SCIENCE AND RESEARCH PLAN

Harris-Galveston Subsidence District

The Harris-Galveston Subsidence District is the leader in groundwater regulation and subsidence monitoring in the State of Texas. Since 1975, the District has taken a reasonable and inclusive approach to groundwater regulation resulting in a dramatic reduction in subsidence rates within the District. Annually, the District prepares a budget for the upcoming fiscal year. The Science and Research objectives in this plan will provide some clarity on the questions that face the District in the near future while providing a firm foundation for future regulatory plan updates.

Michael J. Turco – General Manager

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VISION STATEMENT

The Harris – Galveston Subsidence District's vision is a comprehensive description of how the organization will look in the future:

The Harris-Galveston Subsidence District is the premier water management and subsidence authority in the Upper Gulf Coast Aquifer in Texas. The District plays an integral role in regional water management strategies to insure the long-term viability of all water resources while protecting lives and property within the District from the impacts of subsidence and flooding.

MISSION STATEMENT

The Harris-Galveston Subsidence District protects lives and property within the District from the impacts of future subsidence by providing reasonable groundwater regulation based on the best available science

GOALS

Utilizing the District's mission and strategic vision, the following goals will be the focus of the District through 2025:

- *Conduct research that enhances the understanding and effective management of the Upper Gulf Coast Aquifer System to minimize subsidence in the District*
- *Educate the community on the importance of water resources, the occurrence of subsidence in the region, and promote water conservation*
- *Communicate effectively with regional water providers and stakeholders*
- *Provide reasonable groundwater regulation in support of the District mission*
- *Develop a diverse, highly-motivated, customer service focused organization while maintaining fiscal stability*

Introduction

This plan represents the "strategic direction" for science and research conducted or supported by the Harris-Galveston Subsidence District (HGSD) and, as such, is an essential component of the District's regulatory planning process. The Science Plan is being created in an effort to provide clarity to the strategic direction of the District and guidance to future science and research priorities in support of the District Regulatory Plan.

History of the Subsidence District

It was in the early 1900's that the Houston area began to see the first true signs of human-induced land subsidence — initially attributed to the extraction of oil and gas from beneath the surface, and relegated to the land immediately in and around the center of the oil fields. Increased oil production and the establishment of the Port of Houston in 1925 led to rapid industrial and consequently population growth. The area's plentiful supply of fresh groundwater helped to fuel the massive growth, but ultimately, the community's need outpaced the aquifer's ability to safely sustain their demand for water.

In the early 1940's, new studies began to identify problems due to groundwater extraction. Original land-subsidence benchmarks, established just after the turn of the century, were surveyed in the 40's, and the results verified that subsidence was occurring.

By the 1960's, community leaders began to link the increased frequency and severity of flooding to subsidence. In the sub-tropical, low-lying areas of Houston and Galveston — where tropical storms and hurricanes were a probability, not just a possibility– flooding was real and could be severe. In 1961, Hurricane Carla hit the Houston area the flooding that occurred was beyond what was, in the past, expected from a hurricane of Carla's size. As a result, local area governments began to analyze the serious and very real impact subsidence could have on the area's potential economic growth and quality of life, and, just as important, began to determine what exactly could be done about it.

With a number of studies linking groundwater withdrawal to subsidence — and ongoing measurements confirming those findings — groups of citizens began to work for a reduction in groundwater use in the late 1960's. By 1973, the City of Galveston had begun converting to surface water supplied from Lake Houston, and in May of 1975, the Texas Legislature created the Harris-Galveston Subsidence District (HGSD), the first of its kind in the United States. Authorized as a regulatory agency created to "end subsidence" and armed with the power to restrict groundwater withdrawals, the Subsidence District immediately went to work on a plan to positively impact the critical situation in the coastal areas.

