FIVE-YEAR PLAN 2.0

Corpus Christi Aquifer Storage and Recovery Conservation District

UPDATED FROM 2009 FIVE-YEAR PLAN

This Five-Year Plan, a document separate from the Groundwater Management Plan, is an outline of the steps and timeline necessary for the CCASRCD to fully develop an operational ASR.

By: Environmental and Strategic Initiatives Department of the City of Corpus Christi, using original document by HDR.

Adopted July 2015

FIVE-YEAR PLAN 2.0

Corpus Christi Aquifer Storage and Recovery Groundwater Conservation District

May 1, 2015
Brent Clayton

1. INTRODUCTION

The Corpus Christi Aquifer Storage and Recovery Groundwater Conservation District (District) is a groundwater conservation district (GCD) and was created in accordance with Texas Water Code Chapter 36. As with the 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. In accordance with GCD requirements, the District prepared a Groundwater Management Plan in 2008 and 2013. ~~It~~ The Plan was approved by the Texas Water Development Board (TWDB) both times.

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 Management Plan, 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. As illustrated on the map, most of the District is within Nueces County; however, the District also includes very limited parts of Aransas, Kleberg, and San Patricio Counties.

2. PURPOSE

The primary purpose of the 5-year plan is to provide guidance to the City and District on: (1) the 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 Texas Commission on Environmental Quality (TCEQ) regulations. Since the original Five-Year Plan, progress has been made in all three areas. However, progress was limited and additional guidance is needed.

3. PROPOSED FIVE-YEAR PLAN

The proposed five-year plan consists of the following elements:

- **District operations**—rulemaking, well inventory, well registration and permitting, record keeping, communications with constituents, review and assessment of data and information, TWDB and TCEQ reports, and participation with other water regulatory, management, and planning agencies and groups.
- **Aquifer conditions**—documentation of aquifer's historic and current water levels and water quality.
- **Aquifer characterization**—compilation, analysis and interpretation of geophysical log data, and preparation of aquifer maps, tables and summaries.
- **ASR design guidance**—groundwater flow and mass transport modeling, test drilling, geochemical analyses, and analysis of typical ASR operational scenarios.
- **TCEQ regulatory requirements**—summary of ASR permitting and operational requirements.
- **Feasibility assessments**—engineering study to determine feasibility of constructing and operating ASR for seasonal and long-term water banking at the O.N. Stevens Water Treatment Plant (Stevens WTP) and Mustang Island. Preparation of report and recommendations.

3.1. District operations

3.1.1. Rule making

In 2011, the Board of Directors passed Rules and Regulations for the District. Though these rules meet minimal requirements of the State, they need to be expanded in several areas. Most notably, production limitations for permitted well owners are not outlined. Results of the aquifer characterization study (a part of this Five-Year Plan) will help guide the District to set these limitations.

3.1.2. District activities

Progress on the following has been made since the original Five-Year Plan, but improvements in district activities will be initiated if deemed necessary.
Normal business activities of a GCD include: (1) communicating with individuals and organizations and responding to information requests, (2) reviewing and acting on a variety of well registration and permit requests, (3) participating in water management and regulatory activities of other governmental agencies and groups, (4) responding to requirements by TWDB and TCEQ, (5) maintaining and updating data bases, (6) reviewing and studying information so that the District officials can be current on water issues, (7) holding District meetings, and (8) periodically updating the District's Water Management Plan and Rules.

3.1.3. Well inventory

Since the original plan, the TWDB developed a database for the District as part of the project titled, "Geological Characterization of and Data Collection in the Corpus Christi Aquifer Storage and Recovery Conservation District and Surrounding

Counties[1]". This extensive database was consolidated by staff into one Excel database of wells within the boundaries of the District. This database will be updated and reviewed at least annually.

3.2. Aquifer Conditions

Data to define aquifer conditions are generally considered to be groundwater levels and water quality. These data consist of groundwater level measurements and laboratory analyses of water samples that were collected from wells.

Groundwater level data, primarily gathered by the 2012 Meyer study, will be critical to prepare: (1) regional maps of the water table and potentiometric surface of aquifers which provides information on the direction of groundwater movement and changes (drawdown) over time, and (2) hydrographs at individual wells, which document changes in water levels (drawdown) over time. If there is sufficient data from wells in local areas and with different depths, the vertical movement of water can be determined.

The water quality data are used to: (1) indicate the suitability of the water for various needs, (2) water treatment requirements, and (3) document any changes or trends in water quality, such as saline water intrusion or contamination.

Concerning the ASR program, these data will be useful to: (1) define the approximate direction and magnitude of the drift of a bubble of injected water around an ASR well, and (2) identify any changes in aquifer conditions that could jeopardize the efficient operation of an ASR well and well fields.

Since the original Five-Year Plan, much of this data has been gathered. However, analyzing it will be done in the characterization phase of the plan.

