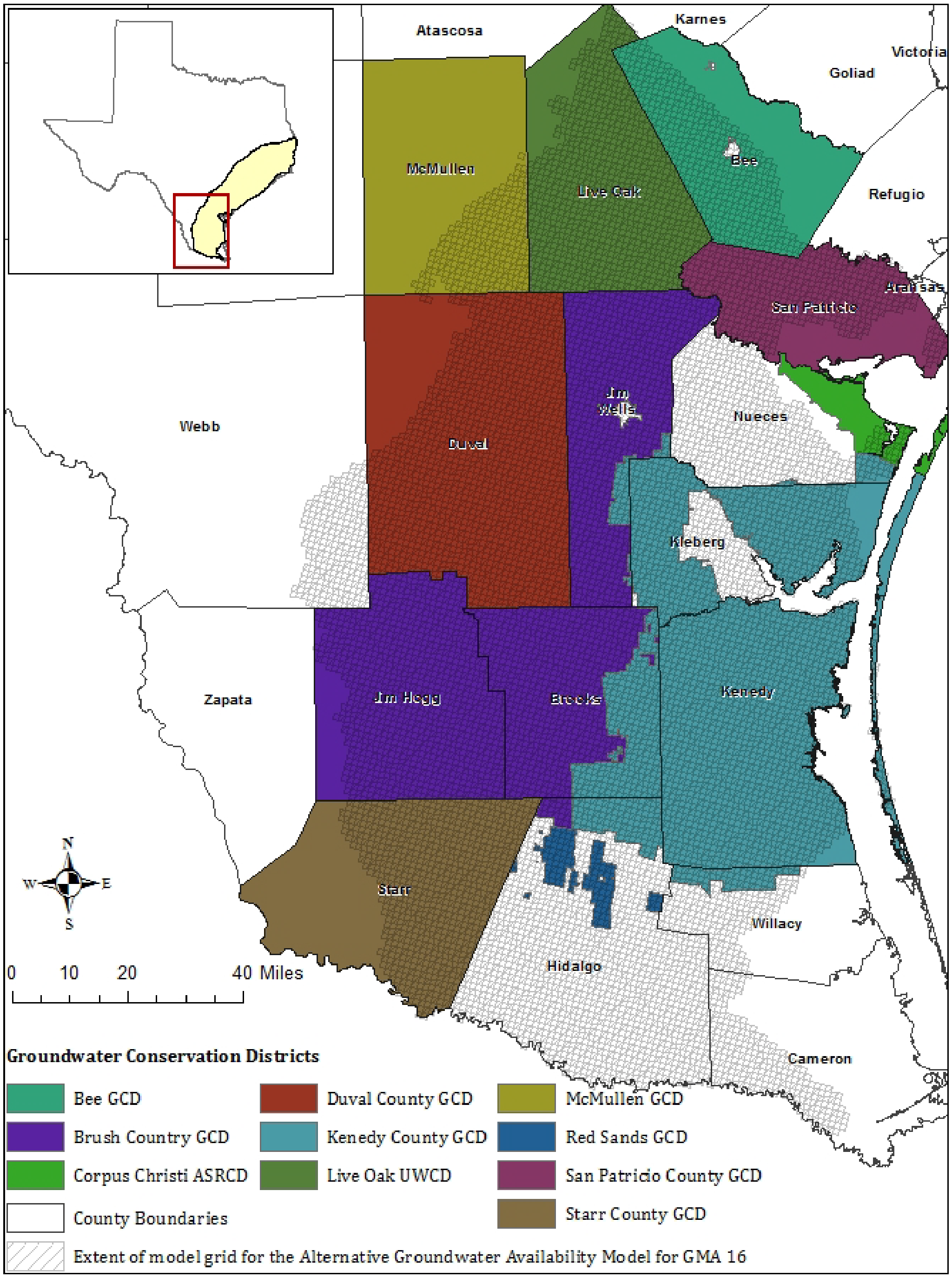

FIGURE 1. MAP SHOWING GROUNDWATER CONSERVATION DISTRICTS (GCDS), COUNTIES, AND GULF COAST AQUIFER SYSTEM EXTENT IN GROUNDWATER MANAGEMENT AREA 16 OVERLAIN ON THE EXTENT OF THE ALTERNATIVE GROUNDWATER AVAILABILITY MODEL FOR GROUNDWATER MANAGEMENT AREA 16.

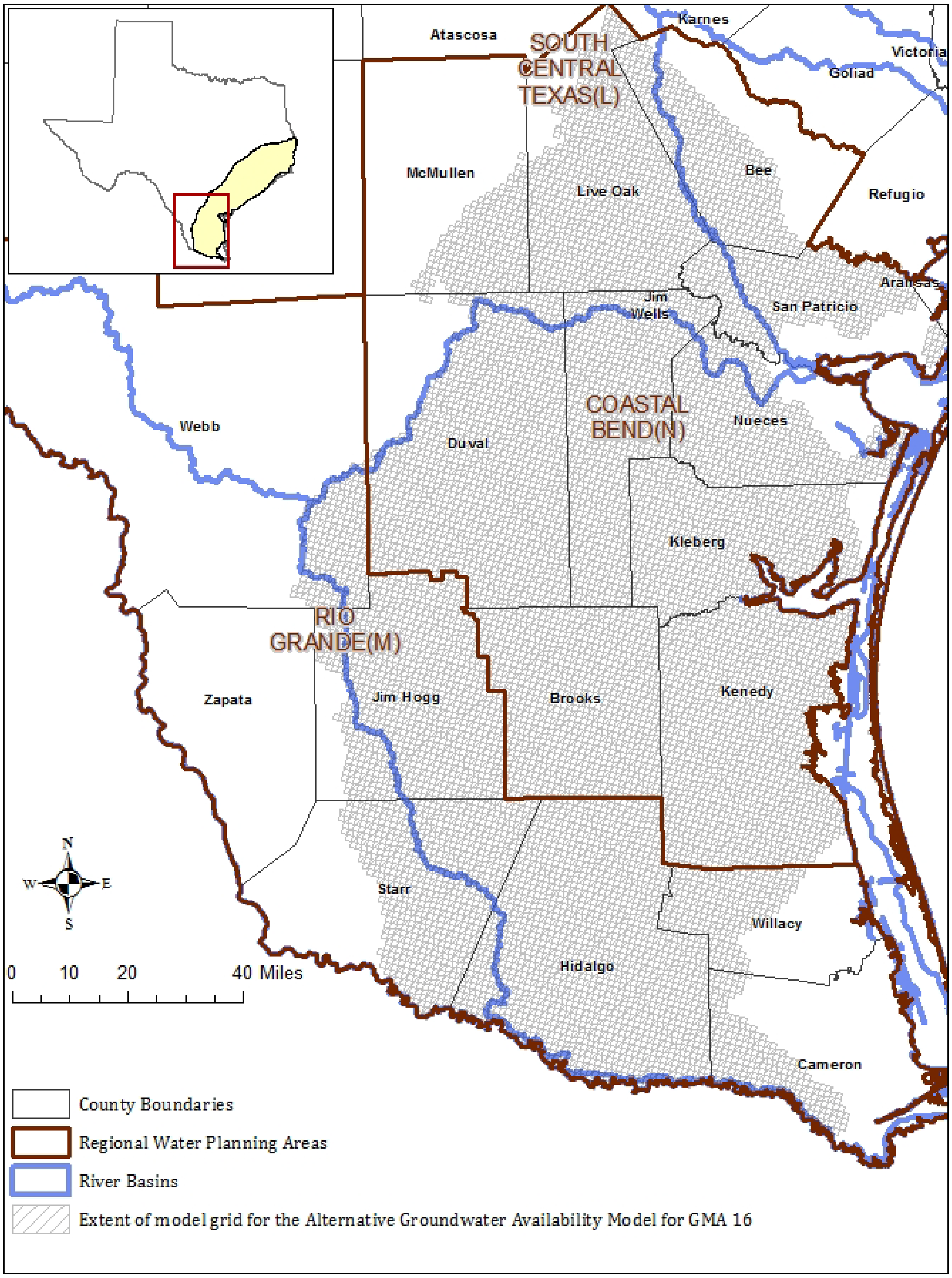

FIGURE 2. **MAP SHOWING THE EXTENT OF THE GULF COAST AQUIFER SYSTEM, REGIONAL WATER PLANNING AREAS, COUNTIES, AND RIVER BASINS IN GROUNDWATER MANAGEMENT AREA 16 OVERLAIN ON THE EXTENT OF THE ALTERNATIVE GROUNDWATER AVAILABILITY MODEL FOR GROUNDWATER MANAGEMENT AREA 16.**

TABLE 1. MODELED AVAILABLE GROUNDWATER FOR THE GULF COAST AQUIFER SYSTEM IN GROUNDWATER MANAGEMENT AREA 16 SUMMARIZED BY GROUNDWATER CONSERVATION DISTRICT (GCD) AND COUNTY FOR EACH DECADE BETWEEN 2010 AND 2060. VALUES ARE IN ACRE-FEET PER YEAR.

Groundwater Conservation District (GCD)	County	Aquifer	2010	2020	2030	2040	2050	2060
Bee GCD	**Bee**	**Gulf Coast Aquifer System**	**7,689**	**8,971**	**10,396**	**11,061**	**11,392**	**11,584**
Brush Country GCD	Brooks	Gulf Coast Aquifer System	3,657	3,657	3,657	3,657	3,657	3,657
Brush Country GCD	Hidalgo	Gulf Coast Aquifer System	131	131	131	131	131	131
Brush Country GCD	Jim Hogg	Gulf Coast Aquifer System	6,174	6,174	6,174	6,174	6,174	6,174
Brush Country GCD	Jim Wells	Gulf Coast Aquifer System	4,220	8,710	9,075	9,403	9,768	10,060
Brush Country GCD		**Gulf Coast Aquifer System**	**14,182**	**18,672**	**19,037**	**19,365**	**19,730**	**20,022**
Corpus Christi ASRCD	**Nueces**	**Gulf Coast Aquifer System**	**328**	**342**	**356**	**370**	**384**	**398**
Duval County GCD	**Duval**	**Gulf Coast Aquifer System**	**18,973**	**20,571**	**22,169**	**23,764**	**25,363**	**26,963**
Kenedy County GCD	Brooks	Gulf Coast Aquifer System	1,155	1,925	2,695	3,465	4,235	4,235
Kenedy County GCD	Willacy	Gulf Coast Aquifer System	289	482	674	867	1,060	1,060
Kenedy County GCD	Hidalgo	Gulf Coast Aquifer System	364	607	849	1,092	1,335	1,335
Kenedy County GCD	Jim Wells	Gulf Coast Aquifer System	261	434	608	783	957	957
Kenedy County GCD	Nueces	Gulf Coast Aquifer System	151	251	351	452	552	552
Kenedy County GCD	Kenedy	Gulf Coast Aquifer System	7,981	13,301	18,621	23,941	29,261	29,261
Kenedy County GCD	Kleberg	Gulf Coast Aquifer System	3,788	6,314	8,839	11,364	13,889	13,889
Kenedy County GCD		**Gulf Coast Aquifer System**	**13,989**	**23,314**	**32,637**	**41,964**	**51,289**	**51,289**
Live Oak UWCD	**Live Oak**	**Gulf Coast Aquifer System**	**6,556**	**8,338**	**9,343**	**8,564**	**8,441**	**8,441**
McMullen GCD	**McMullen**	**Gulf Coast Aquifer System**	**510**	**510**	**510**	**510**	**510**	**510**
Red Sands GCD	**Hidalgo**	**Gulf Coast Aquifer System**	**1,368**	**1,667**	**1,966**	**2,265**	**2,563**	**2,863**
San Patricio County GCD	**San Patricio**	**Gulf Coast Aquifer System**	**14,201**	**43,611**	**45,016**	**46,422**	**47,828**	**49,234**
Starr County GCD	**Starr**	**Gulf Coast Aquifer System**	**2,742**	**3,722**	**4,701**	**5,681**	**6,659**	**7,639**
No District-Bee	Bee	Gulf Coast Aquifer System	0	0	0	0	0	0
No District-Cameron	Cameron	Gulf Coast Aquifer System	5,378	6,688	7,999	9,311	10,620	11,932
No District-Hidalgo	Hidalgo	Gulf Coast Aquifer System	15,908	85,634	90,905	96,175	101,445	106,715

Groundwater Conservation District (GCD)	County	Aquifer	2010	2020	2030	2040	2050	2060
No District-Jim Wells	Jim Wells	Gulf Coast Aquifer System	0	0	0	0	0	0
No District-Kleberg	Kleberg	Gulf Coast Aquifer System	3,857	4,051	4,243	4,436	4,629	4,822
No District-Nueces	Nueces	Gulf Coast Aquifer System	5,753	5,996	6,240	6,487	6,731	6,974
No District-Webb	Webb	Gulf Coast Aquifer System	450	620	789	959	1,129	1,299
No District-Willacy	Willacy	Gulf Coast Aquifer System	544	664	785	905	1,024	1,145
No District-Total		**Gulf Coast Aquifer System**	**31,890**	**103,653**	**110,961**	**118,273**	**125,578**	**132,887**
GMA 16 Total		**Gulf Coast Aquifer System**	**112,428**	**233,371**	**257,092**	**278,239**	**299,737**	**311,830**

TABLE 2. MODELED AVAILABLE GROUNDWATER BY DECADE FOR THE GULF COAST AQUIFER SYSTEM IN GROUNDWATER MANAGEMENT AREA 16. RESULTS ARE IN ACRE-FEET PER YEAR AND ARE SUMMARIZED BY COUNTY, REGIONAL WATER PLANNING AREA (RWPA), RIVER BASIN, AND AQUIFER.

