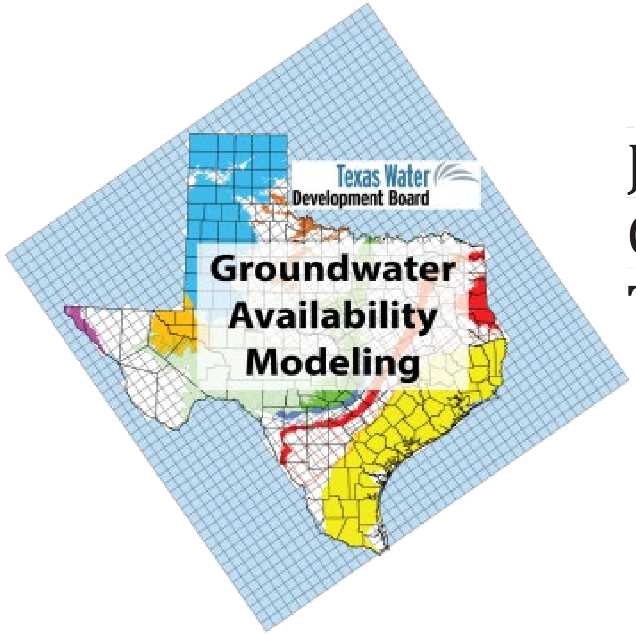
# Texas Water Development Board (TWDB) Groundwater Modeling (GM) Program




Jean Perez (Contract Manager)
Groundwater Availability Modeling Program
Texas Water Development Board

# What is the Texas Water Development Board?

**Not a regulatory agency like the Texas Commission on Environmental Quality (TCEQ).**

**Science**: Groundwater, surface water, innovative water technology, conservation, education, flooding.

**Planning**: Assist with regional planning and state planning (drought and flood plans)

**Funding:** We assist with implementing water projects with funding

# Groundwater Modeling (GM) Program

**Aim**: 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, data, models are available for download from TWDB download page for models.

**Living tools**: Periodically updated.

# Why Stakeholder Advisory Forums?

Keep stakeholders updated about progress of the modeling project

Inform how the groundwater model can, should, and should not be used

Provide stakeholders with the opportunity to provide input and data to assist with model development

# Contact Information

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**https://www.twdb.texas.gov/groundwater/models/gam/mrtn/mrtn.asp**

# Groundwater Availability Model for the Southern Portion of the Queen City, Sparta, and Carrizo-Wilcox Aquifers

GSI ENVIRONMENTAL

Prepared For the Texas Water Development Board

July 22, 2022

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# Project Team

GSI ENVIRONMENTAL

GSI ENVIRONMENTAL

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esi Environmental Simulations Inc.

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**Independent Groundwater Consultant**

# Contents of Presentation

GSI ENVIRONMENTAL

# 1. Introduction and Purpose of Model

# Groundwater Model Background

GSI ENVIRONMENTAL

Groundwater Availability Modeling (GAM) Program (since 1999)

***Goal: To provide useful and timely information for determining groundwater availability for the citizens of Texas.***

Reasons:

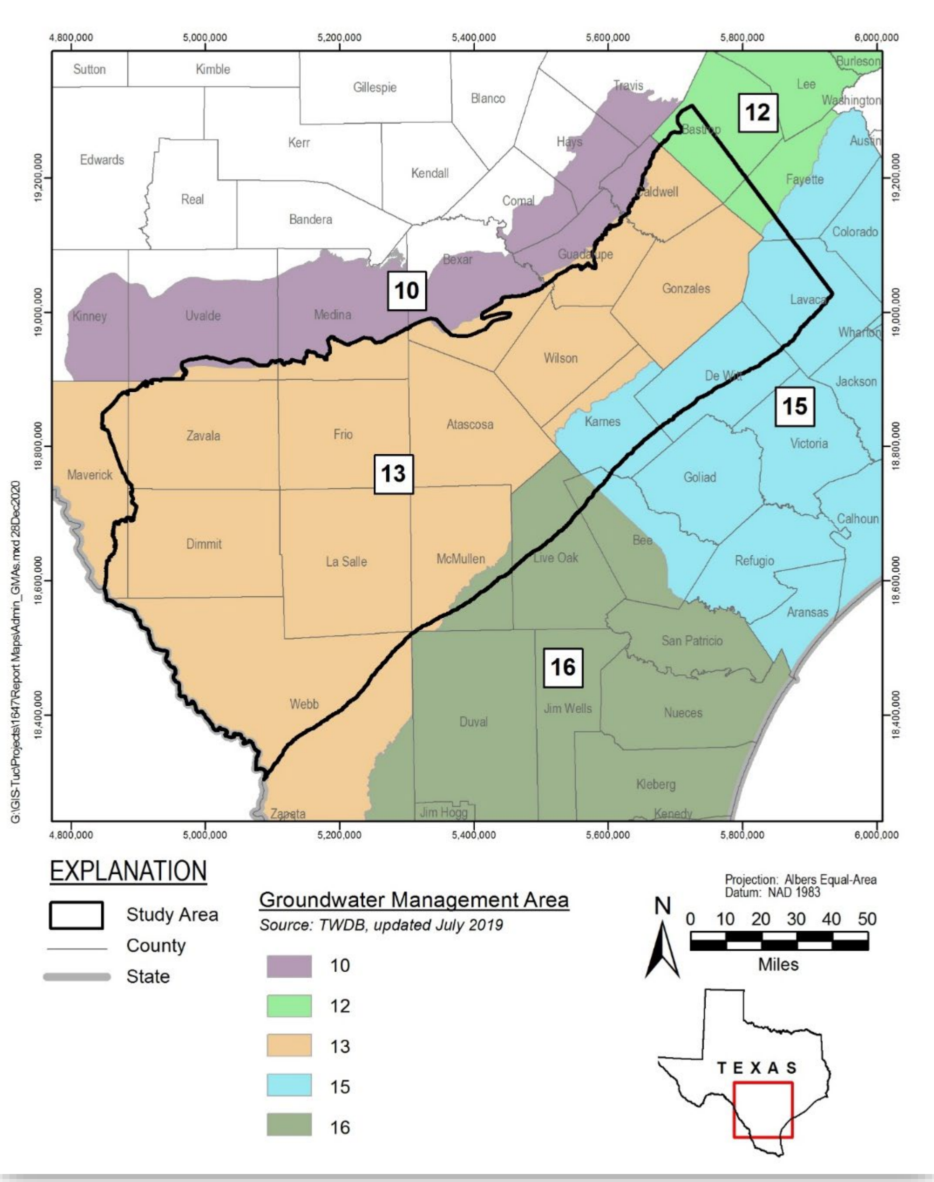
- Projected 70% state-wide population increase by 2070
- Possible future drought conditions
- Groundwater is vital to state resources, health, and economy
- Groundwater is difficult to observe and measure.

Implementation:

- Analyze groundwater management policies for Texas aquifers
- Produce data for major and minor aquifers in Texas
- Include stakeholder input
- Provide results publicly (estimated available groundwater)

# Groundwater Model Background

The groundwater model update is for Groundwater Management Area 13.

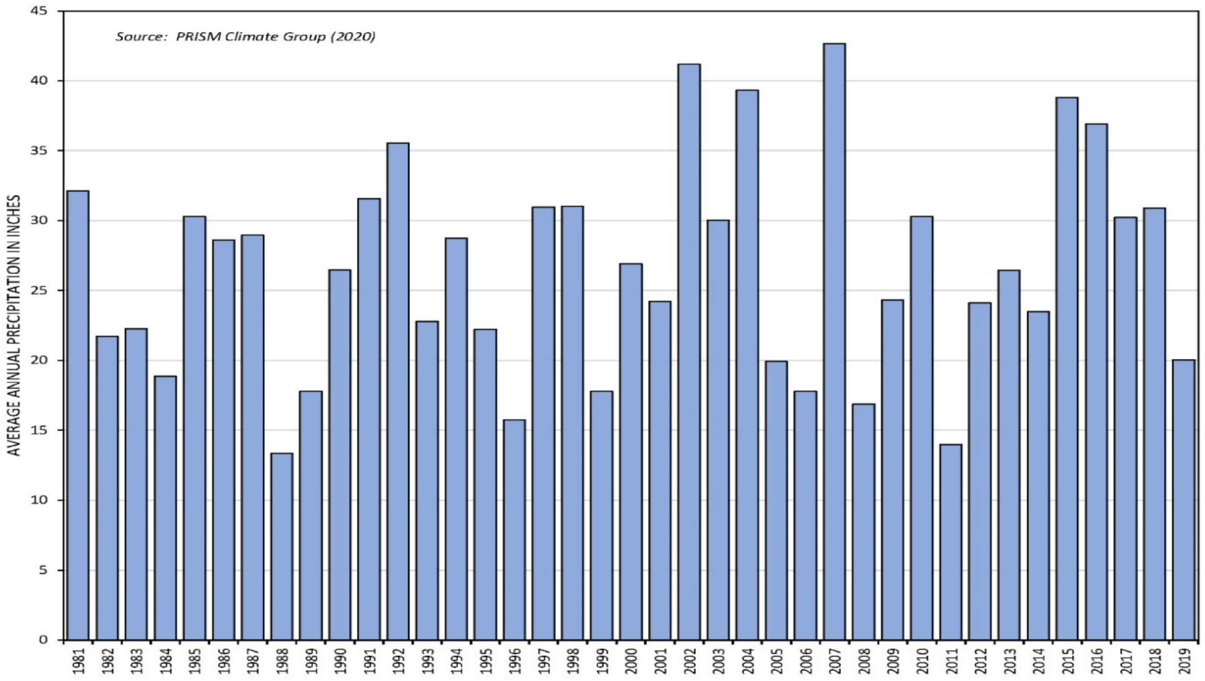


# Groundwater Model Background

GSI ENVIRONMENTAL

GMA 13 had a conceptual model update in 2020 and included the following:

- Groundwater levels
- Groundwater movement
- Surface water features
  (rivers, creeks, etc.)
- Well pumping
- Precipitation
- Hydrostratigraphy
- Geologic unit properties
  (hydraulic conductivity, sand %, etc.)




Example of Updated Parameter:
Annual Rainfall Across Study Area

The conceptual model served as the basis for the 2022 GMA 13 groundwater model update.

# Groundwater Model Background

The model update was completed, and the Draft Final Report was submitted in June 2022.

**Draft Final Numerical Model Report: Update to the Groundwater Availability Model for the Southern Portion of the Queen City, Sparta, and Carrizo-Wilcox Aquifers**

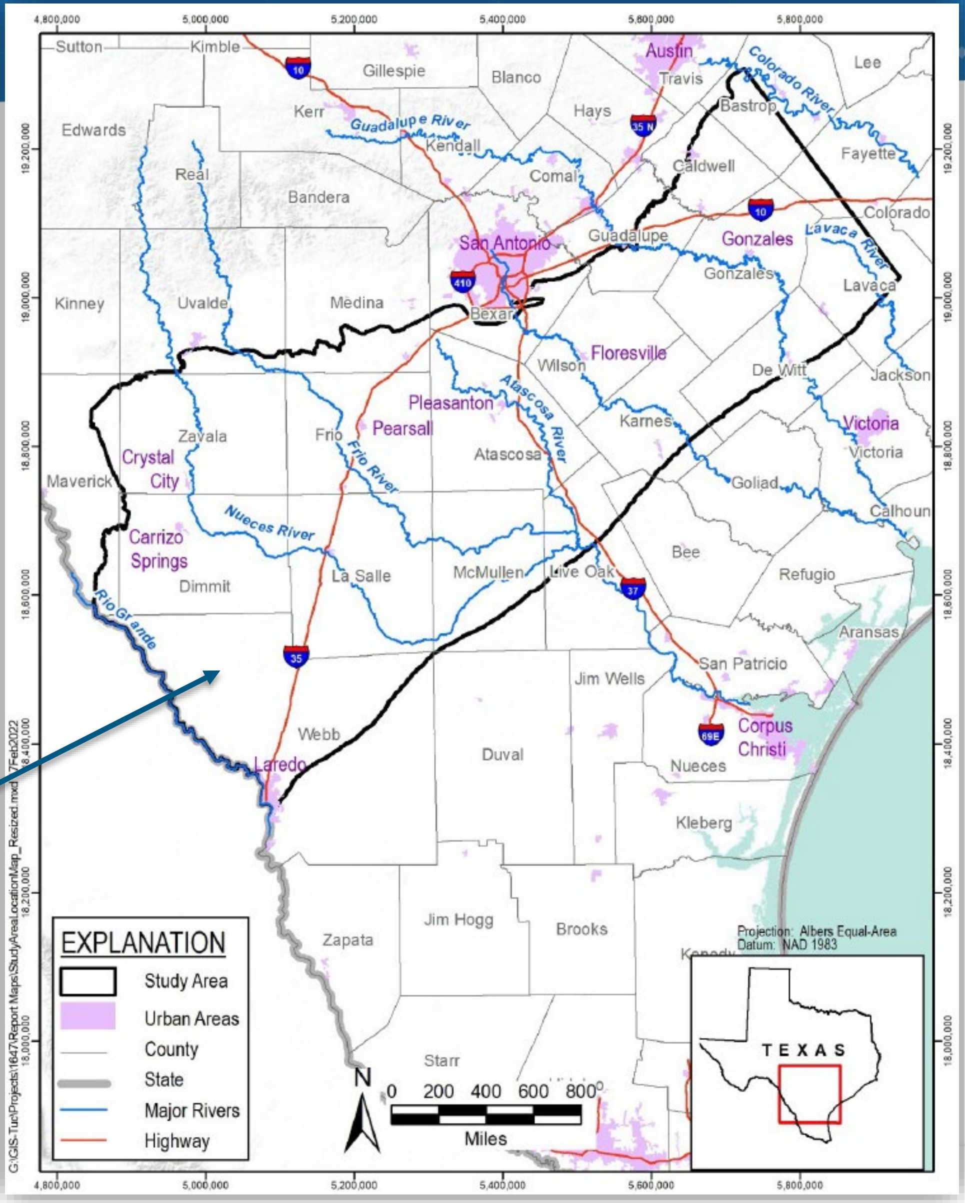
Texas Water Development Board Contract 1948312321

# 2. Model Overview and Packages

# Model Area

The model area includes the GMA 13 area in Texas.

GMA 13



# Model Inputs

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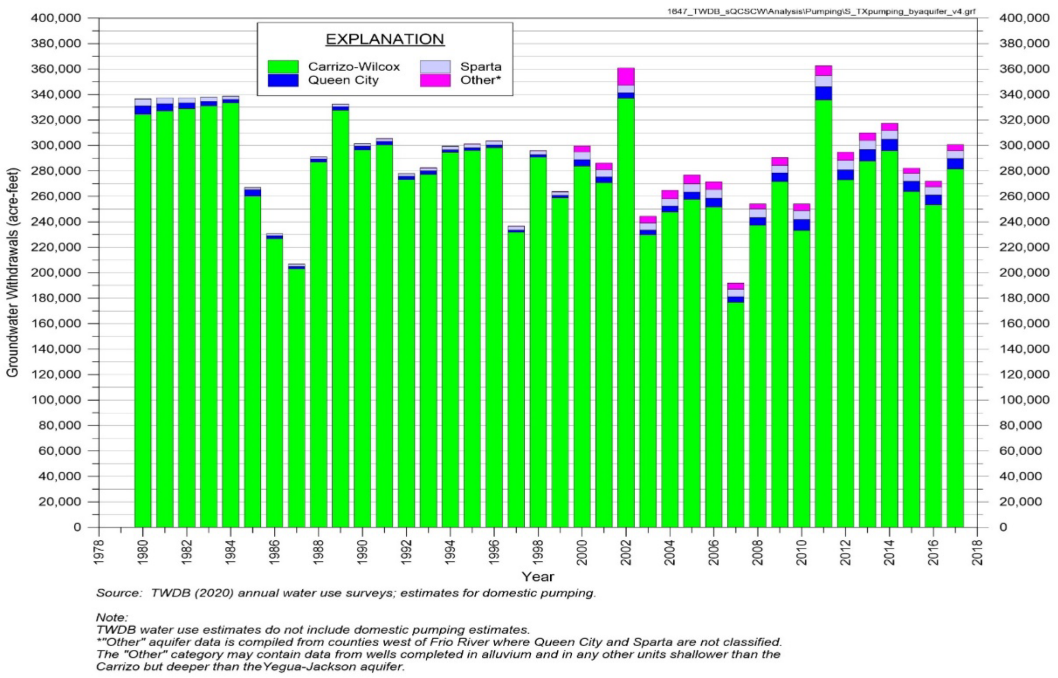
Model inputs consider:

- layering representing the geologic units, along with unit attributes relating to flow – sand fraction, hydraulic conductivity, storage
- pumping well locations and rates
- a separate alluvium layer beneath rivers and creeks
- precipitation infiltration to groundwater (recharge)
- lateral boundary inflows and outflows
- Evapotranspiration, rivers, faults
- monitoring wells

**Model time period:**

- **Predevelopment (no pumping)**
- **1980 through 2017 (38 years)**

Inputs that vary with time were entered as annual values except monitoring well data.




Example of Pumping from all Wells in Study Area from 1980 through 2017

# Aquifer Units

- Groundwater = water present in pore spaces in the subsurface.
- Aquifer = water-bearing geologic units, used for groundwater wells.
- Aquitard = geologic unit that does not readily transmit water (for example, clay units).

MODEL LAYERS | GEOLOGIC UNITS

*Ground Surface*

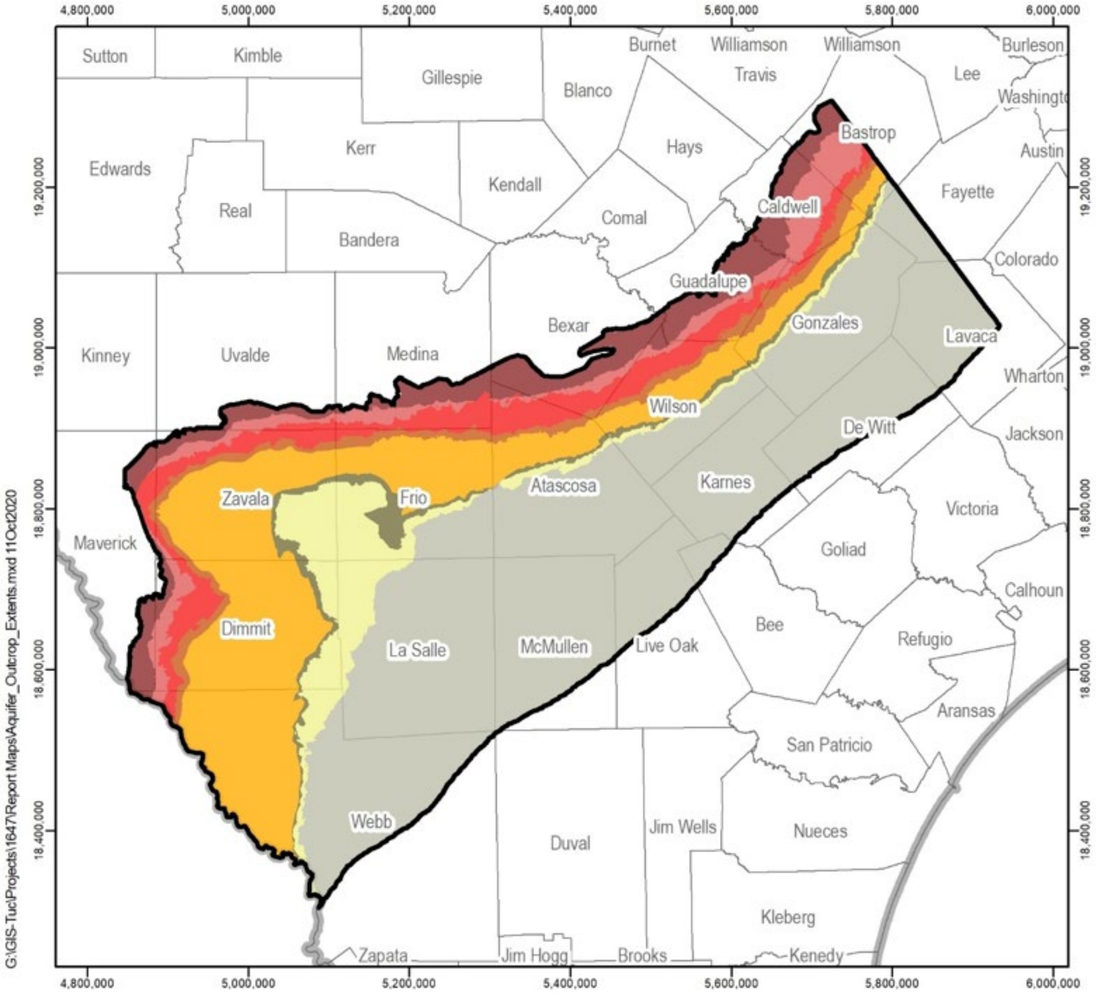
*Subsurface*

*(Increasing Depth)*

| MODEL LAYERS | GEOLOGIC UNITS | |
|---|---|---|
| **Layer 1** | **Quaternary Alluvium** | **(aquifer)** |
| **Layer 2** | **Younger Units** | (boundary) |
| **Layer 3** | **Sparta Aquifer** | **(aquifer)** |
| **Layer 4** | **Weches Formation** | (aquitard) |
| **Layer 5** | **Queen City Aquifer** | **(aquifer)** |
| **Layer 6** | **Reklaw Formation** | (aquitard) |
| **Layer 7** | **Carrizo-Upper Wilcox** | **(aquifer)** |
| **Layer 8** | **Middle Wilcox** | **(aquifer)** |
| **Layer 9** | **Lower Wilcox** | **(aquifer)** |

# Outcrop Map

The 9 aquifer and aquitard units in the model area, shown in plan view.



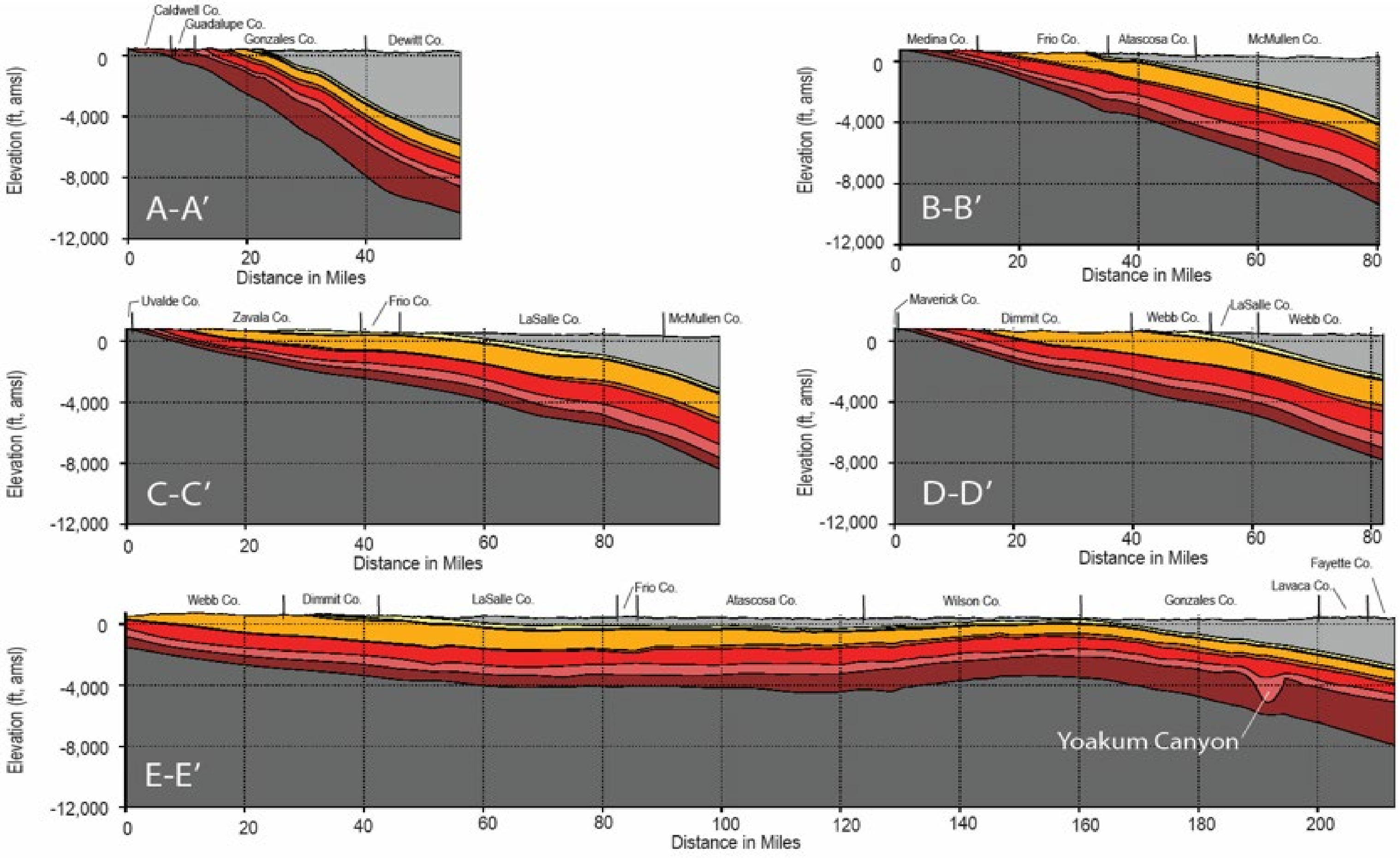

Hydrostratigraphy developed from electronic logs provided by previous GAM and Groundwater Conservation Districts (GCDs).

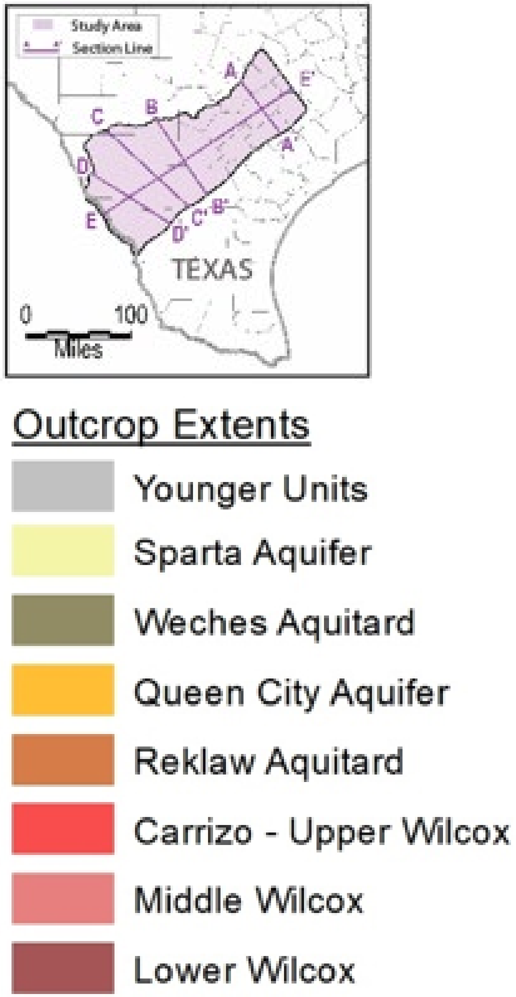
**Outcrop Extents**

- Younger Units
- Sparta Aquifer
- Weches Aquitard
- Queen City Aquifer
- Reklaw Aquitard
- Carrizo - Upper Wilcox
- Middle Wilcox
- Lower Wilcox

# Aquifer Units

The 9 aquifer and aquitard units in the model area, shown in the subsurface. Depths and thicknesses of each unit vary.

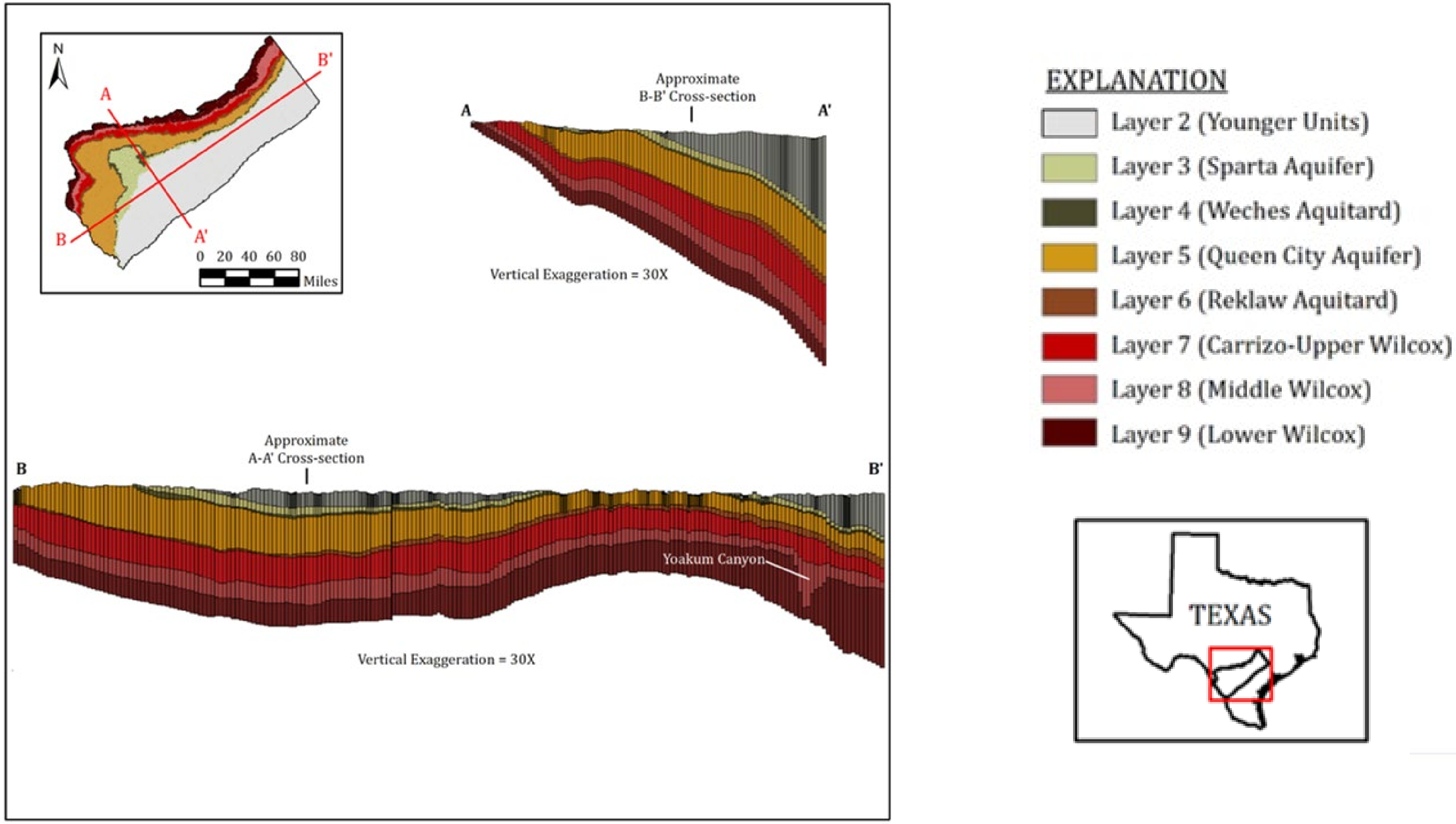



SOURCE: GSI, 2022

# Aquifer Units – In The Model

The groundwater model uses the 2020 conceptual layering.

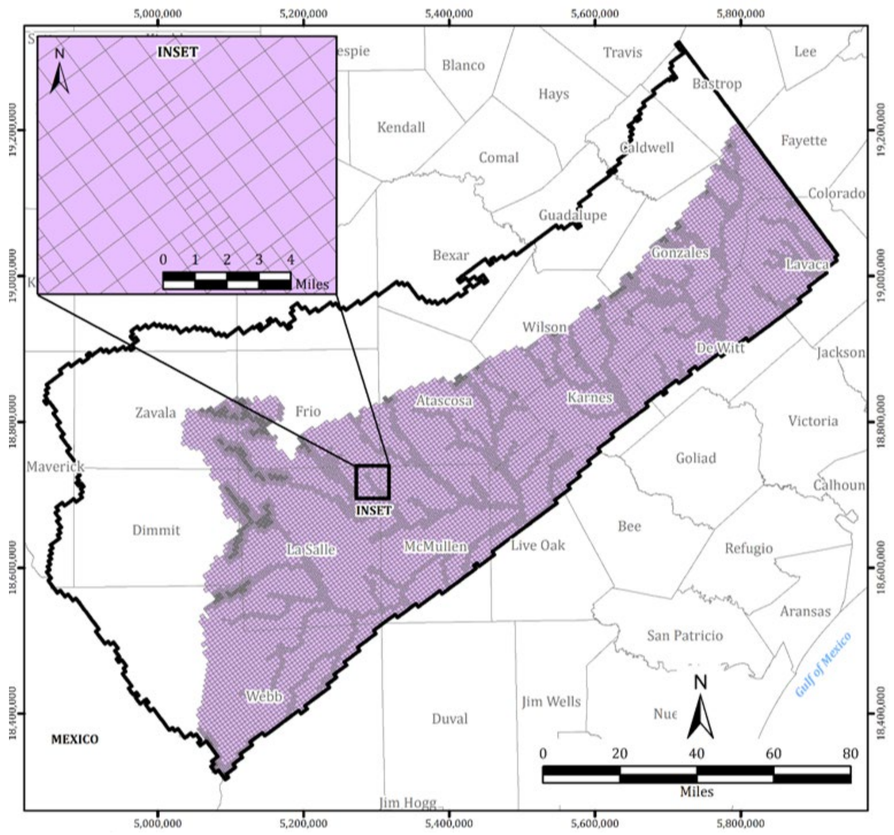


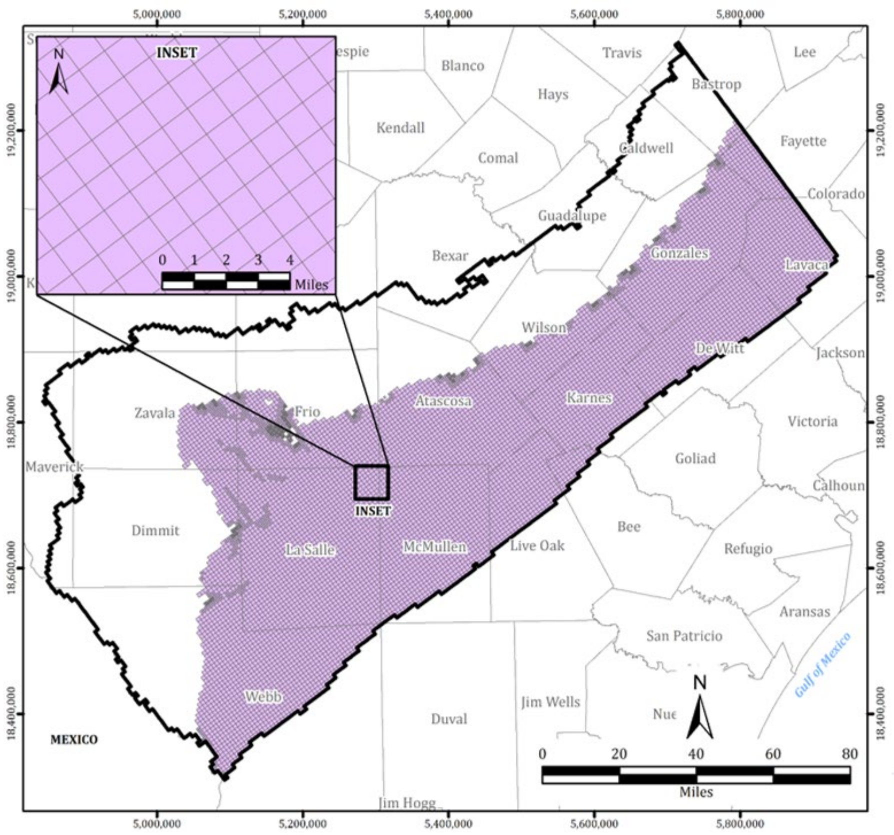
# Model Packages – MODFLOW6

- Name File
- Initial Conditions (IC)
- Model Domain Discretization (DIS)
- Node Property Flow (NPF)
- Storage (STO)
- General Head Boundary (GHB)
- River (RIV)
- Recharge (RCH)
- Evapotranspiration (EVT)
- Well (WEL)
- Hydraulic Flow Barrier (HFB)
- Output Control (OC)
- Solver (IMS)

# Model Packages – Domain Discretization (DIS)

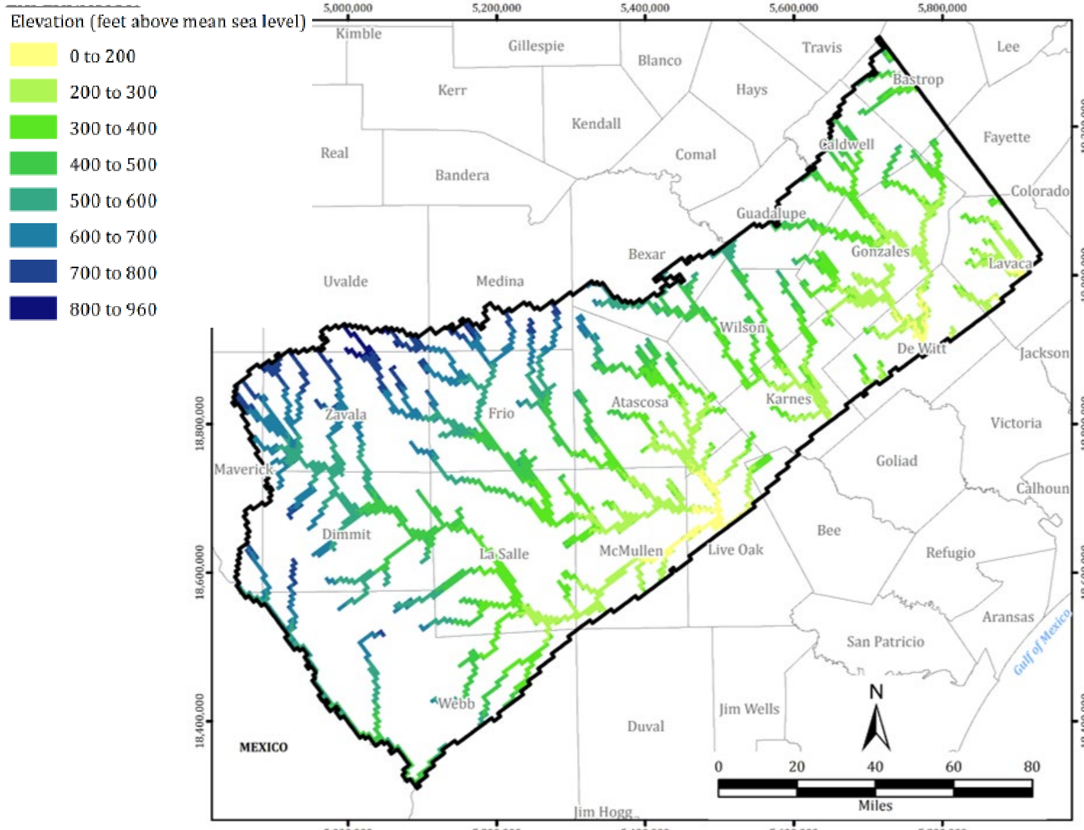
- Grid refinement is finest near surface water features – horizontally and vertically
- Model grid size: 660 ft to 5,280 ft; 382,024 active cells.