3.3. Aquifer Characterization

Aquifer characterization is generally considered to be describing the hydrogeologic characteristics of the geology of the subsurface and the native groundwater that occurs between the land surface and the base of Evangeline Aquifer or possibly the Goliad Sands. The important information to be compiled from subsurface geologic data are the occurrence and thickness of water-bearing (sand) zones and confining beds (silts and clays) and the approximate salinity of water in the sand layers. Some of the more massive layers are believed to be continuous in the District; however, many of the thinner layers will only have a local extent. The proposed approach in developing these data is to study and interpret geophysical logs from oil and gas wells and exploratory test holes. The most suitable logs are the older ones when the drillers did not have to comply with the protection of fresh and brackish water aquifers. These logs usually start within a few hundred feet of the land surface, while the more recent ones start at depths of 1,000

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

to 1,500 ft below land surface which may eliminate the depth of greatest interest. The log analysis is to extend to the base of the Evangeline Aquifer or Goliad Sands. The base of the Evangeline Aquifer at the Stevens WTP is estimated to be about 2,000 ft below land surface. On Mustang Island, the base of this aquifer is about 3,200 ft below land surface. Previous studies suggest there is little or no potential for ASR well fields in formations below the Evangeline Aquifer within the vicinity of the District. The areal extent of the aquifer characterization will extend a few miles beyond the District boundaries so that the data can sufficiently be tied into the regional geologic framework.

Interpretations of the logs are to provide data on the top and bottom of all significant sand and clay layers and estimates of water salinity within the sand layers. These data are to be summarized into tables, charts and maps. The log interpretations are to also include correlation with previous studies to identify the position of the major stratigraphic (geologic) and aquifers and confining systems (hydrogeologic) units within the subsurface.

The proposed plan includes the selection and interpretation of 30-50 logs in the District and vicinity. The summary is to include: (1) tables, several maps and charts that document and illustrate the occurrence of sand layers, and (2) the salinity, especially the 3,000 and 10,000 mg/L concentration of total dissolved solids (TDS) in the sand layers.

These data and analyses will be useful in siting potential ASR well fields and the design of the wells.

A preliminary analysis of this was done by Meyer in 2012, but this characterization will be more in depth and cover three specific areas.

3.4. ASR Design Guidance

Technical support for future design and operational plans of ASR wells and well fields consists of several studies and tests. The major questions to be addressed for the design include:

- What will be the regional direction and rate of drift of the injected freshwater bubble around an ASR well?
- How does the close proximity of high saline groundwater affect ASR well field operations?
- How much well interference is there in an ASR well field? Under what conditions does it become significant?
- Does the difference in density of injected water and native groundwater cause the inject water to rise to the top of the storage zone?
- What is the rise in groundwater levels during the injection cycle; and, the decline in groundwater levels during recovery? Will the rise of water levels be above land surface, which would cause water wells to flow?
- Is the injected water chemically compatible with native groundwater and with formation materials?
- What is the variability of groundwater levels and water quality with depth?

- What is the potential for land surface subsidence?

Several of these questions can only be adequately answered with advanced, computerized groundwater models. Because of the variability of groundwater salinity (density) in the District and the potential high contrast in salinity between the injected ground water and native groundwater water at an ASR well, the proposed groundwater model is known as SEAWAT[2]. This model was developed by the U.S. Geological Survey (USGS) and is capable of simulating three-dimensional, variable density, transient groundwater flow in porous media. This model combines the USGS model for groundwater flow (MODFLOW) and mass transport (MT3DMS) models. The commonly used MODFLOW program assumes all the water in the model to be equivalent to freshwater. MODFLOW is used for all the TWDB Groundwater Availability Models (GAM)

Several other questions can only be addressed by conducting a test drilling program. Three locations are proposed. One is near the Stevens WTP; the second is near the Greenwood Wastewater Treatment Plant; and the third is on Mustang Island.

3.4.1. Groundwater Flow and Mass Transport Modeling

3.4.1.1. Field Scale

A major concern is the tendency of the lighter (lower density) injected freshwater to migrate (float) to the top of the water-bearing formation which contains heavier (higher density) brackish or saline water. If this happens before recovery, the recovery efficiency will be greatly diminished. Figure 2 illustrates this concept. This concept is similar to a lake “turning over” in the late fall or early winter when the upper layer of the water is cooled by the weather and becomes slightly denser than the underlying relatively warm water. As a result, the upper cool layer flows to the bottom of the lake.

A field scale model will be designed to simulate the aquifer response of an injected bubble of freshwater in the immediate vicinity of an ASR well. More specifically, the model is to: (1) represent a water-bearing zone and adjacent geologic layers in the vicinity of the ASR well and (2) calculate the aquifer water levels and movement of the injected water and native water in this zone during injection, storage (idle), and recovery cycles.

The proposed field scale model would be designed to focus on the major water-bearing (storage) zone of an ASR well. This zone and adjacent geologic units would be subdivided into about 25 layers and have model layer thickness of a few tens feet. The aquifer parameters would be taken from data provided by the test drilling program (discussed later) and regional groundwater models or well pumping tests. Little or no calibration is anticipated.

[2] Guo, W. and Langevin, C.D., 2002, User’s Guide to SEAWAT: A computer program for simulation of three-dimensional variable density groundwater flow, U.S. Geological Survey Techniques of Water Resources Investigatons 6-A7.

