Thank you for joining us today for the **Joint Regulatory Plan Review Stakeholder Meeting**

All participants have been joined in “listen only” mode.

For meeting audio, you can use your microphone and speakers (VoIP) or call in using your telephone at **877-309-2074.**
Access code: **802-557-536**

If you are having technical difficulty, please send a message to staff in the chat or email *HgGoToMeetings@subsidence.org*

Before we Begin

This webinar is scheduled for two hours. We have left time for questions.

All participants will be muted during the presentation

Questions can be submitted via the Go To Webinar "Questions" screen at any time.

This webinar is being recorded

We will post slides on our website after the meeting today

2023 Joint Regulatory Plan Review

Stakeholder Meeting 5

14 December 2021

Keys Stakeholder Engagement Opportunities

Meeting attendance and project awareness

Providing data for technical analyses

Providing feedback on draft material

Participate in targeted outreach efforts

1 Develop Population and Demand Projections

Develop projections of population and water demand over a ten-county area through the year 2100.

2 Conduct Alternative Water Supply Assessment

Review alternative water supplies for the capability of reducing future groundwater demand.

3 Develop the Gulf Coast Land Subsidence and Groundwater Flow Model

Development of the GULF-2023 model for simulating regional groundwater flow and subsidence in the Gulf Coast Aquifer.

4 Evaluate Regulatory Scenarios

Evaluate the performance of the HGSD and FBSD regulatory plans and consider refinements to the regulatory plan framework to accommodate future growth, alternative water supplies, and the most recent aquifer science.

Cindy Ridgeway

- TWDB

John Ellis

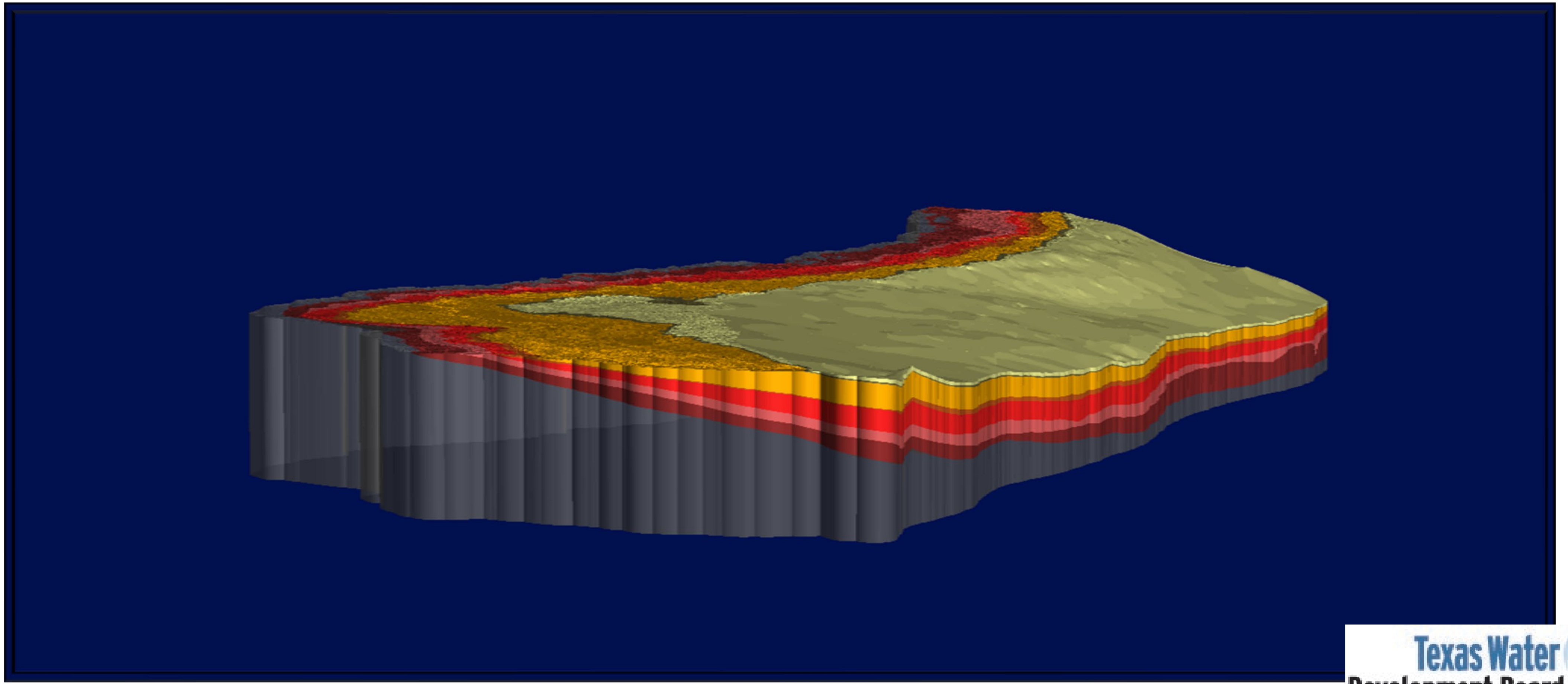
- USGS

Project Elements

Groundwater Availability Modeling

GULF 2023 Model Preliminary Findings

GROUNDWATER AVAILABILITY MODELING



Groundwater Availability Modeling

In Statute: Develop groundwater flow models for the major and minor aquifers of Texas.

Purpose: Tools that can be used to aid in groundwater resources management by stakeholders.

Public process: Stakeholder involvement during model development process.

Models: Freely available, standardized, thoroughly documented. Reports available over the internet.

Living tools: Periodically updated.

Texas Water Development Board

Purpose of Stakeholder Meetings

- Opportunity for input and data to help with model development
- Updates on model progress
- Providing feedback on draft material
- Learn how to best use model & model limitations

GROUNDWATER AVAILABILITY MODELING

Cindy Ridgeway, P.G.

Manager of Groundwater Availability Modeling Section

512-936-2386

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Texas Water Development Board

P.O. Box 13231

Austin, Texas 78711-3231

Web information:

www.twdb.texas.gov/groundwater/models/gam/

Project Elements

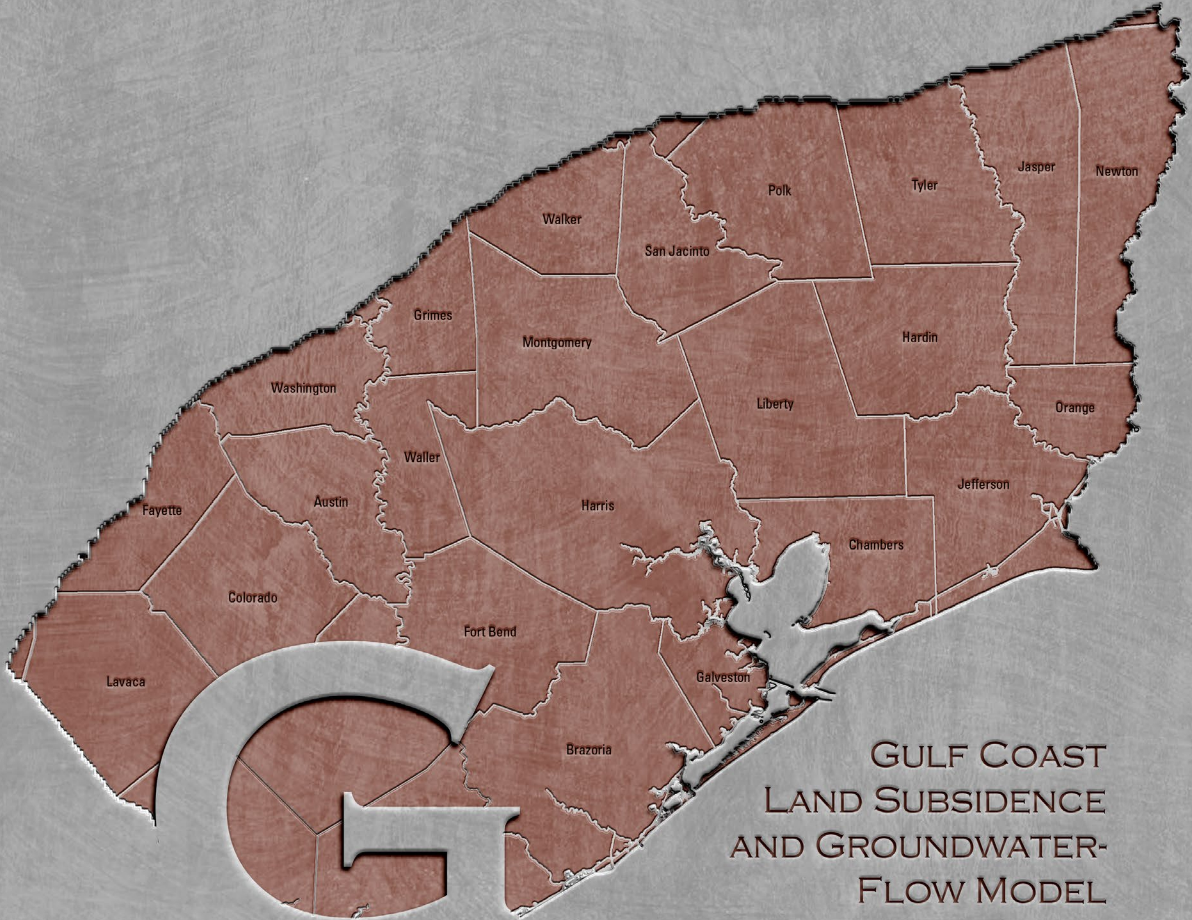
Groundwater Availability Modeling

GULF 2023 Model Preliminary Findings

USGS
science for a changing world

Harris-Galveston Subsidence District

Fort Bend Subsidence District



Gulf Coast
Land Subsidence
and Groundwater-
Flow Model

GULF

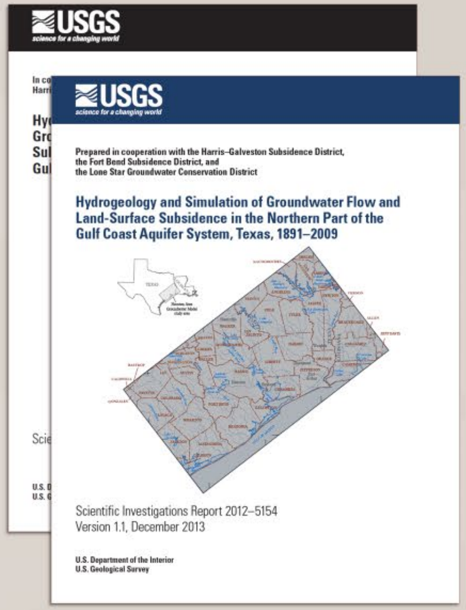
2023

Joint Regulatory Plan Review

John Ellis
jellis@usgs.gov

In cooperation with the
Harris-Galveston and Fort
Bend Subsidence Districts

Overview

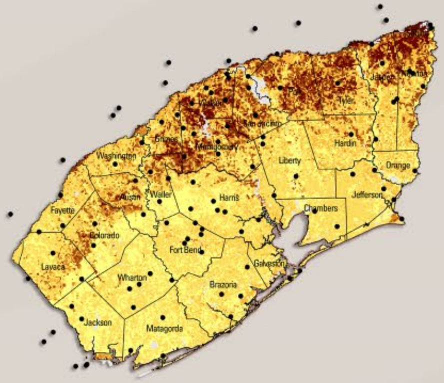

USGS
science for a changing world

Prepared in cooperation with the Harris–Galveston Subsidence District, the Fort Bend Subsidence District, and the Lone Star Groundwater Conservation District

Hydrogeology and Simulation of Groundwater Flow and Land-Surface Subsidence in the Northern Part of the Gulf Coast Aquifer System, Texas, 1891–2009

Scientific Investigations Report 2012–5154
Version 1.1, December 2013

U.S. Department of the Interior
U.S. Geological Survey

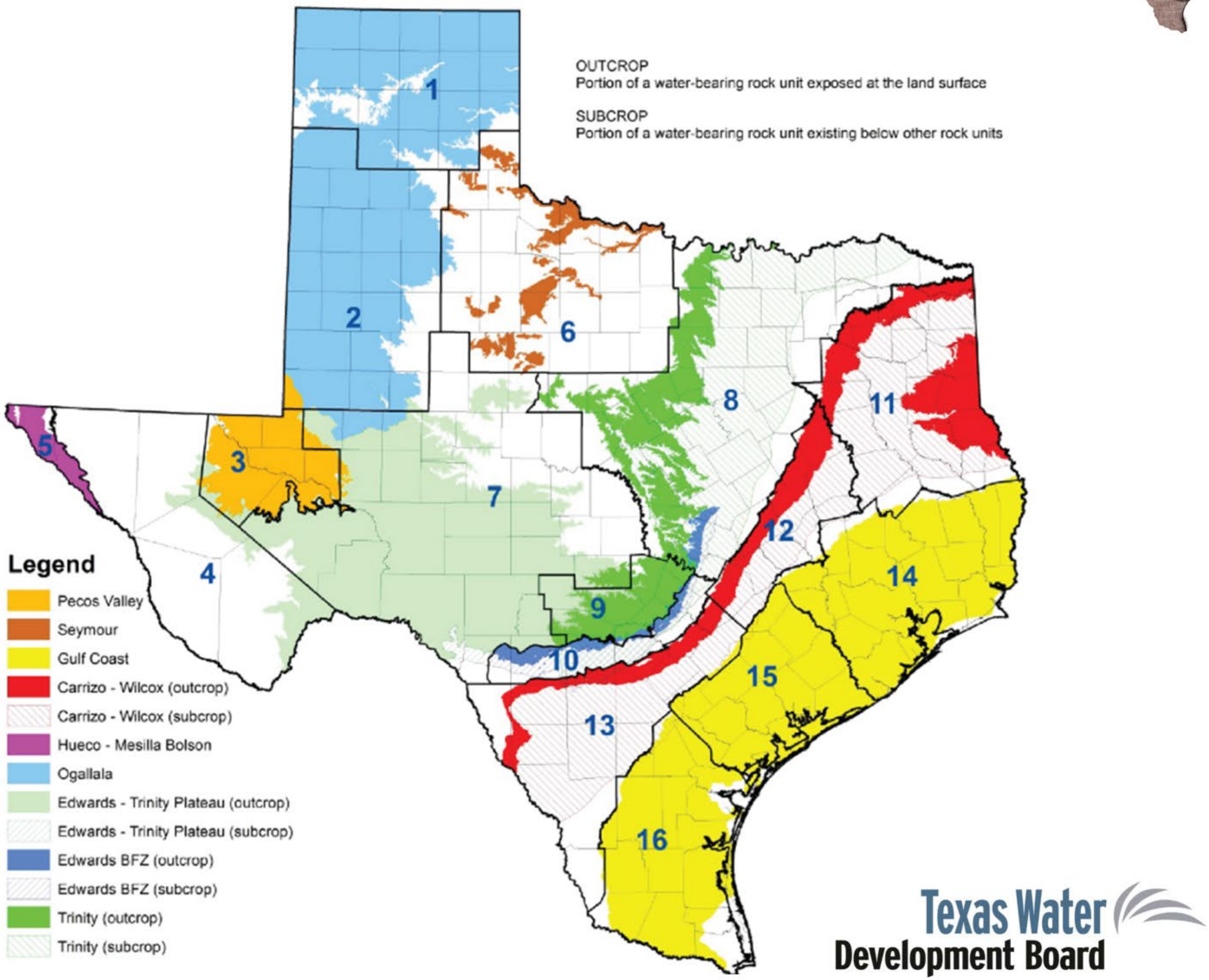


Cooperators	Purpose: HAGM update	CLAS model refinement	Modeling advances

Overview

Groundwater-flow definitions

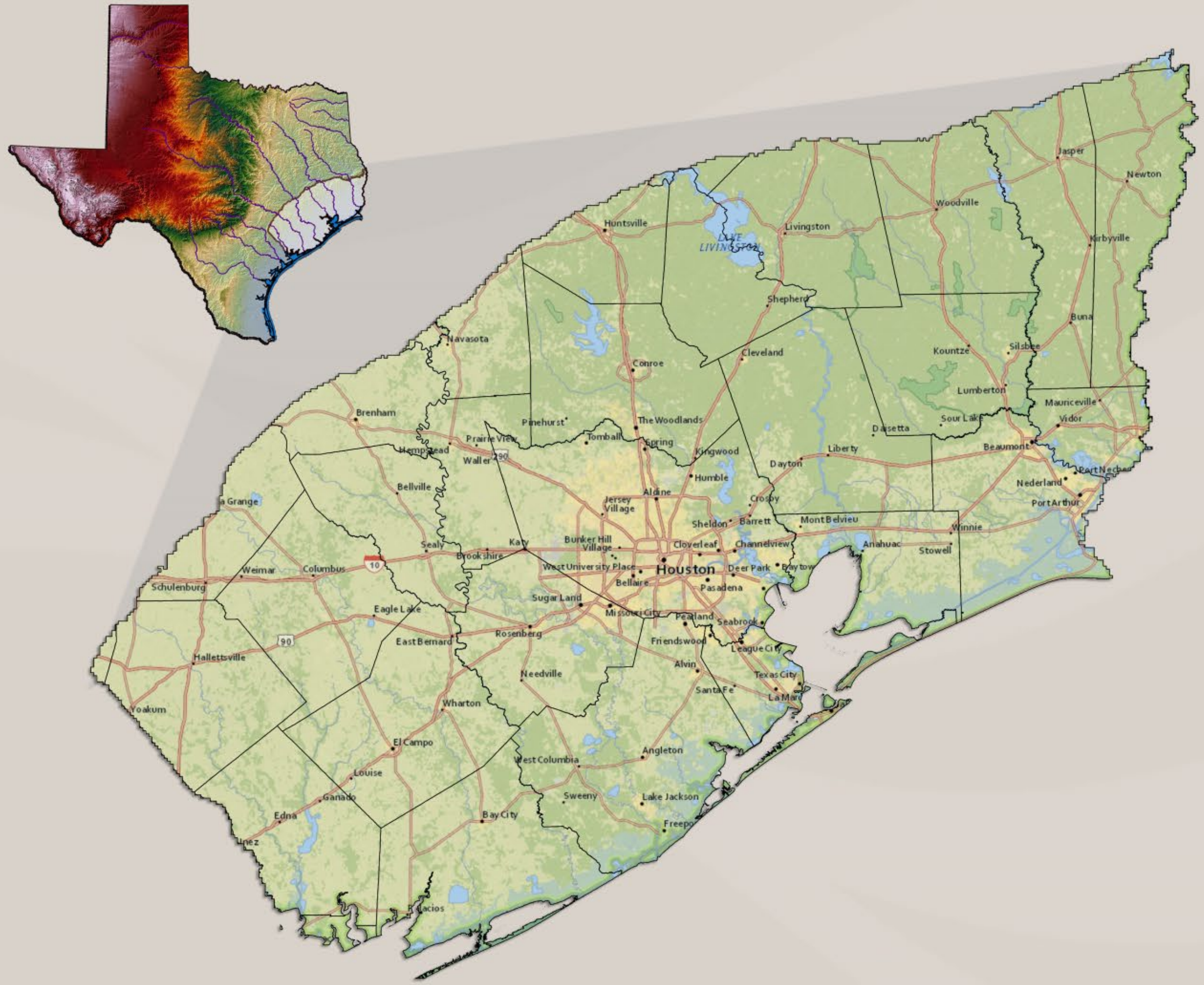
- Aquifer: Water saturated permeable geologic unit that can transmit significant quantities of water
- Water table: The level at which water stands in a shallow screened well in an unconfined aquifer
- Recharge: The entry of water to the saturated zone at the water table
- The primary observable quantity describing groundwater flow is the water level as measured in a well



Study Area

Spatial extent

- Northern boundary corresponds with the upgradient extent of the Catahoula outcrop
- Eastern extent is the TX—LA border (Sabine River)
- Western extent is Lavaca and Jackson Counties
- Southern boundary is nearshore area (to 10 miles offshore—not shown)
- Barrier islands removed in model (shown here and subsequent slides)



Hydrogeology

Geologic classification[1]			Published geologic and hydrogeologic units									Units from this report[2]	
System	Series	Geologic unit	Rose (1943)	White and others (1944)	Lang and others (1950)	Wood and Gabrysch (1965)	Turcan and others (1966)	Jorgensen (1975)	Baker (1979)	Carr and others (1985)	Kasmarek and Strom (2002)	Hydrogeologic	Geologic
Quaternary	Holocene	Alluvium				Confining layer, Alta Loma Sand[3]	Chicot aquifer	Chicot aquifer (upper part)	Chicot aquifer	Chicot aquifer	Chicot aquifer	Chicot aquifer	Alluvium
	Pleistocene	Beaumont Formation		Zone 6	Beaumont Formation								Beaumont Formation
		Lissie Formation: Montgomery Formation			Alta Loma Sand			Chicot aquifer (lower part)					Lissie Formation
		Lissie Formation: Bentley Formation											
		Willis Sand	Zones 6–7[4]		Zones 6–7[4]								Willis Sand
Tertiary	Pliocene	Goliad Sand	Zones 3–5	Zones 3 and 5	Zones 3–5	Heavily pumped layer	Evangeline aquifer	Evangeline aquifer	Evangeline aquifer	Evangeline aquifer	Evangeline aquifer	Evangeline aquifer	Goliad Sand (upper part)
													Goliad Sand (lower part)
	Miocene	Fleming Formation / Lagarto Clay	Zone 2	Zone 2	Zone 2	Zone 2	Burkeville confining unit	Burkeville confining unit	Burkeville confining unit	Burkeville confining unit	Burkeville confining unit		Lagarto Clay (upper part)
												Burkeville confining unit	Lagarto Clay (middle part)
							Jasper aquifer					Jasper aquifer	Lagarto Clay (lower part)
		Oakville Sandstone	Zone 1	Zone 1[5]	Zone 1	--[6]		Jasper aquifer (upper part); Jasper aquifer (upper part)	Jasper aquifer	--[7]	Jasper aquifer		Oakville Sandstone
	Oligocene	Frio Formation			Catahoula Formation		Unnamed aquiclude[8]	--[9]	Catahoula confining system	--[7]	--[10]	Catahoula confining unit	Frio Formation
		Vicksburg Formation											Vicksburg Formation

Model Configuration

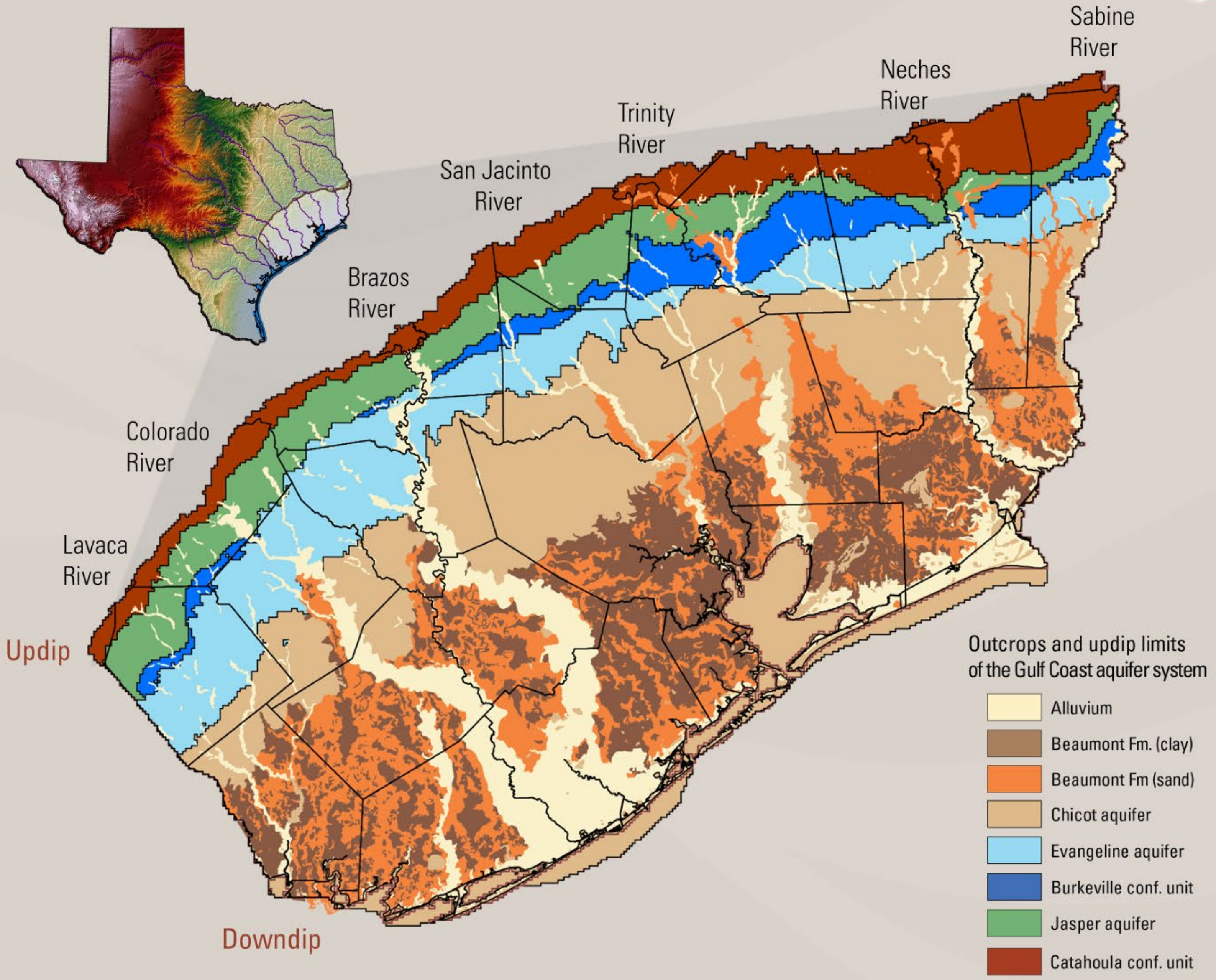
Model layering

- Layer 1: Alluvium and Beaumont Clay
- Layer 2: Chicot Aquifer
- Layer 3: Evangeline Aquifer
- Layer 4: Burkeville Confining Unit
- Layer 5: Jasper Aquifer
- Layer 6: Catahoula Formation

Model time discretization

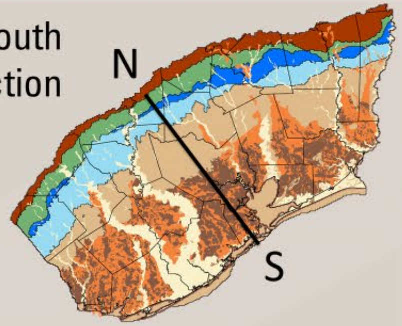
- 1896: 1 (Predevelopment)
- 1897–1939: 3 (about 14 years each)
- 1940–1969: 6 (5 years each)
- 1970–1999: 30 (annual)
- 2000–2018: 228 (monthly)

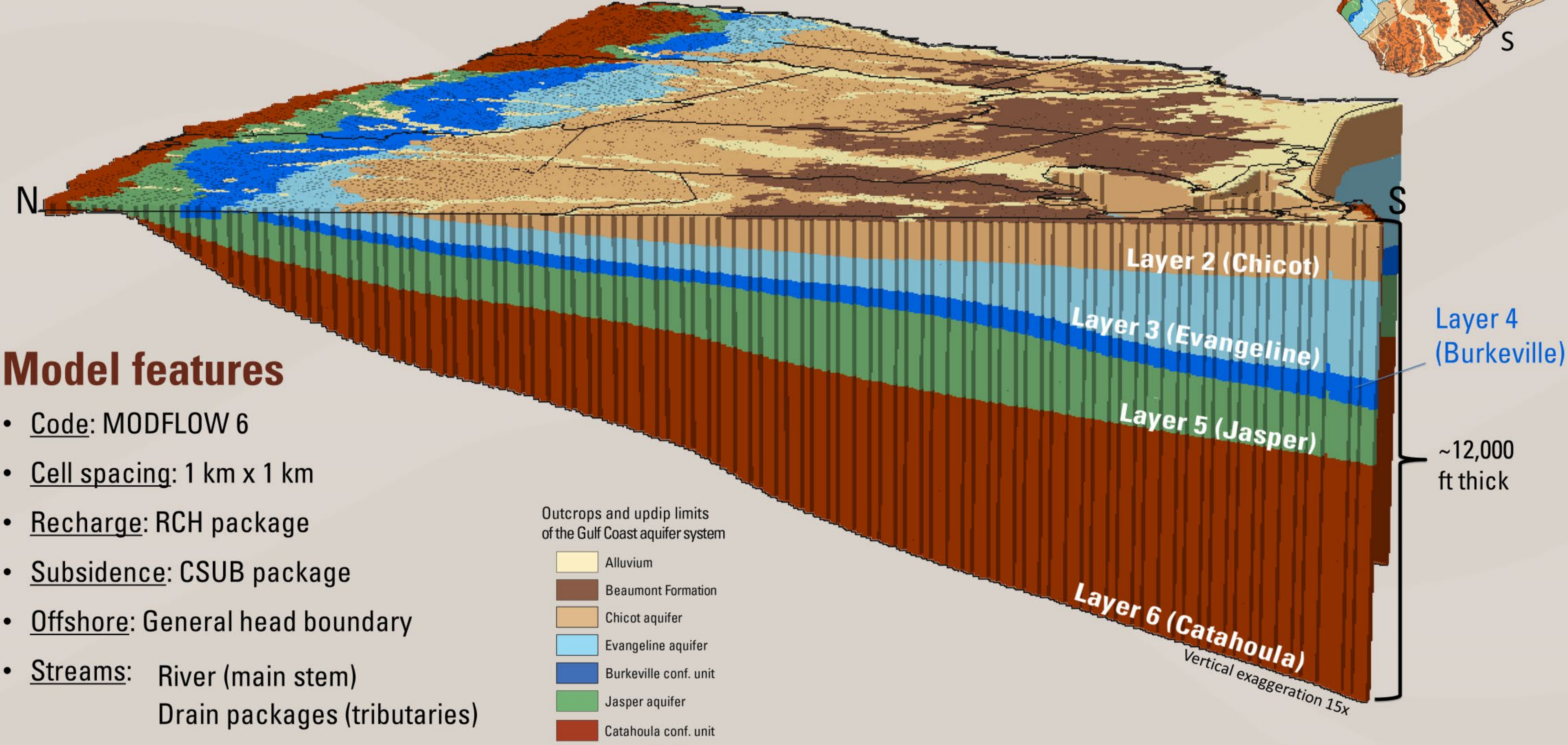
268 total



USGS science for a changing world
HARRIS-GALVESTON SUBSIDENCE DISTRICT
FORT BEND SUBSIDENCE DISTRICT

Model Configuration





Model features

- Code: MODFLOW 6
- Cell spacing: 1 km x 1 km
- Recharge: RCH package
- Subsidence: CSUB package
- Offshore: General head boundary
- Streams: River (main stem)
  Drain packages (tributaries)

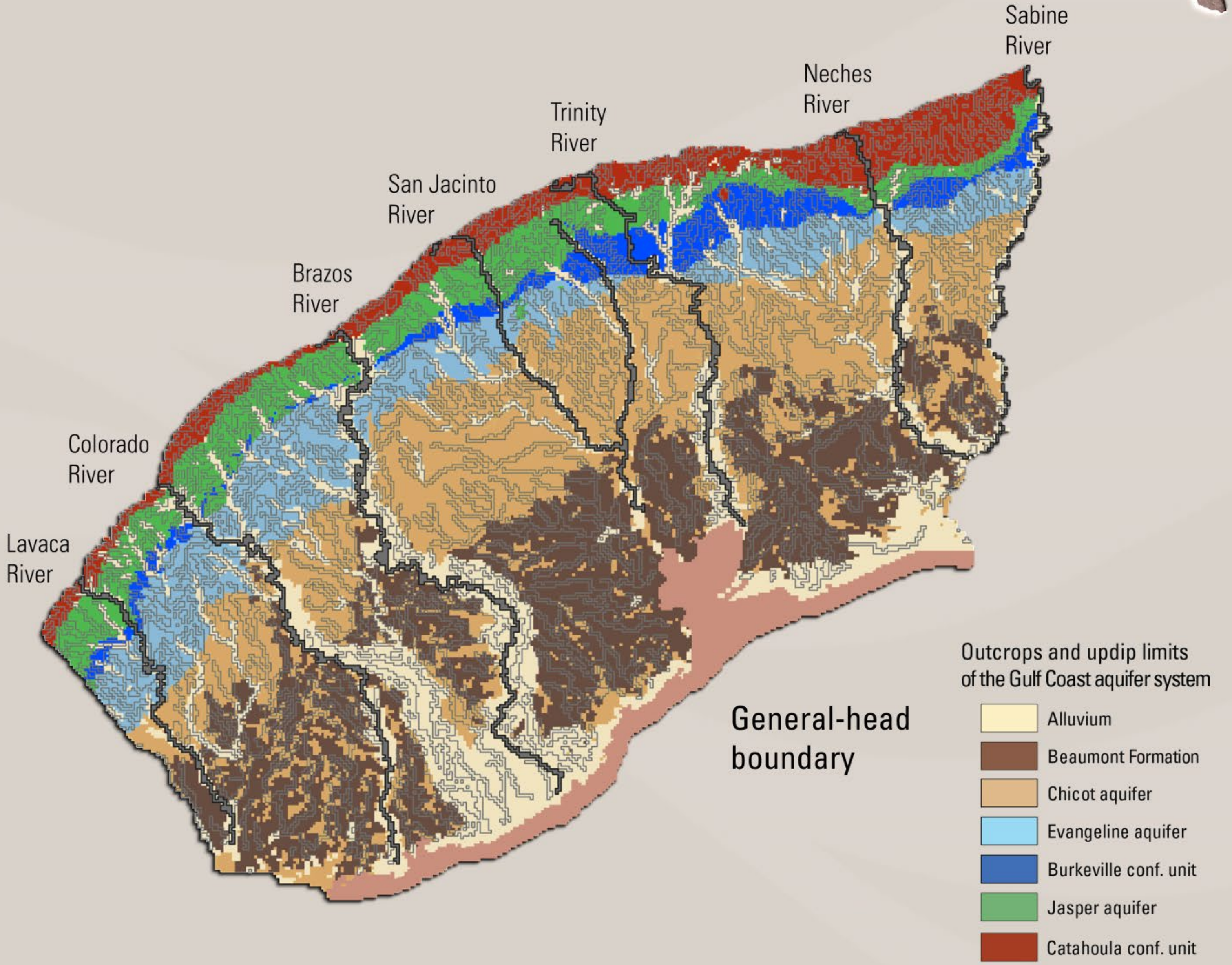
Model Features

Model-area rivers

- Used to route surficial recharge that does not enter the deep system
- River package[1]: used for 7 major rivers (dark shading)
- Drain package[1]: used for named tributary streams (light shading)

