HARRIS-GALVESTON SUBSIDENCE DISTRICT

# Executive Summary —

# Assessment of Subsidence and Regulatory Considerations for Aquifer Storage and Recovery in the Evangeline and Chicot Aquifers


**Prepared by:**

INTERA
GEOSCIENCE & ENGINEERING SOLUTIONS

INTERA Incorporated
9600 Great Hills Trail Suite, 300W
Austin, TX 78759

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# EXECUTIVE SUMMARY

Aquifer Storage and Recovery (ASR) is an alternative water supply strategy that uses an aquifer for storage to increase water supply more cost effectively than traditional storage expansion strategies (Pyne, 2005). Because of the potential benefits of increasing the available water supply in the region, the Harris-Galveston Subsidence District (hereafter referred to as the District) sponsored a study to research the potential occurrence of subsidence from using ASR as a water supply strategy in the Gulf Coast Aquifer System.

Subsidence is the lowering of land surface elevation. Subsidence has occurred and had significant consequences in the Houston region including contribution to flooding. The District was created by the Texas Legislature in 1975 to regulate groundwater withdrawal from the Gulf Coast Aquifer to stop on-going and prevent future subsidence. In the Districts' region, subsidence is caused by the lowering of groundwater levels in the aquifers (depressurization) and compaction of the many clay lenses in the subsurface. Subsidence caused by the compaction of the generally shallow fresh-water portions of the aquifer is well understood and documented.

ASR is the recharge of water into an aquifer through a groundwater well for future recovery from the same recharge well or another well. Because ASR includes a period of pumping during recovery of the stored water, it can potentially cause compaction and potential subsidence. Two types of ASR projects were considered to estimate the potential for subsidence associated with the application of ASR in the District: a project to provide industrial water supply during a drought of record (DOR) and a project to provide for an annual municipal summer peaking water supply. The operational details of these two hypothetical projects were conceptually developed and potential induced subsidence was simulated for each project. To demonstrate the relative benefits of ASR, the predicted subsidence from each simulated hypothetical ASR project was compared to the predicted subsidence that would occur through the utilization of only groundwater pumping for the same water demand.

Subsidence was calculated using groundwater flow models developed using the United States Geological Survey (USGS) groundwater code MODFLOW-NWT. Groundwater models are developed using published computer programs (such as MODFLOW) to numerically represent the natural groundwater system, simulate water levels in the aquifer, and estimate any subsidence that may result from water-level decline. The MODLFOW code used for this study is the standard used in the hydrogeologic community to predict compaction and subsidence and is the code that was used in the development of the District 2013 Regulatory Plan and the Houston Area Groundwater Model.

Model results from each hypothetical ASR project simulated confirmed that there is potential for subsidence associated with the application of ASR in the Gulf Coast Aquifer System in the District. The predicted subsidence associated with the ASR projects is generally greatest within 1,000 feet of the ASR well(s).

This study provides insight into how an ASR project can be designed and operated to minimize compaction and potential subsidence. Results show that ASR, when utilized for seasonal peaking, can result in less subsidence while producing the same volume of groundwater. This study provides a basis for future research on subsidence associated with ASR in the District and provides a framework for consideration by the District for the potential regulation of ASR wells.

## Definition of ASR and Statement of Research Needs

ASR is a proven water supply strategy to increase the availability of either groundwater or surface water through the storage of water in an aquifer using a well or wells. Just as surface water reservoirs are routinely used to increase surface water availability for the future, ASR uses an aquifer to increase availability of either stored surface water, groundwater or reuse water. Like a surface reservoir, a properly designed ASR project will define a yield (storage volume) that the ASR project will supply over some time horizon. **Figure 1** is a schematic of a hypothetical ASR well showing the stored water, often referred to as "the bubble," the buffer zone which represents a volume of mixed recharge and native aquifer groundwater and the target storage volume which encompasses both the bubble and the buffer zone.

