Extension of the Groundwater Availability Model for the High Plains Aquifer System through 2020 (version 1.02)

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Geoscientist Seals

The following professional geoscientists licensed in the State of Texas contributed to the model update and analyses.

Tim Cawthon, P.G.

Tim was the lead modeler and project manager for this work and was responsible for all sections of the report not assigned to supporting modelers. He was the primary author of this report. This document is released for the purpose of interim review under the authority of Tim Cawthon, P.G. on May 9, 2025. It is not to be used for construction or engineering purposes.

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Shirley provided guidance and oversight for this project as a Senior Groundwater Modeler. Shirley was also a support modeler for this work and was responsible for updating the New Mexico portion of the well package and updating the recharge package. This document is released for the purpose of interim review under the authority of Shirley Wade, Ph.D., P.G. on May 9, 2025. It is not to be used for construction or engineering purposes.

Table of contents

List of figures

List of tables

Executive summary

Groundwater availability models provide effective tools for stakeholders to assess regional groundwater flow and the impacts of different factors, such as pumping and recharge, on groundwater supplies. The High Plains Aquifer System Groundwater Availability Model Version 1.01 (Deeds and Jigmond, 2015) was used by stakeholders in the adoption of desired future conditions for the second and third rounds of joint planning in 2016 and 2021.

The original model includes a steady-state stress period for 1929 and transient stress periods from 1930 through 2012. This report documents the work of the Texas Water Development Board (TWDB) Groundwater Modeling Program to extend the model an additional eight years from 2012 through 2020. The only change to the original model prior to 2012 was a decrease in the recharge values in Howard County (see Section 4) based on stakeholder feedback. To maintain consistency, no other changes were made to the original model, and no calibration or recalibration was performed.

The updated model package values for 2013 through 2020 remained the same as the 2012 stress period except for the well package. The process to add 2013 through 2020 groundwater pumping to the well package involved multiple steps (see Sections 2 and 3). Wells that were included as pumping in 2011 or 2012 in the original model were extracted to create a base well dataset. A new well dataset was constructed and merged with the base dataset. Annual pumping data were gathered from various sources and distributed to the wells and then to the model grid cells.

Section 5 of this report covers model extension performance and results. Target wells were selected if they were used in the original model and had water level measurements within 2013 through 2020. Model performance statistics were calculated and hydrographs of simulated versus observed water levels were prepared for all target wells. New maps of 2020 simulated water levels and saturated thickness are included in the report along with new groundwater budgets by county, groundwater conservation district, and state.

One of the primary objectives of the groundwater availability model for the High Plains Aquifer System is to estimate groundwater availability based on predictive pumping scenarios. The final water levels from 2020 were extracted from the model extension and a predictive model was developed from 2021 through 2080. Section 6 includes the results of the predictive model run including maps and tables of total drawdown through 2080.

Ultimately, the model extension performs as well as the original model. Model statistics did not degrade and hydrographs generally maintained trends. The updated groundwater availability model meets the TWDB Groundwater Modeling standards (TWDB, 2023a), and can be used as a tool to assist in groundwater management and planning efforts.

1 Introduction and model overview

The TWDB Groundwater Modeling Program develops groundwater availability models for all major and minor aquifers within the state of Texas to provide groundwater conservation districts and regional water planning groups scientific tools to assist in management and planning efforts (Texas Water Code § 16.012). The TWDB contracted with INTERA to develop version 1.01 of the High Plains Aquifer System groundwater availability model (hereafter referred to as the Original Model) for the Ogallala, Dockum, Rita Blanca, and Edwards-Trinity (High Plains) aquifers (Deeds and Jigmond, 2015). To maintain the model as a living tool, the TWDB extended the groundwater availability model from 2012 through 2020 (hereafter referred to as the Model Extension). This report summarizes the methods, results, and conclusions of the Model Extension.

1.1 Model overview

The code used for the Original Model is MODFLOW-NWT (Niswonger and others, 2011). MODFLOW is a three-dimensional, finite-difference groundwater flow code, which is supported by boundary condition packages to handle recharge, rivers, springs, inter-aquifer flow, and pumping. The Original Model includes a steady-state stress period for 1929 and transient stress periods from 1930 through 2012. The only change to the Original Model prior to 2012 was an update to the Recharge package to decrease the recharge in Howard County based on a stakeholder request. To maintain consistency, no other changes were made to the Original Model, and no calibration or recalibration was performed.

The model grid cell size is 1/2 mile by 1/2 mile and the model includes the following four layers:

- Layer 1 represents the Ogallala and Pecos Valley aquifers.
- Layer 2 represents the Rita Blanca, Edwards-Trinity (High Plains), and Edwards-Trinity (Plateau) aquifers.
- Layer 3 represents the upper Dockum unit.
- Layer 4 represents the lower Dockum unit.

Figure 1-1 shows the geographic boundaries of the aquifers represented by layers 1 through 4, and Figures 1-2 and 1-3 show cross-sections and block schematics of the model layers. For more information about the model framework, refer to the original modeling reports (Deeds and Jigmond, 2015; Deeds and others, 2015).

A MODFLOW model consists of a grouping of input text files—also called “packages”—that describe various components of the groundwater flow system. Table 1-1 shows the input packages and their corresponding filenames. Table 1-2 shows the output files written by MODFLOW. This Model Extension includes updates to the input packages to extend data coverage for the years 2013 through 2020. A description of the contents and changes to each of the input packages shown in Table 1-1 are included in the sections that follow.