General-head boundary

- Simulates offshore area in layer 1 of the model
- GHB cells at downdip model limit in each layer

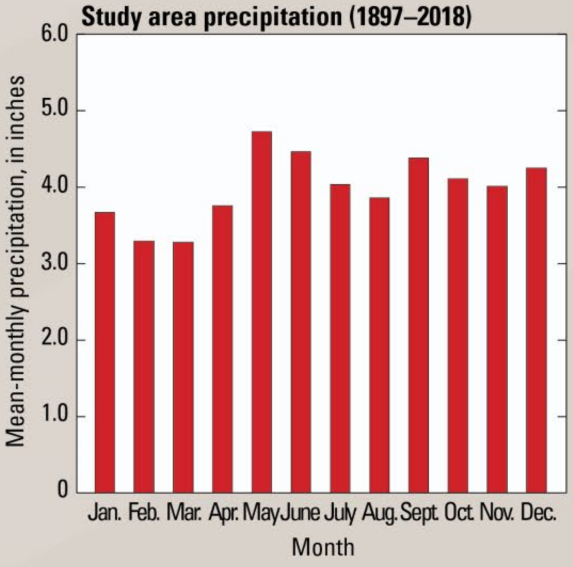


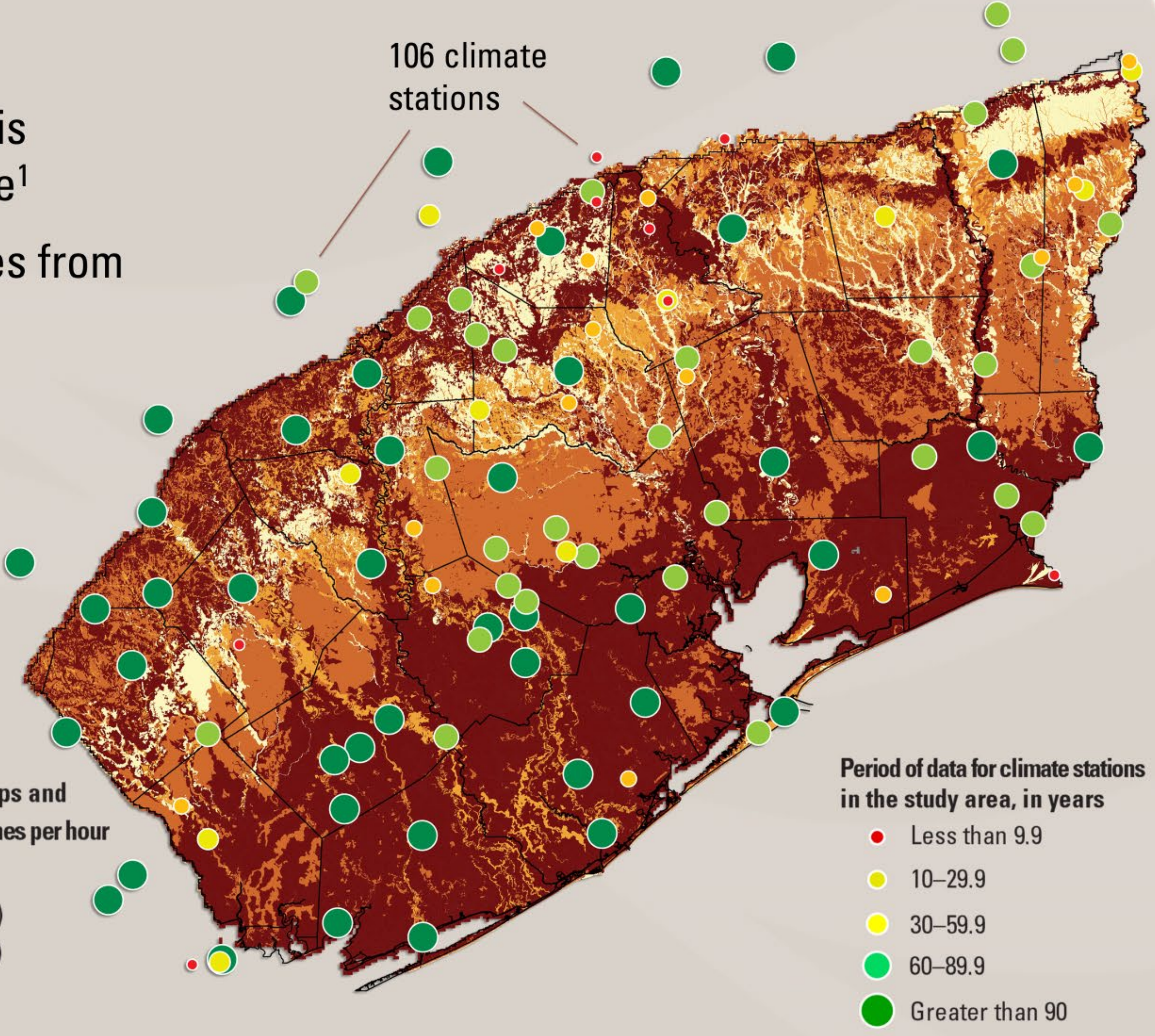
[1]Langevin and others, 2017

Model Features

Recharge

- Can use many different methods to estimate. This project used the USGS Soil-Water-Balance code[1]
- Climate data obtained from NOAA, soil properties from NRCS.





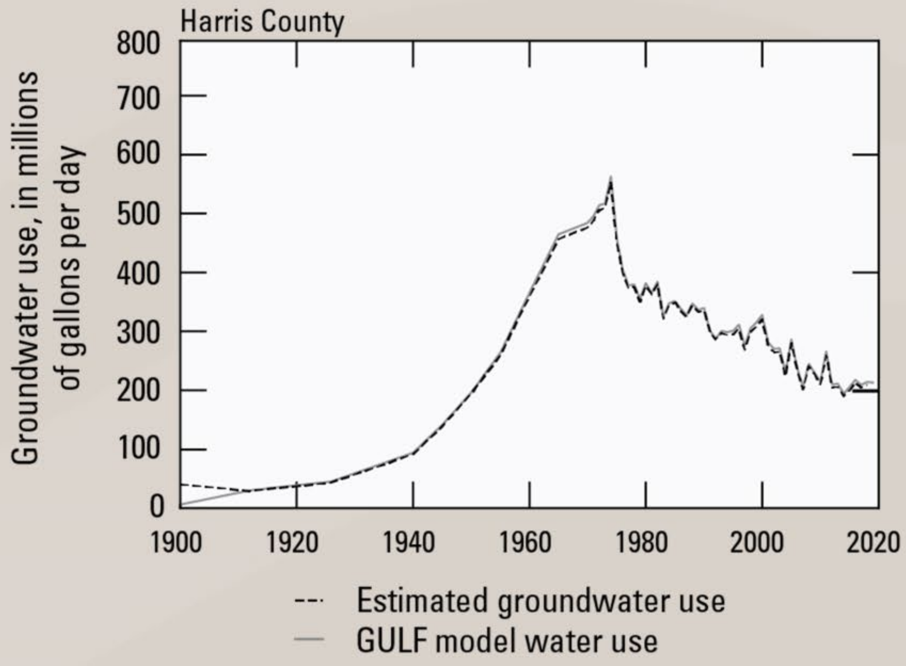
[1]Westenbroek and others, 2010

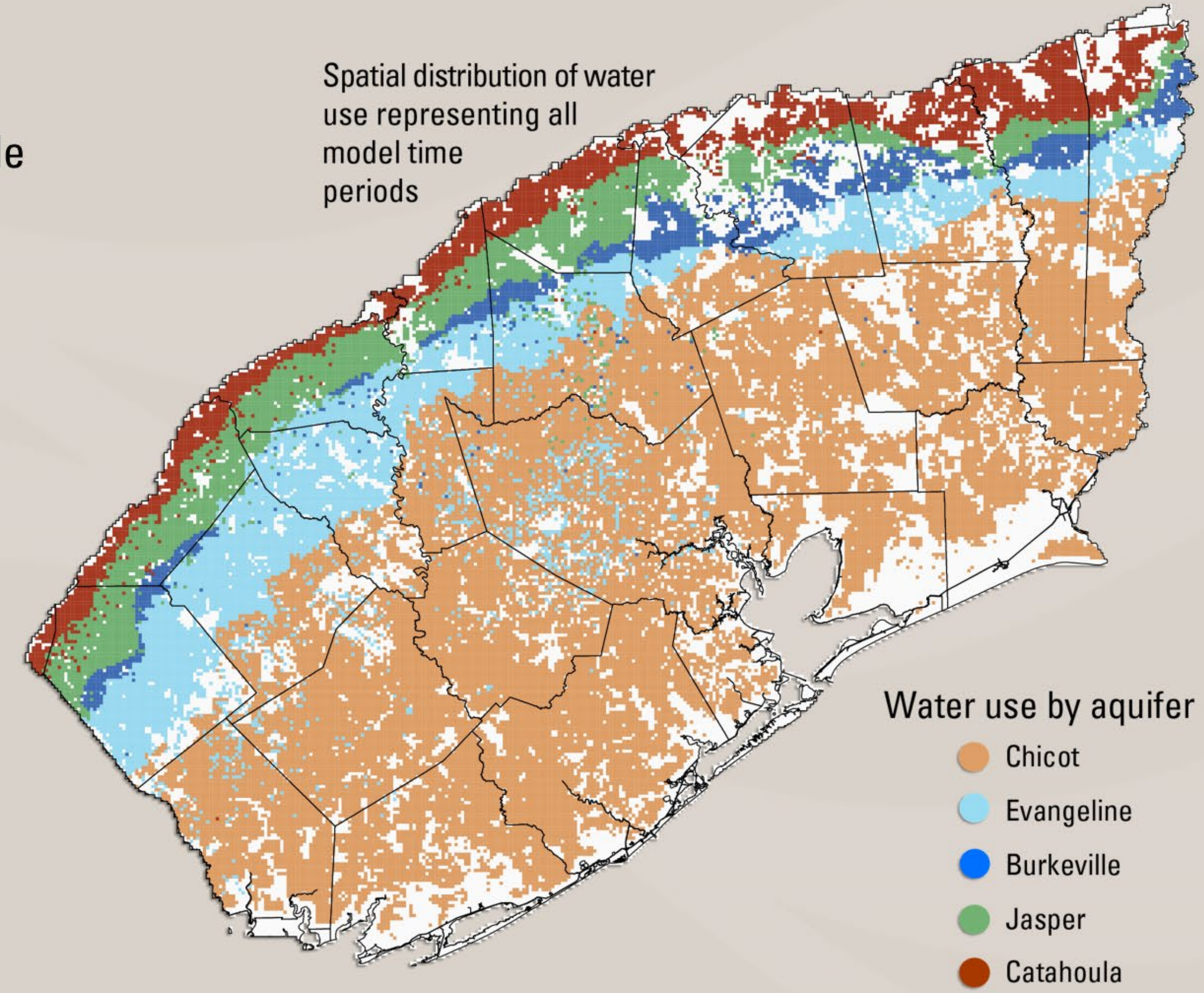
USGS science for a changing world
Harris-Galveston Subsidence District
Fort Bend Subsidence District

Model Features

Groundwater use

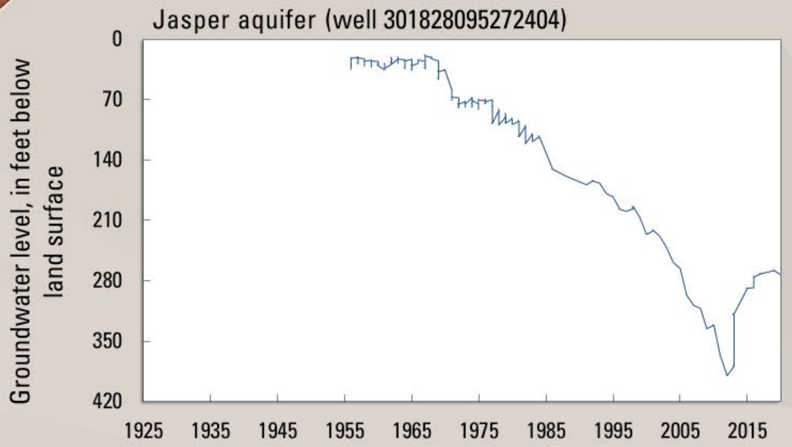
- Groundwater use from Oliver and Harmon (2021)
- To account for uncertainty in estimates, an adjustable range is used during model calibration

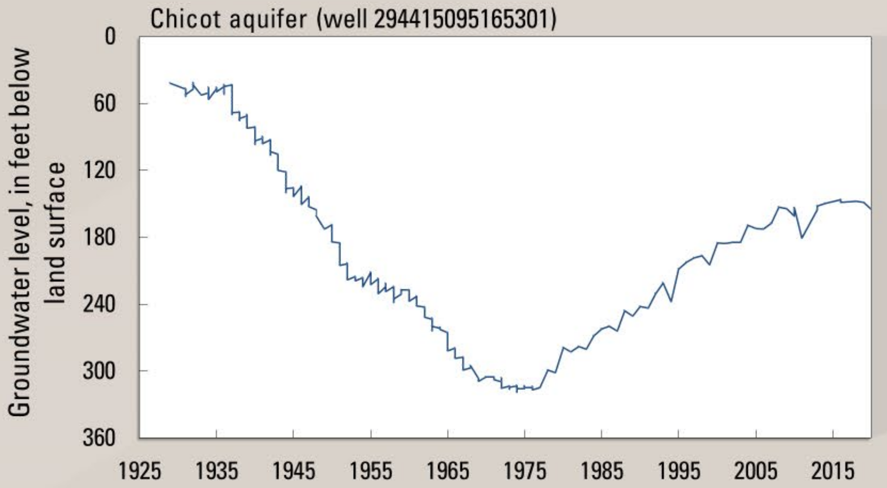


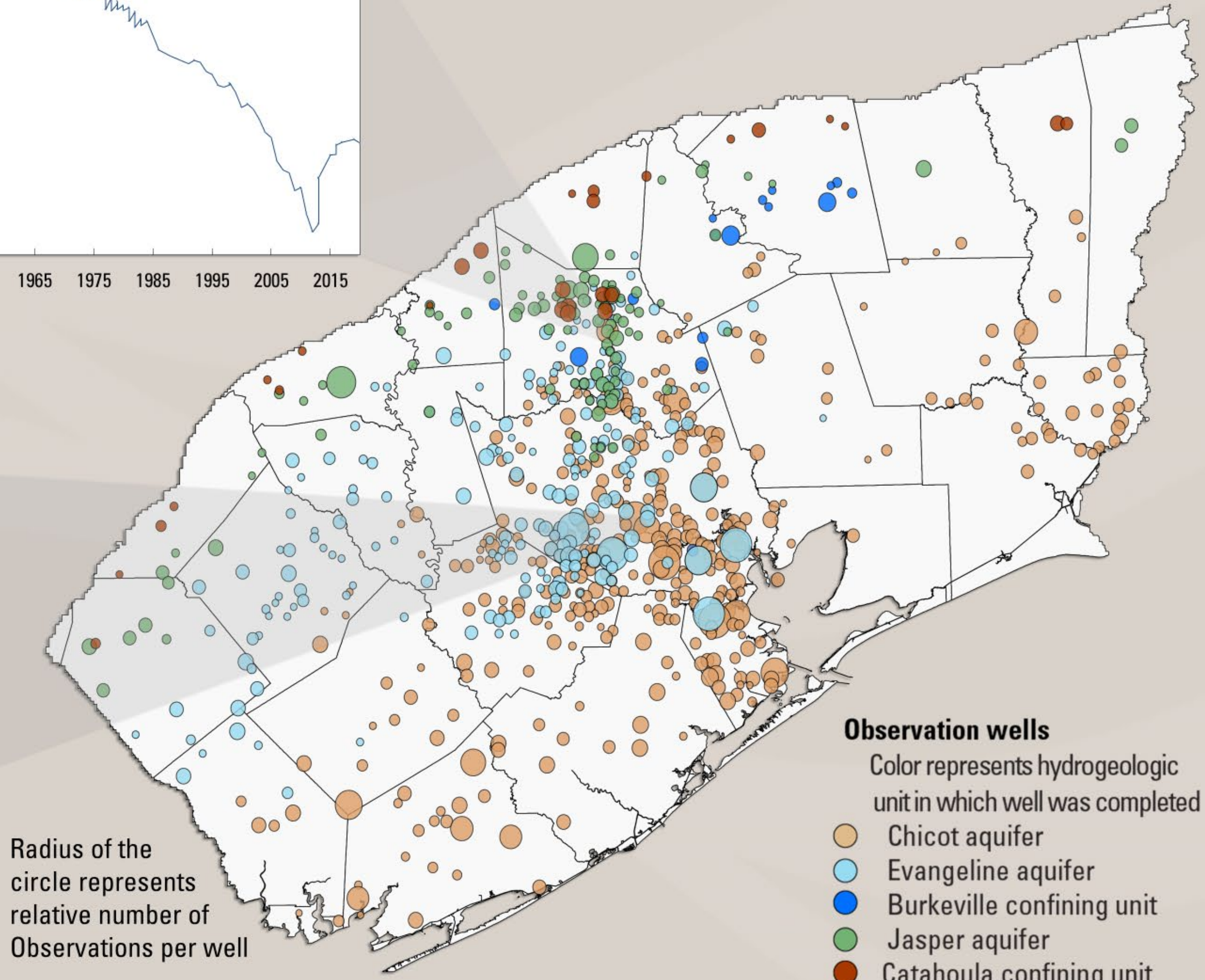


Groundwater Levels

- Changes in groundwater levels occur because of changes in the volume of water stored in the aquifer
- The U.S. Geological Survey, the Texas Water Development Board, and others monitor groundwater levels in the study area



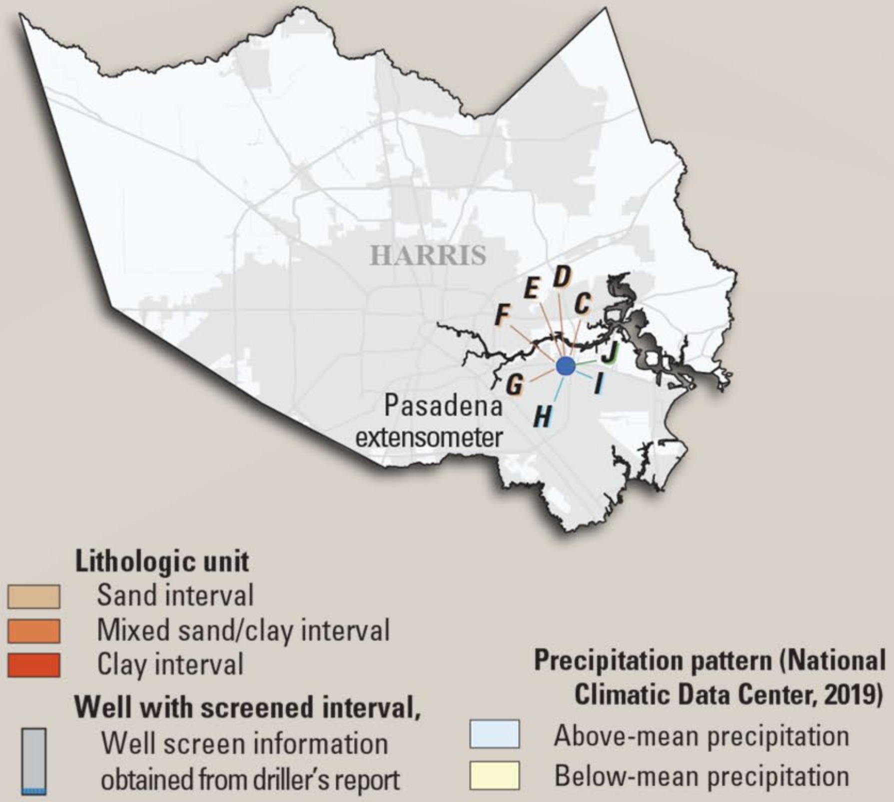


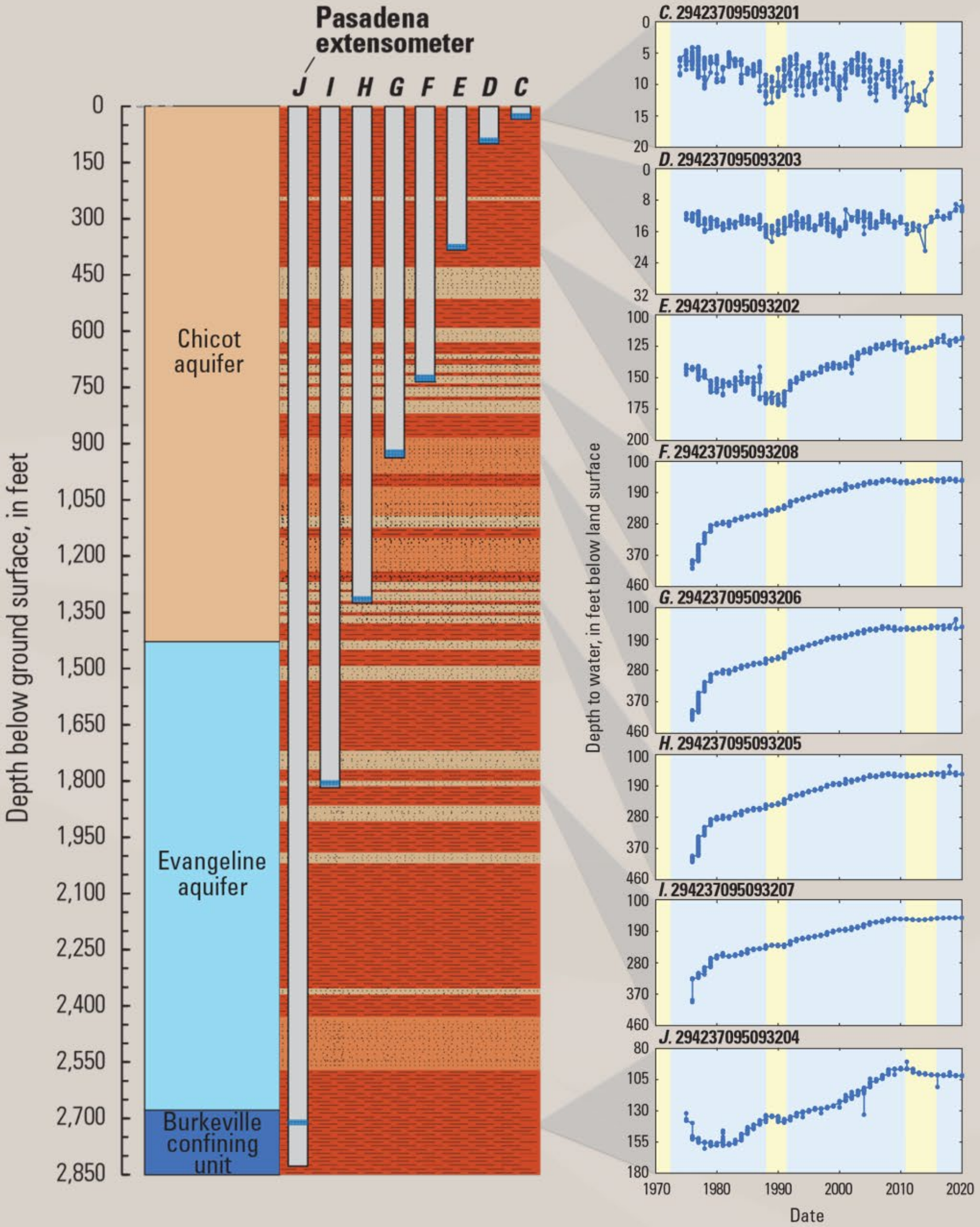


Co-located Groundwater Levels

Pasadena extensometer

- Substantial degree of similarity between groundwater levels across 1,400 feet vertically
- Similarity of groundwater levels at different depth intervals observed as far back as 1937

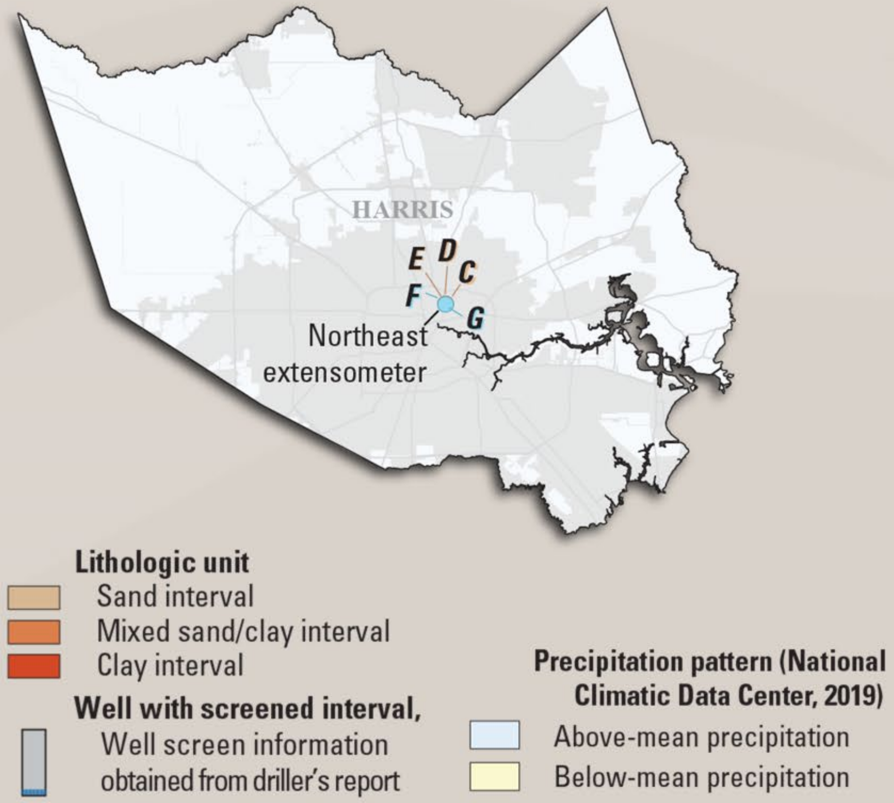


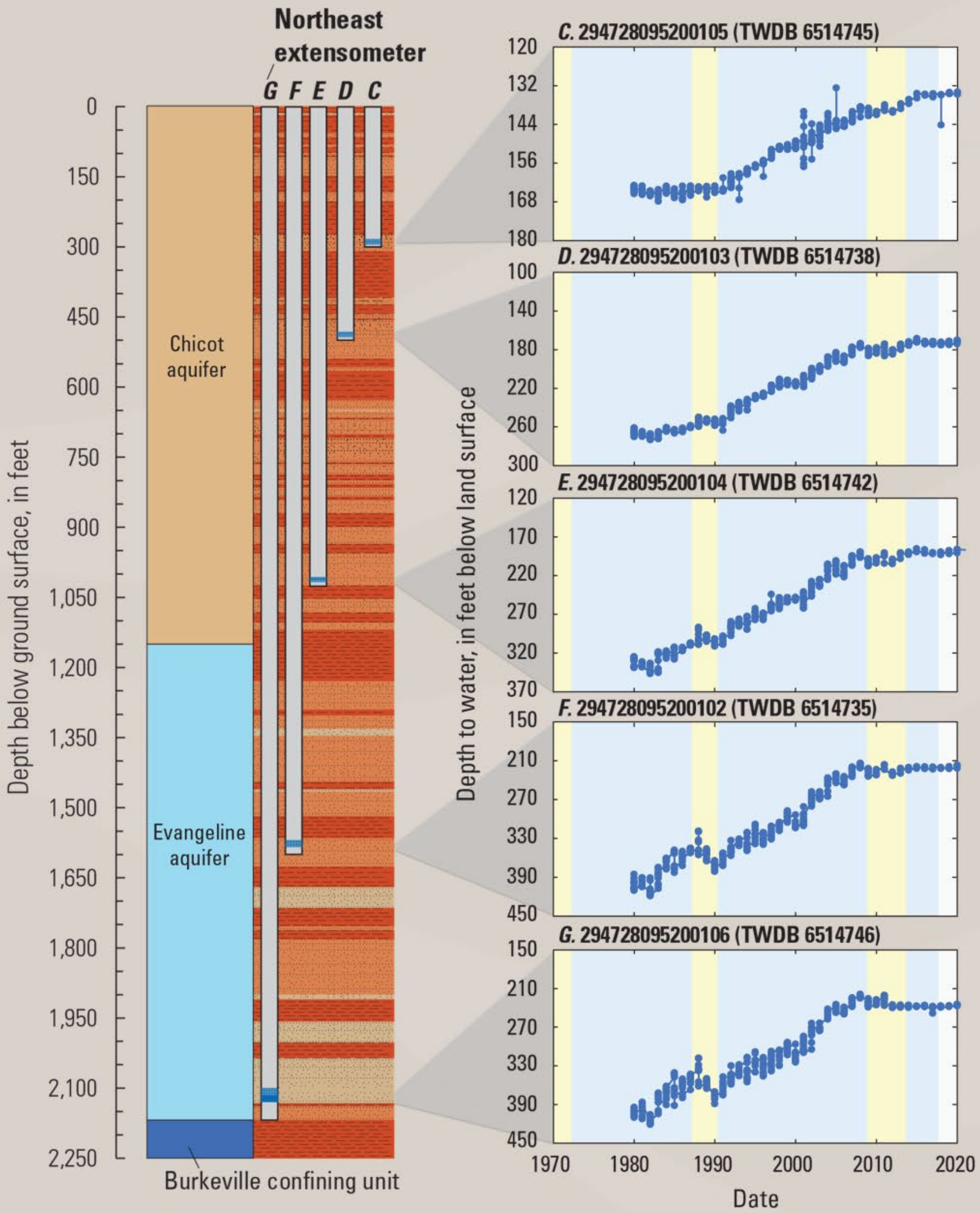


Co-located Groundwater Levels

Northeast extensometer

- Substantial degree of similarity between groundwater levels across 1,800 feet vertically
- Recovery of groundwater levels after a reduction in groundwater use, but not to predevelopment levels

