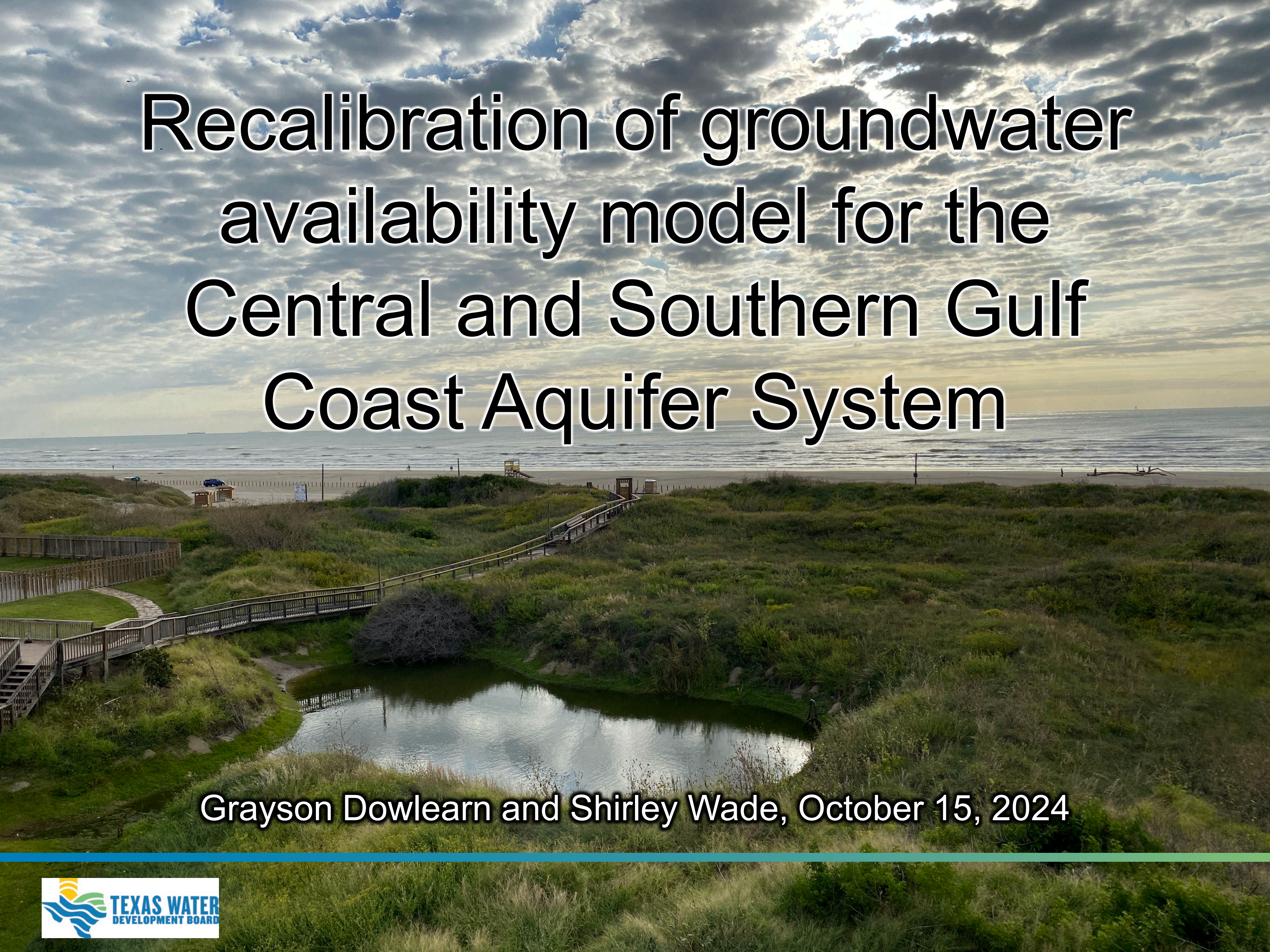

Recalibration of groundwater availability model for the Central and Southern Gulf Coast Aquifer System

Grayson Dowlearn and Shirley Wade, October 15, 2024

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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

Why are we updating the model?

TWDB GW Modeling Goals

New modeling packages complicate routine analyses at the TWDB

New Calibration Software

- Several model updates in progress at the TWDB
- New state-of-the-art software

Model Simplification

Reduce run time for modelers and stakeholders to use the model

Other Reminders

- Goliad County GCD local GAM

- Primary goals of this update:
  - Simplify some model inputs
  - Reduce several budget flow components
  - Improve hydrograph fit (trends)

Outline

- Model overview
- Was the re-calibration successful?
- How was model updated?
- Discussion and questions

In summary

- Updated model compared to 2023 model:
  - Has less error
  - Shows less bias
  - Has better hydrograph agreement
  - Has better agreement with expected groundwater budgets from rivers and general head boundaries
  - Shows expected predictive behavior and drawdown
  - Runs in 40 minutes compared to 5.5 hours

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Limitations

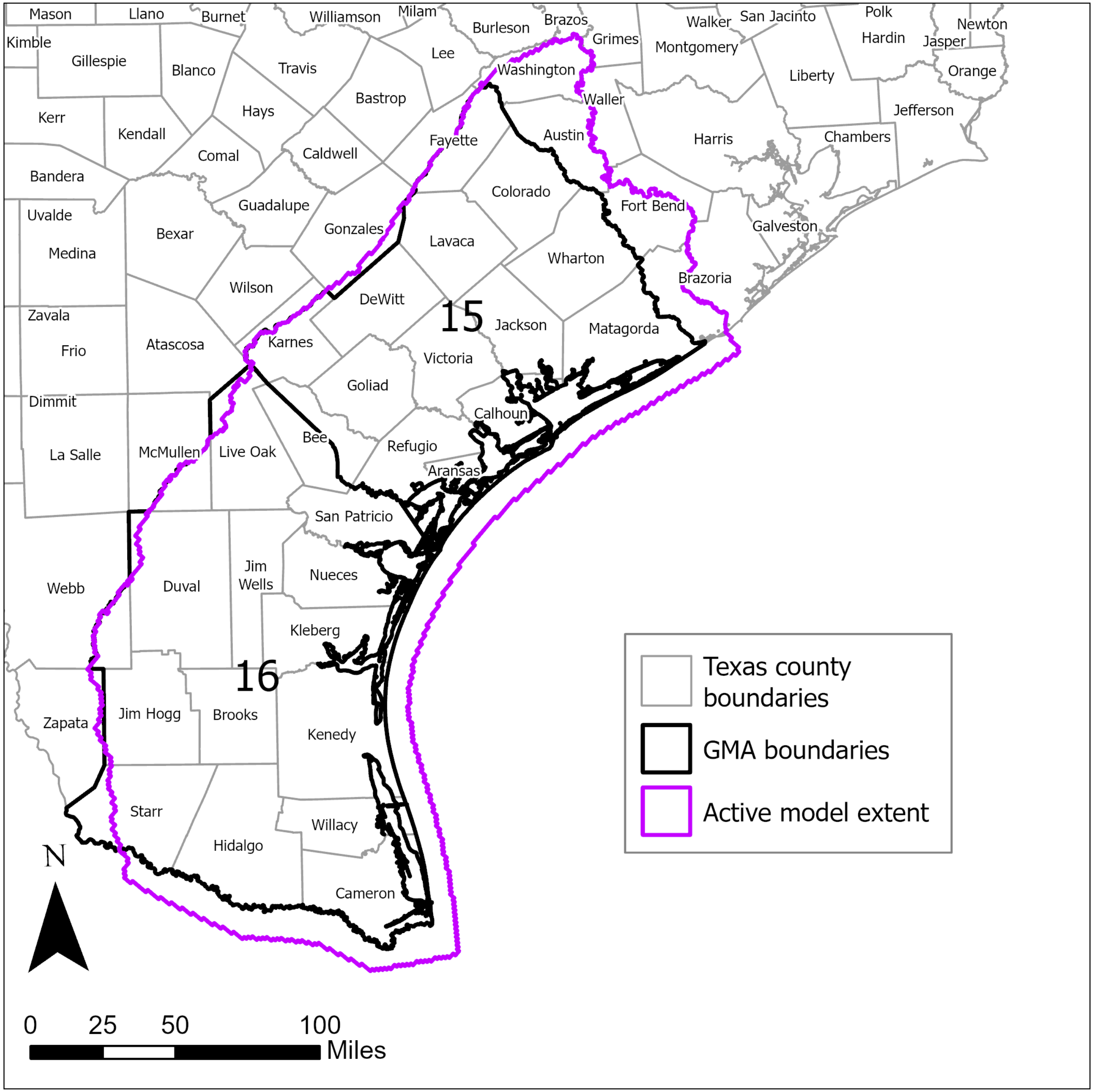
- Predicted drawdowns are not going to match the older central Gulf Coast Aquifer System and GMA 16 models
- Still local limitations
- Individual well drawdowns are not necessarily captured at individual nodes
- Land surface subsidence is included but was not calibrated

Model overview

- Spatial extent covers GMAs 15 and 16
- Temporal extent covers 1980 to 2015
- Model completed in MODFLOW-USG
- 4 layers covering
  - Layer 1: Chicot Aquifer and alluvium aquifer
  - Layer 2: Evangeline Aquifer
  - Layer 3: Burkeville Unit
  - Layer 4: Jasper Aquifer with portions of Catahoula Formation
- Boundaries:
  - General Head
  - Rivers
  - Drains
  - Time-variant Specified-heads
  - No flows

Spatial extent

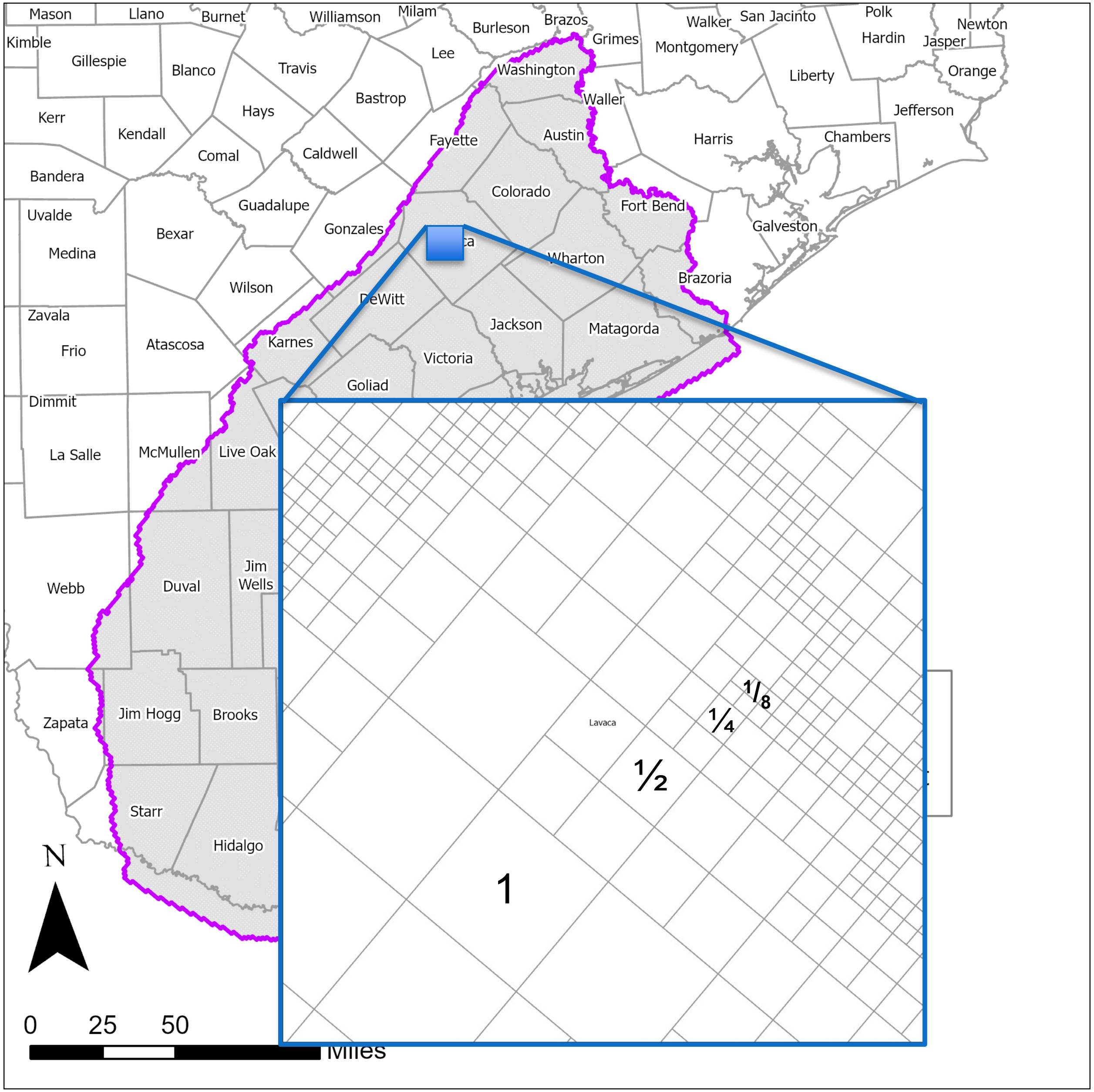
Covers entire Gulf Coast Aquifer System extent within GMAs 15 and 16



MODFLOW-USG Grid

Grid is unstructured, with grid refinement along selected rivers and streams. Node areas step from larger to smaller going from:

- 1 mile by 1 mile to
- ½ mile by ½ mile to
- ¼ mile by ¼ mile to
- 1/8 mile by 1/8 mile



Model layering

4 layers of combined geologic units

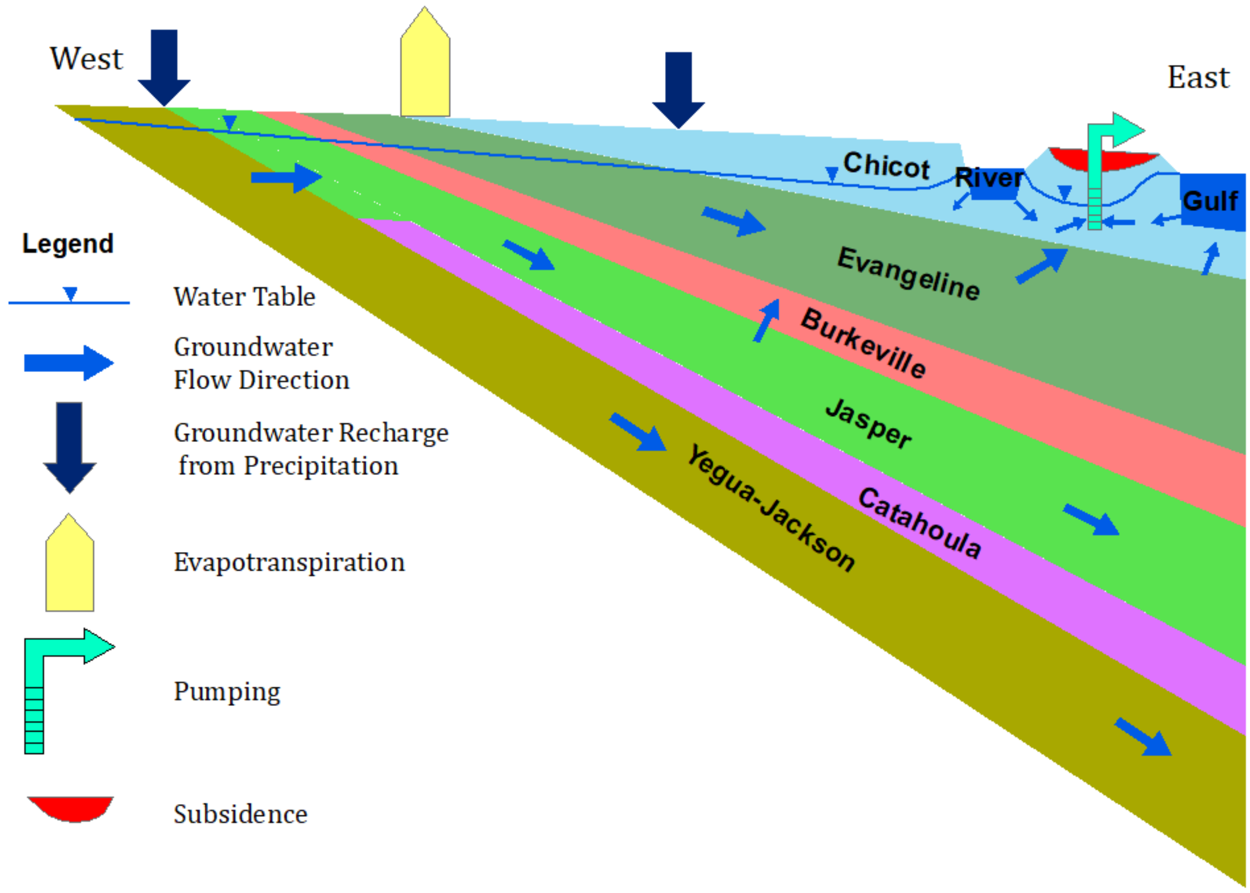
Layer 4 includes the sandy portion of the Catahoula Formation but not the less permeable portions which are further down-dip.

<table>
<tr><th>ERA</th><th colspan="2">Period</th><th>Epoch</th><th>Stratigraphic Unit</th><th colspan="3">Hydrogeologic Unit</th></tr>
<tr><td rowspan="10">Cenozoic</td><td rowspan="4">Quaternary</td><td rowspan="4"></td><td>Holocene</td><td>Alluvium and Eolian Sand</td><td>Alluvium /Eolian Aquifer</td><td rowspan="4">Model Layer 1</td><td rowspan="10">Gulf Coast Aquifer System</td></tr>
<tr><td rowspan="3">Pleistocene</td><td>Beaumont Formation</td><td rowspan="3">Chicot Aquifer</td></tr>
<tr><td>Lissie Formation</td></tr>
<tr><td>Willis Formation</td></tr>
<tr><td rowspan="6">Tertiary</td><td rowspan="5">Neogene</td><td>Pliocene</td><td>Goliad Formation</td><td rowspan="2">Evangeline Aquifer</td><td rowspan="2">Model Layer 2</td></tr>
<tr><td rowspan="4">Miocene</td><td>Upper Fleming Formation</td></tr>
<tr><td>Middle Fleming Formation</td><td>Burkeville Unit</td><td>Model Layer 3</td></tr>
<tr><td>Lower Fleming Formation</td><td rowspan="3">Jasper Aquifer</td><td rowspan="3">Model Layer 4</td></tr>
<tr><td>Oakville Formation</td></tr>
<tr><td>Paleogene</td><td>Oligocene</td><td>Catahoula Formation (sand)</td></tr>
</table>

Model layering

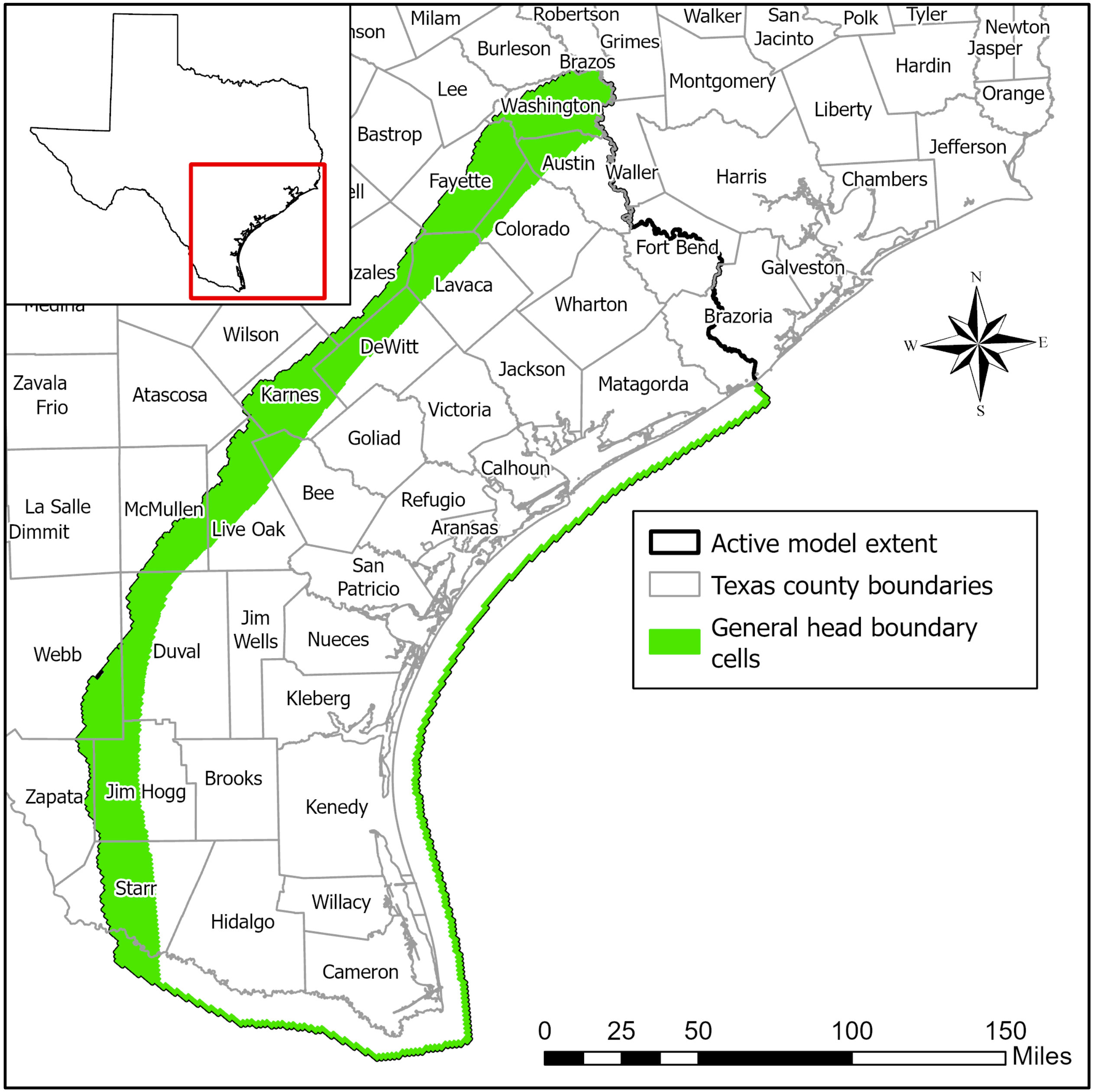
4 layers of combined geologic units

Layer 4 includes the sandy portion of the Catahoula Formation but not the less permeable portions which are further down-dip.



General head boundary

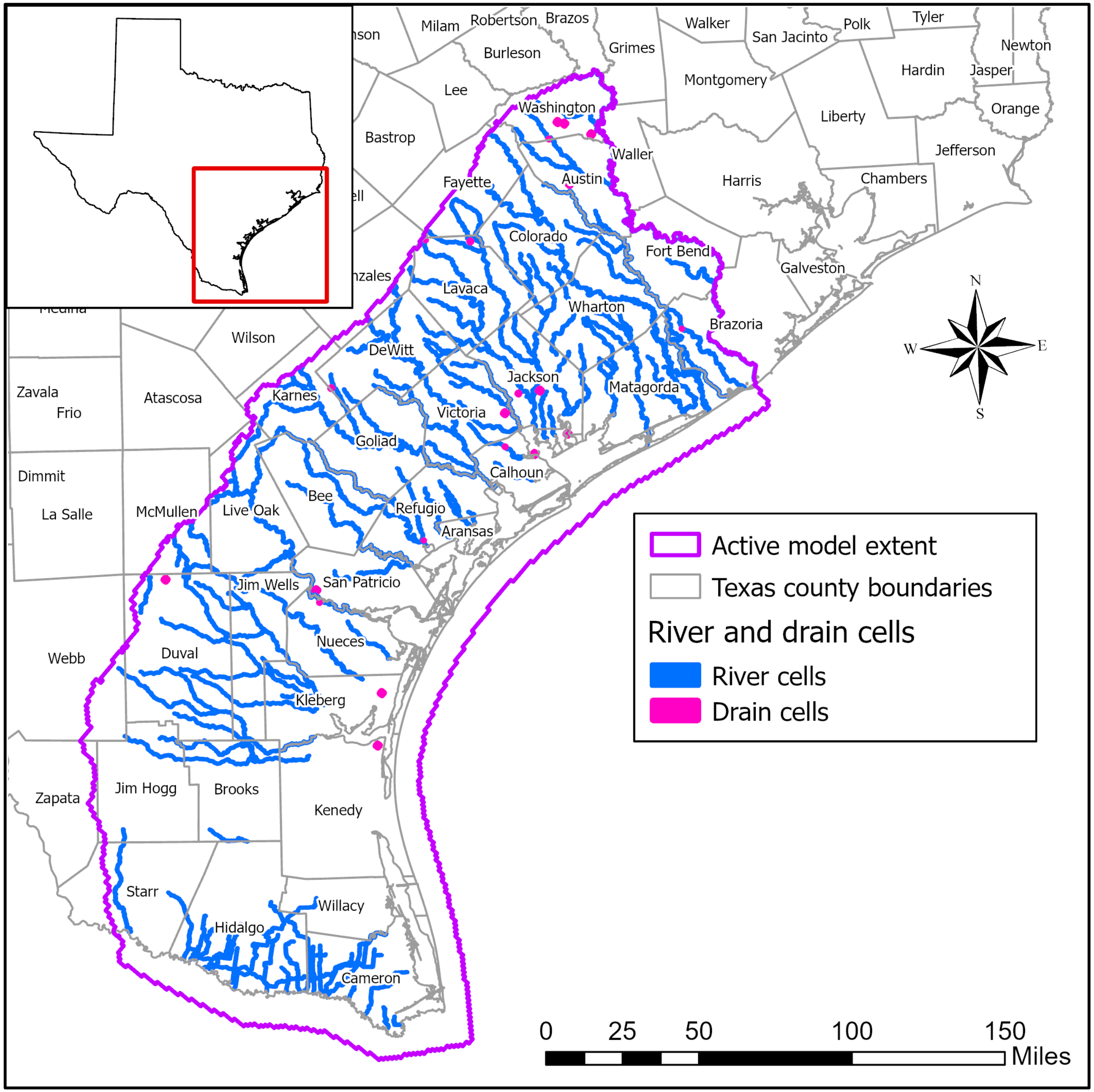
Simulates interaction with aquifers outside of active model area



River and drains

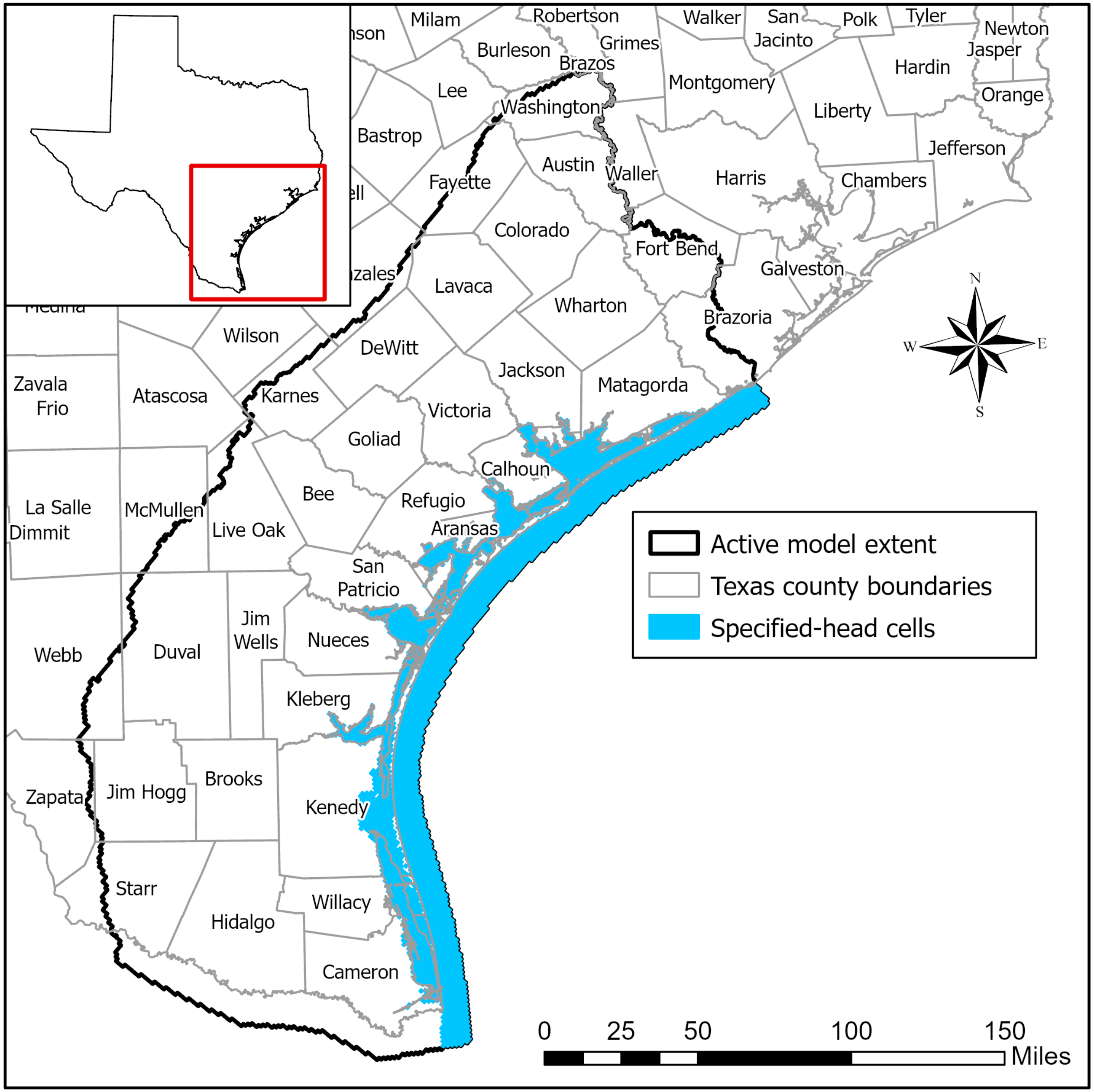
River used to simulate selected streams.