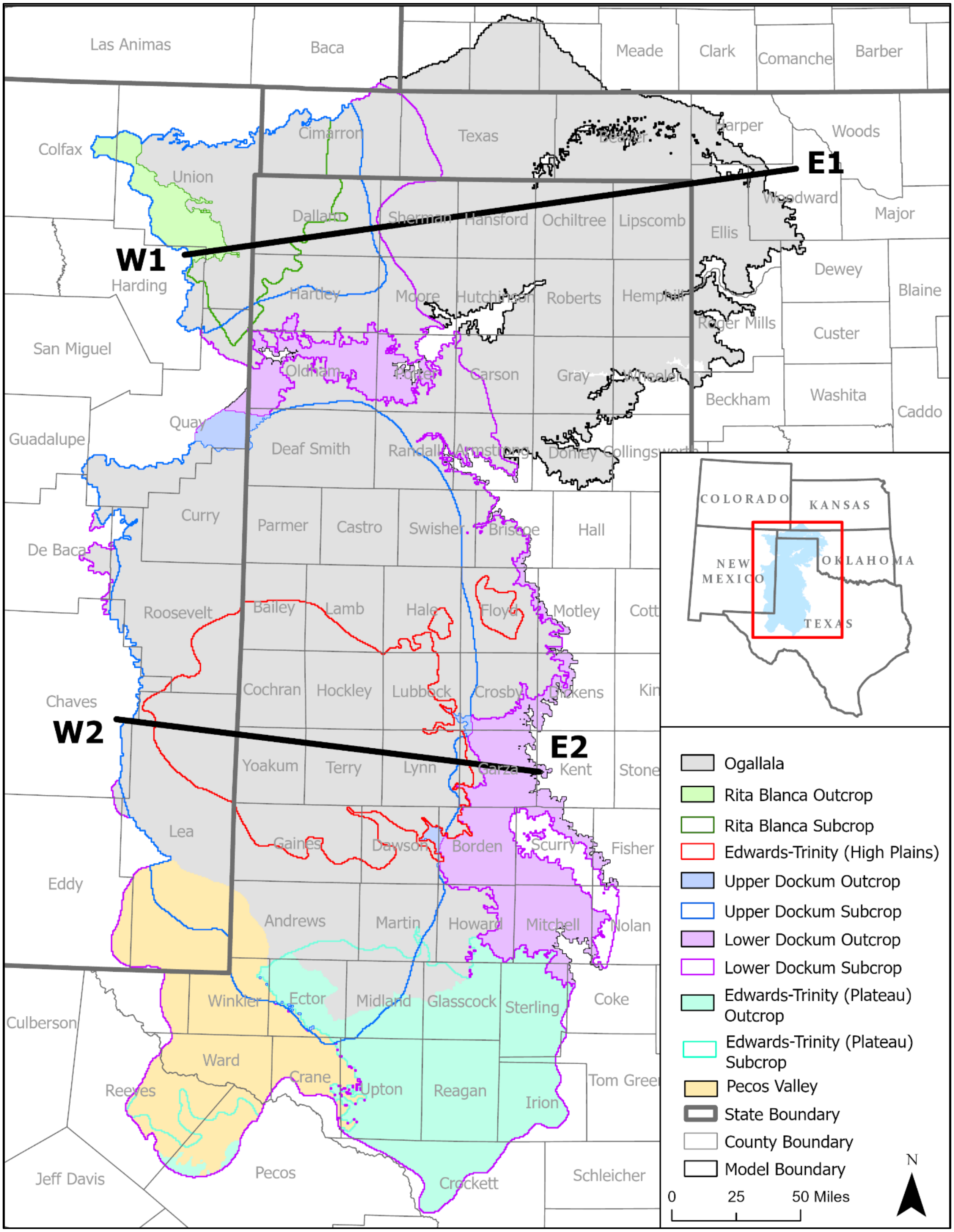

Figure 1-1 Geographic boundaries of the aquifers included in the groundwater availability model for the High Plains Aquifer System.

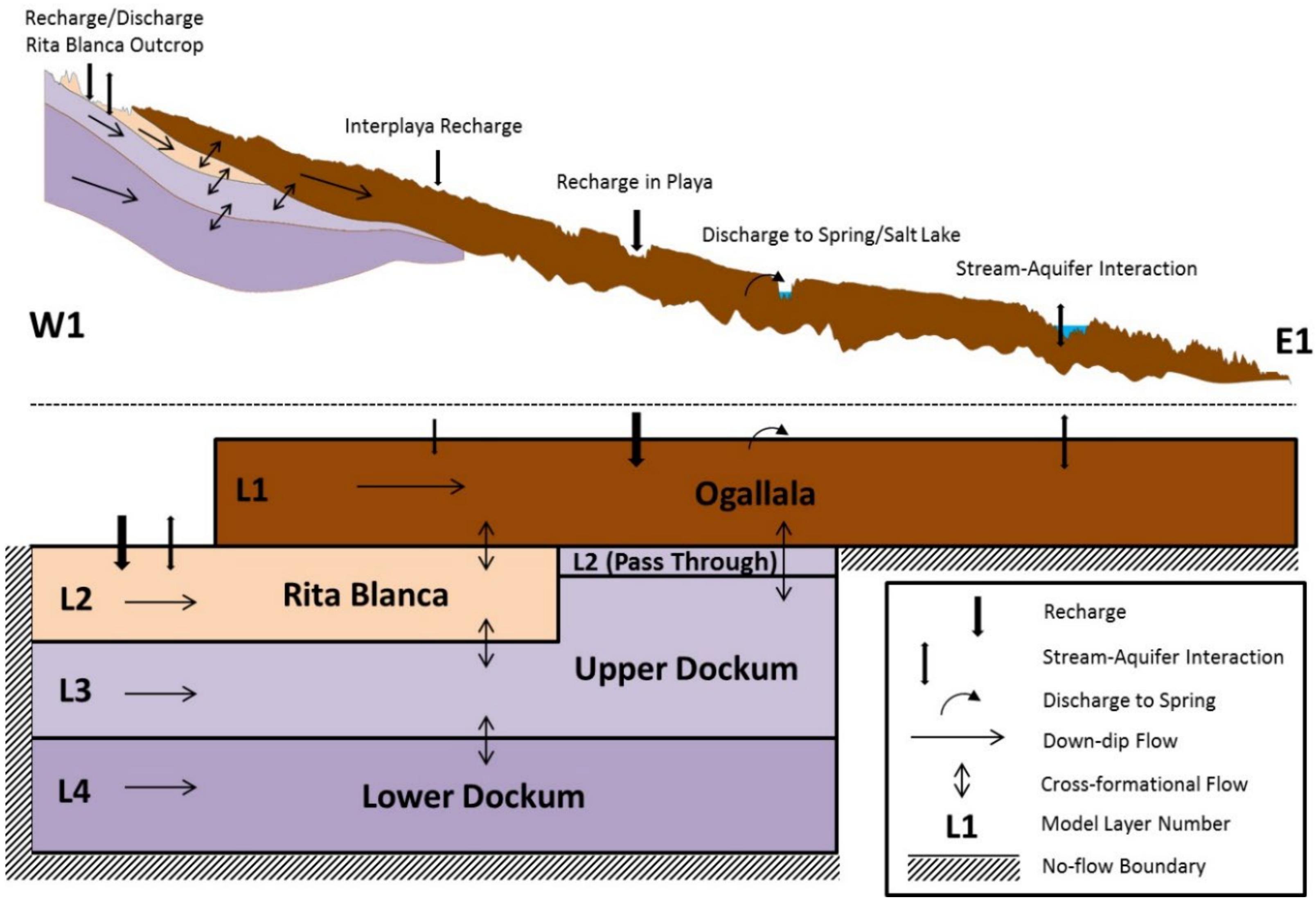

Figure 1-2 **Cross-section along line W1-E1 of Figure 1-1 and block schematic of the northern portion of the model (From Deeds and others, 2015).**

