

Scope of Work

The Victoria County Groundwater Conservation District (VCGCD), in cooperation with the Calhoun County Groundwater Conservation District (CCGCD), the Refugio Groundwater Conservation District (RGCD), and the Texana Groundwater Conservation District (TGCD), collectively referred to as the “cooperating districts”, is requesting funds from the Texas Water Development Board’s (TWDB) Fiscal Year (FY) 2026 Groundwater Research, Science, and Data Collection Grant program to complete a comprehensive subsidence analysis and long-term subsidence monitoring station to support the safe and sustainable development of brackish groundwater resources in the central region of Gulf Coast Aquifer in Texas. The project is referred to as The Development of the CGCBGF Model for Groundwater Management and Planning.

1 – Overall Impact and Value of Project

This project will produce meaningful and measurable outcomes that advance the best available science for groundwater management and planning in Texas. The project will improve the scientific understanding of land subsidence associated with groundwater production within the Central Gulf Coast Aquifer system and provide practical tools that groundwater conservation districts, regional planners, and the Texas Water Development Board (TWDB) can use to evaluate and manage subsidence risks. The project integrates satellite remote sensing, geodetic monitoring, historical groundwater datasets, and numerical groundwater modeling to develop improved datasets and predictive tools for evaluating aquifer compaction and land-surface deformation associated with groundwater withdrawals.

The outcomes of this project will directly support groundwater management decisions within the cooperating districts. Demand for water resources in the central region of Gulf Coast Aquifer continues to increase, particularly for municipal and industrial development. As a result, brackish groundwater resources are increasingly being considered as an important component of future water supply strategies. However, the potential relationship between brackish groundwater production, aquifer pressure decline, and land subsidence remains insufficiently quantified in the central region of Gulf Coast Aquifer in Texas. This project will provide the scientific information and analytical tools necessary for the cooperating districts to evaluate subsidence risks associated with existing and proposed brackish groundwater development and to support science-based groundwater permitting decisions.

The project will also provide important information for the joint planning process of Groundwater Management Area 15. Historically, land subsidence has not been explicitly incorporated into groundwater availability modeling or Desired Future Condition (DFC) evaluations within the management area. By compiling and analyzing satellite-based deformation measurements, groundwater production data, groundwater level trends, and geologic information describing compressible clay interbeds, the project will generate new datasets that can be incorporated into future updates of the Central Gulf Coast Groundwater Availability Model (GAM). These improvements will help ensure that subsidence impacts are considered in future groundwater planning and modeling efforts.

On the state level, the project will support the development of science-based policies and regulatory frameworks governing brackish groundwater production. Recent legislative initiatives in Texas have promoted the development of brackish groundwater resources to meet growing water supply needs. These initiatives promote the development of permitting frameworks and rules that encourage responsible groundwater development while protecting aquifer systems from unacceptable impacts such as land subsidence. The results of this project will provide groundwater conservation districts with the scientific information necessary to evaluate subsidence risks associated with brackish groundwater production and will provide a framework that other districts across Texas can use when developing rules and permitting strategies for brackish groundwater resources.

Land subsidence is particularly important for coastal communities because it compounds the impacts of relative sea-level rise. Previous studies have confirmed that land subsidence is a prominent contributing factor to relative sea-level rise in coastal cities worldwide (Tay et al., 2022). Three of the groundwater conservation districts participating in this project contain significant coastline, with Calhoun County alone containing approximately 570 miles of shoreline. Improved understanding of subsidence patterns in these counties will help local governments, water

planners, and water managers better evaluate long-term risks associated with coastal flooding, infrastructure stability, and ecosystem impacts.

1.1 Key Outcomes of the Project

1. Advancement of Best Available Science for Groundwater Management

- The project will integrate satellite-based Interferometric Synthetic Aperture Radar (InSAR), ground-based Global Navigation Satellite System (GNSS) monitoring, historical groundwater datasets, and MODFLOW-6 CSUB subsidence modeling to create a comprehensive evaluation of subsidence in the Central Gulf Coast Aquifer system. These datasets and modeling tools will improve the scientific understanding of aquifer compaction and subsidence associated with groundwater withdrawals.

2. Improved Groundwater Management Tools for GCDs and Regional Planning

- The project will provide datasets, monitoring infrastructure, and modeling tools that enable groundwater conservation districts to evaluate subsidence risks associated with brackish groundwater development. These tools will support groundwater permitting decisions, joint planning activities in Groundwater Management Area 15, and future updates to groundwater availability models.

3. Statewide Transferability and Long-Term Monitoring Infrastructure

- Installation of a permanent GNSS-based subsidence monitoring station will provide continuous high-precision measurements of vertical land motion within the region. The monitoring data, subsidence datasets, and modeling tools developed through this project will be publicly available and transferable to other regions of Texas where groundwater development and subsidence risks must be evaluated.

Together, these outcomes will improve groundwater science, strengthen groundwater management decisions, and support the safe and sustainable development of groundwater resources throughout the Texas Gulf Coast region and across the state.

2 – Benefits for Groundwater Management

The proposed project will significantly improve groundwater management and planning across the central region of Gulf Coast Aquifer in Texas by expanding the scientific understanding of land subsidence associated with groundwater production and by providing practical tools for evaluating subsidence risks associated with future groundwater development. The project directly supports the safe and sustainable development of groundwater resources, particularly brackish groundwater, while protecting aquifer integrity and minimizing the risk of land-surface subsidence.

2.1 Local Groundwater Management Benefits

The project will provide direct benefits to local groundwater management efforts within the cooperating districts by improving the ability of the districts and permit applicants to evaluate potential subsidence impacts associated with groundwater development projects. In particular, the project will develop scientifically defensible datasets and modeling tools needed to credibly predict subsidence, if any, that may occur as a result of moderate to large-scale brackish groundwater production. The availability of these tools will improve the ability of groundwater conservation districts, permit applicants, and other interested parties to rely on credible scientific information when evaluating proposed groundwater production projects prior to final permitting decisions. In addition, the project will increase certainty that brackish groundwater projects permitted by the cooperating districts can proceed while minimizing the potential for unacceptable subsidence impacts.

The project also directly supports the regulatory framework for managing groundwater production and subsidence of the cooperating districts. The cooperating districts have adopted rules intended to balance the safe development of deep saline groundwater resources with protection against unacceptable land subsidence and/or drawdowns in shallower freshwater zones. These rules include provisions limiting acceptable subsidence impacts, establishing monitoring and reporting requirements for subsidence associated with certain production permits, and potentially requiring curtailment of groundwater production to control or prevent subsidence. See Rule 6.3(1)(1.5), Rule 6.4(4)(4.11), Rule 6.3.2(3), Rule 6.4.3(4)), and Rule 9.1(2) of the Rules of the Victoria County Groundwater Conservation District for more details.

In addition, the cooperating districts have adopted groundwater permitting rules intended to encourage the responsible development of deep-saline groundwater resources. These rules include designation of special groundwater management zones for deep-saline groundwater resources, reduced well spacing requirements for deep-saline production wells, modified well construction requirements, increased production allowances within designated deep-saline groundwater management zones, streamlined permit application requirements, and appropriate permit conditions governing brackish groundwater production. The proposed project will provide the scientific foundation needed to support implementation of these rules and improve the districts' ability to evaluate potential subsidence impacts associated with current and future brackish groundwater development. See Rule 1.1, Rule 2.4(9), Rule 2.3, Rule 6.4(1–2), Rule 6.4(3–4), Rule 6.4.1(1)(1.1–1.3), Rule 6.4.3, and Rule 6.4.4 of the Rules of the Victoria County Groundwater Conservation District for more details.

The project also supports groundwater management planning by providing improved technical information for evaluating Desired Future Conditions (DFCs) during the joint planning process. In particular, the results of the project will help representatives and technical consultants evaluate the factors established under Texas Water Code §36.108, including consideration of the potential impacts of proposed Desired Future Conditions on land subsidence as described in Section 36.108(d)(5). By improving the ability to evaluate the relationship between groundwater withdrawals, aquifer pressure decline, and land-surface deformation, the project will strengthen the scientific basis for groundwater management decisions within the cooperating districts.

2.2 Statewide Benefits and Advancement of Best Available Science

In addition to providing important local benefits, the proposed project will contribute to statewide groundwater science and management efforts by improving the datasets and analytical tools used to evaluate land subsidence across the Texas Gulf Coast region. The project will integrate satellite-based Interferometric Synthetic Aperture Radar (InSAR) measurements, ground-based deformation measurements from NOAA Continuous Operating Reference Stations, historical groundwater production records, groundwater-level data, and geologic information describing compressible clay interbeds within the Gulf Coast Aquifer system. The integration of these datasets will represent a comprehensive evaluation of subsidence in the central region of Gulf Coast Aquifer in Texas.

The project will also refine the Central Gulf Coast Brackish Groundwater Flow Model (CGCBGF Model) and apply the MODFLOW-6 CSUB subsidence module to simulate aquifer compaction and associated land-surface deformation. These modeling tools will improve the ability of groundwater managers and researchers to evaluate the relationship between groundwater withdrawals and subsidence, and they will provide a transferable technical framework that may be applied to other areas of the Texas Gulf Coast where subsidence associated with groundwater development is a concern.

In addition, the installation of a permanent Global Navigation Satellite System (GNSS) subsidence monitoring station will provide continuous high-precision measurements of vertical land motion within the region. These observations will provide independent validation of satellite-based subsidence measurements and support long-term monitoring of aquifer system response to groundwater production. The monitoring data and modeling tools developed through this project will contribute to the body of publicly available scientific information used by groundwater conservation districts, regional water planning groups, and the Texas Water Development Board to support groundwater management, subsidence assessment, and sustainable groundwater development across Texas.

