

**Vertical Land Movement Estimated in the
Harris-Galveston, Texas, Region:**

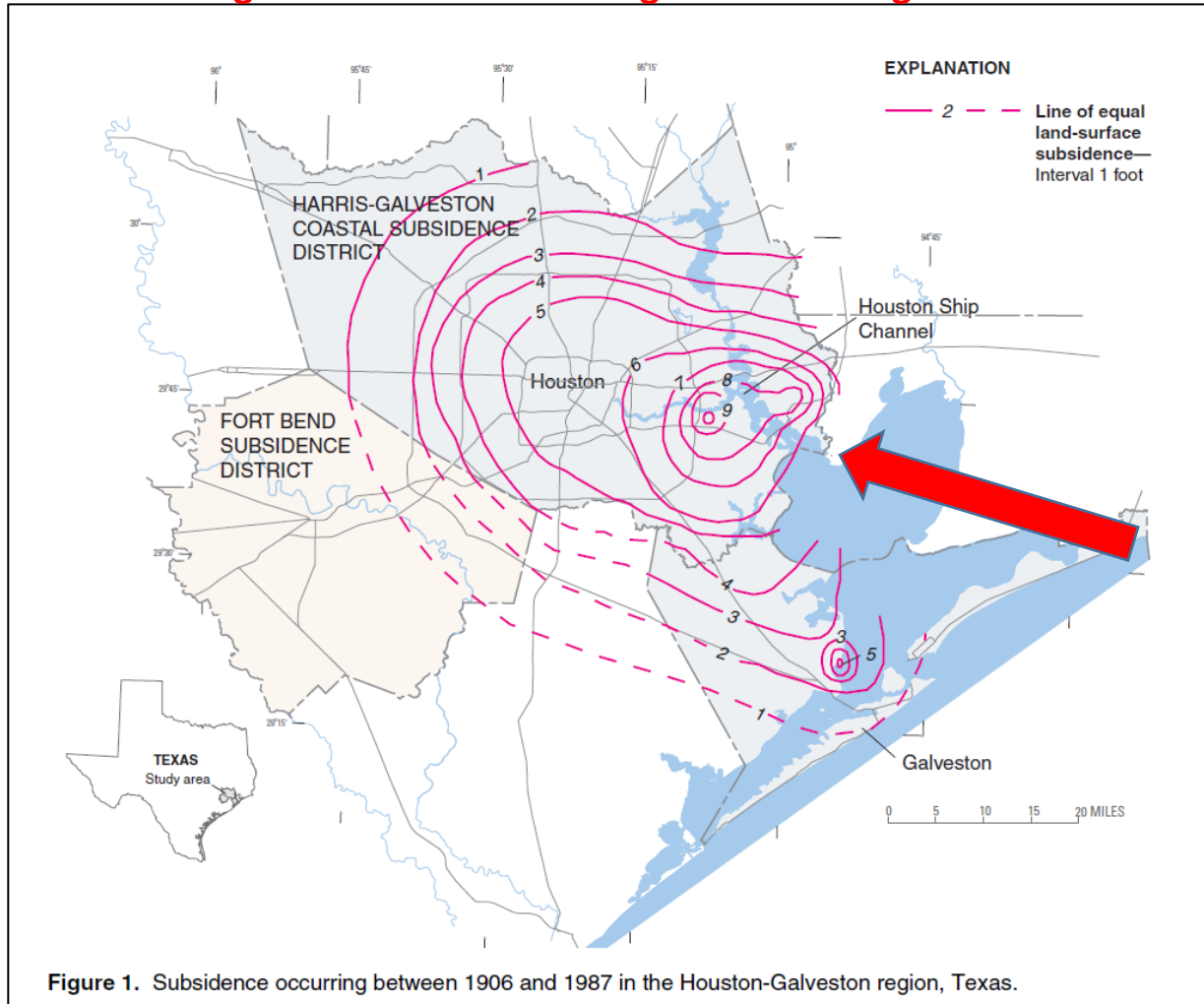
***A Case Study of Using GNSS-Derived Ellipsoid
Heights to Measure Crustal Movement***

**David B. Zilkoski
Geospatial Solutions by DBZ**

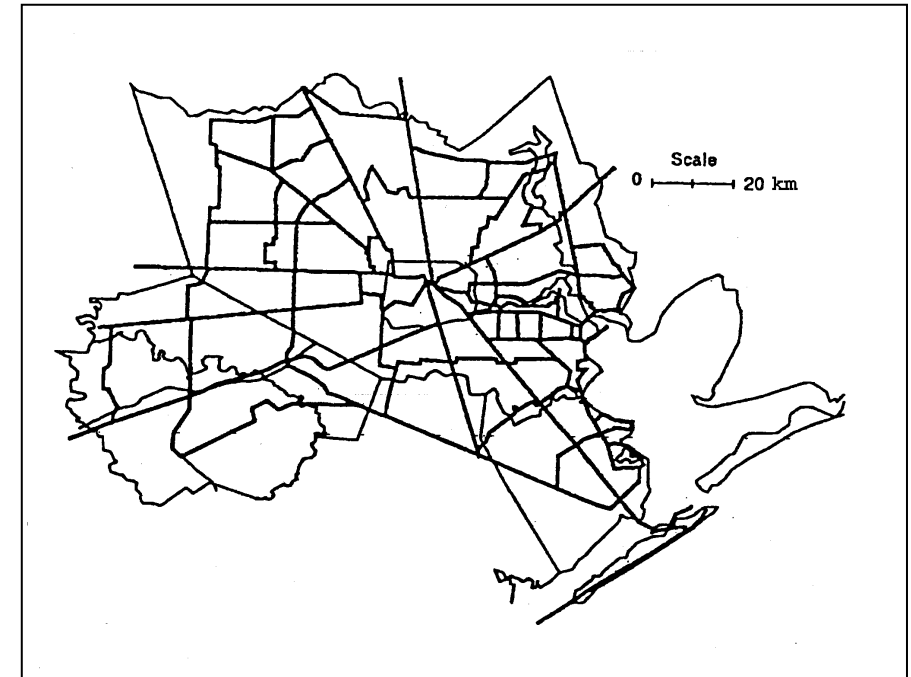
DaveZilkoski@gmail.com

Why Measure Subsidence in the Houston/Galveston Region?

➤ **Large Subsidence Occurring in Coastal Region**

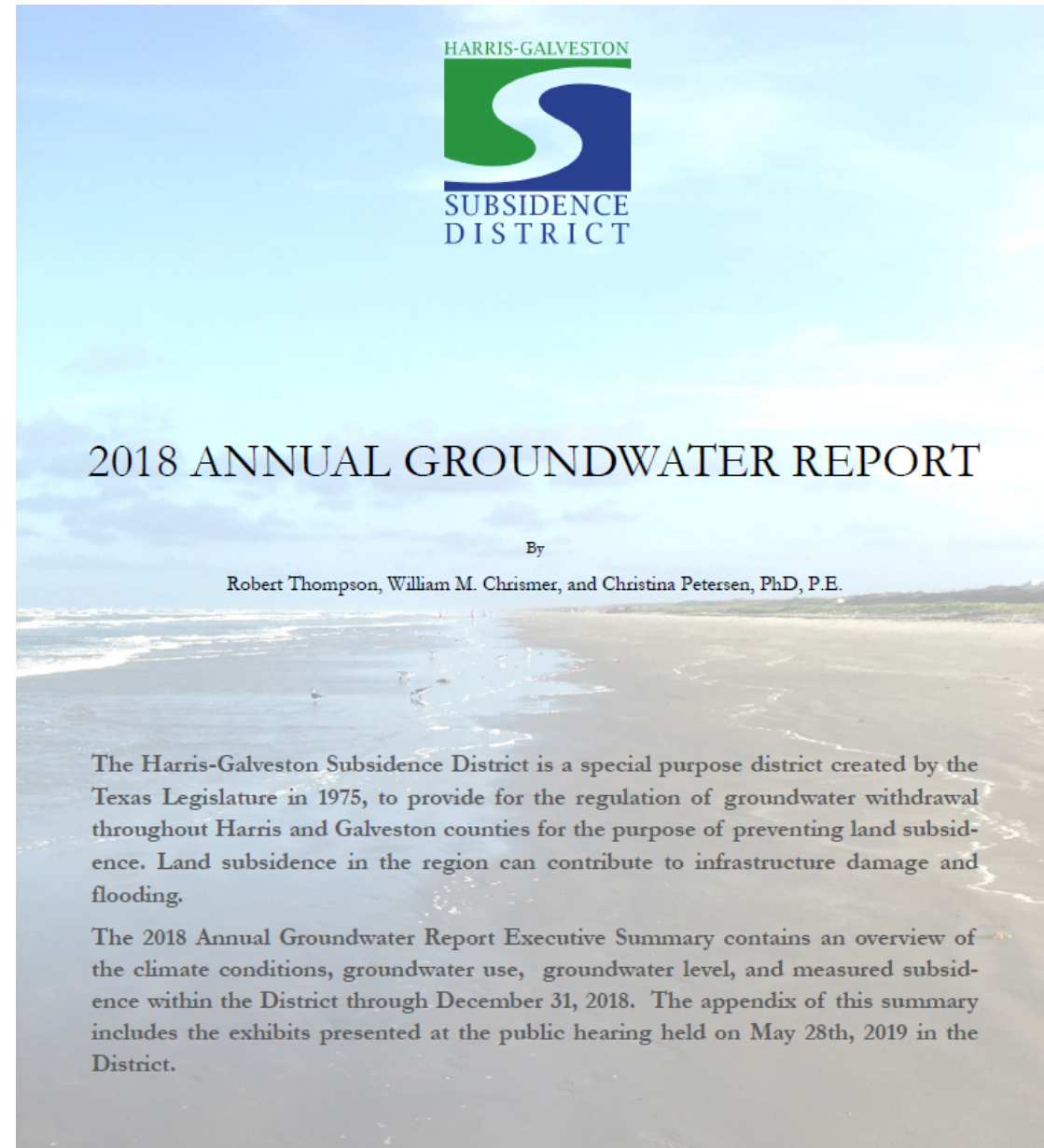


➤ **NGS and other Federal and State Agencies Started Working Together on Projects to Estimate Subsidence Using Leveling Data in the early 1960s**



Why Was the Harris-Galveston Subsidence District Measuring Movement?

