2023 JOINT REGULATORY PLAN REVIEW

STAKEHOLDER MEETING EXECUTIVE SUMMARY

NAME OF MEETING: Stakeholder Meeting 3
DATE: December 10, 2020
LOCATION: Virtual

On Thursday, December 10, 2020 at 10:00 am, the Harris-Galveston and Fort Bend Subsidence Districts (the Districts) held their third Joint Regulatory Plan Review Stakeholder Meeting. This meeting was held as a virtual meeting to comply with best practices and directions provided by the State of Texas for the ongoing COVID-19 pandemic. Numerous board members, elected officials, regional water authorities, and representatives from local, State and Federal agencies joined the meeting, with more than 60 panelists and attendees. A full list of meeting participants is included in **Attachment A**.

The purpose of this meeting was to provide project element updates from the Joint Regulatory Plan Review and also hold the second Stakeholder Advisory Forum for the Gulf Coast Land Subsidence and Groundwater Flow (GULF)-2023 model. The GULF-2023 model will be an update to the Groundwater Availability Model (GAM) for the northern portion of the Gulf Coat Aquifer System.

Dr. Tina Petersen welcomed the stakeholders to the Districts' third virtual stakeholder meeting and introduced the Joint Regulatory Plan Review project team, including Dr. Sunil Kommineni and Dr. Justin Bartlett of KIT Professionals as well as Wade Oliver of INTERA. They discussed the alternative water supply availability and included an assessment of seven (7) shortlisted options.

Ms. Cindy Ridgeway of the Texas Water Development Board (TWDB) provided a brief introduction to the GAM Program and discussed how GAMs are used in Texas water resources planning. She then discussed the importance of the stakeholder process. Then, Mr. John Ellis and Ms. Linzy Foster with the United States Geological Survey presented the following topics relating to the GULF-2023 model:

- Project overview
- Introduction to groundwater flow and numerical groundwater flow modeling
- Study area
- Planned approach, including model properties, features, and parameters
- Calibration of subsidence package and water level observations
- Schedule

The formal presentation concluded with a review of the overall project schedule and upcoming milestones. A copy of the meeting presentation is provided in **Attachment B.**

A question and answer session was held after the presentations. A summary of the questions and responses is provided in **Attachment C.**

ATTACHMENT A – MEETING ATTENDANCE

FIRST	LAST	AFFILIATION
Jason	Afinowicz	Freese and Nichols
Wayne	Ahrens	Dannenbaum Engineering
Jildardo	Arias	City of Friendswood
Delilah	Arolfo	Professional Utility Services
Susan	Baird	HGSD Board Member
Justin	Bartlett	KIT Professionals, Inc.
Amber	Batson	San Jacinto River Authority
James	Beach	WSP
Radu	Boghici	Texas Water Development Board
Andrew	Bohac	City of Needville
John	Burke	John E Burke & Associates LLC
Sarah	Carlock	Undine Texas, LLC.
Ki	Cha	Texas Water Development Board
Jun	Chang	North Harris County Regional Water Authority
Yun	Cho	Texas Water Development Board
Howard	Christian	City of Richmond
Katie	Clayton	City of Sugar Land
Christopher	Dupree	City of Houston
John	Ellis	United States Geological Survey
Mark	Evans	North Harris County Regional Water Authority
Linzy	Foster	United States Geological Survey
Julia	Frankovich	BGE, Inc.
Larry	French	Texas Water Development Board
Jessica	Fritsche	Brown and Caldwell
Matt	Froehlich	BGE, Inc.
Mark	Gehringer	FBSD Board Member
Joseph	Goins	HGSD Board Member
Alberto	Gonzalez	HGSD Board Member
Ashley	Greuter	Harris-Galveston Subsidence District
Linda	Harnist	FBSD Board Member
Zach	Holland	Bluebonnet Groundwater Conservation District
Jace	Houston	San Jacinto River Authority
Bill	Hutchison	Consultant
Kyle	Jones	BGE, Inc.
David	Jordan	INTERA

FIRST	LAST	AFFILIATION
Charles	Kalkomey	City of Rosenberg
Mike	Keester	LRE Water, LLC
Ron	Kelling	San Jacinto River Authority
Jake	Knight	United States Geological Survey
Sunil	Kommineni	KIT Professionals, Inc.
Ivan	Langford	Galveston County WCID#1
Jason	Long	HGSD Board Member
Mac	Martin	Texas A&M Forest Service
John	Martin	Southeast Texas Groundwater Conservation District
Daniel	McGraw	City of Fulshear
Katherine	Mears	HGSD Board Member
Whitney	Milberger	North Fort Bend Water Authority
Christina	Miller	North Fort Bend Water Authority
Brad	Moon	None provided
Jennifer	Morrow	Clear Lake City Water Authority
Laura	Norton	Consultant
Wade	Oliver	INTERA
Veronica	Osegueda	Houston Public Works
Aaron	Pena Rodriguez	Texas A&M
Tina	Petersen	Harris-Galveston Subsidence District
Jon	Polley	Radcliffe Bobbitt Adams Polley PLLC
Mitchell	Ramon	City of Houston
Samantha	Reiter	Lone Star Groundwater Conservation District
Trish	Ricklefsen	None provided
Cindy	Ridgeway	Texas Water Development Board
Patrick	Rightmyer	City of Houston
Curtis	Rodgers	Clear Lake City Water Authority
Kathy	Rogers	HGSD Board Member
William	Seifert	Ground Water Consultants, LLC
Melinda	Silva	Dannenbaum Engineering
Michelle	Sneed	United States Geological Survey
Colleen	Spencer	City of Sugar Land
Gregory	Stanton	United States Geological Survey
Jon	Strange	FBSD Board Member
Kyle	Swank	KIT Professionals
Philip	Taucer	Freese and Nichols
Shaun	Theriot-Smith	HGSD Board Member
Robert	Thompson	Harris-Galveston Subsidence District
Michael	Turco	Harris-Galveston Subsidence District

FIRST	LAST	AFFILIATION
Andrew	Vacek	Lake Management Services, LP
Shirley	Wade	Texas Water Development Board
David	Wheelock	Lower Colorado River Authority
Jeremy	White	INTERA
Booker	Williams	FBSD Board Member

ATTACHMENT B – MEETING PRESENTATION

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.**

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

HARRIS-GALVESTON SUBSIDENCE DISTRICT

FORT BEND SUBSIDENCE DISTRICT

JOINT REGULATORY PLAN REVIEW

Stakeholder Meeting #3

Stakeholder Advisory Forum #2

10 December 2020

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.

Link to Previous Meeting Content

- https://hgsubsidence.org/planning/regulatory-plan-review/

Sunil Kommineni
- KIT

Justin Bartlett
- KIT

Wade Oliver
- INTERA

Cindy Ridgeway
- TWDB

John Ellis
- USGS

Linzy Foster
- USGS

Project Elements

Alternative Water Supply Availability

Groundwater Availability Modeling

GULF-2023 Model Development

AWS Availability Objectives

- Compile and characterize alternative water supplies and their availability for use by systems in the regulatory areas
- Evaluate supplies originating both within (i.e., reclaimed water) and outside the regulatory areas (i.e., seawater, new reservoirs)

AWS Options

Identified 20+ Options

NW - New Water
SS – Storage Solution
RS - Reclaimed Supply
DM - Demand Management

Surface Water Development (SS, NW)
- New Reservoirs
- Off Channel Reservoirs
- Inter-Basin Transfers
- Appropriated but Undeveloped Water

Reclaimed Water (RS)
- Purple Pipe Network
- Direct Potable Reuse
- Indirect Potable Reuse
- Satellite Plants / Onsite Reuse
- Industrial Process Water

Seawater Desalination (NW)
- Onshore Facility Desalination
- Offshore Facility Desalination

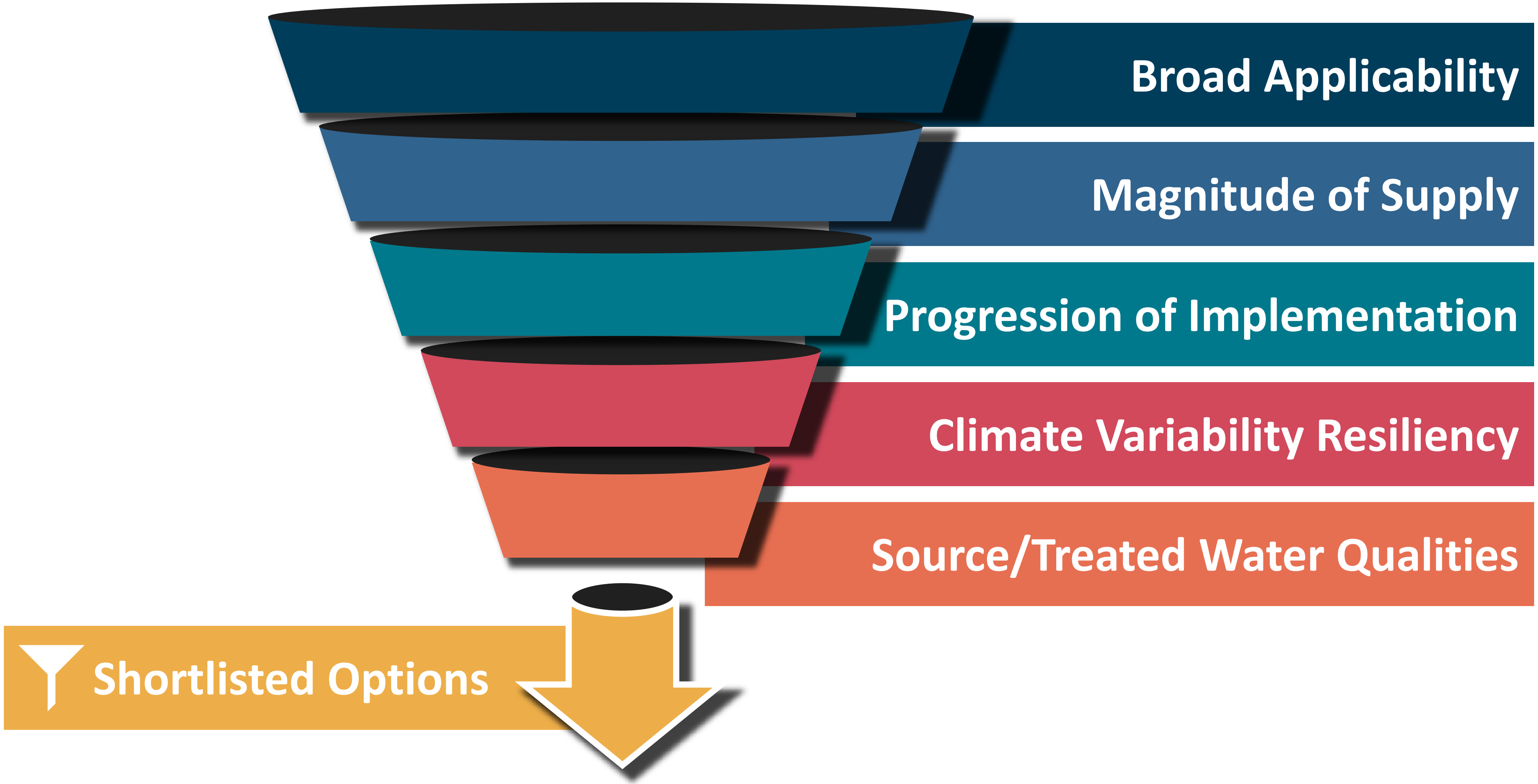
Brackish Groundwater Desalination (NW)
- Brackish Groundwater Wells and Treatment

Aquifer Storage and Recovery (SS)
- ASR w/ Surface Water
- ASR w/ Stormwater
- ASR w/ Reclaimed Water

Stormwater Capture and Reuse (NW)
- Rainwater Harvesting
- Detention Basins
- Amenity Lake Filling

Water Demand Management (DM)
- Baseline Conservation
- Basic Conservation
- Advanced Conservation
- Water Loss Control / Advanced Metering Infrastructure

Shortlisting Approach



SHORTLISTED OPTIONS

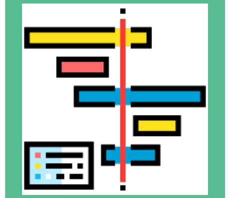
CHARACTERIZATION OF SHORTLISTED OPTIONS

Develop Narrative Descriptions

Estimate Magnitude of Supplies

Prepare Planning Level Cost Estimates

Identify Implementation Timelines



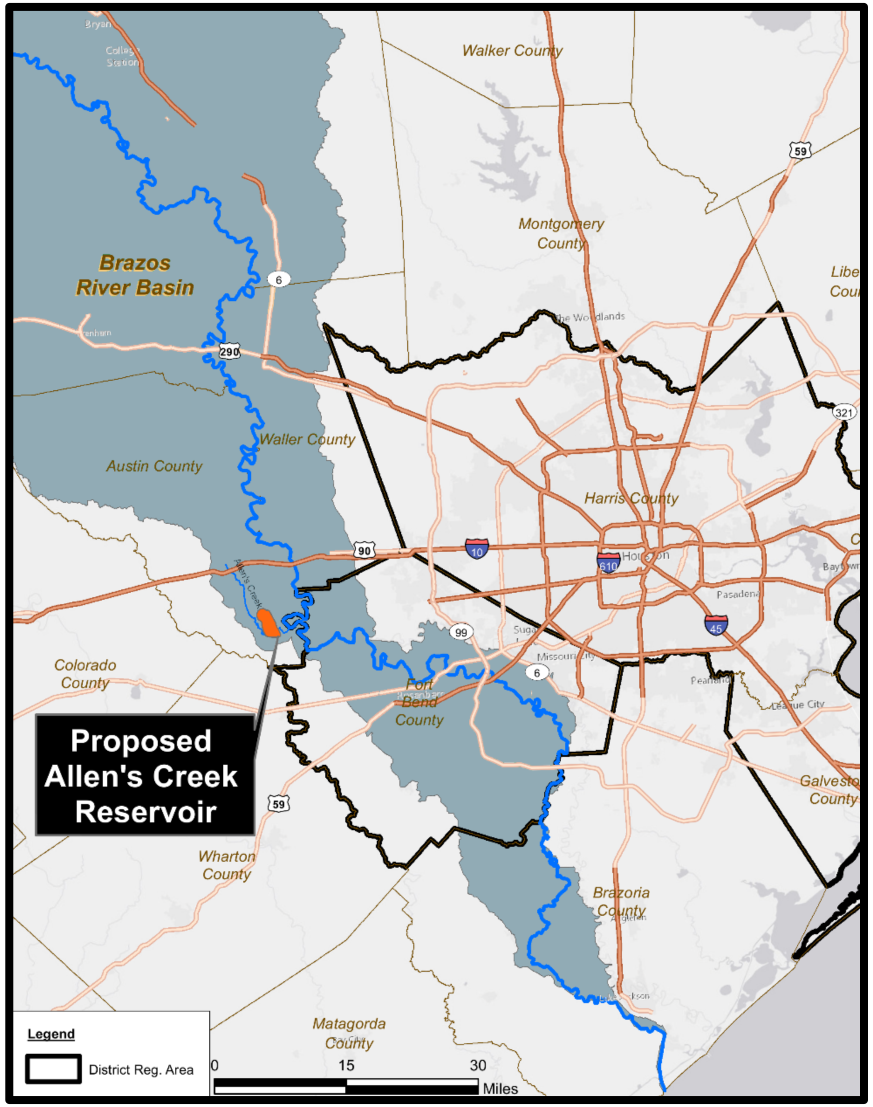
Assess Vulnerability to Climate Change

Stakeholders Outreach

- City of Houston
- Gulf Coast WA
- North Harris CRWA
- West Harris CRWA
- North Fort Bend WA
- City of Sugar Land
- City of Richmond
- Marathon Petroleum
- Missouri City
- League City
- City of Baytown
- Texas City
- Cinco Ranch MUD 1
- San Jacinto River Authority

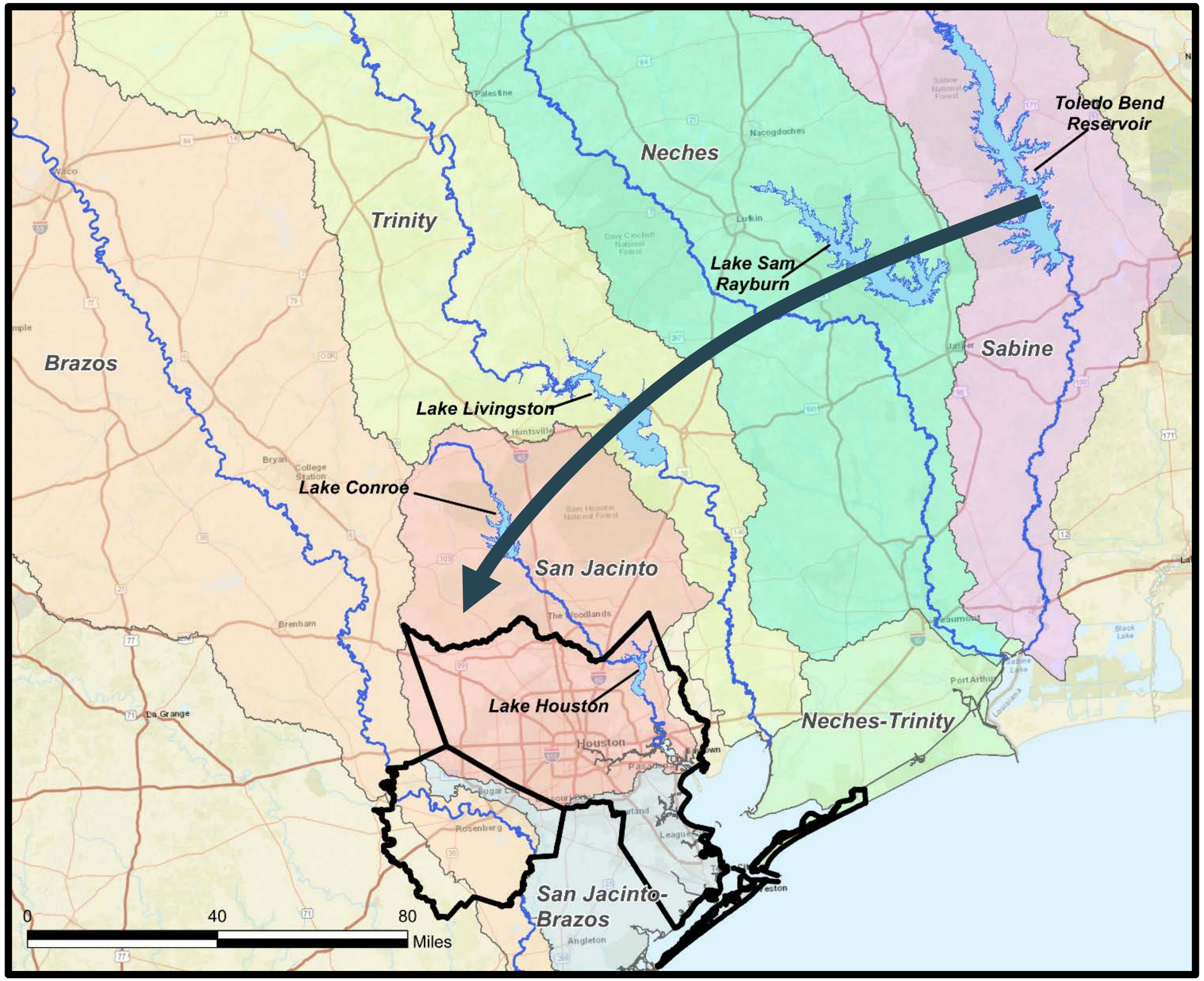
Surface Water Development

- Most prominent alternative water supply
- State Water Plan recommends construction of new reservoirs
- Allens Creek Reservoir
  - Off-channel reservoir on Allens Creek, a tributary of Brazos River, to store surface water and stormwater runoff
  - Water rights are held by City of Houston and Brazos River Authority
  - Assists with meeting future water demands from residential and industrial growth in the region

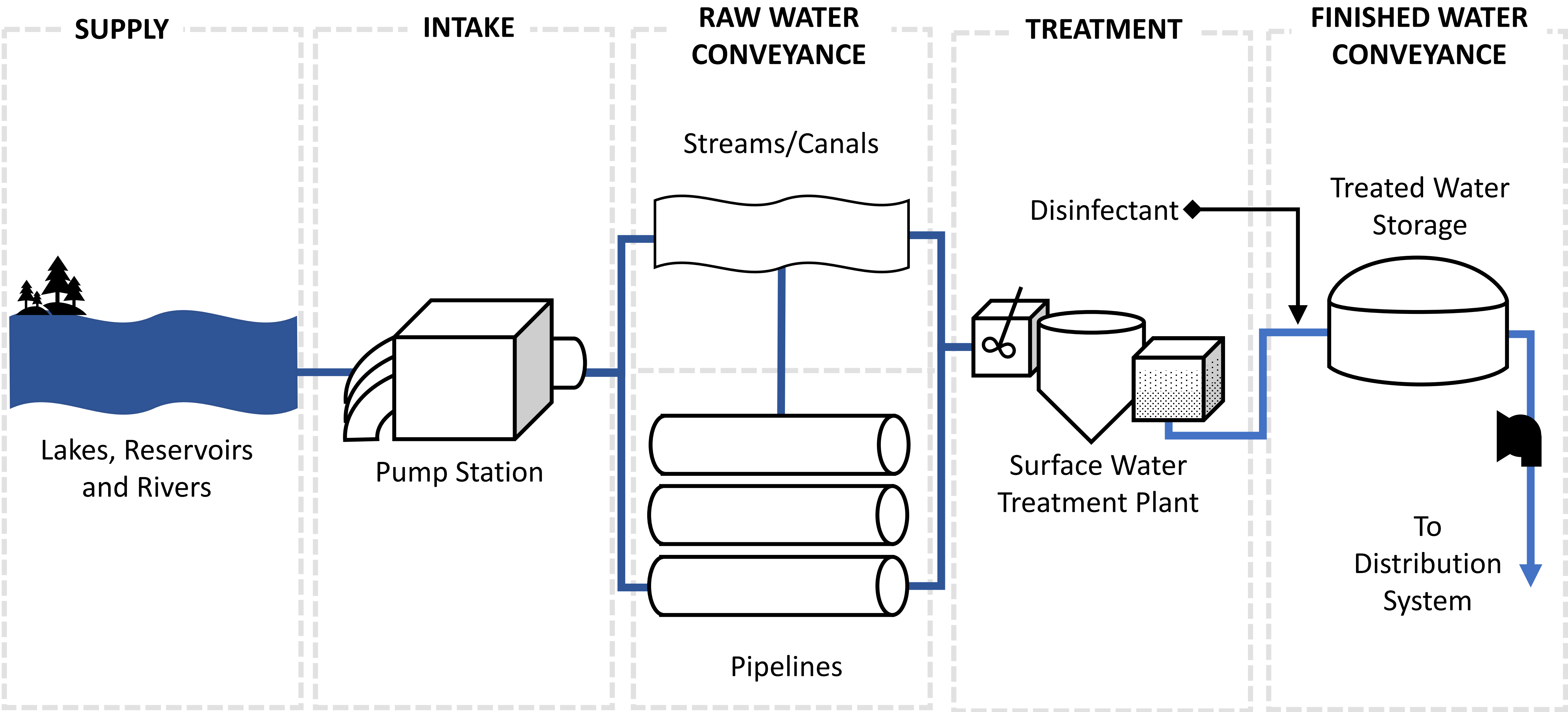


Surface Water Development

- East Texas Water Supplies
  - Transferring water from Sabine / Neches River Basins to Trinity and/or Brazos River Basins
  - Will require inter-basin transfer agreements and cooperation of large water rights holders
  - Need significant infrastructure



Surface Water Development Components



Key to Dashboard

Magnitude of Supply

- Available supply and typical implementation sizes in MGD
- Timeframe of availability is from current to 2100

Implementation Timeline

- Accounts for time to develop a water supply from "concept to completion"
- Includes planning, design, and construction timeframes

Climate Resiliency

- Indicates resiliency of supply to climate variability

Cost Opinions

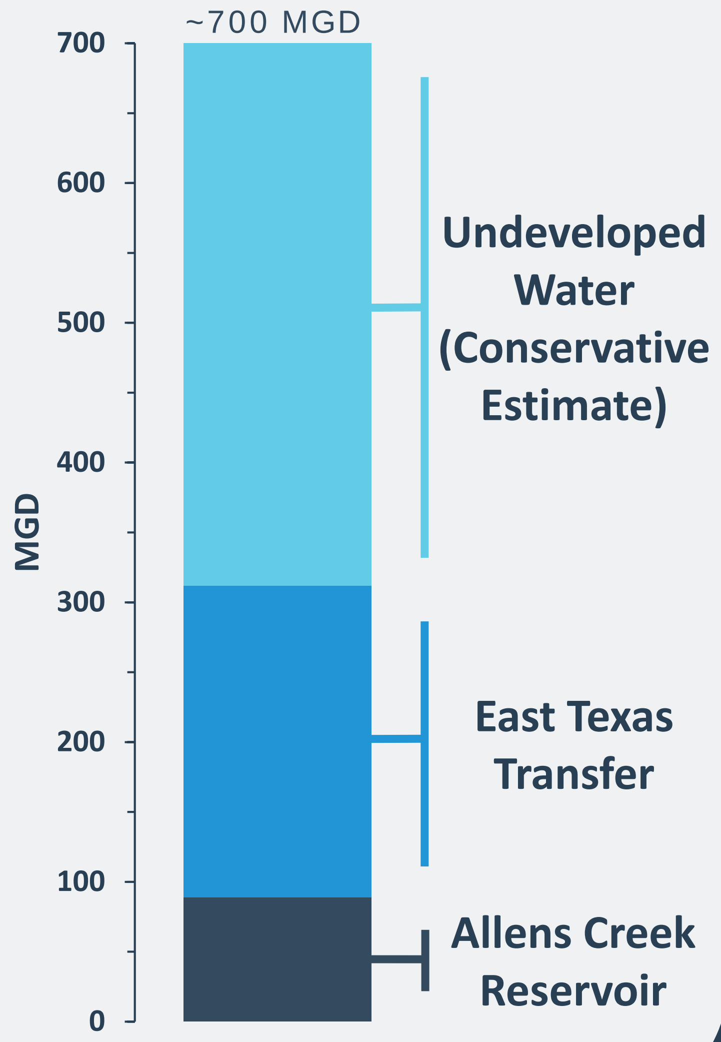
- Planning level, order of magnitude cost estimates
- Costs include: supply development, direct/indirect costs, debt service fee
- Costs exclude: raw water, distribution system & site-specific constraints