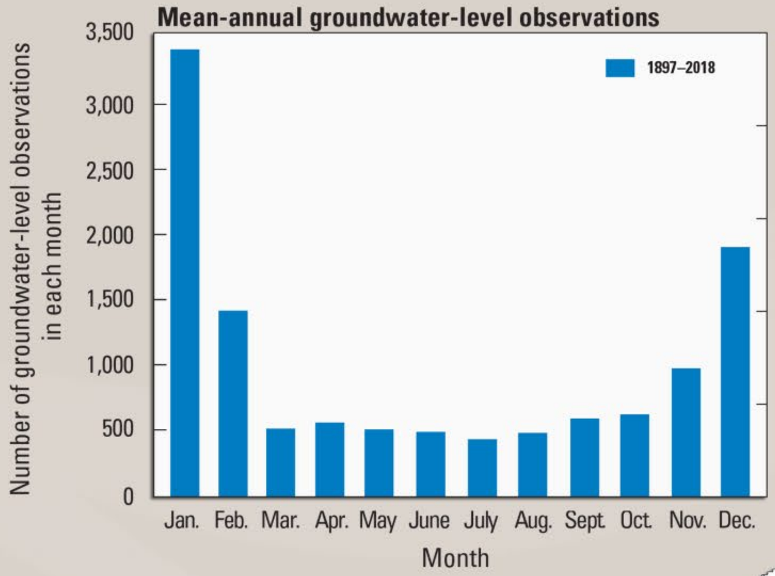


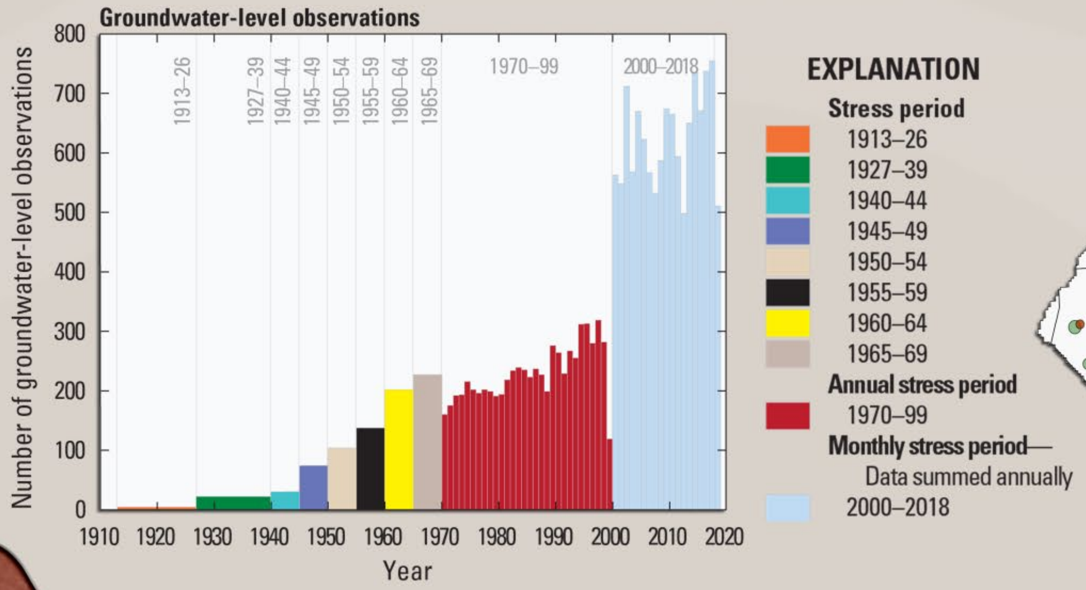


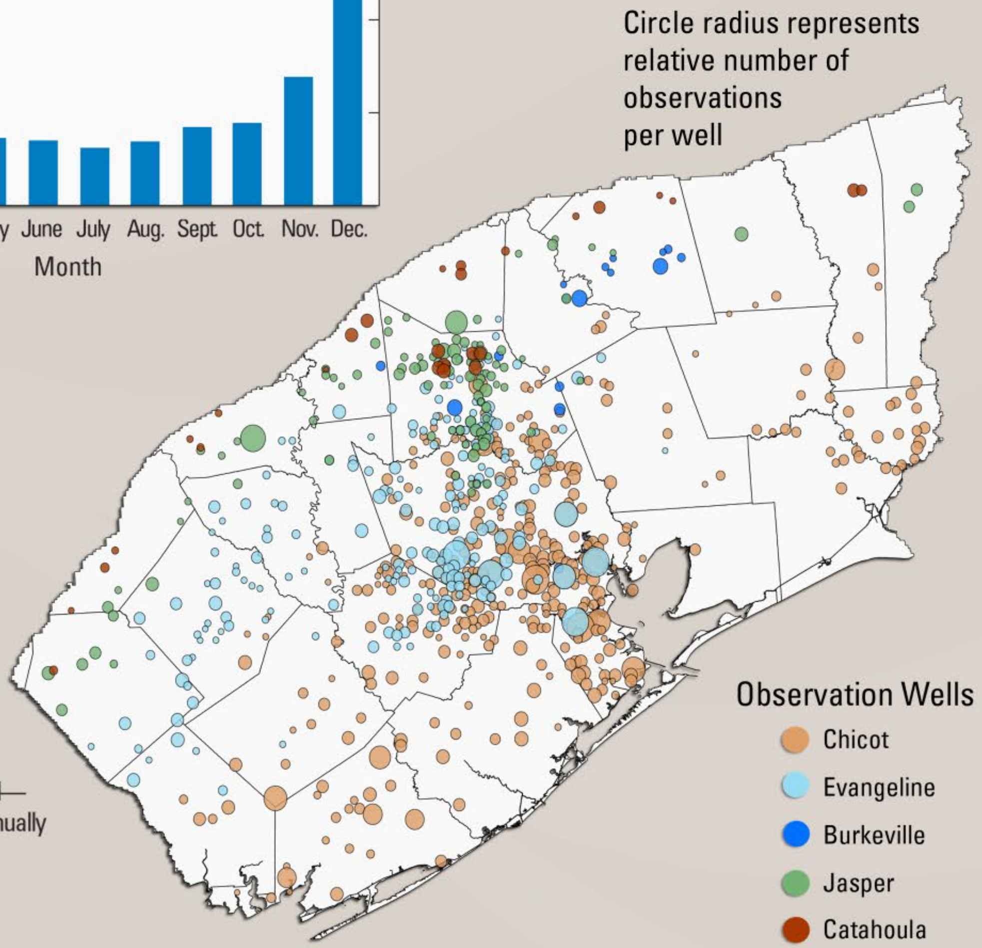
Model Features

Groundwater levels

- Greater number of groundwater levels through time as monitoring in the study area has increased
- Most groundwater levels taken from December–February each year
- A programmatic approach was used to prepare groundwater levels used in the model

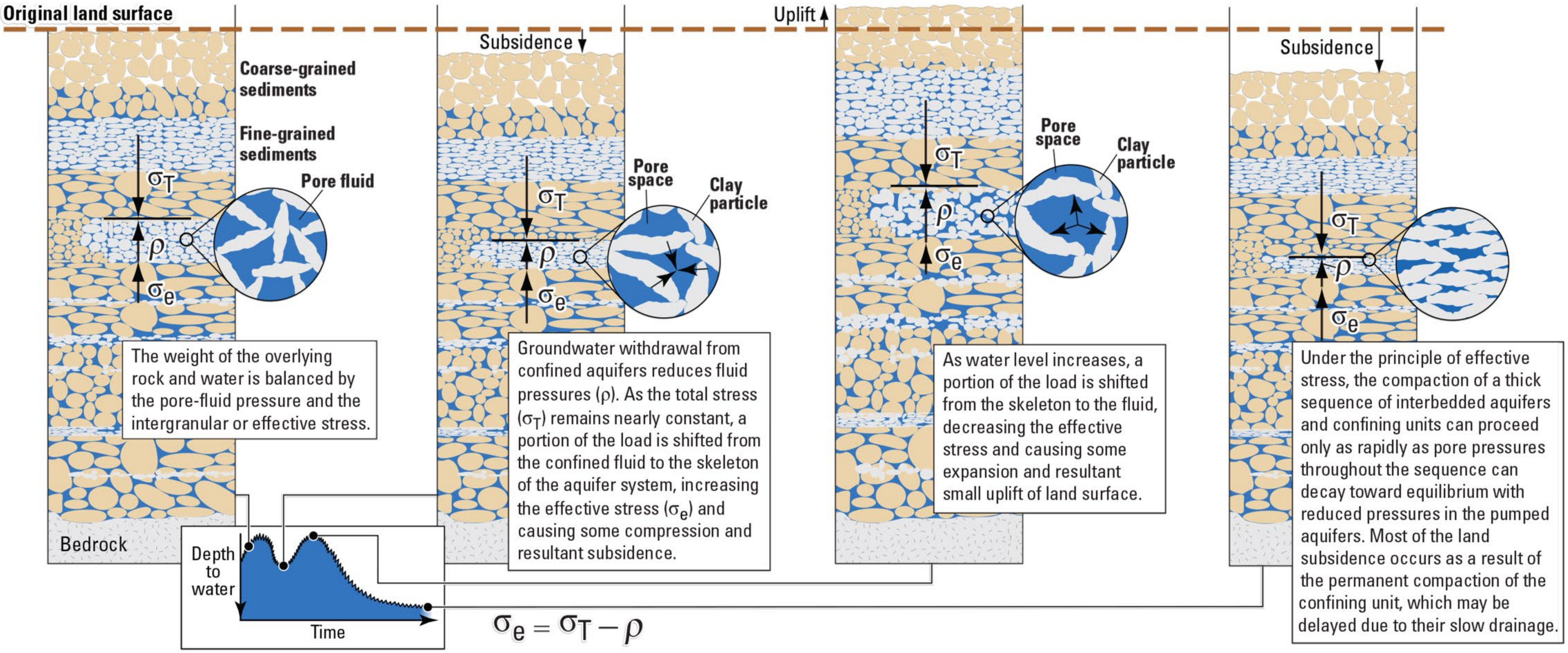






Subsidence

Effective stress and compaction



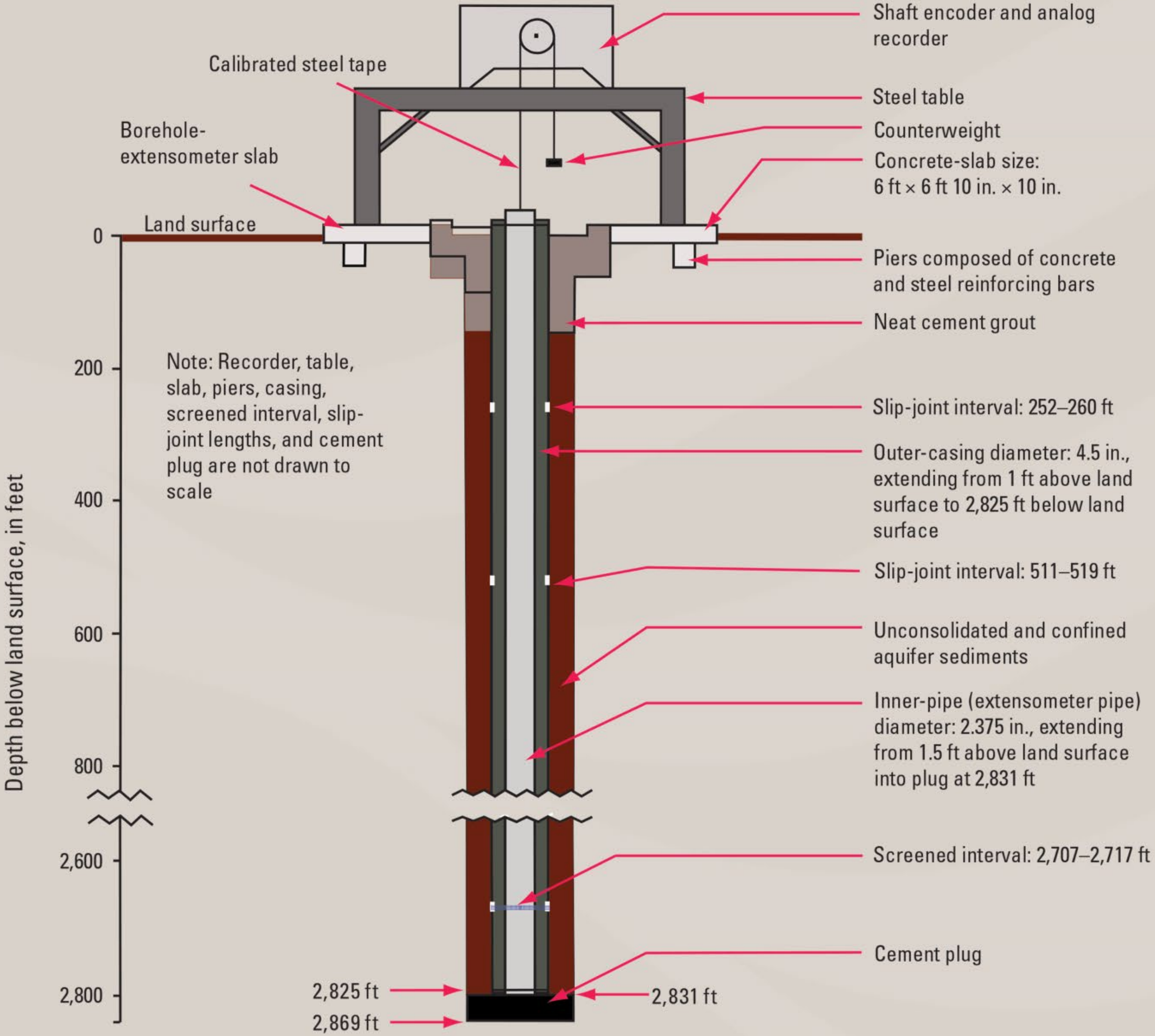
Subsidence

Borehole extensometers

- Basically, a deeply-anchored benchmark in the earth
- During installation, a hole is drilled to a depth where the sediment is stable
- Then, an inner pipe is installed and situated on a cement plug at the bottom
- The distance between the inner pipe and land surface, recorded by the shaft encoder or f-recorder, is the amount of compaction

East End extensometer

Clear Lake (shallow) extensometer



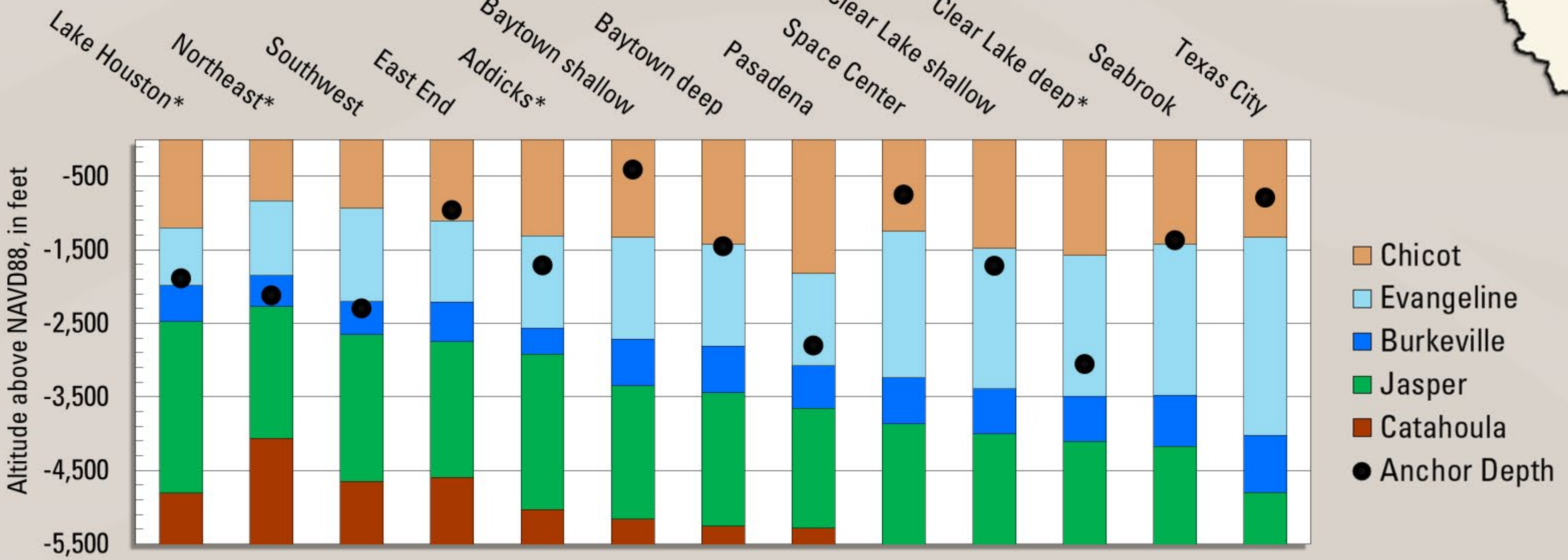
Note: All depths are referenced to land-surface elevation

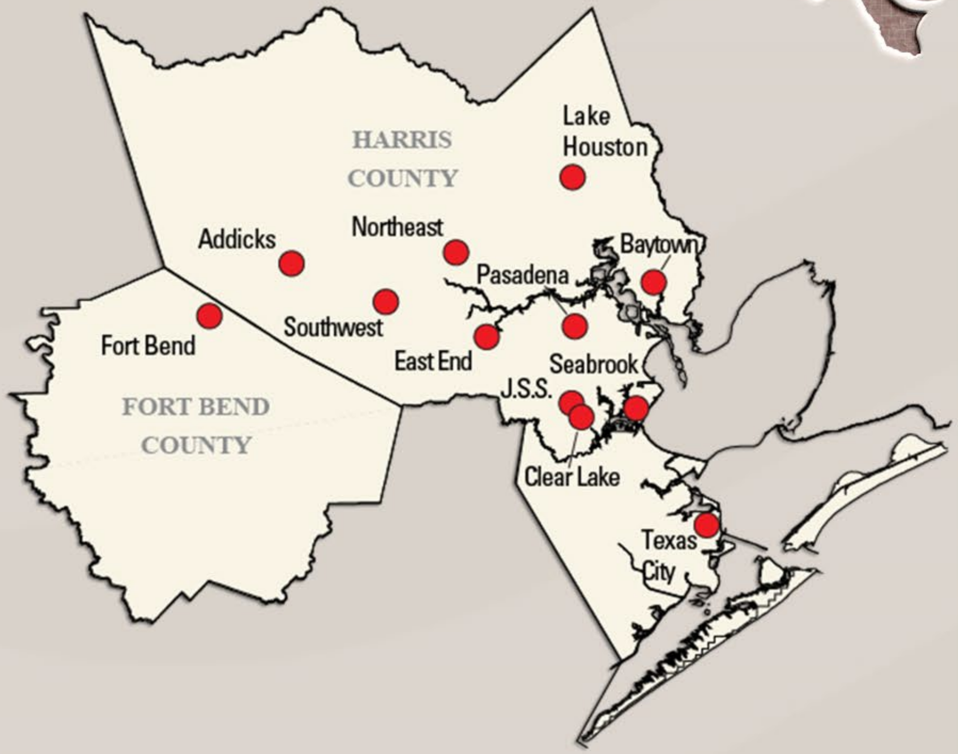
Shown: Pasadena extensometer

Subsidence

Model subsidence datasets

- Extensometers: measure compaction in the aquifer system. Fourteen extensometers at 12 sites (13 in the GULF model).
  - Seven measure compaction in Chicot aquifer, six in Chicot + Evangeline aquifers.
  - 13 extensometers installed between 1958 and 1980





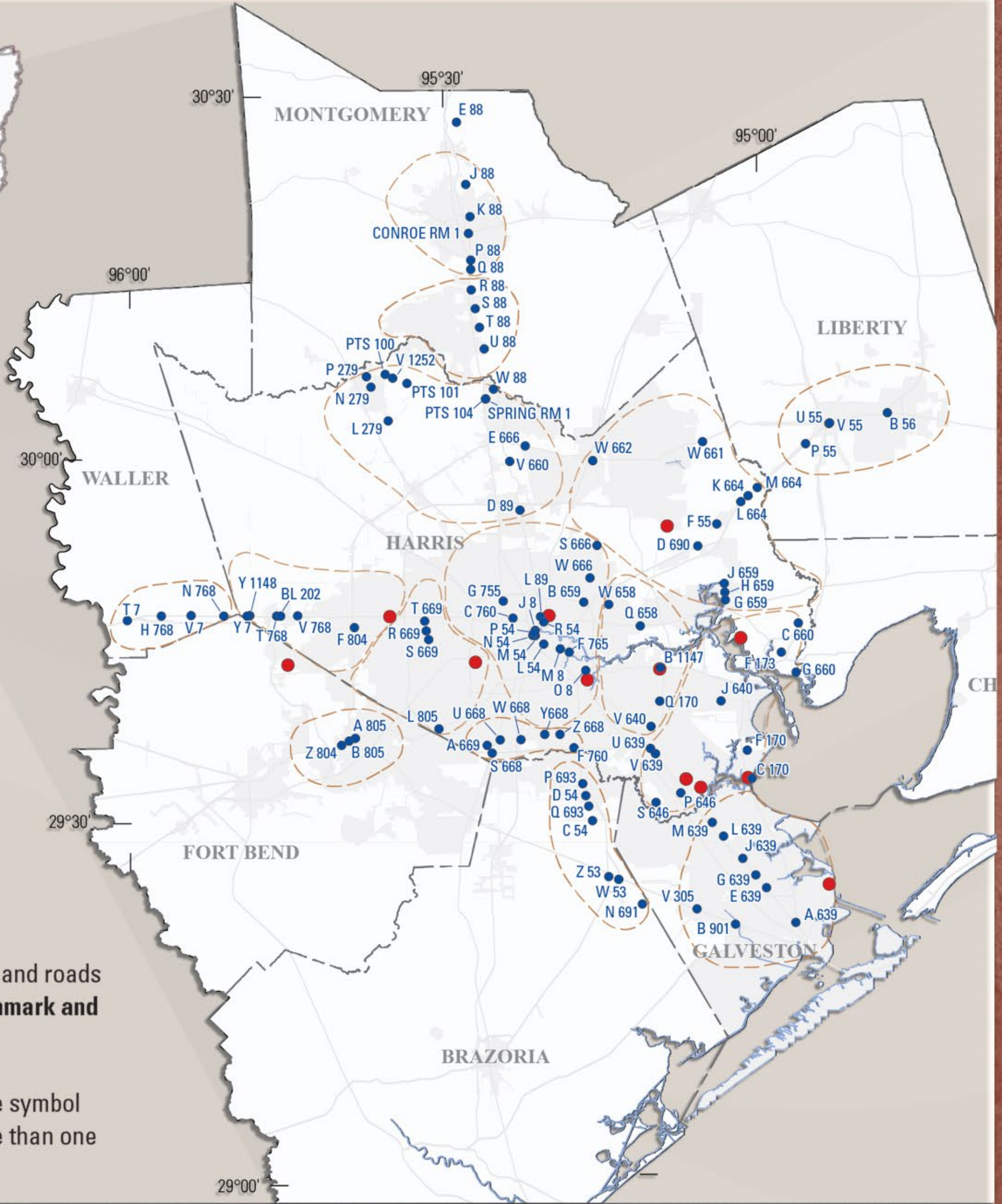

Pasadena extensometer


Lake Houston extensometer

NAVD; North American Vertical Datum of 1988
*CORS site
Ft Bend extensometer not shown

Subsidence

- Benchmarks: The GULF model was calibrated to leveling data at 105 benchmarks
  - 20 benchmarks: Occupations in 1906 or 1918 through 1987 or later
  - 39 benchmarks: Occupations in 1932–33 through 1987 or later
  - 97 benchmarks: Occupations in 1942–43 through 1987 or later
  - 18 benchmarks: Reoccupied in 2019–21. A total of 10 of these benchmarks have data from 1932–33 through 2019–21



Urban area—Cities and roads

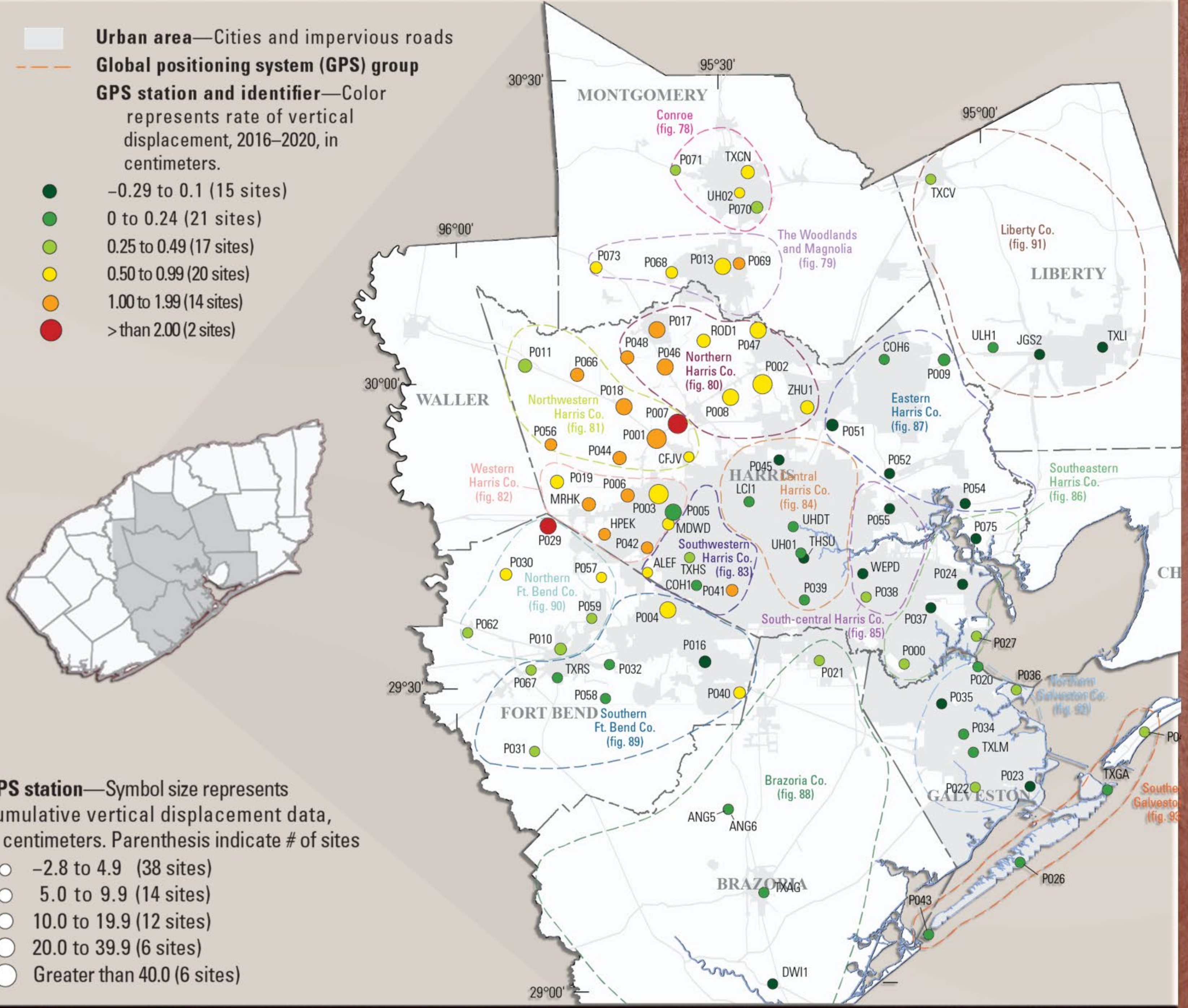
V 55 Monumented benchmark and benchmark name

Benchmark group

Extensometer—one symbol may represent more than one extensometer

Subsidence

- The GULF model was calibrated to vertical-displacement data at 178 GPS stations, 80 of which are in the greater Houston area
- Each report GPS group contains sites geographically clustered to describe vertical-displacement trends
- The same geographic groupings are used for the benchmark, GPS, and groundwater wells for comparability.

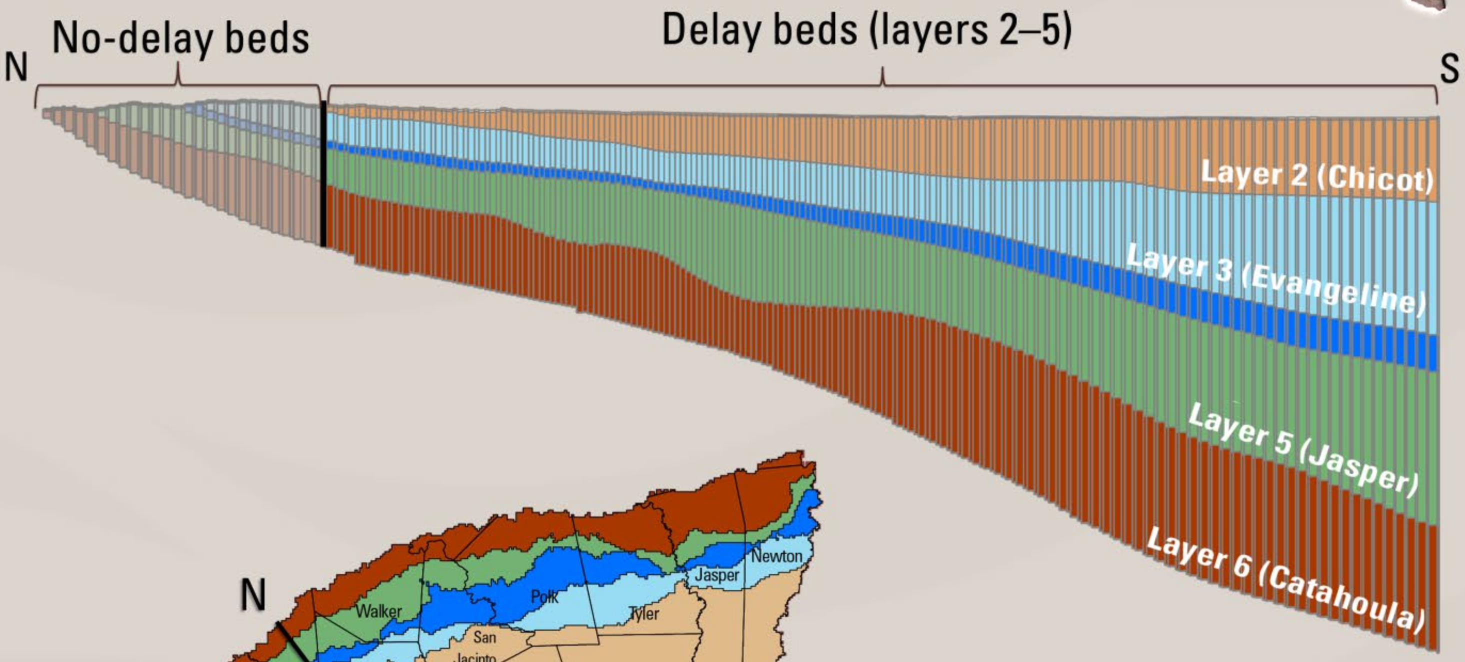


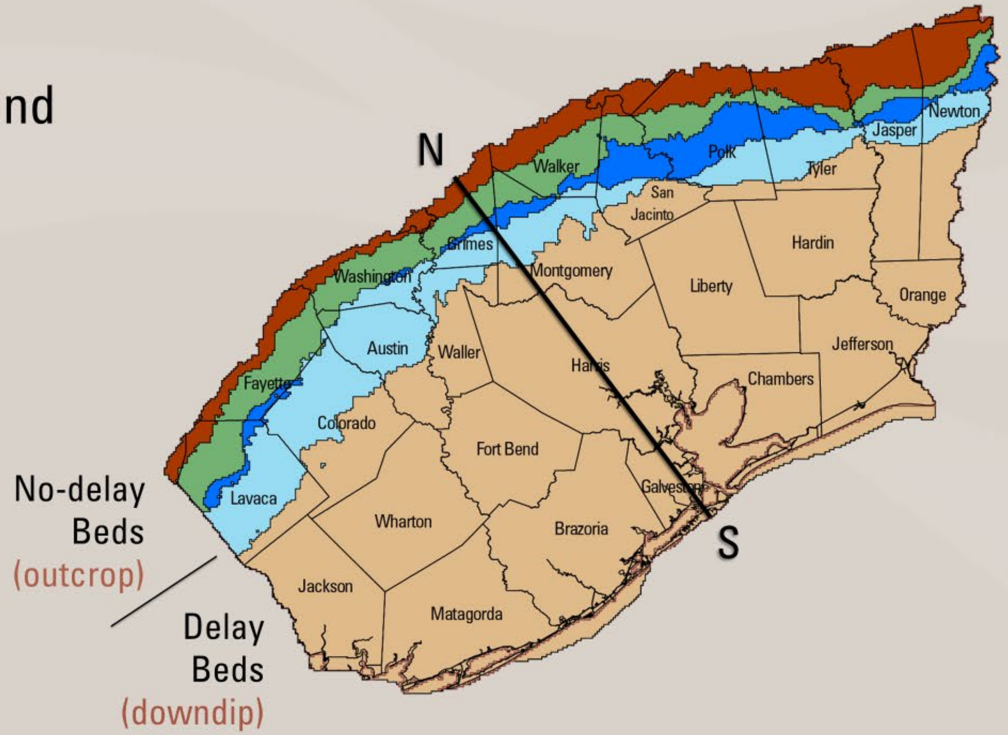
Subsidence

Subsidence package

- Newly formulated subsidence package (CSUB)[1] for the MODFLOW 6 model code
- Simulates groundwater-storage changes and compaction
- Using delay beds in subcrop area, and no-delay beds in outcrop area
- Compaction relation

