# Phase 2
# Subsidence Investigations

LSGCD Stakeholder Meeting

January 26, 2022

R W HARDEN & ASSOCIATES INC
GROUNDWATER RESOURCE PROFESSIONALS

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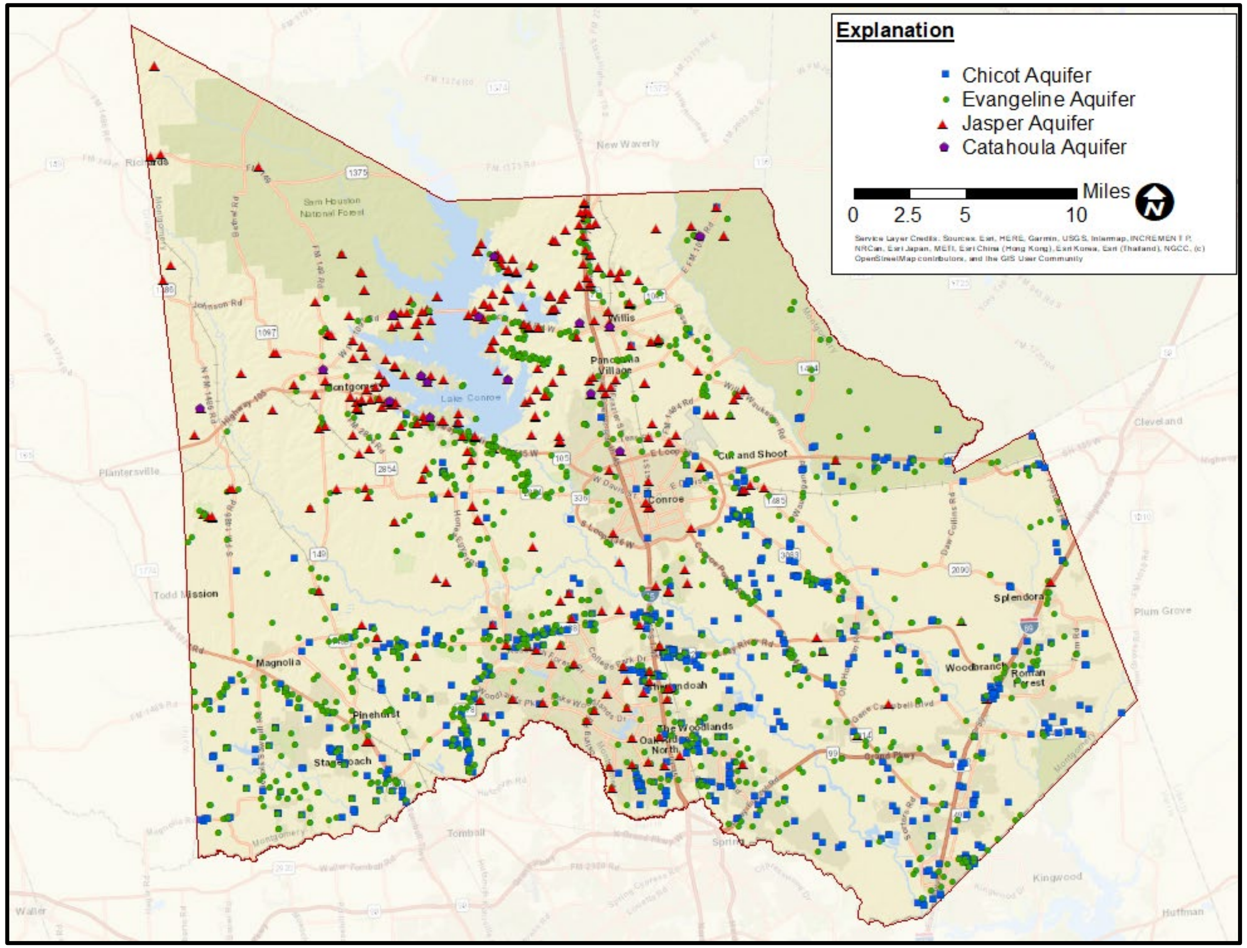
# LSGCD Subsidence Investigations Purpose

- “Control Subsidence”
  - Rule 1.3
  - Rule 1.15
- LSGCD Focus
- Methodical Approach



# LSGCD Subsidence Investigations

- Phase 1 – Background
  - Assessment of Past and Current Investigations
  - 2019-2020
- Phase 2 – Focused Evaluations
  - Specific items from Phase 1
  - 2021-2022
- Phase 3 – Site Specific Geotechnical
  - Real world data
  - 2022-2023
- Phase 4 – Monitoring

# Phase 2 Tasks

- Addressing specific items identified during Phase 1
- Task 1 – Evaluate Brackish Jasper Model (Kelley and others, 2018)
  - Basis for GULF-2023 Model
  - Applicability to Montgomery County
- Task 2 – Geologic Structure
  - Hydrostratigraphy
  - Lithology
- Task 3 – Combined Phase 2 Report
  - Address Comments
  - Recommendations and Plan for Phase 3 (Site-Specific Geotechnical Investigations)

# Phase 2 Subsidence Investigations – Task 1 Summary

Review of "Subsidence Risk Assessment and Regulatory Considerations for the Brackish Jasper Aquifer" by Kelley and others (2018)

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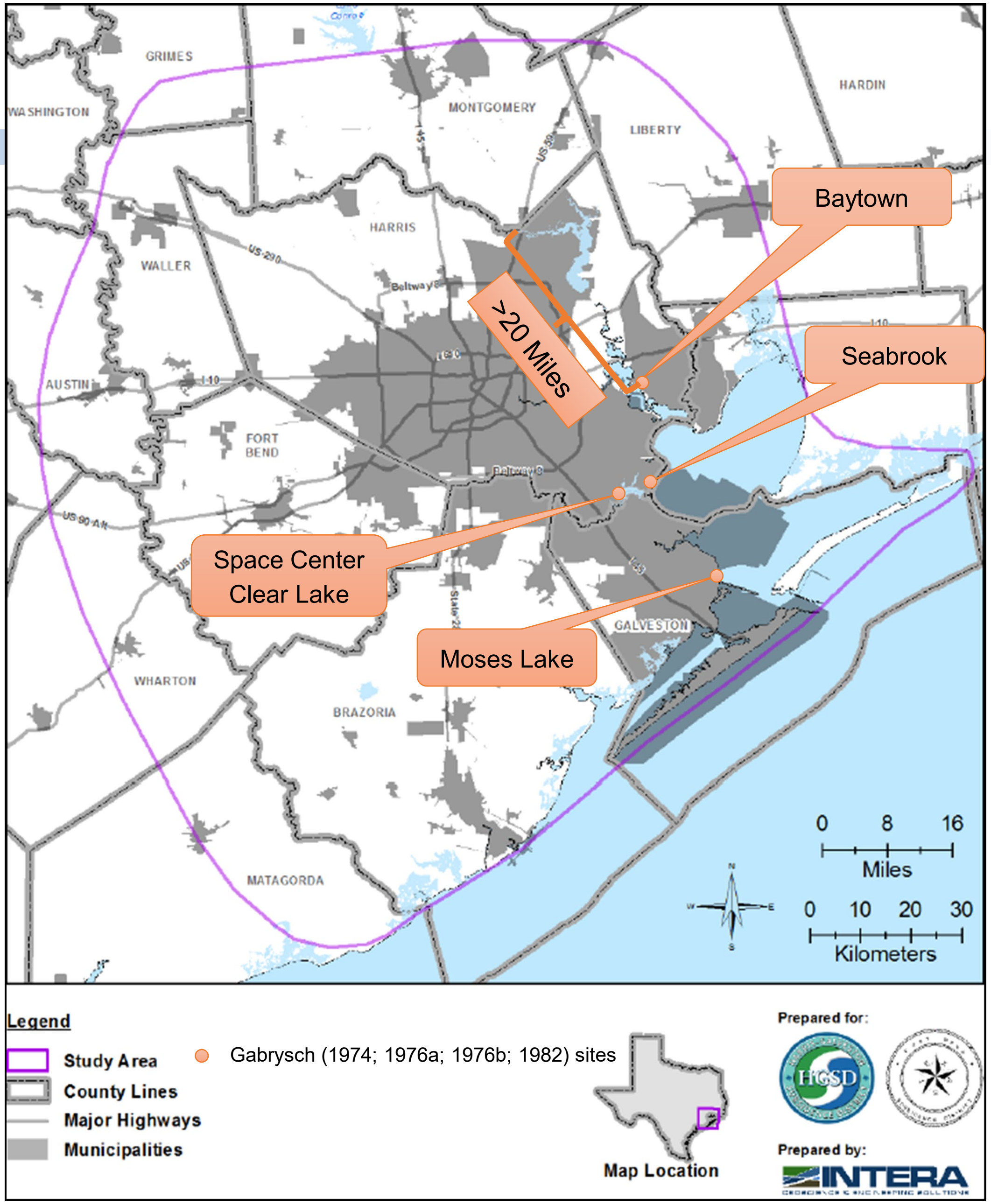
# Background

- ➢Focus on brackish Jasper Aquifer
- ➢Estimate "relative risk of subsidence"
- ➢Two objectives
  1. Assess potential subsidence risk associated with resource development
  2. Provide management guidance
- ➢Developed a model



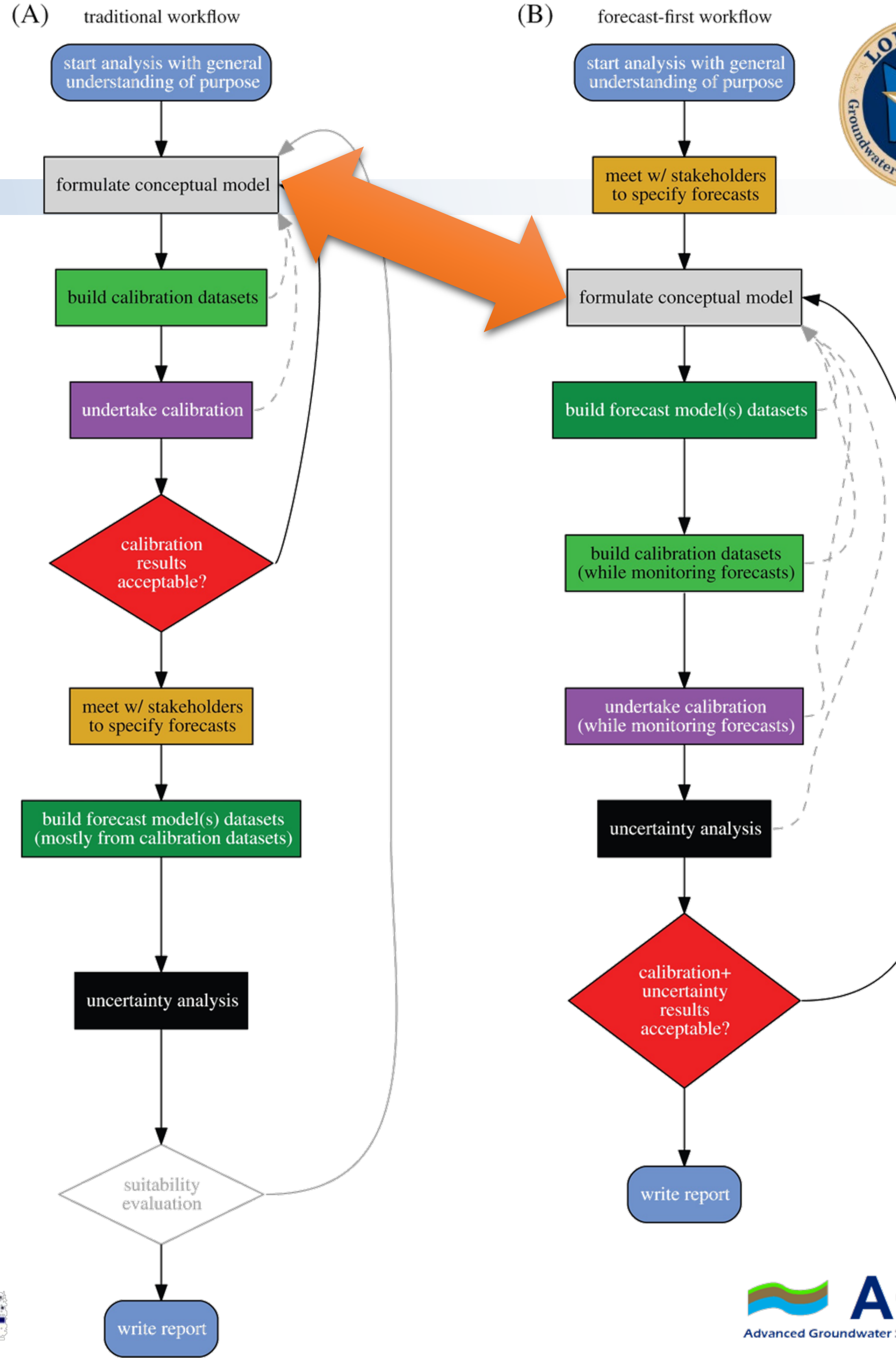

Study area identified by Kelley and others (2018) along with the sites discussed by Gabrysch and Bonnet (1974; 1976a; 1976b) and Gabrysch (1982). Modified from Kelley and others (2018).