Drains used to simulate springs



Specified-head boundary

Used to simulate interaction with the Gulf of Mexico at sea level



No flow boundaries

- No flow boundaries occur in the following locations:
  - Northeast boundary along the Brazos River
  - Northwest boundary where Gulf Coast Aquifer formations pinch out
  - Base of model where general head boundary does not exist

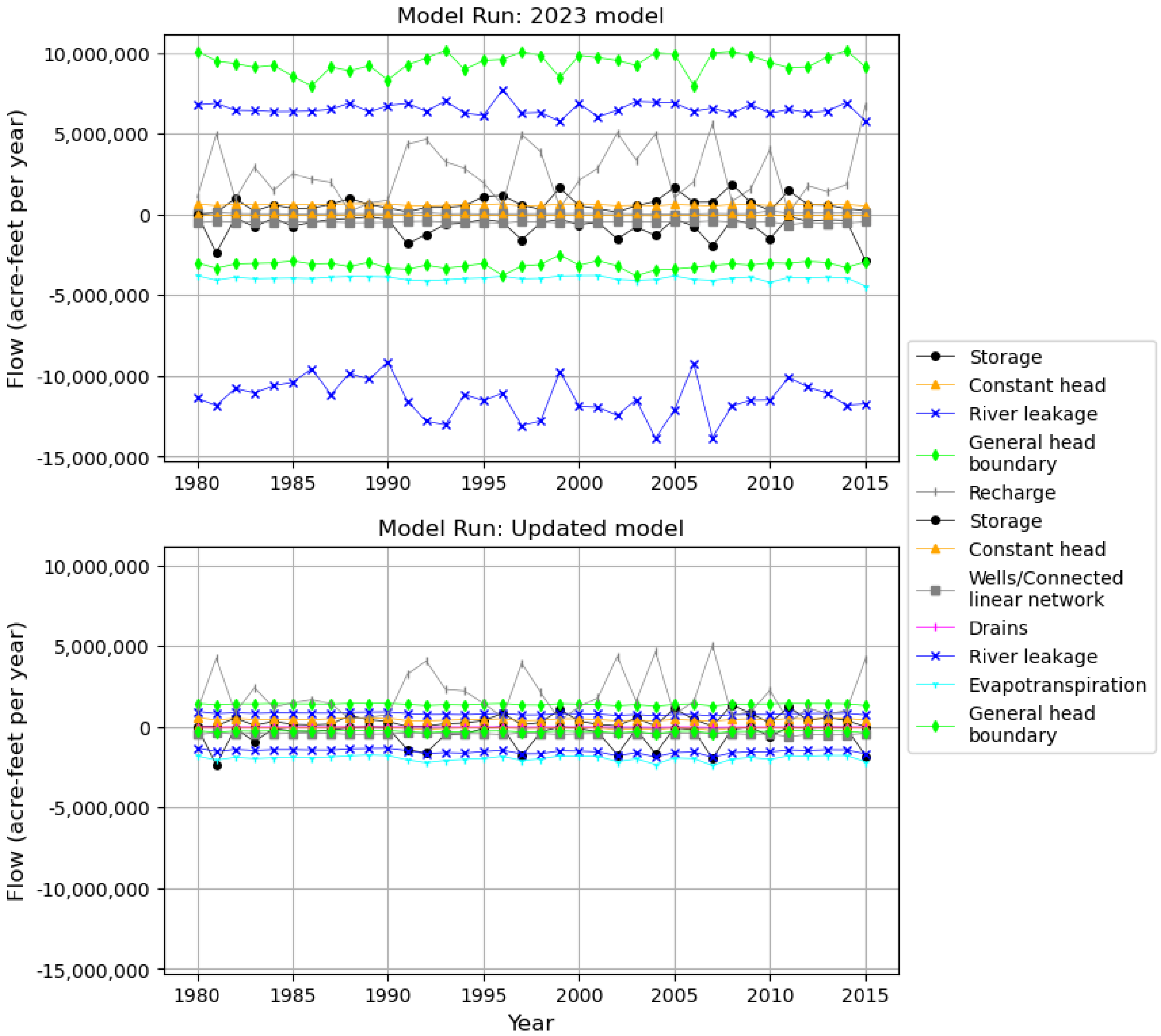
Was re-calibration successful?

- Groundwater budget improvements
- Hydrograph agreement
- Expected drawdown behavior
- Model run times reduced
- Improved model statistics

Groundwater budgets

Flow values through the GHB and RIV boundary conditions were much higher than seen in previous models.

Model-wide groundwater budgets show improvement with a large reduction in flow values for the River leakage and General head boundary (in addition, recharge is on average 25% less than in the 2023 model).



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Hydrograph agreement

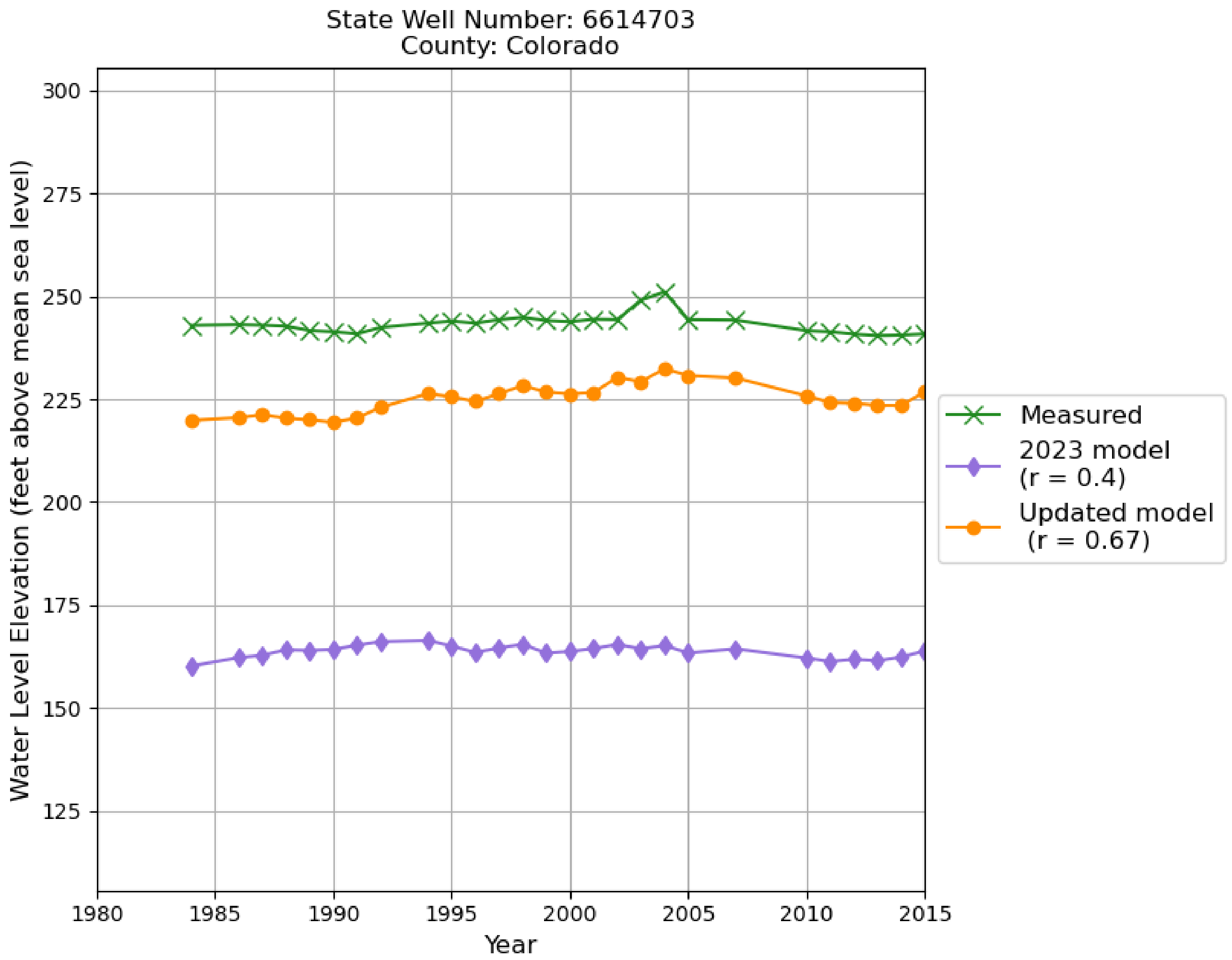
- Correlation coefficient quantifies the match in trends between modeled and measured water levels
- The higher the correlation coefficient value, the better the match with the trend

	2023 model	Updated model
Average correlation coefficient at each well	0.22	0.58

Hydrograph agreement

What do improved correlation coefficients look like?

Low residuals and high hydrograph correlation demonstrate a model's ability to simulate trends and water levels



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Hydrograph agreement

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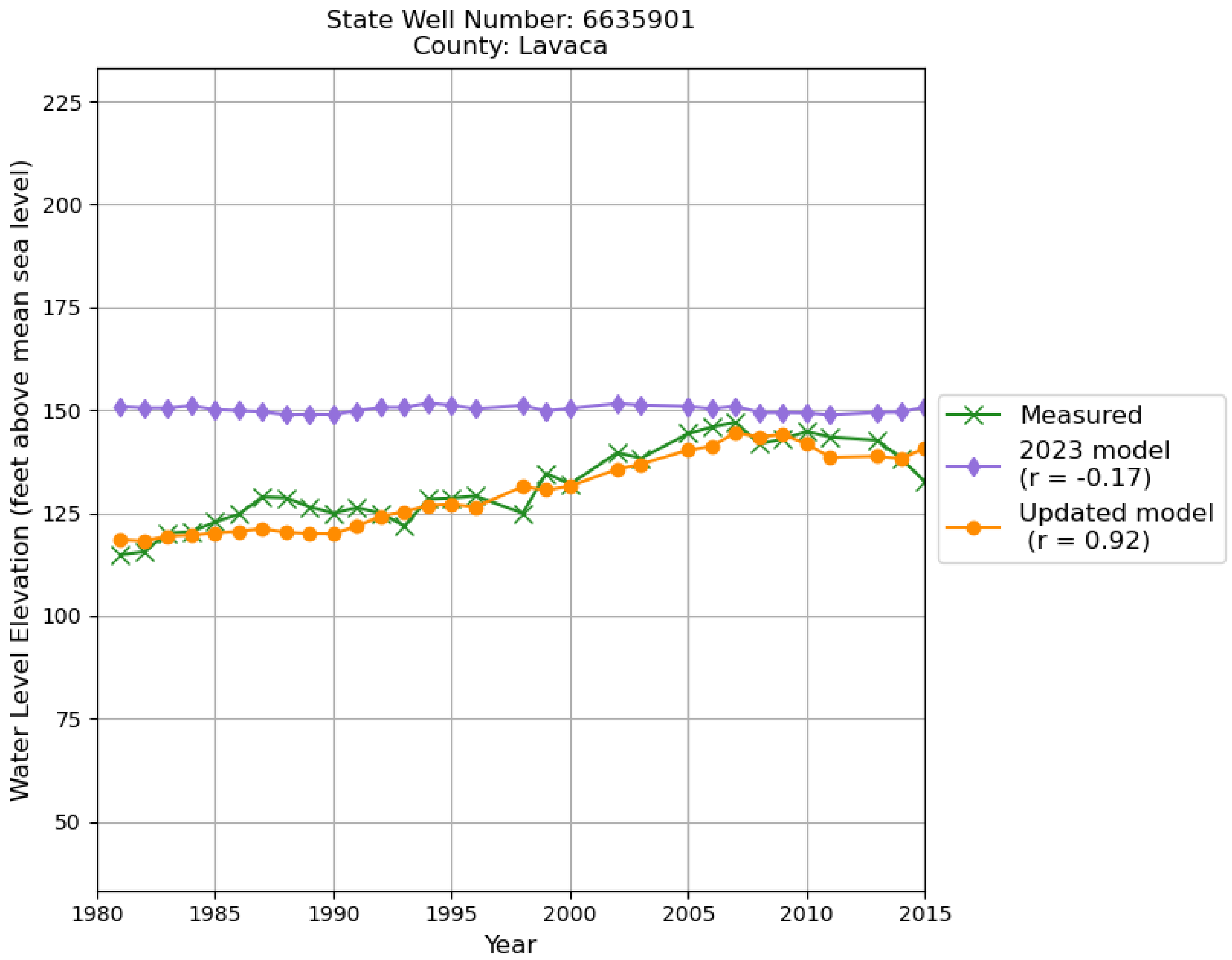
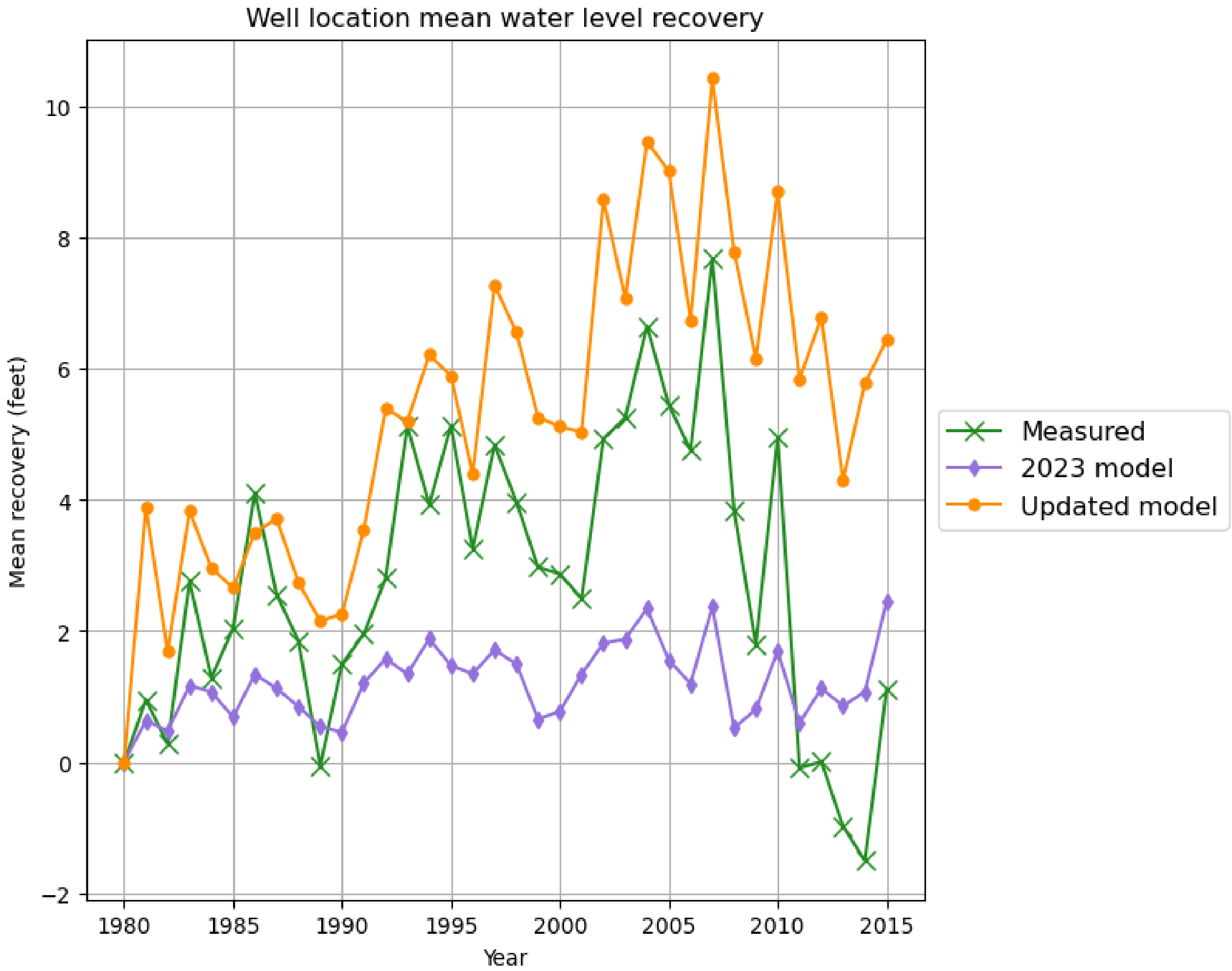


Drawdown/recovery behavior

Comparison of the mean of corresponding simulated water levels to measured water levels per year.

Measured water levels show rising water levels from 1980 to 2007 and then a sharp decline from 2007 to 2014.

Updated model water levels better simulate the magnitude of aquifer response than 2023 model.

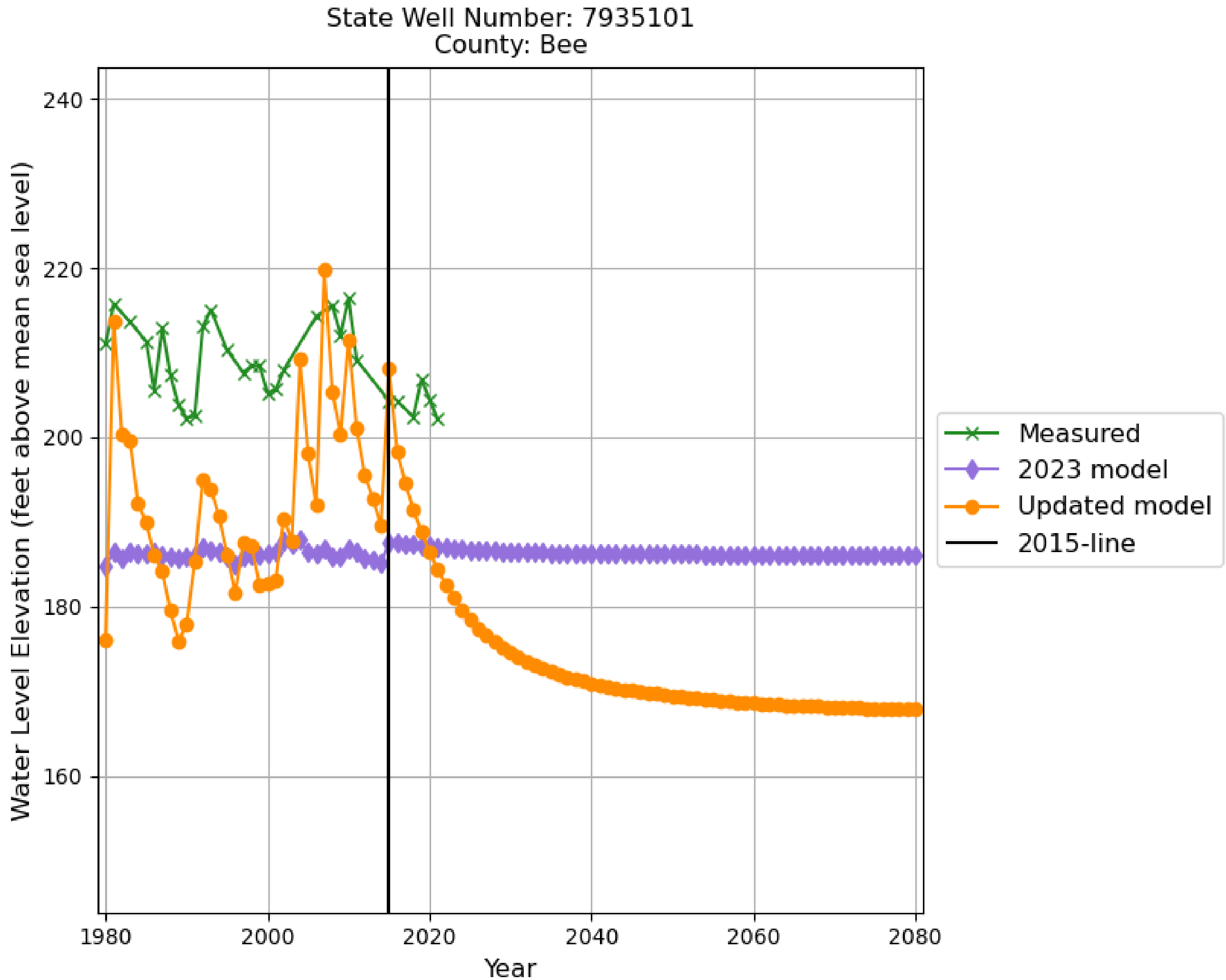


Predictive behavior

Test predictive model runs with median recharge applied to all stress periods after 2015 and predictive pumping from the 2021 joint planning cycle (MAGs)

2023 model shows minor drawdown after 2015 but then flat lines around 2030

Updated model shows a strong immediate decline after 2015 but starts to hit steady-state around 2070

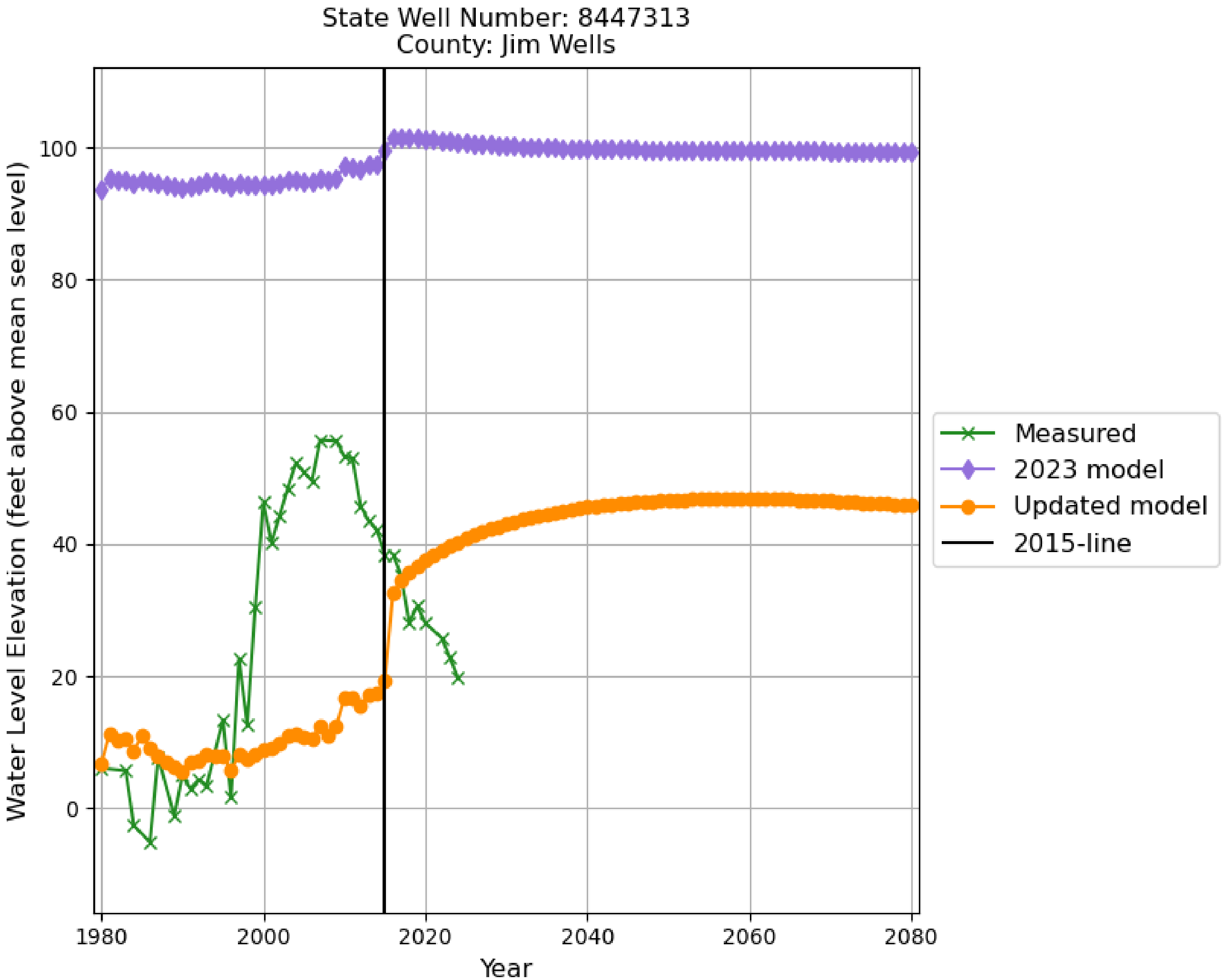


Predictive behavior

Test predictive model runs with median recharge applied to all stress periods after 2015 and predictive pumping from the 2021 joint planning cycle (MAGs)

2023 model shows a decline after 2015 until 2030 when it begins to flat-line

Updated model shows a sharp rebound after 2015 and gradually tapers off until it starts declining around 2060



Drawdown behavior

GMA 15 DFC comparisons:

Drawdown from future pumping provided by GMA 15 during the 2021 joint planning cycle.

GMA-wide drawdowns increased in Updated model. Only two DFC splits show less drawdown than the 2023 model

County	Aquifer	2021 DFC	2023 model	Updated model
GMA 15	Gulf Coast Aquifer System	13	0.76	4.45
Aransas	Gulf Coast Aquifer System	0	0.26	0.78
Bee	Gulf Coast Aquifer System	7	1.84	4.82
Calhoun	Gulf Coast Aquifer System	5	0.02	1.56
De Witt	Gulf Coast Aquifer System	17	3.2	7.88
Fayette	Gulf Coast Aquifer System	44	-1.34	-1.82
Jackson	Gulf Coast Aquifer System	15	0.3	4.42
Karnes	Gulf Coast Aquifer System	22	0.11	-0.14
Lavaca	Gulf Coast Aquifer System	18	2.14	4.59
Refugio	Gulf Coast Aquifer System	5	1.65	4.47
Victoria	Gulf Coast Aquifer System	5	2.41	6.38
Colorado	Chicot and Evangeline	17	-0.57	9.5
Colorado	Jasper	25	-0.91	7.35
Goliad	Chicot	4	2.41	3.76
Goliad	Evangeline	-2	2.04	3.03
Goliad	Burkeville	7	2	3.46
Goliad	Jasper	14	1.94	3.95
Matagorda	Chicot and Evangeline	11	-0.14	0.4
Wharton	Chicot and Evangeline	15	-0.89	5.92

Drawdown behavior

GMA 16 DFC comparisons:

Drawdown from future pumping provided by GMA 16 during the 2021 joint planning cycle.