  $\Delta b = \Delta h S_s b$ Head based



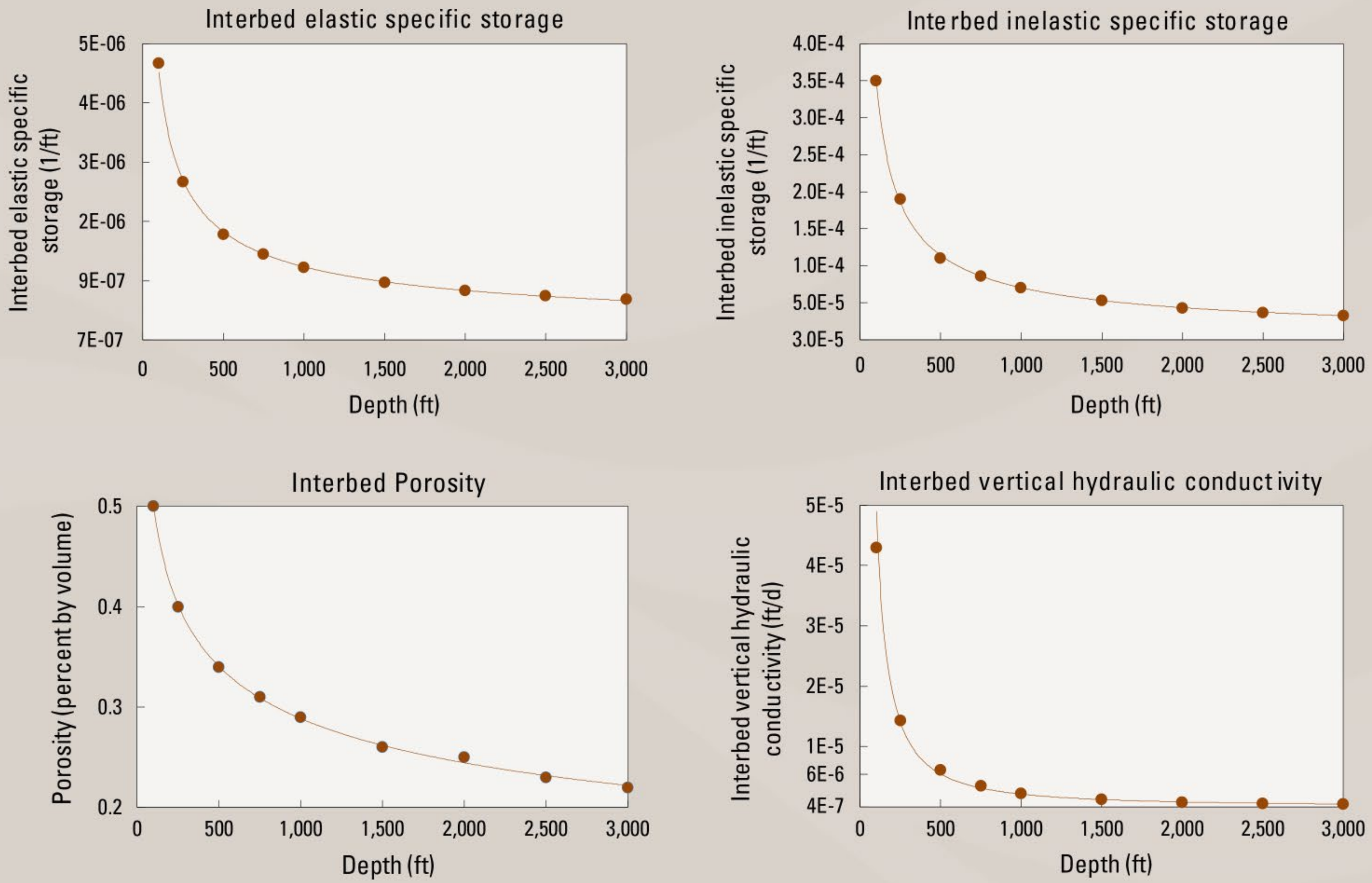


[1]Hughes and others, *in press*

Subsidence

Subsidence package parameters

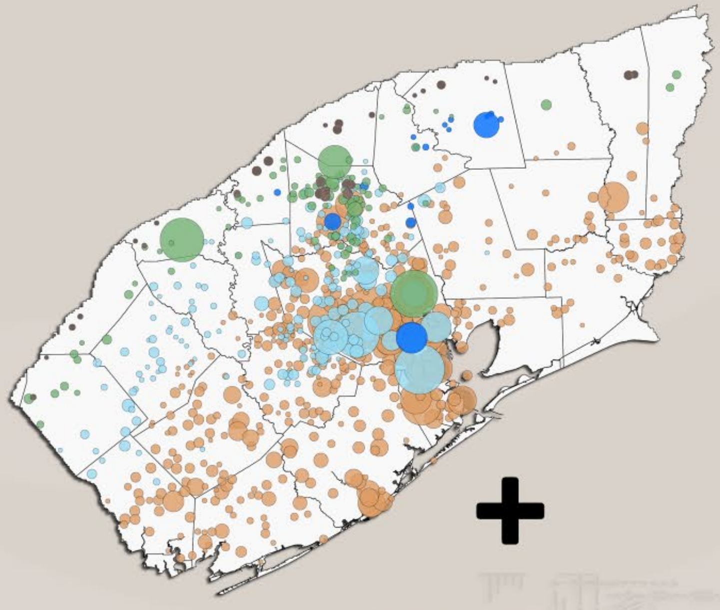
- Fine grained (interbeds)
  - Specific storage (elastic, inelastic)
  - Porosity
  - Vertical hydraulic conductivity
  - Interbed thickness
  - Number of interbeds
- Coarse grained (sand units)
  - Specific storage (elastic)
  - Porosity
- Drawdown at preconsolidation stress



Best fit lines through data from Kelley and others (2018), tables 2-1, 2-2

Model history matching and uncertainty

- Process of changing initial model inputs (parameters) to reduce residuals. Residuals = simulated – observed (or estimated)
- Using PEST++ IES[1] software to history match an ensemble, not just one model
- Use probabilistic approach to assess uncertainty in model results



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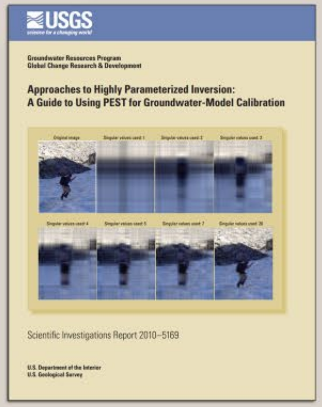
PEST++

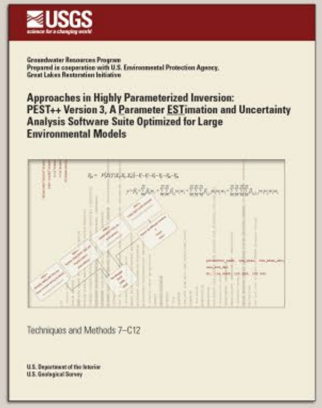
Software Suite for Parameter Estimation, Uncertainty Quantification, Management Optimization, and Sensitivity Analysis

+

HTCondor

High Throughput Computing





[1]White, 2018

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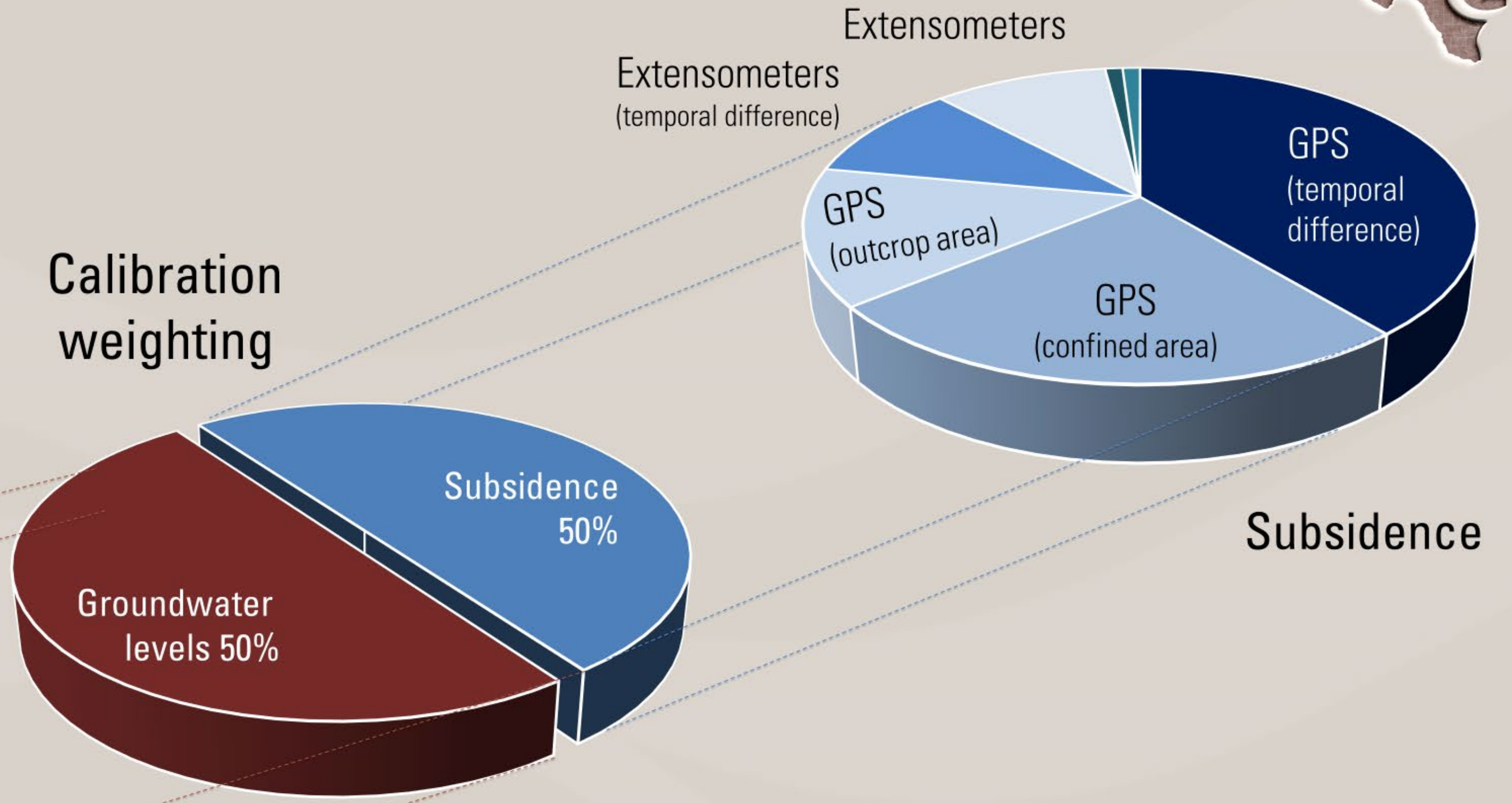
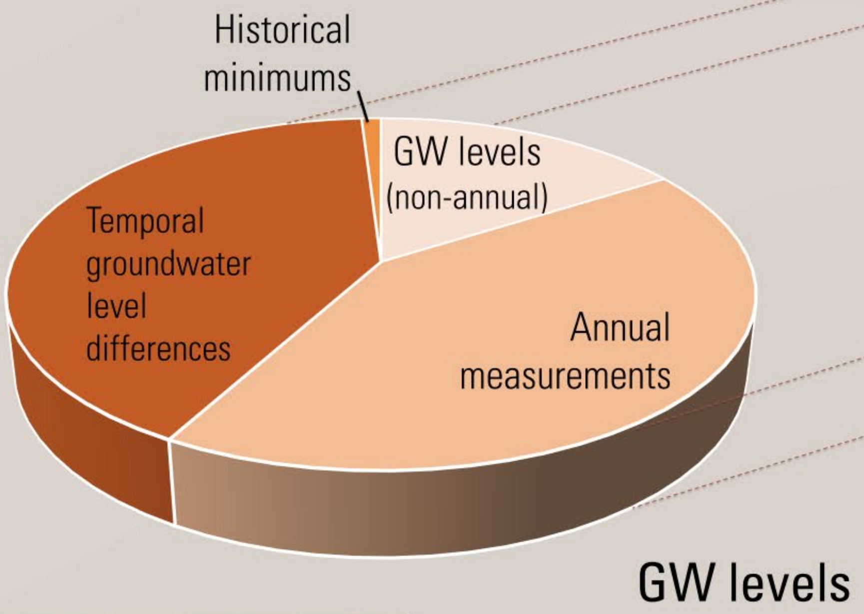
Calibration & Uncertainty

History matching process

- Calibrate to groundwater levels, subsidence
- Group calibration data by type and assign weights based on data importance





Objective Function: Sum of squared weighted residuals, or sum of all quantifiable error

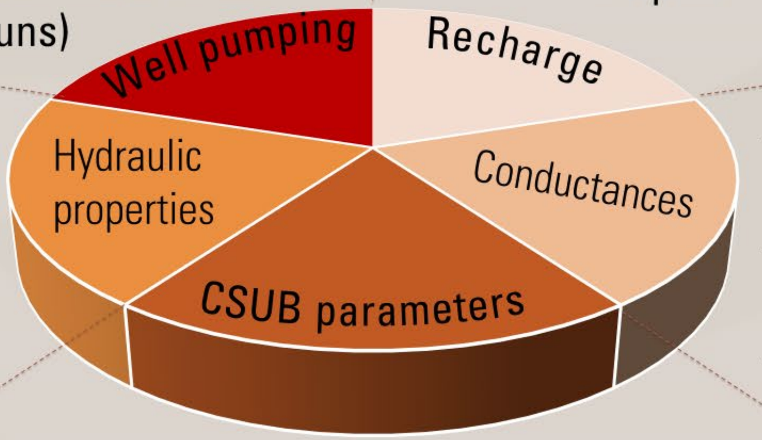
$$\Phi = \sum_{i=1}^{n}[\omega_i(s_i - o_i)]^2$$

Calibration & Uncertainty

Model Parameters

- Thanks to advances in history matching using PEST-IES, currently using 183,207 adjustable parameters.
- Include entire-layer, geostatistical (pilot point), and individual cell parameters

Parameter groups and parameters



From water-use estimates (initial runs)

From SWB outputs

- Horizonal hydraulic conductivity
- Vertical hydraulic conductivity
- Specific Yield

- River conductance
- Drain conductance
- GHB conductance

1.7 million parameters

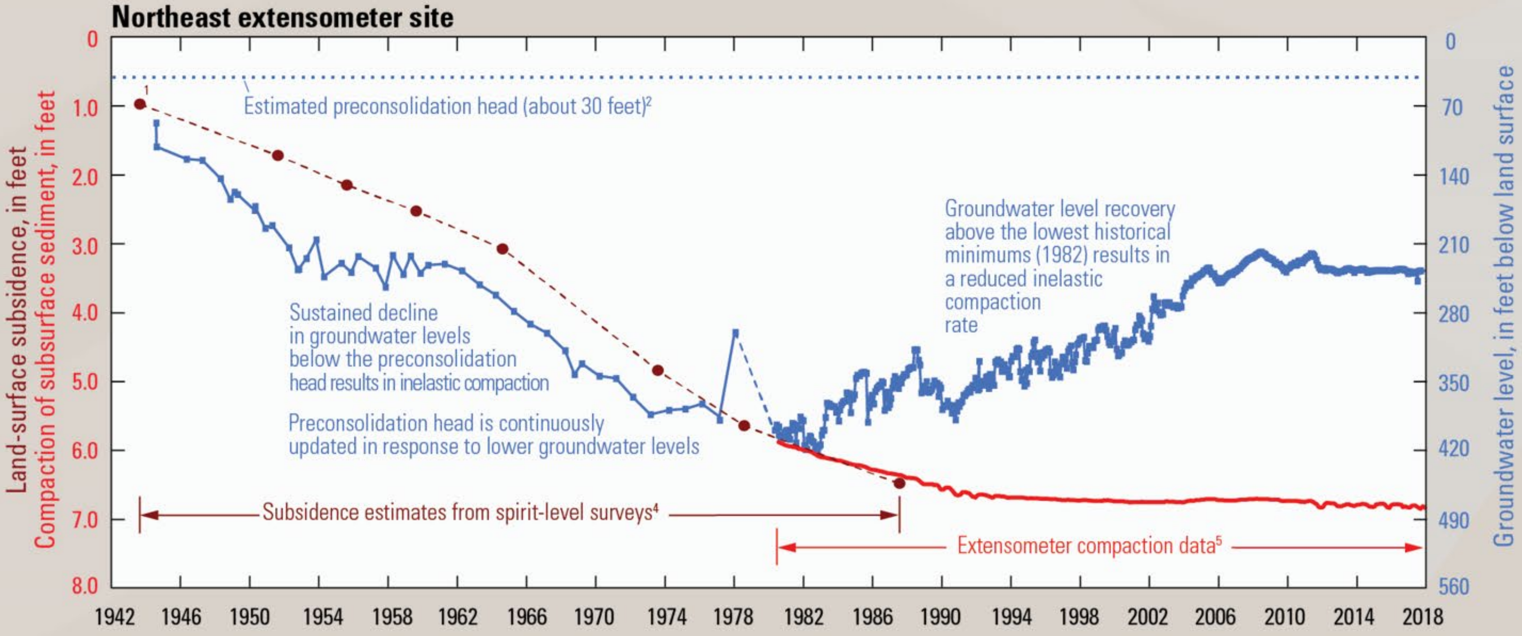
Fine grained
- Elastic specific storage
- Inelastic specific storage
- Porosity
- Vertical hydraulic conductivity

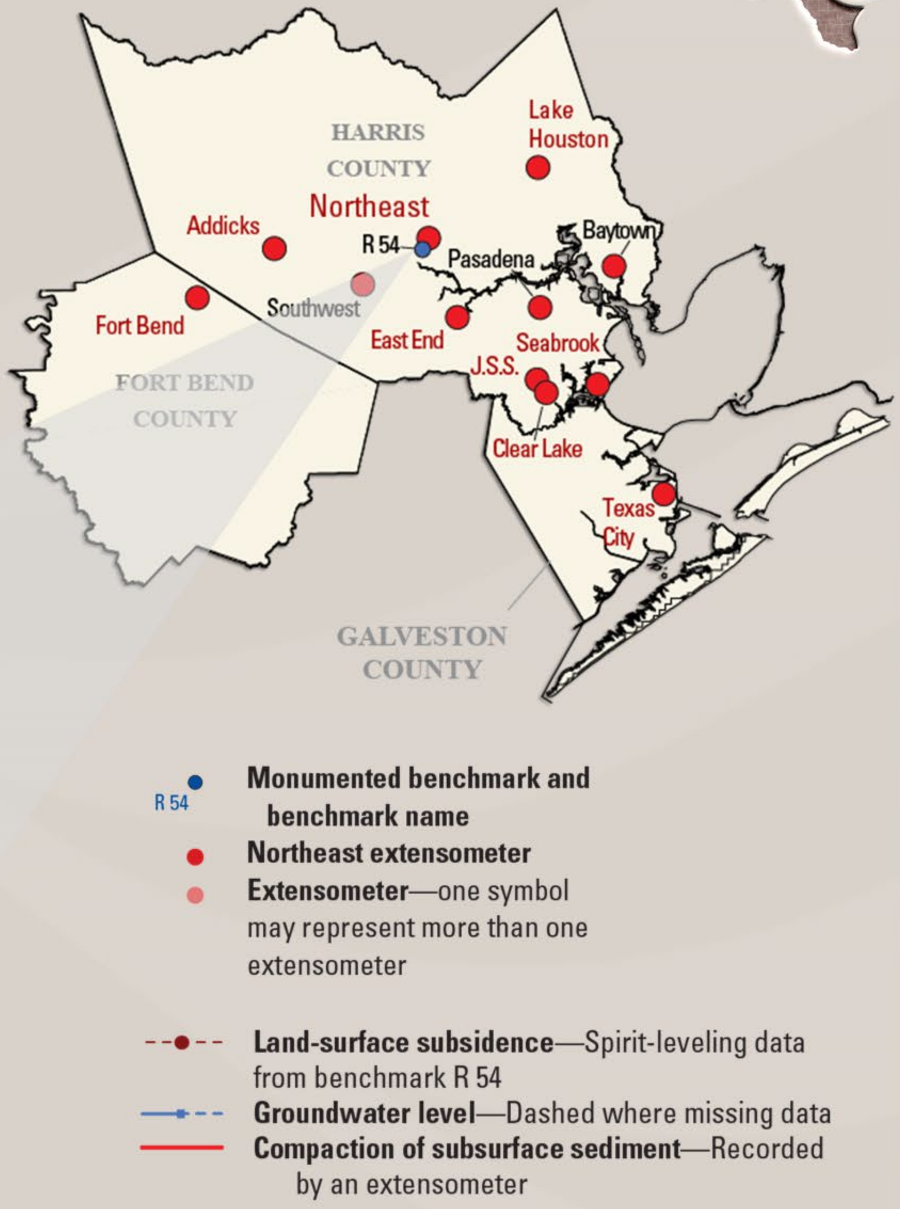
Coarse grained
- Specific storage (elastic)
- Porosity

Cumulative subsidence

PRELIMINARY RESULTS

- Northeast extensometer: About 6.8 feet of subsidence through 2018
  - By 1943, groundwater levels were about 100 feet below land surface, and subsidence was about 0.9 feet.
  - As groundwater levels continued to decline, the aquifer system reached a continually greater level of effective stress, resulting in inelastic compaction.

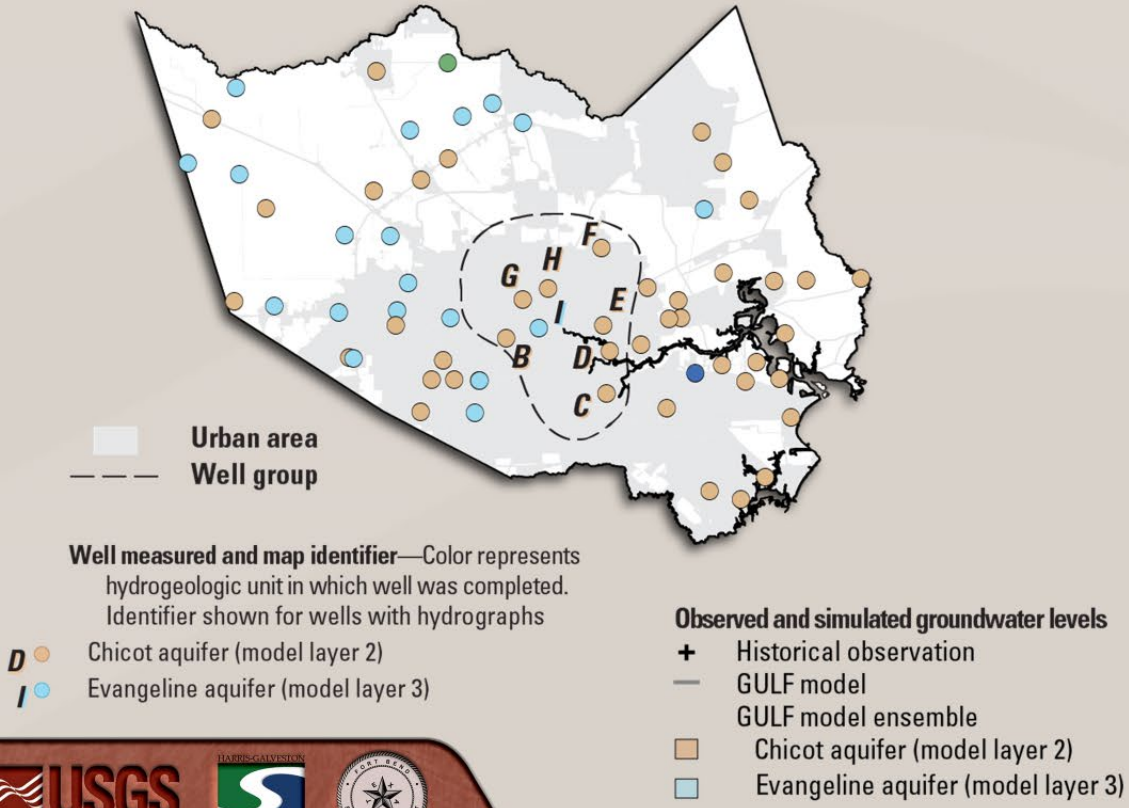


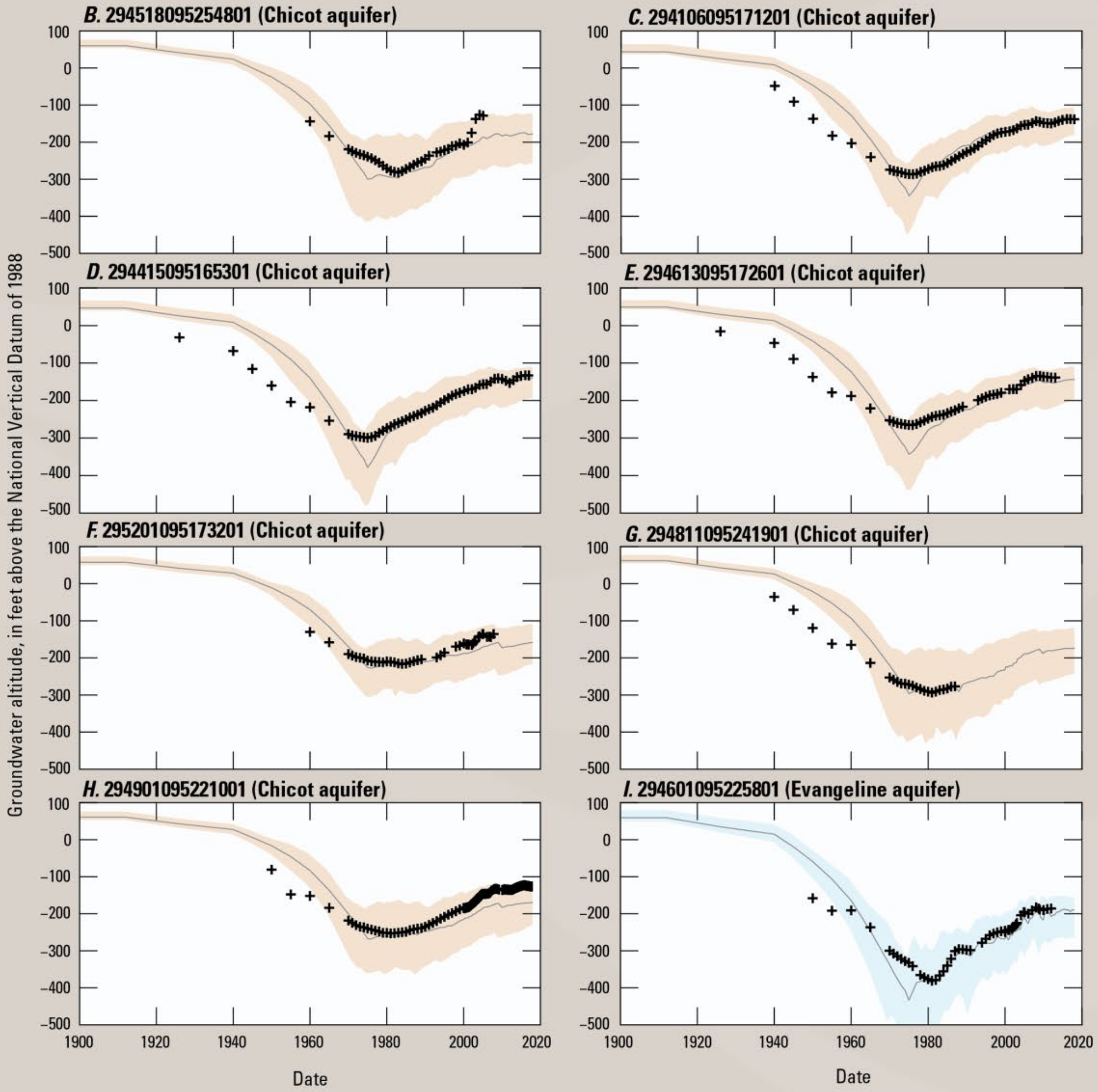


Groundwater Levels

Observed and simulated results

- The range of simulated groundwater levels generally bracket the historical observations
- Historical minimums not fully simulated in some areas



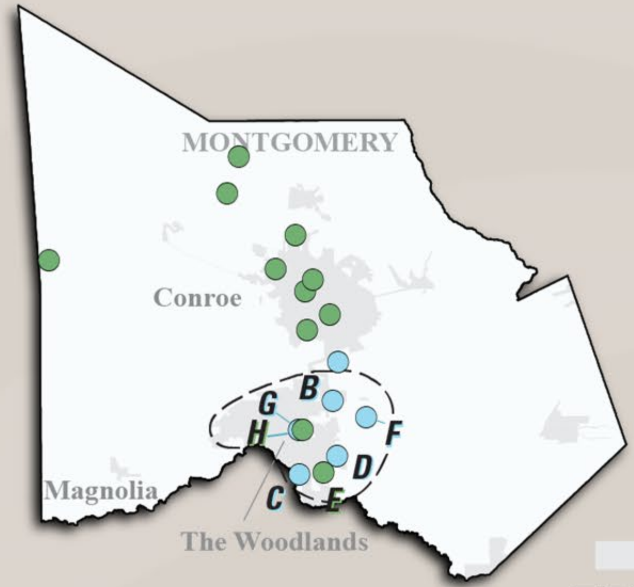


Groundwater Levels

PRELIMINARY RESULTS

Observed and simulated results

- The range of simulated groundwater levels generally bracket the historical observations
- Historical minimums not fully simulated in some areas



Urban area
Well group

Well simulated and map identifier—Color represents hydrogeologic unit in which well was completed. Identifier shown for wells with hydrographs

D Evangeline aquifer (model layer 3)

E Jasper aquifer (model layer 5)

Observed and simulated groundwater levels

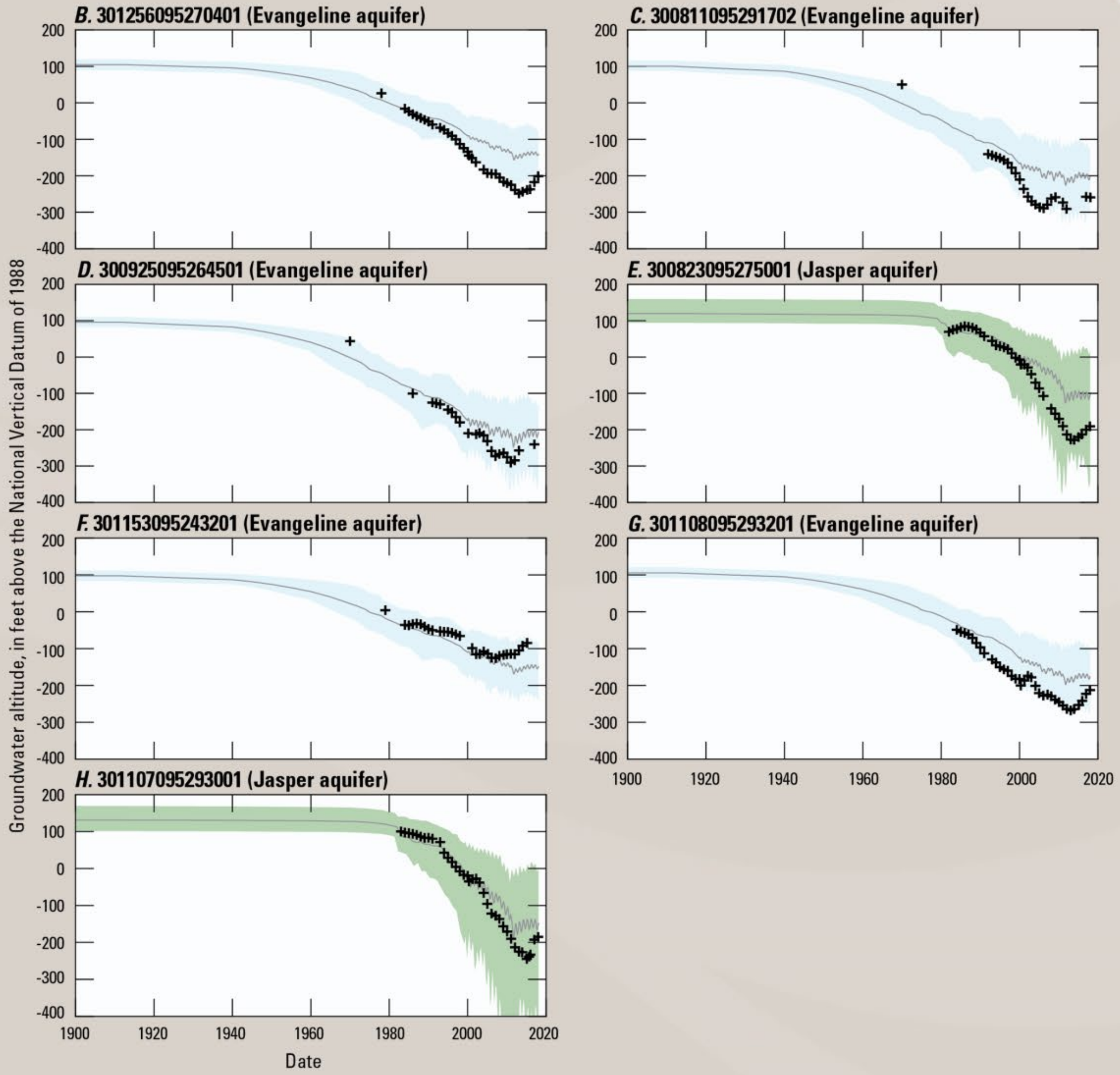
+ Historical observation

— GULF model

GULF model ensemble

Chicot aquifer (model layer 2)

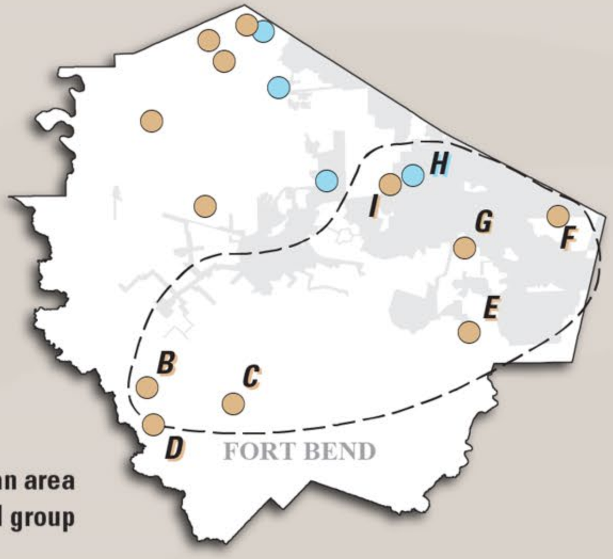
Evangeline aquifer (model layer 3)