# Groundwater Modeling

➢Focus on conceptual model

➢Conceptual errors/uncertainty flow through process

➢Numerical model based on conceptual model

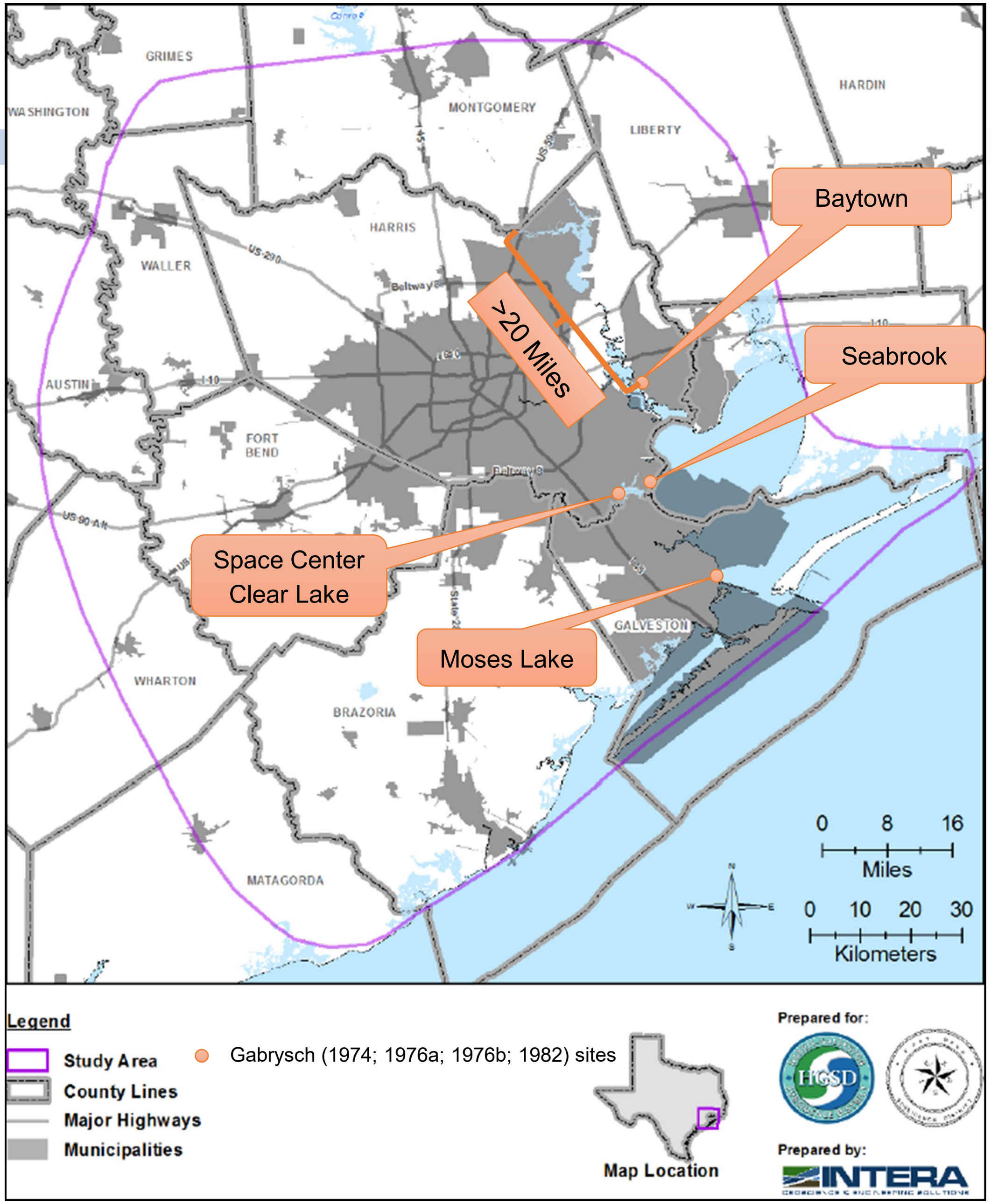



White, J. T., Forecast First: An Argument for Groundwater Modeling in Reverse, Groundwater, v. 55, 5, pp 660-664.

# Site-Specific Data

- U.S. Geological Survey
  - Gabrysch and Bonnet (1974; 1976a; 1976b)
  - Gabrysch (1982)
- Samples and data are from the Chicot and Evangeline

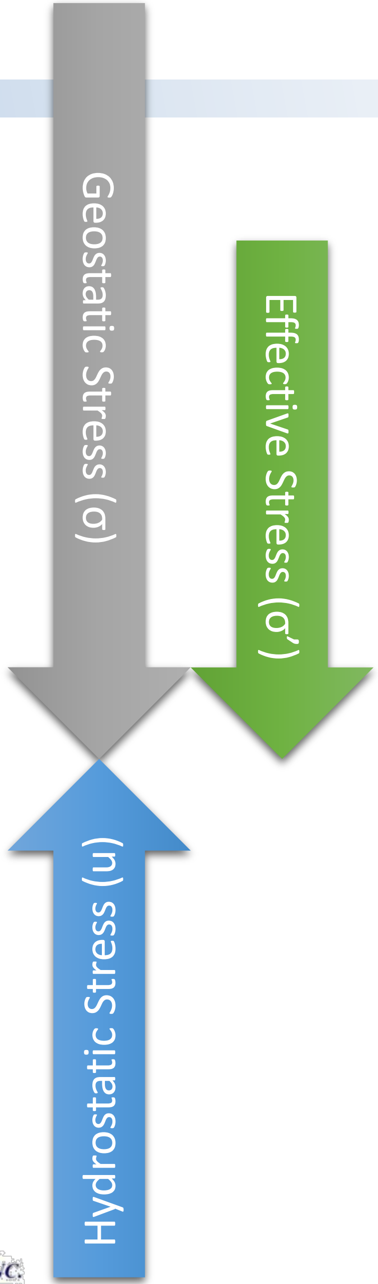
“none of the physical measurements … have been collected at depths representative of the brackish Jasper Aquifer in the Districts.… Properties controlling compaction of the brackish Jasper Aquifer should be considered uncertain.” (Kelley and others, 2018)

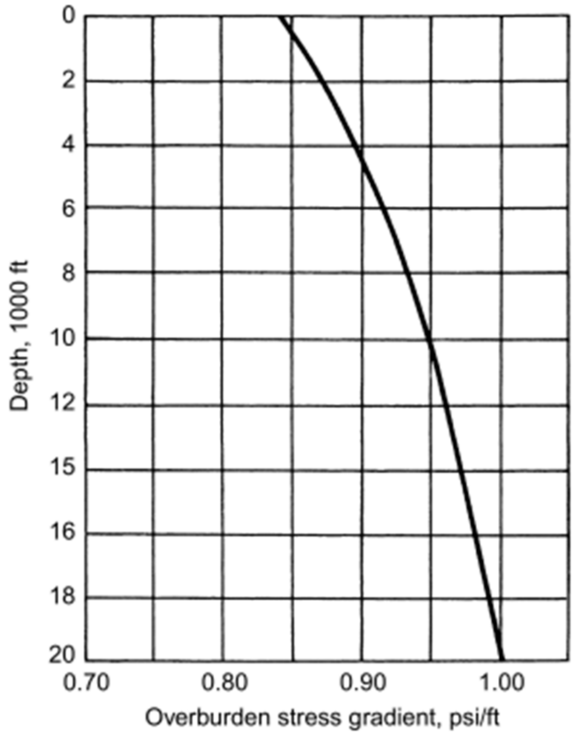



Study area identified by Kelley and others (2018) along with the sites discussed by Gabrysch and Bonnet (1974; 1976a; 1976b) and Gabrysch (1982). Modified from Kelley and others (2018).

# Conceptual Model Data

- $\sigma' = \sigma - u$
  - Effective stress (σ')
  - Geostatic stress (σ)
  - Hydrostatic stress (u)
- Thickness (Phase 2 Task 2)
- Specific storage
- Vertical hydraulic conductivity
- Preconsolidation stress

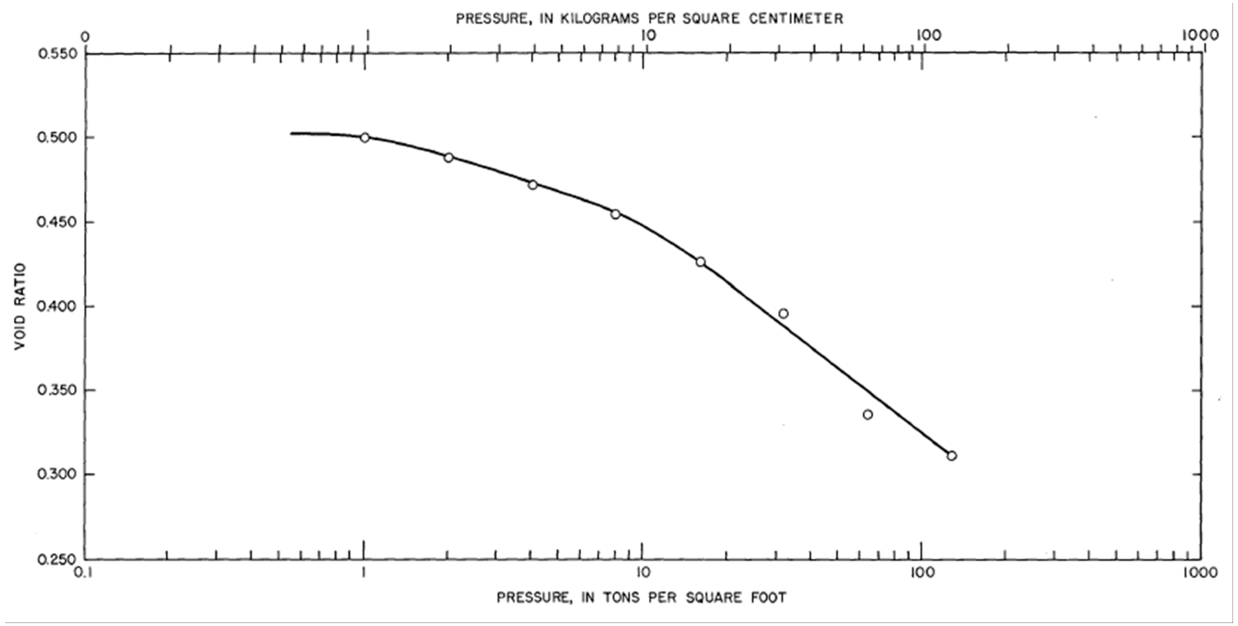


# Gabrysch and Bonnet

- Collected core samples from subsurface
  - Minimum depth: 131 feet
  - Maximum depth: 1,647 feet
- Analyzed void ratio versus applied pressure
  - Porosity calculated from void ratio
  - Clay compressibility calculated from change in porosity with change in applied stress

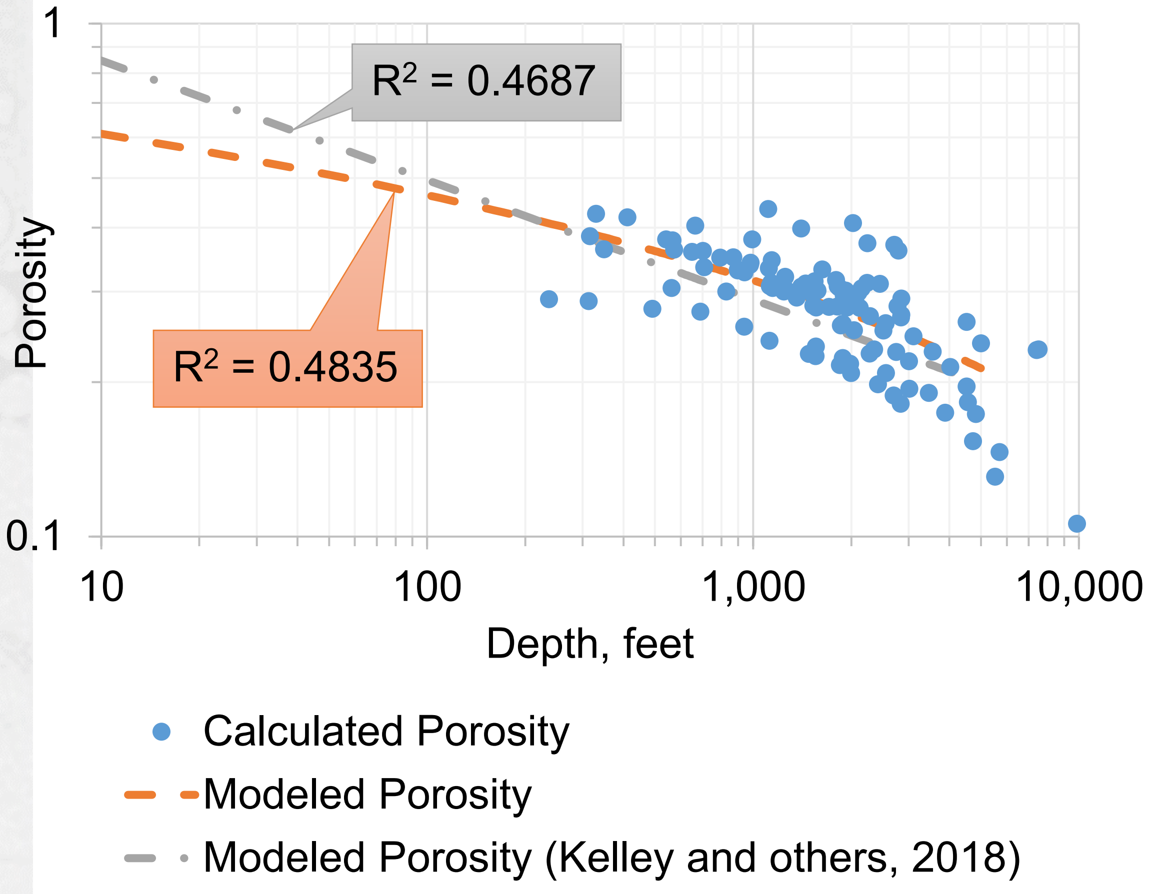
Relation between void ratio and applied pressure for clay sample from depth of 1,004 feet at Baytown site.



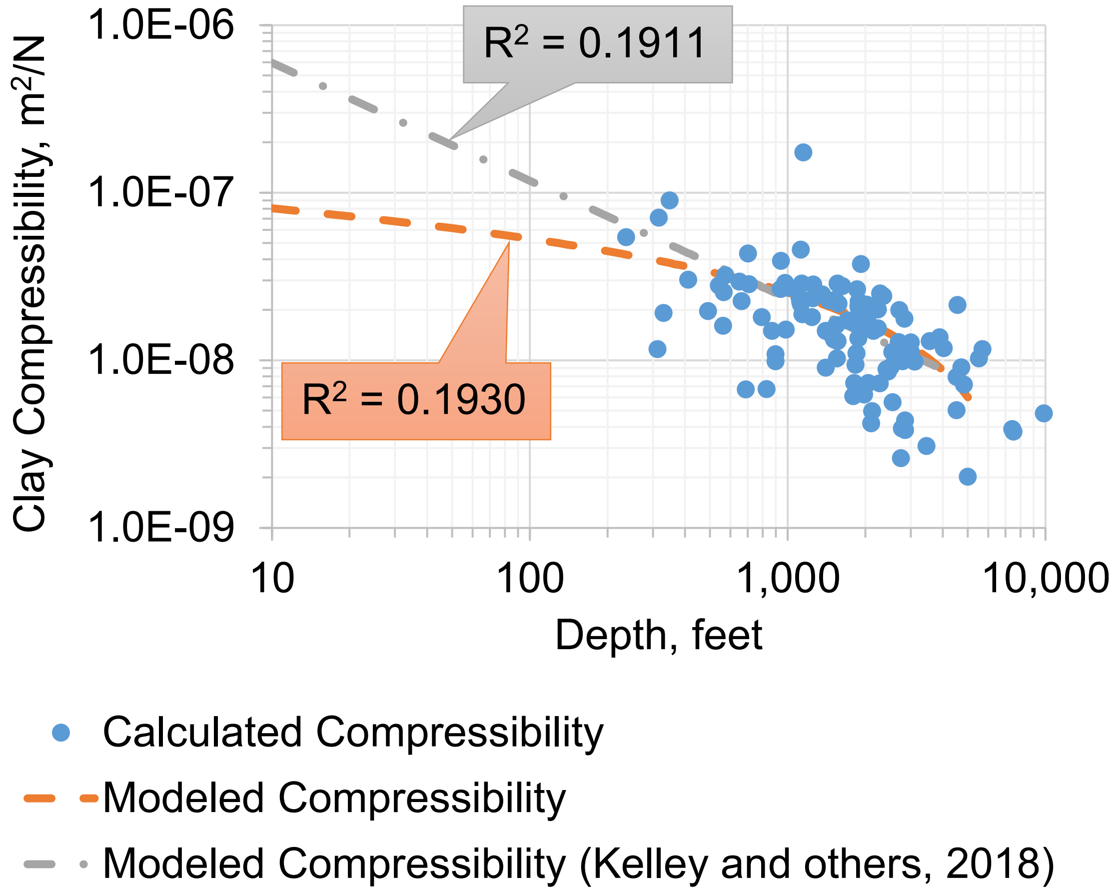

Reproduced from Gabrysch and Bonnet (1974)