GMA-wide drawdowns increased in Update model. Only one DFC split shows less drawdown than the 2023 model

GCD	Aquifer	2021 DFC	2023 model	Updated model
Bee GCD	Gulf Coast Aquifer System	93	4.84	23.33
Live Oak UWCD	Gulf Coast Aquifer System	45	4.56	16.89
McMullen GCD	Gulf Coast Aquifer System	12	7.54	2.16
Red Sands GCD	Gulf Coast Aquifer System	60	1.39	4.49
Kenedy County GCD	Gulf Coast Aquifer System	27	0.71	1.34
Brush Country GCD	Gulf Coast Aquifer System	89	2.41	8.77
Duval County GCD	Gulf Coast Aquifer System	137	3.09	28.84
San Patricio County GCD	Gulf Coast Aquifer System	69	6.2	23.61
Starr County GCD	Gulf Coast Aquifer System	94	1.84	5.22
ND Cameron	Gulf Coast Aquifer System	119	0.25	1.97
ND Hidalgo	Gulf Coast Aquifer System	138	1.05	6.13
ND Kleberg	Gulf Coast Aquifer System	21	0.03	0.07
ND Nueces	Gulf Coast Aquifer System	26	1.69	3.68
ND Webb	Gulf Coast Aquifer System	161	-0.07	-0.01
ND Willacy	Gulf Coast Aquifer System	44	0.38	1.03

Model run times

- Model run times reduced
  - 2023 model run time was 5.5 hours
  - Updated model run time is 40 minutes

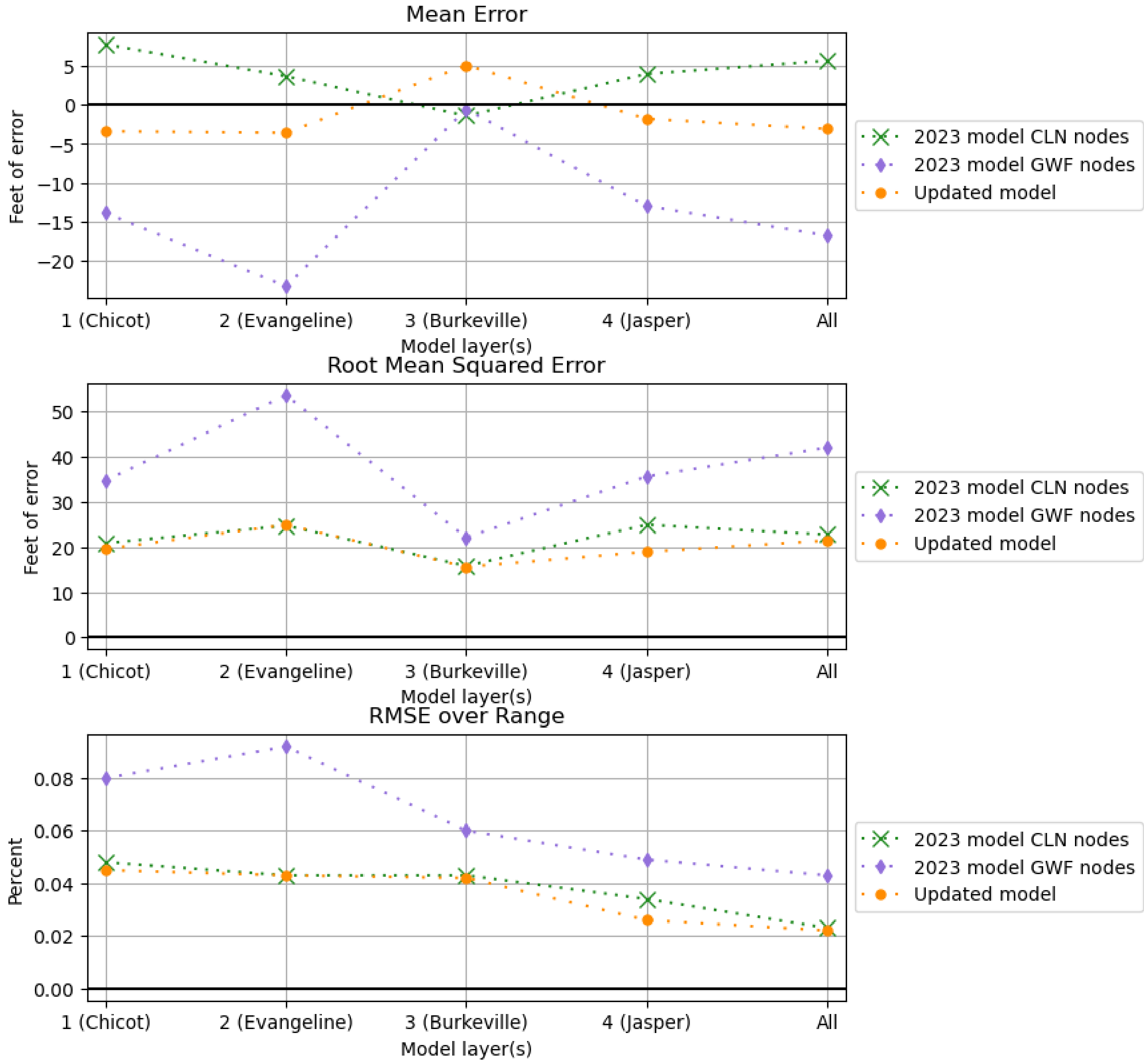
Model statistics

- Two sets of statistics for the 2023 model:
  - One from a combination of modeled water levels from CLN nodes and groundwater flow (GWF) nodes (as documented in the 2023 model report)
  - One from just GWF nodes
- Statistics for the updated model only come from GWF nodes since CLN package was removed

Model statistics

Model-wide statistical comparison

The closer the value to zero, the better the statistic



Was re-calibration successful?

- Updated model:
  - Has less error
  - Shows less bias
  - Has better hydrograph agreement
  - Has better agreement with expected groundwater budgets from rivers and general head boundaries
  - Shows expected predictive behavior and drawdown
  - Runs in 40 minutes compared to 5.5 hours

How was model updated?

- Model simplification
- Re-calibration using state-of-the-art calibration software

Model simplifications

- Packages removed:
  - Connected linear network (CLN) package
    - Caused long run times
    - Represented pumping wells and the Rio Grande
    - Added pumping to Well (WEL) package
    - Added Rio Grande to River (RIV) package
  - Sink and return flow (QRT) package
    - Dependent upon CLN package
    - Represented irrigation return flow volumes
    - Added return flow to Recharge (RCH) package

Model simplifications

Revised packages	Description
River (RIV)	- Added Rio Grande as river cells from the CLN package - Intermittent streams converted to drain cells - RIV head elevations set to higher of 8 feet below top elevation of grid cell or sea level - RIV bed elevations set to 13 feet below top elevation of grid cell
Drain (DRN)	- Converted intermittent streams from river to drain cells - DRN elevation set to 8 feet below top elevation of grid cell for the converted river to drain cells
Well (WEL)	- Converted pumping from CLN nodes to GWF nodes
Time-variant Specified-head (CHD)	- Removed CLN data included in package
Sparse matrix solver (SMS)	- Closure criteria relaxed to MODFLOW-USG user guide recommended values (saved 1 hour of model run time)

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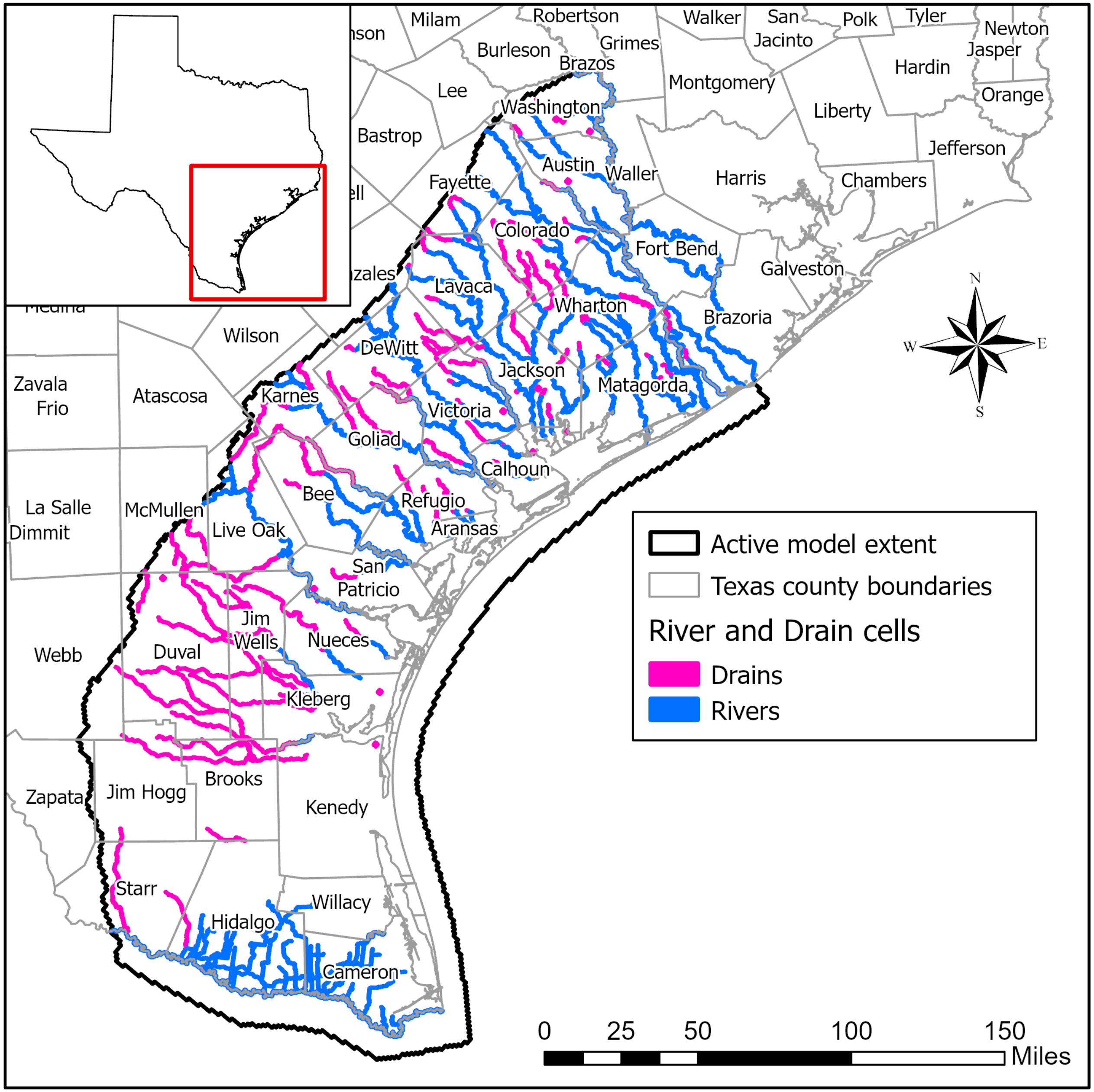
Rivers and drains

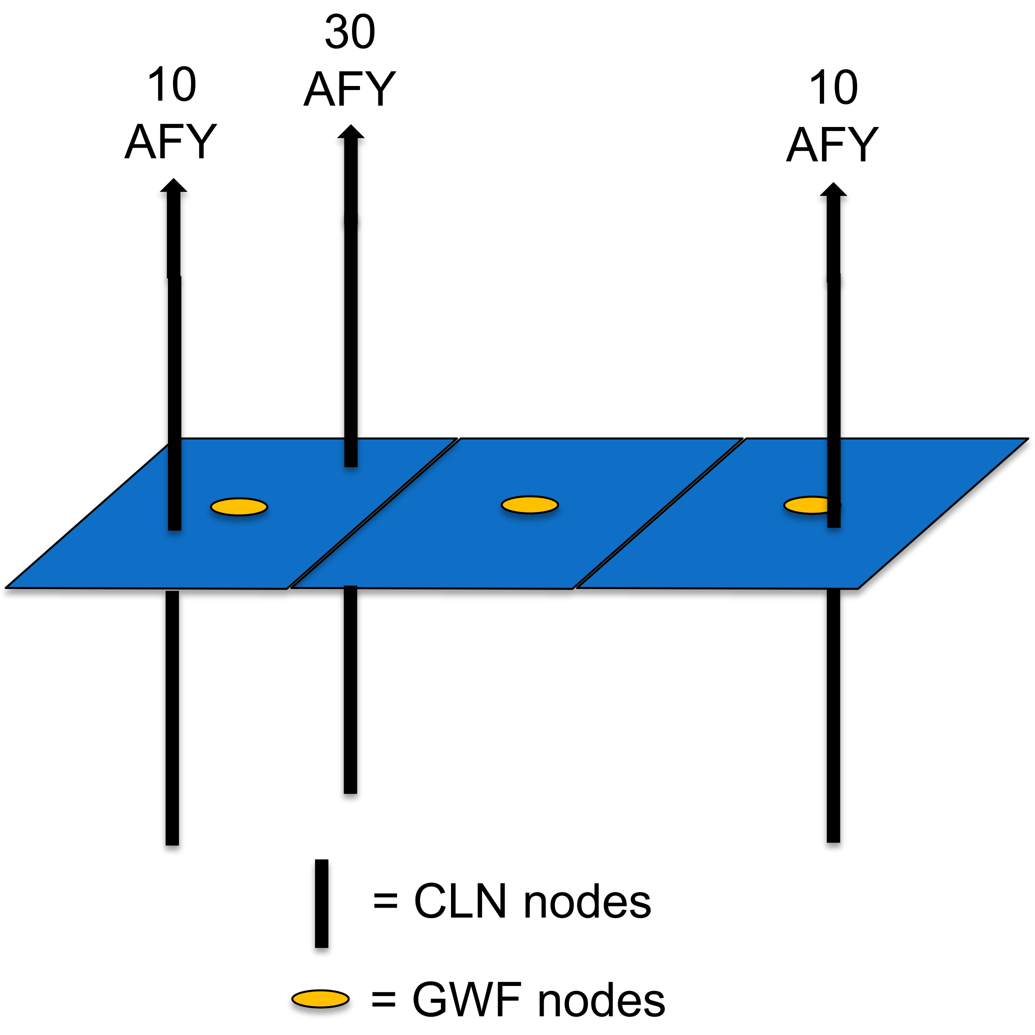
RIV and DRN packages revised by converting river cells to drain cells.



Model revisions

Pumping volume moved from CLN nodes to groundwater flow nodes (GWF) in WEL package

GWF nodes assumed the sum of pumping volumes from all CLN nodes contained within the GWF node boundary



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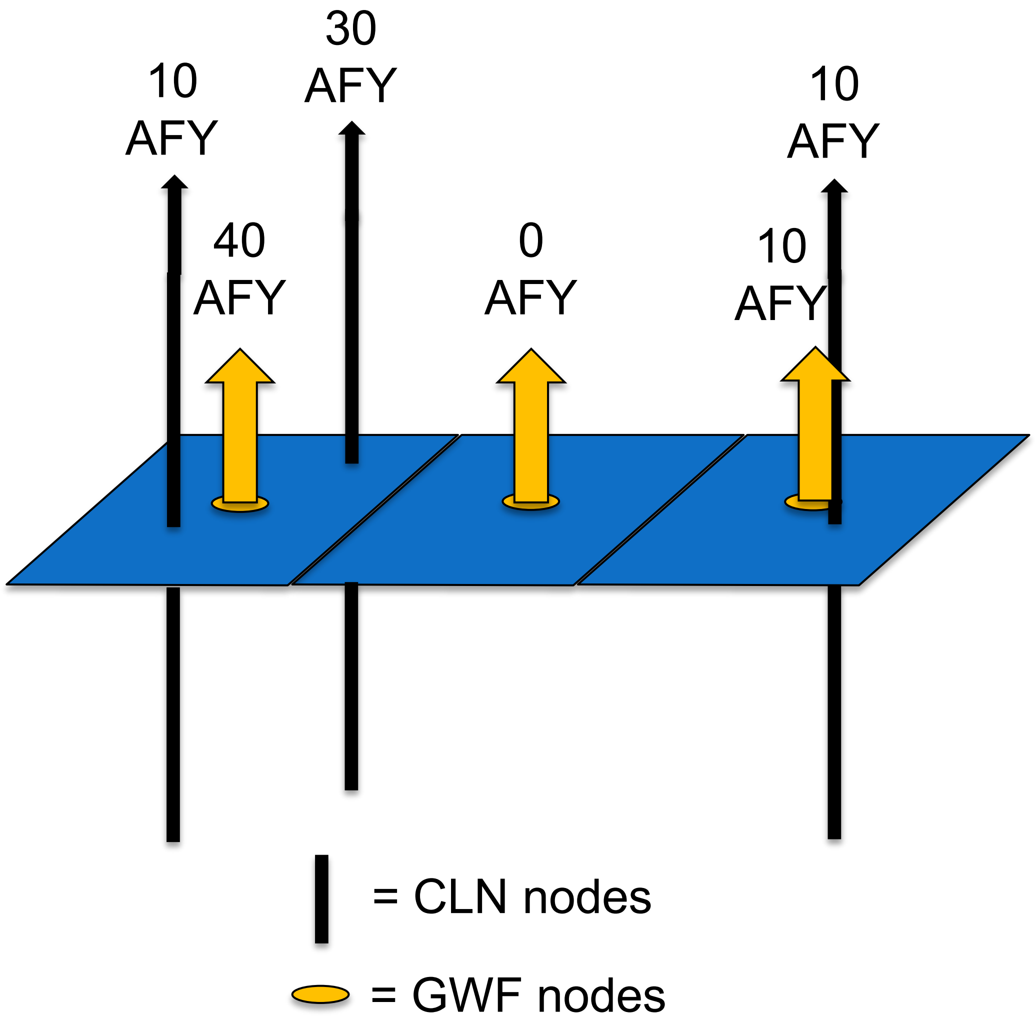
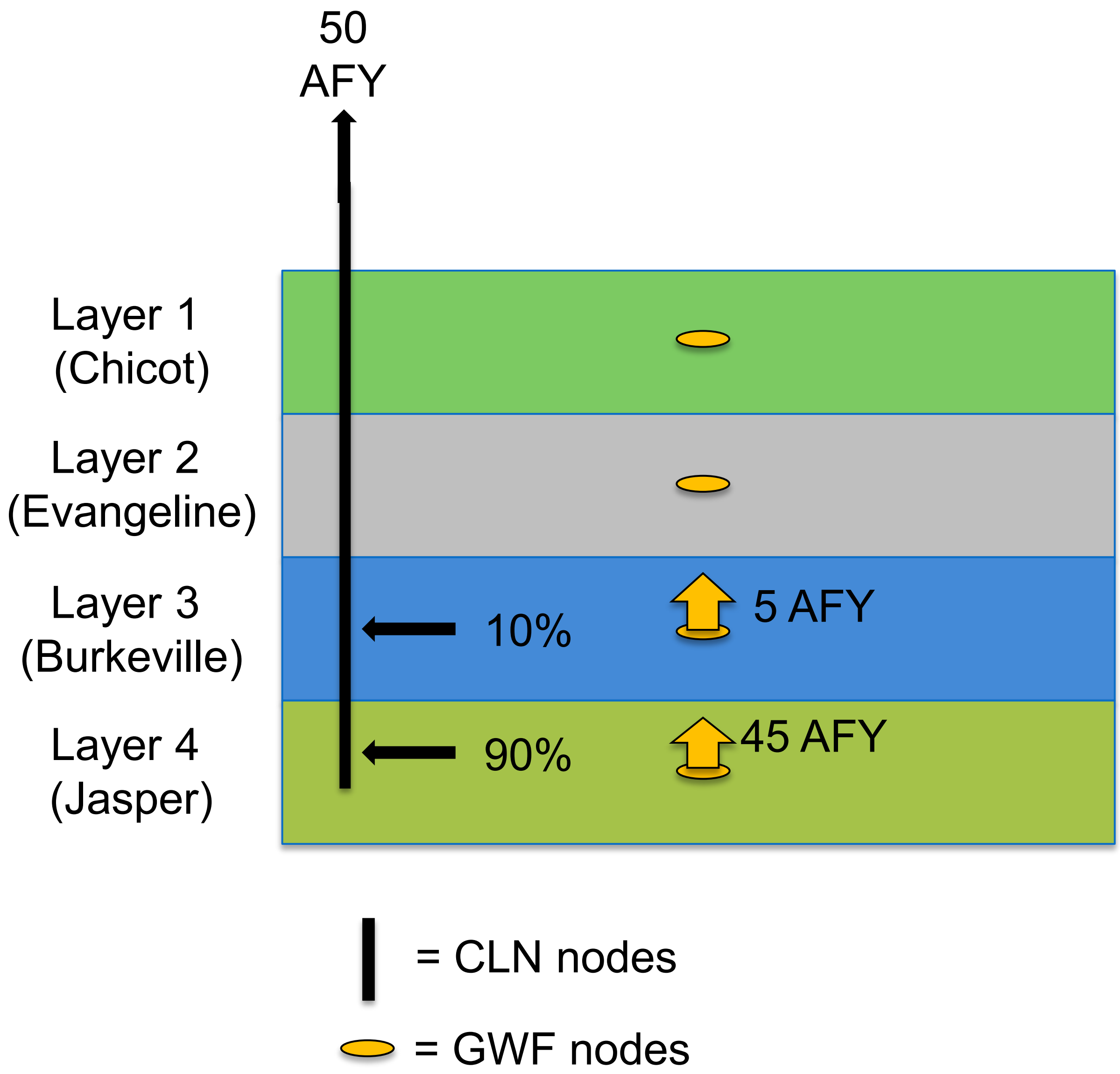


Model revisions

Pumping volume moved from CLN nodes to groundwater flow nodes (GWF) in WEL package

GWF nodes assumed the sum of pumping volumes from all CLN nodes contained within the GWF node boundary

Pumping volumes from multi-layer nodes were distributed based on water budget analysis



Re-calibration

- Model calibrated using PEST++ IES (iterative ensemble smoother)
- Creates an ensemble of models (large group of individual models with different parameter sets)
- Used water levels and hydrograph correlation coefficient as observations to train PEST++ calibration
- Selected final model from an ensemble based on model statistics, bias, and model run time comparisons

Re-calibration

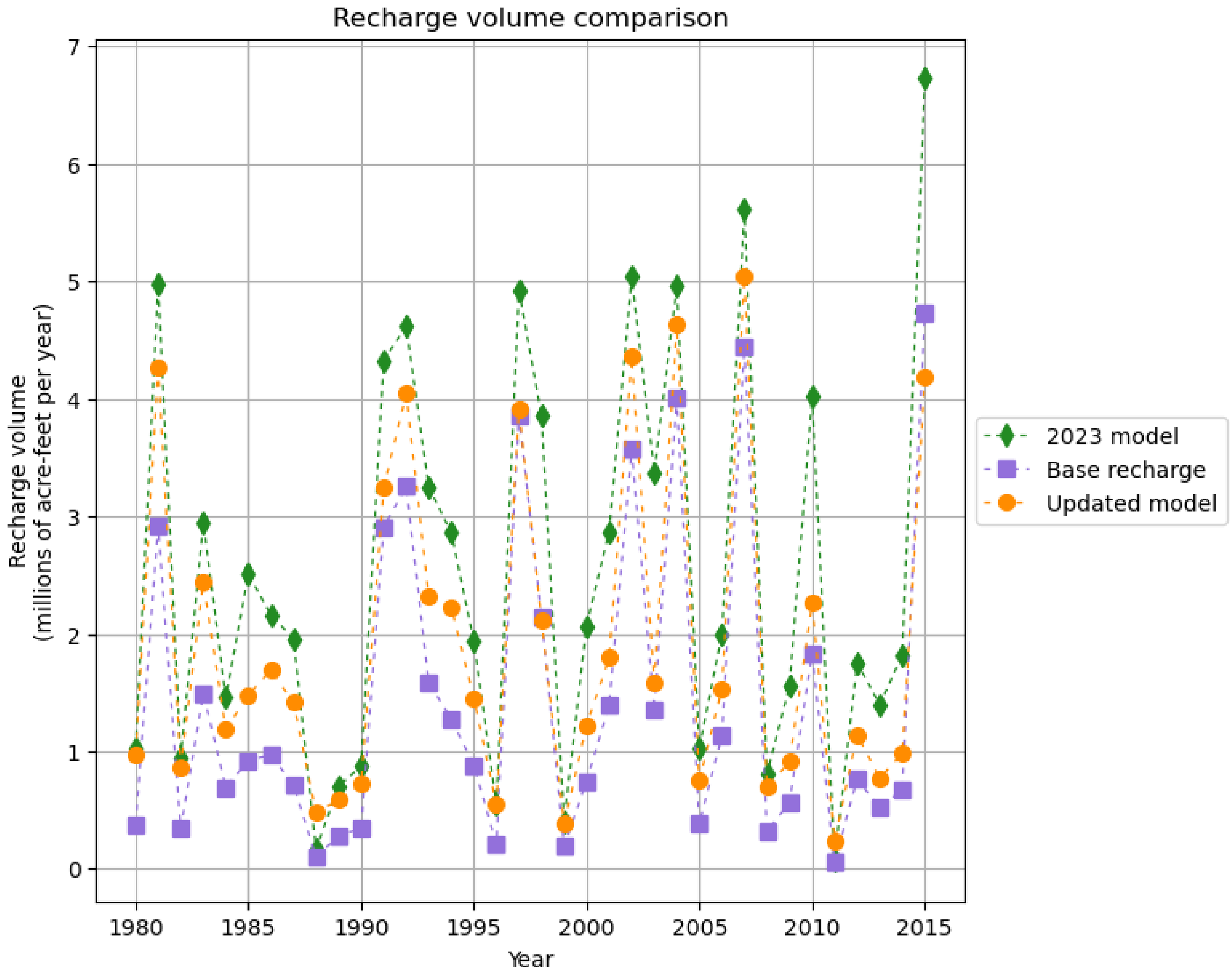
Calibrated packages	Calibrated parameters
River (RIV)	River conductance
Drain (DRN)	Drain conductance
General head boundary (GHB)	GHB conductance
Layer property flow (LPF)	- Horizontal hydraulic conductivity - Storage coefficient - Specific yield
Recharge (RCH)	Recharge

Recharge

Recharge (RCH) package was modified to include more conservative estimates from baseflow analysis than was used for the 2023 model

PEST++ adjusted recharge between one tenth and 2 times the baseflow estimated value

Updated model recharge on average is 25% less than the 2023 model



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Discussion and questions

- Please ask questions and share thoughts

Contact Information

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Web information:
https://www.twdb.texas.gov/groundwater/models/gam/glfc_c_s/glfc_c_s.asp

Other relevant analysis

- Model statistics table
- Recharge pass methods and fitting
- Ensemble hydrographs
- Cross plots
- Subsidence
- Calibration and Pilot points
- WEL distribution

Model results

- Model statistics comparison

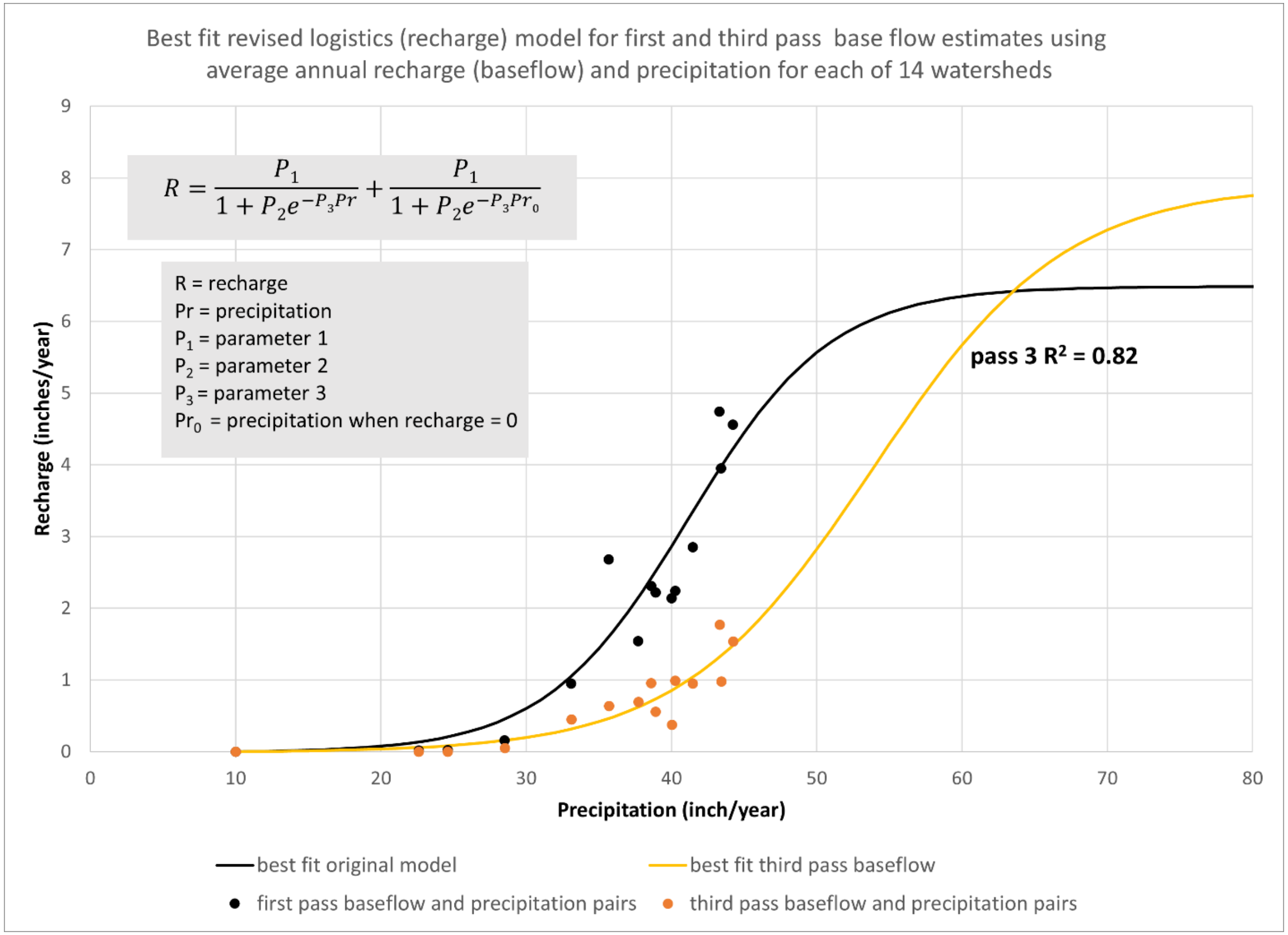
Version	Layer	Count	Mean Error	Mean Absolute Error	Root Mean Squared Error	Range	RMSE over Range
2023 model CLN nodes	1	3175	7.8	14.5	20.8	433.7	0.048
2023 model GWF nodes	1	3175	-13.9	19.9	34.7	433.7	0.080
Updated model	1	3175	-3.4	12.5	19.5	433.7	0.045
2023 model CLN nodes	2	2125	3.7	18.1	24.7	578.02	0.043
2023 model GWF nodes	2	2125	-23.3	34.3	53.5	578.02	0.092
Updated model	2	2125	-3.6	16.4	24.9	578.02	0.043
2023 model CLN nodes	3	103	-1.4	11.0	15.8	367	0.043
2023 model GWF nodes	3	103	-0.6	17.4	22.1	367	0.060
Updated model	3	103	5.1	13.9	15.6	367	0.042
2023 model CLN nodes	4	826	4.0	18.0	24.9	724.38	0.034
2023 model GWF nodes	4	826	-13.0	24.0	35.6	724.38	0.049
Updated model	4	826	-1.8	13.1	18.9	724.38	0.026
2023 model CLN nodes	All	6229	5.7	16.1	22.7	976.1	0.023
2023 model GWF nodes	All	6229	-16.8	25.3	42.0	976.1	0.043
Updated model	All	6229	-3.1	13.9	21.4	976.1	0.022

Recharge pass 1 vs. pass 3 comparison

2023 model used the first pass of the baseflow separation analysis to relate precipitation to recharge.

Updated model used the third pass of the baseflow separation analysis to relate precipitation to recharge.

Both versions fit the equation shown in the plot to relate precipitation to recharge.