By 1976, the District had begun the process of compiling hydrologic information on the characteristics of the Chicot and Evangeline aquifers, engineering planning information on water usage and water supply in Harris and Galveston counties, and implementing regulatory procedures associated with their first groundwater regulatory plan. By converting industries on the Houston Ship Channel to surface water supplied from the recently completed Lake Livingston reservoir, subsidence in the Baytown-Pasadena area was dramatically improved, and has since been largely halted.

But as subsidence was stabilizing in the coastal areas, groundwater levels in inland areas north and west of Houston were rapidly declining. In the Evangeline aquifer, measurements recorded a decline of more than 100 feet between 1977 and 1997.

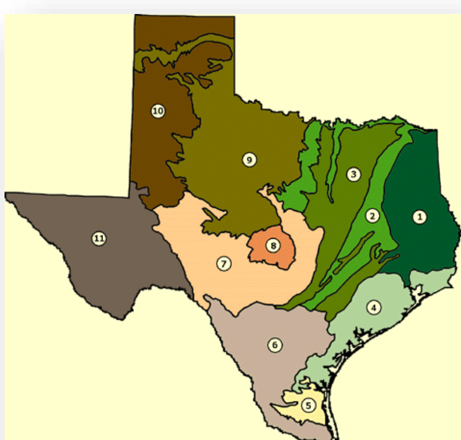
As a result of the increasing threat subsidence posed to these areas, the HGSD adopted a series of regulatory plans to reduce groundwater pumpage, and ultimately mandated, a reduction to only 20% reliance on groundwater by 2035.

Throughout the years, the District has relied on high-quality relevant science to address the needs of the District. Science and research conducted by the District to date include:

- Evaluate the change in effective stress in the aquifer matrix as result of water use changes;
- Development of numerous PRESS sites throughout the District that utilize detailed site specific information to predict future subsidence;
- Development of numerous numerical models that allow the simulation of estimated subsidence as a result of future water demands;
- Annual water-level measurement that has shown the impact of conversion requirements on the water-level in the aquifer;
- Periodic population and water demand studies;
- And numerous other special studies to address specific understanding needs.

Physical Setting and Eco-regions

The State of Texas encompasses an area of nearly 270,000 square miles and extends almost 850 miles in both length and breadth. Its coastline measures more than 367 miles of Gulf shoreline and 3,300 miles of bay and estuary shoreline. The international border with Mexico is about 1,200 miles in length. Mountains, plateaus, hills, plains, beaches, river valleys, and canyon lands make the State of Texas one of the most physically diverse in the nation.



1. Piney Woods
2. Oak Woods & Prairies
3. Blackland Prairies
4. Gulf Coast Prairies & Marshes
5. Coastal Sand Plains
6. South Texas Brush Country
7. Edwards Plateau
8. Llano Uplift
9. Rolling Plains
10. High Plains
11. Trans Pecos

Figure 1. Ecoregions in the State of Texas

The HGSD exists within the ecoregion 4, dominated by Gulf Coast Prairies and Marshes (Figure 1). This nearly level plain area of 13 million acres borders the Gulf of Mexico from the Sabine River to Corpus Christi Bay. Prior to European settlement and twentieth-century development, this landscape included woodlands of sugarberry, pecan, elms, and live oaks, and open prairies with native grasses. The soils of the area range from acidic sands to sandy loams, with clays occurring in the river bottoms.

The Gulf Coast aquifer exists as an accretionary wedge of unconsolidated sediments composed primarily of sand, silt, and clay. Indicative of a transgressive-regressive shoreline, the interbedded sands and clays are not horizontally or vertically continuous at larger than a local scale. The three primary water bearing units include the Chicot, Evangeline, and Jasper aquifers. The Chicot and the Evangeline aquifers are hydrologically connected and are typically differentiated by well yield analysis. The Jasper is the deepest of the three, and isolated by the regionally persistent Burkeville confining unit. Historically, most of the subsidence that has occurred in the region can be sourced to clay-compaction in the shallow water bearing units.