3 – Capacity and Commitment of the Victoria County Groundwater Conservation District

The VCGCD has demonstrated both the administrative capacity and the institutional commitment necessary to successfully manage and complete this project. The project team includes a dedicated grant coordinator who will oversee the administrative and financial responsibilities associated with managing the grant, including documentation, reporting, and compliance with Texas Water Development Board (TWDB) grant requirements. This administrative support ensures the VCGCD has the capability to effectively receive and manage grant funds.

3.1 Victoria County Groundwater Conservation District's Capacity

The organizational structure of the VCGCD is sufficient to manage and administer the proposed project. The operations of the VCGCD are carried out by a staff of seven positions and several consultants who support groundwater management, monitoring, and administrative functions. Management of the VCGCD is provided by Tim Andruss, General Manager, who will serve as the project manager for this project. Administrative support will be provided by Caitlynn Davenport and Lisa Ramirez, Administrative Coordinators, who assist with financial administration, grant documentation, and day-to-day operational support for the VCGCD. Permitting and enforcement activities are supported by Mike Benavides and Corbin Karl, Compliance Specialists, who manage regulatory compliance and permit-related activities within the VCGCD. Field services are provided by Willie Immenhauser, Aquifer Monitoring Technician, along with an additional technician position that supports aquifer monitoring and data collection activities for the VCGCD. This organizational structure provides the personnel and administrative framework necessary to successfully manage project activities, oversee grant administration, and ensure completion of project deliverables.

Project management will be led by Tim Andruss, who has extensive experience overseeing groundwater-related programs and regional water planning initiatives. Mr. Andruss has served as Chair of Groundwater Management Area (GMA) 15 for three joint planning cycles and previously served as Chair of the South Central Regional Water Planning Group Water Planning Group. His experience managing large, multi-agency groundwater initiatives will be instrumental in coordinating the technical team, managing project timelines, and ensuring successful completion of project objectives.

The VCGCD has a strong track record of successfully administering groundwater research projects. One example includes an Aquifer Storage and Recovery (ASR) demonstration study funded through a TWDB groundwater grant of approximately \$285,000 over a three-year period. Mr. Andruss and his team successfully managed the financial, administrative, and technical components of that study. In addition, the districts have previously funded regional investigations of historical subsidence and have already developed a regional brackish groundwater flow model to support evaluation of brackish groundwater development.

3.2 Victoria County Groundwater Conservation District's Commitment

The VCGCD has maintained an active groundwater science program for approximately 15 years, demonstrating a long-standing commitment to advancing groundwater research and improving the scientific basis for groundwater management decisions. The proposed project builds directly upon these prior efforts and reflects the cooperating districts' continued investment in understanding subsidence and groundwater resource development.

The cooperating districts have also demonstrated financial commitment to completing the project. District staff will provide approximately \$10,000 in in-kind services, and the cooperating districts have budgeted \$40,000 in direct funding available to support project implementation. In addition, the districts have sufficient financial resources available to begin work immediately and do not require advance funding from TWDB to initiate project activities.

Importantly, the districts have a clear commitment to using the results of this project to support groundwater management and rulemaking related to brackish groundwater production. The scientific findings generated through this study will help inform the rulemaking process for brackish groundwater development and provide a defensible technical basis for evaluating potential subsidence impacts associated with existing and proposed permits. Ultimately, the districts intend to use the results of this project to support the safe and sustainable development of brackish groundwater resources while protecting aquifer integrity and minimizing the risk of land subsidence.

4 – Technical Approach and Feasibility

The VCGCD proposes a technical approach based on successful projects of a similar nature and has assembled a project team with the expertise and experience to perform their assigned tasks with a high degree of quality and efficiency. The principal investigators of the project team are Steve Young, PhD, PE, PG. of INTERA; Joe Hughes, PhD. of INTERA; Zhong Lu, PhD. of Southern Methodist University; and Guoquan Wang, PhD. of University of Houston.

The Interferometric synthetic aperture radar (InSAR) study to measure land subsidence will be led by Dr. Zhong Lu, who has conducted numerous similar studies along the Texas Gulf Coast, including InSAR investigations for the Harris-Galveston Subsidence District (HGSD) and two groundwater conservation districts (GCDs) in GMA 15.

The development of the CGCBGF Model has been on-going for approximately nine years by INTERA, Inc. INTERA has performed numerous aquifer characterization studies and modeling projects in Texas for the past 20 years. INTERA's experience and expertise in groundwater modeling is strengthened by the recent addition of Dr. Joseph Hughes, who is the principal codeveloper of MODFLOW 6 and the principal developer of the CSUB subsidence package. Dr. Hughes has been working extensively on applying both MODFLOW 6 and CSUB models in the Gulf Coast Aquifer System for the last year and is well positioned to successfully incorporate CSUB into the CGCBGF Model. The approach for calibrating the CSUB module using measured subsidence and water level values is based on similar projects successfully executed by the HGSD in Texas and the California Department of Water Resources.

The construction and operation of the proposed subsidence monitoring station is based on guidelines, instructions, and vendors used by HGSD to develop their successful monitoring network consisting of several hundred stations. To continue that success, INTERA has established communications with all of HGSD major vendors and are planning on using the same vendors to HGSD for the majority of the work.

4.2 Project Tasks

4.2.1 Task 1 – InSAR Study

Interferometric synthetic aperture radar (InSAR), which is a remote sensing technique, has proven to be an effective method for measuring land subsidence in the Northern Gulf Coast (Qu and Lu, 2022). In the northern Gulf Coast region near Houston, InSAR techniques have successfully mapped both groundwater-related subsidence and the locations of geologic faults (Qu and Lu, 2022). As part of this project, InSAR will be used to map land-surface deformation across the four-county study area from 2018 through 2025. The results will also provide an important dataset for evaluating the groundwater-compaction processes that will be simulated in Tasks 2 and 3 of this project.

Land subsidence is particularly of concern for counties with coastlines because of the compounding impact that land subsidence has with sea-level rise on coastal communities. Previous studies have confirmed that land subsidence is a prominent contributing factor of the relative sea level rise in many coastal cities worldwide (Tay et al., 2022). All of the counties within the study area of this project have coastlines with Calhoun County having approximately 570 miles of coastline.

Subtask 1a – Collection and Analysis of InSAR data.

Multiple sets of InSAR data will be collected and analyzed from January 2018 through December 2025 across all of Calhoun, Jackson, Refugio, and Victoria counties. The InSAR data will be collected and analyzed by a team of geophysicists under the supervision of Dr. Zhong Lu, the Shuler-Foscue Endowed Chair Professor of Geophysics in the Huffington Department of Earth Sciences and Professor of Civil Environmental Engineering at Southern Methodist University (SMU). The expected precision of the deformation measurements from the InSAR analysis will be approximately 1 cm/year. Conventional interferometric SAR (InSAR) can be limited by the spatial and temporal decorrelation between radar acquisitions, which can reduce the robustness of deformation estimates (Lu and Dzurisin, 2014). To overcome these limitations, multi-temporal InSAR (MTI) techniques (Ferretti et al., 2001; Berardino et al., 2002; Hooper et al., 2004, Hooper, 2008; Qu et al., 2015, 2019) will be applied. These MTI techniques have been successfully implemented as part of INTERA and SMU joint InSAR studies in Wharton and Matagorda counties (Young et al. 2020a, 2020b).

For each county, time-series of deformation results will be generated from multiple radar scenes (snapshots), supporting the evaluation of changes in land-surface elevation. Multiple scenes will be analyzed each year. Most of the trend analysis will be performed on

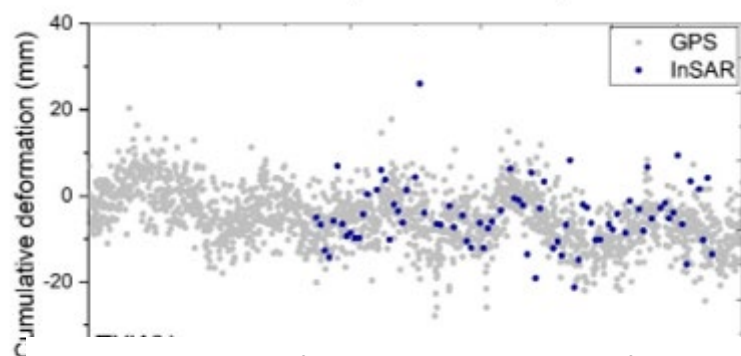


Figure 1- Comparison of InSAR measurements to a Deformation Measured at a Continuous Operating Reference Station (CORS) in Wharton County (Young et al. 2020)

annual average deformation rates. At approximately twenty sites, the results for each scene will be plotted to identify possible seasonality effect as is shown in Figure 1. To verify the accuracy of the InSAR-derived deformation measurements, the results will be compared to the deformation measured at Continuous Operating Reference Station (CORS) operated by the National Oceanic & Atmospheric Agency (NOAA). Relevant stations are located at Victoria, City of Enda, and Port Lavaca in Victoria, Jackson, and Calhoun counties, respectively. Figure 1 presents an example comparison between InSAR-derived deformation measurements and CORS observations from a previous INTERA/SMU InSAR study for Coastal Bend GCD. The comparison demonstrates the consistency between satellite-based deformation measurements and ground-based observations.

Subtask 1b – Prepare Report

INTERA will prepare a technical report documenting methods used for InSAR data collection, processing, and analysis. InSAR measurements can achieve spatial resolutions as fine as approximately 20 meters. However, for reporting and analytical purposes, the spatial datasets will likely be aggregated to grid resolution greater than 100 meters to improve data stability and facilitate interpretation of regional deformation patterns. Temporal averaging will generally be performed on an annual basis to aid in identifying statistically significant trends in land-surface deformation within each county of the project area. The report will include graphical analyses illustrating groundwater level trends and groundwater production over time, along with comparisons to the observed deformation time series derived from the InSAR analysis. These comparisons will be used to evaluate potential correlations between groundwater level declines, pumping patterns, and observed land surface deformation. Where such relationships are identified, the magnitude and statistical significance of the correlations will be quantified. Where appropriate, the maps of the deformation rates will be developed to identify possible locations of geologic faults.