- **The Harris-Galveston Subsidence District was created by the Texas Legislature in 1975**
- **Since 1975, the HGSD has taken a reasonable and inclusive approach to groundwater regulation resulting in a dramatic reduction in subsidence rates within the HGSD regulatory areas**



- **The district is divided into three regulatory areas that define how much groundwater may be utilized as a percentage of total water demand**
- **Area 1 has the lowest total groundwater use in the District and is currently regulated to utilize groundwater for up to 10% of the total water demand.**
- **Currently, groundwater use in area two is regulated to 20% of the total water demand.**
- ***Groundwater use in Area 3 is regulated to 20% of the total water demand unless the permittee has an approved groundwater reduction plan (GRP).***

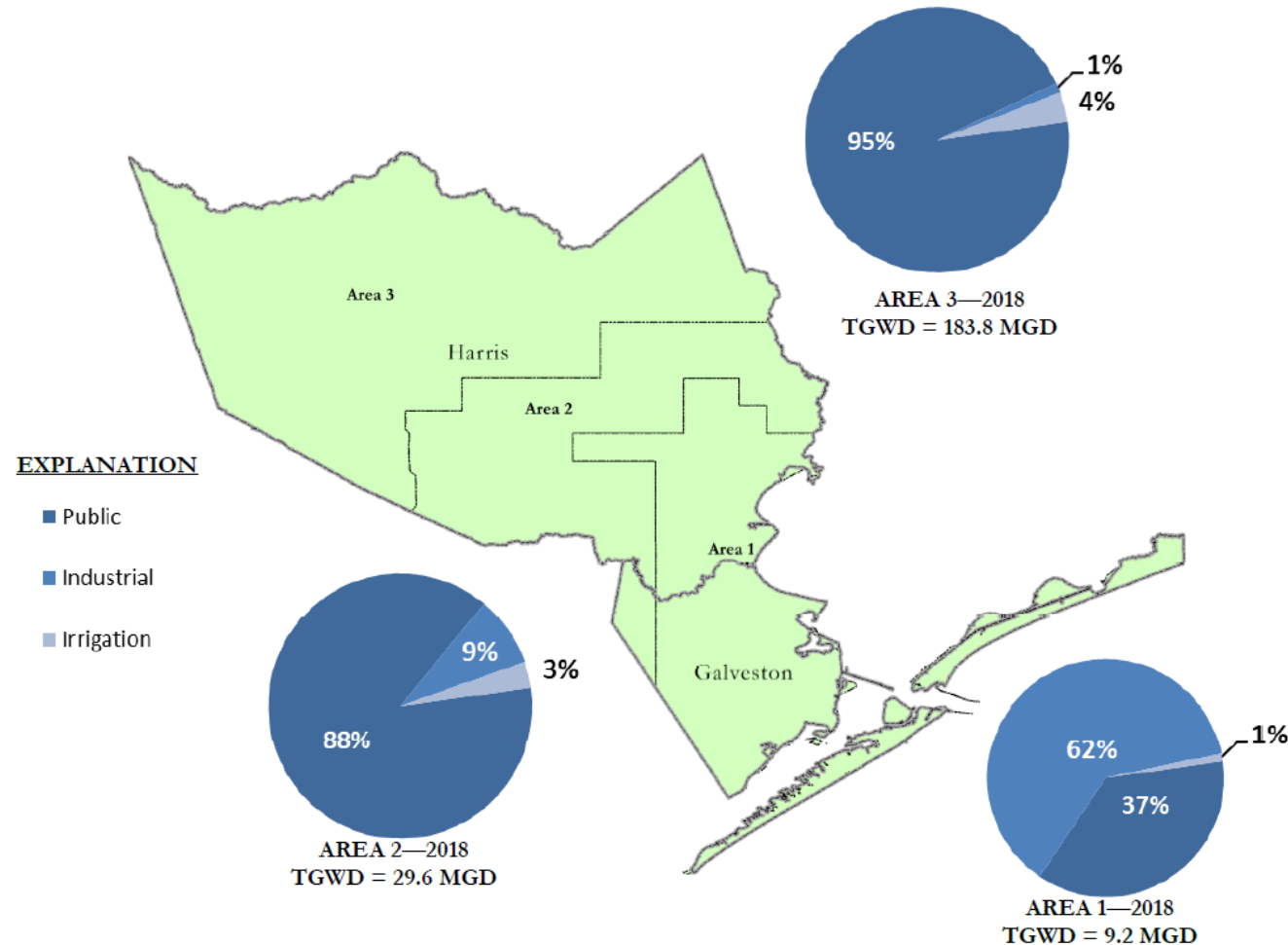


Figure 4. Total groundwater produced by regulatory area with primary use classification as: public/municipal, industrial, and irrigation uses, Harris and Galveston Counties, Texas, 2018.

Why Was the Harris-Galveston Subsidence District Measuring Movement?

The HGSD was authorized to issue (or refuse) well permits, promote water conservation and education, and promote conversion from ground-water to surface-water supplies.

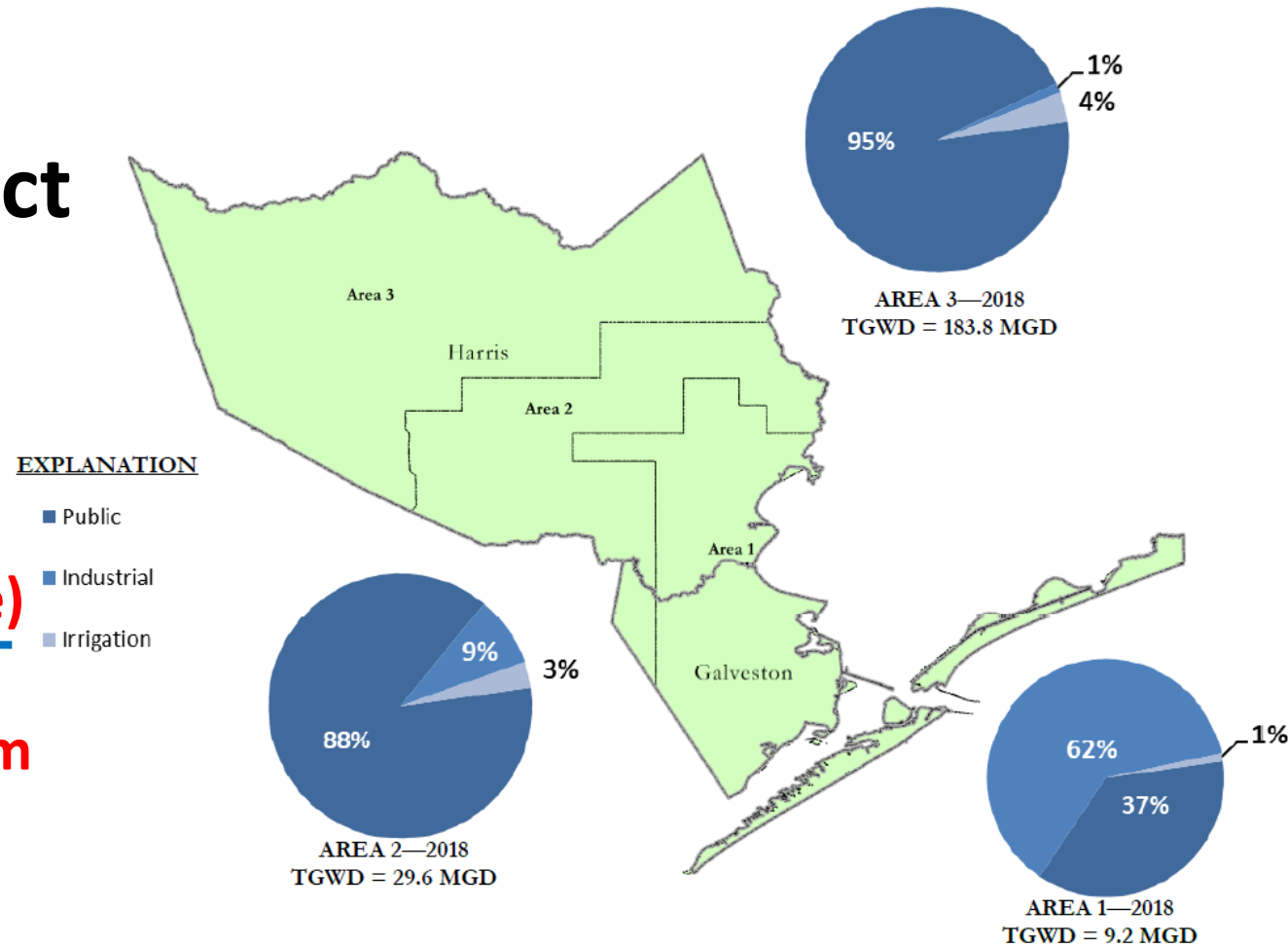
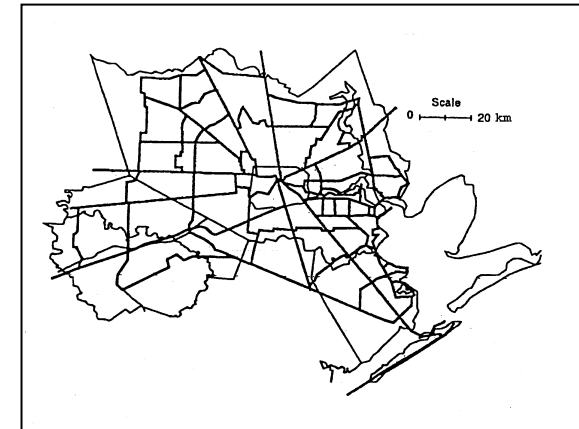


Figure 4. Total groundwater produced by regulatory area with primary use classification as: public/municipal, industrial, and irrigation uses, Harris and Galveston Counties, Texas, 2018.