Subsidence Impacts

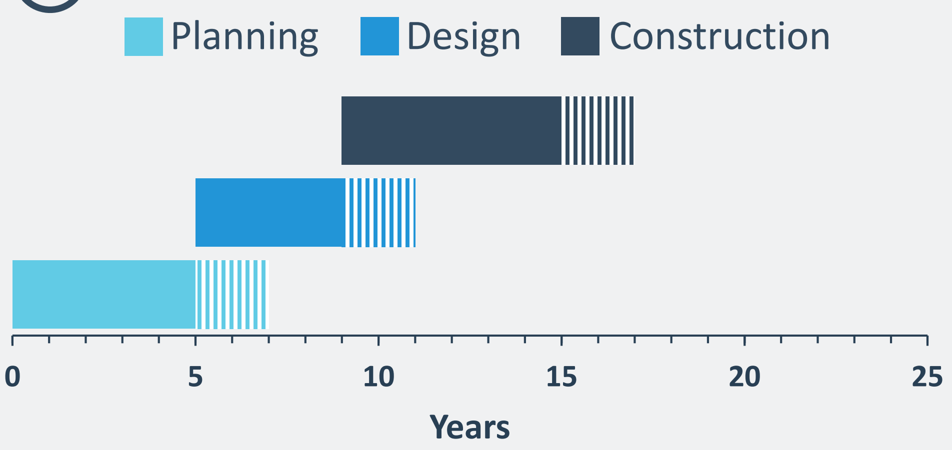
- Specifies impacts to land subsidence

Surface Water Development

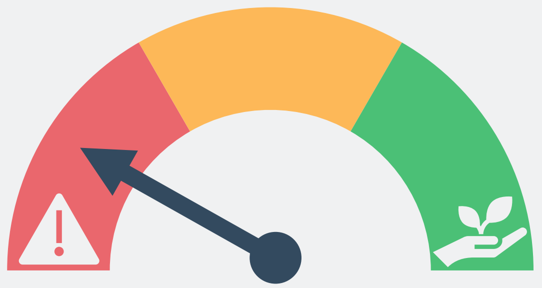
Magnitude of Supply



Implementation Timeline

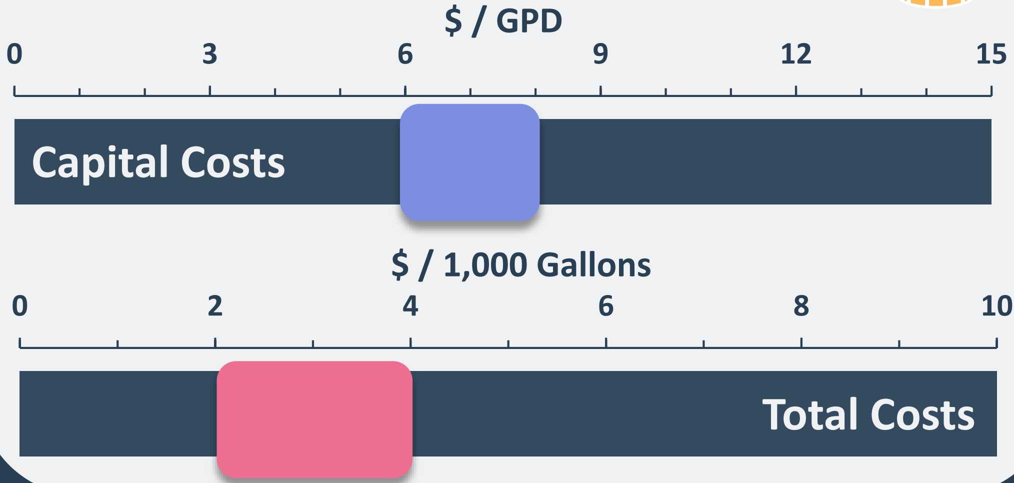


Climate Resiliency



Drought-Susceptible

Cost Opinions



Subsidence Impacts

No Subsidence

Preliminary
Subject to Revisions

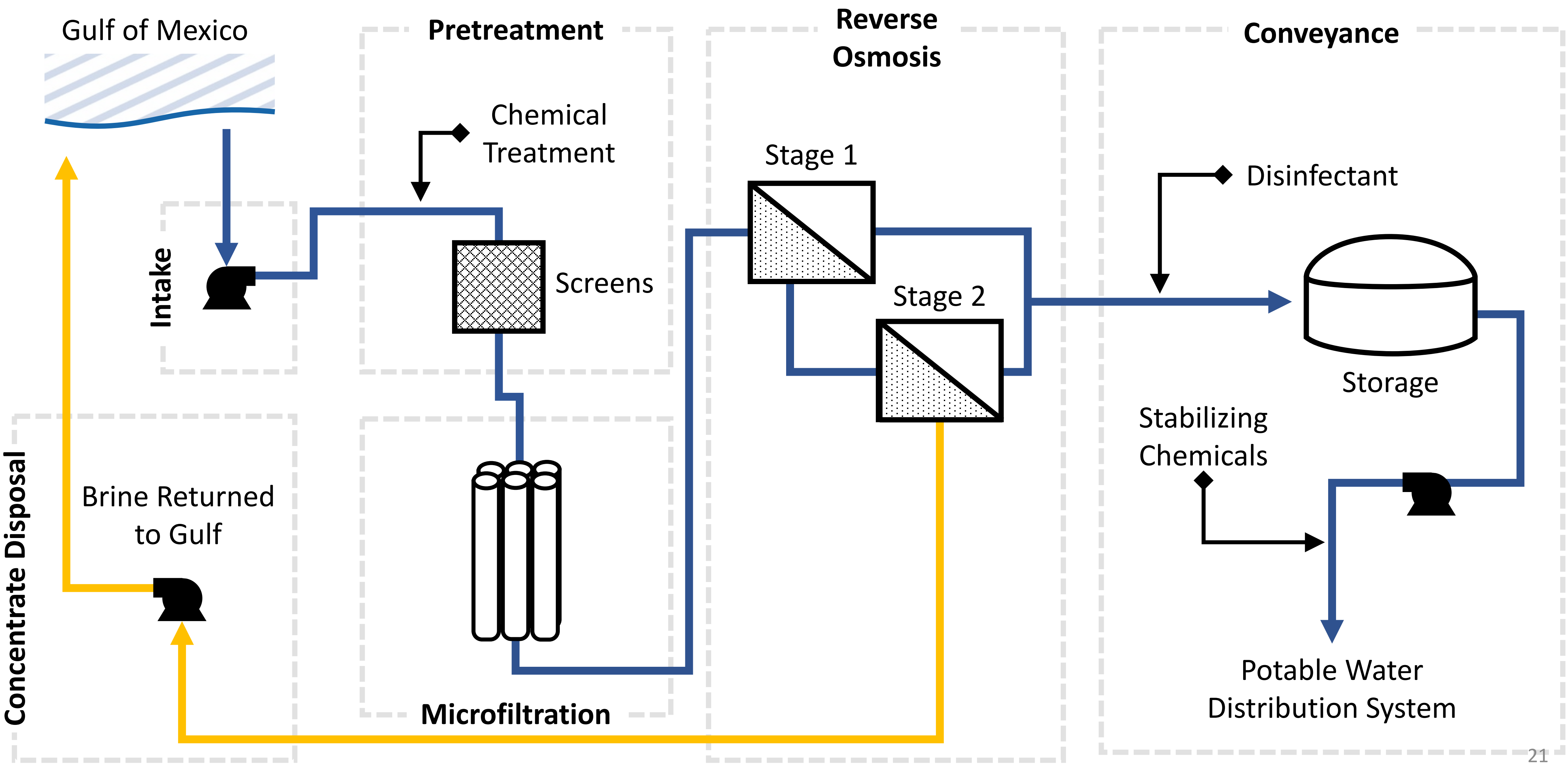
Seawater Desalination

- Emerging alternative water supply
- Drought-proof supply; assists with diversification of supply portfolio
- Scale is limited by infrastructure investment and not supply availability
- Will require a regional consortium or partnership to develop this supply
- Plant will be located close to the Gulf; serves needs of coastal communities w/ participation of inland communities

Seawater Desalination

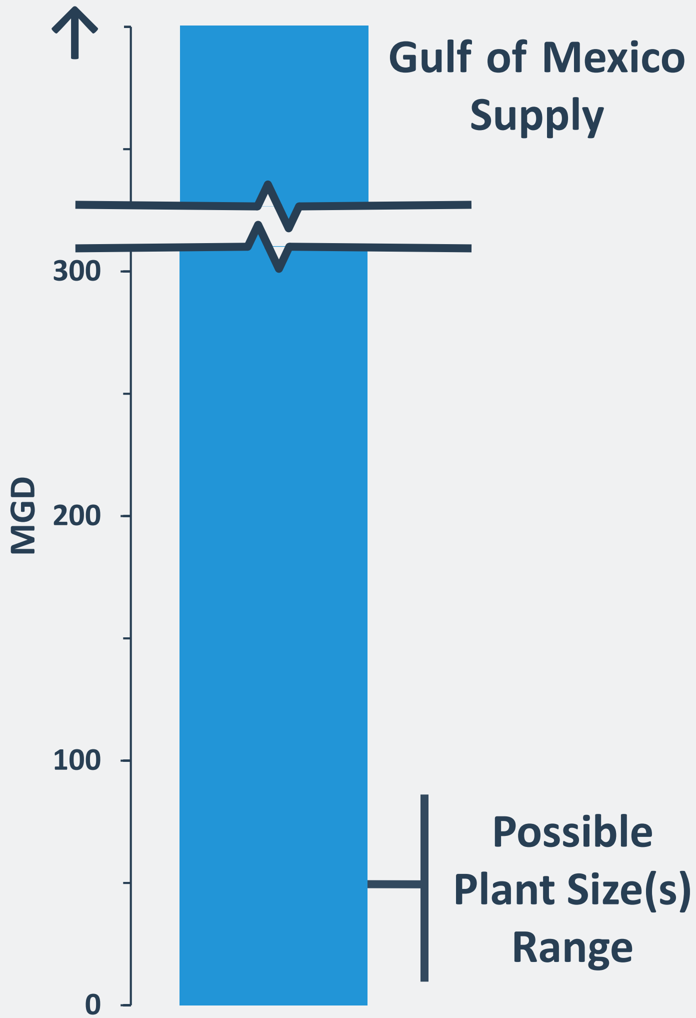
- Proven treatment process in seawater reverse osmosis (RO)
- RO is energy intensive; evolution of membranes and renewable energy technologies may reduce life-cycle costs
- Established in California and Florida
  - Carlsbad Desalination Plant (50 MGD)
  - Tampa Bay Seawater Desalination Facility (25 MGD)
- Corpus Christi is planning for 10-20 MGD seawater desalination supply

Seawater Desalination Components

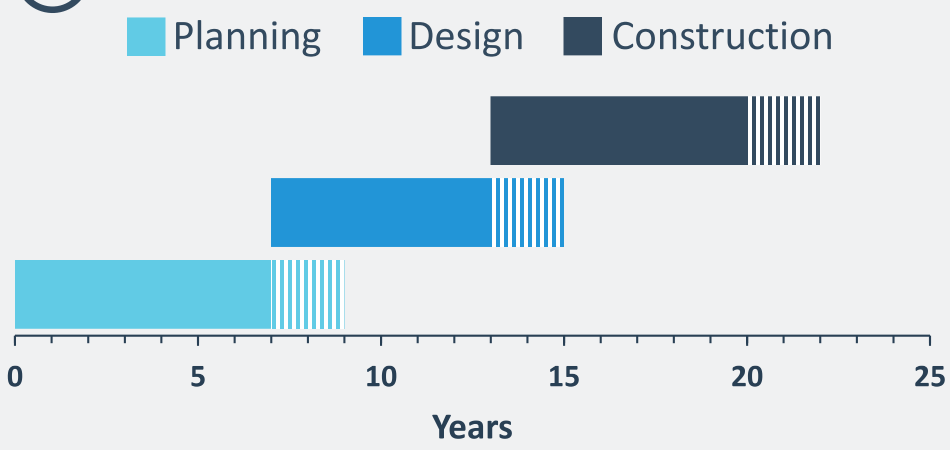


Seawater Desalination

Magnitude of Supply



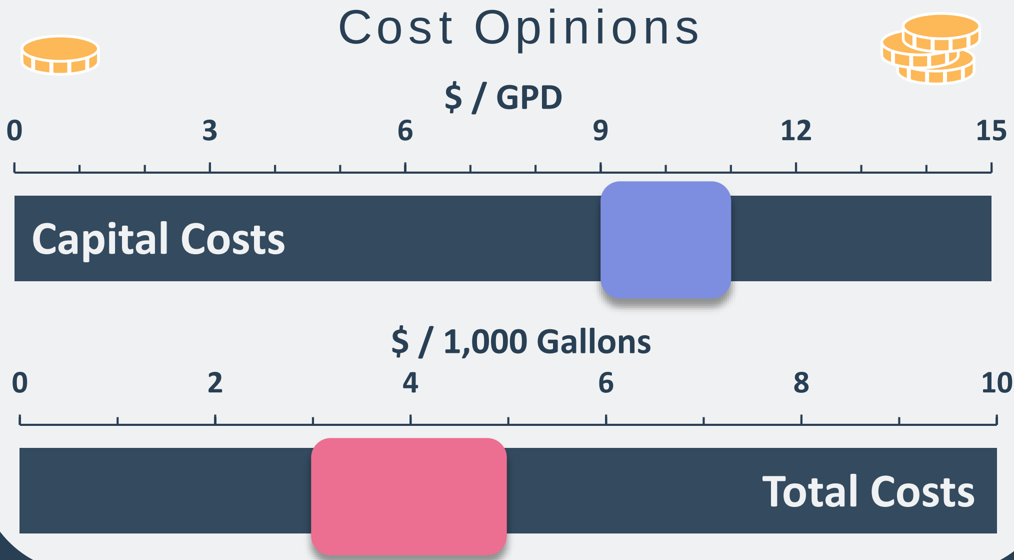
Implementation Timeline



Climate Resiliency

Drought-Proof

Cost Opinions



Subsidence Impacts

No Subsidence

Preliminary
Subject to Revisions

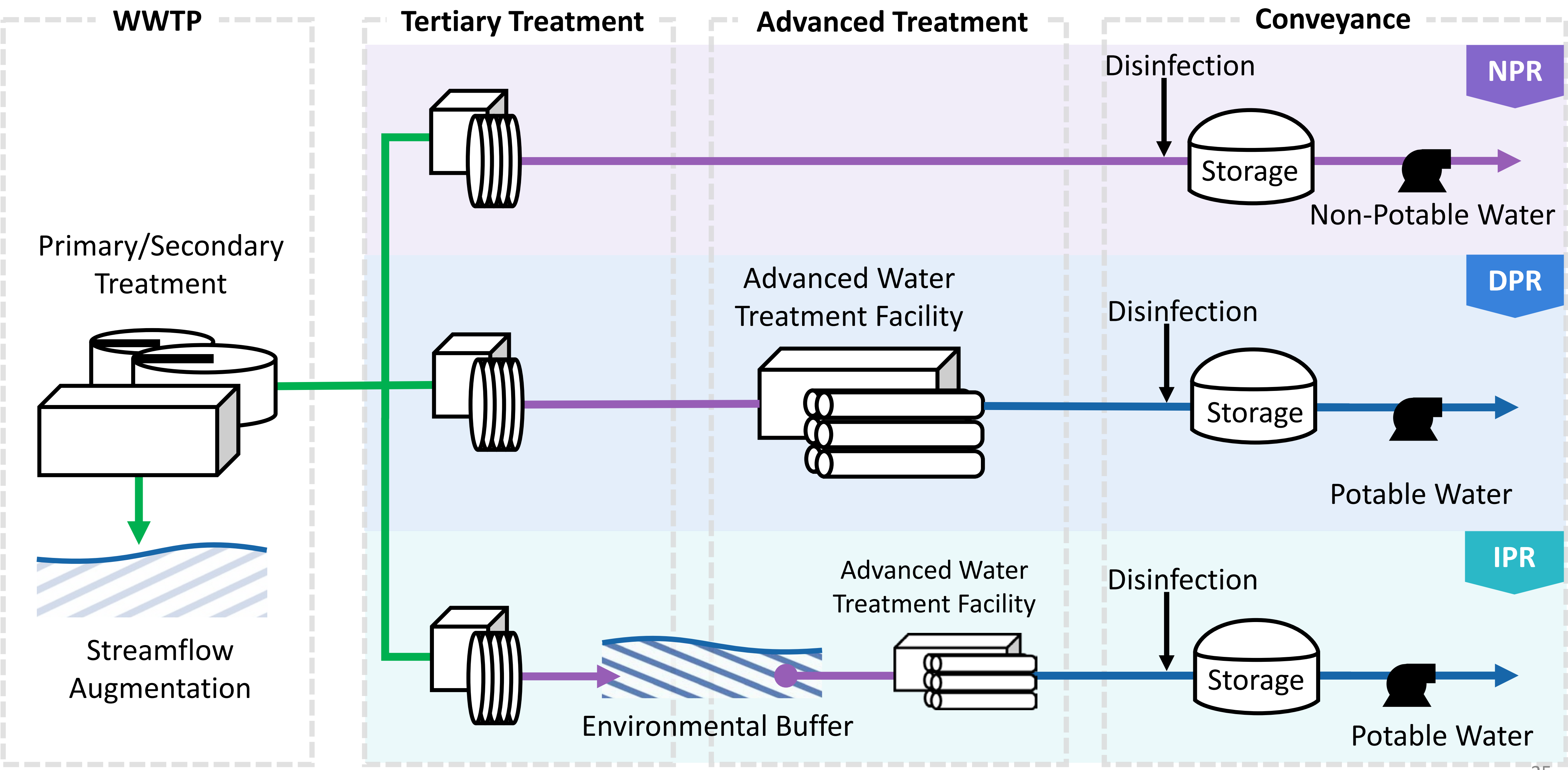
CENTRALIZED RECLAIMED WATER

- Proven alterative water supply
- Drought-proof supply; can supply water for non-potable and potable use
- Non-potable use: purple pipeline network non-potable water for irrigation and lake filling
    - Best for new development
- Potable use: direct potable reuse (DPR) or indirect potable reuse (IPR)
    - Best for developed/urban areas

Centralized Reclaimed Water

- Non-potable uses will continue to be the preferred reclaimed water option within the regulatory areas
    - Cities of Sugar Land, Richmond, and Rosenberg, Bridgeland community, and others have purple pipe networks
- Centralized systems are increasingly gaining acceptance
    - Big Springs integrated the first DPR system in the nation in 2015
    - El Paso Water Utilities is implementing a 10 MGD DPR Facility (2025)

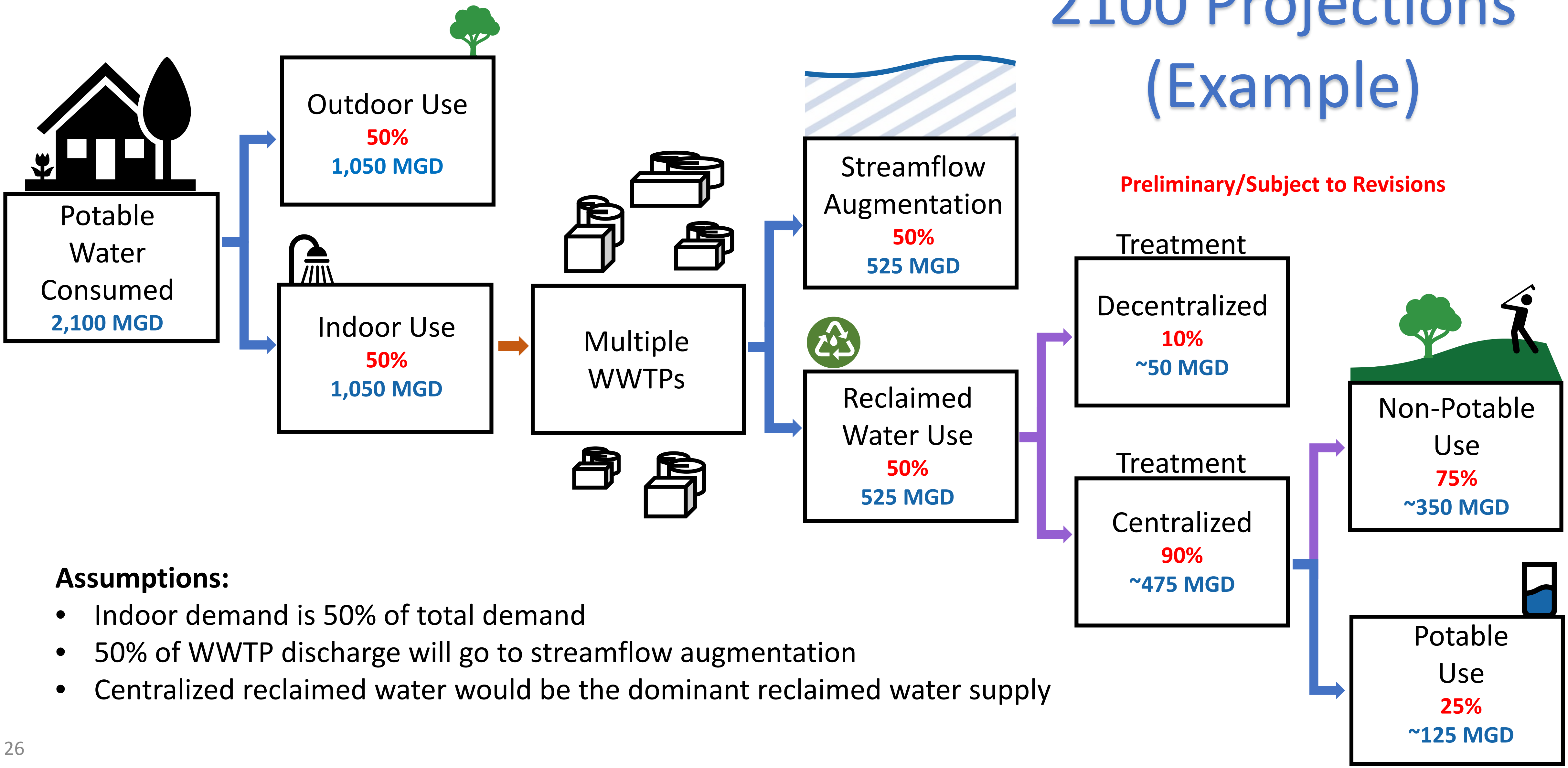
Centralized Reclaimed Water



CENTRALIZED RECLAIMED WATER
WATER BALANCE

2100 Projections (Example)

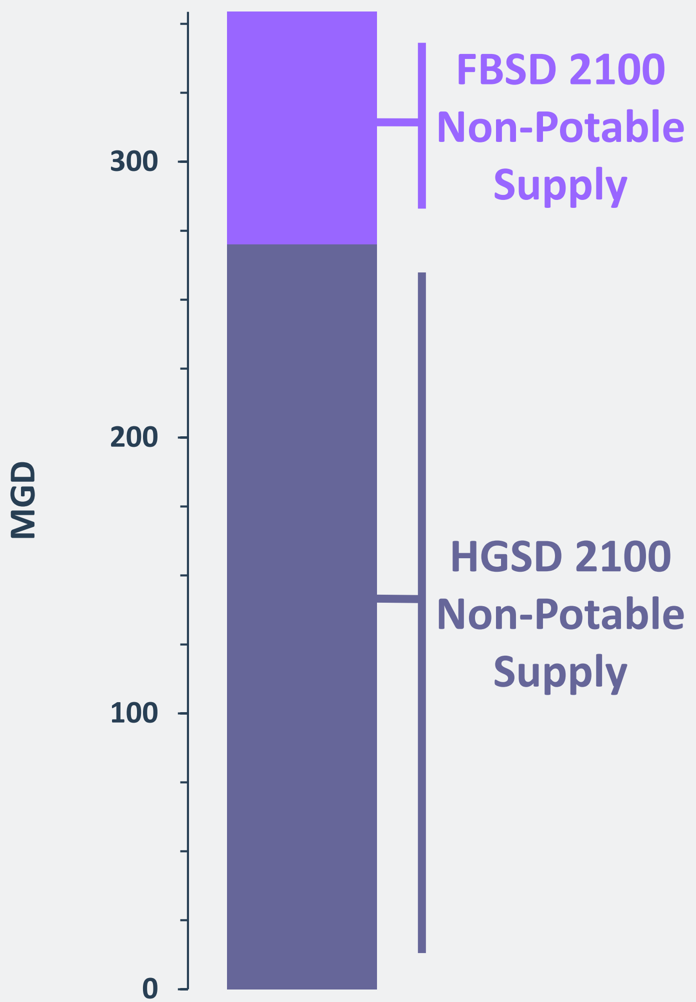
Preliminary/Subject to Revisions



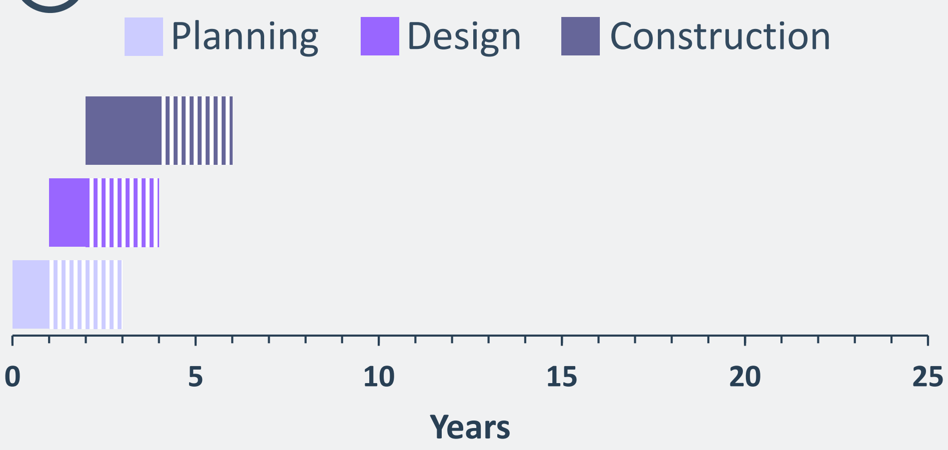
Assumptions:
- Indoor demand is 50% of total demand
- 50% of WWTP discharge will go to streamflow augmentation
- Centralized reclaimed water would be the dominant reclaimed water supply

