Review and Recommendations on "Subsidence Investigations – Phase 1" Report

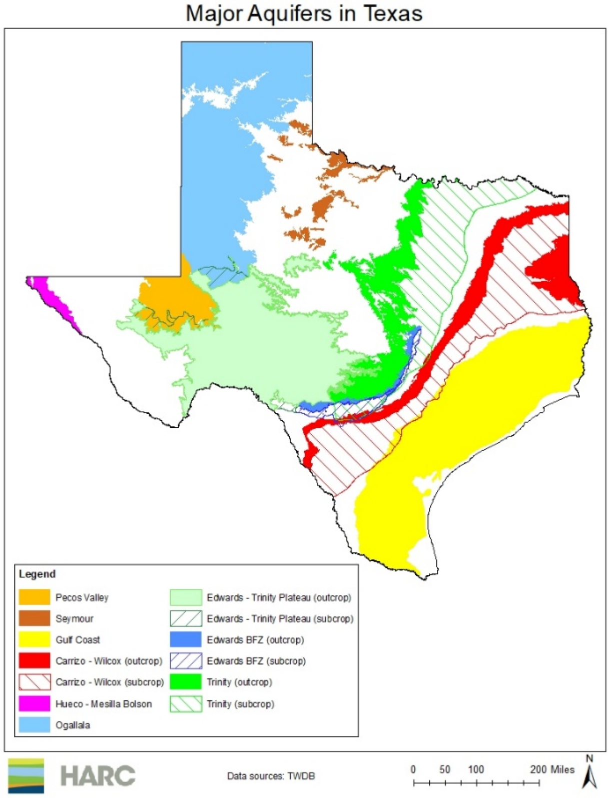
Prepared by the
Groundwater Science Advisory Committee

The Groundwater Science Advisory Committee
is an initiative of the Regional Groundwater Science Partnership

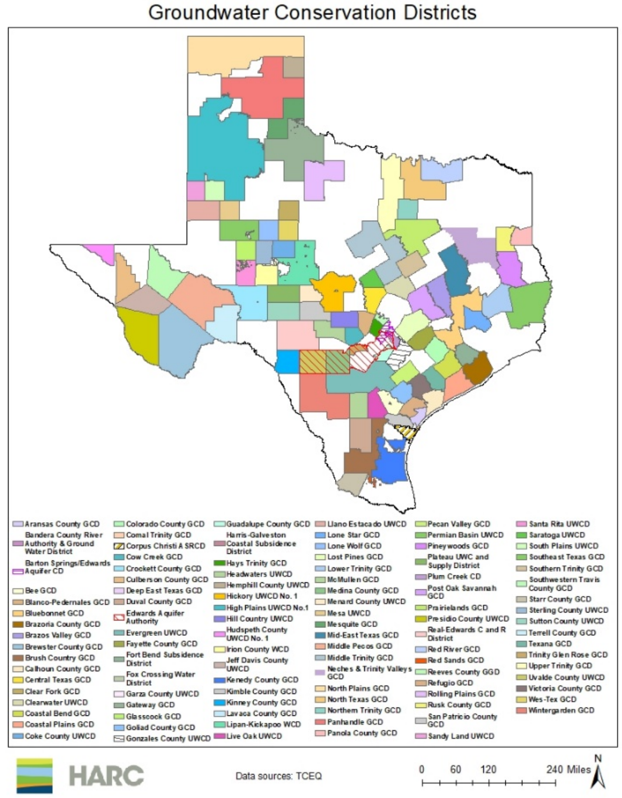
February 5th, 2021

Contents

Major Aquifers in Texas



Groundwater Conservation Districts



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About the Regional Groundwater Science Partnership

The *Regional Groundwater Science Partnership* was created to enable science-based review, community education, and outreach activities in support of regional data and studies relating to groundwater supply, groundwater demand, and land subsidence (hereafter, “subsidence”) in Montgomery and Harris counties, Texas. The work of the Partnership is financially supported by the *Groundwater Research Consortium*, comprised of special-use districts in the greater Houston-Galveston Region interested in independent, science-based groundwater and subsidence research and data analysis. Consortium members receive the same level of scientific information shared with decision-makers and the general public. The *Groundwater Science Advisory Committee (SAC)* is composed of leading researchers from institutions around Texas who have come together to analyze and share a rich array of scientifically-informed data about groundwater resources and regional subsidence.

Groundwater Research Consortium

Members / Funders

Montgomery County Water Control and Improvement District No. 1

Southern Montgomery County MUD

The Woodlands Township

Woodlands Water Agency

Project Manager

Houston Advanced Research Center (HARC)

Groundwater Science Advisory Committee

Facilitator

Stephanie Glenn, Ph.D. – HARC

Members

John Ellis, P.G. – United States Geological Survey

Robert Mace, Ph.D. – Texas State University, The Meadows Center for Water and the Environment

Gretchen Miller, Ph.D. - Texas A&M University

Wade Oliver, P.G. – INTERA Incorporated

John Seifert, PE - Ground Water Consultants, LLC

John “Jack” Sharp, Ph.D. – University of Texas at Austin

John Tracy, Ph.D. – Texas A&M University, Texas Water Resources Institute

Guoquan “Bob” Wang, Ph.D. – University of Houston

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Introduction

Groundwater is a critical resource for Texas and the greater Houston-Galveston region. Careful management of groundwater resources is necessary to meet current water needs, protect future supplies, and minimize land subsidence impacts on infrastructure, flooding, and private property. Accordingly, sustainable management of groundwater resources requires detailed, current, and accurate data.