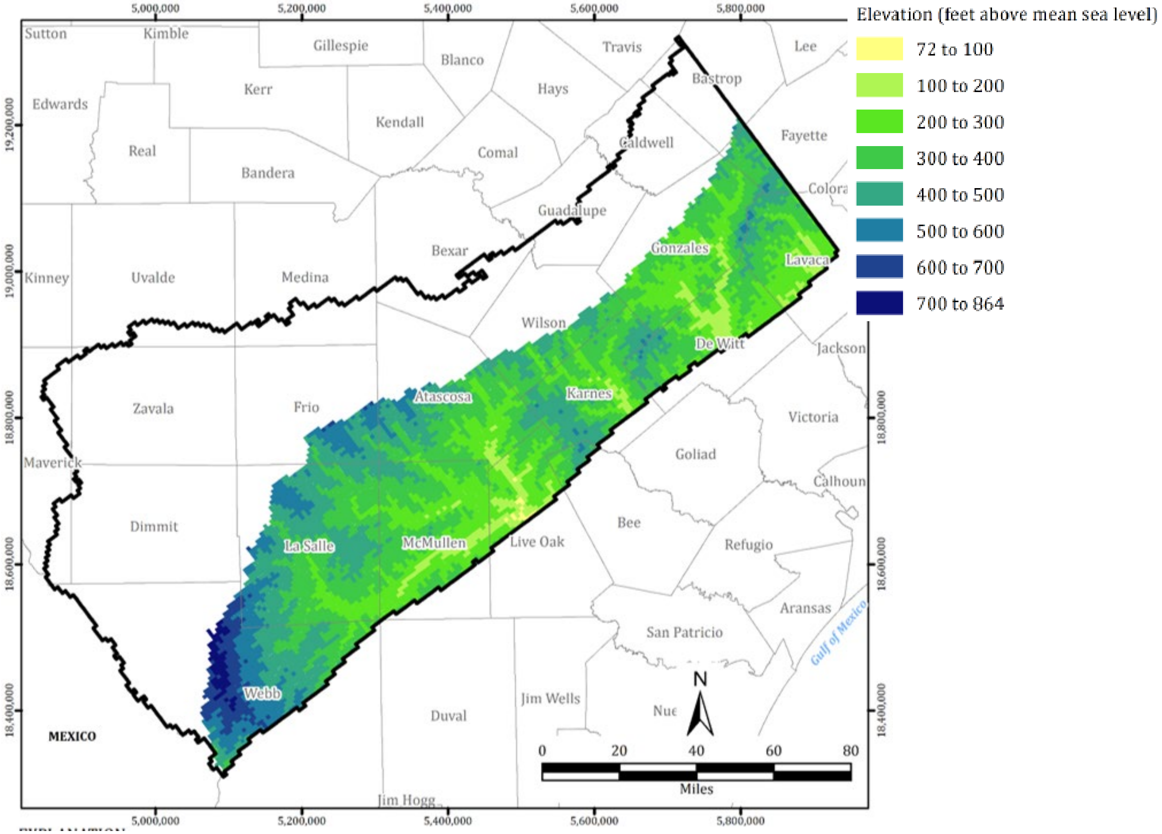


# Model Packages – Domain Discretization (DIS)

- Top elevation of layers.



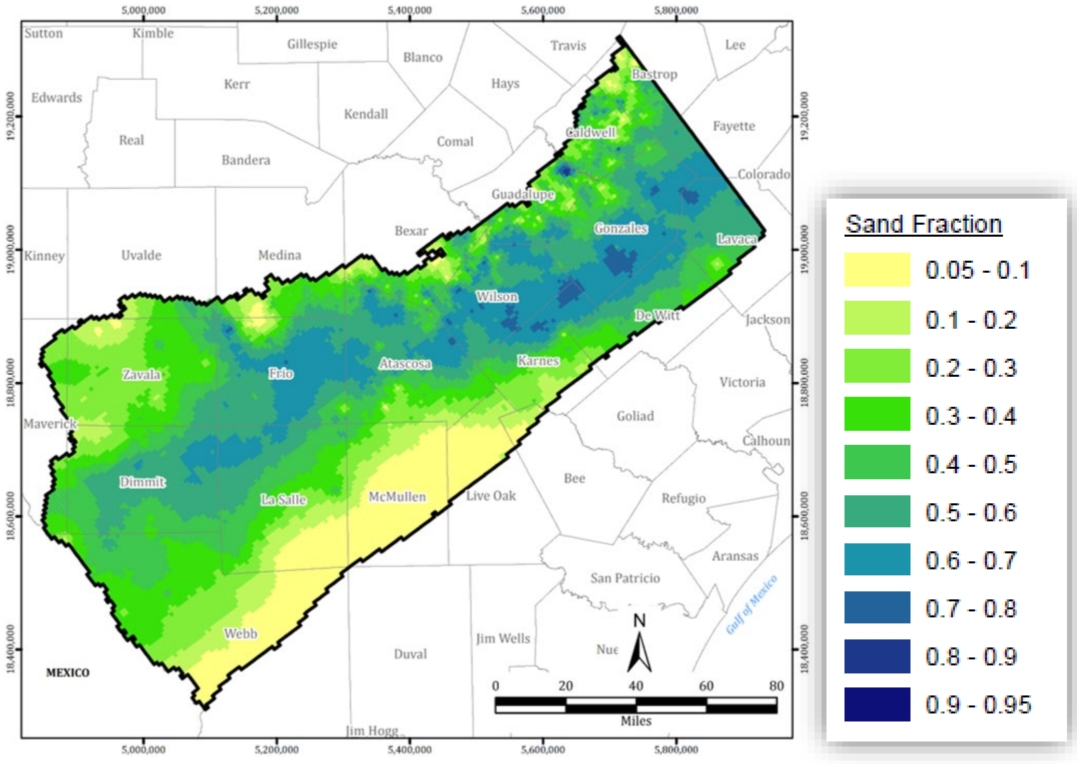



# Model Packages –
# Node Property Flow (NPF)

This package simulates hydraulic conductivity (K).

- Tried approach of using sand fractions within each model layer correlated to K-values.
- Directly calibrated K-values due to difficulties with sand fraction approach.

Sand Fraction in Lower Wilcox (Layer 9)



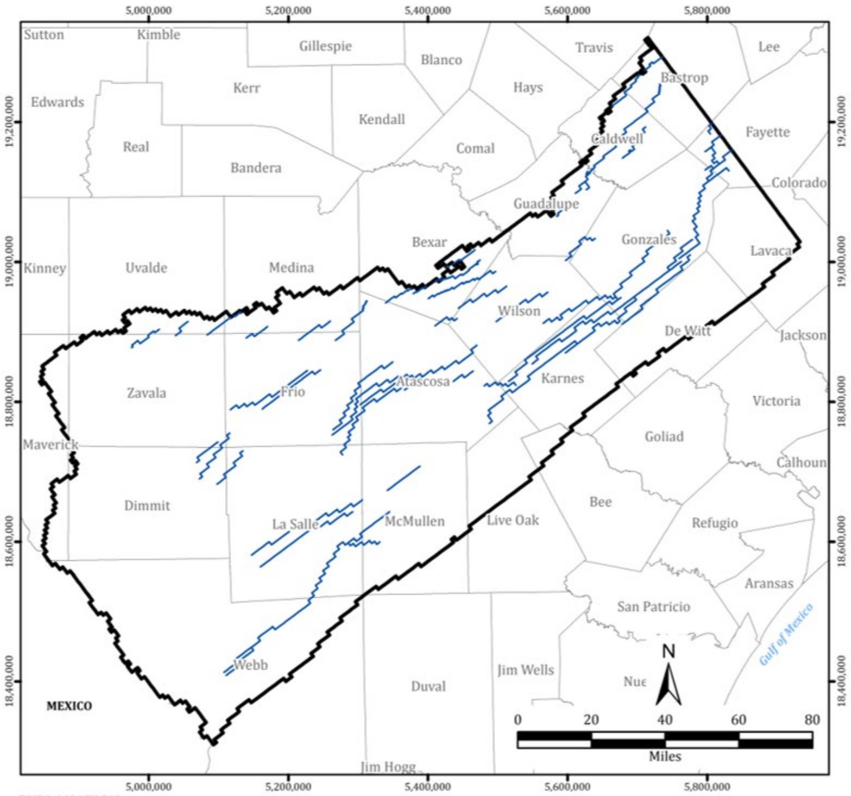

**MODFLOW 6 uses the STO Package for input of specific yield and specific storage values**

# Model Packages – Hydraulic Flow Barrier (HFB)

This package simulates fractures and faults in the aquifers.

- HFB K-values calibrated with PEST (though impact was not controlling).

Simulated faults and flow barriers

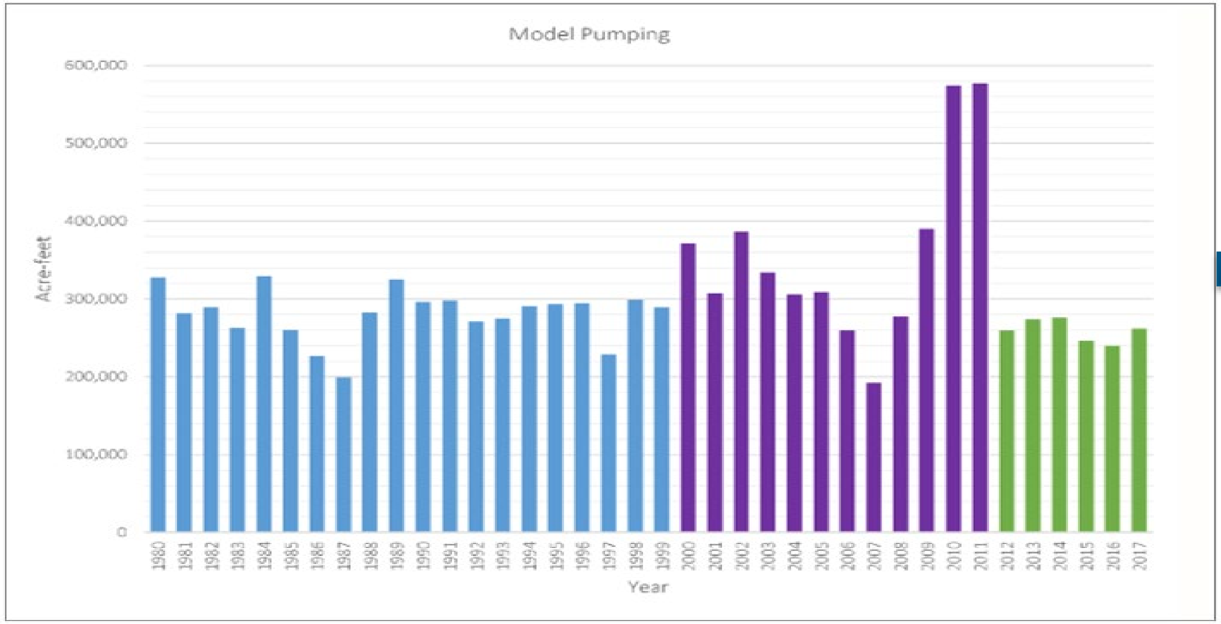


# Model Packages – Well (WEL)

This package simulates the pumping wells in the model.

Pumping dataset was based on annual TWDB water use surveys for the years 1980 through 2017 and evaluated against the following data:

- 1980 to 1999 pumping from 2004 groundwater availability model by Kelley and Others, 2004;
- 2000 to 2011 pumping from Hutchison, 2017;
- 2012 to 2017 model pumping is based on TWDB pumping data or Hutchison, 2017; and
- No pumping for predevelopment period.

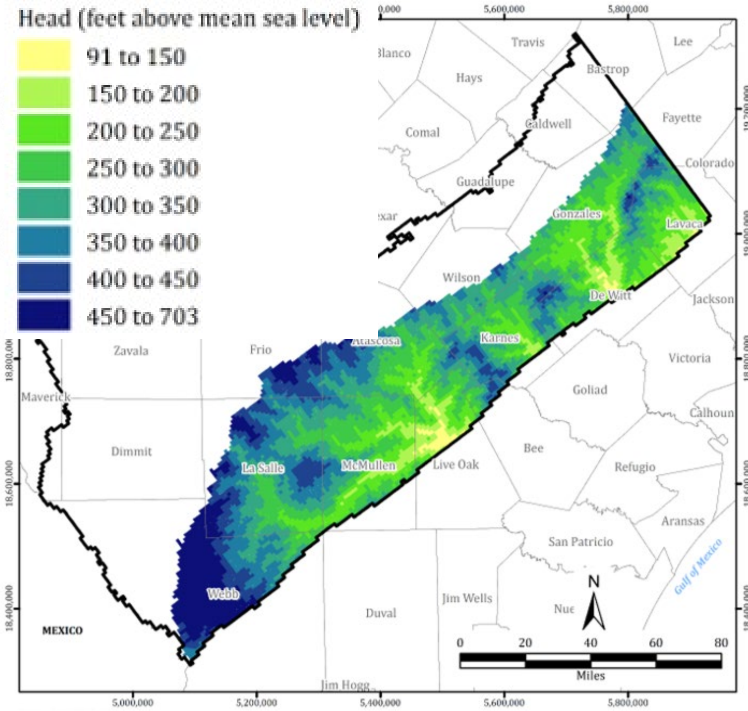



Numerical model identified further deficiencies in pumping data – some calibration conducted

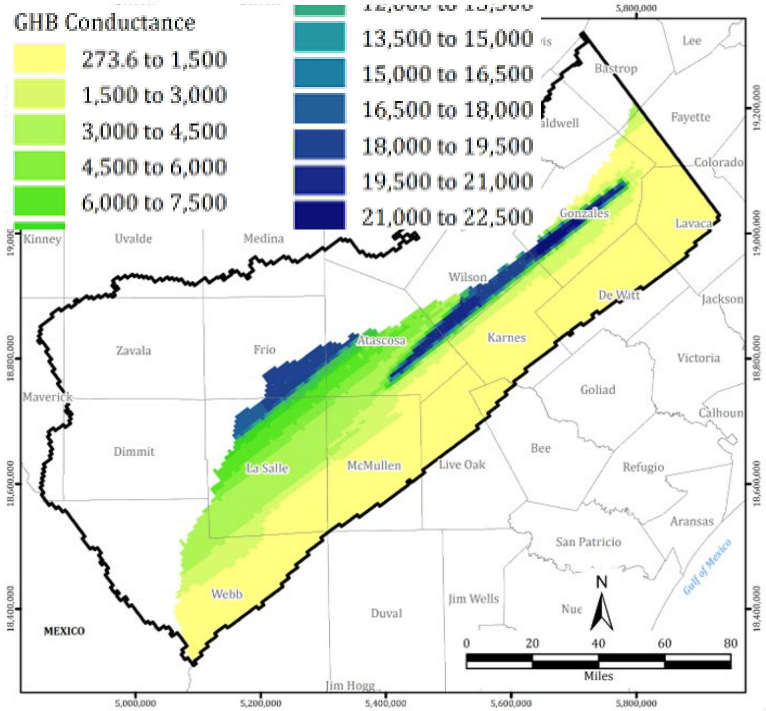
# Model Packages – General Head Boundary (GHB)

This GHB condition simulates flow in and out of the modeled area.

- The Younger Units (Model Layer 2) acts as a boundary to the Sparta below.
- GHBs are also simulated along lateral southern and eastern boundaries in the aquifer units (model layers 3, 5, 7, 8, and 9).




GHB head in Model layer 2

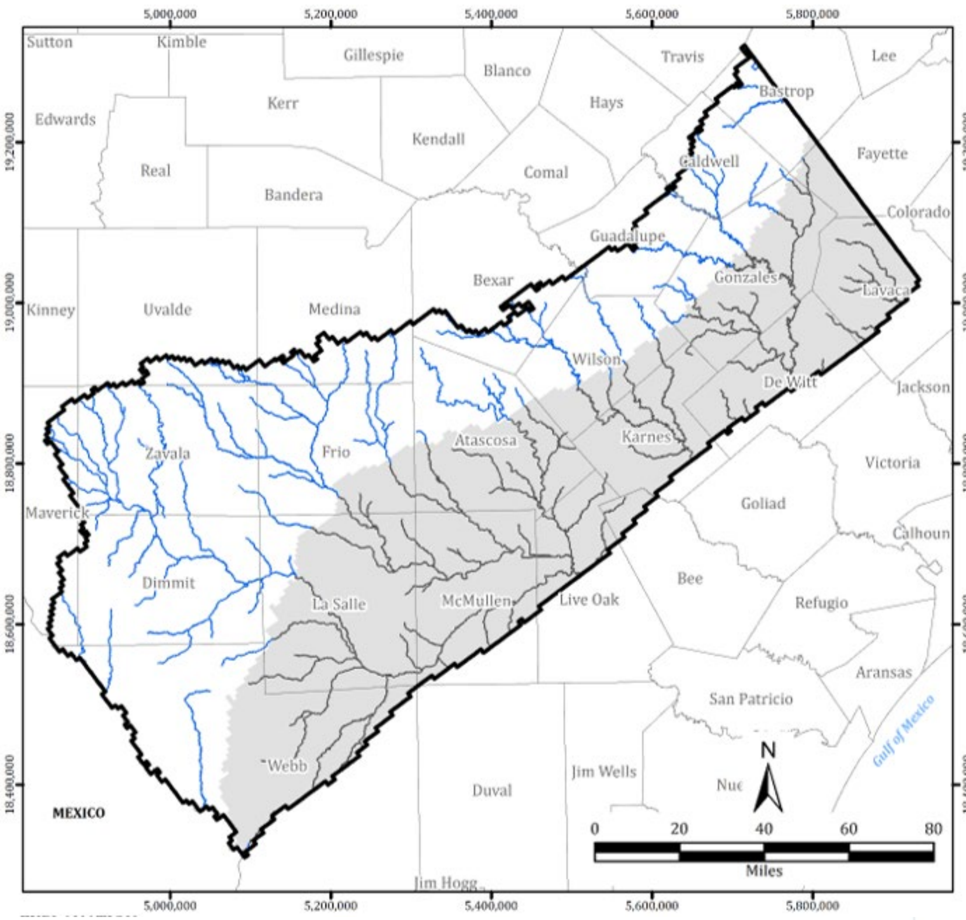



GHB conductance in Model layer 2

# Model Packages – River (RIV)

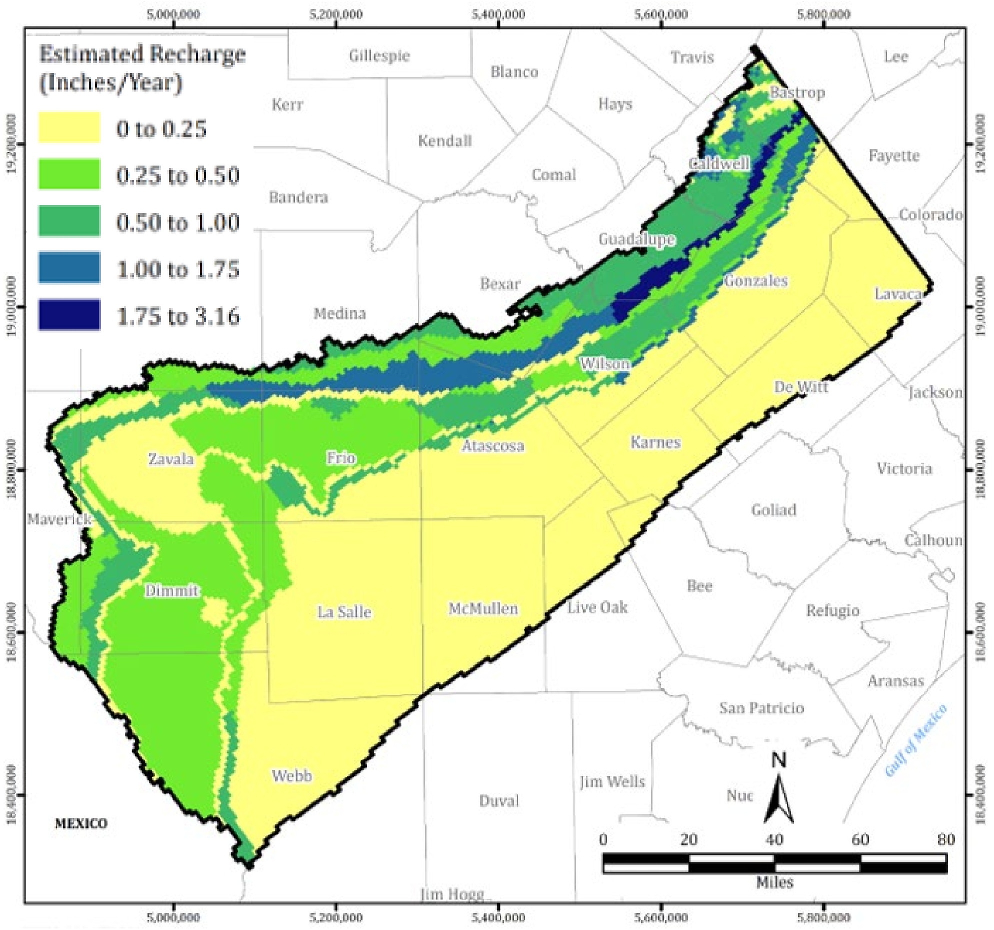
This package simulates the rivers and streams in the model.

- RIV Stage Assumptions
  - 1 foot above riverbed everywhere
  - Constant through time
- RIV bed conductance varied during calibration
- River boundary conditions overlying the Younger Units were deactivated because the Younger Units act as a boundary condition to the underlying aquifers

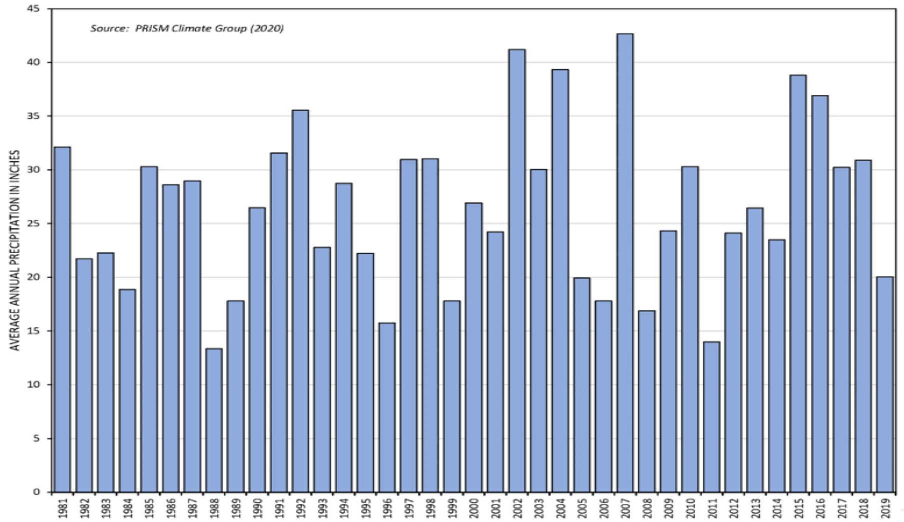


# Model Packages – Recharge (RCH)

This package simulates the amount of precipitation that reaches the subsurface units.

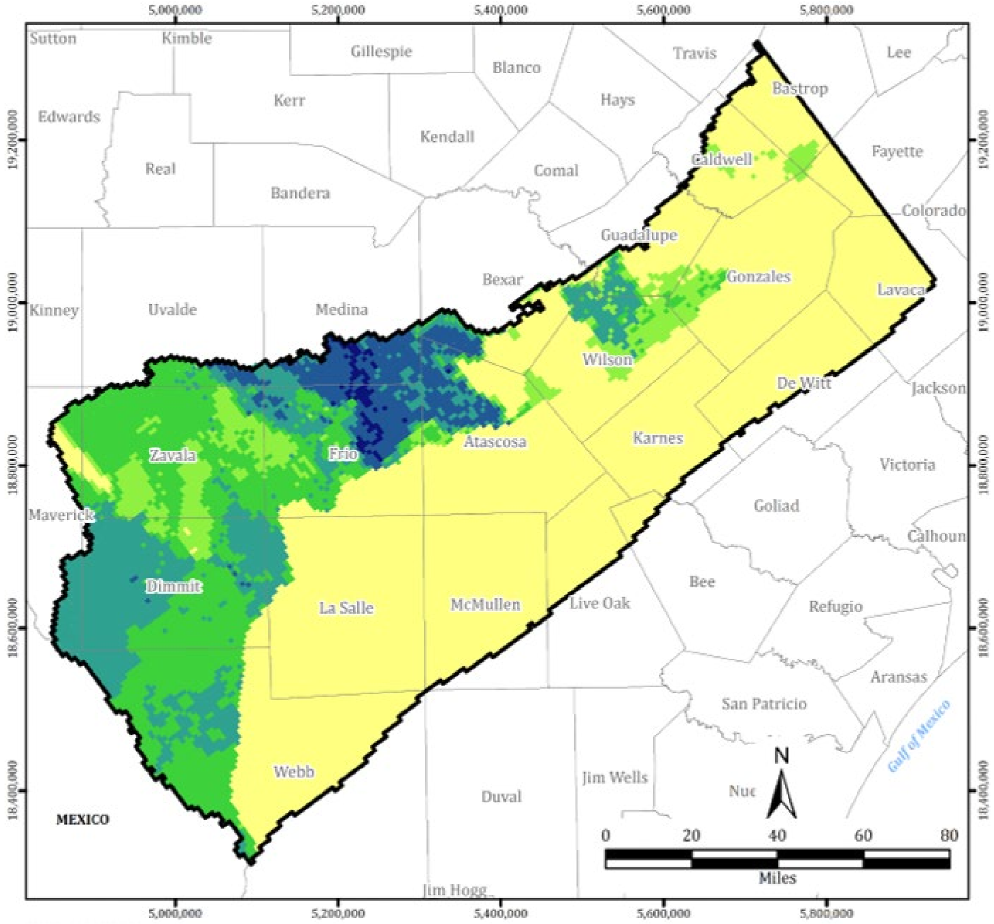



- Distributed as per Kelley and others, 2004
- Recharge is varied annually by a multiplying factor that correlates with annual precipitation

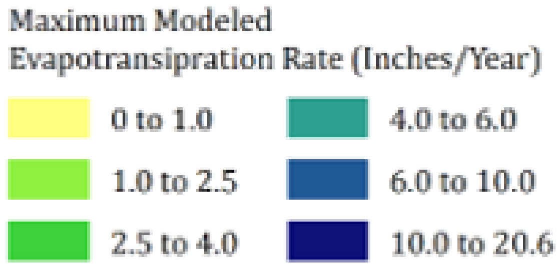


# Model Packages – Evapotranspiration (EVT)

This package simulates water lost from the subsurface units to evapotranspiration.




- PET distribution as per Kelley and others, 2004.
- Extinction depth ranged from less than 1 foot to 7.2 feet.



# Model Inputs – Quality Control

Quality control of raw pumping data:

- Wrong layer (in pinch-out)
- Outliers
- Pumping changes do not reflect observed water level elevation changes
- Downdip areas in Model layer 7 at Zavala, Frio, La Salle, and Dimmit County boundaries

Quality control of water level elevation data:

- Layer assignments inconsistent with adjacent water level elevations
- Water levels below layer bottom
- Water level measurements in aquitards
- Lack of well construction information or multi-aquifer wells
- Data records indicating measurement problems
  - pumping-level measurement;
  - presence of oil and grease in well;
  - possible incorrect well identification;
  - flooding/runoff into the well casing;
  - air leak in the sampling line; and
  - well water level elevations previously flagged

# Model Inputs – Pumping Data Evaluations

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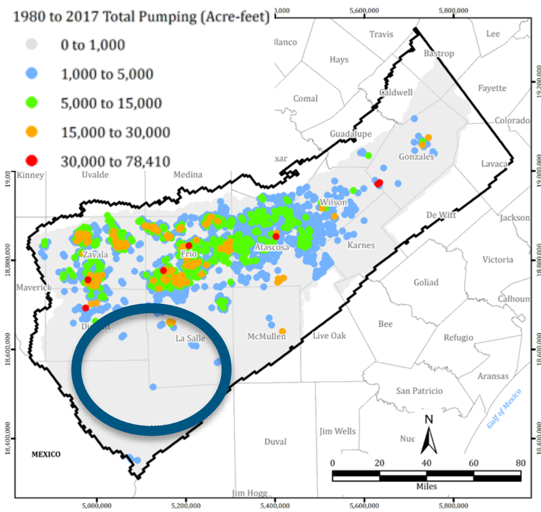
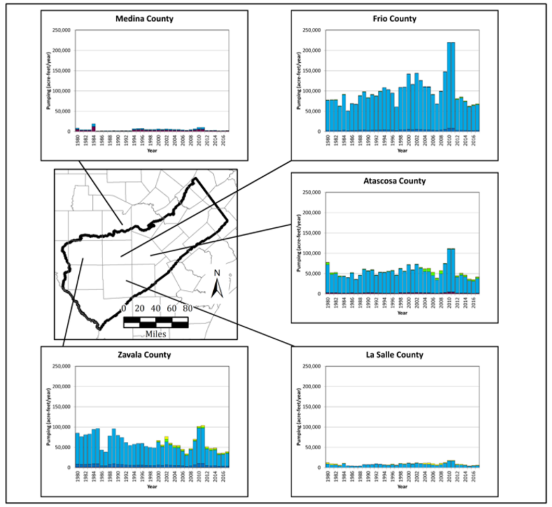
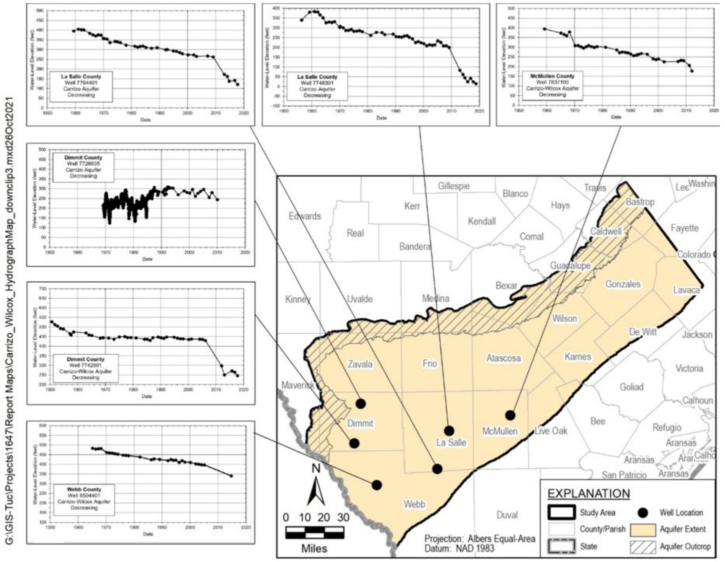
***Large drawdown with small pumping changes***




Pumping Distribution in Model Layer 7 indicates little pumping in Dimmit, Frio, La Salle, and Zavala.




County-wide Pumping through time does not change significantly.




Large drawdowns in Dimmit, Frio, La Salle, and Zavala Counties.

# Model Inputs – Pumping Data Evaluations

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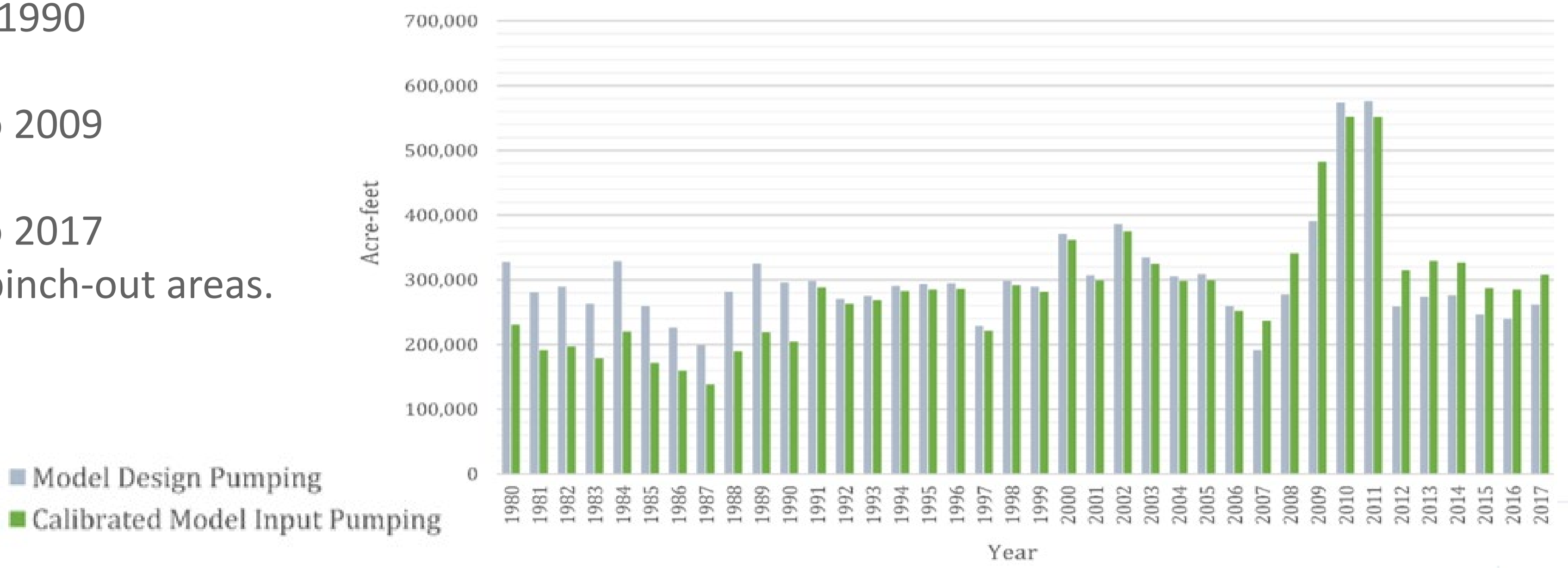
1. Attempted to calibrate model with developed pumping dataset:
   a) Indicated areas of large water level changes with little change in pumping
2. Attempted to use PEST to calibrate pumping for each county:
   a) A program was written to use PEST to adjust pumping in each county by a pumping factor for every year
   b) Computationally insensitive and PEST failed to provide improvements

***Final Solution***

3. Pumping data was manually adjusted to better accommodate water level signatures. In Zavala, Frio, La Salle, and Dimmit Counties in Model Layer 7:
   a) Reduced by 50% from 1980 to 1990
   b) Not scaled 1990 to 2006
   c) Increased by 50% from 2007 to 2009
   d) Not scaled 2010 and 2011
   e) Increased by 50% from 2012 to 2017
4. Corrected pumping outliers and in pinch-out areas.