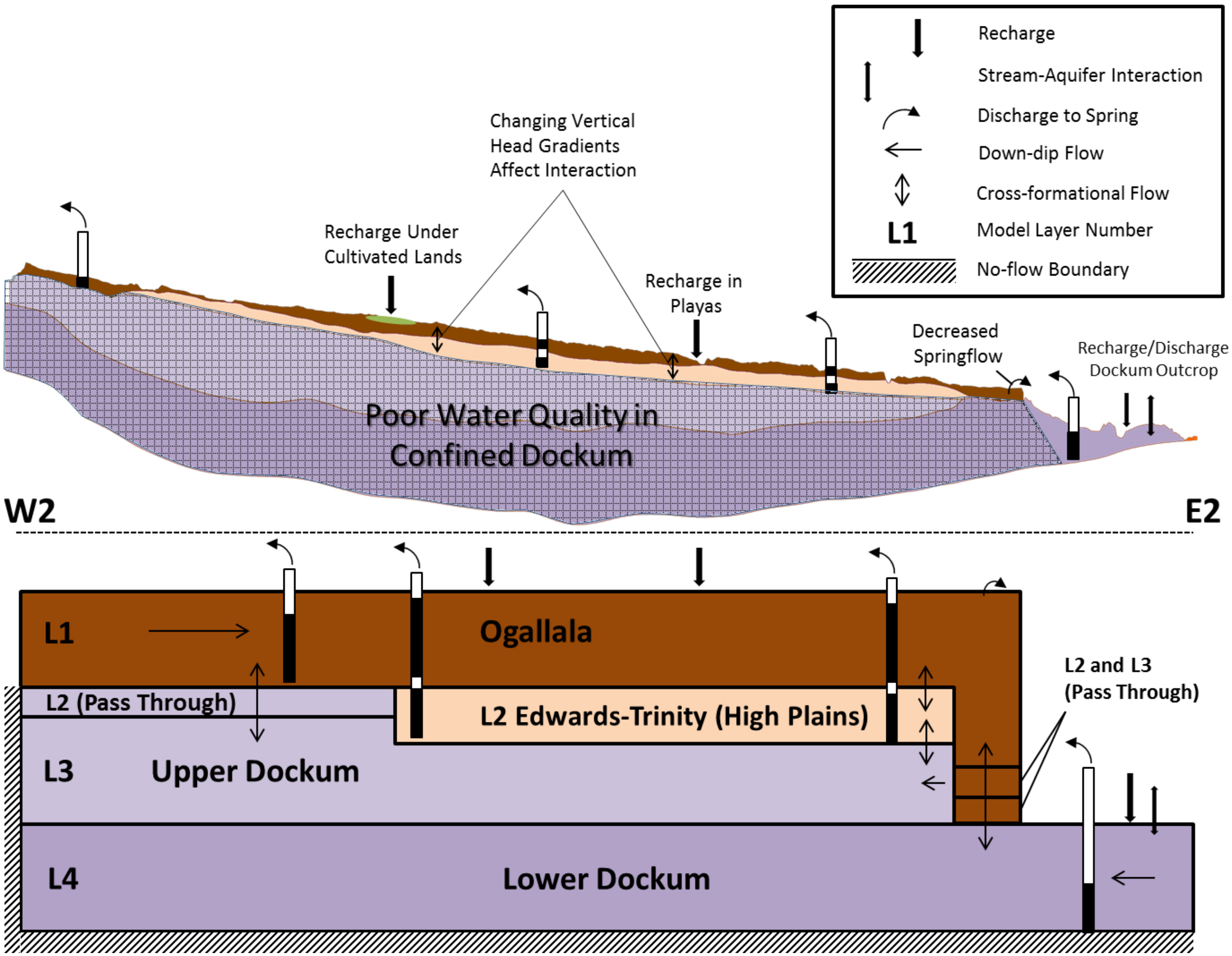

Figure 1-3 **Cross-section along line W2-E2 in Figure 1-1 and block schematic of the southern portion of the model (From Deeds and others, 2015).**

Table 1-1 A list of the input packages and filenames used for the Model Extension.

File type abbreviation	File type	Input file name
BAS6	Basic package	hpas1_02.bas
NAM	Name file	hpas1_02.nam
DIS	Discretization package	hpas1_02.dis
DRN	Drain package	hpas1_02.drn
EVT	Evapotranspiration package	hpas1_02.evt
NWT	Newton solver package	hpas1_02.nwt
OC	Output control option	hpas1_02.oc
RCH	Recharge package	hpas1_02.rch
RIV	River package	hpas1_02.riv
UPW	Upstream-weighting package	hpas1_02.upw
WEL	Well package	hpas1_02.wel

Table 1-2 A list of the output packages and filenames used for the Model Extension.

Name	Type	Output file name
Flow values of cells	Binary	hpas1_02.cbb
Head values of cells	Binary	hpas1_02.hds
Pumping rate reduction	Text	hpas1_02.spf
List file	Text	hpas1_02.lst

1.2 Basic package

No changes were made to this package.

1.3 Name file

The name file contains the names and unit numbers of the input and output files that comprise the numerical model (Tables 1-1 and 1-2).

1.4 Discretization package

Eight additional stress periods representing the years 2013 through 2020 were added to this package.

1.5 Drain package

The Original Model kept all cell values constant for all stress periods. For the Model Extension, cell values for the last stress period (2012) were extended through 2020.

1.6 Evapotranspiration package

The Original Model kept all cell values constant for all stress periods. For the Model Extension, cell values for the last stress period (2012) were extended through 2020.

1.7 River package

This package includes river, reservoir, and general-head boundary cells. The general-head boundary cells are in layers 1 and 2 and represent the Pecos Valley and Edwards-Trinity (Plateau) aquifers, respectively. The Original Model kept all cell values constant for the years 2004 through 2012. For the Model Extension, cell values for the last stress period (2012) were extended through 2020.

1.8 Newton solver package

No changes were made to this package.

1.9 Upstream weighting package

No changes were made to this package.

1.10 Output control file

The MODFLOW output control file specifies when heads and water budget information are saved during the simulation. The output control file was set up to save these results at the end of each stress period.

1.11 Well package

The Original Model has variable pumping for all stress periods. The methodology for adding pumping for 2013 through 2020 is described in Sections 2 and 3.

1.12 Recharge package

The Original Model kept all cell recharge values constant for the years 2004 through 2012. For the Model Extension, cell values for the last stress period (2012) were extended through 2020. The methodology for updating recharge in Howard County is described in Section 4.

2 Well dataset

The process to construct a well dataset for the Model Extension involved multiple steps. Wells and model cells that were included as pumping in 2011 or 2012 in the Original Model were extracted to create a base well dataset. New wells from 2013 through 2020 were downloaded from the Texas Submitted Drillers Report Database (TWDB, 2023b), filtered for relevant water uses, assigned aquifers, and merged with the base dataset. Wells that matched Texas Submitted Drillers Report Database (TWDB, 2023b) plugging reports were removed from the well dataset. Wells in New Mexico and in North Plains Groundwater Conservation District were replaced with the New Mexico Office of the State Engineer (New Mexico Office of the State Engineer, 2023) and North Plains Groundwater Conservation District (North Plains Groundwater Conservation District, 2024a) datasets, respectively. These steps are further described in the following sections.

2.1 New Texas wells

The Texas Submitted Drillers Report Database is a repository for wells drilled in Texas (TWDB, 2023b). Well reports from 2013 through 2020 were downloaded and filtered to include the following proposed uses: domestic, irrigation, rig supply, stock, fracking supply, industrial, and public supply. Wells that matched a plugging report with a plug date of less than two years from the date the well was drilled were removed. Because wells in this database are not assigned to aquifers, the well locations and screened interval depths were intersected with the Original Model framework to assign an aquifer or an aquifer group to each of the wells. If more than 10 percent of a well's cumulative screened interval vertically intersected a model layer it was assigned to that layer. These initial aquifer and aquifer group assignments are shown in tables 2-1 and 2-2 and the spatial distribution is shown in Figure 2-1.

The new wells were compared to the Original Model wells and a relatively large number of the wells were assigned to minor aquifers than in the Original Model (Table 2-1). This was especially the case for the Dockum units and Edwards-Trinity (High Plains) Aquifer assignments (Figure 2-1 and Figure 2-2). The upper Dockum unit (Layer 3) is generally considered an aquitard with total dissolved solids greater than 5,000 milligrams/liter. If the Ogallala Aquifer is included in a multi-aquifer well group, it likely provides a majority of the water (if the saturated thickness is sufficient) because of much higher transmissivities than underlying layers.