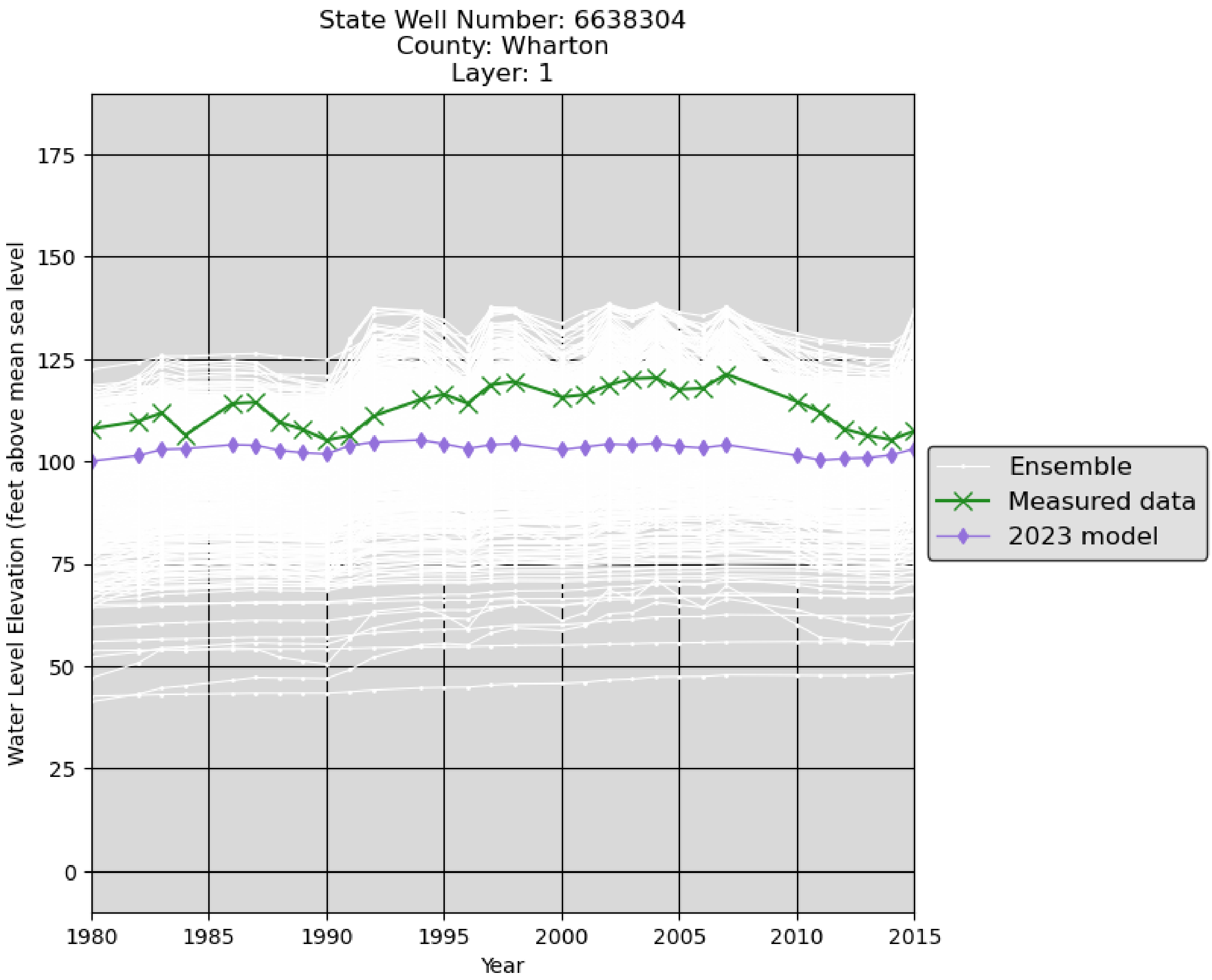


Ensemble hydrographs

- Examples of ensembles

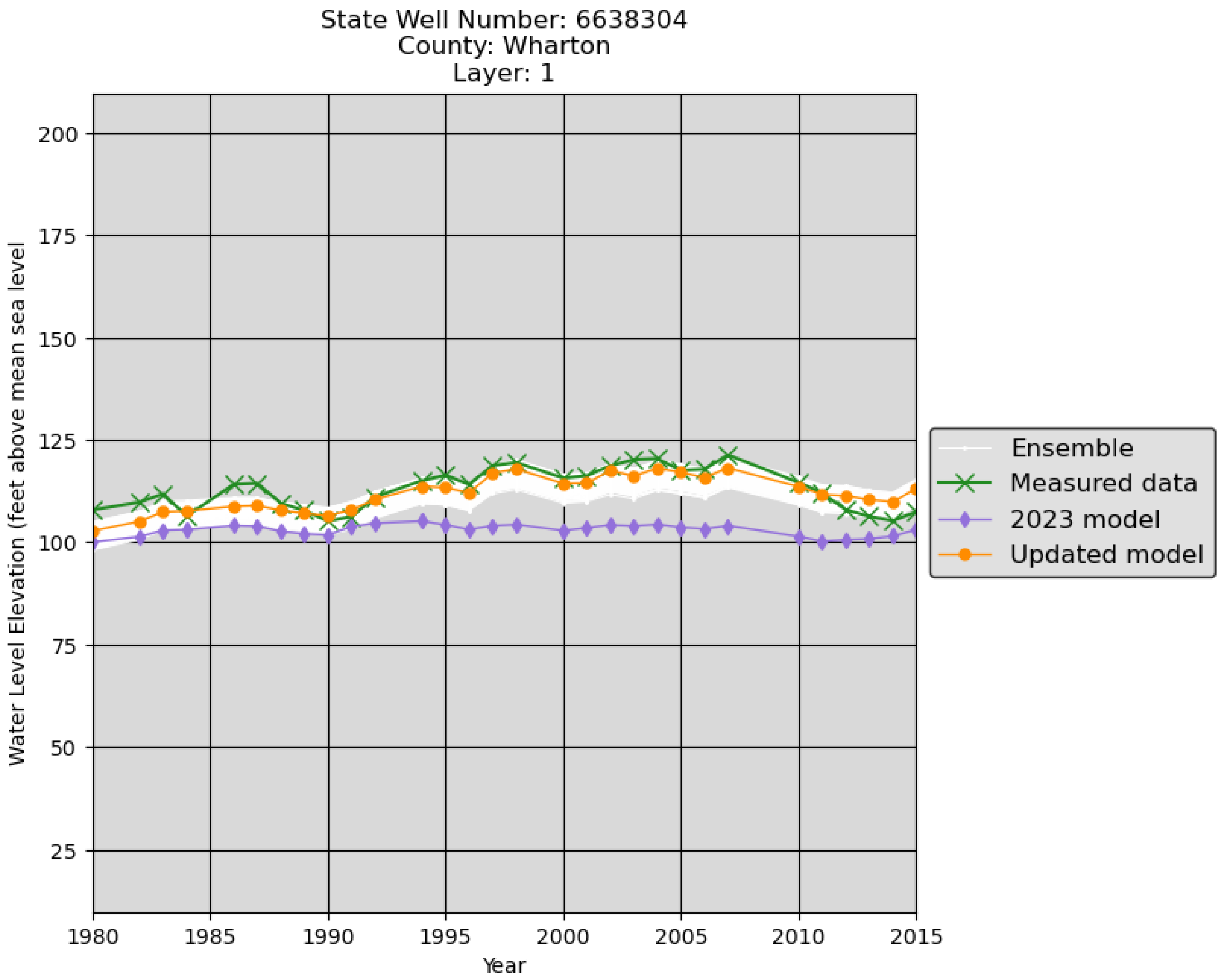
Ensemble hydrographs

Range of possible simulated water levels in the ensemble contains all measured water levels at the well.



Ensemble hydrographs

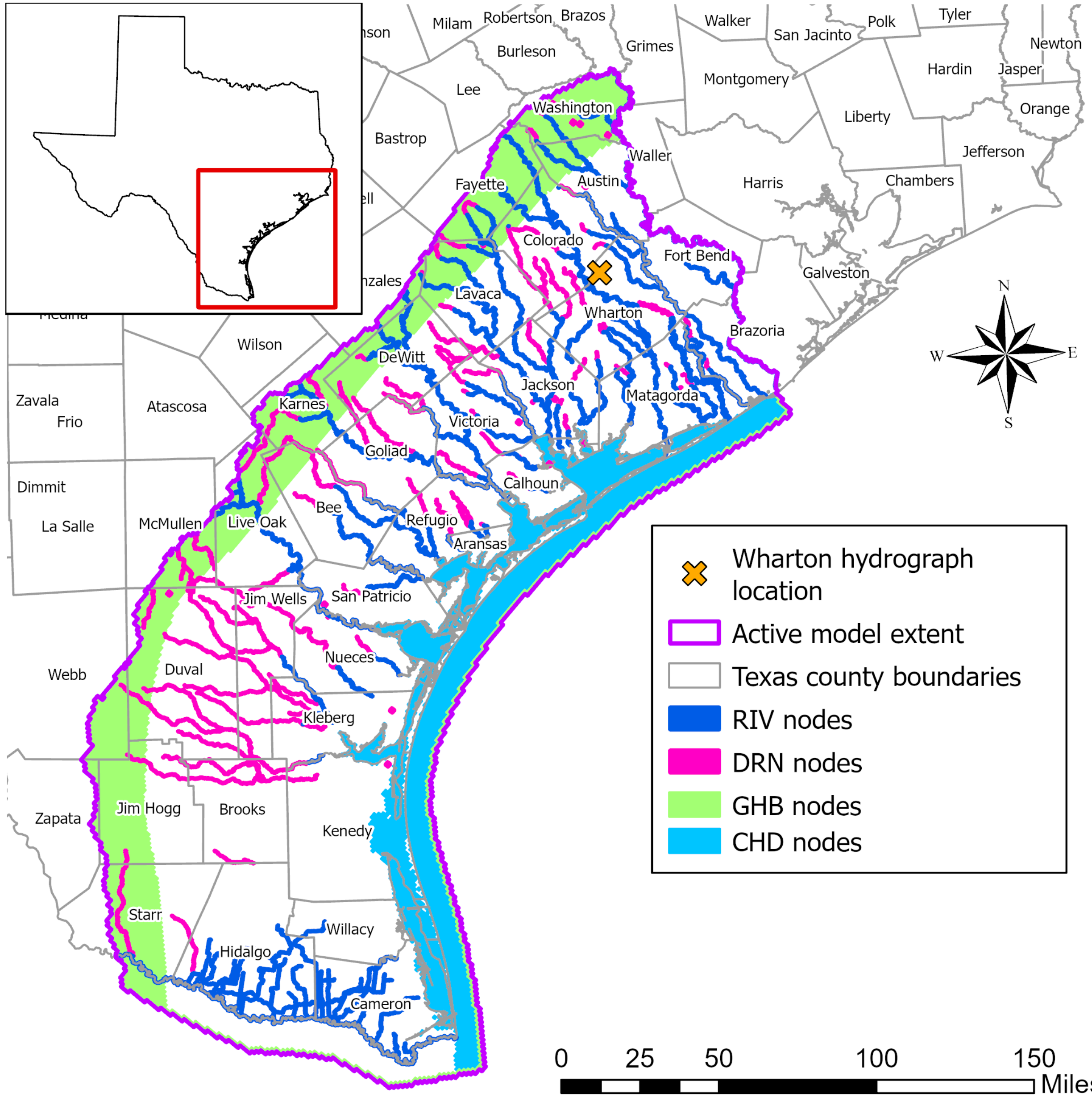
Range of possible simulated water levels constricted but still containing most of the measured water levels.



Ensemble hydrographs location

Location for ensemble hydrograph in Wharton County

Also shown are the RIV, DRN, GHB, and CHD node locations for reference to determine boundary condition effects on water levels at well location.



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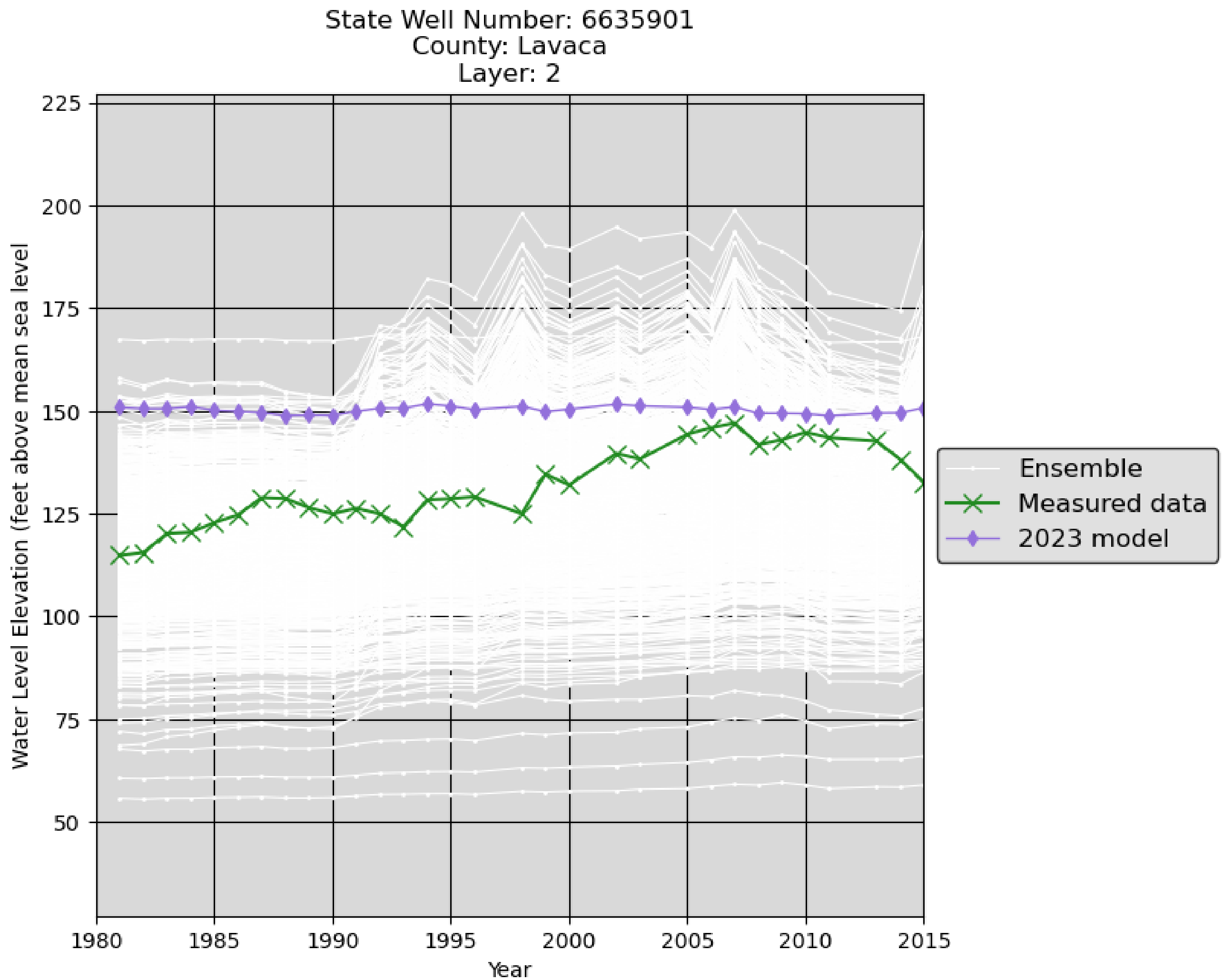

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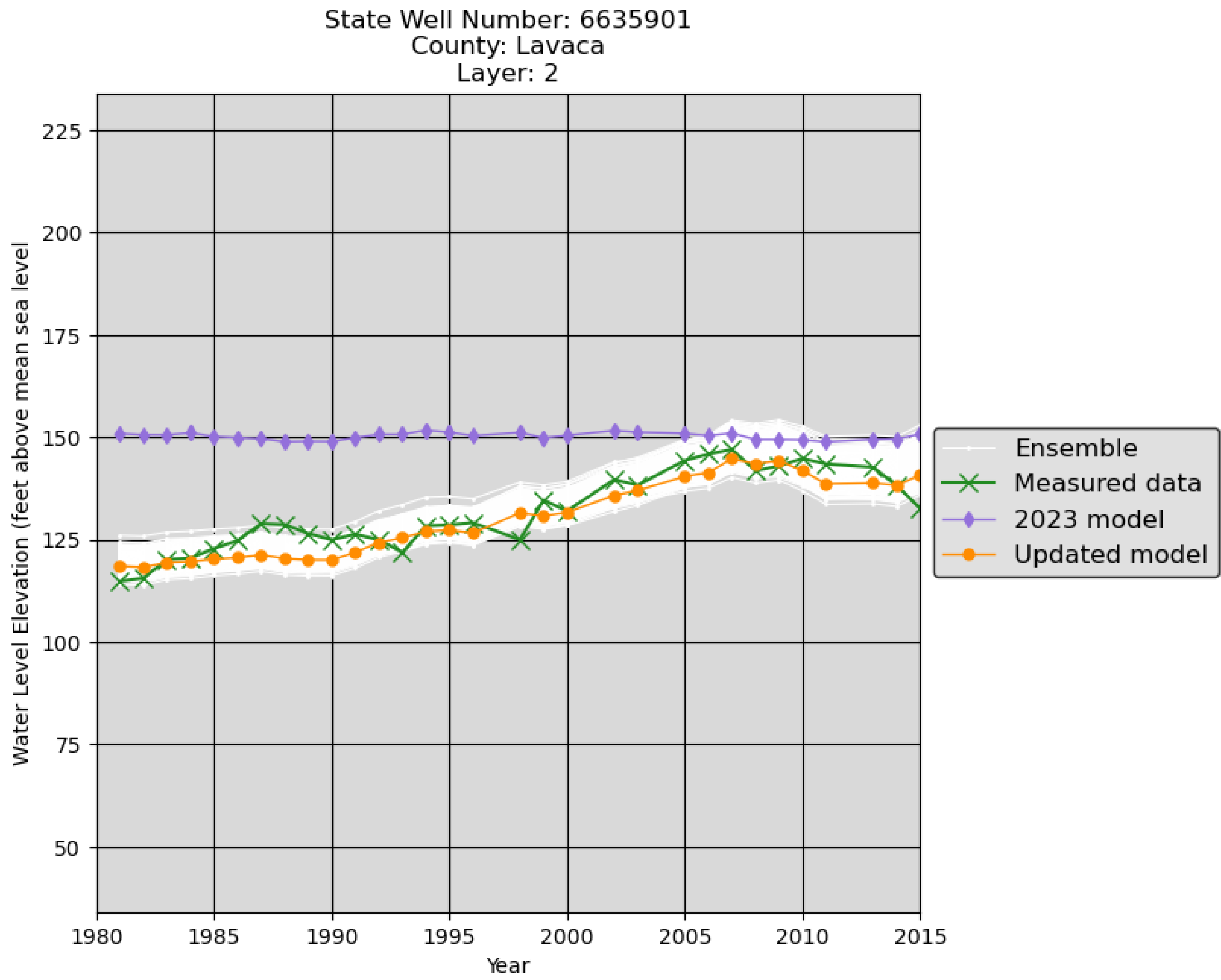
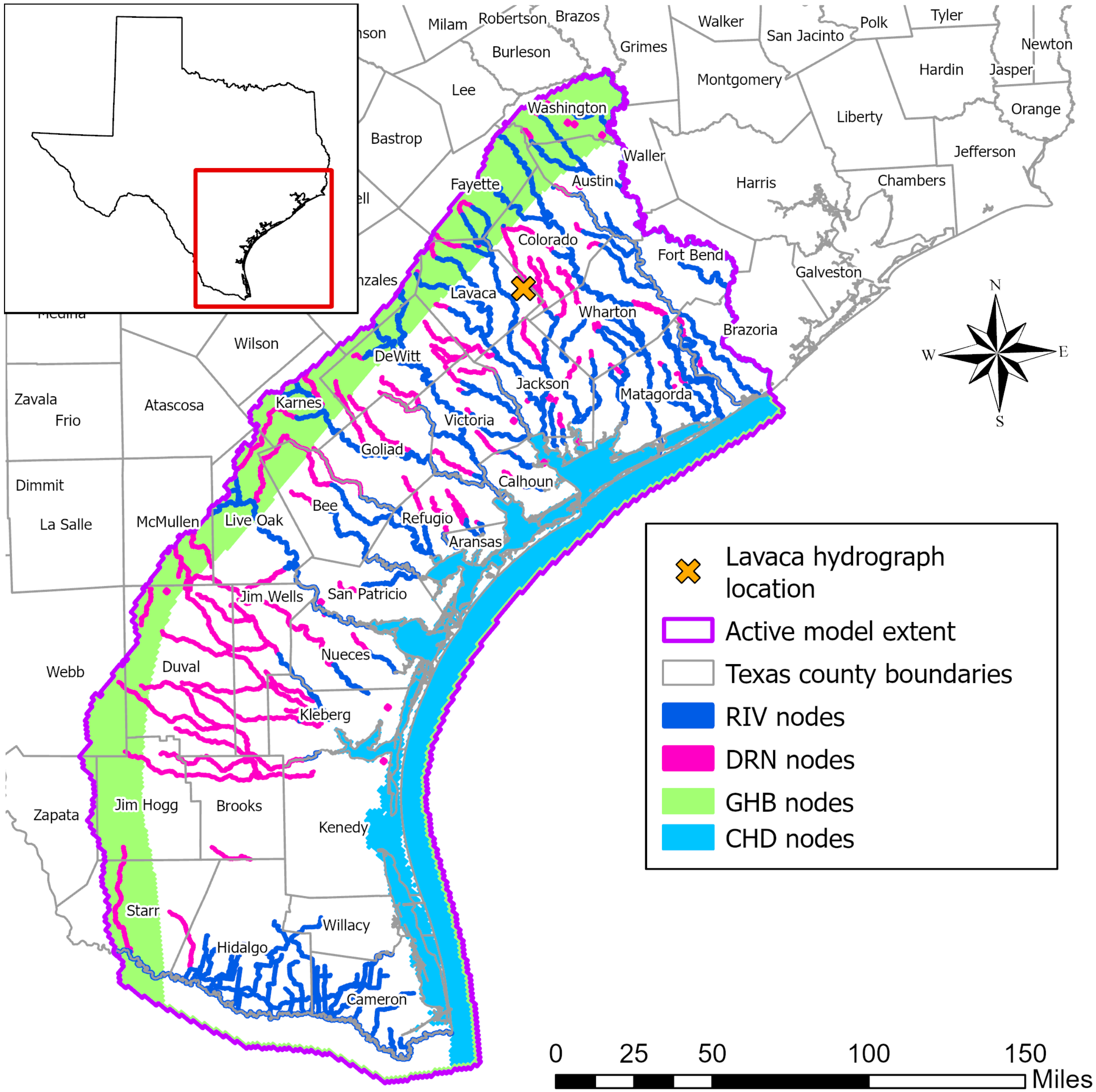


Ensemble hydrographs location

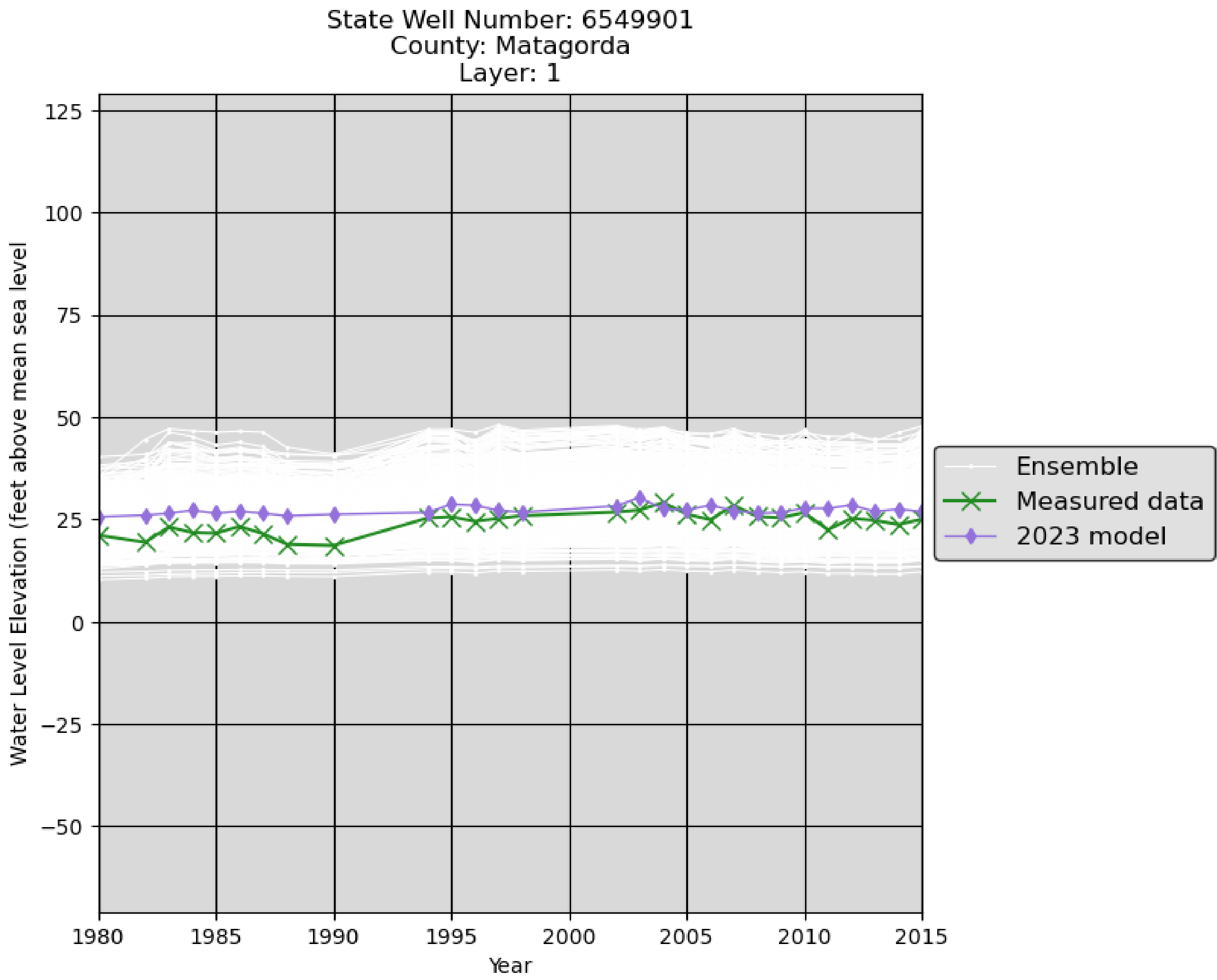
Location for ensemble hydrograph in Lavaca County

Also shown are the RIV, DRN, GHB, and CHD node locations for reference to determine boundary condition effects on water levels at well location.



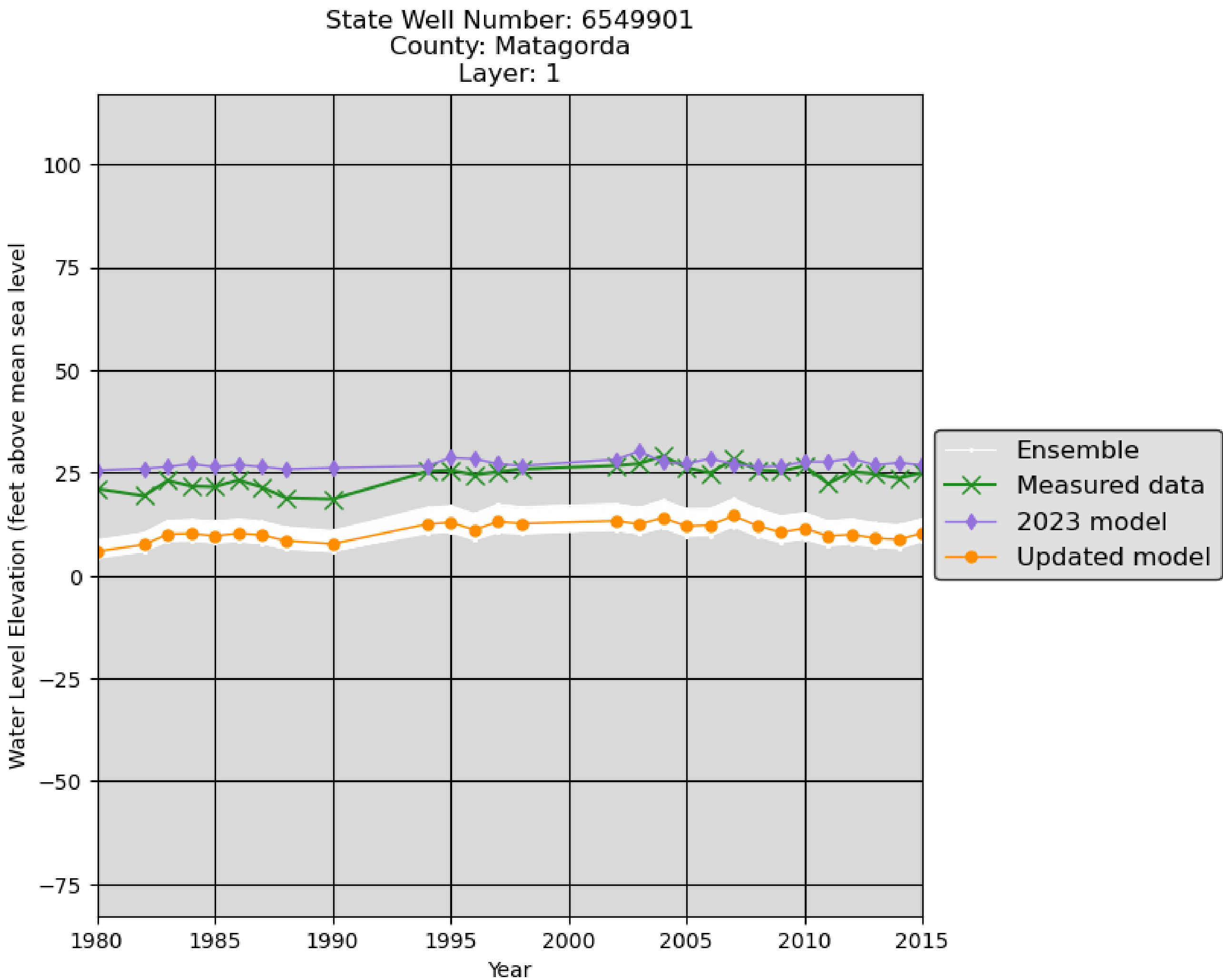
Ensemble hydrographs

Range of possible simulated water levels in the ensemble contains all measured water levels at the well.