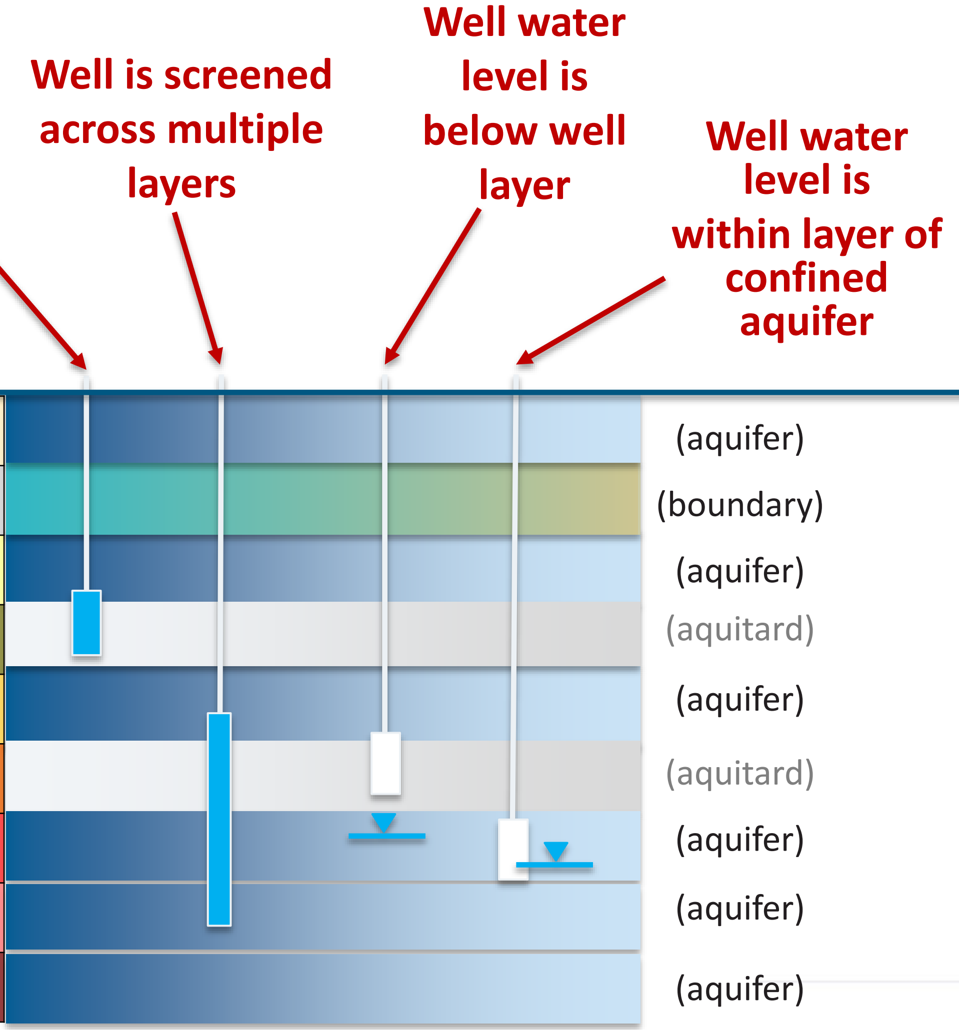
# Model Inputs – Monitoring Well Evaluations

GSI ENVIRONMENTAL

Difficulties encountered with county data:

*Ground Surface*

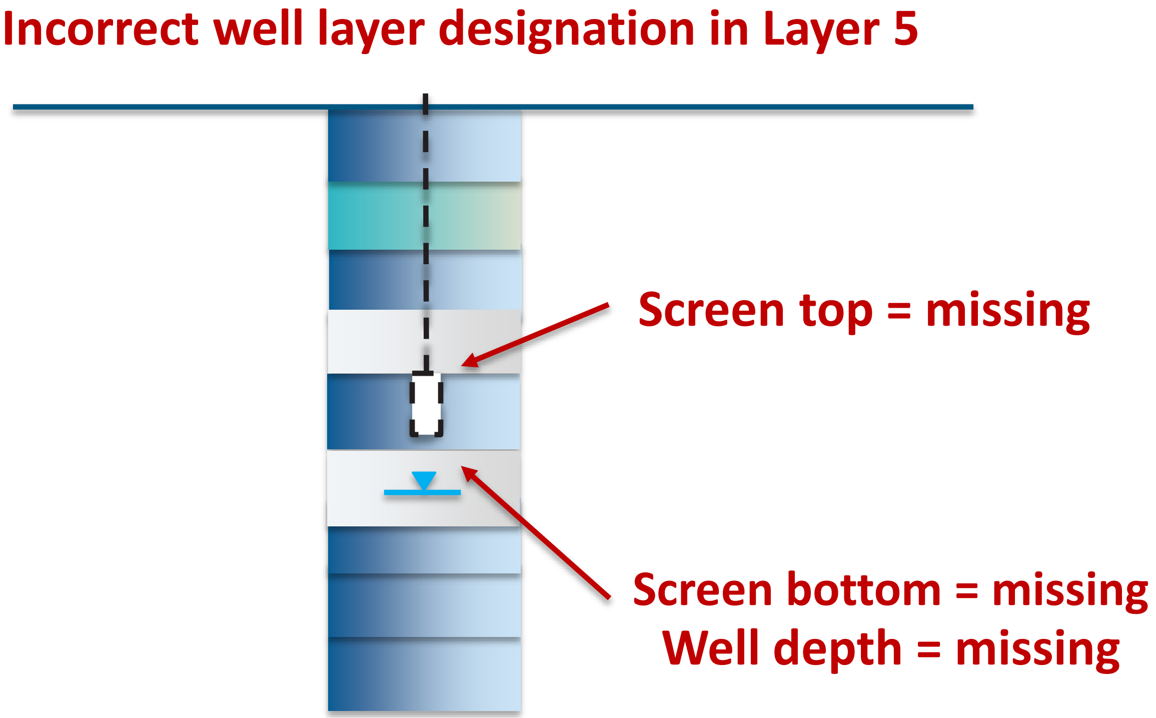
| MODEL LAYERS | GEOLOGIC UNITS | |
|---|---|---|
| Layer 1 | Quaternary Alluvium | (aquifer) |
| Layer 2 | Younger Units | (boundary) |
| Layer 3 | Sparta Aquifer | (aquifer) |
| Layer 4 | Weches Formation | (aquitard) |
| Layer 5 | Queen City Aquifer | (aquifer) |
| Layer 6 | Reklaw Formation | (aquitard) |
| Layer 7 | Carrizo-Upper Wilcox | (aquifer) |
| Layer 8 | Middle Wilcox | (aquifer) |
| Layer 9 | Lower Wilcox | (aquifer) |



# Model Inputs – Monitoring Well Water Level Data Evaluations

Other difficulties encountered:

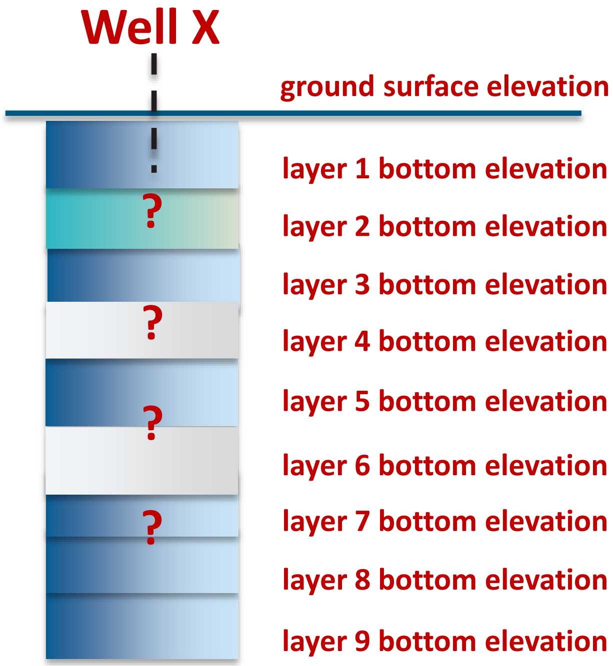
- Few wells have available construction information.
- Locations are approximate for many wells (center of section).
- Water level elevations inconsistent with adjacent wells in same layer.

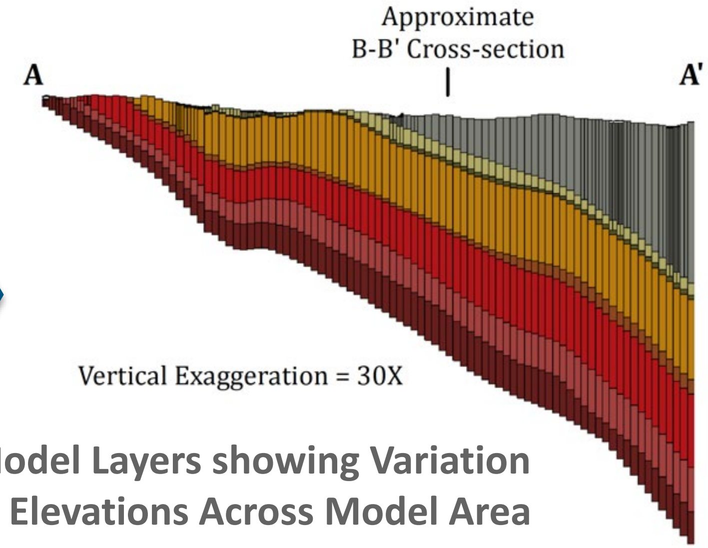


# Model Inputs – Monitoring Well Water Level Data Evaluations

- 23,815 water level elevation records from 2,024 wells between 1980 and 2017.
- 1,433 wells have 1 datapoint.
- 760 data records from 591 wells in the Younger Units used for GHB condition (not targets).
- Multi-aquifer wells tested by model and placed appropriately with lower weighting.
- 671 records from 318 wells excluded due to questionable flags (very low weighting).

**Well elevation is unknown if the areal location of the well is unknown, even if other well details are supplied**




Model Layers showing Variation in Elevations Across Model Area

# Model Inputs – Monitoring Well Water Level Data Evaluations

1. Attempted to calibrate model with monitoring well data provided by TWDB using provided hydrostratigraphic unit designations and available well construction:
   a) This resulted incorrect layer designations and poor PEST calibration.
   b) Time intensive evaluations to categorize various water level and pumping errors.

***Final Solution***

2. Compared the monitoring well water level with the hydrostratigraphic layers:
   a) Created a database with the minimum and maximum water levels for each of the 2,024 wells and the layer elevations for each layer for the well location cell
   b) Compared the minimum water level elevations and layer elevations at each well
   c) Moved the well down if the minimum water level was below the designated layer elevation
   d) Moved the layer down if the water levels were within the designated layer elevation but it was not in the outcrop area (i.e., a saturated layer above exists)
   e) This proved time intensive
   f) This significantly improved calibration and resulted in a more reliable data set
3. Weighted each water level elevation:
   a) This method improved calibration and resulted in a more reliable data set.

# Model Inputs – Using Sand Fractions Gave Small K-Value Range

GSI ENVIRONMENTAL

| Model Layer | Hydro-stratigraphic Unit | Sand Fraction (Percent) | | Hydraulic Conductivity (feet per day) | | Resulting K-h (feet per day) | | Resulting K-v (feet per day) | | K-h Ratio of Maximum to Minimum | K-v Ratio of Maximum to Minimum |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 10th Percentile | 90th Percentile | Sand | Clay | Minimum | Maximum | Minimum | Maximum | | |
| 1 | Quaternary Alluvium | **0.7** | **0.7** | 200 | 0.2 | 140.1 | 140.1 | 0.7 | 0.7 | **1** | **1** |
| 2 | Younger Units | **0.1** | **0.1** | 1 | 0.04 | 0.1 | 0.1 | 0.05 | 0.05 | **1** | **1** |
| 3 | Sparta Aquifer | **0.01** | **0.5** | 40 | 8.0E-04 | 0.4 | 21.8 | 8.1E-04 | 1.8E-03 | **54.4** | **2.2** |
| 4 | Weches Formation | **0** | **0.3** | 3.2 | 6.9E-04 | 6.9E-04 | 1.1 | 6.9E-04 | 1.0E-03 | **1,528.6** | **1.5** |
| 5 | Queen City Aquifer | **0.01** | **0.5** | 300 | 3.0E-07 | 3.0 | 151.0 | 3.0E-07 | 6.0E-07 | **50.3** | **2.0** |
| 6 | Reklaw Formation | **0.01** | **0.4** | 0.19 | 0.0045 | 6.4E-03 | 0.07 | 4.5E-03 | 7.0E-03 | **11.3** | **1.5** |
| 7 | Carrizo-Upper Wilcox | **0.4** | **0.8** | 100 | 0.001 | 35.9 | 75.8 | 1.6E-03 | 4.1E-03 | **2.1** | **2.6** |
| 8 | Middle Wilcox | **0.1** | **0.4** | 5 | 0.1 | 0.5 | 2.1 | 0.1 | 0.1 | **4.3** | **1.6** |
| 9 | Lower Wilcox | **0.0** | **0.6** | 7.7 | 0.9 | 1.1 | 5.1 | 0.9 | 1.9 | **4.8** | **2.2** |

# Model Inputs – Using Sand Fractions

- Provide K-values to sand and clay; use sand fractions to distribute K across model area in each hydrostratigraphic unit:
  - Kh is weighted arithmetic mean of K-sand and K-clay
  - Kv is weighted harmonic mean of K-sand and K-clay
- Sand fraction distribution gave narrow range of Kh and Kv values in each unit. Between $10^{th}$ and $90^{th}$ percentile:
  - Horizontal hydraulic conductivity variation in Carrizo and Wilcox units (layers 7, 8 and 9) is less than factor of 5
  - Vertical hydraulic conductivity variation of all units is less than a factor of 2.6
- Difficult to calibrate a regional model with almost uniform properties.

***Final Solution***

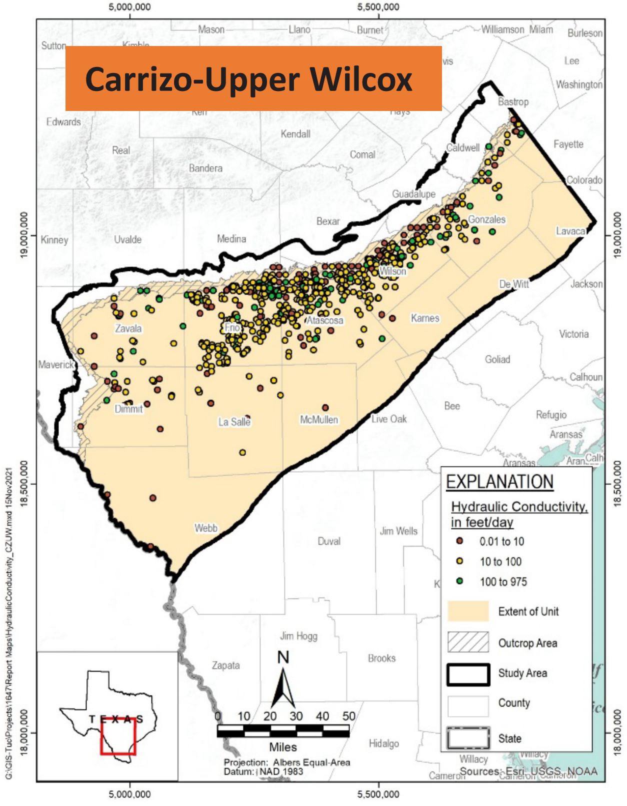
- Used pilot point approach to distribute K-values in each unit.

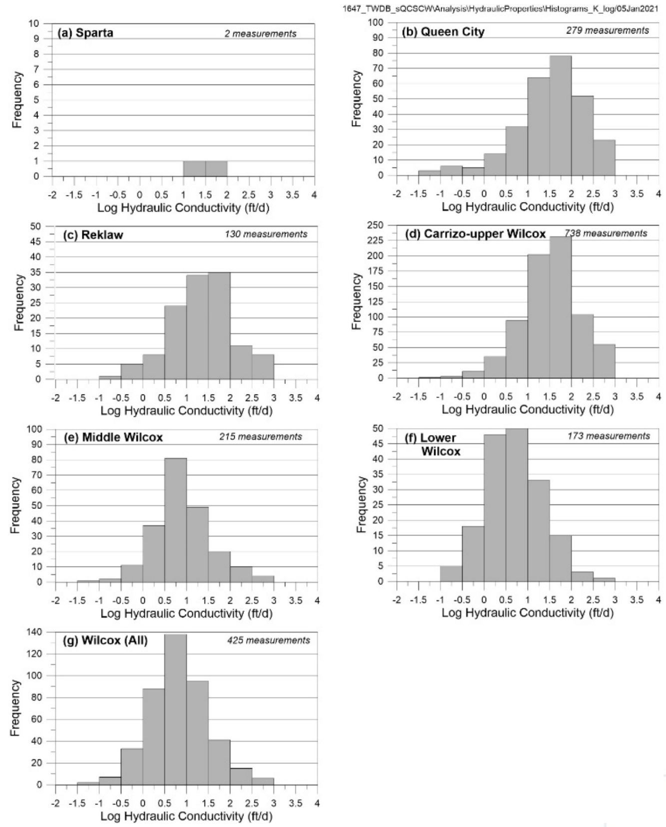
# 3. Model Calibration and Results

# Model Calibration

- Calibration adjusts model parameters to simulate real-world processes.
- A groundwater model simulates flow processes in each cell within the model area (382,024 active cells). Therefore, estimates have to be made between the data points recorded.

Example of Measured Hydraulic Conductivity Values Within Aquifer Units



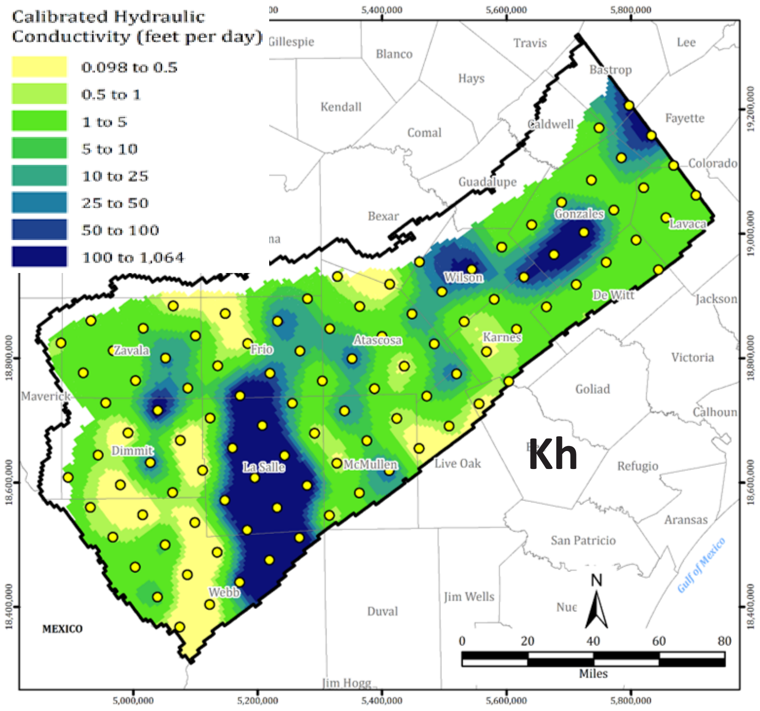



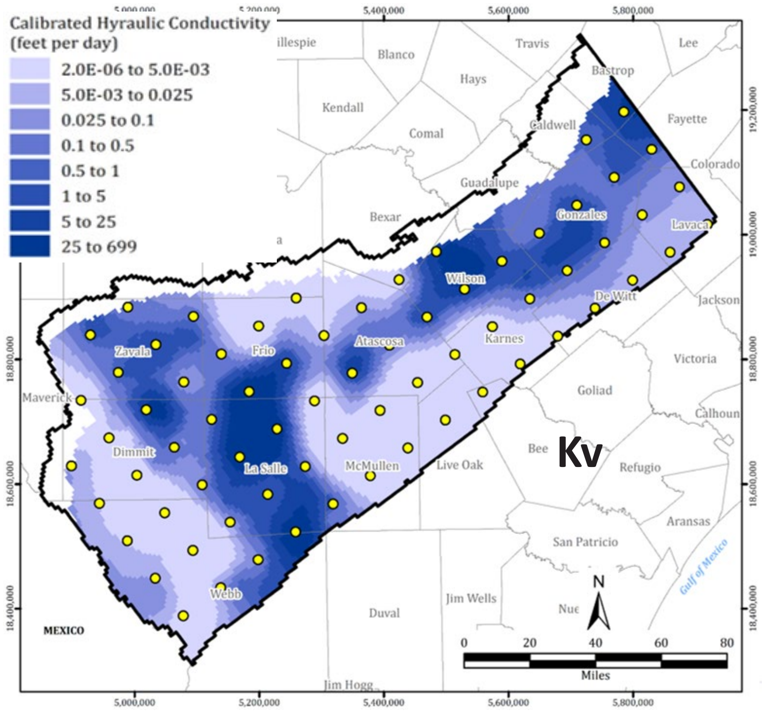

SOURCE: GSI, 2022

# Model Calibration - Parameters

Calibration parameters were:

- Hydraulic conductivity of model layers (using Pilot Points)
- Groundwater flow in and out of Younger Units (GHB conductance)
- Groundwater flow in and out at lateral model boundaries
- Groundwater / surface-water interaction (RIV boundary conductance)




Example of Calibration Parameter: Distribution of K-values for Model Layer 7

# Model Calibration Metrics

Quantitative Metrics:

- Observed versus simulated water levels (i.e., water level residuals)
- Water level target statistics
- Spatial distribution of residuals

Qualitative Metrics:

- Comparing simulated water level elevation hydrographs against measured water level elevation hydrographs at monitoring wells
- Simulated water level contours similar to conceptual model for pre-development and post-development conditions
- Comparing simulated and measured surface-water / groundwater interactions

# Model Calibration – Observed Versus Modeled Water Levels

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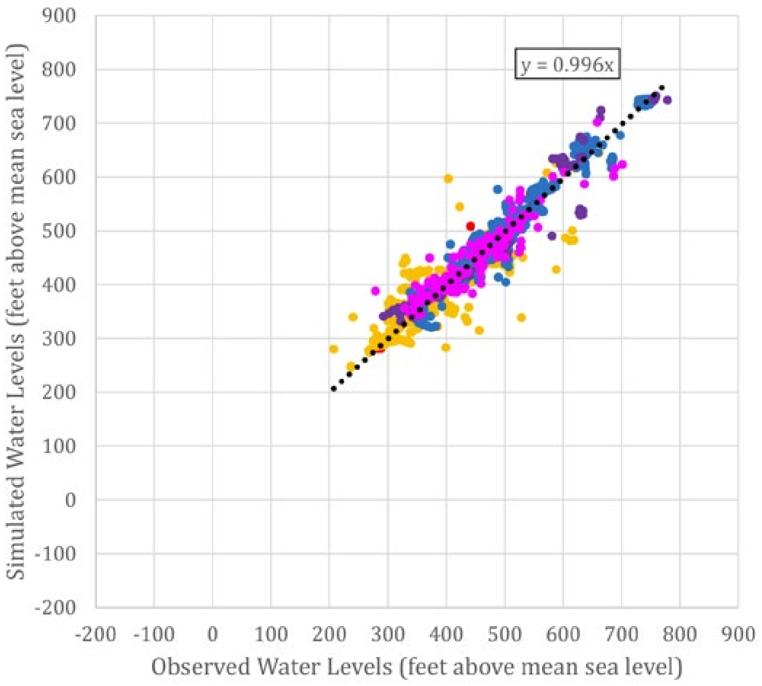
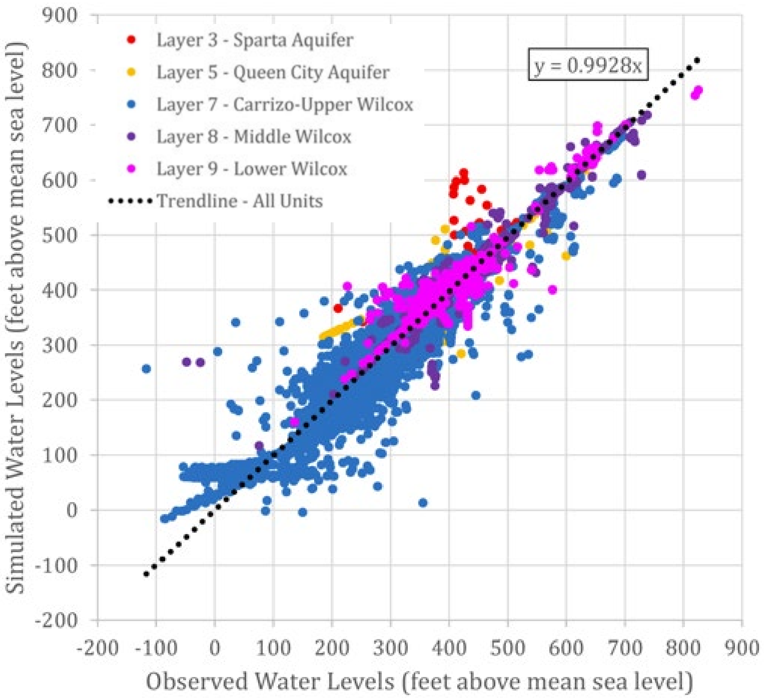
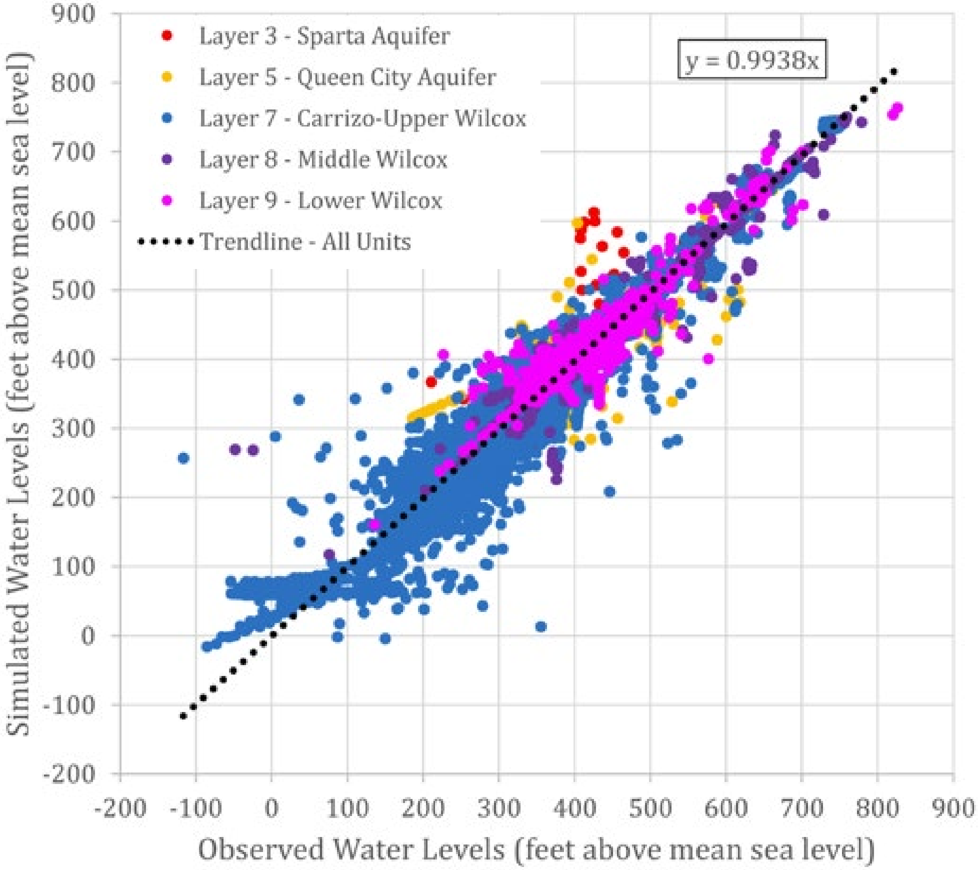
Simulated water level elevations show good correlation with corresponding measured values.

**Unconfined** (**outcrop**) wells: 1980 to 2017.




**Confined** (**downdip**) wells: 1980 to 2017.




SOURCE: GSI, 2022.

# Model Calibration – Statistics

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| Statistic | Layer 3 (Sparta Aquifer) | Layer 5 (Queen City Aquifer) | Layer 7 (Carrizo-Upper Wilcox) | Layer 8 (Middle Wilcox) | Layer 9 (Lower Wilcox) |
|---|---|---|---|---|---|
| Number of observations | 678 | 1,605 | 18,549 | 1,714 | 1,269 |
| Range in observed values | 401.2 | 475.4 | 870.2 | 826.8 | 690.1 |
| Residual mean | -4.8 | -0.74 | 0.46 | 2.39 | 6.05 |
| Absolute residual mean | 11.7 | 16.7 | 19.4 | 10.3 | 18.2 |
| Standard deviation | 23.6 | 29 | 30.3 | 22.3 | 27.3 |
| RMS error | 24.1 | 29 | 30.3 | 22.4 | 28 |
| Scaled absolute residual mean | 2.90% | 3.50% | 2.20% | 1.20% | 2.60% |
| Scaled standard deviation | 5.90% | 6.10% | 3.50% | 2.70% | 4.00% |
| Scaled RMS error | 6.00% | 6.10% | 3.50% | 2.70% | 4.10% |

**Simulated water level elevation errors were less than 10% for each layer, confined / unconfined and model-wide which indicates a good calibration.**

| | |
|---|---|
| Scaled absolute residual mean | 1.9% |
| Scaled standard deviation | 3.1% |
| Scaled RMS error | 3.1% |

SOURCE: GSI, 2022.

# Model Calibration – Spatial Distribution of Residuals

Spatially, the model is well calibrated.

- Residuals are generally small regionally
- No spatial bias
- Large opposing residuals indicate large localized variations

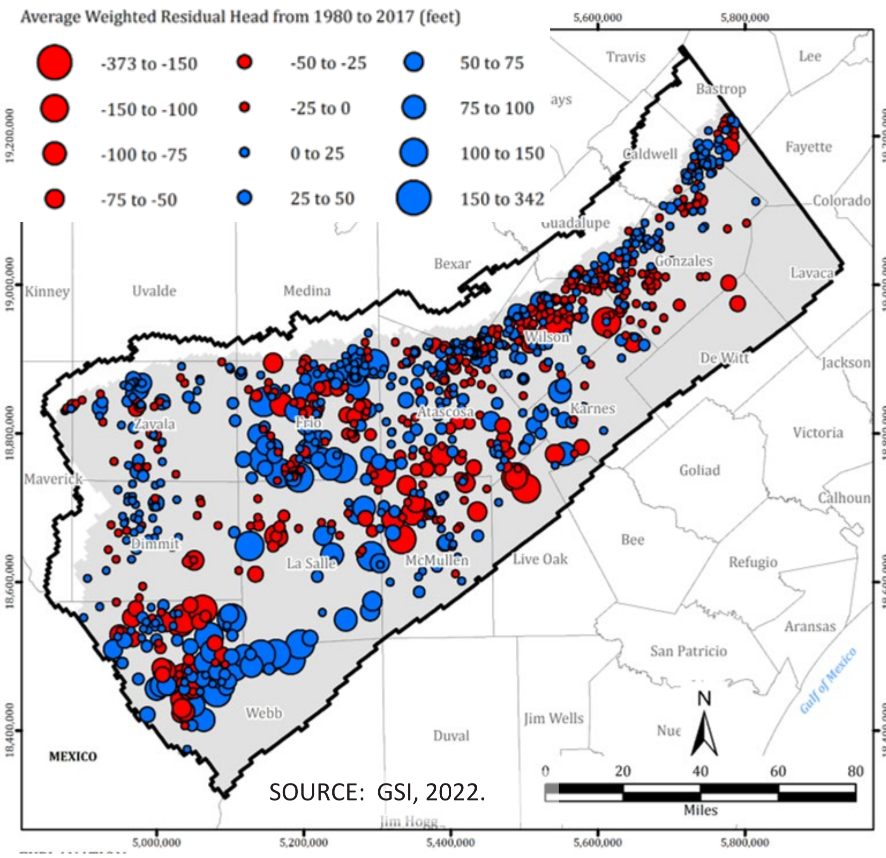
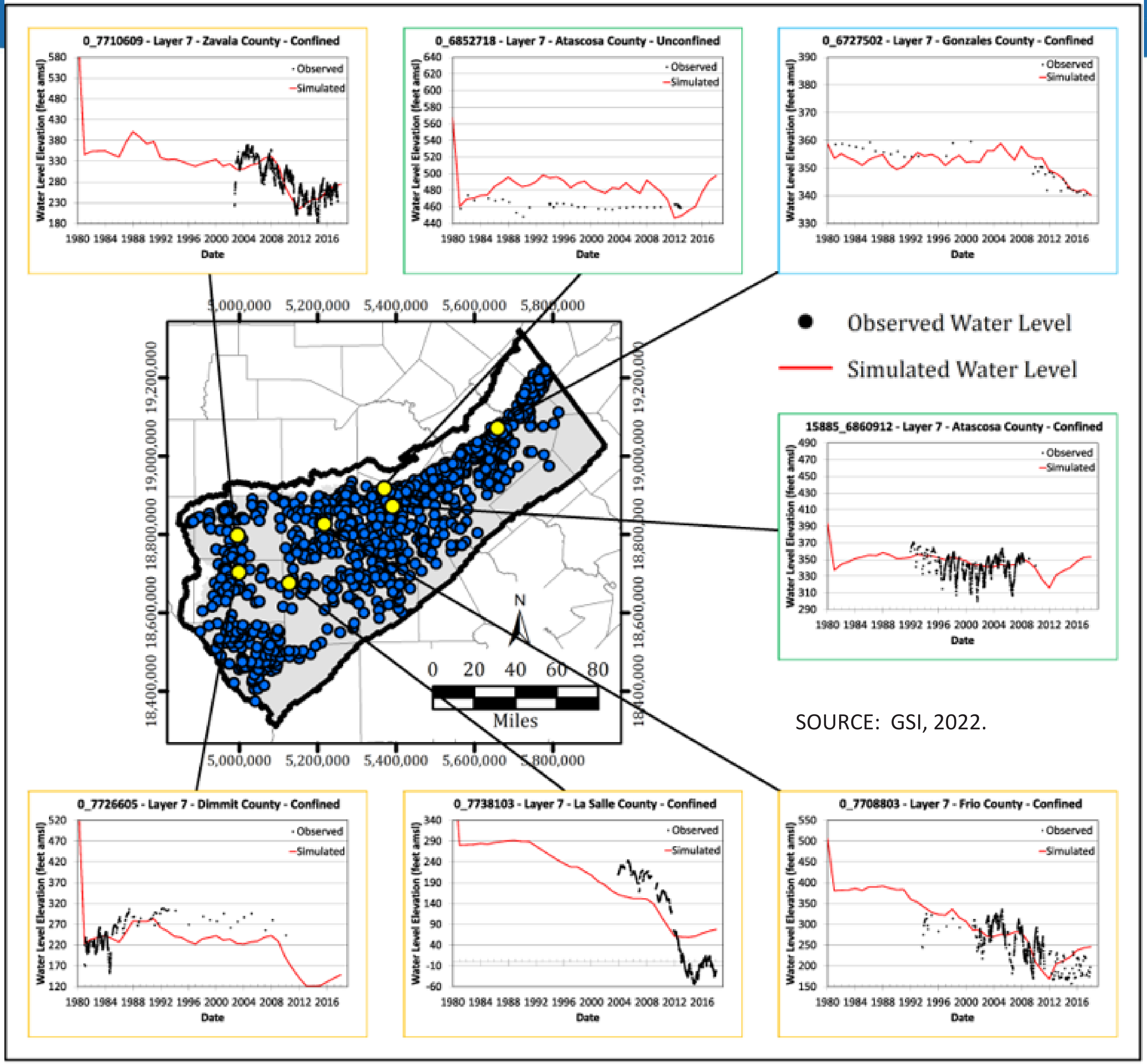



Figure Showing Average Error at Monitoring Wells from 1980 to 2017 (red: negative value; blue: positive value).

# Model Calibration – Transient Water Levels




SOURCE: GSI, 2022.

Hydrographs generally indicate appropriate long-term WLEs and trends.

- Larger fluctuations in downdip areas than outcrop regions
- Large drawdown could not be fully captured in the corners of Dimmitt, La Salle, Zavala, and Frio counties

# Model Calibration –Water Levels Contours

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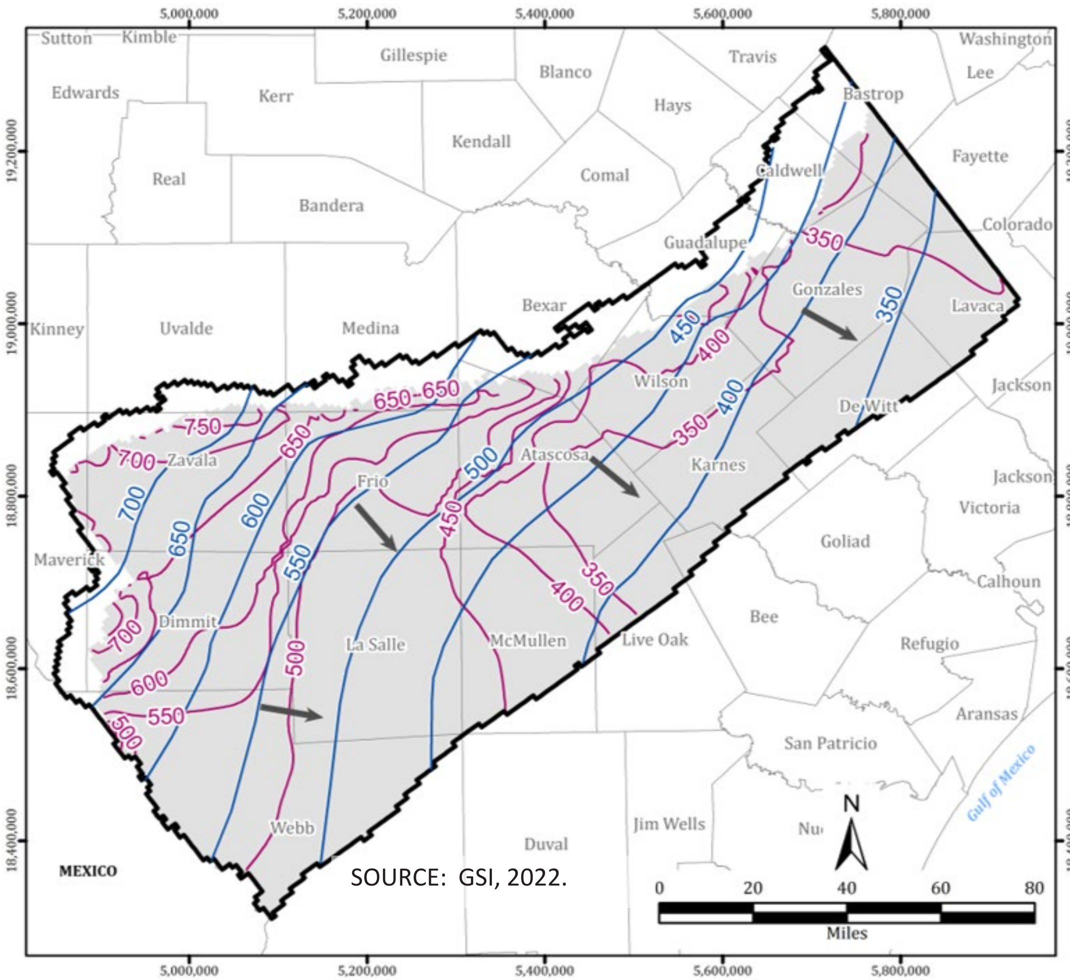
Simulated groundwater contours were similar to interpolated contours based on conceptual model and observed data:

- Predevelopment water levels evaluated qualitatively against conceptual model contours
- 2017 water level contours generally match conceptual water level contours
- Sparta Aquifer water level contours reflect GHB heads prescribed in the overlying Younger Units

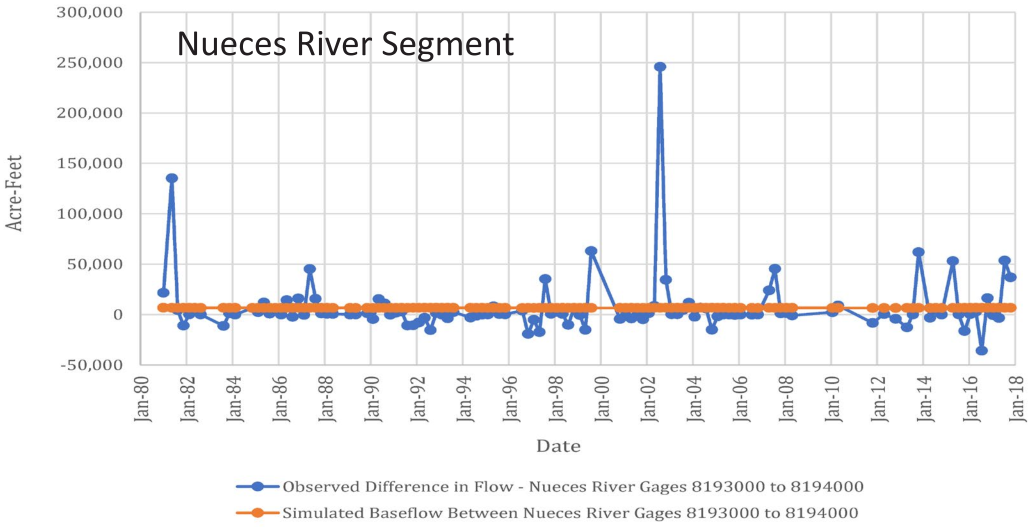


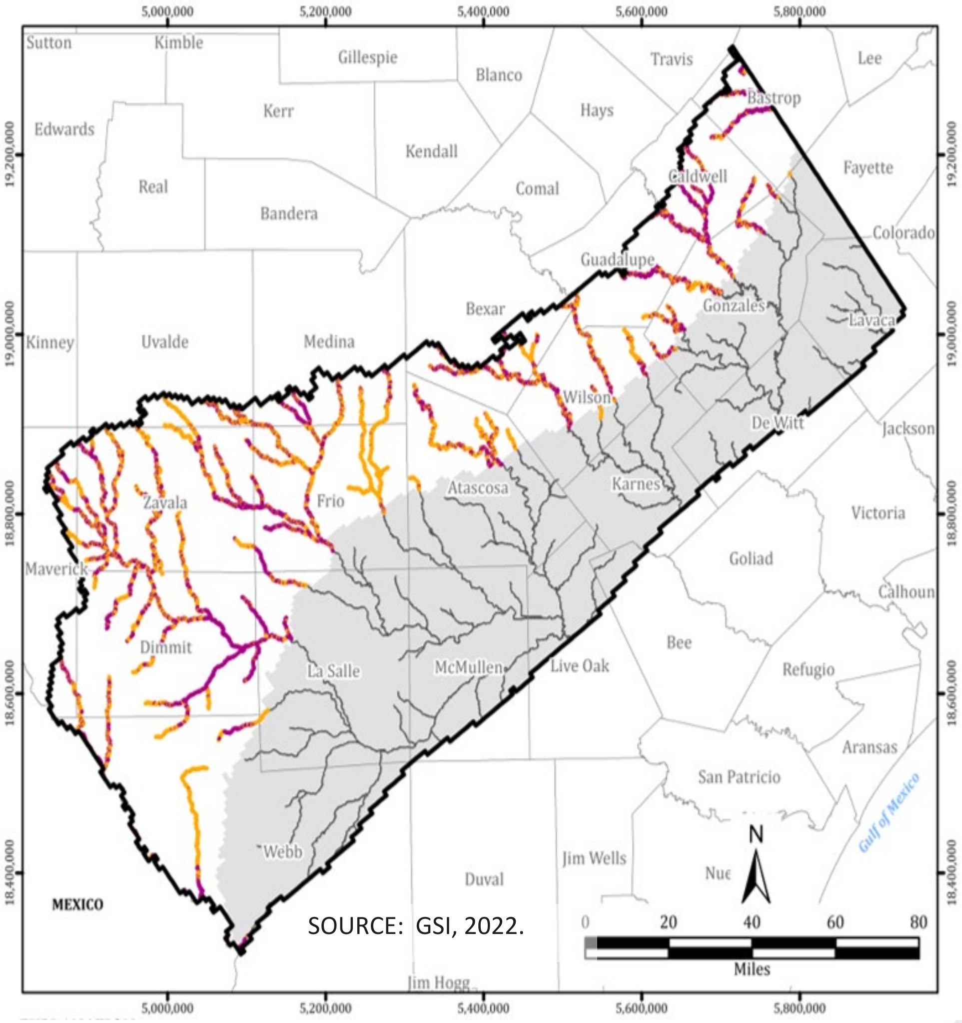

Example flow field for Carrizo-Upper Wilcox Aquifer (Layer 7), showing Simulated (purple) and Measured (blue) for predevelopment conditions.