The model simulation would consist of: (1) injecting into the ASR well over a few month period, which creates a bubble of freshwater around the well, (2) letting the well sit idle for a few years, and (3) pumping the ASR well over a few month period to recover the injected water. The model would calculate the redistribution or movement, if any, of the injected water in the vicinity of the ASR well that is attributed to water density. It would calculate the salinity of the water in the aquifer at selected time intervals and the salinity of the recovered water.

One test would be done with aquifer characteristics and hydrologic conditions at the Stevens WTP where the relative contrast in water densities is small; the next would be for characteristics and conditions on Mustang Island where the relative contrast in water densities is great; a third, in addition to that proposed in the original Five-Year Plan, would be done at the Greenwood Wastewater Treatment Plant.

3.4.1.2. Regional Scale

One of the issues to be addressed with the regional scale model is the drift of the injected freshwater bubble. If there is significant movement, it probably would be toward the Kingsville well field where local groundwater levels have been lowered over 200 ft and its cone of depression extends many miles. The effect of this and other well fields on groundwater movement in the District is largely undetermined. Also, the current single density (freshwater) groundwater models have limited reliability in the vicinity of the saline zones. If drift of the injected water bubble occurs, the ASR recovery efficiency would be reduced, especially for long-term storage. Figure 3 illustrates this concept.

The proposed extent of the model is an area about 50 miles around the District, except toward the Gulf, which would encompass the Kingsville well field and any that may develop in the vicinity of the District. The model would be somewhat generalized with grids of about half mile on a side. The model layers would extend to the base of the Evangeline Aquifer and be represented with 4-6 layers. The model would be calibrated with existing groundwater level data.

Major results from a simulation of a scenario with a regional scale model would be: (1) the direction and rate of groundwater movement at various locations in the District, (2) the area where groundwater levels would be higher than land surface during the injection cycle, and possibly during the idle cycle, (3) well interference, and (4) information to estimate land surface subsidence. Figure 4 illustrates the concept of groundwater levels during predevelopment, injection and recovery. It shows groundwater levels being above the top of a water well, which could cause it to flow.

3.4.1.3. Selected Scenarios for Evaluation

Three ASR sites are proposed for evaluation. One is at the Stevens WTP; the next is on Mustang Island; the third is near the Greenwood Wastewater Treatment Plant. At each of these sites, two operational scenarios are proposed. One scenario would represent an ASR operating on an annual cycle when injection would occur during the fall/winter/spring and recovery would occur during the summer. The other scenario would simulate long-term storage, probably a decade. These simulations would be made with both models.

3.4.2. Test Drilling Program

The proposed test drilling program consists of drilling test holes, collecting core and water samples, and constructing a monitoring well at two locations. This would be done at the three proposed ASR locations.

Key activities during a test drilling program would include:
- Describing the drill cuttings
- Logging the borehole with geophysical tools
- Measuring water levels at several depths
- Collecting water samples from several depths
- Collecting core samples from several depths
- Constructing a monitor well for future monitoring and data collection

Key data include:
- Delineation of the subsurface materials and their approximate permeability
- Emphasis would be on sand and clay layers
- Identifying geologic units
- Vertical variation of water levels and aquifer pressures
- Water quality characteristics
- Basic geochemical data and information that are needed to calculate compatibility of injected water with native water and formation material

3.4.3. Geochemical Compatibility Analyses

Geochemical compatibility analyses are needed to determine:
- If the mixing of the injected water with native groundwater is likely to cause a precipitate to form from various constituents in the water. If a precipitate forms, it probably will cause the well to become partly plugged, which would severely affect the injection rate. Examples include iron oxyhydroxide and organic flocs.
- If the injected water will cause a flocculation of clay particles, which would tend to plug the aquifer and affect injection rates. The flocculation is usually associated with ion exchange, oxidation of minerals, and factors associated with mineral dissolution and solubility.

The data used for the compatibility analyses include: (1) samples collected from the Stevens WTP to provide representative chemistry of the injected water, (2) water samples collected during the test drilling program, and (3) formation samples from the cores that were also collected during the test drilling program.

3.5. Compliance with TCEQ Regulations

TCEQ and the Environmental Protection Agency (EPA) classify ASR wells as Class V injection wells. These wells generally are used to inject non-hazardous fluids into or above an aquifer that is suitable for drinking water.

Implementation of ASR operations in the District will require complying with TCEQ regulations. Some of the major regulations include:

- Area and factors of review: Area is about 0.5 miles from ASR well. Factors include water and formation chemistry, hydrogeology, and population and water use
- Construction standards: Similar to public drinking water wells
- Operating requirements: Injected water meets Drinking Water Standards and limited injection pressures
- Reporting: Monthly and final reports: Approvals require information on as-built data, log and test data, formation and injection fluid analyses, well capacities, and hydrogeologic modeling
- State Water: If the supply of water to be stored underground is classified as “State Water”, a TCEQ permit is required

3.6. Feasibility Assessment

Finally, after the completion of the scientific and engineering studies, the results will be used to prepare preliminary designs for ASR well fields at the Stevens WTP, Mustang Island, and Greenwood WWTP sites. Then, operational scenarios will be prepared for a feasibility assessment. At this time, the scenarios are annual cycling and long-term water banking, which were discussed earlier. Included in the feasibility assessment is (1) matching the supply of potable water for ASR and customer demands, (2) estimating the cost of constructing and operating the ASR facilities, and (3) recovery efficiency of stored water. The costs are to be summarized in a format that facilitates comparison with other water supply options as presented in the approved regional water plan.

