Determination of Groundwater Withdrawal and Effects on Subsidence – 2019

by
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Harris-Galveston Subsidence District Report 2020-01

Harris – Galveston Subsidence District
Friendswood, TX
2020

MICHAEL J. TURCO

GENERAL MANAGER

The Harris-Galveston Subsidence District (District) has been monitoring water use, groundwater levels, and subsidence in Harris, Galveston, and adjacent counties since 1975. Subsidence, the lowering of land-surface elevation, is caused by the depressurization of our aquifers due to wide-spread use of groundwater as a primary water source. The mission of the District is to cease on-going subsidence and prevent the occurrence of future subsidence. As part of this effort, it is important for the District to provide consistent, high-quality information to the public regarding ground water use, aquifer water-levels, and subsidence.

The information contained within this report is the compilation of the largest multi-agency effort in the State of Texas that leverages the resources of both the Harris-Galveston and Fort Bend Subsidence Districts with the City of Houston, the Lone Star Groundwater Conservation District, the Brazoria County Groundwater Conservation District, and the U.S. Geological Survey. This year alone, local, county, regional, and federal partnerships will publish the 44th volume of this important data compilation. This report is intended to exceed the requirements of section 8801.117 of the District's enabling legislation.

On behalf of the Board of Directors of the Harris-Galveston Subsidence District, I would like to thank you for your interest in the District. We look forward to continuing to provide timely, accurate, high-quality data and research to inform the District's Regulatory Planning and water planning throughout the region.

Sincerely,

Michael J. Turco

General Manager

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Acknowledgements

The compilation of the data and analysis contained within this report would not be possible without the concerted effort of many that contributed to the 2019 Annual Groundwater Report. The authors would like to thank the staff of the Harris-Galveston Subsidence District for their diligent field work in collecting and verifying GPS and water use information, Ana Ruiz Flores, Ronald Geesing, Brian Ladd, and Vanson Truong (Harris-Galveston Subsidence District) for their processing and validation of water use data; Dr. Guoquan Wang (University of Houston) and his students for processing and archival of all of the raw GPS data, Joseph Turco (Northeastern University) for the development of computer scripts to aid in the interpretation and visualization of the GPS data; and the engineers, staff, and owners of the nearly 9,000 permitted wells in the District that submitted detailed water use information contained in this report.

BOARD OF DIRECTORS

Public Hearing Notice was posted on:	May 1, 2020
Draft Report Posted on District Website on:	May 26, 2020
Public Hearing held on:	May 28, 2020
Hearing Examiner:	Ms. Helen Truscott
Hearing Record held open for public comment until:	June 5, 2020
Approved by the Board of Directors:	June 10, 2020

Conversions Factors and Datums

Multiply	By	To obtain
inch (in)	2.54	centimeter (cm)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon (gal)	3.785	liter (L)
million gallons per day (MGD)	3785.41	cubic meter (m^3)
million gallons per day (MGD)	3.0688	acre-feet (acre-ft)

List of Acronyms

BCGCD	Brazoria County Groundwater Conservation District
CORS	continuously operating reference station
FBSD	Fort Bend Subsidence District
GPS	global positioning system
GRP	groundwater reduction plan
HGSD	Harris-Galveston Subsidence District
LSGCD	Lone Star Groundwater Conservation District
MGD	million gallons per day
NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
PAM	periodically measured GPS station
POR	period of record
TxDOT	Texas Department of Transportation
UH	University of Houston
USGS	United States Geological Survey

Executive Summary

Groundwater was the primary source of water for the municipal, agricultural, and industrial users over the last century. Rapid increase in population in the 1950s due to the expansion of the industrial complex in the Houston Ship Channel area led to a dramatic increase in water demand and groundwater withdrawal. The reliance on groundwater and subsequent subsidence that was caused by its regional development resulted in the creation of the Harris-Galveston Subsidence District (District) in 1975 and the Fort Bend Subsidence District in 1989. The District's mission is to regulate the use of groundwater in Harris and Galveston counties, to cease ongoing and prevent future subsidence that can lead to infrastructure damage and contribute to flooding.

This report comprises the 44th Annual Groundwater Report for the District. Pursuant to District Resolution No. 2020-1052 passed on February 12, 2020, and amended on April 8, 2020, the Board of Directors held the Annual Groundwater Hearing beginning at 10:00 a.m. on May 28, 2020. This report provides an overview of the information presented during the Public Hearing, including climatic conditions, groundwater use, groundwater levels and measured subsidence within the District through December 31, 2019.

Climate

Annual variations in precipitation can have a significant impact on the total water demand of the District. Water use patterns change during periods of climatic variation, which results in changes in water levels and potentially in subsidence rates. During periods of excessive rainfall, total water demand can decline, conversely, during prolonged dry periods, water use can increase resulting in declining water levels in the aquifer and increasing subsidence. Overall, the 2019 calendar year started out with below normal rainfall accumulations, followed by Tropical Storm Imelda, which resulted in significant flooding across the region. Rainfall totals ended up being at, or slightly above, normal across the District.

Water Use

Since 1976, water users in the District have been working to change their source water from primarily groundwater to alternative sources of water that will not contribute to subsidence, primarily treated surface water. The percent of total water demand sourced from groundwater has dropped from about 60 percent in 1976 to about 23 percent in 2019. Most of the current groundwater use occurs in Regulatory Area Three where the regulatory compliance timeline will not be completed until 2035. The three primary water uses in the District are public supply, industrial, and irrigation. The overall groundwater use within the District is 228.1 MGD, which is a 2 percent increase in pumpage from 2018. Public supply groundwater use remains the largest single use category at 209.2 million gallons per day (MGD), a 2 percent increase from 2018, and accounts for 92 percent of groundwater used in the District. Since the last regulatory conversion milestone in 2010, public supply and industrial uses are generally unchanged where irrigation uses have decreased by about 49 percent.

The District's Regulatory Plan requires permittees to convert to alternative water supplies in order to reduce their reliance on groundwater sources. The primary alternative water supply used in our region is surface water sourced from three river basins, the Brazos River Basin, the San Jacinto River Basin and the Trinity River Basin. Total alternative water use for 2019 was 746.7 MGD, with the Trinity River remaining the single largest source of alternative water providing a total of 531.5 MGD in surface water supply. Groundwater remains the second largest source of water supply within the District as a whole. The total water use for the District was determined to be 974.8 MGD in 2019, which is 3 percent lower than 2018.

Groundwater Levels

Annually, since 1975, the United States Geological Survey (USGS) has measured the water level in hundreds of wells throughout the Houston region in cooperation with the District through a joint funding agreement along with additional cities, subsidence districts and groundwater conservation districts to monitor and provide reports on groundwater level altitude data for the Chicot, Evangeline and Jasper aquifers. Since aquifer water level is the best measure of the pressure in the aquifer, this information is also of vital importance to understanding the impact of changes in water use on subsidence.

The change in water-level in the Chicot and Evangeline aquifers since 1977 clearly shows the impact of District regulation on the aquifers. Generally, Regulatory Areas One and Two have seen a significant rise in the potentiometric water-level up to 200 feet and 240 feet in the Chicot and Evangeline aquifers, respectively. The area of rise is a result of the reduction of groundwater use required by the District's Regulatory Plan. Conversely, in Regulatory Area Three and nearby in northern Fort Bend and southern Montgomery Counties, water-levels continue to be significantly lower than the historical benchmark, declines of nearly 280 feet in the Evangeline and Jasper aquifers. These areas are growing rapidly and the conversion to alternative sources of water will not be completed in the District until 2035 and in the Fort Bend Subsidence District until 2025.

Subsidence

Since the late 1990s, the District has been utilizing global positioning system (GPS) to monitor the land surface deformation in the area. Working collaboratively with the University of Houston researchers, the monitoring network has grown to over 200 monitoring sites throughout the region that area operated by the District, the Fort Bend Subsidence District, the University of Houston, the Lone Star Groundwater Conservation District, and the Brazoria County Groundwater Conservation District.

The average annual rate of movement is a useful measure to show the current activity at a monitoring site. The annual rates of subsidence observed in Regulatory Areas One and Two are generally stable, since both areas have reached their full regulatory conversion level (1990 and 1995, respectively) and potentiometric water-levels have risen. Subsidence rates are generally above 0.5 centimeters per year (cm/yr) throughout Regulatory Area Three as this area is still undergoing conversion to alternative water supply.

Introduction

The Houston region has relied on groundwater as a primary source of water since the early 1900s. During and following the economic boom of the 1940s, rapid population expansion and increased water use resulted in potentiometric water-level declines in the Chicot and Evangeline aquifer of 250 and 300 feet (76 and 91 meters), respectively from 1943 to 1977 (Gabrysch, 1982). The potentiometric surface is the level to which water rises in a well. In a confined aquifer, this surface is above the top of the aquifer unit; whereas, in an unconfined aquifer, it is the same as the water table.

The reliance on groundwater and subsequent subsidence that was caused by regional development resulted in the creation of the Harris-Galveston Subsidence District (District) in 1975 and the Fort Bend Subsidence District in 1989. The District's mission is to regulate the use of groundwater in Harris and Galveston counties to cease ongoing and prevent future subsidence that can contribute to flooding, faulting, and lead to infrastructure damage.

Description of Study Area

The following section provides an overview of the study area, including the hydrogeology and an overview of the District's regulatory planning areas.

Hydrogeology

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. From youngest to oldest, these hydrogeologic units include the Chicot, Evangeline, Burkeville, Jasper, and Catahoula Sandstone aquifers as shown in **Figure 1**.

The three primary water-bearing units located within the District include the Chicot, Evangeline, and Jasper aquifers. The Chicot and the Evangeline aquifers comprise the shallow system of aquifers. These aquifers are hydrologically connected, allowing for the free flow of water between the two units. Historically, nearly all of the groundwater production in the Gulf Coast Aquifer System in the District occurred in the shallow system. The Jasper aquifer is the deepest of the three primary water bearing units and is isolated by the regionally persistent Burkeville confining unit. In the region, the Catahoula Sandstone, deepest water bearing unit in the Gulf Coast Aquifer system and the Burkeville confining unit are utilized as a groundwater supply in areas to the north and west of the District where these units may produce appreciable amounts of water.

Most of the subsidence that has occurred in the District can be sourced to clay compaction in the shallow water bearing units associated with long-term water use and the decline in the aquifers' potentiometric surface. Because of the significant amount of clay material in the primary water bearing units of the aquifer, the risk of compaction is high in areas where the developed portions of the aquifers are within about 2,000 feet of land surface (Yu and others, 2014), under high stress from groundwater development, and have had sustained potentiometric water-level declines.