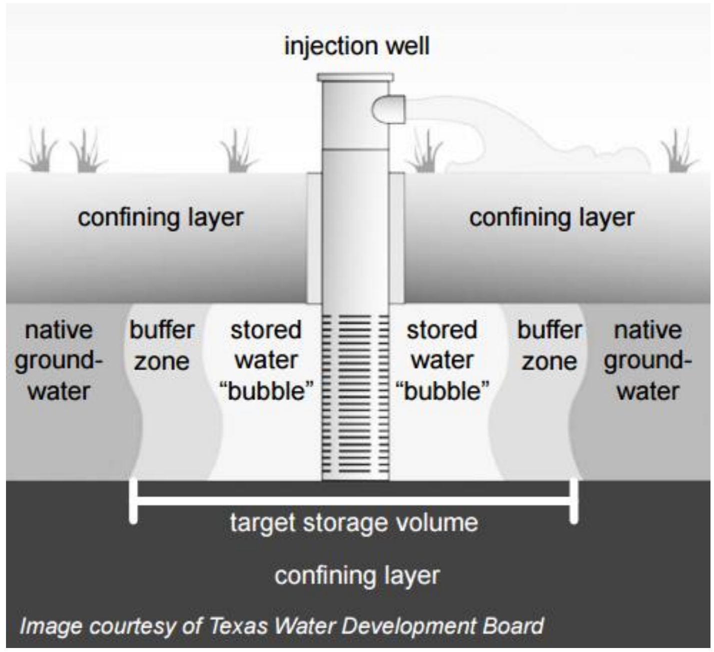


Figure 1 Schematic of an ASR well at the end of recharge and prior to recovery showing the stored water and the buffer zone.

An ASR project includes periods of recharge and periods of recovery (pumping). During recharge periods the water level at and near the well will rise greater than it was prior to recharge. During recovery periods the water level will fall below prior levels just as occurs in standard well pumping. The duration of recharge and recovery periods can vary significantly depending upon the volume of water stored and the needs of the project.

Historically, the Gulf Coast Aquifer System in the District had been the primary water source for the region's municipal, industrial, and agricultural water supply. The Chicot, Evangeline, and Jasper aquifers are the three primary water bearing units of the aquifer system, with the Chicot being the shallowest and the Jasper being the deepest. Extensive development of the Chicot and Evangeline aquifers in the District has resulted in a historical lowering of aquifer water levels and resulting subsidence. Land subsidence can contribute to infrastructure damage, coastal inundation, and inland flooding.

The District identified the need to study the potential for ASR as a viable water management strategy because ASR has been considered by both industrial and municipal water supply users within the District boundaries. The District Science and Research Plan (Turco, 2015) called for an assessment of the potential subsidence neutral yield of an ASR project in the Gulf Coast Aquifer System within the District. This desktop study evaluates the potential subsidence neutral yield of selected ASR project types and provides insight that can support future management and potential regulation of ASR wells in the District.

## Mechanisms of Subsidence and Relevance to ASR

The Gulf Coast Aquifer System is composed of a complex sequence of sands and clays. Compaction and resulting subsidence in the Gulf Coast aquifer in the study area is caused by the reduction of the pore pressure in the clay beds as a result of groundwater pumping. This decline in pressure in the aquifer leads to a decrease in pore pressure within the numerous clay lenses, which then begin to compact. This permanent compaction of the sediments, caused by groundwater withdrawal, is the largest contributor to land subsidence throughout the region (Figure 2).

