Predictive Analysis and Technical Review of the Groundwater Availability Model for the Central and Southern Portions of the Gulf Coast Aquifer System

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SUMMARY

TWDB Groundwater Modeling staff used the groundwater availability model released in May 2023 for the central and southern portions of the Gulf Coast Aquifer System to calculate historical groundwater budgets for several groundwater conservation districts and to estimate drawdowns resulting from pumping the modeled available groundwater for groundwater management areas 15 and 16. Results of those analyses raised concerns about the performance of the new model.

In response to those concerns about the new model performance, we reviewed the model properties and boundary conditions to identify the possible cause of the unexpected model behavior. The model review suggested that several model inputs, including river conductance, general head boundary conductance, and recharge should be reduced to produce more reasonable model results, particularly for water budgets. Therefore, we decided to revise and recalibrate the model to improve its use as a tool for estimating historical water budgets and estimating regional drawdowns for joint planning.

As a first step to revising and recalibrating the new model, we simplified the model to reduce the model simulation time from five and a half hours to 30 minutes while still preserving the model features of recharge, pumping, and boundary conditions. In addition, we adjusted recharge inputs while still adhering to the original conceptual model for recharge.

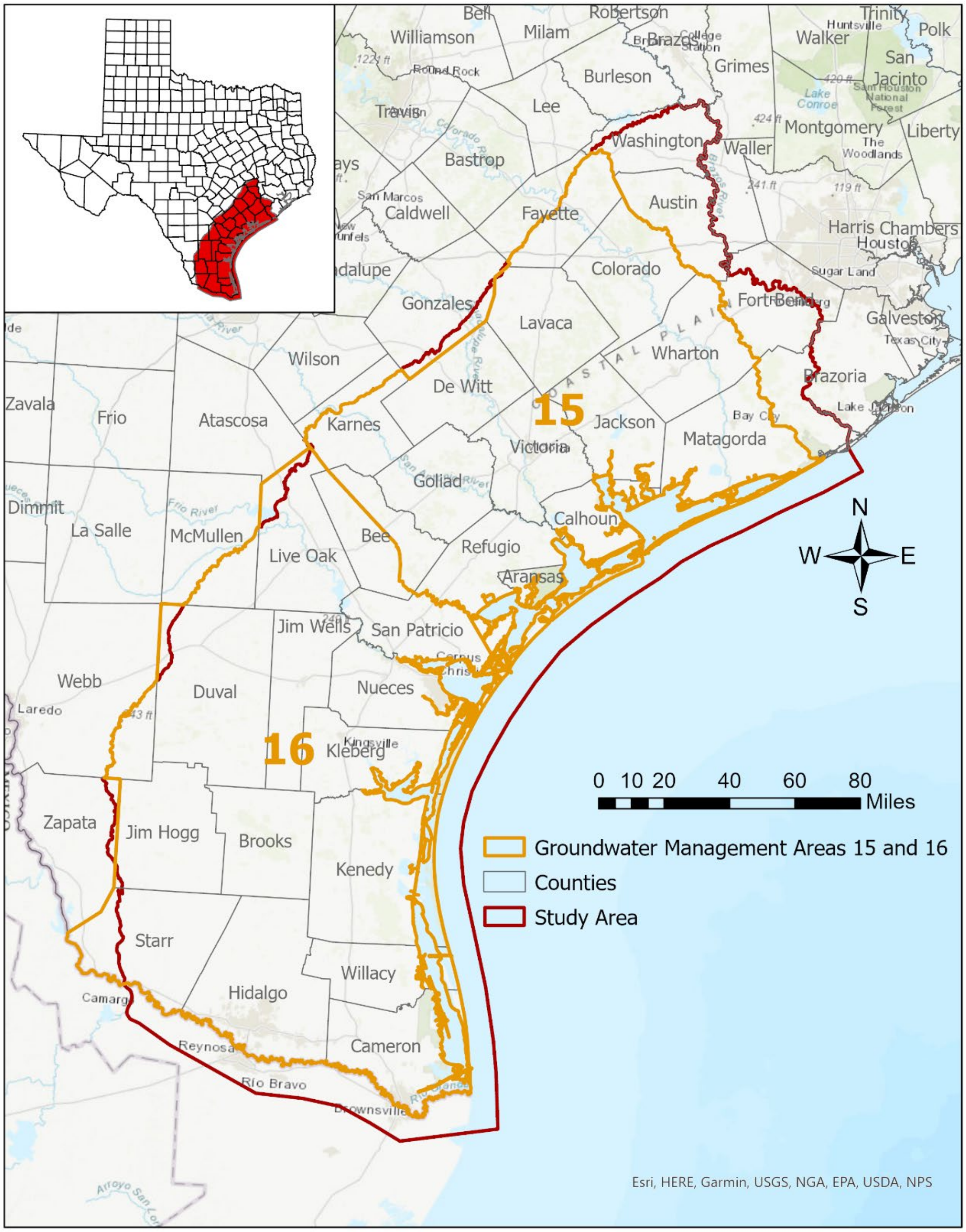
We will recalibrate the model using an automated parameter adjustment program (PEST). As part of the recalibration, we will constrain the river and general head boundary conditions within a more reasonable range of property values to produce acceptable modeled fluxes and water level trends. We will also adjust hydraulic conductivity as part of the automated recalibration. In addition to the measured water level targets used for the original calibration, we will add targets to measure water-level-hydrograph fit. The hydrograph fit targets will indicate how well modeled water levels at certain hydrographs are correlated with the measured water levels at the same hydrograph through time.

BACKGROUND

The TWDB Executive Administrator released the groundwater availability model for the central and southern portions of the Gulf Coast Aquifer System in Texas in May 2023. The new model, developed using MODFLOW-USG, covers the period of 1980 through 2015 and spatially covers most of groundwater management areas (GMAs) 15 and 16 (Figure 1).

Following the model release, we used the model for several analyses, including historical water budget reports for several groundwater conservation districts and analysis of drawdowns resulting from pumping modeled available groundwater. The historical water budgets show significantly greater flows than the previous groundwater availability models for the districts (Tables 1 and 2).

At the request of the groundwater conservation districts in GMAs 15 and 16, we used the new model to calculate the amount of drawdown that would result from pumping the modeled available groundwater from the 2021 round of joint planning. To create a predictive model, we added pumping volumes for each model layer from the 2021 round of joint planning to a MODFLOW-USG well package by mapping pumping volumes from the previous models to the new groundwater availability model grid and then extended the model from 2016 to 2080. In addition, all other MODFLOW-USG input packages were extended to 2080. We then ran the predictive model and calculated drawdowns from 2000 through 2080. Average drawdowns were summarized by county and aquifer. We compared the modeled drawdowns with the 2021 desired future conditions for GMAs 15 and 16 and the modeled drawdowns from the previous models for each GMA. The drawdowns predicted by the new model are significantly less than the desired future conditions and less than predicted by the previous models. Table 3 and Table 4 show drawdown comparisons from the new model predictive run with the 2021 joint planning desired future conditions for GMA 15 and GMA 16, respectively.