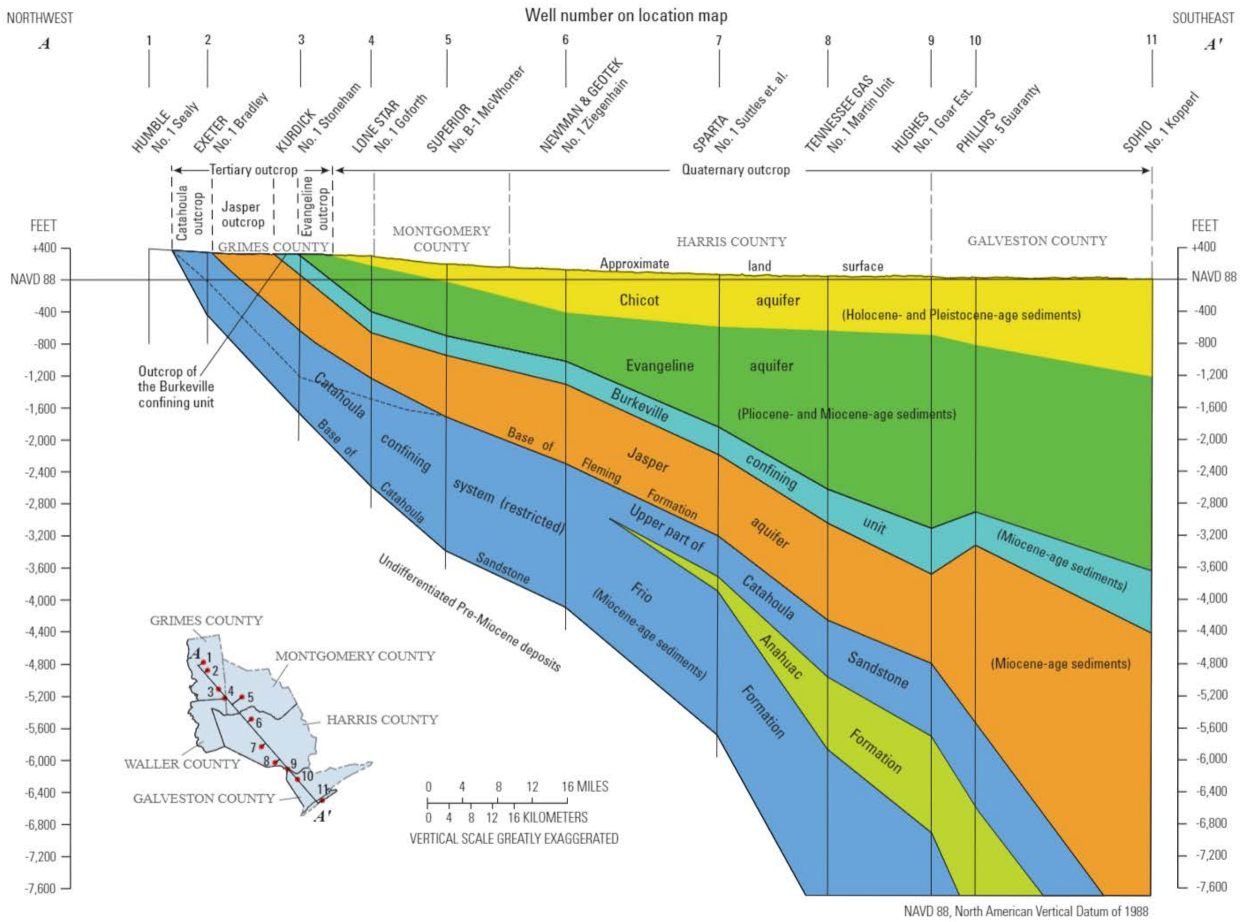

Figure 1. Hydrogeologic section of the Gulf Coast aquifer system in Harris and adjacent counties, Texas (Kasmarek, 2013).

Regulatory Planning

The District's Regulatory Plan was developed to reduce groundwater withdrawal to a level that ceases ongoing subsidence and prevents future subsidence within the District. The District utilizes a novel approach to regulating groundwater withdrawal to prevent subsidence by allowing a portion of the total water demand of a groundwater user to be sourced from groundwater. Total water demand is defined as the total amount of water used by an entity from all sources including groundwater, treated surface water, reclaimed water, etc. The District adopted the most recent Regulatory Plan on January 9, 2013 and it was subsequently amended on May 08, 2013.

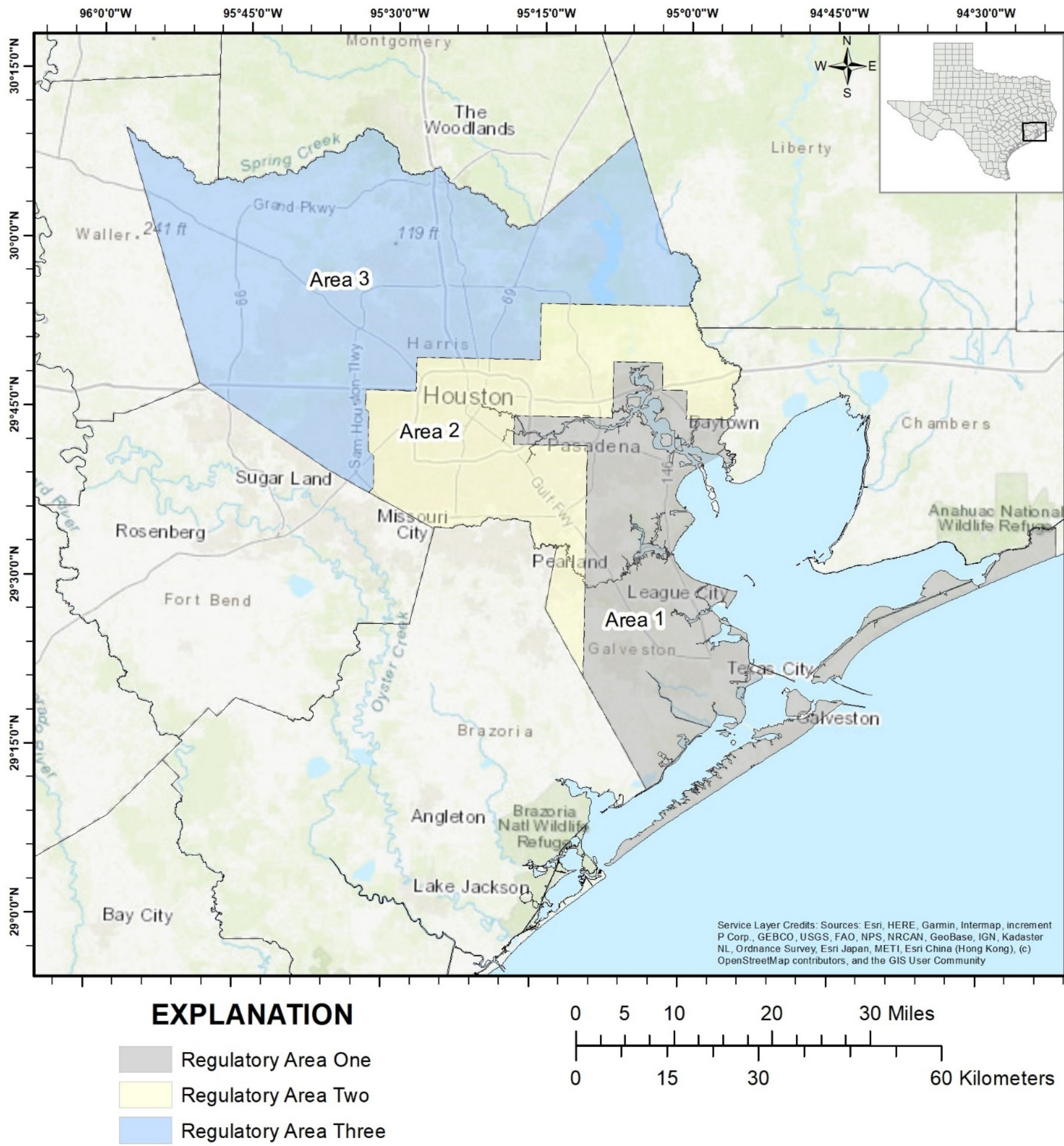

Figure 2. Location of the Harris-Galveston Subsidence District Regulatory Areas.

The District has historically used regulatory areas to guide groundwater conversion deadlines and regulations. The 2013 Regulatory Plan has subdivided Harris and Galveston counties into three regulatory areas (**Figure 2**). Regulatory Area One includes the Houston Ship Channel, Industrial Corridor, and coastal areas of Galveston and Harris Counties. Permittees in this area are required to have no more than 10% of their total water demand come from groundwater sources. Regulatory Area Two is primarily an urban intermediate area that includes the Texas Medical Center. Permittees in this area must have no more than 20% of their total water demand come from groundwater sources. Reduction in groundwater use for both Regulatory Area One and Two began once the District was created in 1975, and by 1990 most of the areas had been fully converted to using alternative sources of water. Both Regulatory Areas One and Two are considered to be fully converted, and no further conversion is currently planned.

However, Regulatory Area Three is still undergoing conversion from groundwater to surface water sources. Regulatory Area Three includes the remaining areas of the District in northern and western Harris County. This area completed its first conversion in 2010 reducing groundwater use from 100% to 70% of total water demand. The District's Regulatory Plan allows permittees with more than ten million gallons per year of total water demand the option to establish groundwater reduction plans (GRPs) that provide a phased approach to conversion. For those permittees operating under a GRP, the conversion deadlines require the following future conversion deadlines:

- In 2025, groundwater withdrawals must not comprise more than 40 percent of the permittee's total water demand.
- In 2035, groundwater withdrawals must not comprise more than 20 percent of the permittee's total water demand.

All other permittees (i.e., those without GRPs) were required to reduce their groundwater withdrawals so that no more than 20 percent of their total water demand was sourced from groundwater.

Surficial Hydrology

The District's Regulatory Plan requires permittees to convert to alternative water supplies in order to reduce their reliance on groundwater sources. The primary alternative water supplies used in the Houston region is surface water sourced from three river basins: the Brazos River Basin, the San Jacinto River Basin and the Trinity River Basin (**Figure 3**)**.**

The Brazos River Basin is the largest river basin in Texas, covering over 45,000 square miles (4,180 sq m) (TWDB, 2020). The headwaters of the Brazos River are located near the Texas-New Mexico border and the river travels over 800 miles (1,287 km) to discharge into the Gulf of Mexico near Freeport, Texas. The Brazos River Authority manages the eleven reservoirs within this basin, eight of which are owned by the Brazos River Authority and three are owned by the U. S. Army Corps of Engineers (Region H Water Planning Group, 2016).

The San Jacinto River Basin is the smallest river basin in Texas, covering almost 4,000 square miles (371 sq m) according to Texas Water Development Board (2020). Lake Conroe and Lake Houston are the two water supply reservoirs located within the San Jacinto River Basin. Lake Conroe is jointly owned by the City of Houston and the San Jacinto River Authority. The San Jacinto River Authority operates Lake Conroe and provides water supply to Harris and Montgomery Counties. Lake Houston is owned by the City of Houston and operated by the Coastal Water Authority.

The Trinity River Basin covers almost 18,000 square miles (1,672 sq m), with headwaters of the basin located in north central Texas (TWDB, 2020). The Trinity River flows through the Dallas-Fort Worth metroplex, traversing 550 miles (885 km) until the river discharges into Trinity Bay near Anahuac, Texas. There are numerous reservoirs located on the Trinity River that are owned and operated by several different agencies, including Lake Livingston which is owned and operated by Trinity River Authority.