County	RWPA	River Basin	Aquifer	2020	2030	2040	2050	2060
Bee	N	Nueces	Gulf Coast Aquifer System	770	893	949	978	995
Bee	N	San Antonio-Nueces	Gulf Coast Aquifer System	8,201	9,503	10,112	10,414	10,589
Brooks	N	Nueces-Rio Grande	Gulf Coast Aquifer System	5,582	6,352	7,122	7,892	7,892
Cameron	M	Nueces-Rio Grande	Gulf Coast Aquifer System	6,301	7,536	8,771	10,005	11,241
Cameron	M	Rio Grande	Gulf Coast Aquifer System	387	463	540	615	691
Duval	N	Nueces	Gulf Coast Aquifer System	326	351	376	401	428
Duval	N	Nueces-Rio Grande	Gulf Coast Aquifer System	20,245	21,818	23,388	24,962	26,535
Hidalgo	M	Nueces-Rio Grande	Gulf Coast Aquifer System	86,405	91,810	97,216	102,620	107,784
Hidalgo	M	Rio Grande	Gulf Coast Aquifer System	1,634	2,041	2,447	2,854	3,260
Jim Hogg	M	Nueces-Rio Grande	Gulf Coast Aquifer System	5,236	5,236	5,236	5,236	5,236
Jim Hogg	M	Rio Grande	Gulf Coast Aquifer System	938	938	938	938	938
Jim Wells	N	Nueces	Gulf Coast Aquifer System	593	593	593	593	593
Jim Wells	N	Nueces-Rio Grande	Gulf Coast Aquifer System	8,551	9,090	9,593	10,132	10,424
Kenedy	N	Nueces-Rio Grande	Gulf Coast Aquifer System	13,301	18,621	23,941	29,261	29,261
Kleberg	N	Nueces-Rio Grande	Gulf Coast Aquifer System	10,365	13,082	15,800	18,518	18,711
Live Oak	N	Nueces	Gulf Coast Aquifer System	8,297	9,297	8,522	8,400	8,400
Live Oak	N	San Antonio-Nueces	Gulf Coast Aquifer System	41	46	42	41	41
McMullen	N	Nueces	Gulf Coast Aquifer System	510	510	510	510	510
Nueces	N	Nueces-Rio Grande	Gulf Coast Aquifer System	5,862	6,191	6,522	6,851	7,079
Nueces	N	Nueces	Gulf Coast Aquifer System	727	756	787	816	845
Nueces	N	San Antonio-Nueces	Gulf Coast Aquifer System	0	0	0	0	0
San Patricio	N	Nueces	Gulf Coast Aquifer System	4,130	4,502	4,874	5,247	5,619
San Patricio	N	San Antonio-Nueces	Gulf Coast Aquifer System	39,481	40,514	41,548	42,581	43,615
Starr	M	Nueces-Rio Grande	Gulf Coast Aquifer System	1,497	1,891	2,285	2,678	3,072

County	RWPA	River Basin	Aquifer	2020	2030	2040	2050	2060
Starr	M	Rio Grande	Gulf Coast Aquifer System	2,225	2,810	3,396	3,981	4,567
Webb	M	Rio Grande	Gulf Coast Aquifer System	98	125	152	179	206
Webb	M	Nueces	Gulf Coast Aquifer System	18	22	27	32	37
Webb	M	Nueces-Rio Grande	Gulf Coast Aquifer System	504	642	780	918	1,056
Willacy	M	Nueces-Rio Grande	Gulf Coast Aquifer System	1,146	1,459	1,772	2,084	2,205
GMA 16-Total			**Gulf Coast Aquifer System**	**233,371**	**257,092**	**278,239**	**299,737**	**311,830**

TABLE 3. COMPARISON OF MEASURED AND MODELED WATER-LEVELS AVERAGED OVER GROUNDWATER MANAGEMENT AREA 16 FROM THE DECADAL YEARS 2000 AND 2010. VALUES OF FIELD MEASURED WATER-LEVELS WERE OBTAINED FROM THE TWDB GROUNDWATER DATABASE (GWDB).

Average water levels in Groundwater Management Area 16 (in feet above mean sea level)		
	Year 2000	**Year 2010**
Field measurements (GWDB)	114.1	114.4
Model estimated	119.5	107.1

LIMITATIONS:

The groundwater model used in completing this analysis is the best available scientific tool that can be used to meet the stated objectives. To the extent that this analysis will be used for planning purposes and/or regulatory purposes related to pumping in the past and into the future, it is important to recognize the assumptions and limitations associated with the use of the results. In reviewing the use of models in environmental regulatory decision making, the National Research Council (2007) noted:

> "Models will always be constrained by computational limitations, assumptions, and knowledge gaps. They can best be viewed as tools to help inform decisions rather than as machines to generate truth or make decisions. Scientific advances will never make it possible to build a perfect model that accounts for every aspect of reality or to prove that a given model is correct in all respects for a particular regulatory application. These characteristics make evaluation of a regulatory model more complex than solely a comparison of measurement data with model results."

A key aspect of using the groundwater model to evaluate historic groundwater flow conditions includes the assumptions about the location in the aquifer where historic pumping was placed. Understanding the amount and location of historic pumping is as important as evaluating the volume of groundwater flow into and out of the district, between aquifers within the district (as applicable), interactions with surface water (as applicable), recharge to the aquifer system (as applicable), and other metrics that describe the impacts of that pumping. In addition, assumptions regarding precipitation, recharge, and streamflow are specific to a particular historic time period.

Because the application of the groundwater model was designed to address regional scale questions, the results are most effective on a regional scale. The TWDB makes no warranties or representations relating to the actual conditions of any aquifer at a particular location or at a particular time.

It is important for groundwater conservation districts to monitor groundwater pumping and groundwater levels in the aquifer. Because of the limitations of the groundwater model and the assumptions in this analysis, it is important that the groundwater conservation districts work with the TWDB to refine this analysis in the future given the reality of how the aquifer responds to the actual amount and location of pumping now and in the future. Historic precipitation patterns also need to be placed in context as future climatic conditions, such as dry and wet year precipitation patterns, may differ and affect groundwater flow conditions.

REFERENCES:

Hutchison, W.R., Hill, M.E., Anaya, R., Hassan, M.M., Oliver, W., Jigmond, M., Wade, S., and Aschenbach, E. 2011. Groundwater Management Are 16 Groundwater Flow Model, Texas Water Development Board, unpublished report.

Harbaugh, A. W., 2009, Zonebudget Version 3.01, A computer program for computing subregional water budgets for MODFLOW ground-water flow models, U.S. Geological Survey Groundwater Software.

Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G., 2000, MODFLOW-2000, The U.S. Geological Survey modular ground-water model- user guide to modularization concepts and the groundwater flow process: U.S. Geological Survey, Open-File Report 00-92.

National Research Council, 2007, Models in Environmental Regulatory Decision Making Committee on Models in the Regulatory Decision Process, National Academies Press, Washington D.C., 287 p., http://www.nap.edu/catalog.php?record_id=11972.

Texas Water Code, 2011, http://www.statutes.legis.state.tx.us/docs/WA/pdf/WA.36.pdf.

G

Appendix G – GAM Run Report 18-012: Corpus Christi Aquifer Storage and Recovery Conservation District Management Plan (June 27, 2018)

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GAM Run 18-012: Corpus Christi Aquifer Storage and Recovery Conservation District Groundwater Management Plan

Shirley C. Wade, Ph.D., P.G.
Texas Water Development Board
Groundwater Division
Groundwater Availability Modeling Department
512-936-0883
June 27, 2018

Shirley C. Wade
6/27/2018

GAM RUN 18-012: CORPUS CHRISTI AQUIFER STORAGE AND RECOVERY CONSERVATION DISTRICT GROUNDWATER MANAGEMENT PLAN

Shirley C. Wade, Ph.D., P.G.
Texas Water Development Board
Groundwater Division
Groundwater Availability Modeling Department
512-936-0883
June 27, 2018

EXECUTIVE SUMMARY:

Texas State Water Code, Section 36.1071, Subsection (h) (Texas Water Code, 2015), states that, in developing its groundwater management plan, a groundwater conservation district shall use groundwater availability modeling information provided by the Executive Administrator of the Texas Water Development Board (TWDB) in conjunction with any available site-specific information provided by the district for review and comment to the Executive Administrator.

The TWDB provides data and information to the Corpus Christi Aquifer Storage and Recovery Conservation District in two parts. Part 1 is the Estimated Historical Water Use/State Water Plan dataset report, which will be provided to you separately by the TWDB Groundwater Technical Assistance Department. Please direct questions about the water data report to Mr. Stephen Allen at 512-463-7317 or stephen.allen@twdb.texas.gov. Part 2 is the required groundwater availability modeling information and this information includes:

1. the annual amount of recharge from precipitation, if any, to the groundwater resources within the district;
2. for each aquifer within the district, the annual volume of water that discharges from the aquifer to springs and any surface-water bodies, including lakes, streams, and rivers; and
3. the annual volume of flow into and out of the district within each aquifer and between aquifers in the district.

The groundwater management plan for the Corpus Christi Aquifer Storage and Recovery Conservation District should be adopted by the district on or before January 12, 2019

and submitted to the Executive Administrator of the TWDB on or before February 11, 2019. The current management plan for the Corpus Christi Aquifer Storage and Recovery Conservation District expires on April 12, 2019.

This report discusses the methods, assumptions, and results from a model run using version 1.01 of the groundwater availability model for the central portion of the Gulf Coast Aquifer System (Chowdhury and others, 2004). This report replaces the results of GAM Run 12-016 (Wade, 2012) because the approach used for analyzing model results has since been refined and GAM Run 12-016 was completed using the alternative model for Groundwater Management Area 16. Table 1 summarizes the groundwater availability model data required by statute and Figure 1 shows the area of the model from which the values in the table were extracted. If, after review of the figure, the Corpus Christi Aquifer Storage and Recovery Conservation District determines that the district boundaries used in the assessment do not reflect current conditions, please notify the TWDB at your earliest convenience.

METHODS:

In accordance with the provisions of the Texas State Water Code, Section 36.1071, Subsection (h), the groundwater availability model for the central portion of the Gulf Coast Aquifer System was used to estimate information for the Corpus Christi Aquifer Storage and Recovery Conservation District groundwater management plan. Water budgets were extracted for the historical model period (1981 through 1999) using ZONEBUDGET Version 3.01 (Harbaugh, 2009). The average annual water budget values for recharge, surface-water outflow, inflow to the district, outflow from the district, and inter-aquifer flow for the aquifers within the district are summarized in this report.

PARAMETERS AND ASSUMPTIONS:

Gulf Coast Aquifer System

- We used version 1.01 of the groundwater availability model for the central part of the Gulf Coast Aquifer System for this analysis. See Chowdhury and others (2004) and Waterstone and others (2003) for assumptions and limitations of the groundwater availability model.

- The model has four layers which represent the Chicot Aquifer (Layer 1), the Evangeline Aquifer (Layer 2), the Burkeville Confining Unit (Layer 3), and the Jasper Aquifer and parts of the Catahoula Formation in direct hydrologic communication with the Jasper Aquifer (Layer 4). Only the Layer 1 is active within Corpus Christi Aquifer Storage and Recovery Conservation District.

- The model was run with MODFLOW-96 (Harbaugh and McDonald, 1996).
- This model assumes a no-flow boundary condition at the base of the model.

RESULTS:

A groundwater budget summarizes the amount of water entering and leaving the aquifers according to the groundwater availability model. Selected groundwater budget components listed below were extracted from the groundwater availability model results for the Gulf Coast Aquifer System located within Corpus Christi Aquifer Storage and Recovery Conservation District and averaged over the historical calibration period, as shown in Table 1.

1. Precipitation recharge—the areally distributed recharge sourced from precipitation falling on the outcrop areas of the aquifers (where the aquifer is exposed at land surface) within the district.
2. Surface-water outflow—the total water discharging from the aquifer (outflow) to surface-water features such as streams, reservoirs, and springs.
3. Flow into and out of district—the lateral flow within the aquifer between the district and adjacent counties.
4. Flow between aquifers—the net vertical flow between the aquifer and adjacent aquifers or confining units. This flow is controlled by the relative water levels in each aquifer and aquifer properties of each aquifer or confining unit that define the amount of leakage that occurs.

The information needed for the district's management plan is summarized in Table 1. It is important to note that sub-regional water budgets are not exact. This is due to the size of the model cells and the approach used to extract data from the model. To avoid double accounting, a model cell that straddles a political boundary, such as a district or county boundary, is assigned to one side of the boundary based on the location of the centroid of the model cell. For example, if a cell contains two counties, the cell is assigned to the county where the centroid of the cell is located.

TABLE 1. SUMMARIZED INFORMATION FOR THE GULF COAST AQUIFER SYSTEM FOR THE CORPUS CHRISTI AQUIFER STORAGE AND RECOVERY CONSERVATION DISTRICT'S GROUNDWATER MANAGEMENT PLAN. ALL VALUES ARE REPORTED IN ACRE-FEET PER YEAR AND ROUNDED TO THE NEAREST 1 ACRE-FOOT.

Management Plan requirement	Aquifer or confining unit	Results
Estimated annual amount of recharge from precipitation to the district	Gulf Coast Aquifer System	7
Estimated annual volume of water that discharges from the aquifer to springs and any surface-water body including lakes, streams, and rivers	Gulf Coast Aquifer System	417[1]
Estimated annual volume of flow into the district within each aquifer in the district	Gulf Coast Aquifer System	202
Estimated annual volume of flow out of the district within each aquifer in the district	Gulf Coast Aquifer System	89
Estimated net annual volume of flow between each aquifer in the district	Flow from brackish units into the Gulf Coast Aquifer System	396

[1] An additional net flow of 65 acre-feet per year also discharges from the aquifer system to bays.

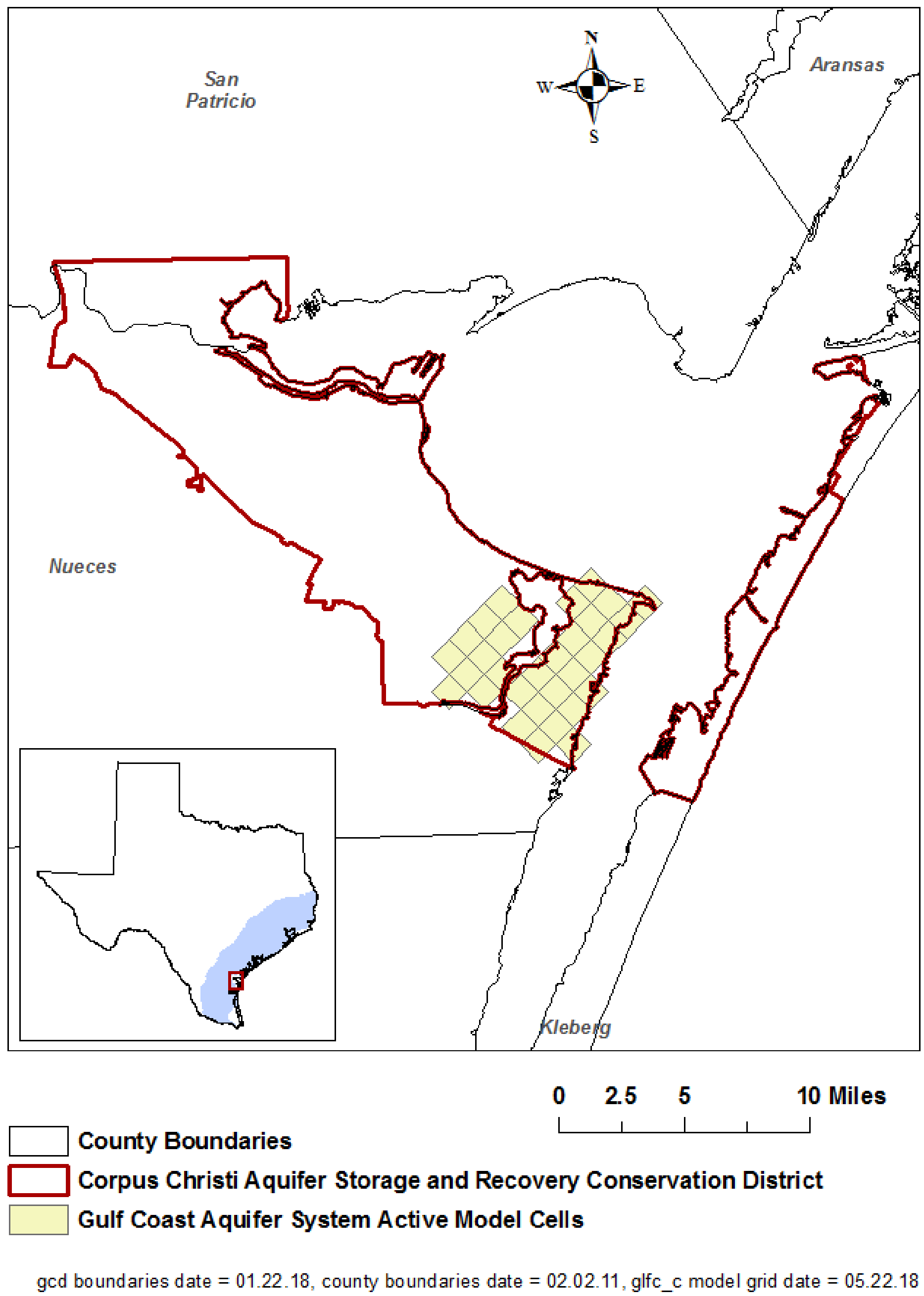

FIGURE 1. AREA OF THE GROUNDWATER AVAILABILITY MODEL FOR THE CENTRAL PART OF THE GULF COAST AQUIFER SYSTEM FROM WHICH THE INFORMATION IN TABLE 1 WAS EXTRACTED (THE AQUIFER SYSTEM EXTENT WITHIN THE DISTRICT BOUNDARY).