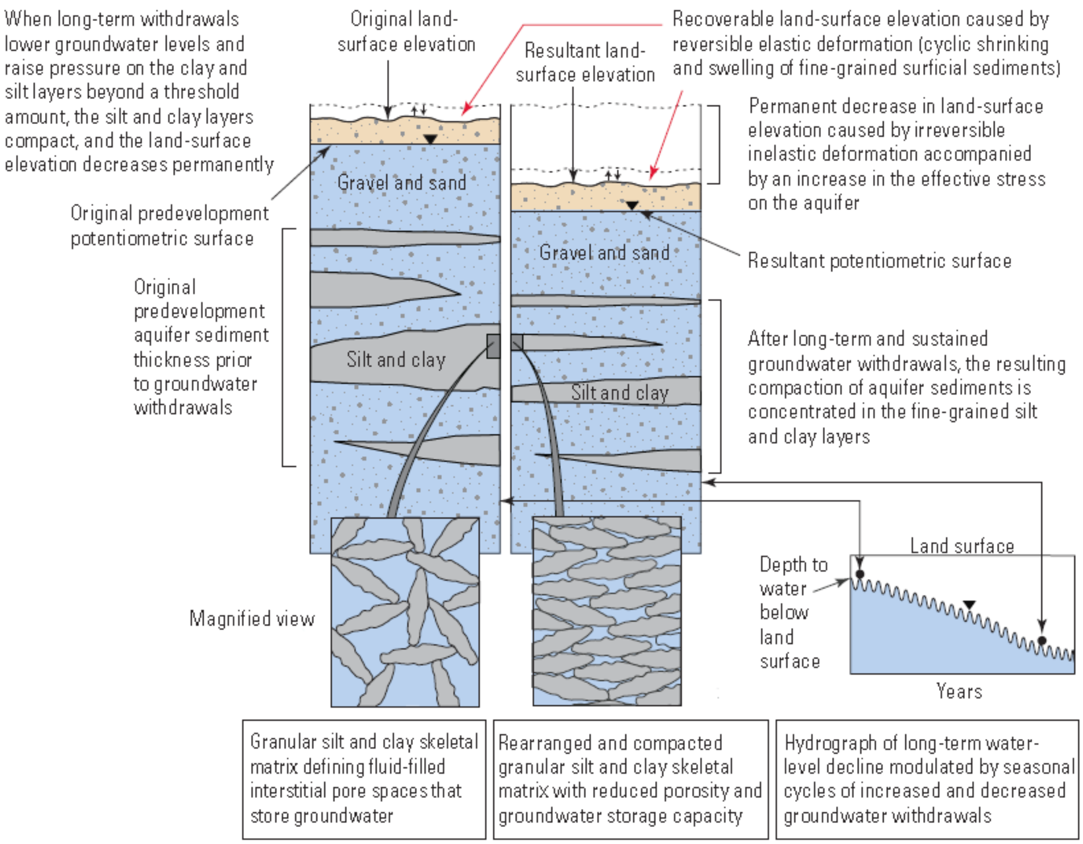


Figure 2 Mechanism of subsidence caused by water level declines induced by groundwater pumping (Source: Kasmarek and others, 2016).

Subsidence is measured as a lowering of ground surface elevation and is the surface manifestation of compaction occurring at depth. Compaction can be a slow process and the time it takes for compaction to occur within a clay bed depends on several clay characteristics. Generally, the thickness of the clay beds, the percentage of clay deposits relative to the total thickness of the aquifer, and the depth of burial of the deposits determine the potential for compaction under groundwater withdrawal and risk for subsidence.

There is potential for an ASR project to induce compaction and potentially contribute to subsidence in the Gulf Coast Aquifer. A literature review was performed on ASR in subsidence prone aquifers and five ASR case studies were reviewed for this study. The literature review showed that well-documented case studies for Managed Aquifer Recharge (MAR) in subsidence prone aquifers outnumbered ASR case studies. There are limited publicly documented case studies of the impacts of ASR in subsidence-prone aquifers. ASR case studies reviewed were the Las Vegas ASR and MAR project and the Antelope Valley, California ASR cycle test performed by the USGS. In both cases subsidence occurred in the vicinity of the ASR projects during their operation or testing.