Ensemble hydrographs

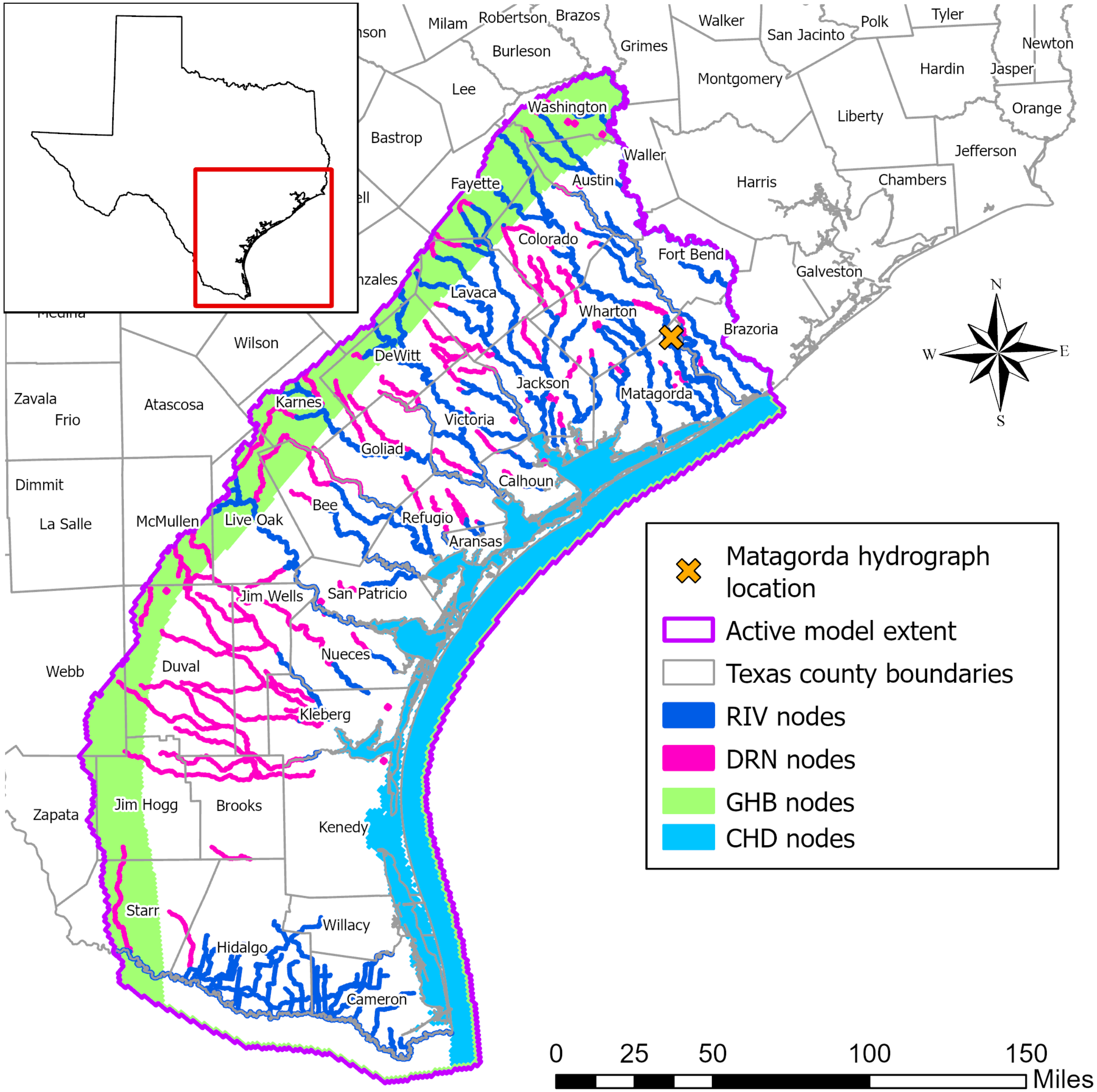
Range of possible simulated water levels constricted but does not contain any of the measured water levels.



Ensemble hydrographs location

Location for ensemble hydrograph in Matagorda County

Also shown are the RIV, DRN, GHB, and CHD node locations for reference to determine boundary condition effects on water levels at well location.



Ensemble hydrographs

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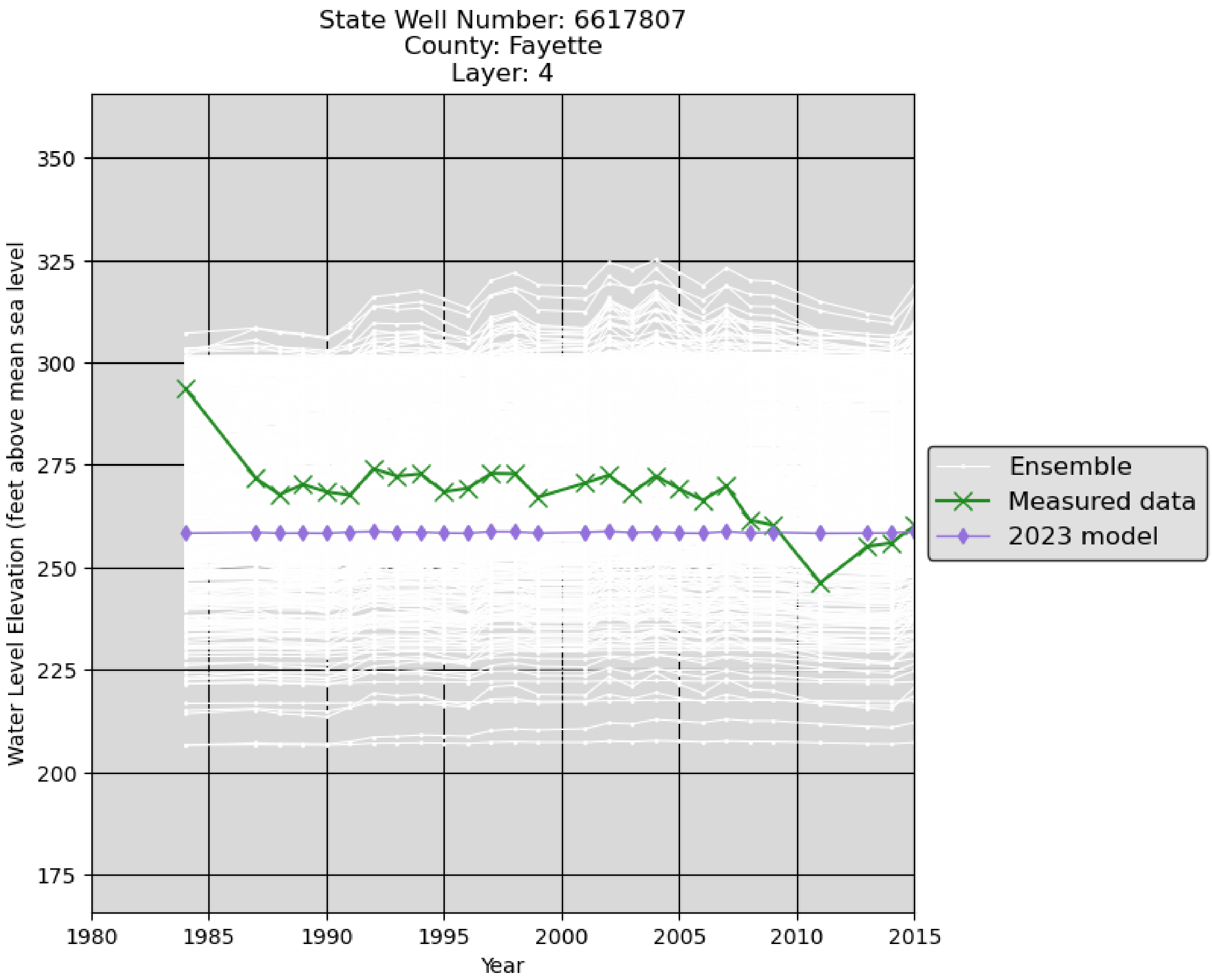
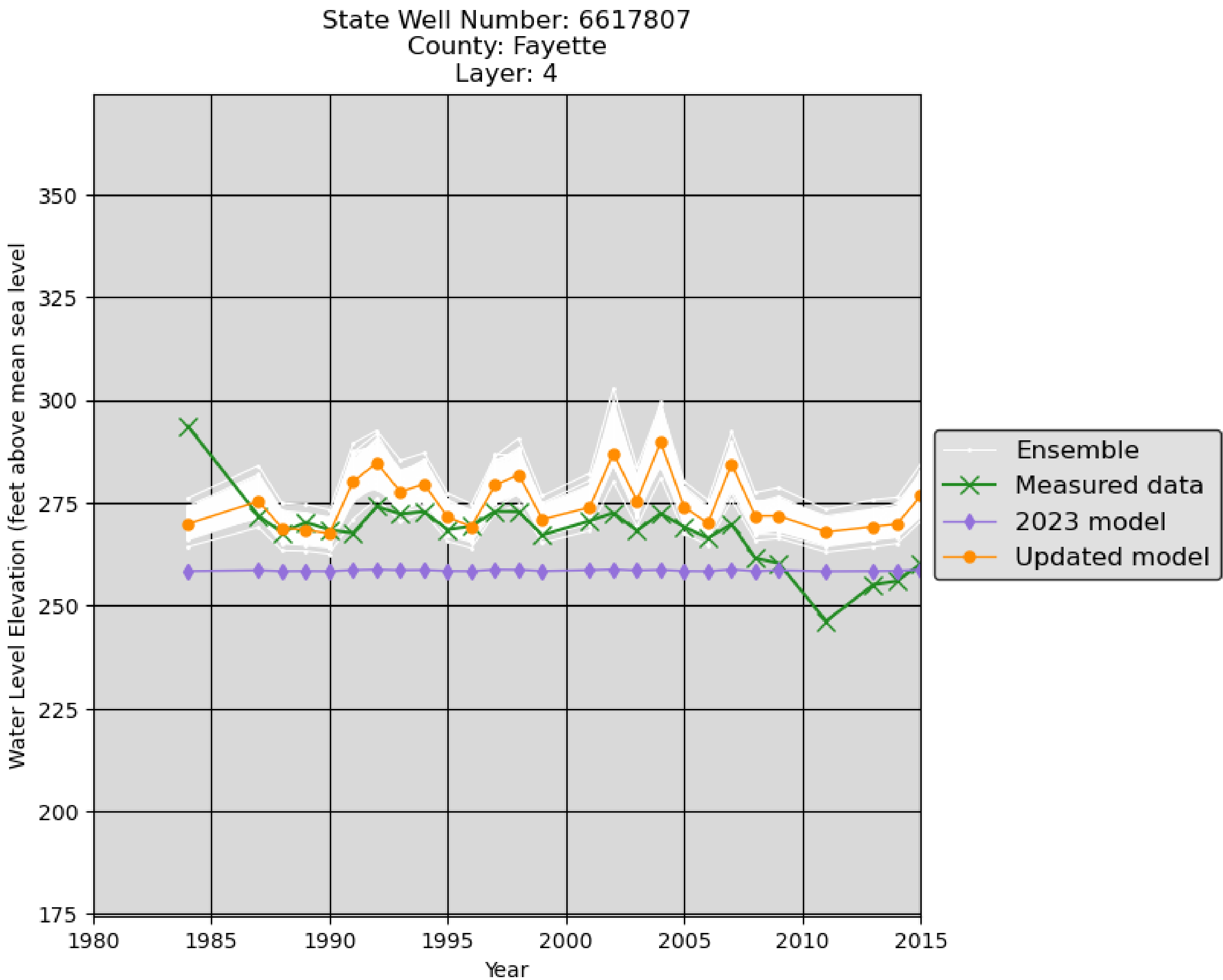


Ensemble hydrographs

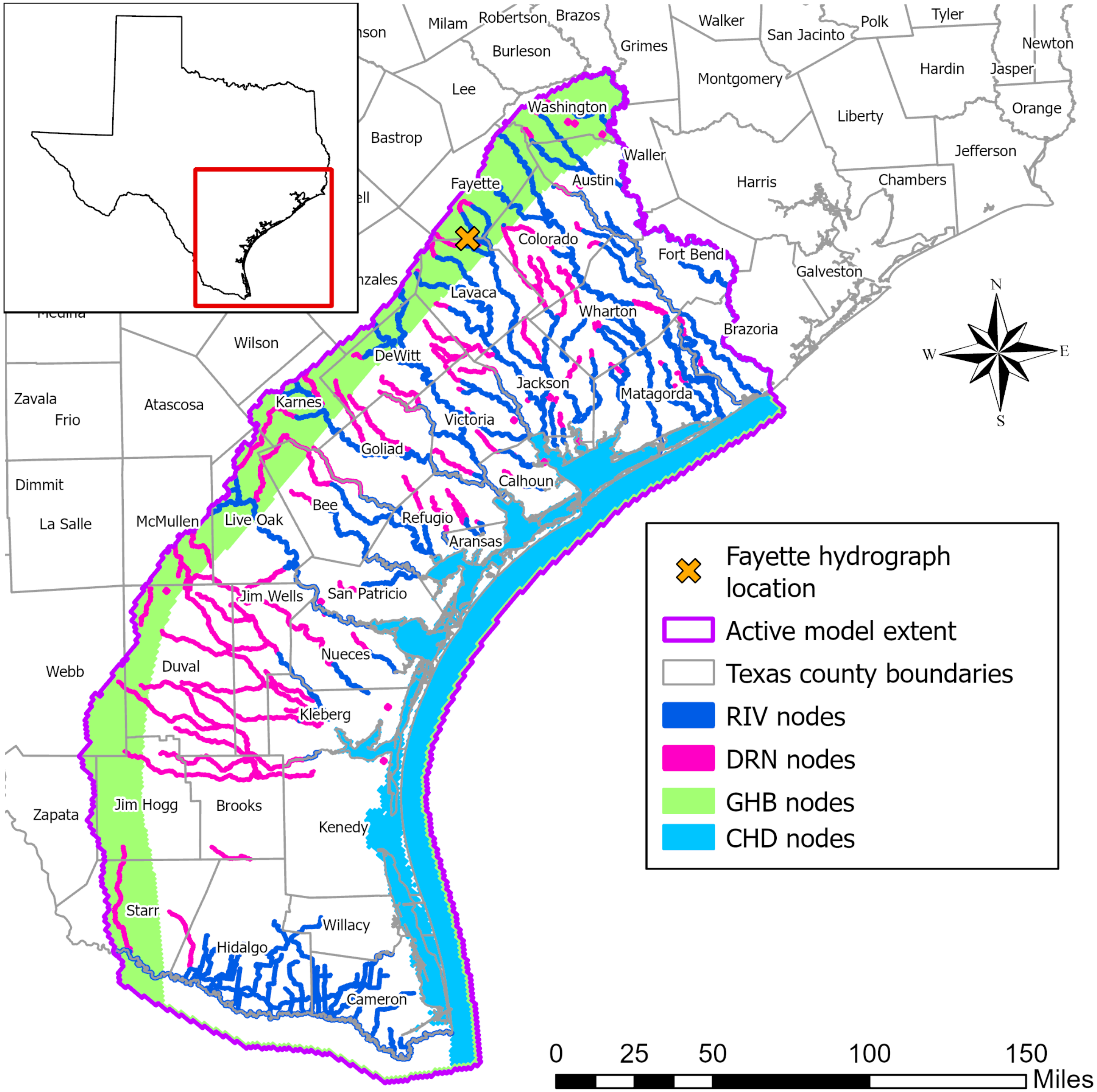
Range of possible simulated water levels constricted but does not contain most of the measured water levels.



Ensemble hydrographs location

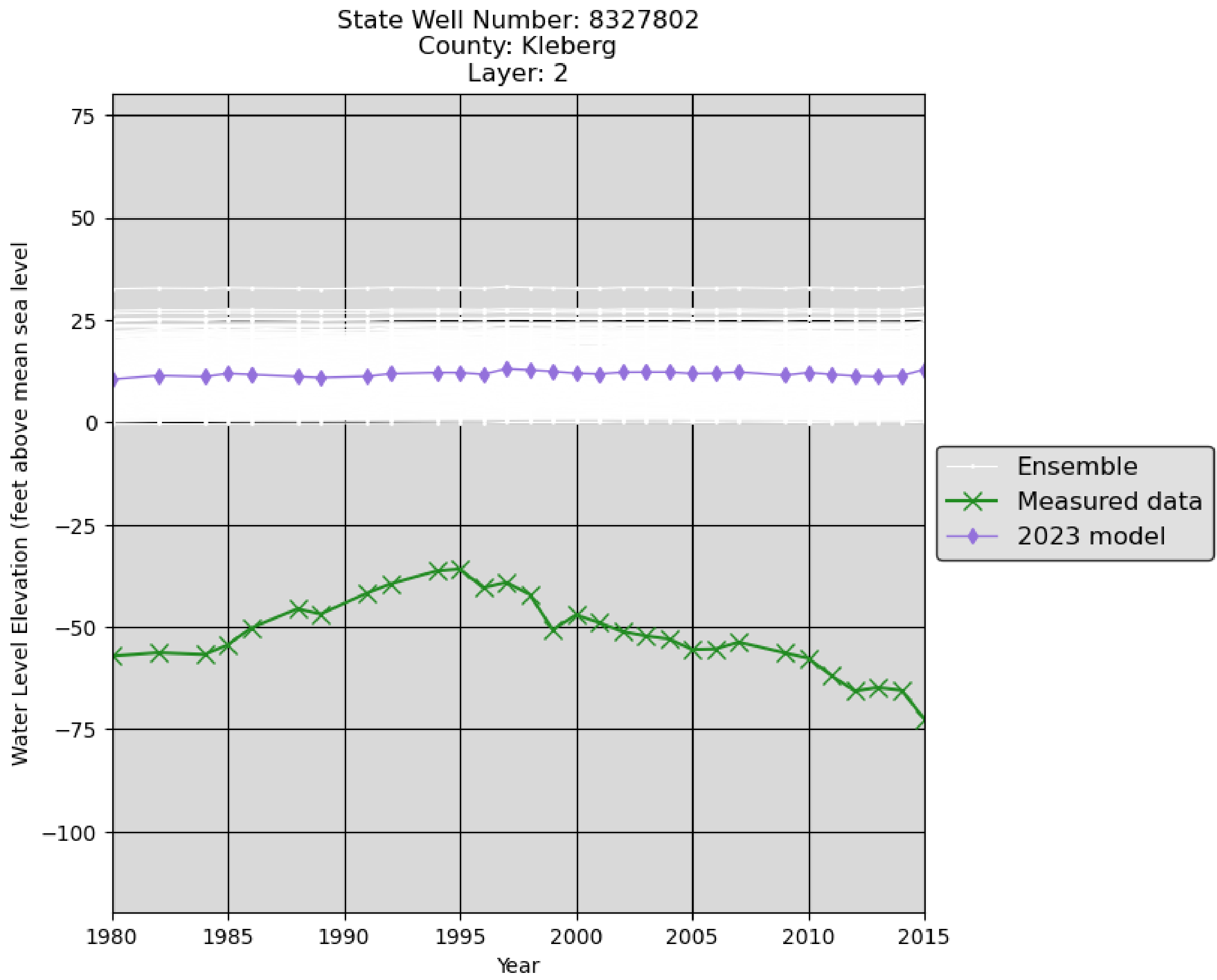
Location for ensemble hydrograph in Fayette County

Also shown are the RIV, DRN, GHB, and CHD node locations for reference to determine boundary condition effects on water levels at well location.



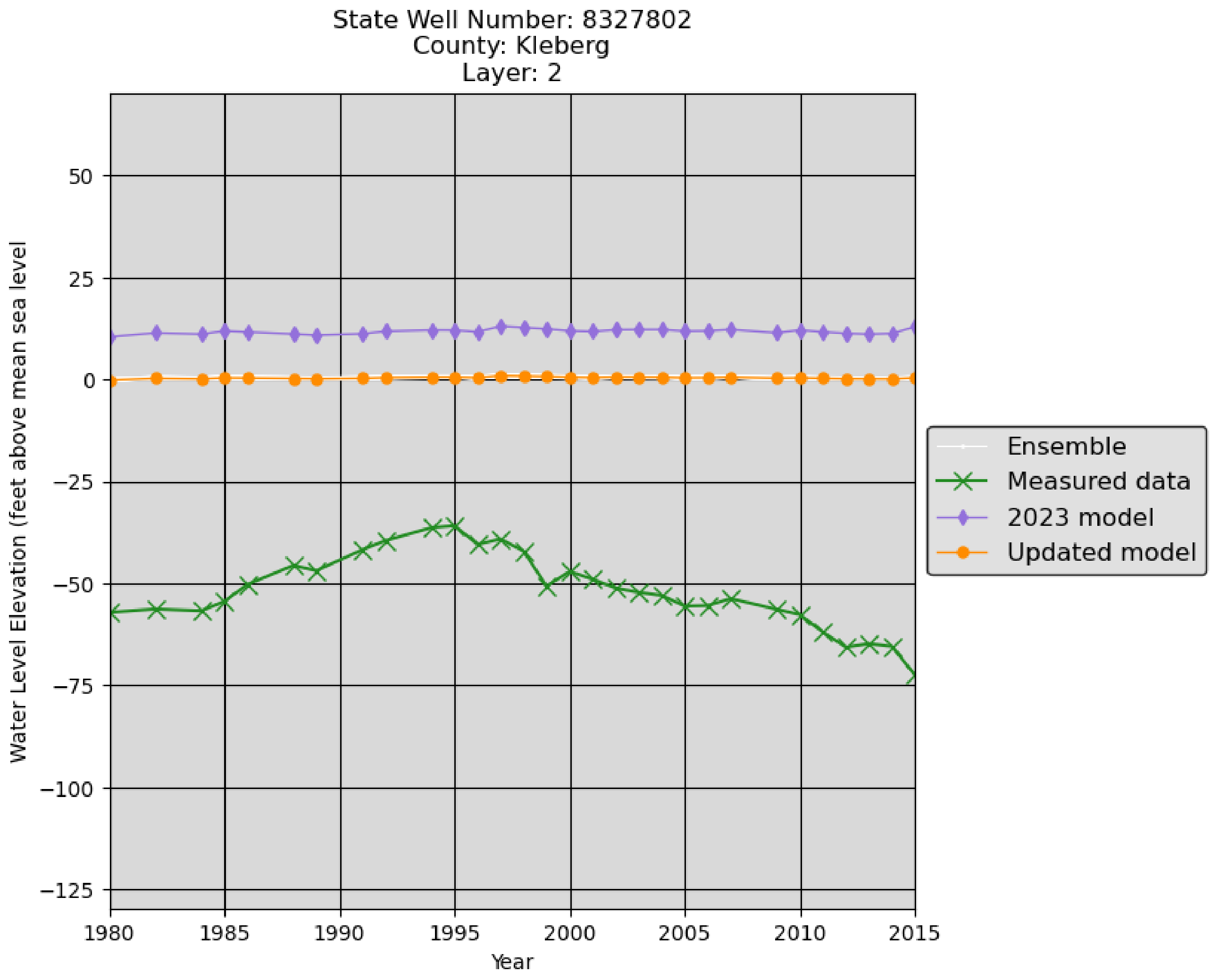
Ensemble hydrographs

Range of possible simulated water levels in the ensemble contains none of the measured water levels at the well.



Ensemble hydrographs

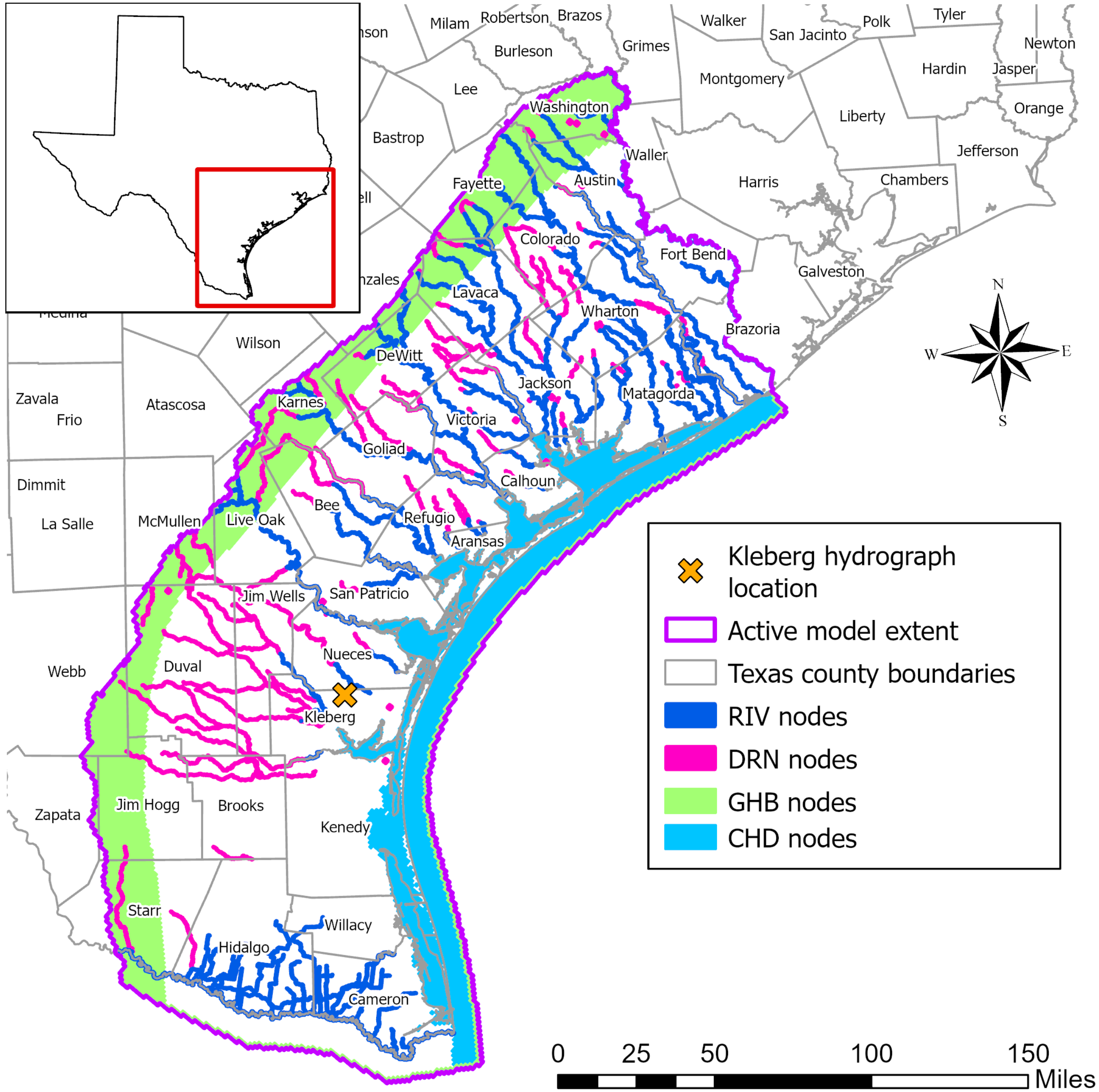
Range of possible simulated water levels constricted but still contains none of the measured water levels.



Ensemble hydrographs location

Location for ensemble hydrograph in Kleberg County

Also shown are the RIV, DRN, GHB, and CHD node locations for reference to determine boundary condition effects on water levels at well location.

