UPDATE: SUBSIDENCE INVESTIGATIONS – PHASE 1

Presented to:

LONE STAR GROUNDWATER CONSERVATION DISTRICT

MARCH 10, 2020

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LONE STAR Groundwater Conservation District

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PHASE 1 – ASSESSMENT OF PAST AND CURRENT INVESTIGATIONS

- Types of Studies and Data Available
- Past Studies – What Did They Say and Conclude?
- HAGM (Current GAM) Modeling
- Regulations and Management
- Stakeholder Input
- Work Scope and Costs for Phase 2
- Final Report and Presentation

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HISTORICAL OVERVIEW

- Subsidence has been recognized in the “Houston-Galveston region of Texas” for almost 100 years
- Goose Creek oil field – 1926
- Associated with groundwater withdrawals – noted in the 1940s and early reports in the 1950s (Winslow, Doyel, Wood and Gabrysch)
- Numerous reports – studies are ongoing
- Since 1970s (at least) – the “Houston-Galveston region of Texas” has included “part of” Montgomery County (as well as parts of Brazoria, Fort Bend, Waller, Liberty and Chambers counties

TYPES OF STUDIES AND DATA AVAILABLE

- Topography and Releveling
- Hydrogeology
- GPS Network (PAM and CORS Sites)
- Extensometers
- Remote Sensing/Satellite Imagery
- Models – GAMs, Other Flow Models, PRESS
- Water Levels and Pumping Records (USGS and Districts)

PAST STUDIES – TOPOGRAPHY AND RELEVELING

- National Geodetic Survey Benchmarks

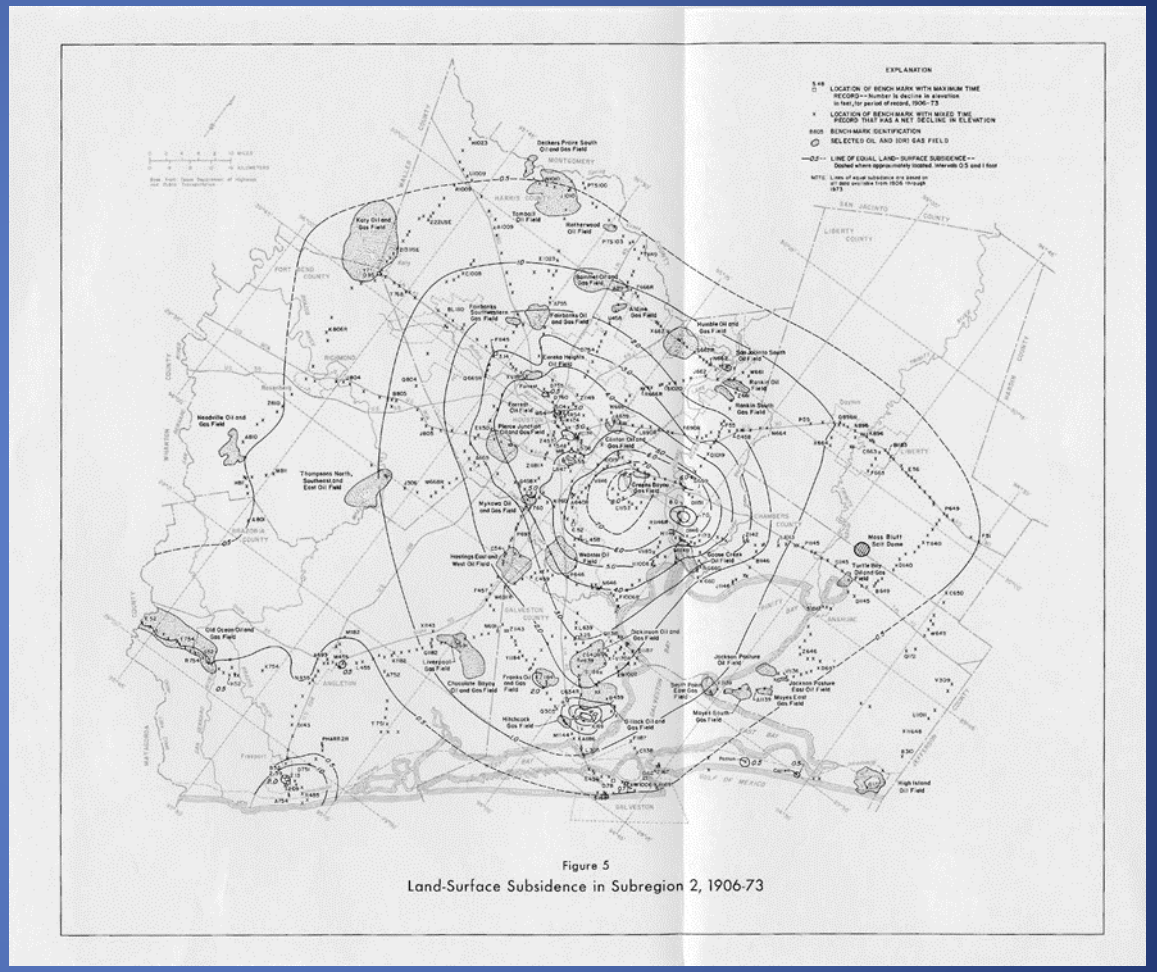


Figure 5
Land-Surface Subsidence in Subregion 2, 1906-73

PAST STUDIES – TOPOGRAPHY AND RELEVELING

- Initially – all subsidence determinations were made by geodetic differential leveling – up to 2,500 benchmarks with some of them dating back to 1906
- Gabrysch reported that "…some subsidence occurred before 1943, but the amount is difficult to determine." But, four "centers" noted – Pasadena, Baytown, Texas City, Goose Creek
- As benchmarks moved due to the regional nature of subsidence – re-leveling was necessary (1978 and 1987)
- Each leveling effort is very expensive
- As technology has developed – other methods are correlated to leveling efforts – GPS, LiDAR, InSAR