Centralized Reclaimed Water – Non-Potable

Magnitude of Supply



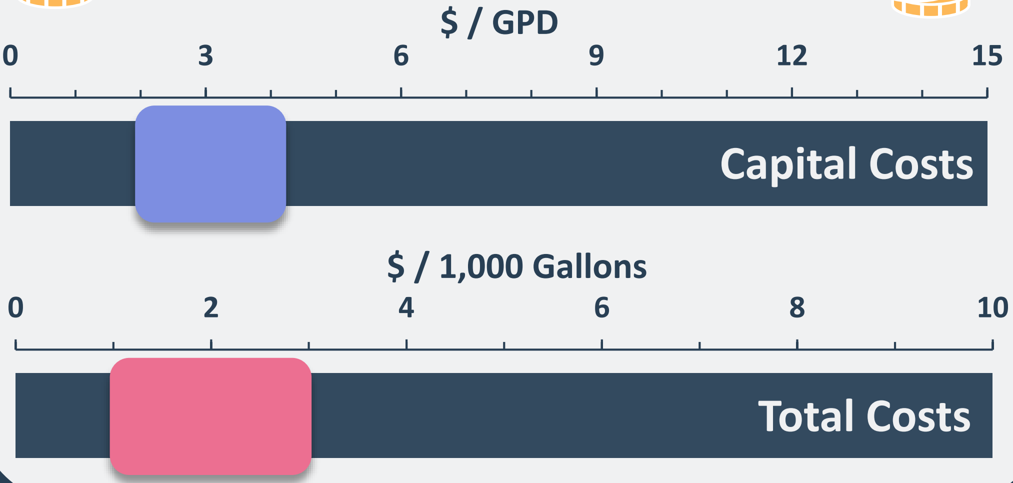
Implementation Timeline



Climate Resiliency

Drought-Proof

Cost Opinions



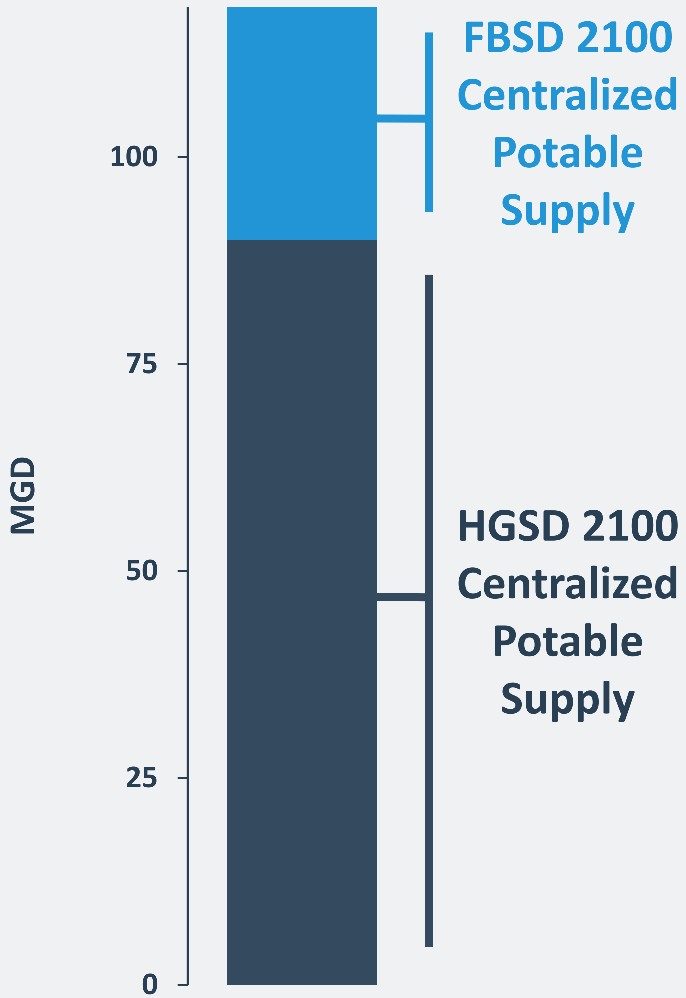
Subsidence Impacts

No Subsidence

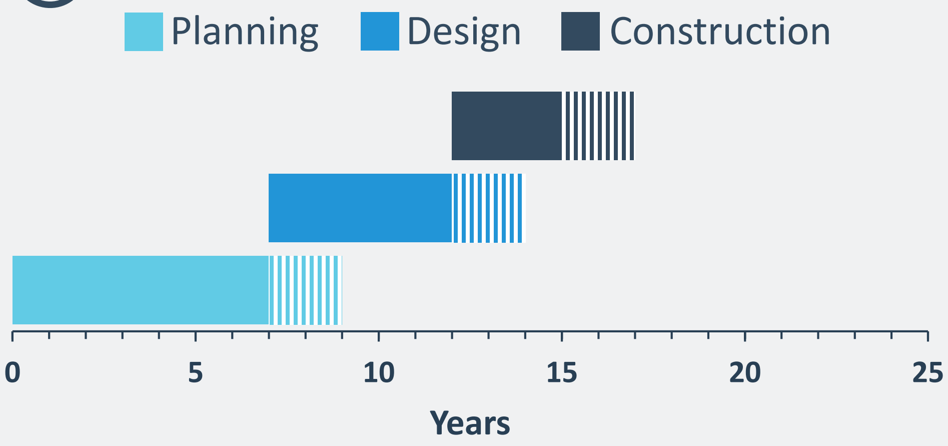
Preliminary/Subject to Revisions

Centralized Reclaimed Water – Potable

Magnitude of Supply



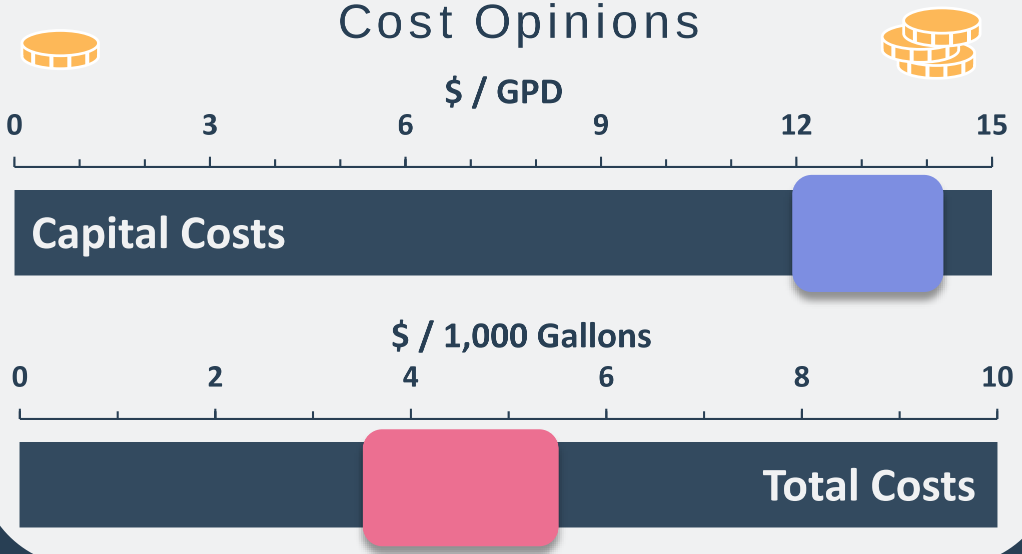
Implementation Timeline



Climate Resiliency

Drought-Proof

Cost Opinions



Subsidence Impacts

No Subsidence

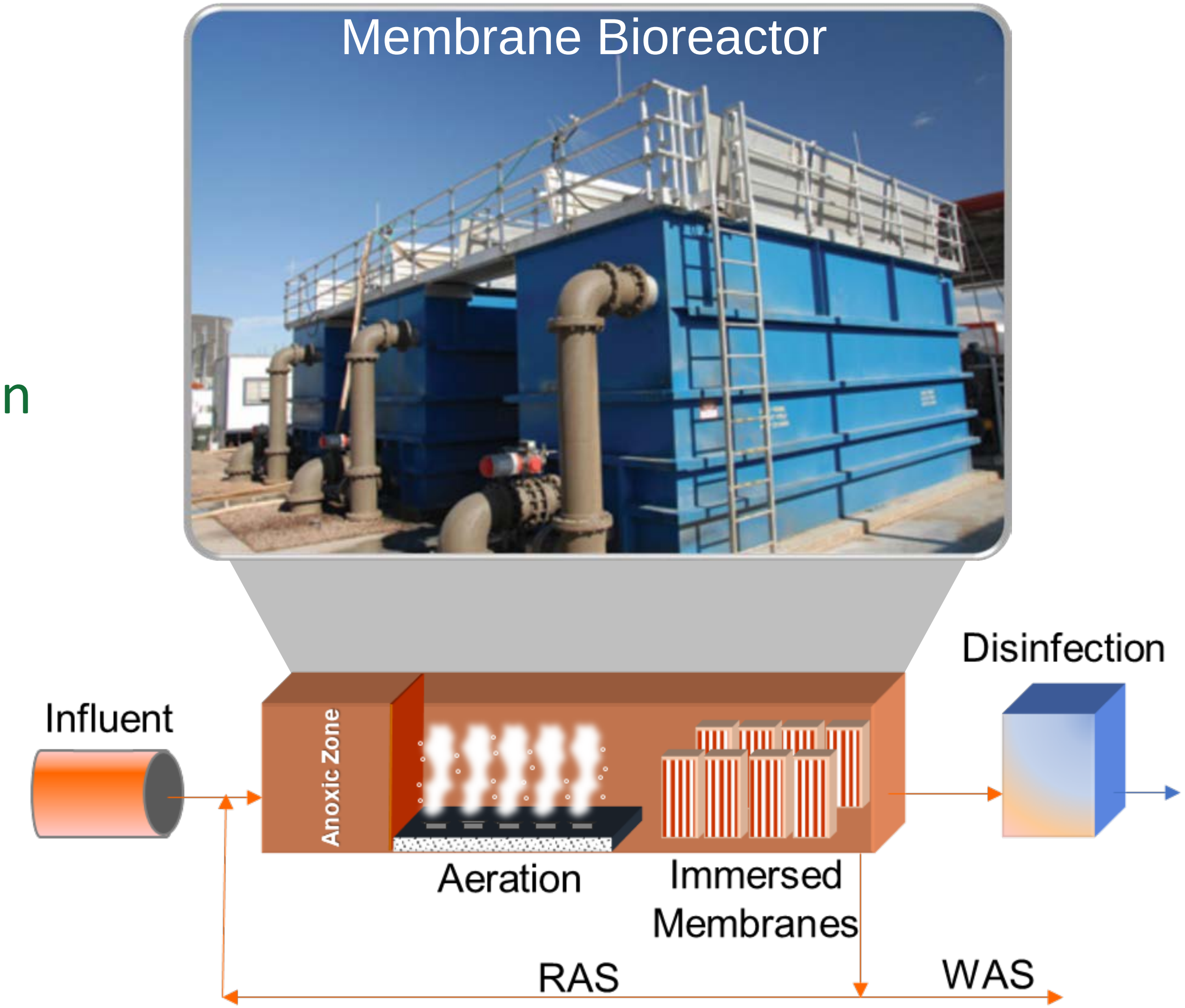
Preliminary/Subject to Revisions

DECENTRALIZED RECLAIMED WATER

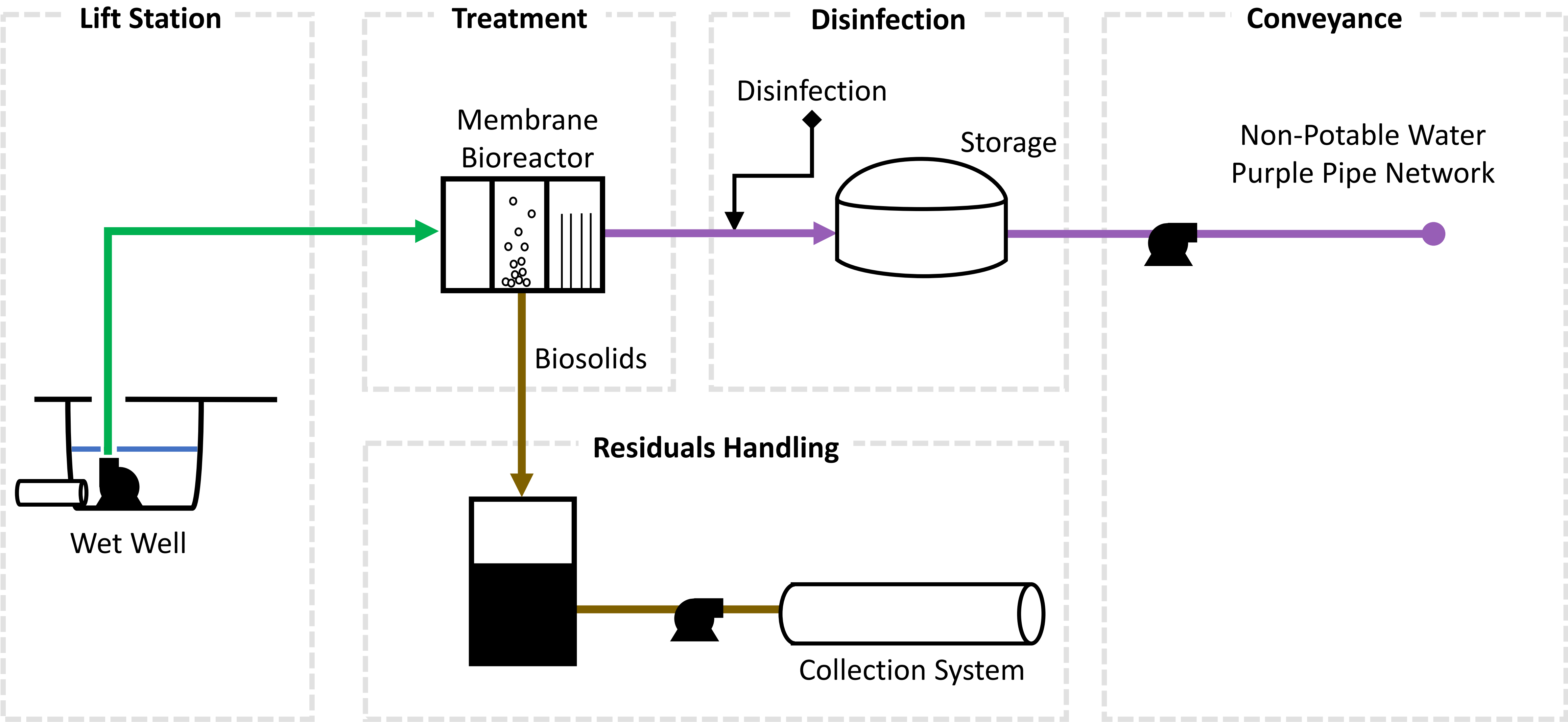
- Flows from collection system are diverted for water reclamation at smaller facilities
- Satellite Plants
  - Reclamation facilities are located at lift stations or near large sewer mains
  - Highly dependent on economy of scale
  - Less cost effective than purple pipe
- Onsite Reuse
  - Reclamation facilities are located at the site of origin
  - Already used by high demand customers (refineries, chemical plants, etc.)

DECENTRALIZED RECLAIMED WATER

- Proven decentralized treatment involves MBR technology
- Membrane Bioreactor technology
  - Automated, less operator attention
  - Preferred for plants that handle high strength streams
- Midland Satellite Reuse Plant
  - First of its kind in Texas
    - 200,000 GPD
    - End use is irrigation

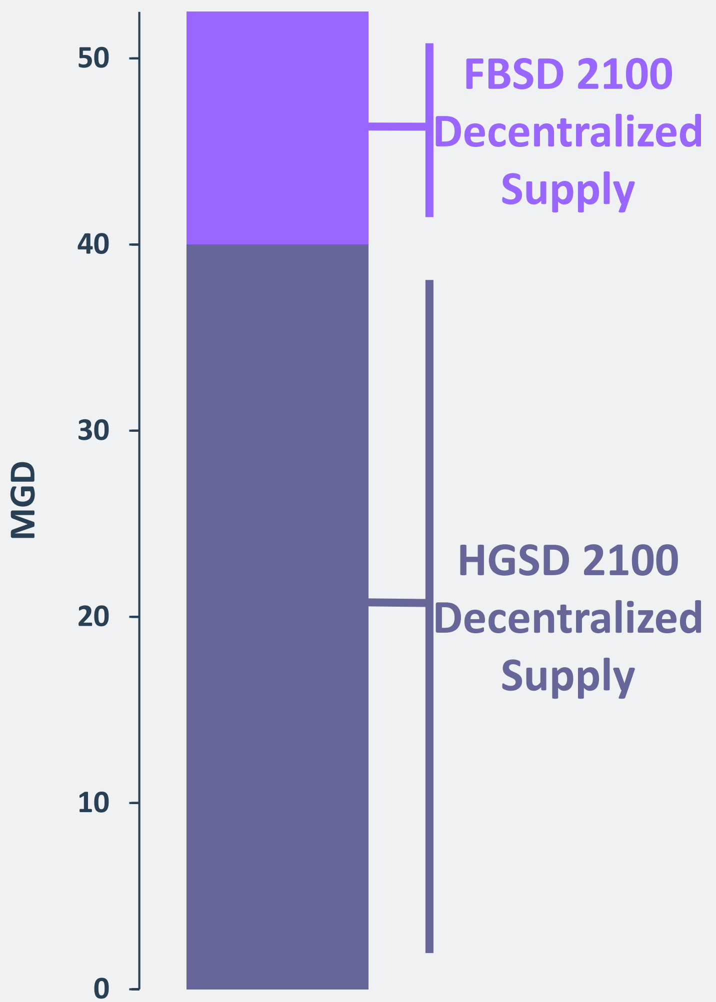


Decentralized Reclaimed Water

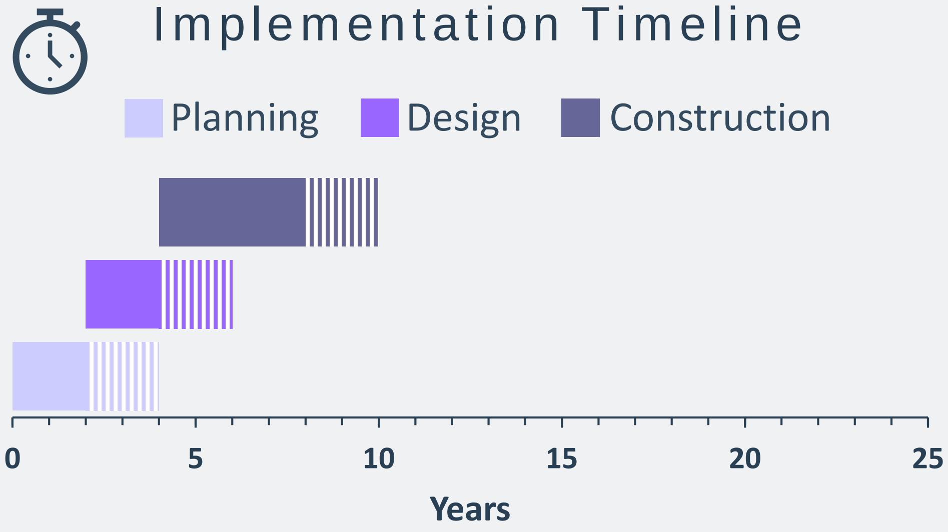


Decentralized Reclaimed Water

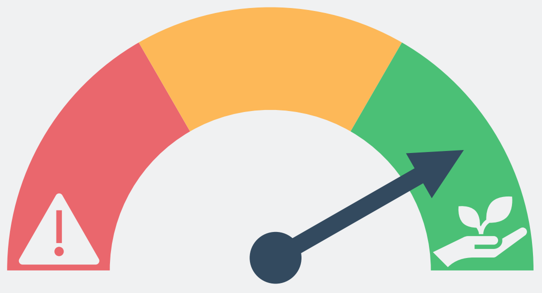
Magnitude of Supply



Implementation Timeline

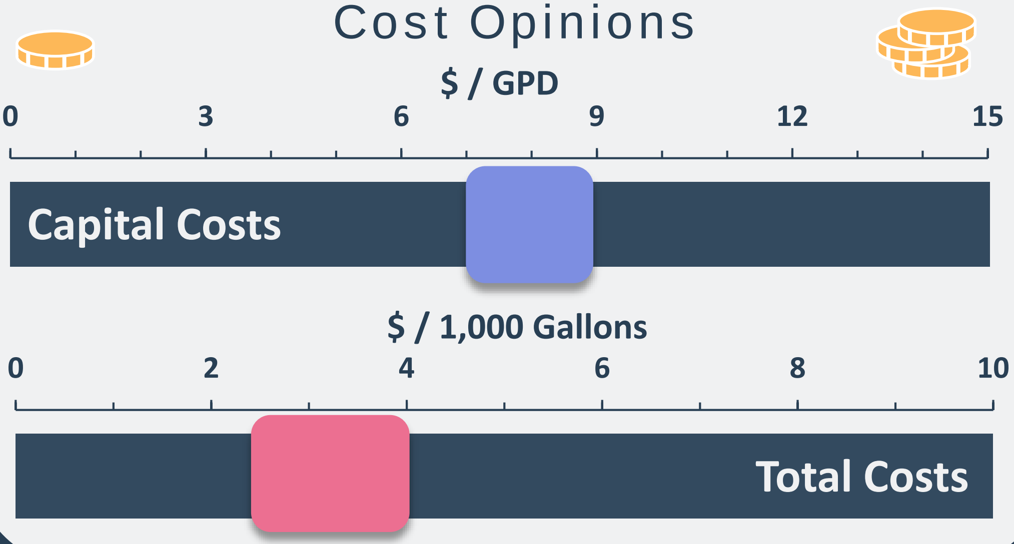


Climate Resiliency



Drought-Proof

Cost Opinions



Subsidence Impacts

No Subsidence

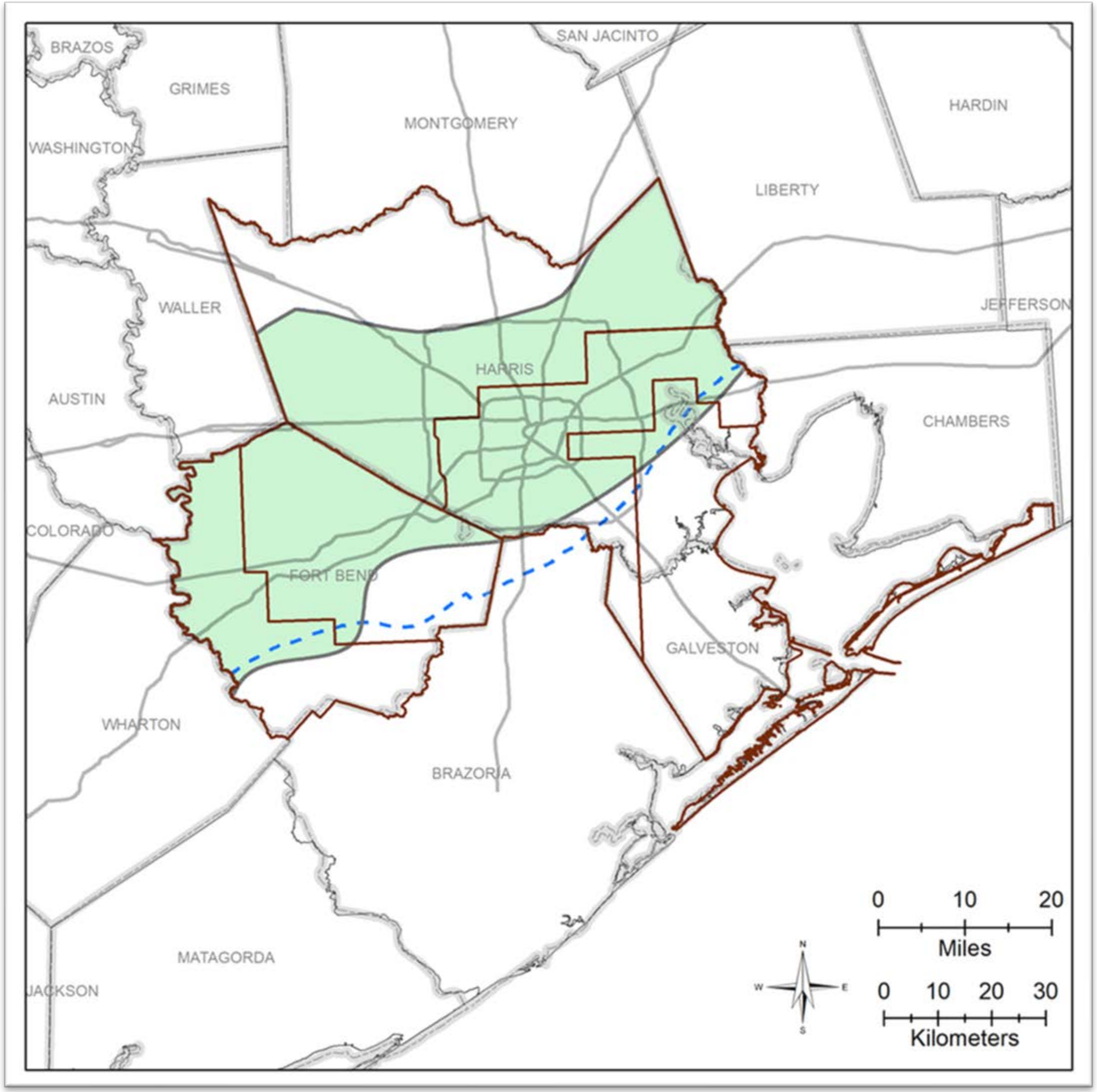
Preliminary/Subject to Revisions

Brackish Groundwater Desalination

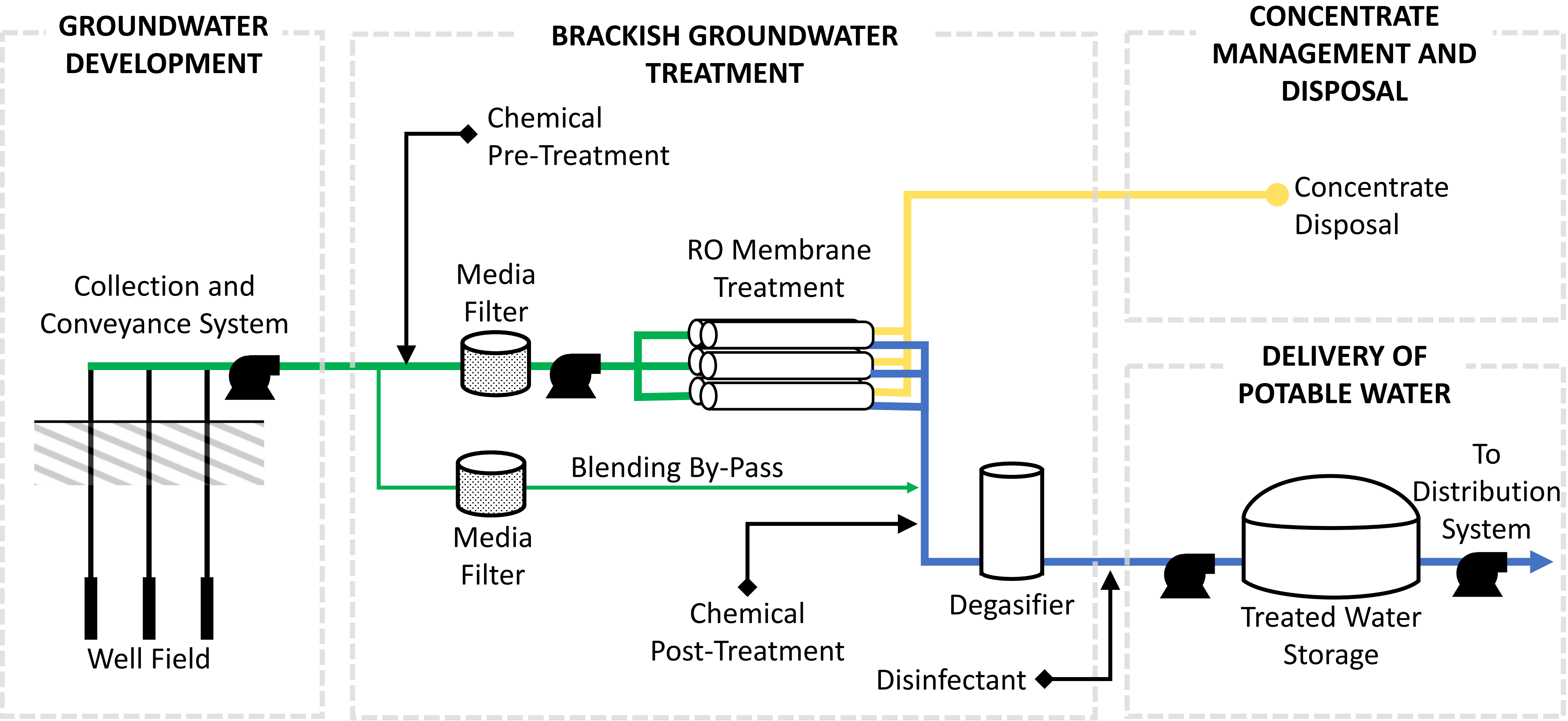
- Emerging alternative water supply
- Brackish water has a TDS of 1,000-10,000 mg/L
- Significant volumes of water are present in the Gulf Coast Aquifer System
- District investigated the impacts of developing brackish groundwater supply on land subsidence
- This study will provide feasible areas and magnitude of yields for brackish water wells