Counties: 07.03.2019
GMA boundaries: 07.03.2019

Figure 1: Study area for the groundwater availability model for the central and southern portions of the Gulf Coast Aquifer System in Texas.

Table 1: Comparison of historical groundwater budgets for Bee Groundwater Conservation District based on the new groundwater availability model (GR23-016 values shown in blue; Avendaño and Dowlearn, 2023) and previous model (GR17-015; Wade, 2018). Budget values are in acre-feet per year.

Management plan requirement	Aquifer or confining unit	GR23-016	GR17-017
Estimated annual amount of recharge from precipitation to the district	Gulf Coast Aquifer System	57,398	21,081
Estimated annual volume of water that discharges from the aquifer to springs and any surface water body including lakes, streams, and rivers	Gulf Coast Aquifer System	110,114	13,055
Estimated annual volume of flow into the district within each aquifer in the district	Gulf Coast Aquifer System	138,135	4,000
Estimated annual volume of flow out of the district within each aquifer in the district	Gulf Coast Aquifer System	271,733	17,080
Estimated net annual volume of flow between each aquifer in the district	From Gulf Coast Aquifer System to underlying older units	110,179	46

Table 2: Comparison of historical groundwater budgets for McMullen Groundwater Conservation District based on the new groundwater availability model (GR23-015 values shown in blue; Pedrazas and Dowlearn, 2023) and previous model (GR17-011; Shi, 2017). Budget values are in acre-feet per year.

Management plan requirement	Aquifer or confining unit	GR23-015	GR17-011
Estimated annual amount of recharge from precipitation to the district	Gulf Coast Aquifer System	7,618	244
Estimated annual volume of water that discharges from the aquifer to springs and any surface water body including lakes, streams, and rivers	Gulf Coast Aquifer System	5,035	809
Estimated annual volume of flow into the district within each aquifer in the district	Gulf Coast Aquifer System	12,048	242
Estimated annual volume of flow out of the district within each aquifer in the district	Gulf Coast Aquifer System	16,500	594
Estimated net annual volume of flow between each aquifer in the district	From Gulf Coast Aquifer System to underlying older units	523,463	Not applicable*

* Model assumes no-flow conditions at the base.

Table 3: **2021 round of joint planning desired future conditions (DFCs) versus modeled drawdown (values shown in blue) for Groundwater Management Area (GMA) 15.**

County	Aquifer	GMA 15 2021 DFCs (feet)*	Modeled drawdown (feet)
GMA 15	Gulf Coast Aquifer System	13	0.13
Aransas	Gulf Coast Aquifer System	0	-0.02
Bee	Gulf Coast Aquifer System	7	0.13
Calhoun	Gulf Coast Aquifer System	5	-0.14
De Witt	Gulf Coast Aquifer System	17	0.96
Fayette	Gulf Coast Aquifer System	44	-1.86
Jackson	Gulf Coast Aquifer System	15	0.05
Karnes	Gulf Coast Aquifer System	22	-1.48
Lavaca	Gulf Coast Aquifer System	18	1.25
Refugio	Gulf Coast Aquifer System	5	0.52
Victoria	Gulf Coast Aquifer System	5	1.52
Colorado	Chicot and Evangeline	17	-0.71
Colorado	Jasper	25	-1.06
Goliad	Chicot	-4	0.48
Goliad	Evangeline	-2	0.09
Goliad	Burkeville	7	0.08
Goliad	Jasper	14	0.04
Matagorda	Chicot and Evangeline	11	0.22
Wharton	Chicot and Evangeline	15	-0.77

* Average feet of drawdown from 2000 to 2080.

Table 4: **2021 round of joint planning desired future conditions (DFCs) versus modeled drawdown (values shown in blue) for Groundwater Management Area (GMA) 16.**

Groundwater conservation district (GCD)	Aquifer	GMA 16 2021 DFC (feet)*	Modeled drawdown (feet)
Bee GCD	Gulf Coast Aquifer System	93	1.48
Live Oak UWCD	Gulf Coast Aquifer System	89	1.57
McMullen GCD	Gulf Coast Aquifer System	137	6.38
Red Sands GCD	Gulf Coast Aquifer System	27	0.87
Kenedy County GCD	Gulf Coast Aquifer System	45	0.11
Brush Country GCD	Gulf Coast Aquifer System	12	0.85
Duval County GCD	Gulf Coast Aquifer System	119	1.82
San Patricio County GCD	Gulf Coast Aquifer System	138	3.2
Starr County GCD	Gulf Coast Aquifer System	21	0.97
Cameron County-ND	Gulf Coast Aquifer System	26	0.19
Hidalgo County-No District	Gulf Coast Aquifer System	161	1.06
Kleberg County-No District	Gulf Coast Aquifer System	44	-0.38
Nueces County-No District	Gulf Coast Aquifer System	60	0.18
Webb County-No District	Gulf Coast Aquifer System	69	-0.37
Willacy County-No District	Gulf Coast Aquifer System	94	0.11

* Average feet of drawdown between January 2010 and December 2079.

In July 2023, the TWDB received a letter from the Goliad County Groundwater Conservation District expressing concern that the newly-released model does not accurately predict water level declines in Goliad County and will therefore not be a useful tool for joint planning (Goliad County Groundwater Conservation District, 2023). We reviewed measured water-level trends within Goliad County and compared those trends with model results for the entire county. Measured water levels between 1980 and 2015 show an average of 7.6 feet of drawdown within Goliad County from the beginning to end of that period. Modeled water levels produce an average of -2.5 feet of drawdown (or a 2.5-foot rise in water levels) by subtracting 2015 modeled water levels from 1980 modeled water levels within Goliad County. Modeled water levels overall are rising in Goliad County between 1980 and 2015, although some years show a decline in water levels (Figure 2).