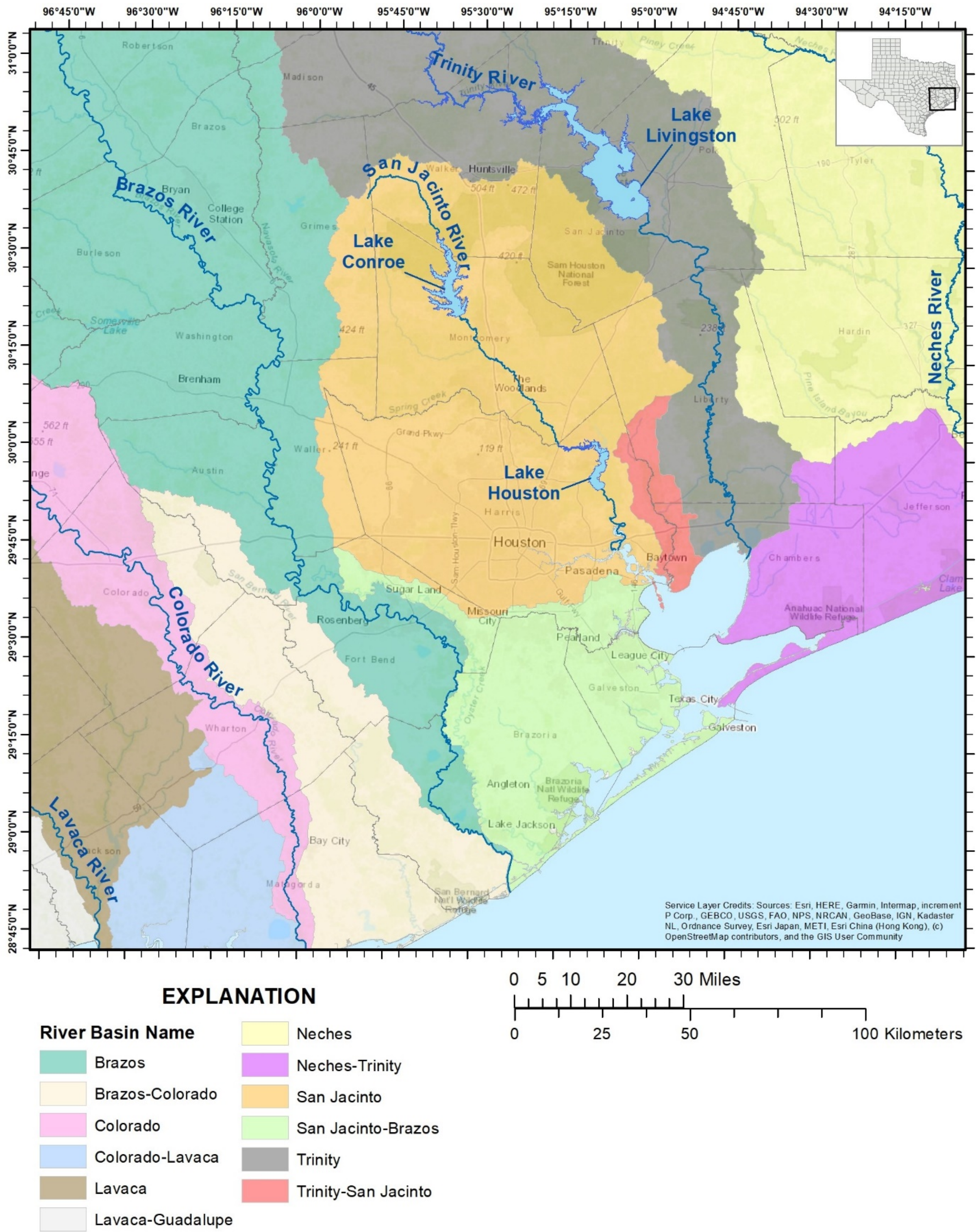

Figure 3: River basins that supply alternative water to Harris and Galveston Counties, Texas.

Alternative Source Waters

In the 1950s, the City of Houston along with other entities in the region began the development of several water supply reservoirs to provide water for the rapidly growing region within the San Jacinto and Trinity River Basins. The water treatment plants served by these surface water sources are operated by the City of Houston, City of Sugar Land, City of Richmond, the Gulf Coast Water Authority, the Brazosport Water Authority, and others.

To meet the Harris-Galveston and Fort Bend Subsidence Districts' regulatory requirements to convert from groundwater to surface water, the City of Houston and four regional water authorities—the Central Harris County Regional Water Authority, North Fort Bend Water Authority, North Harris County Regional Water Authority, and West Harris County Regional Water Authority (collectively, the Water Authorities) began working together to implement a GRP for the planning, design, financing, and construction of several major infrastructure projects. These projects are regional in scale and are interrelated. All the projects must be constructed based on a coordinated timeline to ensure that surface water will be available to northern and western Harris County and northeast Fort Bend County to comply with the District's regulatory conversion schedule.

The first project is called the Luce Bayou Interbasin Transfer Project. The project will pump untreated surface water from the Trinity River through a series of canals and water pipelines to Lake Houston. The project is being constructed by the Coastal Water Authority, but is being funded by the entities that will be purchasing the transferred water, which includes the City of Houston and the Water Authorities.

The second project is called the Northeast Water Purification Plant Expansion Project. This design-build project will expand an existing surface water treatment plant located near Lake Houston from 80 MGD up to 400 MGD, in order to treat the raw surface water conveyed by the Luce Bayou Interbasin Transfer Project into Lake Houston. The City of Houston is the owner of this project, but the Water Authorities have purchased 84 percent of the capacity of the Northeast Water Purification Plant Expansion Project and are each paying their respective shares of the costs.

The third project is a transmission line called the Northeast Transmission Line project, which will convey treated water from the expanded Northeast Water Purification Plant into central and northern Harris County. This transmission line is expected to be primarily a 9-foot (2.7 m) diameter steel water line that is approximately 27 miles (43.5 km) in length. The City of Houston is the owner of this project, but the North Harris County Regional Water Authority and the Central Harris County Regional Water Authority have purchased capacity in the line and are each paying their respective shares of the costs (the West Harris County Regional Water Authority and the North Fort Bend Water Authority are also participating in the initial segment of this transmission line).

The fourth project is another transmission line project called the Surface Water Supply Project, which also includes two pump stations. This project will convey treated water from the expanded Northeast Water Purification Plant into western Harris County and northeastern Fort Bend County. This project is expected to be primarily an 8-foot (2.4 m) diameter steel water line that is approximately 40 miles (64.4 km) in length. The West Harris County Regional Water Authority is the owner of this project, but the North Fort Bend Water Authority has purchased capacity in the line and is paying its share of the costs.

In addition to the four projects described above, the City of Houston and the Water Authorities are each designing and constructing their own distribution systems to convey the treated surface water to their customers.

These interrelated regional projects are planned to be completed by 2025, when the next conversion requirements of Harris-Galveston and Fort Bend Subsidence Districts go into effect.

Purpose and Scope of Report

This document comprises the 44th Annual Groundwater Report for the District. Pursuant to District Resolution No. 2020-1052 passed on February 12, 2020, and amended on April 8, 2020, the Board of Directors held the Annual Groundwater Hearing beginning at 10:00 a.m. on May 28, 2020. The Public Hearing was held as a virtual meeting to comply with best practices and directions provided by the State of Texas for the COVID-19 public health emergency. The public hearing fulfills the requirements of Section 8801.117, Texas Special Districts Local Laws Code, which states that each year, the Board of Directors shall hold a public hearing for the purpose of taking testimony concerning the effects of groundwater withdrawals on the subsidence of land within the District during the preceding year.

Approximately 25 people attended the 2019 Groundwater Hearing including members of the USGS staff, along with members of the District's staff, two Board members, several interested parties and the public. Those giving testimony were Dr. Tina Petersen and Ms. Ashley Greuter of the District and Mr. Jason Ramage, Hydrologist, Gulf Coast Programs Office, Texas-Oklahoma Water Science Center, United States Geological Survey, Department of the Interior. District staff submitted in total, 29 exhibits including topics of precipitation, groundwater withdrawal, alternate-water usage, and subsidence measurements. Mr. Ramage presented 37 exhibits including topics of water-level altitudes, water-level changes, and land surface subsidence.

This report provides an overview of the information presented during the Public Hearing, including climatic conditions, groundwater use, groundwater levels and measured subsidence within the District through December 31, 2019. Appendix A of this report includes the exhibits presented at the public hearing held on May 28, 2020.

2019 Climate Summary

The District reviews local climatic data provided by the National Oceanic and Atmospheric Administration (NOAA) – National Weather Service (NWS) climate stations within the District region (**Figure 4**). Variation in local precipitation, specifically deviation from historical normal, is important to the District because it has a direct impact on the magnitude of the total water demand of water users in the region and the availability of alternative water supplies. During period of above normal precipitation in the region, total water demand remains typically near normal or below normal due to reduced municipal and agricultural water uses. Conversely, during period of below normal precipitation, the total water demand of the region will typically increase due to increased water use. Additionally, during prolonged periods of below normal precipitation, natural limits on alternative supplies may require additional groundwater use – and subsequently result in additional lowering of groundwater aquifer levels, compaction of the aquifer materials, and subsidence observed at land surface.

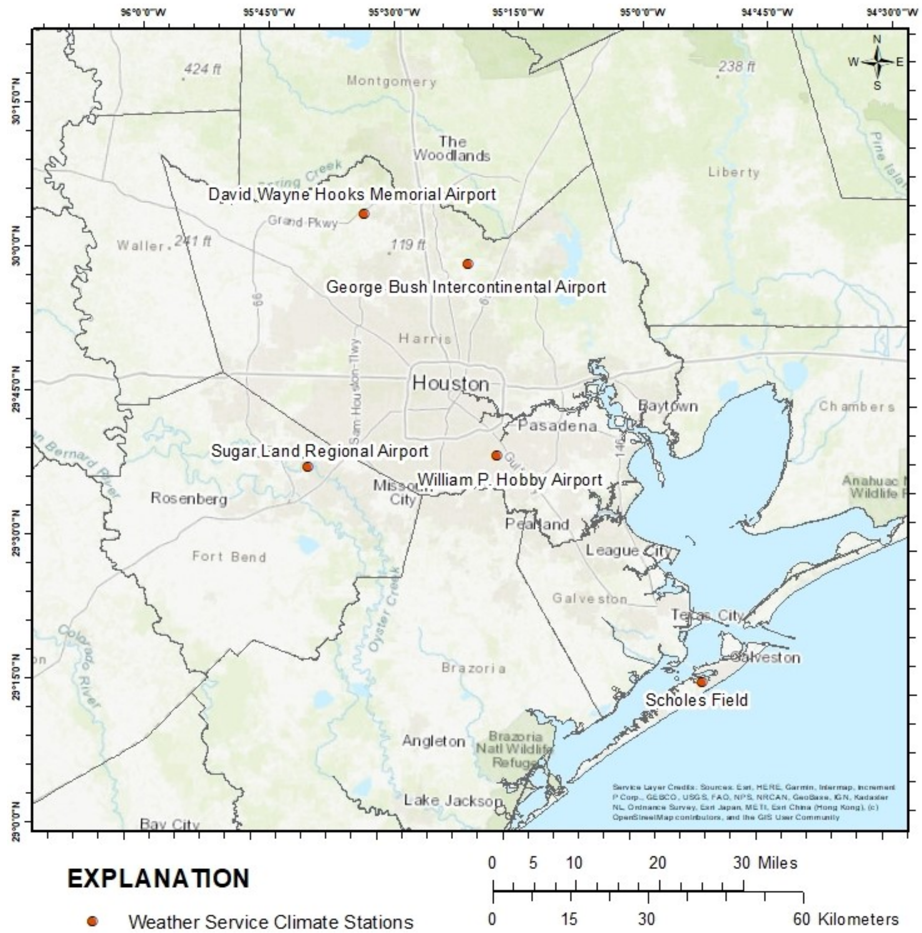

Figure 4. Location of NOAA-NWS climate stations, Houston Region, TX.

As shown in **Figure 5**, precipitation throughout 2019 is marked by periods of about normal rainfall interrupted with a period of significant rainfall associated with Tropical Storm Imelda and prolonged below normal rainfall in the spring and early summer months. The cumulative precipitation departure from 1981-2010 normal precipitation is referenced to the George Bush Intercontinental Airport values for each NWS climate station displayed in **Figure 5**.

Generally normal to below normal precipitation in the winter and early spring is observed and reviewed at all climate stations. Following a large regional storm system in early May, below normal precipitation continued through early September where all stations were below normal cumulative precipitation. This caused a departure from normal precipitation at Scholes Field in Galveston, TX at nearly 11 inches (27.9 cm).