Subtask 1c – Deliverables for Task 1.

Deliverables for Task 1 will include the following:

- GIS-compatible spatial datasets containing processed InSAR deformation measurements for the study area
- time-series deformation datasets derived from the InSAR analysis
- comparison datasets between InSAR-derived deformation and CORS observations
- a technical report prepared by INTERA documenting the methods, datasets, and results of the InSAR analysis

Task 2 – Model Historical Subsidence

From the 1970s through the mid-2000s, most land subsidence investigations in Texas focused almost exclusively on the greater Houston region, particularly studies funded by the Harris–Galveston Subsidence District (HGSD) and the Fort Bend Subsidence District (FBSD). With increased interest and funding associated with the Lower Colorado River Authority–San Antonio Water System Water Project (LSWP), which proposed exporting groundwater from the Lower Colorado River Basin (LCRB) to the City of San Antonio, the geographic focus of subsidence investigations expanded southward to include Wharton, Matagorda, and Jackson counties. These counties have experienced substantial groundwater withdrawals for rice irrigation since the mid-1940s.

Results from previous investigations modeling studies (URS, 2007; Kasmarek, 2012) indicate that notable land subsidence had occurred in these three counties since the 1940s. However, there has yet to be a study to show evidence of measured subsidence. With the possible exception of a TWDB report by Ratzlaff (1982), which compiled a limited amount of land subsidence data in the Gulf Coast, no comprehensive study had documented measured land subsidence across the four counties managed by the Districts had occurred prior to 2015.

In response to growing concerns regarding the potential impacts of subsidence, the cooperating districts joined with three additional groundwater conservation districts within Groundwater Management Area 15 (GMA 15) to fund a regional investigation of land subsidence. This study, conducted by INTERA (Young et al., 2016), concluded that measurable subsidence had occurred in all four counties. The results indicated that sufficient subsidence had already taken place to warrant further evaluation of high-capacity groundwater production wells and their potential to induce additional land subsidence in the region.

Subtask 2a – Literature Search on Historical Subsidence, Production and Water Levels

The objective for Subtask 2a is to assemble information regarding historical subsidence, groundwater production and water levels needed to support the modeling of subsidence in Task 2b. To obtain the historical production and water level data, the project team will query the TWDB groundwater database, the TWDB GAMs for the Central Gulf Coast, and the TWDB county reports. In addition, the project team will query groundwater studies performed by consultants for GCDs and municipalities such as the LWSP (Young and Kelley, 2009). Figure 4-2 shows an example of the type of historical pumping data that can be obtained among the different data sources for Jackson County. We anticipate collecting similar types of data for Calhoun, Refugio, and Victoria counties. For the subject counties, the TWDB has estimates of production since 1988. The most comprehensive source for measured land subsidence will be the aforementioned study by Young et al. (2016). The findings of Young et al. (2016) include:

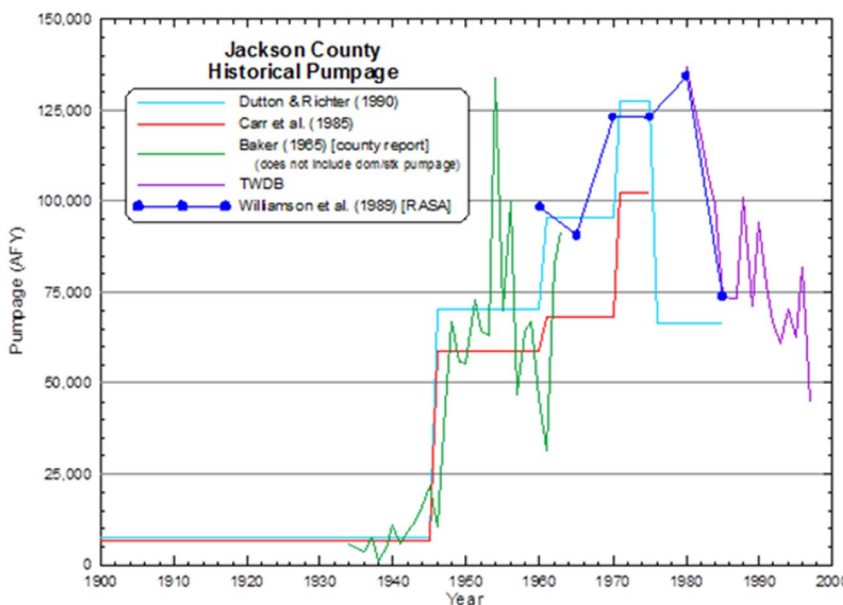


Figure 4-2. Total Groundwater Pumpage in Jackson County between 1900 and 2000 from different information sources

“Estimate historical land subsidence in seven counties in GMA 15. The report presents ground surface elevation data from National Geodetic Survey (NGS) benchmarks called Permanent Identifiers (PIDs), old topographic maps, and Light and raDAR (LIDAR) data from seven counties in GMA 15. The PID data provide ground surface elevations at 1,700 point locations prior to 1950. The topographic maps cover approximately 2,150 square miles and were constructed between 1950 and 1960. To extract point location data from the topographic maps, the maps were digitized and converted to Geographic Information System (GIS) files. The LIDAR data cover approximately 2,500 square miles and were collected after 2006. The joint analysis of these three data sets support the following conclusions:

- *The LIDAR and PID data indicate that DeWitt, Jackson, Matagorda, Refugio, Victoria, and Wharton counties have experienced at least 2 ft of land subsidence, and Calhoun County has experienced at least 1.5 ft of land subsidence.*
- *The LIDAR and topographic map data indicate that Calhoun, DeWitt, Jackson, Matagorda, Refugio, Victoria, and Wharton counties have experienced at least 2 ft of land subsidence since 1950.*
- *An analysis of the PID data, topographic map data, and LIDAR data indicates that more than two feet of average subsidence has occurred across about 100 square miles covering southwest Wharton, southeast Jackson, and northwest Matagorda counties. (p. 48-49)*

Subtask 2b – Site Selection and Parameterization of Subsidence Model

The most advanced MODFLOW package available for simulating aquifer compaction and land subsidence is the Skeletal Storage, Compaction, and Subsidence (CSUB) package (Hughes et al., 2022). CSUB is a module within the MODFLOW 6 groundwater modeling framework (Hughes et al., 2017) that can be run either as part of an integrated groundwater flow model or as a stand-alone subsidence model. For the purposes of this subtask, CSUB will be implemented as a stand-alone model in which measured groundwater levels are used as inputs to simulate compaction and land-surface deformation. The algorithms in that CSUB package that simulate compaction and land subsidence are similar to those used by PRESS (Espey, Huston, and Associates, Inc. 1982), used by the HGSD since the early 1980s to simulate subsidence. Although both CSUB and PRESS can be used as stand-alone models, only CSUB has the ability to be coupled directly within a groundwater flow model.

Both the PRESS and CSUB models simulate land subsidence using Terzaghi's theory of one-dimensional consolidation (Terzaghi, 1925), in which compaction is controlled by changes in groundwater levels (or pore pressure), the geotechnical and hydraulic properties of the clay units, variations in effective stress associated with groundwater level fluctuation, and characterization of the distribution of the clay interbeds within the aquifer system. The characterization of the clay interbeds is typically performed by interpreting individual geophysical logs and interpreting between the logs. When implemented as stand-alone models, both the historical PRESS subsidence models and the CSUB module require groundwater heads to be specified based on measured water levels rather than simulated values from a groundwater flow model which will be achieved with data developed under Subtask 2a.

Land subsidence is primarily controlled by the compaction of fine-grained clay interbeds within the aquifer system. Therefore, accurate representation of the thickness and distribution of clay layers is critical for developing reliable subsidence simulations. For each modeling site, the number and thickness of clay interbeds will be determined through interpolation and interpretation of nearby geophysical logs. Figure 4-3 shows the locations of the approximately 480 geophysical logs that were previously used to construct and calibrate the Central Gulf Coast Brackish Groundwater Flow Model (CGCBGFM) (Yang et al., 2026; Young et al., 2018). These logs provide the stratigraphic framework needed to characterize the distribution of compressible clay units within the aquifer system.

As part of this subtask, CSUB models will be created for at least ten locations. The subsidence history at each site will be developed by integrating deformation estimates from the InSAR analysis described in Subtask 1a with historical groundwater production and water-level datasets compiled in Subtask 2a. Clay interbed properties at each site will be estimated through interpretation of geophysical logs and regional stratigraphic data. The range of geotechnical and hydraulic properties assigned to the clay interbeds will be based on several sources, including results from previously developed PRESS models (Fugro, Inc., 2013), the Gulf Coast Groundwater Availability Model (GAM) developed for GMA 14 (Ellis et al., 2023; Keester et al., 2025), laboratory measurements of clay properties (McClelland Engineering, 1979; Fugro, Inc., 2013), and field measurements of clay compressibility and hydraulic characteristics reported in previous Gulf Coast studies (Gabrysch, 1982).

Subtask 2c– Simulated Historical Subsidence

The CSUB model will be applied in a manner similar to the approach historically used by the HGSD with the PRESS models since the 1980s (Espey, Huston and Associates, Inc., 1982; Fugro, Inc., 2013). HGSD has developed PRESS models for 26 monitoring locations across the greater Houston region. At each site, the PRESS models were calibrated to reproduce the historical subsidence measured at that location. In these models, measured groundwater-levels are entered into PRESS to represent the hydraulic head in the permeable deposits that house the clay interbed. The lowering the pressure in the more permeable deposits leads to a gradual depressurization of compressible clay layers over time, which is a primary cause of land subsidence.