# Model calibration – Surface Water Flow interactions

Surface-water interactions are generally well captured.

- Gaining and loosing reaches appropriately modeled
- Upstream minus downstream flows generally compare
- Simulated flow fluctuations are minimal due to steady-state boundary water levels
- Under-simulated baseflow on Guadalupe River Segment



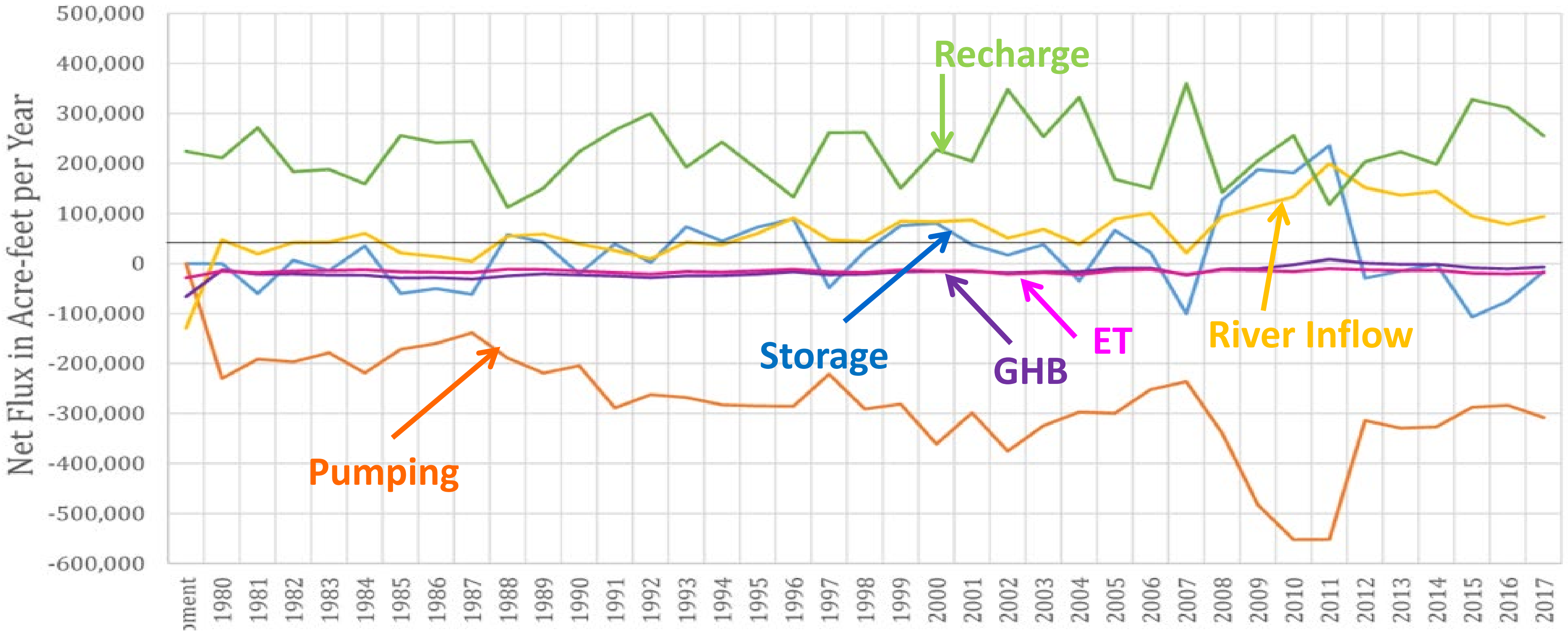




Simulated Rivers Showing Gaining Conditions (orange), Consistent with Measured Conditions.

# Model Results – Water Balance

The transient model water budget shows the following:

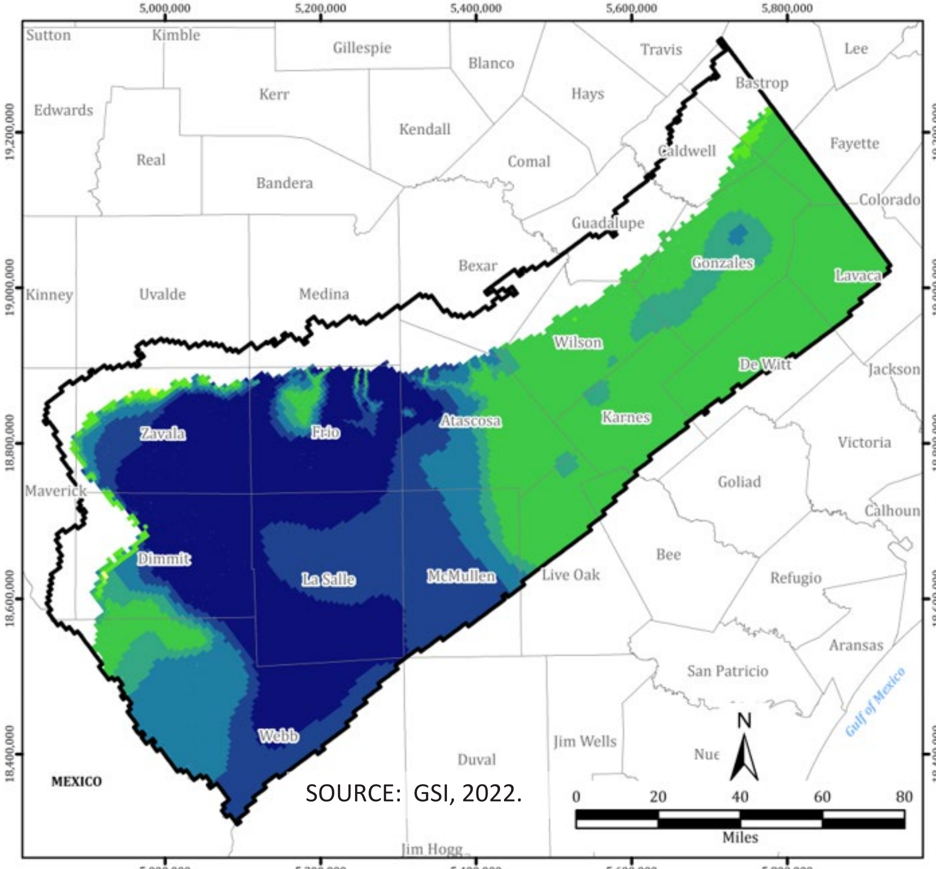
- The largest inflow to the model is recharge.
- The largest outflow is groundwater pumping.



# Model Results – Changes in Water level

Carrizo Aquifer modeled drawdown from 1980 to 2017:

- General drawdown conditions through most of GMA 13 with over 300 feet drawdown in Dimmit, La Salle, Zavala and Frio Counties.




SOURCE: GSI, 2022.

Simulated Change in Water Levels from 1980 to 2017 in Model Layer 7.

**Change in Simulated Water Level Elevations (feet)**

- -311 to -150
- -150 to -100
- -100 to -50
- -50 to -25
- -25 to 0
- 0 to 25
- 25 to 50
- 50 to 3,689

# 4. Model Sensitivity

# Model Sensitivity

Once a model is calibrated, a series of sensitivity simulations is performed.

Each model constructed is unique. The specific design of a model may result in some inputs being very influential to model results, meaning that a small change to an input can create a disproportionately large change in the model results.
**It is important to identify such parameters.**

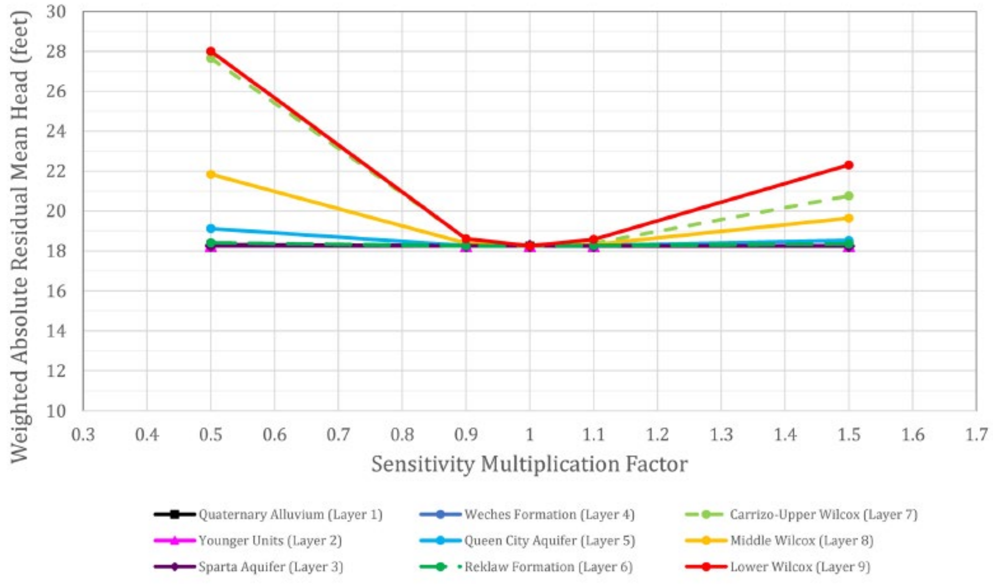
Sensitivities were performed for inputs important to the model:

- Hydraulic Conductivity
- Pumping
- Recharge
- Evapotranspiration
- Specific Yield

Sensitivities were categorized as per ASTM standards.

# Model Sensitivity – Hydraulic Conductivity

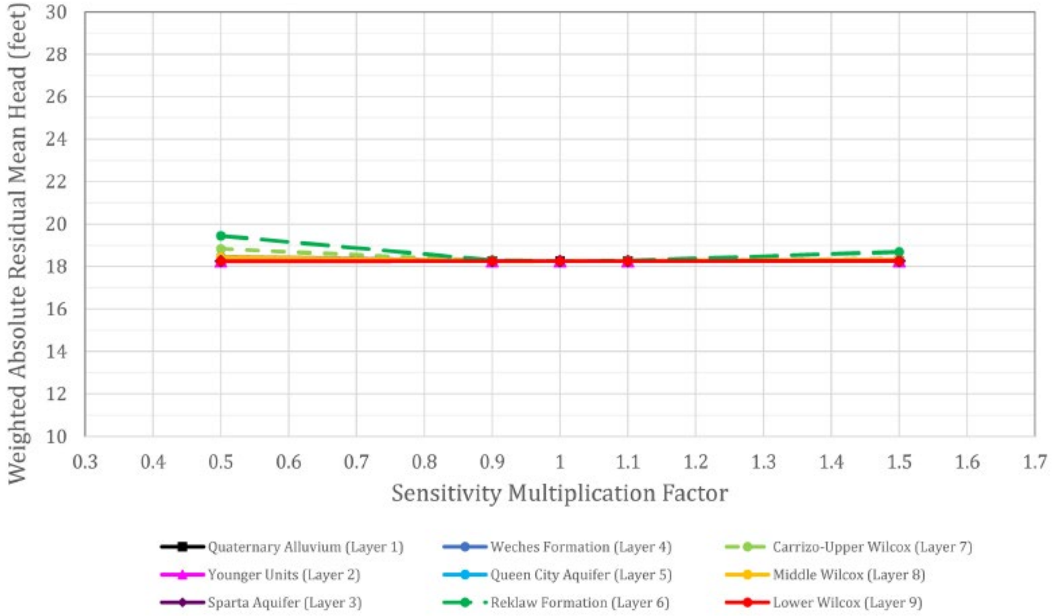
Sensitivity to the horizontal hydraulic conductivity value




Sensitivity to Kh summary:

- Highest – lowering K of Layers 9 and 7
- Middle – lowering K of Layer 8 and raising K of layers 7, 8, and 9
- Remaining layers = no sensitivity

Sensitivity to the vertical hydraulic conductivity value



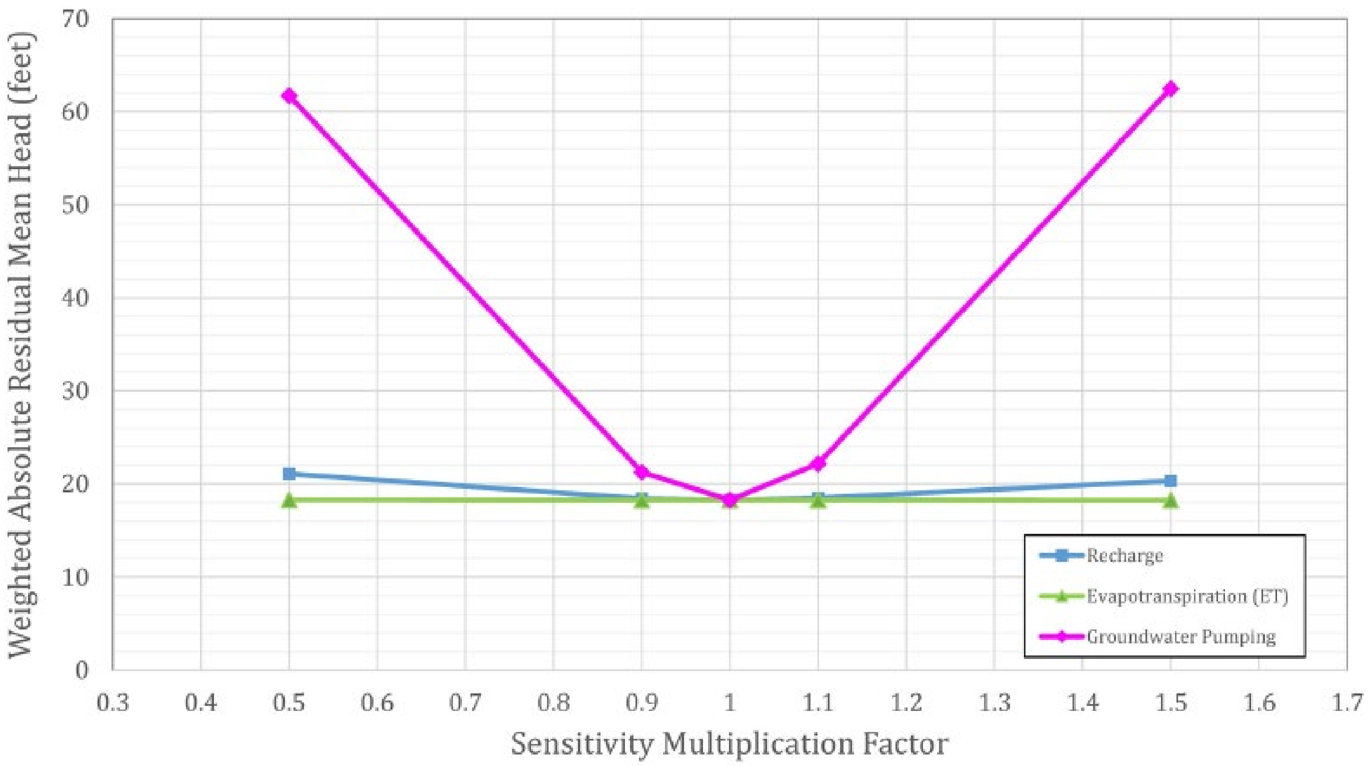

Sensitivity to Kv summary:

- Generally insensitive to small changes in Kv
- Larger ranges may show higher sensitivity

# Model Sensitivity – Model Stresses

Sensitivity to model parameters:

- Highest sensitivity to groundwater pumping
- Low sensitivity to Recharge
- No sensitivity to evapotranspiration



# Model Sensitivity – ASTM Categories

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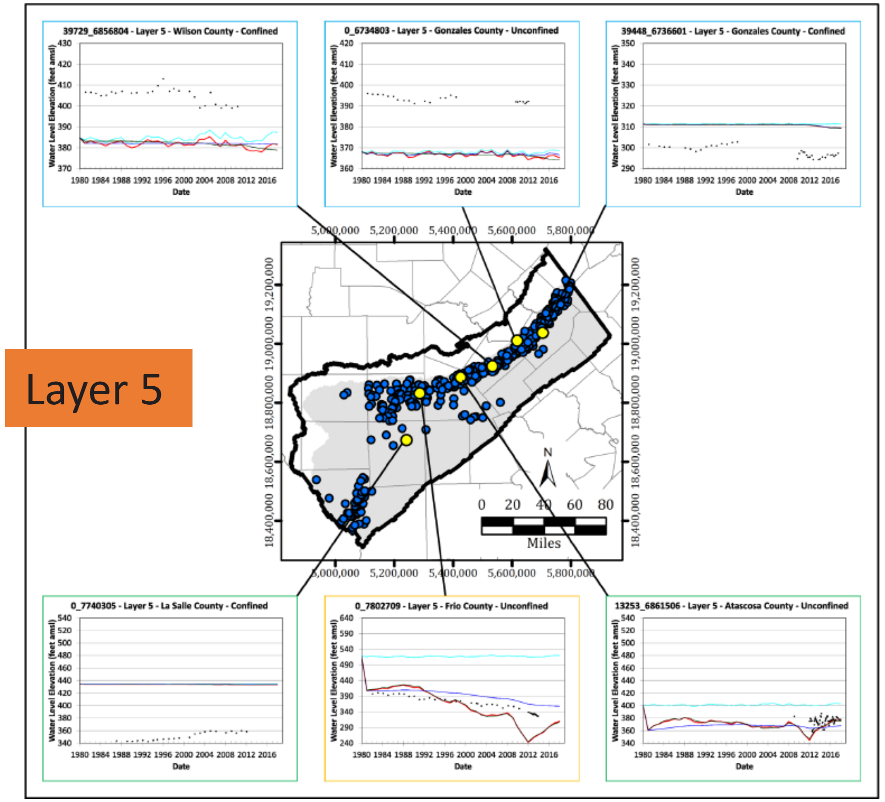
| Model Parameter | Absolute Residual Mean Sensitivity | Root mean square (RMS) Head Error Sensitivity | Possible ASTM Sensitivity Type |
|---|---|---|---|
| **Horizontal Hydraulic Conductivity** | | | |
| Quaternary Alluvium (Layer 1) | No sensitivity | No sensitivity | Type I or IV |
| Younger Units (Layer 2) | No sensitivity | No sensitivity | Type I or IV |
| Sparta Aquifer (Layer 3) | No sensitivity | No sensitivity | Type I or IV |
| Weches Formation (Layer 4) | No sensitivity | No sensitivity | Type I or IV |
| Queen City Aquifer (Layer 5) | Low | Low | Type II or III |
| Reklaw Formation (Layer 6) | No sensitivity | No sensitivity | Type I or IV |
| Carrizo-Upper Wilcox (Layer 7) | High | High | Type II or III |
| Middle Wilcox (Layer 8) | Medium | Medium | Type II or III |
| Lower Wilcox (Layer 9) | High | High | Type II or III |
| **Vertical Hydraulic Conductivity** | | | |
| Quaternary Alluvium (Layer 1) | No sensitivity | No sensitivity | Type I or IV |
| Younger Units (Layer 2) | No sensitivity | No sensitivity | Type I or IV |
| Sparta Aquifer (Layer 3) | No sensitivity | No sensitivity | Type I or IV |
| Weches Formation (Layer 4) | No sensitivity | No sensitivity | Type I or IV |
| Queen City Aquifer (Layer 5) | No sensitivity | No sensitivity | Type I or IV |
| Reklaw Formation (Layer 6) | Low | Low | Type II or III |
| Carrizo-Upper Wilcox (Layer 7) | Low | Low | Type II or III |
| Middle Wilcox (Layer 8) | No sensitivity | No sensitivity | Type I or IV |
| Lower Wilcox (Layer 9) | No sensitivity | No sensitivity | Type I or IV |
| **Recharge** | Low | Low | Type II or III |
| **Pumping** | High | High | Type II or III |
| **Evapotranspiration** | No sensitivity | No sensitivity | Type I or IV |

# Model Sensitivity – Model Stresses

Transient sensitivities were conducted on pumping, recharge, and storage.

- No pumping generally resulted in an increase in water levels – larger in confined areas.
- Constant recharge generally resulted in dampened water level fluctuations in outcrop areas.
- Higher specific yield generally resulted in flattening of water level responses.

Layer 5




Layer 7

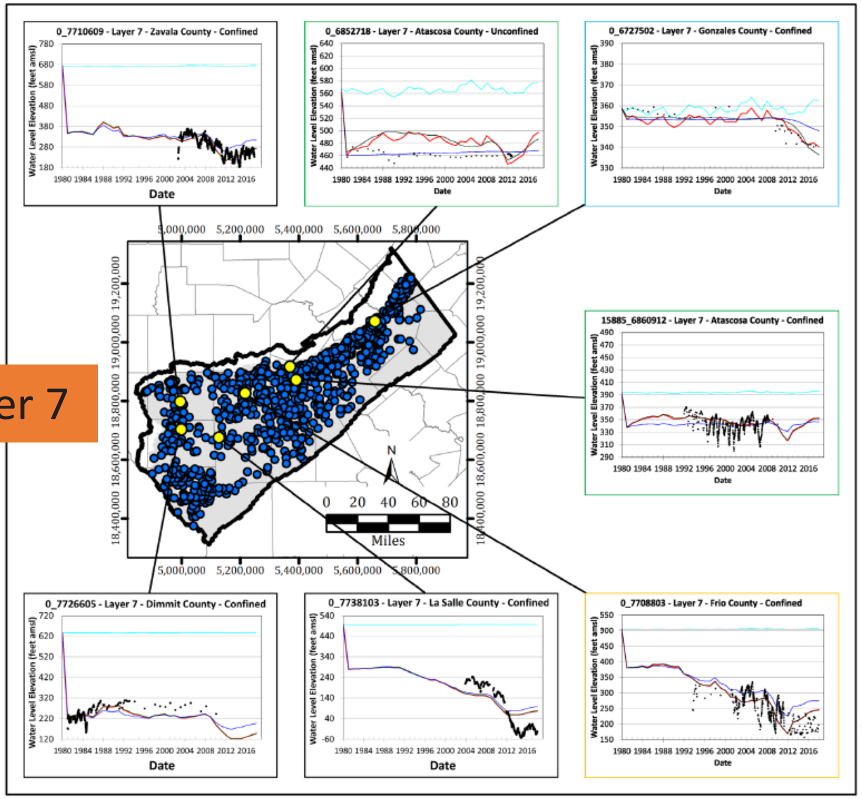



Chart Legend

- Observed Water Level
- Simulated Water Level
- Sensitivity 1 - No Pumping
- Sensitivity 2 - Recharge
- Sensitivity 3 - Specific Yield

# 5. Modeling Limitations

# Model Limitations and Assumptions

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Modeled conditions diverge from actual conditions due to:

- Numerical equation simplifications
- Spatial and temporal time-scales / averaging
- Boundary, geometry and property averaging
- Errors in aquifer conceptualization
- Errors in water level measurements (static)
- Errors in pumping estimates

Modeling uncertainty evaluations performed by:

- Predictive sensitivity analyses and categorizing per ASTM guidelines
- Use of Ensembles in predictions

**80 successful ensembles were generated from the calibrated model for evaluation of prediction uncertainty for any forecast of interest**

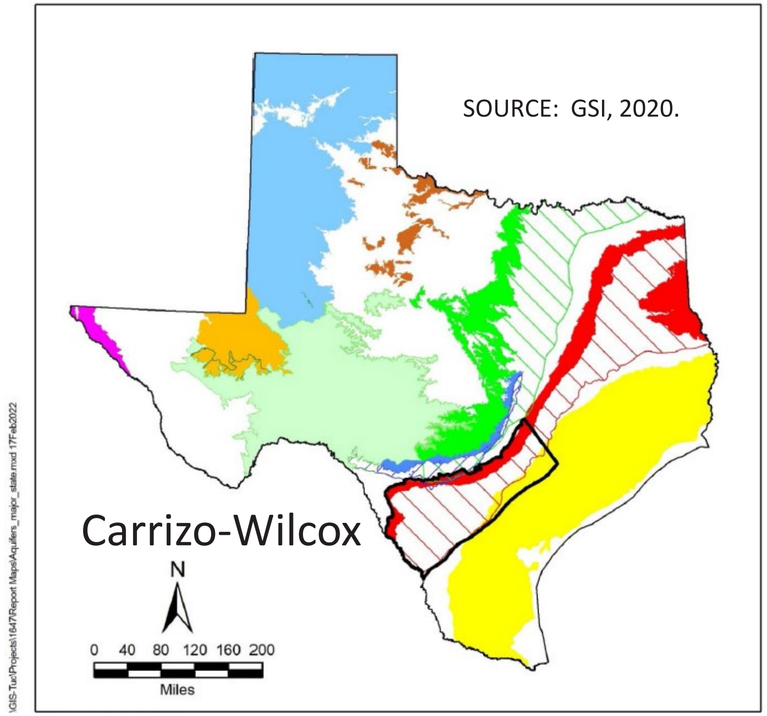
# 6. Summary and Conclusions

# Summary and Conclusions

The 2022 GMA 13 model update summary:

- Aquifer units – Quaternary Alluvium, Sparta, Carrizo, Wilcox units
- Model grid – 9 model layers
- Cell size – 660 ft to 5,280 ft
- 382,024 active cells
- Time period – 38 years from 1980 through 2017
- Monitoring wells – 23,815 water level elevation records from 2,024 wells between 1980 and 2017
- Pumping – annual TWDB water use surveys for the years 1980 through 2017
- Includes HFBs for faults
- Updated precipitation recharge, evapotranspiration, RIV boundaries

**GMA 13 Model Area**



# Summary and Conclusions

The 2022 GMA 13 model calibration and sensitivity:

- Statistically, the model is well calibrated.
- Qualitatively, the model matches observed water levels and flows.
- Model mass balance errors are negligible.
- Water fluxes in and out of the model are consistent with conceptual flow conditions.
- Recharge and pumping are sensitive and the largest inflow and outflow terms for the model.

# Summary and Conclusions

GMA 13 model – future improvement recommendations:

- Pumping history and data distribution were the data gaps with largest impact, especially in La Salle, Dimmit, Frio, and Zavala counties, at the 4-county corners.
- Reliable pumping estimates (pumping rates and aquifer well screen information) would improve accuracy of the groundwater model.
- Improved QA checks on well construction information for pumping and monitoring wells.
- Use clustering techniques to correlate hydrographs to reduce data uncertainty and preprocess data for calibration.
- Use data science approaches to evaluate consistency in pumping, recharge and water level data.
- Evaluate correlations for better understanding of the aquifer systems.
- Evaluate response functions for focused calibration.
- Assess impact of fractures, or inter-aquifer connections.

# Improvement from Previous Model

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- Current model uses all updated information up to 2017.
- Current model predictive behavior is appropriate, while previous model was unusable for predictions in outcrop area.
- Current model provides realistic representation of outcrops, pinch-out, faulting, and hydrostratigraphy.
- Current model includes alluvium layer beneath streams.
- Current model provides appropriate resolution around surface water features.

# 7. Predictive Simulations

# Objective and Topics

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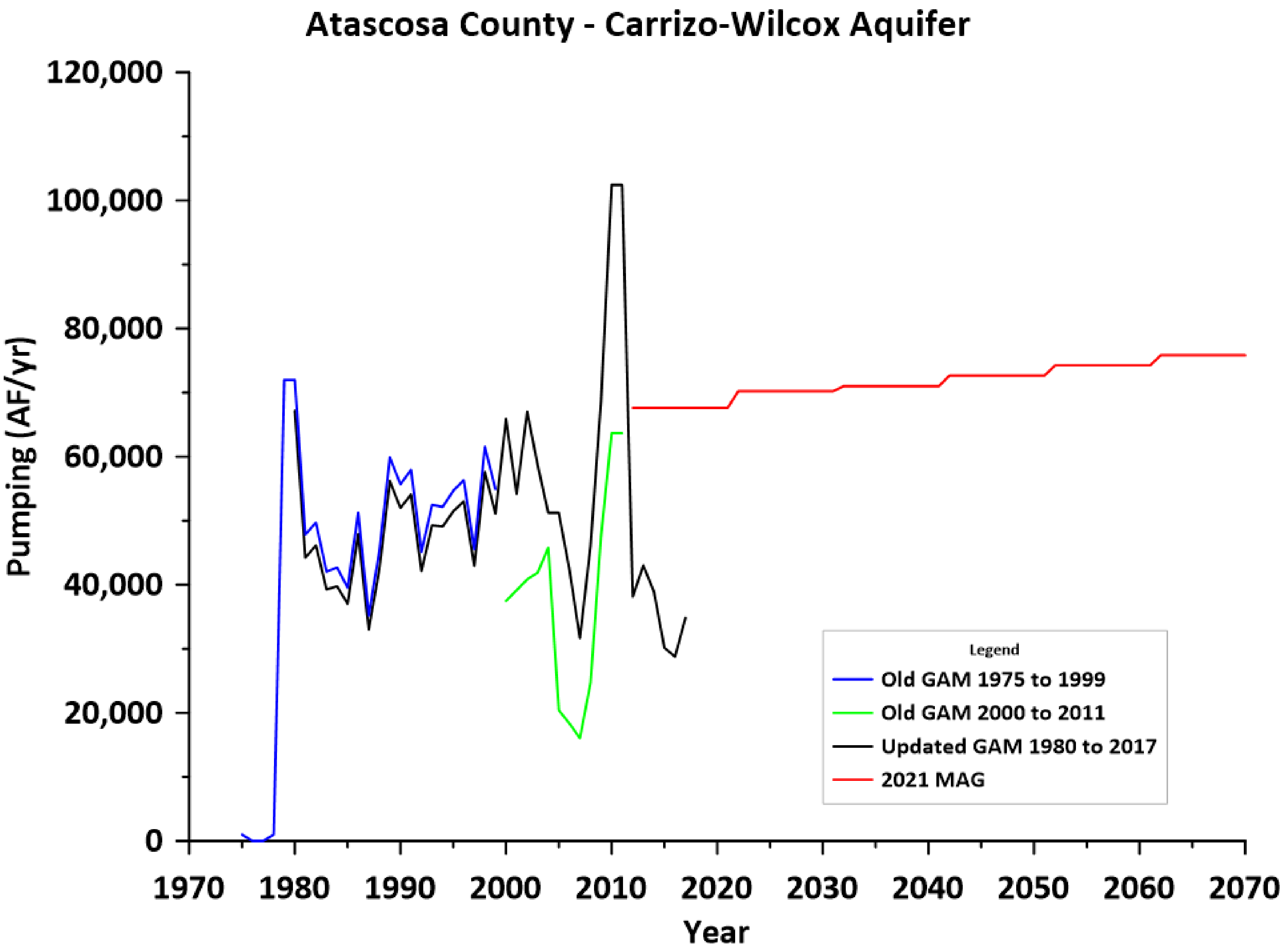
- Objective: Evaluate new GAM for use as a tool in Joint Planning process (DFC development)
- Topics:
  - Pumping comparisons with current MAG
  - Sensitivity of Pumping to average drawdown
  - Sensitivity of Recharge to average drawdown
  - Evaluation of outcrop area volume changes with varying pumping and recharge

# Pumping Comparisons

- Covered in Tech Memo 1 (to be completed)
- Hydrographs of all county-aquifer units
  - Old GAM (1975 to 1999)
  - Old GAM Update (2000 to 2011)
  - New GAM (1980 to 2017)
  - Estimated 2021 MAG (2012 to 2080)

# Example 1

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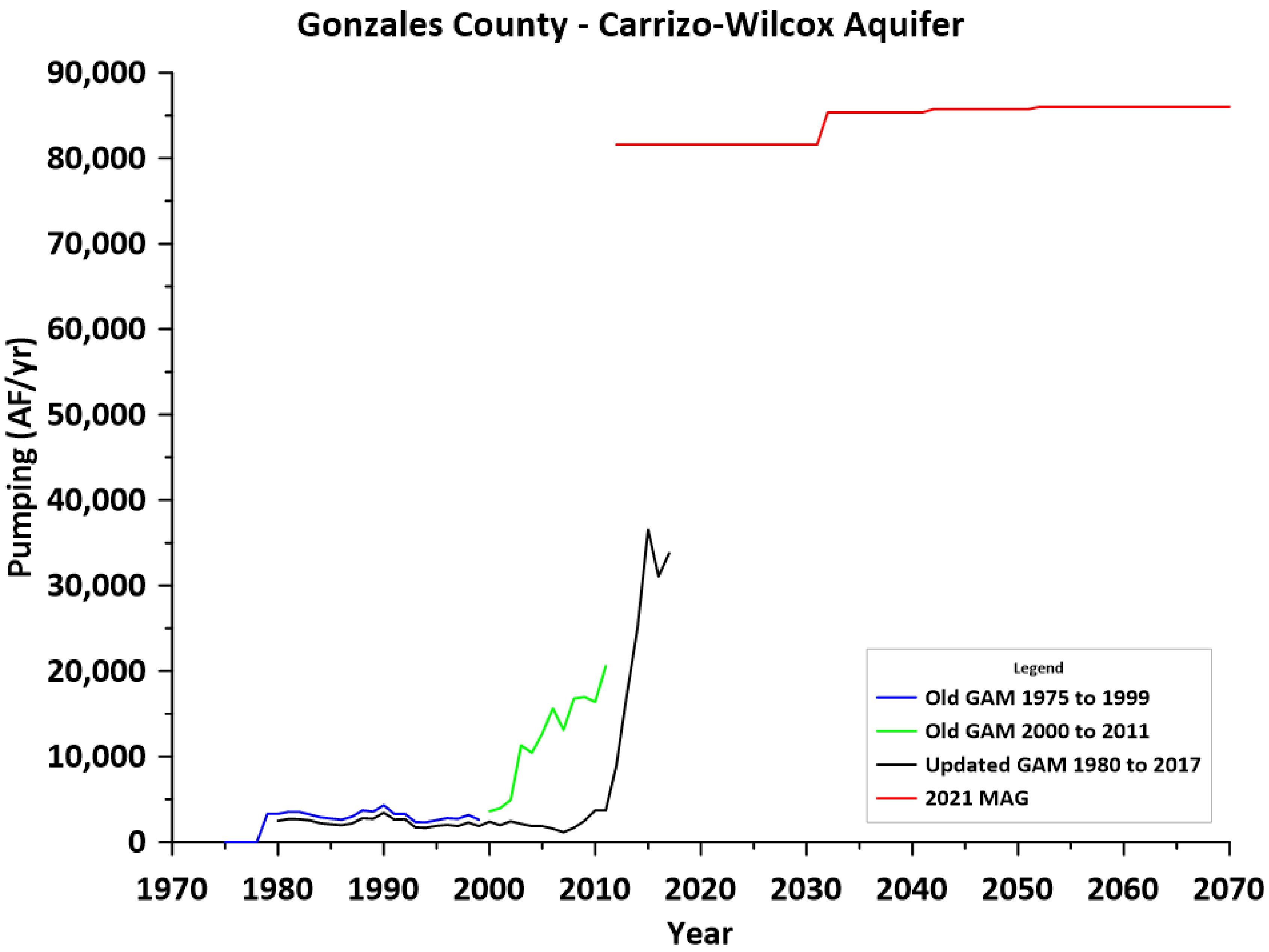
# Example 2