Potential Regulatory Areas Served

- Northern boundary is the approximate limit of freshwater Jasper wells
- Southern boundary is the approximate limit of groundwater less than 10,000 mg/L in the Jasper aquifer

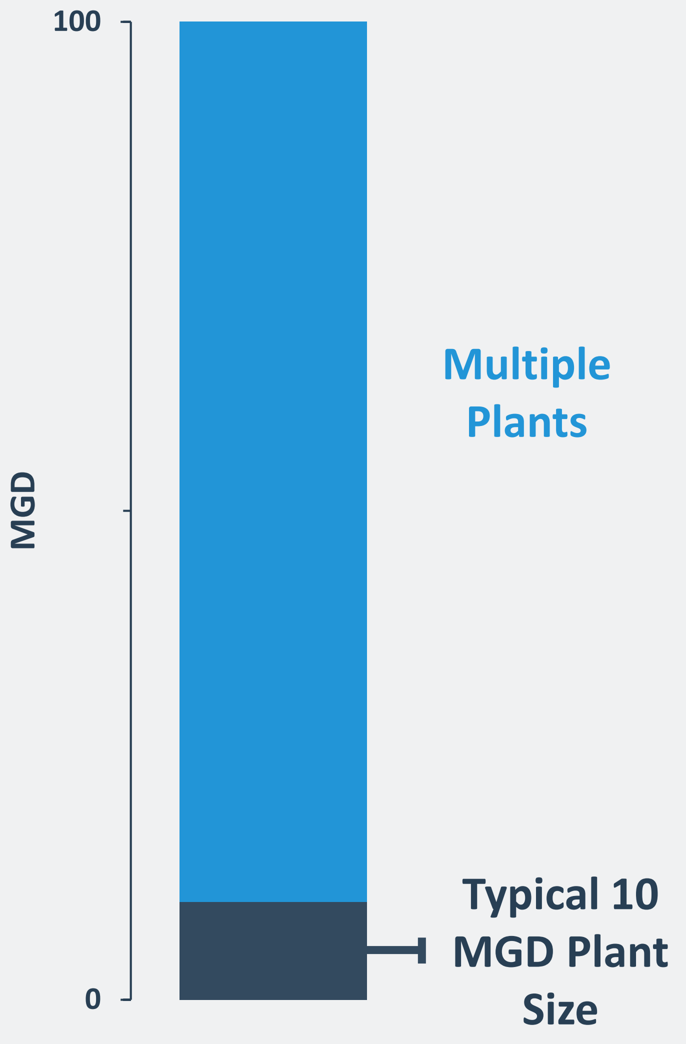


Brackish Desalination Components

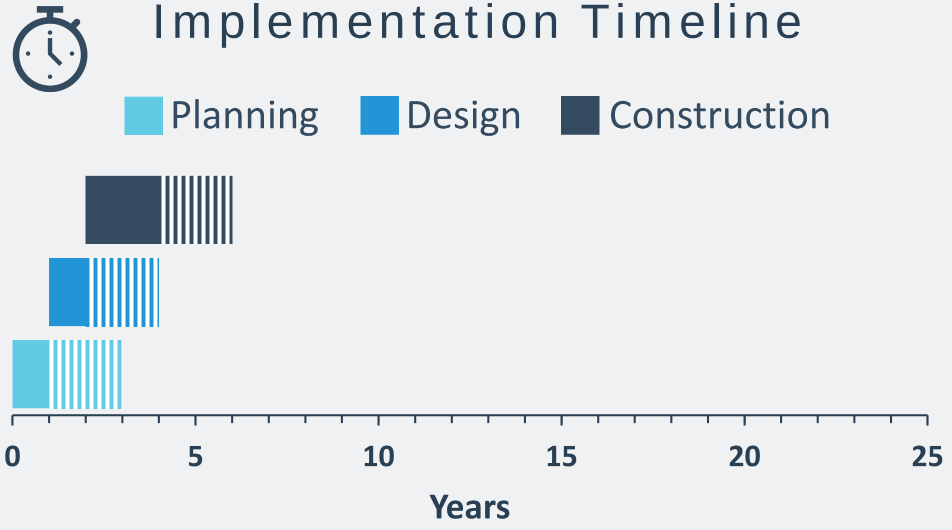


Brackish Groundwater Desalination

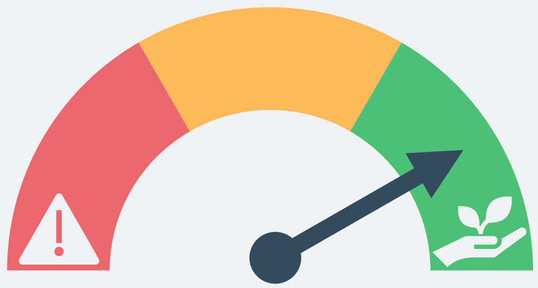
Magnitude of Supply



Implementation Timeline

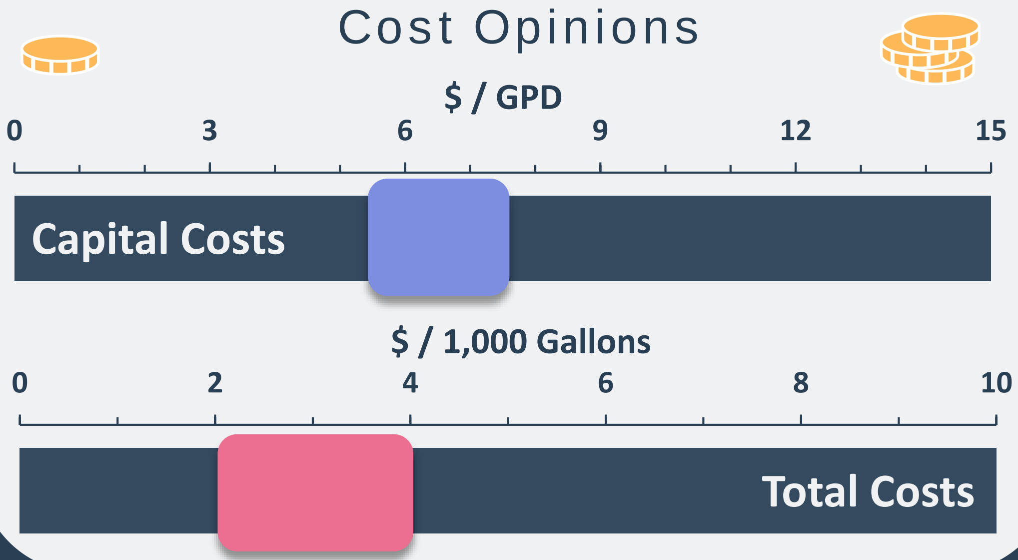


Climate Resiliency



Drought-Proof

Cost Opinions



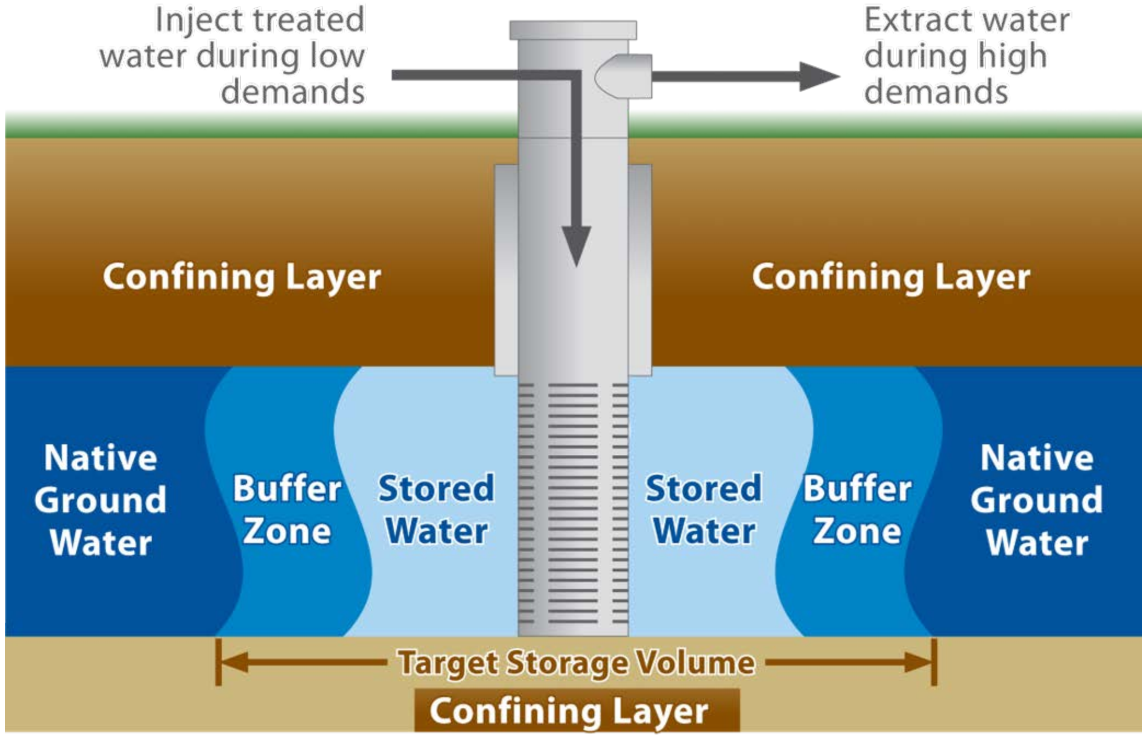
Subsidence Impacts

Being Evaluated

Preliminary
Subject to Revisions

AQUIFER STORAGE AND RECOVERY (ASR)

- Emerging alternative water supply; storage solution
- District is investigating Subsidence Impacts
- Operation as a seasonal peaking option, as opposed to drought storage, reduces subsidence
- Study will provide more details on hydrogeological aspects and magnitude of ASR for the regulatory areas



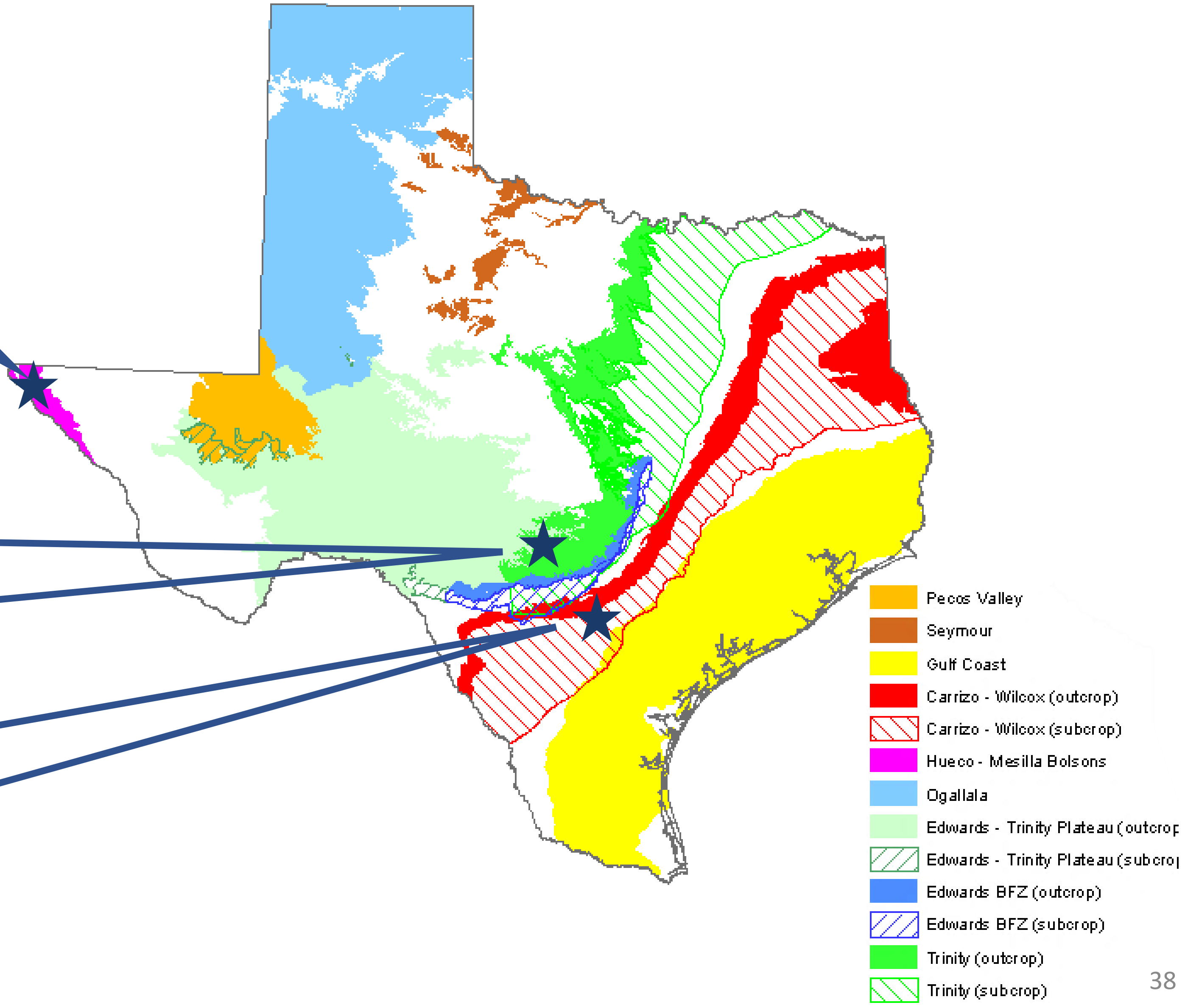
Source: NGWA

ASR - Texas

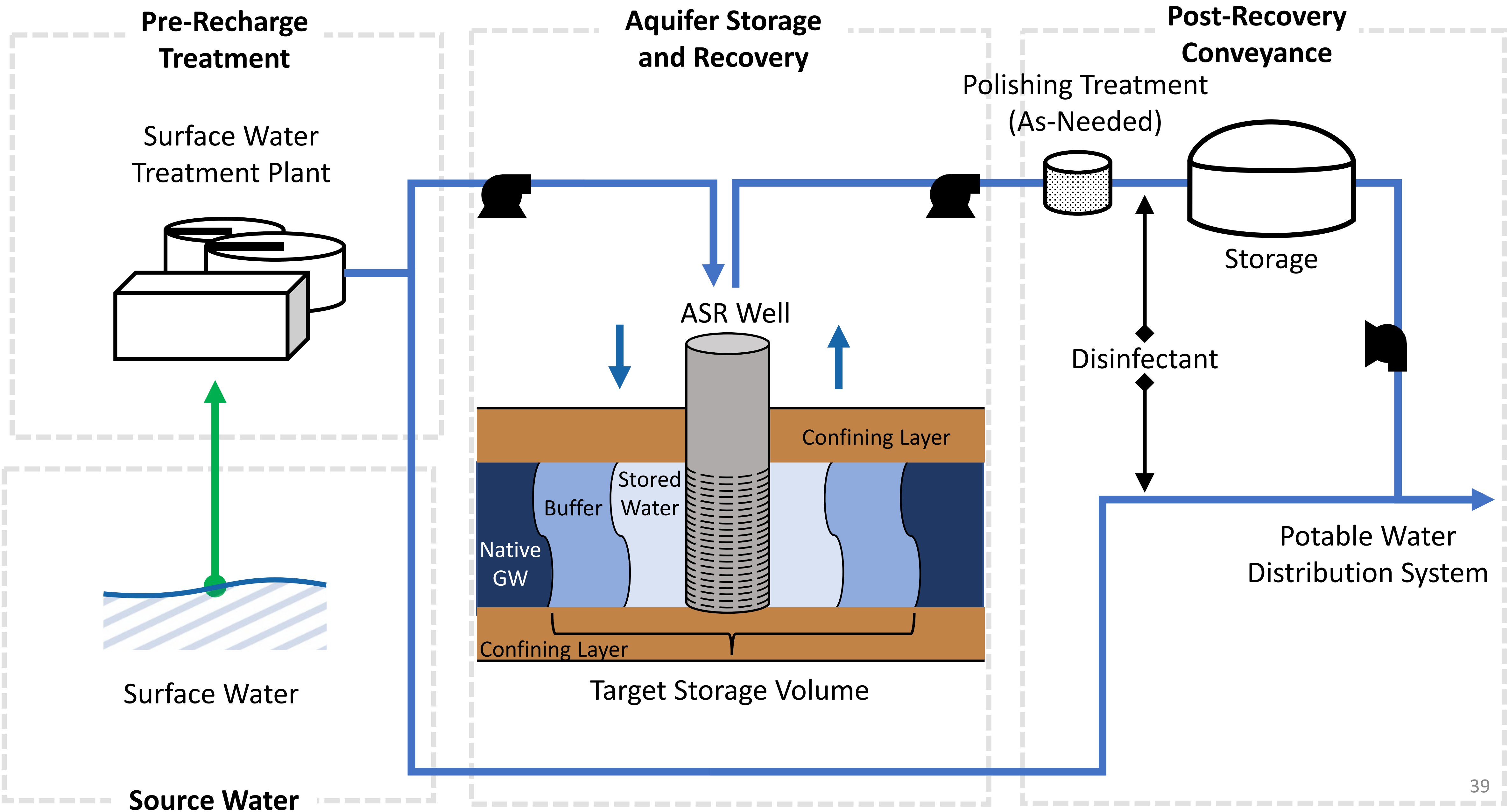
El Paso Water Utilities
Reclaimed Water
Hybrid System – Water is not Drawn from the Same Well it is injected with

City of Kerrville
Surface Water
Recovery Capacity of 3.65 MGD

Twin Oaks ASR Facility
(San Antonio Water System)
Recovery Capacity of 60 MGD, and a Stored Capacity of 70,000 ac-ft

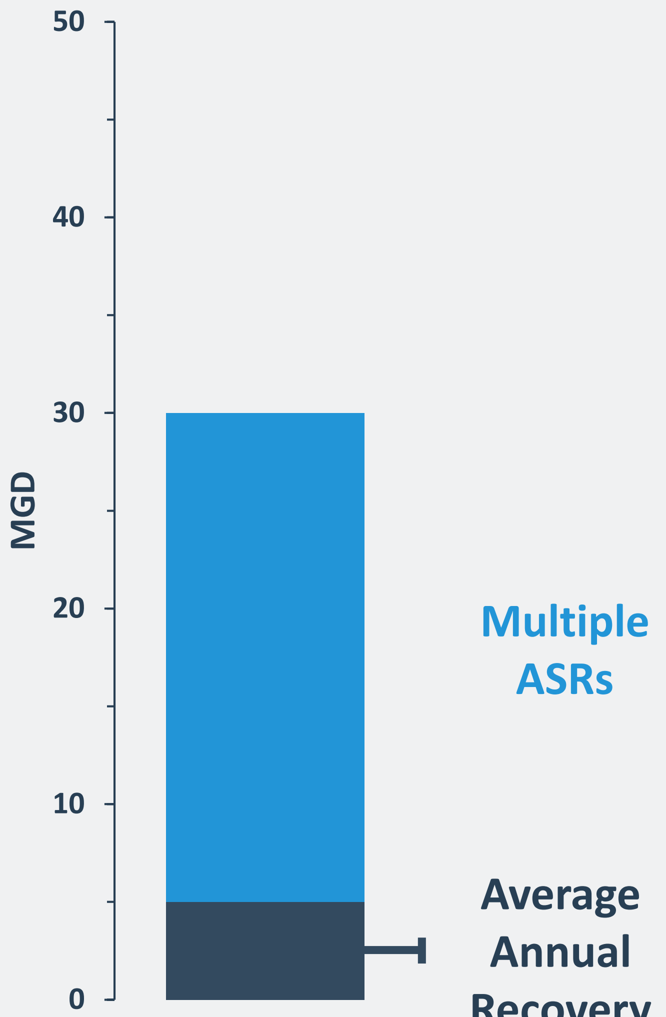


ASR Components

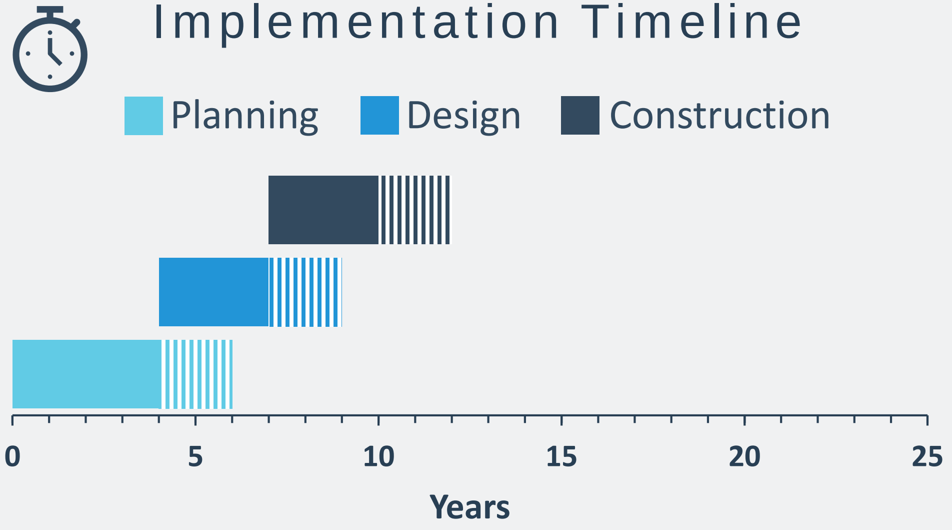


Aquifer Storage and Recovery

Magnitude of Supply



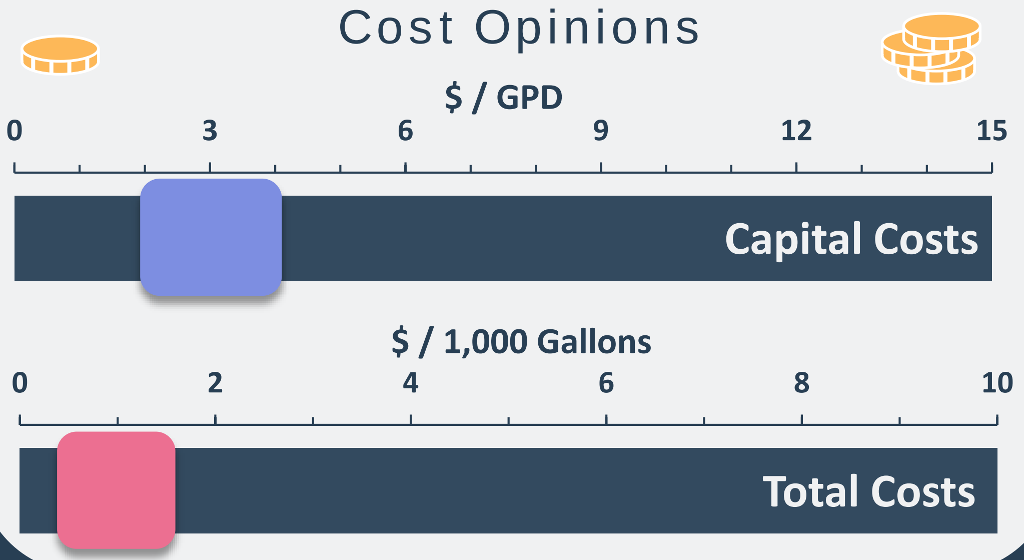
Implementation Timeline



Climate Resiliency

Climate Variable

Cost Opinions



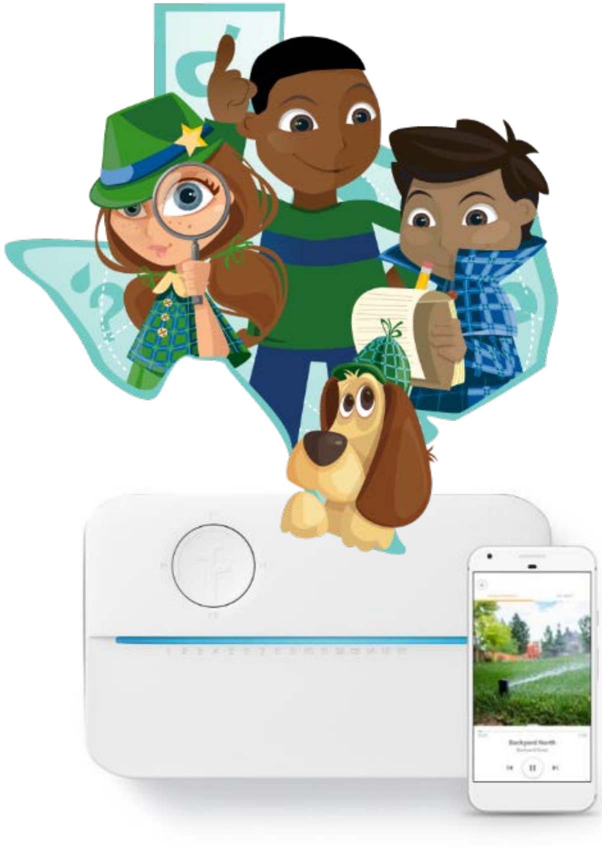
Subsidence Impacts

Being Evaluated

Preliminary
Subject to Revisions

Demand Management

- Participants will continue to conserve water
- Conservation reduces the needed magnitude of alternative water supplies