Measuring the Amount of Subsidence was Critical to Managing the Well Permits, Promoting Water Conservation and Education, and Promoting Conversion from Ground-Water to Surface-Water Supplies

- **Large Leveling Surveys Were Performed in 1963-64, 1974, 1978, and 1986-87 to Estimate the Change in Height on Bench Marks**
- **In 1973-74, 20 local groups and 5 Federal agencies, including the National Ocean Survey (NOS), NOAA, cooperated in releveling the area**
- **HGSD Releveled at the cost of \$500,000 to \$1,000,000**
 - **HGSD Only Needed the Height Differences at Select Locations**

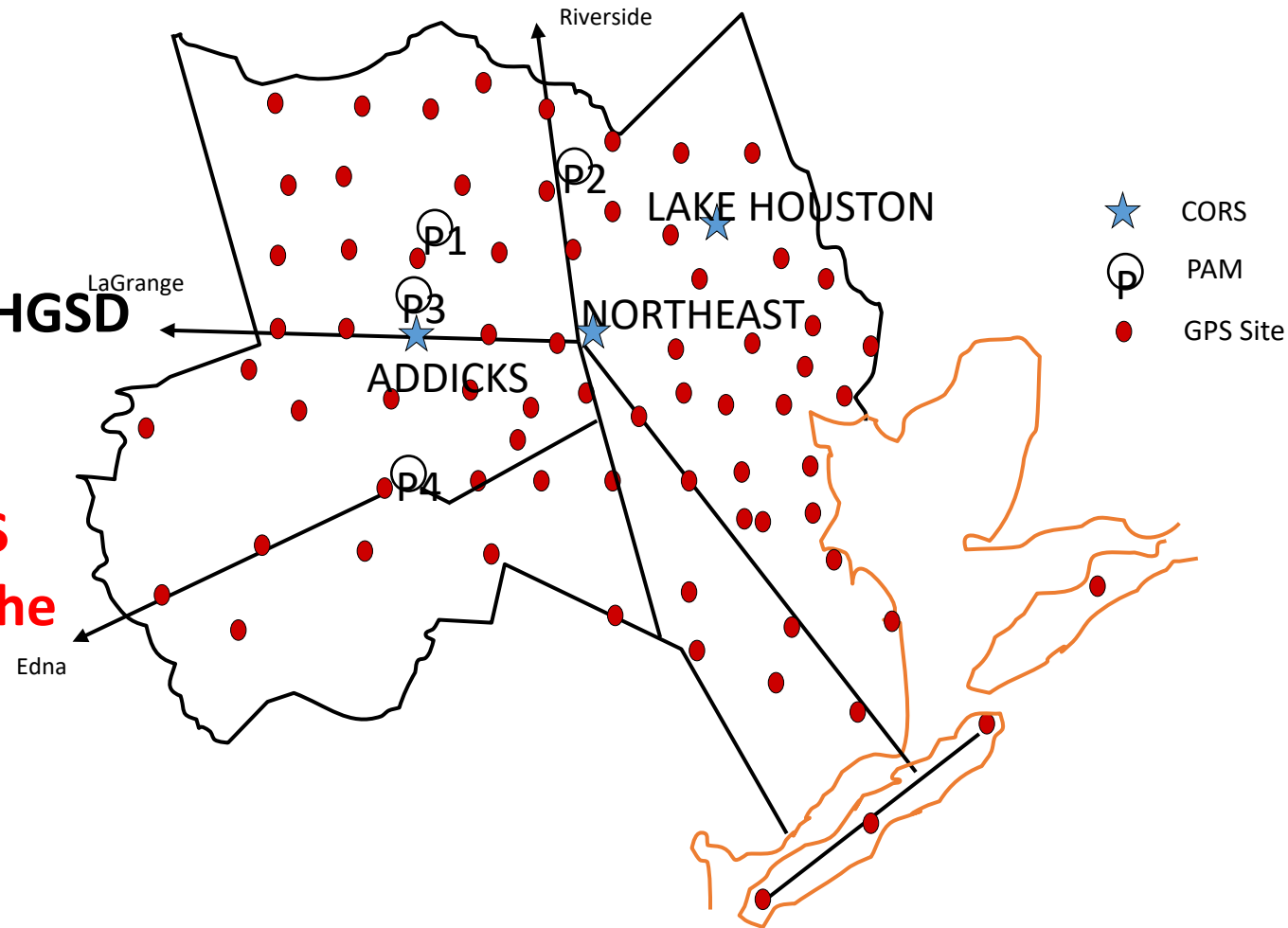


Leveling Network Replaced With a GNSS Network

➤ **Leveling Network Replaced with a GNSS Network in 1987**

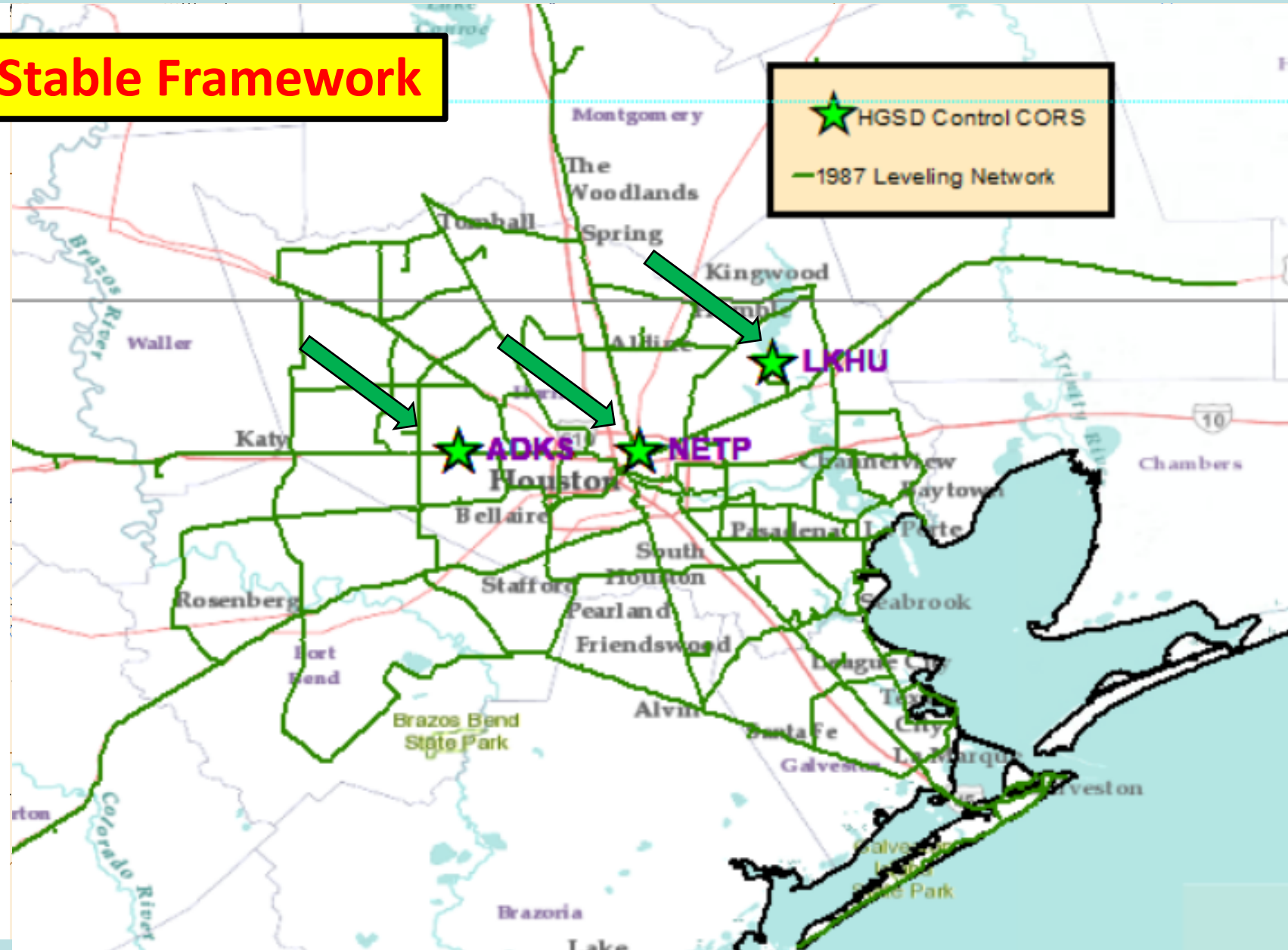
➤ **Established GNSS Framework Where HGSD Needed Information**

➤ **Established NAVD 88 Heights on GNSS Framework (Leveling Performed at the Same Time as GNSS)**