In Southeast Texas, groundwater use and management are inextricably linked with regional subsidence. The Gulf Coast Aquifer system consists of several aquifers, including the Chicot, Evangeline, and Jasper Aquifers. Removal of groundwater from these aquifers can lead to soil compaction and subsidence—the gradual lowering of land elevation. The greater Houston-Galveston region, which stretches from the Gulf Coast at Galveston to more northern reaches of the Trinity and San Jacinto rivers in Montgomery County, has a history of subsidence with some areas subsiding nine feet or more since 1900 (HARC, 2020).

Consequences of subsidence in the greater Houston-Galveston region include: a reduced capacity for aquifer storage, submerged lands, increased frequency and severity of flooding, collapsed water well casings, disruption of irrigation ditches, damage to foundations of commercial and residential real estate, and damage to public infrastructure such as roads and bridges (USGS, 2019).

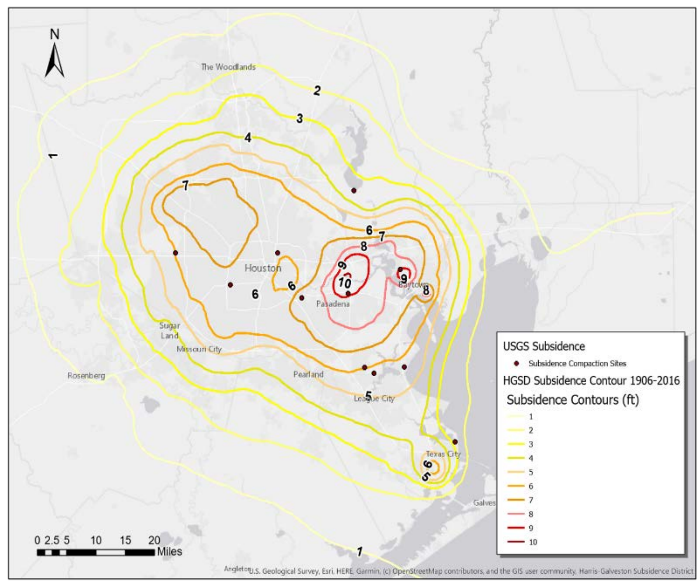

Figure 1. Estimated subsidence in feet from 1906-2016 using measured land surface elevation change at benchmarks surveyed in 2000 and estimated annual subsidence rates from 2011-2016 at HGSD GPS subsidence network assuming a constant rate of subsidence from 2010-2016. Image credit: (Houston Advanced Research Center 2020); Data source: (Harris-Galveston Subsidence District 2019).

Groundwater and Subsidence Management in Montgomery and Harris Counties

The Texas Legislature created groundwater conservation districts (GCDs) to manage groundwater resources at the local level. Chapter 36 of the Texas Water Code outlines the responsibility of GCDs in developing and implementing comprehensive groundwater management plans. Ninety-eight GCDs cover 70% of the state's land area and overlay 72% of major and minor aquifers in Texas (TWDB, 2021). Sixteen groundwater management areas (GMAs) exist in Texas, with the greater Houston-Galveston Region residing in GMA 14. The GMA 14 includes five GCDs: Bluebonnet GCD, Brazoria County GCD, Lone Star GCD, Lower Trinity GCD, Southeast Texas GCD, the Harris-Galveston Subsidence District, and the Fort

Southeast Texas GCD, the Harris-Galveston Subsidence District, and the Fort Bend Subsidence District. The Lone Star Groundwater Conservation District (LSGCD) was established by the Texas State Legislature in 2001 to regulate the groundwater resources of Montgomery County. Chapter 36 of the Texas Water Code designates LSGCD to serve the public interest of developing, promoting, and implementing water conservation, augmentation, and management strategies to both conserve and utilize groundwater resources for the benefit of the citizens, economy, and environment of Montgomery County, Texas.