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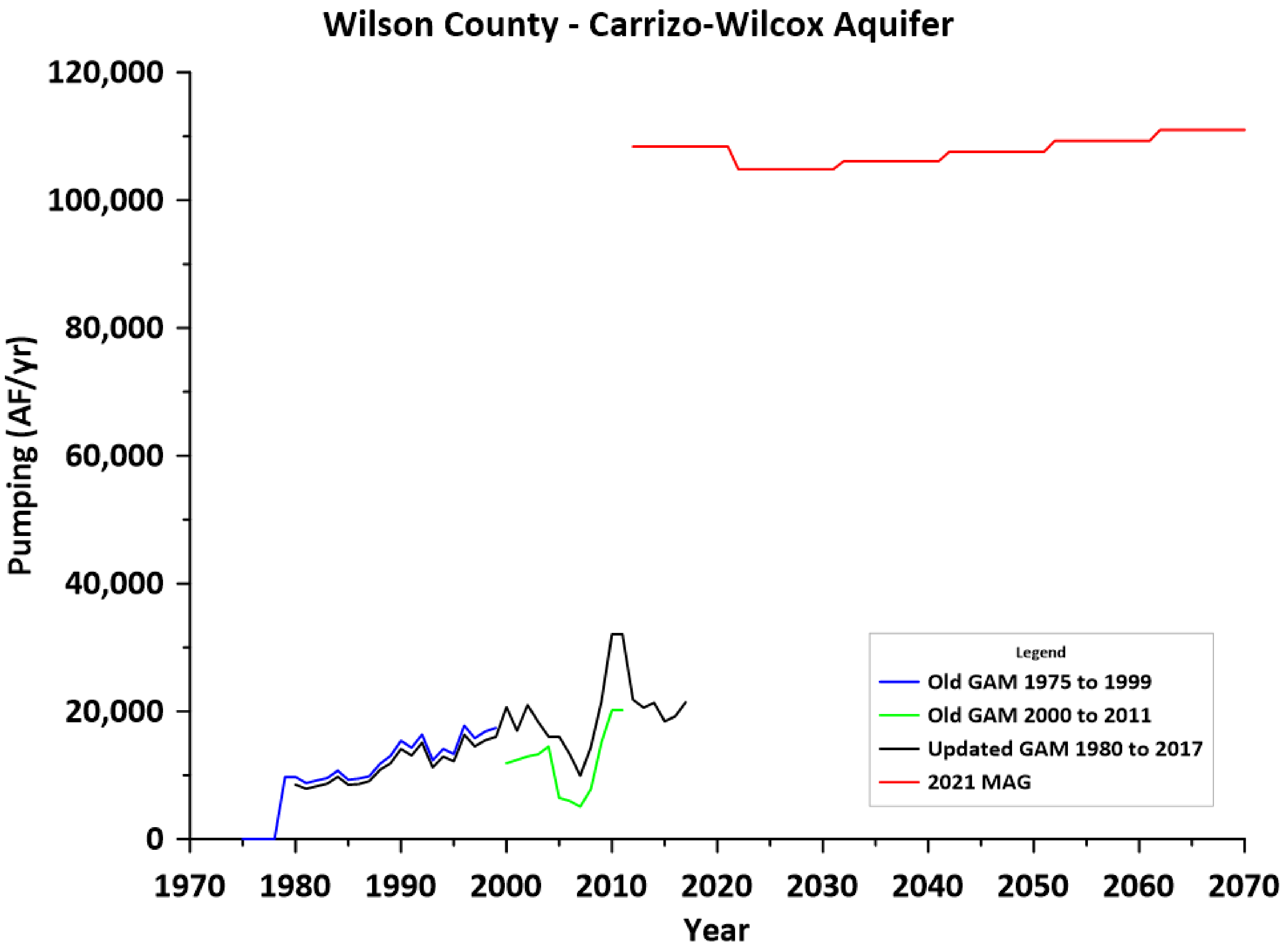
# Example 3

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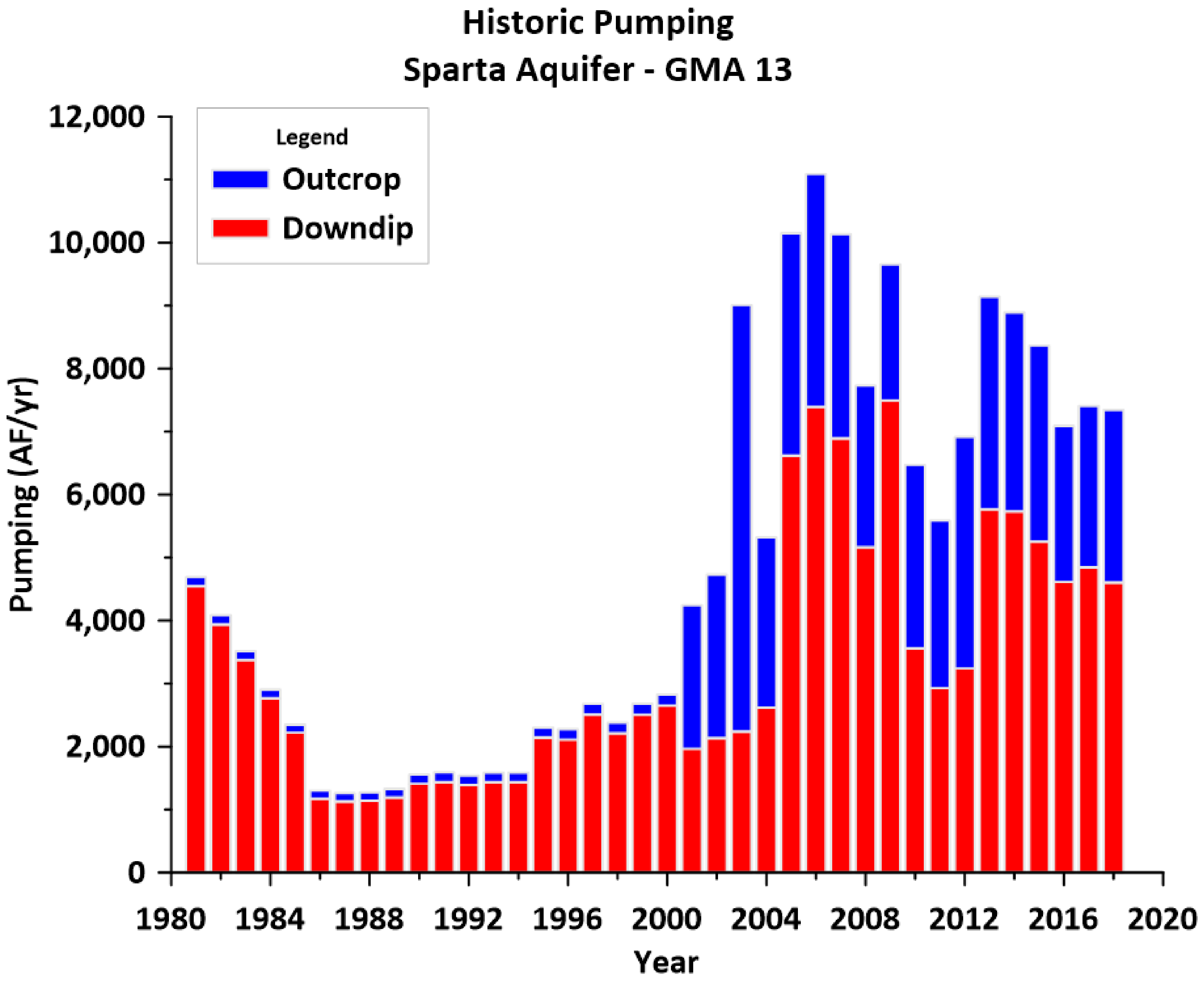
# Outcrop/Downdip Pumping Comparisons

- Covered in Tech Memo 1 (to be completed)
- Bar graphs of historic pumping (GMA 13 only)
  - Sparta Aquifer
  - Queen City Aquifer
  - Carrizo-Wilcox Aquifer

# Sparta

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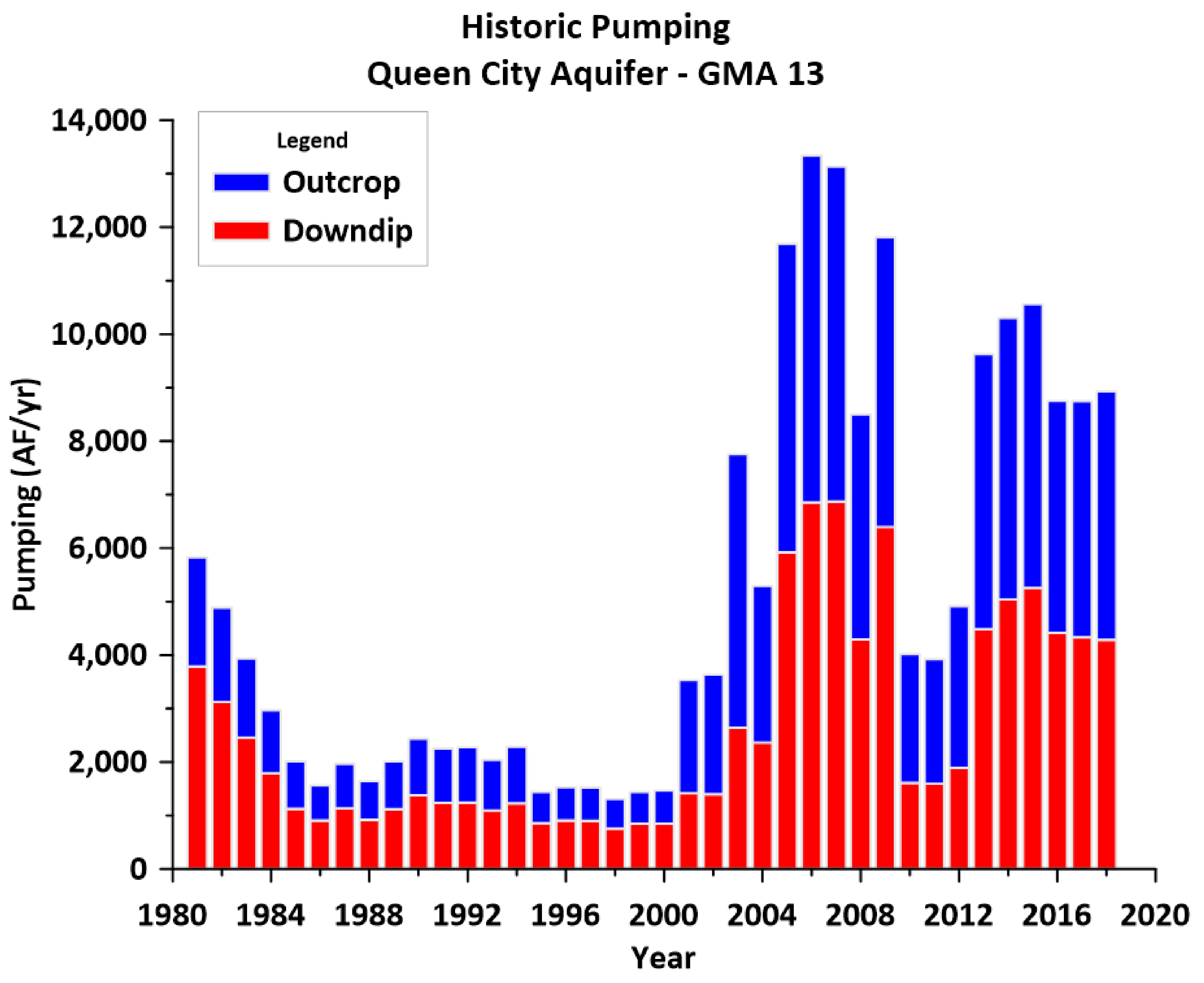
# Queen City

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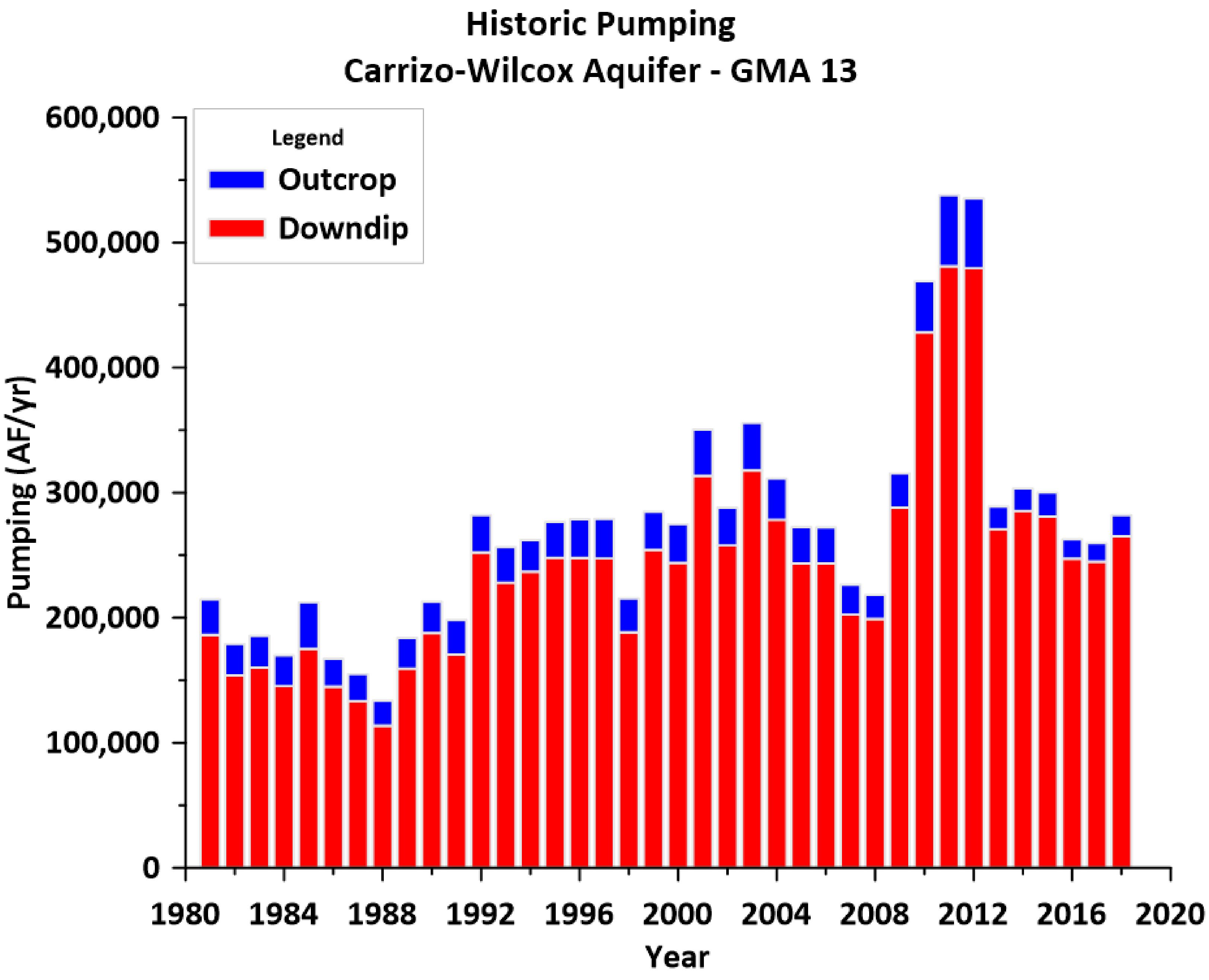
# Carrizo-Wilcox

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# Average Drawdown Concepts

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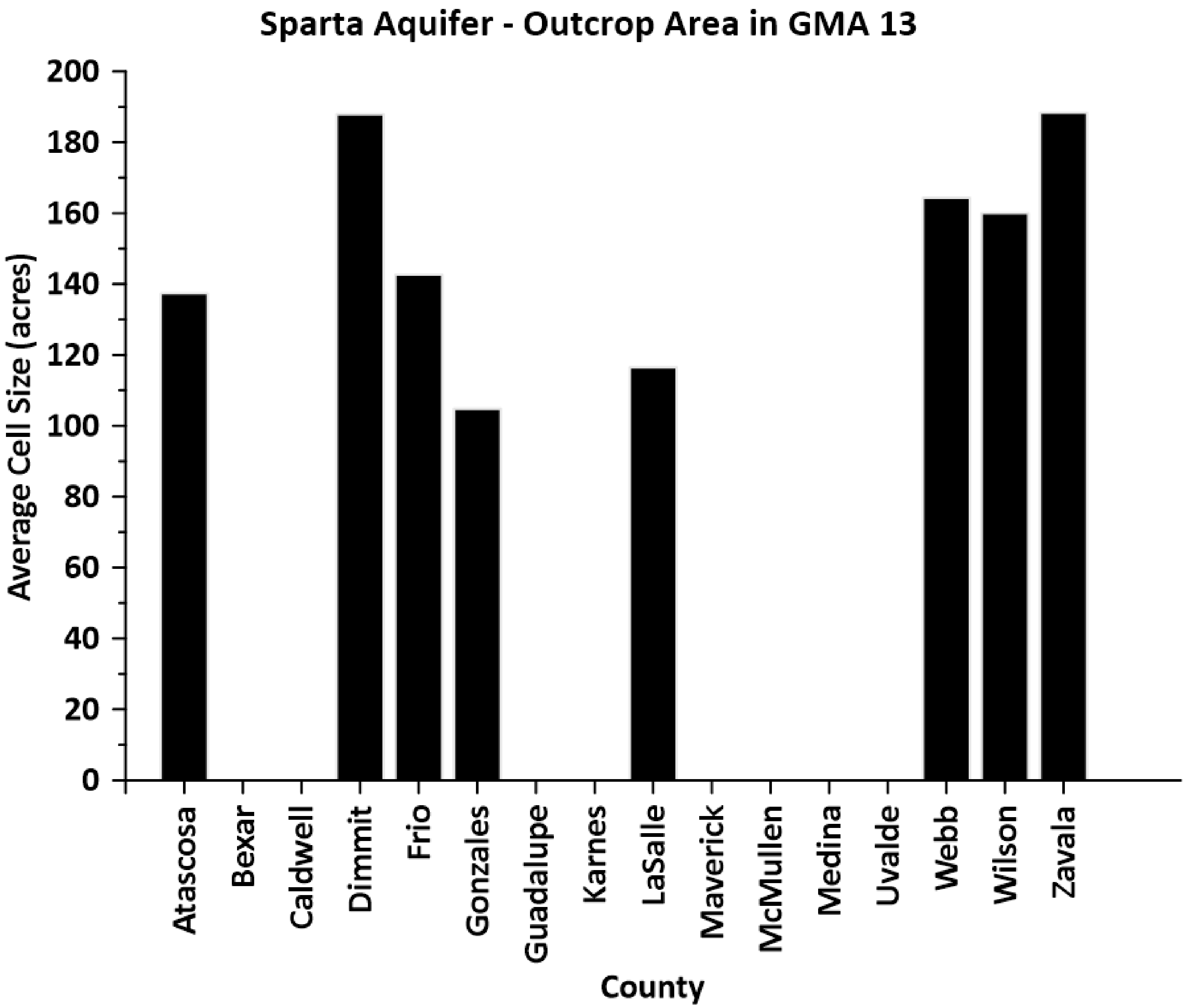
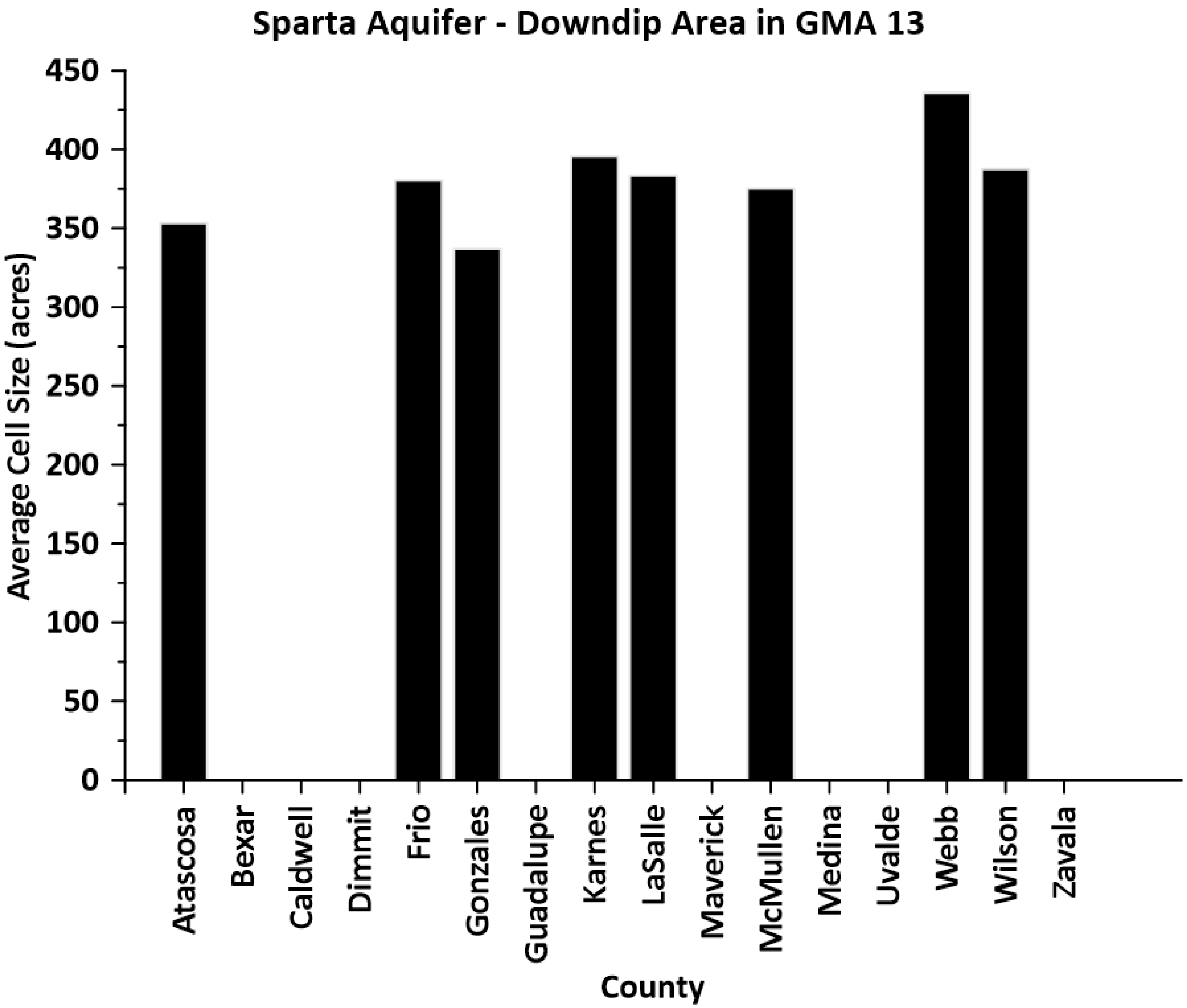
- Old GAM: Regular grid (1 square mile or 640 acres)
  - Average drawdown = Total drawdown/number of cells
- New GAM: Variable grid (10 acres to 640 acres)
  - Average drawdown = drawdown per acre (area weighted average)
- Comparison of Outcrop and Downdip area average cell size by county for each aquifer (Sparta, Queen City, Carrizo-Wilcox)

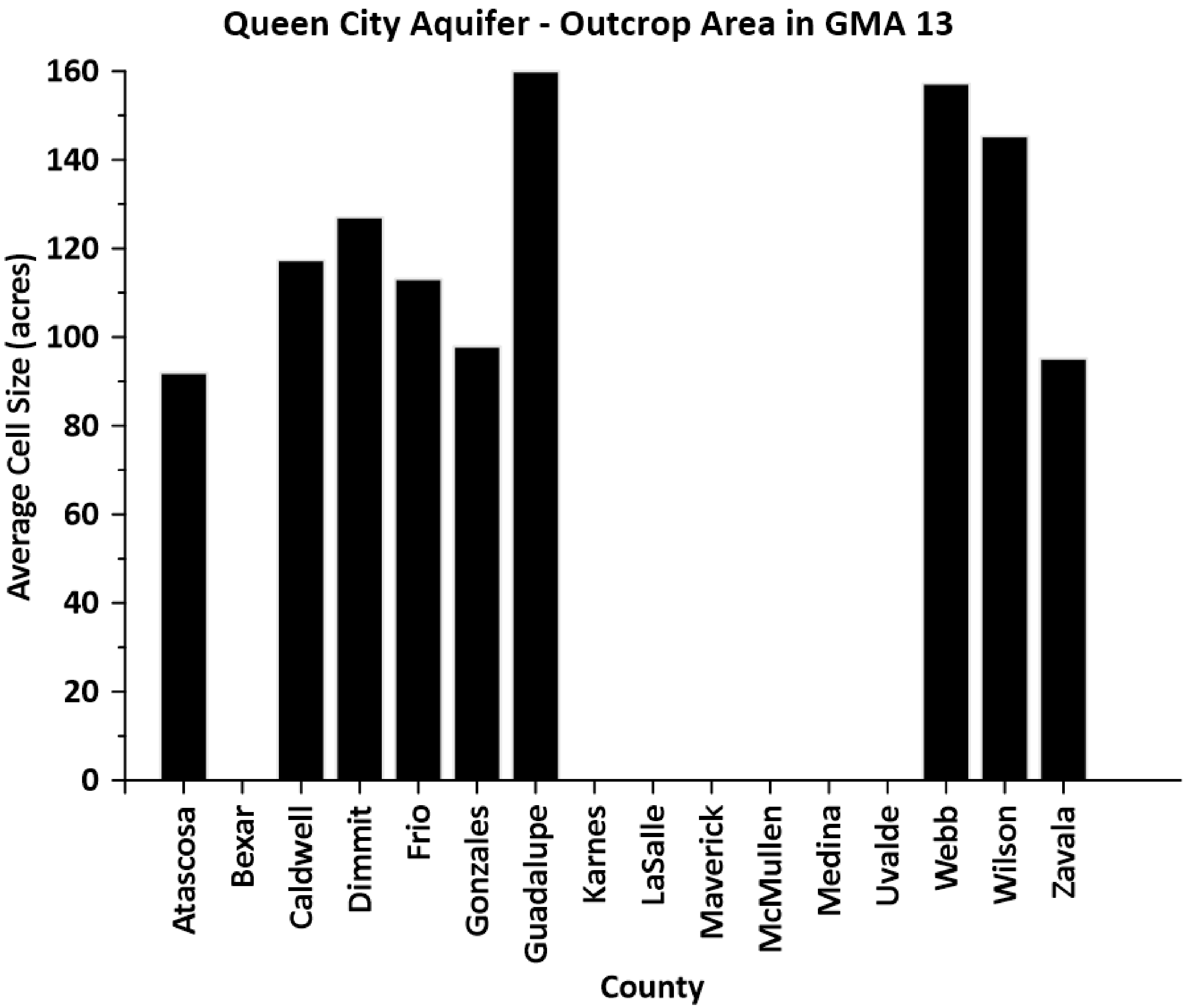
# Sparta Outcrop



# Sparta Downdip



# Queen City Outcrop

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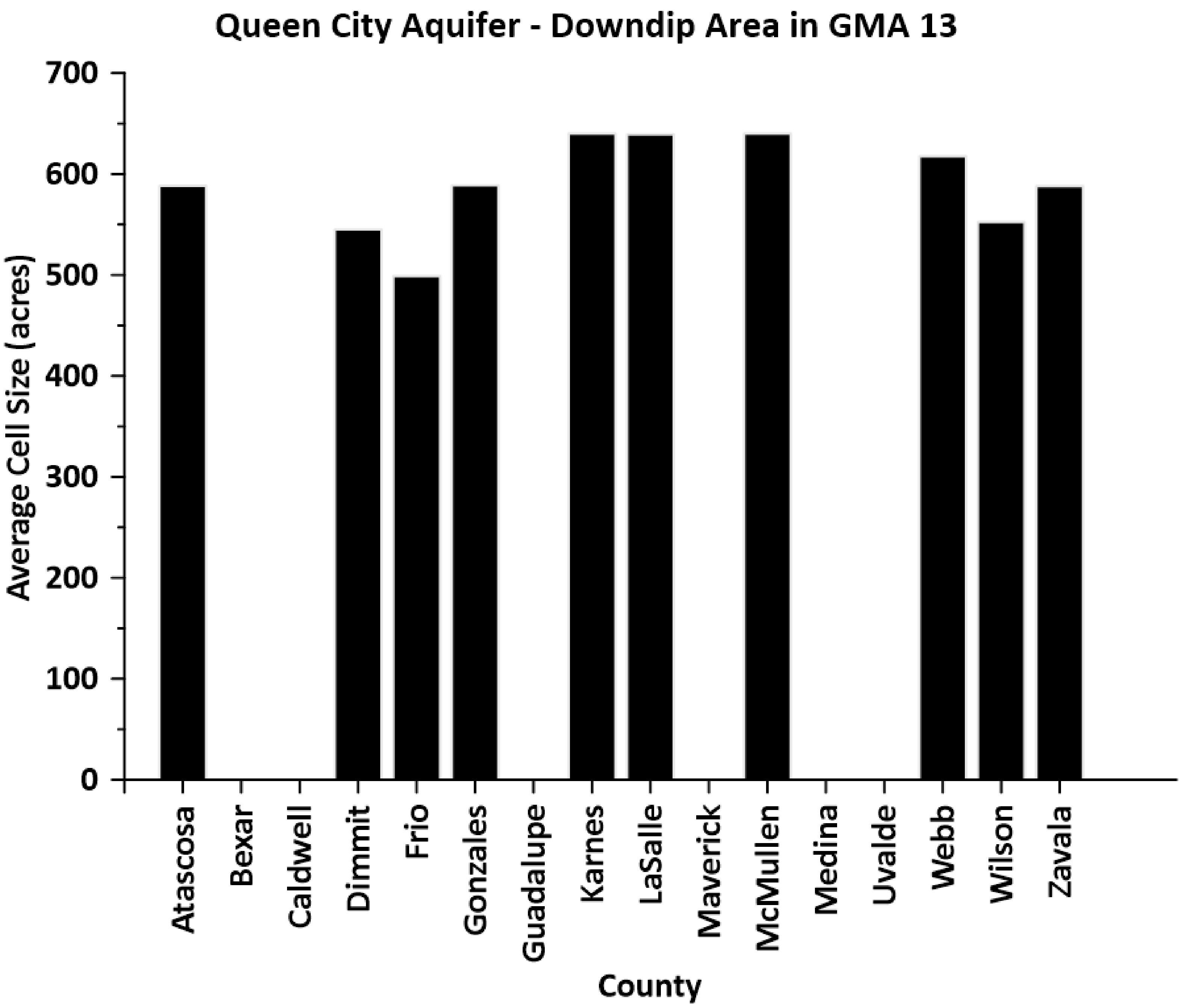
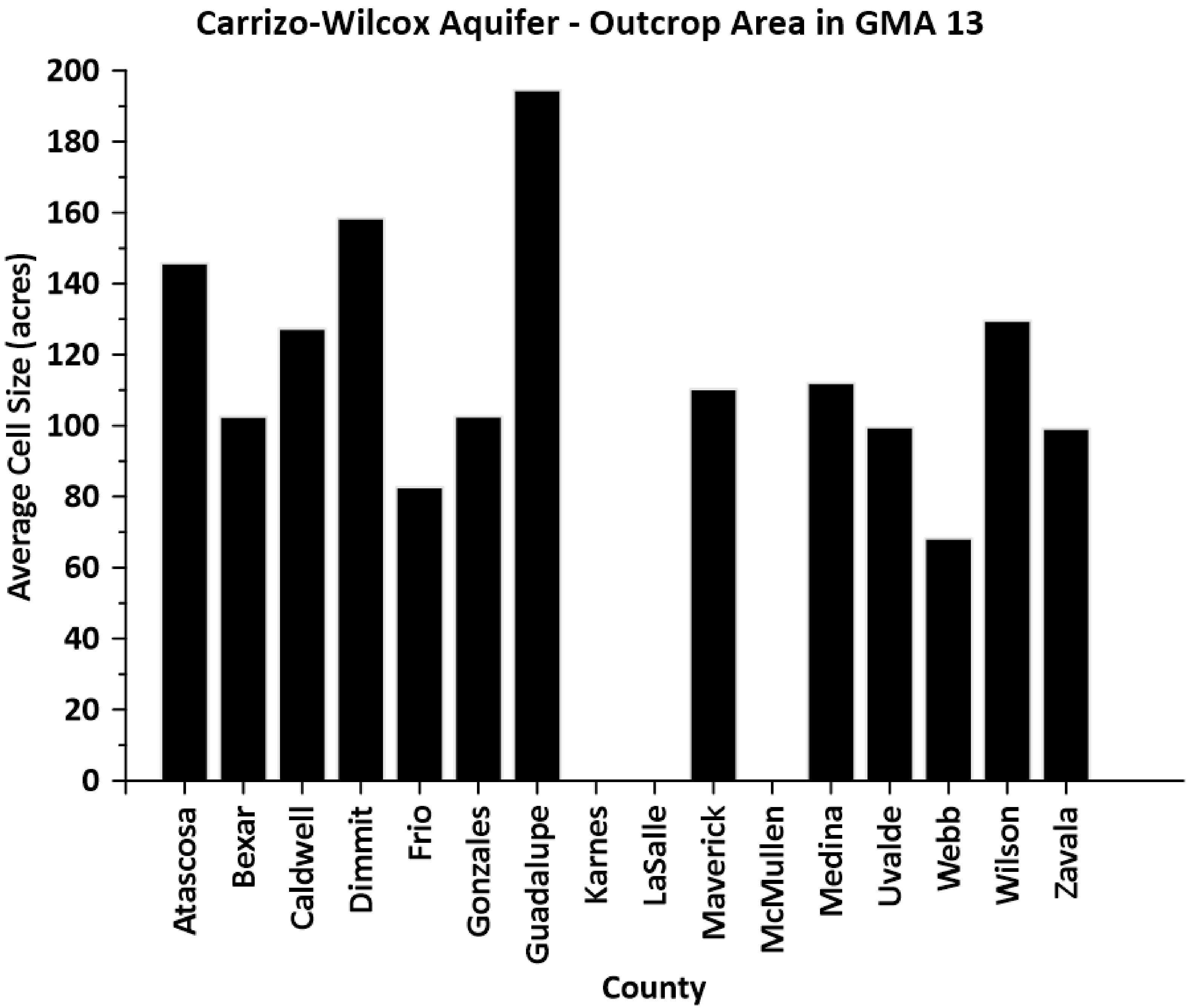
# Queen City Downdip



# Carrizo-Wilcox Outcrop

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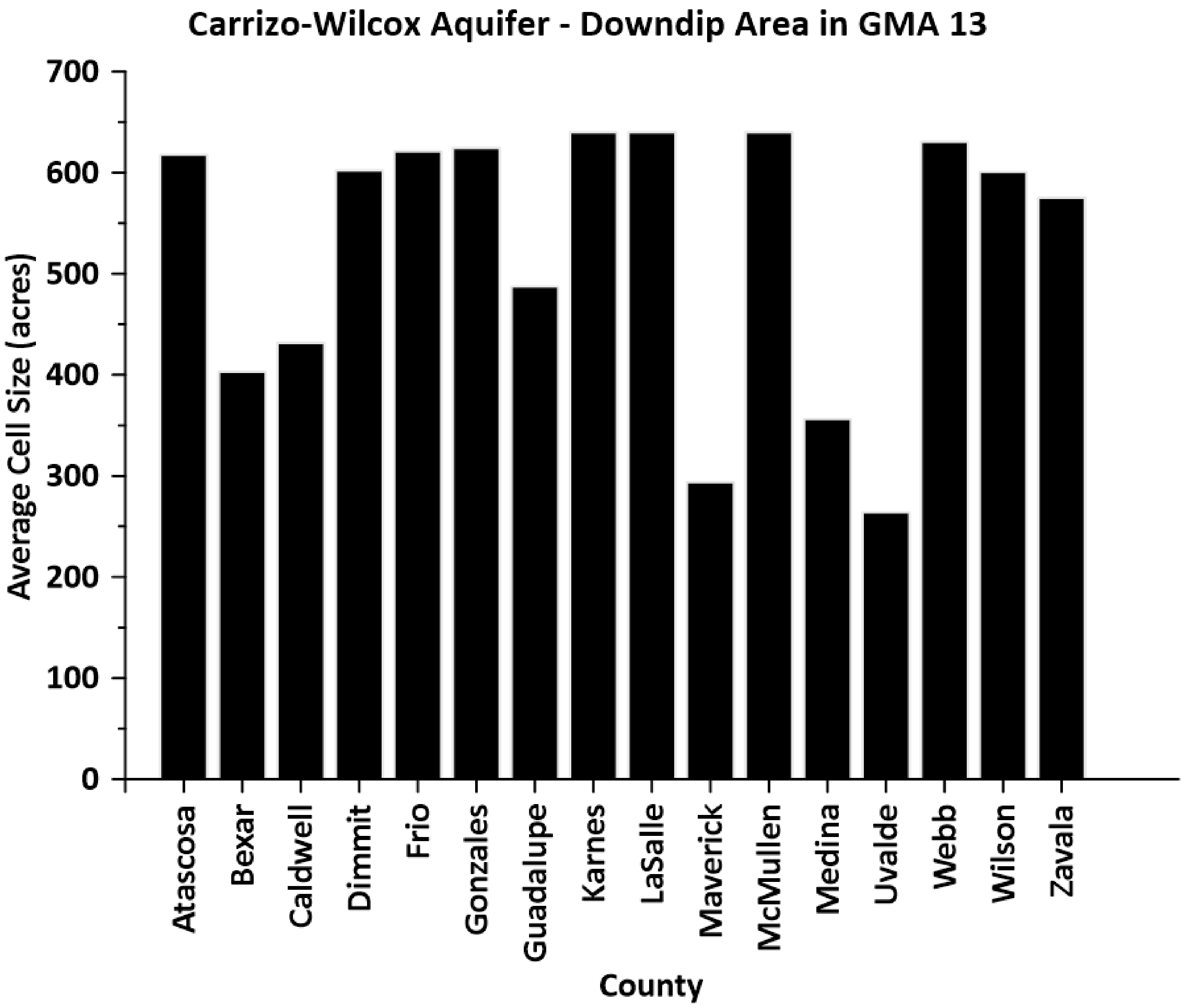
# Carrizo-Wilcox Downdip