Baseline Conservation

- Plumbing Code Updates

Basic Conservation - Incentive

- Education
- Rebates & Retrofits
- Water-use Audits
- Rate Structure

Advanced Conservation - Policy

- Outdoor Watering Restrictions

Schedule

	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		Direct Stakeholder Process, Final Projections			Scenario Development
2023				Scenario Testing	Scenario Testing, Recommendations

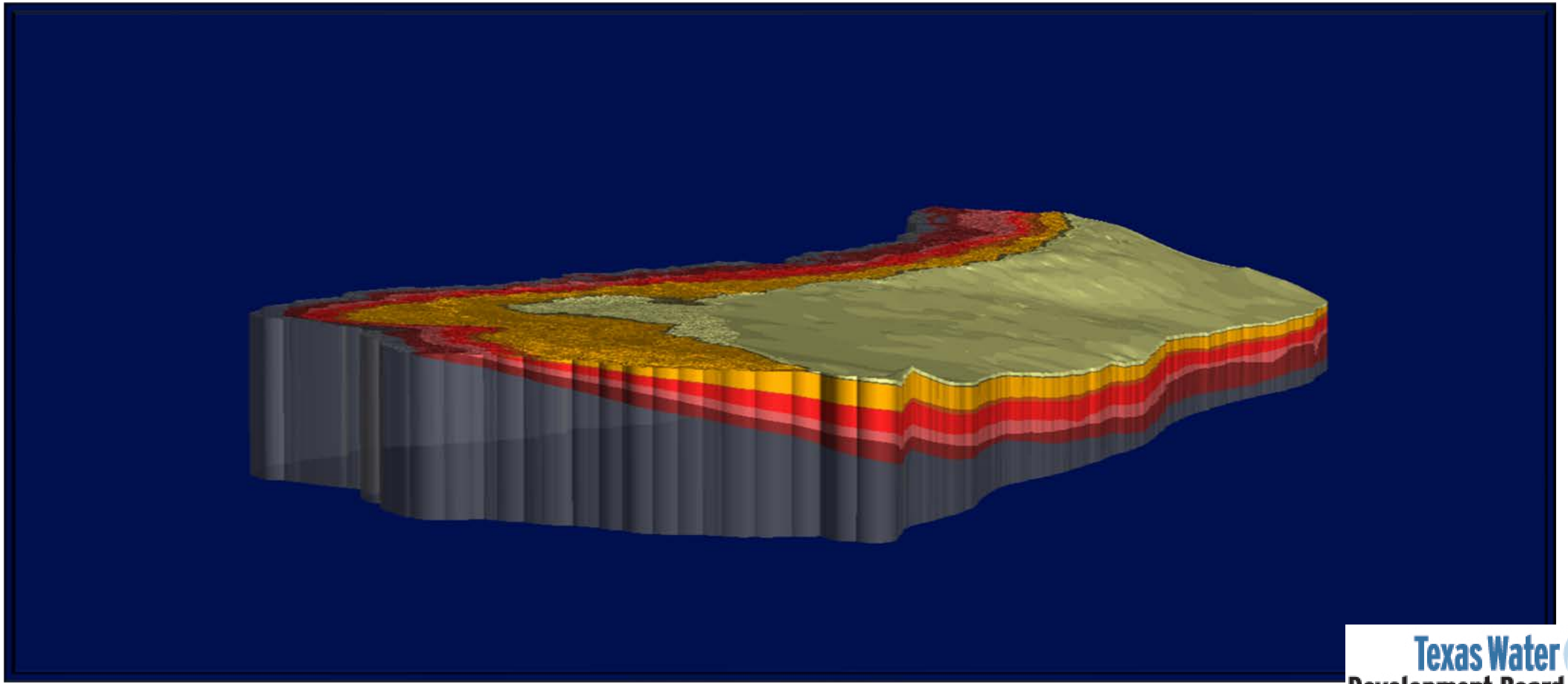
Project Elements

Alternative Water Supply Availability

Groundwater Availability Modeling

GULF-2023 Model Development

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

Texas Water Development Board

Groundwater Availability Modeling

Cindy Ridgeway, P.G.

Manager of Groundwater Availability Modeling Section

512-936-2386

Cindy.ridgeway@twdb.texas.gov

Texas Water Development Board

P.O. Box 13231

Austin, Texas 78711-3231

Web information:

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

Project Elements

Alternative Water Supply Availability

Groundwater Availability Modeling

GULF-2023 Model Development

USGS
science for a changing world

Gulf Coast Branch

Harris-Galveston Subsidence District

Fort Bend Subsidence District

Gulf Coast Land Subsidence and Groundwater-Flow Model

GULF 2023

Stakeholder Meeting 12/10/2020

John Ellis
jellis@usgs.gov

Linzy Foster
lfoster@usgs.gov

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

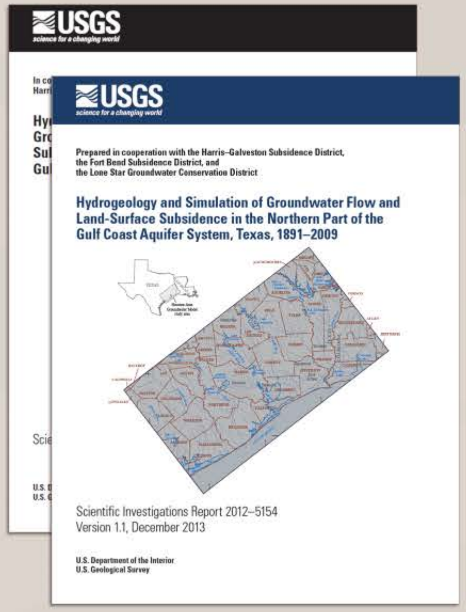
1 Overview

FORT BEND SUBSIDENCE DISTRICT TEXAS

HARRIS-GALVESTON SUBSIDENCE DISTRICT

+

GMA-14 Districts



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

INTERA

| Cooperators | Purpose: HAGM update | CLAS model refinement | Model Scenarios |

Project Objectives

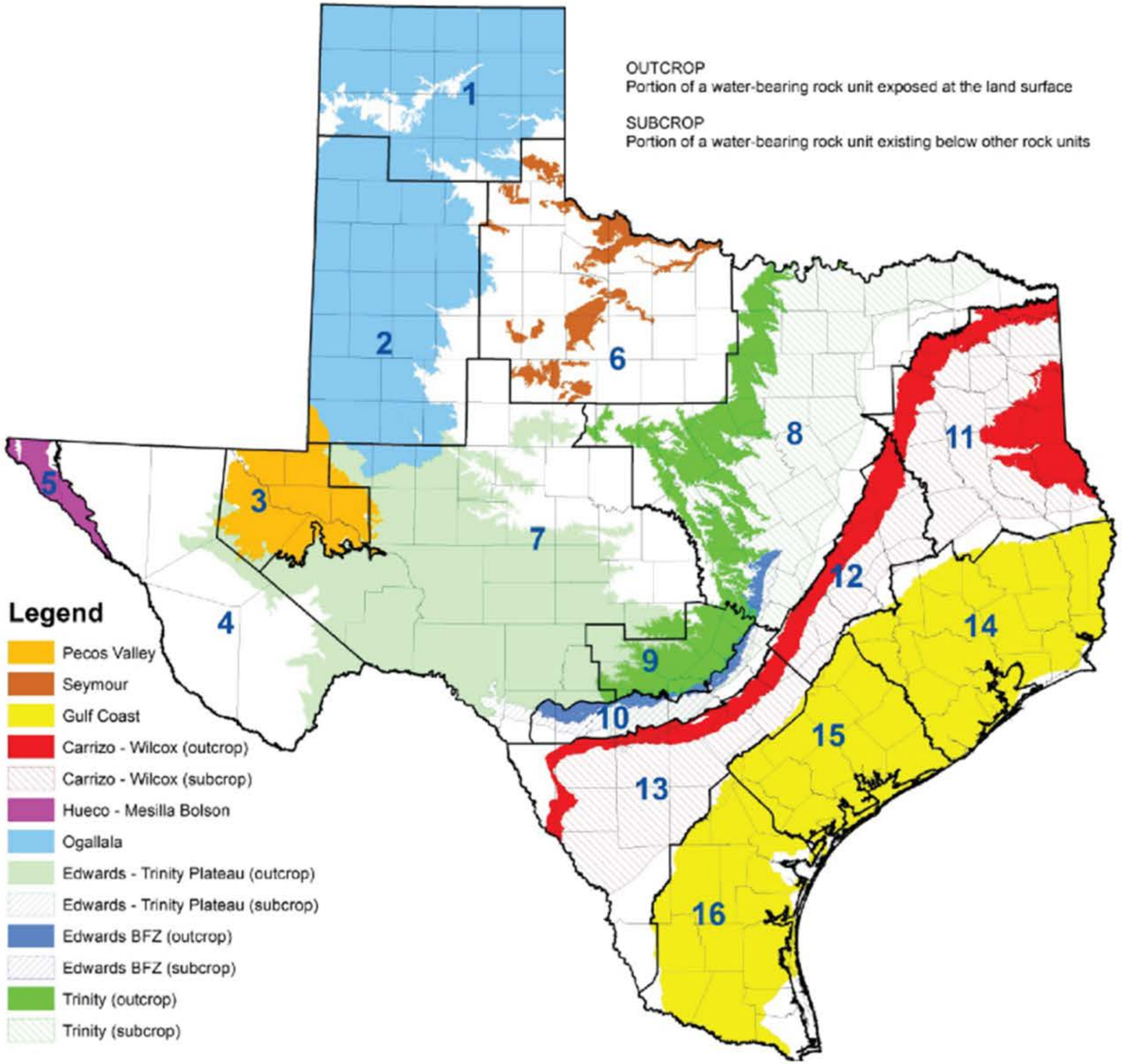
QA/QC

Construct & calibrate model	Support groundwater management decisions	Develop climate scenarios	Quality assurance assistance

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

Major aquifers of Texas

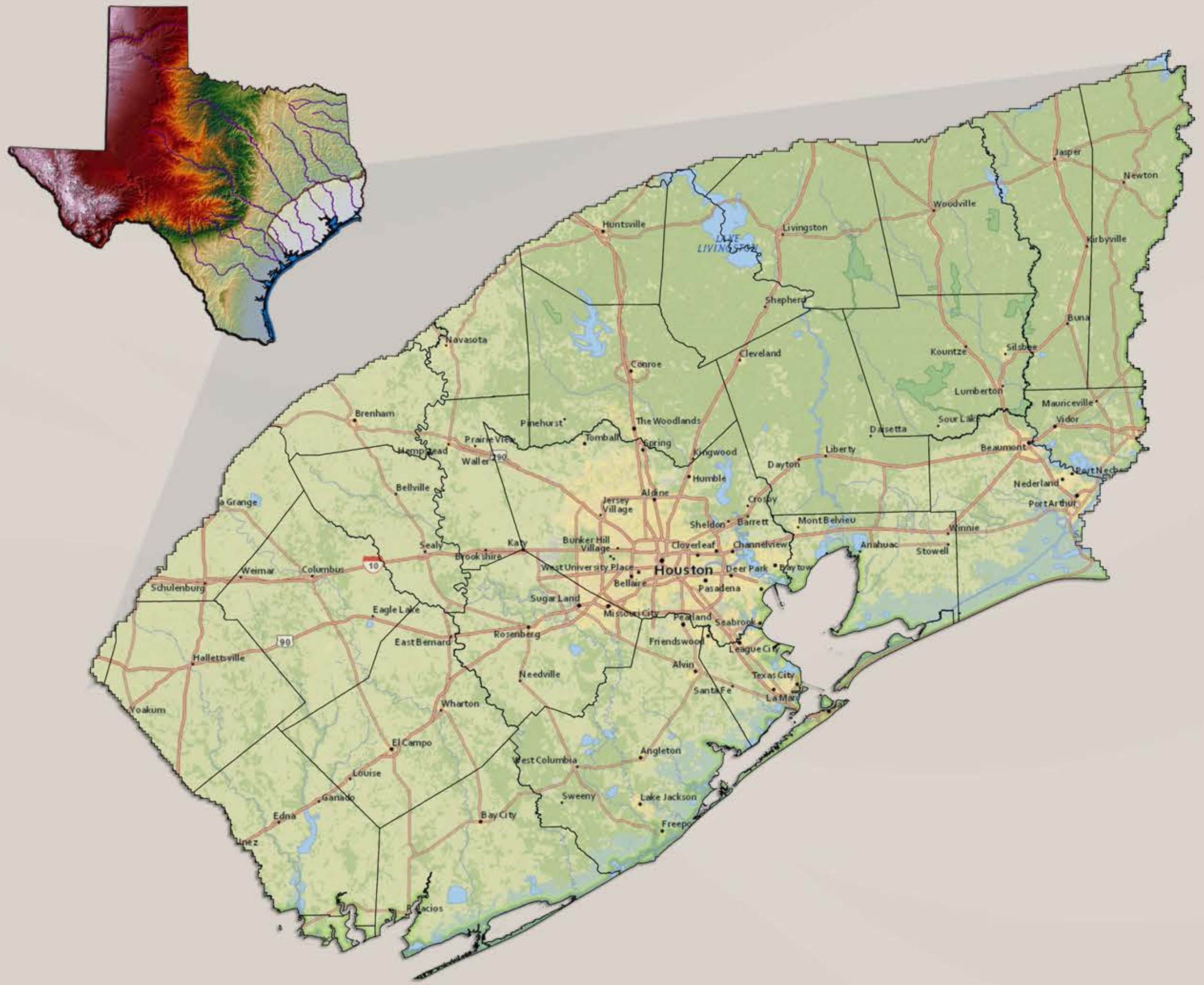


Texas Water Development Board

2 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)



Model Properties

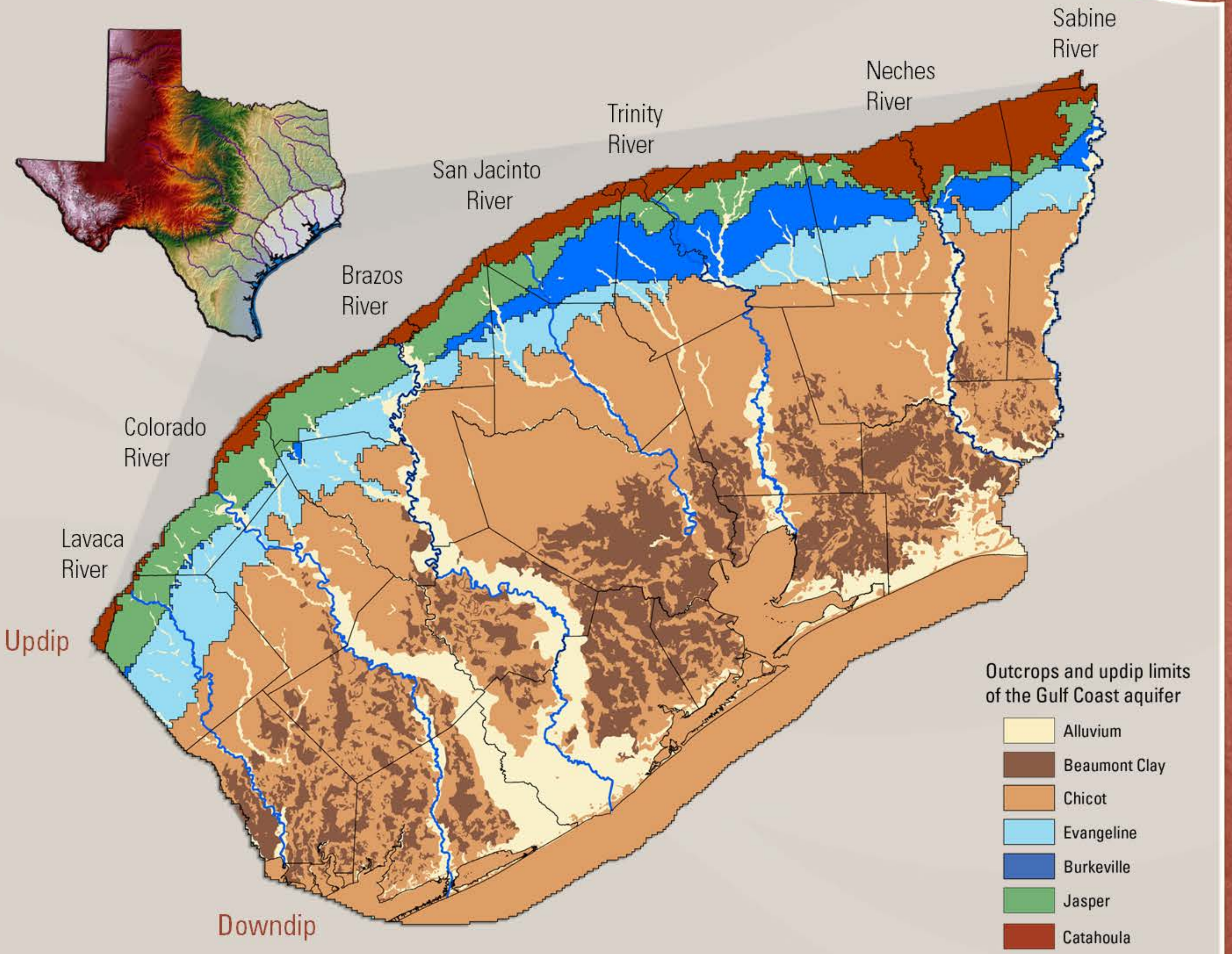
Model layering

- **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 ⟵ New

Model time discretization

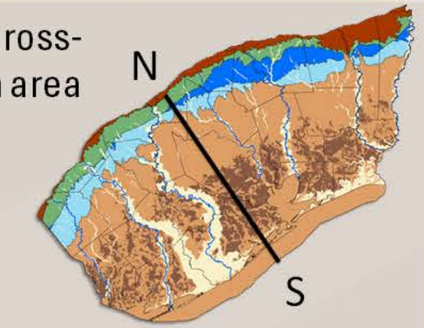
- 1896: 1 (Predevelopment)
- 1897–1939: 3 (about 14 years each)
- 1940–1969: 6 (5 years each)
- 1970–1999: 30 (annual)
- 2000–2018: <u>228</u> (monthly)

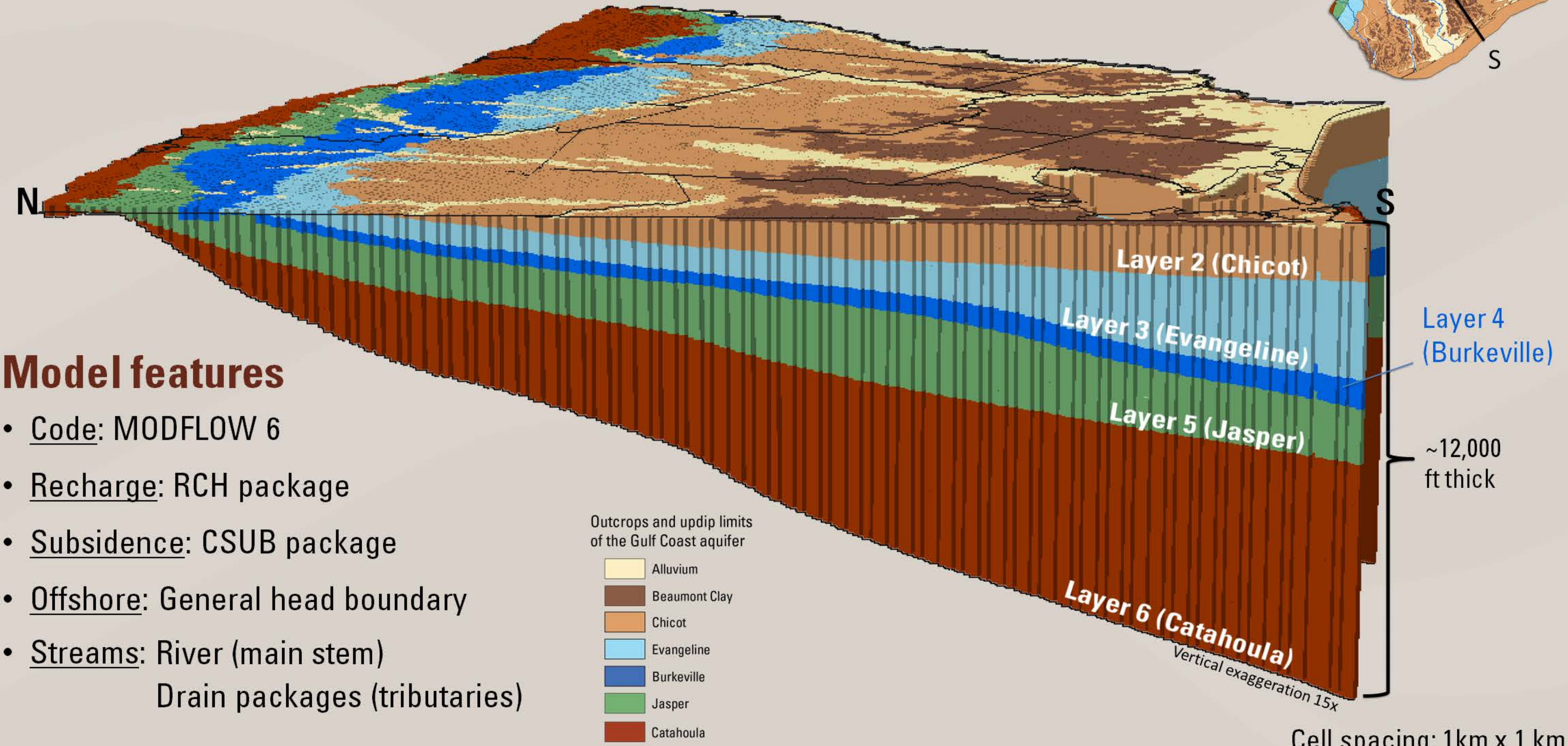
268 Total



Model Properties

North-South cross-section in Houston area





Model features

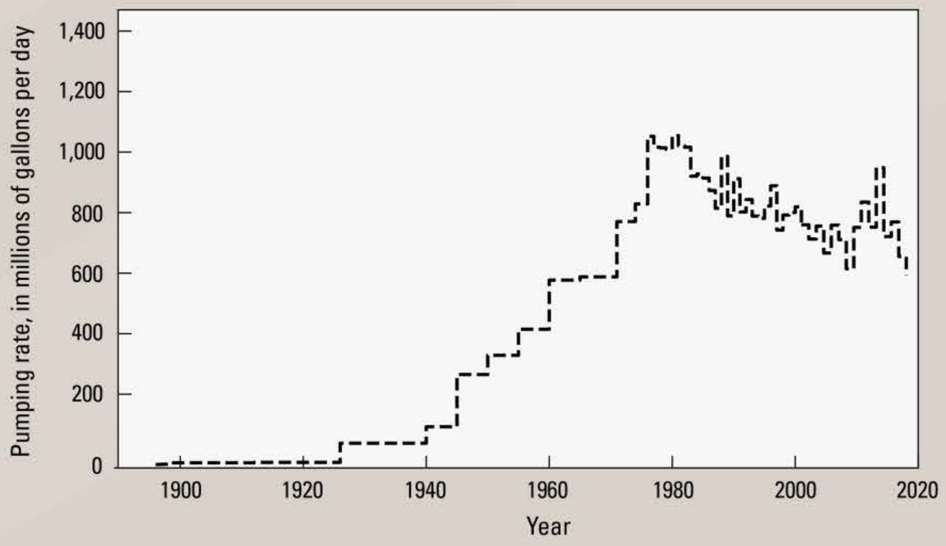
- Code: MODFLOW 6
- Recharge: RCH package
- Subsidence: CSUB package
- Offshore: General head boundary
- Streams: River (main stem)
  Drain packages (tributaries)

Cell spacing: 1km x 1 km

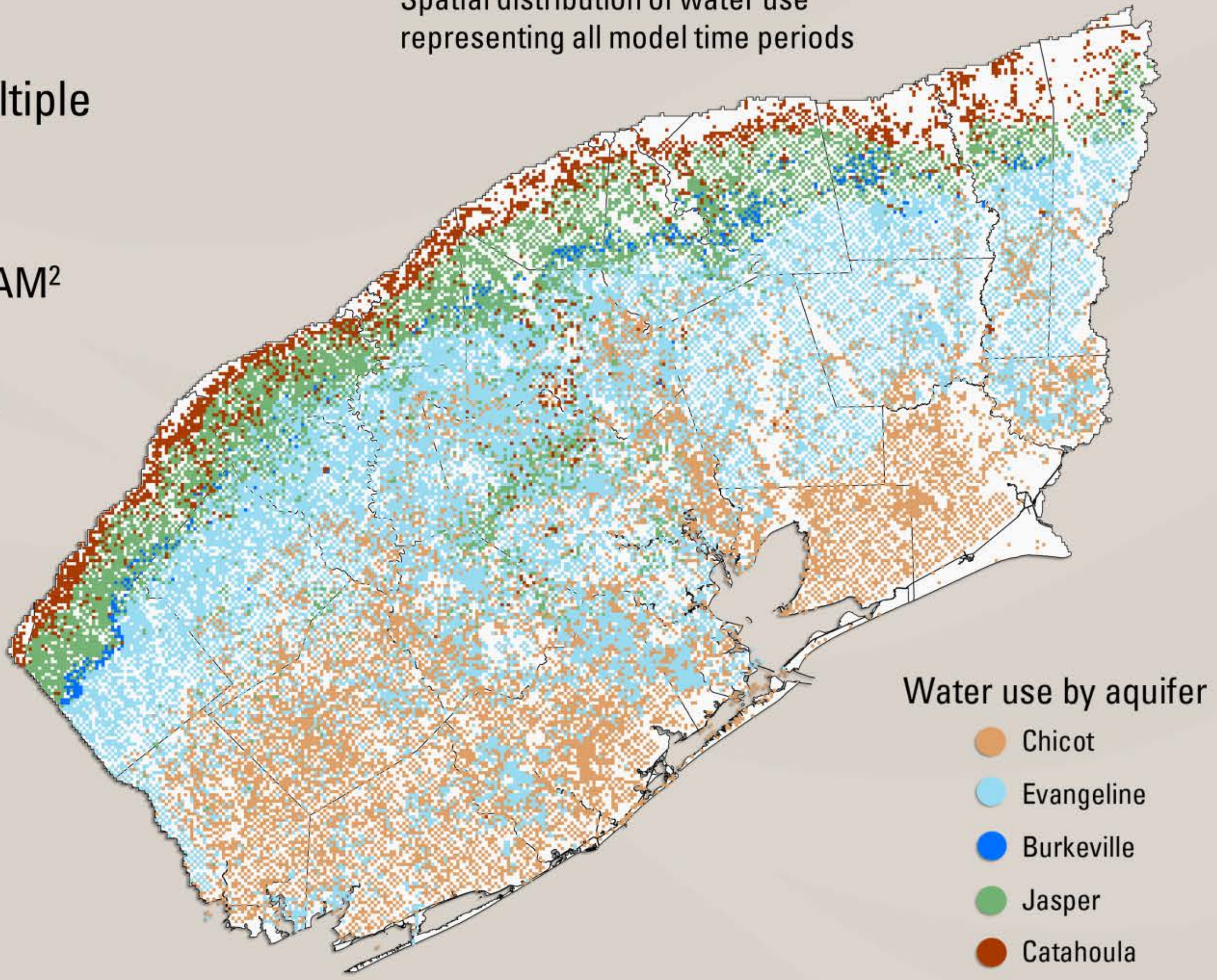
Model Features

Groundwater use

- The GULF model uses water-use data from multiple sources:
  - 1897–1999: HAGM[1], Central GAM[2]
  - 2000–2018: TWDB water-use database, Central GAM[2]
  - To account for uncertainty in estimates, a small adjustable range is used during model calibration