3.7. Detailed Summary of Proposed Elements and Tasks in 5-Year Plan

A detailed summary of the proposed 5-year plan's elements and associated tasks are presented in Table 1.

Table 1. Detailed List of Elements in Proposed 5-year Plan for CCASRGCD

Element	Tasks
District Operations	1) Update District Rules as needed 2) Establish a well permitting process 3) Improve District management operations to conduct day-to-day business, participate in regional and state water management activities, and comply with TWDB and TCEQ regulations 4) Maintain and update data base a) Continue to compile water well data on water wells and load into the data base i) Search for TWDB and TCEQ well records within the District, including paper records at TCEQ ii) Within selected counties, search only TWDB computerized data base b) Compile injection well data from RRC and load into data base
Aquifer Conditions	1) Continue to compile historical water level and water quality data from TWDB data base for water wells 2) Summarize these data with aquifer maps and hydrographs 3) Prepare report
Aquifer Characterization	1) Geophysical Log Analysis a) Select 30-50 electric logs of oil and gas test holes and wells in the vicinity of the District, map the locations, and review for coverage. b) Analyze and interpret the logs for occurrence of significant clay and sand layers. Compile contacts into a spreadsheet c) Estimate the approximate salinity for each of the major sand layers from the resistivity logs d) Aggregate the sand and clay layers into major hydrogeologic units or zones e) Prepare charts on the occurrence of sand for each of the logs f) Summarize the major sand units or zones on maps g) Summarize the water salinity on maps h) Identify the stratigraphic (geologic) units i) Prepare report

Element	Tasks
ASR Design Guidance	1) Field-Scale Groundwater Model (SEAWAT) a) Design the model to represent an area within a mile or so of a conceptual ASR well at Stevens WTP, Mustang Island, and the Greenwood WWTP. This includes the gridding and layering of the model. b) Compile aquifer parameters from a regional model, geophysical log data and well data c) Estimate the salinity and density of water in the model layers d) Code the model to represent a test of the potential upward movement of the injected water bubble around an ASR well e) Conduct the simulation and review the results at selected time intervals f) Document the model and results 2) Regional Groundwater Model (SEAWAT) a) Design the model to represent an area within about 50 miles of the District. This includes the gridding and layering of the model. b) Compile aquifer parameters from the Central Gulf Coast Groundwater Availability Model (CGCGAM), USGS models, and technical reports. c) Estimate the salinity and density of water in the various aquifer layers d) Prepare model calibration data sets e) Code the model, make initial test runs, and perform calibration f) Prepare documentation g) Formulate an ASR test for ASR operations at the Stevens WTP, and Mustang Island, and Greenwood WWTP h) Conduct the tests and summarize the results 3) Test Drilling a) Prepare designs and specifications for test drilling at Stevens WTP, and Mustang Island, and Greenwood WWTP. The data to be collected include, description of subsurface materials, geophysical logs, up to 10 core samples, water levels and water quality samples from about 5 depth intervals, and installation of a monitor well. b) Advertise and bid the test drilling contract c) Collect data during construction d) Chemically analyze the water and core samples e) Summarize the data and findings 4) Geochemical Compatibility Analyses a) Select a geochemical blending model. A model commonly used for this purpose is a USGS model known as PHREEQC b) Compile water quality and geologic core data c) Code the model and make simulations with various water blending ratios

	d) Prepare modeling predictions e) Summarize findings and describe potential adverse impacts from ASR operations

Element	Tasks
TCEQ Regulations	1) Rules and Regulations a) Compile and summarize regulations b) Evaluate the potential difficulty, if any, of complying with them
Feasibility Assessment	1) Selection of Potential Operational Scenarios a) Compile information of water supplies and demands b) Discuss with District officials 2) Preliminary Engineering a) Prepare preliminary well and infrastructure designs for selected scenarios b) Estimate cost of construction and operation c) Estimate ASR recovery efficiency d) Prepare summaries in a format for comparison with other options
Report	1) Prepare a report on the major findings 2) Prepare recommendations of ASR design and operations

4. Proposed Schedule

The overall approach in the preparation of the proposed schedule for the 5-year plan is based on:

- Identifying the sequence of data and information needed for later tasks
- Performing basic tasks early to allow the District to develop a comfort and confidence with the implementation of the 5-year plan
- Addressing some of the most important and potentially adverse factors in the development of an ASR program at an early stage
- Deferring some of the less critical tasks and/or more expensive tasks to later stages

Table 2 is an outline of the proposed schedule for the major elements in the plan.