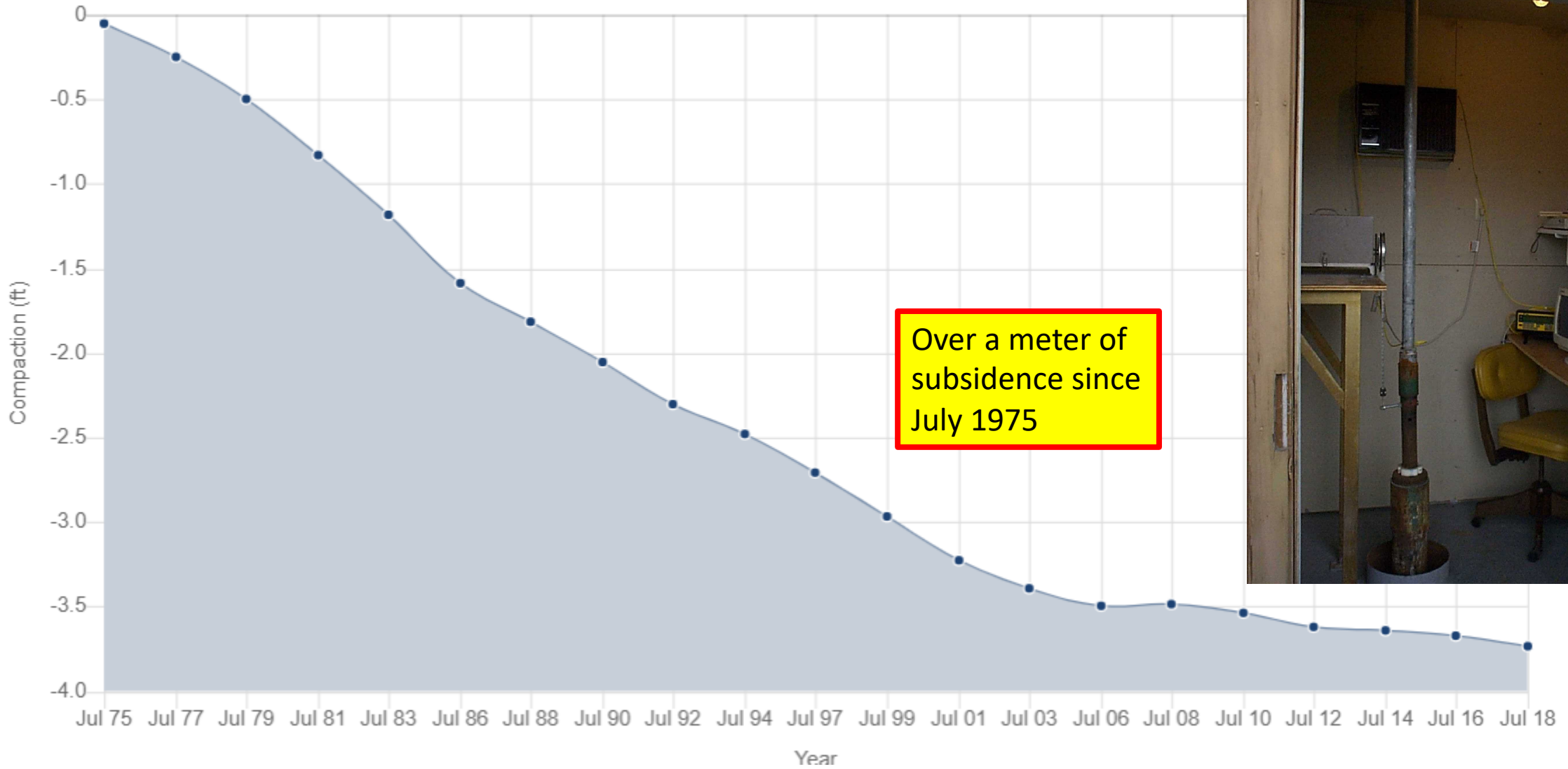
Establishment of a Stable Framework

- Installed CORs on Three Extensometers
- Performed Leveling to Establish NAVD 88 Heights on “Stable” CORs
- Stable CORs Provided Control for future NAVD 88 GNSS-Derived Orthometric Heights



[Details](#)

Addicks Extensometer (July 1975 – July 2018)



Details

Port-a-Measure: PAM

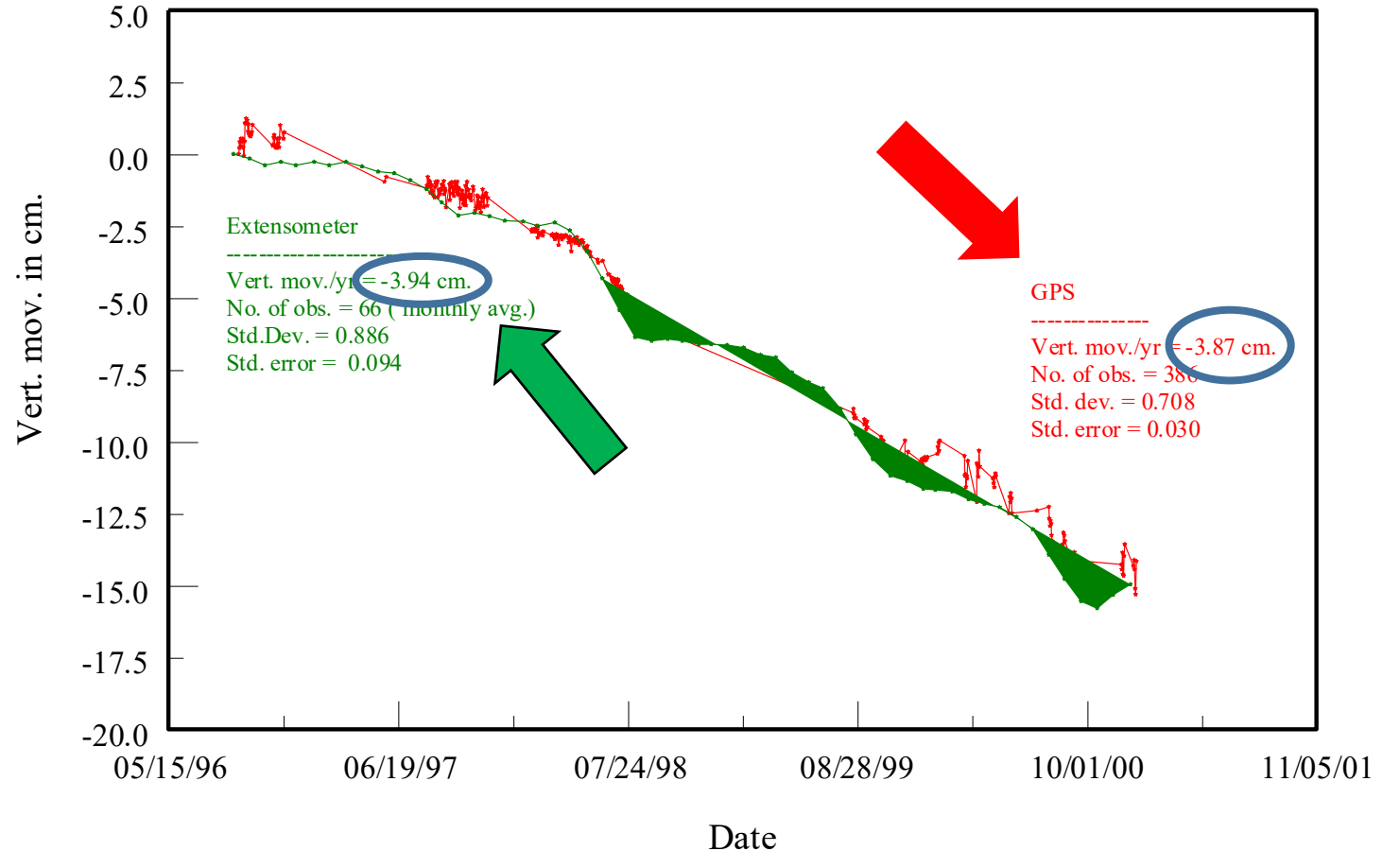
Allowed HGSD to Install a Station Where They
Wanted to Obtain Subsidence Information



Proof of Concept of Using PAMs

Collocated a PAM
Next to the
Addicks Extensometer

Comparison between Extensometer and GPS data at Addicks



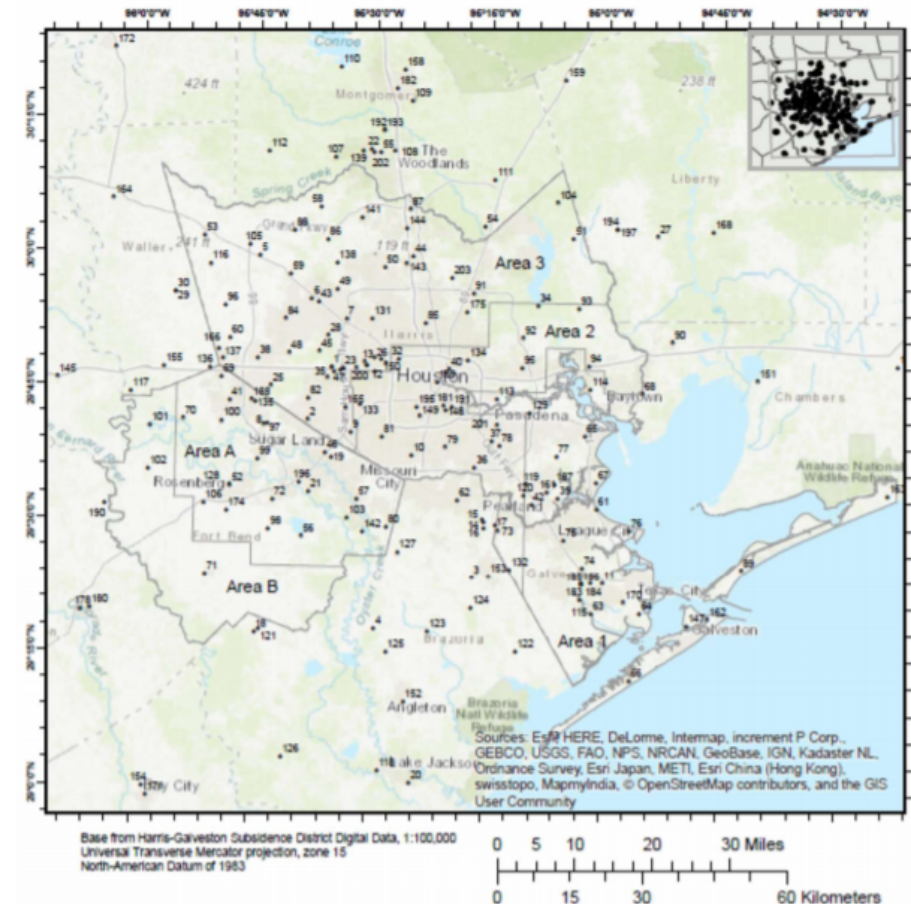
What Does The Project Look Like Today

HCSD is now Collaborating with the University of Houston Researchers to Estimate Subsidence Using CORs and PAMs

Excerpts from a HGSD Report titled "2018-HGSD-AGR-2019-001-Full Report.pdf"
(<https://hgsubsidence.org/wp-content/uploads/2019/06/2018-HGSD-AGR-2019-001-Full-Report.pdf>)

Daily GPS heights are derived at each of the occupied sites:

- Using thirty seconds data epoch
- Seven Day Period, every eight weeks
- Daily Height Value Computed
- Reference is denoted as the *stable Houston reference frame Houston 16*



HGSD EXHIBIT 17. Annual subsidence rate, in centimeters per year, estimated from three or more years of periodic and continuous GPS data measured at subsidence monitoring sites, Harris and Galveston Counties, 2014-2018.