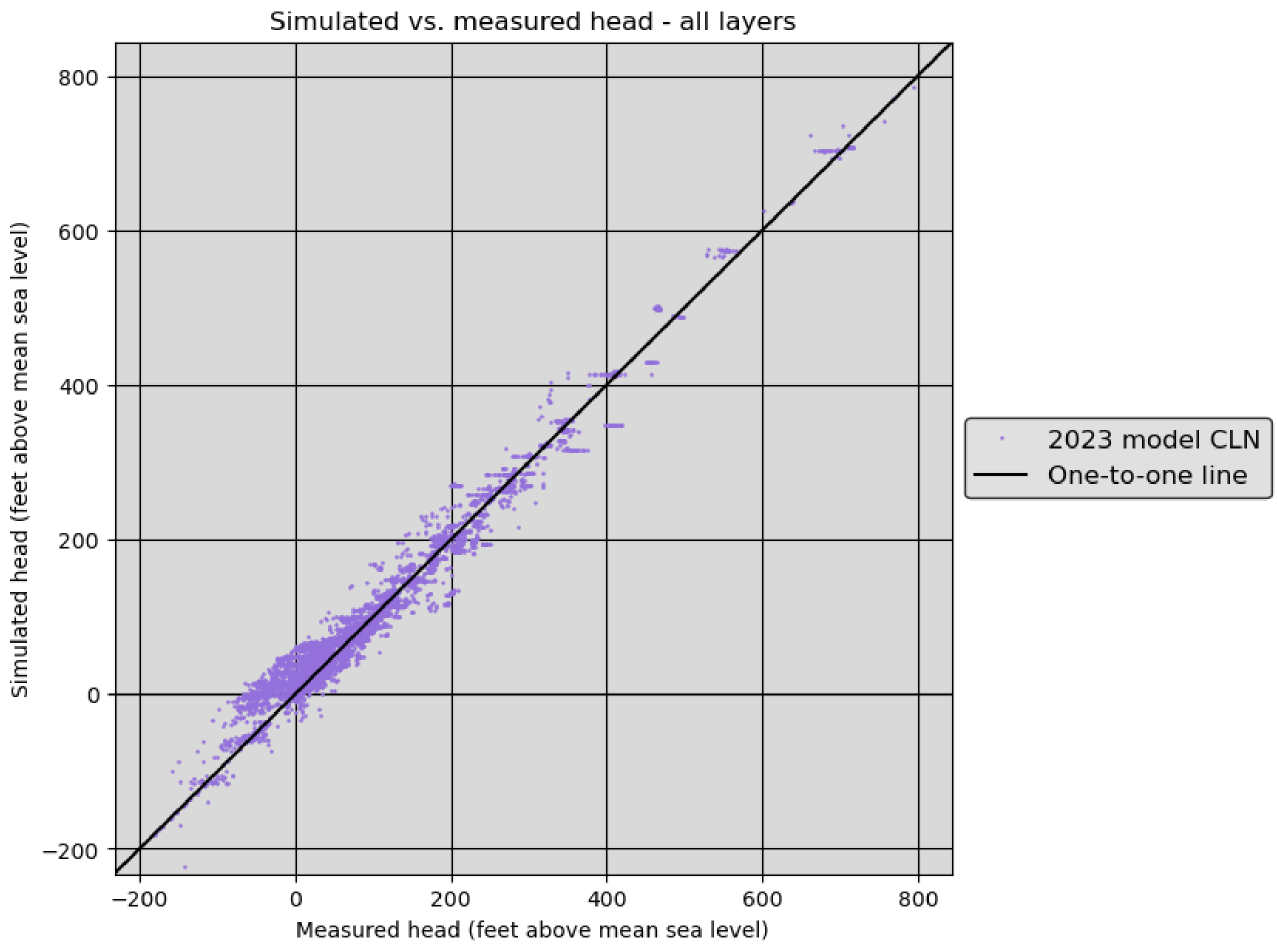


Model results

- Plotted comparisons
  - Cross plots
  - Ensemble hydrographs

Cross-plots
All layers

Cross-plot showing measured versus simulated water levels. A perfect fitting model would show all points along the one-to-one line. The tighter the fit to the one-to-one line, the better the model results.



Cross-plots
All layers

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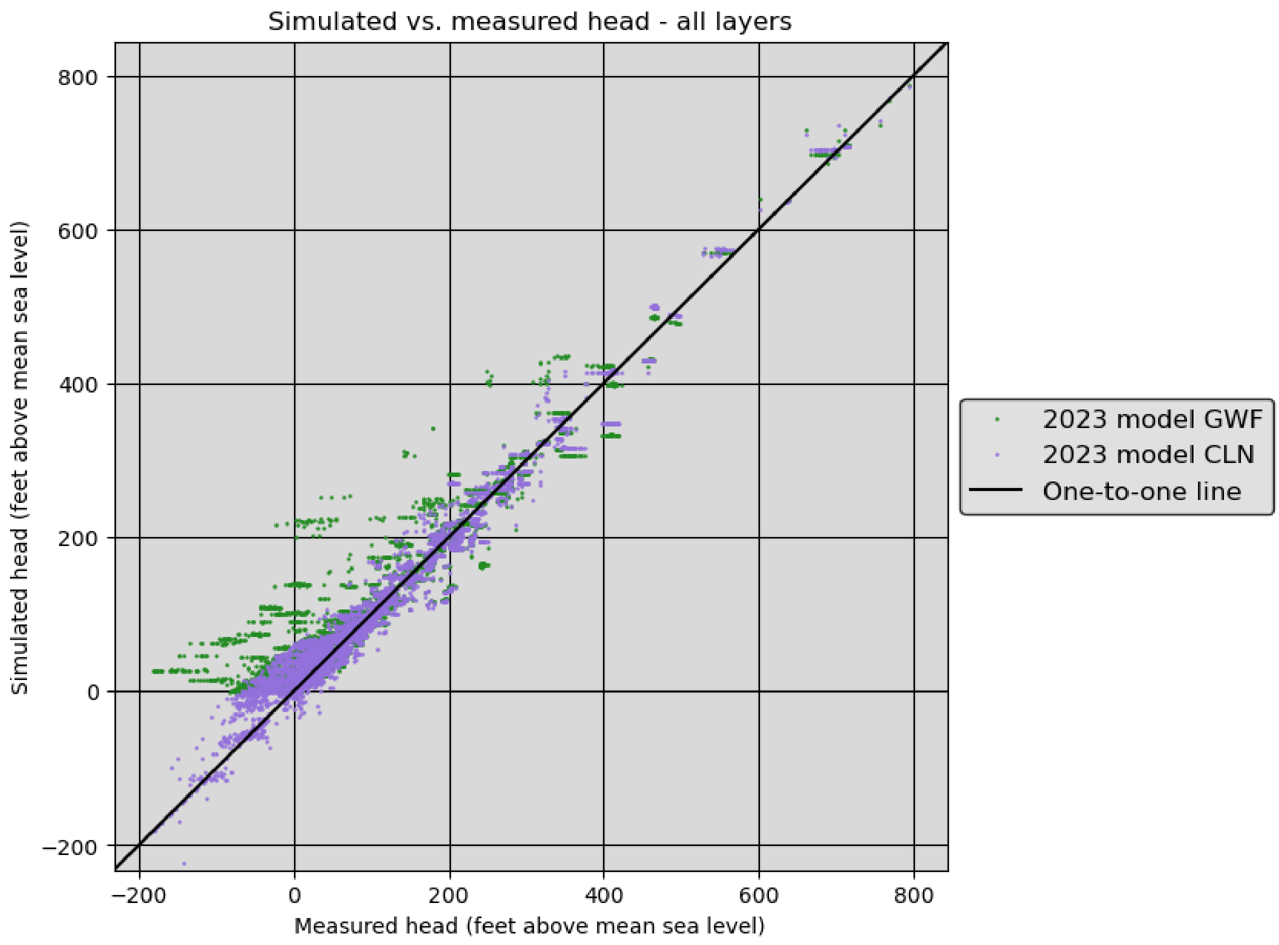

Cross-plots
All layers

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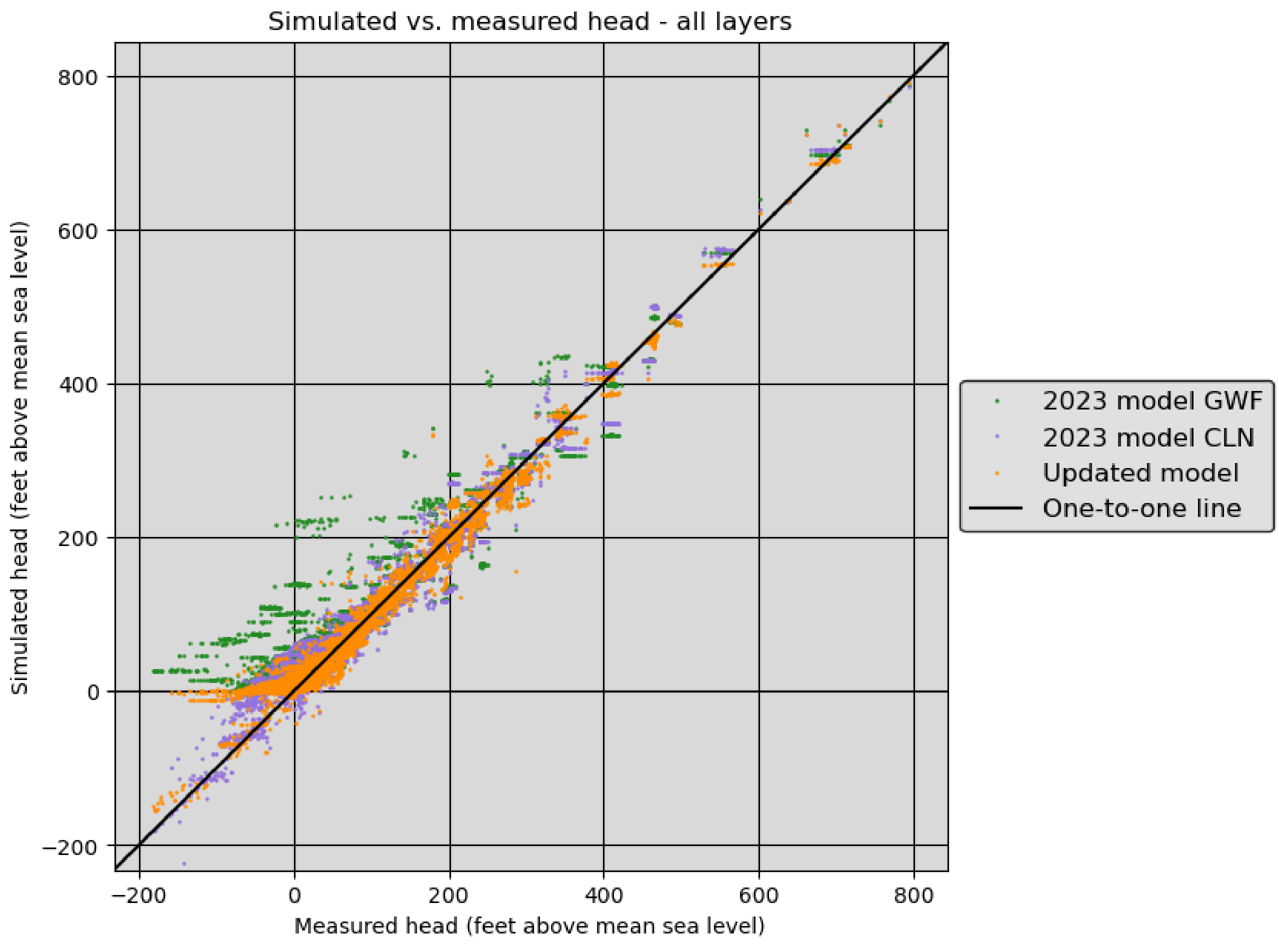
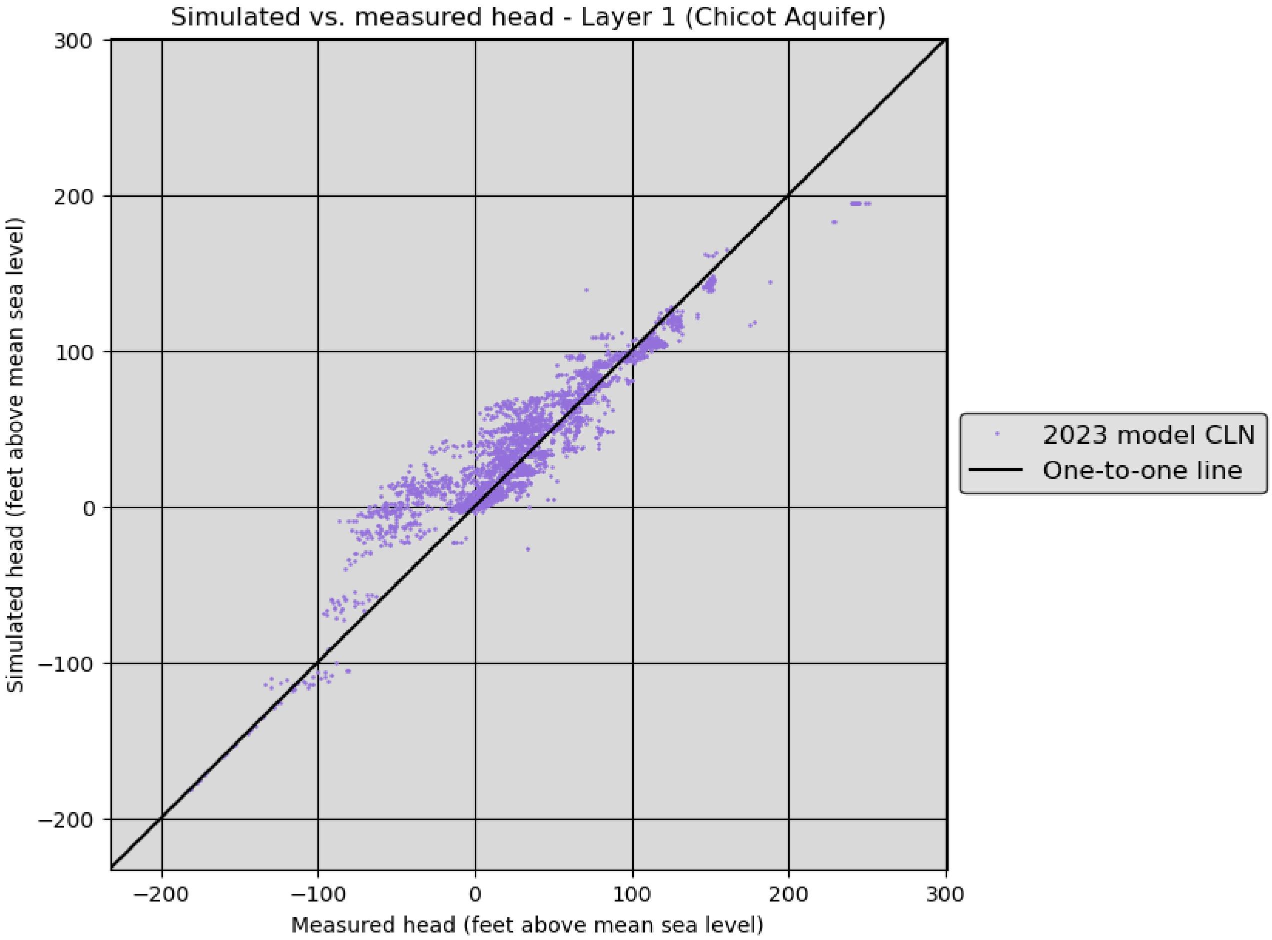


Cross-plots
Layer 1

Cross-plot showing measured versus simulated water levels. A perfect fitting model would show all points along the one-to-one line. The tighter the fit to the one-to-one line, the better the model results.



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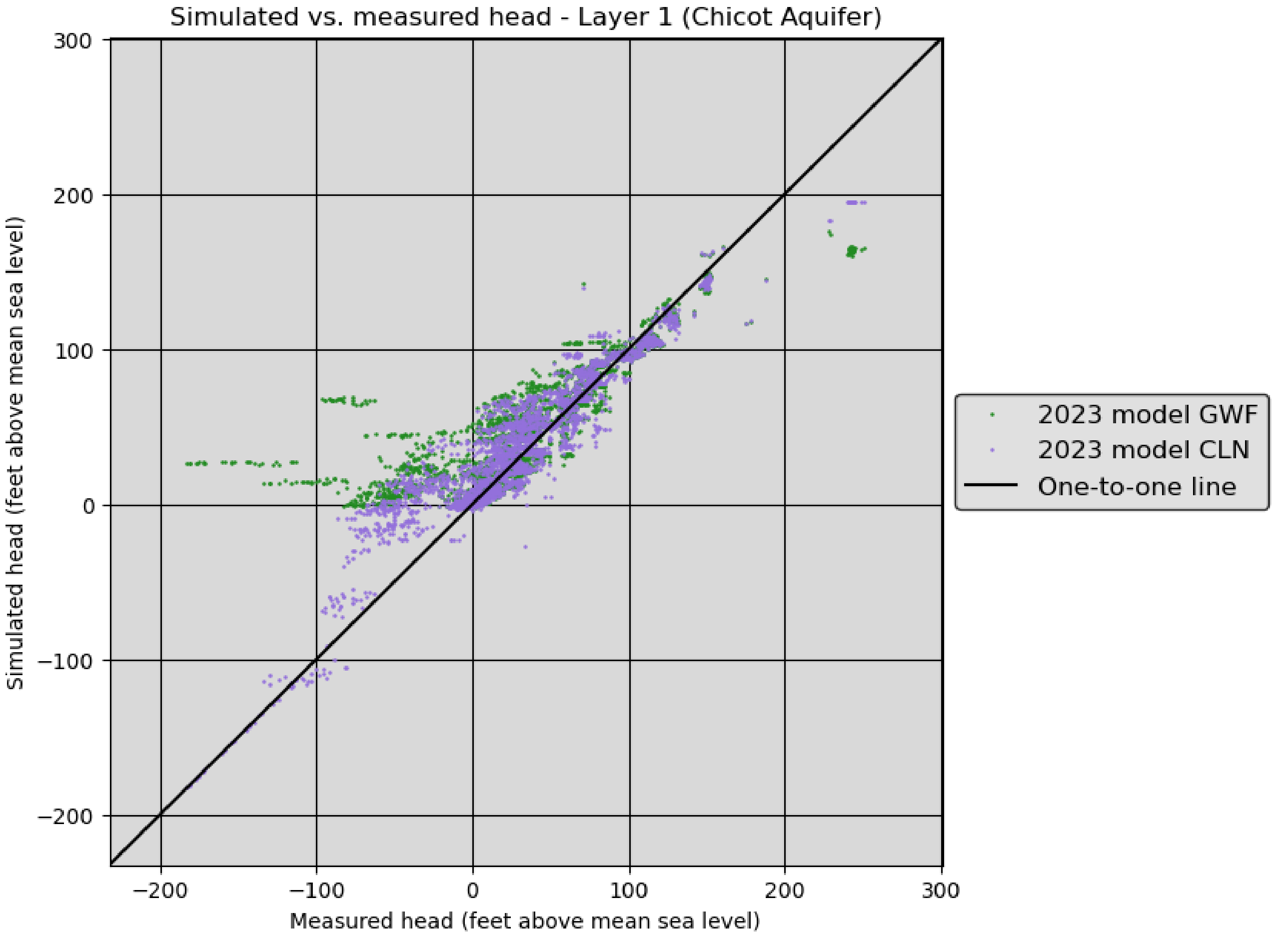

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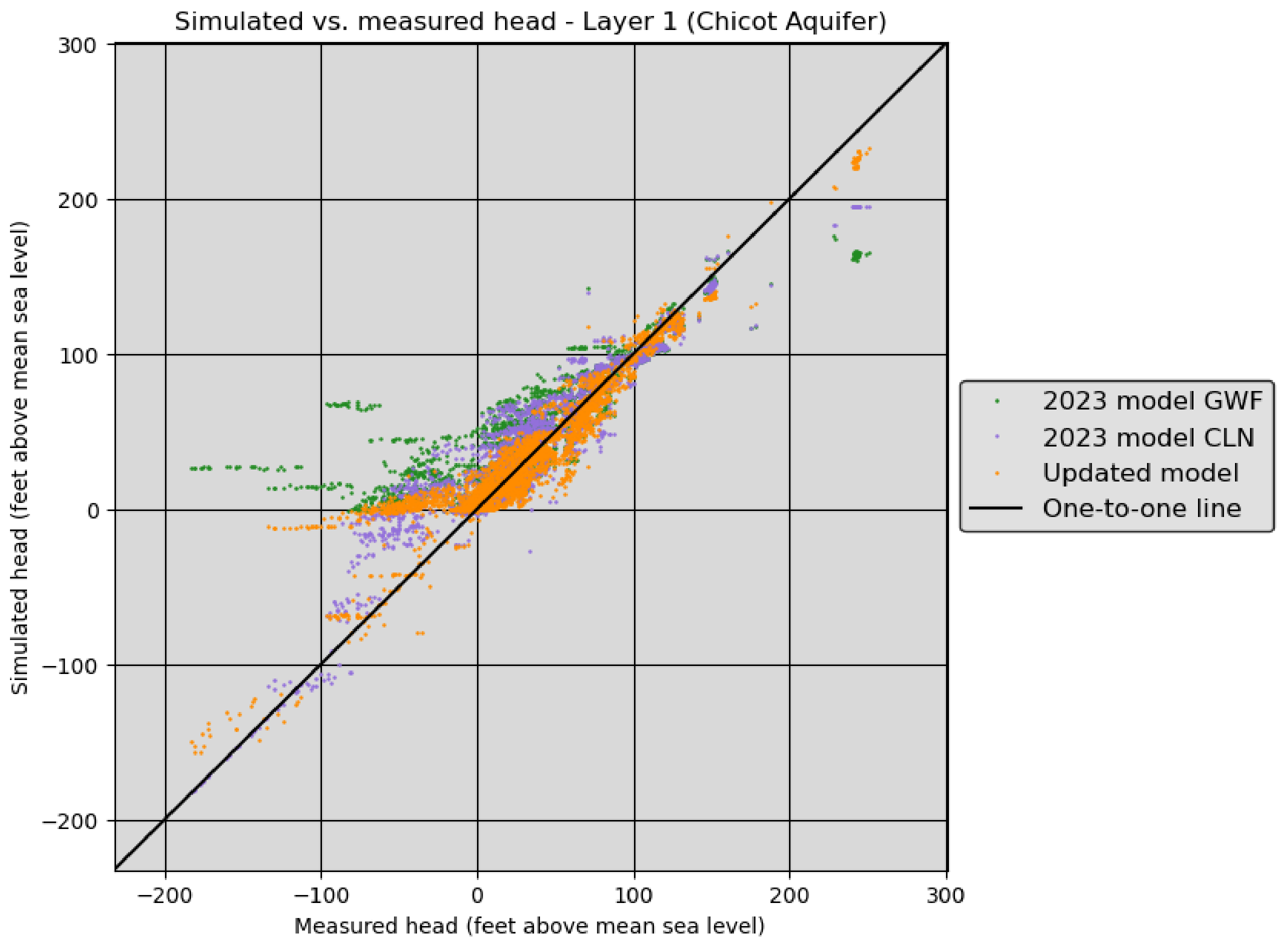
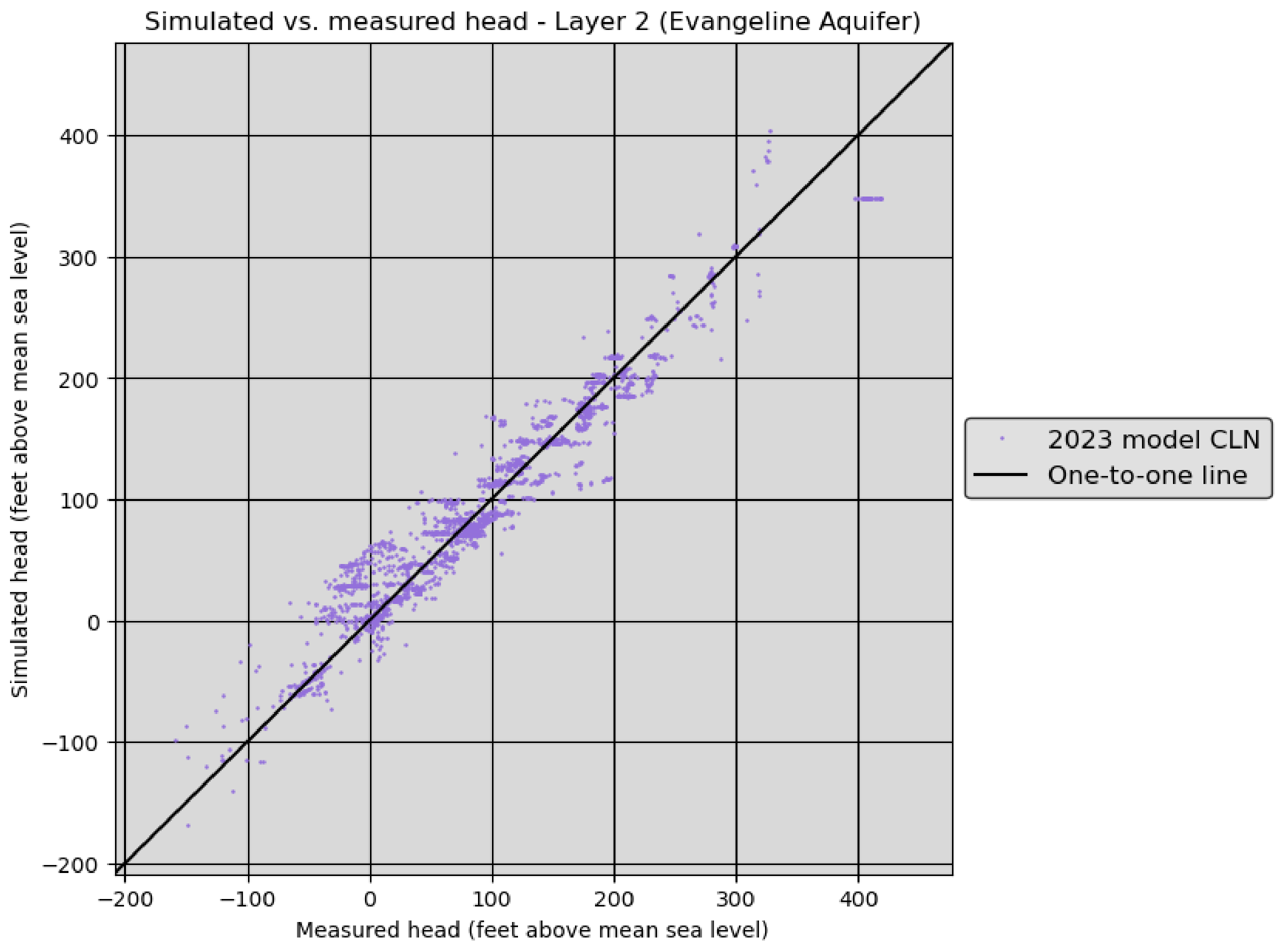


Cross-plots
Layer 2

Cross-plot showing measured versus simulated water levels. A perfect fitting model would show all points along the one-to-one line. The tighter the fit to the one-to-one line, the better the model results.