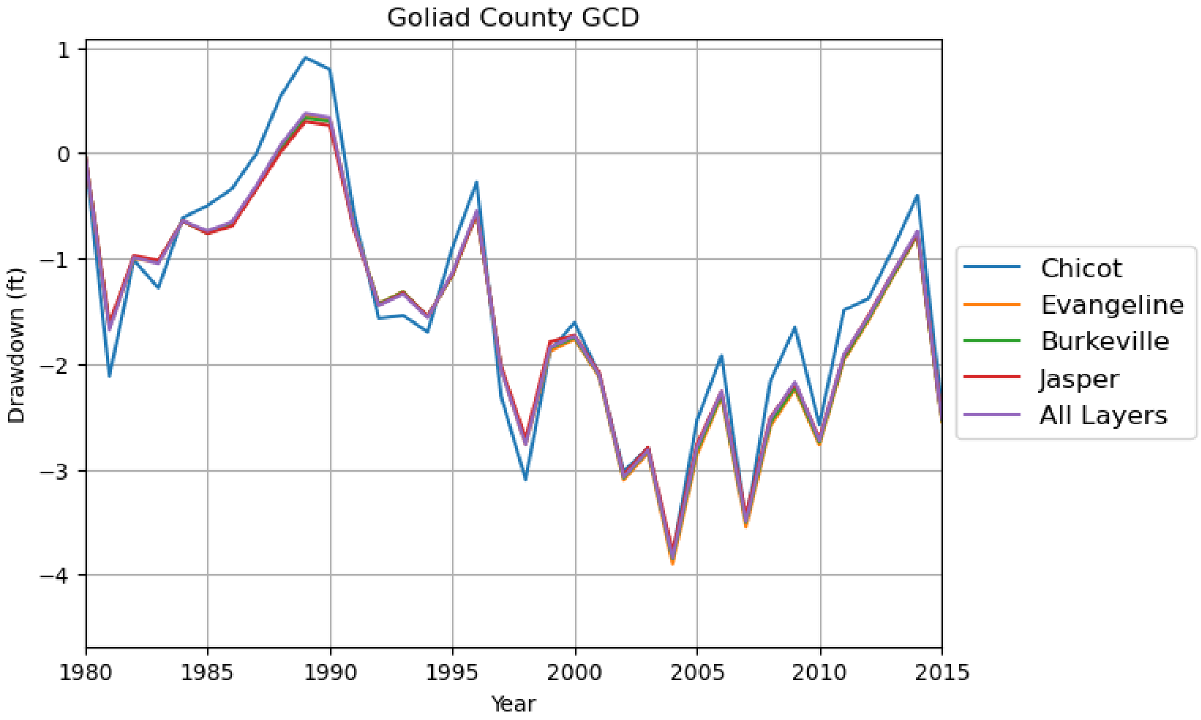


Figure 2: Plot showing average drawdown per model layer per stress period within Goliad County Groundwater Conservation District.

MODEL REVIEW

To address the concerningly large flows in the groundwater budgets and lack of drawdown predicted by the new groundwater availability model for the central and southern portions of the Gulf Coast Aquifer System in Texas, we conducted a review of several model inputs including the MODFLOW Recharge, River, and General Head Boundary packages. Our review consisted of calculating statistics for model properties within the packages and comparing those statistics with other models or data sources, in the case of the recharge package.

Recharge package inputs

In reviewing the model recharge, we compared the annual values of recharge with the baseflow-precipitation analysis results documented in the conceptual model report and corresponding geodatabase (Shi and others, 2022). Shi and others (2022) developed the distributed recharge for the groundwater availability model for the central and southern portions of the Gulf Coast Aquifer System in Texas from a stream baseflow analysis correlated with precipitation data. The contribution of groundwater to stream flow was estimated at 14 select river basins using a baseflow separation computer code. Average precipitation for the same watershed over the same years was calculated from maps of distributed rainfall. A correlation equation relating estimates of recharge from baseflow to precipitation was developed from the 14 data pairs to distribute recharge for the entire model area based on annual rainfall maps (Shi and others, 2022). Our review indicated that the model recharge values honor the information documented in the conceptual model.

We then compared the estimated model recharge to other estimates of recharge for the same area (Tables 5 and 6). Scanlon and others (2012) produced a map of long-term recharge in inches per year for the Gulf Coast Aquifer System based on the chloride mass balance method (Figure 3). We calculated county recharge totals in acre-feet per year based on the Scanlon and others (2012) chloride mass balance derived map and compared the values with the annual recharge in the new model for an average year (1981), a dry year (2011) and a wet year (2015). The chloride mass balance estimates for recharge are significantly lower than the average and wet-year model estimates but are much greater than the dry-year estimates (Table 5).

Ellis and others (2023) used the Soil Water Balance (SWB) code (Westenbroek and others, 2010) to estimate recharge for the newly released groundwater availability model for the northern portion of the Gulf Coast Aquifer System. The Soil-Water-Balance recharge estimates were provided as a raster map of long-term (1897 to 2018) annual recharge in inches per year with the source data for the model. To compare with the recharge estimates for overlapping areas with the model for the central and southern portions of the Gulf Coast Aquifer System, we calculated county recharge totals in acre-feet per year from the raster map. For counties with 100 percent overlap between the two models recharge estimates are similar (Table 6).