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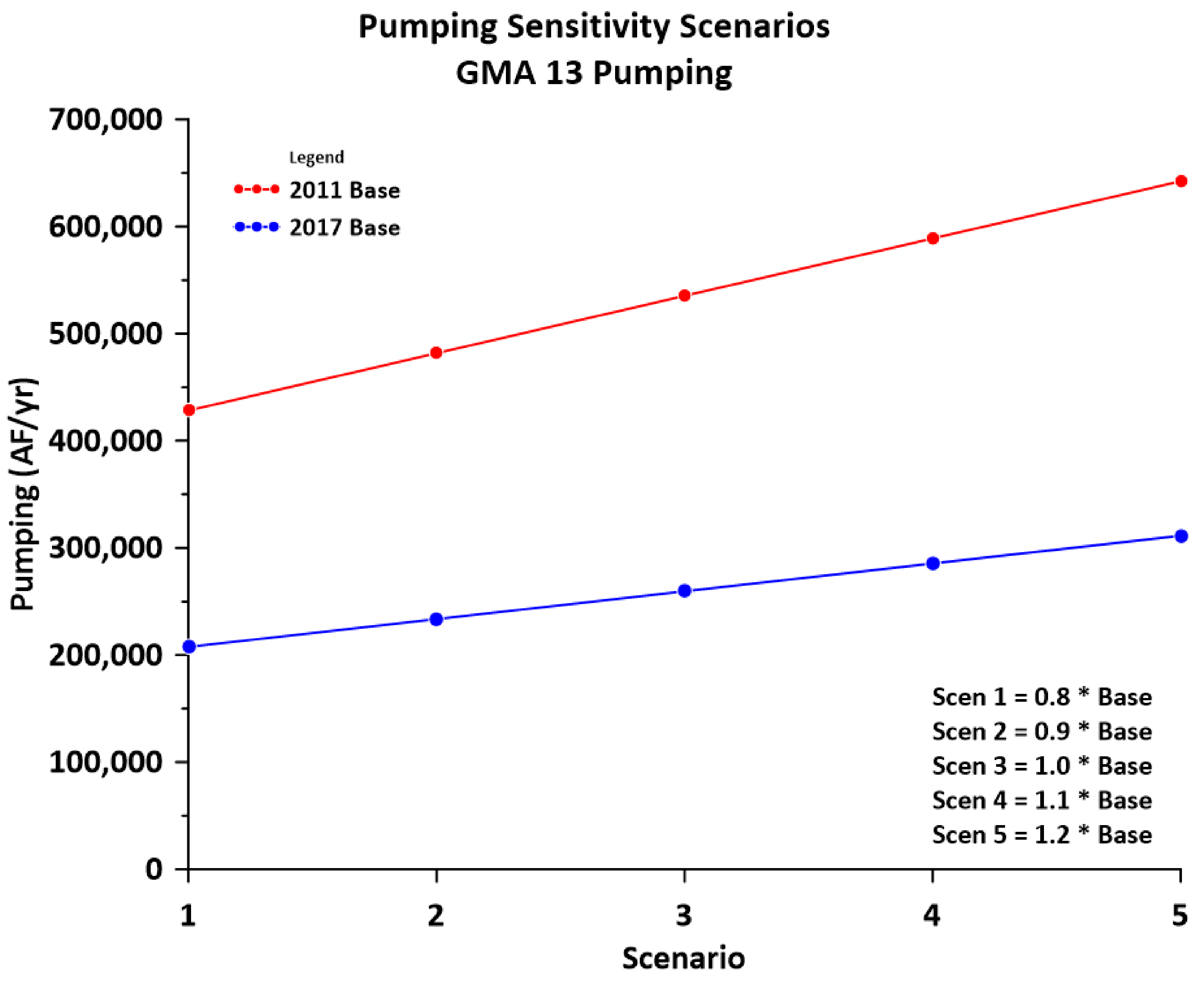
# Pumping Sensitivity

- Assumed average recharge
- 2 Alternate base pumping (2011 and 2017)
  - 2011 = 535,318 AF/yr (drought period)
  - 2017 = 259,507 AF/yr
- 5 scenarios for each base group:
  - 1) 0.8*base
  - 2) 0.9*base
  - 3) 1.0*base
  - 4) 1.1*base
  - 5) 1.2*base
- Assumed constant pumping from 2018 to 2080

# Pumping Scenarios

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# Pumping Sensitivity Results

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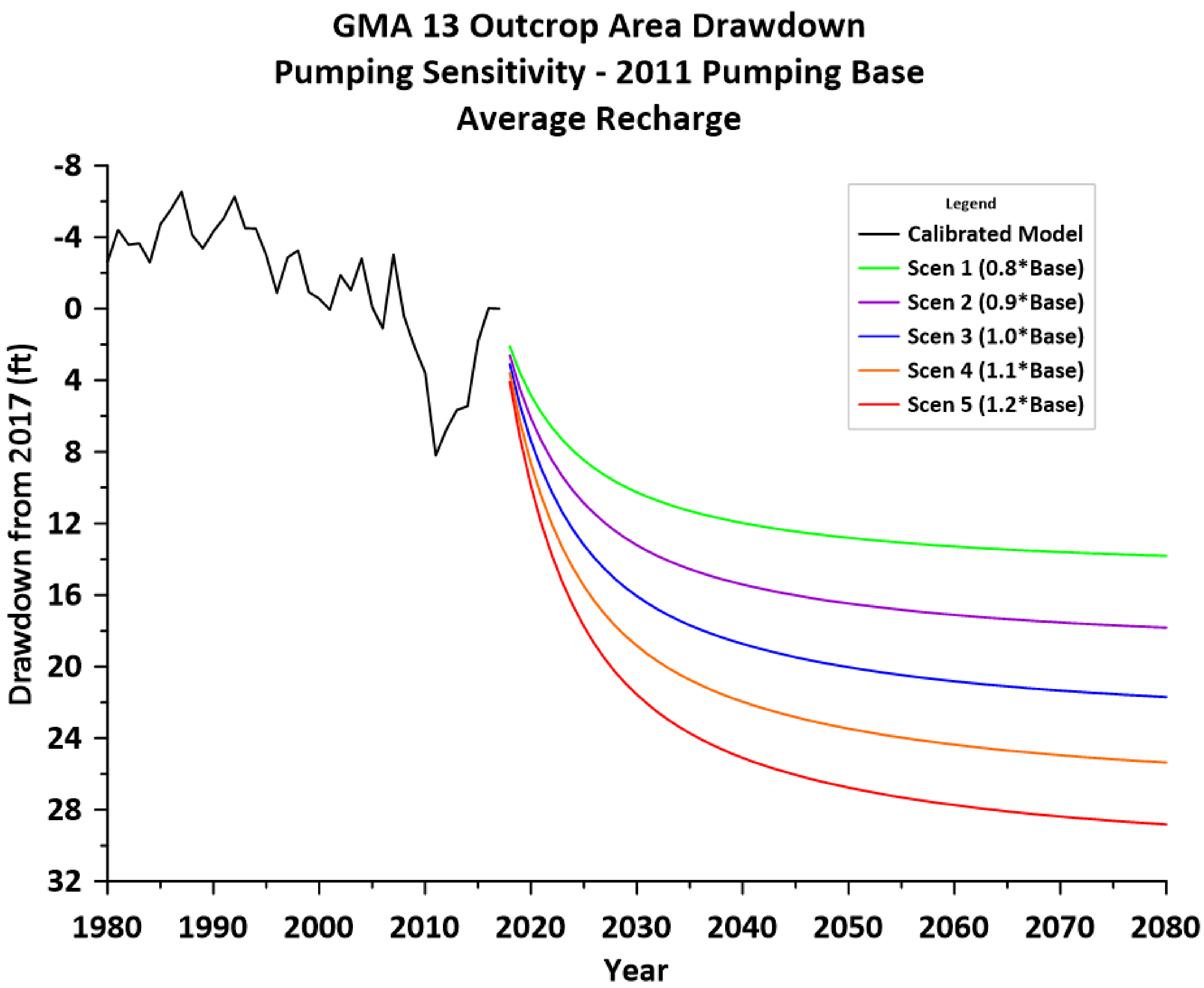
- Covered in Tech Memo 2 (to be completed)
- GMA 13 results (Outcrop, Downdip, Total)
  - Calibrated period average drawdown (2017 base: 1981 to 2017)
  - Scenario average drawdown (2017 base: 2018 to 2080)

# 2011 Base Outcrop

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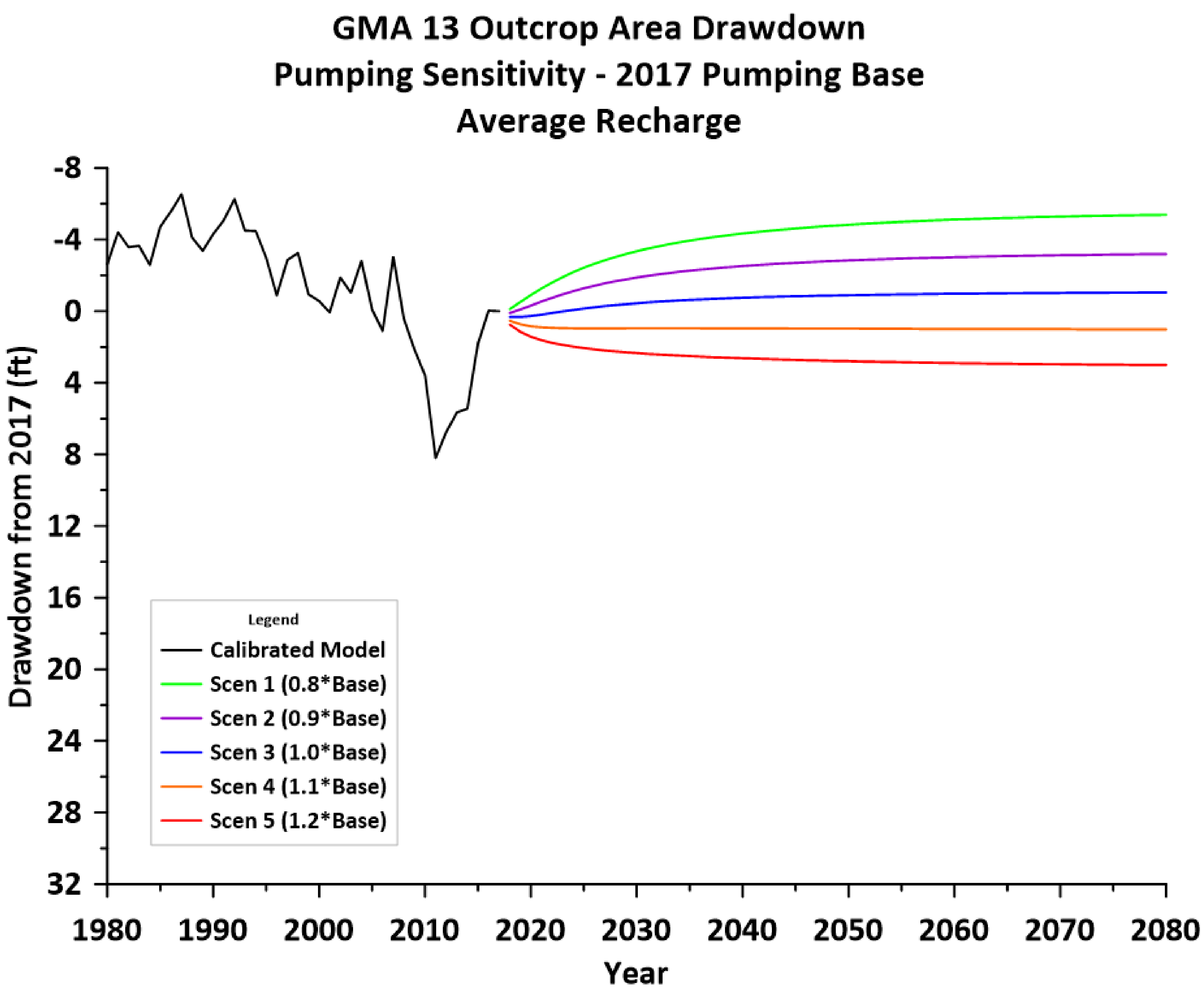
# 2017 Base Outcrop

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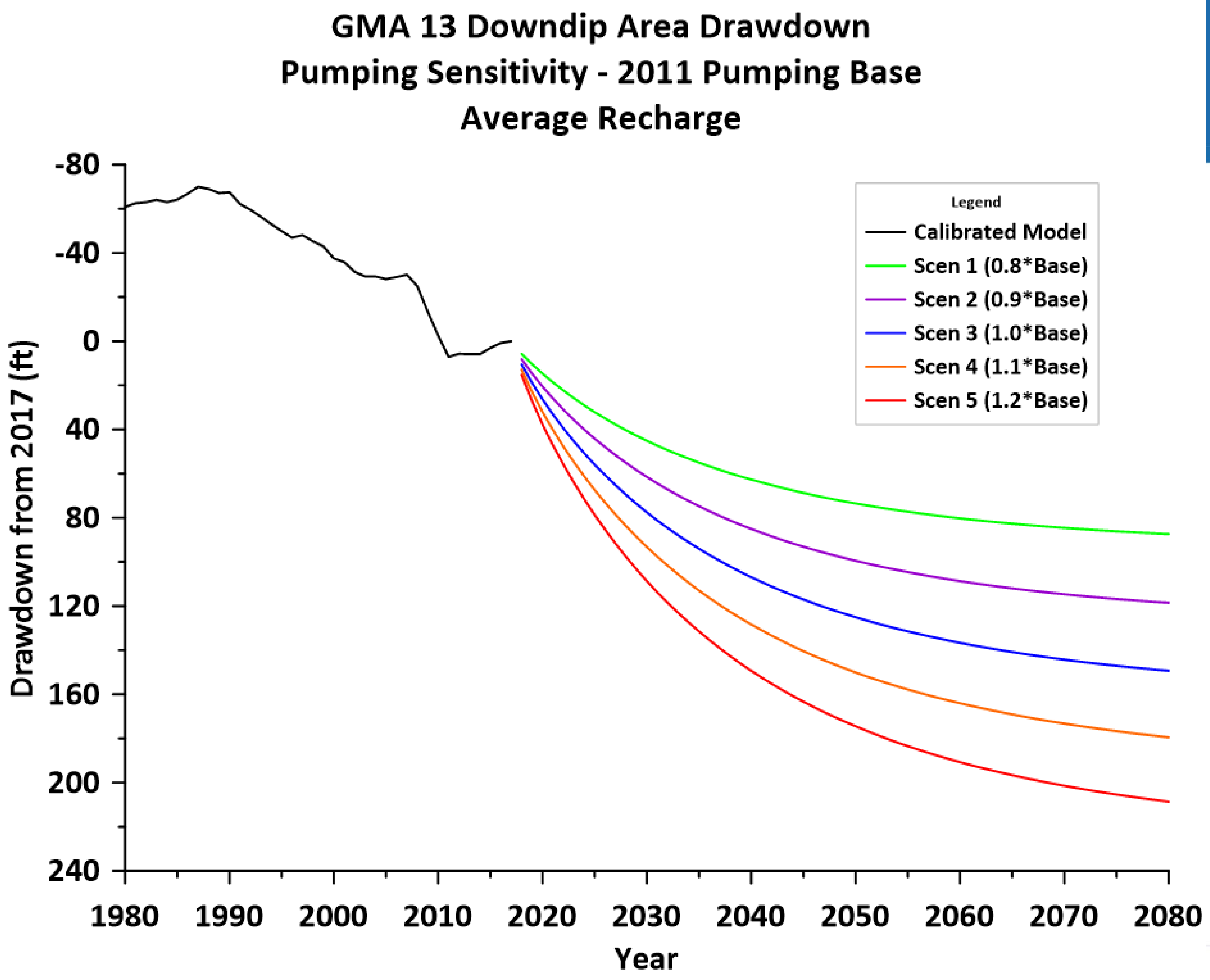
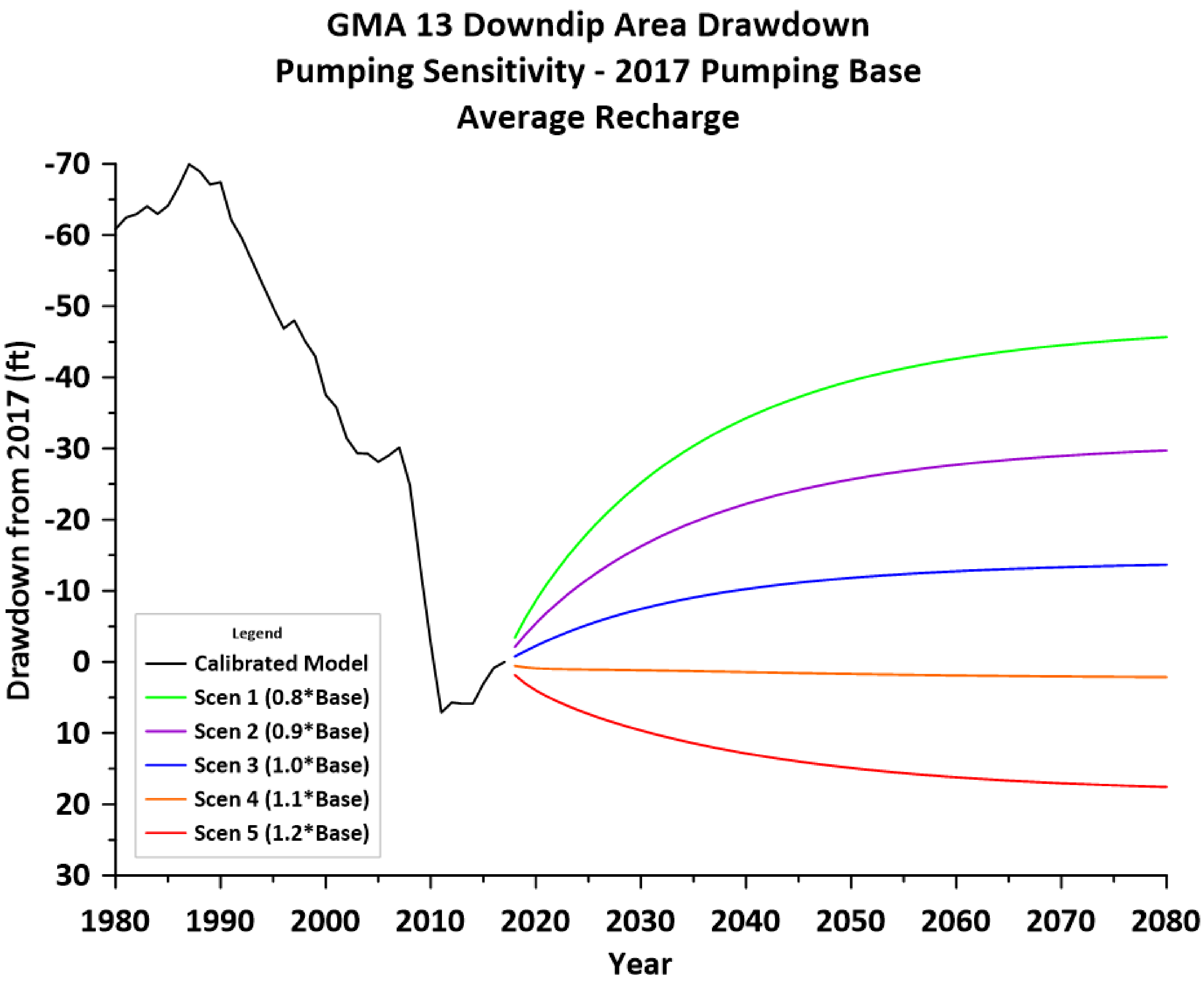
# 2011 Base Downdip




GSI ENVIRONMENTAL

# 2017 Base Downdip

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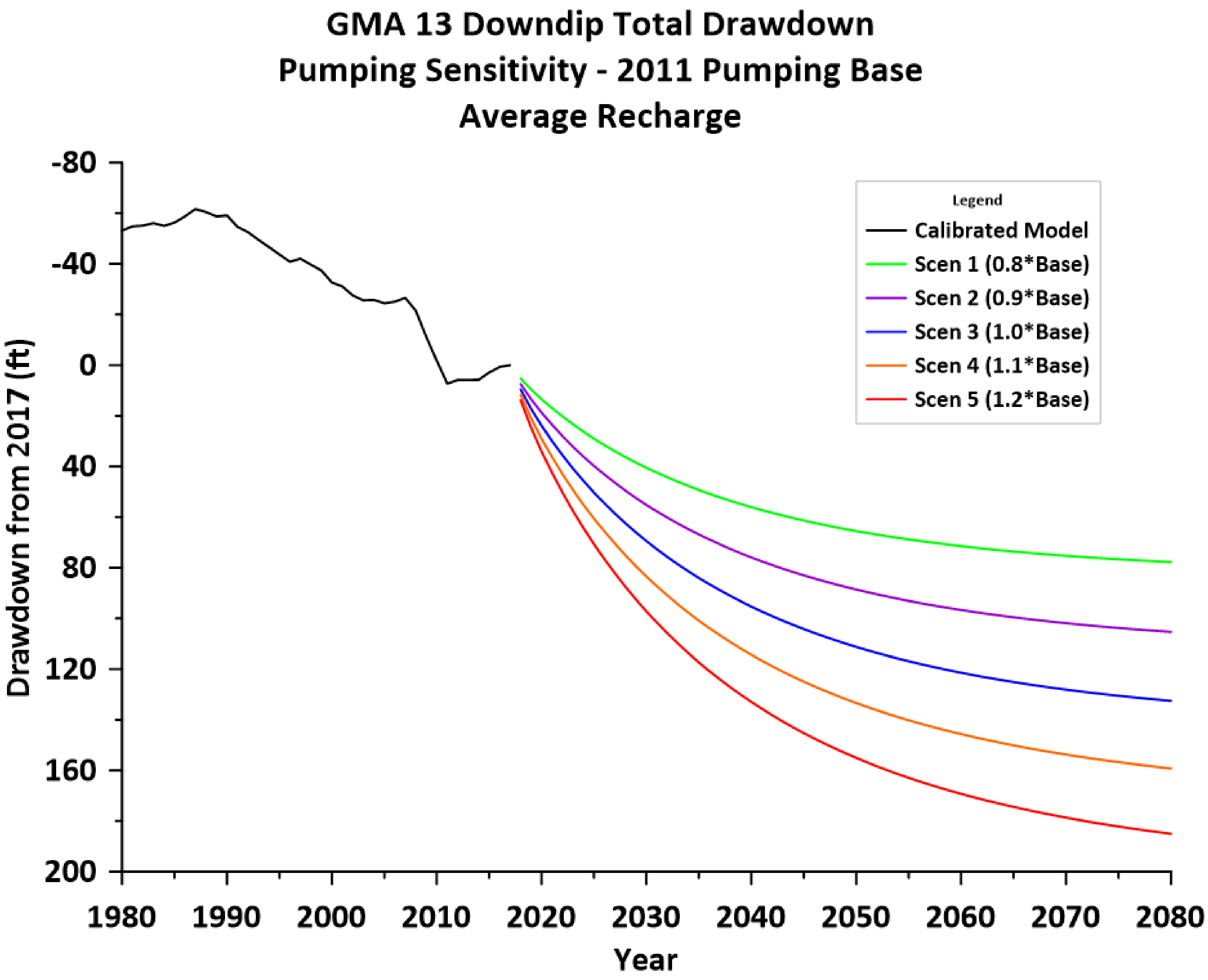
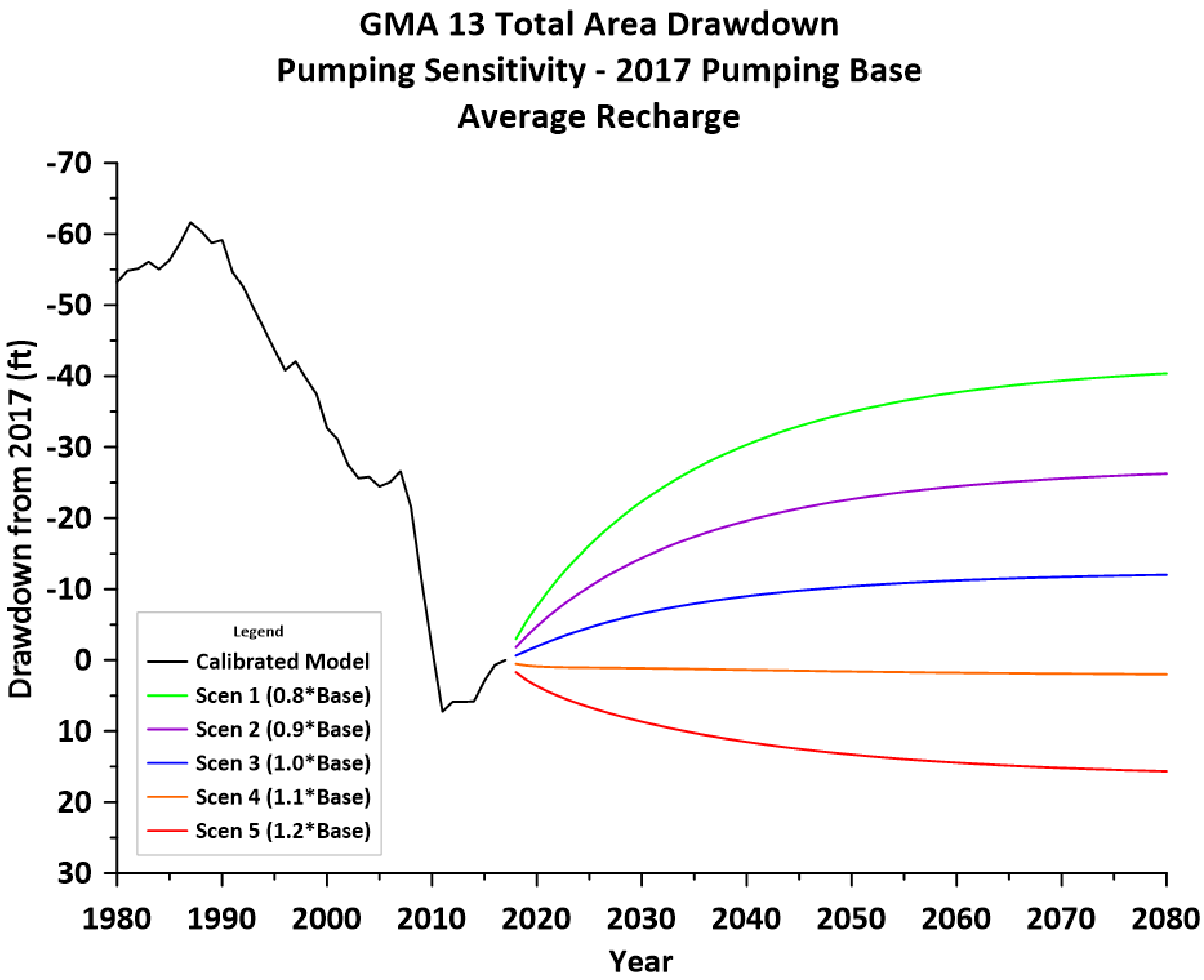
# 2011 Base Total




GSI ENVIRONMENTAL

# 2017 Base Total




GSI ENVIRONMENTAL

# Recharge Sensitivity

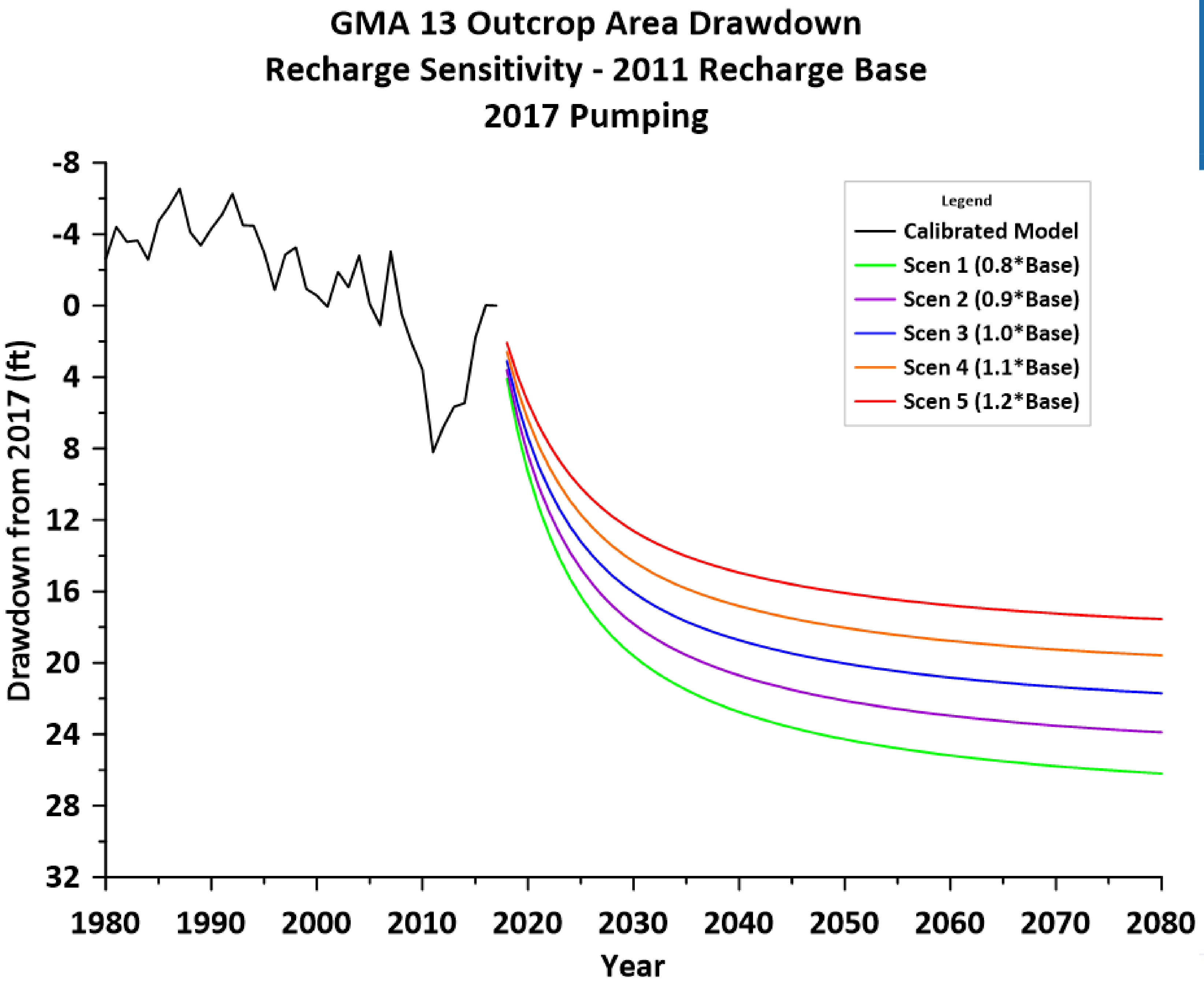
- Assumed 2017 pumping
- 2 Alternate base recharge (2011 and 2017)
  - 2011 = 0.53 of average recharge (drought period)
  - 2017 = 1.14 of average recharge
- 5 scenarios for each base group:
  - 1) 0.8*base
  - 2) 0.9*base
  - 3) 1.0*base
  - 4) 1.1*base
  - 5) 1.2*base
- Assumed constant recharge from 2018 to 2080

# Recharge Sensitivity Results

GSI ENVIRONMENTAL

- Covered in Tech Memo 3 (to be completed)
- GMA 13 results (Outcrop, Downdip, Total)
  - Calibrated period average drawdown (2017 base: 1981 to 2017)
  - Scenario average drawdown (2017 base: 2018 to 2080)

# 2011 Base Outcrop

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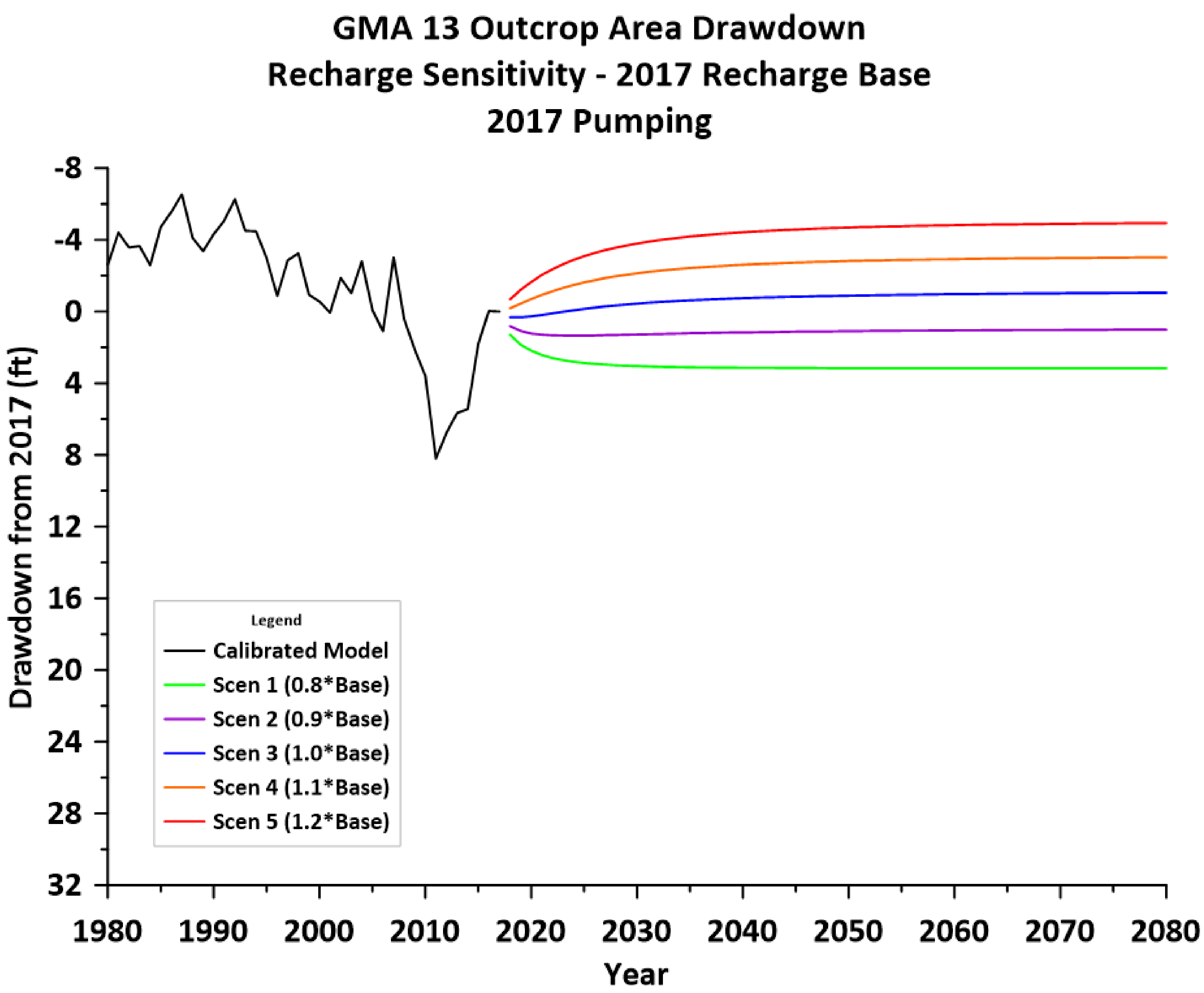
# 2017 Base Outcrop

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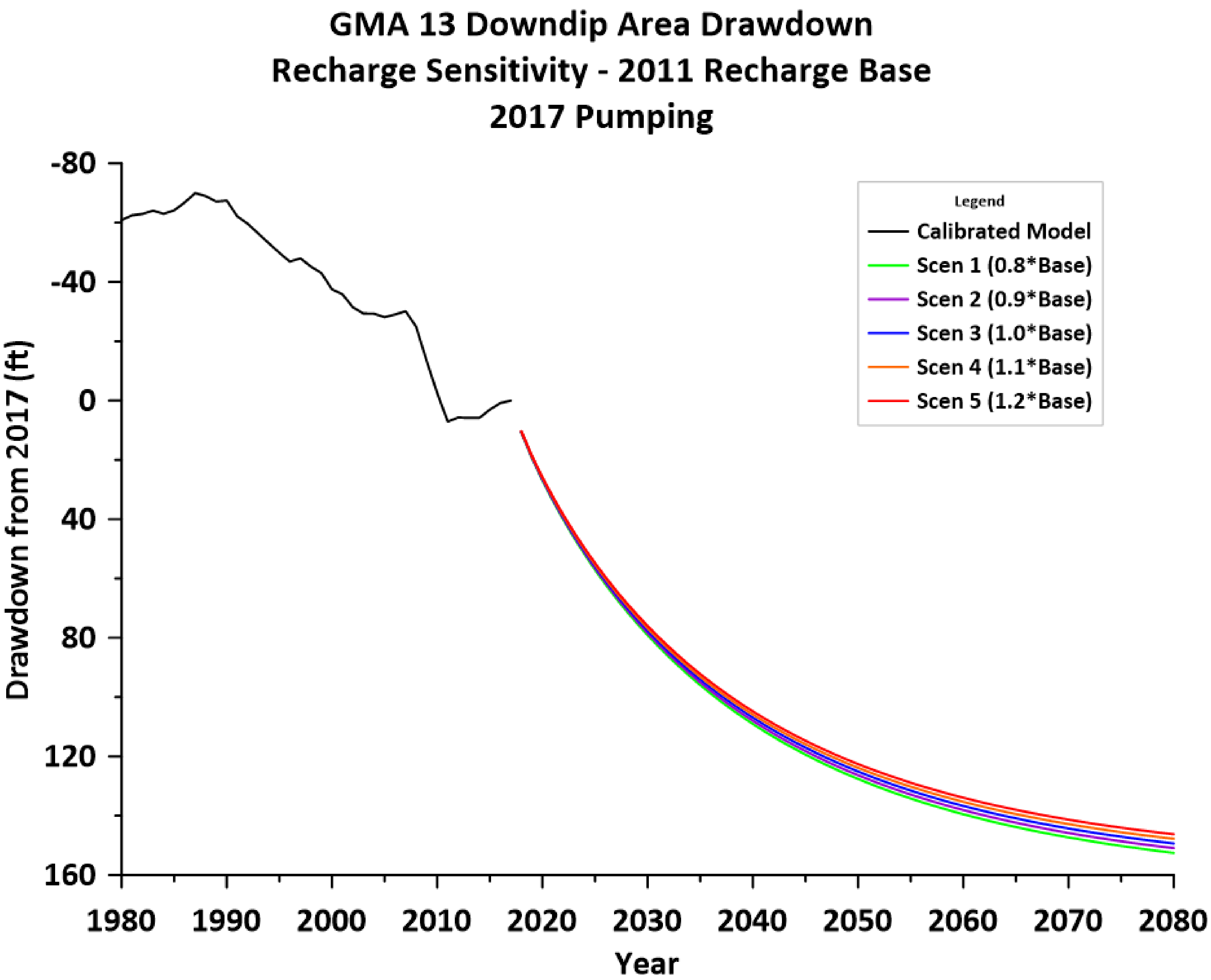
# 2011 Base Downdip