Cross-plots
Layer 2

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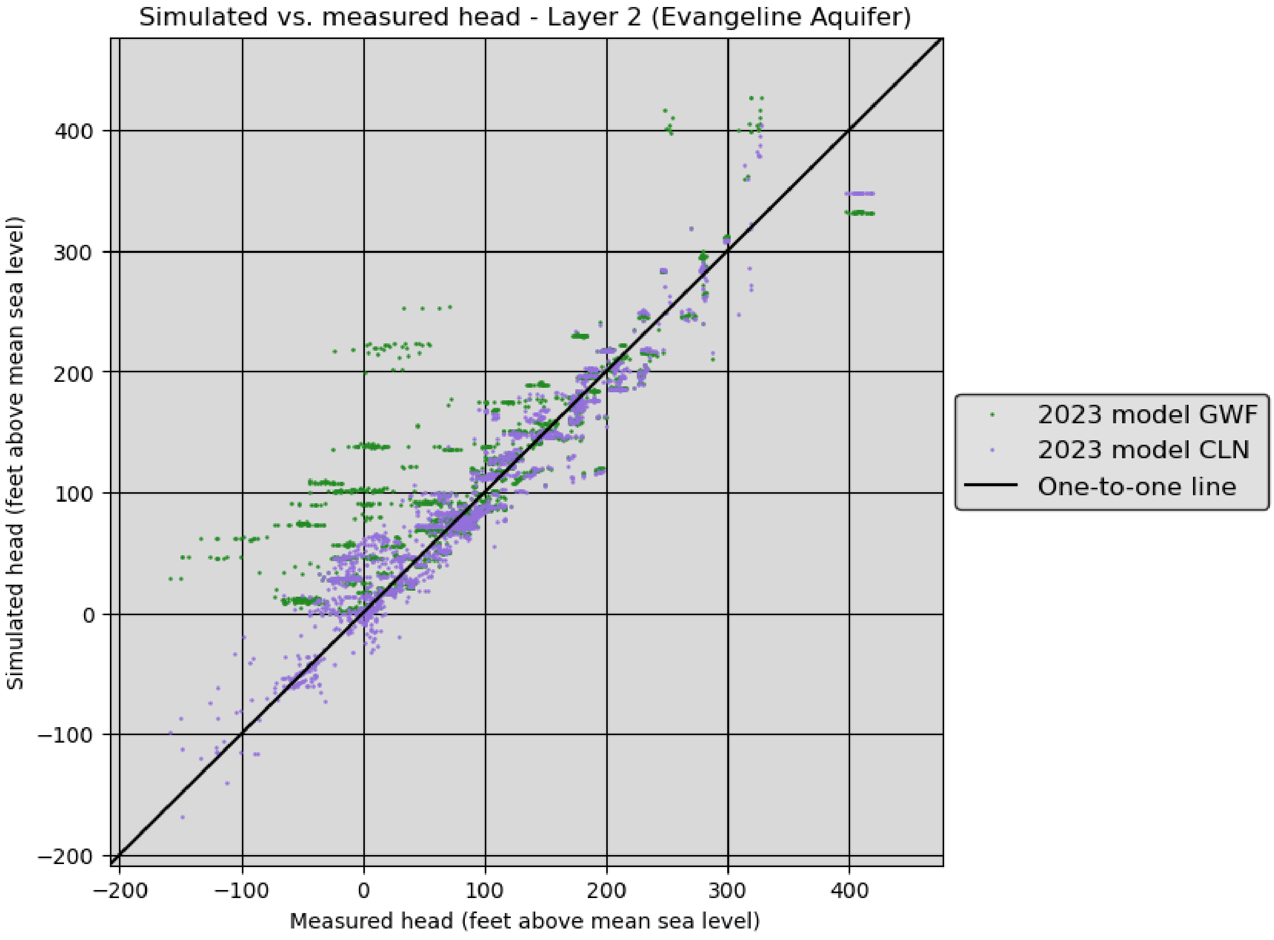

Cross-plots
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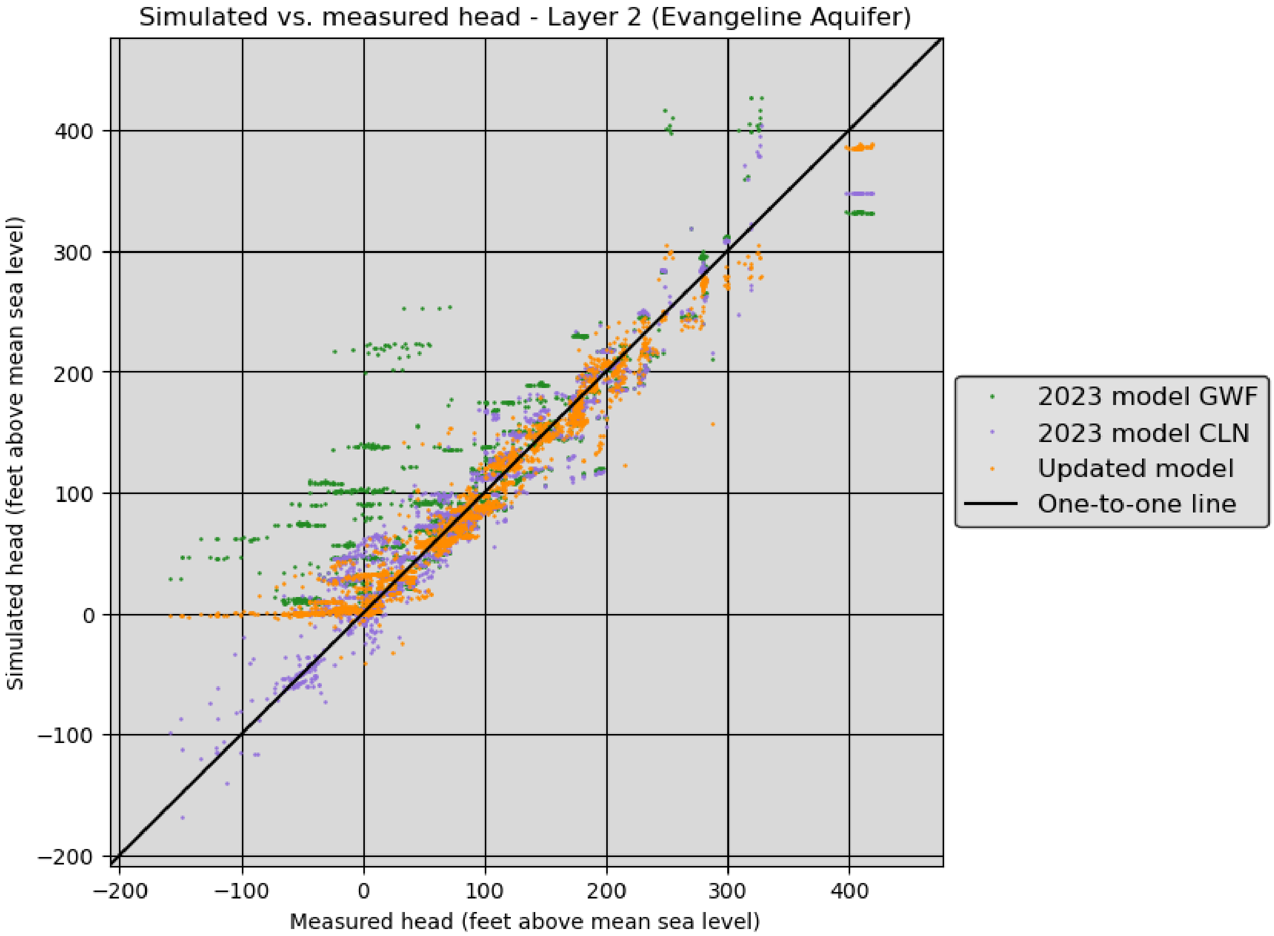
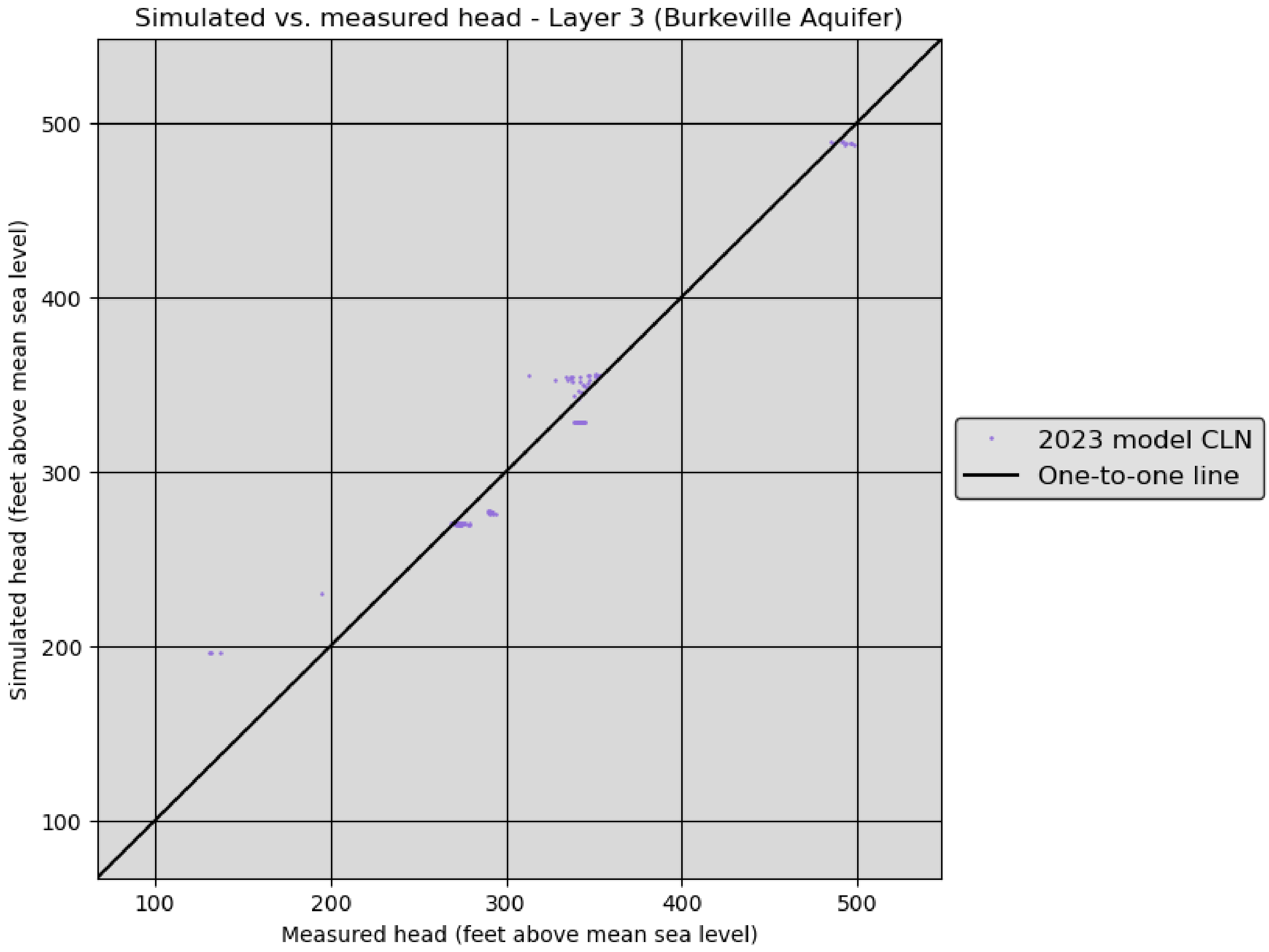
Cross-plot showing measured versus simulated water levels. A perfect fitting model would show all points along the one-to-one line. The tighter the fit to the one-to-one line, the better the model results.



TEXAS WATER DEVELOPMENT BOARD

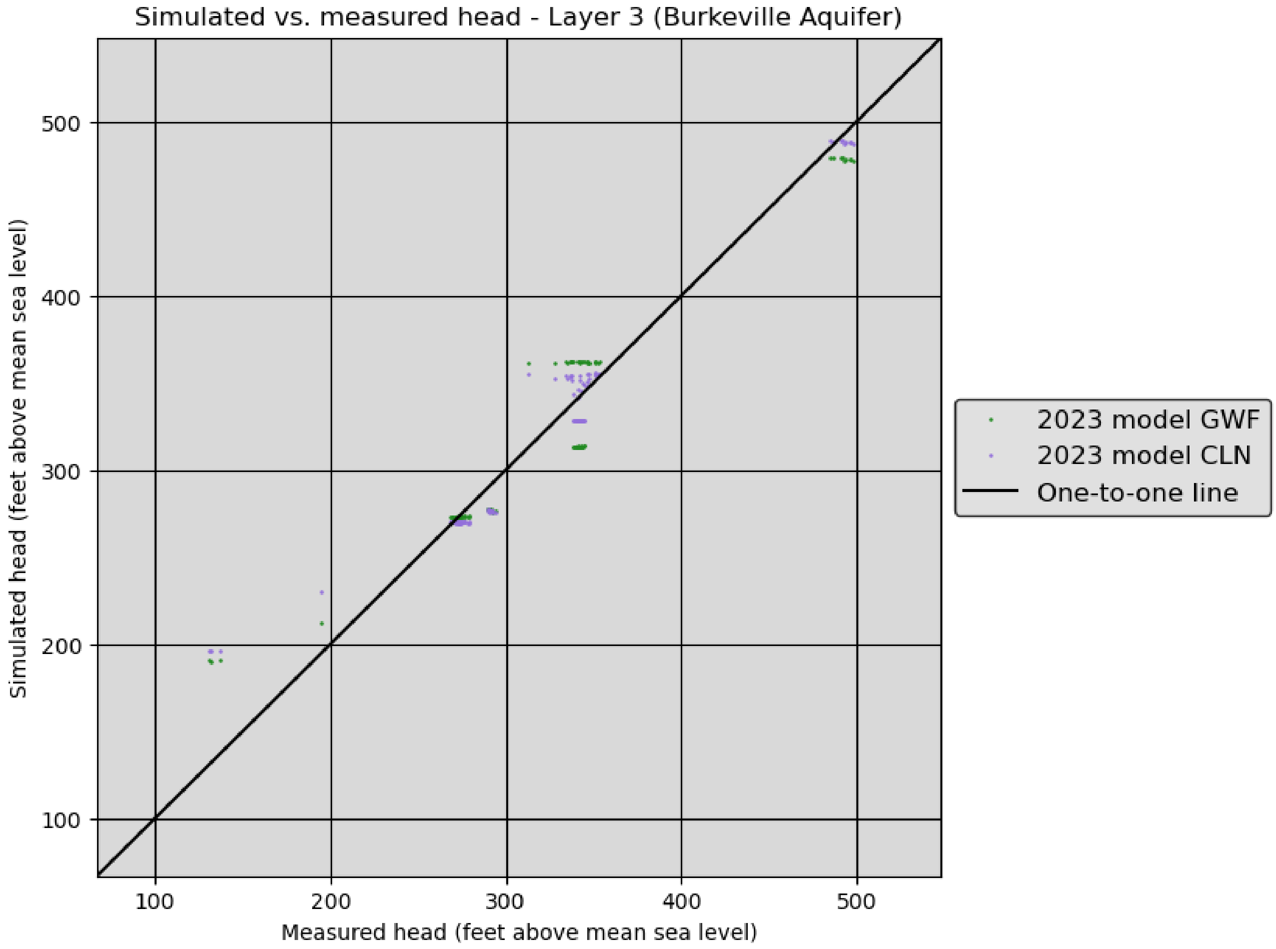
Cross-plots
Layer 3

Cross-plot showing measured versus simulated water levels. A perfect fitting model would show all points along the one-to-one line. The tighter the fit to the one-to-one line, the better the model results.



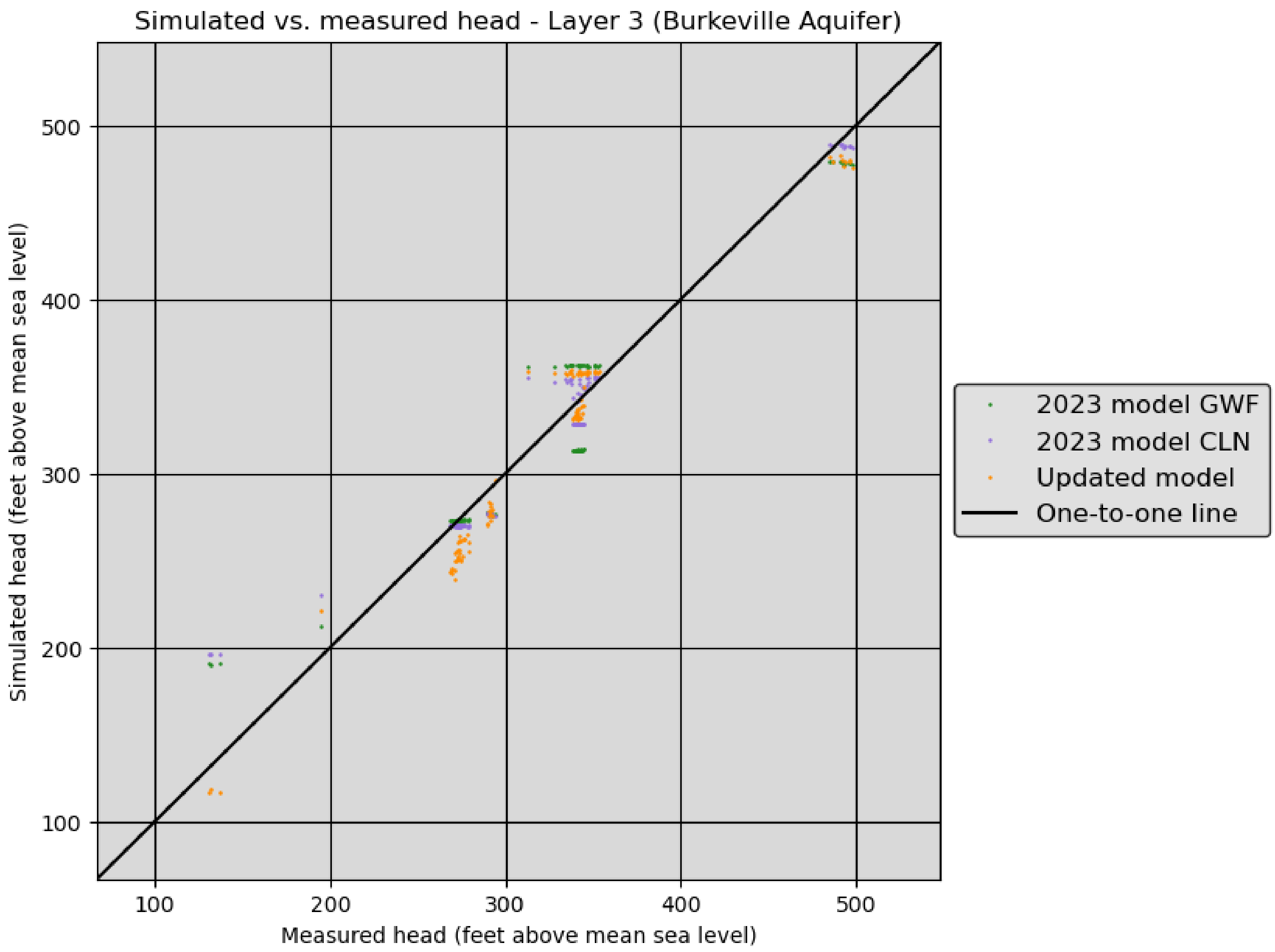
Cross-plots
Layer 3

Cross-plot showing measured versus simulated water levels. A perfect fitting model would show all points along the one-to-one line. The tighter the fit to the one-to-one line, the better the model results.



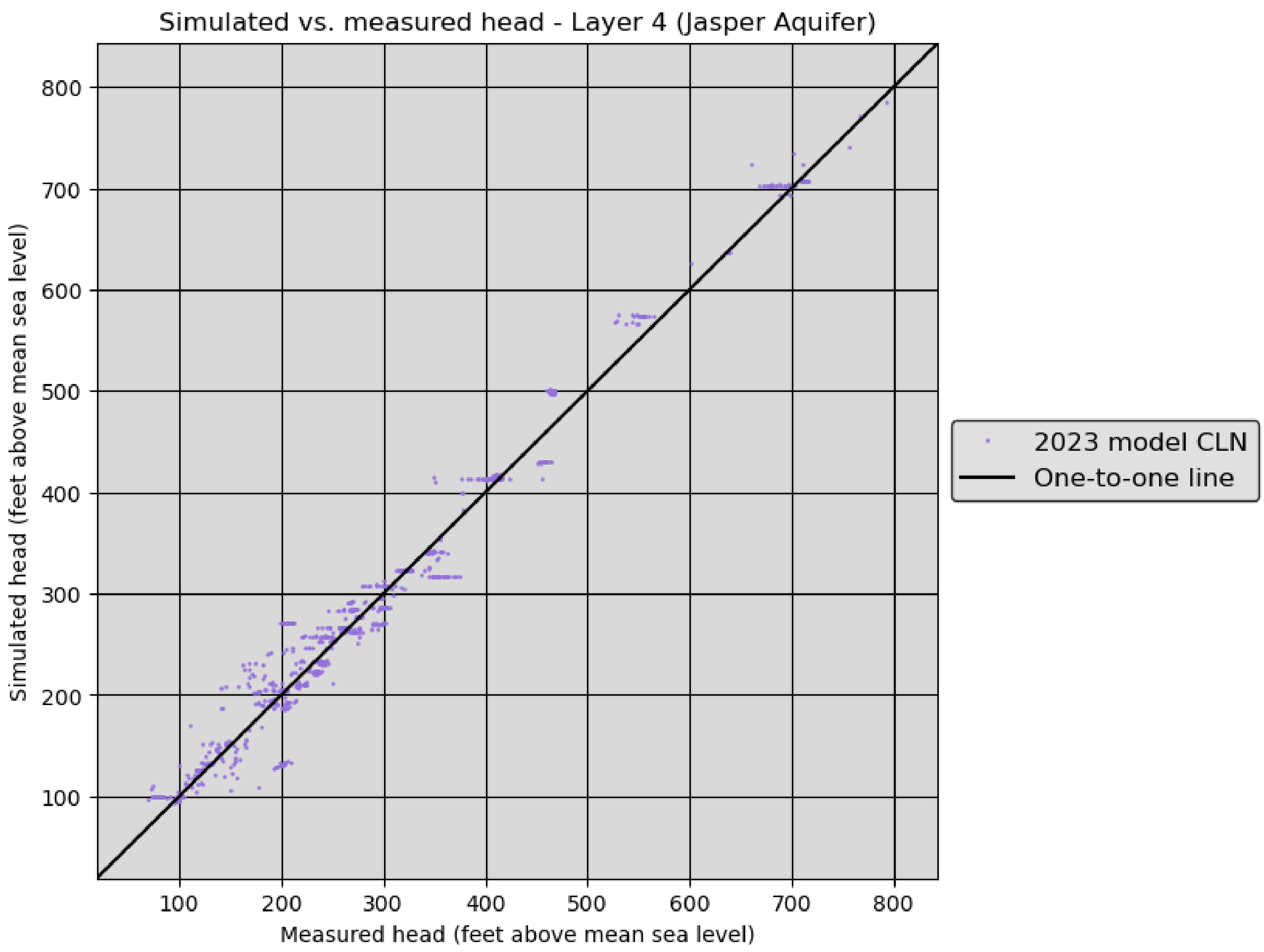
Cross-plots
Layer 3

Cross-plot showing measured versus simulated water levels. A perfect fitting model would show all points along the one-to-one line. The tighter the fit to the one-to-one line, the better the model results.



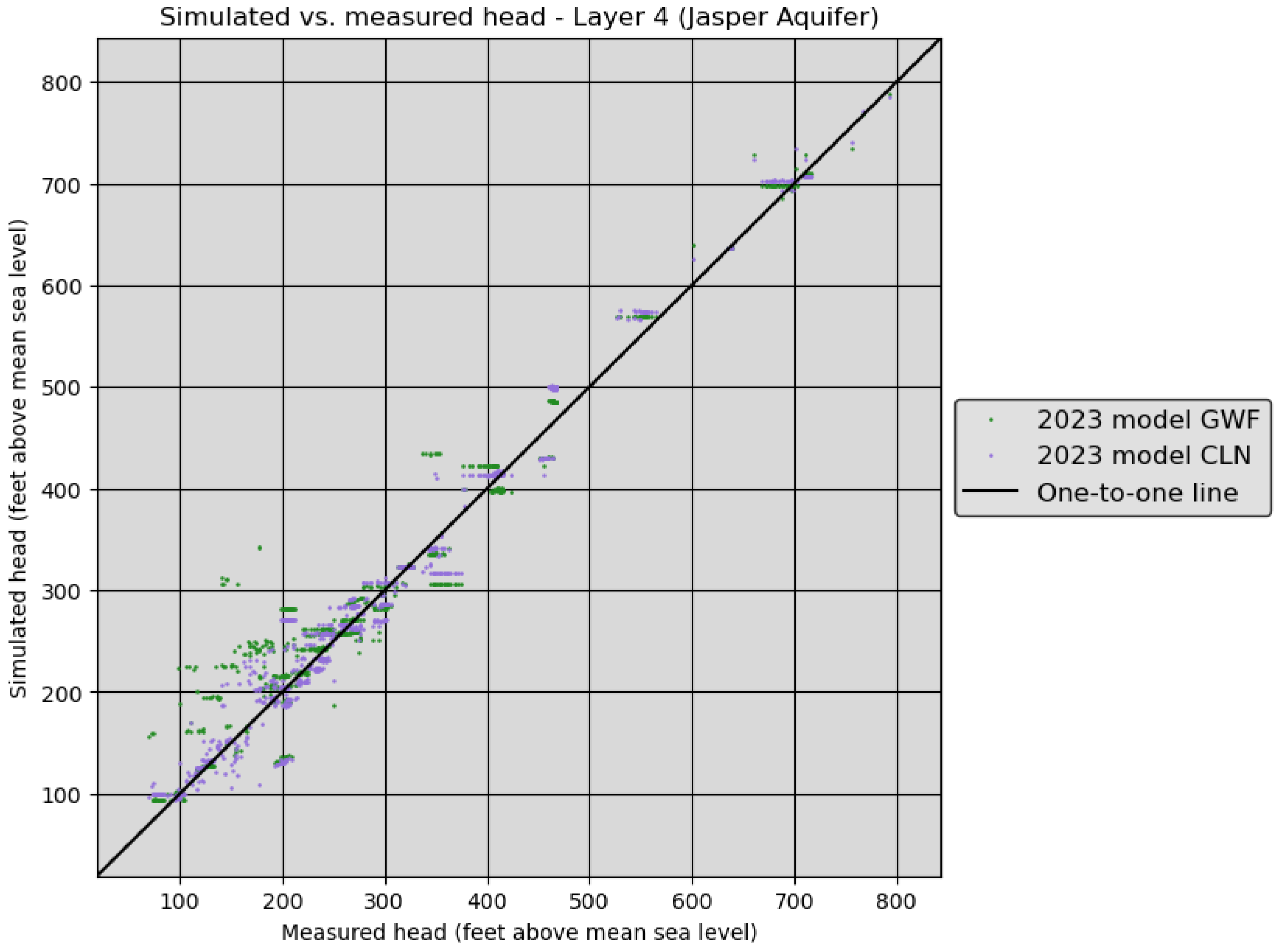
Cross-plots
Layer 4

Cross-plot showing measured versus simulated water levels. A perfect fitting model would show all points along the one-to-one line. The tighter the fit to the one-to-one line, the better the model results.



Cross-plots
Layer 4

Cross-plot showing measured versus simulated water levels. A perfect fitting model would show all points along the one-to-one line. The tighter the fit to the one-to-one line, the better the model results.



Cross-plots
Layer 4

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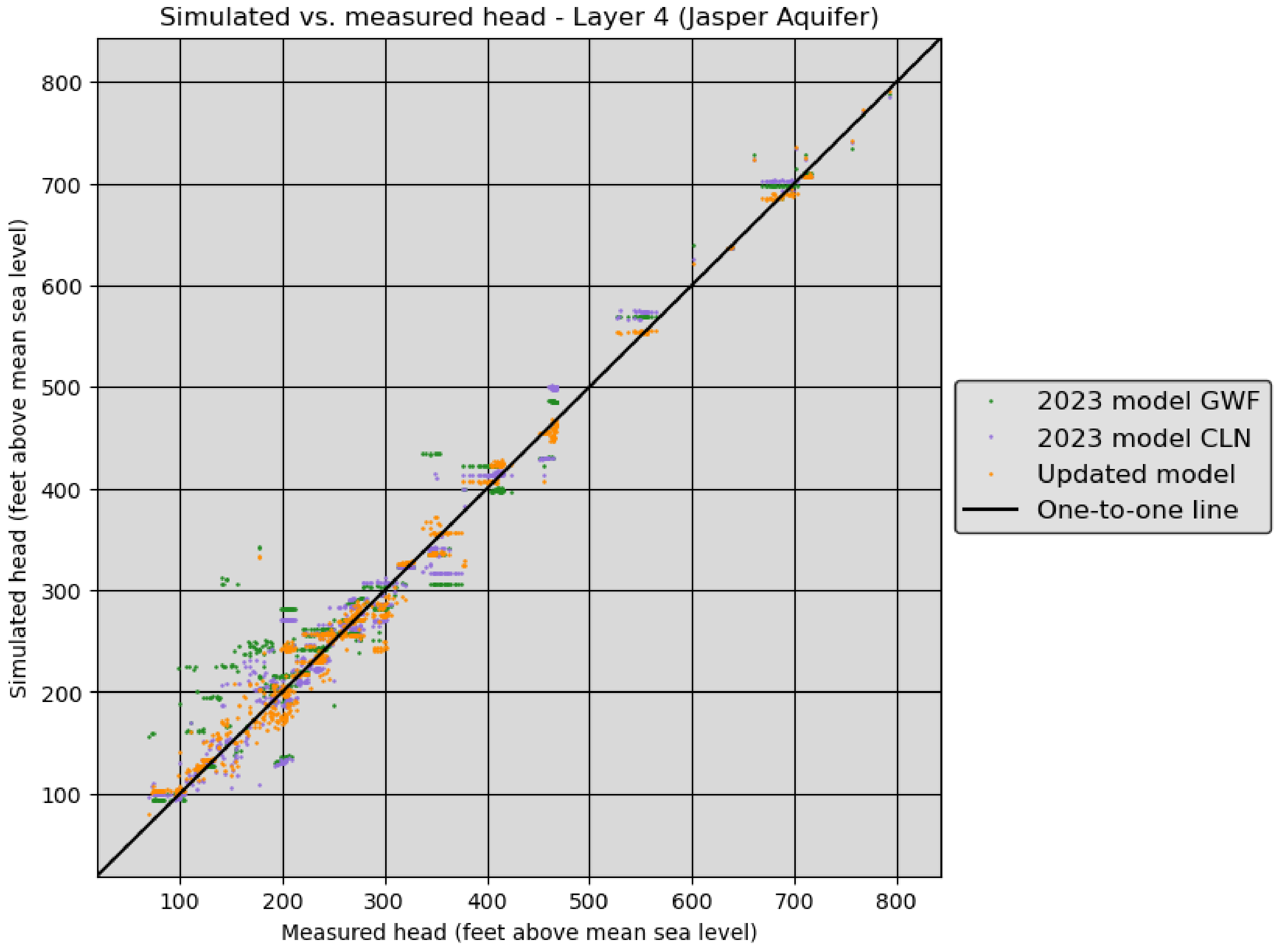
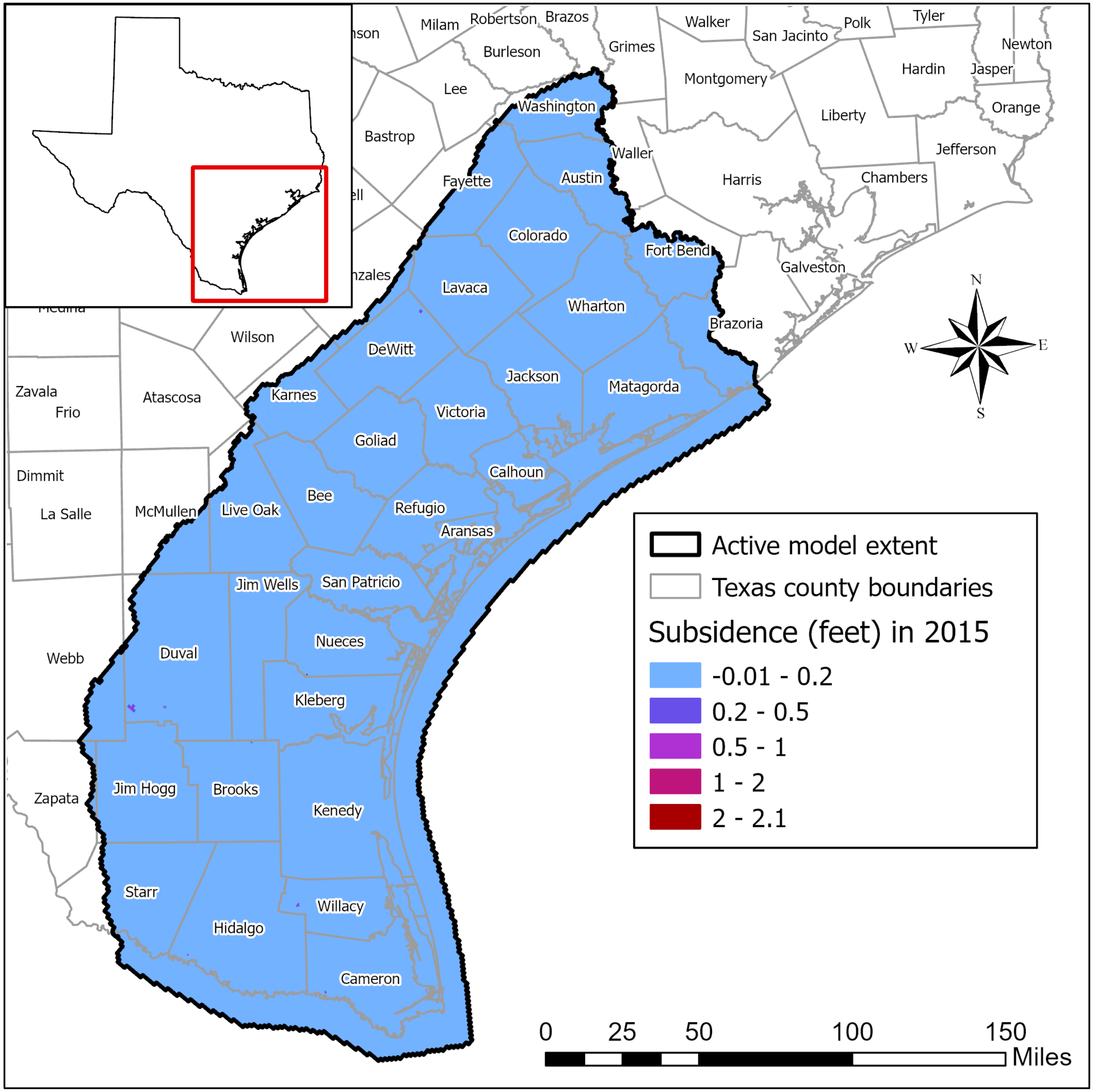