The most significant finding from the case study review is that, in aquifers that have undergone significant regional subsidence, such as the Gulf Coast Aquifer System in the District, subsidence rates can increase again in response to additional pumping even when water levels remain above historical minimums. This has been documented in several areas of California and has been observed in the District in response to increased pumping during a regional drought in 2011. Therefore, maintaining water levels above historical lows does not guarantee the cessation of subsidence. These facts complicate the analysis of ASR projects impacts in aquifers that have experienced significant regional subsidence such as the Gulf Coast Aquifer System in the District.

## Hypothetical ASR Cases and Simulation of Resulting Compaction

The base case hypothetical ASR project considered in this study is a water supply strategy for industrial water users to address the drought of record near Texas City. To develop the operational details for an ASR project, an analysis of industrial water demand and availability during drought was performed for industrial clients of the Gulf Coast Water Authority in Texas City. To investigate hydrogeologic variability in Regulatory Area 1, two additional project locations were considered: one on Galveston Island (downdip site) and one just southeast of Loop 610 in the area that comprises the Galena Park PRESS Site (updip site) in the far northwest edge of Regulatory Area 1. As the study progressed, a municipal ASR alternative water supply strategy to meet annual summer peak demands was added to the study. The summer peaking case was also simulated at the three hypothetical locations used for the DOR case.

A numerical groundwater flow model was developed to estimate compaction associated with the hypothetical ASR projects. The numerical model was developed using the United States Geological Survey (USGS) code MODFLOW-NWT which supports the USGS subsidence (SUB) package. The SUB package is the standard code used in the hydrogeologic community to predict compaction and subsidence and is the code that was used in the development of other groundwater models in the area.

The water source for the hypothetical ASR projects simulated was assumed to be treated surface water from Gulf Coast Water Authority's Thomas S. Mackey Water Treatment Plant. An analysis of geochemical compatibility of the source water with groundwater was performed based upon measured groundwater quality data and inferred formation mineralogy. Results of the geochemical analysis suggest that there could be potential for calcite precipitation which could reduce the ability of the aquifer to store and transmit water. Additionally, there could be potential for other chemical reactions as result of mixing the source water with groundwater which could mobilize arsenic and other metals, increasing the total dissolved solids of the recovered water. Pre-recharge treatment of the injected water and proper design of an ASR buffer zone can mitigate any potential water quality issues identified in this study.

## Potential of Subsidence Induced by Compaction from ASR in the Chicot and Evangeline Aquifers

Using the numerical groundwater flow model, compaction was simulated for the DOR case and the summer peaking case at each of the three hypothetical sites. In addition, a simplified hypothetical ASR model was developed simulating a single ASR well completed in one hydrogeologic unit to isolate how various aquifer characteristics and ASR operational parameters can affect compaction.

Figure 3 plots predicted compaction versus time in the immediate vicinity of the well for the hypothetical DOR case and the summer peaking case at the Texas City location. Figure 3 also plots predicted compaction versus time for both sites from only production of an equal volume of groundwater. The difference in predicted compaction between the two curves provides a measure of the relative benefit of ASR over just groundwater pumping for an equal volume of groundwater. Model simulations predict that up to 0.3 feet of aquifer compaction will occur as a result of the hypothetical ASR projects analyzed as shown in Figure 3. At a radial distance of 1,000 feet from the ASR well(s), predicted compaction ranged from 25 to 30% of predicted compaction in the immediate vicinity of the ASR well(s). For both the DOR and summer peaking cases, ASR results in less compaction than production with no recharge. For the hypothetical DOR case, the benefit of ASR versus only groundwater production is 50% reduction in compaction after the first year of recovery, and approximately 3% reduction in compaction at the end of a 5-year recovery period (Figure 3). In the summer peaking case, the benefit of ASR versus only groundwater pumping is greater than 30% reduction in compaction after 20 years of annual operation (Figure 3).