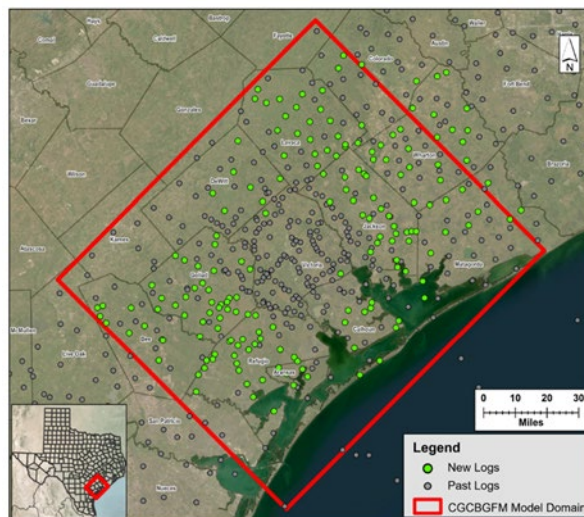


Figure 4-3. Location of 480 geophysical logs in the Central Gulf Coast Brackish Groundwater Flow Model

During calibration of the PRESS models, the hydraulic properties (such as hydraulic conductivity) and geotechnical properties (such as the coefficient of compressibility) were adjusted until acceptable agreement between simulated and observed subsidence was achieved. For predictive simulations, the PRESS models were subsequently driven by groundwater-level changes simulated by regional groundwater flow models, while retaining the clay properties determined during the calibration process.

This modeling approach has recently been adopted by the State of California as part of a Best Management Practice (BMP) framework for evaluating and mitigating land subsidence (Ellis et al., 2025; INTERA, 2025). In California's implementation, the CSUB model is used instead of the PRESS model to simulate interbed compaction. Approximately 50 locations were evaluated in California using this approach to reconstruct historical subsidence and support groundwater management planning.

As described in Subtask 2b, at least ten representative sites within the project area will be selected for developing site-specific CSUB models to simulate historical subsidence. The estimated subsidence at each site will be based on comparisons between historical National Geodetic Survey (NGS) benchmark elevations and modern elevation datasets spanning approximately 50 years. Figure 4-4 shows the locations of the NGS benchmarks used in the study by Young (2018), which represent candidate locations for the CSUB simulations.

Site selection will consider several criteria, including the availability of nearby water wells that provide historical groundwater-level records and the presence of geophysical logs that can be used to characterize the thickness and distribution of clay interbeds. In addition, the selection process will consider locations where significant subsidence has already been estimated. Table 4-1 lists locations within the counties shown in Figure 4-4 where more than 1.5 feet of subsidence was calculated by Young (2018) for NGS benchmarks located within two miles of one another.

A report will be prepared by INTERA documenting the development, calibration, and application of the CSUB models used to simulate historical subsidence within the study area.

Table 4-1 Number of Paired PID locations where land subsidence is greater than 1.5 feet and 2.0 ft by county from before 1950 to after 2006 (from Young, 2018)

County	Number of Instances where the calculated land subsidence is greater than 1.5 ft (or 2.0 ft) at NGS benchmarks that are within 2 miles of each other	
	1.5 ft	2 ft
Calhoun	3	0
DeWitt	14	8
Jackson	23	16
Matagorda	63	29
Refugio	16	6
Victoria	11	9
Wharton	64	38

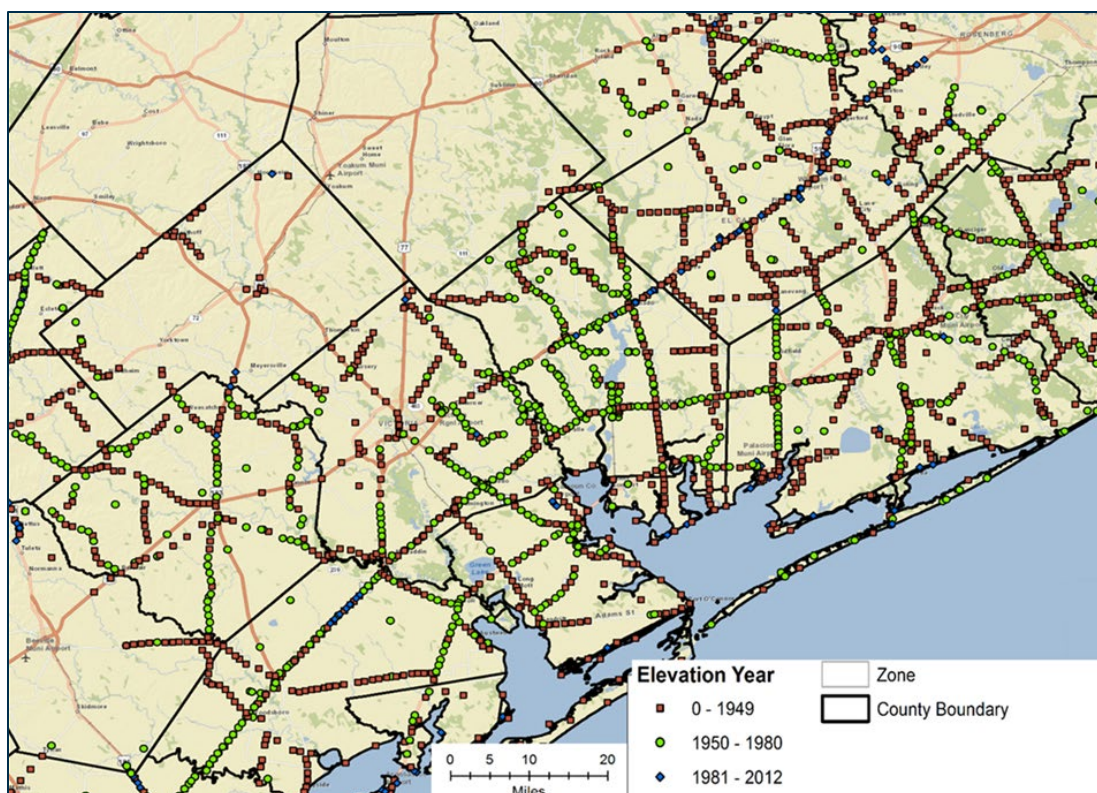


Figure 4-4 The dataset of NGS benchmarks downloaded from <http://geodesy.noaa.gov/> and used to determine the amount of land subsidence by comparing their elevations to LIDAR elevations measured after 2006 (from Young, 2018)

Subtask 2d– Deliverables

The deliverables for Task 2 will consist of documentation and modeling files describing the development and application of the CSUB models used to simulate historical land subsidence. These deliverables will include a report that summarizes the data compilation, modeling methodology, calibration procedures, and results of the subsidence simulations conducted for the selected study sites.

The deliverables will also include electronic copies of the CSUB model input and output files developed for the selected locations. These model files will allow the cooperating district, TWDB, and other interested parties to reproduce the subsidence simulations and provide a foundation for incorporating the calibrated subsidence parameters into the regional groundwater flow model described in Task 3.

Task 3 – Model Update the Central Gulf Coast Brackish Groundwater Flow Model (CGCBGF Model)

The CGCBGF model (Yang et al. 2025) is a MODFLOW 6 model that includes all or portions of 19 counties in the Central Gulf Coast of Texas. Figure 4-3 shows the 11,730 square miles covered by the model domain. The cooperating districts developed the CGCBGF Model to help estimate the impacts of brackish water development on fresh groundwater resources and to help develop rules for permitting brackish groundwater production. The CGCBGWF model uses 15 model layers to represent the nine formations that comprise the Chicot, Evangeline, Burkeville, and Jasper hydrogeologic units (Young et al. 2010). The refined three-dimensional structure in the CGCBGWF Model provides for significantly better vertical placement of well screens, of pumping, and of differences in transmissivity than the four-layer structure of the current GAM (Chowdhury et al. 2004).

Subtask 3a – Integrate Subsidence Module into CGCBGWF Model

One of the intended purposes of the CGCBGF Model is to provide a tool for potential permit applicants to use to access the feasibility of developing brackish groundwater. The CCGCD, RGCD, and TGCD are in the process of finalizing the development of rules, similar to those previously completed by the VCGCD, to promote brackish production by providing a significantly higher maximum production allocation per acre than allowed for fresh groundwater. The higher allocation is provided with the requirement that curtailment of production will be enforced if triggers for either drawdown in selected monitoring wells or land subsidence at designated monitoring stations are exceeded. Hence, the permittee has a major incentive to perform an appropriate level of aquifer characterization and groundwater model prior to construction a well field. The cooperating districts offer the CGCBGF Model to permit applicants as a starting point from which to perform site specific analysis and then use the results of the analysis to modify the parameters in the CGCBGWF Model accordingly.

Currently, there are no tools that are well suited for assessing the impacts of brackish production on subsidence for the central portion of the Gulf Coast Aquifer. In order to provide permitting applicants and the cooperating districts with a practical tool for predicting subsidence, CSUB will be integrated into the CGCBGF Model. Dr. Joe Hughes, who is the primary developer of CSUB and a copincipal developer of MODFLOW 6, will incorporate CSUB into the CGCBGF Model.

Following the successful integration of CSUB, the capabilities of CGCBGF Model to provide reasonable predictions of subsidence will be tested by simulating drawdowns and subsidence for several of the historical subsidence simulation sites modeled in Task 2. The resulting outcomes of these simulations will be documented in a report that will be available to the public.

Subtask 3b – Simulate Future Subsidence for Modeled Available Groundwater (MAG).