To account for possible uncertainty in the model framework, transmissivity weighting was implemented for wells that were screened across multiple aquifers. We extracted the 2012 simulated transmissivity values for layers 1 through 4 from the Original Model and calculated new transmissivity-weighted vertical intersection percents for each aquifer using equations 1 and 2. Table 2-3 includes an example of how Equation 1 was applied to one of the multi-aquifer wells. If an aquifer's new intersection percent (SCR_{wtpct}) was below 10 percent, then the aquifer was removed from the aquifer group. This reduced the number of new wells screened in the Rita Blanca Aquifer and Dockum units (tables 2-1 and 2-2). However, the number of wells in the Edwards-Trinity (High Plains) Aquifer were not significantly reduced because its transmissivity values are of similar magnitude to the overlying Ogallala Aquifer.

The model framework for the Edwards-Trinity (High Plains) Aquifer was investigated and compared to the framework of the groundwater availability model of the Edwards-Trinity (High Plains) Aquifer (Blandford and others, 2008), which includes three layers that represent the Edwards-Trinity (High Plains) Aquifer. These three layers include 1) a confining shale layer below the Ogallala Aquifer, 2) the limestone portion of the Edwards-Trinity (High Plains) Aquifer, and 3) the Antlers Sand portion of the Edwards-Trinity (High Plains) Aquifer. The Original Model combined all three of these layers into Layer 2, which represents the Edwards-Trinity (Plateau) Aquifer.

The wells with Edwards-Trinity (High Plains) aquifer assignments (both single- and multi-aquifer wells) were intersected with the framework for the groundwater availability model of the Edwards-Trinity (High Plains) (Blandford and others, 2008) and many did not penetrate below the confining shale layer. Therefore, we decided to use the base of the confining shale layer as a filter and assign any wells screened above the base of the shale to the Ogallala Aquifer and wells screened below to the Edwards-Trinity (High Plains) Aquifer. This resulted in 2,679 of the wells with initial Edwards-Trinity (High Plains) Aquifer assignments (both single- and multi- aquifer wells) being screened only in the overlying Ogallala Aquifer.

The final dataset includes a total of 27,496 new wells screened in the Ogallala Aquifer (including 3,557 multi-aquifer wells) and a total of 9,005 new wells screened in minor aquifers (Figure 2-3). The number of new minor aquifer wells is six times the number of minor aquifer wells in the Original Model (Table 2-1). The majority of the new Ogallala Aquifer wells are domestic or irrigation wells, followed by fracking and rig supply wells (Table 2-4).

Table 2-1 Number of initial and final aquifer assignments by aquifer for 2013 through 2020 Texas Submitted Drillers Report Database wells (TWDB, 2023b) compared to the Original Model active Texas wells for 2011 or 2012. An Original Model well was considered active if pumping was assigned in the well package for 2011 or 2012.

Aquifer	Layer	Initial new wells	Final new wells	Original Model active wells
Ogallala	1	26,264	27,496	28,240
Rita Blanca	2	317	181	34
Edwards-Trinity (High Plains)	2	6,018	3,149	534
Upper Dockum	3	7,929	184	28
Lower Dockum	4	8,944	5,491	746
Total aquifer assignments		**49,472**	**36,501**	**29,582**

Table 2-2 Number of initial and final aquifer assignments by aquifer group for 2013 through 2020 Texas Submitted Drillers Report Database wells (TWDB, 2023b).

Aquifer group	Layer	Initial	Final
Ogallala	1	12,632	23,932
Rita Blanca	2	31	131
Edwards-Trinity (High Plains)	2	597	1,444
Upper Dockum	3	1,150	101
Lower Dockum	4	4,083	4,248
Ogallala and Rita Blanca	1, 2	74	18
Ogallala and Edwards-Trinity (High Plains)	1, 2	4,492	1,699
Ogallala and Edwards-Trinity (Plateau)	1, 2	2,323	1,196
Ogallala and upper Dockum	1, 3	3,987	21
Ogallala and lower Dockum	1, 4	1,905	623
Ogallala and Permian (below Layer 4)	1, -	850	0
Lower Dockum and Pecos Valley	1, 4	163	170
Lower Dockum and Edwards-Trinity (Plateau)	2, 4	1,533	413
Lower Dockum and Permian (below Layer 4)	4, -	803	0
All other layer combinations		3,185	79
Total wells included in Model Extension		**37,808**	**34,075**
Permian only (below Layer 4)	-	205	205
Pecos Valley	1	600	715
Edwards-Trinity (Plateau)	2	2,533	6,151
Total wells excluded from Model Extension		**3,338**	**7,071**