LIMITATIONS:

The groundwater models used in completing this analysis are the best available scientific tools that can be used to meet the stated objectives. To the extent that this analysis will be used for planning purposes and/or regulatory purposes related to pumping in the past and into the future, it is important to recognize the assumptions and limitations associated with the use of the results. In reviewing the use of models in environmental regulatory decision making, the National Research Council (2007) noted:

> *"Models will always be constrained by computational limitations, assumptions, and knowledge gaps. They can best be viewed as tools to help inform decisions rather than as machines to generate truth or make decisions. Scientific advances will never make it possible to build a perfect model that accounts for every aspect of reality or to prove that a given model is correct in all respects for a particular regulatory application. These characteristics make evaluation of a regulatory model more complex than solely a comparison of measurement data with model results."*

A key aspect of using the groundwater model to evaluate historical groundwater flow conditions includes the assumptions about the location in the aquifer where historical pumping was placed. Understanding the amount and location of historical pumping is as important as evaluating the volume of groundwater flow into and out of the district, between aquifers within the district (as applicable), interactions with surface water (as applicable), recharge to the aquifer system (as applicable), and other metrics that describe the impacts of that pumping. In addition, assumptions regarding precipitation, recharge, and interaction with streams are specific to particular historical time periods.

Because the application of the groundwater models was designed to address regional-scale questions, the results are most effective on a regional scale. The TWDB makes no warranties or representations related to the actual conditions of any aquifer at a particular location or at a particular time.

It is important for groundwater conservation districts to monitor groundwater pumping and overall conditions of the aquifer. Because of the limitations of the groundwater model and the assumptions in this analysis, it is important that the groundwater conservation districts work with the TWDB to refine this analysis in the future given the reality of how the aquifer responds to the actual amount and location of pumping now and in the future. Historical precipitation patterns also need to be placed in context as future climatic conditions, such as dry and wet year precipitation patterns, may differ and affect groundwater flow conditions.

REFERENCES:

Chowdhury, A.H., Wade, S., Mace, R.E., and Ridgeway, C., 2004, Groundwater Availability Model of the Central Gulf Coast Aquifer System: Numerical Simulations through 1999- Model Report, 114 p., http://www.twdb.texas.gov/groundwater/models/gam/glfc_c/TWDB_Recalibration_Report.pdf.

Harbaugh, A. W., 2009, Zonebudget Version 3.01, A computer program for computing subregional water budgets for MODFLOW ground-water flow models: U.S. Geological Survey Groundwater Software.

Harbaugh, A. W., and McDonald, M. G., 1996, User's documentation for MODFLOW-96, an update to the U.S. Geological Survey modular finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 96–485, 56 p.

National Research Council, 2007, Models in Environmental Regulatory Decision Making Committee on Models in the Regulatory Decision Process, National Academies Press, Washington D.C., 287 p., http://www.nap.edu/catalog.php?record_id=11972.

Texas Water Code, 2015, http://www.statutes.legis.state.tx.us/docs/WA/pdf/WA.36.pdf.

Wade, S., 2012, GAM Run 12-016: Corpus Christi Aquifer Storage and Recovery Conservation District Management Plan, 11 p., http://www.twdb.texas.gov/groundwater/docs/GAMruns/GR12-012.pdf

Waterstone Environmental Hydrology and Engineering Inc. and Parsons, 2003, Groundwater availability of the Central Gulf Coast Aquifer: Numerical Simulations to 2050, Central Gulf Coast, Texas Contract report to the Texas Water Development Board, 157 p.

H

Appendix H – Estimate Historical Groundwater Use and 2017 State Water Plan Datasets: Corpus Christi Aquifer Storage and Recovery Conservation District (December 11, 2018)

Estimated Historical Groundwater Use And 2017 State Water Plan Datasets:

Corpus Christi Aquifer Storage and Recovery Conservation District

by Stephen Allen
Texas Water Development Board
Groundwater Division
Groundwater Technical Assistance Section
stephen.allen@twdb.texas.gov
(512) 463-7317
December 11, 2018

GROUNDWATER MANAGEMENT PLAN DATA:

This package of water data reports (part 1 of a 2-part package of information) is being provided to groundwater conservation districts to help them meet the requirements for approval of their five-year groundwater management plan. Each report in the package addresses a specific numbered requirement in the Texas Water Development Board's groundwater management plan checklist. The checklist can be viewed and downloaded from this web address:

http://www.twdb.texas.gov/groundwater/docs/GCD/GMPChecklist0113.pdf

The five reports included in this part are:

1. Estimated Historical Groundwater Use (checklist item 2)

   from the TWDB Historical Water Use Survey (WUS)

2. Projected Surface Water Supplies (checklist item 6)
3. Projected Water Demands (checklist item 7)
4. Projected Water Supply Needs (checklist item 8)
5. Projected Water Management Strategies (checklist item 9)

   from the 2017 Texas State Water Plan (SWP)

Part 2 of the 2-part package is the groundwater availability model (GAM) report for the District (checklist items 3 through 5). The District should have received, or will receive, this report from the Groundwater Availability Modeling Section. Questions about the GAM can be directed to Dr. Shirley Wade, shirley.wade@twdb.texas.gov, (512) 936-0883.

DISCLAIMER:

The data presented in this report represents the most up-to-date WUS and 2017 SWP data available as of 12/11/2018. Although it does not happen frequently, either of these datasets are subject to change pending the availability of more accurate WUS data or an amendment to the 2017 SWP. District personnel must review these datasets and correct any discrepancies in order to ensure approval of their groundwater management plan.

The WUS dataset can be verified at this web address:

http://www.twdb.texas.gov/waterplanning/waterusesurvey/estimates/

The 2017 SWP dataset can be verified by contacting Sabrina Anderson (sabrina.anderson@twdb.texas.gov or 512-936-0886).

The values presented in the data tables of this report are county-based. In cases where groundwater conservation districts cover only a portion of one or more counties the data values are modified with an apportioning multiplier to create new values that more accurately represent conditions within district boundaries. The multiplier used in the following formula is a land area ratio: (data value * (land area of district in county / land area of county)). For two of the four SWP tables (Projected Surface Water Supplies and Projected Water Demands) only the county-wide water user group (WUG) data values (county other, manufacturing, steam electric power, irrigation, mining and livestock) are modified using the multiplier. WUG values for municipalities, water supply corporations, and utility districts are not apportioned; instead, their full values are retained when they are located within the district, and eliminated when they are located outside (we ask each district to identify these entity locations).

The remaining SWP tables (Projected Water Supply Needs and Projected Water Management Strategies) are not modified because district-specific values are not statutorily required. Each district needs only "consider" the county values in these tables.

In the WUS table every category of water use (including municipal) is apportioned. Staff determined that breaking down the annual municipal values into individual WUGs was too complex.

TWDB recognizes that the apportioning formula used is not perfect but it is the best available process with respect to time and staffing constraints. If a district believes it has data that is more accurate it can add those data to the plan with an explanation of how the data were derived. Apportioning percentages that the TWDB used are listed above each applicable table.

For additional questions regarding this data, please contact Stephen Allen (stephen.allen@twdb.texas.gov or 512-463-7317).

Estimated Historical Water Use
TWDB Historical Water Use Survey (WUS) Data

Groundwater and surface water historical use estimates are currently unavailable for calendar year 2017. TWDB staff anticipates the calculation and posting of these estimates at a later date.

NUECES COUNTY *19.76% (multiplier)* All values are in acre-feet

Year	Source	Municipal	Manufacturing	Mining	Steam Electric	Irrigation	Livestock	Total
2016	GW	299	533	159	0	97	47	1,135
	SW	12,002	5,946	0	379	0	2	18,329
2015	GW	309	465	141	0	56	47	1,018
	SW	10,955	6,217	0	407	13	2	17,594
2014	GW	326	481	137	0	71	48	1,063
	SW	10,198	6,303	1	79	0	2	16,583
2013	GW	378	537	155	0	145	57	1,272
	SW	10,098	6,666	0	80	0	2	16,846
2012	GW	339	487	717	0	3	48	1,594
	SW	11,293	7,170	0	68	301	2	18,834
2011	GW	413	526	677	0	126	62	1,804
	SW	12,873	6,494	67	78	2	2	19,516
2010	GW	306	640	162	0	294	62	1,464
	SW	10,051	6,139	80	77	2	2	16,351
2009	GW	214	456	159	0	49	78	956
	SW	14,406	6,499	125	39	0	3	21,072
2008	GW	156	444	162	0	61	71	894
	SW	11,757	6,707	119	25	0	3	18,611
2007	GW	134	316	67	0	139	37	693
	SW	9,274	6,746	49	327	2	1	16,399
2006	GW	167	327	101	0	173	57	825
	SW	11,279	7,623	52	0	0	2	18,956
2005	GW	159	492	101	0	59	57	868
	SW	13,092	6,932	48	26	20	2	20,120
2004	GW	152	537	75	0	24	17	805
	SW	10,207	7,052	105	25	15	37	17,441
2003	GW	156	478	75	0	21	18	748
	SW	11,391	6,053	104	31	52	39	17,670
2002	GW	140	240	0	0	3	17	400
	SW	12,330	7,066	250	148	288	37	20,119
2001	GW	116	210	0	0	3	18	347
	SW	11,707	7,418	254	563	337	39	20,318

SAN PATRICIO COUNTY

2.88% (multiplier)

All values are in acre-feet

Year	Source	Municipal	Manufacturing	Mining	Steam Electric	Irrigation	Livestock	Total
2016	GW	46	0	0	0	159	4	209
	SW	198	270	0	0	6	4	478
2015	GW	54	0	0	0	180	4	238
	SW	303	263	0	0	3	4	573
2014	GW	53	1	0	0	220	6	280
	SW	220	308	0	0	4	6	538
2013	GW	60	0	0	0	180	4	244
	SW	250	296	0	0	7	4	557
2012	GW	64	0	0	0	330	6	400
	SW	215	342	0	0	7	6	570
2011	GW	71	0	4	0	416	6	497
	SW	222	342	4	0	6	6	580
2010	GW	78	0	4	0	207	6	295
	SW	201	339	5	0	0	6	551
2009	GW	76	0	4	0	296	4	380
	SW	212	224	5	0	0	4	445
2008	GW	71	0	3	0	401	7	482
	SW	339	138	4	0	0	7	488
2007	GW	65	0	0	0	168	4	237
	SW	182	227	0	0	16	4	429
2006	GW	71	0	0	0	287	8	366
	SW	211	230	0	0	0	8	449
2005	GW	69	0	0	0	271	6	346
	SW	297	220	0	0	6	6	529
2004	GW	61	0	0	0	258	1	320
	SW	218	220	0	0	6	12	456
2003	GW	62	0	0	0	227	0	289
	SW	205	220	0	0	4	9	438
2002	GW	68	0	0	0	129	1	198
	SW	222	233	0	0	0	12	467
2001	GW	69	0	0	0	127	1	197
	SW	351	166	0	0	0	13	530

Projected Surface Water Supplies
TWDB 2017 State Water Plan Data

NUECES COUNTY *19.76% (multiplier)* All values are in acre-feet

RWPG	WUG	WUG Basin	Source Name	2020	2030	2040	2050	2060	2070
N	AGUA DULCE	NUECES-RIO GRANDE	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	66	69	71	72	74	75
N	AGUA DULCE	NUECES-RIO GRANDE	TEXANA LAKE/RESERVOIR	66	70	72	73	74	75
N	ARANSAS PASS	SAN ANTONIO-NUECES	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	1	1	1	1	1	1
N	ARANSAS PASS	SAN ANTONIO-NUECES	TEXANA LAKE/RESERVOIR	2	2	2	2	2	2
N	BISHOP	NUECES-RIO GRANDE	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	176	193	202	209	215	220
N	BISHOP	NUECES-RIO GRANDE	TEXANA LAKE/RESERVOIR	176	193	202	209	216	220
N	CORPUS CHRISTI	NUECES	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	5,174	5,502	5,546	5,547	5,546	5,529
N	CORPUS CHRISTI	NUECES	TEXANA LAKE/RESERVOIR	12	13	156	268	380	476
N	CORPUS CHRISTI	NUECES-RIO GRANDE	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	59,487	63,263	63,775	63,778	63,766	63,576
N	CORPUS CHRISTI	NUECES-RIO GRANDE	TEXANA LAKE/RESERVOIR	143	153	1,793	3,087	4,372	5,477
N	COUNTY-OTHER, NUECES	NUECES	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	16	17	17	17	17	17
N	COUNTY-OTHER, NUECES	NUECES	NUECES RUN-OF-RIVER	6	6	5	5	5	5
N	COUNTY-OTHER, NUECES	NUECES	TEXANA LAKE/RESERVOIR	14	14	15	15	15	15
N	COUNTY-OTHER, NUECES	NUECES-RIO GRANDE	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	16	18	19	20	20	20
N	COUNTY-OTHER, NUECES	NUECES-RIO GRANDE	NUECES RUN-OF-RIVER	25	25	25	25	25	25
N	COUNTY-OTHER, NUECES	NUECES-RIO GRANDE	TEXANA LAKE/RESERVOIR	17	19	20	21	22	22
N	DRISCOLL	NUECES-RIO GRANDE	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	52	55	56	57	58	59