# Core Data Evaluations

## Porosity



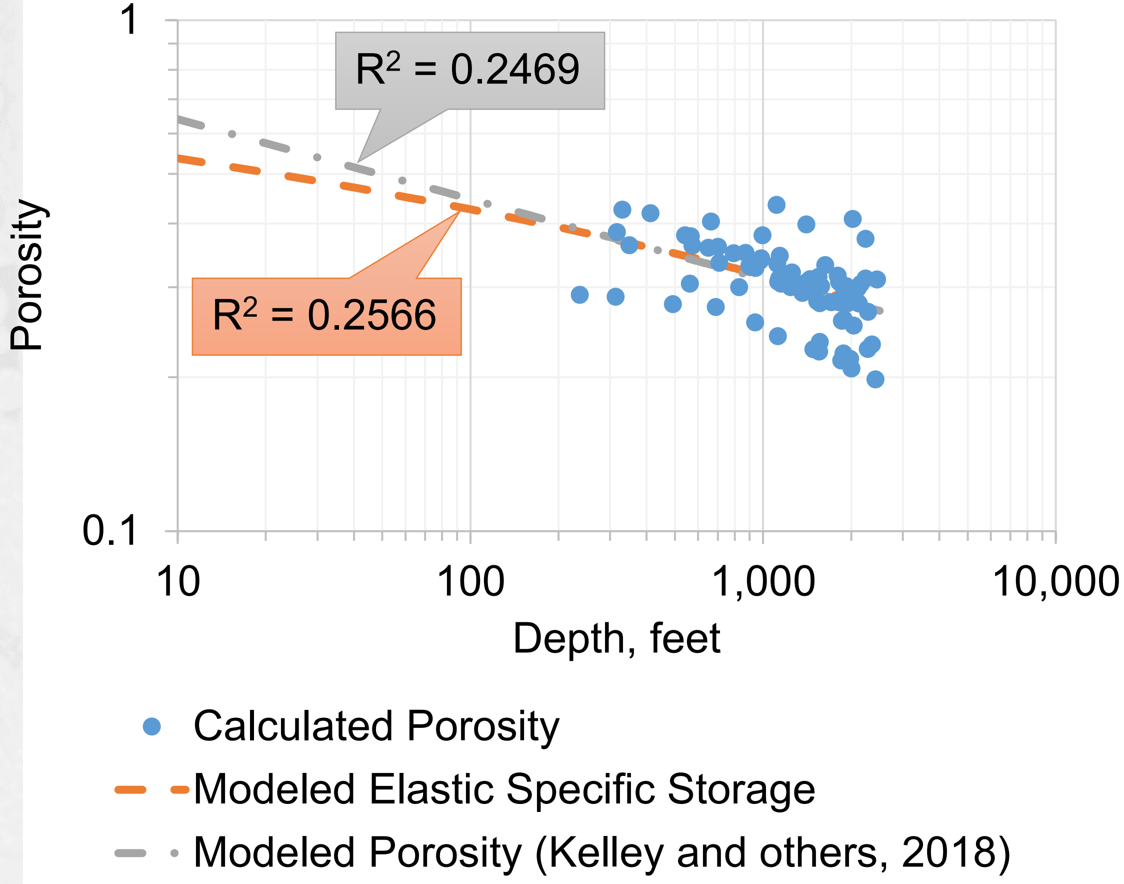

## Clay Compressibility



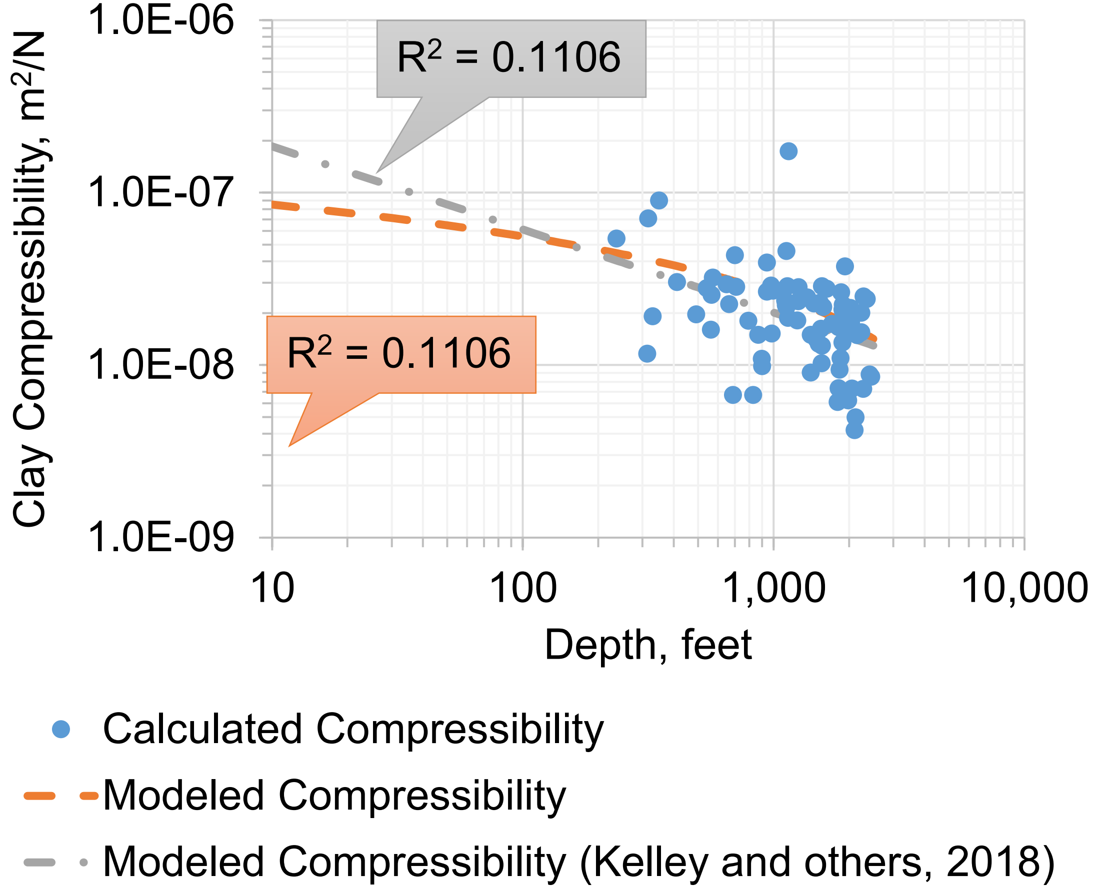
# Core Data Evaluations (Shallow Focus)

Lone Star Groundwater Conservation District

## Porosity




## Clay Compressibility

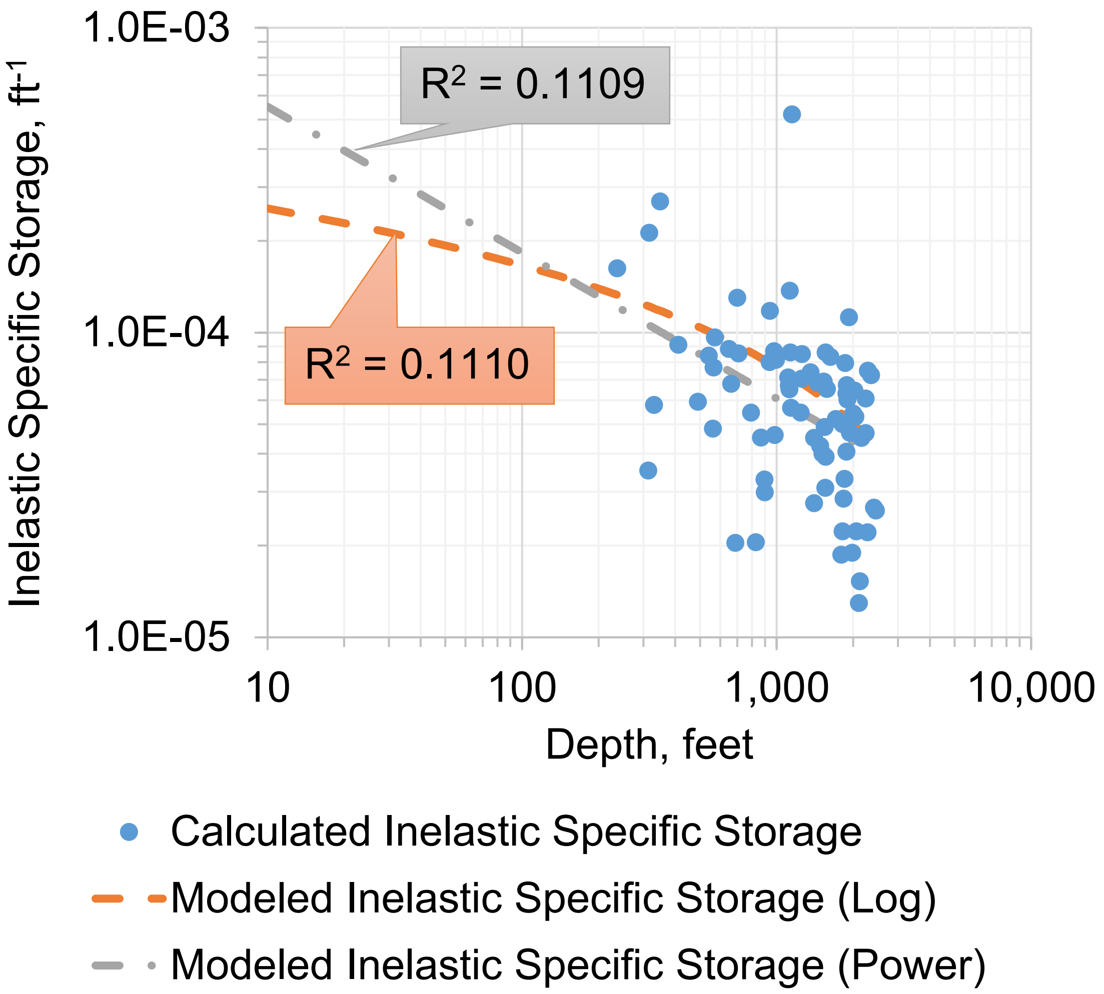


# Specific Storage

- Two types: Inelastic & Elastic

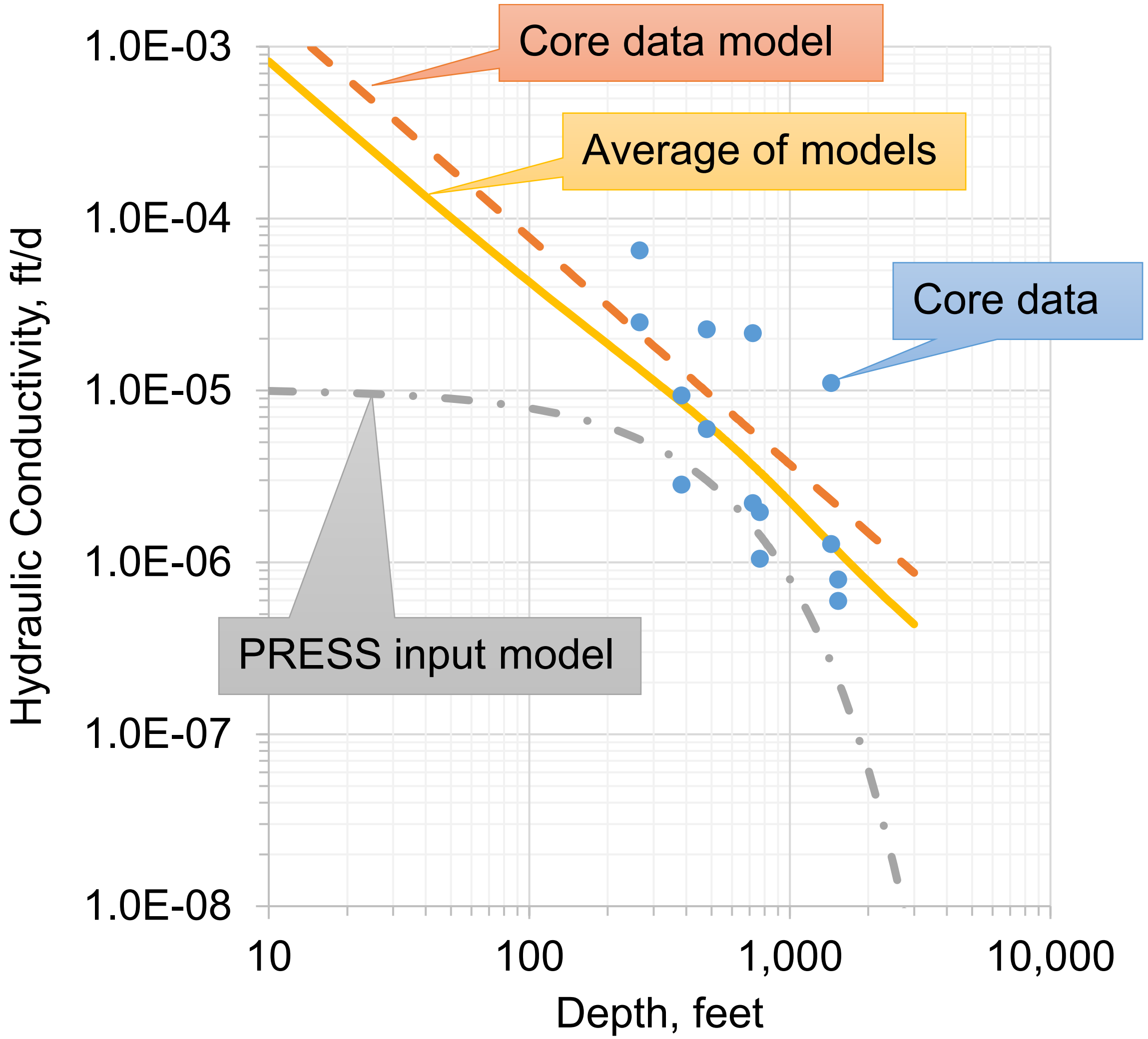
$$S_{skv} \approx S_s = \rho g(\alpha + n\beta)$$

- Generally similar results
  - We had lower values for shallower depths (~<500 feet)
  - We had higher values for deeper depths (~>500 feet)
- All data are from upper GCAS
  - Not necessarily representative of the Jasper
  - Large variability in the measurements



# Vertical Hydraulic Conductivity

- ➢Reported data for hydraulic conductivity
  - ➢Not explicit if vertical or horizontal
  - ➢Values consistent with horizontal
- ➢PRESS model values
  - ➢Vertical component
  - ➢Calibrated for Chicot/Evangeline
- ➢Kelly and others (2018) used average of two models
  - ➢Skewed to higher values
  - ➢Much higher the calibrated PRESS models