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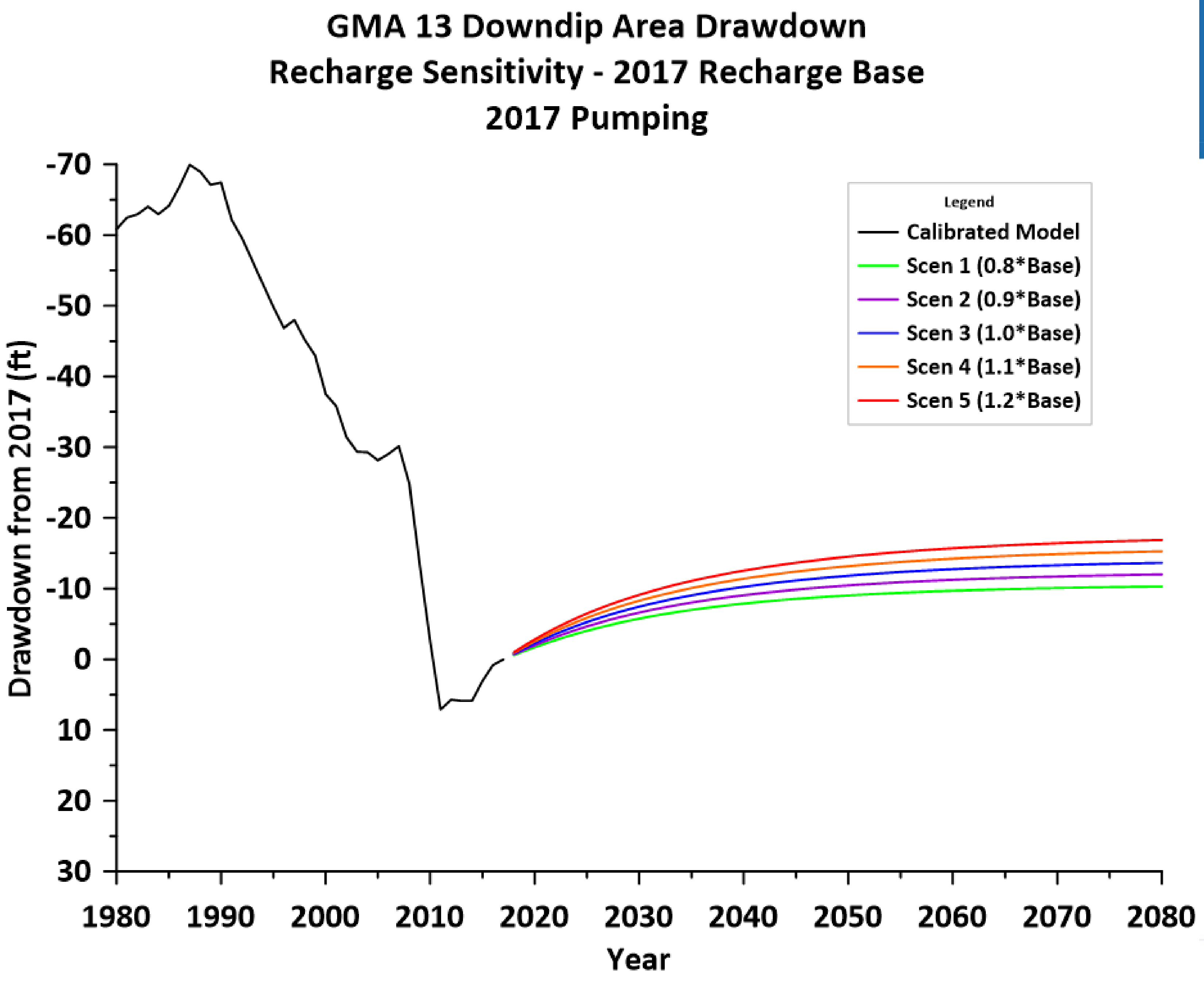
# 2017 Base Downdip

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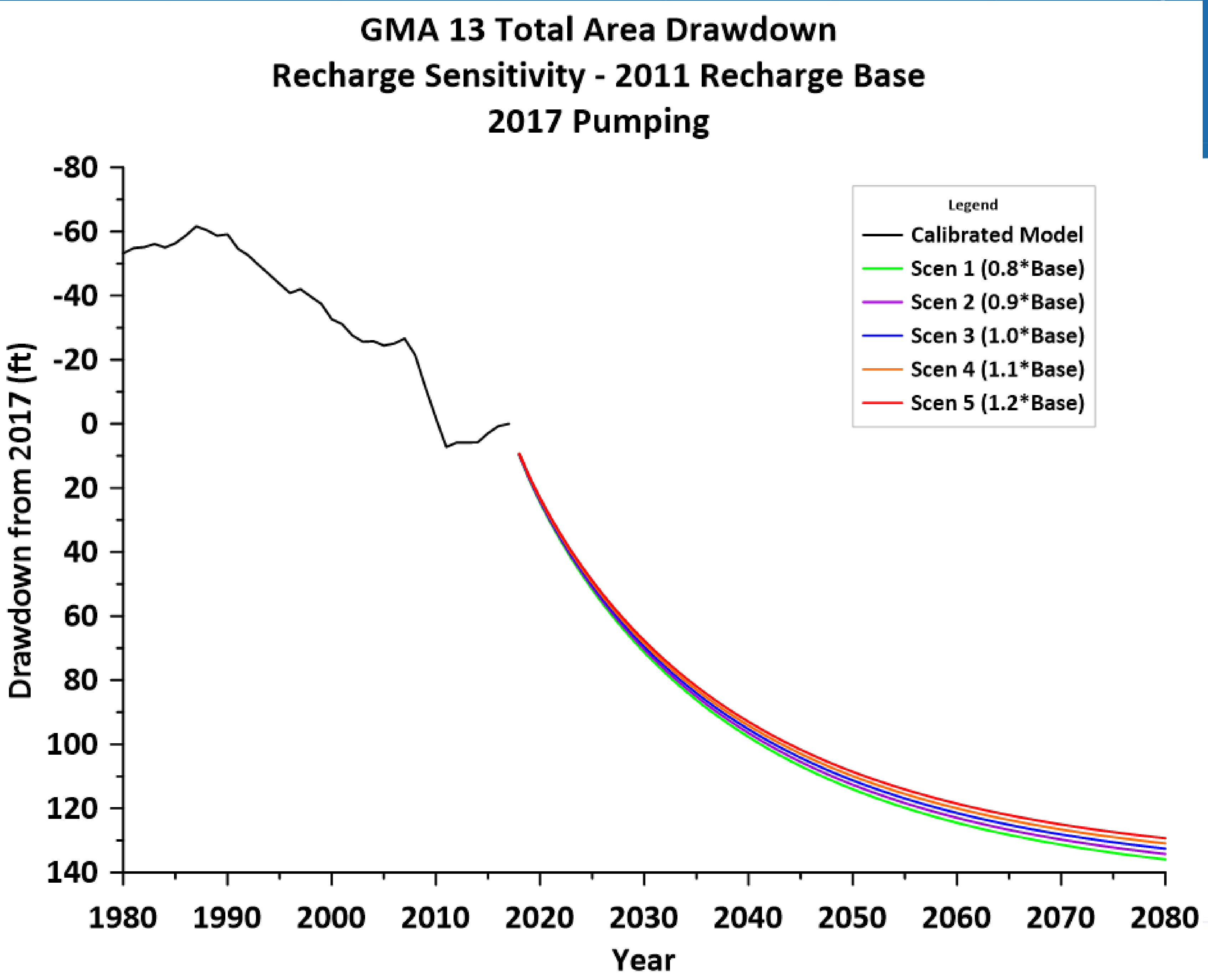
# 2011 Base Total

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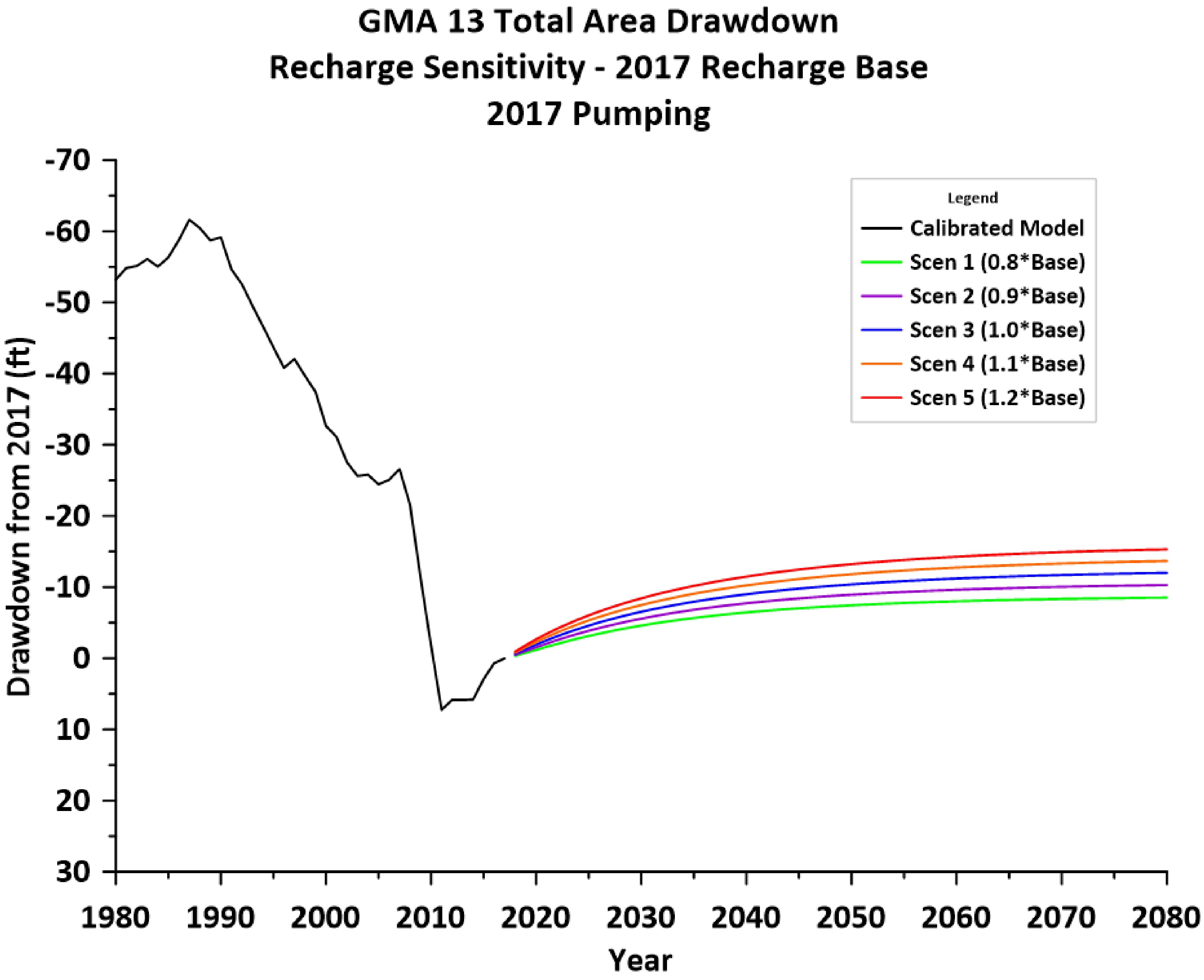
# 2017 Base Total

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# Outcrop Volume Analysis

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- Current Primary DFC (2021 Explanatory Report):
  - All GMA 13 aquifer: Sparta, Queen City, and Carrizo-Wilcox
  - "75 percent of the saturated thickness in the outcrop at the end of 2012 remains at the end of 2080"
  - "Due to limitations of the current Groundwater Availability Model, this desired future condition cannot be simulated as documented during 2016 Joint Planning in GMA 13 Technical Memorandum 16-08."

# Objective of Analysis

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- Demonstrate that new GAM can provide results that can be used in next round of joint planning
- Used volume analysis to provide additional context
  - Saturated thickness * Area * Specific Yield
- Could also use "saturated thickness" as stated in current DFC
  - Need to evaluate both during joint planning and make a policy-level decision

# Outcrop Analysis Results

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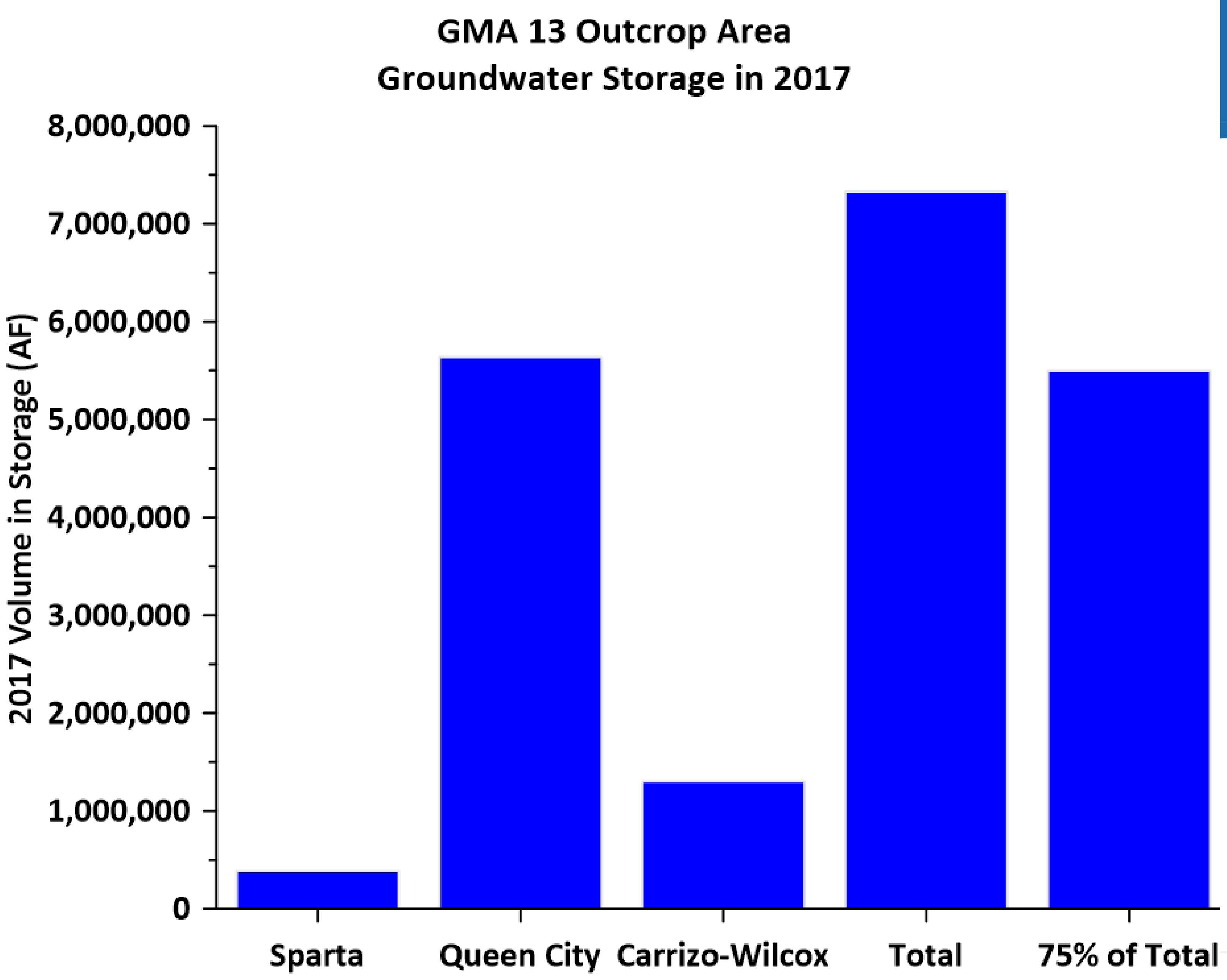
- Covered in Tech Memos 2 and 3 (pumping and recharge scenarios)
- 2017 Volumes (Assumed New Baseline)
  - Sparta, Queen City, Carrizo-Wilcox, Total
- Results from 20 Scenarios
  - 10 pumping scenarios (2011 and 2017 base)
  - 10 recharge scenarios (2011 and 2017 base)
  - Sparta, Queen City, Carrizo-Wilcox, Total

# 2017
# Outcrop Area

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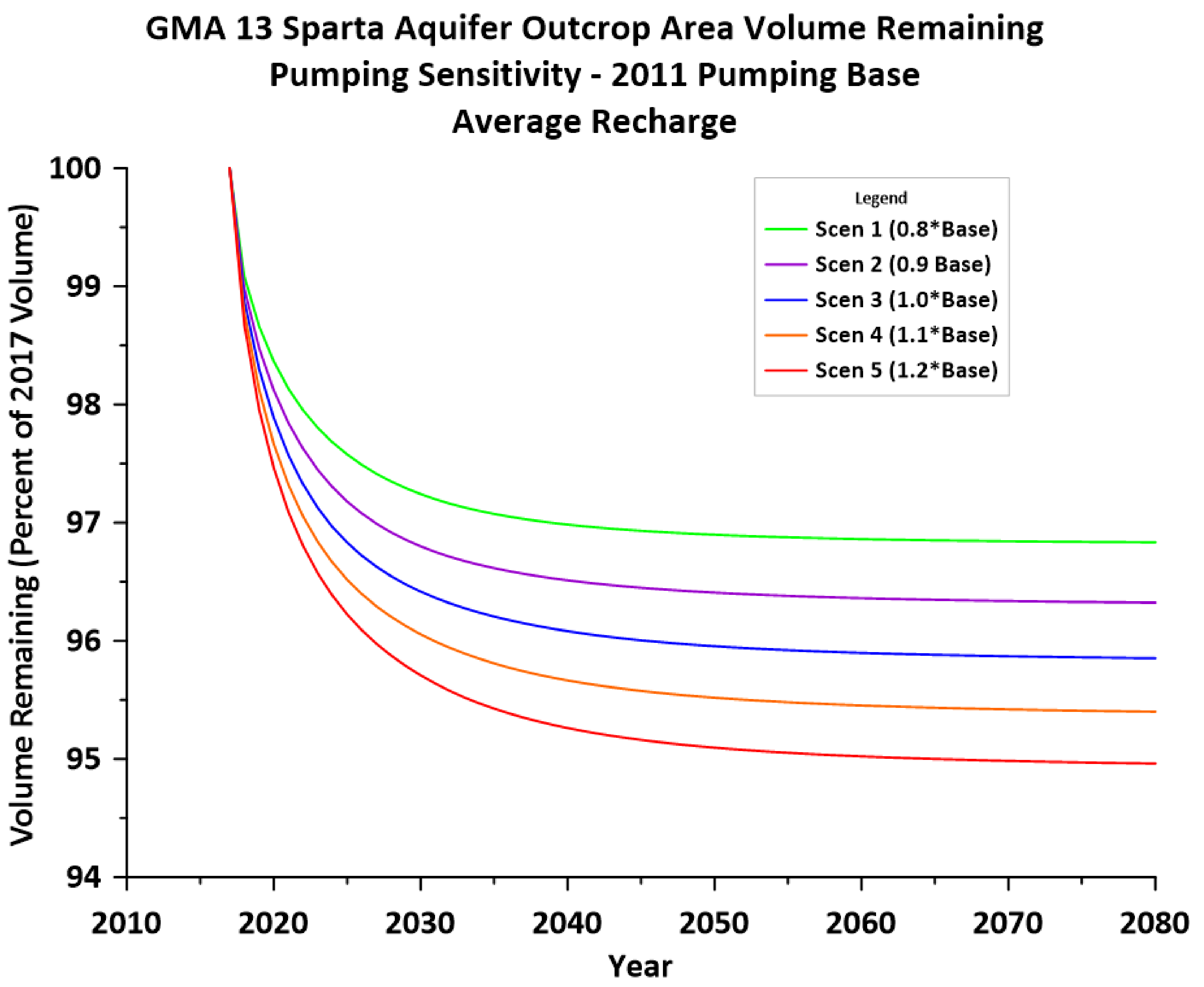
# 2011 Pumping Sparta

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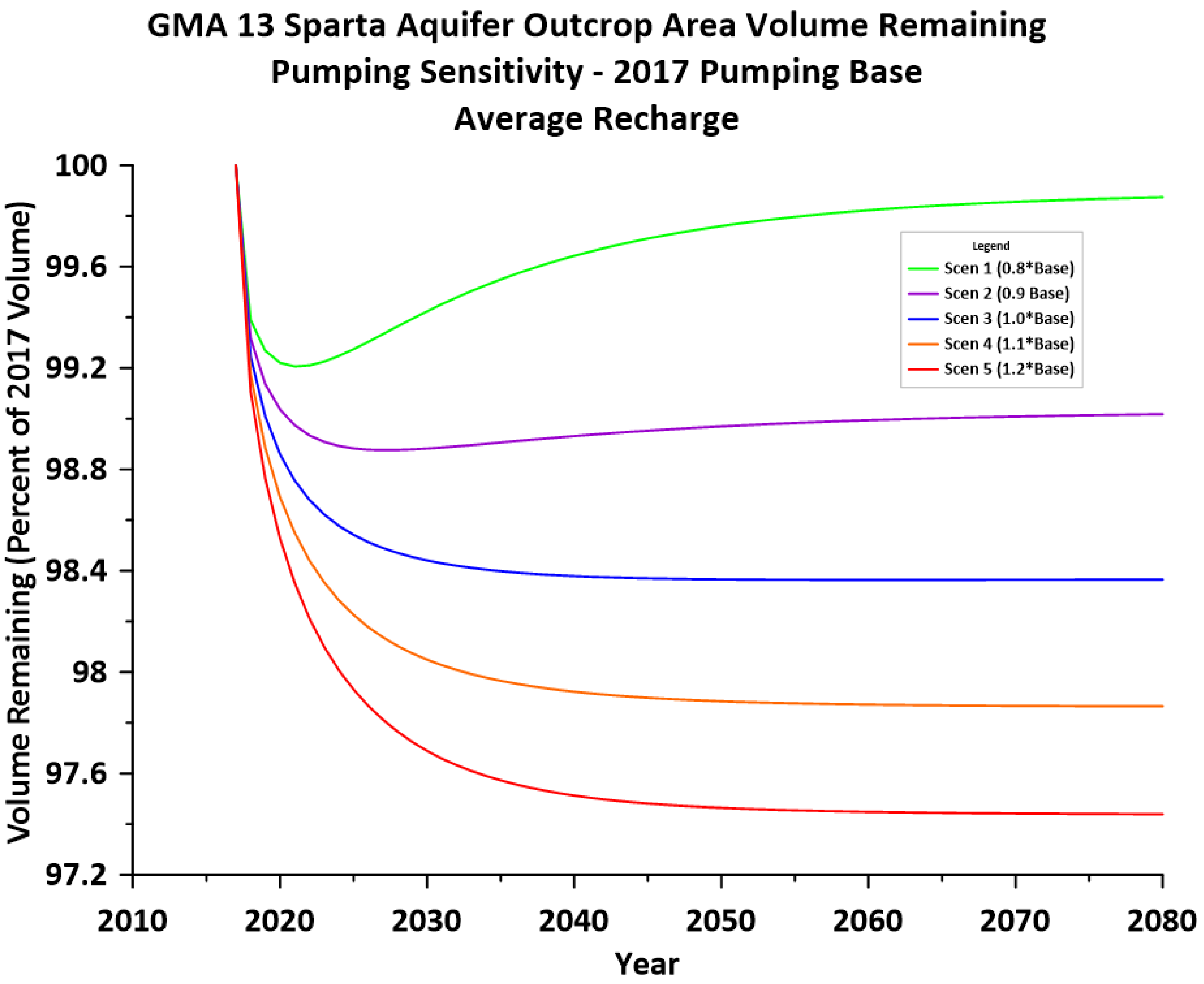
# 2017 Pumping Sparta

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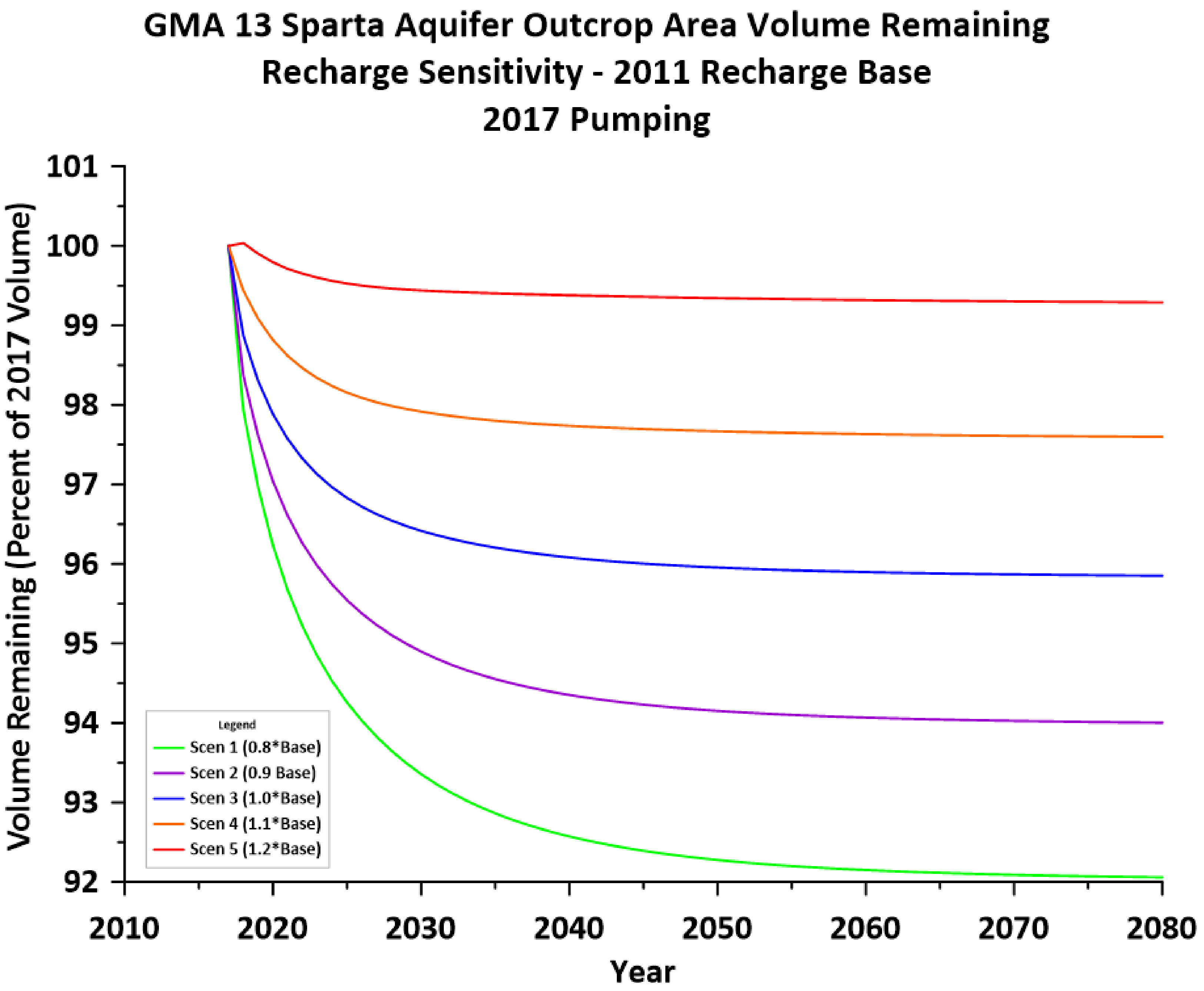
# 2011 Recharge Sparta

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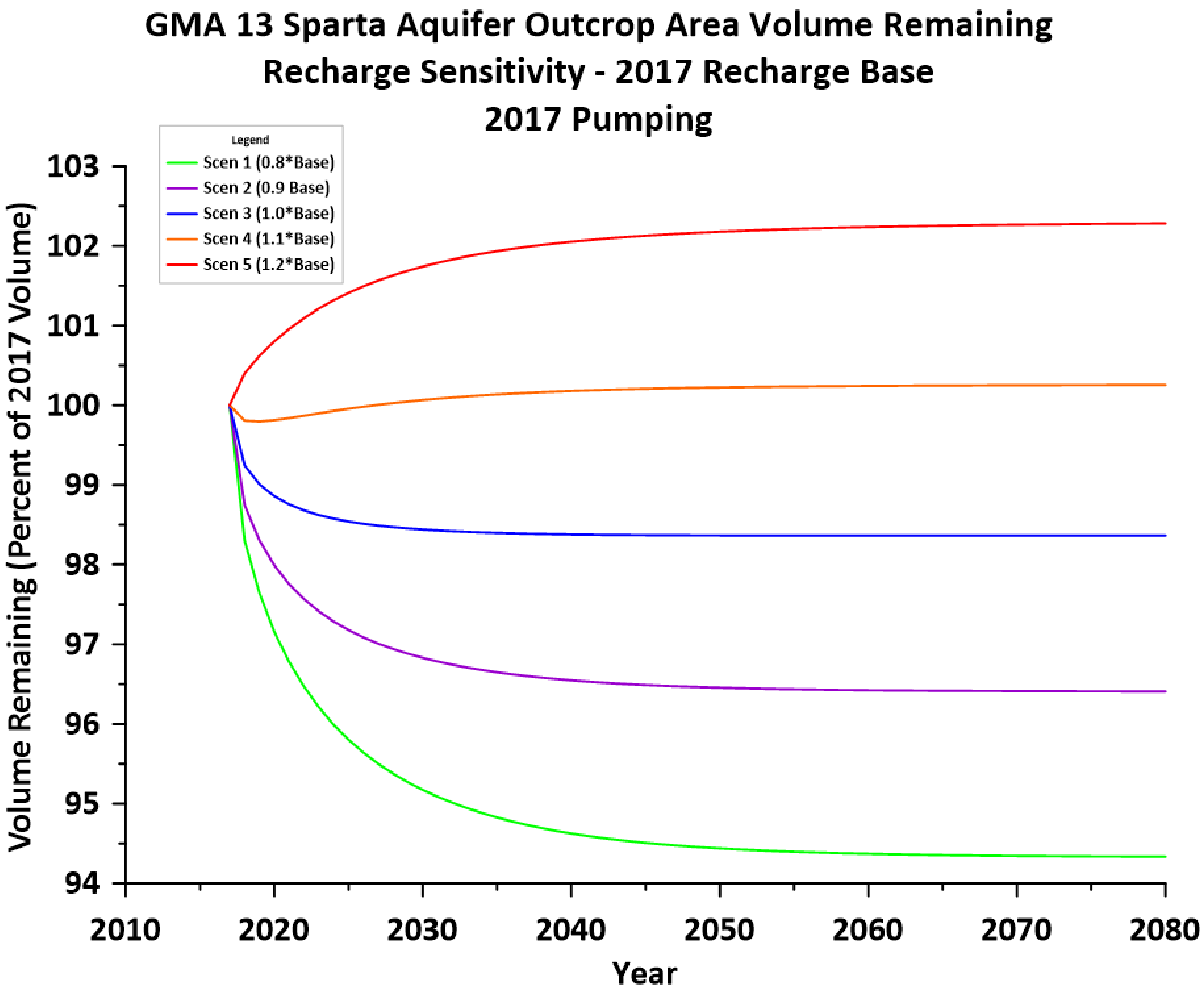
# 2017 Recharge Sparta

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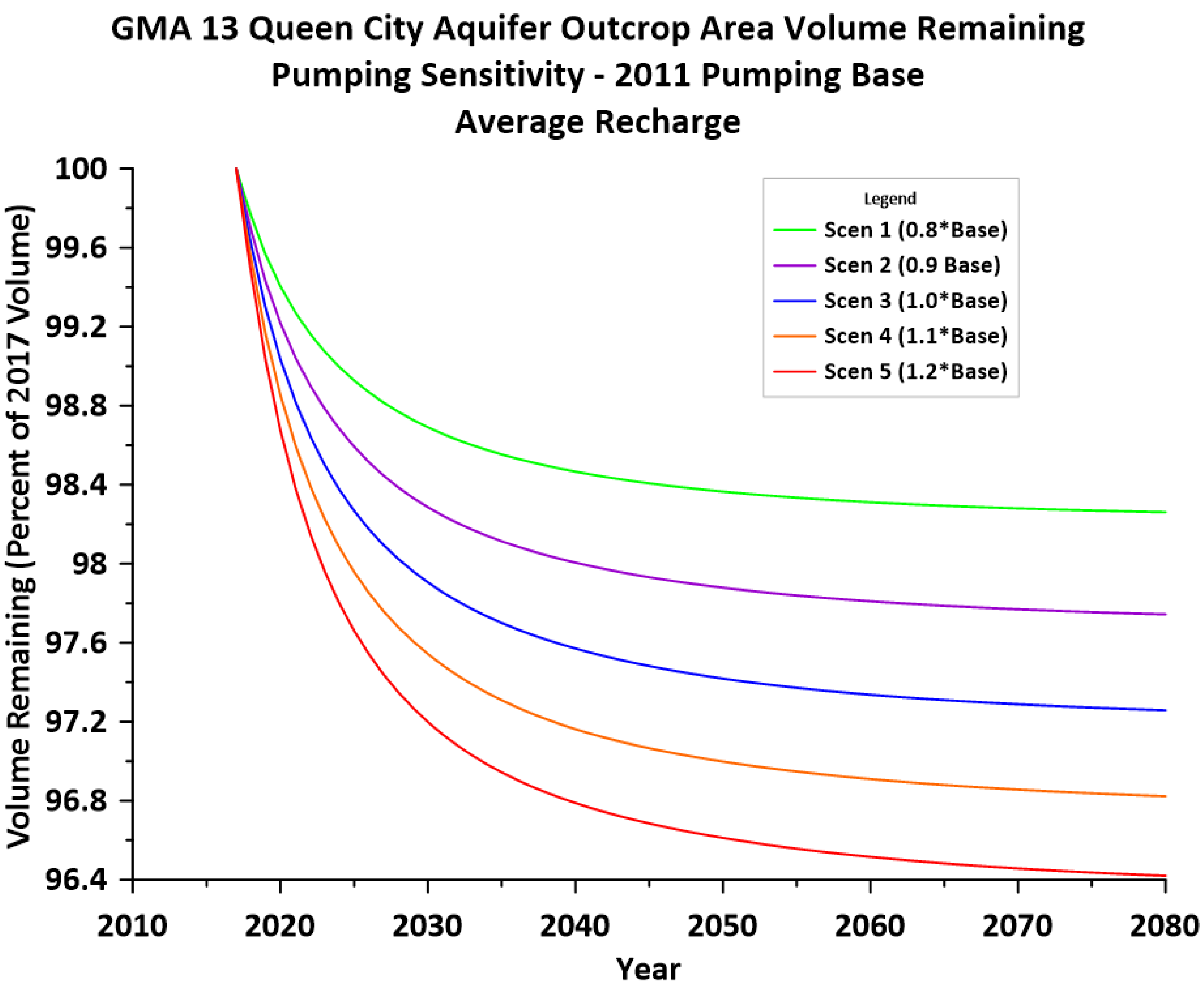
# 2011 Pumping Queen City

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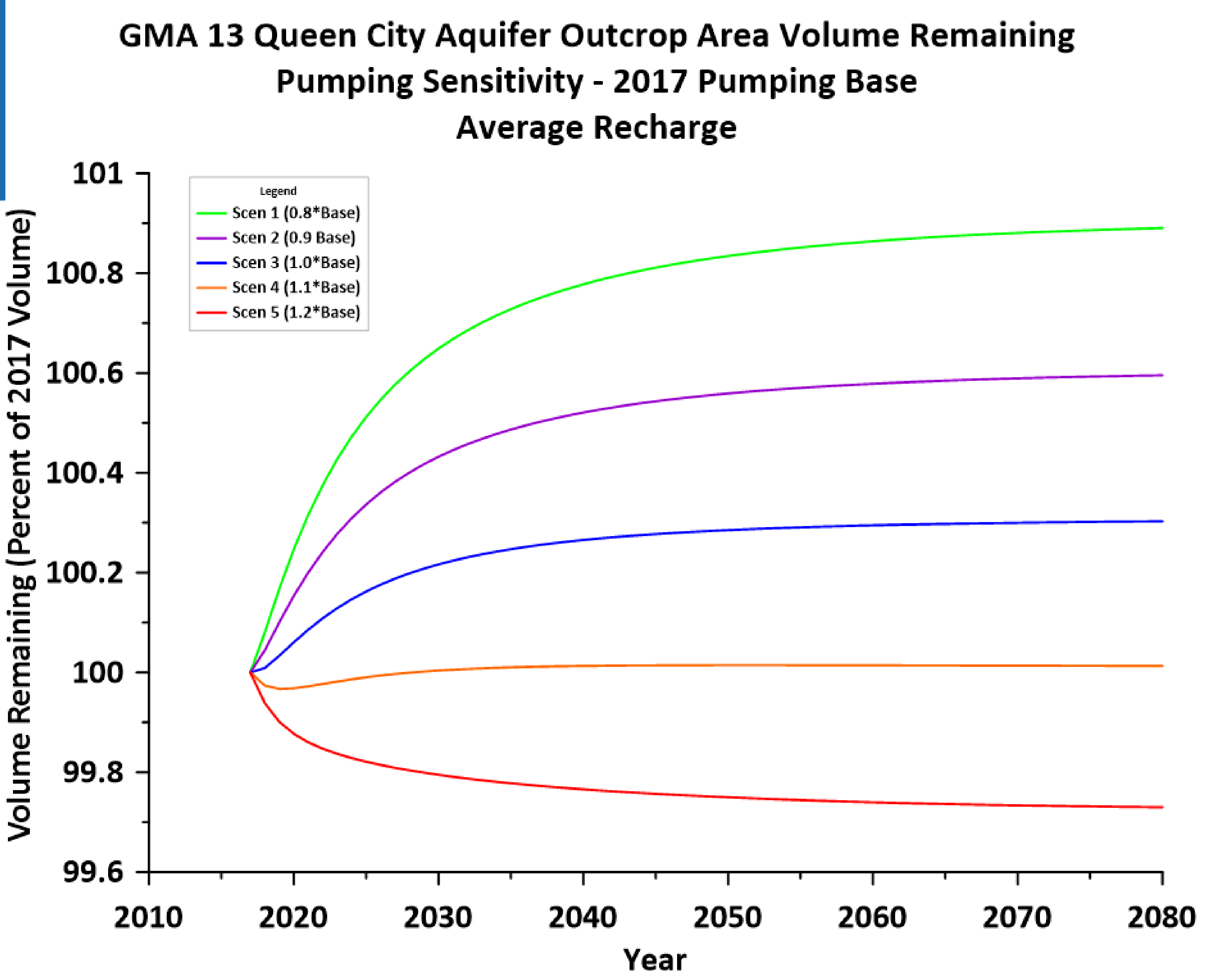
# 2017 Pumping Queen City