The representatives of Groundwater Management Area 15 (GMA 15) have historically adopted drawdown-based Desired Future Conditions (DFC) without the benefit of an assessment of simulated land subsidence. However, representatives have expressed interest in considering potential land subsidence in the development of desired future conditions for relevant aquifers of GMA 15. For this subtask, the CGCBGF Model with CSUB will be used to predict and document the spatial distribution of land subsidence, if any, that will occur through 2080 based on the groundwater pumping scenario used to demonstrate feasibility for the adopted DFC.

Subtask 3c – Deliverables for Task 3.

The deliverables for Task 3 will include the model files for the CGCBGWF Model for simulating the MAG and a report summarizing the land subsidence predictions developed under Subtask 3b.

4.2.4 Task 4 – Install Subsidence Monitoring Station

The installation of a permanent subsidence monitoring station (SMS) represents a critical component of this project. The SMS will provide direct, continuous, and independently verifiable measurements of land-surface elevation change within the District that can be used to evaluate simulated land subsidence impacts and improve the future modifications of the CSUB packet coupled with the CGCBGF Model. While Tasks 1 through 3 focus on the interpretation of remote sensing data (InSAR), historical subsidence, and predictive modeling using the MODFLOW 6 CSUB package, Task 4 establishes the ground-based geodetic measurements that are required to validate relationship between groundwater production and any measurable land surface changes.

Remote sensing methods such as InSAR provide spatially extensive measurements of deformation; however, these techniques benefit from calibration and validation using high-precision ground-based geodetic monuments. The monitoring station installed as part of this project will provide a stable reference point for evaluating deformation trends detected in the InSAR analysis described in Task 1. Additionally, the time-series elevation measurements generated by the station will support evaluation of subsidence predicted by the CSUB simulations described in Task 2 and Task 3.

From a groundwater management perspective, the monitoring station will provide the cooperating districts with continuous and defensible measurements of vertical land motion, allowing the districts to detect early signs of subsidence acceleration associated with brackish groundwater withdrawals. These data will inform future evaluations of groundwater production rules, Desired Future Conditions (DFC) compliance, and long-term aquifer

sustainability assessments. The monitoring station will also provide the districts with an early warning capability, allowing managers and decision-makers to identify areas where groundwater withdrawals may be producing undesirable compaction of aquifer sediments before significant infrastructure damage or irreversible aquifer compaction occurs.

Current and anticipated brackish production rules require that a land subsidence monitoring station be installed at actively permitted brackish wellfields. Installation of this monitoring station provides the cooperating district with meaningful experience to guide and assist in the installation of future stations.

The monitoring station will be designed following engineering practices similar to those used by the HGSD which operates one of the most successful subsidence monitoring networks in the United States. The design will ensure the monument is anchored below the zone of seasonal soil moisture fluctuations and shallow ground movement so that the station measures true land-surface deformation rather than shallow soil movement.

The following subtasks describe the procedures used to identify the optimal station location, construct the monitoring monument, install geodetic instrumentation, and process the resulting deformation measurements.

Subtask 4a– Site Selection, Engineering Design, and Purchase of Equipment

The first step in establishing the monitoring station is to identify an appropriate installation site that maximizes the value of the measurements for groundwater management while ensuring long-term monument stability. Site selection will be conducted through a structured process that integrates hydrogeologic considerations, groundwater production patterns, infrastructure proximity, and monument stability requirements.

Initial candidate locations will be identified through a desktop screening analysis. This screening will evaluate areas where subsidence risk is expected to be greatest based on groundwater production data, aquifer characteristics, and the results of the InSAR analysis described in Task 1. Particular attention will be given to locations associated with high-capacity groundwater production from the Gulf Coast Aquifer system, including brackish groundwater production wells. Three major well fields currently operating or planned in the region provide particularly relevant monitoring targets. One of these wellfields is expected to produce approximately 3,400 acre-feet of brackish groundwater per year (AFY), another wellfield associated with a barge canal project is expected to produce approximately 11,200 AFY of brackish groundwater, and another municipal wellfield is permitted to produce at approximately 11,700 AFY of relatively fresh groundwater. These high-capacity pumping centers represent areas where aquifer compaction and associated subsidence may occur if groundwater withdrawals induce significant declines in pore pressure within compressible sediments.

The desktop analysis will evaluate candidate locations based on several criteria including:

- proximity to major groundwater production centers
- representation of areas identified as potential deformation zones in the InSAR analysis
- availability of stable ground conditions suitable for monument installation
- land ownership and accessibility
- long-term protection from disturbance or vandalism
- proximity to infrastructure that could be impacted by subsidence

Following the desktop screening, the project team will conduct field reconnaissance visits to evaluate the most promising candidate sites. Field investigations will assess ground stability, site security, potential obstructions to satellite reception, solar exposure for the power systems, and logistical considerations for installation and maintenance.

Once a preferred site has been selected, the engineering design for the monument and instrumentation platform will be finalized. All required land access agreements, permits, and permissions will be secured prior to construction.

Dr. Guoquan Wang of the University of Houston has agreed to provide technical guidance on the electronic configuration of the station and the processing of the resulting GNSS data using workflows comparable to those employed by the Harris–Galveston Subsidence District. Vendors for all major equipment components have been contacted, and cost estimates have been obtained in 2026 dollars, ensuring that the equipment procurement portion of the project can be executed efficiently once the site selection process is completed.

Subtask 4b– Construction and QA/QC of Monitoring Station

Following completion of site selection and engineering design, the monitoring station monument will be installed. The monument design is based on the Port-A-Measure (PAMS) stations used by the HGSD and is illustrated in Figure 4-5. While the design will follow this proven configuration, minor modifications may be made to accommodate site-specific conditions encountered during installation.

The monument will consist of a deep-anchored pipe structure designed to isolate geodetic measurements from shallow soil movement. The principal components of the monument include:

- 34 feet total embedment below ground surface
- 4-inch Schedule 40 PVC outer casing
- 2-inch galvanized steel inner pipe
- Concrete plug installed approximately 6 feet from bottom
- Two centering bands to reduce internal movement
- 8 feet of exposed galvanized pole above ground
- 5 x 5 ft Concrete slab with 10-inch tube form to separate pole from slab
- Protective bollards around slab

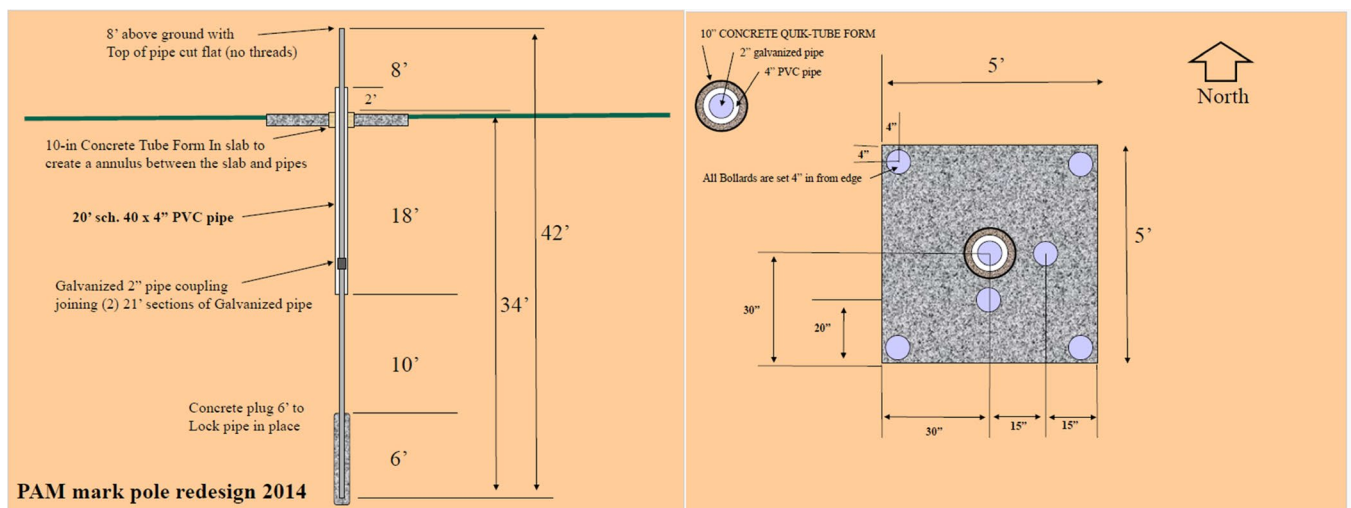


Figure 4-5 Subsidence monitoring station design from HGSD that the proposed subsidence stations is based. Certain measurements and design features will be modified based on information gathered during the site selection process.

The drilling contractor will be responsible for constructing the borehole, installing the outer casing, and setting the inner galvanized pipe. The concrete plug placed near the bottom of the installation locks the inner pipe in place and creates a rigid connection with deeper subsurface materials. This configuration produces a monument that is effectively decoupled from shallow soil deformation, allowing it to accurately measure vertical land motion associated with aquifer compaction.

Centering bands installed between the inner pipe and the outer casing reduce internal movement and ensure the inner pipe remains stable over time. Above ground, the galvanized pipe will extend approximately eight feet above

the ground surface, providing adequate height for installation of GNSS equipment while minimizing risk of vandalism or signal interference.

The concrete slab surrounding the monument will be poured using a tube form that isolates the monument pole from the slab mass. This design prevents expansion or contraction of the slab due to soil moisture variations from influencing the monument's vertical stability. Protective bollards will be installed around the slab to prevent accidental impacts from vehicles or equipment.

Once the monument has been installed, geodetic instrumentation will be mounted and configured. The final station configuration will resemble the example shown in Figure 4-6.