EXPLANATION
• Subsidence monitoring station and map id. (see appendix)

PAM Design on 1990s



PAM Design Today



- This map shows the locations of the GNSS sites throughout the area.
 - Analysis Involves more than HGSD PAMs
 - Includes other CORS in Region
- The colored dots represent the average compaction over the past five years for each site, in centimeters.
- They range from 0.0 cm/year to greater than 2.5 cm/year.

**Subsidence Rate (2014-2018)
cm/year**

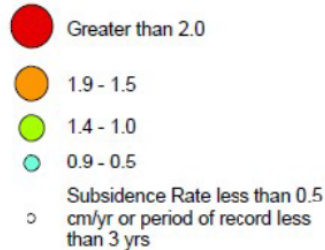
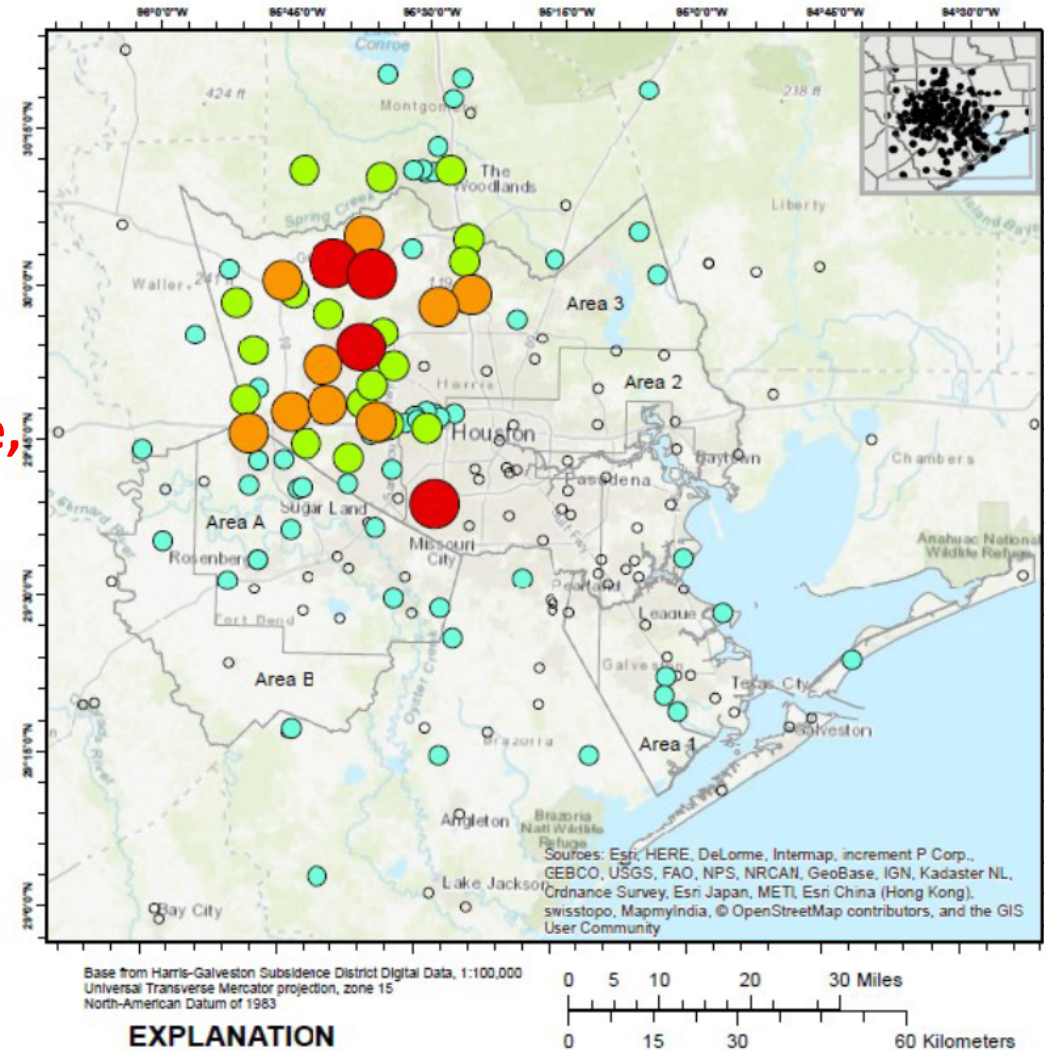


Figure 7. Rate of land surface subsidence, referenced to the Horizontal Reference Frame 16, at GPS monitoring stations with more than three years of data, operated by the Harris-Galveston Subsidence District and the University of Houston, Houston Region, Texas, 2014-2018.

Harris Galveston Subsidence District Resolution 2019-1032

[Details](#)



Excerpts from a HGSD Report titled “2018-HGSD-AGR-2019-001-Full-Report.pdf”

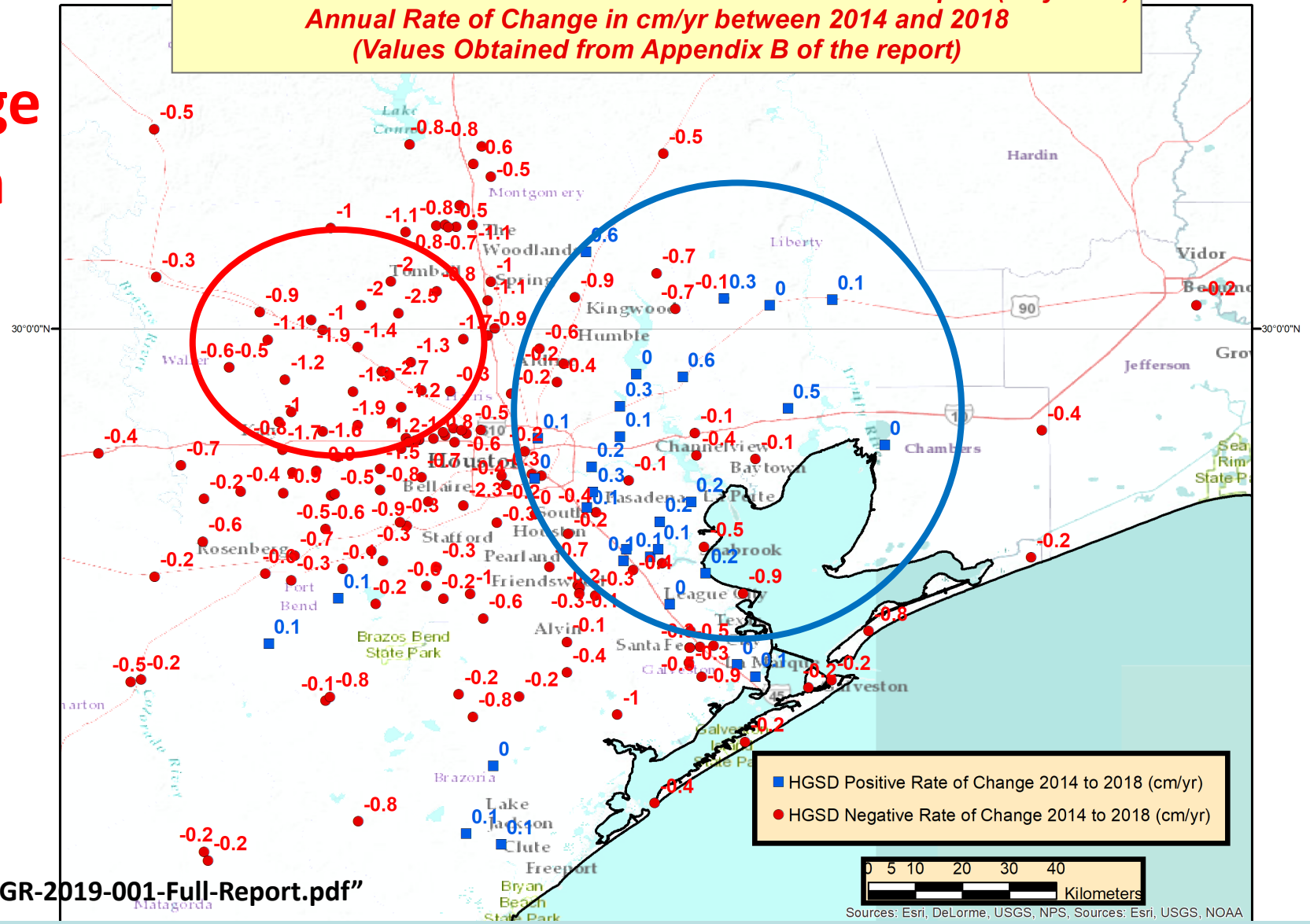
<https://hgsubsidence.org/wp-content/uploads/2019/06/2018-HGSD-AGR-2019-001-Full-Report.pdf>

Annual Rate of Change in cm/year between 2014 and 2018

Some of the Stations are Indicating Uplift

Some of the Stations are Still Subsiding at a Significant Rate

Subsidence Rates from HGSD 2018 Annual Groundwater Report (May 2019)
Annual Rate of Change in cm/yr between 2014 and 2018
(Values Obtained from Appendix B of the report)