N	DRISCOLL	NUECES-RIO GRANDE	TEXANA LAKE/RESERVOIR	53	55	57	57	58	59
N	IRRIGATION, NUECES	NUECES-RIO GRANDE	NUECES-RIO GRANDE RUN-OF-RIVER	0	0	0	0	0	0
N	IRRIGATION, NUECES	SAN ANTONIO-NUECES	NUECES-RIO GRANDE RUN-OF-RIVER	0	0	0	0	0	0
N	LIVESTOCK, NUECES	NUECES	NUECES LIVESTOCK LOCAL SUPPLY	7	7	7	7	7	7
N	LIVESTOCK, NUECES	NUECES-RIO GRANDE	NUECES-RIO GRANDE LIVESTOCK LOCAL SUPPLY	0	0	0	0	0	0
N	MANUFACTURING, NUECES	NUECES	COLORADO RUN-OF-RIVER	240	244	247	258	254	258
N	MANUFACTURING, NUECES	NUECES	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	37	79	141	174	148	120
N	MANUFACTURING, NUECES	NUECES	TEXANA LAKE/RESERVOIR	239	231	202	175	147	122
N	MANUFACTURING, NUECES	NUECES-RIO GRANDE	COLORADO RUN-OF-RIVER	3,761	3,817	3,873	4,040	3,984	4,040
N	MANUFACTURING, NUECES	NUECES-RIO GRANDE	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	718	1,373	2,347	2,732	2,312	1,885
N	MANUFACTURING, NUECES	NUECES-RIO GRANDE	TEXANA LAKE/RESERVOIR	3,751	3,626	3,167	2,745	2,309	1,905
N	MINING, NUECES	NUECES	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	43	69	88	102	124	149
N	NUECES WSC	NUECES	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	8	9	9	9	9	10
N	NUECES WSC	NUECES	TEXANA LAKE/RESERVOIR	9	9	9	10	10	10
N	NUECES WSC	NUECES-RIO GRANDE	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	158	168	175	179	182	184
N	NUECES WSC	NUECES-RIO GRANDE	TEXANA LAKE/RESERVOIR	158	169	175	178	182	184
N	PORT ARANSAS	NUECES-RIO GRANDE	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	1,125	1,216	1,274	1,307	1,333	1,351
N	PORT ARANSAS	NUECES-RIO GRANDE	TEXANA LAKE/RESERVOIR	1,126	1,218	1,274	1,307	1,334	1,352
N	RIVER ACRES WSC	NUECES	NUECES RUN-OF-RIVER	426	450	463	470	479	486
N	ROBSTOWN	NUECES	NUECES RUN-OF-RIVER	1	1	1	1	1	1
N	ROBSTOWN	NUECES-RIO GRANDE	NUECES RUN-OF-RIVER	1,373	1,349	1,336	1,329	1,320	1,313
N	STEAM ELECTRIC POWER, NUECES	NUECES	COLORADO RUN-OF-RIVER	1,023	1,038	1,053	1,099	1,084	1,099
N	STEAM ELECTRIC POWER, NUECES	NUECES	CORPUS CHRISTI-CHOKE CANYON	117	427	812	1,257	1,445	1,546

			LAKE/RESERVOIR SYSTEM						
N	STEAM ELECTRIC POWER, NUECES	NUECES	TEXANA LAKE/RESERVOIR	1,140	1,199	1,269	1,351	1,445	1,546
N	STEAM ELECTRIC POWER, NUECES	NUECES-RIO GRANDE	COLORADO RUN-OF-RIVER	311	315	320	334	329	334
N	STEAM ELECTRIC POWER, NUECES	NUECES-RIO GRANDE	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	35	130	247	382	439	469
N	STEAM ELECTRIC POWER, NUECES	NUECES-RIO GRANDE	TEXANA LAKE/RESERVOIR	346	364	386	411	439	469
	Sum of Projected Surface Water Supplies (acre-feet)			**81,654**	**87,176**	**90,909**	**93,320**	**94,182**	**94,713**

SAN PATRICIO COUNTY

2.88% (multiplier)

All values are in acre-feet

RWPG	WUG	WUG Basin	Source Name	2020	2030	2040	2050	2060	2070
N	ARANSAS PASS	SAN ANTONIO-NUECES	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	565	574	574	577	583	588
N	ARANSAS PASS	SAN ANTONIO-NUECES	TEXANA LAKE/RESERVOIR	566	574	575	578	584	588
N	COUNTY-OTHER, SAN PATRICIO	NUECES	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	3	3	4	4	5	5
N	COUNTY-OTHER, SAN PATRICIO	NUECES	TEXANA LAKE/RESERVOIR	1	2	2	3	3	3
N	GREGORY	SAN ANTONIO-NUECES	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	169	172	174	177	179	180
N	GREGORY	SAN ANTONIO-NUECES	TEXANA LAKE/RESERVOIR	170	172	174	177	179	181
N	INGLESIDE	SAN ANTONIO-NUECES	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	526	531	530	532	537	542
N	INGLESIDE	SAN ANTONIO-NUECES	TEXANA LAKE/RESERVOIR	525	531	530	532	537	541
N	INGLESIDE ON THE BAY	SAN ANTONIO-NUECES	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	38	39	39	39	39	39
N	INGLESIDE ON THE BAY	SAN ANTONIO-NUECES	TEXANA LAKE/RESERVOIR	39	39	39	39	40	40
N	IRRIGATION, SAN PATRICIO	SAN ANTONIO-NUECES	SAN ANTONIO-NUECES RUN-OF-RIVER	0	0	0	0	0	0
N	LIVESTOCK, SAN PATRICIO	NUECES	NUECES LIVESTOCK LOCAL SUPPLY	3	3	3	3	3	3
N	LIVESTOCK, SAN PATRICIO	SAN ANTONIO-NUECES	SAN ANTONIO-NUECES LIVESTOCK LOCAL SUPPLY	0	0	0	0	0	0
N	MANUFACTURING, SAN PATRICIO	NUECES	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	374	389	402	414	430	446

N	MANUFACTURING, SAN PATRICIO	NUECES	TEXANA LAKE/RESERVOIR	61	60	59	59	58	58
N	MANUFACTURING, SAN PATRICIO	SAN ANTONIO-NUECES	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	439	456	472	486	504	523
N	MANUFACTURING, SAN PATRICIO	SAN ANTONIO-NUECES	TEXANA LAKE/RESERVOIR	72	70	70	69	68	68
N	MATHIS	NUECES	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	335	338	336	339	342	345
N	MATHIS	NUECES	TEXANA LAKE/RESERVOIR	335	338	336	340	343	346
N	ODEM	SAN ANTONIO-NUECES	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	189	192	192	193	195	198
N	ODEM	SAN ANTONIO-NUECES	TEXANA LAKE/RESERVOIR	190	192	192	194	196	196
N	PORTLAND	SAN ANTONIO-NUECES	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	1,315	1,342	1,349	1,359	1,373	1,385
N	PORTLAND	SAN ANTONIO-NUECES	TEXANA LAKE/RESERVOIR	1,316	1,342	1,349	1,359	1,374	1,385
N	RINCON WSC	SAN ANTONIO-NUECES	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	173	177	179	181	183	184
N	RINCON WSC	SAN ANTONIO-NUECES	TEXANA LAKE/RESERVOIR	173	178	180	182	183	185
N	TAFT	SAN ANTONIO-NUECES	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM	232	235	235	238	240	242
N	TAFT	SAN ANTONIO-NUECES	TEXANA LAKE/RESERVOIR	232	235	234	237	240	242
	Sum of Projected Surface Water Supplies (acre-feet)			**8,041**	**8,184**	**8,229**	**8,311**	**8,418**	**8,513**

Projected Water Demands
TWDB 2017 State Water Plan Data

Please note that the demand numbers presented here include the plumbing code savings found in the Regional and State Water Plans.

NUECES COUNTY

19.76% (multiplier)

All values are in acre-feet

RWPG	WUG	WUG Basin	2020	2030	2040	2050	2060	2070
N	AGUA DULCE	NUECES-RIO GRANDE	132	139	143	145	148	150
N	ARANSAS PASS	SAN ANTONIO-NUECES	3	3	3	3	3	3
N	BISHOP	NUECES-RIO GRANDE	594	628	646	660	673	682
N	CORPUS CHRISTI	NUECES	5,186	5,515	5,702	5,815	5,926	6,005
N	CORPUS CHRISTI	NUECES-RIO GRANDE	59,630	63,416	65,568	66,865	68,138	69,053
N	COUNTY-OTHER, NUECES	NUECES	61	64	66	67	68	69
N	COUNTY-OTHER, NUECES	NUECES-RIO GRANDE	246	286	310	323	336	344
N	DRISCOLL	NUECES-RIO GRANDE	105	110	113	114	116	118
N	IRRIGATION, NUECES	NUECES	11	12	12	13	14	14
N	IRRIGATION, NUECES	NUECES-RIO GRANDE	75	79	83	87	92	96
N	IRRIGATION, NUECES	SAN ANTONIO-NUECES	0	0	0	0	0	0
N	LIVESTOCK, NUECES	NUECES	11	11	11	11	11	11
N	LIVESTOCK, NUECES	NUECES-RIO GRANDE	52	52	52	52	52	52
N	MANUFACTURING, NUECES	NUECES	596	634	670	701	751	803
N	MANUFACTURING, NUECES	NUECES-RIO GRANDE	9,338	9,923	10,495	10,987	11,760	12,588
N	MINING, NUECES	NUECES	127	150	167	180	199	222
N	MINING, NUECES	NUECES-RIO GRANDE	10	12	13	14	16	17
N	MINING, NUECES	SAN ANTONIO-NUECES	6	7	8	8	9	10
N	NUECES WSC	NUECES	17	18	18	19	19	20
N	NUECES WSC	NUECES-RIO GRANDE	316	337	350	357	364	368
N	PORT ARANSAS	NUECES-RIO GRANDE	2,251	2,434	2,548	2,614	2,667	2,703
N	RIVER ACRES WSC	NUECES	426	450	463	470	479	486
N	ROBSTOWN	NUECES	3	3	3	3	3	3
N	ROBSTOWN	NUECES-RIO GRANDE	2,954	2,894	2,845	2,840	2,836	2,836
N	STEAM ELECTRIC POWER, NUECES	NUECES	2,279	2,665	3,134	3,707	4,405	5,235
N	STEAM ELECTRIC POWER, NUECES	NUECES-RIO GRANDE	692	810	952	1,126	1,338	1,590
		Sum of Projected Water Demands (acre-feet)	**85,121**	**90,652**	**94,375**	**97,181**	**100,423**	**103,478**

SAN PATRICIO COUNTY

2.88% (multiplier)

All values are in acre-feet

RWPG	WUG	WUG Basin	2020	2030	2040	2050	2060	2070
N	ARANSAS PASS	SAN ANTONIO-NUECES	1,131	1,148	1,149	1,155	1,167	1,176

N	COUNTY-OTHER, SAN PATRICIO	NUECES	14	14	14	14	15	15
N	COUNTY-OTHER, SAN PATRICIO	SAN ANTONIO-NUECES	32	33	33	34	34	34
N	GREGORY	SAN ANTONIO-NUECES	339	344	348	354	358	361
N	INGLESIDE	SAN ANTONIO-NUECES	1,051	1,062	1,060	1,064	1,074	1,083
N	INGLESIDE ON THE BAY	SAN ANTONIO-NUECES	77	78	78	78	79	79
N	IRRIGATION, SAN PATRICIO	NUECES	32	35	39	43	48	54
N	IRRIGATION, SAN PATRICIO	SAN ANTONIO-NUECES	287	317	351	387	428	483
N	LAKE CITY	NUECES	64	65	64	64	65	66
N	LIVESTOCK, SAN PATRICIO	NUECES	6	6	6	6	6	6
N	LIVESTOCK, SAN PATRICIO	SAN ANTONIO-NUECES	6	6	6	6	6	6
N	MANUFACTURING, SAN PATRICIO	NUECES	526	571	615	654	702	755
N	MANUFACTURING, SAN PATRICIO	SAN ANTONIO-NUECES	618	670	722	767	825	886
N	MATHIS	NUECES	670	676	672	679	685	691
N	MINING, SAN PATRICIO	NUECES	2	3	3	3	3	3
N	MINING, SAN PATRICIO	SAN ANTONIO-NUECES	8	10	10	10	11	12
N	ODEM	SAN ANTONIO-NUECES	379	384	384	387	391	394
N	PORTLAND	SAN ANTONIO-NUECES	2,631	2,684	2,698	2,718	2,747	2,770
N	RINCON WSC	SAN ANTONIO-NUECES	346	355	359	363	366	369
N	SINTON	SAN ANTONIO-NUECES	1,409	1,448	1,463	1,478	1,495	1,507
N	TAFT	SAN ANTONIO-NUECES	464	470	469	475	480	484
		Sum of Projected Water Demands (acre-feet)	**10,092**	**10,379**	**10,543**	**10,739**	**10,985**	**11,234**

Projected Water Supply Needs
TWDB 2017 State Water Plan Data

Negative values (in red) reflect a projected water supply need, positive values a surplus.