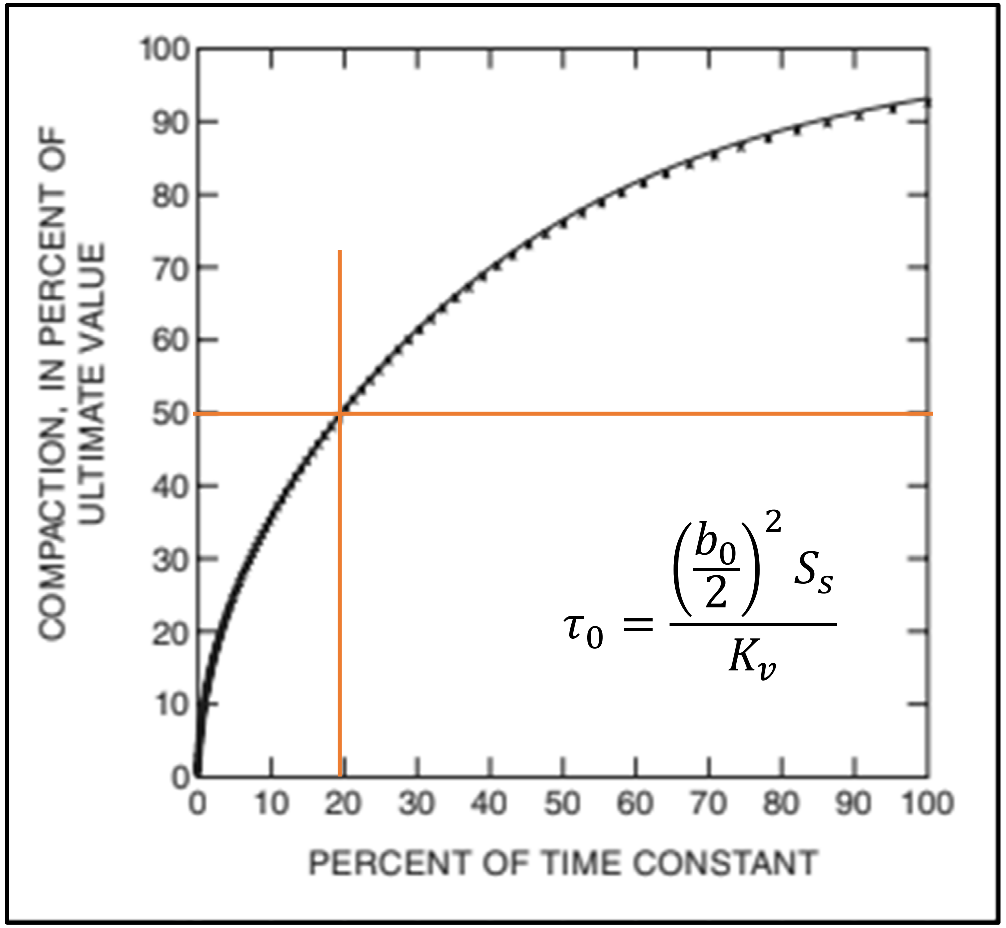


# Vertical Hydraulic Conductivity

- Key value in determining rate of compaction

- 50 percent of compaction in 20 percent of time

**Lower Kv = Slower Compaction**

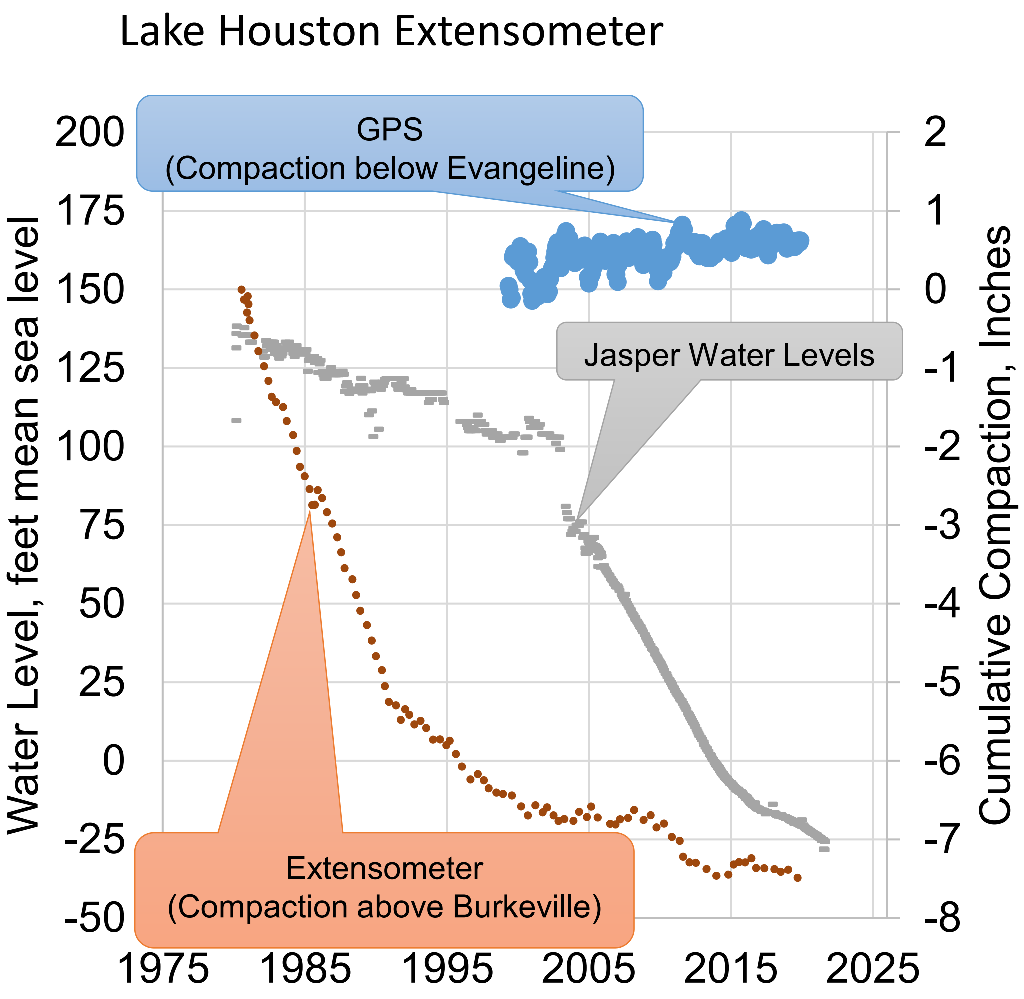



$$\tau_0 = \frac{\left(\frac{b_0}{2}\right)^2 S_s}{K_v}$$

Modified from Hoffman and others (2003).

# Preconsolidation Stress

- "drawdown at preconsolidation stress" (Kelley and others, 2018)
  - 75 at surface
  - 0 feet at depths below 870 feet
- HAGM
  - Pre-development water level minus 70 feet
  - Termed preconsolidation head
- Lake Houston Extensometer
  - Closest site to Montgomery County
  - No observed compaction below anchor



# Other Considerations

- Geometry of geologic units (see Task 2)
  - Geologic structure
  - Clay thickness/distribution of individual beds and aggregate layers
- Depositional environments – type/distribution of materials deposited
- Mineralogy, geochemistry and diagenesis
  - Clay type
  - Affect on compressibility
  - Complex systems beyond scope of this study
  - However, can verify by site- and interval-specific sampling
- Geologic age
  - Dissolution/cementation (i.e., time for diagenesis)
  - Unclear of affect on compaction

# Task 1 Conclusions

- Potential errors in Jasper conceptualization
  - Vertical hydraulic conductivity may be too high
  - Drawdown at preconsolidation stress may be inaccurate
- Kelley and others (2018) Jasper compaction conceptual model:
  - Compaction below Evangeline should be observed at Lake Houston
  - Potential for higher rate of compaction than expected in deep formations
  - Compaction may be simulated to occur sooner than observed
- Data used for Jasper compaction conceptual model
  - **Are not from the Jasper**
  - **May not be representative of Jasper properties**

# Phase 2 Subsidence Investigations – Task 2 Summary

Geologic Structure of the Gulf Coast Aquifer System within Montgomery County

# Task 2 Objectives

- Perform an in-depth evaluation of the subsurface geology of Montgomery County
- Update the mapping of the elevation of the top and bottom of the hydrogeologic formations
- Improve the understanding of the thicknesses of sand and clay intervals within the formations in the study area

# Aquifers and Geology

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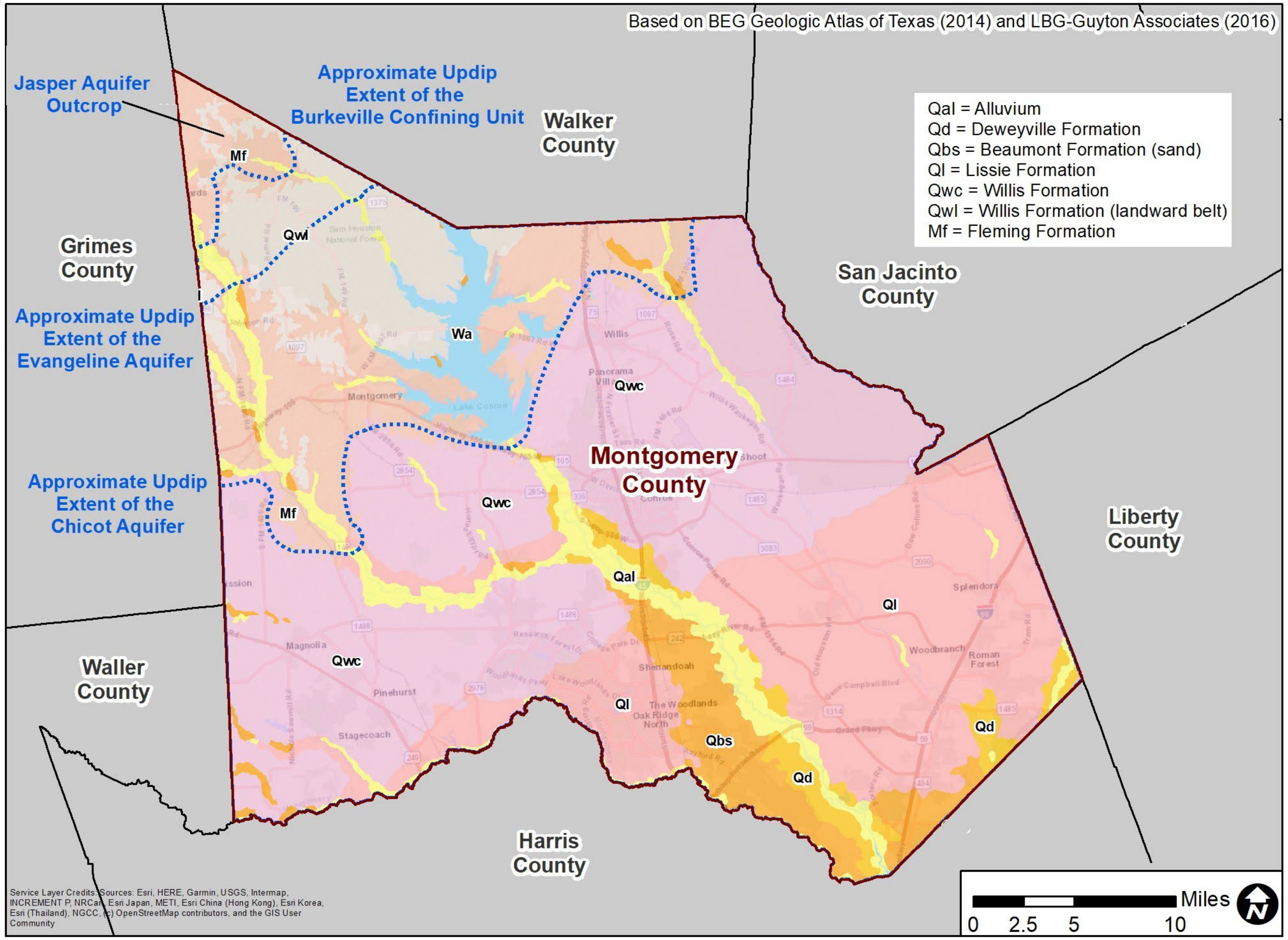
| Epoch | Hydrogeologic Unit | Geologic Unit | | |
|---|---|---|---|---|
| Holocene | Alluvium | | | |
| Pleistocene | Chicot Aquifer | Beaumont Clay | | |
| | | Lissie Formation | | |
| Pliocene | | Willis Formation | | |
| Miocene | Evangeline Aquifer | Goliad Sand | | Upper |
| | | | | Lower |
| | | Fleming Formation | Lagarto | Upper |
| | Burkeville Confining Unit | | | Middle |
| | Upper Jasper Aquifer | | | Lower |
| | Lower Jasper Aquifer | | Oakville | |
| Oligocene | Catahoula | | Catahoula | |

Hydrogeologic and Geologic Units of the Gulf Coast Aquifer System Within and Near Montgomery County (Popkin, 1971; Young and Draper, 2020).