PAST STUDIES – HYDROGEOLOGY AND GEOTECHNICAL

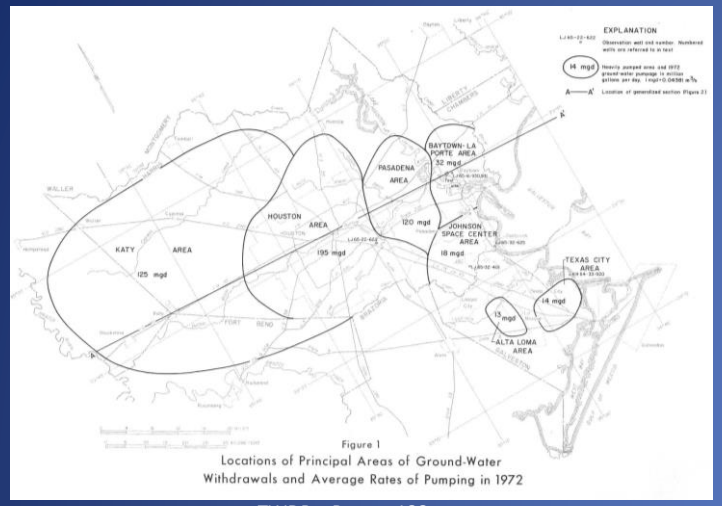
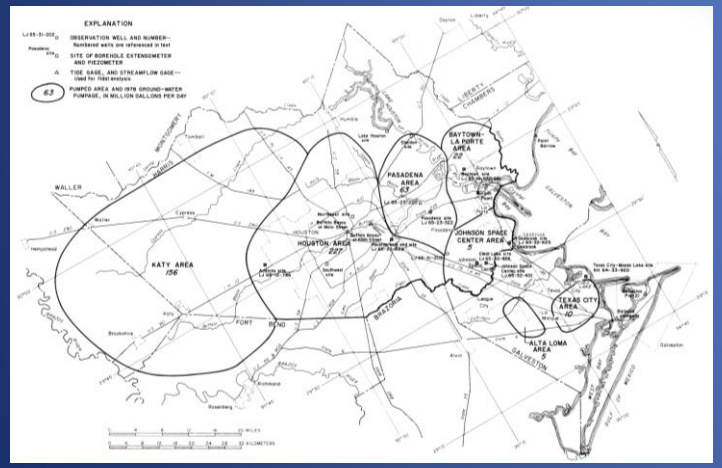
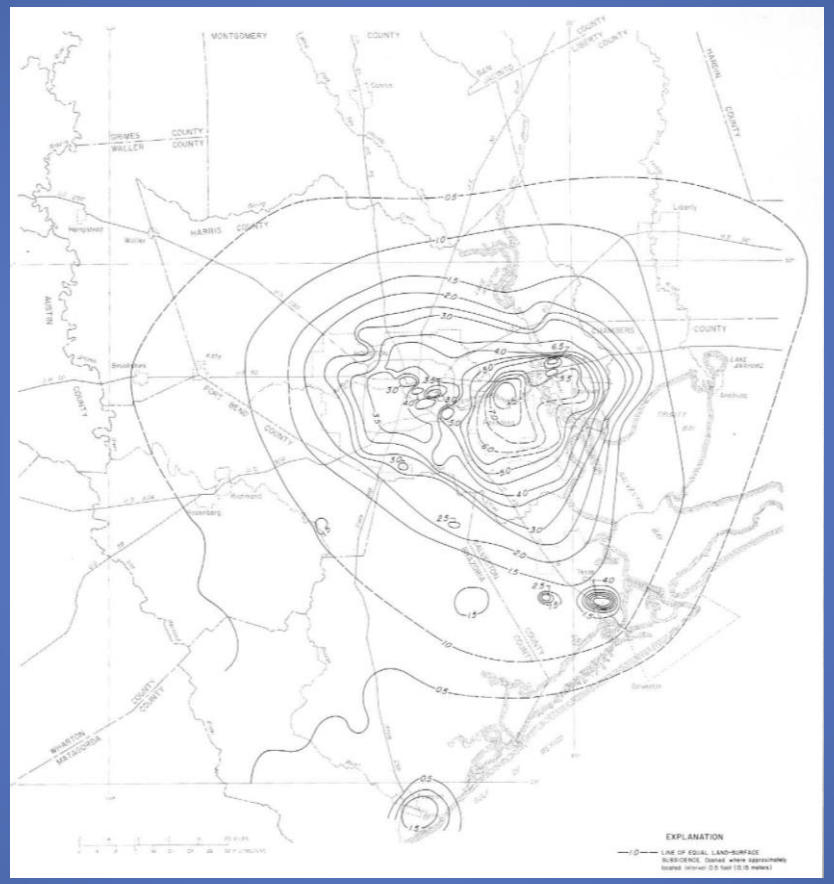


Figure 1
Locations of Principal Areas of Ground-Water Withdrawals and Average Rates of Pumping in 1972

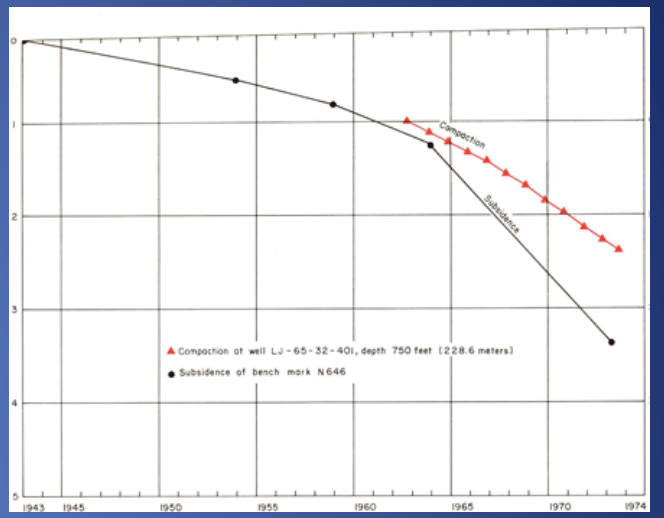
TWDB – Report 188



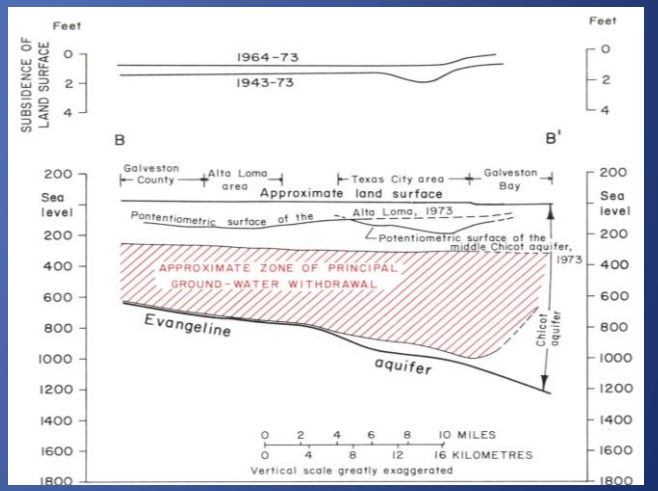
TWDB – Report 287



TWDB – Report 188



USGS WRI 21-74,Gabrysch & Bonnet



USGS WRI 76-32,Gabrysch & Bonnet

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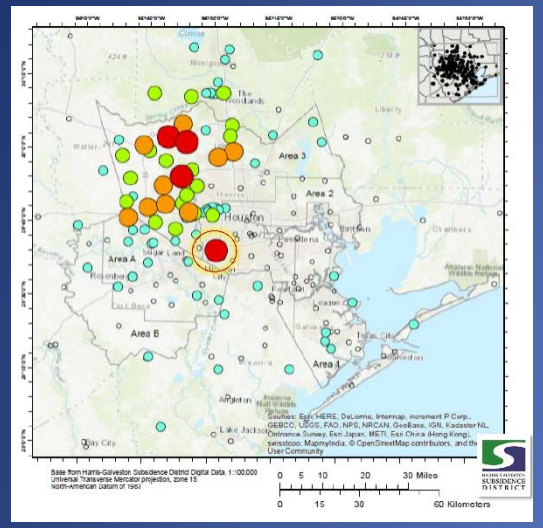
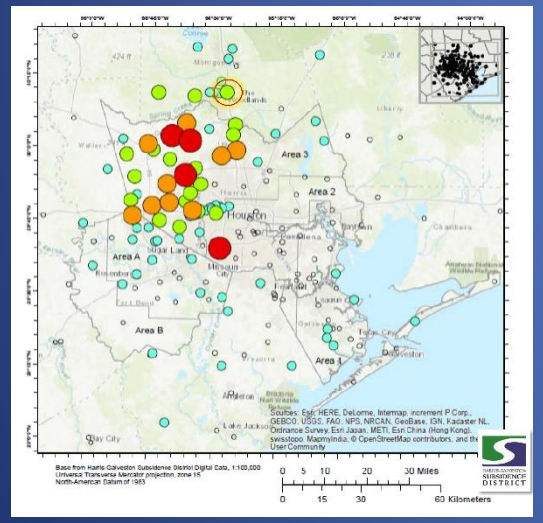
PAST STUDIES – HYDROGEOLOGY AND GEOTECHNICAL