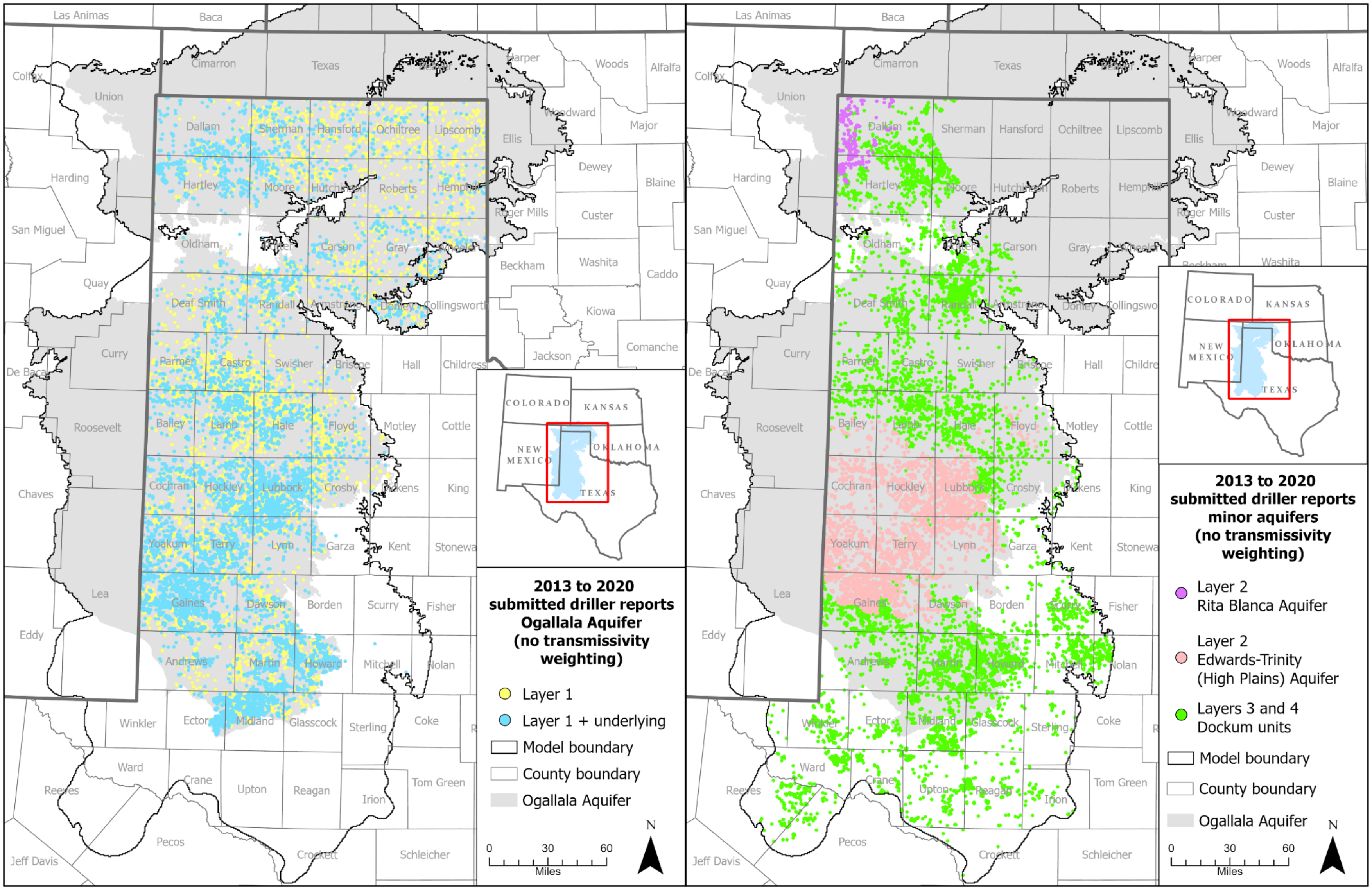

Figure 2-1 **Distribution of initial aquifer assignments for Texas Submitted Drillers Report Database wells between 2013 and 2020 before applying transmissivity weighting. Layer 1 wells shown on left; layers 2, 3, and 4 wells shown on right.**

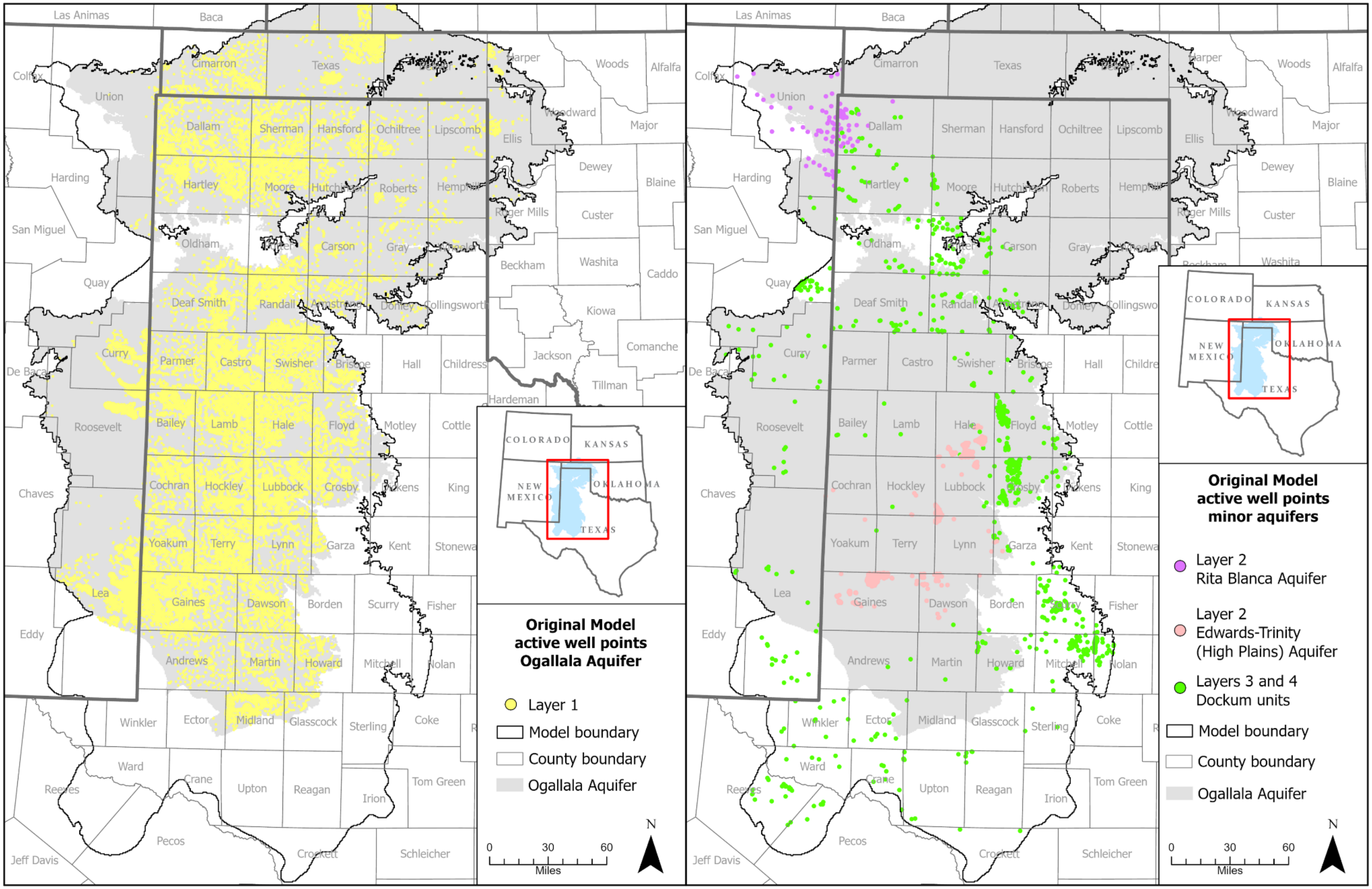

Figure 2-2 Distribution of active well points for the Ogallala Aquifer (left) and minor aquifers (right) in the Original Model. A well was considered active if pumping was assigned in the Original Model well package for 2011 or 2012.

$$SCR_{\text{wt}} = SCR_{\text{lyr}} * \left(\frac{TR_{\text{lyr}}}{TR_{\text{min}}}\right) \qquad \textbf{(Equation 1)}$$

Where: SCR_{wt} = Transmissivity-weighted screen thickness for aquifer.

SCR_{lyr} = Vertical length (feet) of the intersection of the model layer and well screen.

TR_{lyr} = The 2012 transmissivity value ($feet^2$/day) for the grid cell of the model layer the well point intersects.

TR_{min} = The lowest 2012 transmissivity value ($feet^2$/day) of the aquifer group the well screen intersects.

$$SCR_{\text{wtpct}} = \frac{\text{SCR}_{\text{wt}}}{\Sigma\ \text{SCR}_{\text{wt}}} * 100 \qquad \textbf{(Equation 2)}$$

Where: SCR_{wtpct} = Transmissivity-weighted screen percentage for aquifer.

SCR_{wt} = Transmissivity-weighted screen thickness for aquifer.

$\sum SCR_{wt}$ = Sum of all transmissivity-weighted screen thicknesses in the aquifer group.

Table 2-3 Example of applying transmissivity weighting for a well (Submitted Driller's Well Report 536929) screened in three aquifers. The upper Dockum unit is removed from the aquifer group because its SCR_{wtpct} is below 10 percent.