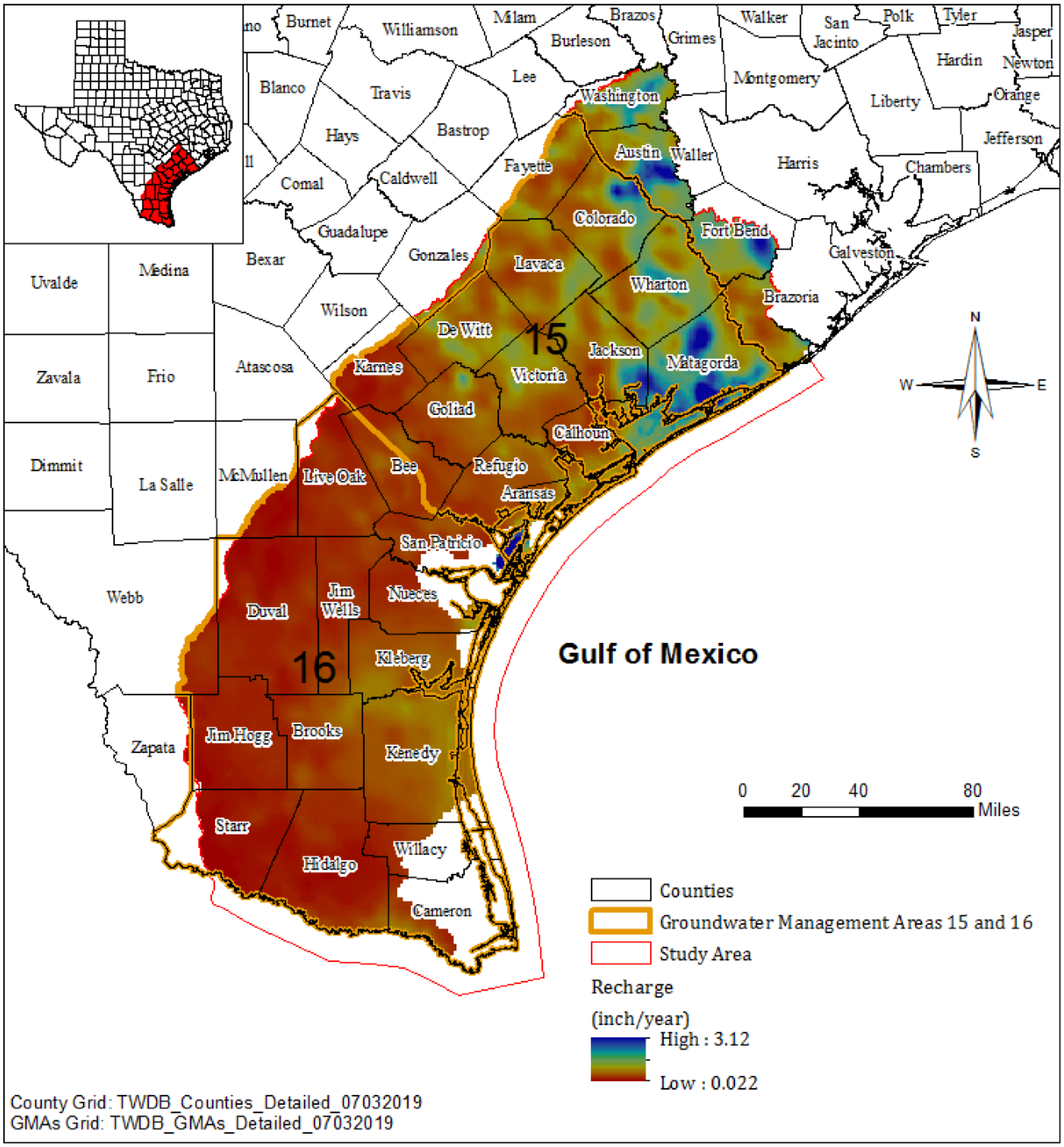


Figure 3: **Distribution of recharge estimated using chloride mass balance analysis (from Shi and others [2022] and Scanlon and others [2012]).**

Table 5: Comparison of chloride mass balance estimates of recharge (Scanlon and others, 2012) with central and southern portions of the Gulf Coast Aquifer System model estimates.

County	Chloride mass balance estimate (acre-feet per year)	1981 model input (acre-feet per year)	2011 model input (acre-feet per year)	2015 model input (acre-feet per year)
Aransas	10,922	151,946	928	144,376
Atascosa	0	6	0	34
Austin	30,536	160,688	2,463	225,674
Bee	9,315	173,506	1,439	218,513
Brazoria	12,650	166,724	5,611	172,888
Brazos	7	42	1	62
Brooks	11,057	72,908	1,096	110,722
Calhoun	20,903	304,998	2,474	271,486
Cameron	3,333	44,085	3,045	150,574
Colorado	31,355	283,606	3,483	334,030
De Witt	20,585	198,644	4,355	260,220
Duval	8,968	101,484	1,878	253,324
Fayette	11,667	155,702	1,924	189,113
Fort Bend	27,104	166,188	3,122	183,083
Goliad	14,282	239,342	3,374	260,252
Gonzales	3,501	32,087	560	39,996
Grimes	3	30	1	39
Hidalgo	8,839	54,463	1,337	217,700
Jackson	26,232	256,542	2,070	278,387
Jim Hogg	5,523	38,032	685	31,945
Jim Wells	7,316	125,876	1,320	187,819
Karnes	3,905	44,508	1,491	114,648
Kenedy	32,018	117,589	3,099	409,026
Kleberg	15,010	148,597	1,583	246,246
Lavaca	21,723	297,099	3,614	314,202
Live Oak	6,874	96,690	1,563	153,326
Matagorda	79,986	459,452	9,701	465,318
McMullen	785	12,083	227	33,113
Nueces	7,512	201,598	1,811	266,225
Refugio	11,914	262,115	2,145	247,687
San Patricio	7,123	196,482	1,434	188,847
Starr	3,277	26,967	482	45,889
Victoria	20,696	245,961	2,953	284,658
Waller	81	439	7	611
Washington	23,387	104,994	2,955	186,769
Webb	1,793	10,497	284	15,511
Wharton	39,132	311,298	3,523	369,436
Willacy	2,085	43,798	1,809	158,517
Zapata	172	1,598	38	1,734

Table 6: Comparison of recharge estimates for the Central and Southern Gulf Coast Aquifer System model and the soil water balance recharge estimates for the GULF 2023 model (Ellis and others, 2023).

County	Central and Southern Gulf Coast Aquifer System model average recharge 1981 through 2015 (acre-feet per year)	Soil Water Balance code for GULF 2023 model average recharge 1897 through 2018 (acre-feet per year)
Austin	116,179	119,844
Colorado	167,852	190,569
Fayette	79,498	85,259
Jackson	153,839	118,720
Lavaca	148,429	138,605
Matagorda	241,459	172,538
Washington	89,014	80,891
Wharton	224,677	177,321

River package inputs

Water budget results revealed that the River package produced much larger flux values, both to and from the aquifer, than anticipated. We reviewed the River package properties by summarizing statistics for the conductance property within the River package and comparing those values to the river conductance values from other similar models. We also conducted a sensitivity analysis by reducing the river conductance by 50 percent, 10 percent, 5 percent, and 1 percent of the original conductance values to determine the effect of reducing conductance on modeled heads and model-wide groundwater budgets.

The amount of flow between a river and an aquifer is determined by the river conductance and the difference between the water level in the river and the head in the aquifer. We summarized the river conductance values for this model and five other groundwater availability models in Table 7. Additionally, since conductance is a function of the length of the river reach, which we assumed to be the length of the model cell, we converted conductance into a conductivity so that property values in the different models could be compared equally. Of the six models, the southern and central Gulf Coast Aquifer System, the northern Carrizo-Wilcox Aquifer, the southern Carrizo-Wilcox Aquifer, and the Brazos River Alluvium Aquifer models have 660 by 660-foot models cells along the rivers. The central Carrizo-Wilcox Aquifer model has 1280 by 1280-foot model cells along the rivers and the central Gulf Coast Aquifer System model has 5280 by 5280-foot model cells along rivers. Table 8 contains the river cell sizes and conductance converted into conductivity values for equal comparison.