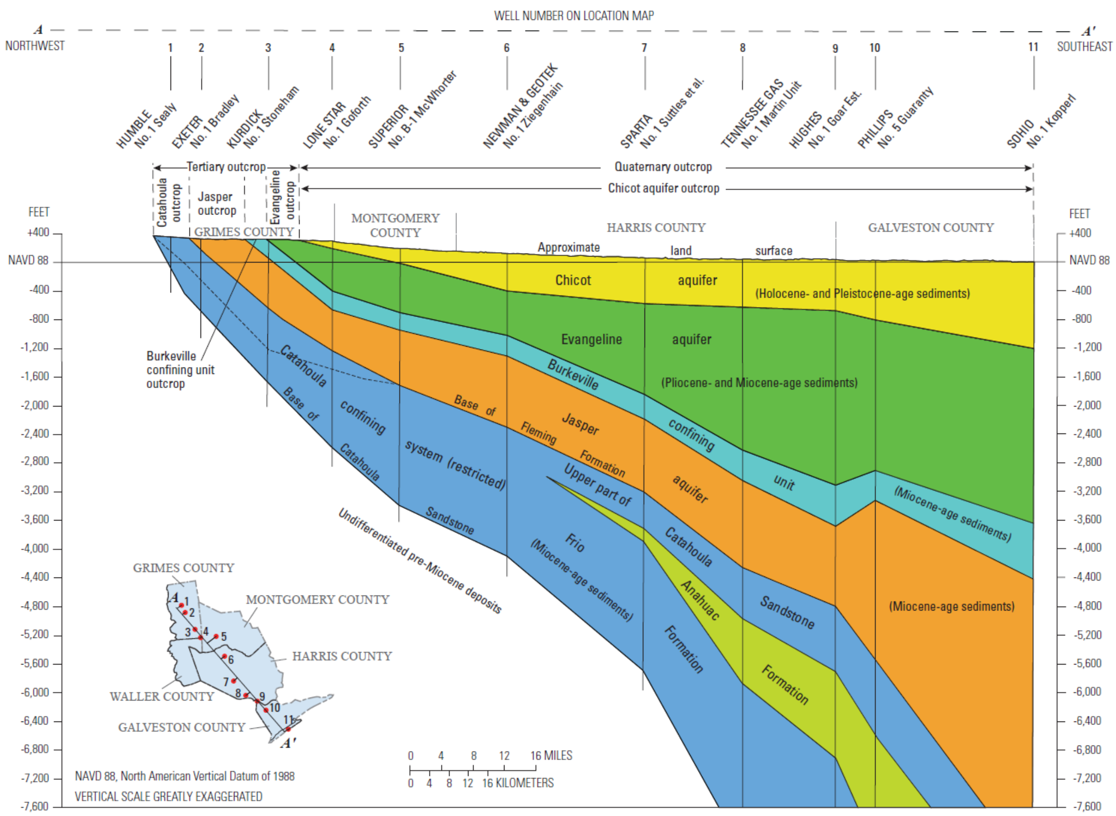


Figure 2. Hydrogeologic section *A–A'* of the Gulf Coast aquifer system in Grimes, Montgomery, Harris, and Galveston Counties, Texas (modified from Baker, 1979, fig. 4 in Kasmarek and others, 2014).

The HGSD Science and Research Fund

In 2015, the Board of Directors of the Harris Galveston Subsidence District created the Science and Research Fund for the purpose of conducting science and research in support of the District's Regulatory Plan. The overall scope of the fund is to support all action related to the effective development and maintenance of the regulatory policy of the District including data management, special topic research, and policy analysis

Fiscal Considerations

The Science and Research fund (SRF) was created by the District Board of Directors during fiscal year 2015. In 2015 about $1.4 million was transferred from the District's general fund to the SRF. The SRF receives revenue annually from the collection of disincentive fees as determined by the District Regulatory plan. Disincentive fee revenue is not consistent from year to year. The Science plan summarizes potential project scopes that may have a wide range of cost.