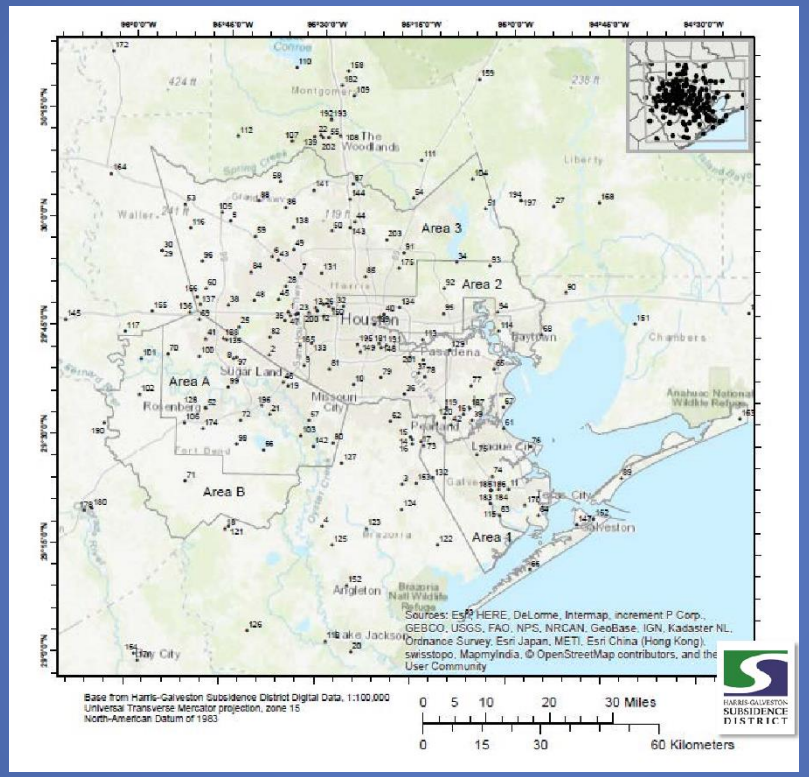
- Numerous growth-fault studies in 1970s and 1980s
- Defining subsidence studies in 1970s (continued to early 1980s)
- Focus of Harris and Galveston counties in areas of most subsidence
- Three key sites (initially) – Seabrook, Lake Moses, Baytown area
- Cores samples/geophysical logs/water levels –
  - Chicot and Upper Evangeline aquifers – depths to about 1,340 feet at local sites
  - Clay thickness, character and compressibility with depth – variability
  - Extensometers (10 at 8 sites by 1980 – 3 more added in early 1980s)
  - Correlated water-level changes, clay properties and compaction

"Records of compaction at different depth intervals obtained from extensometers, subsidence based on elevation data, and laboratory testing show that most of the subsidence is due to compaction of shallow material. It is suspected that compressibility of the material is related both to the age of sediment and the depth of burial" (Gabrysch, 1984)

PAST STUDIES – GPS NETWORK (CORS AND PAM SITES)







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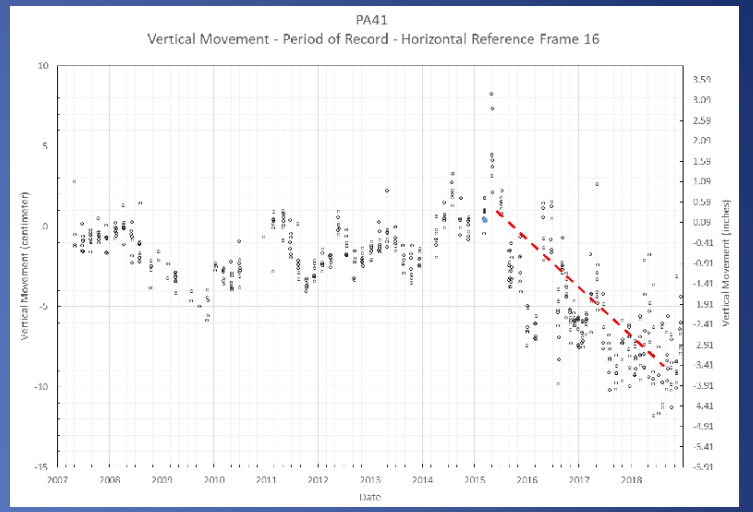

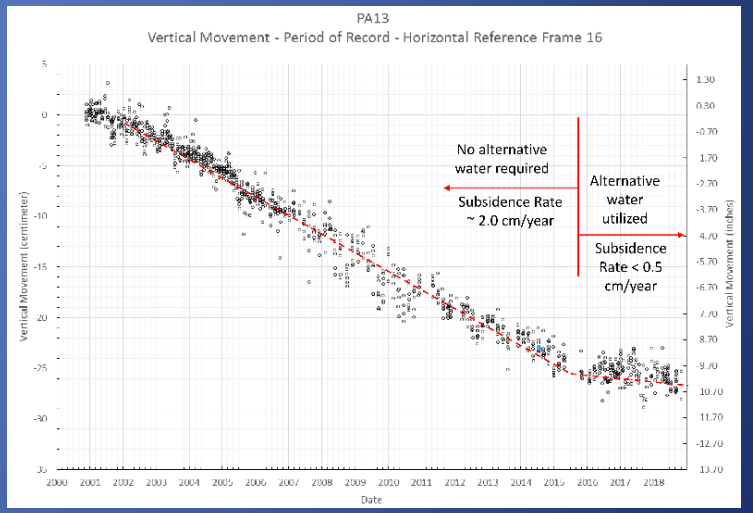

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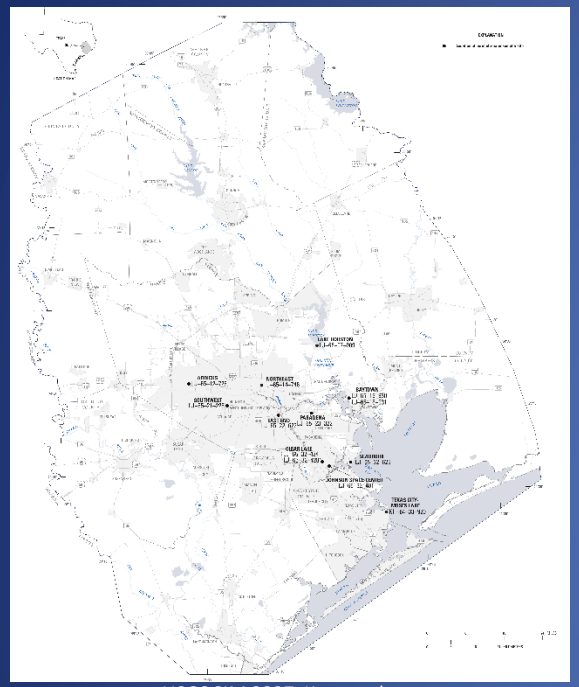
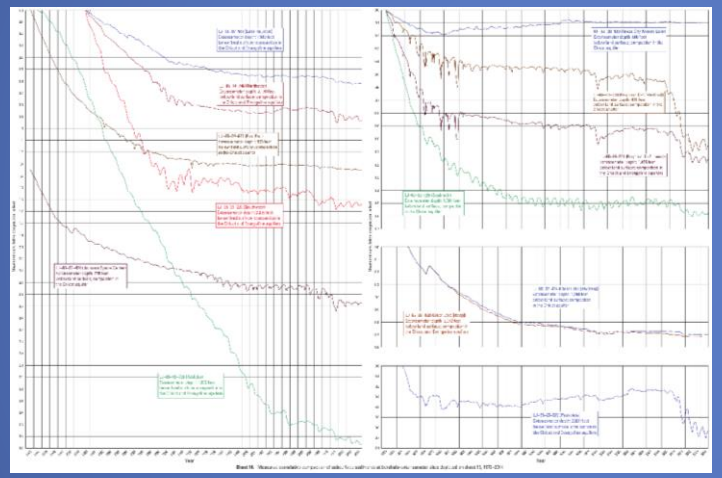
PAST STUDIES – GPS NETWORK (CORS AND PAM SITES)

- Began in the late 1980s – 15 permanent sites prior to 2000
- Deep borehole extensometers provide stable benchmarks and are equipped with GPS antennas – reference for other sites
- Permanent – Continuously Operating Reference Stations (CORS)
- Portable – Port-A-Measure Sites (PAM)
- Provides relatively continuous data; good coverage; cost effective
- Reportedly 170 GPS stations by 2014; 203 sites now (HGSD and UH)
- Requires post-processing of data to account for satellite orbit, clock information, atmospheric conditions – technology improving
- Reported “daily ambiguity” – 6 to 8 mm vertically; less horizontally