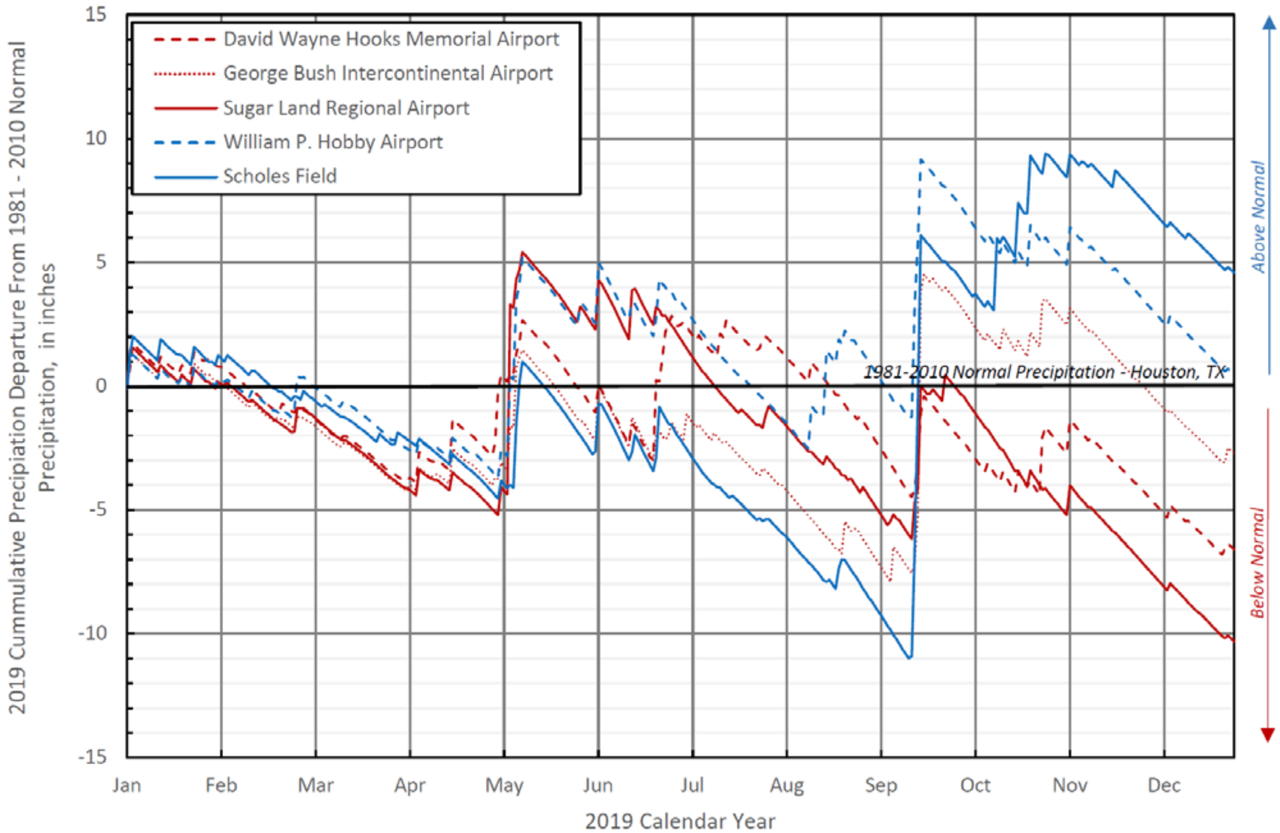

Figure 5. Cumulative precipitation departure, in inches, from 1981-2010 normal precipitation (Arguez, et al., 2010) at selected NOAA-NWS Climate Stations in the Houston region, 2019 (Menne et al., 2012a, 2012b, 2012c, 2012d, 2012e).

As the Houston area was below to significantly-below normal precipitation totals in early September, Tropical Storm Imelda produced large amounts of rainfall over much of the region. This was a short-lived tropical storm that moved inland near Freeport, Texas. Just after it developed in the late morning through early afternoon hours on September 17, 2020 (NOAA - National Weather Service, 2019) the system and its remnants meandered inland for several days after landfall and produced historic rainfall totals and devastating flooding over portions of Southeastern Texas. As the system stalled across Southeast Texas, significant convection developed with a feeder band southwest of the center the evening of the September 17 into the morning of the September 18, with significant flooding across Galveston to Houston. Storm totals exceeded 30 inches (76.2 cm) in just three days over southeast Montgomery, northeast Harris and Chambers counties. Imelda broke several rainfall records in the United States. As of February 1, 2020, Imelda is currently the seventh wettest tropical cyclone to impact the United States, the fifth wettest in the contiguous United States and the fourth wettest in Texas.

Except for a period of coastal storms throughout most of October, precipitation was generally below normal through the remainder of 2019. The largest cumulative rainfall recorded at the reviewed NOAA-NWS stations was 59.23 inches (150.44 cm) at Scholes Field in Galveston, Texas which is 4.57 inches (11.6 cm) above the 1981-2010 normal annual precipitation. The lowest cumulative rainfall of 44.34

inches (112.62 cm) was recorded at Sugar Land Memorial Airport, Sugar Land, Texas which is 10.31 inches (26.2 cm) below normal.

2019 Water Use

The District collects groundwater and alternative water supply use annually from permittees. This information provides an understanding of how much groundwater is being used within the District, how permittees are using groundwater and perspective on the conversion from groundwater to surface water for the various regulatory areas.

In 2019, there were a total of 8,354 permitted wells in the District. As of May 2020, a total of 7,033 of these permittees had submitted their annual water use data for the District to compile and use in this report. The groundwater withdrawals associated with these missing reports was estimated based on permitted allocations to be 2.64 MGD which equates to 1.2 percent of the reported withdrawals. The number of missing reports is higher than would be typically expected. It is possible that the public health emergency underway in March 2020 as a result of the COVID-19 pandemic may have affected annual report submittals to some extent.

In addition to providing water use data for 2019, this report also provides updated groundwater withdrawal totals for the previously reported year of 2018. These changes are made during the normal permitting and reporting process as part of the exchange between the District and its permittees. The changes include updating estimated amounts with actual amounts, correction of data entry errors, and errors in the submitted data. The reported 2018 groundwater withdrawal total was reduced by 3.8 MGD to a new total of 222.8 MGD.

The following sections provide a summary of the information presented at the Public Hearing held on May 28, 2020. The exhibits used to provide testimony during the hearing are included in **Appendix A – Exhibits Presented at Public Hearing held on May 28, 2020**.

Overall Water Use

The three primary water uses in the District are public supply, industrial, and irrigation. The total amount of groundwater withdrawal for 2019 is 228.1 MGD, a slight increase over 2018 (**Table 1**), with public supply being reported to be 91.7 percent of the overall use. As a result of the District's Regulatory Plan, groundwater withdrawals have decreased since the District's inception in 1975 (**Figure 6**), with a 50 percent decline from 456.3 MGD in 1976 to 228.1 MGD in 2019. Patterns in groundwater use have shifted over time, resulting in reduced groundwater use for industrial and agricultural needs compared with the 1970s, 1980s and 1990s.

The District is divided into three regulatory areas that define how much groundwater may be utilized as a percentage of the total water demand. The groundwater withdrawals are grouped by regulatory area in **Figure 7**. This chart shows the impact of the District's Regulatory Plan, requiring conversion from groundwater to surface water over time and as a result the reduction in groundwater withdrawals in regulatory areas that have fully converted to surface water (i.e., Regulatory Areas One and Two). As a result, the majority of groundwater use within the District is occurring within Regulatory Area Three. The following sections provide additional information regarding groundwater withdrawals by Regulatory Area.

Table 1. Summary of Reported Groundwater Water Use (in MGD) by Regulatory Area.

Water Use Category	Area 1			Area 2			Area 3			Total		
	2018	2019	Change between 2018 and 2019	2018	2019	Change between 2018 and 2019	2018	2019	Change between 2018 and 2019	2018	2019	Change between 2018 and 2019
Public	3.3	2.9	-13%	26.1	31	19%	175	175.2	0%	204.4	209.2	2%
Industrial	5.8	6.5	12%	2.56	2.61	2%	2.2	2.4	7%	10.6	11.5	8%
All Irrigation	0.107	0.113	5%	0.95	0.84	-12%	6.7	6.5	-4%	7.8	7.4	-4%
Total	9.2	9.5	3%	29.6	34.5	16%	184.0	184.1	0%	222.8	228.1	2%

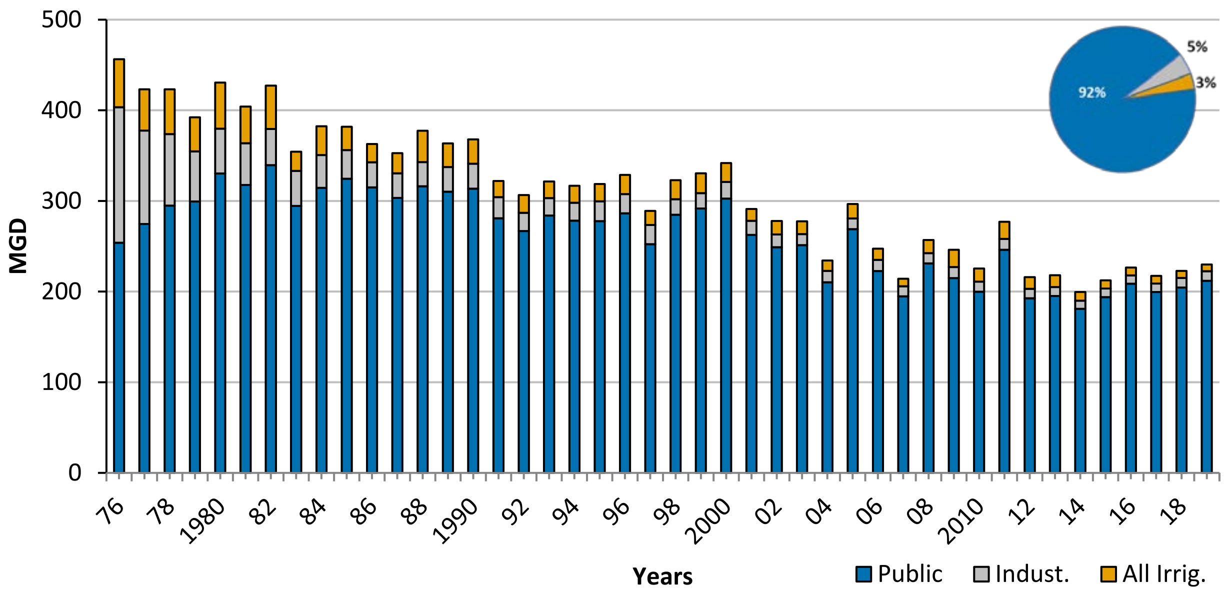

Figure 6: Groundwater withdrawals, in million gallons per day, by water use category from 1976 to 2019. The total groundwater used in the District was 228.1 MGD in 2019, with over 91 percent of the use being public supply.