Initial aquifers	SCR_{lyr}	TR_{lyr}	TR_{min}	SCR_{wt}	SCR_{wtpct}	Final aquifers
Ogallala	61.06	529.99	0.76	42,580.51	89%	Ogallala
Rita Blanca	249.08	15.90	0.76	5,211.02	11%	Rita Blanca
Upper Dockum	111.86	0.76	0.76	111.86	0%	

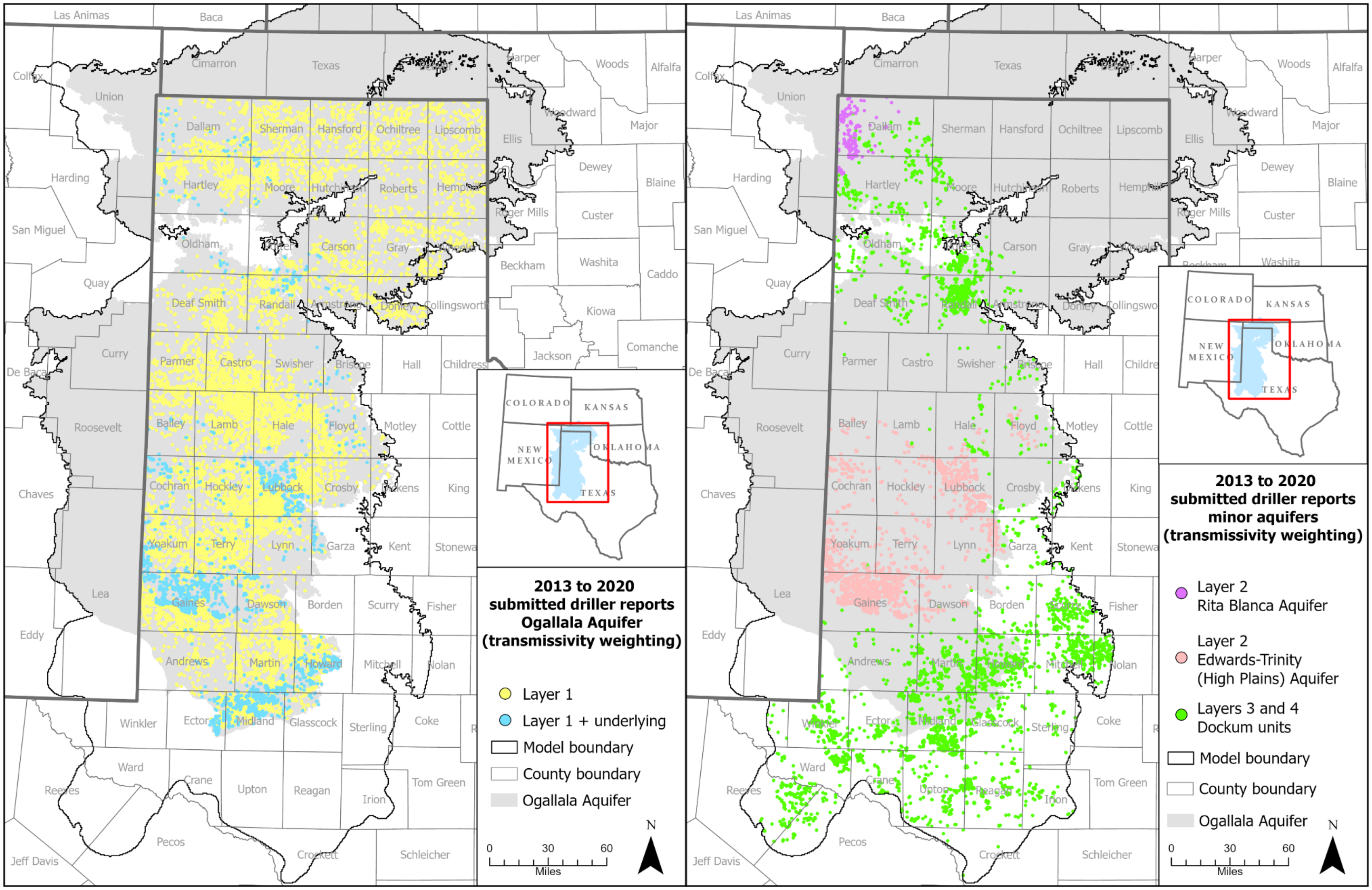

Figure 2-3 **Distribution of final aquifer assignments for Texas Submitted Drillers Report Database wells between 2013 and 2020 with transmissivity weighting applied. Layer 1 wells shown on left; layers 2, 3, and 4 wells shown on right.**

Table 2-4 Number of 2013 through 2020 Texas Submitted Drillers Report Database wells (TWDB, 2023b) by final aquifer and water use category.

Use	Ogallala	Rita Blanca	Edwards-Trinity (High Plains)	Dockum
Domestic	10,878	10	1,384	1,954
Livestock	960	19	43	356
Irrigation	10,540	150	1,666	1,005
Public Supply	129	2	7	110
Industrial	275	0	37	252
Rig Supply or Fracking Supply	4,714	0	12	1,998
Total	**27,496**	**181**	**3,149**	**5,675**

2.2 Original model well points

The pumping distribution for the Original Model was developed from various sources including previous groundwater models for the four aquifers (Deeds and others, 2015). The well package of the Original Model includes wells and pumping distribution for 83 transient stress periods from 1930 through 2012. The last stress period of the model is 2012, but the TWDB Water Use Survey (TWDB, 2023c) 2011 pumping values were used to assign pumping for the 2012 stress period because the 2012 water use data values had not been published at the time. Wells with pumping assigned for either 2011 or 2012 were extracted from the Original Model and joined with the well dataset table (included in the Original Model geodatabase) based on unique identification numbers included in both the well package and the well table (Table 2-5 and Figure 2-2). A total of 2,006 Ogallala Aquifer and 36 minor aquifer wells matched Texas Submitted Drillers Report Database plugging report identification numbers and were removed.

2.3 Original model added pumping cells

The Original Model well package includes many Ogallala Aquifer model cells with assigned pumping for which there is no record of a well point from a database (Figure 2-4). These model cells were tagged with “CR”, “SP”, and “+” codes in the Original Model well package, and will hereafter be referred to as additional irrigated land cells, redistributed pumping cells, and additional adjacent cells respectively.

Section 2.5 of the Original Model report states that for irrigation pumping there were some counties where the distributed pumping exceeded the maximum feasible production rates for those wells. This was an indication that the well dataset was missing some irrigation wells and that additional well locations were needed. For the Original Model, they identified additional pumping locations using the High Plains Underground Water Conservation District and Panhandle Groundwater Conservation District digitized irrigated lands for their respective districts (Deeds and Jigmond, 2015). Model cells that intersected an irrigated land polygon but did not intersect an irrigation well point were added to the well package and assigned production. There were 14,762 of these additional irrigated land cells added to the Original Model for the High Plains Underground Water Conservation District and Panhandle Groundwater Conservation District (Table 2-6).

The MODFLOW-NWT executable for the Original Model was set up to reduce input pumping for cells if the saturated thickness dropped below 30 feet, and attempts were made to redistribute reduced pumping amounts to cells of higher saturated thickness within the same county. This procedure and some additional procedures where the pumping distribution may have been manually adjusted are documented on pages 3-7, 3-8, 5-2, 7-1, and 7-2 of the Original Model report (Deeds and Jigmond, 2015). This iterative redistribution process and other manual adjustments made to pumping distributions made it difficult to replicate the pumping distribution process for the Model Extension.

The Original Model includes extra irrigation pumping in some Ogallala Aquifer cells adjacent to an irrigation well point if the pumping exceeded the production capacity as stated in the Original Model report. If excess pumping was redistributed to adjacent cells, a unique identification number was created in the well package for the new cells by adding “+”, “++”, “+++”, and so forth to the identification number of the original well point.