The monitoring station will include the following equipment:

- Trimble Alloy multi-frequency GNSS receiver
- Trimble Zephyr Geodetic 3 antenna
- Precision Machining antenna adapter (pole cap)
- Ameresco Solar 40W solar panel
- Battery and solar regulator
- Weatherproof enclosure and mounts
- Telemetry system (T4D or equivalent)
- DAC SIM card for cellular transmission
- Antenna and power cabling



Figure 4-6 Example of a complete subsidence monitoring station with all geodetic instrumentation and power supply equipment installed.

Following installation, the project team will conduct quality assurance and quality control checks to ensure that the monument and instrumentation are operating correctly. These checks will include verification of satellite signal reception, power system performance, and initial geodetic data acquisition.

Subtask 4c– Process and Record Measured Subsidence

Although monument installation is mechanically straightforward, processing high-precision GNSS data to derive reliable vertical deformation measurements requires specialized expertise and significant computational resources. Because of this complexity, GNSS data processing will be subcontracted to Dr. Guoquan Wang at the University of Houston, who has extensive experience processing geodetic data from subsidence monitoring networks.

Two potential operational configurations are available for acquiring and processing GNSS data from the monitoring station.

Remote Data Configuration

In this configuration the station will operate autonomously and transmit data continuously to a remote processing server. The system will provide:

- continuous GNSS data streaming
- automated data upload through the cellular network

This configuration minimizes the need for field visits and allows the cooperating districts to access deformation measurements soon after they are collected.

Manual Data Retrieval Configuration

Under this alternative configuration, GNSS data would be retrieved manually through periodic site visits. This configuration would involve:

- monthly field visits to download data from the receiver
- local storage and transfer of data files
- manual submission to the processing center

Although the manual configuration is operationally feasible, the remote configuration is expected to be preferred because it minimizes field labor and provides continuous monitoring capability.

Processed data will produce a time-series record of vertical land motion at the monitoring station, typically reported as millimeters or centimeters of vertical displacement relative to a stable geodetic reference frame. These data will be archived and integrated with the deformation datasets developed in Task 1 and the modeling results generated in Tasks 2 and 3.

Subtask 4d– Deliverables

The primary deliverables for Task 4 will consist of the following:

- installation of a fully operational subsidence monitoring station within the project area
- documentation of the station design, installation procedures, and equipment configuration
- processed GNSS datasets representing time-series measurements of vertical land motion

These deliverables will provide the cooperating districts and interested parties with a long-term geodetic monitoring asset that will continue generating subsidence measurements beyond the duration of the grant project. The resulting dataset will complement the remote sensing analyses performed in Task 1 and provide critical ground-truth observations for evaluating the subsidence.

4.3 Equipment Purchases

The project proposes purchasing the following equipment associated with the subsidence monitoring stations under section 4.2.4, subtask 4b - Construction and QA/QC of Monitoring Station. Itemized breakdown of equipment cost included in the budget attachment as part of this application.

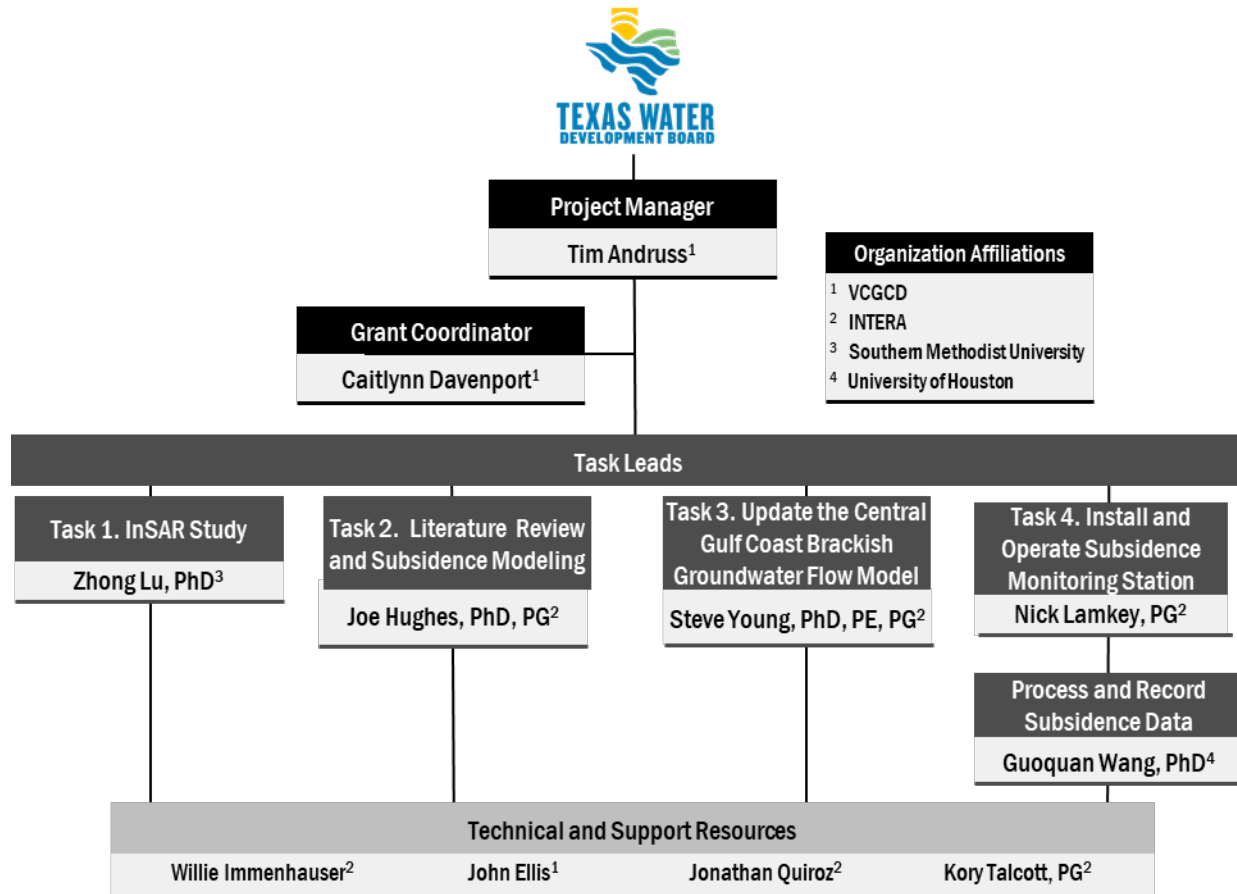
4.4 Deliverables

Deliverables to the TWDB for this project are clearly defined at the end of each task in section 4 of this report in the subheading labeled Deliverables.

4.5 Project Schedule

Task	2026						2027												2028				
	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M
Task 1 – InSAR Survey (2018 to 2025)																							
1a. Collection and Analysis of InSAR Data																							
1b. Prepare Report																							
1c. Deliverables																							
Task 2 – Model Historical Subsidence																							
2a. Literature Search on Historical Subsidence, Production and Water Levels																							
2b. Selection and Parameterization of Subsidence Models																							
2c. Simulate Historical Subsidence																							
2d. Deliverables																							
Task 3– Update the Central Gulf Coast Brackish Flow Model																							
3a. Integrate Subsidence Module into Flow Model																							
3b. Simulate Future Subsidence for Model Available Groundwater																							
3c. Deliverables																							
Task 4– Install Subsidence Monitoring Station																							
4a. Site Selection, Engineering Design, and Purchase Equipment																							
4b. Install and Test Subsidence Monitoring Station																							
4c. Process and Record Measured Subsidence																							
4c Deliverables																							

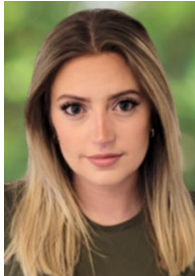
4.6 Project Team



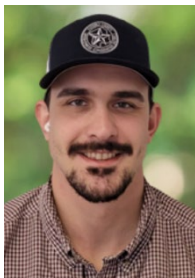
Project Manager – Tim Andruss. Tim Andruss serves as General Manager for the Victoria County Groundwater Conservation District (VCGCD), Calhoun County Groundwater Conservation District (CCGCD), Refugio Groundwater Conservation District (RGCD), and Texana Groundwater Conservation District (TGCD). Tim has worked for the districts since 2007 and holds a BS degree in wildlife and fisheries science, ecology from Texas A&M University. Tim serves as the Chair of GMA 15 and is a representative and past chair of the South Central Texas Regional Water Planning Group (SCTRWPG/Region L). Tim has successfully managed and participated in numerous initiatives and projects, including projects funded by the TWDB, during his tenure as general manager GCDs. Tim will oversee the completion of all tasks and activities undertaken in the proposed project and serve as the primary point of contact for TWDB for this project. Tim’s experience and involvement with technical investigations and projects includes technical investigations related to aquifer monitoring and assessment, brackish groundwater resources and associated regulations, subsidence and subsidence monitoring options, aquifer storage and recovery feasibility, groundwater/surface water interactions, evapotranspiration estimation, as well as the installation and automated aquifer monitoring sites.