Spatial distribution of water use representing all model time periods

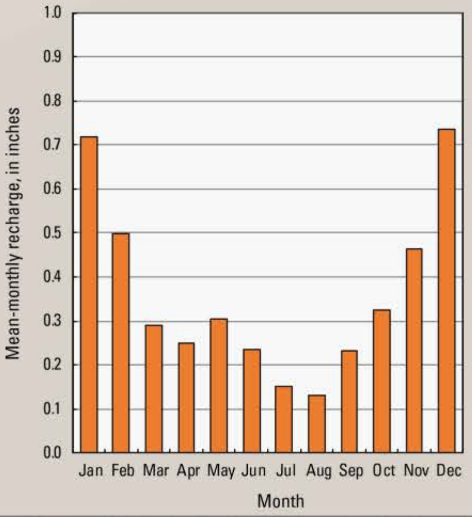


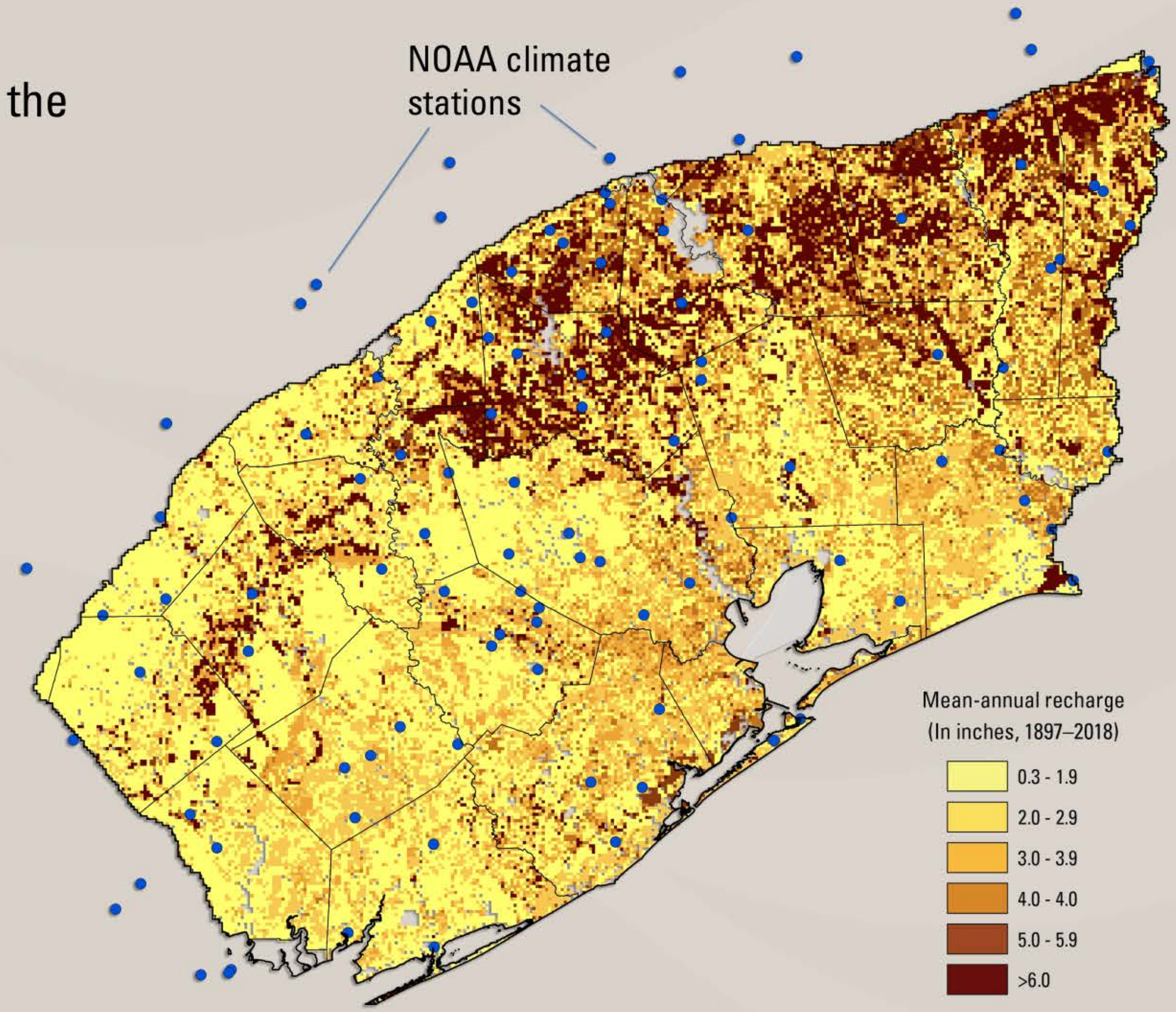
[1]Kasmarek (2012) | [2]Chowdhury and others (2004)

Model Features

Recharge

- Water that infiltrates from land surface to the top of the water table
- Can use many different methods to estimate. This project used the USGS Soil-Water-Balance code[1]
- SWB-derived recharge occurs primarily in aquifer outcrop area (dark brown colors on map)
- Majority of the estimated recharge is discharged to streams





[1]Westenbroek and others, 2010

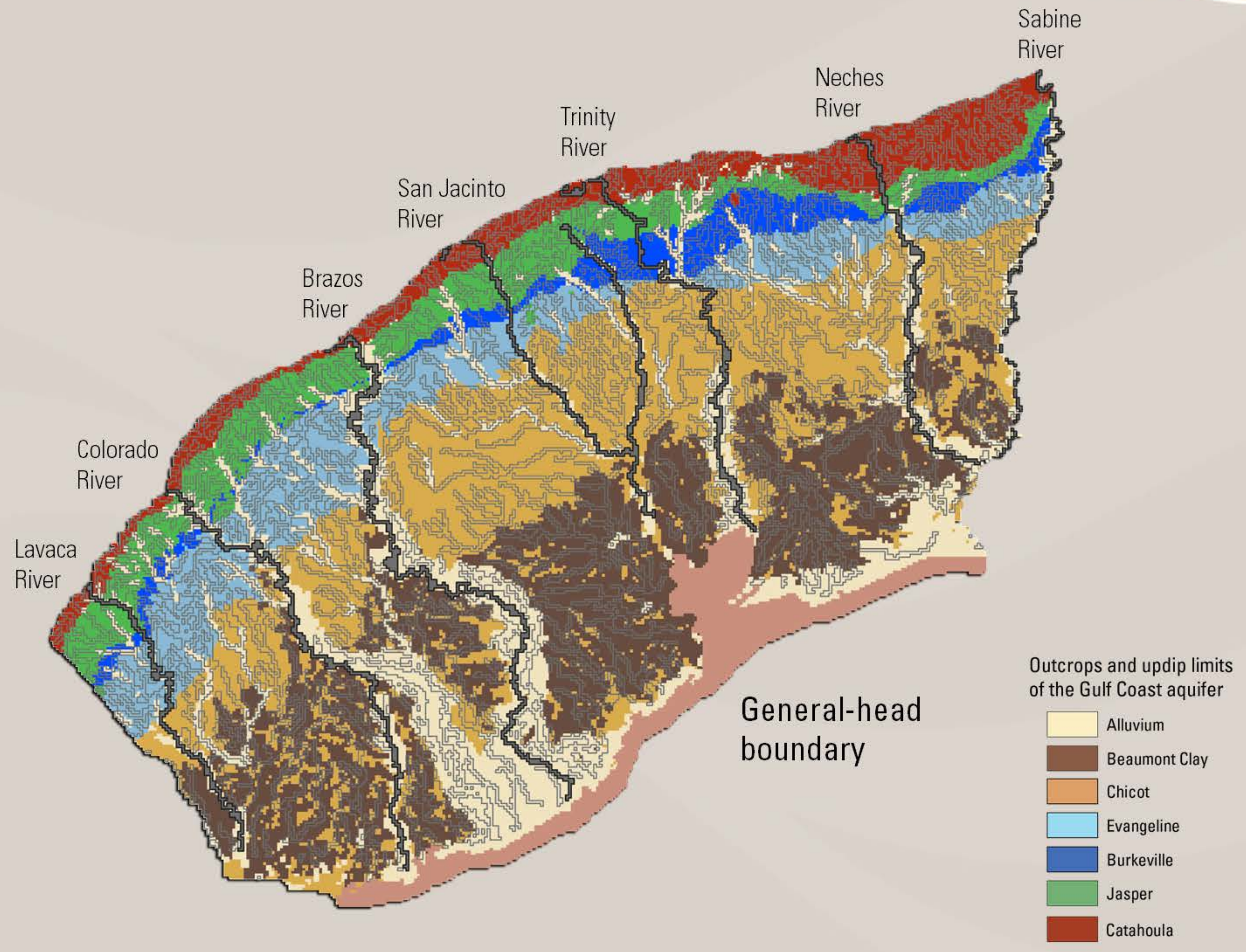
4 Model Features

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
- May be added to eastern and western edges of model for lateral flow



[1]Langevin and others, 2017

5 Subsidence

Subsidence mechanics

Long-term withdrawals lower groundwater levels

This raises pressure on the silt and clay layers beyond a threshold amount

Silt and clay layers then compact, and the land-surface elevation decreases permanently

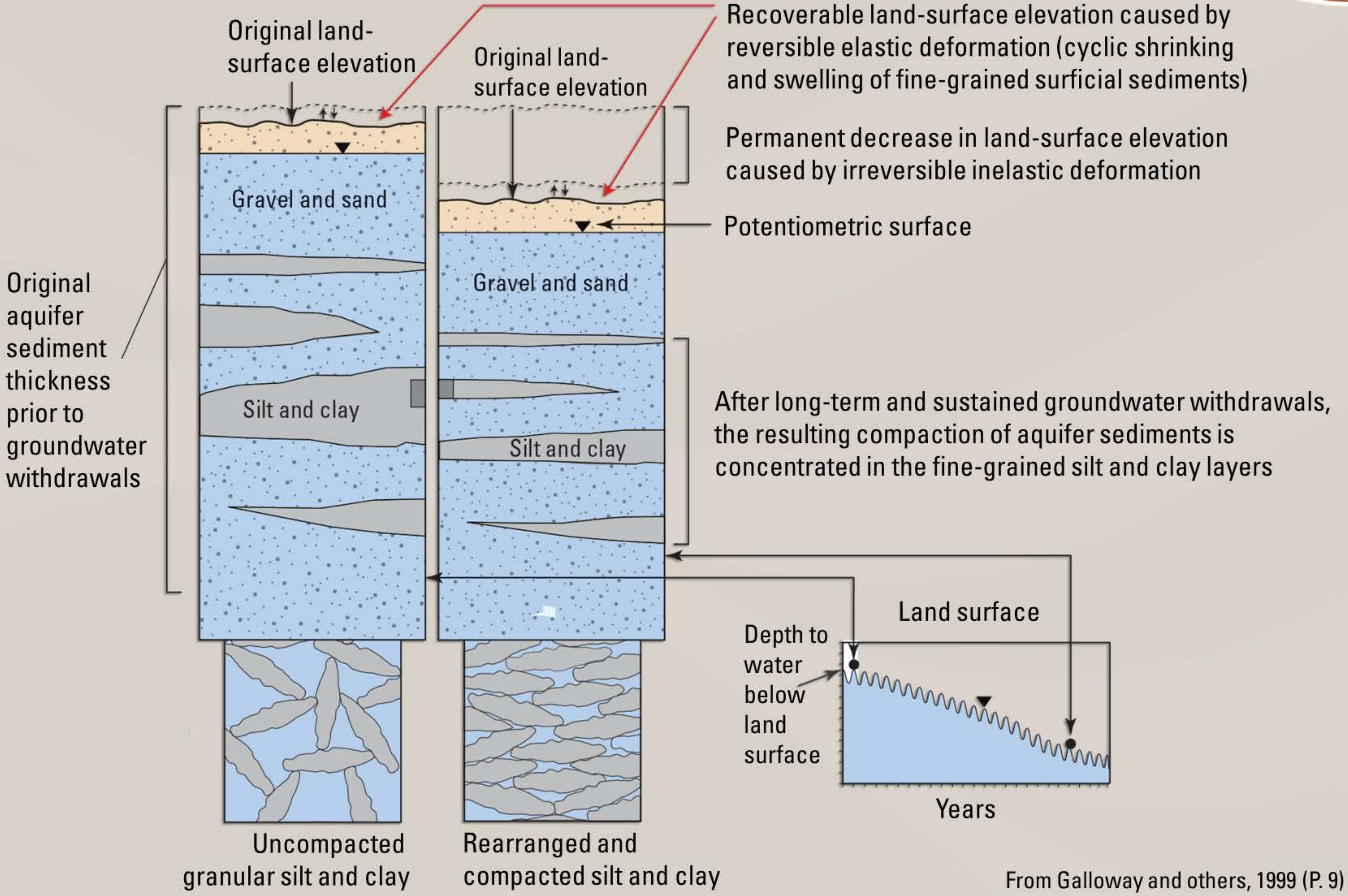
Theoretical basis for compaction[1]

$$\sigma' = \sigma - u$$

σ' Effective stress

σ Geostatic stress

u Hydrostatic stress



From Galloway and others, 1999 (P. 9)

[1]Terzaghi (1925)

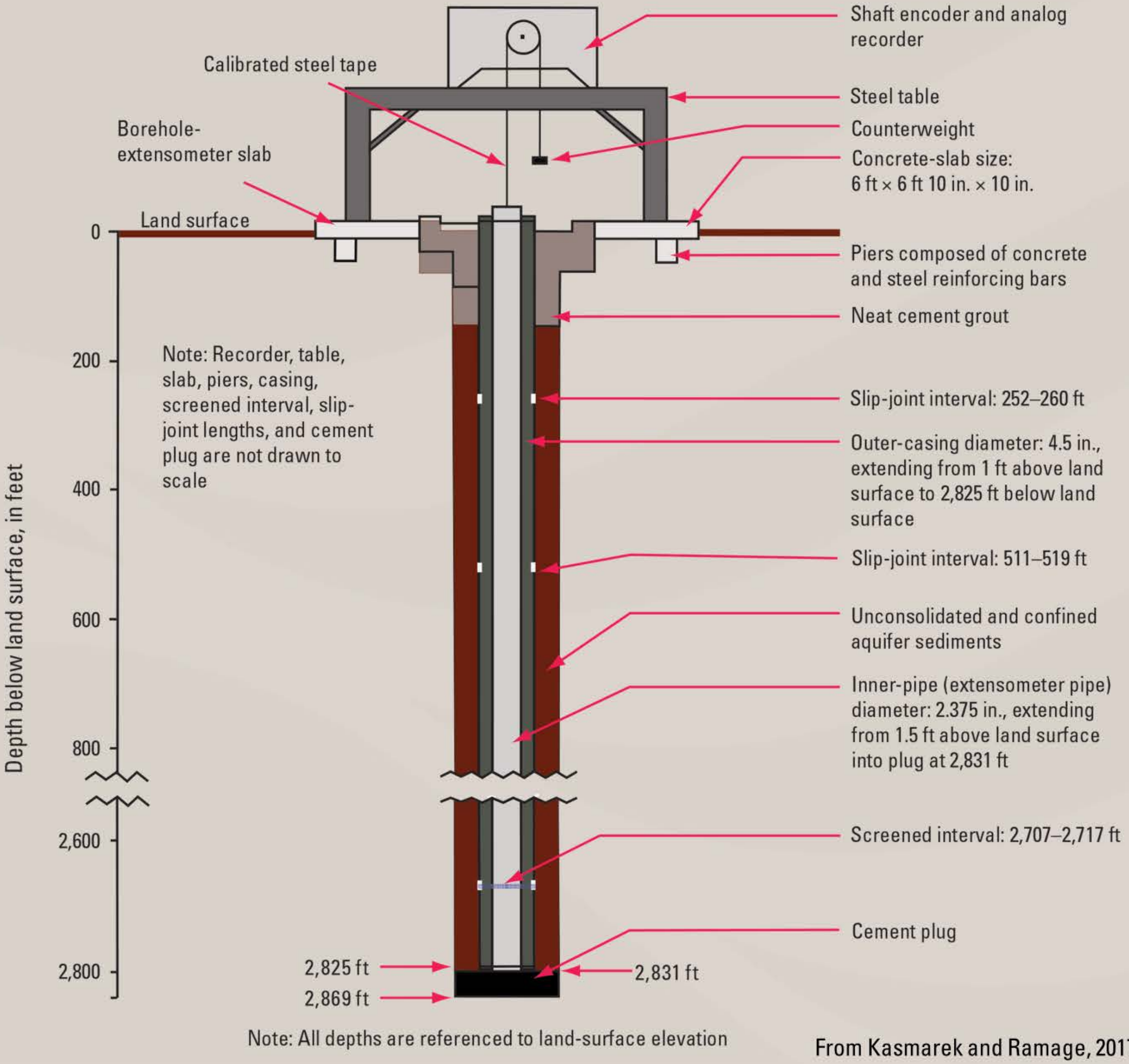
5 Subsidence

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

Clear Lake (deep) Extensometer

Clear Lake (shallow) Extensometer



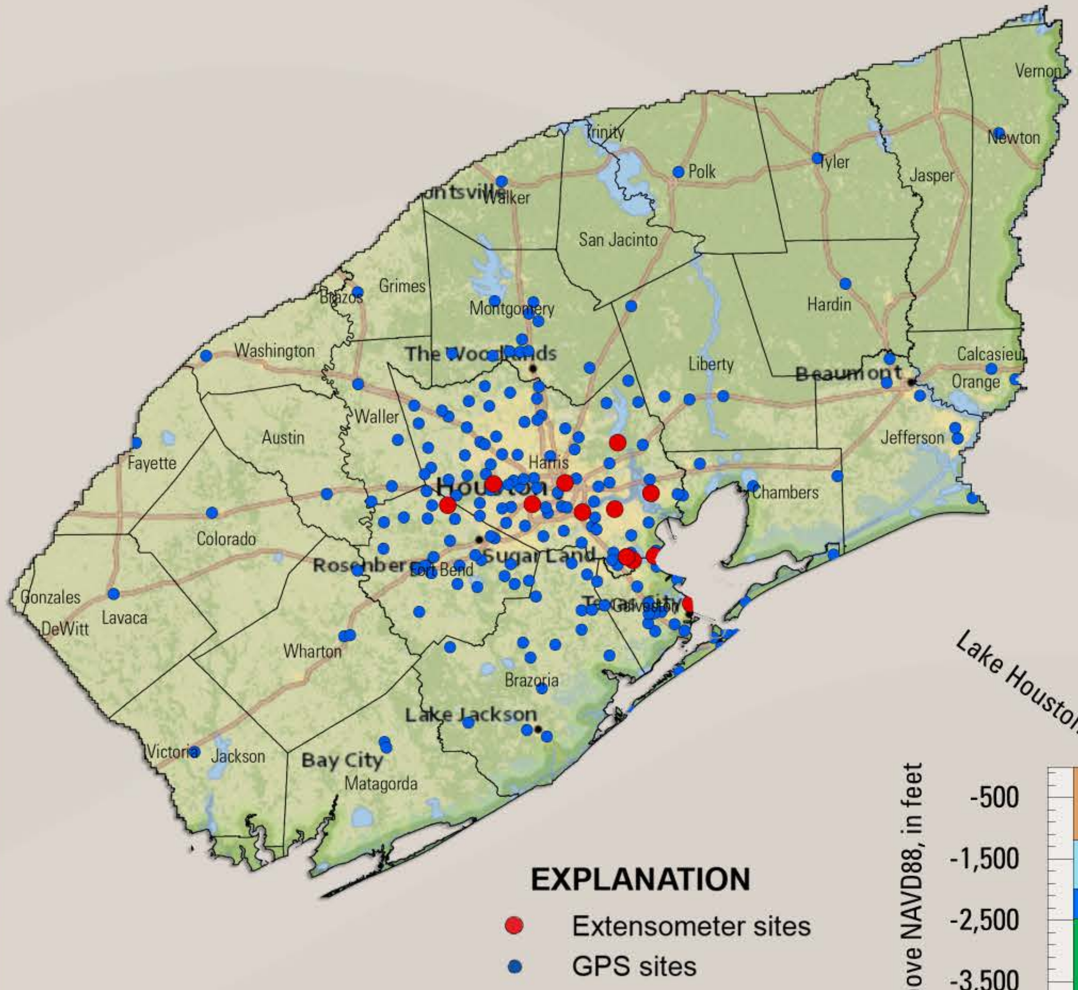
From Kasmarek and Ramage, 2017

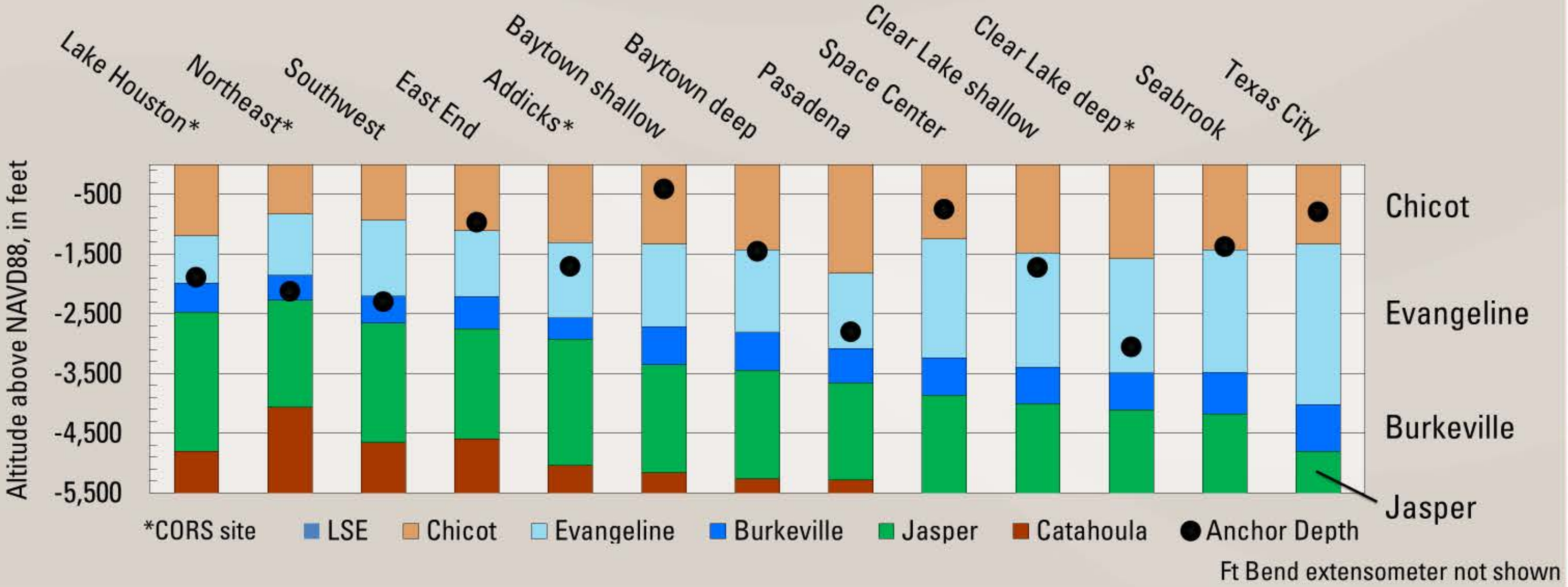
5 Subsidence

GULF 2023 — Gulf Coast Land Subsidence and Groundwater-Flow Model

Subsidence estimation methods

- Extensometers: measure compaction in the aquifer system. Fourteen extensometers at 12 sites
  - Seven measure compaction in Chicot aquifer, six in Chicot + Evangeline aquifers.
- GPS sites, leveling: measure total vertical displacement
  - GPS: 181 sites
  - Leveling data: 60-70 measurements, about half prior to 1960





5 Subsidence

GULF 2023 — Gulf Coast Land Subsidence and Groundwater-Flow Model

Primary subsidence data sources

- Subsidence/Leveling data:
  - Gabrysch (1969, 1974, 1975, 1982)
  - Gabrysch and Bonnet (1975)
  - Lofgren (1977)
- Extensometer data
  - USGS data releases on ScienceBase (variously dated)
- GPS data
  - Harris-Galveston Subsidence District
  - National Geodetic Survey
  - University of Houston
- Cumulative subsidence
  - Kasmarek and others (2009)