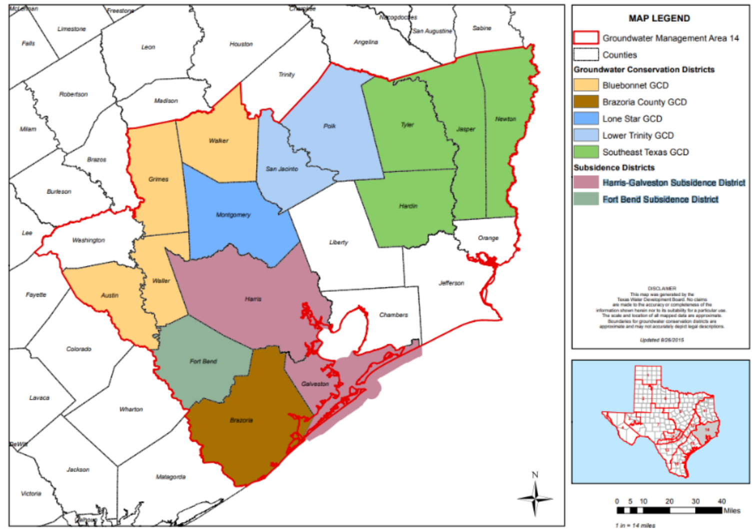

Figure 2. Map of the Groundwater Management Area (GMA) 14 planning region. Source: Texas Water Development Board.

Science Advisory Committee

The consortium engaged the Houston Advanced Research Center (HARC) to convene a Science Advisory Committee (SAC) comprising nationally respected scientists to review and analyze research findings describing groundwater resources and subsidence in Montgomery and Harris counties in Southeast Texas. The SAC findings will be summarized in reports and outreach products for community members and decision-makers in the greater Houston-Galveston region. The scientists participating in the SAC neither make nor recommend specific policy decisions; rather, they provide unbiased and independent advice on the science used to support regional policy decisions. The SAC members are experts in their field and the discussion and recommendations below reflects their collective scientific knowledge and consensus; where appropriate, papers or references are cited if they are discussed in detail.

Stakeholder Engagement

Gathering stakeholder questions and concerns is an important objective of the *Regional Groundwater Science Partnership*. HARC held a series of introductory conversations with a variety of entities, such as community organizations, local groundwater districts, river authorities, subsidence districts, utility districts, local elected officials, chambers of commerce, and municipalities. Stakeholders expressed interest in:

- Ensuring long-term groundwater supplies of high quality,
- Supporting science-based management decisions and policies to address multiple values and competing interests,
- Connecting the general public and decision-makers to independent science on groundwater and subsidence,
- Fostering a greater understanding of groundwater resources and subsidence in the context of regional systems,
- Monitoring and collecting additional scientific data to support robust models, and
- Incorporating climate change and drought information into planning frameworks.

A common theme from stakeholder conversations included a request to review a recently published technical memorandum prepared for the Lone Star Groundwater Conservation District titled, "Subsidence Investigations – Phase 1 Assessment of Past and Current Investigations" (hereafter "Phase 1 Report") (Thornhill and Keester, 2020). Stakeholders also expressed interest in understanding compaction and subsidence in the Jasper Aquifer and the impact of groundwater pumping in Montgomery County.

To best assist the consortium and respond to stakeholder interests, the SAC considered an assessment of the following items: (1) Gulf Coast Aquifer susceptibility to compaction and subsidence, (2) compaction and subsidence in the Jasper Aquifer, and (3) the impact of groundwater pumping and subsidence in Montgomery County. Examining the Phase 1 Report in the context of these questions may assist the consortium members and stakeholders in conducting and planning subsidence monitoring for the greater Houston-Galveston region.

Phase 1 Report findings

The written summary of initial findings from the SAC on the Phase 1 Report is presented below in this document. The Phase 1 Report is currently available on LSGCD's website at https://www.lonestargcd.org/subsidence).

General Comments

The Phase 1 report was a literature review of groundwater data and subsidence studies in the greater Houston-Galveston region. The Phase 1 Report focuses on groundwater pumping and subsidence differences and impacts in Harris and Montgomery Counties. It would be beneficial to decision-makers and the public to include additional historical context such as: groundwater pumping differences in the different counties of the region, analyses of subsidence in Montgomery County as pumping changed over time, and the level of oil and gas depressurization contributing to compaction.

A SAC review of the available subsidence data indicates a correlation between groundwater pumping and subsidence. When Montgomery County converted to include water supplies other than groundwater beginning in 2015, the water-levels for wells located in Conroe and The Woodlands have generally risen after yearly declines between the time monitoring began through 2015. Correspondingly, subsidence rates have attenuated in these areas during the same period. This adjustment is reflected in the land surface elevation changes at GPS stations P071 and TXCN (Conroe area); P013 and P069 (The Woodlands); and P047, P017, and ROD1 (northern Harris County). The remaining GPS stations in Conroe and The Woodlands do not have sufficient data prior to 2015; therefore, longer-term trends in subsidence from these stations cannot be assessed. Notably, a substantial amount of groundwater use occurs south of The Woodlands GPS stations in lower Montgomery County; therefore, additional subsidence monitoring in this area would be beneficial as the current GPS stations may not capture the extent of subsidence.

The Phase 1 Report states that the greatest rates and amounts of subsidence occur in Harris County (p.8). On page 13, the report states,

"UH [University of Houston] reports the average subsidence rate based on GPS data for the period from 2005 to 2014 to be between 17 and 19 millimeters per year (mm/yr), or 0.67 to 0.75 inches per year (in/yr)."