Projects addressing the priority themes contained within the Science and Research Plan may be funded through multiple mechanisms. Projects may be completed by District staff, other state agencies, Federal agencies, Universities, or private consulting firms. Projects may be funded directly in total or in cooperation with other agencies. The typical project will be funded directly and will last 6-18 months. Board approval of projects will be required based on the District's fiscal and investment policy.

Table 1. Types of entity the District may work with to accomplish Science and Research objectives.

Entity	Typical Type of Funding	Typical Scope	Funding Mechanism
Federal Agencies	Cooperative Water Program, Direct, Collaboration	Regional	Joint Funding Agreement
Harris-Galveston Subsidence Dist.	Direct	Regional - Local	Transfer to General Fund
Local Agencies	Collaboration	Regional-Local	Interlocal Agreement
Private Consulting Firm	Direct	Regional-Local	Direct contract
Texas Water Development Board	Direct, In-Kind Cooperation, Collaboration	Regional	Inter-local Agreement
University	Direct, Match	Regional-Local	Direct contract

Priority Science and Research Themes

The District's Regulatory Plan (last updated in 2013) provides some direction for the priority science and research themes focused on three primary components: hydrogeology and subsidence and regulatory policy analysis. The primary components focus on understanding needs ahead of the next regulatory plan update. Each of these components will be considered as part of the next regulatory plan update. The purpose of the science and research themes are to generally define the technical objectives for future data management, research, and policy analysis needs.

Hydrogeology and Subsidence

The District has spent millions of dollars and man-hours understanding the effects of stress on the primary water bearing units of the Gulf Coast aquifer within the District. However, in recent years, what was historically undevelopable waters in the aquifer have become economically viable. This is evident in the recent interest in the utilization of the Jasper aquifer. These "new" resources and water management strategies will require thorough study to insure that the development of these resources or the implementation of these new techniques do not have the unintended consequence of subsidence.

Gulf Coast Aquifer Hydrostratigraphy

Through the process of regional water planning, local and state water managers and planners utilize historical surface water and ground water data to determine the current available water and sustainable use of the various source waters. Groundwater under the influence of surface water and other transitional waters are of particular importance to this planning process as they are difficult to quantify and may cause an over or under estimation of the available water in an area.

Recently, the lower portion of the Brazos River Basin was studied to evaluate the interaction of the river and the underlying alluvial and bedrock aquifers. Results from this study showed that it is possible that specific zones of interaction occur over specific aquifer units, and likely occur in other river basins that cross these units in other parts of the state.

There has been some recent work on the hydrostratigraphy of the Gulf Coast completed by the Texas Water Development Board. The conceptual model of groundwater movement in the aquifer has been well studied. Future questions will be more local in focus, and will require a compilation scalable view of the available hydrogeologic information in the region.

Objective: *Develop a more vertically and horizontally resolute depiction of the hydrostratigraphy of the District and surrounding areas.*

Simulation of Groundwater Flow and Subsidence

Numerical and analytical models are used to adequately predict the impact of the regulatory plan on the groundwater system and subsidence. All models are developed based on historical information. Over time, as more data is made available for analysis, models are validated, updated, and recalibrated to minimize uncertainty within the model, improving the models predictive capability. The District has recently updated the regional groundwater flow model, which is referred to as the Houston Area Groundwater Model (HAGM).

The District has historically utilized two types of models for the prediction of Subsidence: a numerical model developed by the USGS utilizing the MODFLOW model and the analytical PRESS model recently updated by FUGRO. The MODFLOW model provides a regional depiction of the aquifer whereas the PRESS provide predictions at the local scale at several locations throughout the District. Reducing the uncertainty of model predictions while providing a wide depiction of subsidence is an important objective for the District' regulatory plan.