Montgomery County Surface Geology and Approximate Aquifer Outcrop Areas (Based on BEG Geologic Atlas of Texas, 2014; LBG-Guyton, 2016)

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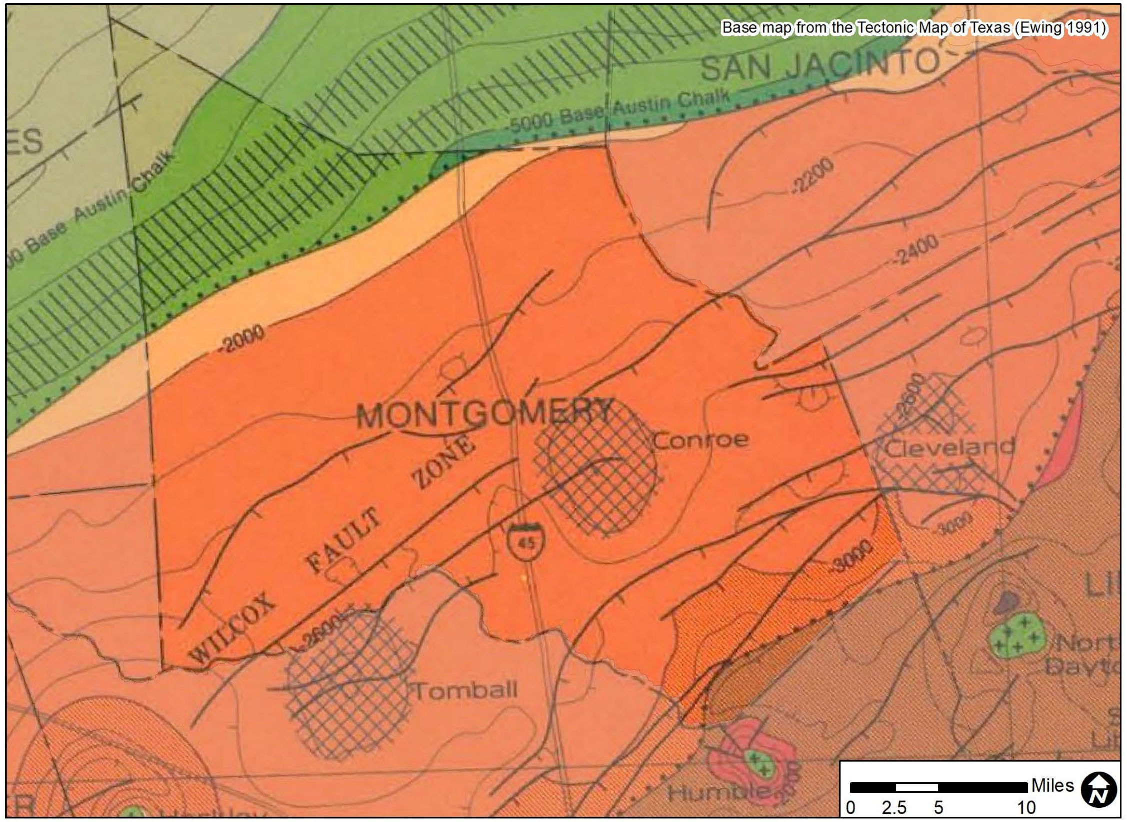
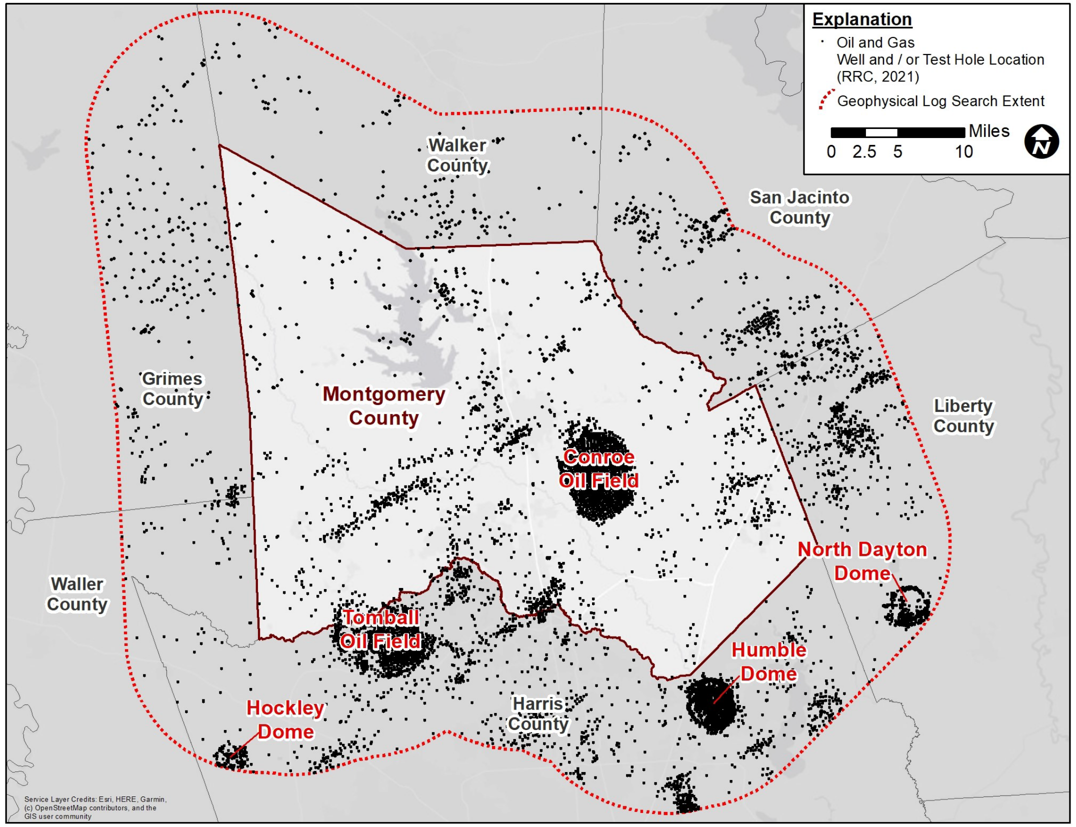
# Subsurface Faults and Oil and Gas Well/Test Hole Locations




Subsurface Faults and Large Oil and Gas Fields in the Vicinity of Montgomery County (base map from the Tectonic Map of Texas, Ewing, 1991)




Locations of Oil and Gas Wells or Test Holes (Based on available data from the RRC, 2021)

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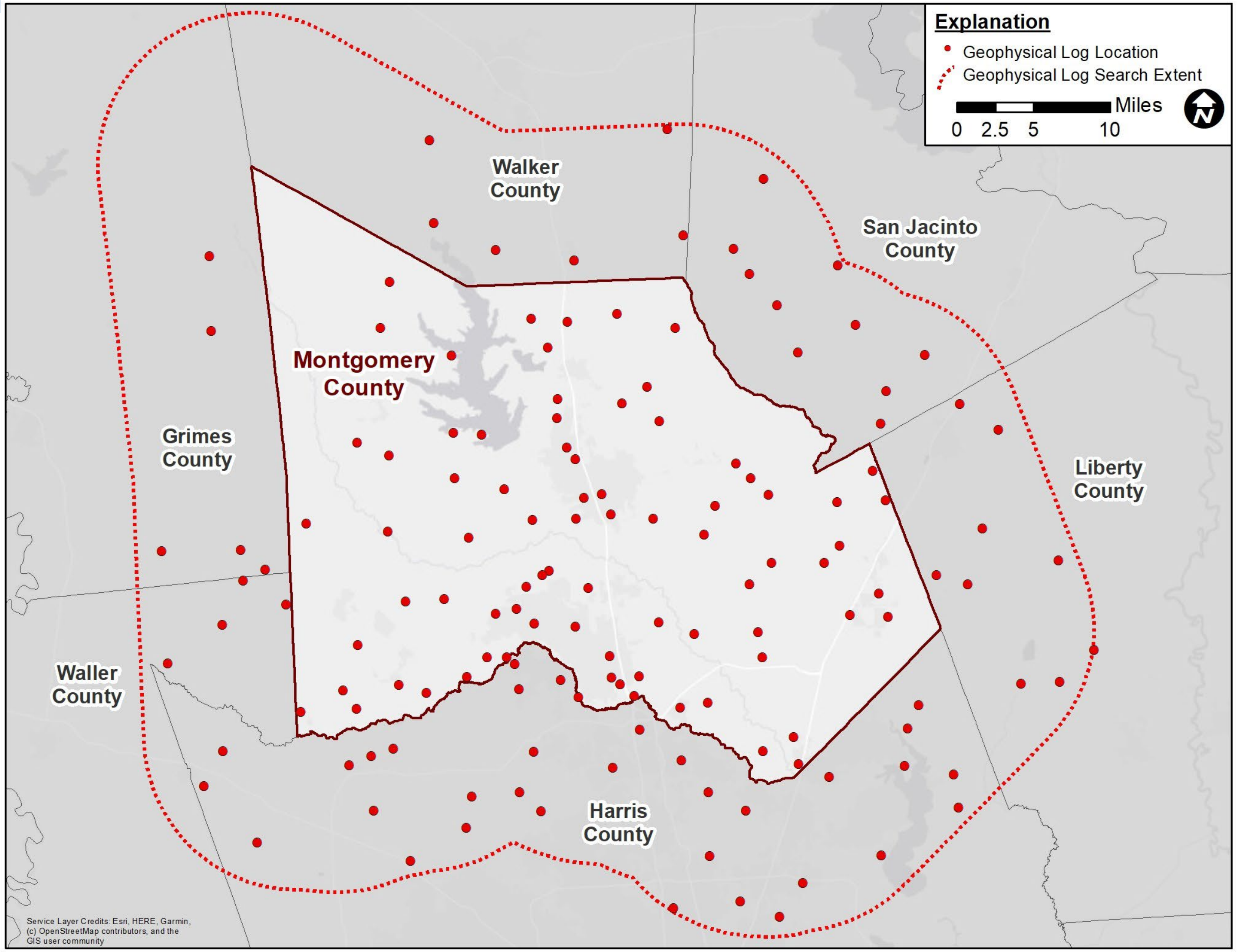
# Geophysical Log Locations

- ➢146 Geophysical Logs

  Montgomery County: 78

  Surrounding Counties: 68




Locations of Geophysical Logs Evaluated for this Study

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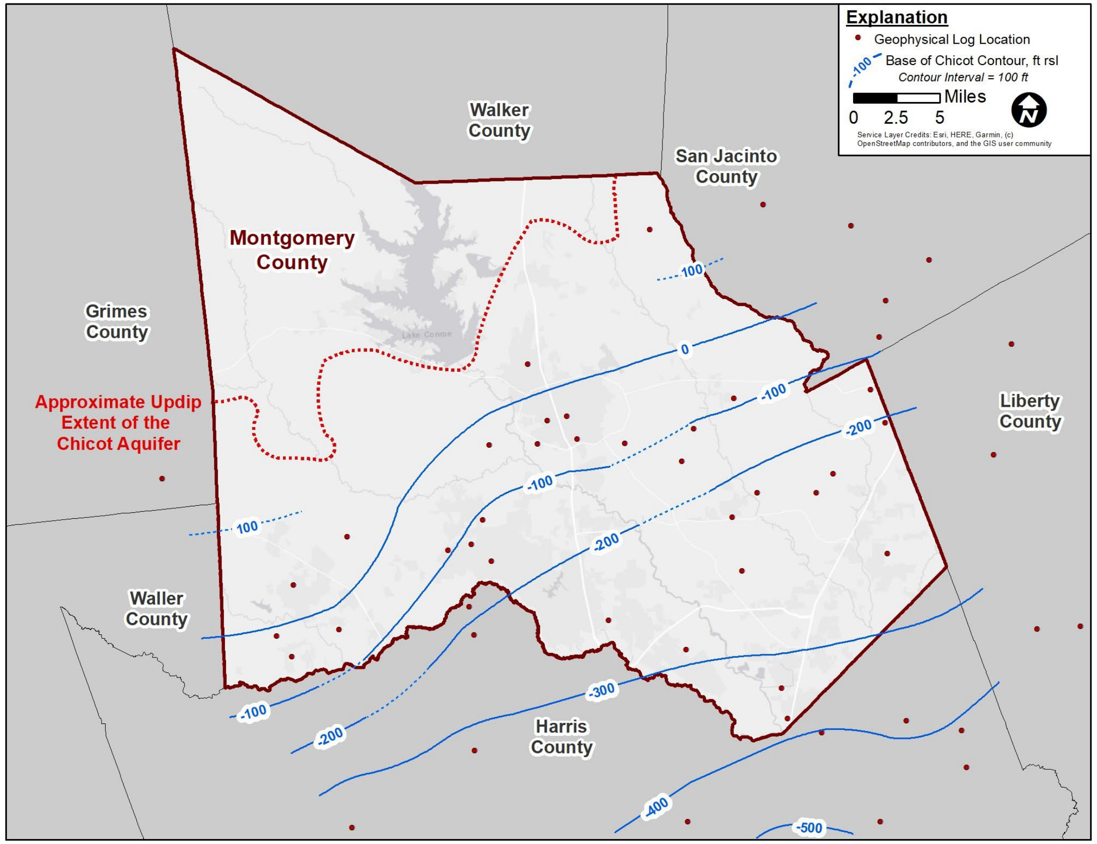
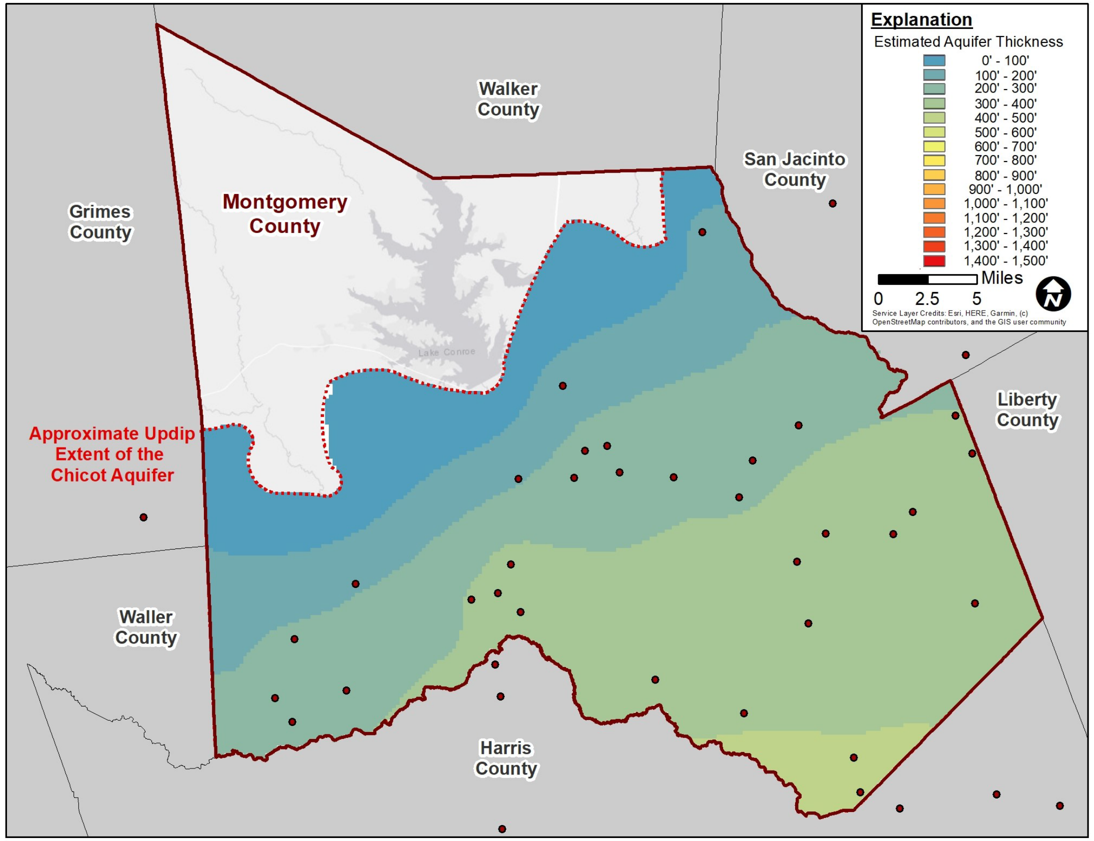
# Chicot Aquifer

Estimated base of the Chicot Aquifer within Montgomery County




Estimated Thickness of the Chicot Aquifer within Montgomery County




**<u>Base of Chicot Aquifer (elevation):</u>**

Estimated to occur about -**375 feet rsl** in the southeast part of Montgomery County

**<u>Chicot Aquifer Thickness:</u>**

Maximum estimated thickness of about **470 feet** in southeast part of the county