For consistency with the Original Model pumping distribution, the center points of the additional irrigated land cells, redistributed pumping cells, and additional adjacent cells were added to the Model Extension well dataset and assigned as irrigation wells since they are in areas of high saturated thickness or areas with high groundwater production. To account for changes to irrigated lands since 2012, the additional irrigated land cells and additional adjacent cells were compared to a recent center pivot polygon GIS dataset developed by Hassani and others (2021). This dataset includes center pivot polygons mapped from satellite imagery for all of the High Plains (Figure 2-5). A 1/2-mile buffer was applied to the center pivot polygons and the resulting layer was intersected with the additional irrigated land cells and additional adjacent cells. If a cell did not intersect an irrigated polygon, it was removed from the dataset and not carried forward to the Model Extension period. A total of 1,113 additional irrigated land cells and 295 additional adjacent cells were removed (Table 2-6). No redistributed pumping cells were removed, since these were intended to redistribute pumping from areas of low saturated thickness to areas of high saturated thickness regardless of whether the higher saturated thickness cell intersected irrigated land.

Table 2-5 Original Model active 2011 or 2012 well points by aquifer and state.

Aquifer	Layer	Wells	Texas	New Mexico	Oklahoma	Kansas
Ogallala	1	34,076	28,240	3,656	1,803	377
Rita Blanca	2	86	34	52	0	0
Edwards-Trinity (High Plains)	2	534	534	0	0	0
Upper Dockum	3	28	28	0	0	0
Lower Dockum	4	826	746	80	0	0
Total		**35,550**	**29,582**	**3,788**	**1,803**	**377**

Table 2-6 Ogallala Aquifer cells assigned pumping in the Original Model and Model Extension well packages with no corresponding well point.

State	Year	Additional irrigated land cells	Redistributed pumping cells	Additional adjacent cells	Total cells
Texas	1990	14,570	3,787	1,083	19,440
Texas	2000	14,752	3,787	1,205	19,744
Texas	2011	14,753	3,787	1,693	20,233
Texas	2012	14,754	3,787	1,694	20,235
Texas	2013	13,641	3,787	1,399	18,827
Texas	2020	13,641	3,787	1,399	18,827
New Mexico	1990	3	1,689	890	2,582
New Mexico	2000	3	1,689	890	2,582
New Mexico	2011	3	1,689	890	2,582
New Mexico	2012	3	1,689	890	2,582
New Mexico	2013	0	0	0	0
New Mexico	2020	0	0	0	0
Oklahoma	1990	0	46	0	46
Oklahoma	2000	0	46	0	46
Oklahoma	2011	0	46	0	46
Oklahoma	2012	0	46	0	46
Oklahoma	2013	0	46	0	46
Oklahoma	2020	0	46	0	46
Kansas	1990	0	0	0	0
Kansas	2000	0	0	0	0
Kansas	2011	0	0	0	0
Kansas	2012	0	0	0	0
Kansas	2013	0	0	0	0
Kansas	2020	0	0	0	0

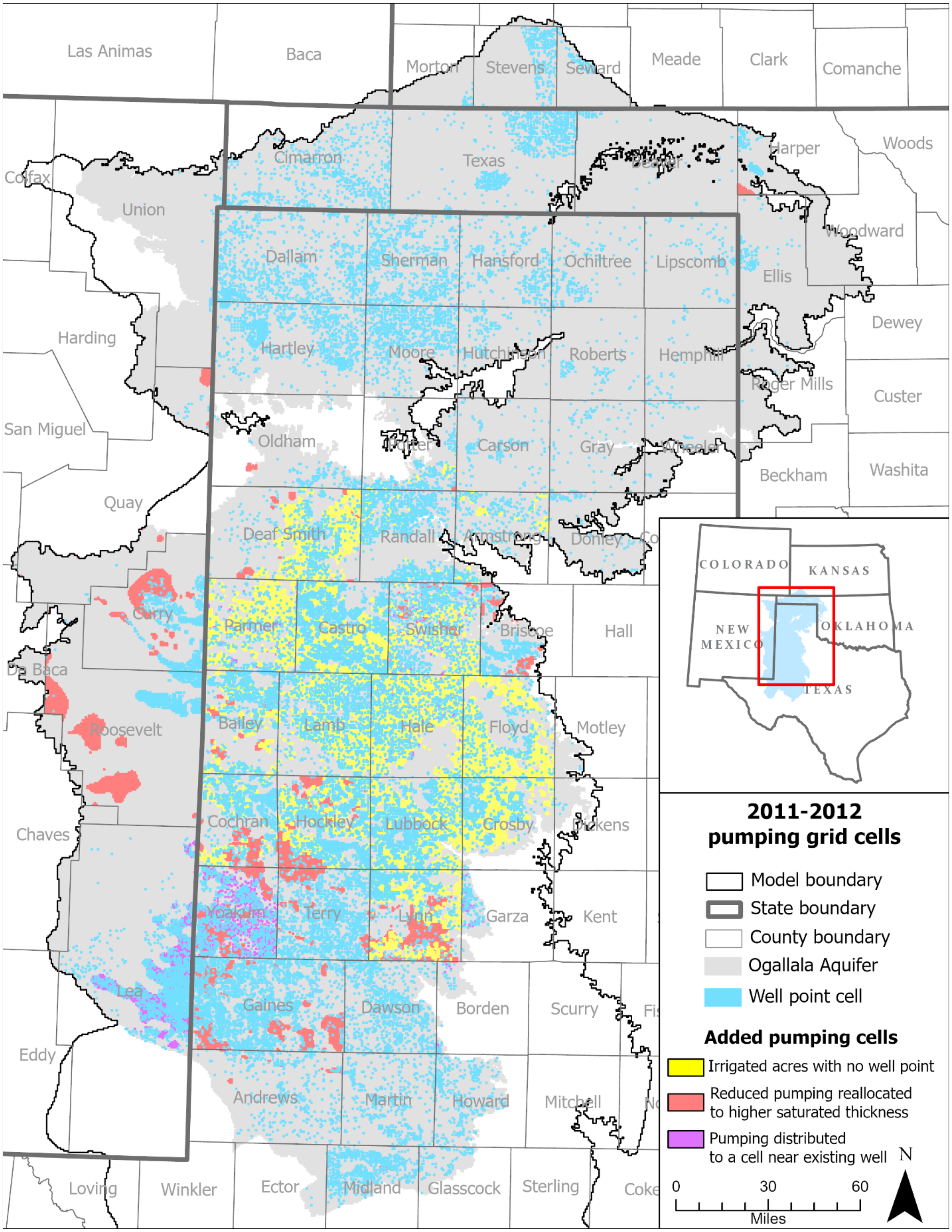

Figure 2-4 Distribution of Ogallala Aquifer model cells assigned pumping for 2011 or 2012 in the Original Model well package.