- **A GIS-based Multi-Criteria Decision Making Approach for Establishing A Regional-Scale Groundwater Monitoring Network (Uddameri, 2011)**
- **A Statistical Power Analysis Approach to Estimate Groundwater Monitoring Network Size in Victoria County Groundwater Conservation District, Texas (Uddameri, 2011)**

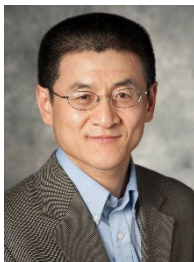
- **Streamflow, Groundwater Hydrology, and Water Quality in the Upper Coletto Creek Watershed in Southeast Texas, 2009-10 (USGS, 2011)**
- **Development of a Regional Plan for Aquifer Storage and Recovery and Off Channel Storage in the Golden Crescent Region of Texas (Arcadis, 2014)**
- **Victoria Aquifer Storage and Recovery Demonstration Project (Arcadis, 2019)**
- **Investigations Regarding the Design and Management of Aquifer Storage and Recovery Operations in Victoria County (INTERA, 2019)**
- **Estimates of Land Subsidence in GMA 15 Based on Ground Surface Elevation Data and Model Results (INTERA, 2016)**
- **Water Level Evaluation - Chicot and Evangeline Aquifers (Golder Associates, 2018-2019)**
- **Characterization of Brackish Groundwater Resources in Victoria County (INTERA, 2018)**
- **Options for Monitoring Land Subsidence Data in Victoria County, Texas (INTERA, 2019)**
- **Effects of Huisache Removal on Rangeland Evapotranspiration in Victoria County, South-Central Texas, 2015–18 (USGS, 2020)**
- **Application of Geostatistical Techniques to Quantify Changes in Water Levels (INTERA, 2021-2023)**



Grant Coordinator – Caitlynn Davenport. Caitlynn Davenport serves as Administrative Coordinator at the Victoria County Groundwater Conservation District, with 11 years of experience managing governmental financial records, coordinating documentation, and supporting organizational operations. Skilled in budgeting, data tracking, compliance processes, and maintaining accurate reporting, she is highly organized with strong attention to detail and has the ability to coordinate multiple deadlines and administrative tasks that will ensure funding compliance, budget revisions and grant coordination. Caitlynn will provide all financial record and information tracking services for this project.



Technical Support, Monitoring Field Technician – Willie Immenhauser. Willie Immenhauser serves as Aquifer Monitoring Technician with the Victoria County Groundwater Conservation District (VCGCD), with four years of experience supporting groundwater resource monitoring and data collection in Calhoun County, De Witt County, Jackson County, Refugio County, and Victoria County, Texas. Willie’s expertise includes hands-on groundwater sample collection and processing (e.g., field filtration, preservation, chain-of-custody, and coordination with certified labs per industry standards); field measurement collection and documentation (e.g., manual and automated water level measurements in monitoring wells, aquifer test data, specific conductance, pH, temperature, and flow rates using multiparameter instruments and data loggers, with detailed field logs, photos, and GPS records for data integrity); data entry and processing (e.g., transcription into district databases, QA/QC validation, error checking, and preparation of formatted datasets for model inputs and analysis); equipment calibration and configuration (e.g., routine calibration of water level tapes, water quality handhelds, and loggers; setup and troubleshooting of monitoring equipment to ensure accurate, reliable long-term data); and report drafting (e.g., compiling field summaries, data tables, graphs, and technical narratives for quarterly monitoring reports, aquifer assessments, well assistance program documentation, and support materials).



Task Lead, InSAR Study– Zhong Lu, PhD. Zhong Lu is the Shuler-Foscue Endowed Chair Professor of Geophysics in the Huffington Department of Earth Sciences and Professor of Civil Environmental Engineering at Southern Methodist University. He holds a PhD in Geophysics from the University of Alaska and MS and BS degrees in Geophysics from Peking University. His research interests include advancing InSAR processing methods and applying them to study land subsidence, landslides, volcanoes, earthquakes, coastal processes, and other geophysical phenomena. Zhong has authored or coauthored over 300 peer-reviewed journal articles and book chapters focused on InSAR techniques and applications, and a book, “InSAR Imaging of Aleutian Volcanoes: Monitoring a Volcanic Arc from Space” (Springer, 2014). He

served on several NASA science teams, including the NISAR and VenSAR missions, and NASA/JPL OPERA Project. He is a Fellow of the American Geophysical Union (AGU) and the American Association for the Advancement of Science (AAAS), and an SAIC Technical Fellow. Zhong received a Ford Senior Research Fellowship, a Science of Risk Prize, several U.S. Geological Survey Performance Awards, a Leica Geosystems Award from the American Society for Photogrammetry & Remote Sensing, a Science Applications International Corporation Science & Technology Award, and several NASA Group Achievement Awards. Some of his previous positions include serving as a Physical Scientist with the USGS Cascades Volcano Observatory and a Principal Scientist and Technical Fellow with Science Applications International Corporation.



Technical Expert, MODFLOW 6 and Subsidence Modeling – Joe Hughes, PhD, PG.

Joe Hughes is a Principal Hydrologist at INTERA with a PhD in hydrogeology, an MS in geochemistry, a BS in geology, and 32 years of research and applied experience in hydrologic software development and modeling and analysis of hydrologic systems, including water availability, water budgets, flow, and transport. He is the co-developer of MODFLOW 6, an internationally recognized software product for simulating groundwater flow and transport. Joe also co-developed FloPy, an internationally recognized software product for pre- and post-processing MODFLOW-based model input and output and analyzing simulated results. He has developed software for simulating natural and managed surface-water flow, subsurface

compaction and land subsidence, density-dependent groundwater flow and transport, and integrated surface water/groundwater flow and transport. He also regularly teaches workshops and courses on groundwater flow and transport modeling, MODFLOW 6, and Python programming. Joe has experience in uncertainty and importance analyses as applied to modeling studies and has used numerous uncertainty analysis and optimization codes, such as MODMAN, MODSIM, PEST, PEST++, and UCODE. He has worked on surface water, groundwater, and integrated surface water/groundwater projects throughout the United States and has taken a project management and/or technical lead role in many water resources modeling studies, including integrated surface water/groundwater interaction studies in support of groundwater permit applications. He has served as a technical manager or technical lead quantifying processes such as recharge, hydraulic conductivity, and surface water/groundwater interaction in support of regional and sub-regional groundwater modeling projects. Some of Joe’s project and software development experience, particularly relevant to developing the model under this grant from TWDB, includes:

- **Coordination of Hydrologic Software Development Activities, U.S. Geological Survey, Reston, VA. PROJECT MANAGER AND SOFTWARE DEVELOPER**
- **MODFLOW 6 Software Enhancements, U.S. Geological Survey, Reston, VA. PROJECT CO-LEADER**
- **FloPy Development, U.S. Geological Survey, Reston, VA. TEAM LEADER**
- **MODFLOW 6 Development, U.S. Geological Survey, Reston, VA. PROJECT CO-LEADER**
- **Seawater Intrusion Package, U.S. Geological Survey Groundwater Resources Program, Reston, VA. PROJECT MANAGER AND SOFTWARE DEVELOPER**
- **Long Island Sound Compound Flooding Study, New York Water Science Center, Troy, NY. SOFTWARE DEVELOPER AND LEAD MODELER**
- **Evaluation of the Causes of Saltwater Intrusion in Central and South Broward County, Broward County Environmental Planning and Community Resilience Division, Ft. Lauderdale, FL. PROJECT MANAGER**

- **Inundation Changes in Response to Increased Sea Level and Changing Climate Conditions in Broward County, Broward County Environmental Planning and Community Resilience Division, Ft. Lauderdale, FL. PROJECT MANAGER**
- **Quantification of the Effect of Groundwater Pumpage and Increased Sea Level on Canal Leakage and Regional Groundwater Flow in Miami-Dade County, Miami-Dade Water and Sewer Department, Miami, FL. PROJECT MANAGER AND LEAD MODELER**



Task Lead, Hydrogeologic Data Collection & Analysis; Update of the Central Gulf Coast Brackish Groundwater Flow Model – Steve Young, PhD, PE, PG. Dr. Steve Young is a Principal Geoscientist and Engineer at INTERA with a PhD in earth sciences, an MS in environmental engineering, a BS in environmental science, and 44 years of experience in characterizing and solving water supply and groundwater remediation challenges. He has worked on a wide-range of water development issues, including characterizing groundwater resources, developing and applying groundwater models, and designing water supply wellfields. His expertise includes assessing fresh and brackish groundwater resources through the analysis of geophysical logs, aquifer test data, and geochemical data. Working with water management agencies and commercial

industry, Steve has evaluated groundwater resources in Texas that include the Gulf Coast Aquifer System, the Northern Trinity Aquifer, and the Carrizo-Wilcox Aquifer. He has managed a wide range of water projects across Texas, working with more than 20 GCDs to help develop management plans, groundwater rules, groundwater databases, and gain a better understanding of groundwater resources. He has participated in joint planning activities with several GMAs and helped with the development of GAMs under TWDB's Groundwater Availability Modeling Program. Some of Steve's project experience, particularly relevant to developing the model under this grant from TWDB, includes:

- **Development and Application of an Operational and Management Groundwater Model for Post Oak Savannah Groundwater Conservation District, Bureau of Reclamation, TX. PROJECT MANAGER AND LEAD HYDROGEOLOGIST**
- **Development and Application of an Operational and Management Groundwater Model for Post Oak Savannah Groundwater Conservation District, Bickerstaff Heath, Delgado, Acosta, LLP, TX. EXPERT WITNESS**
- **Evaluation of Groundwater Resources in Carrizo-Wilcox Aquifer for Long-Term Water Supply, City of Georgetown, TX. PROJECT MANAGER**
- **Evaluation of Land Subsidence in the Woodlands in Montgomery County, San Jacinto River Authority, TX. PROJECT MANAGER**
- **Conversion of Oil and Gas Wells to Water Wells, Post Oak Savannah Groundwater Conservation District, Burleson County, TX. HYDROGEOLOGIST**
- **Development of Groundwater Monitoring Network, Post Oak Savannah Groundwater Conservation District, Milano, TX. HYDROGEOLOGIST AND PROJECT MANAGER**
- **Review of Well Permit Applications, Post Oak Savannah Groundwater Conservation District, Milano, TX. PROJECT MANAGER**
- **Technical Support, Post Oak Savannah Groundwater Conservation District, Milano, TX. PROJECT MANAGER**
- **Characterization of the Carrizo Aquifer and Evaluation of the Groundwater Availability Model for GMA 13, Evergreen Underground Conservation, TX. PROJECT MANAGER AND SENIOR HYDROGEOLOGIST**