Estimated average thickness of about **250 feet**

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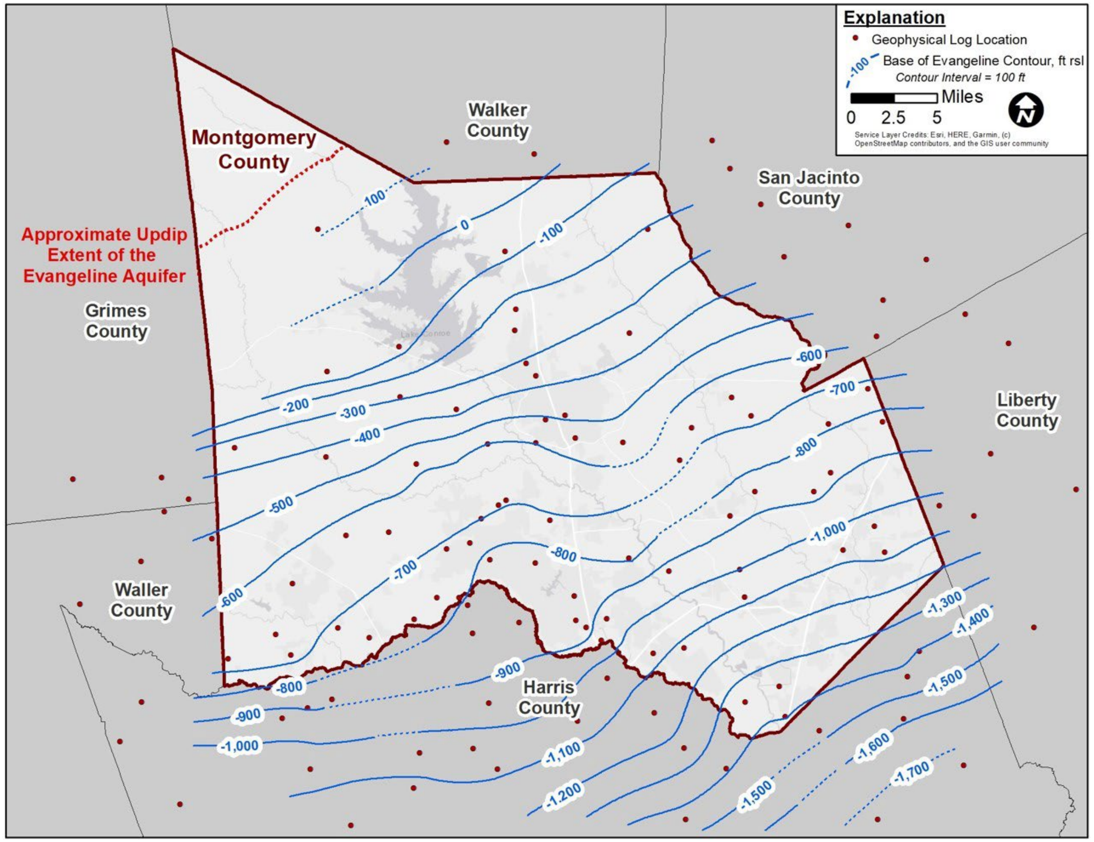
# Evangeline Aquifer

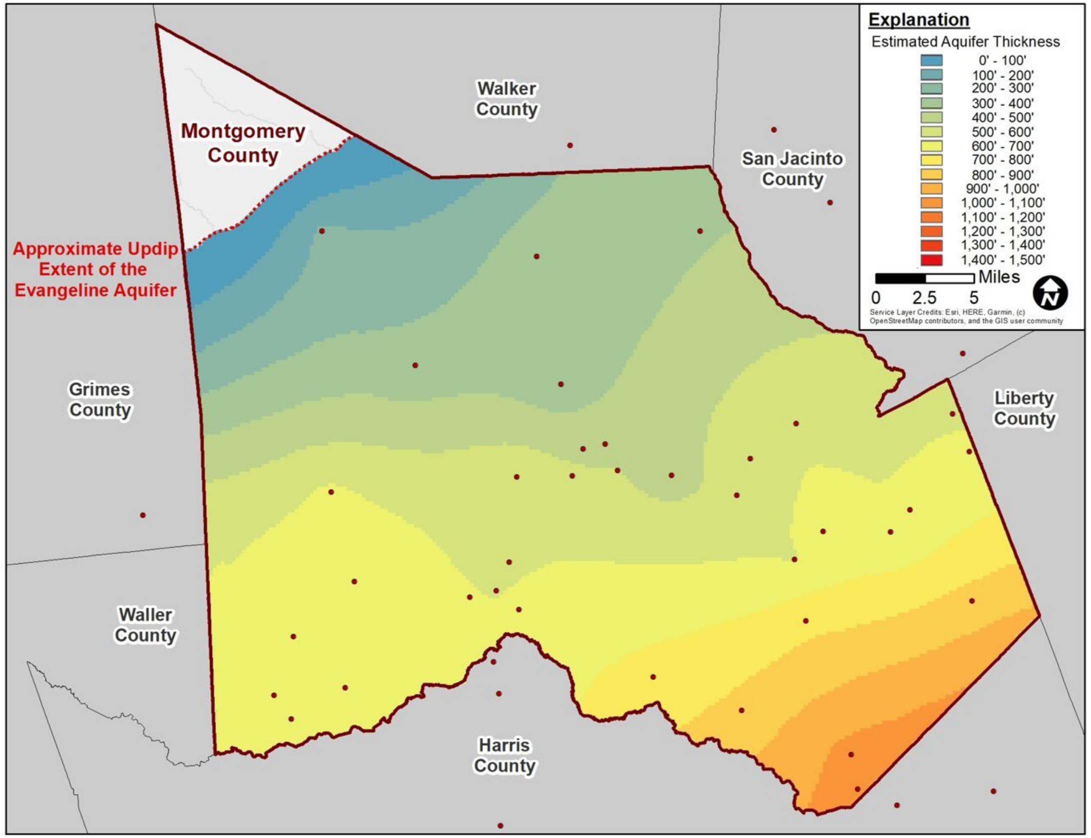
Estimated base of the Evangeline Aquifer within Montgomery County




**Base of Evangeline Aquifer (elevation):**

Estimated to occur about **-800 feet rsl** in the southwest part of the county and about **-1,400 feet rsl** in the southeast part of Montgomery County

Estimated Thickness of the Evangeline Aquifer within Montgomery County



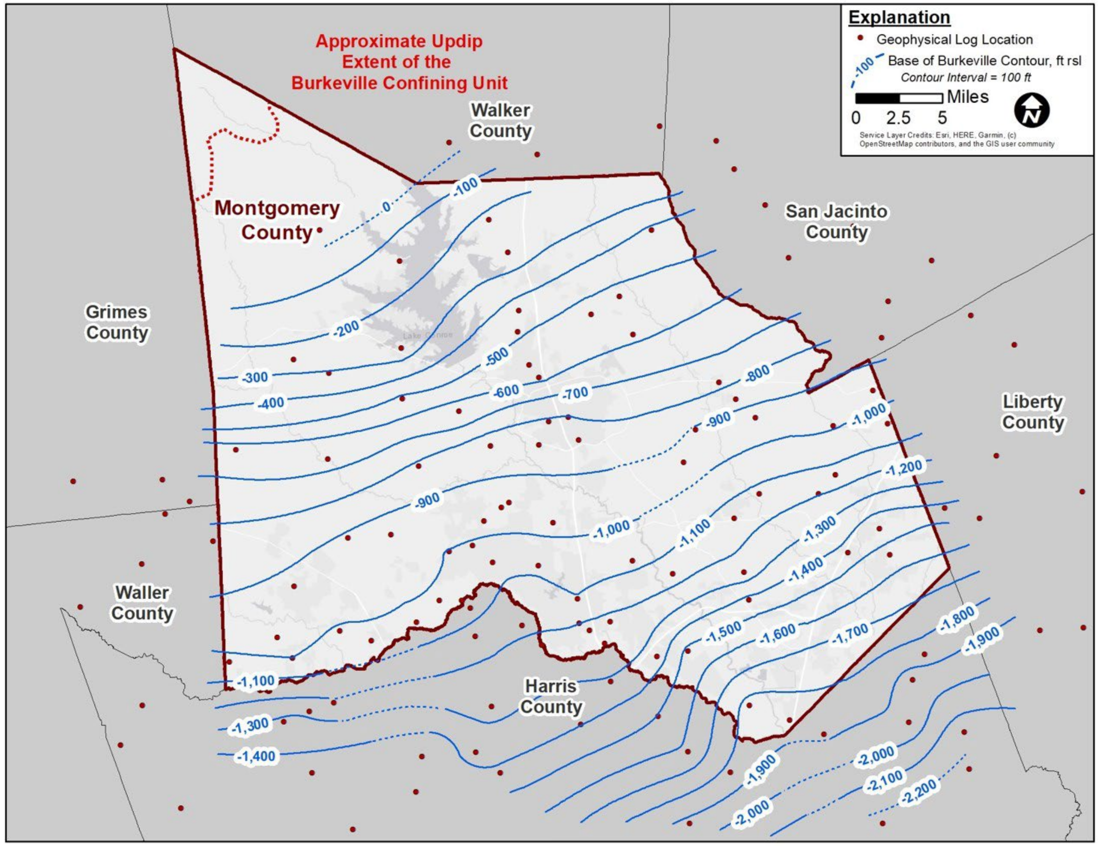

**Evangeline Aquifer Thickness:**

Maximum estimated thickness of **>1,000 feet** in southeast part of the county

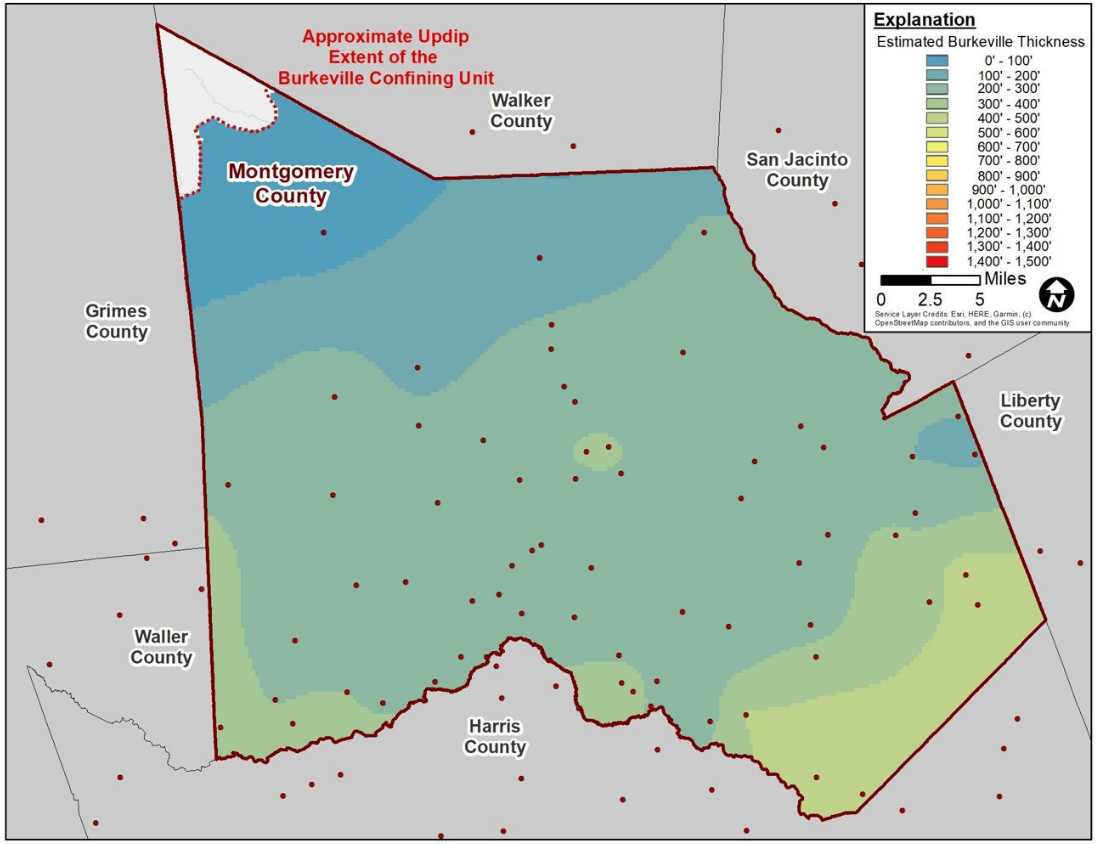
Estimated average thickness of about **540 feet**

# Burkeville Confining Unit

Estimated base of the Burkeville Confining Unit within Montgomery County




Estimated Thickness of the Burkeville Confining Unit within Montgomery County




**Base of Burkeville Confining Unit (elevation):**

Estimated to occur about **-1,100 feet rsl** in the southwest part of the county and about **-1,870 feet rsl** in the southeast part of the county

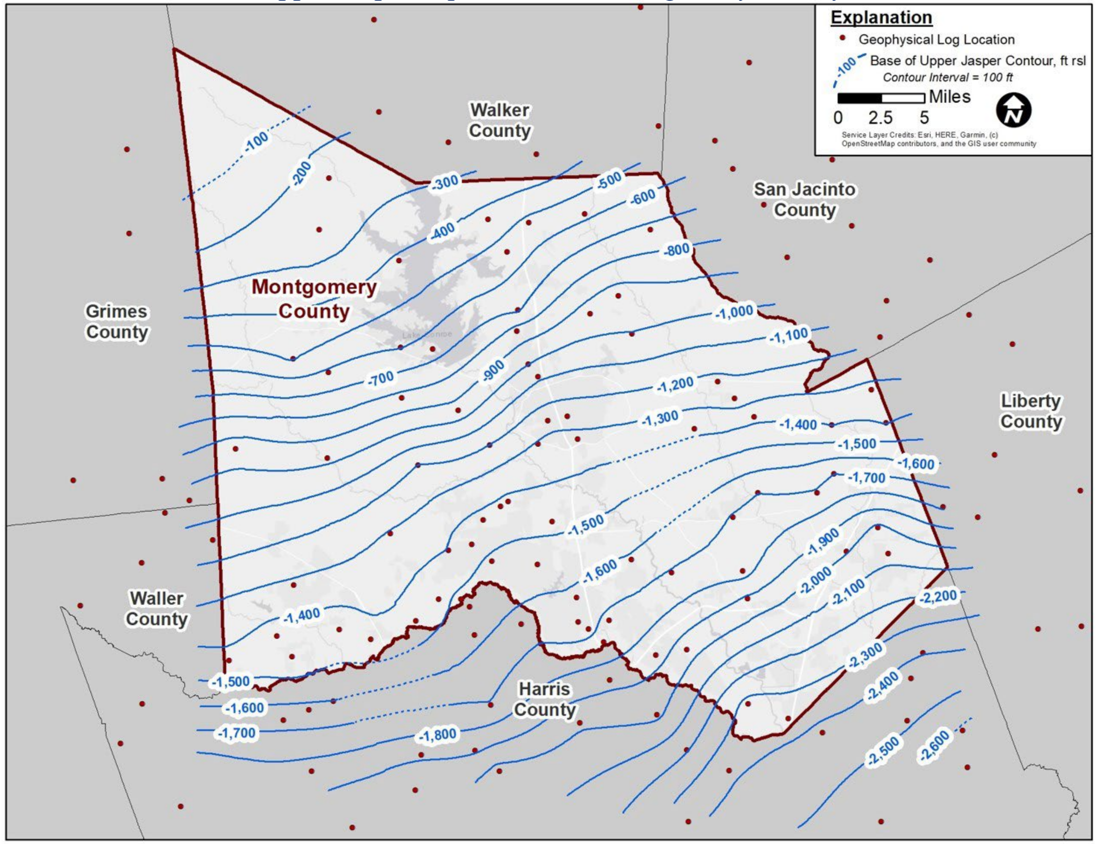
**Burkeville Confining Unit Thickness:**