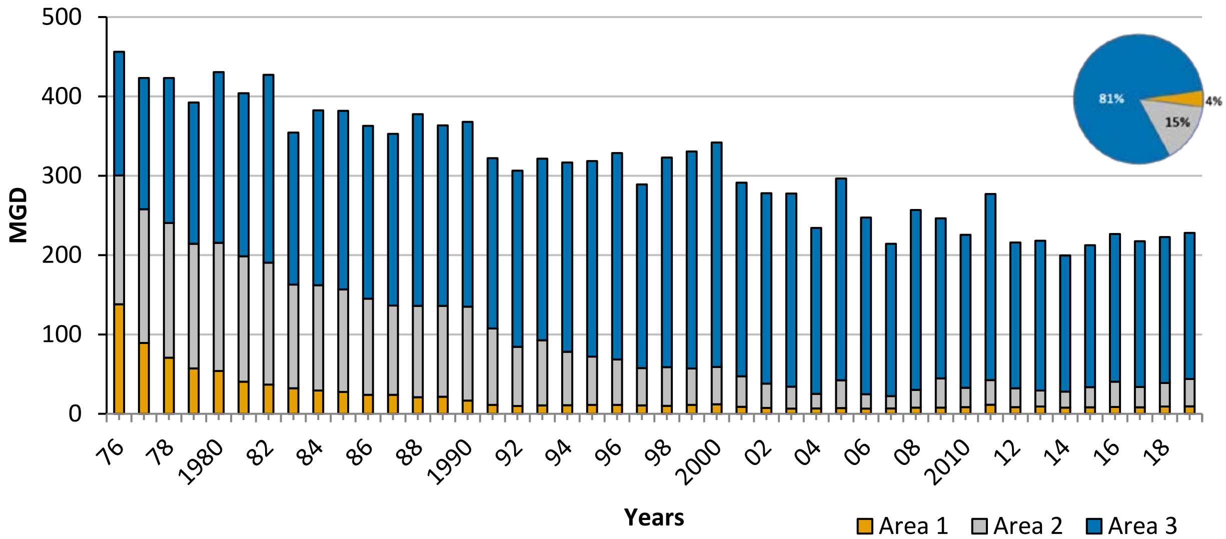

Figure 7: Groundwater withdrawals, in million gallons per day, by regulatory area from 1976 to 2019. In 2019, a total of 9.5 MGD of groundwater was used in Regulatory Area One, with 34.5 MGD used in Regulatory Area Two and 184.1 MGD used in Regulatory Area Three.

Regulatory Area One

Regulatory Area One covers most of Galveston County and the southeastern portion of Harris County. Cities and villages included are Bacliff, Baytown, Bayou Vista, Channelview, Clear Lake Shores, Deer Park, Dickinson, El Lago, Galena Park, Galveston, Highlands, Hitchcock, Kemah, La Marque, La Porte, League City, Morgan's Point, Nassau Bay, Pasadena, San Leon, Santa Fe, Texas City, Seabrook, Shoreacres, Taylor Lake Village, Tiki Island, and Webster. Also included are Clear Lake, Johnson Space Center, and Bolivar Peninsula Areas. This area converted to alternate water sources back in the 1970s, 1980s and early 1990s.

In 2019, total groundwater withdrawal in Regulatory Area One was 9.5 MGD, a 3 percent increase from the previous year (**Figure 8**). The majority of groundwater use in Regulatory Area One is associated with industrial use, which comprises over 68 percent of the use in the area. Industrial has been increasing since 2016, which groundwater use for public supply has remained relatively stable since 2002. Irrigation water use is typically correlated to climate and rainfall patterns. The amount of groundwater used for irrigation increased by 5 percent in 2019 to 0.11 MGD, but is much lower than the 0.47 MGD used during the 2011 drought. Historically, groundwater withdrawals have declined in Regulatory Area One from a maximum of 138.1 MGD in 1976 to 9.5 MGD in 2019.

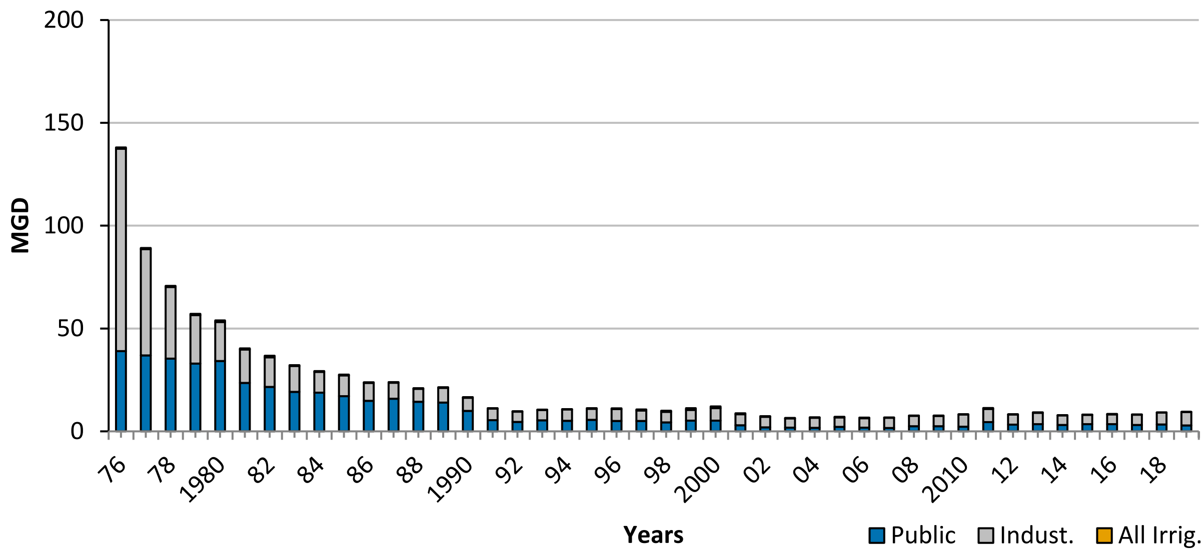

Figure 8: Groundwater withdrawals for Regulatory Area One, in million gallons per day, by water use category from 1976 to 2019. A total of 9.5 MGD of groundwater was used in Regulatory Area One in 2019, with 61% of the withdrawals being used for industrial use.

Regulatory Area Two

Regulatory Area Two covers a small northwestern slice of Galveston County and southern and eastern Harris County. Cities, entities, and areas included are Bellaire, Cloverleaf, Crosby, Friendswood, Highlands, Hobby Airport, Pasadena, Sheldon, South Houston, the Villages, West University, and large portions of the City of Houston. Like Regulatory Area One, Regulatory Area Two has been converted to alternate water sources since the late 1980s or early 1990s, where possible.

Total groundwater withdrawal increased in Regulatory Area Two from 29.6 MGD in 2018 to 34.5 MGD in 2019 with public supply use accounting for most of the increase (**Figure 9**). Public supply groundwater use increased by 19 percent over 2018 to 31.0 MGD. Industrial groundwater usage remained largely the same at 2.6 MGD and irrigation usage decreased to 0.84 MGD, a 12 percent decline in use. Groundwater withdrawals have declined in Regulatory Area Two from a maximum of 169.8 MGD in 1978 to 34.5 MGD in 2019.

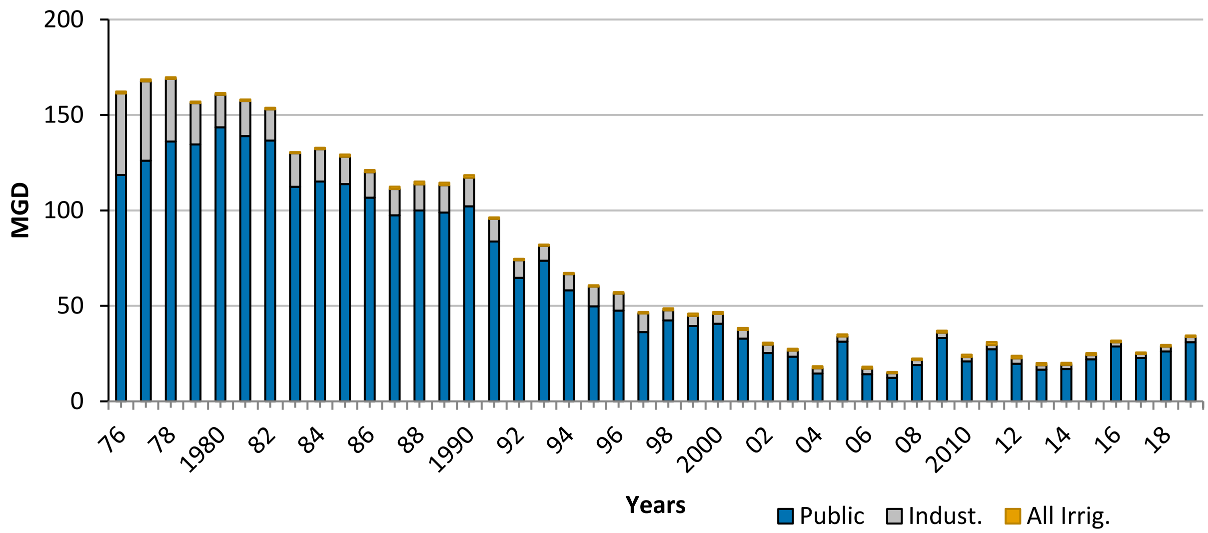

Figure 9: Groundwater withdrawals for Regulatory Area Two, in million gallons per day, by water use category from 1976 to 2019. A total of 34.5 MGD of groundwater was used in Regulatory Area Two in 2019, with 90% of the withdrawals being used for public supply.

Regulatory Area Three

Regulatory Area Three covers north and west Harris County. Cities, entities and areas included in this region are the City of Jersey Village, the City of Humble, Kingwood, City of Tomball, Cypress, Hockley, and Spring. Entities in this regulatory area were required to convert to alternate water beginning in 2010, with this conversion facilitated by the City of Houston and the Regional Water Authorities. Two subsequent conversion deadlines in 2025 and 2035 remain for permittees with groundwater reduction plans.

Groundwater pumpage in Regulatory Area Three was generally stable between 2018 and 2019 (**Figure 10**). The largest category of water use is public supply use, which was reported at 175.2 MGD and accounts for 95 percent of the groundwater use in the area. Industrial water use increased by 7 percent to 2.4 MGD, while irrigation water use decreased by 4 percent to 6.5 MGD.

Groundwater withdrawals in Regulatory Area Three have been varied since 1978, reflecting the impacts of climate, population increases as development of this region progressed, and the District's Regulatory Plan that required the first alternative water conversion in 2010**.** As shown in the graph, groundwater use has remained relatively constant since 2012, varying between 171.4 MGD and 188.8 MGD.

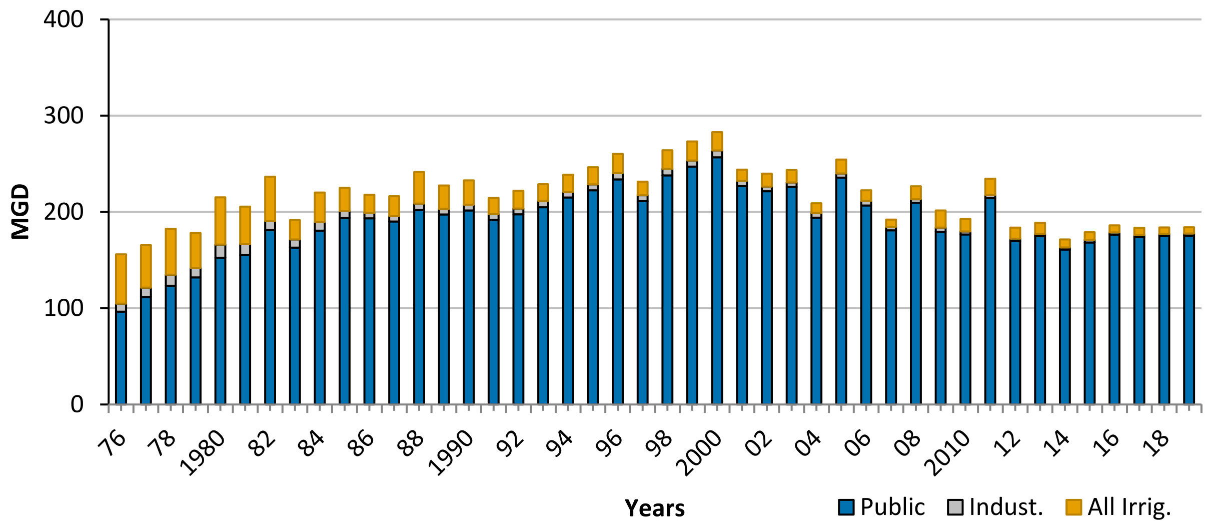

Figure 10: Groundwater withdrawals for Regulatory Area Three, in million gallons per day, by water use category from 1976 to 2019. A total of 34.5 MGD of groundwater was used in Regulatory Area Three in 2019, with 92% of the withdrawals being used for public supply.