Upon reviewing Tables 7 and 8, we confirmed that river conductance in the central and southern portions of the Gulf Coast Aquifer System model are high compared to other models with similar use of the MODFLOW River package. The central and southern portion of the Gulf Coast Aquifer System model includes the largest conductivity value by two orders of magnitude. However, the southern portion of the Carrizo-Wilcox Aquifer model has the largest mean conductivity.

We adjusted river conductance by 50 percent, 10 percent, 5 percent, and 1 percent of the original conductance values and ran the model for each reduction as a measure of model sensitivity to river conductance. Model-wide mean head elevations per model run are shown in Figure 4. Model-wide groundwater budgets for the original river conductance values and the model with river conductance values at 1 percent of the original river conductance values are shown in Figure 5. As shown in Figure 4, reducing river conductance reduces model-wide mean head elevations but maintains the original model's water level trends. Figure 5 shows that the groundwater budgets improve as reducing river conductance values also lowers the flow from the General Head Boundary.

Table 7: River conductance summary for different models. Values for the groundwater availability model for the central and southern portions of the Gulf Coast Aquifer System are shown in blue.

Model	Minimum hydraulic conductance (feet^2 per day)	Mean hydraulic conductance (feet^2 per day)	Maximum hydraulic conductance (feet^2 per day)	Standard deviation of hydraulic conductance (feet^2 per day)
Central and Southern Gulf Coast Aquifer System	0.03	611,006	86,939,352	3,106,923
Central Gulf Coast Aquifer System	490	1,337	3,250	761
Northern Carrizo-Wilcox	253	12,992	33,800	5,854
Central Carrizo-Wilcox	1,000	22,052	58,188	17,070
Southern Carrizo-Wilcox	0	2,475,954	5,095,870	2,540,087
Brazos River Alluvium	132	36,544	105,600	43,775

Table 8: Cell size and conductance converted to hydraulic conductivity based on river cell size summary for different models. Values for the groundwater availability model for the central and southern portions of the Gulf Coast Aquifer System are shown in blue.

Model	Cell Size (feet)	Minimum hydraulic conductivity (feet per day)	Mean hydraulic conductivity (feet per day)	Maximum hydraulic conductivity (feet per day)	Standard deviation of hydraulic conductivity (feet per day)
Central and Southern Gulf Coast Aquifer System	660	0	926	131,726	4,707
Central Gulf Coast Aquifer System	5280	0.09	0.25	0.62	0.14
Northern Carrizo-Wilcox	660	0.38	20	51	9
Central Carrizo-Wilcox	1280	0.76	17	44	13
Southern Carrizo-Wilcox	660	0	3,751	7,721	3,849
Brazos River Alluvium	660	0.2	55	160	66

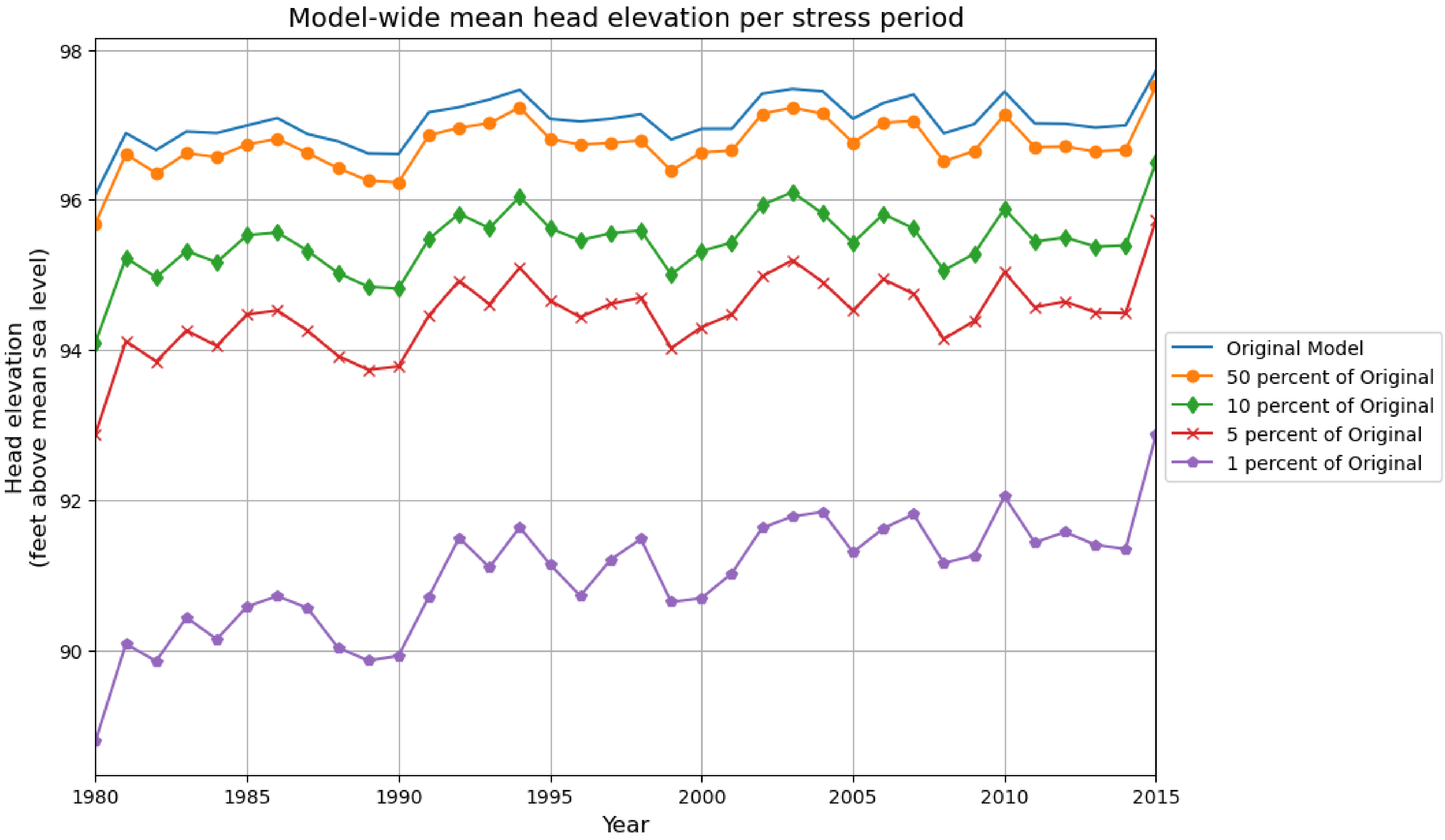


Figure 4: Model-wide mean head elevations per stress period for each model run in the river sensitivity analysis. Head elevations are reduced by reducing conductivity, though water-level trends remain consistent.