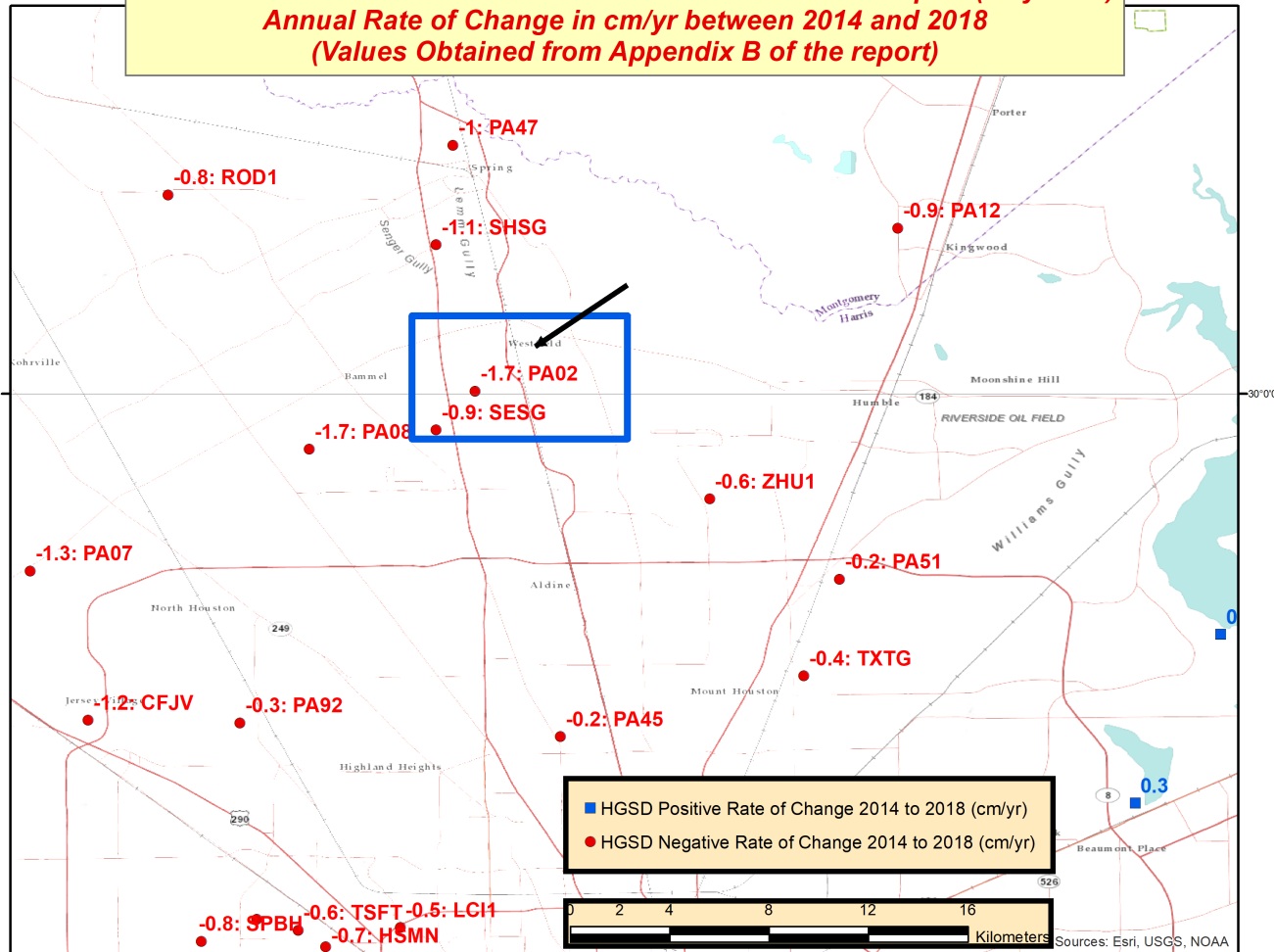
Data from a HGSD Report titled "2018-HGSD-AGR-2019-001-Full-Report.pdf"

Sources: Esri, DeLorme, USGS, NPS, Sources: Esri, USGS, NOAA

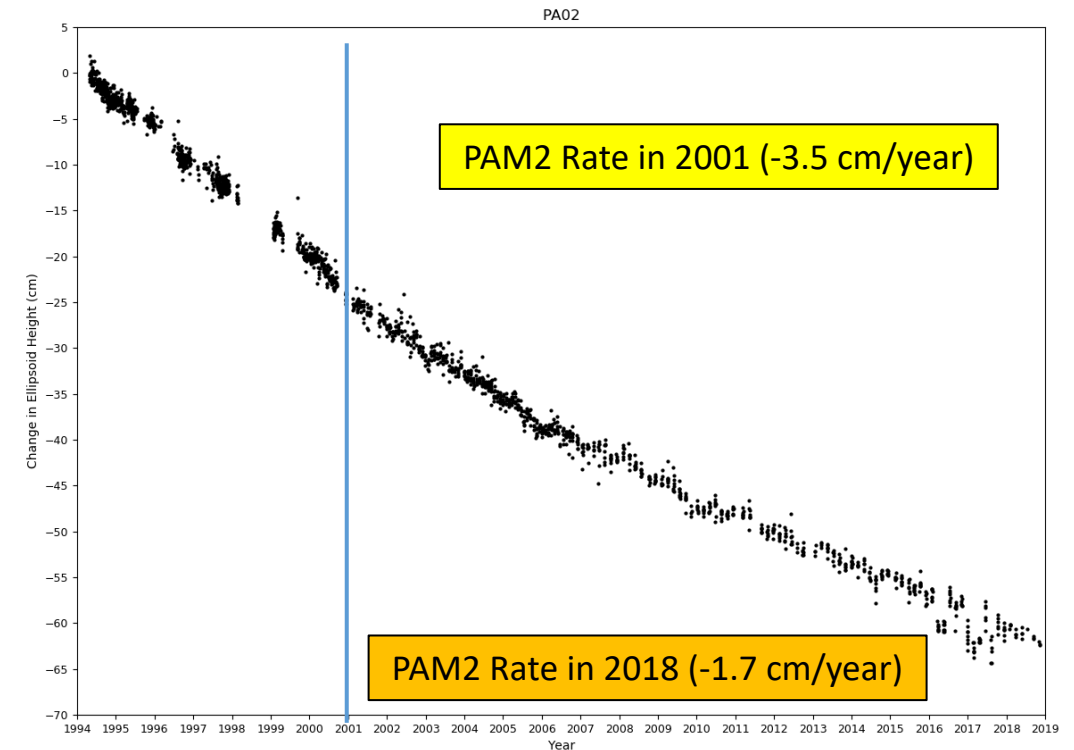
Integrated and Collaborative Organizations Create Geospatial Solutions

Excerpts from a HGSD Report titled "2018-HGSD-AGR-2019-001-Full-Report.pdf"

**Subsidence Rates from HGSD 2018 Annual Groundwater Report (May 2019)
Annual Rate of Change in cm/yr between 2014 and 2018
(Values Obtained from Appendix B of the report)**



PAM 02 has measured approximately 61 cm (almost one inch per year), but the rate of decline has decreased very slightly in recent years.