Groundwater Levels

Observed and simulated results

- The range of simulated groundwater levels generally bracket the historical observations
- Historical minimums not fully simulated in some areas



Urban area

Well group

Well measured and map identifier—Color represents hydrogeologic unit in which well was completed. Identifier shown for wells with hydrographs

D Chicot aquifer (model layer 2)

H Evangeline aquifer (model layer 3)

Observed and simulated groundwater levels

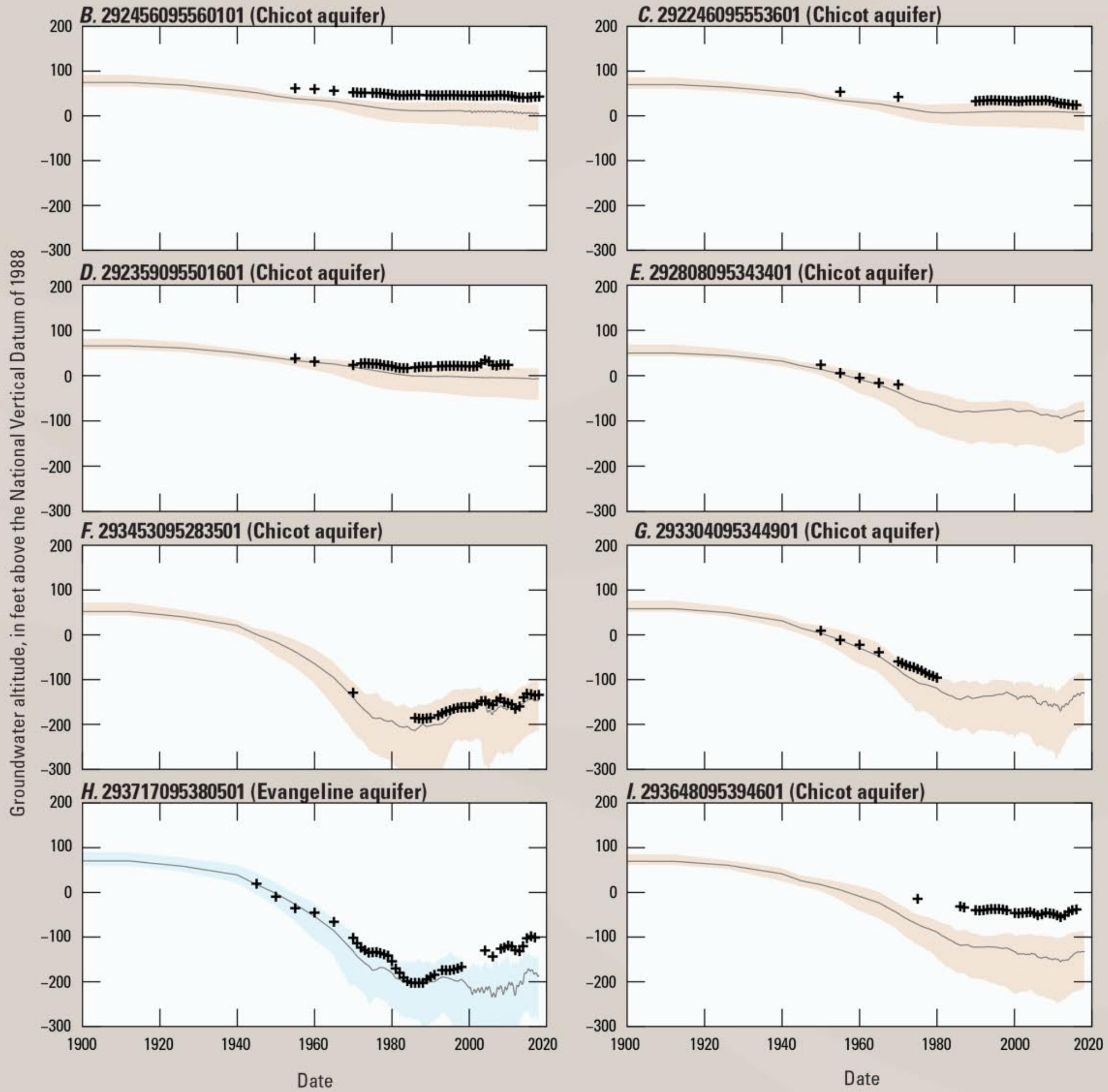
+ Historical observation

GULF model

GULF model ensemble

Chicot aquifer (model layer 2)

Evangeline aquifer (model layer 3)



Groundwater Levels

PRELIMINARY RESULTS

Observed and simulated results

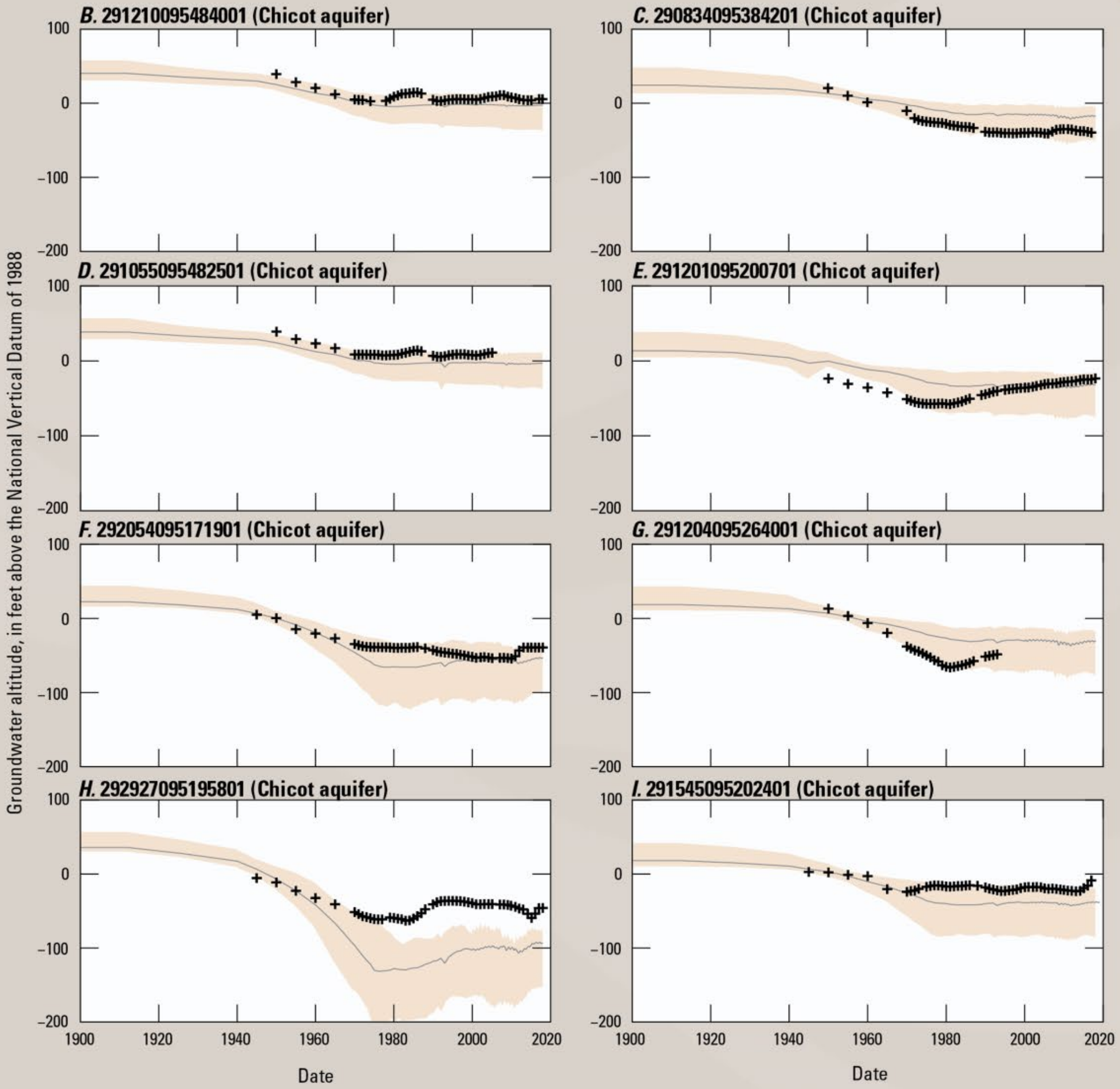
- The range of simulated groundwater levels generally bracket the historical observations
- Historical minimums not fully simulated in some areas

Observed and simulated groundwater levels

- + Historical observation
- GULF model
- GULF model ensemble
  - Chicot aquifer (model layer 2)

Well simulated and map identifier—Color represents hydrogeologic unit in which well was completed. Identifier shown for wells with hydrographs

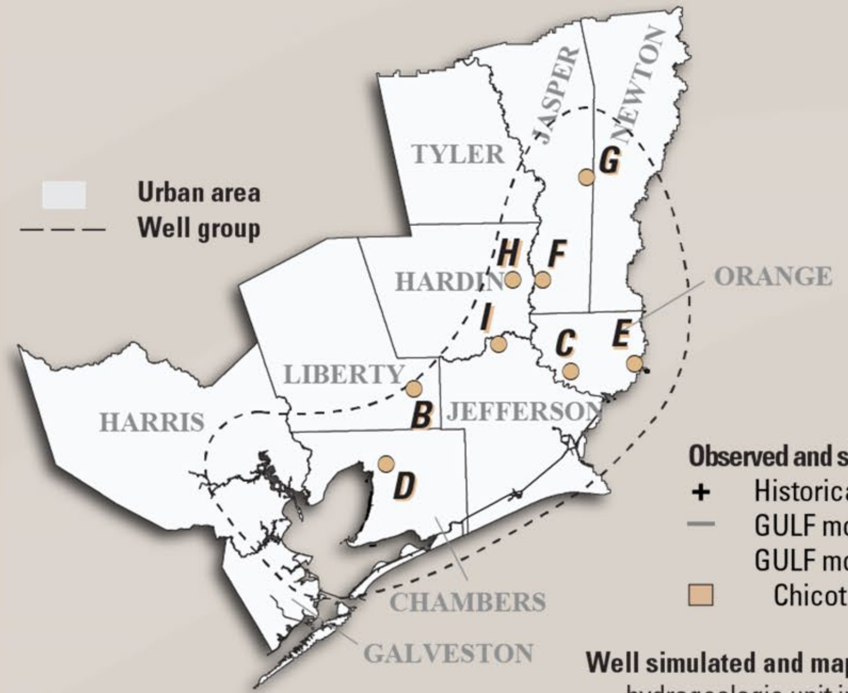
D Chicot aquifer (model layer 2)



Groundwater Levels

Observed and simulated results

- The range of simulated groundwater levels generally bracket the historical observations
- Historical minimums not fully simulated in some areas

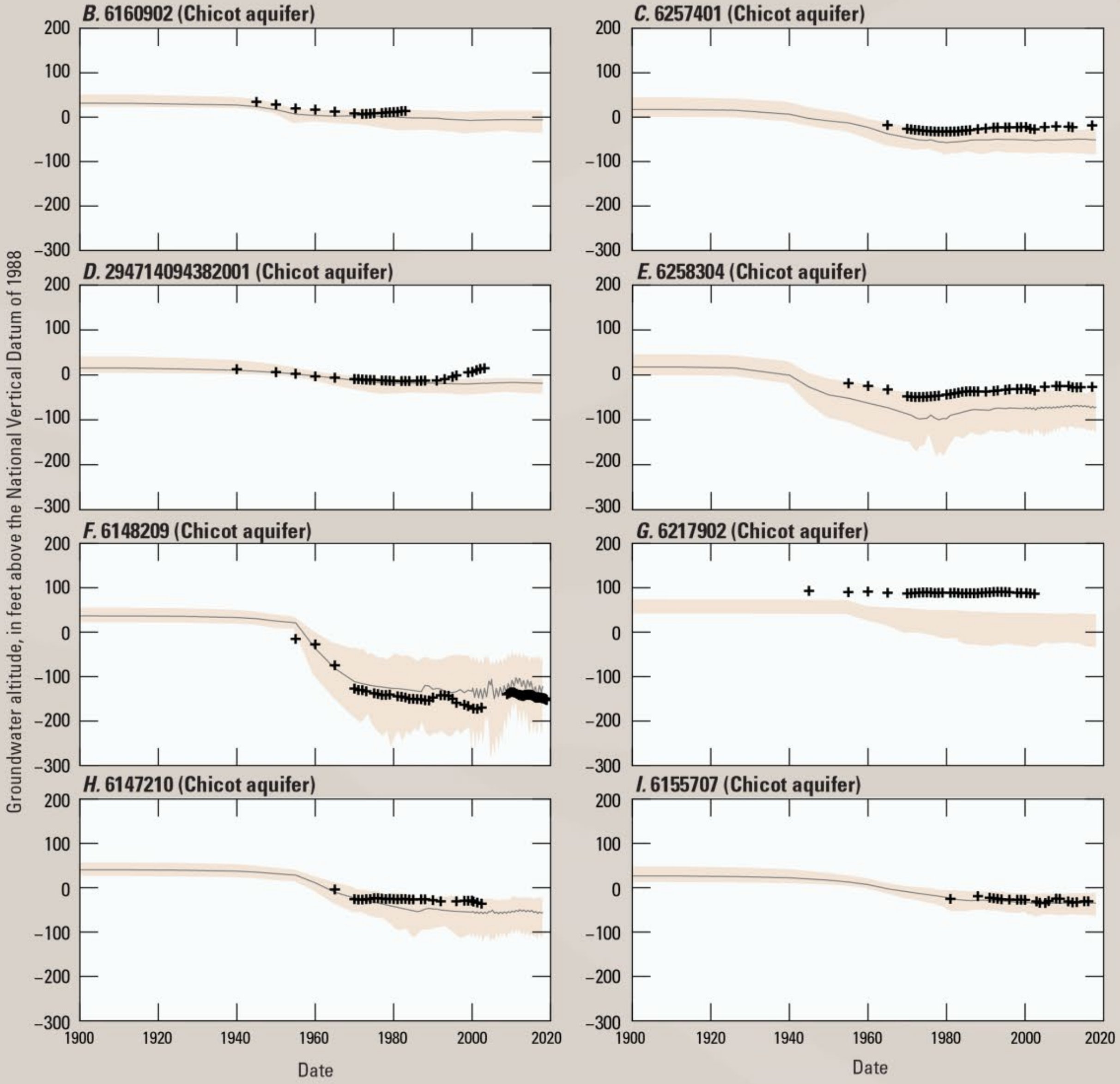


Observed and simulated groundwater levels

- + Historical observation
- — GULF model
- GULF model ensemble
  - Chicot aquifer (model layer 2)

Well simulated and map identifier—Color represents hydrogeologic unit in which well was completed. Identifier shown for wells with hydrographs

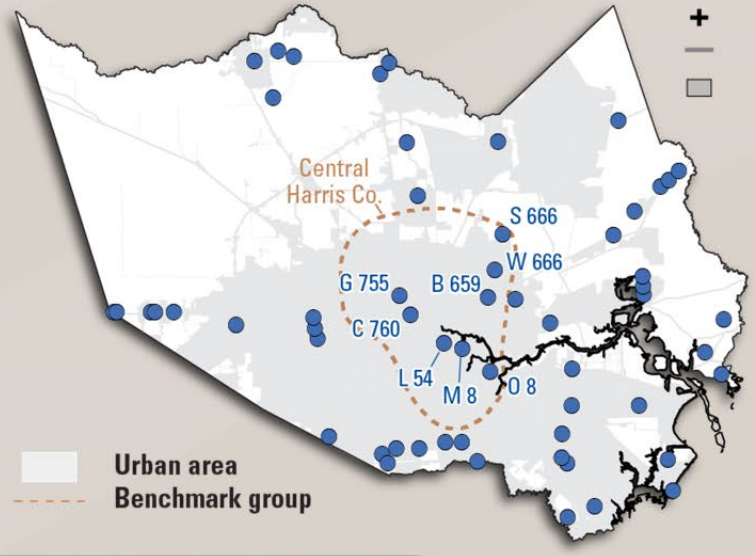
D ● Chicot aquifer (model layer 2)



Subsidence

Observed and simulated results

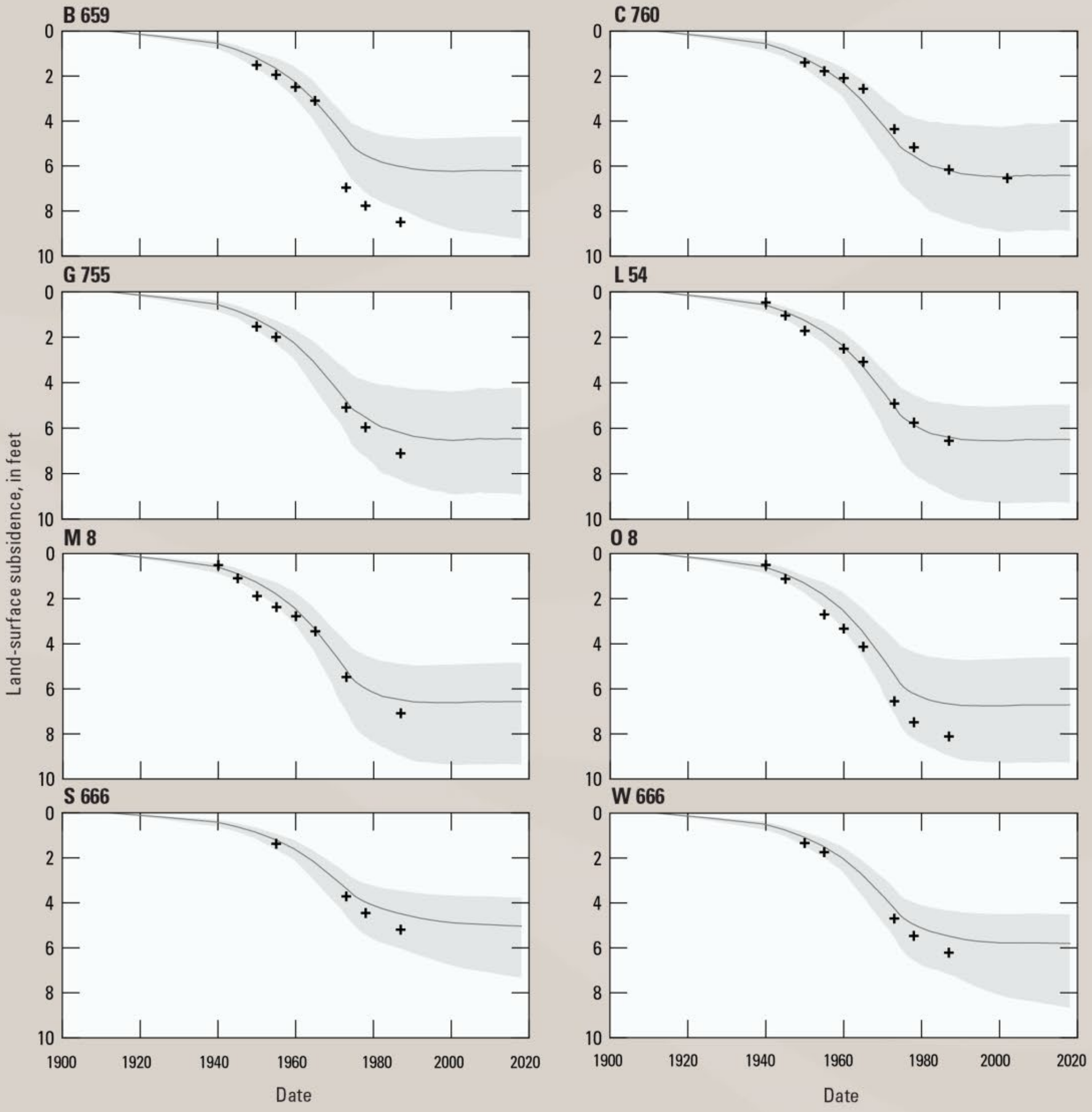
- The range of simulated subsidence generally brackets the historical observations



V 55 Monumented benchmark and benchmark name

Observed and simulated cumulative subsidence

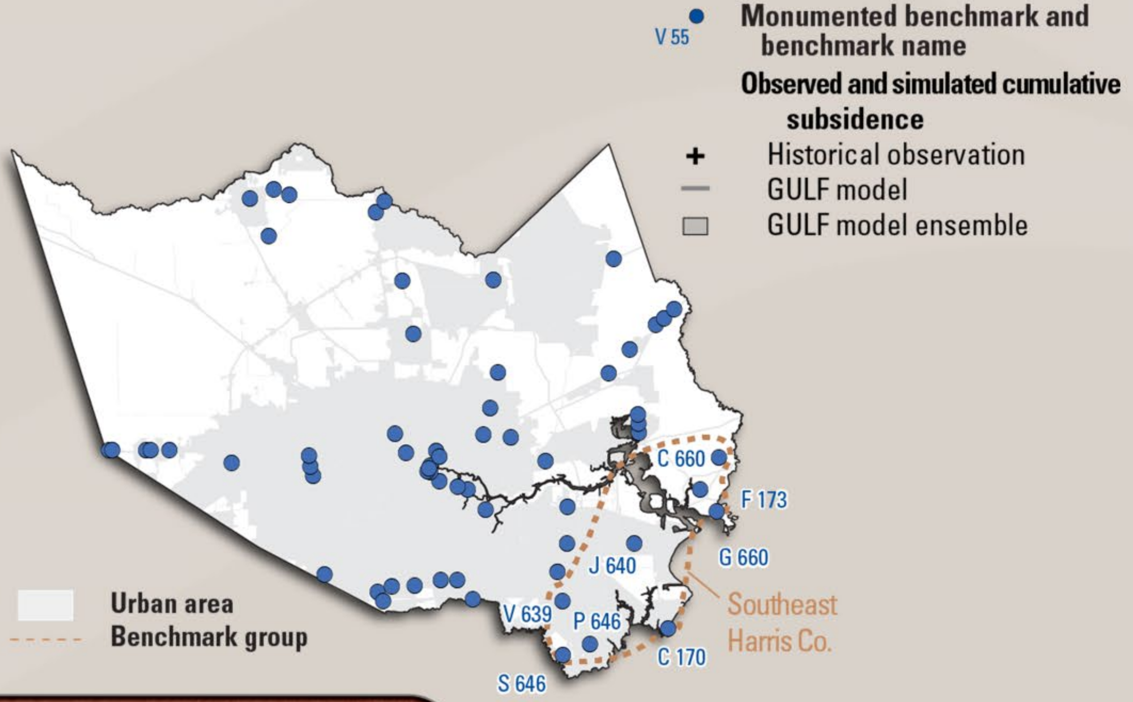
- + Historical observation
- GULF model
- GULF model ensemble

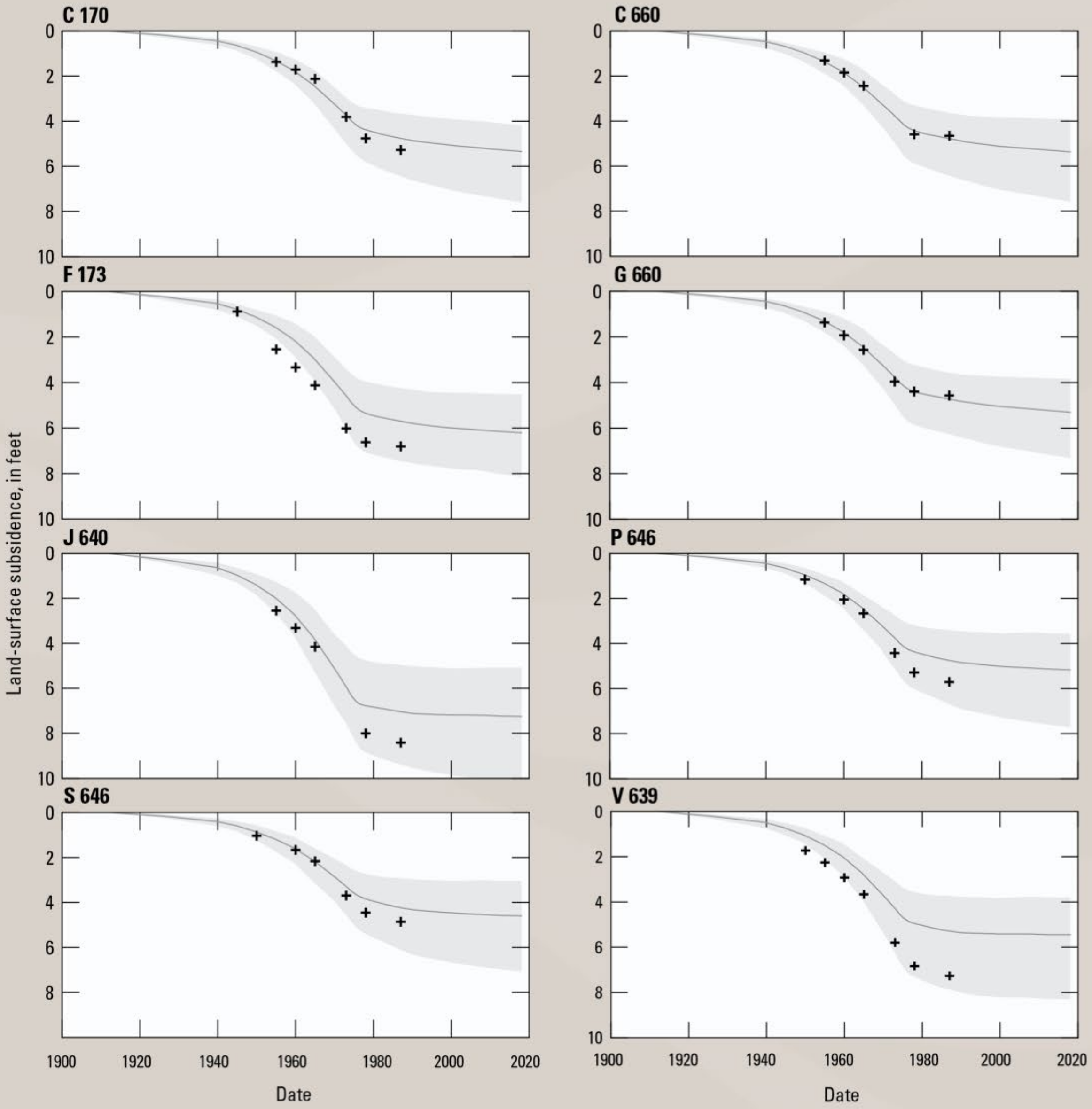


Subsidence

Observed and simulated results

- The range of simulated subsidence generally brackets the historical observations
- In southeast Harris County, some subsidence occurred prior to installation of benchmarks

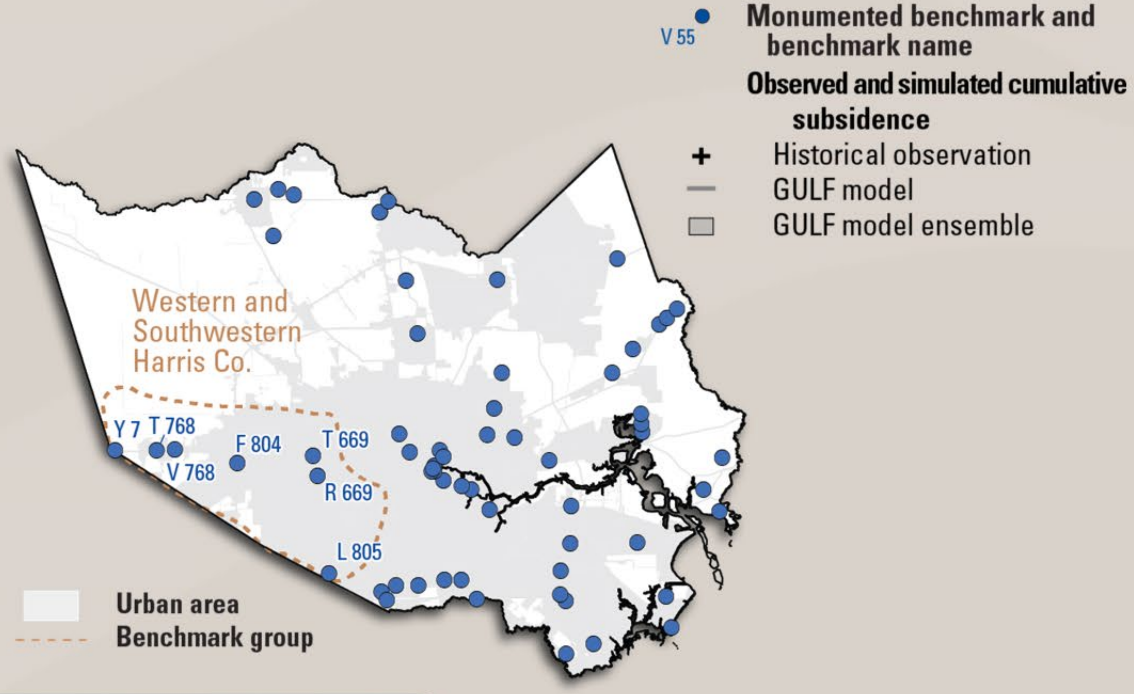


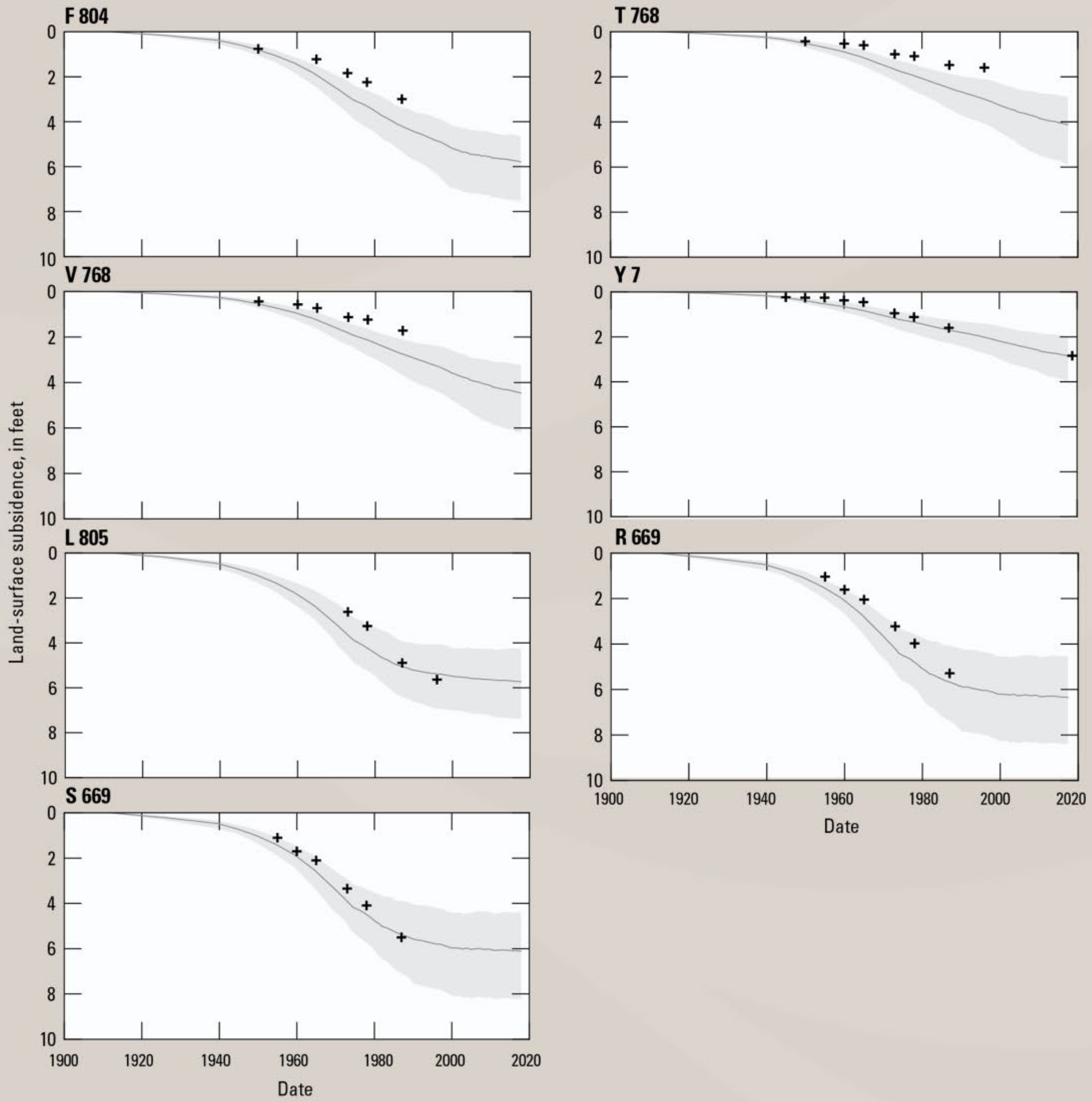


Subsidence

Observed and simulated results

- The range of simulated subsidence generally brackets the historical observations