Table 2. Proposed Schedule for Major Elements of 5-Year Plan

Element	Year				
	1	**2**	**3**	**4**	**5**
District Operations					
• Development of Well Data Base	X				
Aquifer Conditions					
• Load water level and water quality data	X				
Aquifer Characterization					
• Geophysical Log Analyses					
ASR Design Guidelines					
• Field-Scale Groundwater Model					
• Regional Groundwater Model					
• Test Drilling					
• Geochemical Compatibility Tests					
TCEQ Regulations					
Feasibility Assessments					
Report and Recommendations					

X = Either complete or partially complete

4.1. First Year

Since the original version of this plan, components of tasks 1 and 2 below tasks have either been completed or partially completed. Work on these will continue as needed for future work. Task 3 will be completed with the aquifer characterization study. Major tasks to be that have been undertaken in the first year include: (1) selecting the format of the District's data base and obtaining training, if needed, for District staff, (2) compiling basic data on water and injection wells within and in the vicinity of the District and loading into the data base, and (3) preparing a description of the subsurface geology in the District by compiling, interpreting, and summarizing geophysical logs of oil and gas wells.

4.2. Second and Third Years

The major tasks are the development of the field scale groundwater model and the test drilling program. The results from this model are very important in determining if there are potential adverse effects of relatively high groundwater density on the efficiency of an ASR operation. Results from the test drilling will provide data and information on the design of the model and setting model parameters.

4.3. Fourth Year

The major tasks for the fourth year is beginning the development of the regional model and conducting geochemical compatibility tests.

4.4. Fifth and Final Year

The major tasks for the fifth and final year are concluding the development and application tests with the regional model, compiling TCEQ regulatory requirements that will need to be considered by the District, conducting the feasibility assessments, and preparing a report on findings and recommendations.

5. Estimated Cost

The summary of the estimated costs for the major elements and tasks in the plan are listed in Table 3.

Table 3. Estimated Costs for Major Elements of 5-Year Plan[1]

Element	Year					
	1	2	3	4	5	Total
Project Management	$5,000	$20,000	$20,000	$10,000	$20,000	$75,000
District Operations						
• Development of Well Data Base	None[2]					$0
Aquifer Conditions						
• Water Level and Water Quality Data	None[2]					$0
Aquifer Characterization						
• Geophysical Log Analyses	$42,000					$30,000
ASR Design Guidance						
• Field-Scale Groundwater Model		$25,000	$35,000			$60,000
• Regional Groundwater Model				$40,000	$40,000	$80,000
• Test Drilling		$300,000	$300,000			$600,000
• Geochemical Compatibility Tests				$30,000		$30,000
TCEQ Regulations						
• Rule Review					$5,000	$5,000
Feasibility Assessment						
• Preliminary Design and Operation					$20,000	$20,000
• Cost Estimates					$20,000	$20,000
• Report					$30,000	$30,000
TOTAL	$47,000	$345,000	$355,000	$80,000	$135,000	$962,000

Notes:
1: Prices as in the original 2009 Plan, except for the Aquifer Characterization estimate, which was made in 2015.
2: Assumes District Staff will perform task.

As shown in Table 3, a very large part of the total cost is associated with test drilling. It's estimated that the well drilling contract will be about $250,000 for each of the two wells, and professional engineering, geophysical logging and laboratory services will cost about $50,000 per well.

With passage of this plan, the Board of Directors voted to direct staff to apply for available grants to assist in funding the projects outlined above in years 1-3. This include developing scopes of work for the various projects and submitting grant applications.

6. Summary

A proposed five-year plan has been developed with elements consisting of:

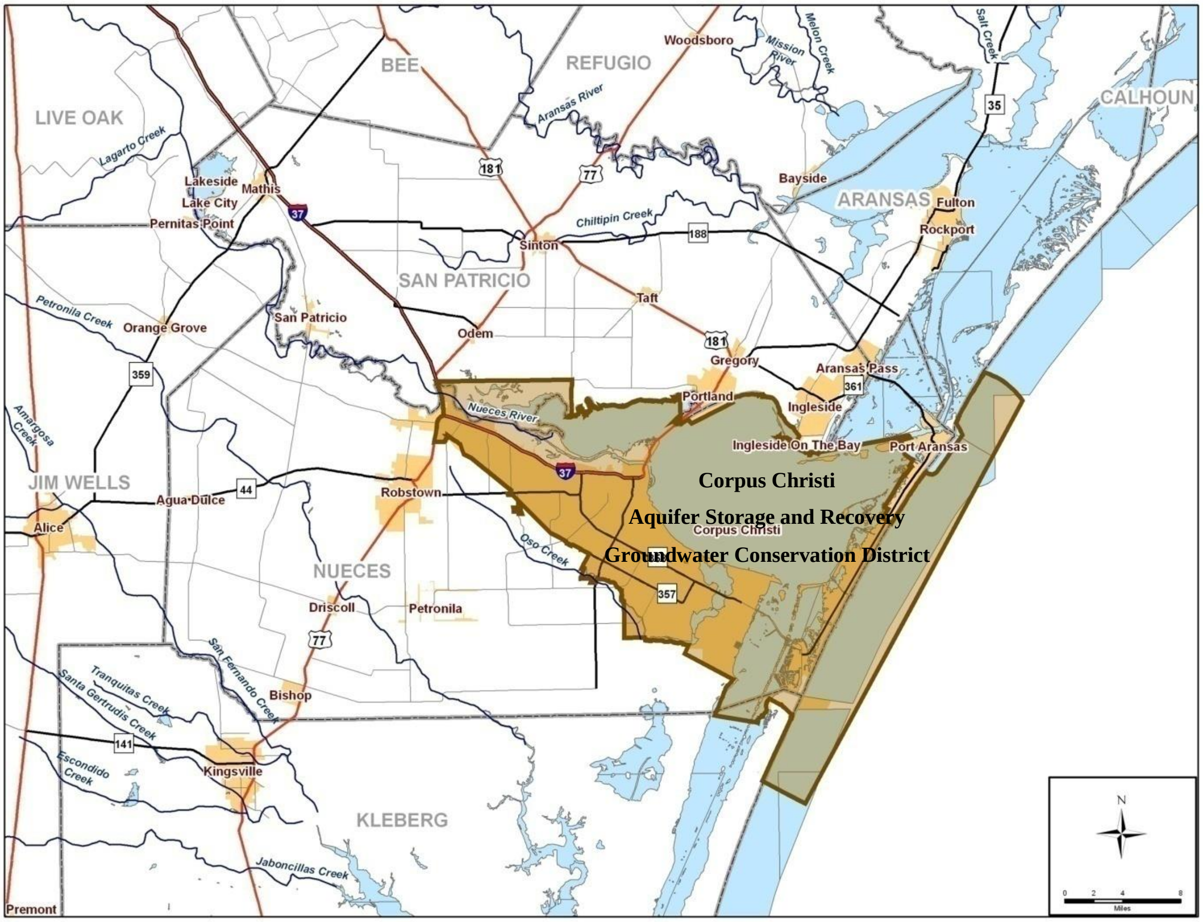
1. Performing District operations required or normally expected of a groundwater conservation district in Texas, including the development of data base(s);
2. Compiling water level and water quality data and preparing summaries;
3. Characterizing the geology of the subsurface by defining the occurrence of sand and clay layers and the salinity of water within the sand layers;
4. Conducting test drilling, groundwater modeling and geochemical studies that are believed to be necessary in the planning and design of ASR wells and an ASR program;
5. Reviewing TCEQ regulations regarding ASR wells; and
6. Preparing a feasibility assessment of two types of ASR operations at two sites.

A summary of major annual activities for the proposed 5-year plan follow:

- First Year:
    - Compiling well, water level and water quality data and loading into a data base
    - Compiling, interpreting and summarizing subsurface geology and water salinity information from oil and gas logs
- Second Year:
    - Conduct the test drilling program at one of the two test sites
    - Develop a field scale groundwater model
- Third Year:
    - Conduct the test drilling program at the second test site
    - Conduct a variety of tests with the field scale model
- Fourth Year:
    - Develop the regional scale groundwater model
    - Perform the geochemical compatibility analyses
- Fifth Year:
    - Apply the regional scale model for selected scenarios
    - Review TCEQ rules and regulations regarding ASR construction and operations
    - Prepare a feasibility assessment for two potential ASR programs
    - Prepare a report that summarized the findings and recommendations

The total estimated cost to execute the 5-year plan is $962,000. The greatest expense is an estimated $600,000 test drilling program, which would be conducted in the second and third years. The annual cost range from an estimated $47,000 in the first year to $355,000 in the third year.

FIGURES



R:\00119127 Corpus_Christi ASR District\5-Year ASR Plan, v1\Figures\GIS\map_docs\arcmap\CorpusChristi_ASR_Map.mxd

Figure1. Location of Corpus Christi Aquifer Storage and Recovery Groundwater Conservation District.