It should be noted that all UH reports and results regarding GPS-derived subsidence are limited to specific times and locations. Anthropogenic subsidence shows significant temporospatial variations, making it important to specify subsidence rates within a specific time range and area. GPS sites are more heavily weighted towards areas of known subsidence; if these sites were averaged to calculate county-wide subsidence, the result would be based on spatially biased data. Based on GPS and historical leveling data, the subsidence contours from Petersen and others (2019) show cumulative subsidence between 1 and 3 feet in southern Montgomery County. It is notable that these values are based on collected data, not groundwater model estimates or projections.

On page 22 of the Phase 1 Report, it is stated,

"…there are many ways to present the results from the HAGM [Houston Area Groundwater Model]. Examples of the various presentations include average drawdown, average subsidence, change in storage, or percent remaining available drawdown…"

It is important to ensure that the modeled scenarios also include the maximum subsidence and drawdown, which are shown spatially on a figure. Maximum subsidence and drawdown results from the modeled scenarios are generally not presented together in the Phase 1 Report but are vital to landowners and public supply entities. Averaging subsidence and/or drawdown spatially may mask the effects of groundwater use at a sub-county scale.

Additionally, on page 23, the Phase 1 Report states,

"…a significant portion of the simulated subsidence is due to pumping outside of the District"

and cites Figure 50 as the basis for this determination. Figure 50 is titled "Calculated subsidence due to simulated pumping in the subsidence districts near Montgomery County." This determination does not appear to be supported by the analysis approach and the way subsidence is represented in the HAGM. The report also does not include an analysis of land subsidence due to pumping in Montgomery County for comparison. It is recommended that a more complete discussion of this information be included in the report. Based on water-level data, the area's downdip in Harris County may be affected by updip groundwater use in Montgomery County.

The SAC suggests that the following represent remaining information gaps that are vital for decision-makers:

a) What do the data show to date for Montgomery County in terms of land subsidence? What are the conclusions for the county? The Phase 1 Report appears to focus on subsidence primarily in the greater Houston-Galveston region.

b) What are the trends in historical and current groundwater use? How have these changed through time, and how are they related to subsidence?

c) Drought should be considered in terms of water usage/resource planning since those are the conditions under which water demand increases significantly. What does the historical record reflect during periods of drought for water level changes and subsidence?

Jasper Aquifer Subsidence

On page 23, the Phase 1 Report presents a discussion on the relationship between average drawdown and simulated maximum compaction and provides references to report figures 47–49. Little discussion of the simulation methodology is provided, and it is unclear how the simulated results are produced and presented on the plots. Although the Phase 1 Report discusses some of the limitations of the HAGM [Groundwater Availability Model] (p.16), it makes no mention of well-known limitations when using the model to estimate potential subsidence in Montgomery County, particularly compaction of the Jasper Aquifer.

The development of the clay compaction properties in the HAGM are described in Kasmarek (2013):

> *"The initial values of elastic-clay storativity used in the HAGM for the Burkeville confining unit and the Jasper Aquifer were calculated by multiplying existing GAM values of clay thickness by 1.0×10^{-6}. The initial values of inelastic clay storativity for the Burkeville confining unit and Jasper Aquifer were derived by multiplying the values of elastic-clay storativity by 100."*

Due to the limited information regarding the compaction properties of the deeper units, the clay storativity values in the model for the Burkeville and Jasper units were based on the clay thickness estimates from the GAM developed in 2004 and an assumed factor which was applied to the entire model area. A justification for the use of the factor is not presented in Kasmarek (2013). In practice, the model's known limitations result in a low and conservative estimate that produces the very limited compaction potential of the Jasper Aquifer in the model. A new GAM is being developed by the USGS (GULF 2023), which will include Jasper Aquifer clay compaction estimates that were not available when the HAGM was developed. The GULF 2023 project is scheduled to end by December 2022, but initial reports are scheduled to be released by January 2022.

Given the (1) similarity of aquifer material properties between the Chicot, Evangeline, and Jasper units (Kelley and others, 2018), (2) heterogeneous combination of interbedded sand, silt, and clay material, (3) limitations of the HAGM model concerning the Jasper Aquifer, and (4) extensometer data for the Chicot and Evangeline Aquifers that do not show substantial differences in susceptibility to compaction, a simple linear plot used for the conclusions made in the Phase 1 Report (i.e., the Jasper susceptibility 1,000 times less than the Chicot) has the potential to mislead what the data reflect. Further investigation is needed to assess the potential compaction of the Jasper Aquifer in Montgomery County.

Data collected from the co-located extensometer and GPS units at the Lake Houston site suggest little ongoing compaction of the Jasper Aquifer in this area. However, differences between this site and the area of lower Montgomery County exist, namely the depth to the Jasper Aquifer strata in this area (approximately 2,500 ft) and a minor amount of water use from the Jasper

Aquifer in this area. Thus, these data do not imply that compaction in the Jasper Aquifer is not occurring in lower Montgomery County.