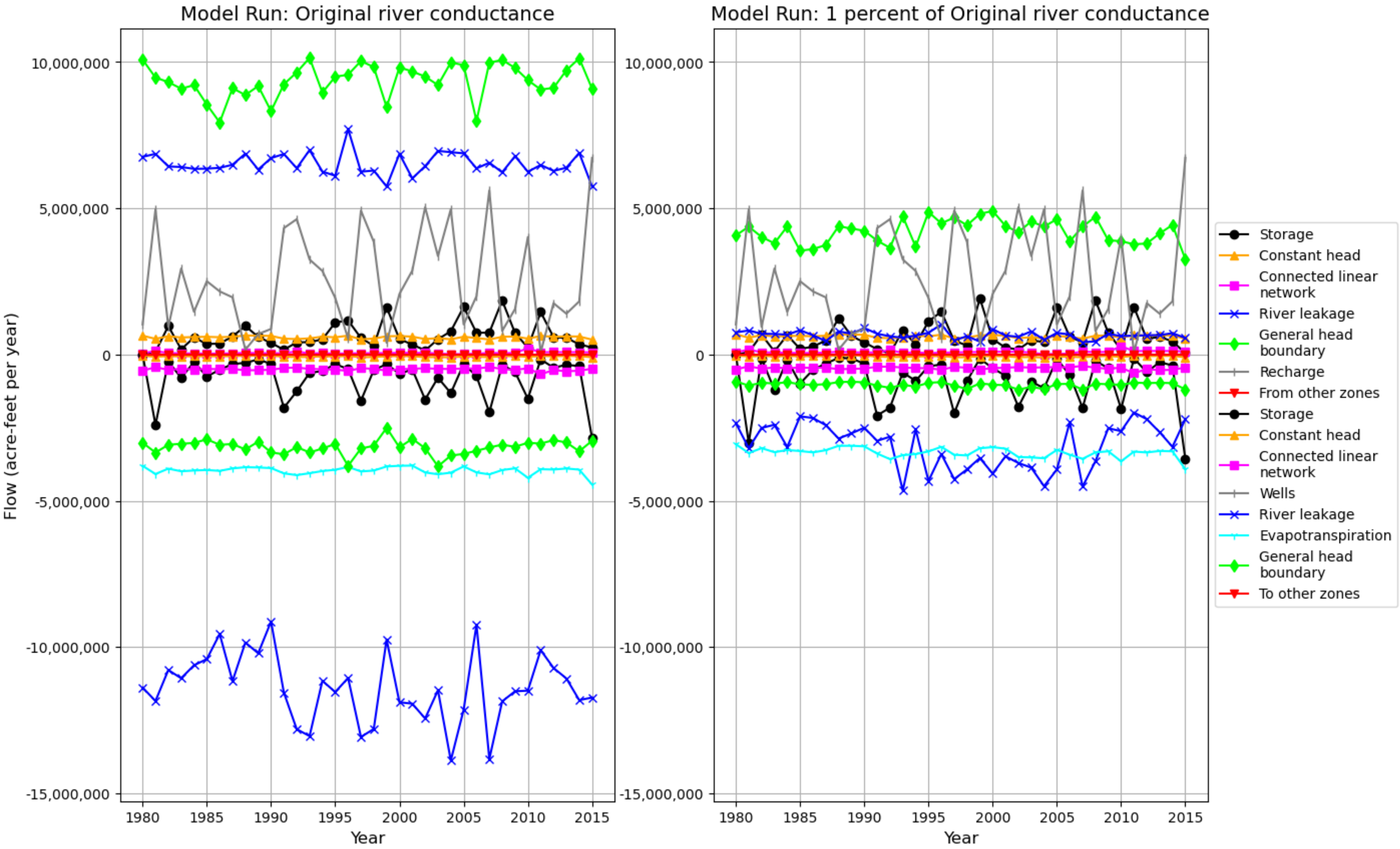


Figure 5: **Comparison of model-wide water budgets for the original river conductance values versus one percent of the original river conductance values. Reducing river conductance to one percent of the original river conductance values shows a large improvement in modeled groundwater budget results.**

General Head Boundary package inputs

We reviewed the General Head Boundary package properties to help diagnose why the fluxes are so large compared to results for previous models. The review consisted of comparing general head conductance values from the new model with general head conductance values from other models where the general head boundary was used to represent similar inter-aquifer flows.

In Layer 4 of the new model the general head boundary is used to model interaction between the underlying Yegua-Jackson Aquifer and the Gulf Coast Aquifer System. Other similar groundwater availability models that use general head boundaries to represent interaction between overlying or underlying aquifers include the model for the Yegua-Jackson Aquifer and the model for the central portion of Carrizo-Wilcox Aquifer. In the Yegua-Jackson Aquifer model, the general head boundary represents flow between the Catahoula formation and the overlying Jasper aquifer. In the central Carrizo-Wilcox Aquifer model the general head boundary represents interaction between the Sparta Aquifer and overlying younger units.

We compiled average values of general head boundary conductance for areas of the Yegua-Jackson Aquifer model and the central Carrizo-Wilcox Aquifer model representing vertical interaction with overlying units and compared results with the average general head boundary conductance of the new model for areas representing the vertical interaction with the underlying units (Table 9). The mean, median, and maximum hydraulic conductance values in the new model are significantly greater than the values used in the other two models (Table 9).

Table 9: Comparison of hydraulic conductance values from two other models where general head boundary represents vertical exchange with another aquifer. Values for the groundwater availability model for the central and southern portions of the Gulf Coast Aquifer System are shown in blue.

Model	Minimum hydraulic conductance (feet^2 per day)	Median hydraulic conductance (feet^2 per day)	Mean hydraulic conductance (feet^2 per day)	Maximum hydraulic conductance (feet^2 per day)
Central and Southern Gulf Coast Aquifer System	0.48	2,690	6,208	323,742
Central Carrizo-Wilcox	10	10	13.3	100
Yegua-Jackson	0.41	9.8	40.1	24,649

PLANNED APPROACH FOR MODEL REVISIONS

Our approach to improve and revise the new groundwater availability model for the central and southern Gulf Coast Aquifer System is to revise the River, General Head Boundary, and Recharge packages to reduce the simulated water budget fluxes of the model. We will also recalibrate the hydraulic conductivity distribution in areas showing the most disagreement with water-level data (areas of highest residuals). Below describes the work we have completed to simplify and revise the model as well as our plan to recalibrate the model in the coming months.