Objective: *Evaluate numerical depiction of the aquifer system and improve resolution where appropriate.*

***Objective:** Evaluate alternative numerical methods by which to simulate the interaction of the primary water bearing units with surficial processes (precipitation, streamflow, evapotranspiration).*

***Objective:** Evaluate the method by which the HAGM simulates subsidence and determine approaches for further improvement.*

***Objective:** Update PRESS model sites and determine potential locations for future press site development.*

Brackish Groundwater Resources

The state is continuing to be innovative in the search for new water supplies. The TWDB reports that and estimated 2.7 billion acre-feet of brackish groundwater is available in Texas. Once again the Regional Water Planning Groups (RWPGs) were on the forefront of this effort with the publication of the Brackish Groundwater Manual for Texas Regional Water Planning Groups in 2003. This publication raised the level of interest across the state in the development of brackish groundwater as a source of supply for desalination.

Little is known about the hydrogeology of the parts of most aquifers that contain brackish water compared to the parts that contain freshwater, because the need to utilize brackish ground water has been limited. A need exists to better understand the occurrence of brackish waters in the deeper sediments of the Gulf Coast Aquifer and their viability as municipal or industrial resources verses the potential for compaction and subsidence.

***Objective**: Determine the occurrence and hydrogeologic characteristics of the brackish resources within the District and surrounding areas.*

Aquifer Storage and Recovery

The drought experienced by those that depend on the Brazos River for their alternative water supply was significant and raised concerns on the long-term viability of that resource. This is of particular importance for those in area 1 which rely on that resource for 90% of their total water demand.

Aquifer storage and recovery (ASR) is the process by which a water source is injected into the aquifer and stored for a period of time, after which it is withdrawn at a theoretical “no-net” loss to the aquifer. ASR projects have been successful throughout the country with some good examples in Florida and Nevada. In Las Vegas, ASR is used as a water management strategy to provide water for the desert city as well as cease subsidence, and it has been successful.

ASR studies in the Texas Gulf Coast are limited. The City of Texas City attempted an ASR project several years ago without success. Of primary concern from the subsidence perspective is the length of time between injection and withdrawal and how that relates to a water-level/subsidence neutral yield.

***Objective:** Conduct a risk assessment on the subsidence neutral yield of an ASR project in the Gulf Coast aquifer.*

Subsidence Monitoring

The District currently (2015) maintains an 80 node network of GPS land deformation monitoring sites (PAM) throughout the District and surrounding counties. This network is constantly evolving and requires consistent investment to insure it adequately captures the intended dataset.

Recently, the District has observed compaction in portions of regulatory area 1. Compaction in this area, where water use has been converted to 90% alternative water and 10% groundwater is anomalous. Further investigation into this area and the extensometers is needed.

Considering the surface area of the District, remote sensing of subsidence throughout the region will provide a more resolute picture of current land surface change. Remote sensing can be accomplished through the use of LIDAR or INSAR methods. When combined with the periodically and continuous stations, this type of information would periodically provide coverage between the GPS network nodes.

Objective: *Develop a better understanding of the land surface deformation throughout the District and surrounding areas.*