Alternative Water Supply and Total Water Use

The District's Regulatory Plan requires permittees to convert to alternative water supplies in order to reduce their reliance on groundwater sources. The primary alternative water supply used in our region is surface water sourced from three river basins, the Brazos River Basin, the San Jacinto River Basin and the Trinity River Basin (**Table 2**).

The Trinity River, as it has been since 1992, is still the single largest source of alternative water used within the district. Groundwater remains the second largest source of water supply within the District as a whole. Reclaimed water is also used as an alternative water supply, but to a much smaller degree. Compared with 2018, use of the San Jacinto River Basin supply was down by 7 percent, while reported reclaimed water use was much lower than 2018, although the amount of reclaimed water is use quite small overall.

Table 2. Summary of Reported Alternative Water Supply Use and Total Water Use (in MGD)

Source		2018	2019	Change between 2018 and 2019
Alternative Supplies	Brazos River Basin	71.2	70.3	-1%
	San Jacinto River Basin	155.4	144.6	-7%
	Trinity River Basin	550.0	531.5	-3%
	Reclaimed Water	0.9	0.3	-68%
	Subtotal	777.5	746.7	-4%
Groundwater		222.8	228.1	2%
Total Water Use		1000.3	974.8	-3%

Use of the Trinity River Basin supply has increased over time, from 8.7 MGD in 1976 to 531.5 MGD in 2019 (**Figure 11**). The Brazos River Basin water use has stayed relatively constant over the years, with an average use over the District's 45-year history of 76.2 MGD. The total water use for the District was determined to be 974.8 MGD in 2019, which is 3 percent lower than 2018.

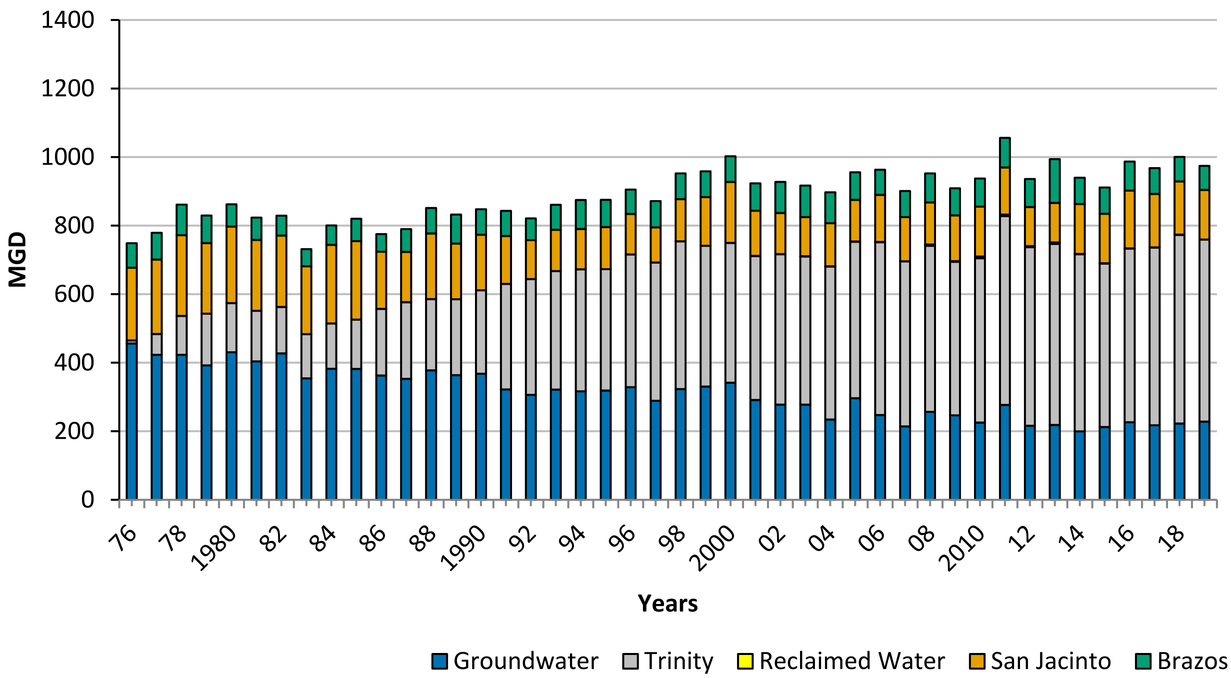

Figure 11: Total water use for District, in million gallons per day, by source water, from 1976 to 2019. The reported total water use for the District in 2019 was 974.8 MGD.

2019 Groundwater Level Summary

All groundwater used in the District is sourced from the Gulf Coast Aquifer System, which is comprised of three primary water bearing units. The two units most widely used in the District are the Chicot and Evangeline aquifers. The Chicot is the shallowest aquifer in the District which is directly connected to the Evangeline aquifer immediately below. The Burkeville confining unit lies beneath the surficial aquifers and isolates the third primary aquifer, the Jasper aquifer. The Jasper aquifer is not widely used in the District but is a primary source of water for Montgomery County to the north.

Annually, since 1975, the U.S. Geological Survey (USGS) has measured the water level in hundreds of wells throughout the Houston Region in cooperation with the Harris-Galveston Subsidence District through a joint funding agreement along with additional cities, subsidence districts and groundwater conservation districts to monitor and provide reports on groundwater level altitude data for the Chicot, Evangeline and Jasper aquifers. Since aquifer water level is the best measure of the pressure in the aquifer, this information is also of vital importance to understanding the impact of changes in water use on subsidence.

For example, the potentiometric surface data from the Evangeline aquifer shows the areas of primary stress on the aquifer occurs in northern and western Harris County, and southern Montgomery County (**Figure 12**). The change in water-level in the Evangeline aquifers since 1977 clearly shows the impact of District regulation on the aquifer. Generally, Regulatory Areas One and Two have seen a significant rise in the potentiometric water-level up to 240 feet (73.2 meters) in the Evangeline (**Figure 13**) aquifer. The area of rise is a result of the reduction of groundwater use required by the District's Regulatory Plan. Conversely, in Regulatory Area Three and nearby in Northern Fort Bend and Southern Montgomery Counties, water-levels continue to be significantly lower than the historical benchmark, reaching declines of nearly 280 feet (85.3 meters) in the Evangeline aquifer. These areas are growing rapidly and the conversion to alternative sources of water will not be completed in the District until 2035 and in the Fort Bend Subsidence District until 2025.

Groundwater levels in southern Montgomery County are of particular concern. The primary cone of depression in both the Evangeline and Jasper aquifers exists just across the county line in southern Montgomery County near The Woodlands, TX. Recent changes in the management plan of Montgomery County's Lone Star Groundwater Conservation District will lead to de-regulation of the groundwater use in Montgomery County and result in additional potentiometric water level declines in these aquifers in southern Montgomery County and Northern Harris County.

The information presented in this section are a brief summary of the provisional data presented at the Public Hearing held on May 28, 2020. The exhibits used to provide testimony during the hearing are included in **Appendix A – Exhibits Presented at Public Hearing held on May 28, 2020**. A USGS Scientific Investigation Report will be released later this year documenting the status of groundwater level altitudes and the long-term changes in the Chicot, Evangeline and Jasper aquifers.

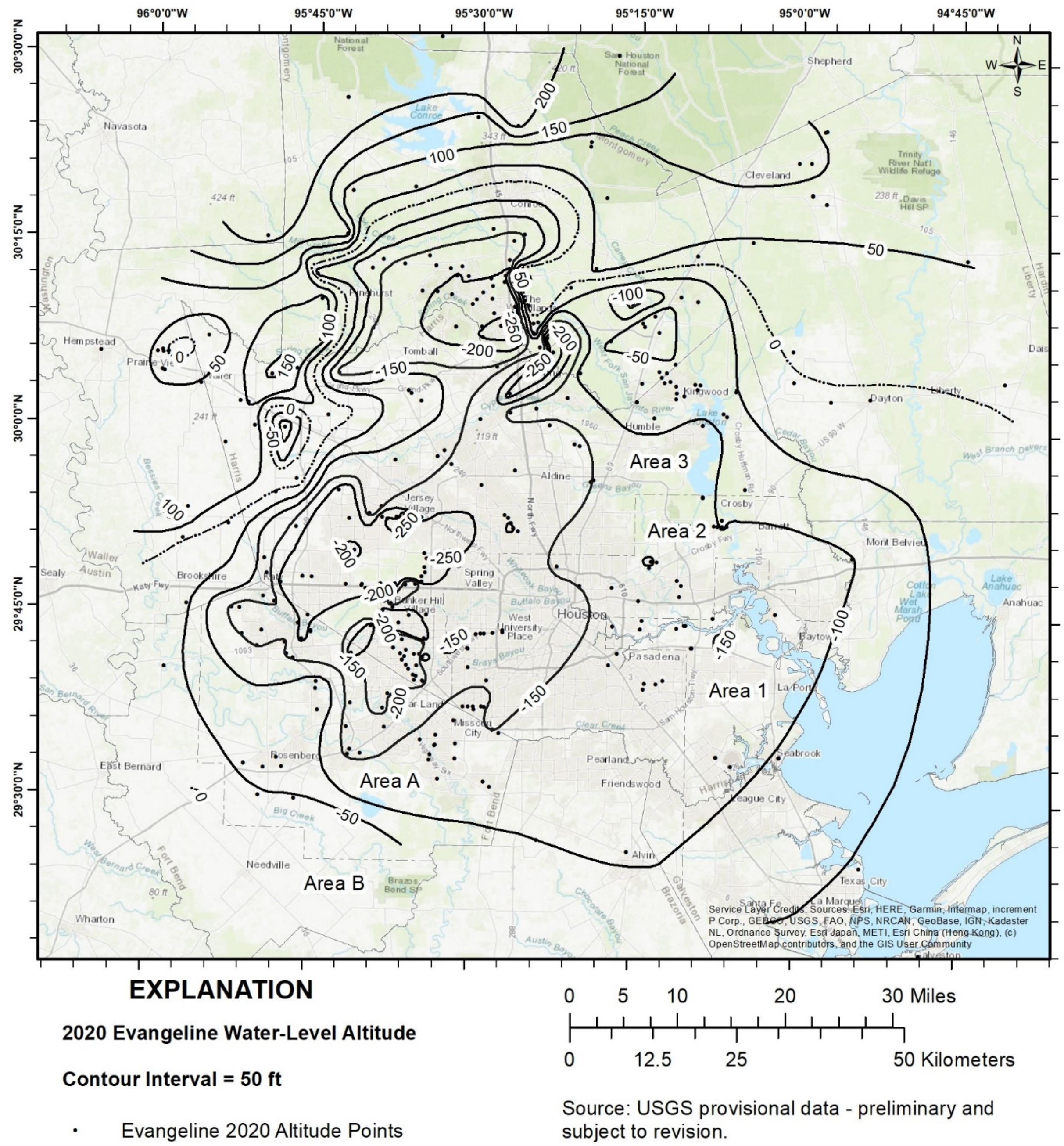

Figure 12: Altitude of the potentiometric surface determined from water-levels measured in tightly cased wells screened in the Evangeline aquifer, Houston region, Texas, 2020 (Source: USGS provisional data – preliminary and subject to change).