NUECES COUNTY

All values are in acre-feet

RWPG	WUG	WUG Basin	2020	2030	2040	2050	2060	2070
N	AGUA DULCE	NUECES-RIO GRANDE	0	0	0	0	0	0
N	ARANSAS PASS	SAN ANTONIO-NUECES	0	0	0	0	0	0
N	BISHOP	NUECES-RIO GRANDE	0	0	0	0	0	0
N	CORPUS CHRISTI	NUECES	0	0	0	0	0	0
N	CORPUS CHRISTI	NUECES-RIO GRANDE	0	0	0	0	0	0
N	COUNTY-OTHER, NUECES	NUECES	43	26	17	11	6	0
N	COUNTY-OTHER, NUECES	NUECES-RIO GRANDE	445	266	159	97	41	3
N	DRISCOLL	NUECES-RIO GRANDE	0	0	0	0	0	0
N	IRRIGATION, NUECES	NUECES	152	149	146	143	140	137
N	IRRIGATION, NUECES	NUECES-RIO GRANDE	110	91	71	50	27	4
N	IRRIGATION, NUECES	SAN ANTONIO-NUECES	0	0	0	0	0	0
N	LIVESTOCK, NUECES	NUECES	0	0	0	0	0	0
N	LIVESTOCK, NUECES	NUECES-RIO GRANDE	0	0	0	0	0	0
N	MANUFACTURING, NUECES	NUECES	0	0	0	-73	-618	-1,135
N	MANUFACTURING, NUECES	NUECES-RIO GRANDE	0	0	0	-1,832	-10,363	-18,468
N	MINING, NUECES	NUECES	0	0	0	0	0	0
N	MINING, NUECES	NUECES-RIO GRANDE	0	0	0	0	0	0
N	MINING, NUECES	SAN ANTONIO-NUECES	0	0	0	0	0	0
N	NUECES WSC	NUECES	0	0	0	0	0	0
N	NUECES WSC	NUECES-RIO GRANDE	0	0	0	0	0	0
N	PORT ARANSAS	NUECES-RIO GRANDE	0	0	0	0	0	0
N	RIVER ACRES WSC	NUECES	0	0	0	0	0	0
N	ROBSTOWN	NUECES	-2	-2	-2	-2	-2	-2
N	ROBSTOWN	NUECES-RIO GRANDE	-1,581	-1,545	-1,509	-1,511	-1,516	-1,523
N	STEAM ELECTRIC POWER, NUECES	NUECES	0	0	0	0	-2,183	-5,286
N	STEAM ELECTRIC POWER, NUECES	NUECES-RIO GRANDE	0	0	0	0	-663	-1,607
		Sum of Projected Water Supply Needs (acre-feet)	**-1,583**	**-1,547**	**-1,511**	**-3,418**	**-15,345**	**-28,021**

SAN PATRICIO COUNTY

All values are in acre-feet

RWPG	WUG	WUG Basin	2020	2030	2040	2050	2060	2070
N	ARANSAS PASS	SAN ANTONIO-NUECES	0	0	0	0	0	0
N	COUNTY-OTHER, SAN PATRICIO	NUECES	0	0	0	0	0	0

N	COUNTY-OTHER, SAN PATRICIO	SAN ANTONIO-NUECES	0	0	0	0	0	0
N	GREGORY	SAN ANTONIO-NUECES	0	0	0	0	0	0
N	INGLESIDE	SAN ANTONIO-NUECES	0	0	0	0	0	0
N	INGLESIDE ON THE BAY	SAN ANTONIO-NUECES	0	0	0	0	0	0
N	IRRIGATION, SAN PATRICIO	NUECES	1,160	1,045	916	0	0	0
N	IRRIGATION, SAN PATRICIO	SAN ANTONIO-NUECES	2,196	1,152	0	-499	-2,063	-4,191
N	LAKE CITY	NUECES	6	5	6	6	5	4
N	LIVESTOCK, SAN PATRICIO	NUECES	0	0	0	0	0	0
N	LIVESTOCK, SAN PATRICIO	SAN ANTONIO-NUECES	0	0	0	0	0	0
N	MANUFACTURING, SAN PATRICIO	NUECES	-3,177	-4,259	-5,327	-6,269	-7,456	-8,733
N	MANUFACTURING, SAN PATRICIO	SAN ANTONIO-NUECES	-3,274	-4,545	-5,799	-6,903	-8,298	-9,796
N	MATHIS	NUECES	0	0	0	0	0	0
N	MINING, SAN PATRICIO	NUECES	37	27	23	18	12	3
N	MINING, SAN PATRICIO	SAN ANTONIO-NUECES	156	117	102	87	61	29
N	ODEM	SAN ANTONIO-NUECES	0	0	0	0	0	0
N	PORTLAND	SAN ANTONIO-NUECES	0	0	0	0	0	0
N	RINCON WSC	SAN ANTONIO-NUECES	0	0	0	0	0	0
N	SINTON	SAN ANTONIO-NUECES	560	521	506	491	474	462
N	TAFT	SAN ANTONIO-NUECES	0	0	0	0	0	0
		Sum of Projected Water Supply Needs (acre-feet)	**-6,451**	**-8,804**	**-11,126**	**-13,671**	**-17,817**	**-22,720**

Projected Water Management Strategies
TWDB 2017 State Water Plan Data

NUECES COUNTY

WUG, Basin (RWPG)

All values are in acre-feet

Water Management Strategy	Source Name [Origin]	2020	2030	2040	2050	2060	2070
BISHOP, NUECES-RIO GRANDE (N)							
MUNICIPAL WATER CONSERVATION (SUBURBAN)	DEMAND REDUCTION [NUECES]	16	39	27	23	23	23
		16	**39**	**27**	**23**	**23**	**23**
CORPUS CHRISTI, NUECES (N)							
MUNICIPAL WATER CONSERVATION (URBAN)	DEMAND REDUCTION [NUECES]	184	588	879	853	861	872
		184	**588**	**879**	**853**	**861**	**872**
CORPUS CHRISTI, NUECES-RIO GRANDE (N)							
MUNICIPAL WATER CONSERVATION (URBAN)	DEMAND REDUCTION [NUECES]	2,121	6,766	10,106	9,814	9,904	10,026
		2,121	**6,766**	**10,106**	**9,814**	**9,904**	**10,026**
MANUFACTURING, NUECES, NUECES (N)							
ADDITIONAL REUSE - CORPUS CHRISTI	DIRECT REUSE [NUECES]	0	1,211	1,211	1,211	1,211	1,211
GBRA LOWER BASIN OFF-CHANNEL RESERVOIR	GBRA LOWER BASIN OFF-CHANNEL LAKE/ RESERVOIR [RESERVOIR]	0	312	312	312	312	312
MANUFACTURING WATER CONSERVATION	DEMAND REDUCTION [NUECES]	30	33	35	38	40	43
O.N. STEVENS WTP IMPROVEMENTS	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM [RESERVOIR]	1,245	786	339	0	0	0
SEAWATER DESALINATION	GULF OF MEXICO [GULF OF MEXICO]	0	540	540	540	540	540
		1,275	**2,882**	**2,437**	**2,101**	**2,103**	**2,106**
MANUFACTURING, NUECES, NUECES-RIO GRANDE (N)							
ADDITIONAL REUSE - CORPUS CHRISTI	DIRECT REUSE [NUECES]	0	18,967	18,967	18,967	18,967	18,967
GBRA LOWER BASIN OFF-CHANNEL RESERVOIR	GBRA LOWER BASIN OFF-CHANNEL LAKE/ RESERVOIR [RESERVOIR]	0	4,888	4,888	4,888	4,888	4,888
MANUFACTURING WATER CONSERVATION	DEMAND REDUCTION [NUECES]	471	509	548	588	628	666
O.N. STEVENS WTP IMPROVEMENTS	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM [RESERVOIR]	19,494	12,309	5,317	0	0	0
SEAWATER DESALINATION	GULF OF MEXICO [GULF OF MEXICO]	0	8,460	8,460	8,460	8,460	8,460
		19,965	**45,133**	**38,180**	**32,903**	**32,943**	**32,981**

PORT ARANSAS, NUECES-RIO GRANDE (N)

MUNICIPAL WATER CONSERVATION (SUBURBAN)	DEMAND REDUCTION [NUECES]	160	374	589	792	985	1,161
		160	**374**	**589**	**792**	**985**	**1,161**

RIVER ACRES WSC, NUECES (N)

MUNICIPAL WATER CONSERVATION (SUBURBAN)	DEMAND REDUCTION [NUECES]	9	0	0	0	0	0
		9	**0**	**0**	**0**	**0**	**0**

ROBSTOWN, NUECES (N)

LOCAL BALANCING RESERVOIR - ROBSTOWN	NUECES RUN-OF-RIVER [NUECES]	2	2	2	2	2	2
MUNICIPAL WATER CONSERVATION (SUBURBAN)	DEMAND REDUCTION [NUECES]	0	0	1	1	1	1
		2	**2**	**3**	**3**	**3**	**3**

ROBSTOWN, NUECES-RIO GRANDE (N)

LOCAL BALANCING RESERVOIR - ROBSTOWN	NUECES RUN-OF-RIVER [NUECES]	1,581	1,581	1,581	1,581	1,581	1,581
MUNICIPAL WATER CONSERVATION (SUBURBAN)	DEMAND REDUCTION [NUECES]	125	336	531	747	883	883
		1,706	**1,917**	**2,112**	**2,328**	**2,464**	**2,464**

STEAM ELECTRIC POWER, NUECES, NUECES (N)

GBRA LOWER BASIN OFF-CHANNEL RESERVOIR	GBRA LOWER BASIN OFF-CHANNEL LAKE/ RESERVOIR [RESERVOIR]	0	3,068	3,068	3,068	3,068	3,068
MANUFACTURING WATER CONSERVATION	DEMAND REDUCTION [NUECES]	31	31	31	31	31	31
O.N. STEVENS WTP IMPROVEMENTS	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM [RESERVOIR]	5,588	3,529	1,524	0	0	0
SEAWATER DESALINATION	GULF OF MEXICO [GULF OF MEXICO]	0	3,390	3,390	3,390	3,390	3,390
		5,619	**10,018**	**8,013**	**6,489**	**6,489**	**6,489**

STEAM ELECTRIC POWER, NUECES, NUECES-RIO GRANDE (N)

GBRA LOWER BASIN OFF-CHANNEL RESERVOIR	GBRA LOWER BASIN OFF-CHANNEL LAKE/ RESERVOIR [RESERVOIR]	0	932	932	932	932	932
MANUFACTURING WATER CONSERVATION	DEMAND REDUCTION [NUECES]	9	9	9	9	9	9
O.N. STEVENS WTP IMPROVEMENTS	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM [RESERVOIR]	1,698	1,072	463	0	0	0
SEAWATER DESALINATION	GULF OF MEXICO [GULF OF MEXICO]	0	1,030	1,030	1,030	1,030	1,030
		1,707	**3,043**	**2,434**	**1,971**	**1,971**	**1,971**
Sum of Projected Water Management Strategies (acre-feet)		**32,764**	**70,762**	**64,780**	**57,277**	**57,746**	**58,096**

SAN PATRICIO COUNTY

WUG, Basin (RWPG)

All values are in acre-feet

Water Management Strategy	Source Name [Origin]	2020	2030	2040	2050	2060	2070
GREGORY, SAN ANTONIO-NUECES (N)							
MUNICIPAL WATER CONSERVATION (SUBURBAN)	DEMAND REDUCTION [SAN PATRICIO]	8	11	6	6	5	5
		8	**11**	**6**	**6**	**5**	**5**
IRRIGATION, SAN PATRICIO, NUECES (N)							
IRRIGATION WATER CONSERVATION	DEMAND REDUCTION [SAN PATRICIO]	0	0	0	149	206	279
		0	**0**	**0**	**149**	**206**	**279**
IRRIGATION, SAN PATRICIO, SAN ANTONIO-NUECES (N)							
GULF COAST AQUIFER - SAN PATRICIO IRRIGATION	GULF COAST AQUIFER [SAN PATRICIO]	0	0	0	237	237	237
IRRIGATION WATER CONSERVATION	DEMAND REDUCTION [SAN PATRICIO]	0	0	0	1,345	1,857	2,516
SUPPLY REDUCTION FOR SAN PATRICIO IRRIGATION	GULF COAST AQUIFER [SAN PATRICIO]	0	0	0	466	466	466
		0	**0**	**0**	**2,048**	**2,560**	**3,219**
MANUFACTURING, SAN PATRICIO, NUECES (N)							
GBRA LOWER BASIN OFF-CHANNEL RESERVOIR	GBRA LOWER BASIN OFF-CHANNEL LAKE/ RESERVOIR [RESERVOIR]	0	3,680	3,680	3,680	3,680	3,680
MANUFACTURING WATER CONSERVATION	DEMAND REDUCTION [SAN PATRICIO]	248	268	287	306	325	344
SEAWATER DESALINATION	GULF OF MEXICO [GULF OF MEXICO]	0	4,140	4,140	4,140	4,140	4,140
SPMWD INDUSTRIAL WTP IMPROVEMENTS	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM [RESERVOIR]	3,432	2,875	2,402	1,956	1,399	812
		3,680	**10,963**	**10,509**	**10,082**	**9,544**	**8,976**
MANUFACTURING, SAN PATRICIO, SAN ANTONIO-NUECES (N)							
GBRA LOWER BASIN OFF-CHANNEL RESERVOIR	GBRA LOWER BASIN OFF-CHANNEL LAKE/ RESERVOIR [RESERVOIR]	0	4,320	4,320	4,320	4,320	4,320
MANUFACTURING WATER CONSERVATION	DEMAND REDUCTION [SAN PATRICIO]	292	314	337	359	381	404
PORTLAND REUSE PIPELINE	DIRECT REUSE [SAN PATRICIO]	2,240	2,240	2,240	2,240	2,240	2,240
SEAWATER DESALINATION	GULF OF MEXICO [GULF OF MEXICO]	0	4,860	4,860	4,860	4,860	4,860
SPMWD INDUSTRIAL WTP IMPROVEMENTS	CORPUS CHRISTI-CHOKE CANYON LAKE/RESERVOIR SYSTEM [RESERVOIR]	4,028	3,375	2,820	2,297	1,642	953
		6,560	**15,109**	**14,577**	**14,076**	**13,443**	**12,777**
PORTLAND, SAN ANTONIO-NUECES (N)							
MUNICIPAL WATER CONSERVATION (SUBURBAN)	DEMAND REDUCTION [SAN PATRICIO]	74	49	0	0	0	0
		74	**49**	**0**	**0**	**0**	**0**
SINTON, SAN ANTONIO-NUECES (N)							
MUNICIPAL WATER CONSERVATION (SUBURBAN)	DEMAND REDUCTION [SAN PATRICIO]	62	170	277	385	447	451

	62	**170**	**277**	**385**	**447**	**451**
Sum of Projected Water Management Strategies (acre-feet)	**10,384**	**26,302**	**25,369**	**26,746**	**26,205**	**25,707**

Exhibit H Memo - Cost Estimate

Memo

Date:	Friday, August 30, 2019
Project:	Corpus Christi ASR Feasibility Study- E16265
To:	Steve Ramos and Larijai Francis, PE
From:	Kristi Shaw, PE; John Marler, PE; William Wehner, PE
Subject:	Preliminary Costs for Tertiary Treatment Processes for Greenwood WWTP Effluent and Wellfield Infrastructure for Piloting, Phase I and Phase II

Background

HDR is nearing the completion of a three-year Aquifer Storage and Recovery (ASR) Feasibility Study for the City of Corpus Christi. Key tasks included (1) developing a field testing approach (2) conducting an exploratory test drilling and sampling program (3) performing a geochemical analysis for source and groundwater compatibility (4) developing a groundwater model and simulating potential ASR operations for long-term drought and supply augmentation during peaking and (5) evaluating ASR operating policies for project implementation.

Upon completion of primary tasks, City Staff requested that HDR develop preliminary costs of treatment strategies to successfully produce a reuse wastewater stream at the Greenwood Wastewater Treatment Plant (WWTP) suitable for indirect non-potable reuse through ASR including infrastructure, wells, and well field piping needed to operate a phased ASR project for up to 18 MGD future supply. The reuse stream needs to be of sufficient quality to be readily injected into the Gulf Coast Aquifer for storage and subsequent recovery while not degrading the groundwater or causing excessive clogging that would affect operations and maintenance. Currently, the Greenwood WWTP has a capacity of roughly 5 million gallons per day (5 MGD) and treats the wastewater influent through a conventional activated sludge process. Effluent from the plant is discharged into the La Volla Creek, a tributary of Oso Bay, with a small amount being reused for landscaping at golf courses.