A recent Southern Methodist University (Qu and others, 2019) concludes that,

> *"…newly discovered fault activation appears to be related to the stress associated with fluid pressure reductions caused by excessive water extraction from Montgomery County aquifers". [p.12]*

Specifically, the study states that the cause of the faulting determined from the 2007 through 2011 Interferometric Synthetic Aperture Radar (InSAR) imagery is related to,

> *"…excessive groundwater exploitation" and "…continuous mining of groundwater from the Jasper Aquifer…" in Montgomery County (Qu and others, 2019)." [p.12]*

When viewed in the aggregate, the combination of (1) conclusions from the Qu and others (2019) study, (2) the currently available datasets for water-level altitudes in the Chicot, Evangeline, and Jasper Aquifers, and (3) vertical displacement data from the GPS sites in Montgomery County, suggests susceptibility in the Jasper Aquifer to compaction. While direct evidence in the Jasper Aquifer is limited, the available data do not rule out subsidence susceptibility—rather, it strengthens the case for further study and monitoring.

Minor Comments

Some terminology in the Phase 1 Report is imprecise and subjective, and therefore not technical. For example, terminology such as "considerable amount," as referenced in the Phase 1 Report conclusions, would benefit from quantification to assist readers in better understanding the discussion.

The SAC has some concern with public comments seeming to be given more weight in reaching scientific conclusions than the available scientific literature and datasets (examples below). Stakeholder concerns should be heard and addressed, as they have the collective knowledge and expertise from lived experience. While water management should aim to meet stakeholder needs and it is critical to incorporate the lived experience of community members into policymaking, it is important to ensure opinion does not outweigh science-driven determinations in decision making.

> *"Dr. Norman concluded that the slight movements at some of the measured benchmarks are too small to indicate fault activation or movement. Some area residents disagree with that finding." [p. 12]*

> *"…a professional engineer representing the Lake Conroe Citizens Network (LCCN) provided public comments to LSGCD (and others) questioning the accuracy and validity of reported data and results for CORS-TXCN near the City of Conroe (Massey, 2015)." [p. 13]*

The possible effects of subsidence from petroleum production are not discussed. While the magnitude of subsidence from petroleum production will not be the same as the magnitude from groundwater production, it should be considered. It would likely be a secondary, but not necessarily insignificant, source and could impact the 100-year floodplain definitions.

SAC Summary of Phase 1 Findings

- The current state of the science on the Jasper Aquifer is that it is likely susceptible to compaction. It is important to verify this conclusion with Jasper Aquifer scientific monitoring data.
- The Phase 1 Report describes the Jasper Aquifer as being 1,000 times less susceptible to subsidence than the Chicot Aquifer based on simulations using the HAGM. This statement is misleading. The HAGM was constructed with very limited data and conservative assumptions that clay compaction properties would be applicable to the Jasper Aquifer. The GULF 2023 model currently under development will reflect more recent research on the compaction potential of the Jasper Aquifer and improved modeling approaches.
- As a literature review, the Phase 1 Report does not concentrate on Montgomery County, but instead focuses on the greater Houston-Galveston region. Further studies would benefit from a focus on Montgomery County that addresses questions such as:
    - What do the data show for Montgomery County in terms of land subsidence that has occurred historically?
    - How susceptible is each aquifer to compaction in Montgomery County, and what data are available to support these conclusions?
    - How did subsidence rates change following the recent conversion from groundwater to surface water?
    - How have rates of fault movement changed following the recent conversion from groundwater to surface water?
- The SAC has concerns about Figure 50 in the Phase 1 Report and what it represents. It is misleading to suggest that Harris County is responsible for 80-90% of subsidence in Montgomery County. A reverse analysis using the same assumptions employed in the Phase 1 Report may yield a very different result. While pumping impacts do not stop at county lines, water levels and subsidence are generally most affected by the heaviest use in the immediate area (i.e., greatest sustained drawdown over the longest period), the lowest historical water level, and the clay content of the pumped aquifer unit in that immediate area. This is clearly demonstrated by the water level recoveries and changes in subsidence rates associated with the recent conversion from groundwater to surface water in the county.
- Drought and its impacts on water levels and subsidence was not discussed in the Phase 1 Report. Drought is an important consideration when reviewing historical data and forecasting water declines, subsidence, and pumping. The SAC recommends drought be considered in terms of water usage/resource planning since those are the conditions under which water demand increases significantly.
- The possible effects of subsidence from petroleum production are not discussed in the Phase 1 Report. While the magnitude of subsidence from petroleum production will not be the same as the magnitude from groundwater production, the SAC recommends it be considered to determine impacts.

Recommendations for Phase 2

The Phase 1 Report discusses possible tasks for a Phase 2 study. It is encouraging to see that plans for monitoring and research are included and hopefully will include a cooperative effort with the Harris-Galveston Subsidence District (HGSD). The SAC recommends decision-makers work with area scientists and experts on data collection, data analysis, and regional studies.