Maximum estimated thickness of about **480 feet** in southeast part of the county

Estimated average thickness of about **240 feet**

# Upper Jasper Aquifer

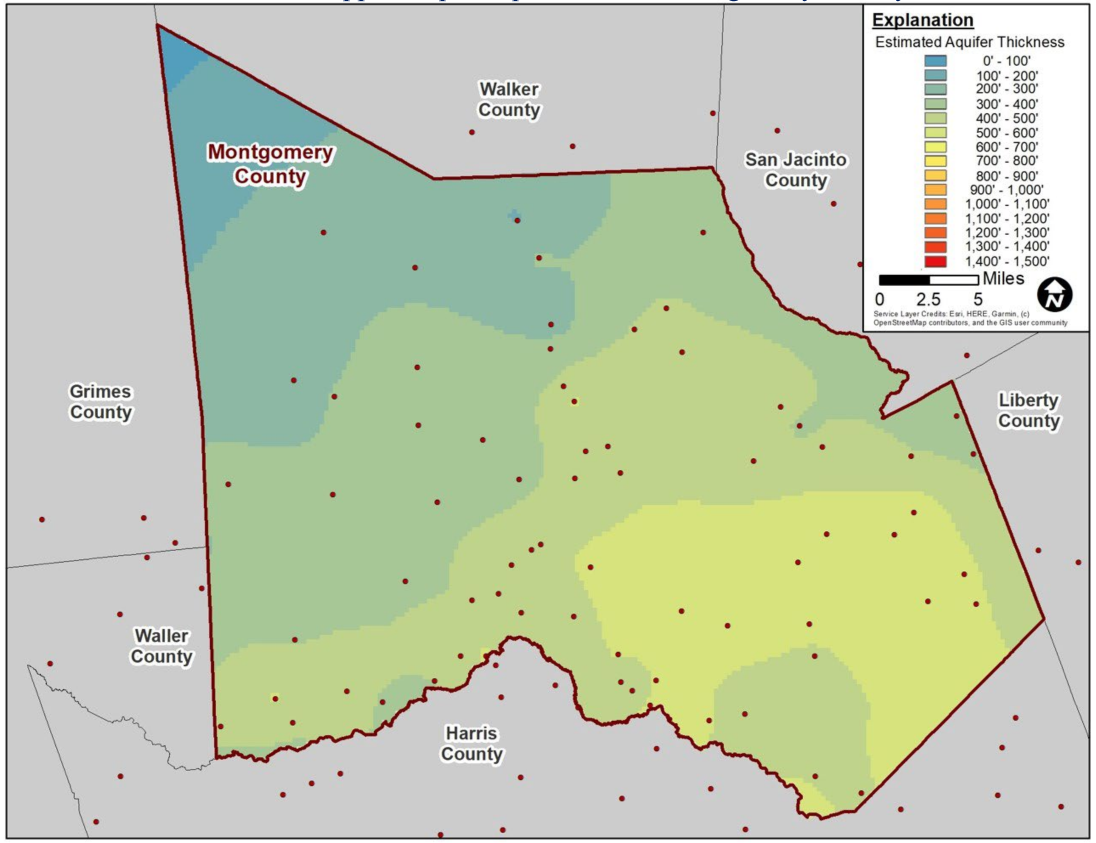
Estimated base of the Upper Jasper Aquifer within Montgomery County




**Base of Upper Jasper Aquifer (elevation):**

Estimated to occur about **–1,500 feet rsl** in the southwest part of the county and about **-2,350 feet rsl** in the southeast part of the county

Estimated Thickness of the Upper Jasper Aquifer within Montgomery County



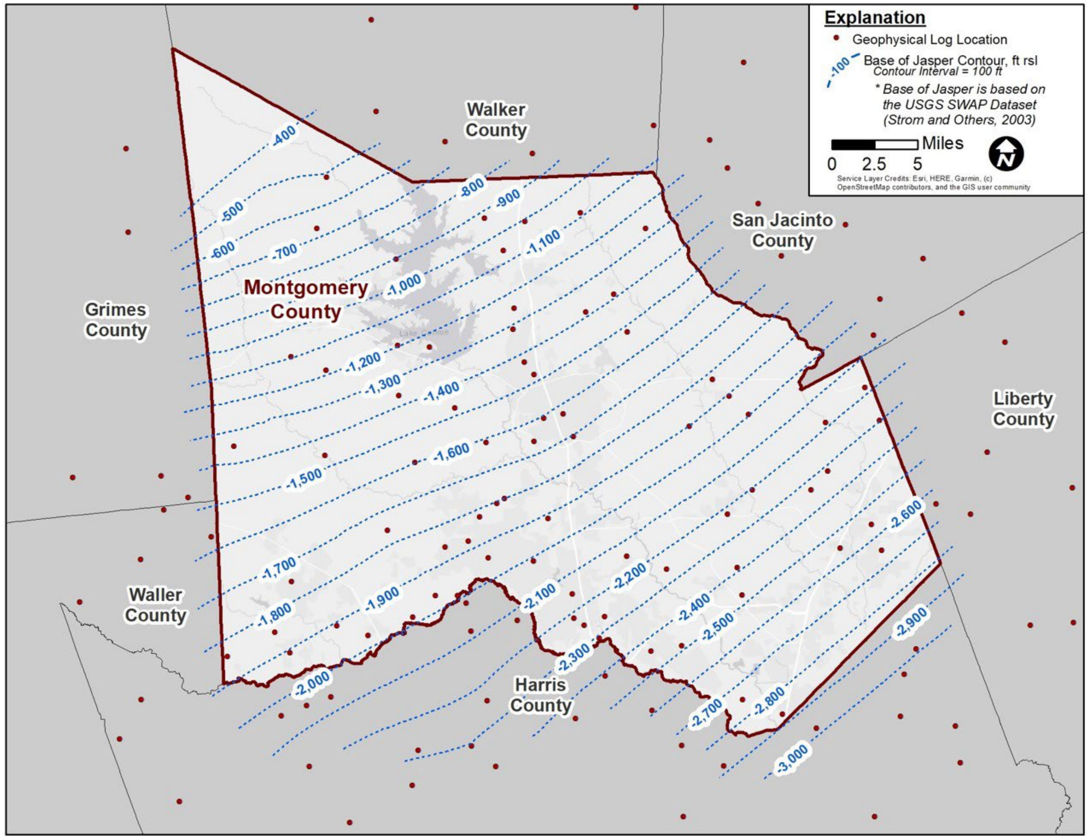

**Upper Jasper Aquifer Thickness:**

Maximum estimated thickness of about **570 feet** in southeast part of the county

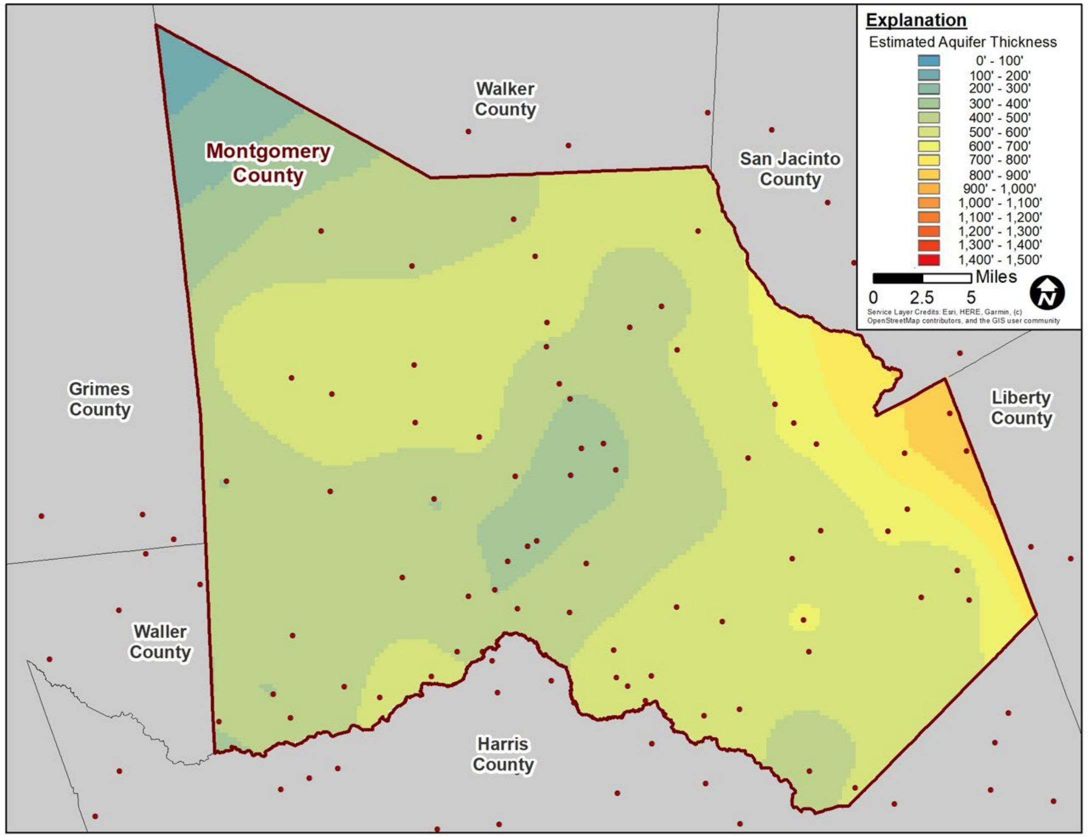
Estimated average thickness of about **390 feet**

# Lower Jasper Aquifer

Estimated base of the Lower Jasper Aquifer within Montgomery County




Estimated Thickness of the Lower Jasper Aquifer within Montgomery County




**Base of Lower Jaser Aquifer (elevation):**

Estimated to occur about **-2,000 feet rsl** in the southwest part of the county and about **-2,900 feet rsl** in the southeast part of Montgomery County

**Lower Jasper Aquifer Thickness:**

Estimated thickness of about **100 feet** in northwest part of the county

Maximum estimated thickness of about **900 feet** in east part of the county

Estimated average thickness of about **500 feet**

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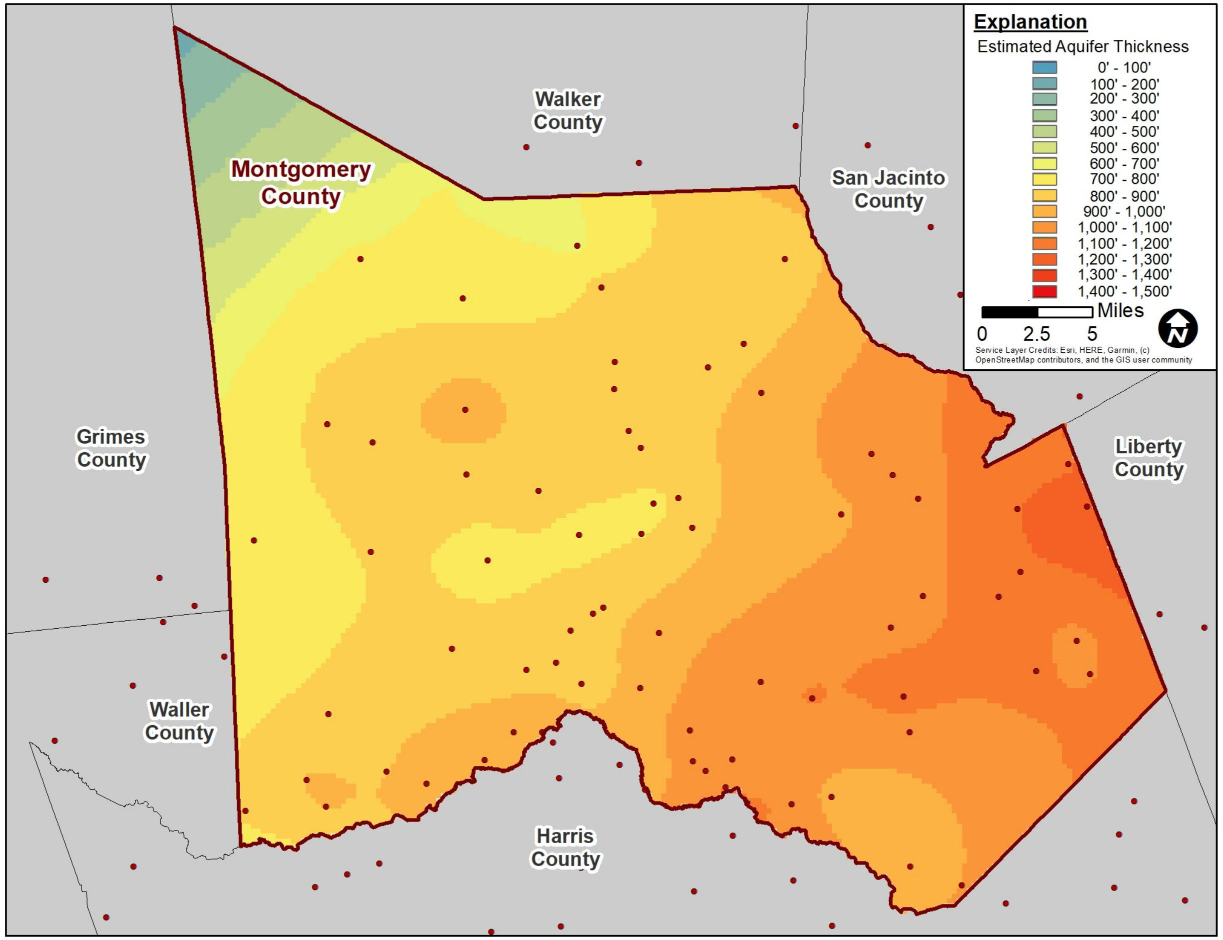
# Jasper Aquifer Thickness (Combined Upper & Lower)

- **USGS SWAP Base of Jasper Aquifer** (Strom and others, 2003)
  - Estimated thickness of about **150 feet** in northwest part of the county
  - Maximum estimated thickness of about **1,280 feet** in east part of the county
  - Estimated average thickness of about **890 feet**

- **Base of Jasper Aquifer** (Popkin, 1971)

- Estimated thickness to range from of about **1,490 feet** to **3,040 feet** in Montgomery County