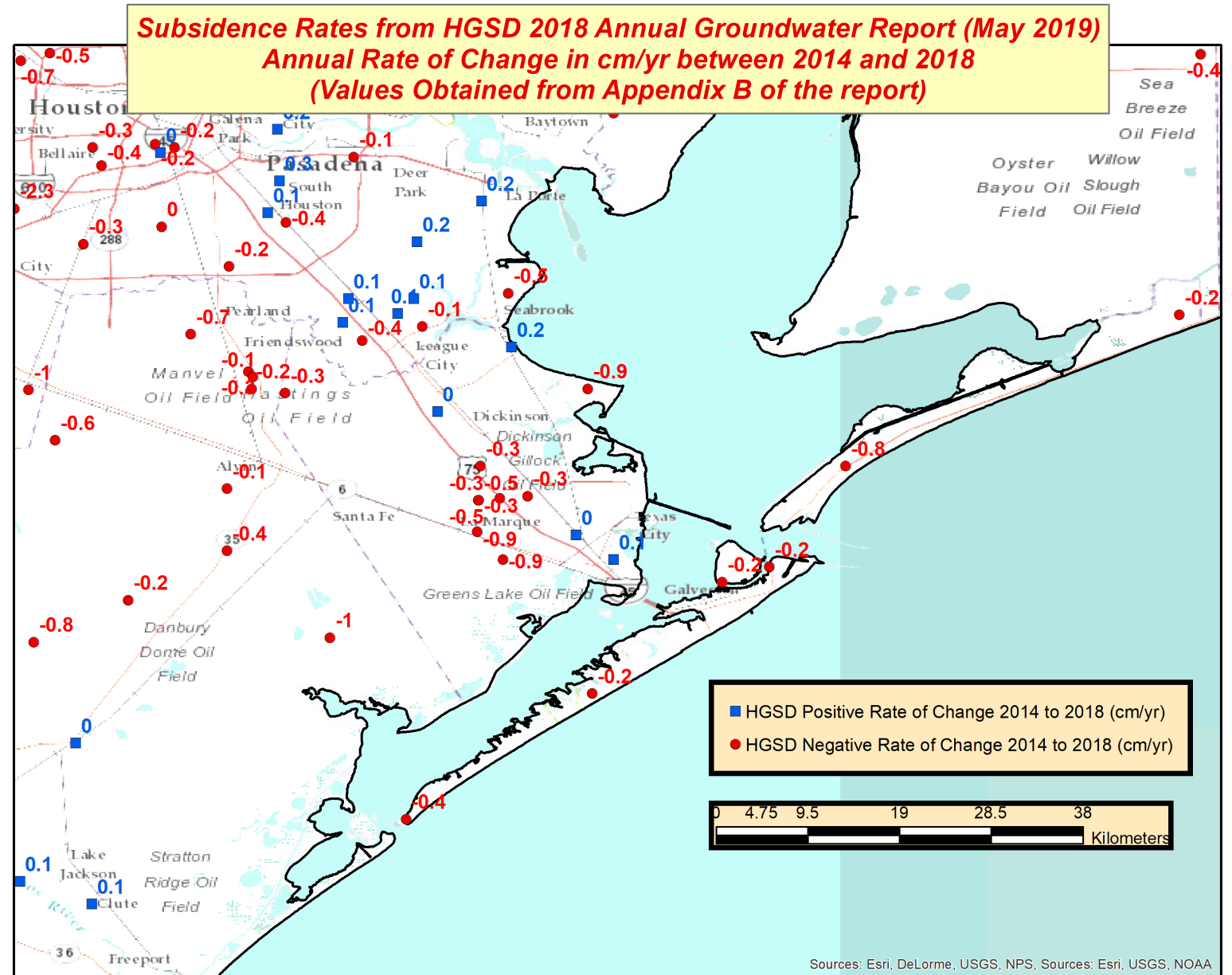


Galveston Region

Annual Rate of Change
in cm/year between
2014 and 2018

Negative Rate of Change
from a couple of mm/year
to a cm/year

Notice the Positive Rate of
Change

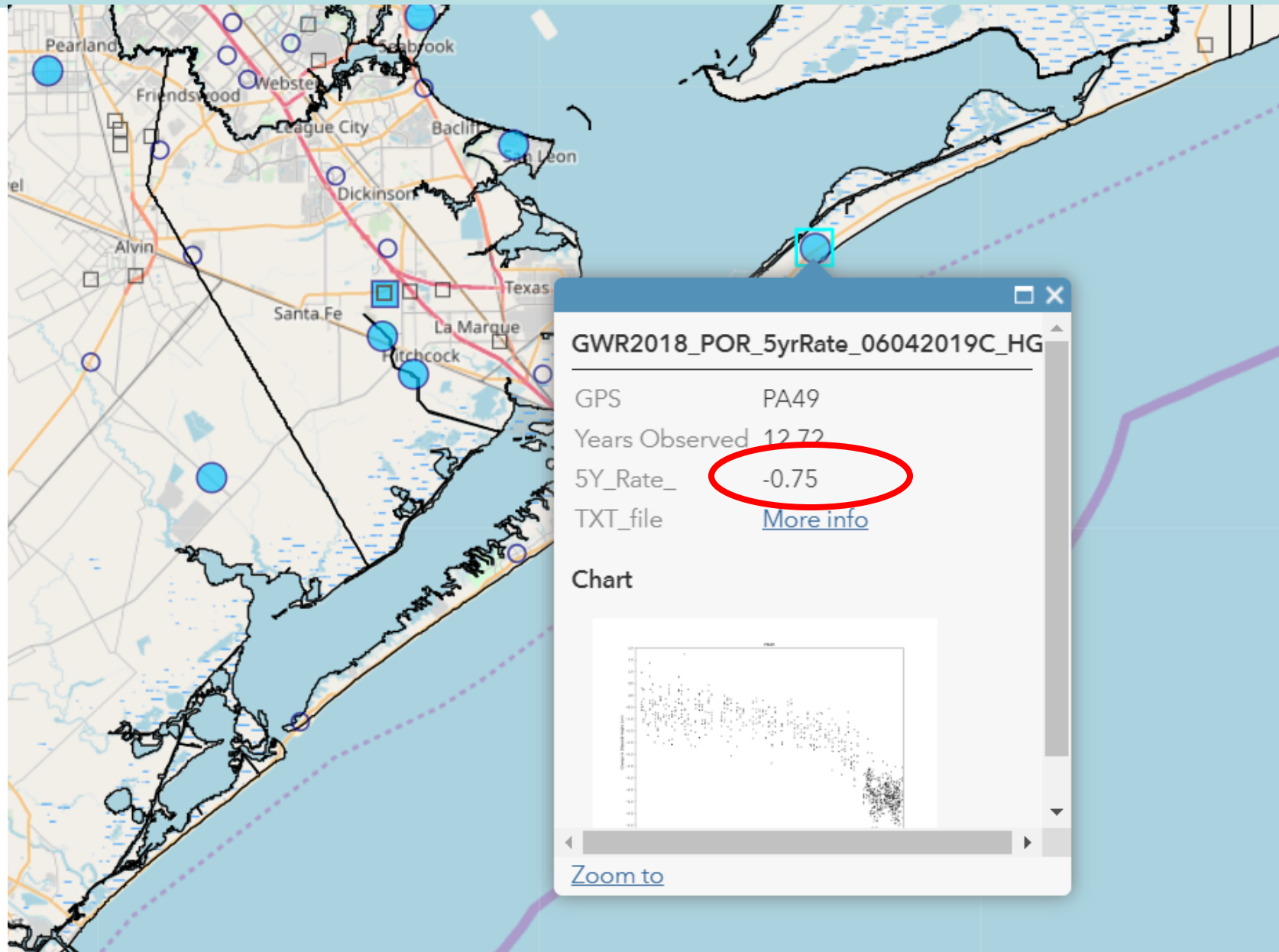


[Details](#)

Galveston Region PAM 49

Annual Rate of Change
in cm/year between
2014 and 2018
-0.75 cm/year


Downloaded from HGSD Website:
<https://www.arcgis.com/home/webmap/viewer.html?webmap=945232d7efbf40e18608a55a6fd5fcc0&extent=-96.7212,28.8727,-93.5351,30.8212>



City of Galveston Hazard Mitigation Plan

The broad goals of the City of Galveston Hazard Mitigation Plan, as determined by the HMPSC, are as follows:

Goal 1: Improve education and outreach efforts, specifically to the public, elected officials, municipal employees and local businesses, regarding the potential impacts of hazards and the identification of specific measures that can be taken to reduce those impacts.



Goal 2: Improve capabilities, coordination and opportunities at the municipal level to plan and implement hazard mitigation projects, programs and activities, especially using GIS, coordination with universities and colleges, and public/private partnerships.

Goal 3: Develop hazard mitigation policies and programs designed to reduce the impact of natural and human caused hazards to people and property.

Goal 4: Identify and implement hazard mitigation projects to reduce the impact of hazard events and disasters.

<https://www.galvestontx.gov/AgendaCenter/ViewFile/Item/4081?fileID=12882>

City of Galveston Hazard Mitigation Plan

The City of Galveston, Texas
Appendix C: Meeting Documentation

Goal #2: Improve capabilities, coordination and opportunities at the municipal level to plan and implement hazard mitigation projects, programs and activities, especially through the use of GIS, coordination with universities and colleges, and public/private partnerships.

Objective #2.1: Acquire and maintain detailed data regarding vulnerabilities, including critical facilities and historic assets, so that these resources can be prioritized and assessed for mitigation actions.

Action Description:	Hazards to be Addressed:	Responsible Entity:	Timeframe for Completion:	Estimated Cost:	Priority:	Notes/Update:
Work cooperatively with NOAA and other agencies to conduct workshop/study on sea level rise in Galveston.	Coastal Erosion; Coastal Retreat; Coastal Subsidence; Sea Level Change	Development Department	2011-2016	\$5,000+	Moderate	Keep- this is ongoing.

<https://www.galvestontx.gov/AgendaCenter/ViewFile/Item/4081?fileID=12882>

City of Galveston Hazard Mitigation Plan

City of Galveston - Mitigation Action Plan								
Proposed Action	Hazard(s) Addressed	New or Existing Action	Estimated Cost	Potential Funding Source(s)	Agency / Department Responsible	Implementation Schedule	Comments	Priority
Develop detailed inventory of critical facilities, to include elevations, square footage and contents inventory.	Biologic Event; Coastal Hazards; Drought; Environmental Disaster; Extreme Heat; Extreme Wind; Expansive Soils; Flooding; Hail; Hazardous Materials Incident; Lightning; Sea Level Change; Severe Winter Storm; Tsunami; Wildfire / Urban Fire; Tropical Systems and Hurricanes; Tornadoes	Existing (On-going)	\$5,000	General Funds	Development Department, Municipal Utilities, Office of Emergency Management	2016-2021	Applies to existing and future development.	High

<https://www.galvestontx.gov/AgendaCenter/ViewFile/Item/4081?fileID=12882>

Integrated and Collaborative Organizations Create Geospatial Solutions

City of Galveston – Mitigation Action Plan								
Proposed Action	Hazard(s) Addressed	New or Existing Action	Estimated Cost	Potential Funding Source(s)	Agency / Department Responsible	Implementation Schedule	Comments	Priority
Develop proposed land use mapping to allow easier consideration of hazards in future development.	Biologic Event; Coastal Hazards; Drought; Environmental Disaster; Extreme Heat; Extreme Wind; Expansive Soils; Flooding; Hail; Hazardous Materials Incident; Lightning; Sea Level Change; Severe Winter Storm; Tsunami; Wildfire / Urban Fire; Tropical Systems and Hurricanes; Tornadoes	Existing (On-going)	\$10,000	General Funds, CDBG	Development Department	2016-2021	Applies to future development.	Moderate
Consider / Development of structural acquisition plan/procedures.	Flooding	Existing (On-going)	\$10,000	General Funds	Development Department	2016-2021	Applies to existing structures.	Moderate
Consider / Development of structural elevation plan/procedures.	Flooding	Existing (On-going)	\$10,000	General Funds	Development Department	2016-2021	Applies to existing structures.	Moderate

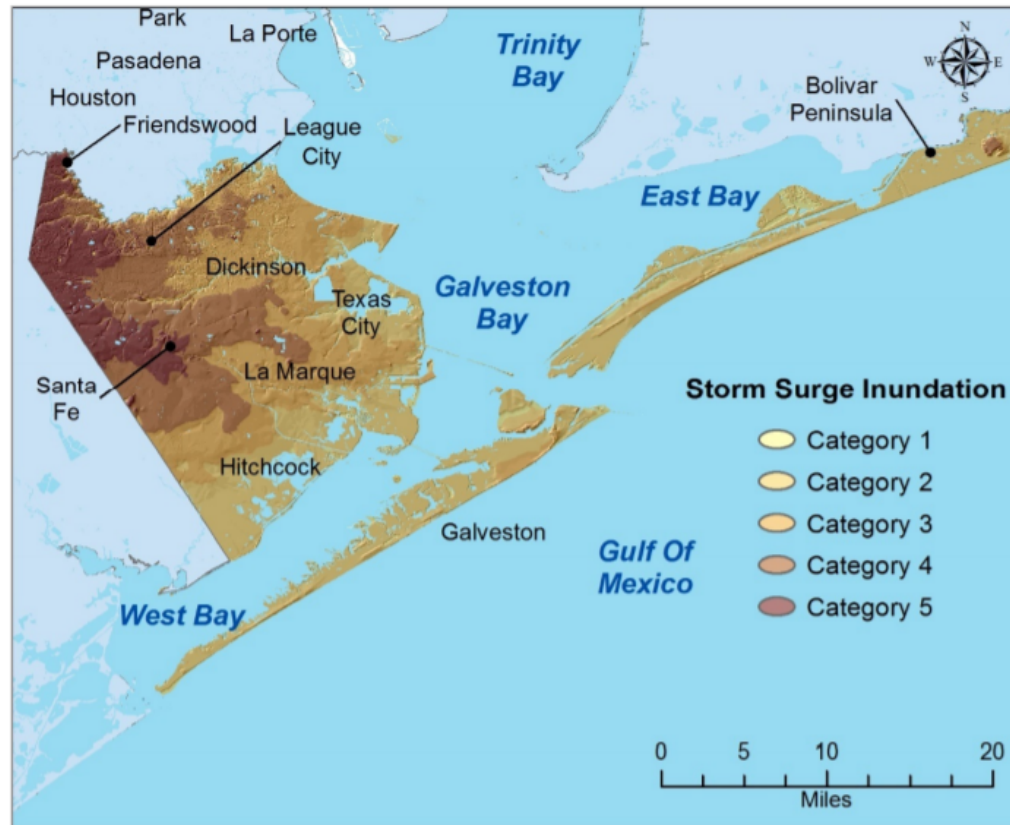
<https://www.galvestontx.gov/AgendaCenter/ViewFile/Item/4081?fileID=12882>