PAST STUDIES – EXTENSOMETERS



USGS SIM 3337, Kasmarek



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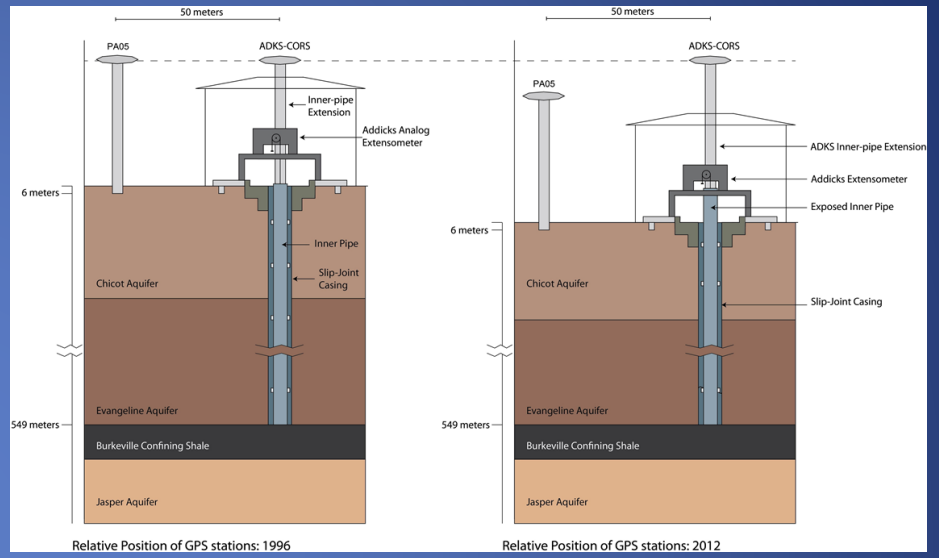
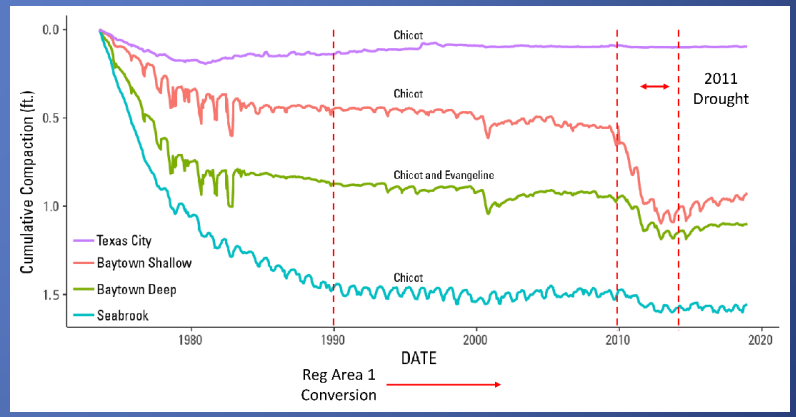


Wang and others, 2014



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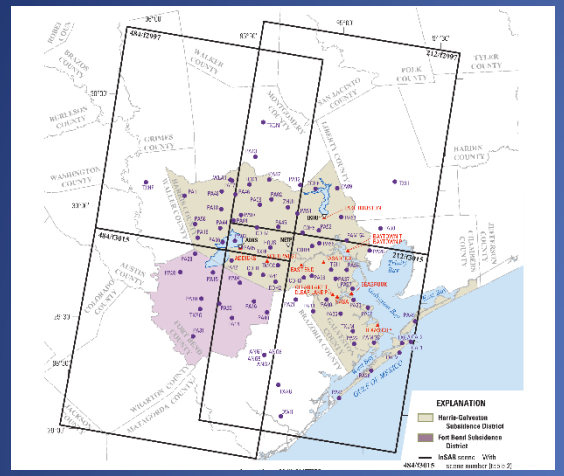
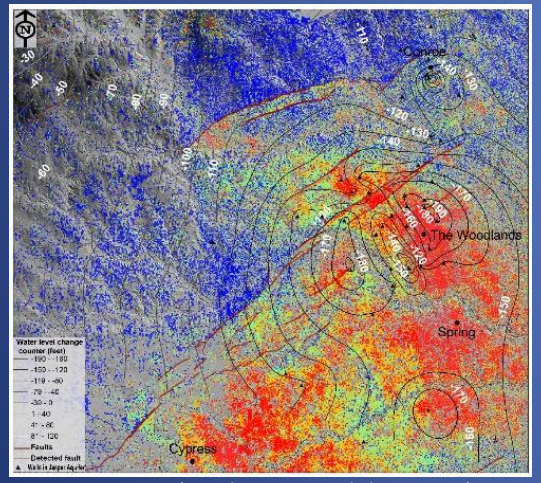
PAST STUDIES – EXTENSOMETERS

- One means of directly measuring compaction in an interval
- 12 total sites with 14 extensometers
  - Baytown and Clear Lake sites have deep and shallow
- Some to depths greater than compaction – stable "anchor"
- Slip joints in outer casing
- Measures compaction above the base – where co-located can differentiate compaction between intervals
- Continuous measurements relative to bedrock

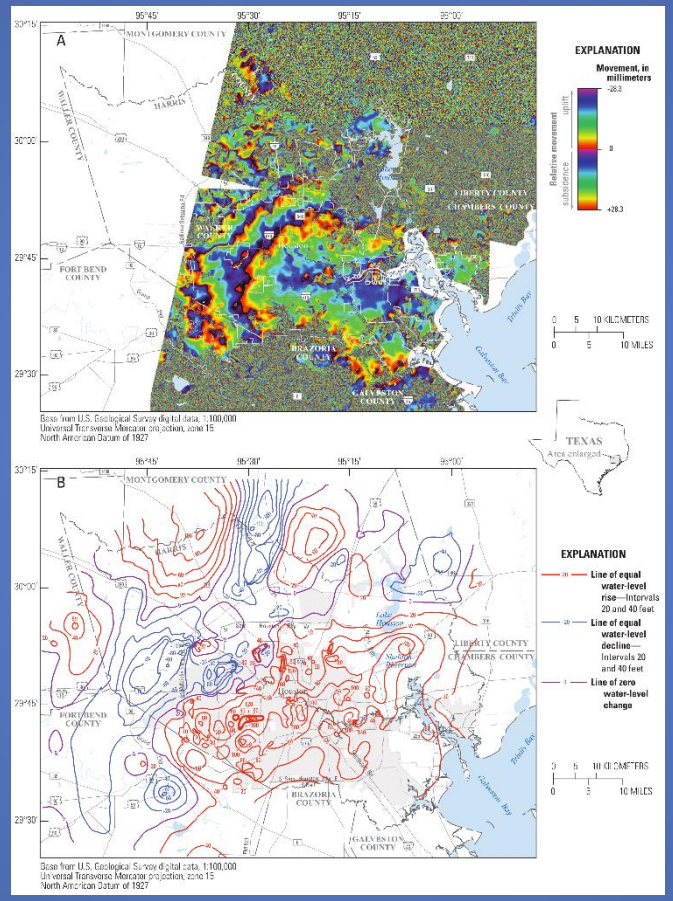
PAST STUDIES – REMOTE SENSING/SATELLITE IMAGERY



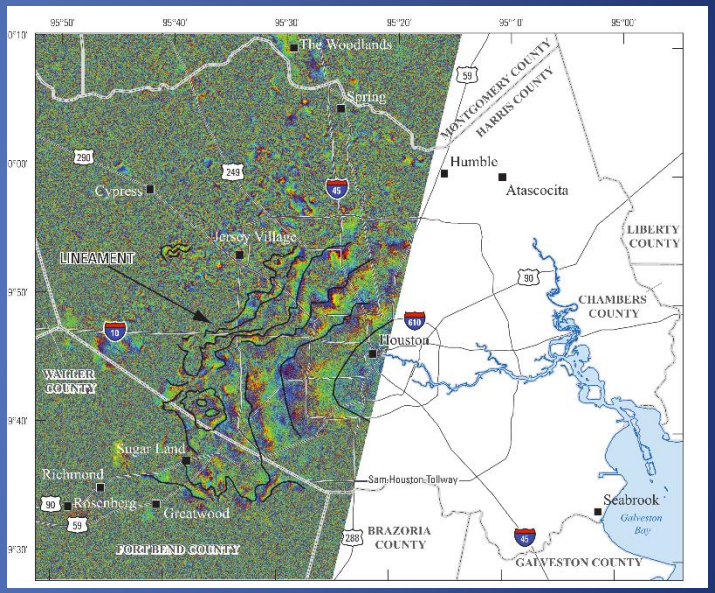
USGS SIR 2012-5211, Bawden



SMU Report (Qu, Zhong, Kim and Zheng, 2019)