The ASR project seeks to upcycle the City's Greenwood WWTP effluent for beneficial water supply for use by industries and drought mitigation. Phase I is focused on 10 wells at the Corpus Christi International Airport site and Phase II would add an additional 5 wells to the east of Phase I. The following information applies to Phase I and II, based on the findings from the Corpus Christi Aquifer Storage and Recovery Feasibility Project:

<u>Phase I</u>

- Phase I limits recharge to 5 MGD, which is based on current available Greenwood WWTP capacity after considering existing contracts and would be capable of providing up to 8 MGD through recovery at ASR wells.

- If tertiary treated Greenwood WWTP effluent by-passes ASR and is delivered concurrent with ASR recovery, then the combined water supply would be 13 MGD for Phase I.

Phase II

- Based on City Staff input, Greenwood WWTP will likely be expanded to 10 MGD by 2030 to 2035. With tertiary treatment expansion to 10 MGD, it is assumed that up to 8 MGD would be available for ASR and/or delivery to industrial customers.
- Phase I and II operated conjunctively would be capable of providing about 10 MGD from ASR well operation, or up to 18 MGD with Greenwood WWTP expansion[1].

Prior to implementing Phase I and II, a piloting program will be conducted at Greenwood WWTP to verify field tests and confirm water treatment processes necessary to obtain a TCEQ permit for ASR production, which requires that the source water for recharge to be treated to a sufficient quality so as to not impact or impair the aquifer formation or groundwater. To meet this requirement, the Greenwood WWTP will need to be improved with additional treatment upgrades. The following constituents in the existing effluent could affect the groundwater environment or well operations and thereby are currently limiting the injection potential:

- Total Suspended Solids (TSS)
- Nitrate (NO_3)
- Total Organic Carbon (TOC)
- Manganese (Mn)
- Bacteria

This memo discusses potential treatment configurations for piloting and a range of costs for Phase I and II ASR based on these treatment configurations. Upon receipt of pilot test results, the Phase I and II costs will need to be revisited based on actual treatment needs. It is anticipated that the ASR supplies would be used for industrial purposes and would not need to be treated to potable standards. If this condition changes or potable supplies are sought, additional treatment may be required.

Potential Treatment Configurations

To adequately treat wastewater for the above mentioned constituents, the secondary treatment process will need to be upgraded and a tertiary treatment system will need to be installed. The secondary treatment process at Greenwood WWTP is shown in **Figure 1**. Based on information from City Staff, currently planned treatment alterations include removing the primary clarifiers from service along with converting the anaerobic digesters to aerobic digesters.

[1] Based on City staff feedback, Greenwood WWTP expansion to 12 MGD by Year 2025-2030 would result in about 8 MGD treated effluent available for potential ASR use.

To determine the exact levels of treatment and properly assess the most effective treatment regime, a pilot system for the secondary treatment improvements and the additional tertiary system is recommended. To sufficiently support an ASR injection pilot, a minimum flow of 50 GPM is recommended. The proposed pilot plant arrangement is shown in **Figure 2**.

Secondary Treatment Upgrades and Modifications

The current secondary treatment process at the Greenwood WWTP consists of a conventional, activated sludge treatment system. The system effectively reduces the biochemical oxygen demand (BOD) and nitrifies the influent ammonia. However, augmentations to the secondary treatment system are required to reduce the effluent nitrate (NO_3). A Modified Ludzack-Ettinger (MLE) process is proposed to complete this treatment. To denitrify the converted NO_3 to nitrogen gas (N_2), an anoxic zone will be required with sufficient biodegradable carbon. The secondary treatment consist of an anoxic zone before flowing through an aerobic zone. An internal recycle (IR) pump will return a portion of the flow stream back to the anoxic zone to convert the nitrate to nitrogen gas. This process will reduce NO_3 to less than 10 mg/L, the maximum contaminant level (MCL).

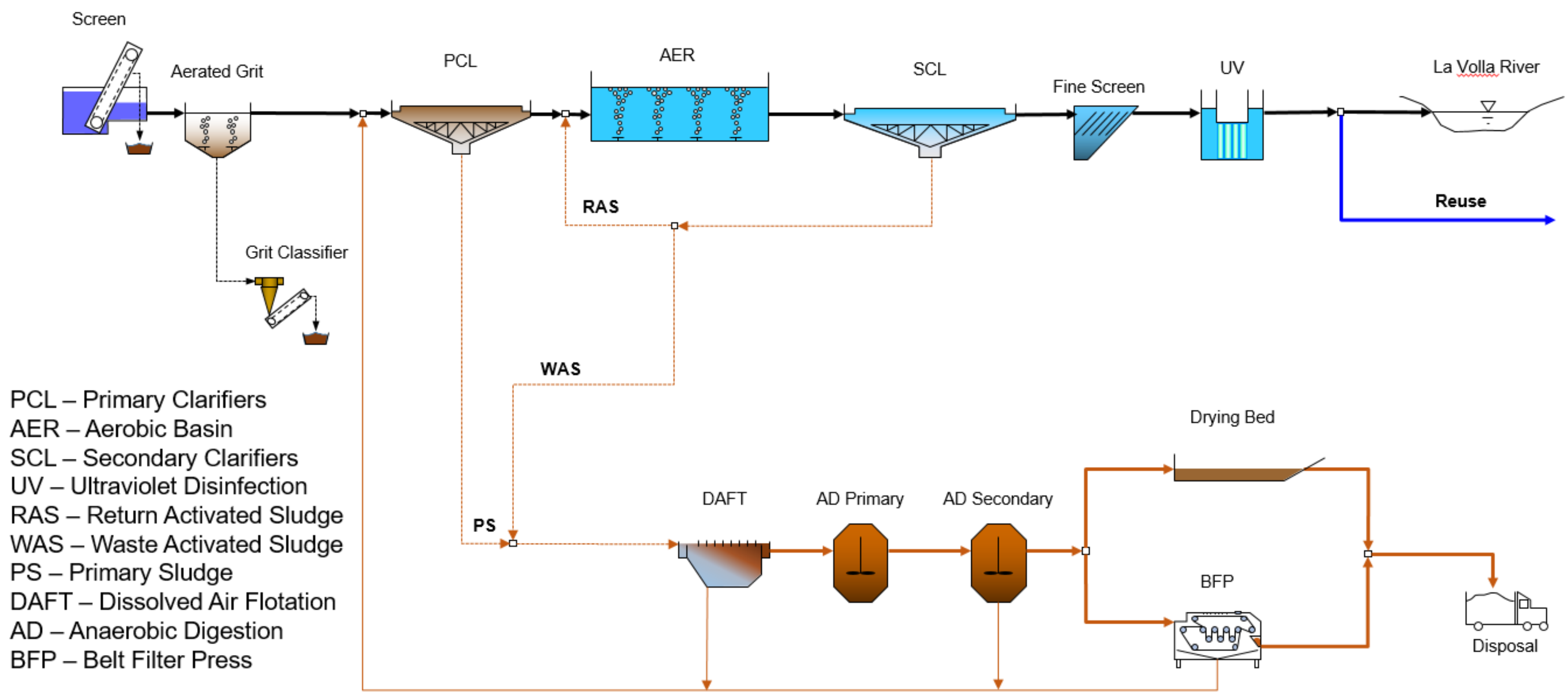

Figure 1: Current Greenwood WWTP Configuration Process Flow Diagram

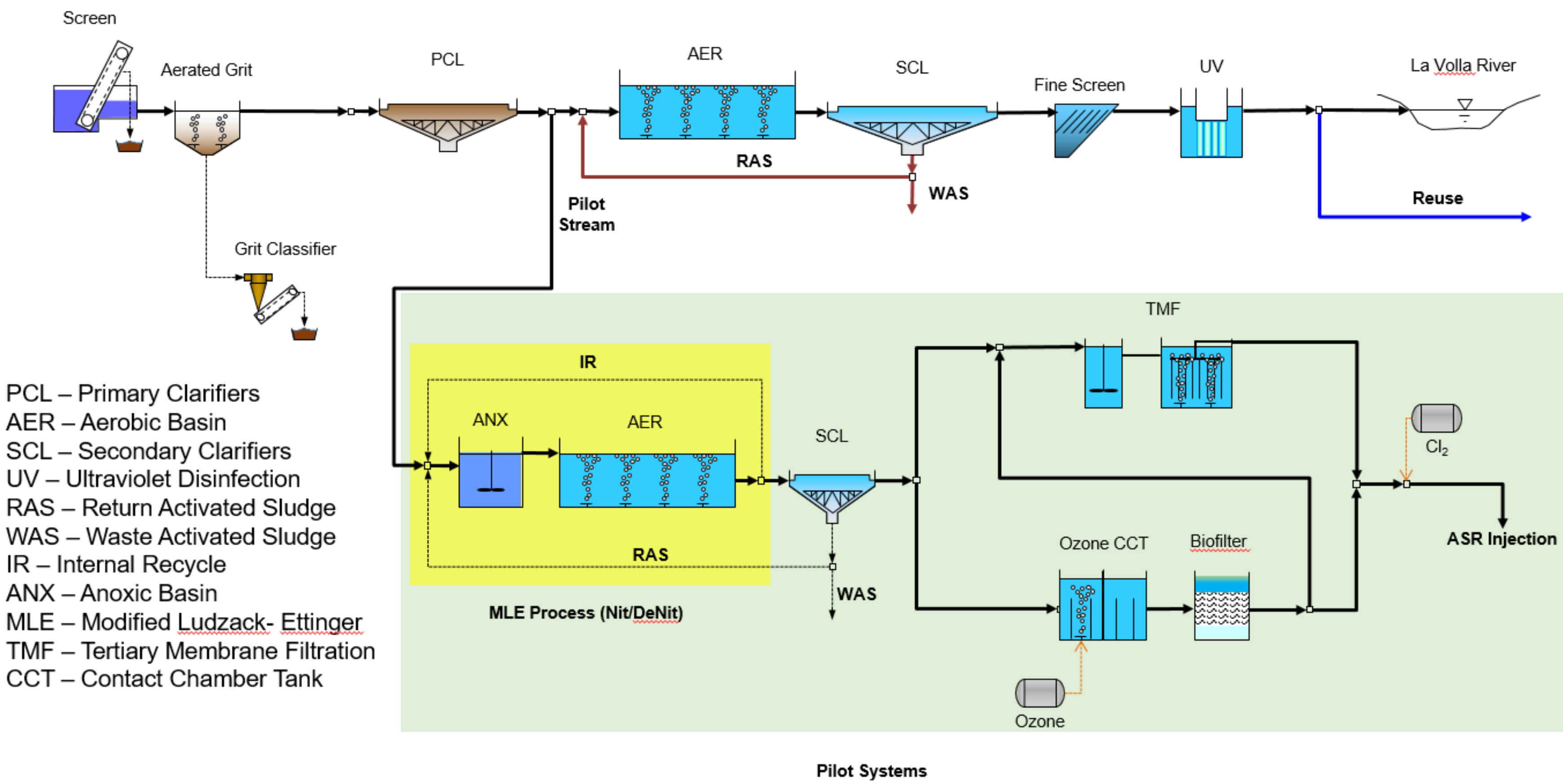

Figure 2: Proposed Pilot System Configuration Process Flow Diagram

Tertiary Treatment Addition

To fully treat the wastewater effluent after the MLE process to sufficient quality to be able to inject it into the aquifer, additional unit processes will likely be required. The main parameters to be reduced or removed in the tertiary system are Manganese (Mn), Total Suspended Solids (TSS), Total Organic Carbon (TOC), and bacteria. Three treatment trains are recommended to be compared during the pilot system which will inform and direct the Phase I and II project construction and later expansion of the treatment plant:

- Tertiary Membrane Filtration, (TMF or Microfiltration)
- Ozone and Biologically Active Filter (BAF)
- Ozone and BAF with Microfiltration polishing

Microfiltration (TMF)

The standard method for removing suspended particles is typically through a membrane filter. Microfiltration, or Tertiary Membrane Filtration (TMF), through hollow fiber membranes is an efficient system to effectively remove particles larger than 1 μm, which includes most bacteria. The system will use a submerged membrane configuration and be maintained with an air scouring system with periodic cleaning using acid based cleaners. The physical filtration mechanism should therefore be able to efficiently remove TSS and bacteria once the MLE system removes NO_3. Microfiltration treatment is limited, however, as it will likely not sufficiently remove TOC or dissolved Mn.

Ozone and BAF

Biologically active filters (BAF) operate in a similar way as a traditional slow sand filter. However, a biologically active layer is allowed to develop at the surface of the filter to further treat organic constituents. Ozone is used as an oxidizer before the filter to breakdown recalcitrant TOC that was not available to be processed in the secondary treatment. The biological layer for the BAF will then consume the now biodegradeable TOC. An additional benefit of the configuration is that any remaining Mn is expected to be oxidized and removed. Potential inefficiencies of the treatment systems is that the bacteria from the biologically active area may be carried into the effluent and will TSS likely not be sufficient reduced.

Ozone and BAF with Microfiltration polishing

The combination of the two treatment systems should effectively treat the effluent to a level that will not significantly impact the aquifer environment. All constituents of concern should be removed to meet water quality requirements for ASR injection as detailed through the aforementioned mechanisms. This option should effectively eliminate any individual limitations for the TMF and Ozone/BAF systems.

Pilot System Treatment Cost Estimate

A proposal for the pilot system has been developed by Suez and included in **Appendix A**.

The pilot system will be comprised of three (3) distinct subsystems; the MLE process tankage, the Ozone/BAF system, and the TMF system. The mobilization cost for the pilot unit is $200,000 with additional monthly rental of $105,000. As mentioned earlier, it is necessary to test each process independently to assess the total cumulative effect. The proposed treatment trains will be configured as shown in **Figure 3, Figure 4, and Figure 5.** It is anticipated that recharge of pilot system water would occur for a six to nine month period to develop an adequate storage volume and test each process independently. The pilot project results will provide operational parameters for the Phase I and II program and narrow the assumptions for future construction estimates. A test well drilled to 800 ft and four monitoring wells for piloting are estimated to cost about $600,000.

Treatment Cost Analysis for Phase I and II

A cost analysis was developed to determine the estimated improvement costs for the additional treatment technologies for the next 20 years for the Phase I and Phase II projects.

The pilot is expected to last approximately one (1) year during which the appropriate tertiary treatment technology would be determined. The following year, 2021, will therefore be the starting year for the 20-year Present Value Analysis. Over the course of 20 years, a 3% average inflation factor was assumed along with a 4% discount factor per year. In the first year, the secondary treatment upgrade to the MLE process will be installed in addition to the determined tertiary treatment system from the pilot to treat the current average plant flow of 5 MGD. A benefit of the MLE process, is that the existing aeration basins can be modified to accommodate the upgrades for the MLE system without expanding the volume of the tanks. Also, the amount of air used for the MLE process is less than the air used for the existing conventional system. Therefore, the annual operating cost will be reduced due to the lower aeration requirements. The annual costs were determined by using the existing aeration blowers at the Greenwood WWTP at the current capacity and comparing it to the air flow requirements for the MLE system. Energy cost was estimated at roughly $0.08/kWh.