Galveston County Multi-Jurisdictional Hazard Mitigation Plan

32

Figure 6.1: Coastal Flood Inundation Zones in Galveston County



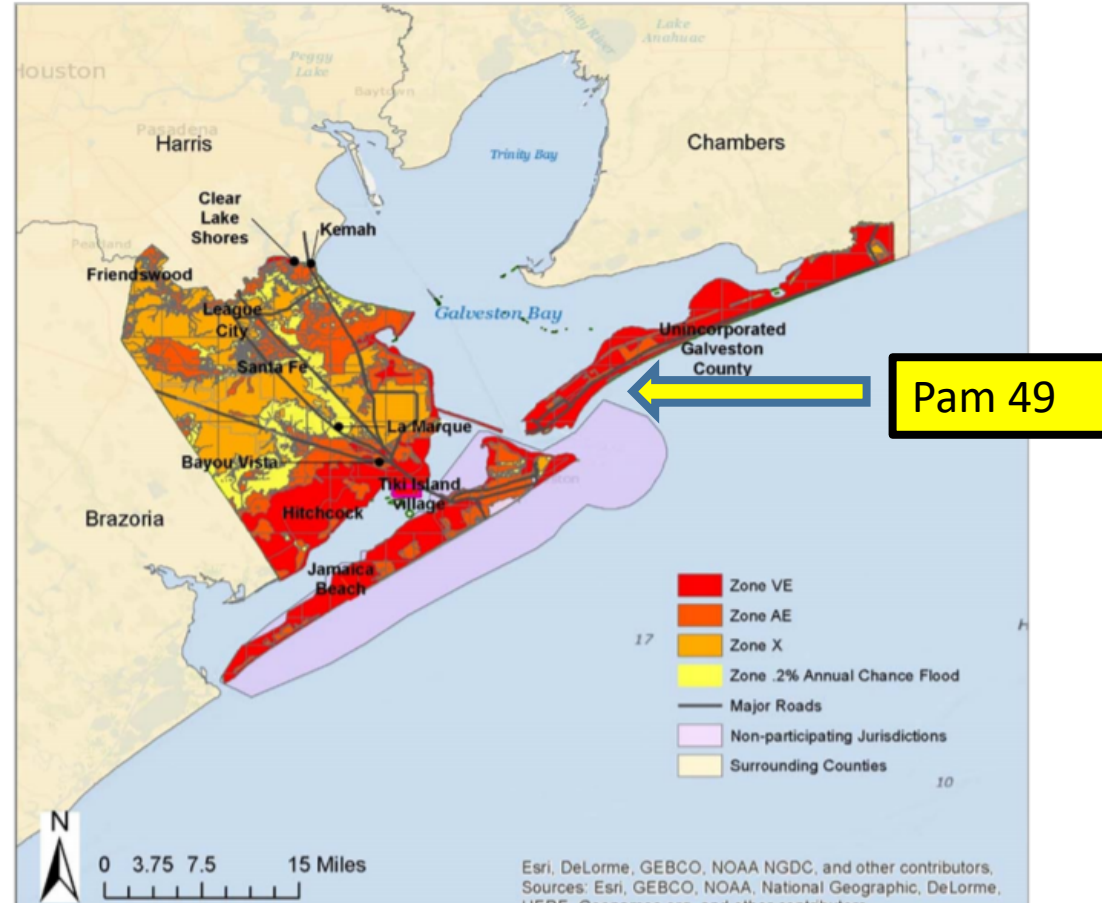
http://www.galvestoncountytexas.gov/CJ/Lists/Announcements/Attachments/275/Galveston%20County%202016%20HMP_Draft%20Review.pdf

Galveston County Multi-Jurisdictional Hazard Mitigation Plan



42

Figure 6.2: Coastal/Inland V Zone Flooding Potential (County Wide)



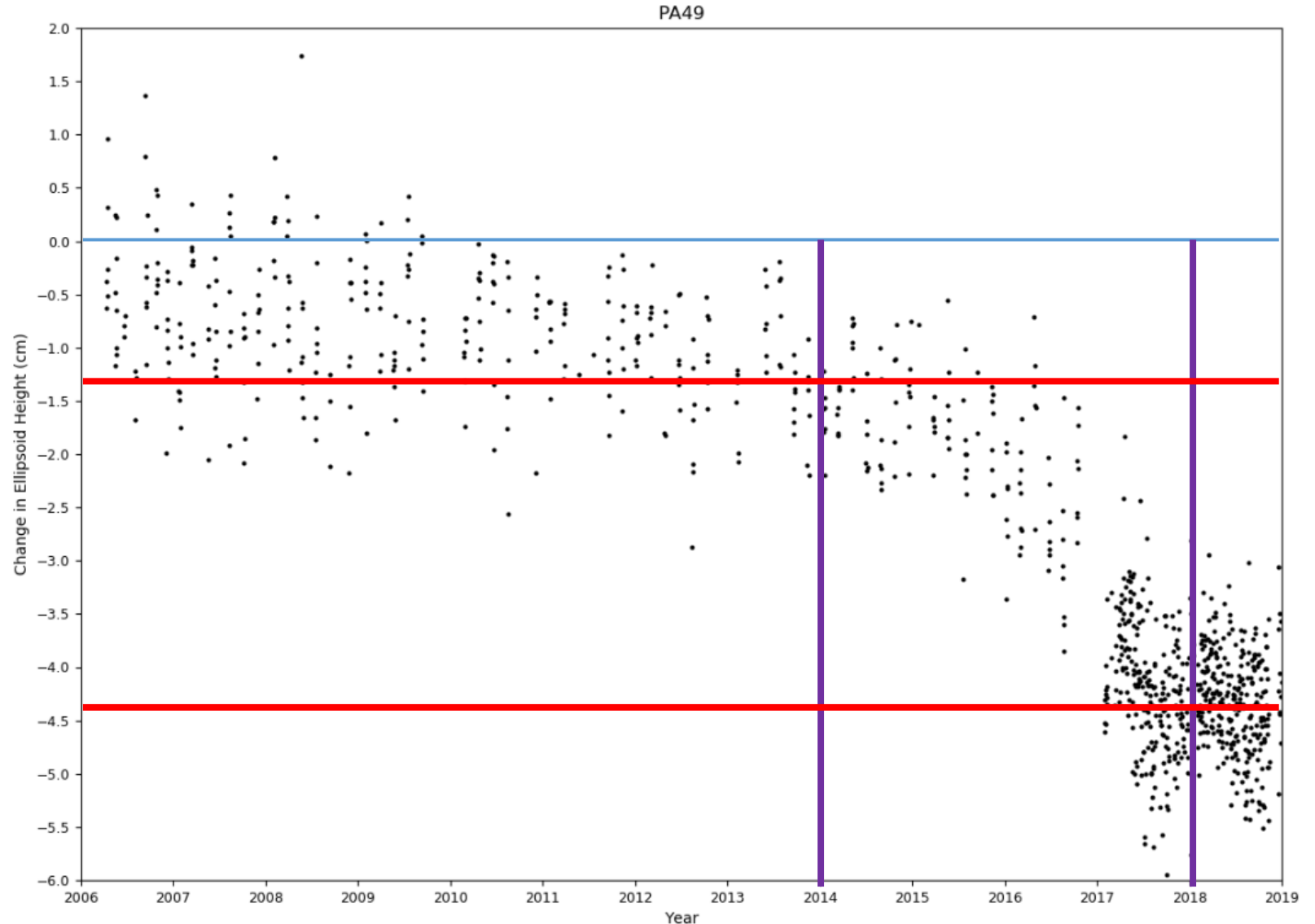
http://www.galvestoncountytexas.gov/CJ/Lists/Announcements/Attachments/275/Galveston%20County%202016%20HMP_Draft%20Review.pdf

Galveston Region PAM 49

Change in Height (cm)
between
2006 and 2018
(-0.75 cm/year between
2014 and 2008)

Plot from HGSD Website:

<https://www.arcgis.com/home/webmap/viewer.html?webmap=945232d7efbf40e18608a55a6fd5fcc0&extent=-96.7212,28.8727,-93.5351,30.8212>



Summary

- **NGS/HGSD Developed an Automated GPS Subsidence Measuring System**
 - Project met the Requirements of the Harris-Galveston Subsidence District
 - **Reduced the Cost of Monitoring Subsidence in the Region**
 - PAMs Allowed the HGSD to Efficiently and Effectively Measure Subsidence in Areas of Interest
 - **Established a Stable Reference Frame Using Extensometer and CORS**
 - Verified that the PAMs Could be Used to Estimate Subsidence to the mm/year

- **State and Local Governments are Using the Information to Make Management Decisions**

- **The Number of Monitoring Stations has Increased to over 200 sites**
 - **Monitoring Sites Consist of CORS and PAMs**
 - **Monitoring Sites Indicate That Reduction in Groundwater Withdrawal has Decreased Subsidence**

One Final Thought From a Very Intelligent Individual

At Least He Believes He's Intelligent

My Brother

If you geodesists did it correctly the first time you wouldn't have to keep performing adjustments and changing the values.

Just do it right the first time.

August 2012

Mark W. Zilkoski, MD

My Response

**LIFE IS A
CONTINUOUS
PROCESS OF
ADJUSTMENT**

INDIRA GANDHI

Thanks