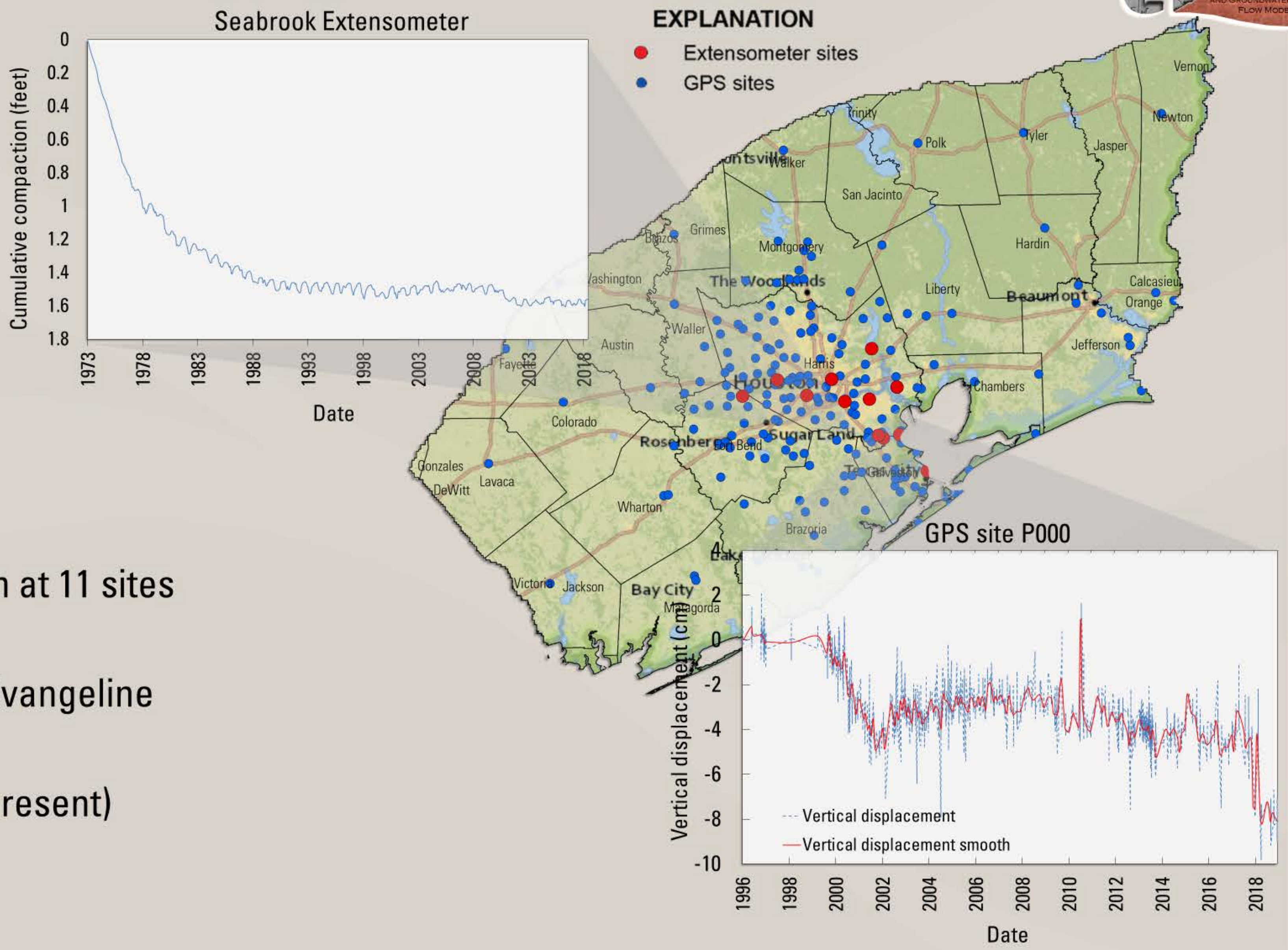
5 Subsidence

GPS sites

- Smooth applied: preserves signal and long-term trends while filtering out high-frequency noise
- Duplicate sites in same model cell removed
- Shorter period of record (1995 – present)

Extensometers

- Use end-of-month recorded compaction at 11 sites across the period of record
- Measure compaction in Chicot and/or Evangeline units
- Longer period of record (early 1970s – present)

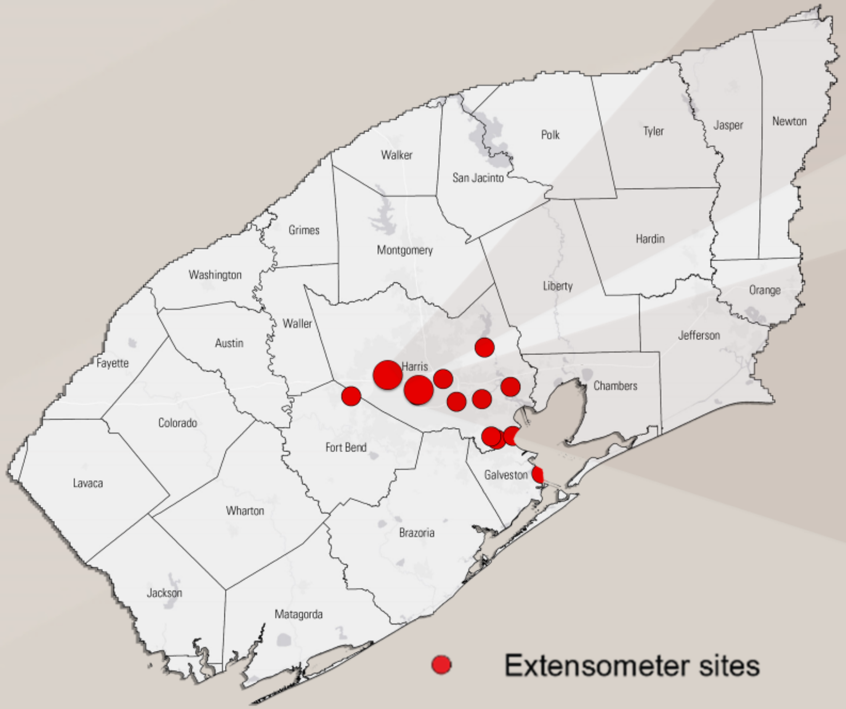


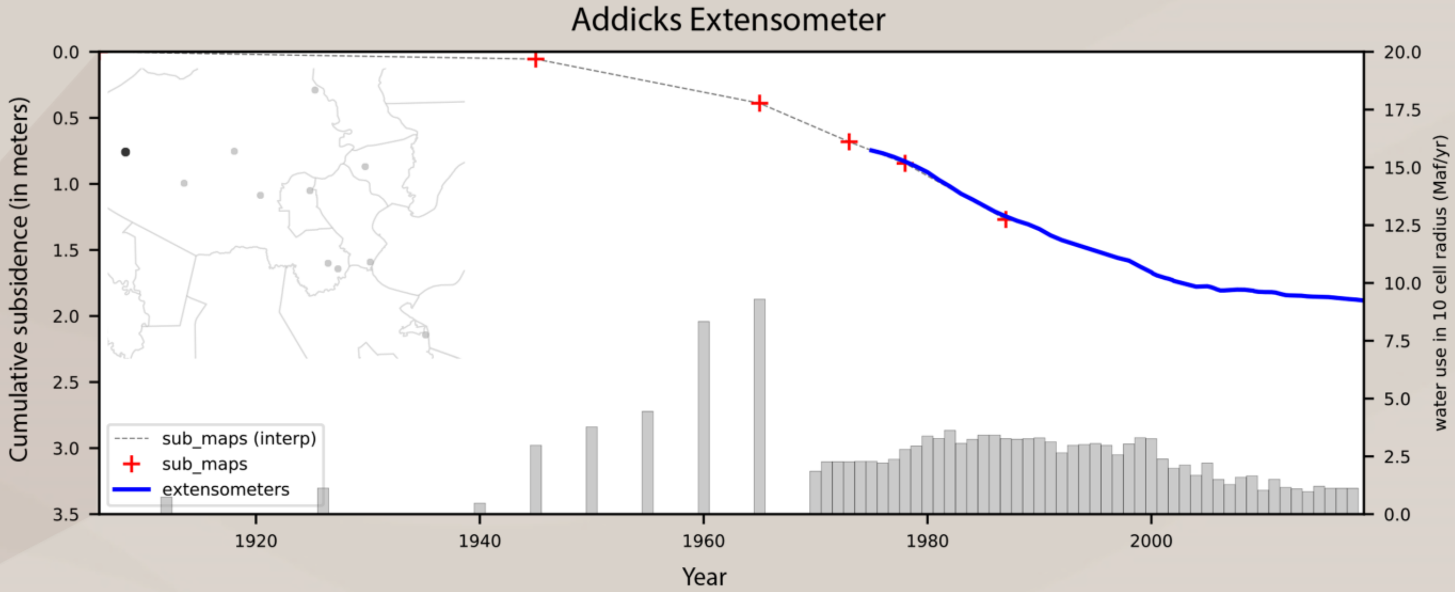
5 Subsidence

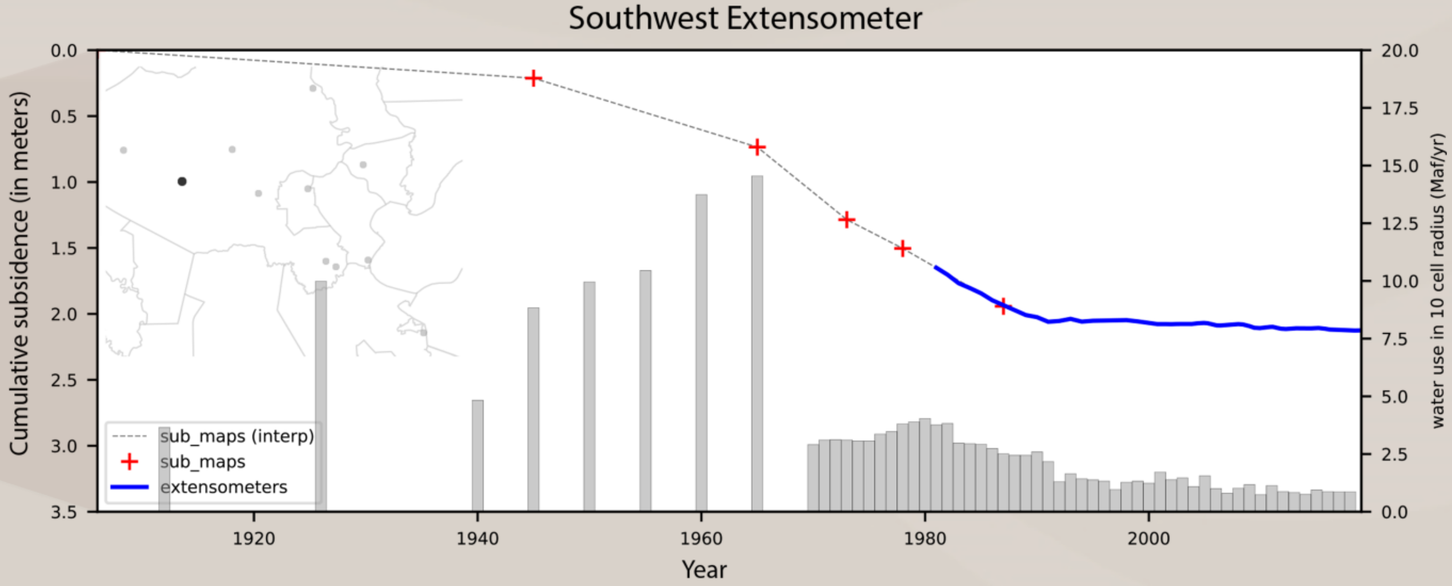
Subsidence calibration approach

Cumulative compaction verification using Kasmarek and others (2009)

- Match overall cumulative subsidence through model period (1896–2018)
- Specific subsidence datasets used:
  - Historic leveling data (red '+' on map)
  - Time-series of cumulative extensometer compaction data (blue line on map)
  - GPS vertical displacement





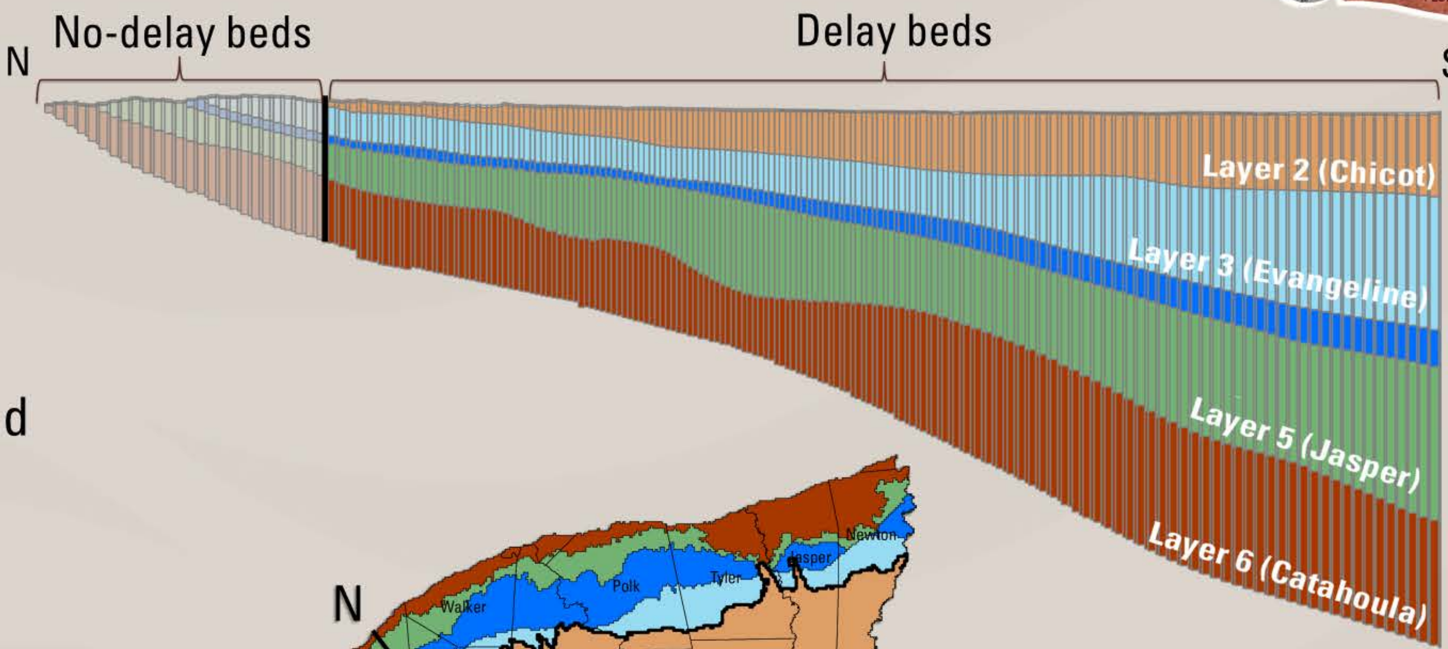


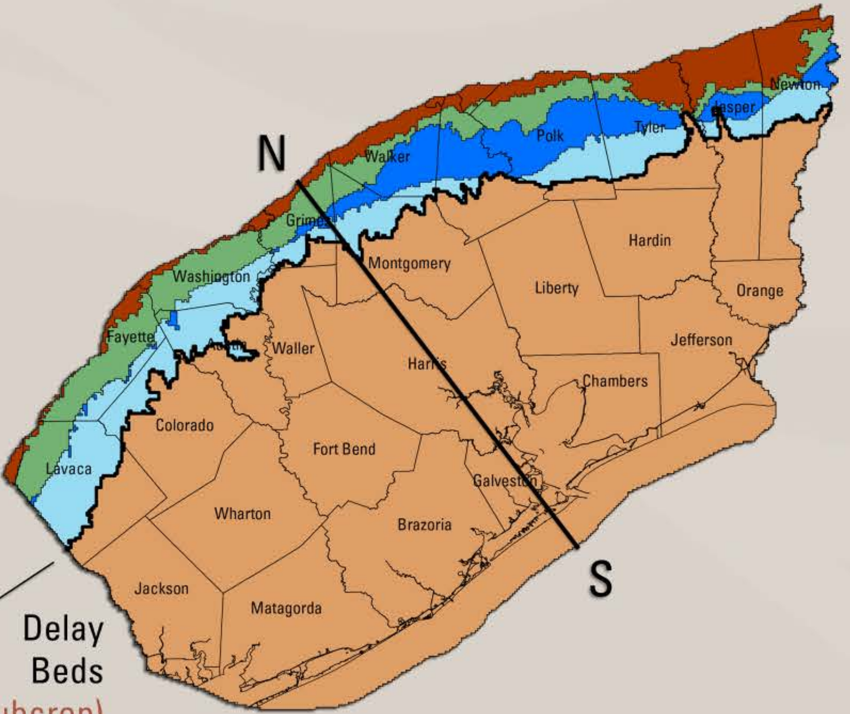
Subsidence package

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

$\sigma' = \sigma - u$ Effective-stress based

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



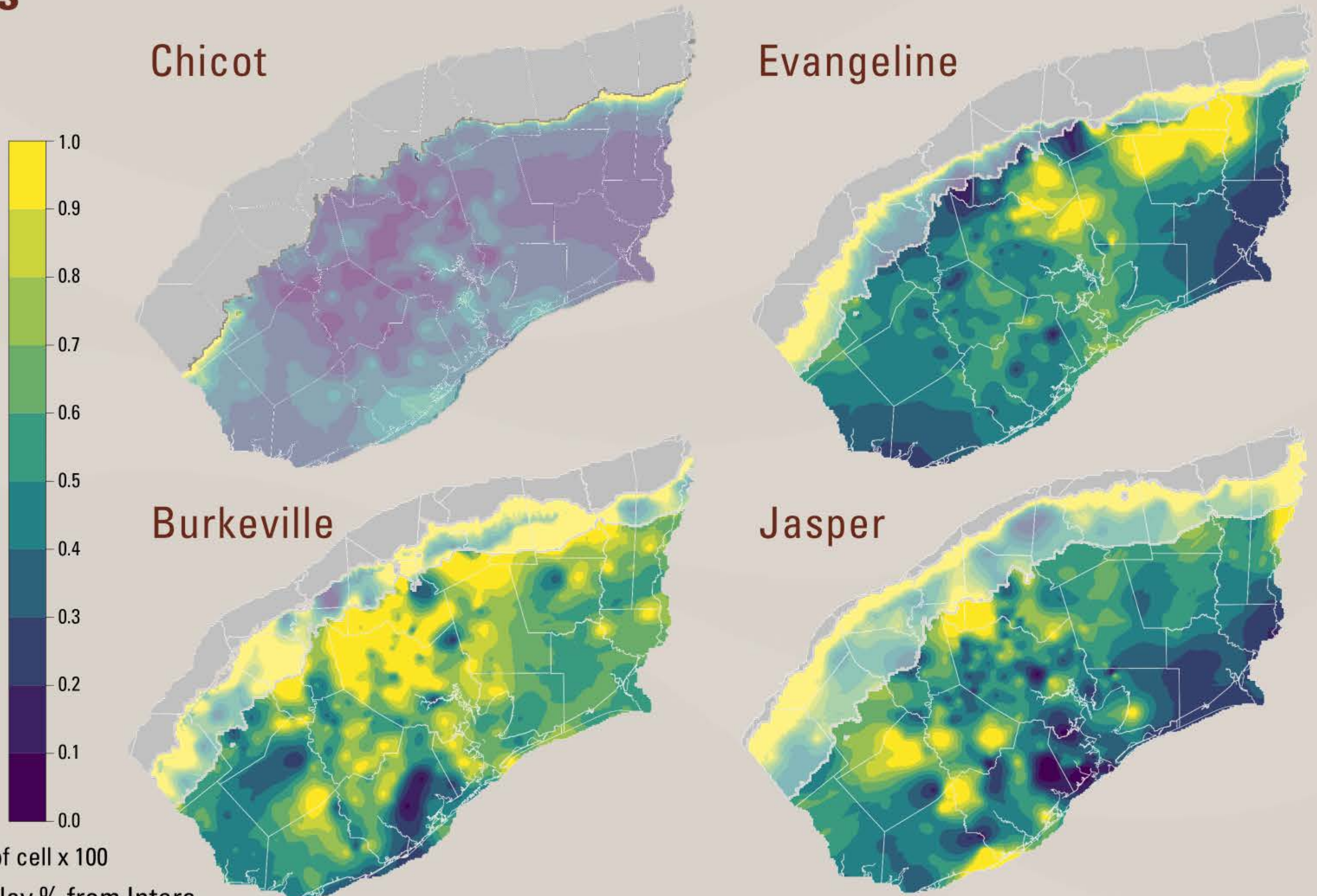


[1] Hughes and others, *in press*

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

Clay thickness (% of aquifer thickness)



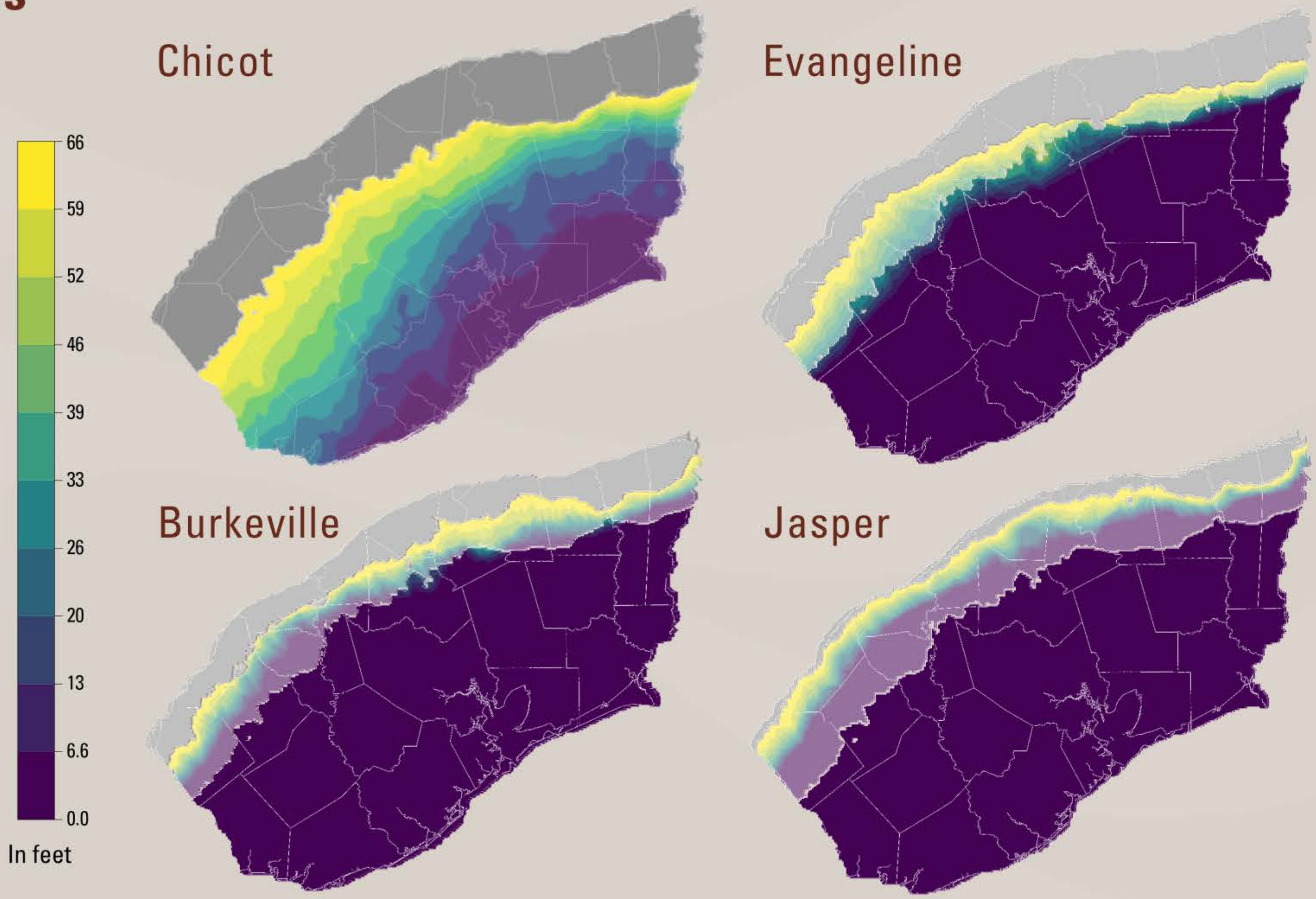
Interpolation of sand/clay % from Intera

Subsidence

Subsidence package parameters

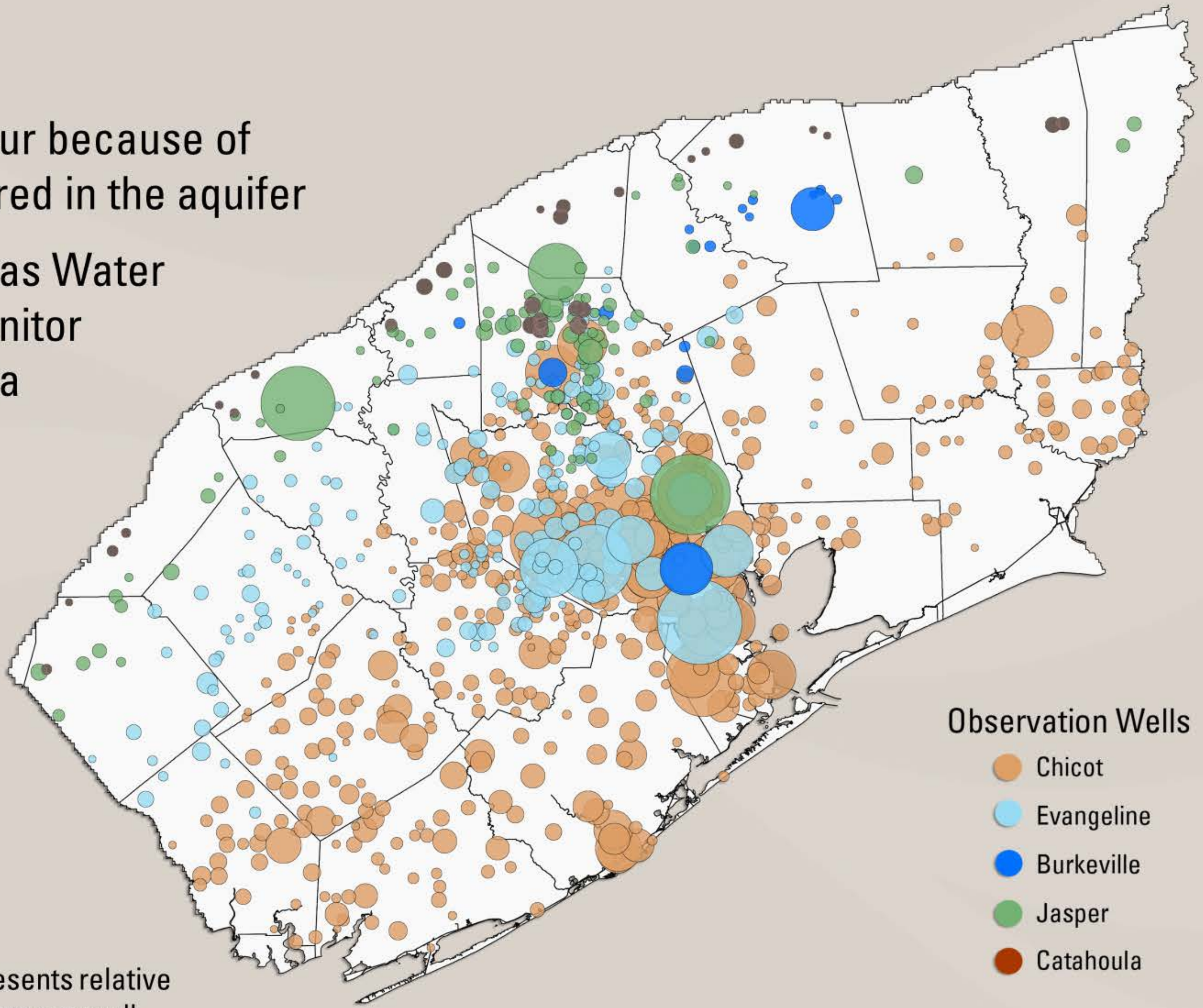
- Fine grained (interbeds)
  - Specific storage (elastic, inelastic)
  - Porosity
  - Vertical hydraulic conductivity
  - Interbed thickness
  - Number of interbeds
- Coarse grained (sand units)
  - Specific storage (elastic)
  - Porosity
- Drawdown at preconsolidation stress