In 2030, the plant is planned to expand from 5 MGD to 10 MGD. The cost for the MLE process only considers the upgrade of the system from the conventional activated sludge system to MLE. The included cost does not include expanding the volume of the tankage, air distribution system, nor expanding the air supply system as these are expected as part of the regular expansion of the conventional treatment regimen in which the plant is currently operating. These costs would be associated with the expansion of the conventional treatment system which is independent of the ASR project.

Table 1: Present Value Analysis Results for Phase I and Phase II

	Alternative 1: Microfiltration		Alternative 2: Ozone + BAF		Alternative 3: Ozone + BAF and Microfiltration	
	Phase 1: 5 MGD Modifications to Existing Plant	Phase 2: 5 MGD Expansion to 10 MGD (in 2030)	Phase 1: 5 MGD Modifications to Existing Plant	Phase 2: 5 MGD Expansion to 10 MGD (in 2030)	Phase 1: 5 MGD Modifications to Existing Plant	Phase 2: 5 MGD Expansion to 10 MGD (in 2030)
Tertiary Treatment Capital Costs	$15,094,000	$20,893,000	$10,000,000	$13,843,000	$25,094,000	$34,736,000
MLE Upgrade Capital Costs[1]	$2,018,000	$2,793,000	$2,018,000	$2,793,000	$2,018,000	$2,793,000
Tertiary Treatment Annual Costs	$335,000	$565,000	$913,000	$1,825,000	$1,248,000	$2,390,000
MLE Annual Costs[1]	**-$99,000**	**-$198,000**	**-$99,000**	**-$198,000**	**-$99,000**	**-$198,000**
Present Value		**$ 46,446,000**		**$ 51,508,000**		**$ 95,923,000**

[1]As compared to normal expansion of conventional aerobic biological process

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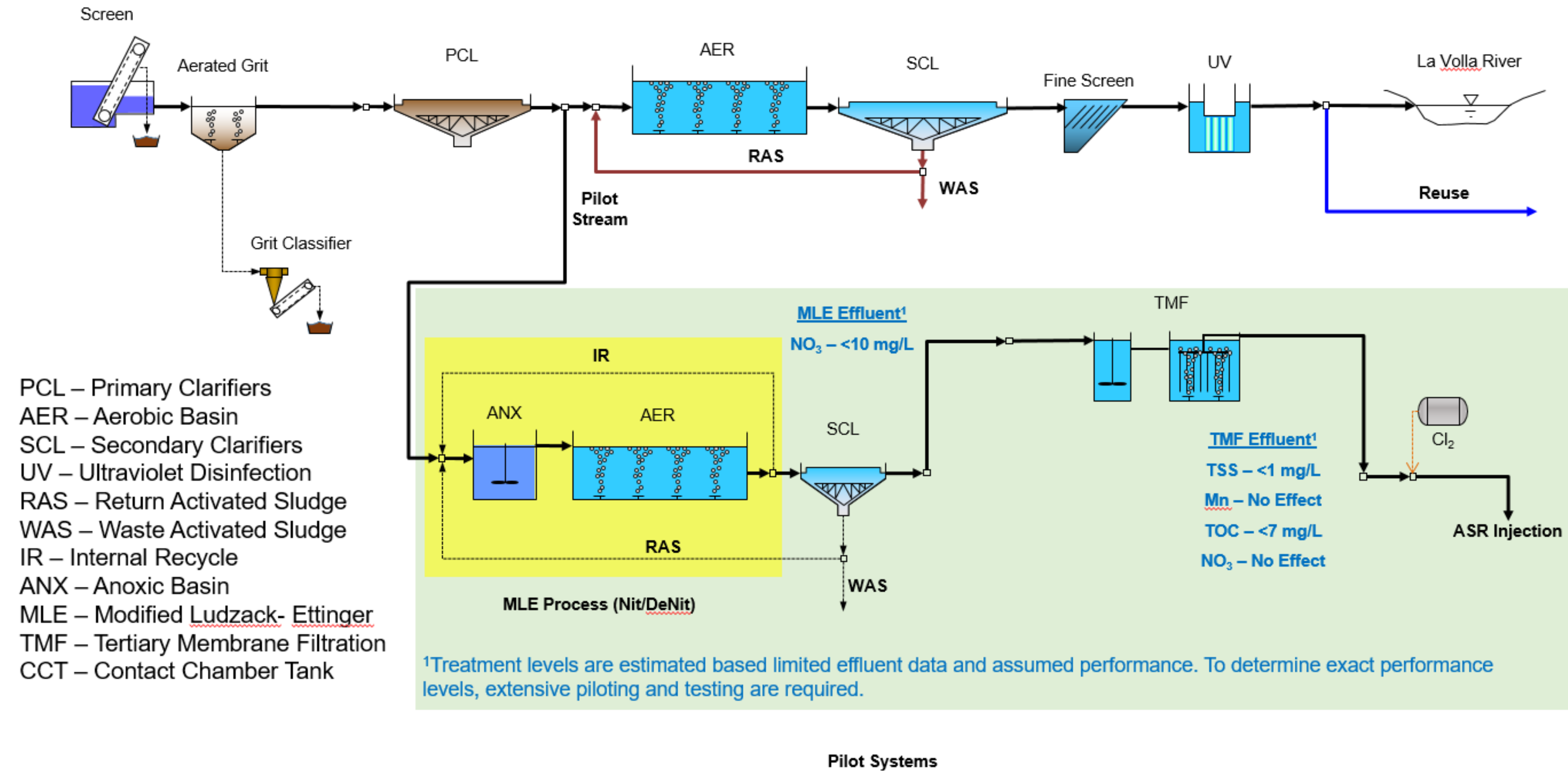

Figure 3: MLE to TMF Pilot Configuration

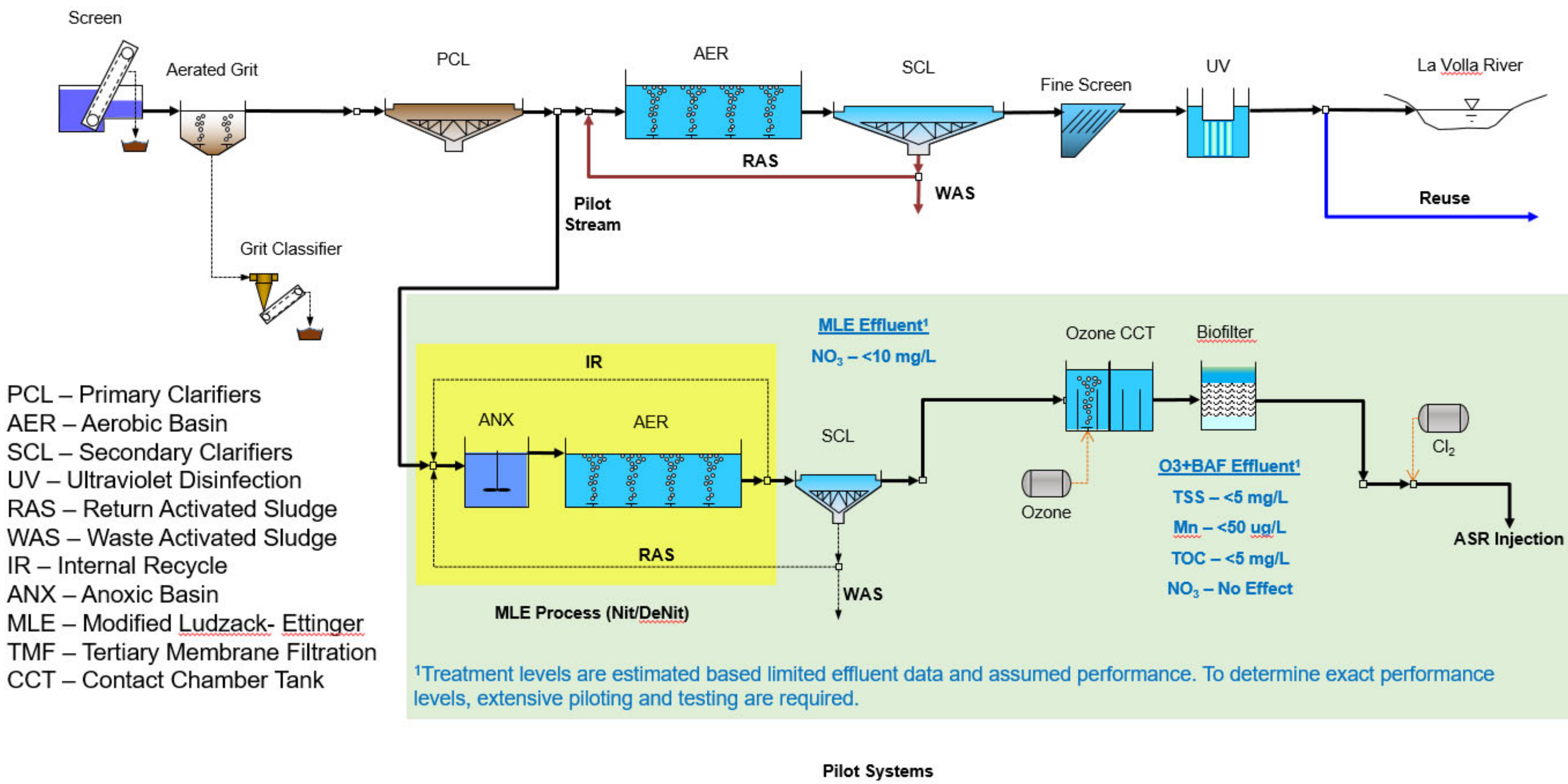

Figure 4: MLE to Ozone/BAF Pilot Configuration

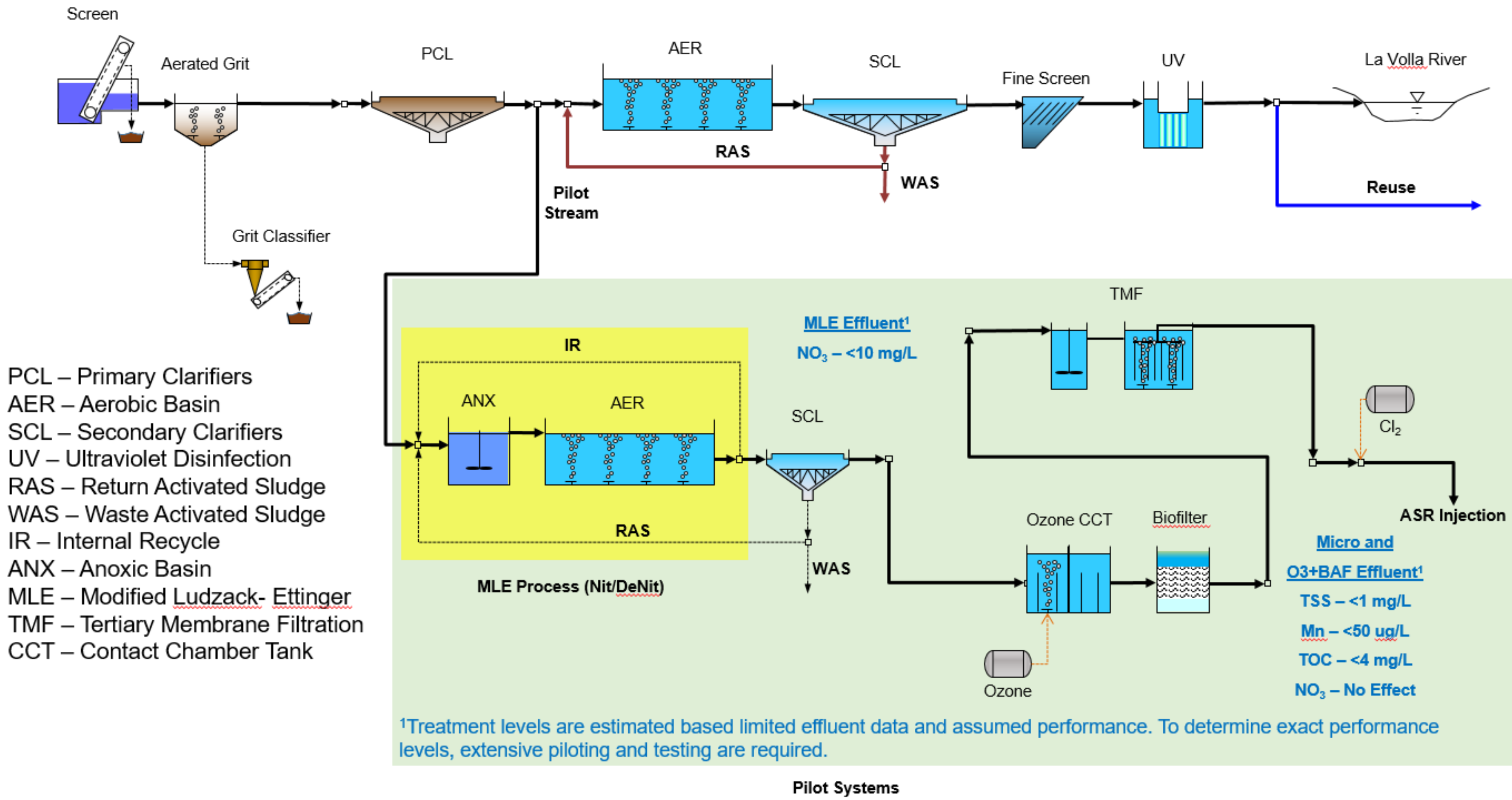

Figure 5: MLE to Ozone/BAF with TMF Polishing Pilot Configuration

Phase I Wellfield Configuration

Phase I includes 10 wells at the Corpus Christi International Airport site and limits recharge to 5 MGD, which is based on current available Greenwood WWTP capacity after considering existing contracts. Phase I *recharge* infrastructure capacities and anticipated conceptual operation is shown in **Figure 7**. Phase I *recovery* infrastructure capacities and anticipated conceptual operation is shown in **Figure 8**.

Phase I Cost Estimate

The Phase I planning-level cost estimate includes:

- 10 wells constructed and equipped to:
    - Recharge up to 415 gpm each (total 5.976 MGD, or about 20% extra to account for well downtime and/or maintenance)
    - Recover up to 685 gpm each (total 9.8 MGD, or about 23% to account for well downtime and/or maintenance)
- 5 MGD pump station at Greenwood WWTP (for recharge)
- 10.9 MGD booster pump station near Phase I wellfield (for recovery)
- 24-inch transmission pipeline from tertiary treatment facilities at Greenwood WWTP to Phase I well field and 8-inch to 30-inch well field piping
- 30-inch diameter pipe to deliver total Phase I supply produced by 10 wells to a delivery point located to the north west of the Corpus Christi International Airport on Agnes Road, south of the intersection of Bronco Road and Interstate Hwy 44
- 2 MG terminal storage tank
- SCADA estimated at 3% of construction costs
- Easement acquisition of 96 acres at cost of $10,000 per acre
- Survey and geotech costs estimated at $55,000 per mile
- Tertiary treatment (5 MGD)
    - MLE treatment
    - Additional tertiary treatment (low to high)
        - Alternative 2: Ozone + BAF (low)
        - Alternative 3: Ozone + BAF + Microfiltration (high)
- Yields up to 13 MGD during recovery
    - 8 MGD through ASR wellfield operation plus
    - 5 MGD through bypass from tertiary treatment facilities at Greenwood WWTP.