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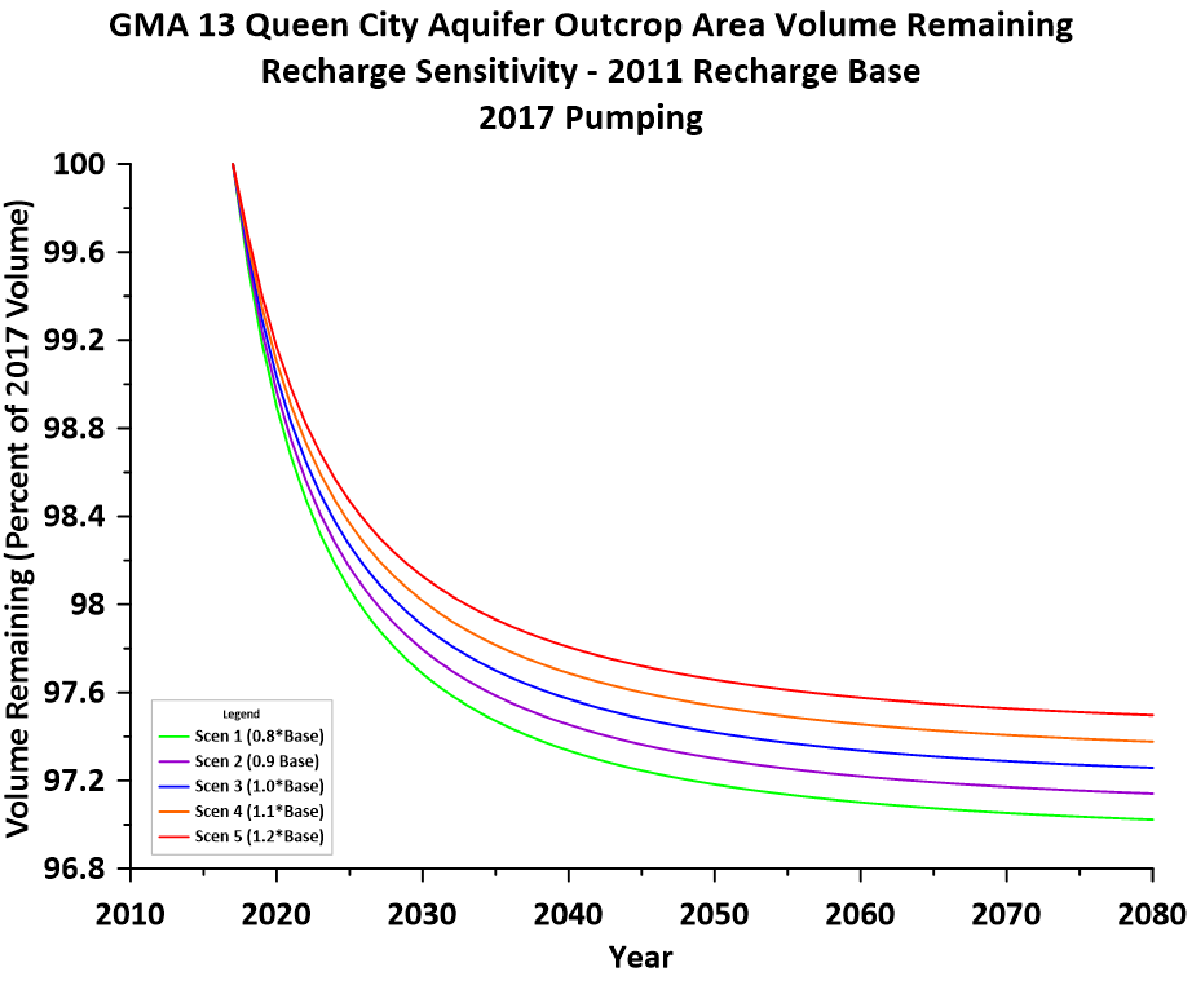
# 2011 Recharge Queen City

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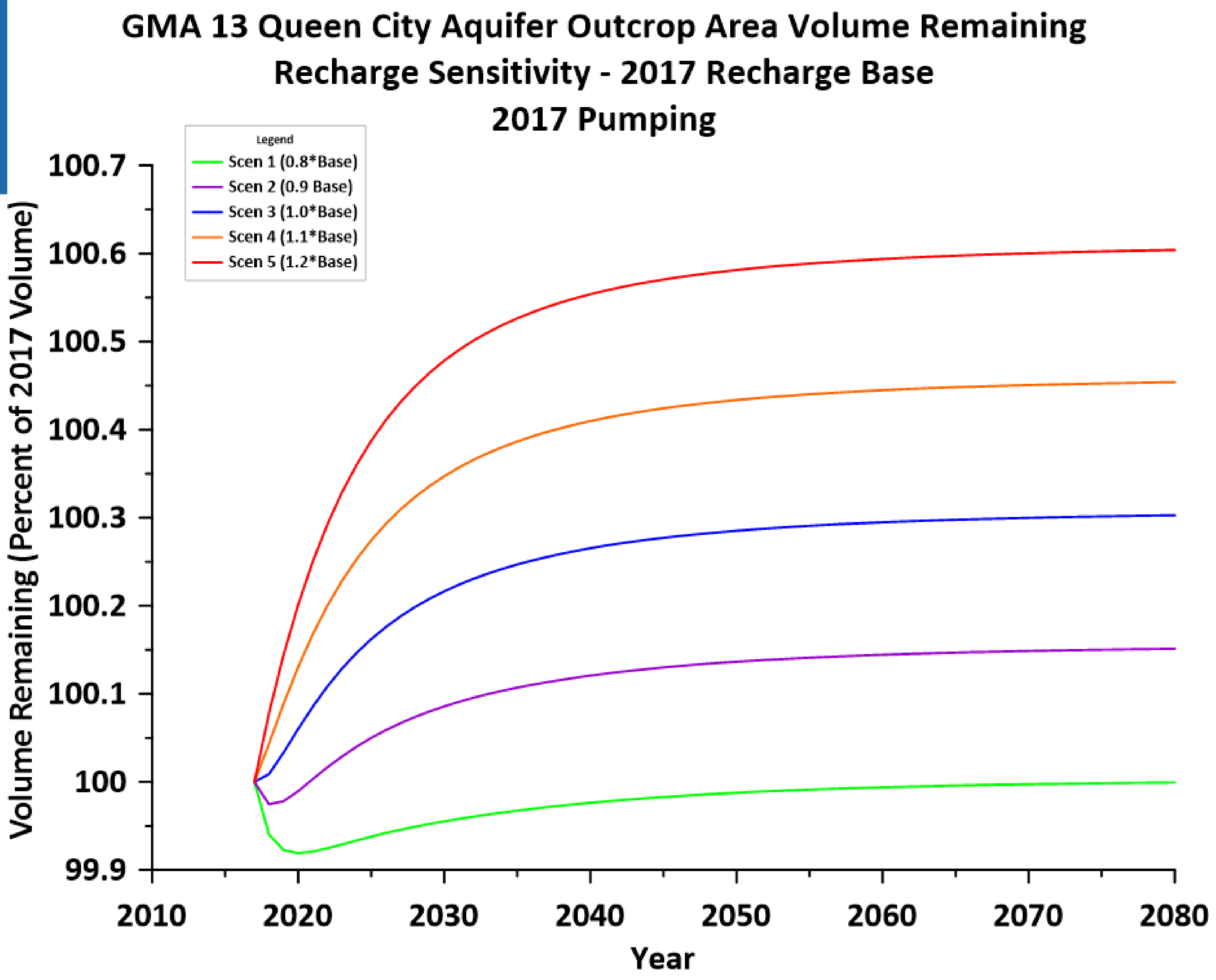
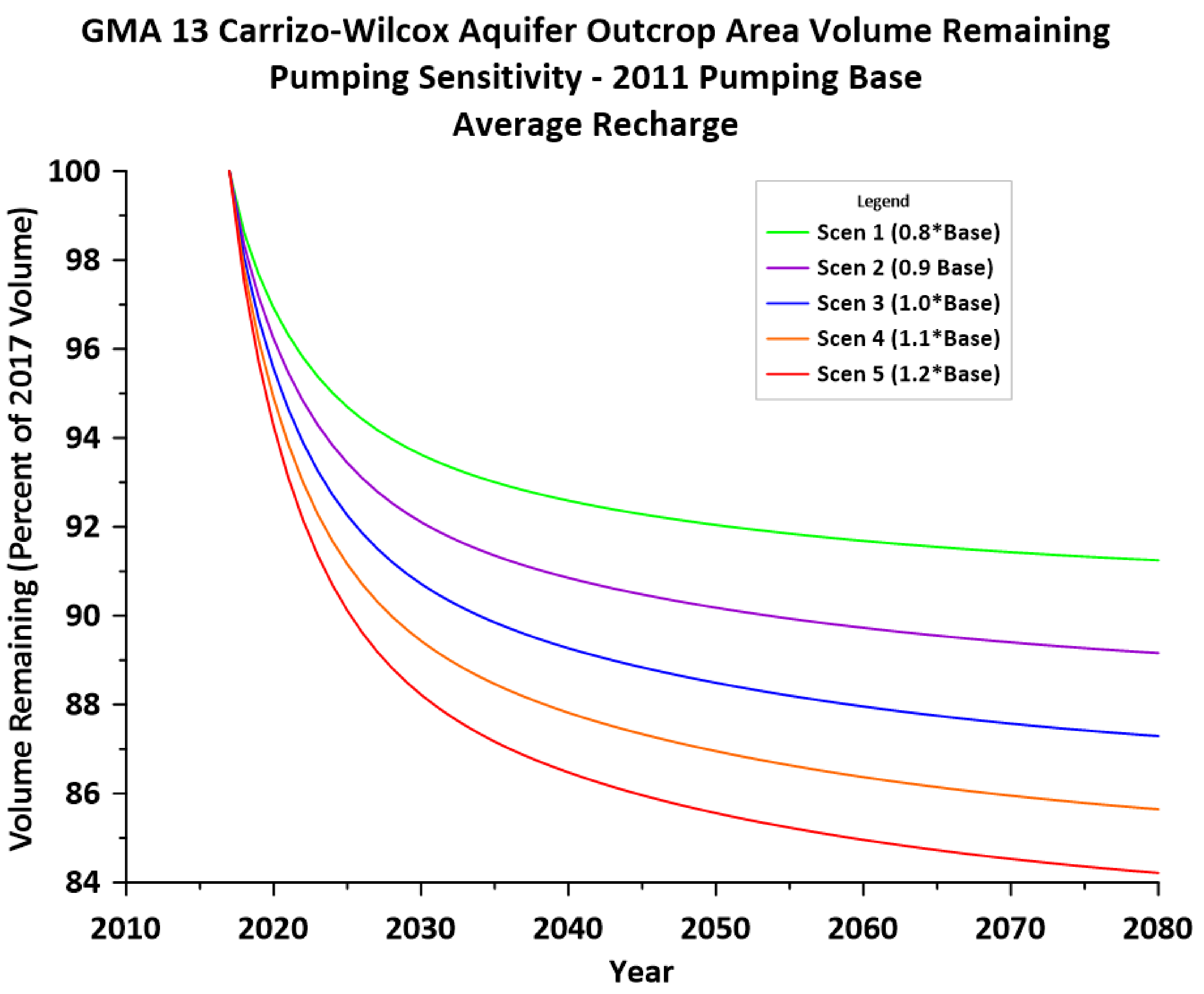
# 2017 Recharge Queen City



# 2011 Pumping Carrizo-Wilcox

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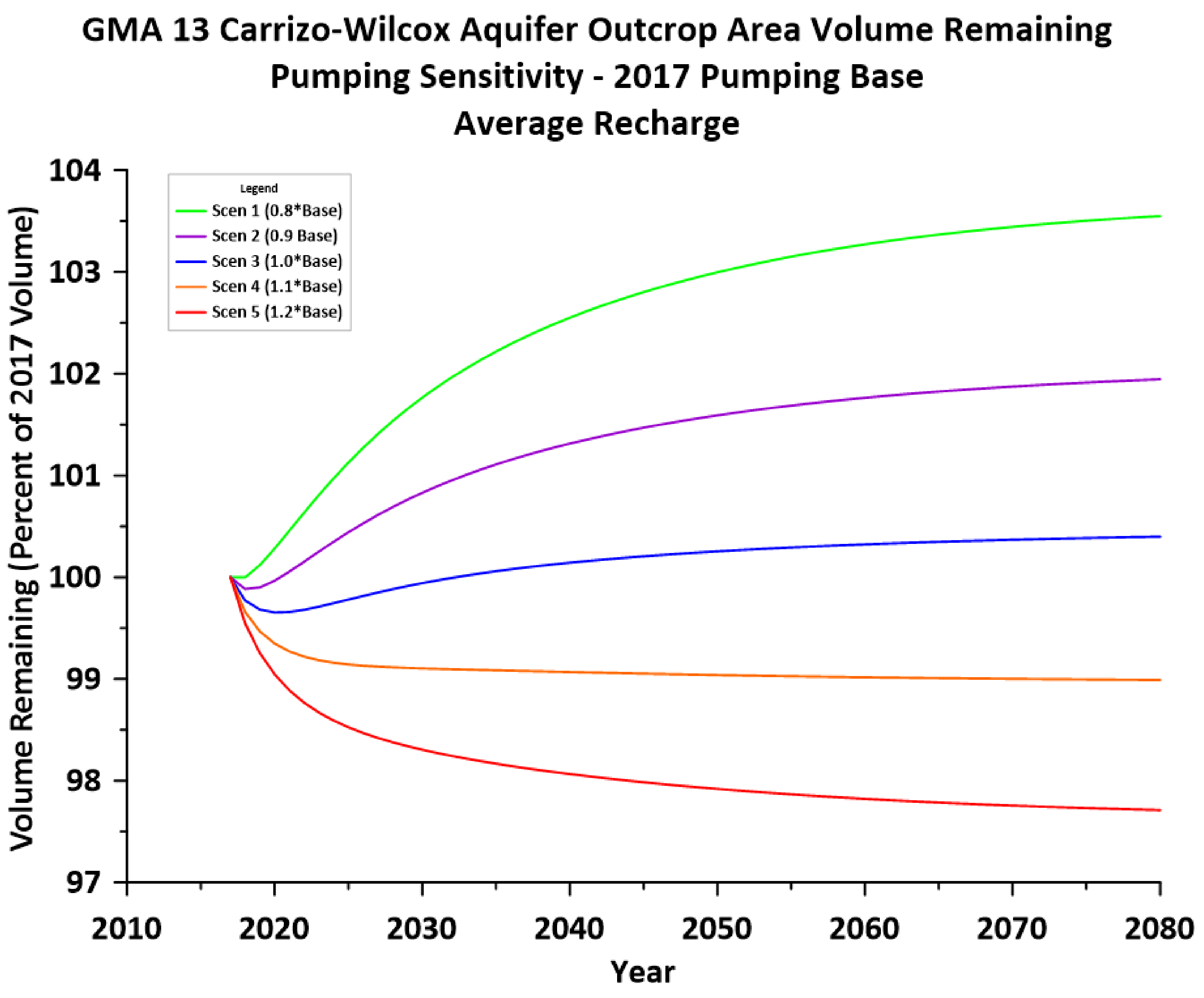
# 2017 Pumping Carrizo-Wilcox

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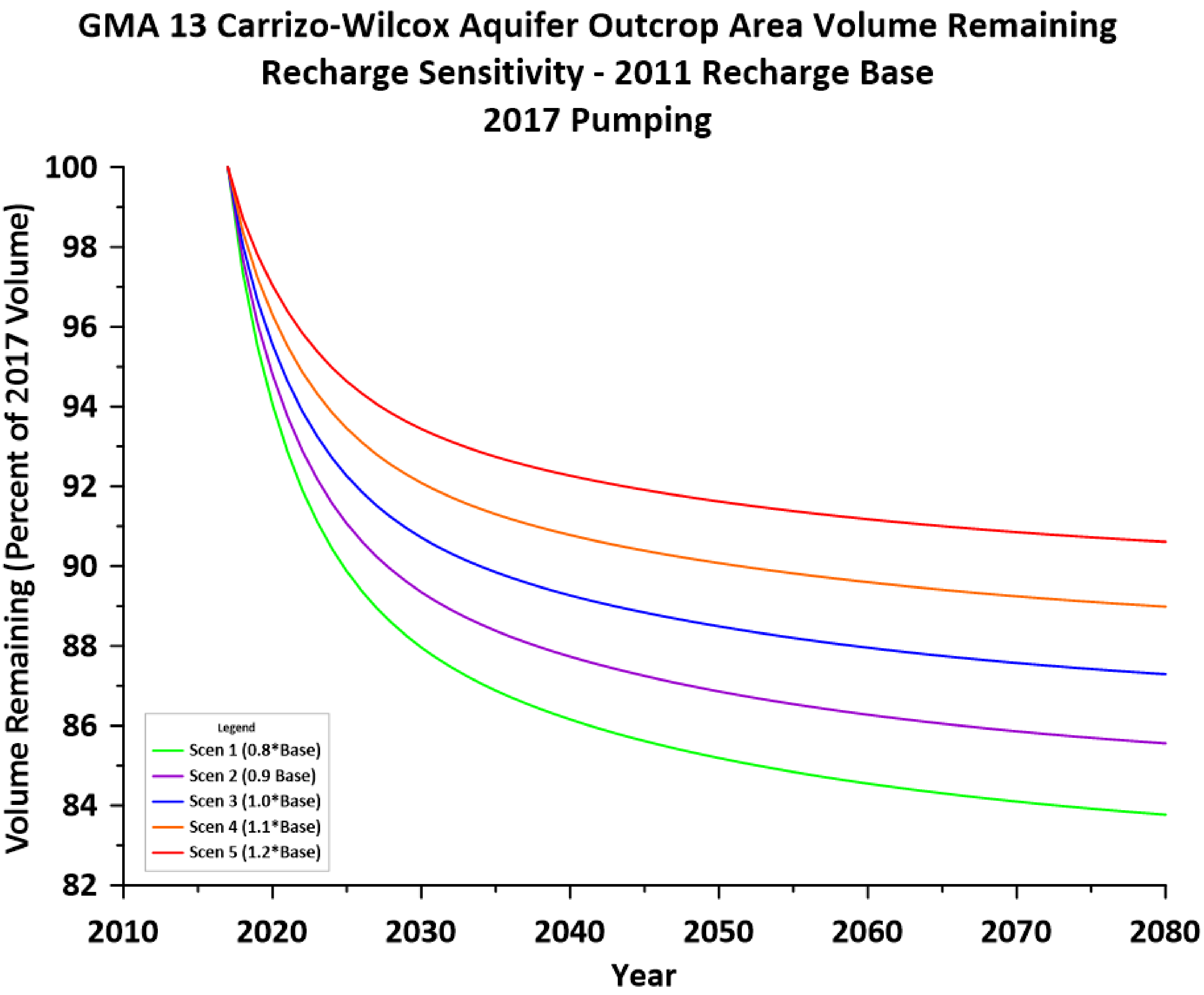
# 2011 Recharge Carrizo-Wilcox

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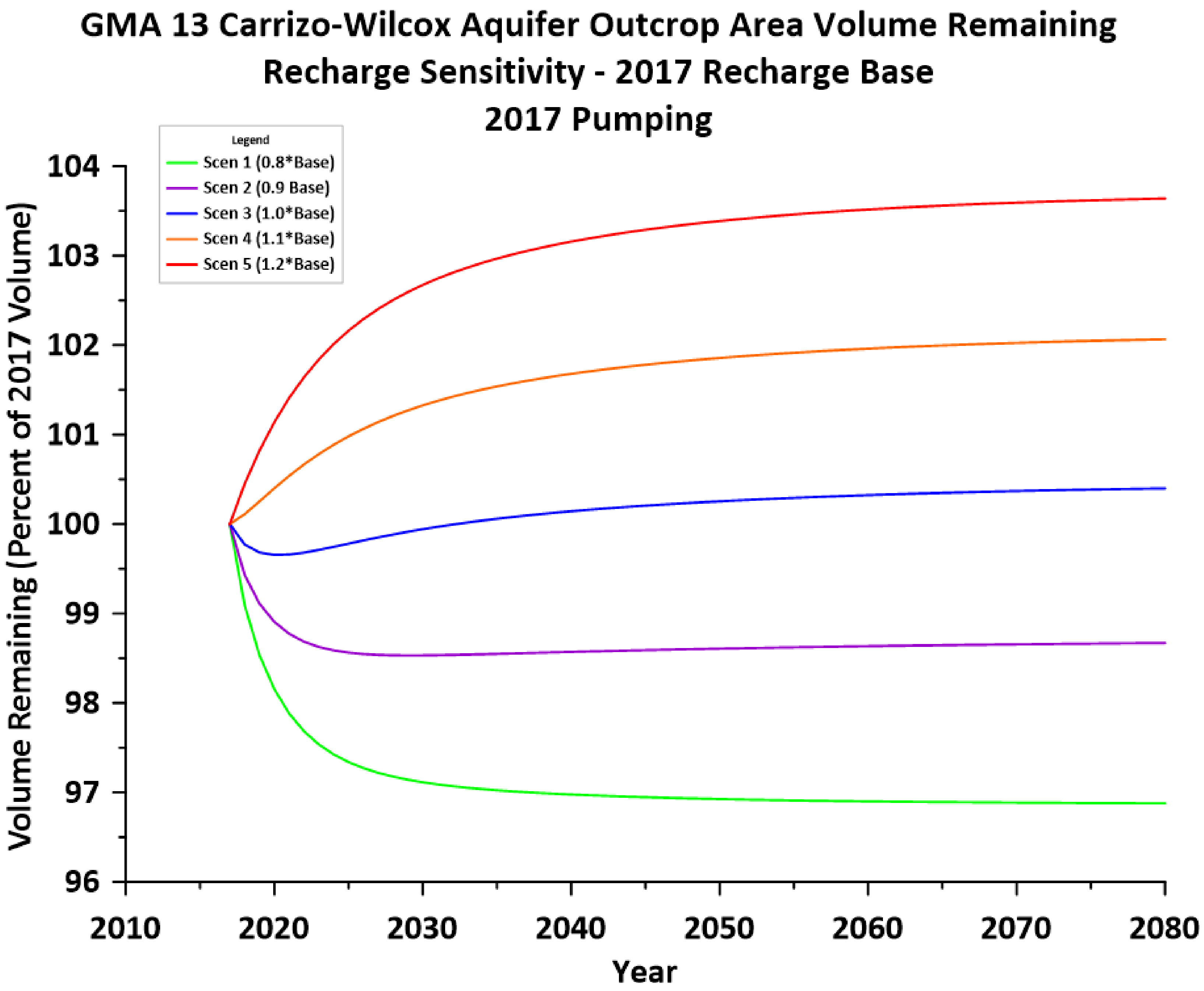
# 2017 Recharge Carrizo-Wilcox

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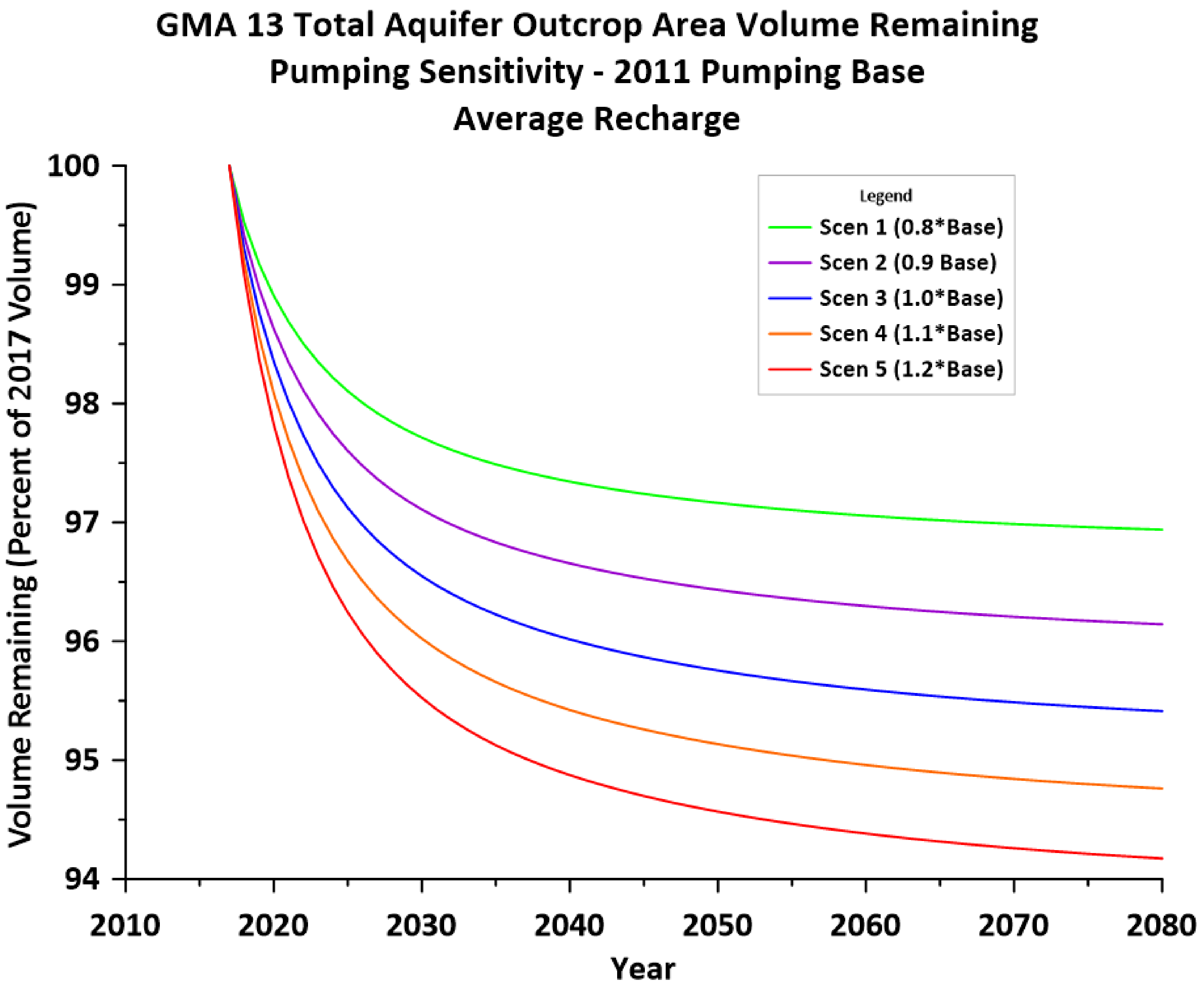
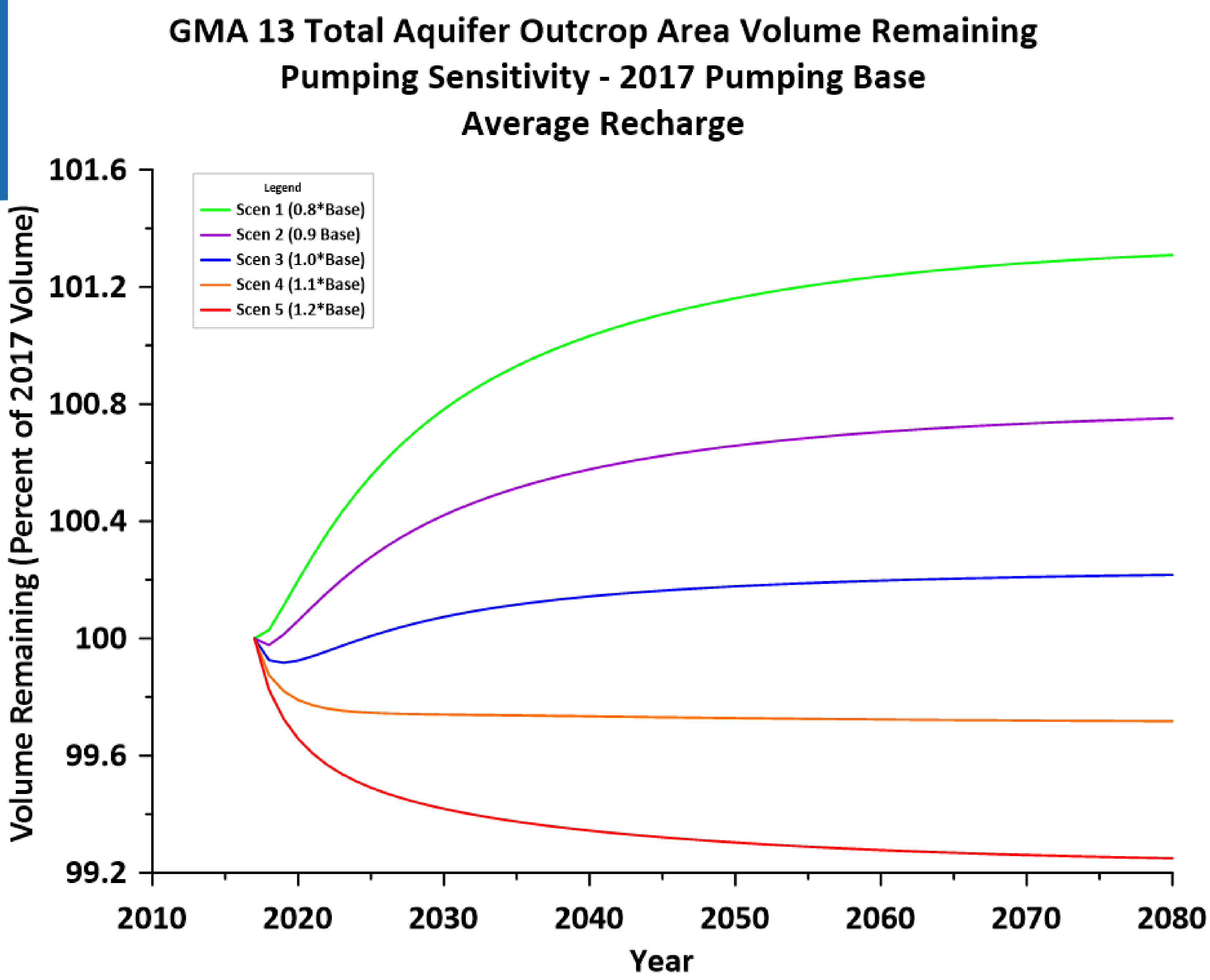
# 2011 Pumping Total




GSI ENVIRONMENTAL

# 2017 Pumping Total

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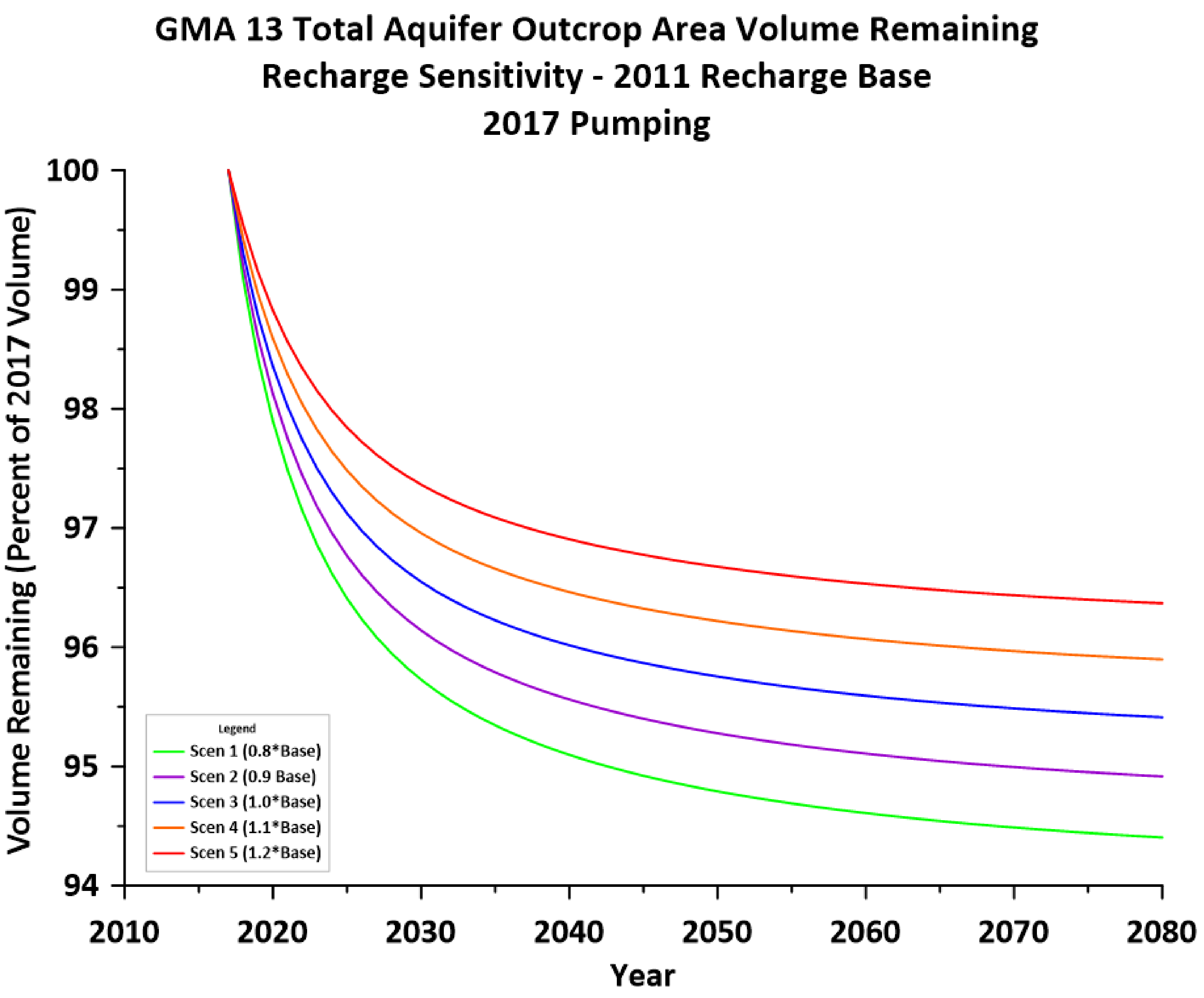
# 2011 Recharge Total

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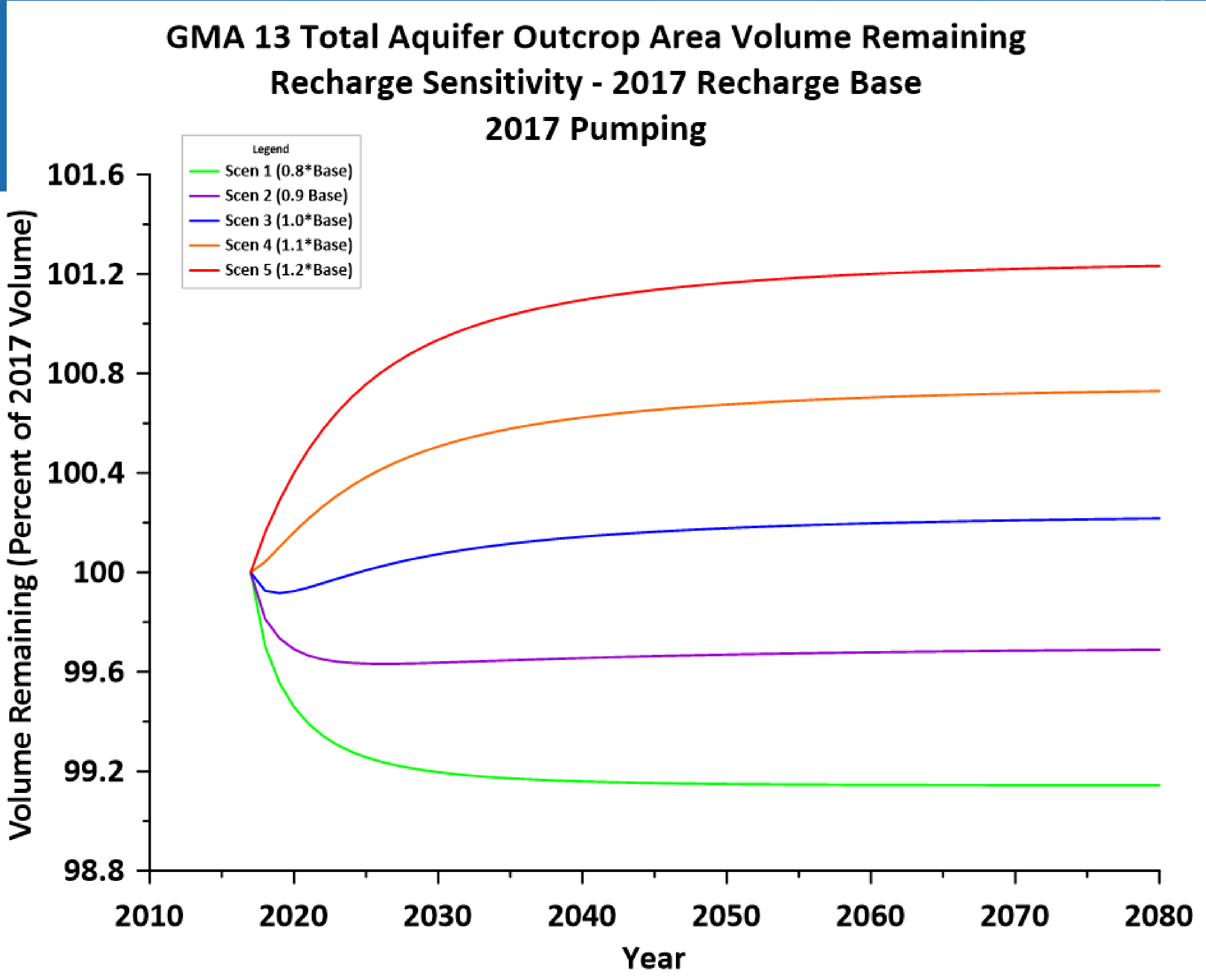
# 2017 Recharge Total

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# To Be Completed

- Calculate “new” DFC with “current” MAG (Tech Memo 4)
- Calculate “new” MAG with “current” DFC (Tech Memo 5)
- Issues:
  - Identify “new wells” from current MAG run and place in new grid
  - Not a simple matter of adjusting pumping with calibrated model wells (method used for sensitivity runs)

# 8. Takeaways for Joint Planning (DFCS and MAGS)

# Discussion Points (1)

- Smaller grid cells near surface water features
  - More accurate gradient simulation
  - More refinement in outcrop areas
- Outcrop “problem” has been addressed in new model
- New model is calibrated through 2017
  - New baseline?

# Discussion Points (2)

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- Primary DFC for all aquifers
  - Volumetric analysis shows how Queen City dominates calculation
  - Is the real interest the Carrizo-Wilcox?
  - Separate saturated thickness/outcrop volume DFCs for each aquifer?
- Secondary DFC for all aquifers
  - Downdip only or total?
  - Alternative approaches for “secondary” DFC
    - GMA 13-wide?
    - County-aquifer based?
    - GCD-aquifer based?
    - Other?

# QUESTIONS?