Simplify and revise model inputs

As a first step to revising and recalibrating we have simplified the model to reduce model run time for calibration and for future predictive modeling. The new model originally required five to six hours for the historical model (1980 through 2015) to complete. To simplify the model, we removed the Connected Linear Network (CLN) package. The CLN package was used in the new model to simulate groundwater pumping wells and the Rio Grande. Additionally, the CLN package was connected to the Water Mover (QRT) package, which takes water from the CLN package and distributes it as recharge over a specified area.

We have replaced the CLN node pumping wells with groundwater node wells typically used for most MODFLOW models. The CLN package had the feature of allowing pumping to be distributed across multiple layers to simulate pumping wells screened across multiple layers. Pumping wells using groundwater nodes can only pump from a single model layer. To distribute the pumping across layers in the same way as the original model, we used a water budget analysis to determine what fraction of pumping came from each layer. The pumping was then distributed to the groundwater nodes by layer based on the pumping fraction.

We replaced the Rio Grande CLN nodes with River package cells. In addition, we revised the River package conductance to have the same value for all stress periods. In the original version of the new model the river conductance varies from stress period to stress period. As a result of the simplifications, the revised model requires only 30 minutes for the historical model to complete. All revisions are summarized in Table 10.

Table 10: Summary of models edits to improve model run times

Package	Revision	Related model update(s)
CLN	Package removed	- Pumping data transferred to the Well package - Rio Grande converted into a river in the River package
QRT	Package removed	- Pumping information evenly distributed to associated nodes in the Recharge package
RIV	Simplified	- Rio Grande added - Conductance values made constant through time - River head elevations set to 8 feet below the model node top elevation or 0 feet in elevation - Riverbed elevation set to 13 feet below the model node top elevation or negative 5 feet below sea level
GHB	Simplified	- Conductance values made constant through time
SMS	Relaxed	- HCLOSE raised from 1e-4 to 1e-2 - HICLOSE raised from 1e-5 to 1e-3

In addition to simplifying the new model we also adjusted the recharge inputs. As discussed in the *Recharge package inputs* section, recharge for the new model is based on a correlation between baseflow estimates for recharge and precipitation. The baseflow estimates were derived from a baseflow separation computer code, which uses a technique to separate high- from low-amplitude components of stream flow through three passes (Shi and others, 2023).

Baseflow for the original model was based on the first pass (least reduction in amplitude) of the baseflow separation because it was assumed that baseflow separation underestimates recharge (Shi and others, 2022). However, our review of the model suggests the overall water budget is too high, including recharge. We revised the recharge in the new model using a more conservative estimate of recharge by correlating the third pass (lowest estimate) of baseflow with precipitation. We used the same correlation model to relate recharge to precipitation to be consistent with the conceptual model and we estimated new parameters for the precipitation-recharge equation.

Recalibration Approach

The original model calibration adjusted horizontal hydraulic conductivity, general head boundary conductance, river conductance, and recharge. River conductance was adjusted for each stress period and recharge was adjusted only for the first stress period. The calibration targets (data values to be compared with model-calculated values) consisted of measured water levels and baseflow estimates.

For recalibration, the general head boundary conductance, river conductance, and hydraulic conductivity will be adjusted using PEST (Watermark Numerical Computing, 2018). PEST is a model-independent, industry-standard, parameter estimation code. Each of the parameters to be adjusted will be constrained to only include values between the ranges shown in Table 11.

River conductance and general head boundary conductance will be constant through time but are allowed to spatially vary and will be calibrated using pilot points. Pilot points are parameters specified at discrete points, but not at every model cell. The parameter estimation program (PEST) estimates the values at each discrete pilot point and a preprocessing program interpolates values for each model cell between the points. Hydraulic conductivity will also be recalibrated using a grid of pilot points. However, recalibration of hydraulic conductivity will be conducted by focusing on areas with high residuals for head and hydrograph correlation.

Figure 6 shows the mean residual between measured head and modeled head from original model for each county containing a water-level measurement used as a calibration target. Figure 7 shows the mean hydrograph fit, or mean residual between a perfect correlation or the value of 1, and the modeled correlation coefficient from original model for each county which contains wells with 10 or more years with water level measurements used as targets for calibration. Allowable hydraulic conductivity ranges will be set as 70 percent of the minimum and 130 percent of the maximum hydraulic conductivity within a local area from the original model hydraulic conductivity.

The recalibration will use measured water levels and water-level-hydrograph fit as targets. The hydrograph fit targets will indicate how well modeled water levels at certain hydrographs are correlated with the measured water levels at the same hydrograph through time. Baseflow estimates will not be used for the revised calibration.

Table 11: Minimum and maximum parameter values allowed during calibration for river and general head boundary conductance.

Parameter	Minimum value (feet^2 per day)	Maximum value (feet^2 per day)
River conductance	100	40,000
GHB conductance (660 by 660-foot model cells)	1	600
GHB conductance (1,320 by 1,320-foot model cells)	3	2,500
GHB conductance (2,640 by 2,640-foot model cells)	12	9,000
GHB conductance (5,280 by 5,280-foot model cells)	50	35,000