Drawdown at preconsolidation stress



Groundwater levels

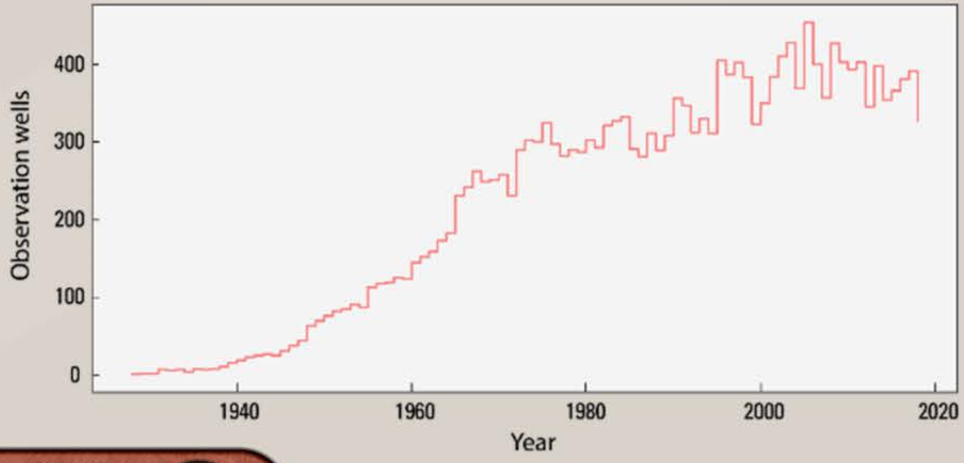
- Changes in groundwater levels occur because of changes in the volume of water stored in the aquifer
- The U.S. Geological Survey, the Texas Water Development Board, and others monitor groundwater levels in the study area
- The model includes wells representative of aquifer units and water-level changes through time
- A match to the groundwater levels in these wells is attempted during model history matching



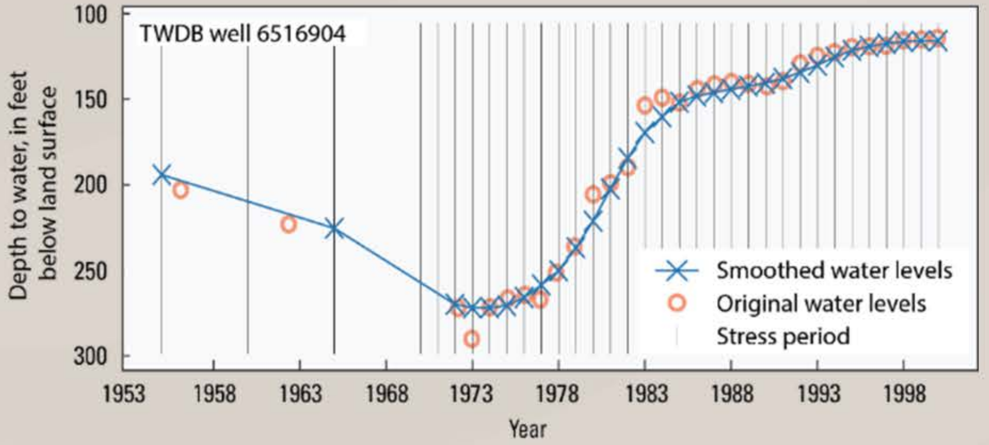
Radius of circle represents relative number of observations per well

Groundwater level processing

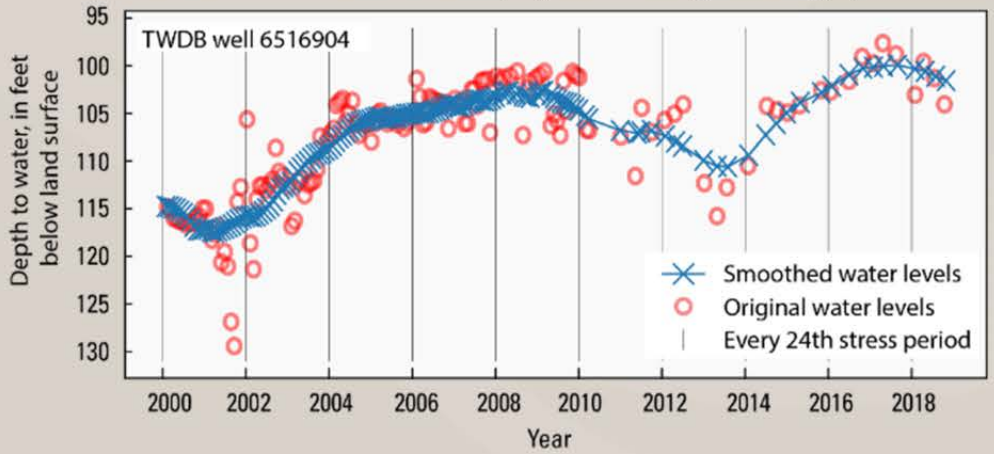
- Include dataset of wells representative of aquifer units and water-level trends through time
- Goals:
  - Disparate water levels don't occur in a spatially dense area
  - All model areas are represented during calibration
- Final dataset: 908 wells with a total of about 63,000 observations to use for model calibration



Pre-2000 observations (5-year rolling average)



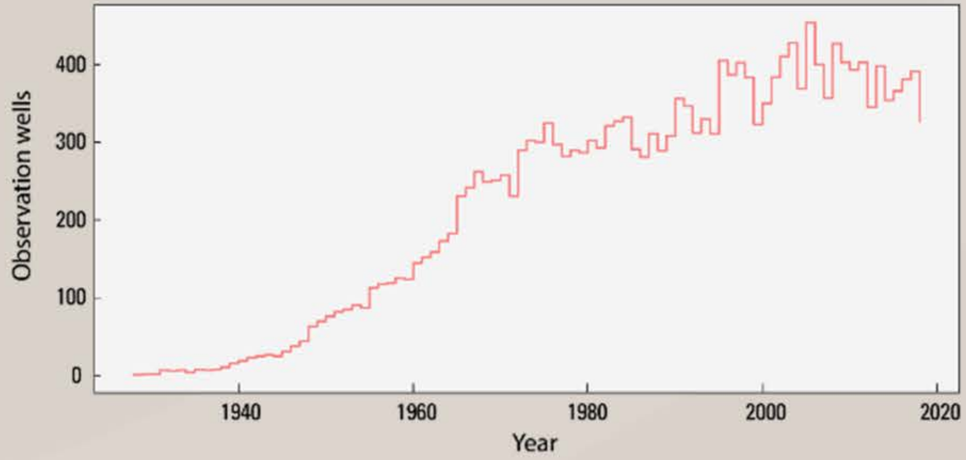
Post-2000 observations (2-year rolling average)

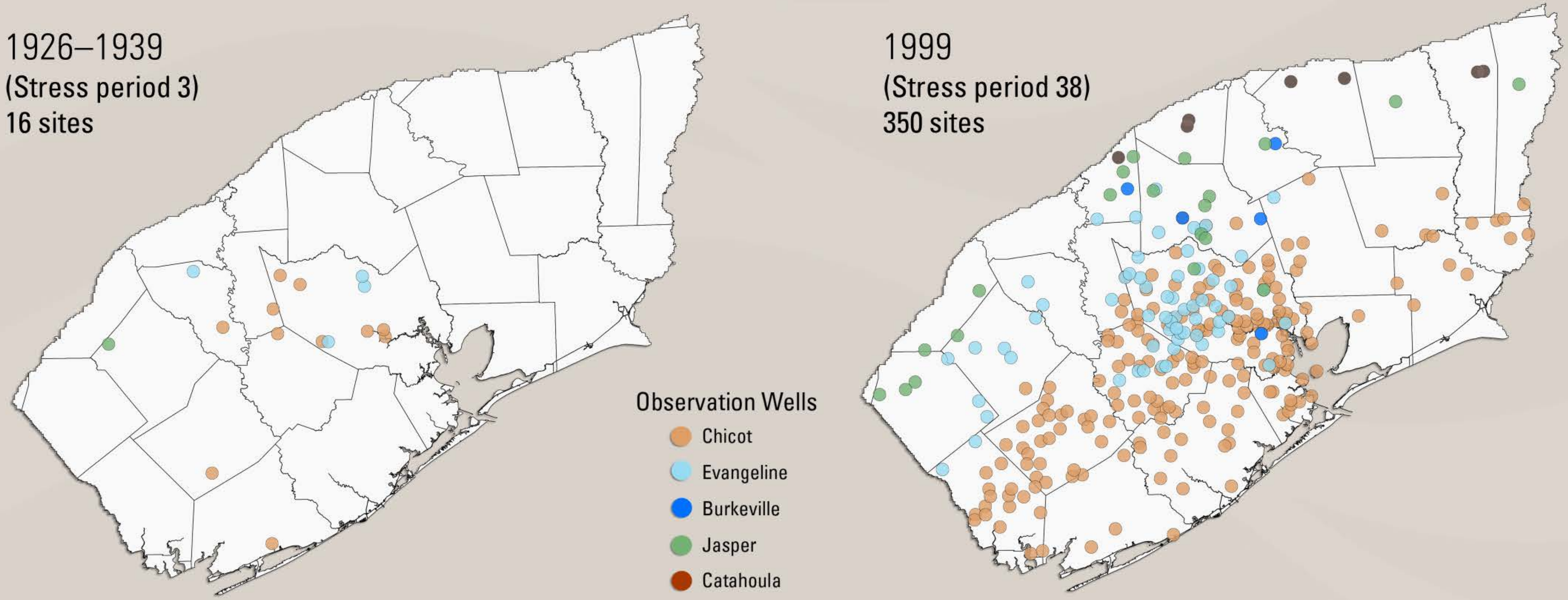


6 Water levels

Observations through time

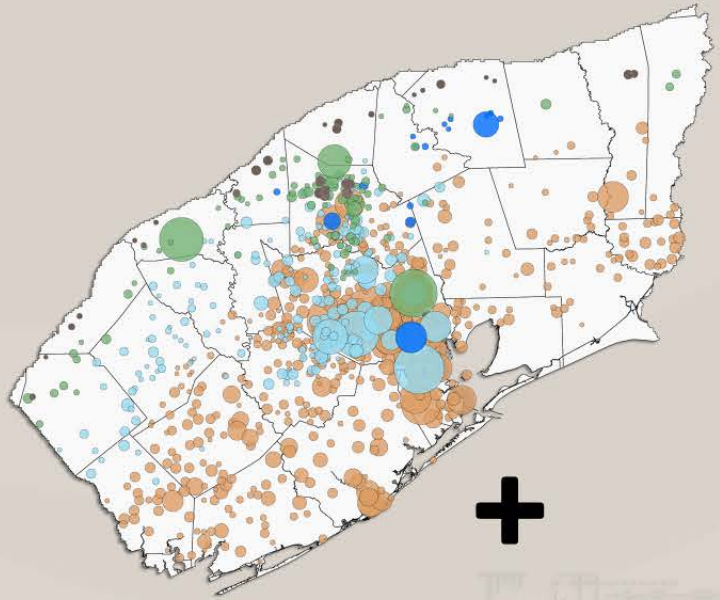
- Substantially more groundwater data available later in the model period
- By the 1980s, there were regularly more than 300 observation wells available





Model history matching and uncertainty

- Process of changing initial model inputs (parameters) to improve fit of residuals. Residuals = simulated – observed (or estimated)
- Using PEST++ IES[1] software to history match to 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


USGS science for a changing world

Groundwater Resources Program
Global Change Research & Development

Approaches to Highly Parameterized Inversion:
A Guide to Using PEST for Groundwater-Model Calibration

Scientific Investigations Report 2010–5169

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


Environmental Modelling & Software

A model-independent iterative ensemble smoother for efficient history-matching and uncertainty quantification in very high dimensions

Jeremy T. White


USGS science for a changing world

Groundwater Resources Program
Prepared in cooperation with U.S. Environmental Protection Agency,
Great Lakes Restoration Initiative

Approaches in Highly Parameterized Inversion:
PEST++ Version 3, A Parameter ESTimation and Uncertainty Analysis Software Suite Optimized for Large Environmental Models

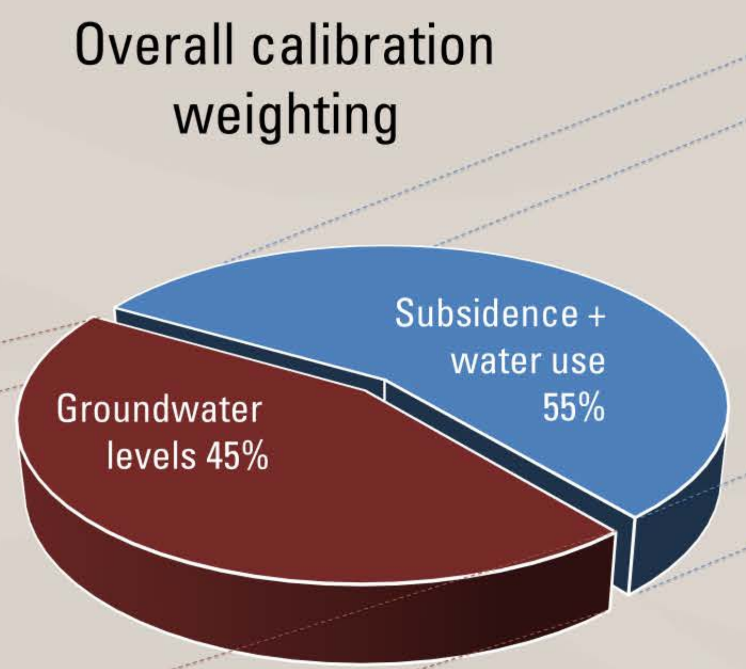
Techniques and Methods 7–C12

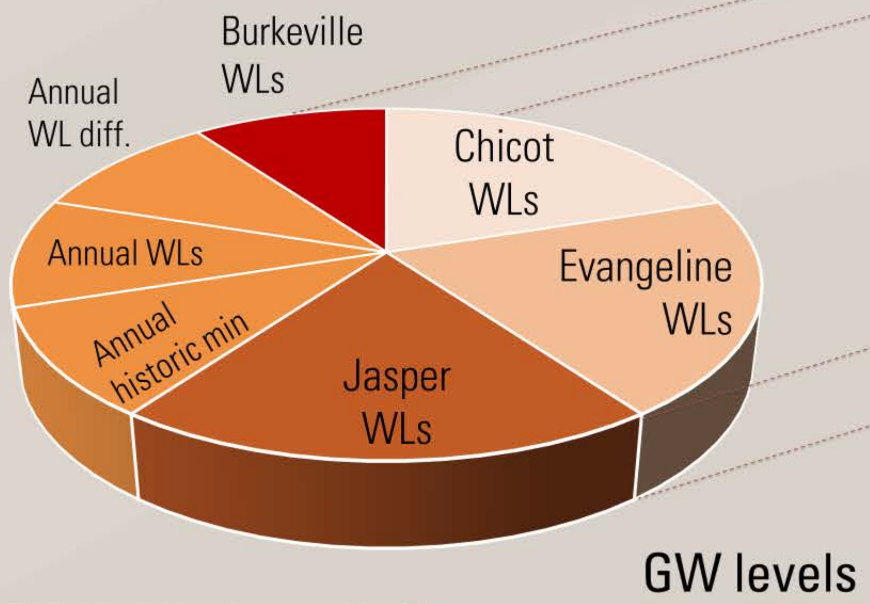
U.S. Department of the Interior
U.S. Geological Survey

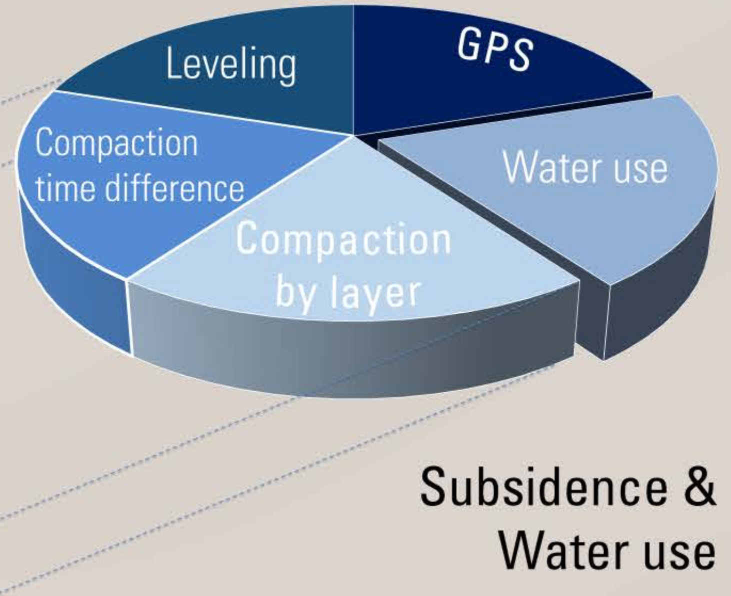
[1]White, 2018

History matching process

- Calibrate to groundwater levels, subsidence, and water use
- 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

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

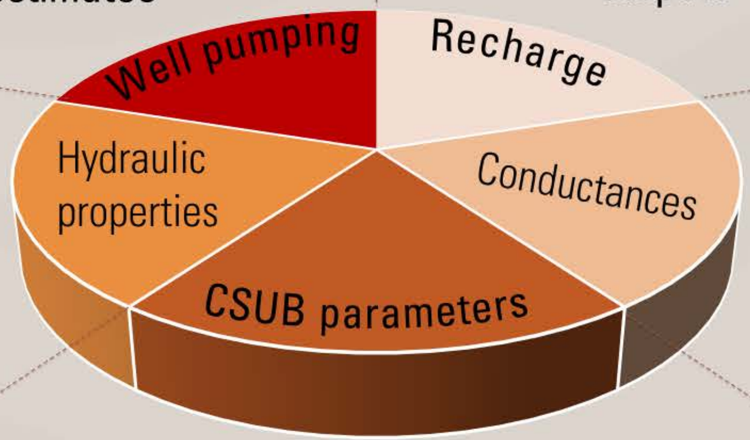
Model Parameters

- Thanks to advances in history matching using PEST-IES, currently using 2.95 million model parameters.
- Include entire-layer, geostatistical (pilot point), and individual cell parameters
- By parameter type:
  - Entire layer: 585
  - Individual cell: 2,925,767
  - Geostatistical: 28,247

Parameter groups and parameters

From water-use estimates

From SWB outputs



– River conductance
– Drain conductance
– GHB conductance

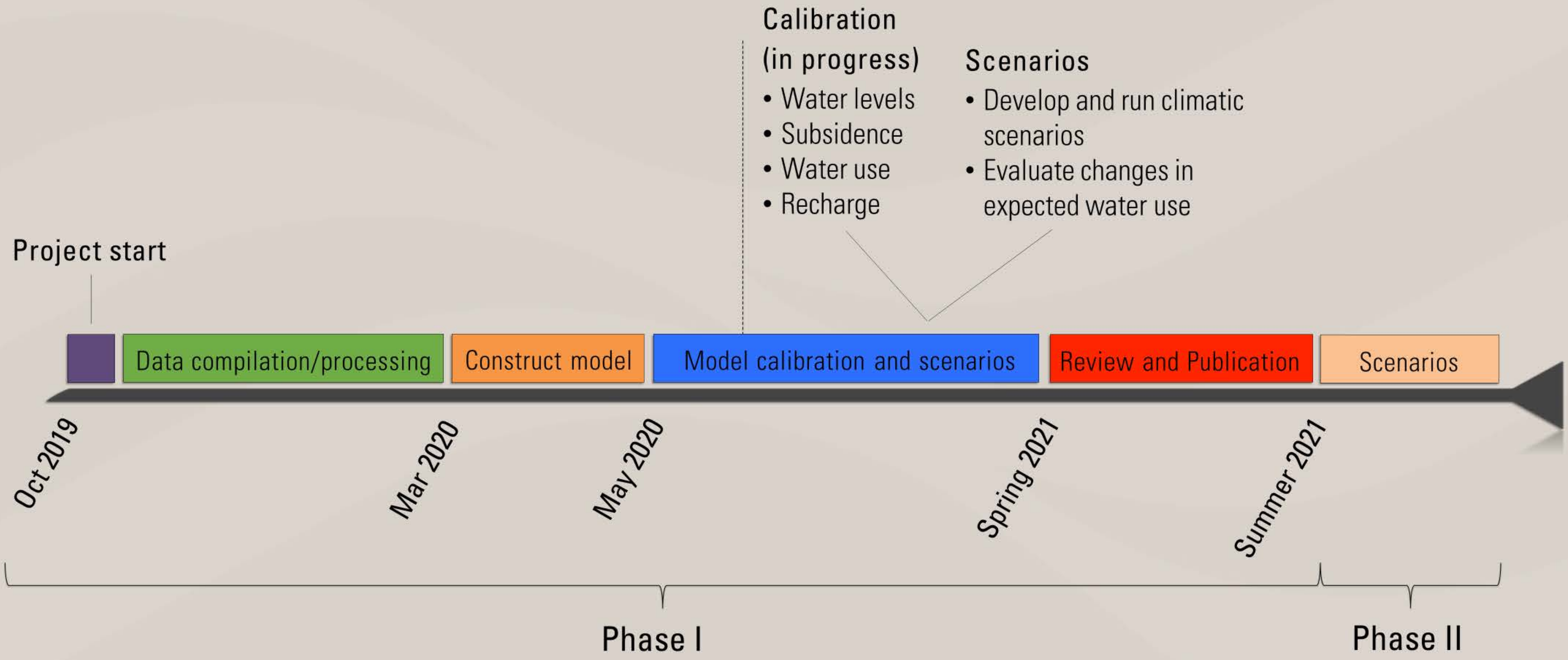
– Horizonal hydraulic conductivity
– Vertical hydraulic conductivity
– Specific Yield

1.7 million parameters

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

Coarse grained
– Specific storage (elastic)
– Porosity

Timeline


Calibration
(in progress)
• Water levels
• Subsidence
• Water use
• Recharge
Scenarios
• Develop and run climatic scenarios
• Evaluate changes in expected water use
Project start
Data compilation/processing
Construct model
Model calibration and scenarios
Review and Publication
Scenarios
Oct 2019
Mar 2020
May 2020
Spring 2021
Summer 2021
Phase I
Phase II

USGS science for a changing world

Gulf Coast Branch

Harris-Galveston Subsidence District

Fort Bend Subsidence District

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
Linzy Foster |lfoster@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	
STATUS					
2021	Complete Model Update	Population and Demand Projections	Technical Characterization, Final Report		
2022		Direct Stakeholder Process, Final Projections			Scenario Development
2023				Scenario Testing	Scenario Testing, Recommendations

Upcoming Milestones

Early 2021

- Population and Demand Projections
- Alternative Water Supply Assessment

Thank you.

- Questions and answers.

Thank you for attending the Joint Regulatory Plan Review Stakeholder Meeting

We appreciate your interest and engagement in this meeting.

https://hgsubsidence.org/planning/regulatory-plan-review/

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.

ATTACHMENT C – Question and Answer Session

The following summary documents questions that were received during the stakeholder meeting as well as formal responses provided for the record.

Questions with Responses

1. ***Would the cost of managing arsenic contaminated sludge be cost prohibitive?***

   Aquifer storage and recovery (ASR) water management strategies are proving to be a viable approach to maximize water availability in some areas of Texas. As with any strategy, the cost of water treatment and mitigation of waste is a primary consideration when determining economic viability. The occurrence and potential to mobilize arsenic in the Gulf Coast Aquifer will be a consideration for future ASR projects.

2. ***Cell size is 1kmx1km. Are model units metric or do you convert the cell size into feet?***

   The GULF-2023 model is in metric units.

3. ***Why is Catahoula not included in subsidence?***

   There are currently limited data available on the compaction potential of the Catahoula that could lead to subsidence. Additionally, the Catahoula layer was an addition to the model fairly late in the development cycle and therefore couldn't be included in the subsidence simulation presented at this time.

4. ***What value are monthly stress periods when you use a 2-year rolling average for water level calibration data?***

   The model is designed to represent stress patterns in a temporally meaningful way and is primarily focused on simulating long-term changes in water levels and subsidence at a spatially regional scale. The goal with the water-level data is to look at the long-term trend in water levels and attempt the best match to this trend at a monthly time interval, when these data are available.

5. ***Are smoothed water level data acceptable within GAM standards?***

   Yes, use of smoothed water level data to calibrate the model is acceptable. To ensure the model is within GAM standards for the quality of fit between measured and modeled water levels, USGS will also compare the calibrated model to raw water levels (i.e., non-smoothed data).

6. ***Allen Reservoir permits are expiring. Is Fort Bend going to take over the lead in advancing the project?***

   The Fort Bend Subsidence District is supportive of the development of the Allen's Creek Reservoir Project and will continue to work with the City of Houston, the Brazos River Authority, the Gulf Coast Water Authority and other regional water suppliers to develop alternative water resources for Fort Bend County.

QUESTIONS WITH RESPONSES

7. ***Is clay percent a layered or dispersed model?***

   The clay percentages are based on logs that were interpreted by INTERA. The clay percentages are broken up into each model layer, which are input as a thickness in meters in the model CSUB package. This clay thickness is then internally multiplied in the code by an interbed material factor equivalent number of interbeds in the interbed system. Therefore, the clay thickness is layered within the model. The clay as a percentage of the model cells was shown for the ease of viewing during the stakeholder meeting.

8. ***Do normal faults and fractures around salt domes affect the models?***

   Faults and fractures, whether they are around salt domes or elsewhere, are not explicitly incorporated into the model. The hydrogeologic framework used in the GULF 2023 model follows that of previous GAMs for the northern Texas Gulf Coast, which did not include these features. Faults may impede or act as a local barrier to the flow of groundwater; however, the model is regional in scale and the current cell size (1 km x 1 km) cannot easily simulate these sorts of localized features. However, salt domes do impact the hydrogeologic surfaces of the aquifer. See Young and others (2012) for a detailed description of salt domes and hydrogeologic surface development for the Gulf Coast Aquifer System.

9. ***Compared to groundwater, does the non-potable reclaimed water have any of the nutrients (i.e., gardening, etc.) or is the water re-used just simply 'wet'?***

   Yes, reclaimed water typically has micronutrients such as nitrogen and phosphorus which are beneficial for irrigation. Some advancing treatment technologies may remove those micronutrients thereby making it comparable to treated surface water.

10. ***Could there be a summary chart, in the next presentation, summarizing the cost/benefit/opportunity among all the options?***

    Yes, a summary chart of the shortlisted alternative water supply options that serve the region including cost effectiveness and benefits will be provided at the next stakeholder meeting.