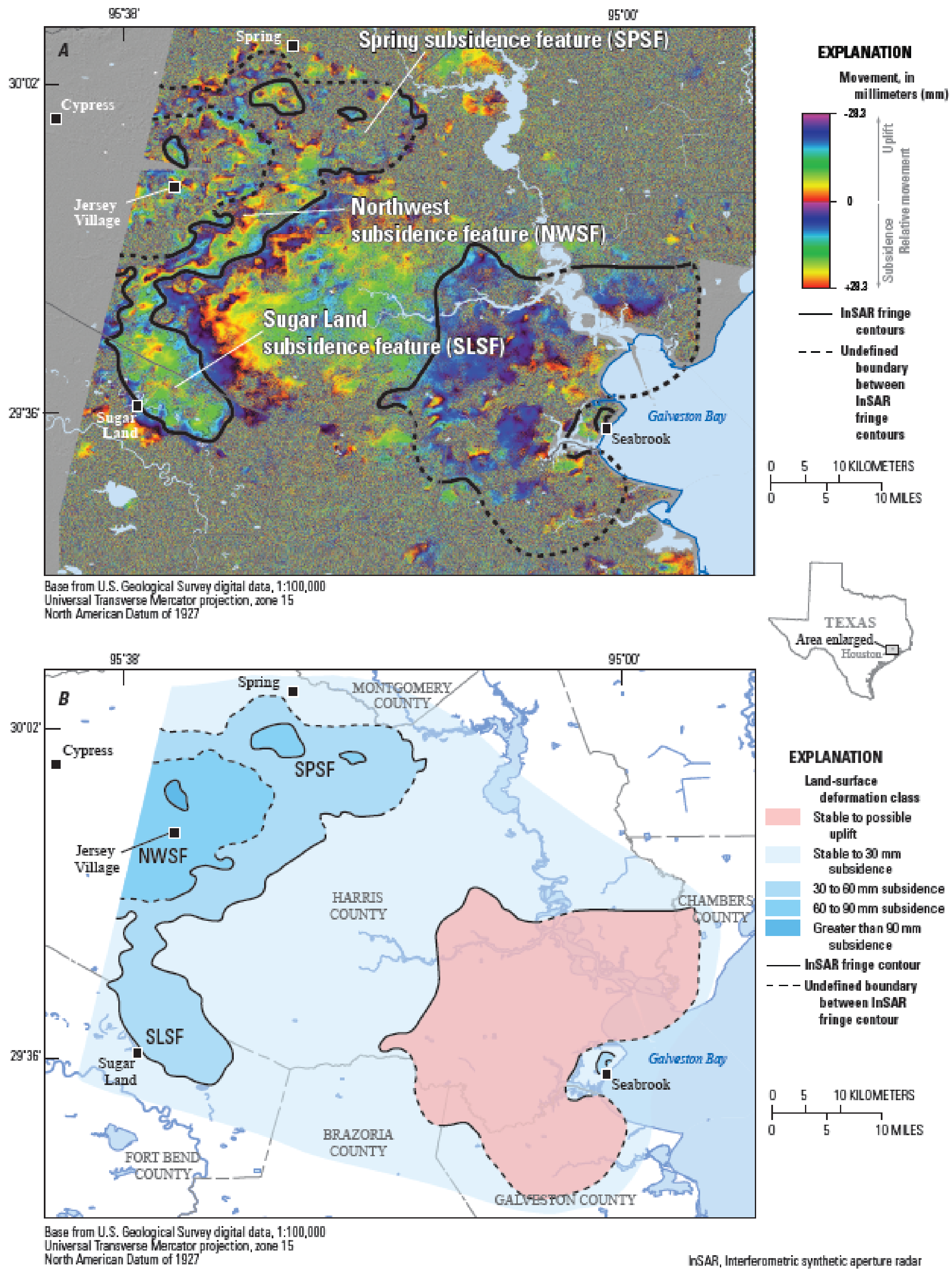


Figure 3. Interferogram for January 30, 1996, to December 30, 1997 showing primary areas of subsidence. *A*, The named subsidence features to the northwest. *B*, Interpolated land-surface deformation contours. The blue- and red-shaded areas represent regions with subsidence or uplift. (Bawden and others, 2012).

Groundwater Use and Permit Tracking

The District has participated in the developed of several Groundwater Flow models over the last forty years. In each instance the most important model parameter has been water use. The historical water use data has been a vital metric for the District since 1975. The District works closely with permitees to gather accurate water use information annually. Over the years the District has amassed a wealth of information. With this comes the requirement of proper archival and the need for ancillary data sets to better understand the context of the groundwater use.