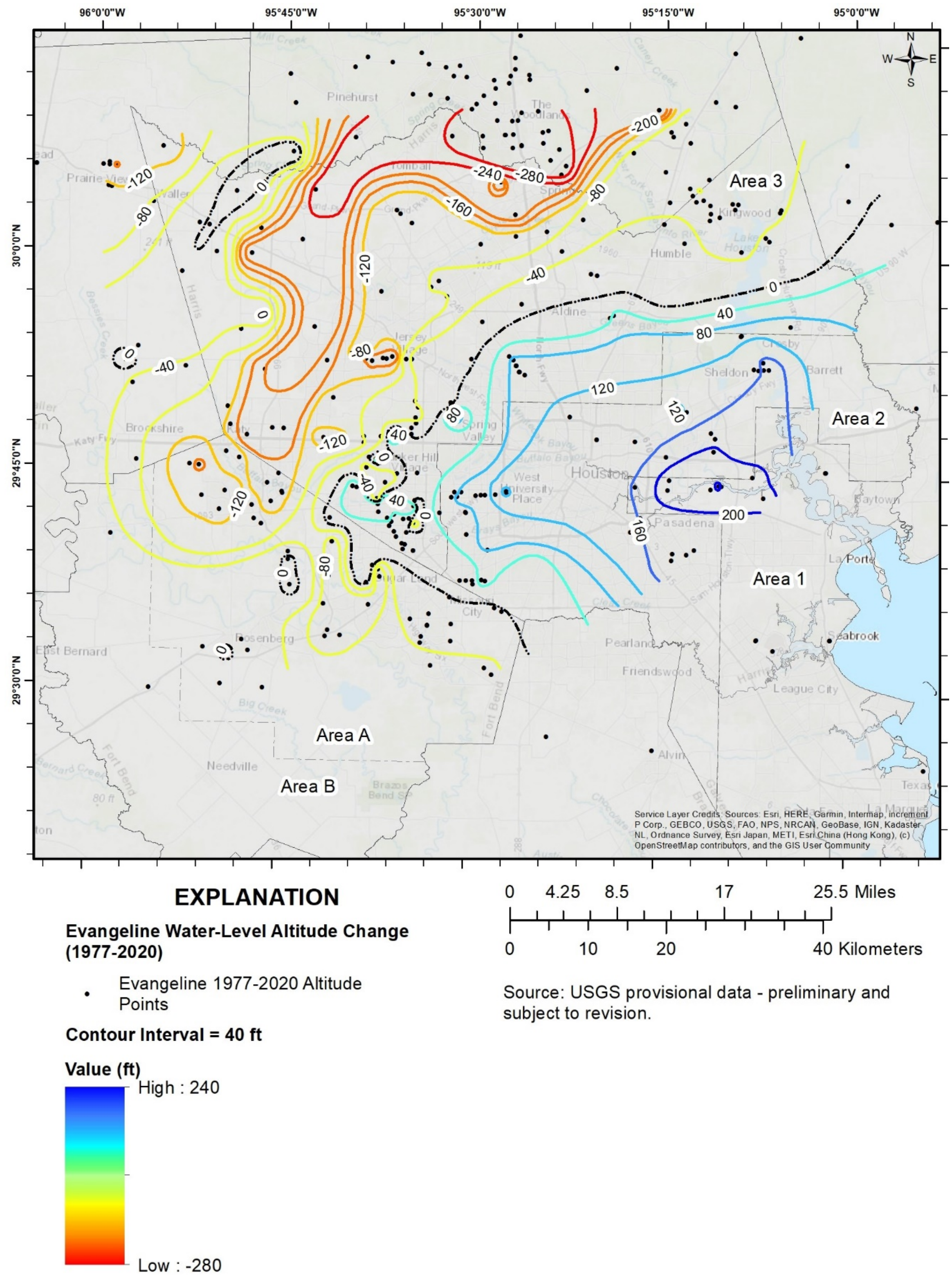

Figure 13: Potentiometric water-level change at wells screened in the Evangeline aquifer, Houston region, Texas, 1977 to 2020 (Source: USGS provisional data – preliminary and subject to change).

Subsidence Trend Analysis

Subsidence is the lowering of land surface elevation. In the Houston-Galveston region, subsidence occurs from the compaction of clays due to groundwater withdrawal for municipal, industrial, and irrigation water supply. As the water level of the aquifer declines, fine-grained sediments, such as silt and clay, in the aquifer depressurize and compact in order to fill the void space created by the extracted water. This compaction results in the lowering of overlying stratigraphic units and is observed as subsidence at the land surface.

Global positioning system (GPS) monitoring sites have been installed in various locations across southeast Texas in order to track subsidence since the 1990s. This GPS network consists of a collaboration between the District, Fort Bend Subsidence District (FBSD), University of Houston (UH), Lone Star Groundwater Conservation District (LSGCD), Brazoria County Groundwater Conservation District (BCGCD), the National Geodetic Survey (NGS), the USGS, the City of Houston, and the Texas Department of Transportation (TxDOT). The GPS network has grown to over 230 sites throughout the region. Additional information on the GPS network is provided in **Appendix B – Subsidence Monitoring Data** and **Appendix C – Period of Record Data.**

GPS data are collected from GPS monitoring sites and processed quarterly by Dr. Guoquan Wang at UH. The GPS monitoring site data is compared to a stable regional reference frame designated as Houston20 that uses 25 continuously operating GPS sites which have a long history (greater than eight years) and are located outside the greater Houston area (Agudelo, et al., 2020). The District interprets these GPS data in two ways: 1) period of record and 2) as an average annual subsidence rate to understand both short-term and long-term subsidence trends within the GPS network. Additional information on the average annual subsidence rate and period of record data for each GPS monitoring site is provided in **Appendix C**.

Period of Record Data

The period of record includes GPS data measurements of the ellipsoidal height that are collected over the lifespan of each GPS monitoring site. It is used to track the full history of subsidence and is represented as a vertical displacement time series. The vertical displacement is determined by the change in ellipsoidal height, which is the distance from a point on the earth's surface to the reference ellipsoid. The reference ellipsoid is a mathematical representation of the earth's surface. Period of record plots give a historical context to understand local to regional subsidence trends. Period of record plots for each GPS monitoring site are provided in **Appendix C**.

Average Annual Subsidence Rate

The average annual subsidence rate is a useful measure to show the recent change in land surface elevation at each GPS monitoring site. The subsidence rate, presented in this report, is determined by using linear regression (i.e., the statistically determined best fit straight line through a scatter plot of data points) of the last five years of data for GPS monitoring sites with more than three years of GPS data. **Figure 14** depicts the average annual subsidence rate from 2015 to 2019 for the 203 GPS monitoring sites in the greater Houston area.

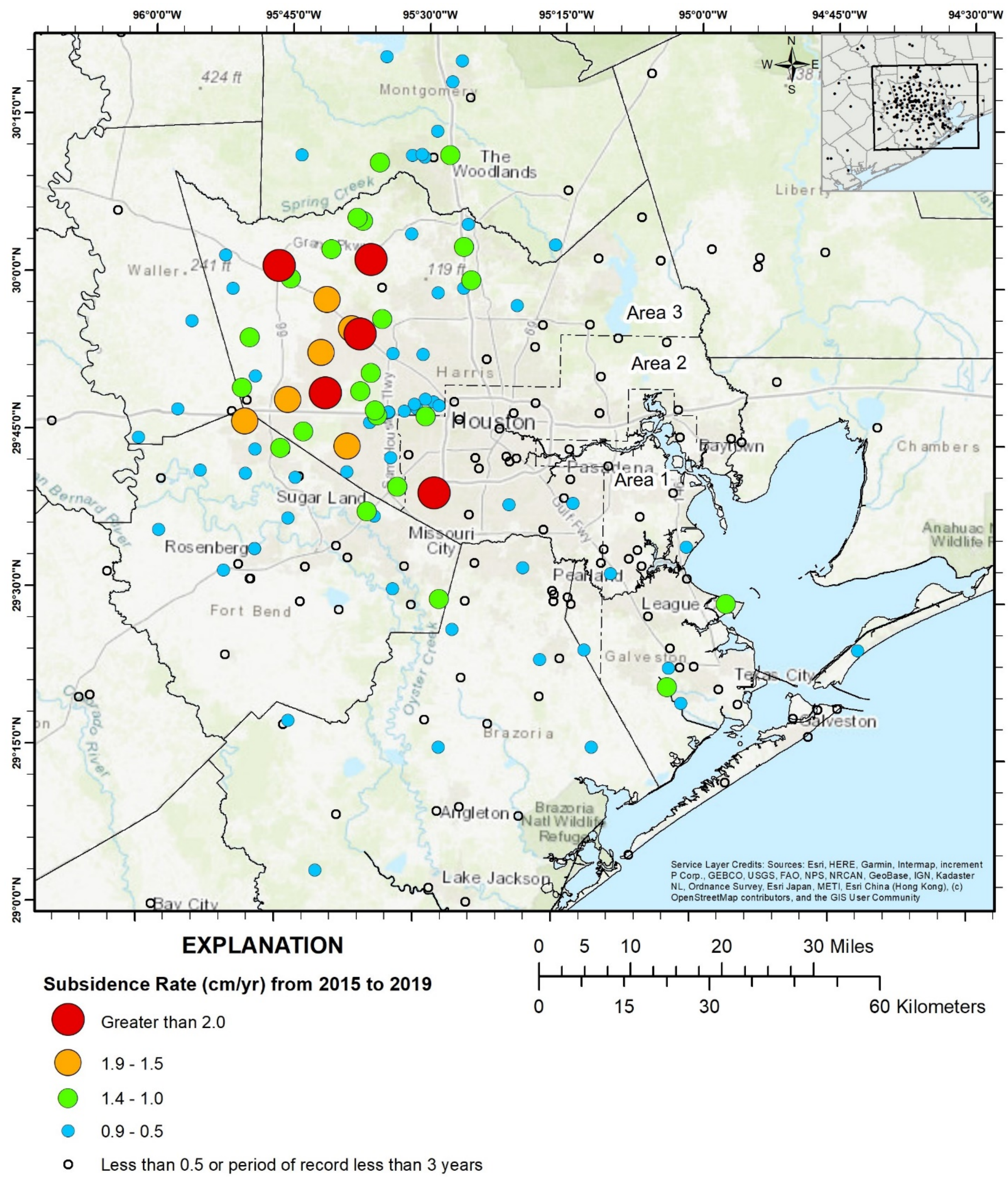

Figure 14: Annual subsidence rate, measured in centimeters per year, referenced to Houston20 and estimated from three or more years of GPS data collected from GPS monitoring sites in Harris and surrounding counties, Texas, averaged from 2015 to 2019.

Regulatory Areas One and Two show similar subsidence rates as both areas have been fully converted since the 1990s and USGS monitoring data show that potentiometric water levels have risen. The majority of the GPS monitoring sites in Regulatory Area One have very low subsidence rates (under 0.5 cm per year) and even some uplift is observed. Sites in Regulatory Area Two also showed low subsidence rates (under 0.5 cm per year), with one exception in the southwest area at P041. The highest subsidence rate in Regulatory Area Two was 2.08 cm per year at P041, which is located southwest of the intersection between South Loop Freeway West and South Post Oak Road. The subsidence rate observed at P041 was generally about zero between 2007 and 2016, then began to decrease from 2016 to 2019 (**Figure 15**).