Task Lead, Install and Operate Subsidence Monitoring Station – Nick Lamkey, PG. Nick Lamkey is a Hydrogeologist at INTERA with an MS in geology, a BS in geoscience, and eight years of experience in the water resources industry. He specializes in groundwater model development, remote sensing, aquifer test analysis, and data management. His skills include Python programming and GIS. Nick has applied these skills across diverse projects, including developing and updating GAMs, investigating river-aquifer interactions, and assessing nitrate contamination sources in shallow alluvial aquifers. He has also used analytical element models to optimize well spacing for future residential developments. Nick has completed projects for clients that include POSGCD, Central Texas GCD, TWDB, as well as private commercial and investment firms, with work spanning the Carrizo-Wilcox, Edwards, Trinity, and Ogallala aquifers. Some of his project experience, particularly relevant to developing the model under this grant from TWDB, includes:

- **Five-Year Review, Post Oak Savannah Groundwater Conservation District, Central TX. HYDROGEOLOGIST**
- **Trinity Aquifer Sensitivity Study in the Briggs and Oakalla Area, Central Texas Groundwater Conservation District, Burnet, TX. MODELER**
- **Yegua Jackson Groundwater Availability Model Verification, TWDB Austin, TX. LEAD MODELER**
- **Nacatoch Groundwater Availability Model Verification, TWDB, Austin, TX. MODELER**
- **Modeled Available Groundwater Peak Factor Analysis for Brazoria County in Region H, Freese and Nichols, Inc., TX. 2024. MODELER**
- **Fort Cavazos Aquifer Storage and Recovery Well Field Modeling, CDSM, Bell County, TX. 2024. MODELER**
- **Hydrogeologic Assessment of Goodnight Site, Kimley-Horn, Armstrong County, TX. HYDROGEOLOGIST AND MODELER**
- **Groundwater Availability Assessment, Private Investment Firm, Central TX. HYDROGEOLOGIST AND MODELER**
- **Investigation of Water Losses in a Sand Mine Dredge Pond, Private Sand Mining Company, Western TX. PROJECT MANAGER**



Senior Geological Consultant, Process and Record Subsidence Data– Guoquan Wang, PhD. Dr. Guoquan Wang is a Professor in the Department of Earth and Atmospheric Sciences at the University of Houston and serves as Assistant Director of the University of Houston Coastal Center. He is an internationally recognized expert in geodesy, coastal and geological hazards, and natural hazard monitoring, with more than two decades of academic and research experience spanning the United States, Europe, and Asia. Dr. Wang holds a PhD in solid earth geophysics, an MS degree in hydrogeology and engineering geology, and a BS degree in geology. Dr. Wang's research focuses on coastal hazards, land subsidence, sea-level change, faulting, and earthquake-related ground motion, with particular emphasis on the Gulf Coast and Caribbean regions. He is known for advancing the application of GNSS, GPS seismology, LiDAR, InSAR, and numerical modeling techniques to monitor ground deformation, structural health, and geological risk. His work has led to the development of multiple stable geodetic reference frames and long-term monitoring networks used by researchers and practitioners worldwide. A recipient of the NSF CAREER Award and numerous teaching and professional honors, Dr. Wang has authored an extensive body of peer-reviewed publications and has supervised graduate students and postdoctoral researchers, contributing significantly to both scientific advancement and workforce development in geoscience and engineering.



Technical Resource – Jonathan Quiroz. Jonathan Quiroz is a Hydrogeologist at INTERA with an MS in hydrology, a BS in environmental engineering, and 9 years of experience in numerical flow and transport modeling for water resources applications for both surface and groundwater. Mr. Quiroz has developed skills in model planning through utilizing GIS, remote sensing, and map analysis and composition. He has advanced knowledge of applied modeling codes such as MODFLOW, MT3DMS, SEAWAT, SWAT and PRMS. Additionally, he has experience in automated numerical optimization and uncertainty with codes such as PESTP/PEST++. His software experience also includes GIS through software such as QGIS, GRASS-GIS, and ESRI products. His programming languages include Python, Fortran, and SQL, which he applies to a variety of hydrogeologic data for model development. He has worked independently and with teams on a wide range of diverse projects for state, private, and international organizations. Some of Jonathan's project experience, particularly relevant to developing the model under this grant from TWDB, includes:

- **Development of an Operational Model, Post Oak Savannah Groundwater Conservation District, Central TX. HYDROGEOLOGIST**
- **Technical Assistance and Groundwater Modeling to Support the Regulatory Plan Review, Harris-Galveston and Fort Bend Subsidence Districts, Houston, TX. HYDROGEOLOGIST**
- **Well Field Design in the Evangeline/Laguna Groundwater Project, Evangeline/Laguna LP, San Patricio County, TX. HYDROGEOLOGIST**
- **Model Building and Design of a Dewatering System for an Open-Pit in the Las Bambas Mining Project, Hatarilabs / Gidahatari, Apurimac, Peru. HYDROGEOLOGIST**
- **Saline Water Intrusion Analysis in the Chilca Aquifer, Hatarilabs / Gidahatari, Lima, Peru. HYDROGEOLOGIST**
- **Arsenic Transport Modeling from a Tailing Deposit Leaching into the Mantaro river, Hatarilabs / Gidahatari, Junin, Peru. HYDROGEOLOGIST**
- **Groundwater Modeling in the Navidad Mining Project and Particle Travel Time Analysis, Hatarilabs / Gidahatari, Chubut, Argentina. HYDROGEOLOGIST**
- **Development of the Hydrogeologic Model for the Transboundary Aquifer Zarumilla, Hatarilabs / Gidahatari, Peru-Ecuador. HYDROGEOLOGIST**
- **Karst Modeling in the Micro-Basin Tulum, Hatarilabs / Gidahatari, Tulum, Mexico. HYDROGEOLOGIST**

Technical Resource – Kory Talcott, PG. Kory Talcott is a Geologist at INTERA with an MS in geosciences, a BS in petroleum geology, and eight years of combined experience in reservoir characterization and subsurface resource evaluation. His Wolfcamp Formation graduate research advanced understanding of diagenesis and reservoir quality in the Midland Basin. He has planned and geosteered multi-well pads in the Permian and South Texas, developed petrophysical models and regional frameworks that improved development economics and supported strategic business decisions, and critically tested software to implement innovative goals to improve operation metrics and prospect evaluation. Kory has also directed technical support for groundwater protection initiatives, including implementation of the state-funded Leaking Water Well Grant Program, modernization of the State Water Well Report Viewer, and authorship of legislative analyses and Governor's letters. As a licensed Professional Geoscientist in Texas, Kory integrates rigorous academic research, applied exploration and production experience, and regulatory hydrogeology to deliver innovative, data-driven solutions for complex subsurface challenges. Some of Kory's project experience, particularly relevant to developing the model under this grant from TWDB, includes:



- **Leaking Water Well Grant Program, Texas Commission on Environmental Quality, TX. TECHNICAL GEOLOGIST**
- **Water Well Report Viewer Modernization, Texas Commission on Environmental Quality, TX. TECHNICAL GEOLOGIST**

- Groundwater Protection and Texas Groundwater Protection Committee Support, Texas Commission on Environmental Quality, TX. TECHNICAL GEOLOGIST
- Permian & South Texas Operations, SM Energy, TX. LEAD OPERATIONS GEOLOGIST
- Permian Asset Development, SM Energy, TX. ASSET DEVELOPMENT GEOLOGIST AND EXECUTIONER
- Wolfcamp D Reservoir Evaluation, SM Energy, TX. PROJECT MANAGER AND LEAD GEOLOGIST
- South Texas Gulf Coast Business Development, SM Energy, TX. BUSINESS DEVELOPMENT GEOLOGIST



Technical Resource – John Ellis, PG.. John Ellis is a Principal Hydrogeologist at INTERA with MS degrees in environmental science and hydrogeology, a BS degree in geology, and 18 years of experience in integrated groundwater modeling and uncertainty quantification, land subsidence, data analysis, water resources planning and management, distributed computing networks, and information technology. He also has a background in environmental laws and regulations, site remediation, contaminant transport, and managing teams investigating water quality. He has led several regional scale groundwater availability modeling projects in Texas and Oklahoma to support water resource planning and aquifer management. He is experienced using the MODFLOW-2005, NWT, MODPATH, MT3DMS, and SWB codes and the PEST, PEST++, and PEST-IES calibration codes. He is also experienced in GIS software and performing programmatic workflows and data analysis using Python and VBA. John has more than 15 years of management experience leading multi-disciplinary teams of up to 60 staff, \$25 million in assets, and annual project budgets of more than \$3 million.

- Subsidence Technical Services and Extreme Weather Monitoring, California Department of Water Resources, CA. SUBSIDENCE AND MODELING TASK LEAD
- Technical Assistance and Groundwater Modeling to Support the Subsidence Regulatory Plan Review, Harris-Galveston and Fort Bend Subsidence Districts, Houston, TX. PROJECT MANAGER
- Chicot and Evangeline Geostatistical Study, Harris-Galveston Subsidence District, TX. ASSOCIATE PROJECT MANAGER
- Groundwater Science Advisory Committee – Subsidence Investigations, Houston Advanced Research Center, TX. COMMITTEE MEMBER
- Northern Texas Gulf Coast Aquifer System – Groundwater Availability Model, Harris-Galveston Subsidence District, TX. PROJECT MANAGER AND TECHNICAL LEAD
- Hydrogeologic Assistance for Groundwater Management, Northern Trinity Groundwater Conservation District, TX. PROJECT MANAGER AND PRINCIPAL HYDROGEOLOGIST

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