USGS SIR 2012-5211, Bawden



USGS SIR 2012-5211, Bawden

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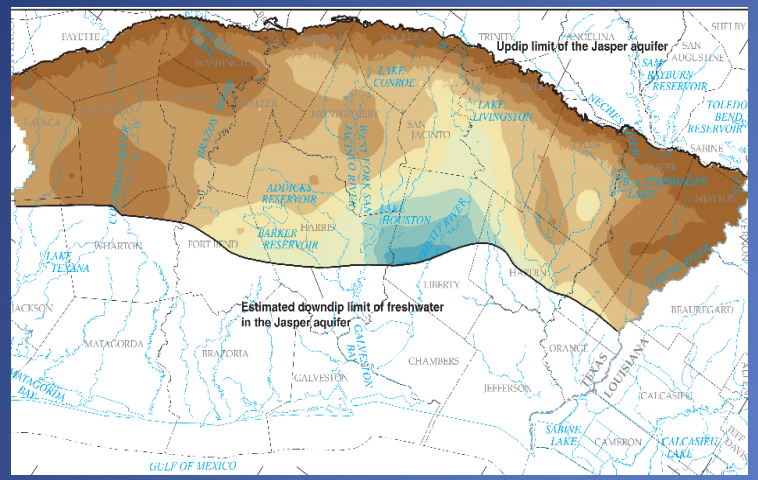
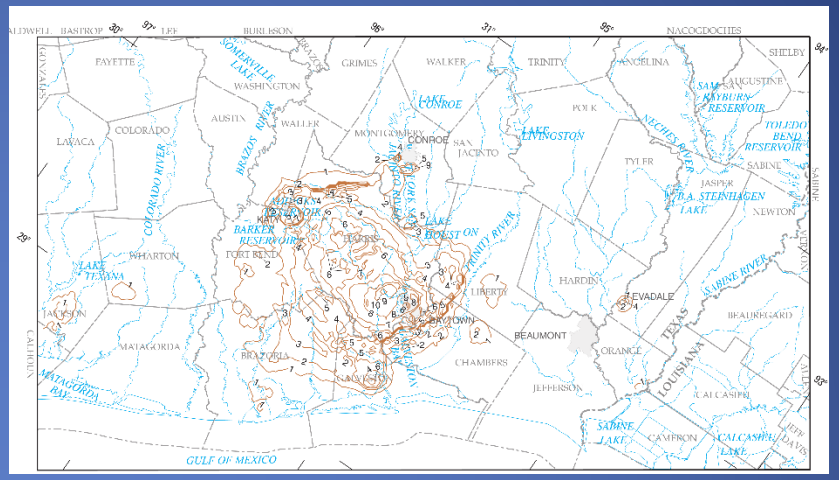
PAST STUDIES – LIDAR AND INSAR (REMOTE SENSING)

- LiDAR – used in several studies to identify growth faults and verify topography – usually smaller areas
- InSAR – recent studies – faults characterization and subsidence
- Relatively new – now getting enough coverage for comparisons over larger time periods
- Relatively inexpensive and very high spatial density
- SMU says new fault movement directly due to "…excessive groundwater exploitation from the Jasper aquifer in Montgomery County."
- Allows for expanded area of study (New HGSD Study)

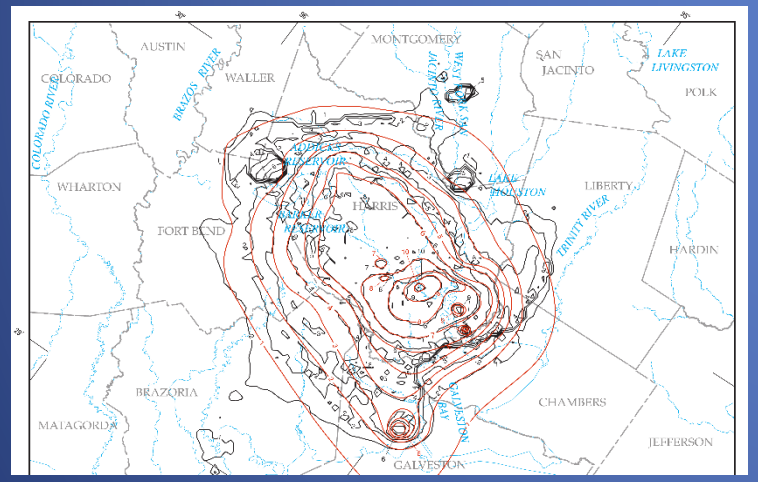
PAST STUDIES – MODELS



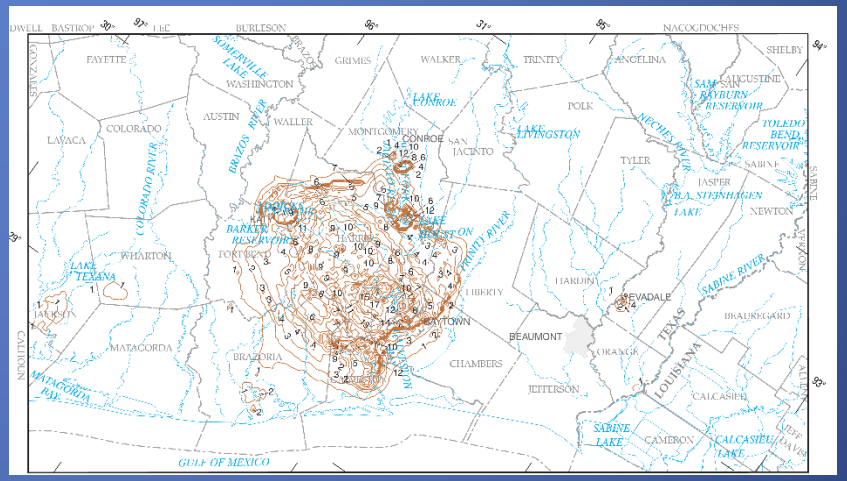
USGS – SIR 2004-5102



USGS – SIR 2005-5024



USGS – SIR 2004-5102



USGS – SIR 2005-5024

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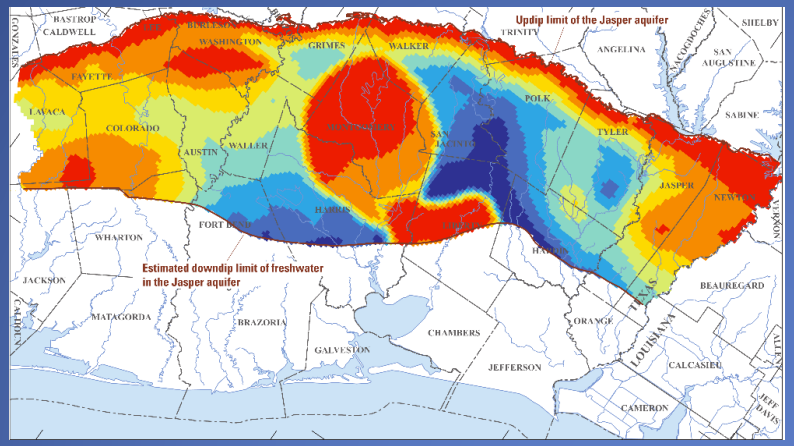
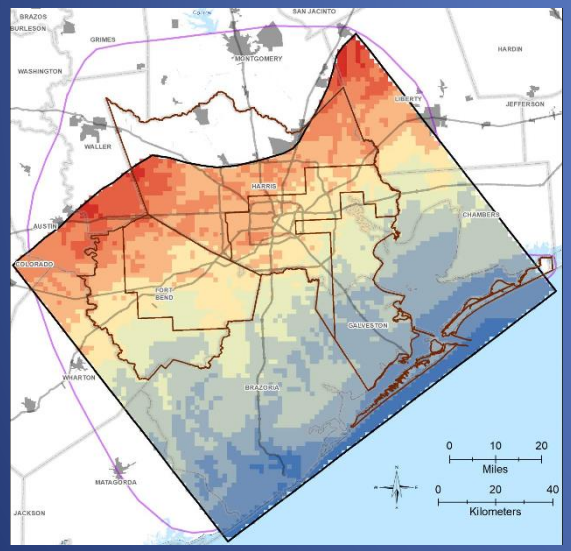
PAST STUDIES – MODELS