- Estimated average thickness of about **2,100 feet**




Estimated Total Thickness of the Jasper Aquifer within Montgomery County as the difference between the base of the Burkeville Confining Unit as defined in this study and the base of the Jasper Aquifer as defined by the USGS SWAP Dataset

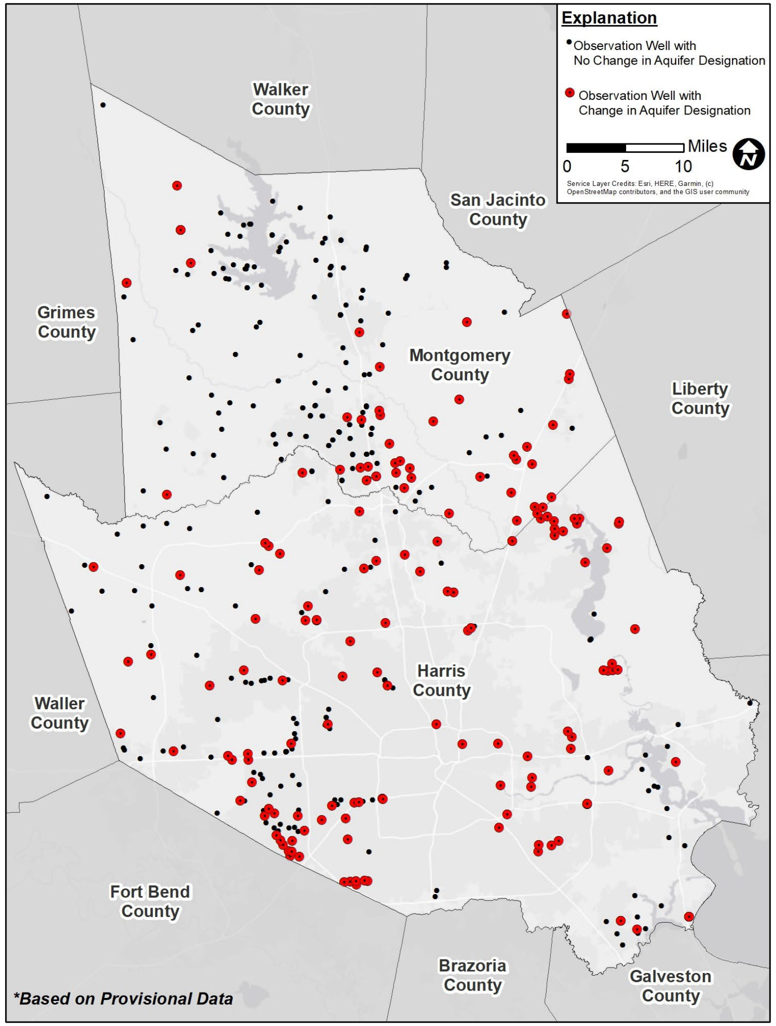
# Gulf 2023 Groundwater Flow Model – New Approach

- **Chronostratigraphic Approach**
  (Young and others, 2012)
- **Chronostratigraphic** approach and sequence stratigraphy identify **clay-dominated flooding surfaces of the same age**
- Subdivide the Chicot, Evangeline and Jasper aquifers and Burkeville Confining Unit into sub-aquifer layers
  - Chicot Aquifer
    - 1) Beaumont Clay; 2) Lissie Formation; 3) Willis Formation
  - Evangeline Aquifer
    - 4) Upper Goliad; 5) Lower Goliad; 6) Upper Lagarto;
  - Burkeville Confining Unit
    - 7) Middle Lagarto;
  - Jasper Aquifer
    - 8) Lower Lagarto; 9) Oakville Formation; and 10) Catahoula Formation

- **Combined Chronostratigraphic and Lithostratigraphic Approach**
  (Young and Draper, 2020)
  - Update to **Chicot/Evangeline contact** and **top and bottom of the Burkeville Formation** in support of the development of the **Gulf 2023 Groundwater Flow Model**
  - Update to **Burkeville Confining Unit**: **Lithostratigraphic** based Burkeville unit created by correlating sand and clay sequences of Upper, Middle and Lower Lagarto
  - **Chicot Aquifer** was selected to represent a **transition** from the **sand-rich basal Chicot Aquifer** to the **sand-poor top of Evangeline Aquifer**

# Gulf 2023 Hydrogeologic Surface Comparison

- The **Lithostratigraphic** based approach applied to the **Burkeville Confining Unit**:
  - **Generally similar** picks for most parts of Montgomery County
- The **Chronostratigraphic** approach used to update the base of **Chicot Aquifer**:
  - **Generally deeper** picks relative to this study and previous studies
  - Increasingly deeper in the southeast part of Montgomery County
  - Larger increases in depth in parts of Liberty and Harris counties.
  - Can be significantly deeper in parts of northeast and east Harris County than defined in previous studies




USGS Observation Wells that will be Assigned a New Aquifer Designation based on the Gulf 2023 Groundwater Flow Model (based on provisional data provided by the USGS in May 2021).

# Clay Layer Thickness

- Most compaction in sediments occurs in layers dominated by clay
- The thickness of clay layers within aquifers is one important part of understanding the amount of subsidence that may occur in areas of groundwater withdrawal.
- USGS conducted some of the definitive work relating to the depth of burial and the compressibility of clay layers in the Chicot and Evangeline aquifers in selected areas of southern Harris County and Galveston County
  - "The time lag between loading and ultimate consolidation is dependent upon the thickness and permeability of the clay bed" (Gabrysch and Bonnet, 1976)

# Relationship between the Aquifer Sands and Clay Interbed

- INTERA noted the relationship between the fluid-pressure reductions in groundwater producing zones (i.e., sands), the thickness of individual clay beds (sometimes called interbeds), the vertical hydraulic conductivity of the clay layers and the time it takes for compaction to occur (Kelley and others, 2018).

- Figure illustrates the relationship of the positioning and thickness of clay interbeds and the compaction of a clay layer between aquifer sand zones (reproduced from Kelley and others 2018)

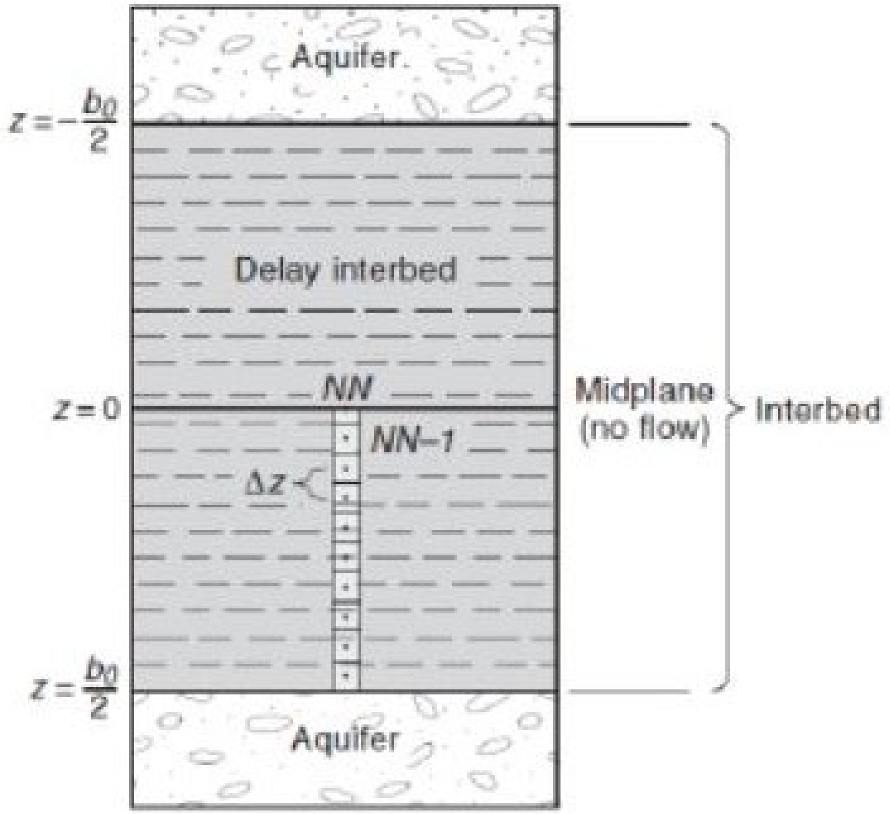


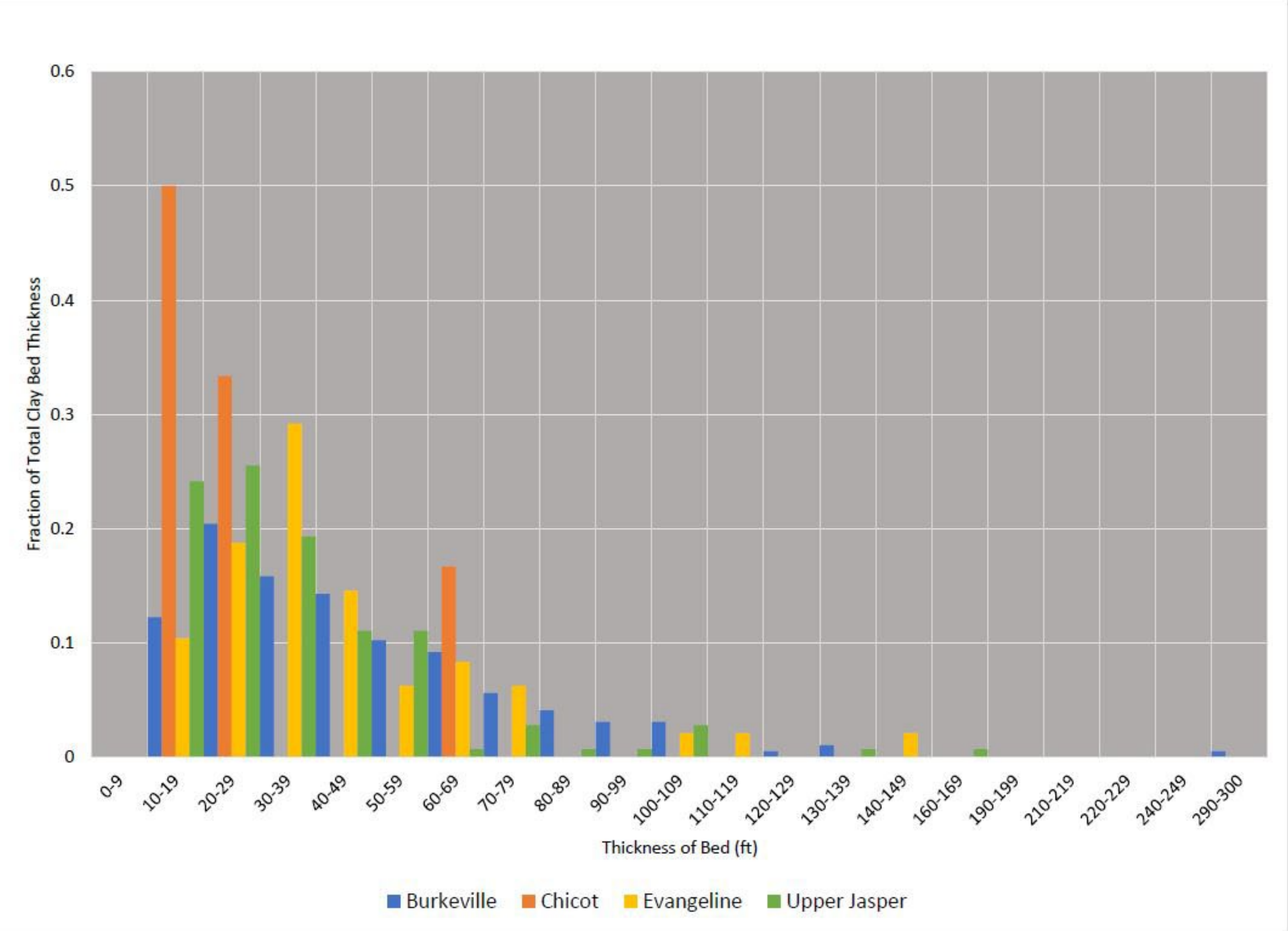

Illustration of the Relationship between the Aquifer Sands and Clay Interbed (reproduced from Kelley and others, 2018).

# Clay Layer Analysis

- Analyzing geophysical logs and making picks categorized as sand, silty or clayey sand, silty or sandy clay and clay.
  - For this evaluation to date, zones were categorized as either being “clay” or “sand”
- Evaluating the clay layers for the Chicot, Evangeline and Jasper aquifers and the Burkeville Confining Unit
  - Total clay thickness and average clay-layer thickness
- Selecting potential high production sand intervals and evaluating the clay layers within the interval that would likely be screened in a well
  - determining the number of clay interbeds, the total clay thickness, the minimum and maximum clay-bed thicknesses, and average interbed thickness

# Results of Log Analysis

- Most clay layers are relatively thin
- Evangeline Aquifer and Burkeville Confining Unit have generally thicker clay layers
- Chicot Aquifer and Upper Jasper Aquifer generally have thinner clay layers




Distribution of Clay Bed Thickness by Hydrogeologic Unit for Montgomery County

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# Results of Log Analysis – 7 Selected Sites

- Exhibits typical variability expected in GCAS
- Average percent clay – Evangeline, Burkeville and Upper Jasper
  - 58 percent, 79 percent, and 39 percent, respectively
- Within zones that would likely be “screened” in wells
  - 38 percent and 34 percent for Evangeline and Upper Jasper, respectively
- Delineation of the Upper Jasper is important consideration

# Task 2 Summary

- In-depth evaluation of the subsurface geology of Montgomery County
  - Update hydrogeologic formation mapping
  - Improve understanding of sand and clay thickness
- Divided the Jasper Aquifer into two units: Upper Jasper /Lower Jasper
  - Clay layers likely affected by depressurization and potential compaction are likely much thinner than the cumulative clay thickness of the entire Jasper Aquifer
  - The distribution and thickness of clay layers related to groundwater production zones should also be a consideration for all future studies and developing parameters for modeling efforts.

# Long-term Goals

- LSGCD focus
  - First of its kind study
  - Develop site-specific data for the formations comprising the GCAS
- Develop robust and defensible monitoring
  - Distributed
  - Strategic
- Phases and tasks are designed to develop strategic monitoring
  - Resource management
  - Fiscal responsibility

# LSGCD Subsidence Investigations

- Phase 1 – Background
  - Assessment of Past and Current Investigations
  - 2019-2020
- Phase 2 – Focused Evaluations
  - Specific items from Phase 1
  - 2021-2022
- Phase 3 – Site Specific Geotechnical
  - Real world data
    - Test drilling
    - Geophysical logging
    - Rotary sidewall coring
    - Geotechnical analysis
  - Plan in Phase 2 Task 3 report
  - 2022-2023
- Phase 4 – Monitoring

03/25/2022

- Task 1 and Task 2 Stakeholder Comments Due

05/06/2022

- Task 1 and Task 2 Final Report Due
- Task 3 Draft Report Due

# Questions/Discussion

Phase 2 Subsidence Investigations

LSGCD Stakeholder Meeting

January 26, 2022