The evolution of technology and the needs of a data driven regulatory plan will require the update and re-tooling of our District database and permit tracking system.

Objective*: Migrate the Districts database to a more widely used platform and develop web application tools to improve data analysis and dissemination.*

Regulatory Policy Analysis

The District Regulatory Plan requires Regional Water Authorities to provide for the availability of alternative sources of water to replace the mandated reduction in groundwater use. Future alternative source waters will include: reclaimed water, desalinated seawater, surface water, and water savings realized through water conservation. Alternative sources of water are finite, and may become short supplied during even short periods of drought.

Reclaimed water is a significant component to the water management strategies for Region H, particularly in Harris and Galveston Counties. Alternative water supplies are lynchpins to the District's regulatory plan, without available alternative water supplies groundwater will be utilized and subsidence will occur. However, reclaimed water does not come without its drawbacks. For example, historically, waste water discharge is the primary component of base flow in many of the rivers, streams, and bayous within the District. A reduction discharge quantity can have a direct impact on the amount of surface water available to downstream users.

Seawater from the Gulf of Mexico is the most abundant non-groundwater source water in the region. The development of surface desalination plants is a widely used world-wide (i.e. Australia, Israel) but also within the U.S in California and Florida. The largest seawater desalination plant in the country, which is slightly larger than the groundwater desalination plant in El Paso, TX, operates in Florida.

During future droughts, groundwater credits will be utilized to offset shortfalls in alternative supply. Groundwater credits may be earned through over-conversion, the utilization of reclaimed waters, or participation in the District's Water Conservation Program. Although, the District has incorporated "normal" non-drought related groundwater credit use into the 2013 regulatory plan, the impact of wide-spread utilization of credits during a time of prolonged drought has not been specifically investigated.

Groundwater Credit Program

The District's regulatory plan provides for the utilization of groundwater in lue of a portion of the conversion requirement through the use of groundwater credits with the intent of providing some relief from the regulatory plan during periods limited alternative source water availability. Groundwater credits may be earned through the District's Water Conservation Program or bought from other groundwater credit holders.

Climatic variability impacts both the supply and the demand for water and therefore plays a crucial role in water management. As water resources are exploited to or beyond their natural limits, climatic variations are of greater concern in all kinds of hydrologic systems.

Increased air temperature in the future will increase rates of evaporation resulting in decreased stream flows by lowering contributions from runoff and groundwater sources. A decrease surface water baseflow may have an impact on reservoir volumes and availability of run-of river resources – causing a renewed dependence on groundwater particularly in Galveston County where recent droughts continue to effect the availability of the Brazos River.

Objective: *Develop a risk analysis on the impacts of sustained drought on the District regulatory plan.*

Objective: *Estimate the impact of over-conversion and groundwater credits on the aquifer during a period of sustained drought.*

Objective: *Develop a risk analysis on impacts of widespread groundwater credit use in the coastal areas.*

The District is nearly completely surrounded by Groundwater Conservation Districts governed by chapter 36 of the Texas Water Code. Policies in those Districts that allow for groundwater withdrawal without the consideration for subsidence could have detrimental effects on the long-term success of the regulatory plan. Additionally, changes in regulatory structure, which was counted on in the 2013 regulatory plan, may also have a negative impact on subsidence within the District.

Objective: *Develop risk analysis of potential regulatory changes in bordering Districts on subsidence within the District.*

Communications Plan

The priority themes outlined in the Science and Research Plan will require an effective review and communication of project objectives, plan, progress, and results. Most projects will be initiated through the utilization the Professional Services Act to engage the best qualified entity. Quarterly, the General Manager will provide an update of each ongoing project funded by the District. All project will be required to document all aspects of the project and summarize the project results in a final report. Each project will require a final report that is adequately quality assured and approved.

All data, interpretations, and final reports will be the property of the District and properly archived in the Districts database. Final reports will be available to the public on the District's web site.