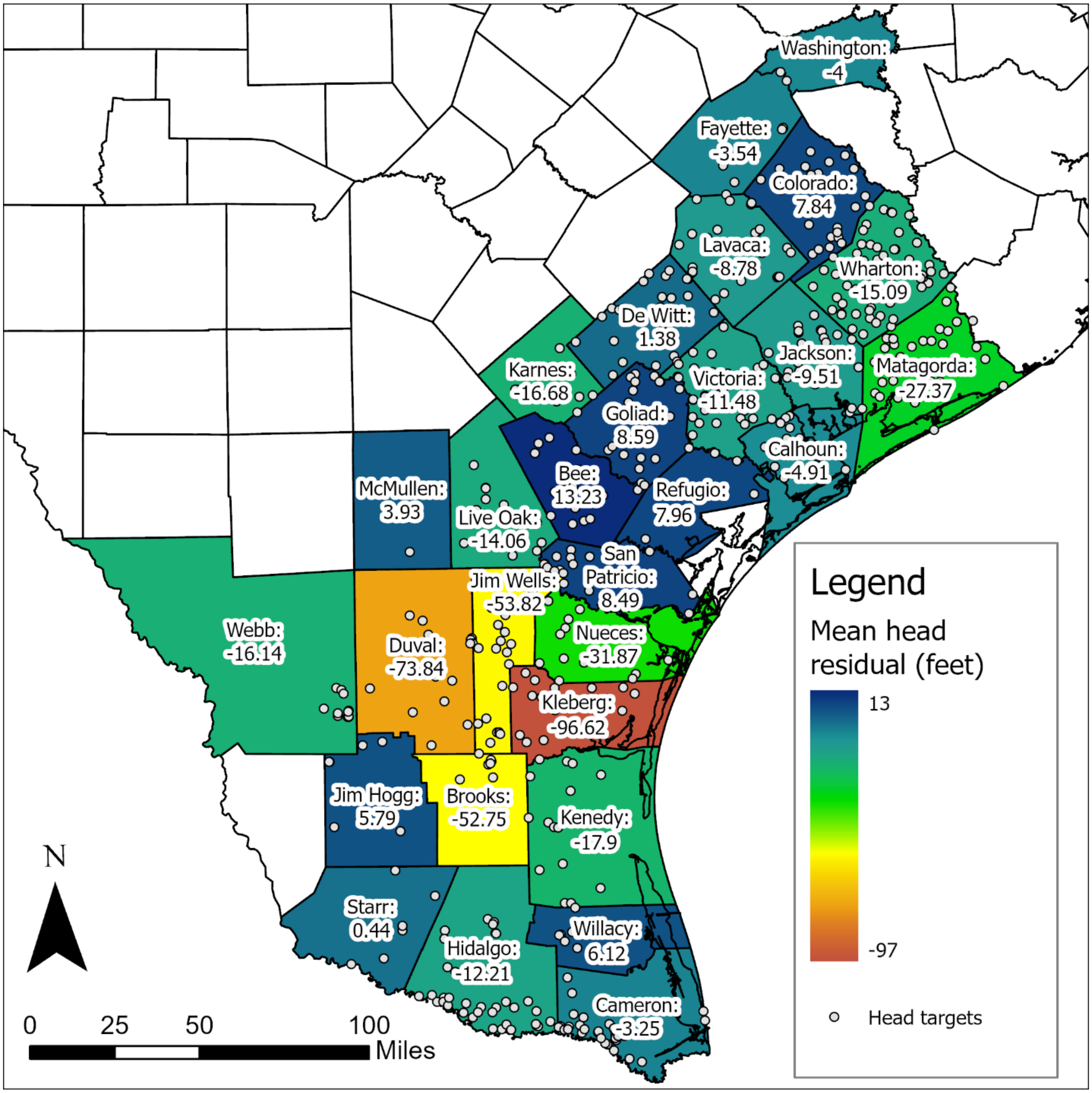


Figure 6: **Map of mean head residual (measured water levels minus modeled water levels) from original model for each county that contains a water level measurement used as a calibration target.**

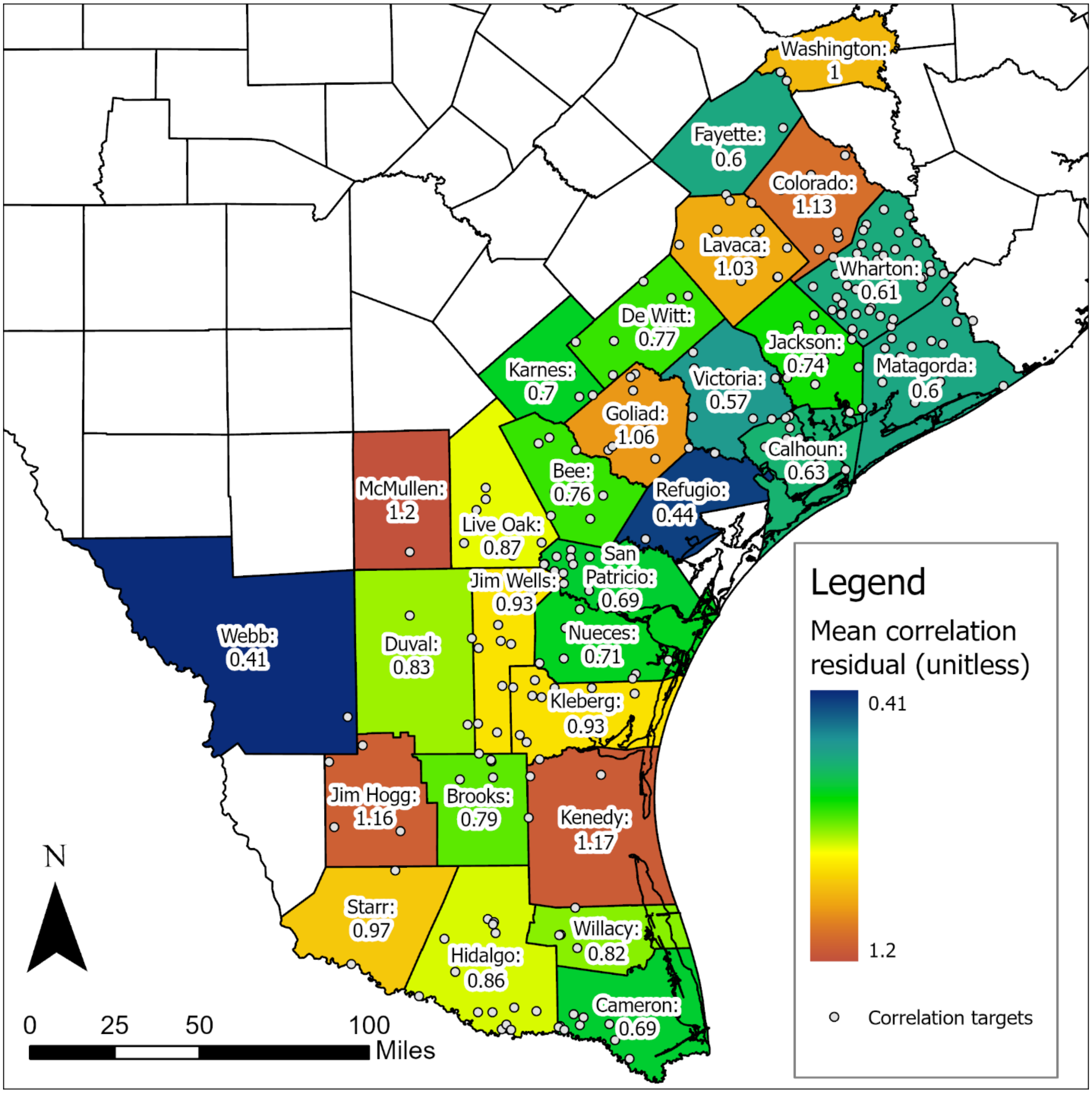


Figure 7: **Map of mean correlation residual (1 minus modeled water level correlation coefficient) from original model for each county which contains a well with ten or more years of water level measurements used as a target for model calibration.**

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