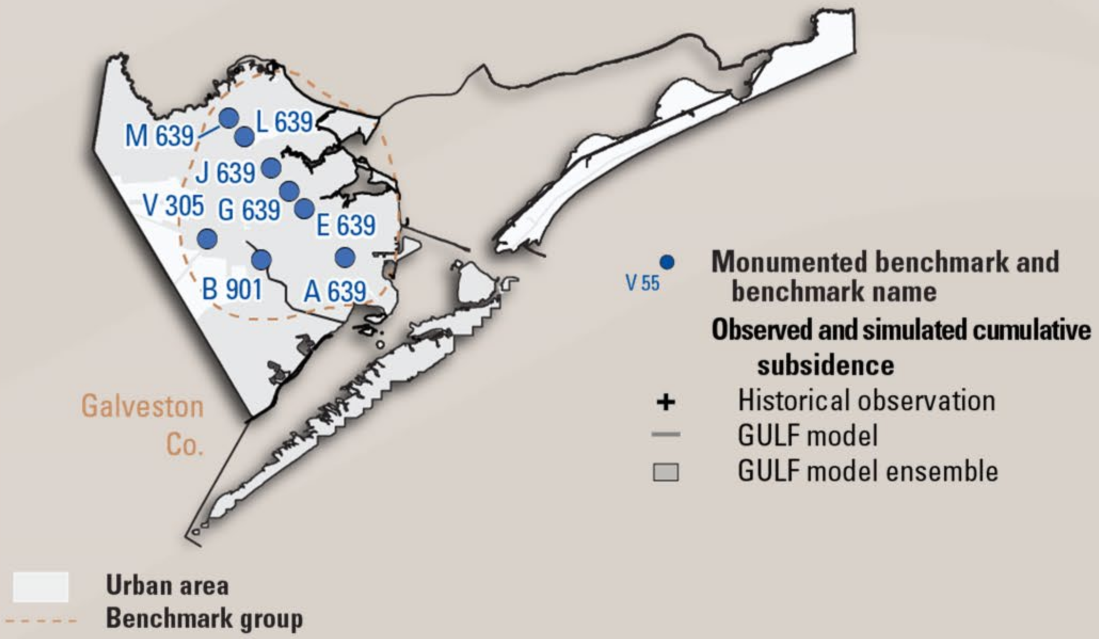


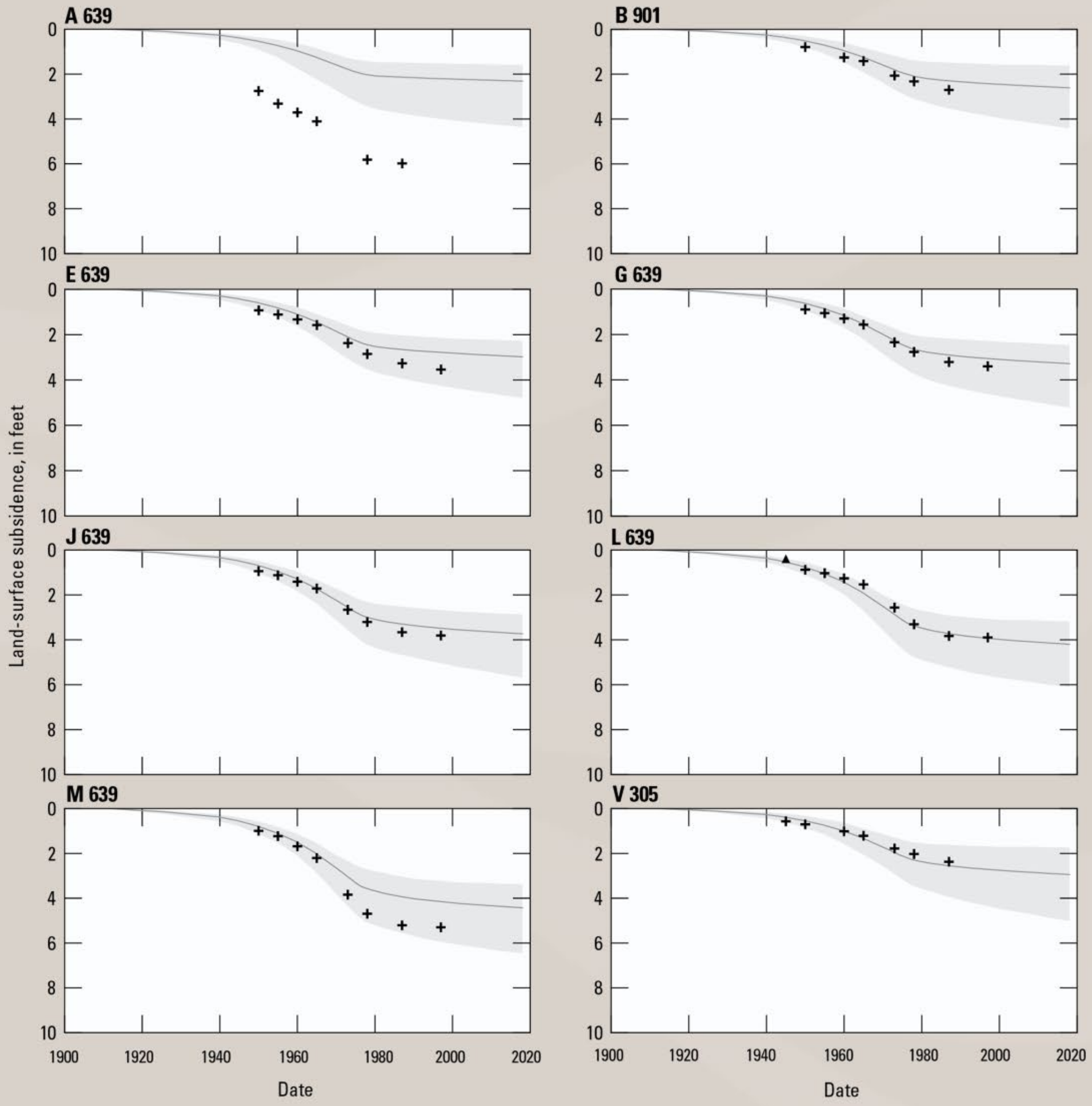


Subsidence

Observed and simulated results

- The range of simulated subsidence generally brackets the historical observations
- Subsidence is undersimulated at benchmark A 639, where subsidence increased substantially over a short distance





Subsidence

PRELIMINARY RESULTS

Observed and simulated results

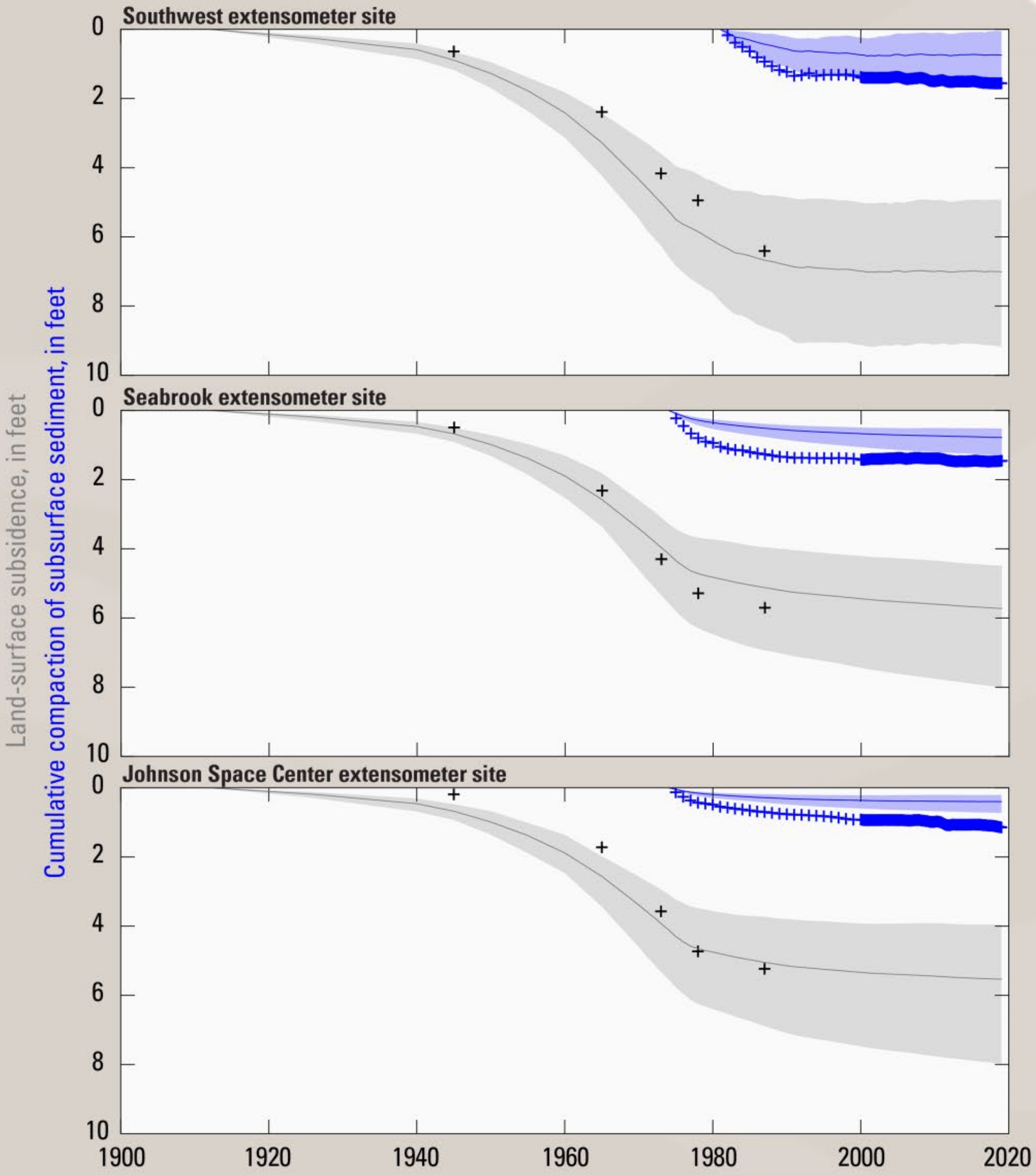
- The range of simulated subsidence and compaction generally brackets the historical observations
- Compaction was undersimulated at some extensometers

Estimated and simulated subsidence, in feet

- + Estimated subsidence
- — GULF model
- ☐ GULF model ensemble

Observed and simulated aquifer-unit compaction, in feet

- + Historical observation
- — GULF model
- ☐ GULF model ensemble

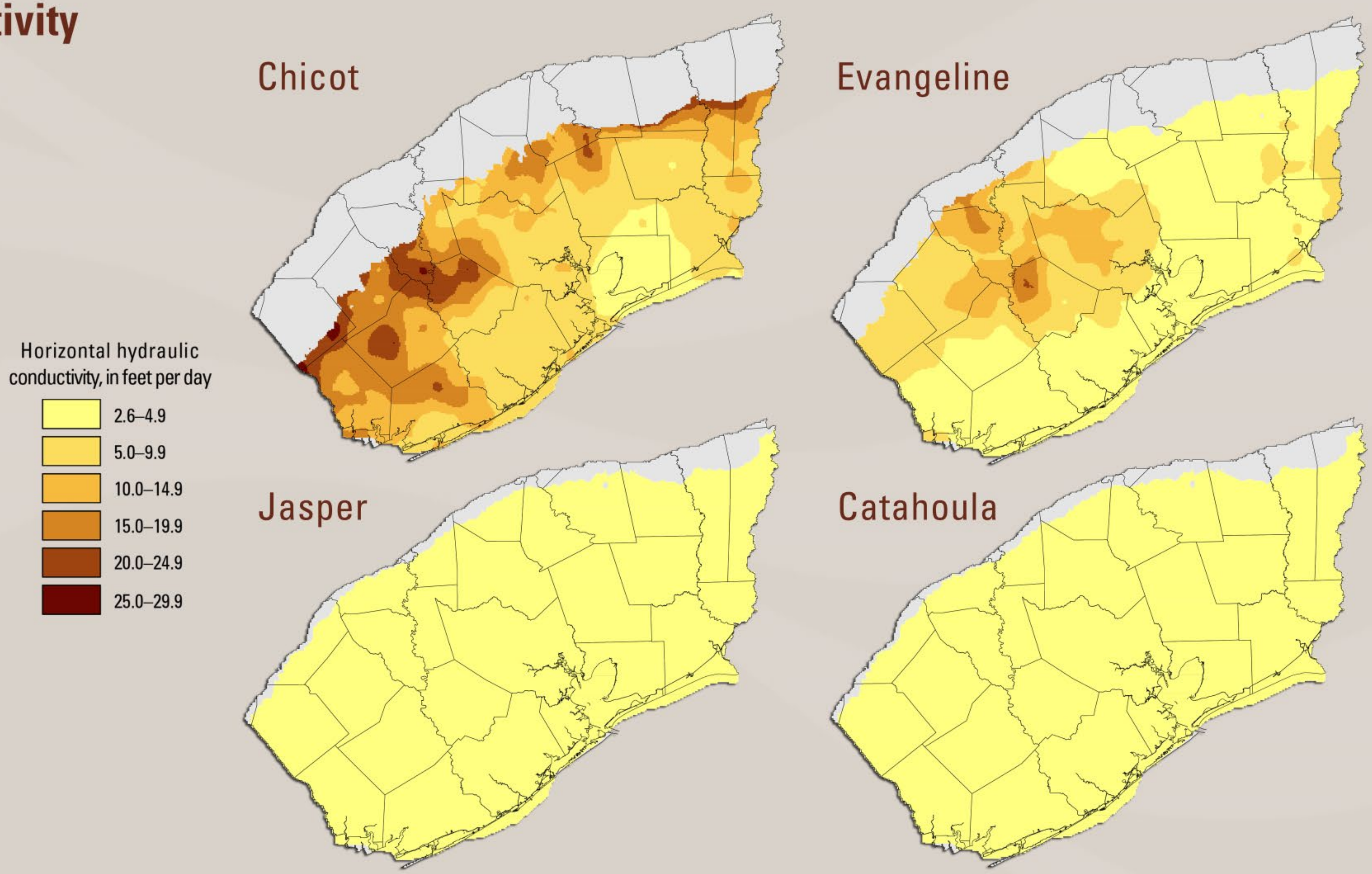


Parameters

PRELIMINARY RESULTS

Horizontal hydraulic conductivity

- Chicot aquifer
  - Mean: 11.1 ft/d
  - 95% range: 4.1–20.0 ft/d
- Evangeline aquifer
  - Mean: 5.4 ft/d
  - 95% range: 2.1–12.9 ft/d
- Jasper aquifer
  - Mean: 0.6 ft/d
  - 95% range: 0.27–1.2 ft/d
- Catahoula confining unit
  - Mean: 1.8 ft/d
  - 95% range: 1.0–3.0 ft/d

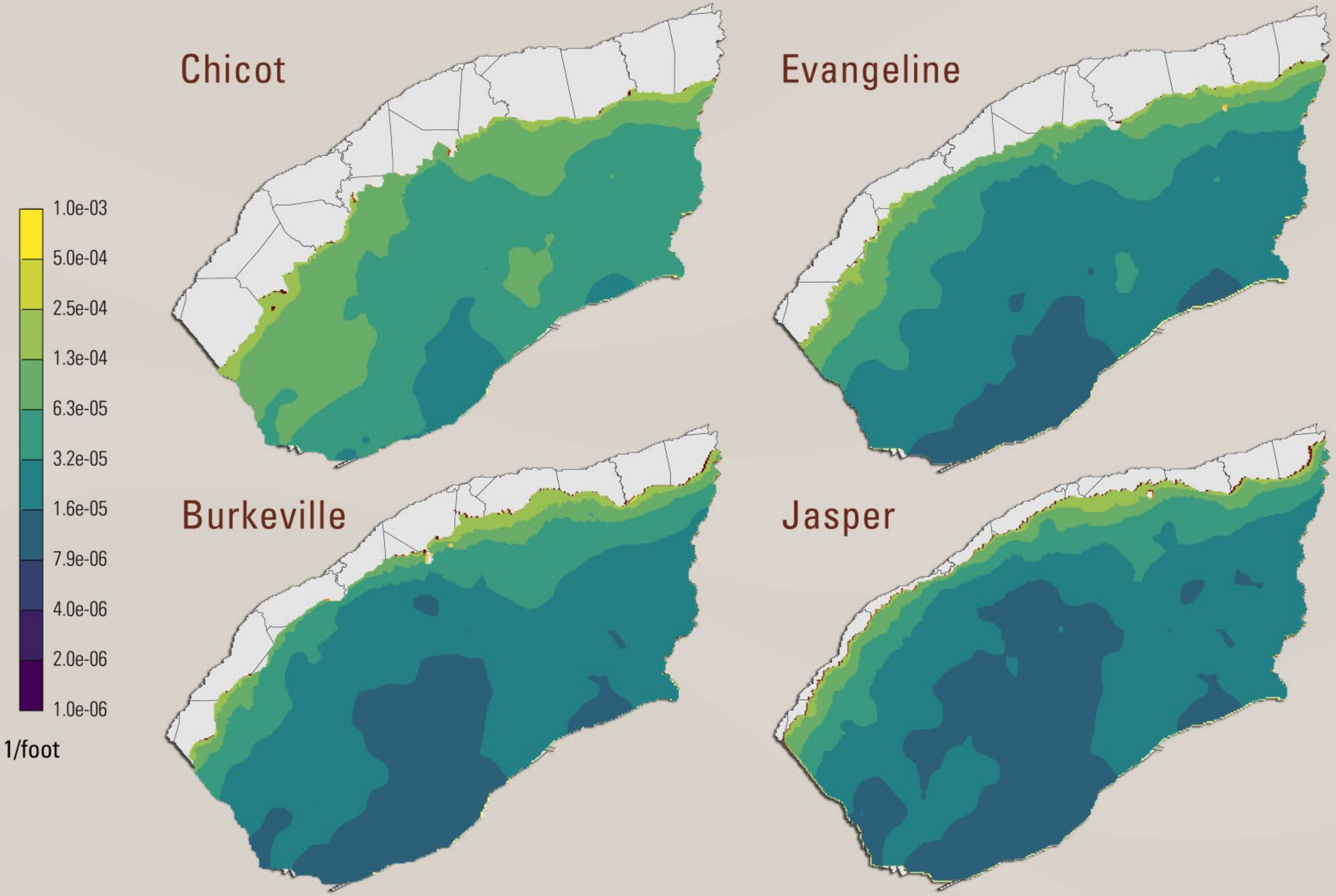


Parameters

PRELIMINARY RESULTS

Interbed inelastic spec. storage

- Chicot aquifer
  - Mean: $6.2E^{-5}$ ft^{-1}
- Evangeline aquifer
  - Mean: $3.7E^{-5}$ ft^{-1}
- Burkeville confining unit
  - Mean: $3.2E^{-5}$ ft^{-1}
- Jasper aquifer
  - Mean: $3.0E^{-5}$ ft^{-1}

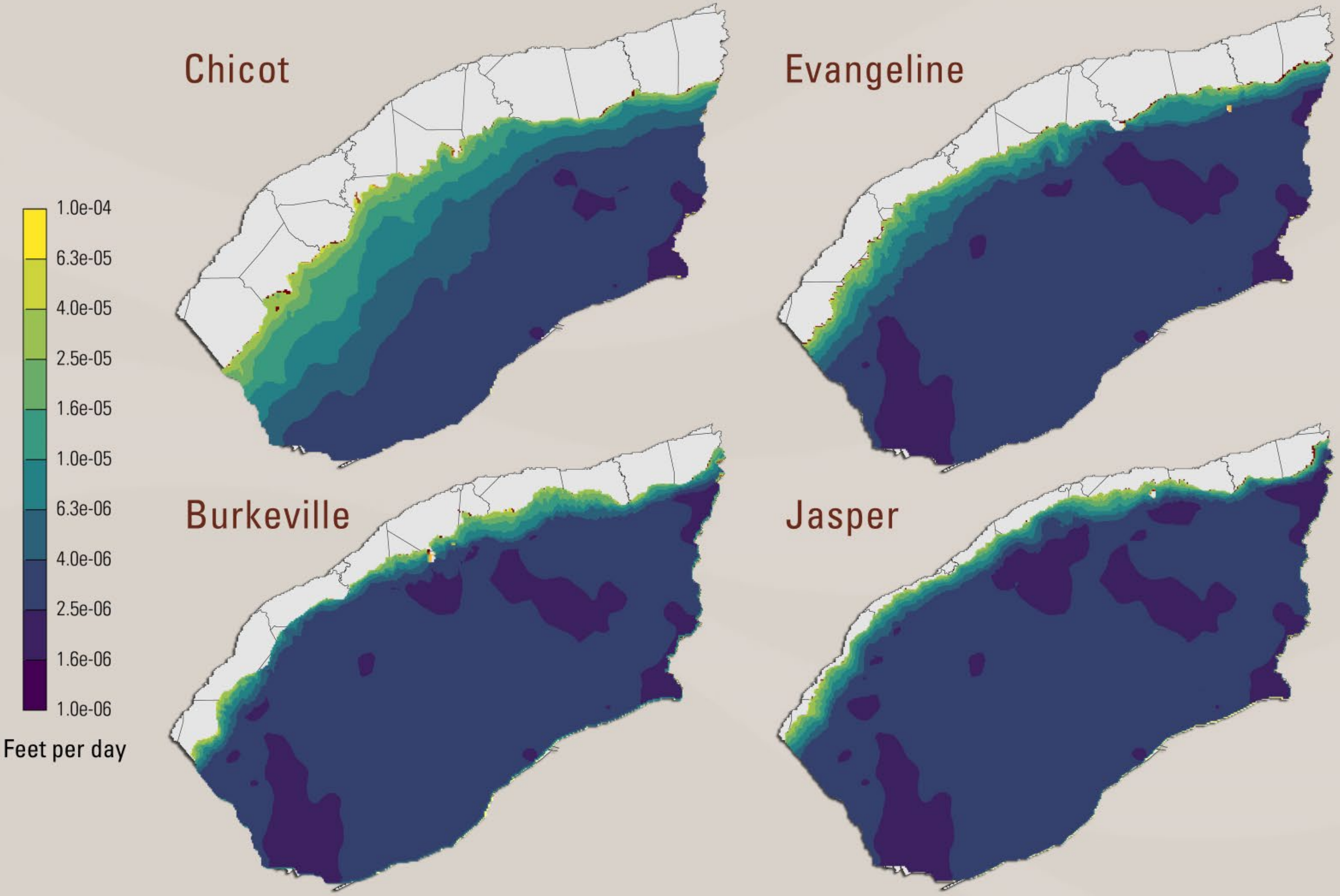


Parameters

PRELIMINARY RESULTS

Interbed vertical hydraulic conductivity

- Chicot aquifer
  - Mean: $6.6E^{-6}$ ft/d
- Evangeline aquifer
  - Mean: $4.3E^{-6}$ ft/d
- Burkeville confining unit
  - Mean: $3.9E^{-6}$ ft/d
- Jasper aquifer
  - Mean: $3.9E^{-6}$ ft/d

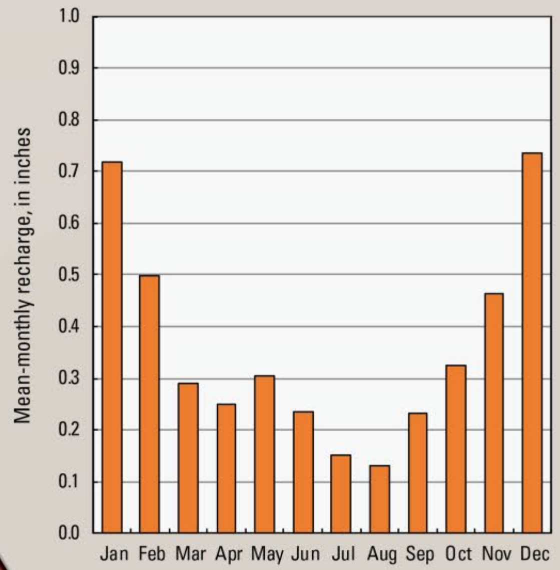


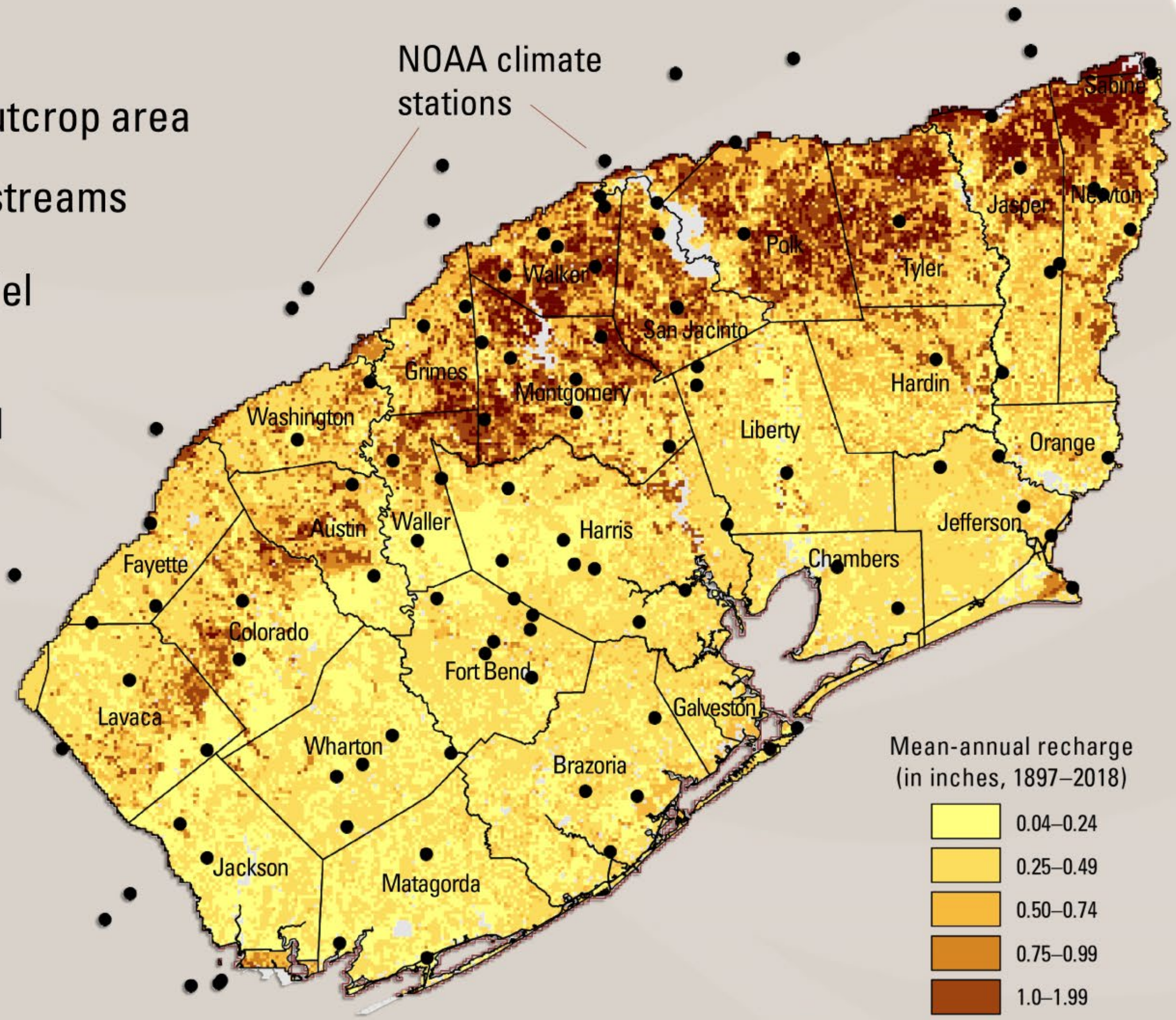
Recharge

PRELIMINARY RESULTS

Calibrated recharge

- SWB-derived recharge occurs primarily in aquifer outcrop area
- Majority of the estimated recharge is discharged to streams
- Spatially-distributed recharge at right applied to model layer 1.
- Deep recharge (next slide) is net flux between layer 1 and underlying layers





Recharge

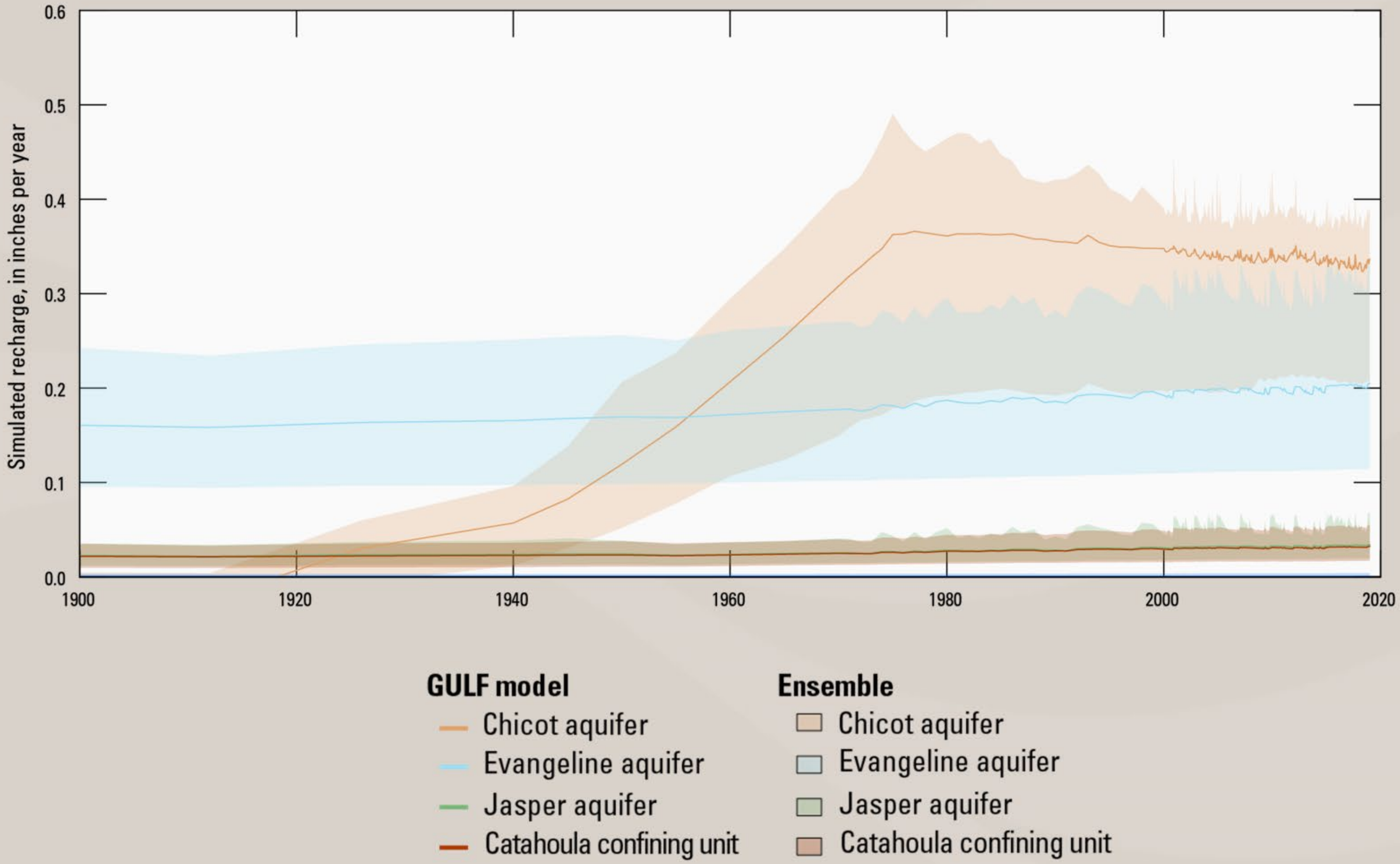
PRELIMINARY RESULTS

Deep recharge (mean annual):

- Chicot: 0.31 inches
- Evangeline: 0.19 inches
- Jasper: 0.03 inches
- Catahoula: 0.03 inches

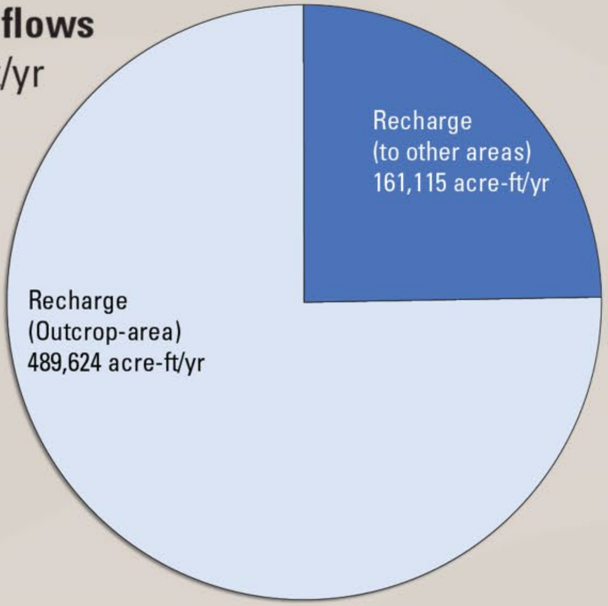
Comparison:

- Chicot:
  - HAGM: 0.56 inches (2009)
  - NGC-GAM: 0.4, 0.55 inches (1977, 2000)
- Evangeline:
  - HAGM: 0.23 inches (2009)
  - NGC-GAM: 0.12, 0.11 inches (1977, 2000)
- Jasper
  - HAGM: 0.07 inches (2009)
  - NGC-GAM: 0.06, 0.07 inches (1977, 2000)

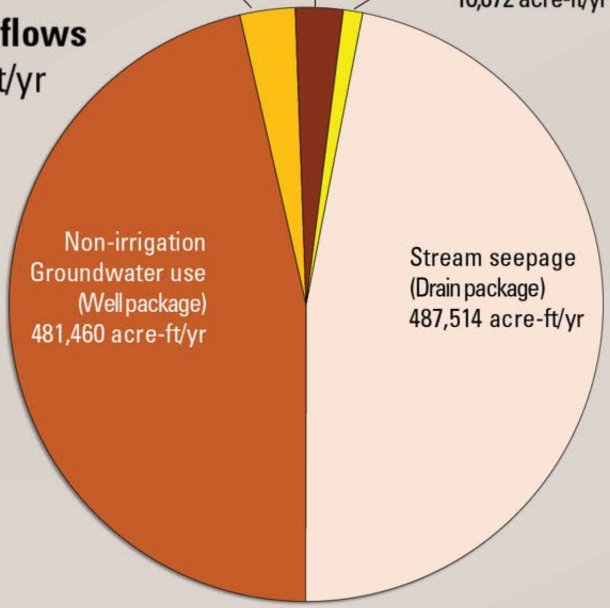


Water Budget

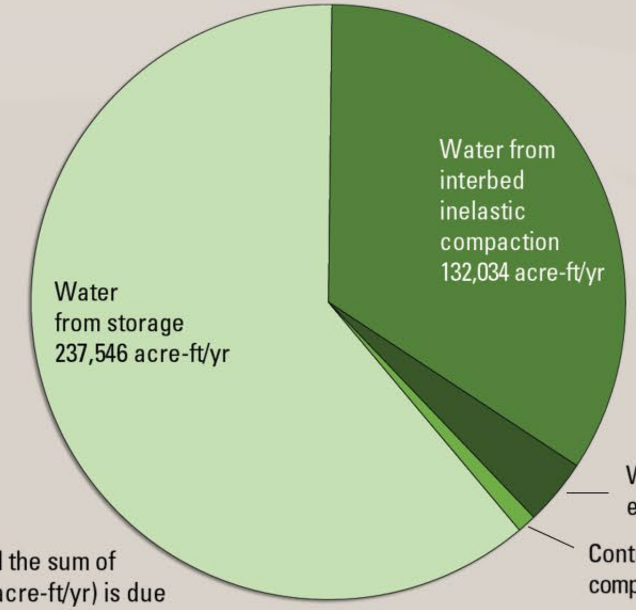
GULF model inflows
650,739 acre-ft/yr



GULF model outflows
1,037,903 acre-ft/yr



GULF model change in storage
Total: 387,501 acre-ft/yr



The difference between the outflows and the sum of the inflows and change in storage (337 acre-ft/yr) is due to water from interbed elastic compaction and solver error

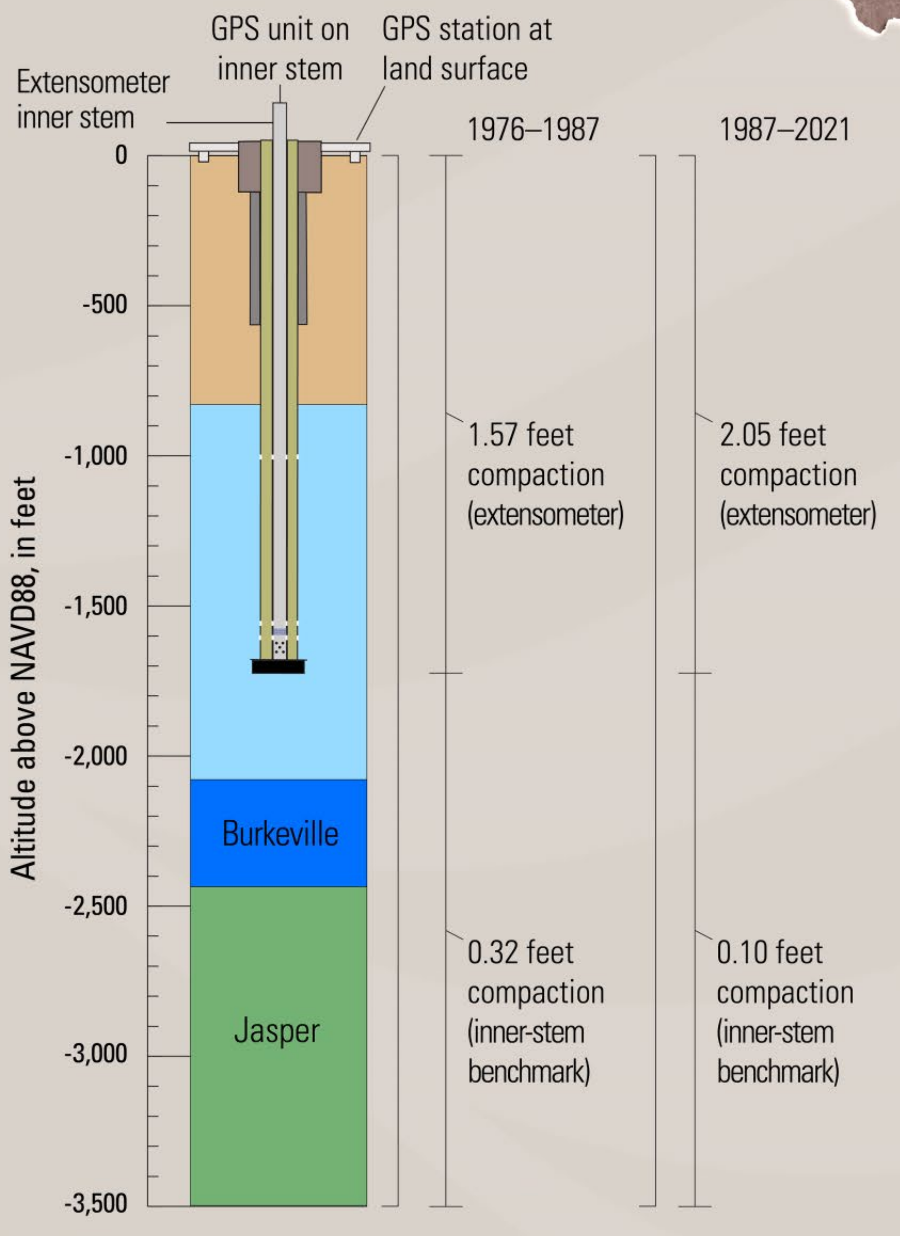
Deep-seated compaction

PRELIMINARY RESULTS

Addicks extensometer

- Cumulative compaction of 0.37–0.42 ft in sediment below the extensometer inner stem between 1978 and 2021.

1976–87		1987–2021	
K 1226:	1.86 ft subsidence	K 1226:	NA ft subsidence
Extensometer:	1.57 ft compaction	Extensometer:	2.05 ft compaction
Inner stem BM:	0.32 ft compaction	Inner Stem BM:	0.10 ft compaction



Chicot Evangeline Burkeville Jasper

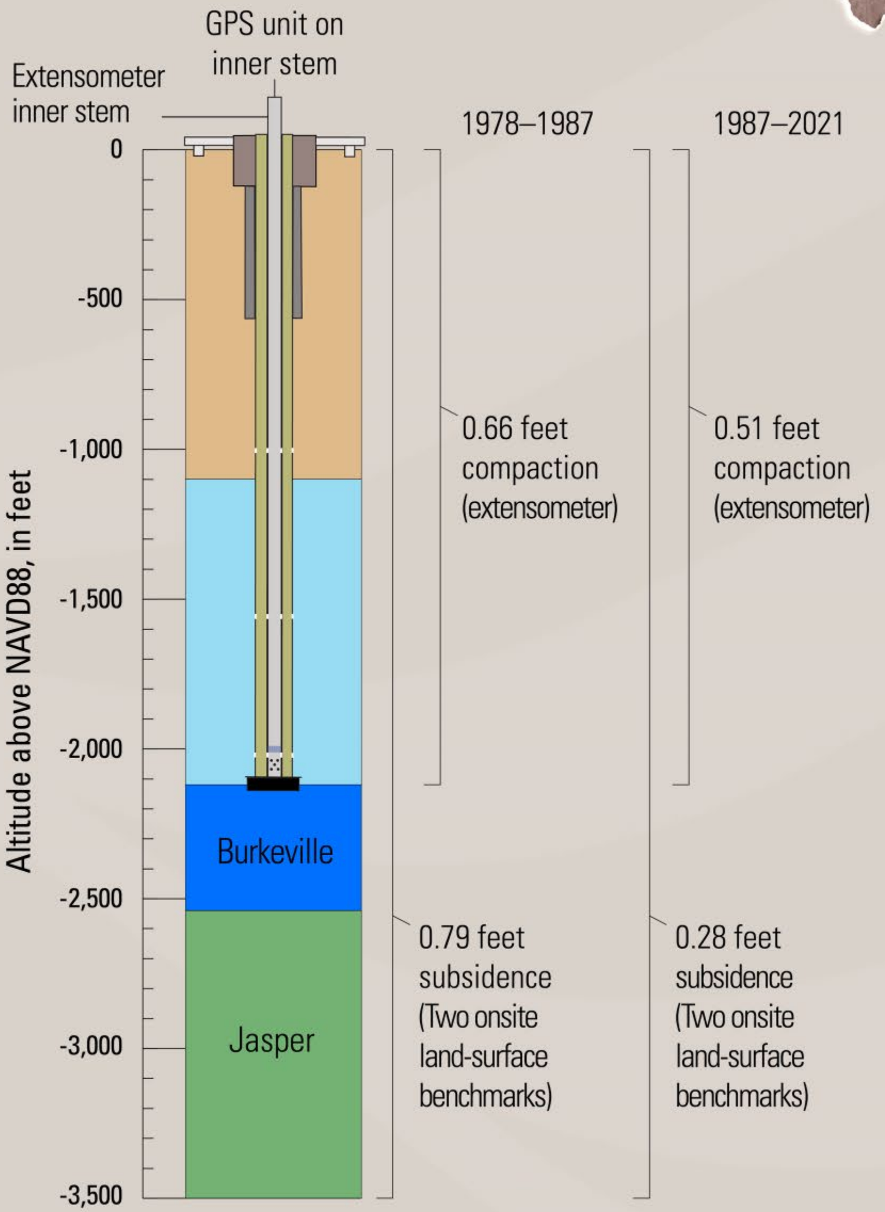
About 370 ft of Evangeline aquifer sediment below the extensometer anchor depth

Deep-seated compaction

PRELIMINARY RESULTS

Northeast extensometer

- Net compaction of zero in sediment below the extensometer inner stem between 1978 and 2021.



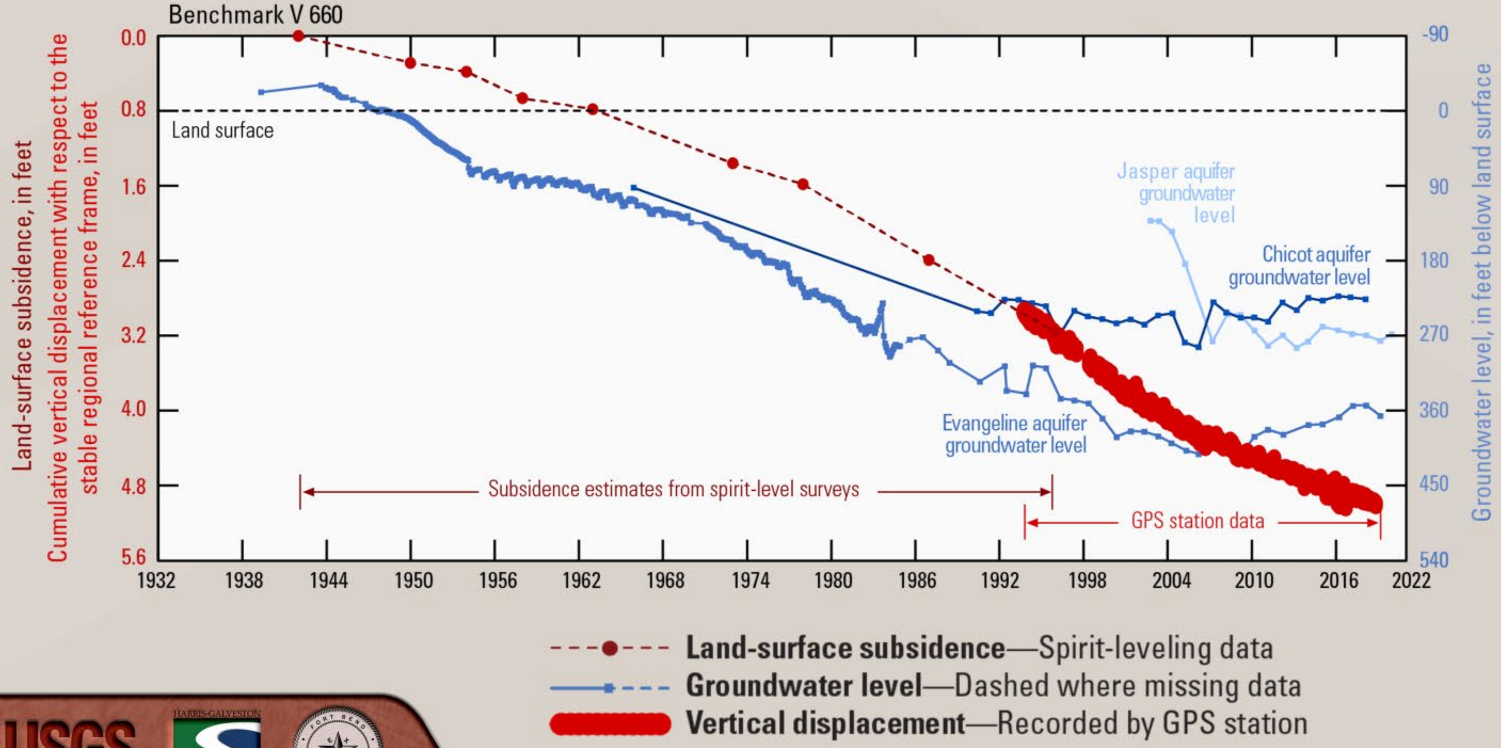
1978–87		1987–2021	
W 1278 | V 1278:	0.79 ft subsidence	W 1278 | V 1278:	0.28 ft subsidence
Extensometer:	0.66 ft compaction	Extensometer:	0.51 ft compaction
Deep interval:	0.13 ft compaction	Inner stem BM:	-0.14 ft compaction

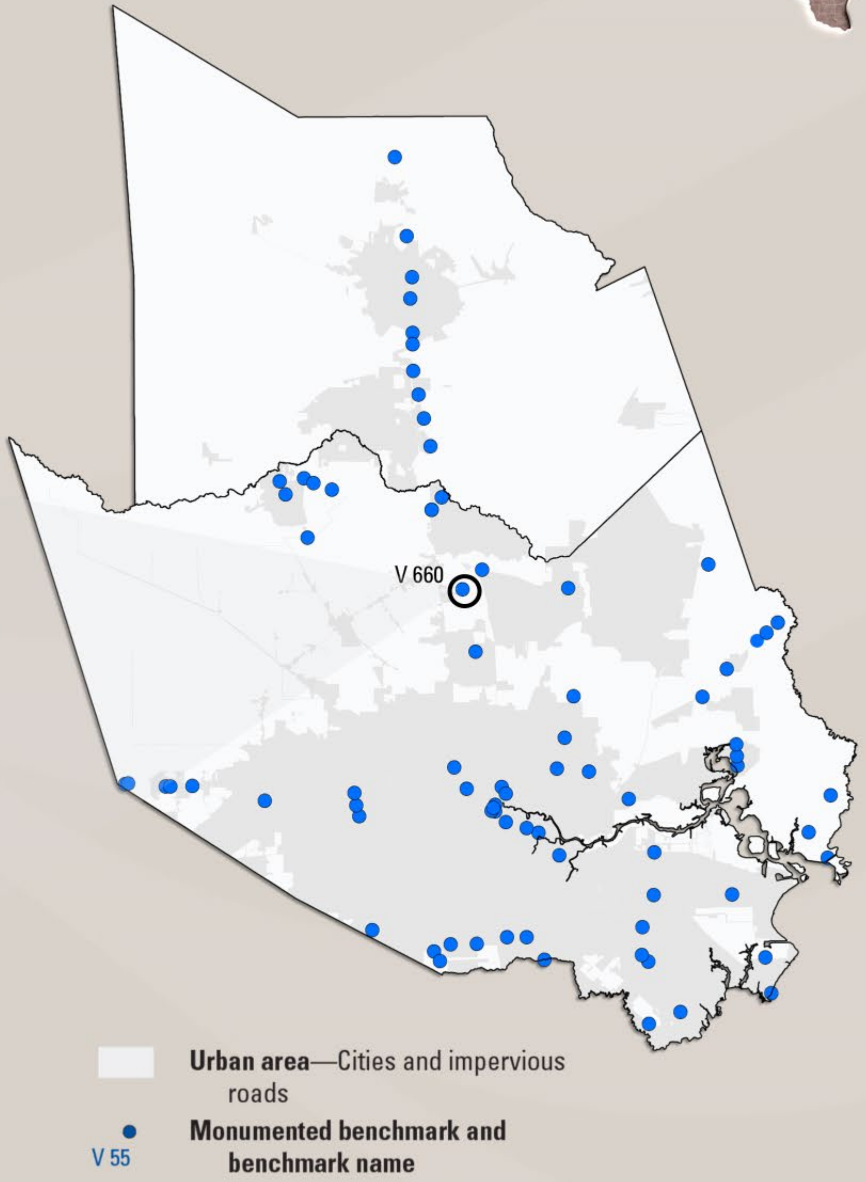
Chicot | Evangeline | Burkeville | Jasper

Cumulative subsidence

PRELIMINARY RESULTS

- Benchmark V 660: 5.2 feet of subsidence through 2021
- Similarities between water level declines and subsidence from 1943 to 1996.
- After 1996, residual compaction occurring due to water levels remaining near historical minimums

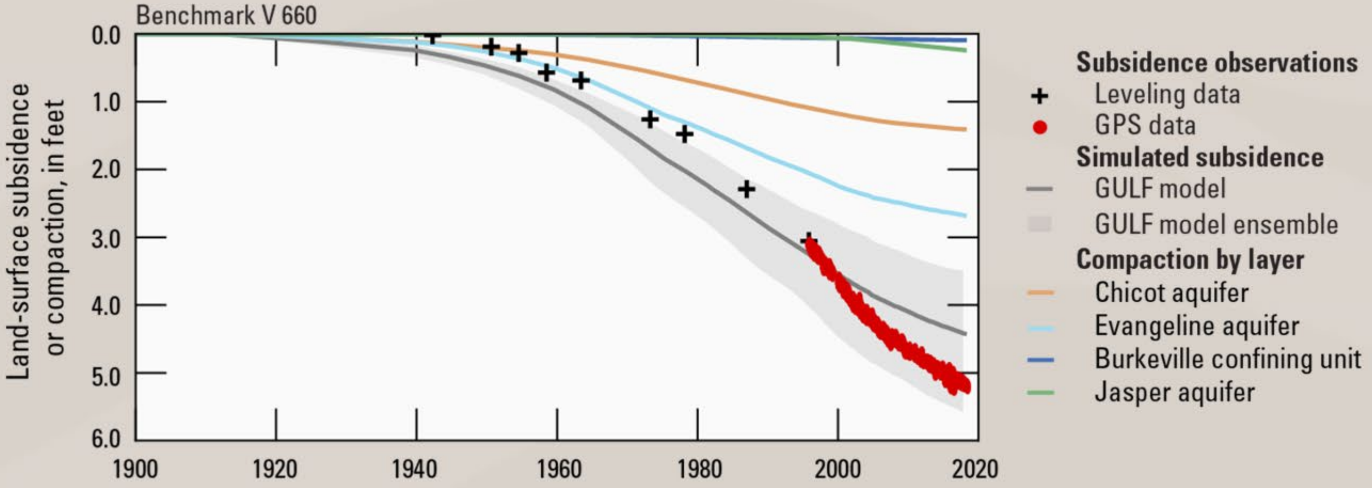


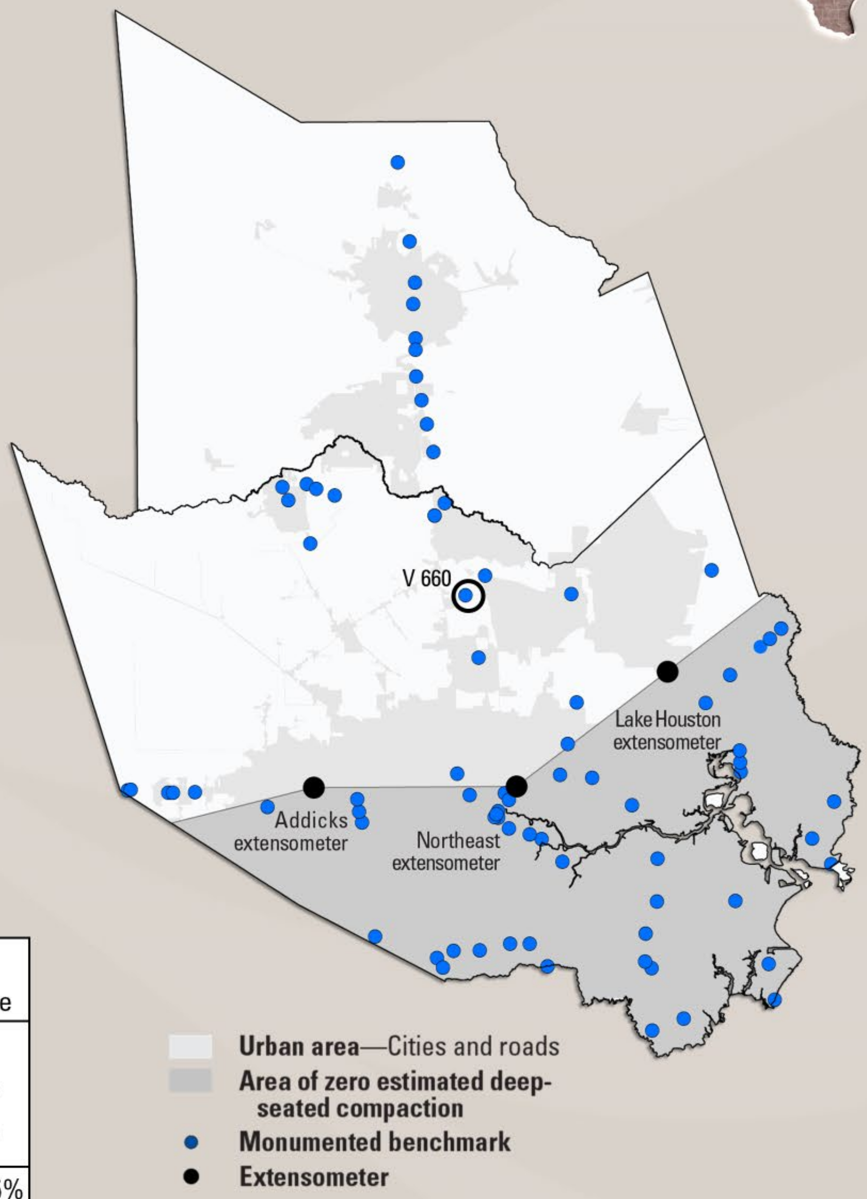


Cumulative compaction

Simulated Jasper aquifer compaction – V 660

- 0.2 feet, or 5 percent of simulated subsidence
- The top of the Jasper aquifer in this area is at -1,650 feet above NAVD 88
- Similar to the Clear Lake extensometer, where only 3 percent of compaction occurs below -1,722 feet above NAVD 88



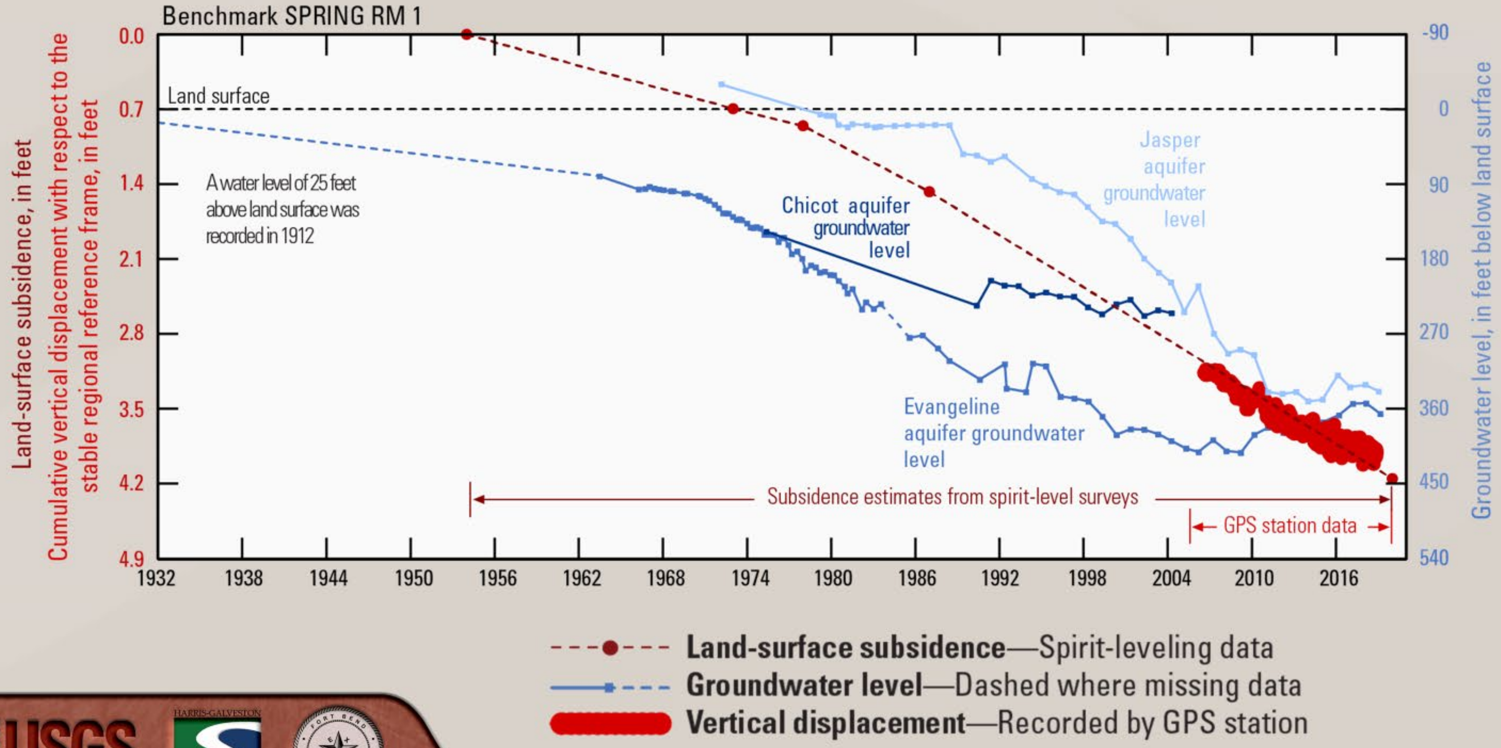


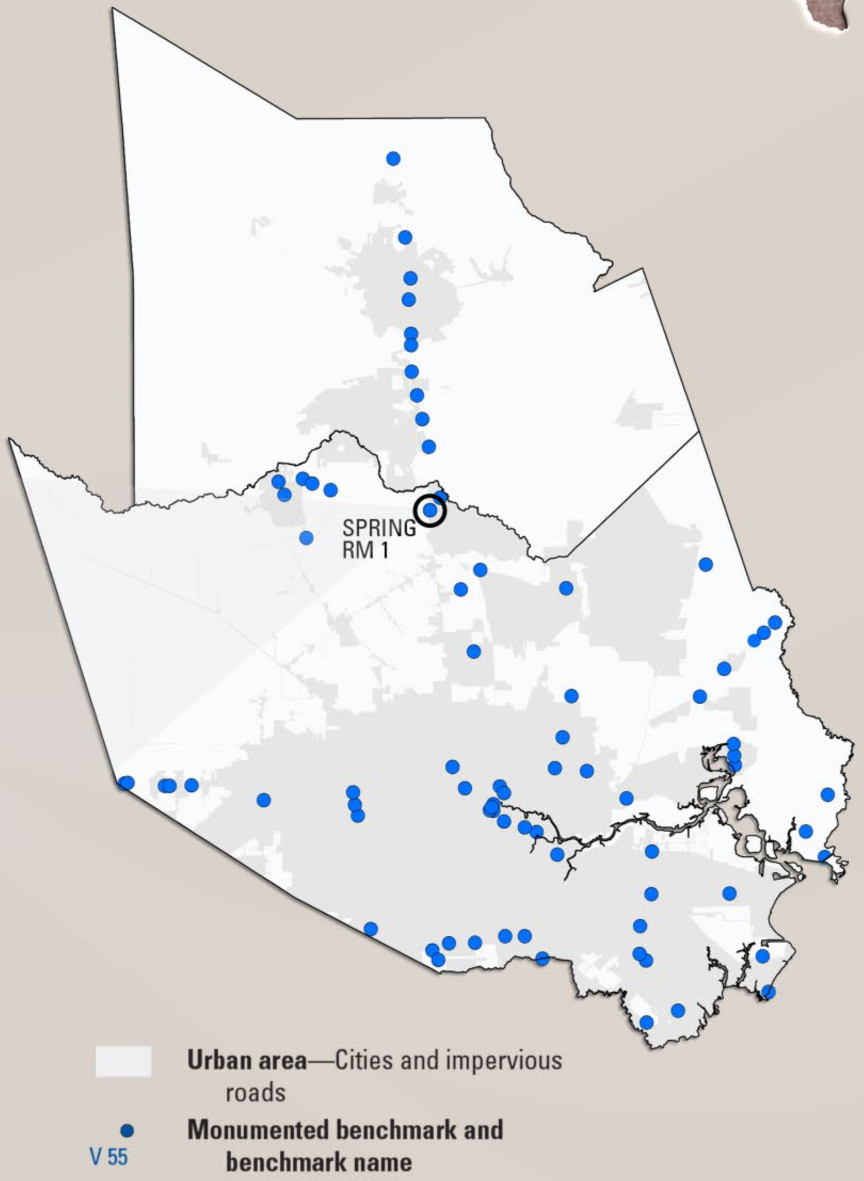
Benchmark	County	Simulated hydrogeologic unit compaction as a percentage of simulated land-surface subsidence			
		Layer 2 (Chicot aquifer)	Layer 3 (Evangeline aquifer)	Layer 4 (Burkeville confining unit)	Layer 5 (Jasper aquifer)
V 660	Harris	32%	61%	2%	5%

Cumulative subsidence

PRELIMINARY RESULTS

- Benchmark SPRING RM 1: 4.2 feet of subsidence through 2021
- Subsidence not expected at this site prior to 1954 based on leveling data at a nearby benchmark
- Greater Jasper aquifer groundwater-level decline compared to benchmark V 660