Currently, HGSD and UH routinely process GPS data from 14 permanent GPS stations (7 UH, 6 HGSD, 1 Texas Department of Transportation), within Montgomery County (Wang and others, 2015). Those datasets provide first-hand information about ongoing subsidence within The Woodlands and Conroe areas. However, the coverage of GPS is too sparse to assess the overall subsidence on a county-wide basis. The SAC recommends the establishment of a dense GPS network within Montgomery County like those in HGSD and Fort Bend Subsidence District. The SAC suggests installation of, at a minimum, twenty additional (new) continuous GPS stations co-located or closely spaced with Jasper groundwater wells with regular water level monitoring within Montgomery County. Since the focus is on the Jasper Aquifer, a closely spaced water level and subsidence monitoring system will provide critical information about the Jasper Aquifer. Installation of one GPS station is about $10,000, with an annual operation cost of about $1,000. LSGCD could work with HGSD and expand the current GPS network within the greater Houston-Galveston region. Within three years, LSGCD would have new insights into ongoing subsidence within Montgomery County, which is fundamental for future groundwater management and planning.

There is mention in the Phase 1 Report on page 29 of installing an extensometer to measure subsidence of the formations that make up the Jasper Aquifer. The SAC strongly supports this plan of an extensometer installation. USGS and HGSD operate 14 extensometer stations within the greater Houston-Galveston region. They recently installed a deep extensometer station southeast of Katy, TX. Three GPS stations were also installed adjacent to the Katy extensometer. The extensometer and GPS integrated system is designed to be able to differentiate shallow and deep compaction within different aquifers without the cost of a Jasper-specific extensometer. The SAC recommends assessing a similar approach that could be applied in Montgomery County.

The use of InSAR was discussed in the Phase 1 report. While GPS and extensometers provide precise measurements of subsidence, the data are limited spatially to the point of measurement (Kasmarek and Ramage, 2015). InSAR can supplement those techniques by evaluating changes over larger areas of the land surface between their locations (Stork and Sneed, 2002). Additionally, InSAR imagery can help the district better position future extensometers or GPS stations (Bawden and others, 2003). The three techniques work well together to provide a fuller representation of subsidence. The technique is used in other areas and could have some applicability in this region. The potential of InSAR in the region should be studied further. The SAC will review InSAR to make more specific recommendations.

The Phase 1 report states on page 27 that evaluating models to assess flooding and subsidence as part of the tasks for the Phase 2 study. To begin to incorporate flooding into the analysis, the SAC recommends closely following the results of the Spring Creek subsidence and flooding study (HGSD and the Harris County Flood Control District are working collaboratively on this study). The methods and results of that study could help Montgomery County better understand the potential impacts of subsidence on flooding and the approaches that would work best in other watersheds.

SAC Members

John Ellis, P.G.
Supervisory Hydrologist
USGS Oklahoma-Texas Water Science Center
John Ellis is currently a Supervisory Hydrologist with the Texas Water Science Center. He began his USGS career in 2014 at the Oklahoma Water Science Center leading a hydrologic investigation of the Canadian River alluvial aquifer in cooperation with the Oklahoma Water Resources Board. John's subsequent projects included the North Fork and Rush Springs aquifer studies focused on integrated surface water and groundwater resources. These projects included constructing the aquifer hydrogeologic framework, determining hydraulic properties, and running modeling simulations. His projects also included modeling the Washita River alluvial aquifer and evaluating the impacts of future climate variability on aquifer and reservoir storage. In 2019, John moved to the Texas Water Science Center to serve as the Gulf Coast Branch Studies Chief. In this capacity, he works with a variety of cooperators to investigate issues related to water quality, land subsidence, and groundwater level changes. John holds a M.S. in Hydrogeology from The University of Alabama, a M.S. in Environmental Science from Hardin-Simmons University, and a B.S. in Geology from The University of Texas at Dallas.

Robert Mace, Ph.D.
Executive Director and Chief Water Policy Officer
The Meadows Center for Water and the Environment
Robert Mace is the Executive Director and Chief Water Policy Officer at The Meadows Center for Water and the Environment and a Professor of Practice in the Department of Geography at Texas State University. Robert has over 30 years of experience in hydrology, hydrogeology, stakeholder processes, and water policy, mostly in Texas. Before joining Texas State University in 2017, Robert worked at the Texas Water Development Board for 17 years ending his career there as the Deputy Executive Administrator for the Water Science & Conservation office. While at the Board, Robert worked on understanding groundwater and surface water resources in Texas; advancing water conservation and innovative water technologies such as desalination, aquifer storage and recovery, reuse, and rainwater harvesting; and protecting Texans from floods. Prior to joining the Texas Water Development Board, Robert worked nine years at the Bureau of Economic Geology at The University of Texas at Austin as a hydrologist and research scientist. Robert has a B.S. in Geophysics and an M.S. in Hydrology from the New Mexico Institute of Mining and Technology and a Ph.D. in Hydrogeology from The University of Texas at Austin.