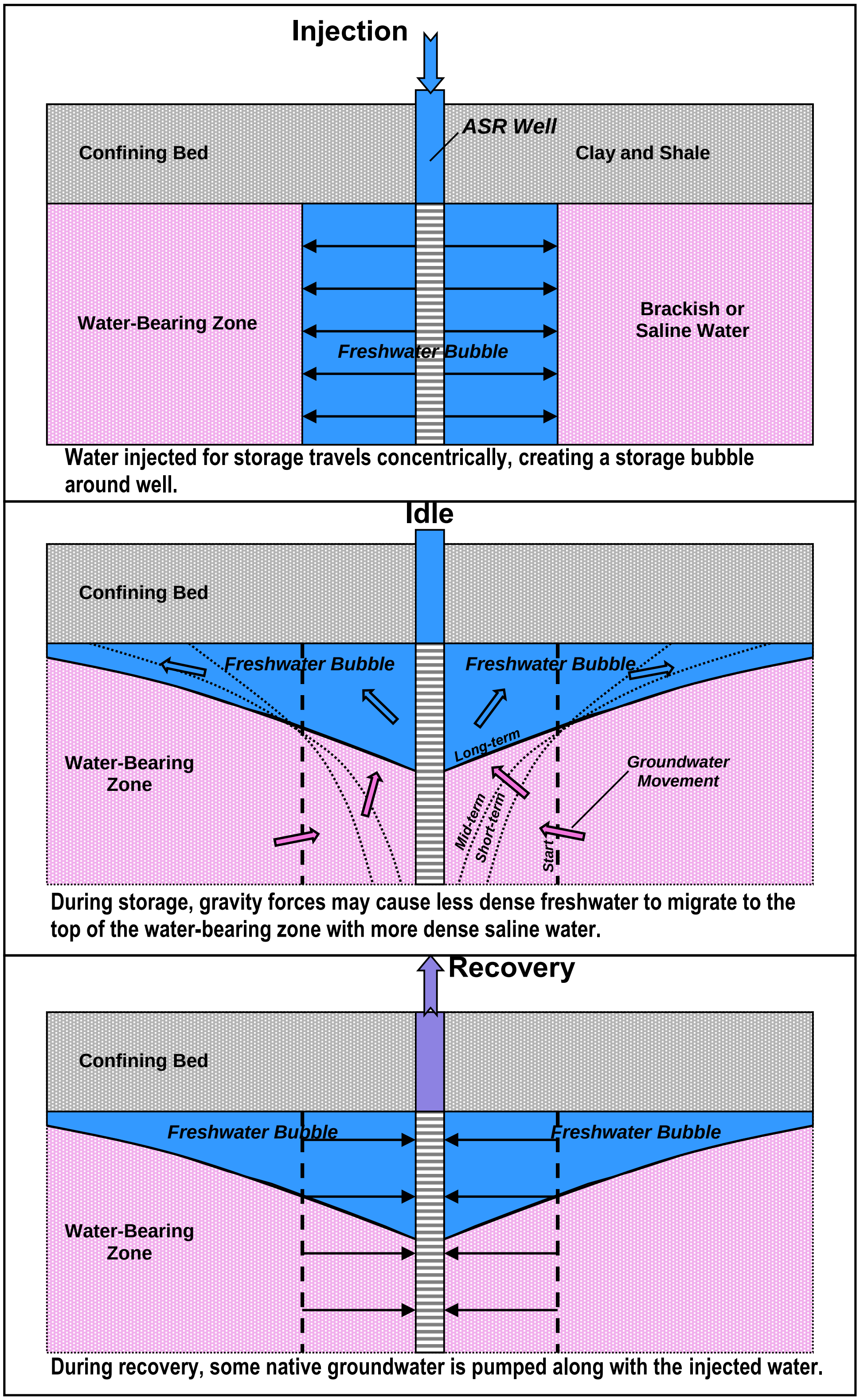


Figure 2.Schematic illustrating the potential movement of injected freshwater around an ASR well to the top of the water-bearing zone and reduced recovery efficiency.