Future ASR projects would require a site-specific analysis of their potential benefits as compared to traditional groundwater pumping based upon that project’s operational details and the detailed hydrogeology at the site. However, generally, model simulation results suggest that ASR projects can reduce the “effective drawdown” on the aquifer for a given groundwater yield and thus result in less compaction and potential subsidence.

The simulations also provide evidence that an ASR project can be designed and operated to minimize potential compaction. Simulations found that the key components of an ASR project to limit the potential compaction are: (1) maximizing the well spacing; (2) decreasing the recovery rate(s); (3) decreasing recovery duration prior to the next recharge cycle; and (4) targeting high transmissivity, low clay content intervals as the storage formation(s).

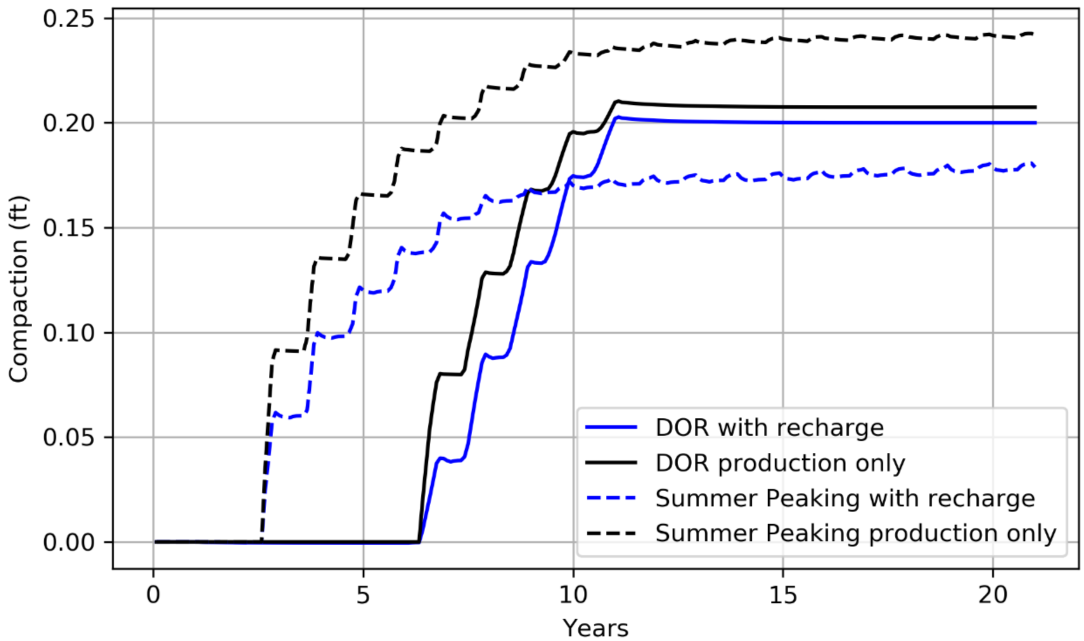


Figure 3 Compaction versus time for the DOR and summer peaking projects, comparing ASR simulations (recharge and production) to simulations with only production.

## Relevance and Potential Impact on Future Regulations

This study is the first District study of the potential for subsidence from the implementation of ASR. This study provides new insight for how compaction may occur with the development of ASR in the Chicot and Evangeline aquifers.

TCEQ has the sole regulatory authority to permit Class V ASR injection wells. However, the TCEQ does not have primacy over the regulation of production from Class V ASR wells within the District. The results of this study have led to the development of recommendations for future data and research requirements for ASR projects in the District. Recommendations are based upon the need for data collection and research to better understand aquifer performance and to better manage subsidence risk. This study resulted in several recommendations that may be used in the development of future District policies or form the basis for future District rules specific to ASR development within Harris and Galveston Counties.

HARRIS-GALVESTON
SUBSIDENCE
DISTRICT

1660 West Bay Area Blvd.
Friendswood, TX 77546-2640
281.486.1105

hgsubsidence.org