Gretchen Miller, Ph.D.
Associate Professor
Zachry Department of Civil Engineering at Texas A&M University
Gretchen Miller, Ph.D., P.E., is an associate professor of water resources engineering in the Zachry Department of Civil Engineering at Texas A&M University, where she teaches fluid dynamics and groundwater engineering. Gretchen specializes in ecohydrology and groundwater sustainability, focusing on the interactions between groundwater, soil moisture, and vegetation and their implications for managing water resources. Her work with the Texas Water Observatory focuses on using data to improve a range of models, including Texas Groundwater Availability Models, such as that of the Brazos River Alluvium Aquifer (BRAA), and highly complex Earth system models, like the Community Earth System Model (CESM). She also has expertise in methods for monitoring evapotranspiration (e.g., eddy covariance, sap flow) and subsurface water storage. Her awards include a National Science Foundation CAREER grant, a reviewer commendation from Water Resources Research, and the Texas A&M Dean of Engineering Excellence Award. Prior to joining Texas A&M, she earned her Ph.D. in Environmental Engineering at the University of California at Berkeley and her M.S. and B.S. in Geological Engineering at the Missouri University of Science and Technology. She is registered as a professional engineer in the state of Texas.

Wade Oliver, P.G.
Senior Hydrogeologist
INTERA
Wade Oliver's professional experience has focused on the characterization of groundwater systems and the development and application of numerical flow models to analyze these systems. His experience includes characterizing the structure, water quality, and water levels of aquifers, updating aquifer management plans for groundwater conservation districts (GCDs), and developing groundwater availability models to support water planning strategies for both public and private entities. He also has extensive experience characterizing brackish aquifer resources in water-scarce areas of Texas, New Mexico, and Oklahoma for energy companies to help them secure reliable water for operations while protecting local fresh water supplies. Prior to coming to INTERA and during his time working for a Texas state agency, he led more than 90 projects involving evaluations of aquifer recharge, groundwater-surface water interaction, inter-aquifer flow, and future groundwater conditions and availability for local and regional groundwater management entities in Texas. This information was frequently used to evaluate various water management strategies by GCDs and groundwater management areas (GMAs) and included presenting results and fielding questions at public meetings. Through this experience, Wade has in-depth knowledge of the Texas Groundwater Availability Modeling Program and groundwater laws and regulations in Texas, especially the desired future condition (DFC) process. In modeling and data analysis studies, he has experience with groundwater codes, including MODFLOW, as well as the application of PEST for calibrating and optimizing numerical models. Wade earned his M.S. in Geology from the University of Utah and his B.S. in Environmental Geoscience from Texas A&M University. He is a licensed Professional Geologist in Texas.

John Seifert, PE
Principal
Groundwater Consultants, LLC
John Seifert' is a groundwater consultant based in Houston. His experience over the past 35 years includes groundwater availability and water quality studies; groundwater conservation district management and water resource studies; artificial recharge and recovery; regional water planning studies; lignite and gold mine dewatering and water management projects; planning of test hole drilling programs and monitoring of test hole drilling; design, construction inspection, and testing of public supply water wells, rehabilitation of large-capacity wells and estimation of the effects of groundwater withdrawals. He has served as Project Manager for studies of the availability of groundwater from the Hickory Sandstone, Chicot, Evangeline, Jasper and Catahoula Aquifers of the Gulf Coast Aquifer system the Ogallala aquifer and Carrizo-Wilcox aquifer in Texas and for other aquifers in other states and in Mozambique. He also has participated in projects studying the availability of brackish groundwater from most major aquifers in Texas. He has managed groundwater studies of alluvial aquifer systems including the Brazos River Alluvium. He has served as Project Manager on assignments for providing design and construction management services for 500 to 7,000 gallons per minute public supply wells and brackish groundwater supply wells drilled to depths ranging from 950 to 3,100 feet in Texas and other states. He has directed studies of groundwater resources for two Senate Bill 1 planning regions, Region H and Region P. John earned a B.S. in Agricultural Engineering from Texas A&M University and an M.S. in Agricultural Engineering from Texas A&M University.

Jack Sharp, Ph.D.
Dave P. Carlton Centennial Professor Emeritus in Geology
Department of Geological Sciences, Jackson School of Geosciences, University of Texas
Dr. Jack Sharp joined the University of Texas at Austin in 1982. His hydrogeological research covers flow in fractured rocks, thermohaline free convection, fracture skin effects, regional flow in carbonate rocks, hydrology of arid and semi-arid zones, subsidence and coastal land loss, effects of urbanization, and alluvial aquifers. Jack has long-term interests in the hydrogeology of sedimentary basins and hydrological processes in ore deposit formation. He also is known for developing the first mathematical model of the effects of physical changes that occur on the surfaces of fractured rocks and of how layers of water with different densities can overturn of their own accord in sedimentary systems. As an offshoot of his analyses of natural springs in Central Texas, Washington D.C., and elsewhere, he uncovered the way waterborne contaminants use the sandy material that surrounds underground utility pipes as conduits for transport. In fall 1974, he first began sharing his love of learning on faculty at the University of Missouri–Columbia. Over 100 graduate students and postdoctorates have benefited from his guidance. Jack has given keynote addresses in five countries, is a past president of the Geological Society of America, and a past president and treasurer for the U.S. chapter of the International Association of Hydrogeologists, among a multitude of professional roles. Jack earned a Ph.D in Hydrogeology from the University of Illinois at Urbana–Champaign, studying the movement of heat through layers of sediment. The work earned him the O.E. Meinzer Award — hydrogeology's highest honor.