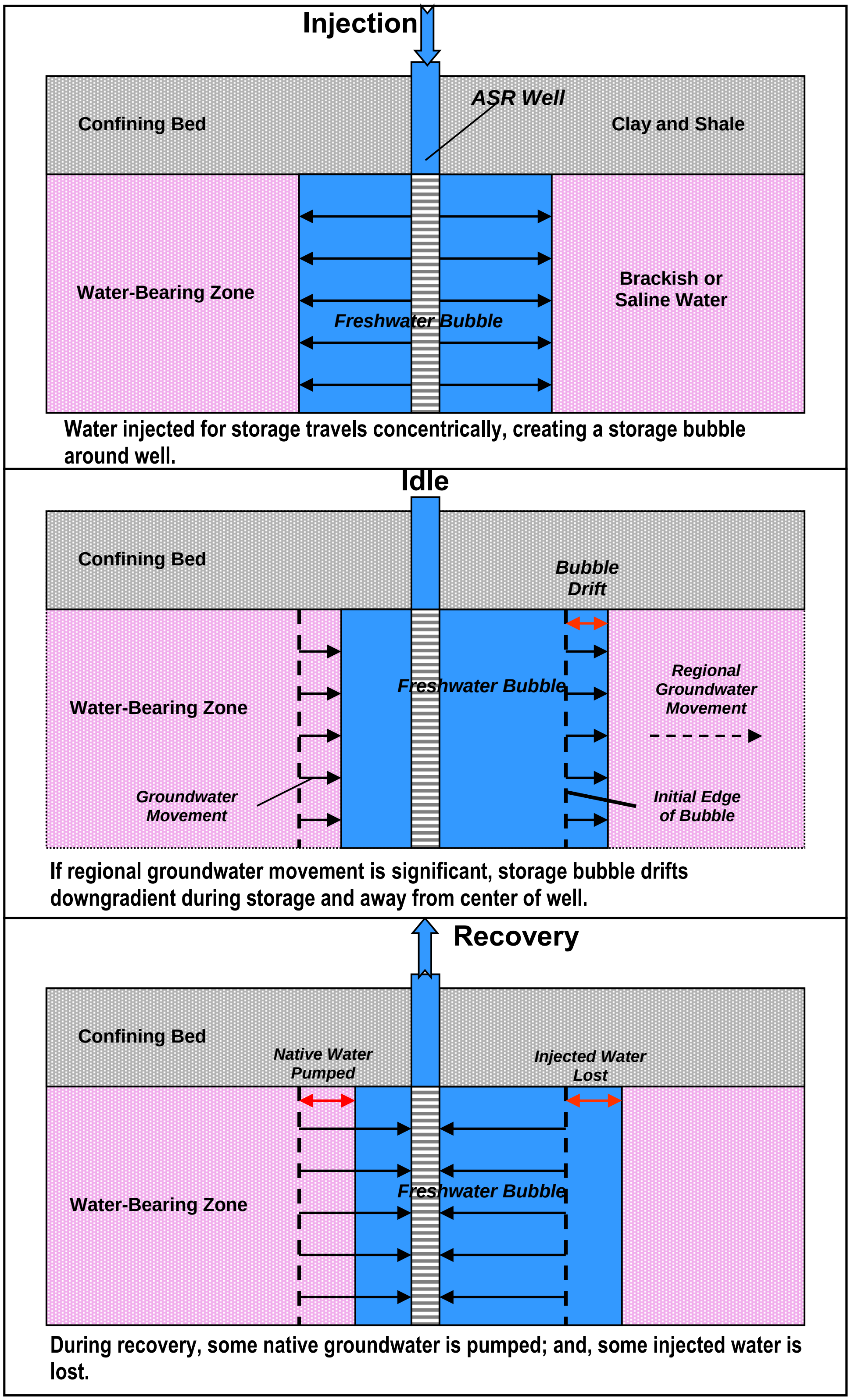


Figure 3. Schematic illustrating the drift of injected freshwater around an ASR well away from the well and reduced recovery efficiency.

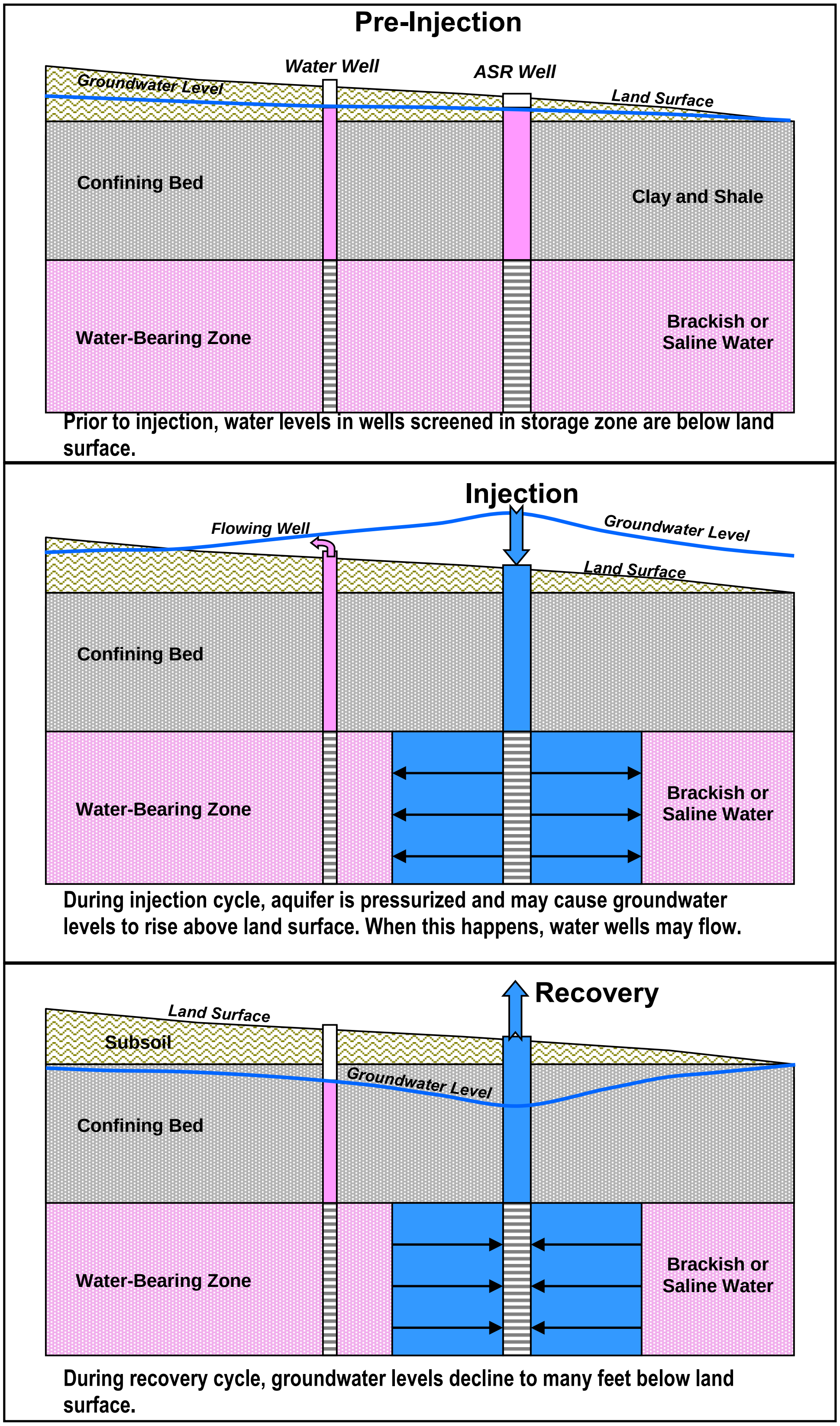


Figure 4. Schematic illustrating the change in groundwater water levels during ASR operations and potential flowing wells during the injection cycle.