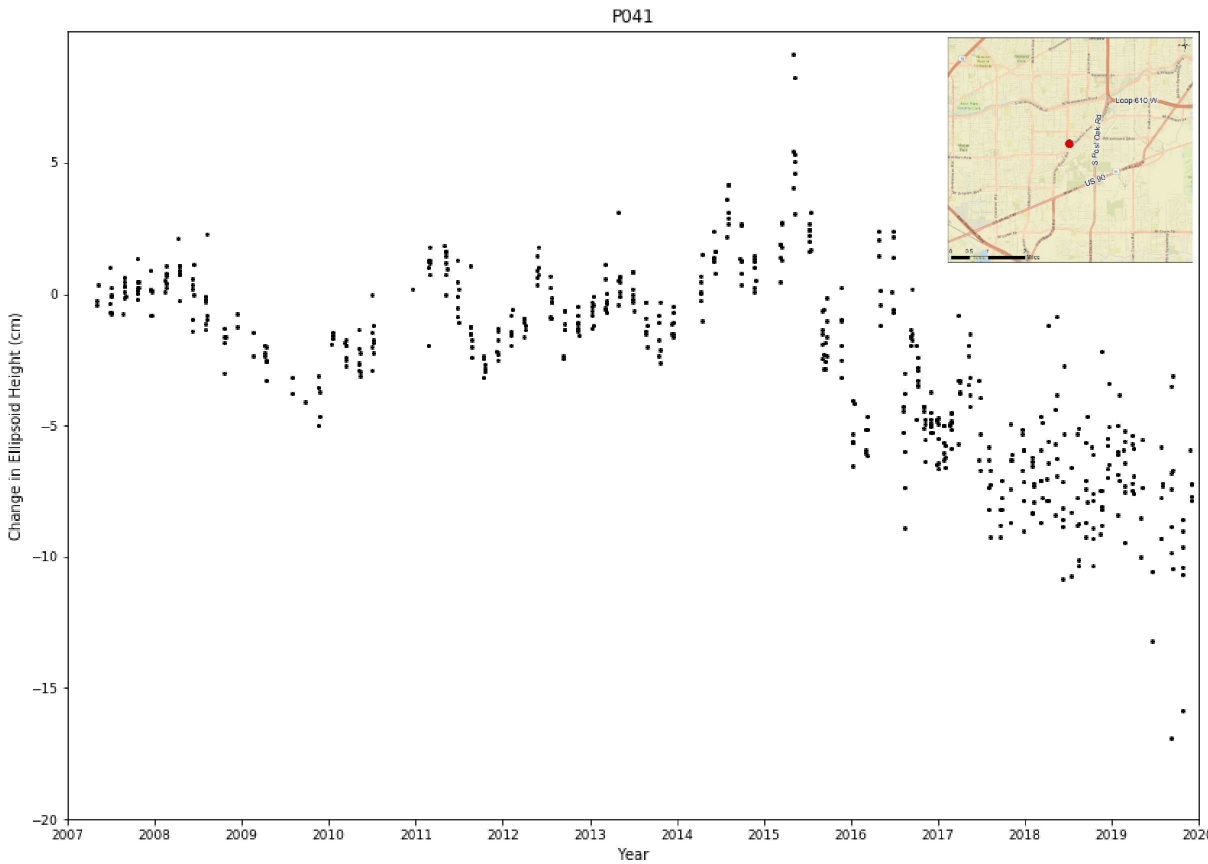

Figure 15: Period of record data from GPS monitoring site P041 located in Westbury neighborhood (Brays Oak district of Southwest Houston), Texas, 2007 to 2019. Inset map shows the location of P041, the red circle within the black box.

The highest subsidence rates (greater than 2 centimeters per year) occur in Regulatory Area Three within northwestern and western Harris County. GPS monitoring site P001, located in Jersey Village, has the highest subsidence rate estimated at 2.54 cm per year (**Figure 16**). Other nearby neighborhoods in Regulatory Area Three such as Fairfield (P066), Kohrville (P046), and Cypress (P018) have subsidence rates at 2.22 cm per year, 2.0 cm per year, and 1.94 cm per year, respectively.

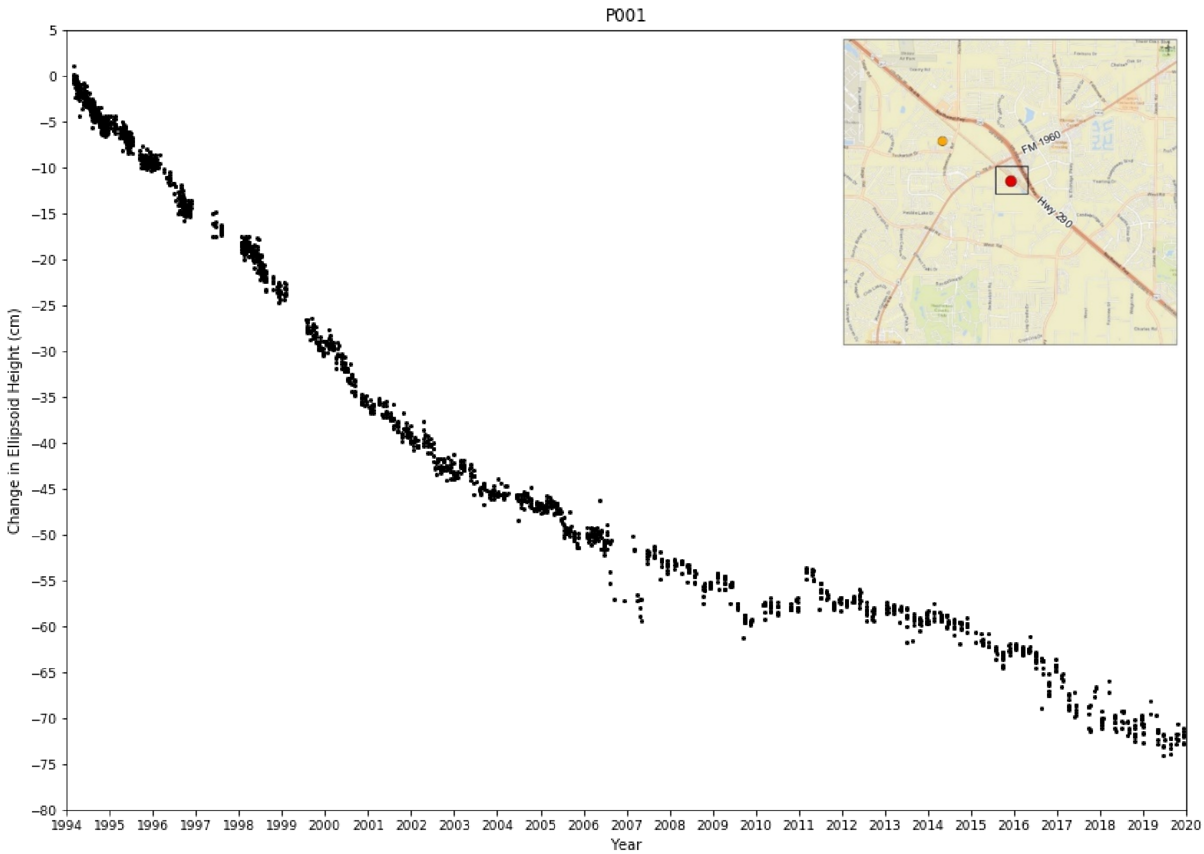

Figure 16: Period of record data from GPS monitoring site P001 located in Jersey Village, Texas, 1994-2019. Inset map shows the location of P001, the red circle within the black box.

Based on the GPS data collected in the greater Houston area, subsidence is occurring in Regulatory Area Three, as this area is still undergoing conversion to alternative water supplies. The average of the annual subsidence rate for the 57 GPS monitoring sites in Regulatory Area Three is 0.94 cm per year and the highest rates are observed in western Harris County.

Past benchmark surveys and current GPS monitoring led by the District have illustrated subsidence magnitudes greater than 9 feet (2.7 meters) since 1906 throughout the District and 1 foot (0.31 meters) within adjacent counties (**Figure 17**). Additional GPS monitoring sites are expected to be installed in the future in order to track subsidence in the Texas Gulf Coast.

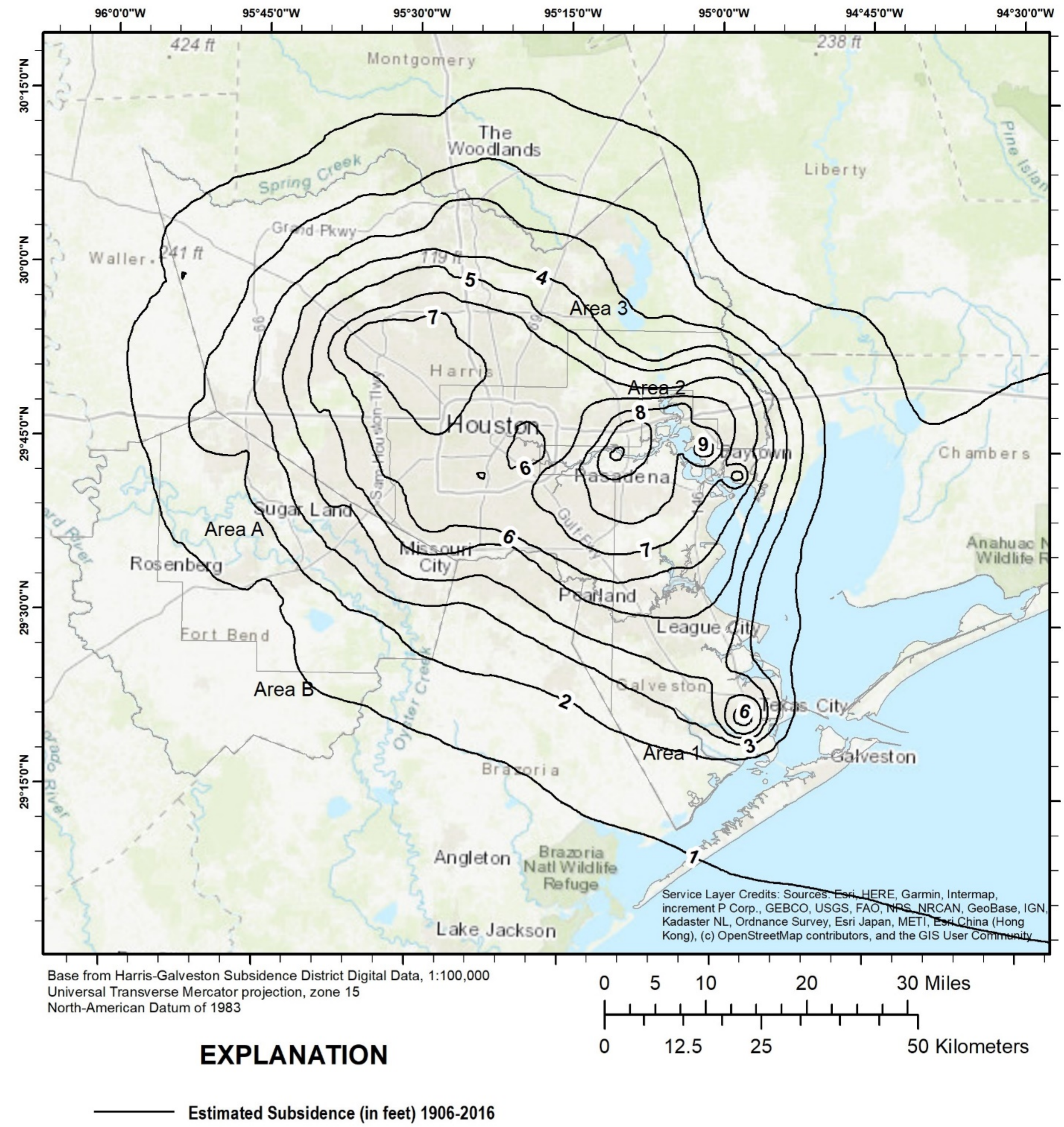

Figure 17: Estimated subsidence from 1906 to 2016 using measured land surface elevation change at benchmarks surveyed in 2000 and estimated annual subsidence rates from 2011 to 2016, assuming a constant rate of subsidence from 2010 to 2016.

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