John Tracy, Ph.D.
Executive Director
Texas Water Resources Institute, Texas A&M University
As director of the Texas Water Resources Institute, Dr. John Tracy works to connect Texas A&M University faculty and staff with a wide range of local, state, federal and private entities, to develop and move forward initiatives that address pressing water resources issues facing Texas, the region and the nation. John is a Professor of Water Resources in the Zachry Department of Civil Engineering in the Dwight Look College of Engineering at Texas A&M University. He joined Texas A&M in the fall of 2015 and has been involved in a wide range of research initiatives focused on understanding and developing sustainable water resource management practices across the western United States, including the western High Plains, Northern Plains, Great Basin and Pacific Northwest hydro-climatological regions. His recent work focuses on developing an integrated understanding of the behavior of water resource systems under the influence of changing hydrologic, economic, and social conditions, as well as improving methods of engaging water managers and users in advancing their understand of water resource systems. During his career, John has been engaged in a diverse range of research topics that has resulted in publications in civil, mechanical, agricultural, electrical and chemical engineering professional journals, in addition to being published in environmental, biological, ecological, textile, chemistry and interdisciplinary water resource professional journals. He started his academic career at Kansas State University in the Department of Civil Engineering in 1989, where his research focused on modeling phytoremediation processes, and developing models to aid in the conjunctive administration of surface and groundwater rights. John received his B.S. in Civil Engineering at Colorado State University in 1980 and his M.S. and Ph.D. in Engineering at the University of California at Davis in 1986 and 1989, respectively.

Bob Wang, Ph.D.
Professor of Geophysics, Geodesy and Geosensing Systems Engineering
University of Houston
Dr. Bob Wang has been with the University of Houston since 2011 and is currently a Professor in the Department of Earth and Atmospheric Sciences and the Department of Civil and Environmental Engineering. Prior to his time at the University of Houston, Bob was an Associate Professor in the Department of Geology at the University of Puerto Rico at Mayaguez. His research interests include coastal hazards (e.g., sea-level change, faulting, subsidence, wetland loss), GPS seismology, applications of GPS and LIDAR technologies in natural hazards studies, and geological hazard risk analysis and mitigation. Bob is the director of the Houston GPS Network (HoustonNet), which comprises over 70 permanent continuous GPS stations within the greater Houston-Galveston region. Bob earned his Ph.D. in Solid Earth Geophysics at the Institute of Geology of the China Earthquake Administration. He earned his M.S. in Hydrogeology and Engineering Geology at Nanjing University and his B.S. in Geology at China University of Geosciences.

SAC Facilitator
Stephanie Glenn, Ph.D.
Director, Water & Hydrology Program
HARC
Stephanie Glenn is responsible for the development and supervision of projects to improve the sustainable management of water and ecological resources. Her current research focuses on coastal groundwater quality and quantity, watershed protection and surface water quality, and developing ecological tools for management. Dr. Glenn recently served as the PI for the EPA and Texas State and Soil Water Conservation Board funded project, “Developing a Watershed Protection Plan for Double Bayou”. Dr. Glenn served as PI of the USGS funded, multi-partner NBII CSWGCIN project from 2002-2011 and as PI on the Texas Water Development Board’s, Developing a Texas Groundwater Monitoring Strategy initiative. Dr. Glenn joined HARC in January of 2003 after completing a Ph.D. in Environmental Science and Engineering from Rice University in Houston, Texas. Previous degrees include a M.S. in Environmental Science from Indiana University and a B.A. in Mathematics from Northwestern University. She previously worked for the Department of Energy in Defense Programs as a specialist in information management and technical writing. She has also worked for The National Park Service as an ecological scientist.

About HARC
The Houston Advanced Research Center (HARC) is a 501(c)(3) nonprofit applied research organization located in The Woodlands, Texas founded in 1982 by George P. Mitchell. HARC is committed to sustainability. HARC’s Water Program focuses on disseminating data and information in support of water resource protection; working with stakeholders to identify and implement best practices to improve water quality; and assessing barriers to community resilience and sustainability. HARC water projects support the development of regional policies and community outreach programs relating to important topics such as the preservation and management of Galveston Bay, watershed planning, climate resilience, waterway trash and marine debris and stormwater management. For more information about HARC and its programs, please visit www.HARCresearch.org.

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