- Early Groundwater Flow Models
  - Focused in Harris/Galveston – Chicot (with Alta Loma) and Evangeline only
  - Assigned 50 percent compaction to each – Chicot and Evangeline
  - Clay thickness from CL of Evangeline to CL of Chicot
- PRESS Model
  - Site-by-site model developed in 1980s (EH&A); updated 1997 (Fugro/LBG)
  - Calculations correspond to measurements at extensometers
- Previous GAM (used for 2010 DFCs and MAGs)
  - Incorporated subsidence calculations for Chicot and Evangeline
  - "Compaction of clays in the Jasper aquifer and the Burkeville confining unit were not simulated because the sediments of those units are geologically older, more deeply buried, and therefore more consolidated relative to the sediments of the Chicot and Evangeline aquifers." (Kasmarek and Robinson, 2004)
  - Over-predicted subsidence in Montgomery County (see also 2005 report)

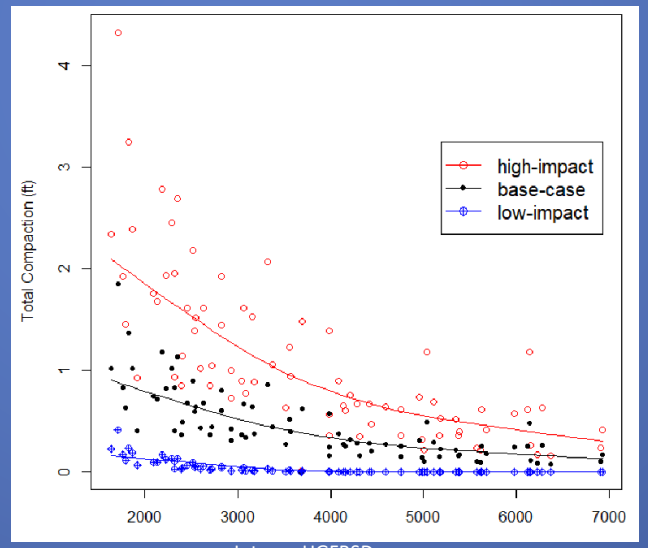
PAST STUDIES – ADDRESSING THE JASPER AQUIFER



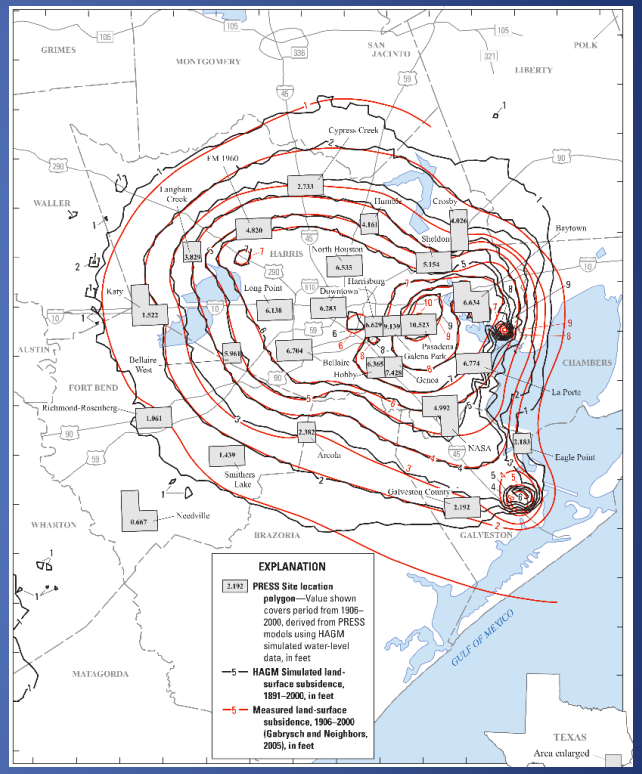
USGS – SIR 2012-5154



Intera Subsidence Risk Assessment



Intera - HGFBSD



USGS – SIR 2012-5154

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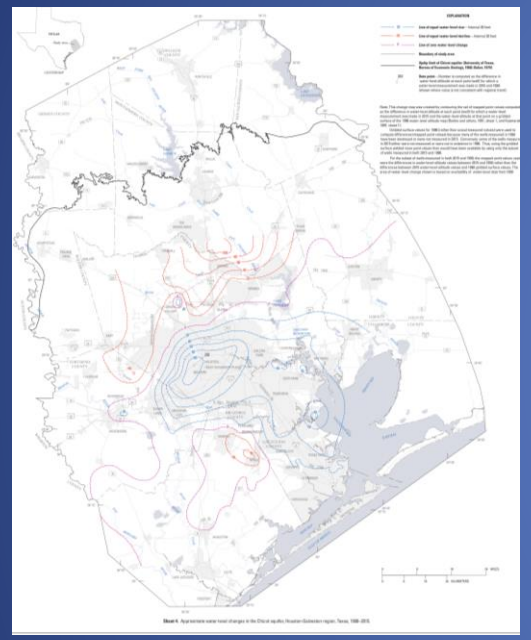
PAST STUDIES – ADDRESSING THE JASPER AQUIFER

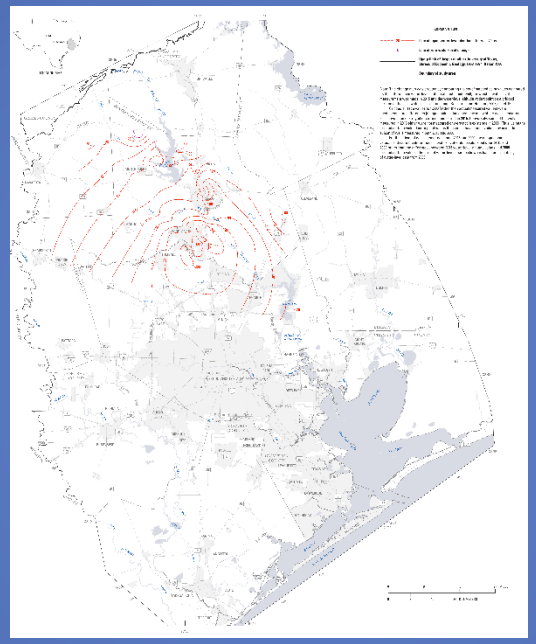
- The HAGM (Kasmarek, 2013)
  - Currently accepted GAM for GMA 14
  - Recognized change of pumping distribution
  - Simulates compaction in the Chicot, Evangeline, Burkeville and Jasper
  - Standard model limitations; some specific model design issues
  - Burkeville and Jasper inelastic-clay storativity is generally three orders and two orders of magnitude, respectively, less than the Chicot and Evangeline

- INTERA Study for HGSD
  - Provides "relative" risk assessment – range in possible compaction amounts
  - Used Chicot/Evangeline core results from Seabrook, Moses Lake, Baytown
  - Adjusted porosity, compressibility, specific storage and vertical hydraulic conductivity for depth of burial
  - Modeled 500 feet of pressure decline centered for 9 mile X 9 mile cells
  - Risk factors – Jasper compaction, depth (i.e., proxy) and flood plains