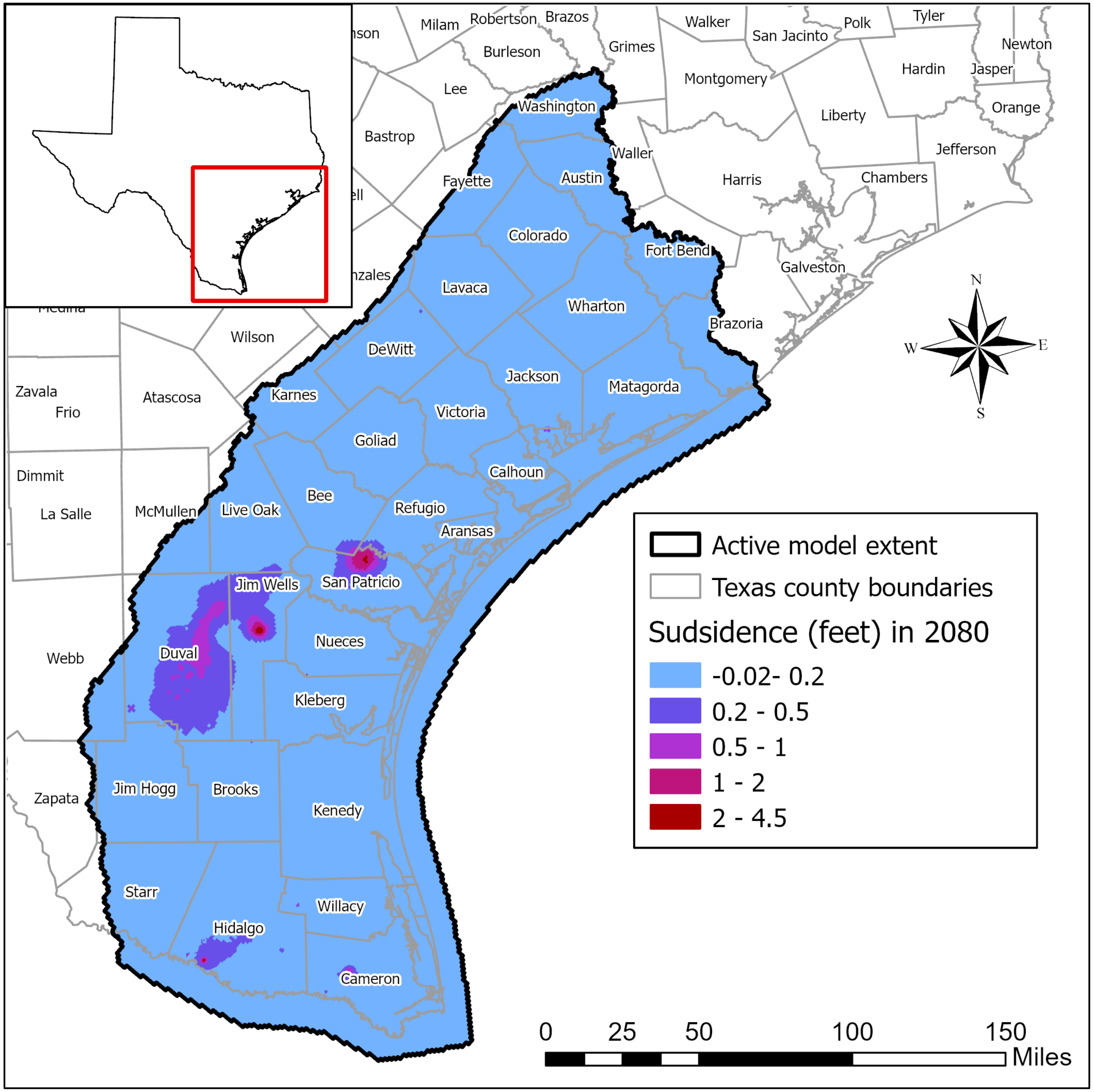
Subsidence

Subsidence in 2015



Subsidence

Subsidence in 2080

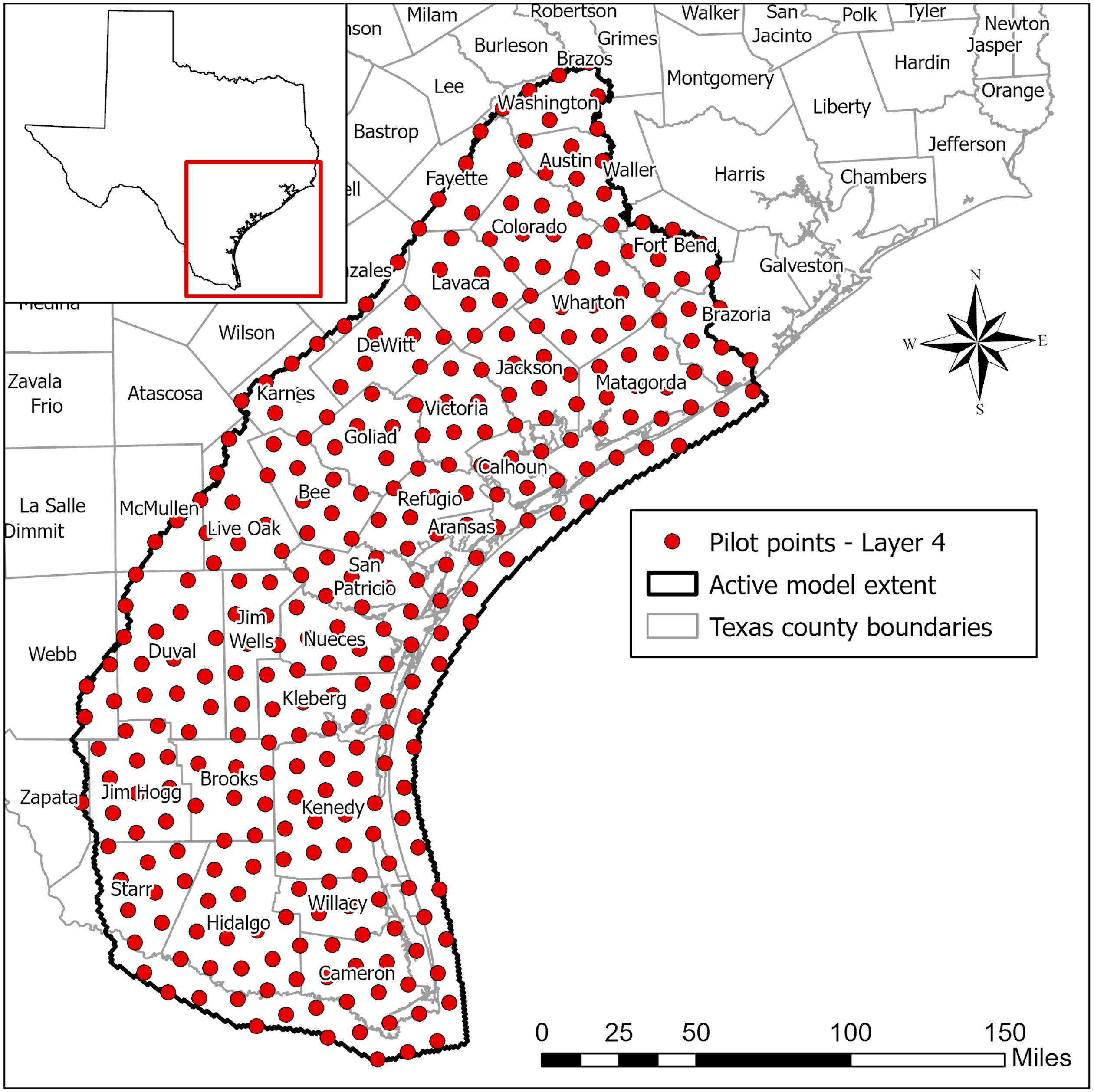


Calibration and pilot points

Pilot points

Pilot point locations used for calibration of horizontal hydraulic conductivity, storage coefficient, and recharge

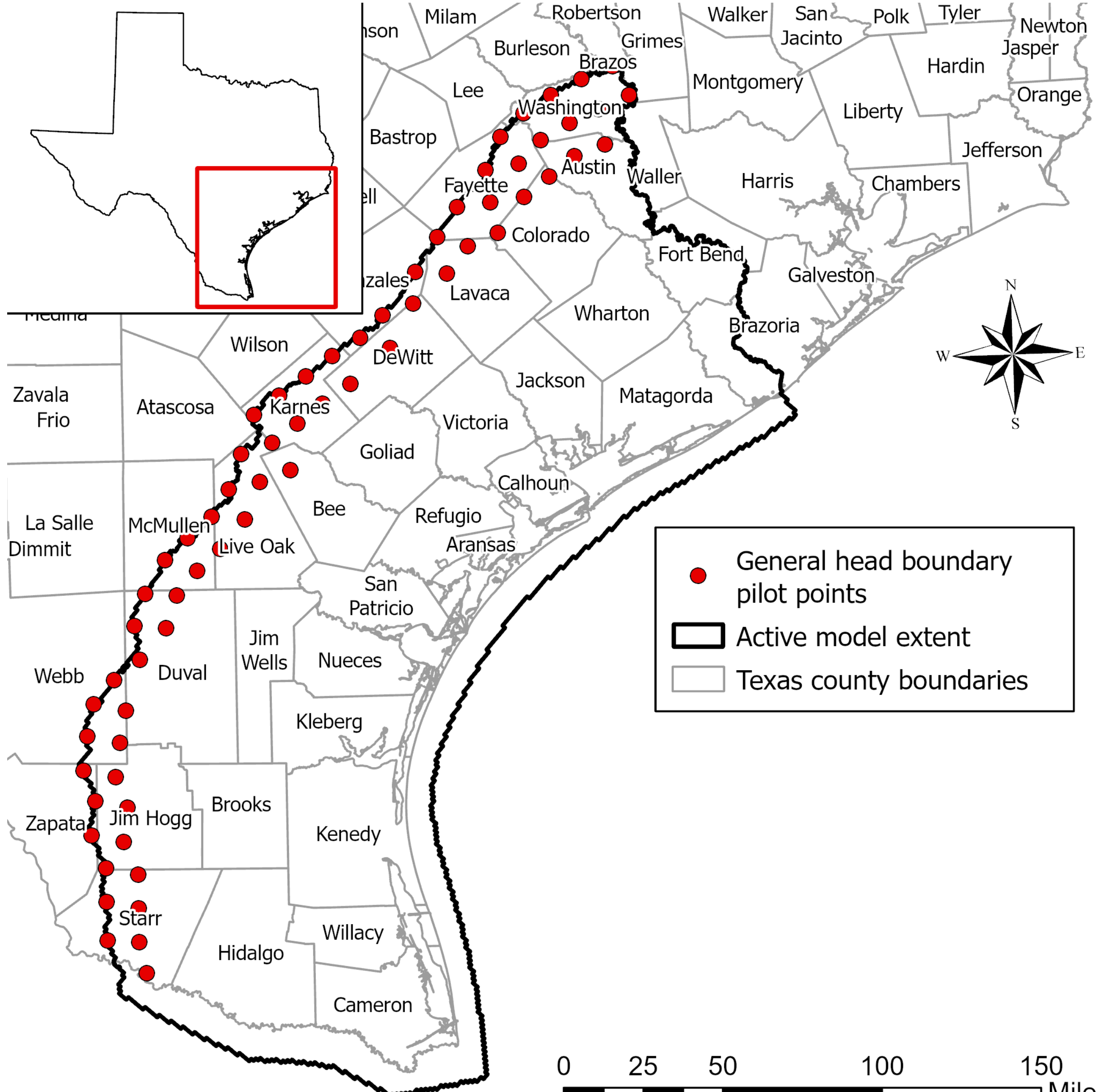
A modified inverse distance weighting method was used to interpolate between the pilot points



Pilot points

Pilot point locations for calibration of GHB conductance

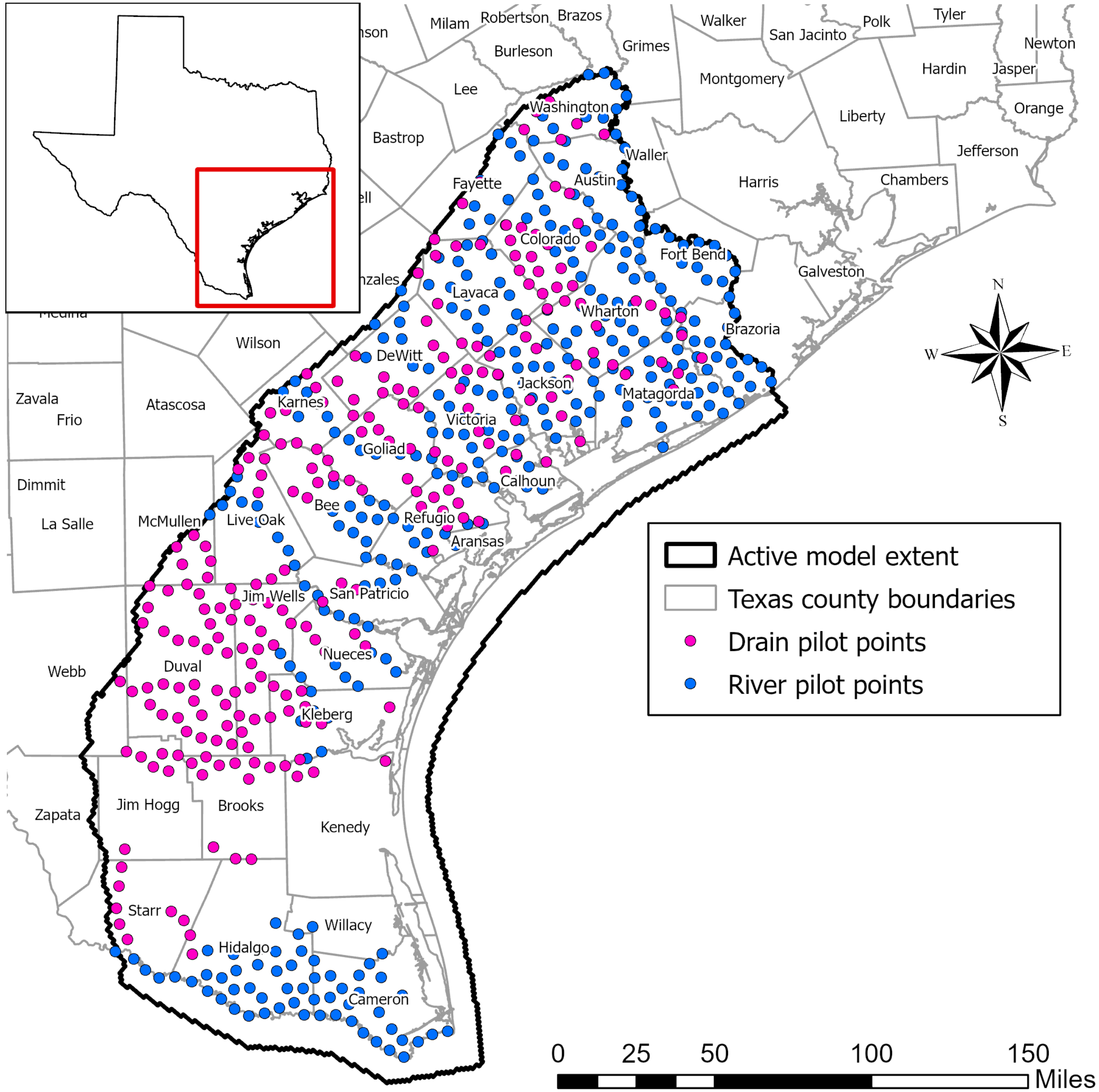
A modified inverse distance weighting method was used to interpolate between the pilot points



Pilot points

Pilot point locations used for calibration of DRN and RIV conductance values

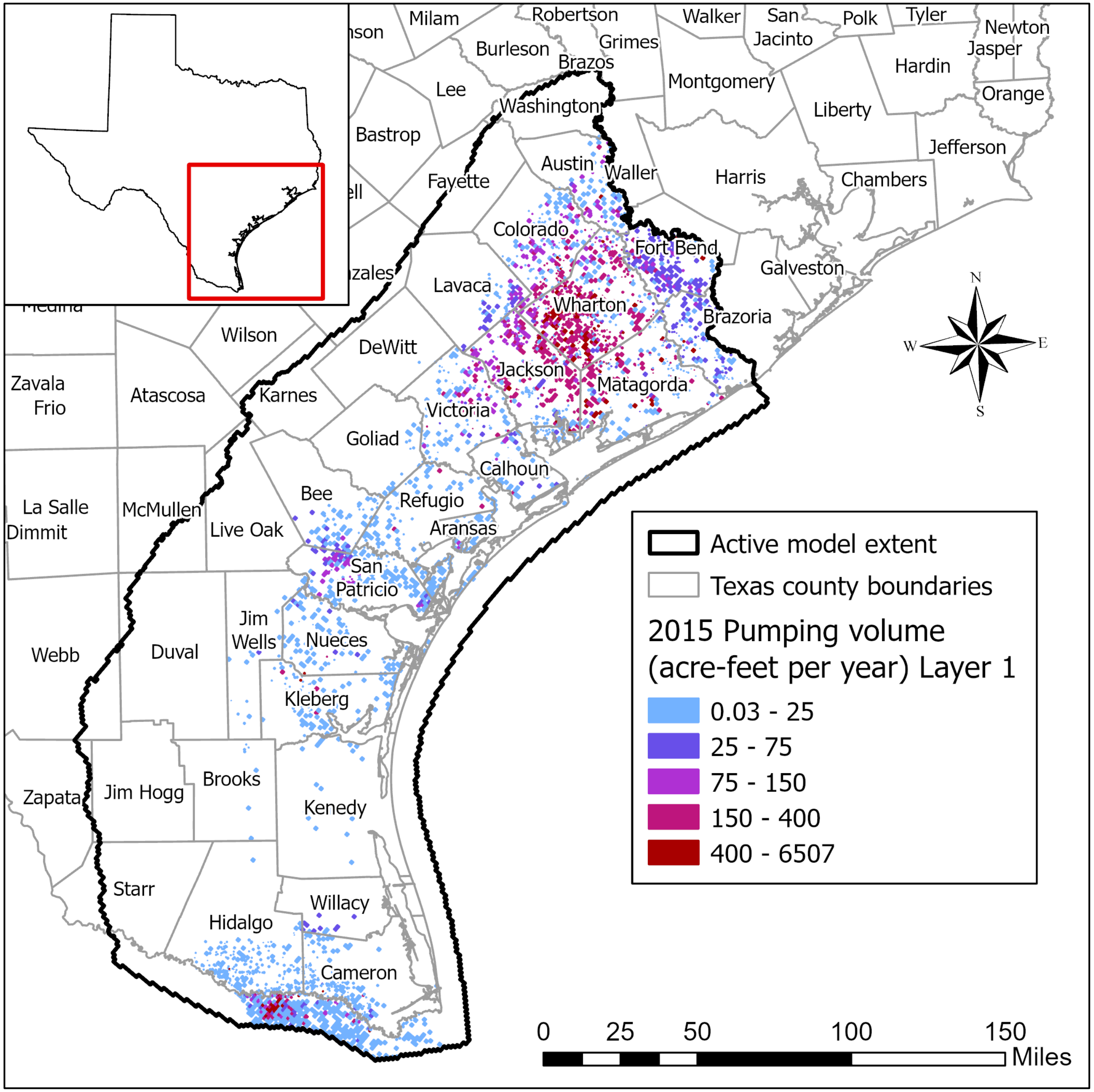
A modified inverse distance weighting method was used to interpolate between the pilot points



WEL distribution

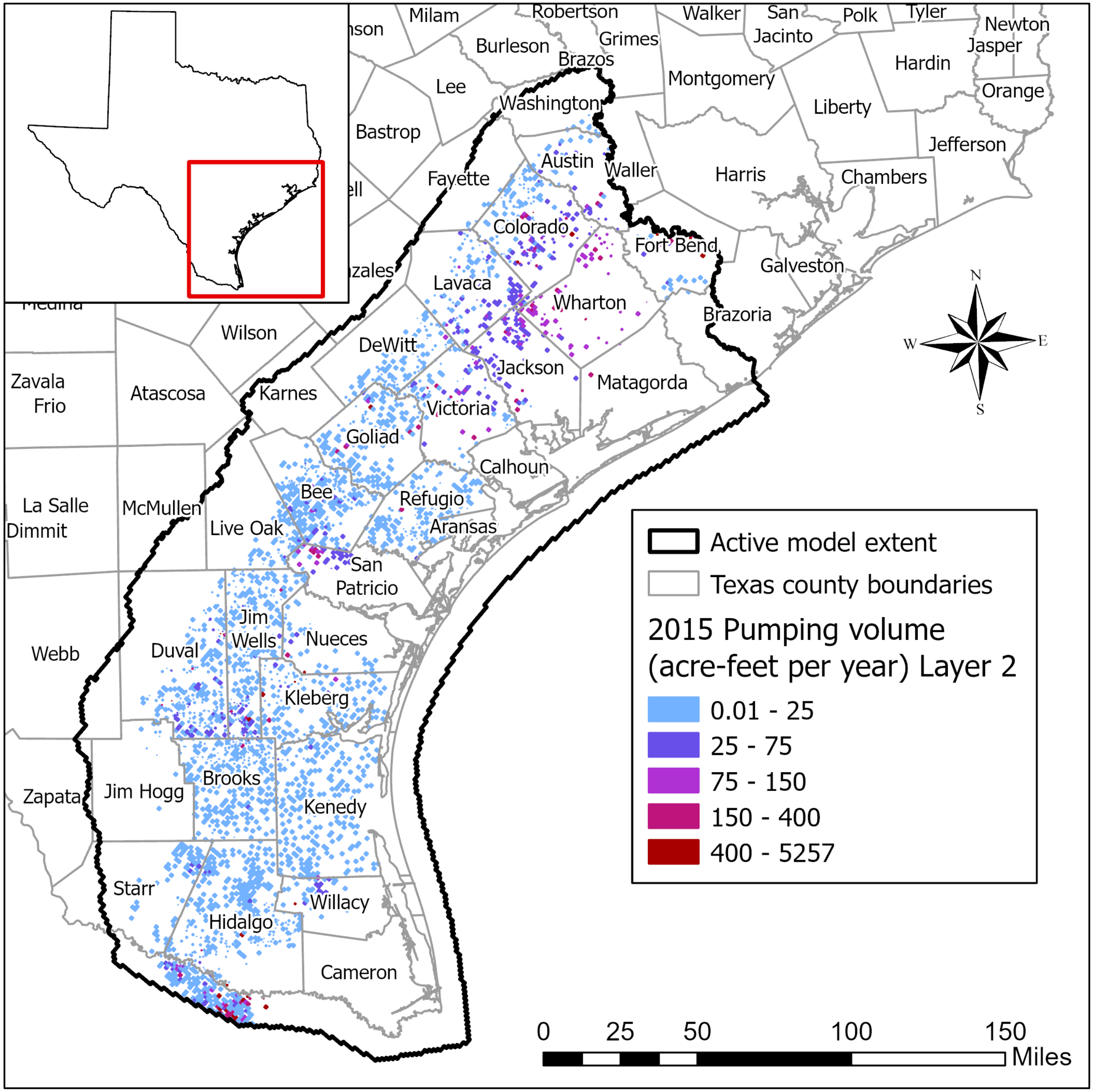
WEL distribution

Pumping distribution for Layer 1 in the year 2015



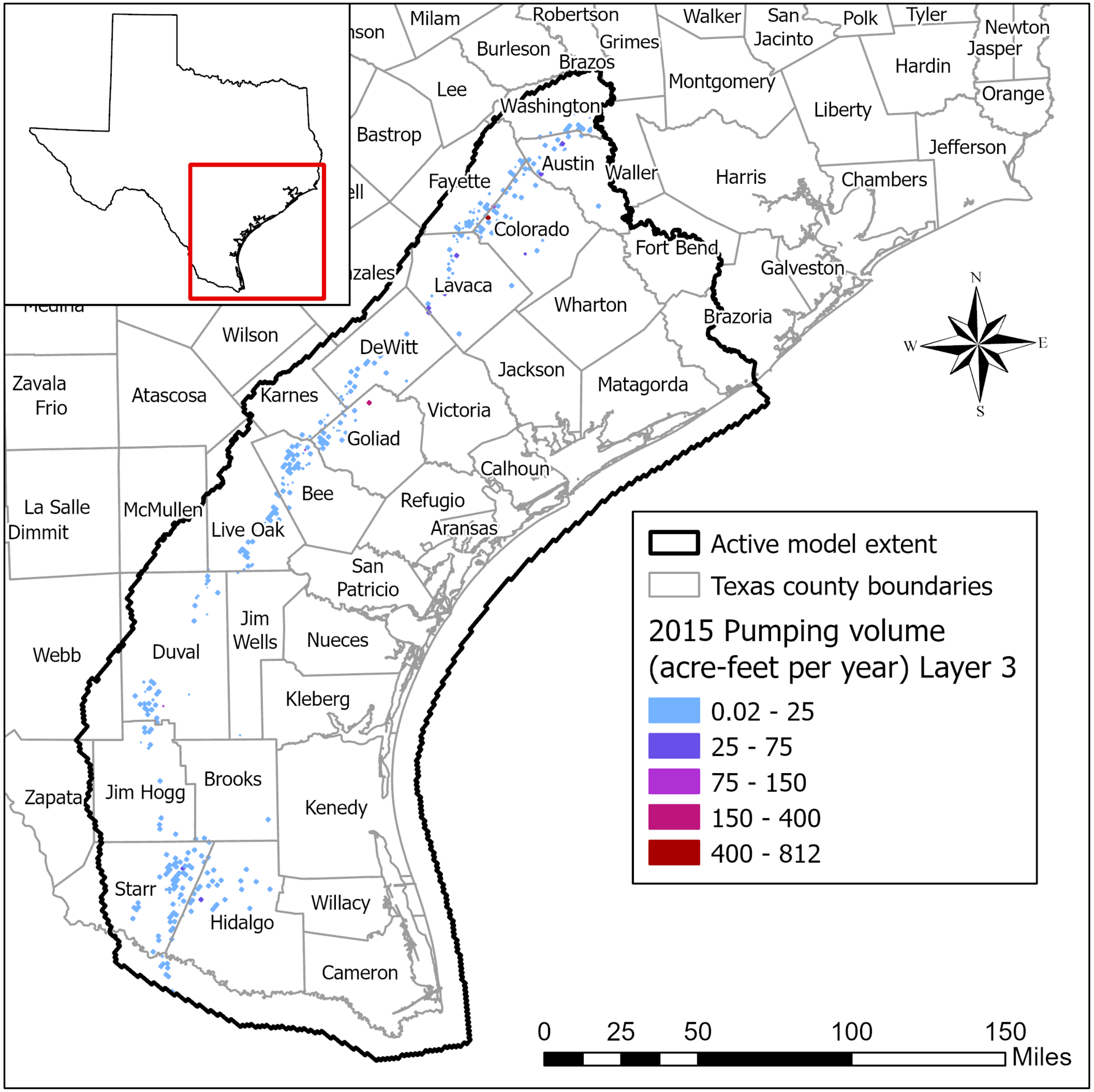
WEL distribution

Pumping distribution for Layer 2 in the year 2015



WEL distribution

Pumping distribution for Layer 3 in the year 2015



WEL distribution

Pumping distribution for Layer 4 in the year 2015