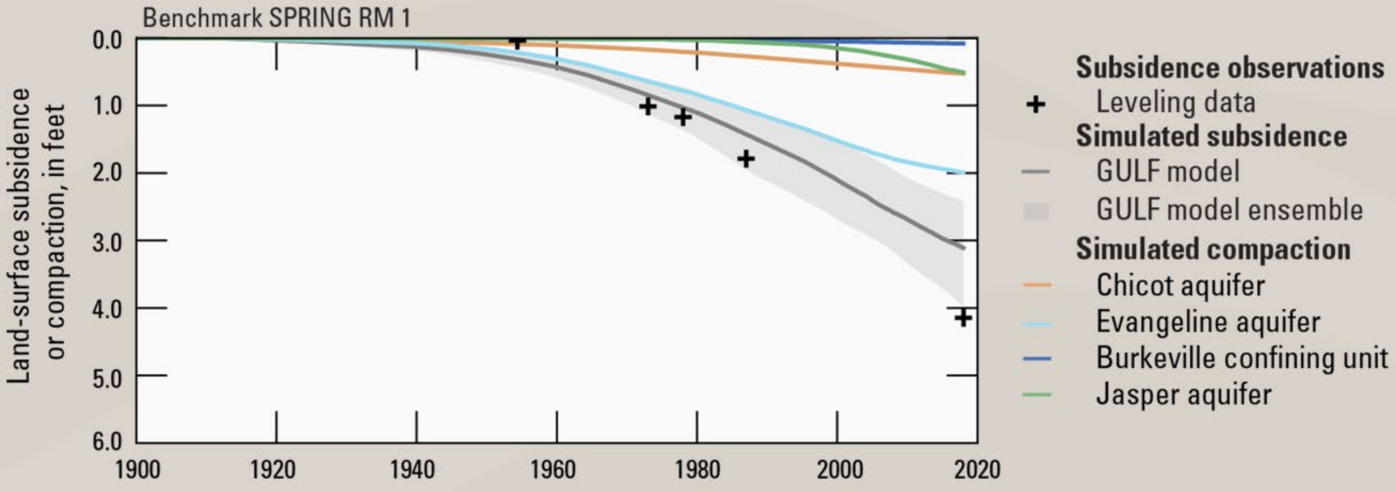


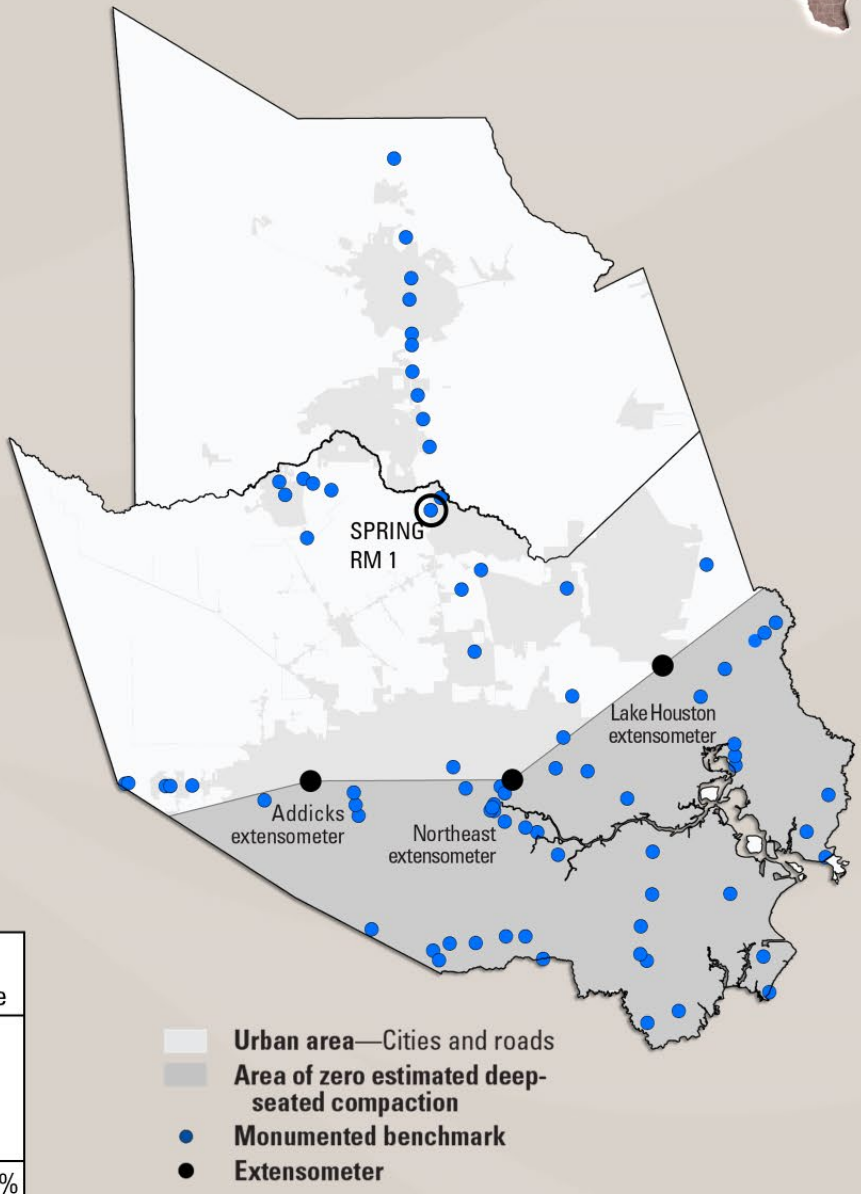


Cumulative compaction

Simulated Jasper aquifer compaction – SPRING RM 1

- 0.5 feet, or 16 percent of simulated subsidence
- The top of the Jasper aquifer in this area is at -1,350 feet above NAVD 88, or 300 feet shallower than at benchmark V 660

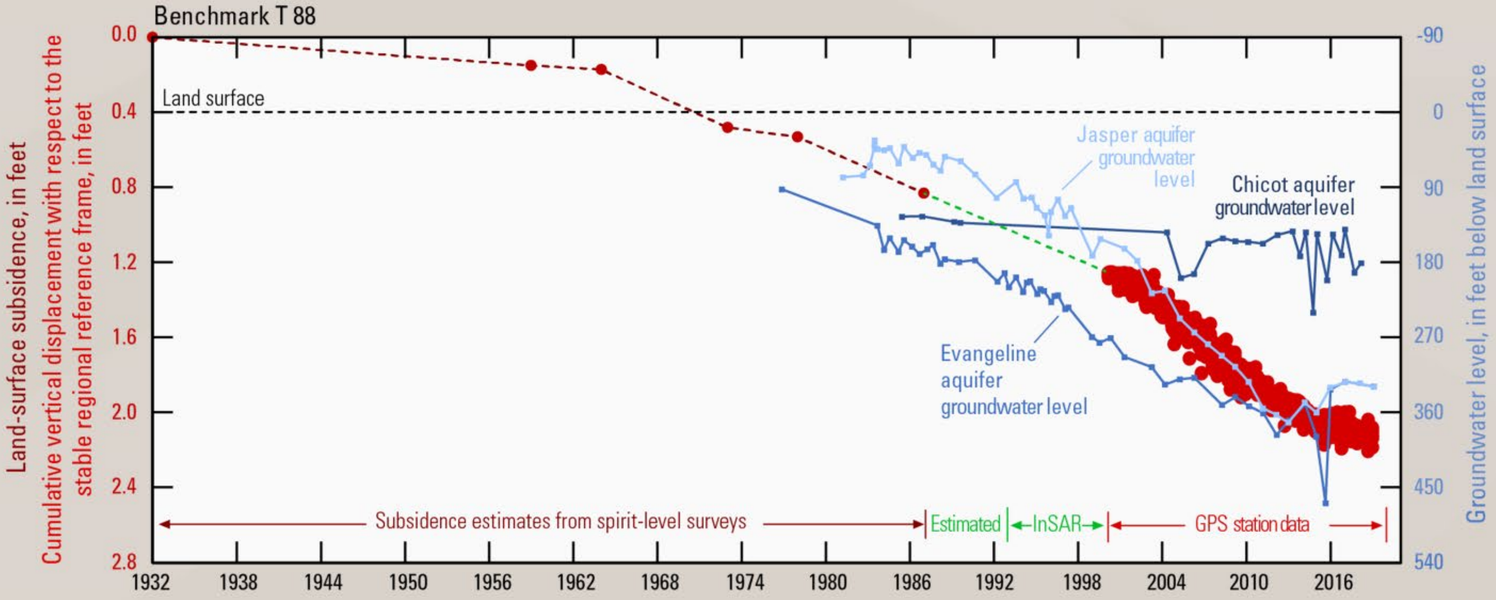




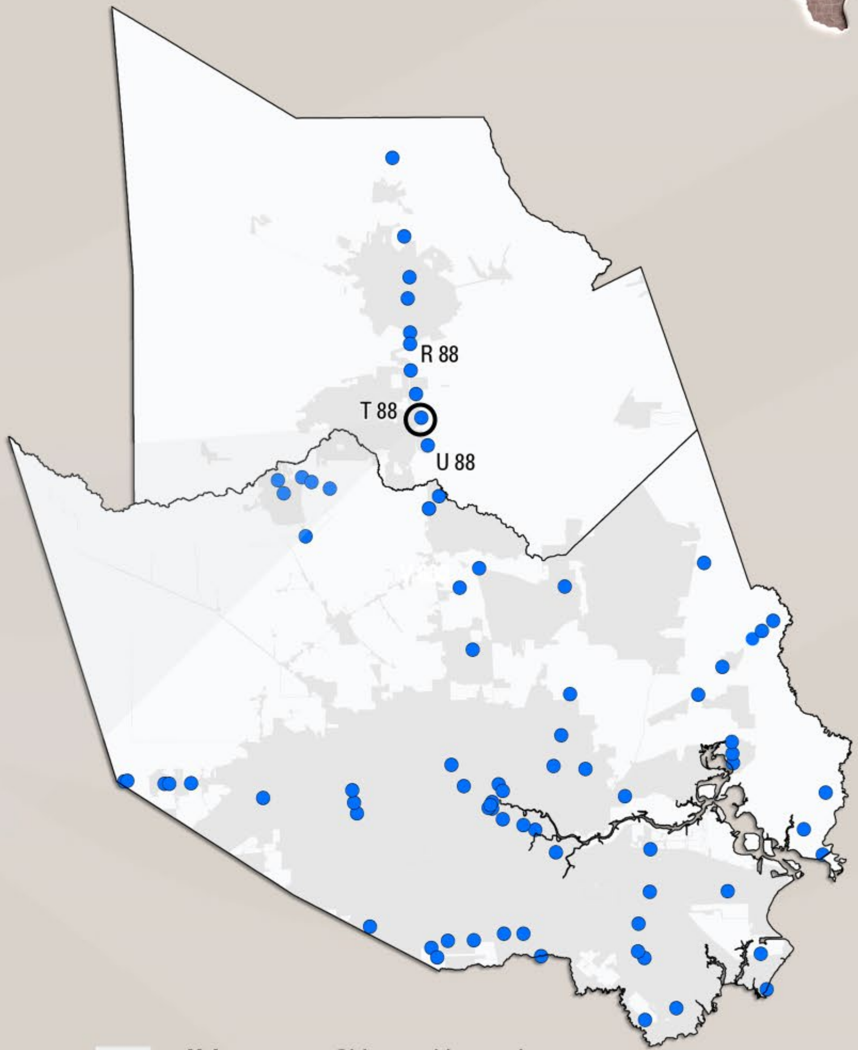
Benchmark	County	Simulated hydrogeologic unit compaction as a percentage of simulated land-surface subsidence			
		Layer 2 (Chicot aquifer)	Layer 3 (Evangeline aquifer)	Layer 4 (Burkeville confining unit)	Layer 5 (Jasper aquifer)
SPRING RM 1	Harris	16%	65%	3%	16%

Cumulative subsidence

- Benchmark T 88: 2.2 feet of subsidence through 2021
- Range of estimated subsidence in The Woodlands along I-45:
  - Benchmark R 88: 1.3 feet
  - Benchmark U 88: 2.5 feet
- Similar Jasper aquifer groundwater-level decline compared to benchmark SPRING RM 1



Land-surface subsidence—Spirit-leveling data
Groundwater level—Dashed where missing data
Vertical displacement—Recorded by GPS station
Land-surface subsidence—InSAR interferograms



Urban area—Cities and impervious roads

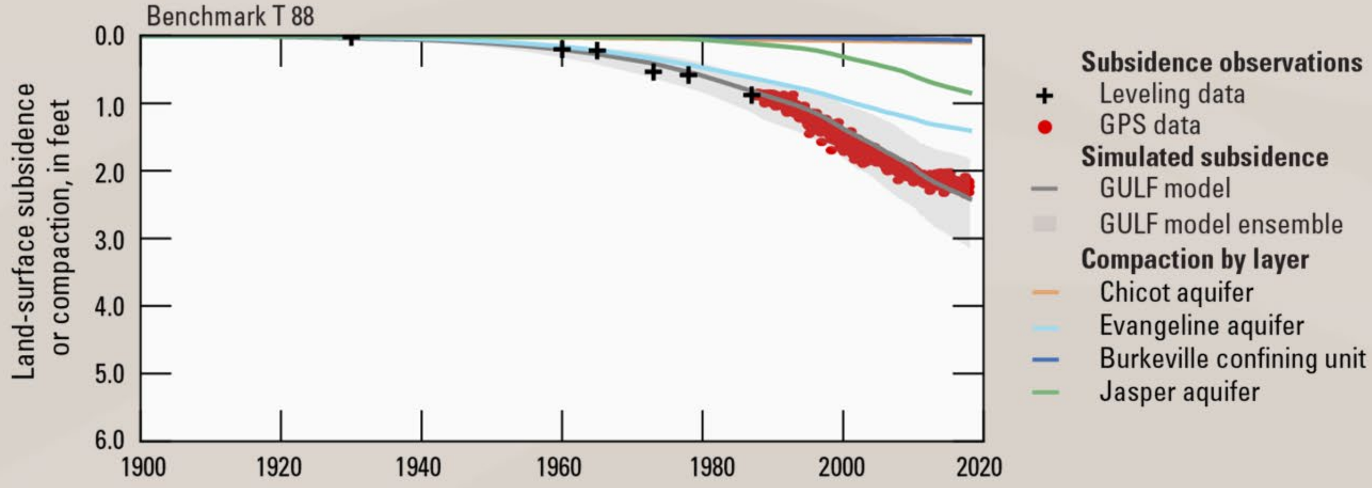
V 55 **Monumented benchmark and benchmark name**

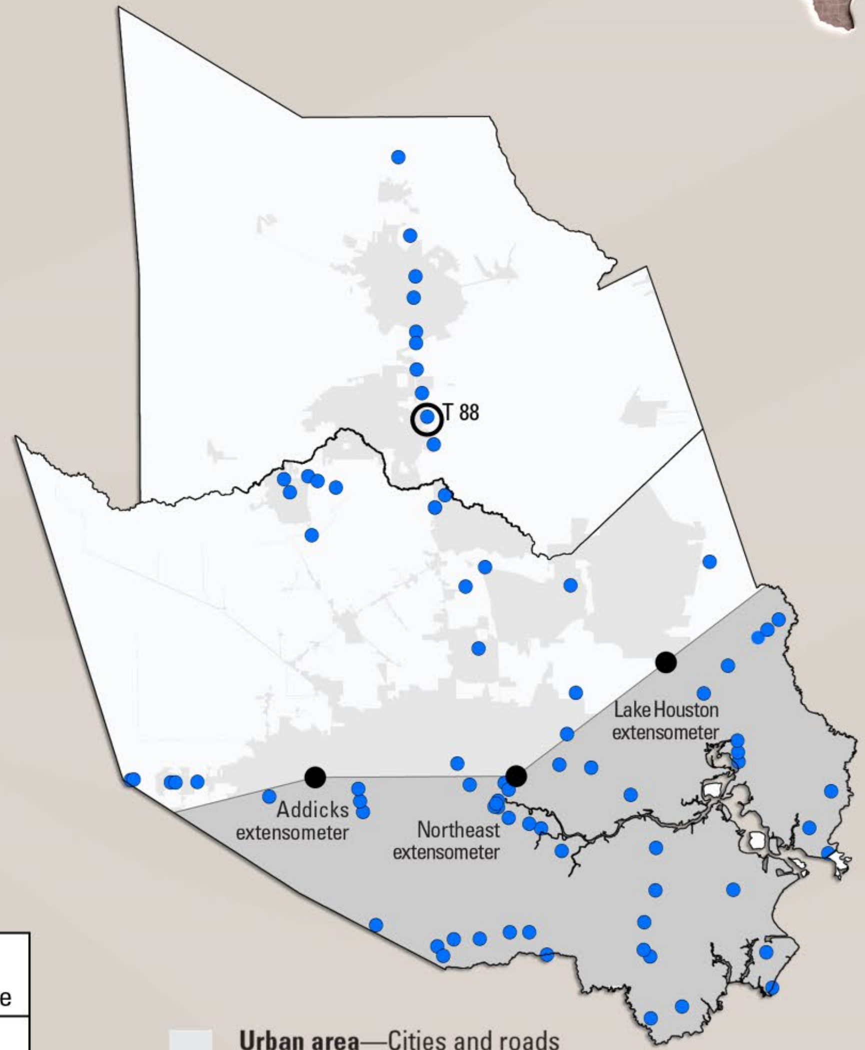
Cumulative compaction

PRELIMINARY RESULTS

Jasper aquifer compaction – T 88

- 0.8 feet, or 33 percent of simulated subsidence
- The top of the Jasper aquifer in this area is at -1,100 feet above NAVD 88, or about 250 feet shallower than at benchmark SPRING RM 1





Benchmark	County	Simulated hydrogeologic unit compaction as a percentage of simulated land-surface subsidence			
		Layer 2 (Chicot aquifer)	Layer 3 (Evangeline aquifer)	Layer 4 (Burkeville confining unit)	Layer 5 (Jasper aquifer)
T 88	Montgomery	4%	58%	3%	33%

The percentage of compaction by hydrogeologic unit does not sum to 100 percent due to rounding

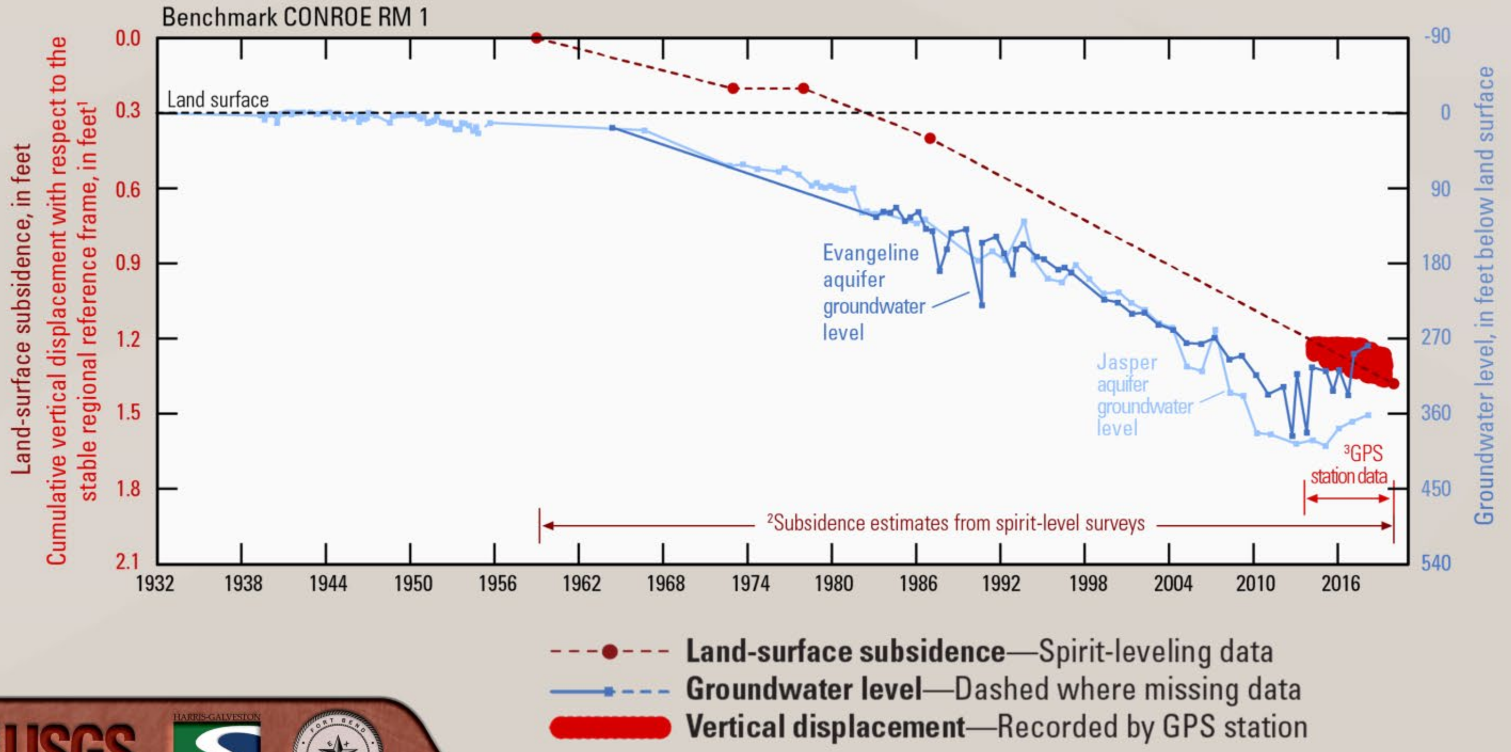
USGS science for a changing world

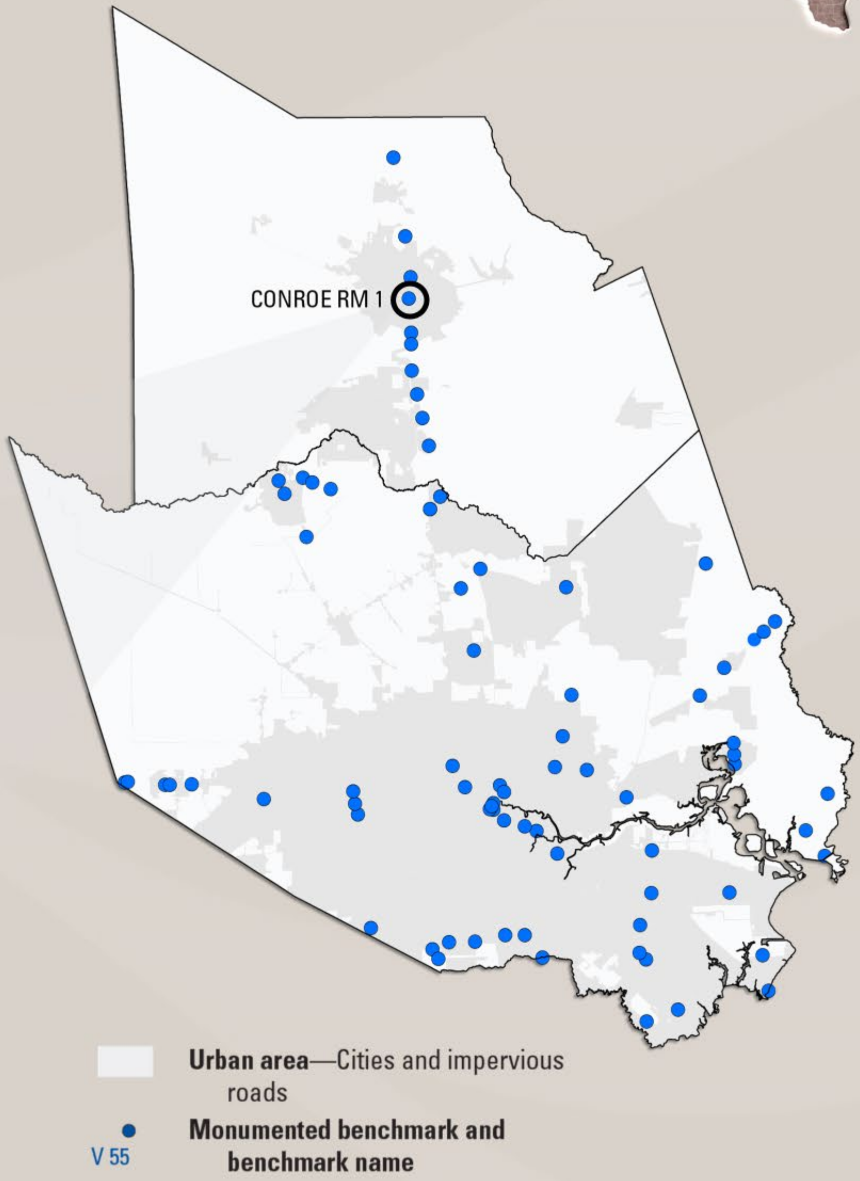
HARRIS-GALVESTON SUBSIDENCE DISTRICT

Cumulative subsidence

PRELIMINARY RESULTS

- Benchmark CONROE RM 1: 1.5 feet of subsidence through 2021
- 1.4 feet of subsidence from benchmark reoccupation, 0.1 feet subsidence occurred prior to 1958 at nearby benchmarks
- Greater Jasper aquifer groundwater-level decline compared to benchmarks T 88, SPRING RM 1, and V 660

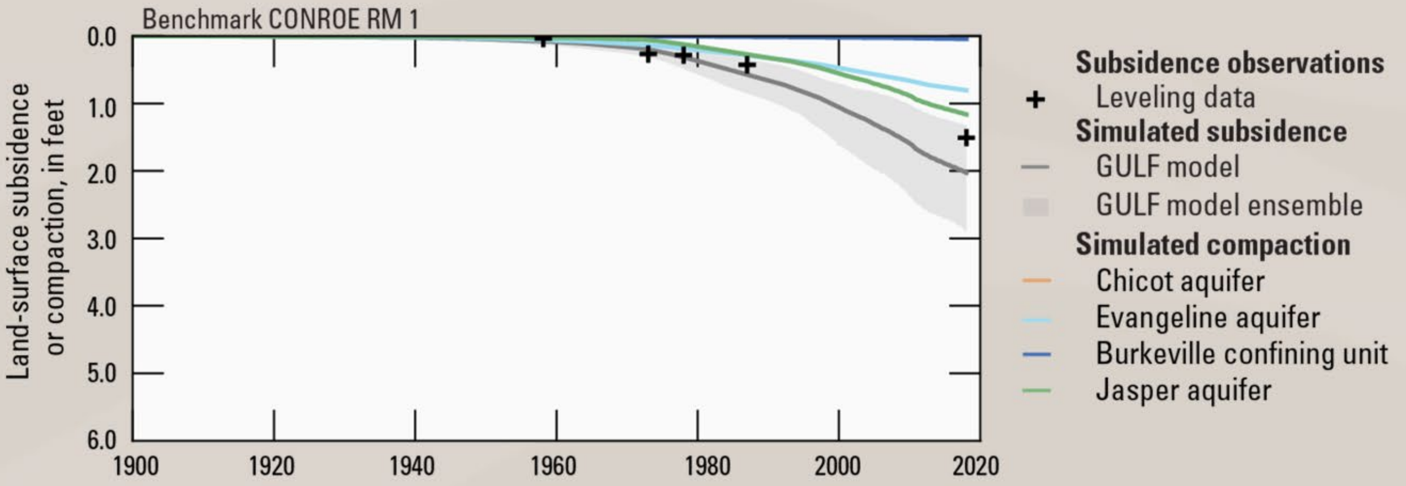


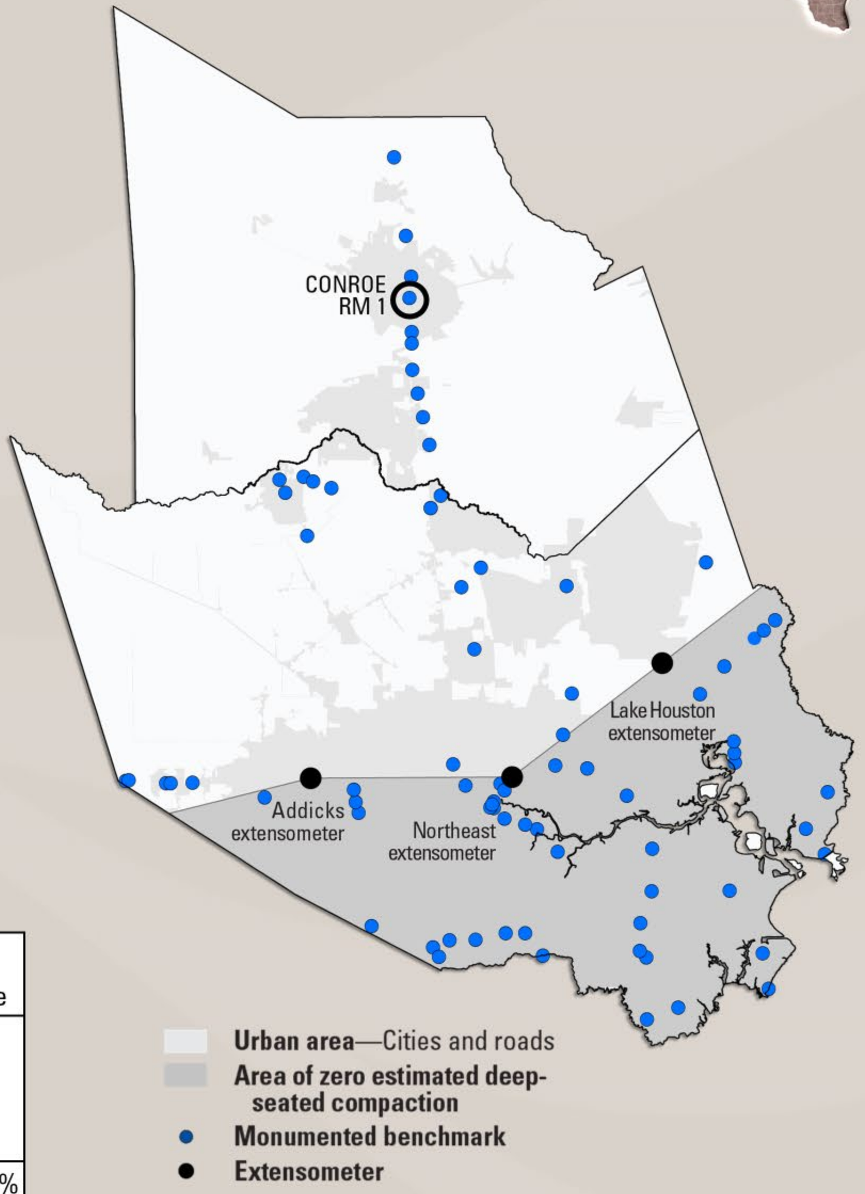


Cumulative compaction

Jasper aquifer compaction – CONROE RM 1

- 1.1 feet, or 57 percent of simulated subsidence
- The top of the Jasper aquifer in this area is at -700 feet above NAVD 88, or about 400 feet shallower than at benchmark T 88

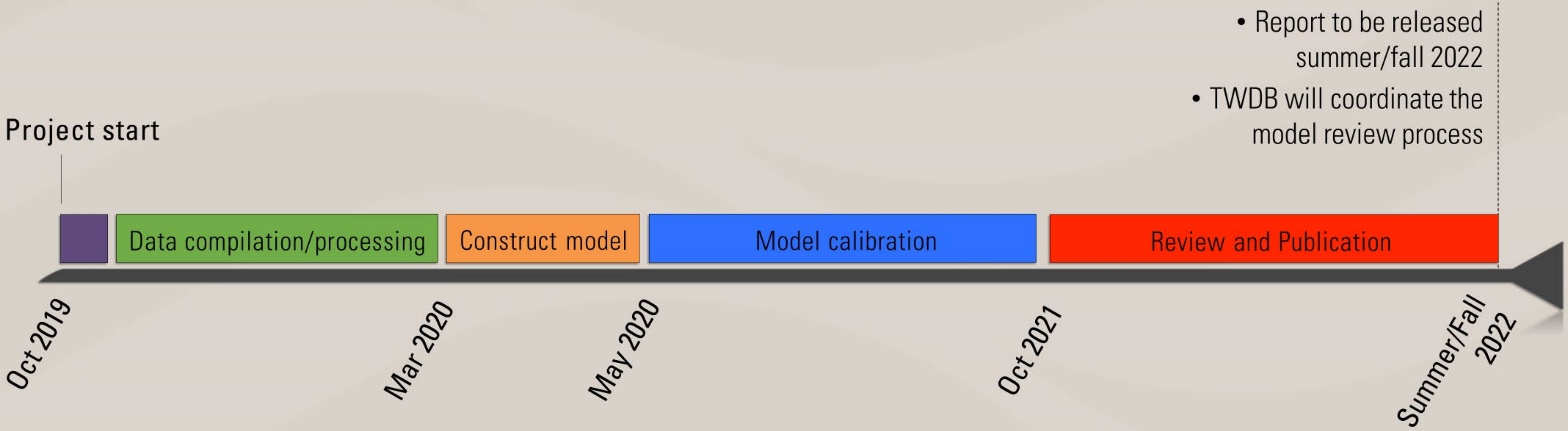




Benchmark	County	Simulated hydrogeologic unit compaction as a percentage of simulated land-surface subsidence			
		Layer 2 (Chicot aquifer)	Layer 3 (Evangeline aquifer)	Layer 4 (Burkeville confining unit)	Layer 5 (Jasper aquifer)
CONROE RM 1	Montgomery	1%	38%	2%	57%

The percentage of compaction by hydrogeologic unit does not sum to 100 percent due to rounding

Timeline



• Report to be released summer/fall 2022
• TWDB will coordinate the model review process
Project start
Data compilation/processing
Construct model
Model calibration
Review and Publication
Oct 2019
Mar 2020
May 2020
Oct 2021
Summer/Fall 2022

Groundwater Availability Model

GULF

2023

Gulf Coast Land Subsidence and Groundwater Flow Model

In cooperation with the Harris-Galveston Subsidence District
In cooperation with the Fort Bend Subsidence District

John Ellis | jellis@usgs.gov

Schedule and Next Steps

	GULF 2023 Model	Projected Water Needs	Alternative Water Supplies	PRESS Assessment	Water Use Scenarios
2020	Model Conceptual Report	Methodology, Model Updates	Overview of Alternatives	PRESS Model Validation	
2021	Complete Model Update	Population and Demand Projections	Technical Characterization, Final Report		
2022	Complete Model Update	Direct Stakeholder Process, Final Projections			Scenario Development
2023				Scenario Testing	Scenario Testing, Recommendations

STATUS

Upcoming Milestones

Q2 2022

- Population Projections

Questions and Answers

Thank you for attending the Joint Regulatory Plan Review Stakeholder Meeting

We appreciate your interest and engagement in this meeting.

If you have time, please take a moment to complete the survey at the end of this webinar. We will also include a link to the survey in a follow-up email if you cannot complete the survey now.