PAST STUDIES – WATER LEVELS AND PRODUCTION



USGS SIM 3337, Kasmarek



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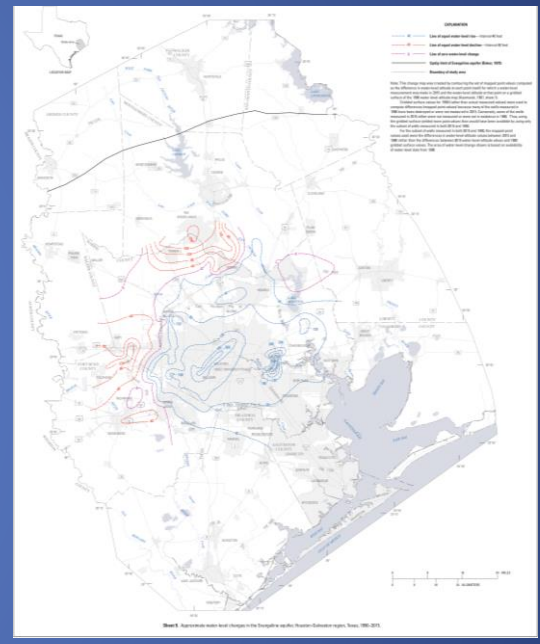

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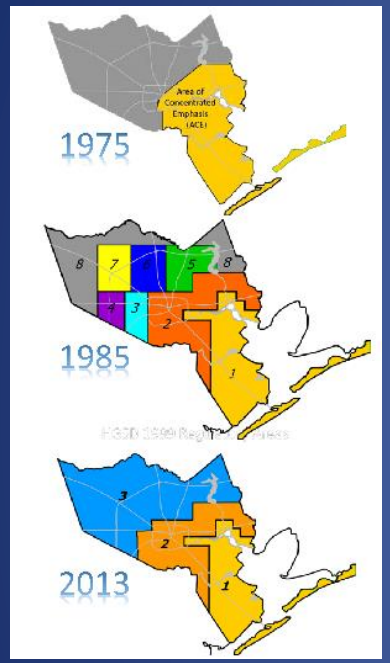
REGULATIONS AND MANAGEMENT



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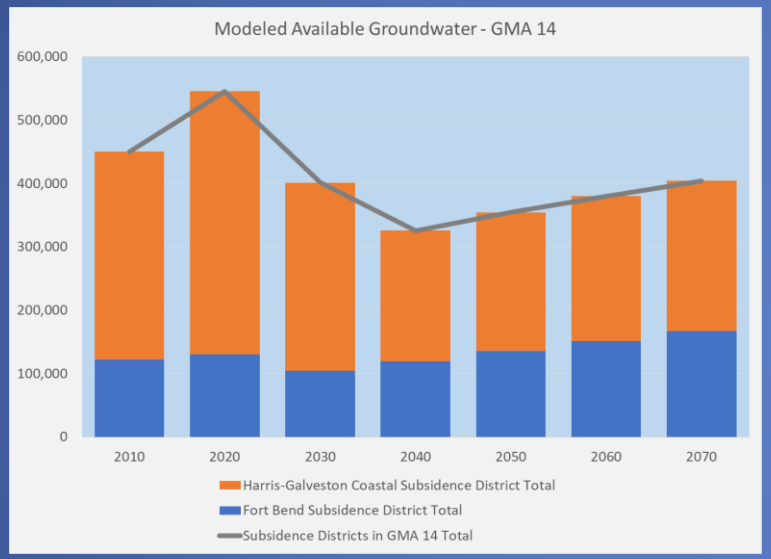
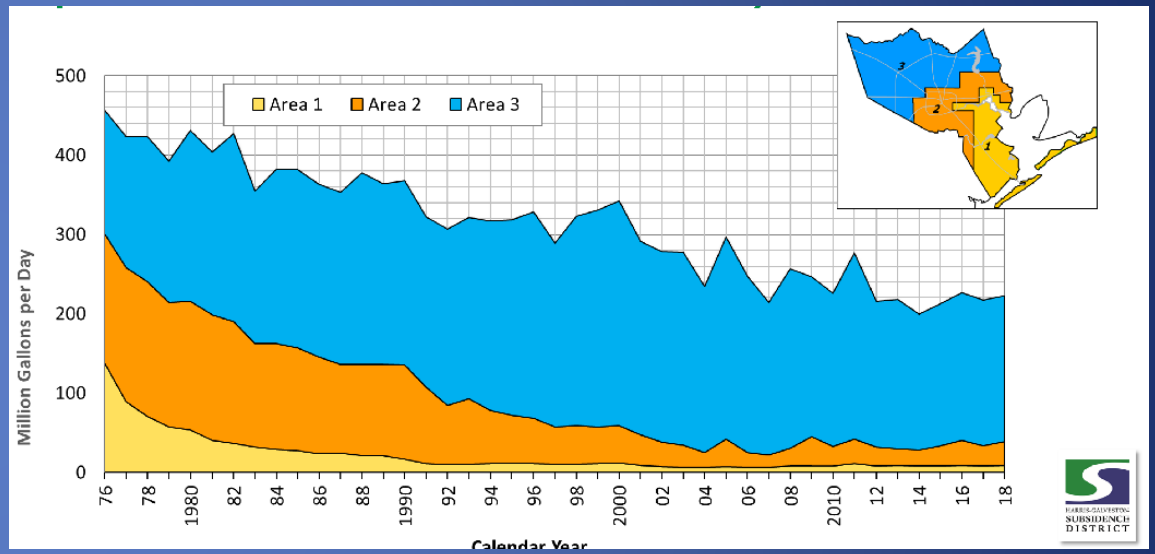


GMA-14 MAG



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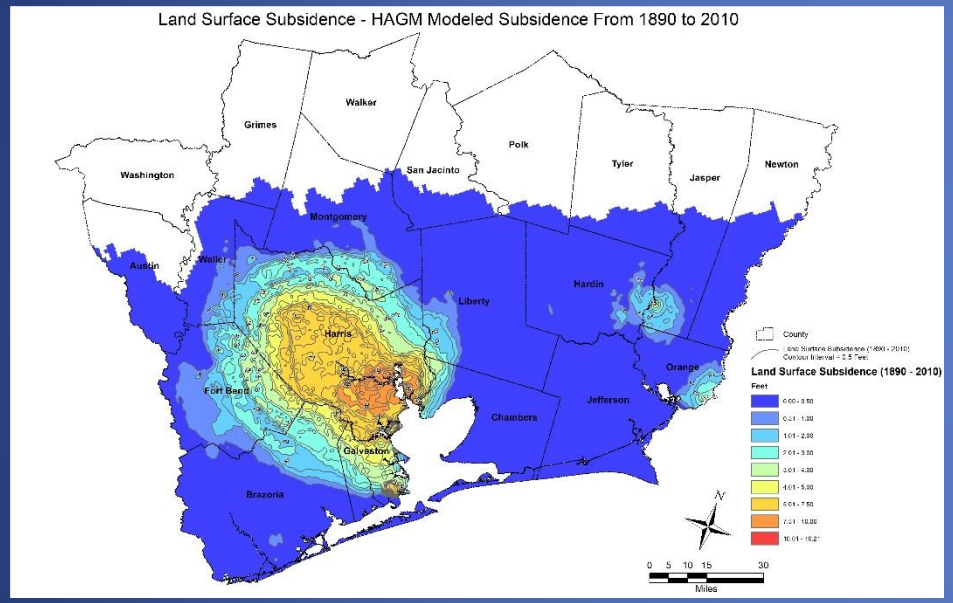
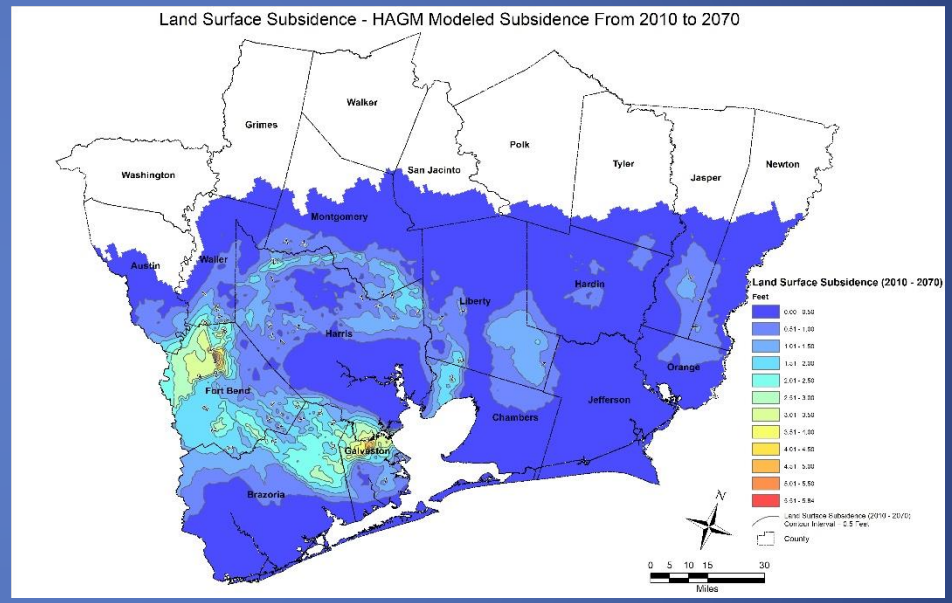
REGULATIONS AND MANAGEMENT