A cost estimate for Phase I wells and transmission pipelines needed for recharge, recovery, and conveyance of water to the delivery point for industrial customer use is shown in **Table 2.** The costs shown represent a range of treatment processes that will be identified during piloting for subsequent refinement of Phase I costs, accordingly. As part of the recent ASR feasibility study,

Cost Estimate Summary
Water Supply Project Option, September 2018 Prices
City of Corpus Christi - ASR Phase I (Low to High Range Based on Treatment)

Item	Estimated Costs with Ozone + BAF (Low)	Estimated Costs with Ozone + BAF + Microfiltration (High)
CAPITAL COST		
Greenwood WWTP Pump Station (5 MGD Phase 1)	$3,914,000	$3,914,000
Booster Pump Station(s) & Storage Tank(s) (10.9 MGD Phase 1)	$3,402,000	$3,402,000
Wellfield Piping (13.4 mi (P1), 8 IN - 30 IN dia.)	$13,855,000	$13,855,000
ASR Wells (10 wells, 685 gpm, 700 ft depth)	$11,653,000	$11,653,000
Terminal Storage Tank (2 MG)	$1,516,000	$1,516,000
Tertiary Treatment and MLE Upgrade, 5 MGD	$12,018,000	$27,112,000
SCADA	$1,171,000	$1,624,000
TOTAL COST OF FACILITIES	**$47,529,000**	**$63,076,000**
Engineering and Feasibility Studies, Legal Assistance, Financing, Bond Counsel, and Contingencies (30% for pipes & 35% for all other facilities)	$16,547,000	$21,989,000
Environmental & Archaeology Studies and Mitigation	$548,000	$548,000
Land Acquisition (96 acres (P1))	$964,000	$964,000
Surveying and Geotechnical (22 miles (P1))	$1,207,000	$1,207,000
Interest During Construction (3% for 1 years with a 0.5% ROI)	$1,837,000	$2,415,000
TOTAL COST OF PROJECT	**$68,632,000**	**$90,199,000**
ANNUAL COST		
Debt Service (3.5 percent, 20 years)	$4,829,000	$6,347,000
Operation and Maintenance		
Pipeline, Wells, and Storage Tanks (1% of Cost of Facilities)	$297,000	$301,000
Intakes and Pump Stations (2.5% of Cost of Facilities)	$147,000	$147,000
Tertiary Treatment (Ozone + BAF)	$913,000	$1,248,000
Pumping Energy Costs (@ 0.08 $/kW-hr)	$793,000	$793,000
TOTAL ANNUAL COST	**$6,979,000**	**$8,836,000**
Available Project Yield (acft/yr)	14,573	14,573
Capacity Cost ($/gpd)	$5.28	$6.94
Annual Cost of Water ($ per acft), during recovery	$479	$606
Annual Cost of Water After Debt Service ($ per acft), during recovery	$148	$171
Annual Cost of Water ($ per 1,000 gallons), during recovery	$1.47	$1.86
Annual Cost of Water After Debt Service ($ per 1,000 gallons),	$0.45	$0.52

P. Newell *7/11/2019*

Phase II Wellfield Configuration

Phase II includes an additional 5 wells to the east of the Phase I wellfield at the Corpus Christi International Airport site (15 wells total) and recharge of up to 8 MGD, that would be made available through Greenwood WWTP expansion. Well recharge for the additional 5, Phase II wells was based on 500 gallon per minute (gpm) injection rate per well. Well recovery of 750 gpm for the additional 5, Phase II wells was used to allow for flexible operating conditions at project build-out. Phase II *recharge* infrastructure and anticipated operations is shown in **Figure 9**. Phase II *recovery* infrastructure and anticipated operations is shown in **Figure 10**.

Phase II Cost Estimate

The Phase II planning-level cost estimate includes:

- 15 wells constructed and equipped to:
    - Recharge up to 415 gpm each for Phase I wells and 500 gpm for Phase II wells (total 9.6 MGD, or about 30% for well downtime and/or maintenance)
    - Recover up to 685 gpm each for Phase I wells and 750 gpm for Phase II wells (total 15.3 MGD to account for well downtime and/or maintenance)
- 10 MGD pump station at Greenwood WWTP (for recharge)
- 17 MGD booster pump station(s) total
- Phase I pipelines + 12-inch transmission pipeline from tertiary treatment facilities at Greenwood WWTP to Phase II well field and well field piping
- 30-inch diameter pipe to deliver total Phase II supply to a delivery point located to the north west of the Corpus Christi International Airport on Agnes Road, south of the intersection of Bronco Road and Interstate Hwy 44
- Two- 2 MG terminal storage tanks (4 MG total)
- SCADA estimated at 3% of construction costs
- Land acquisition of 155 acres at cost of $10,000 per acre
- Survey and geotech costs estimated at $55,000 per mile
- Tertiary treatment (10 MGD, total)
    - MLE treatment
    - Additional tertiary treatment (low to high)
        - Alternative 2: Ozone + BAF (low)
        - Alternative 3: Ozone + BAF + Microfiltration (high)
- Yields up to 18 MGD during recovery
    - 10 MGD through ASR wellfield operation plus
    - 8 MGD through bypass from tertiary treatment facilities at Greenwood WWTP after expansion.

A cost estimate for Phase II wells and transmission pipelines needed for recharge, recovery, and conveyance of water to the delivery point for industrial customer use is shown in **Table 3.** The costs shown represent a range of treatment processes that will be identified during piloting for subsequent refinement of Phase II costs, accordingly. As part of the recent ASR feasibility study, the field scale groundwater model was used to simulate three potential ASR operations for the Phase II wellfield for long-term drought and seasonal peaking. For **Table 3**, the pumping energy cost for well field operations is the average cost of the three Phase II operation scenarios. The unit cost of water is estimated to be $604 to $812 per ac-ft during recovery, which is the firm yield expected during drought conditions. *As mentioned previously the range of ASR operating conditions that are possible based on industrial needs and water quality desires and without piloting results, a full unit cost for the project to account for both recovery and recharge conditions cannot be assessed at this time.*

Cost Estimate Summary
Water Supply Project Option
September 2018 Prices
City of Corpus Christi - ASR Phase II (Low to High Range Based on Treatment)

Item	Estimated Costs with Ozone + BAF (Low)	Estimated Costs with Ozone + BAF + Microfiltration (High)
CAPITAL COST		
Greenwood WWTP Pump Station (10 MGD Phase II)	$5,689,000	$5,689,000
Booster Pump Station(s) & Storage Tank(s) (16.9 MGD, 500 HP Phase II)	$4,778,000	$4,778,000
Wellfield Piping (24.5 mi (P1+2), 8 IN - 30 IN dia.)	$23,517,000	$23,517,000
ASR Wells (15 wells, 685-750 gpm, 700-800 ft depth)	$18,190,000	$18,190,000
Terminal Storage Tank (4 MG)	$3,033,000	$3,033,000
Tertiary Treatment and MLE Upgrade, 10 MGD	$28,654,000	$64,641,000
SCADA	$2,202,000	$3,281,000
TOTAL COST OF FACILITIES	**$86,063,000**	**$123,129,000**
Engineering and Feasibility Studies, Legal Assistance, Financing, Bond Counsel, and Contingencies (30% for pipes & 35% for all other facilities)	$29,806,000	$42,779,000
Environmental & Archaeology Studies and Mitigation	$791,000	$791,000
Land Acquisition (155 acres (P1+P2))	$1,553,000	$1,553,000
Surveying and Geotechnical (32 miles (P1+P2))	$1,741,000	$1,741,000
Interest During Construction (3% for 1 years with a 0.5% ROI)	$3,299,000	$4,675,000
TOTAL COST OF PROJECT	**$123,253,000**	**$174,668,000**
ANNUAL COST		
Debt Service (3.5 percent, 20 years)	$8,672,000	$12,290,000
Operation and Maintenance		
Pipeline, Wells, and Storage Tanks (1% of Cost of Facilities)	$485,000	$496,000
Intakes and Pump Stations (2.5% of Cost of Facilities)	$222,000	$222,000
Tertiary Treatment	$1,825,000	$2,390,000
Pumping Energy Costs (@ 0.08 $/kW-hr)	$985,000	$985,000
TOTAL ANNUAL COST	**$12,189,000**	**$16,383,000**
Available Project Yield (acft/yr)	20,178	20,178
Capacity Cost ($/gpd)	$6.84	$9.70
Annual Cost of Water ($ per acft), during recovery	$604	$812
Annual Cost of Water After Debt Service ($ per acft), during recovery	$174	$203
Annual Cost of Water ($ per 1,000 gallons), during recovery	$1.85	$2.49
Annual Cost of Water After Debt Service ($ per 1,000 gal), recovery	$0.53	$0.62

P. Newell *7/11/2019*

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Appendix A: Pilot Submittal Information from Suez

This information is not included in this report because it is proprietary.

Exhibit I Draft Final Report - TWDB Comments & Resolutions

Draft Final Report for Corpus Christi Aquifer Storage and Recovery Feasibility Project

TWDB Contract # 1600011956 TWDB Comments, 8/5/2019

Proposed Responses are Italicized

General Comments

- For Task 7 TCEQ Experimental Permit Support of the scope of work, please provide on update on the work completed for this task and include it in the report.
  Response- *The City of Corpus Christi was unable to authorize an amendment to develop a TCEQ Experimental Permit in time for this report. However, we have added Section 6 in Exhibit G- ASR Operating Policy Considerations to summarize the TCEQ Experimental Permit process for others to use as a guide. We wanted to include this information in the spirit of furthering value for the TWDB and with humble gratitude for the TWDB and legislature's investment in the District's interest to understand groundwater resources beneath its jurisdiction and the City's pursuit of innovative water supplies.*

- Please consider enlarging figures to fit the whole page when possible.
  Response- *Comment accepted and text updated accordingly.*

Model Comments

- The model was well designed and met its objective. I did not see any fundamental issues.
  Response- *Thank you. No comment to address.*

- I recommend applying cautiousness when using a numerical model for engineering design purpose because the model was not calibrated to either flow or mass transport.
  However, the project team seemingly had a good plan by first implementing a pilot study, which should give a more realistic evaluation of the ASR well field.
  Response- *Agreed. Yes, pilot study results will help refine model values.*

- Please consider conducting a recoverability sensitivity model run by using lower effective porosity values for both sand (such as 0.1 to 0.15) and clay (such as 0.05 to 0.1) layers. A transport simulation is very sensitive to effective porosity. As a result, it affects simulated plume size, migration velocity, and well spacing. In the model, the effective porosity was assigned a value of 0.25 based on literature review. This value appears a little too high for a porous medium such as silty sand or fine sand with a hydraulic conductivity of about 10 feet per day from the pumping tests at the study area. This value is definitely high for a shaly or clayey confining unit.
  Response- *A recoverability sensitivity analysis was performed to evaluate the impact of lowering the porosity values for both sand and clay in the model, as requested. The*

porosity values that were tested are summarized in the table below. A discussion and summary of results is included in Section 6 of Exhibit F-Groundwater Model and Results of ASR Operating Scenario Simulations.

For this analysis, two scenarios were evaluated (Scenario B and D1) representative of drought and seasonal operations respectively. See Table 1-1 in Exhibit F for scenario descriptions and parameters. The porosity values that were tested for model sensitivity are shown in Table 6-1 (Exhibit F). A summary of the porosity sensitivity results is shown in Table 6-2. For Scenario B, decreasing the porosity of the sand to 15% and leaving the porosity of the clay at 25% (Scenario Bn3) resulted in the greatest increase of the recovered water TDS and specific conductivity of 30 mg/L, each at the end of the first recovery cycle. A reduction in the porosity of clay to 10% and sand to 15% (Scenario Bn4) resulted in a decrease of the recovered TDS and specific conductivity of 890 mg/L and 35 mg/L, respectively, at the end of the first recovery cycle. Changes in porosity resulted in minimal changes to salinity at the end of six recovery cycles.

For Scenario D1, changes to porosity in the clay and sand units had very minimal impact to recovered water salinity, which is likely due to the shorter recharge and recovery cycles when compared to Scenario B. Maximum changes in the recovered water TDS and specific conductance was about 50 to 65 mg/L.

Overall, the recovered water salinity is not very sensitive to minor changes in porosity of the sand and clay units.

Sensitivity Run	Sand Porosity	Clay Porosity
Bn1	0.2	0.05
Bn2	0.1	0.05
Bn3	0.15	0.25
Bn4	0.15	0.1
D1n1	0.2	0.05
D1n2	0.1	0.05
D1n3	0.15	0.25
D1n4	0.15	0.1

Geology Comments

- Pleases provide all data related to the exploratory drilling and geochemical analysis. The TWDB may have some of the data already.

  Response*- Provided in Data folder on thumb drive.*

- Please provide the cross-sections in Exhibit F, if they were prepared as large-format files. The figures in the report are so small they cannot be reviewed.

  <u>Response</u>*- The report has been updated with higher resolution and larger figures. This information is included in High Resolution Figures folder on thumb drive.*

- Please provide the digital geophysical well logs that were obtained from the Bureau of Economic Geology used in all cross-sections in Exhibit F.
  <u>Response</u>*- The report has been updated with higher resolution and larger figures. This information is included in High Resolution Figures folder on thumb drive.*

<u>Specific Comments</u>

- Page 4. Section 2.1, first paragraph. Please expand on the reason Site 2 and 6 were not selected for Phase II testing.

  <u>Response</u>*- Additional discussion has been added to the Executive Summary.*

- Page 5. Section 2.2 and Section 2.3. Please expand on why ASR wells were modeled in areas Site 2 and 6 that were not recommended for further testing.
  <u>Response</u>*- Additional discussion has been added to the Executive Summary.*

- Page 9. Section 3, last paragraph. States TCEQ mostly like will require treatment to drinking water standards, but Section 5 discuss the newer rules passed in 2015. Please update paragraph to reflect new rules or discussions with TCEQ and reference the sections within the report that expand on the permitting.
  <u>Response</u>*- Additional discussion has been added to the Executive Summary, including referencing ASR Regulations (Section 5) and Permitting (Section 6) discussions in Exhibit G.*

- Attachment C, Section 6.1: Please remove phone and cell numbers within the paragraph or redact the section for security reasons.
  <u>Response</u>*- Comment accepted and text updated accordingly.*

- Attachment C, Figure NS1, NS2, and W-E: Please enlarge cross section figures.
  <u>Response</u>*- Comment accepted and figures updated accordingly.*

- Attachment F, Figure 3-6: Please enlarge because the figure is not readable.
  <u>Response</u>*- Comment accepted and figure updated accordingly.*

- Attachment G, Appendix D: Please remove or redact "evidence of public notice and adoption by district" for security reasons.
  <u>Response</u>*- Comment accepted and text updated accordingly.*

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