- Subsidence Districts
  - Not GCDs
  - Regulatory Plans – staged reductions in the allowable percentage of groundwater of the total water demands
    - Both HGSD/FBSD – 40% by 2025; 20% by 2035
- GCDs – Chapter 36 of the Texas Water Code (mostly) says to "control subsidence" – twice says "prevent subsidence"
- GMA 14
  - One district has subsidence DFCs – Bluebonnet GCD
  - Subsidence is statutorily mandated consideration in joint planning
  - HAGM is the currently accepted model by TWDB

OVERVIEW





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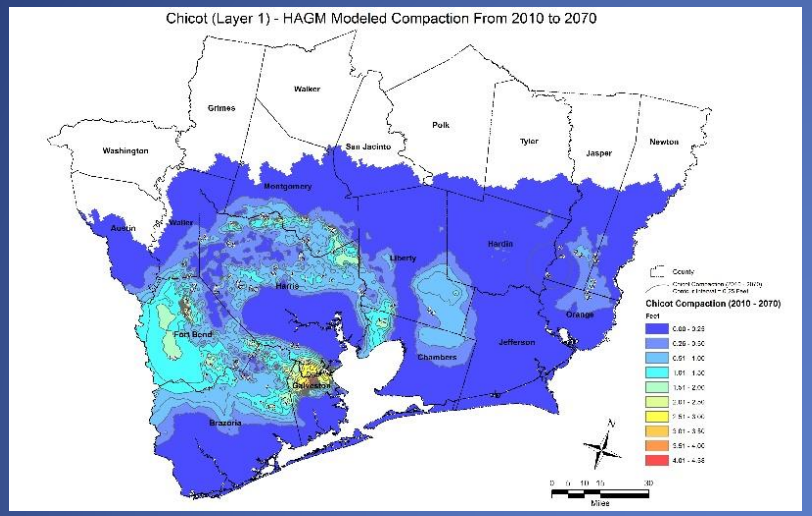

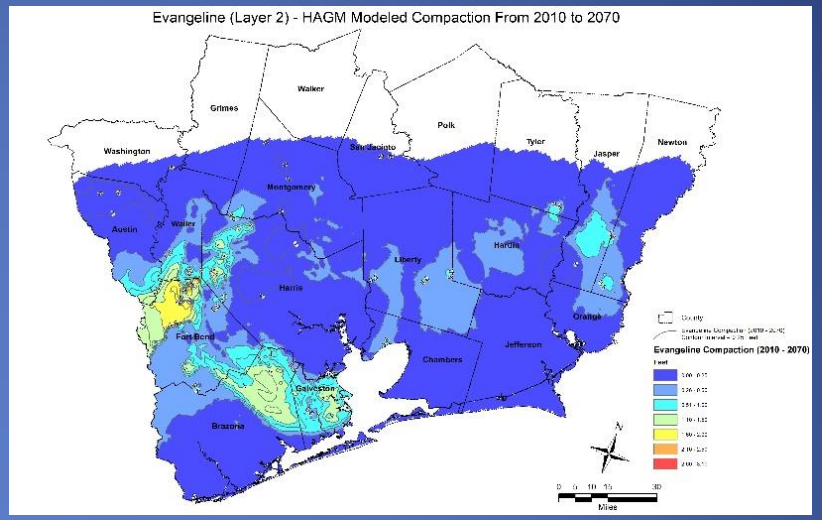

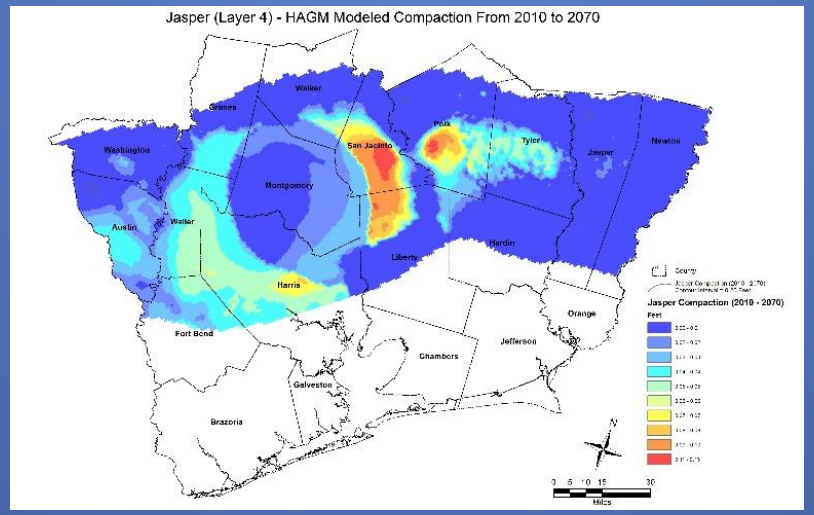

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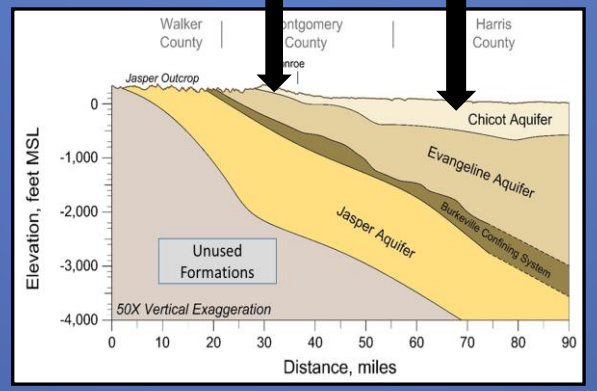

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OVERVIEW

- Subsidence recognized in Harris County since 1920s
- Studies have increased since the 1970s – subsidence and growth faults
- Subsidence varies with the age, character, thickness, depth of clay layers and the magnitude and timing of artesian pressure reduction
- Regulation and population growth/migration have resulted in subsidence essentially ceasing in some areas and increasing in others
- Good body of work done; however, there are many questions and specific considerations for Montgomery County that must be assessed
- We have compiled the background data and working knowledge to conduct detailed evaluations and assess previous conclusions

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FINISHING UP PHASE 1

- Stakeholders/Agencies Input
  - Particularly subsidence districts and USGS
  - Accuracy and make sure we have all data/information possible
  - Ongoing and planned future studies – GAM Update and InSAR Studies
  - Input for Phase 2
- Plan Phase 2 – Detailed Technical Evaluation of Data and Modeling
  - Address specific issues related to Montgomery County
  - Verify and/or correct some data, information and/or representation
  - Develop analyses of distributions of subsidence as related to three-dimensional aquifer/clay conditions and distribution (in space and time) of pumping
- Final Report and Presentation