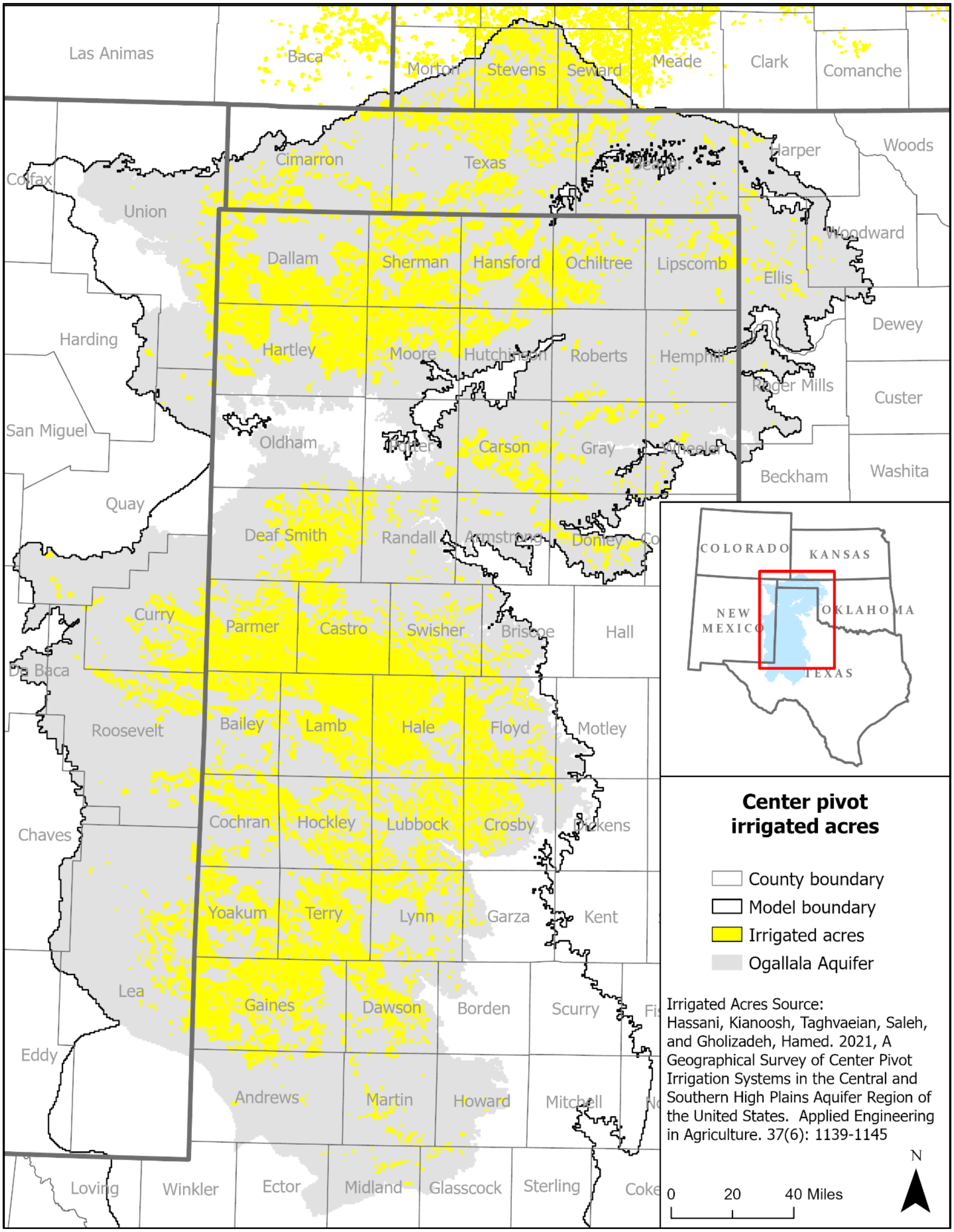

Figure 2-5 Center pivot polygons mapped by Hassani and others (2021).

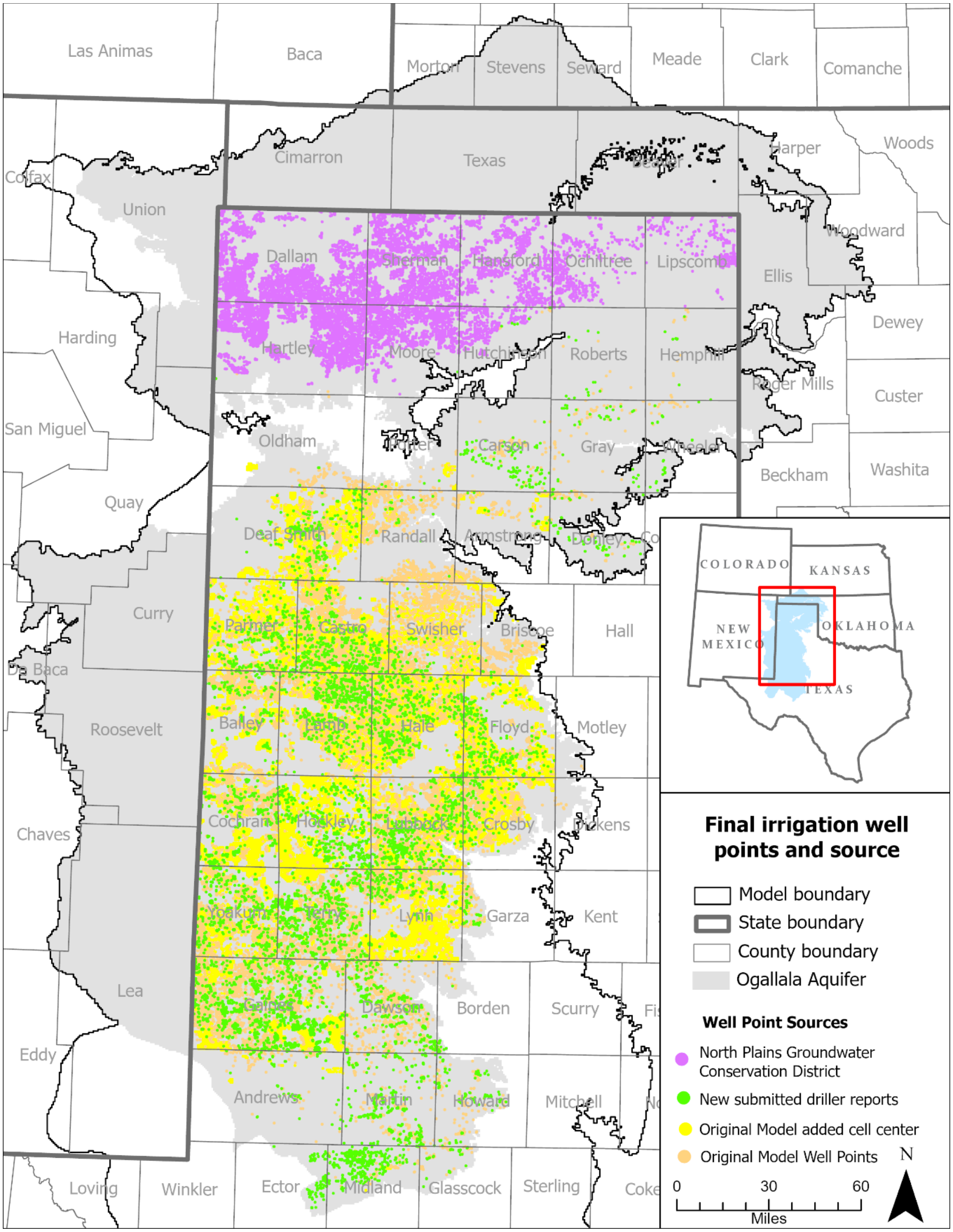

Figure 2-6 **Model Extension Ogallala Aquifer irrigation well points and data source. Original Model added cell centers (in yellow) correspond to Original Model added cells for additional irrigated land cells, redistributed pumping cells, and additional adjacent cells. (See Figure 2-4 and Table 2-6).**

2.4 North Plains Groundwater Conservation District wells

North Plains Groundwater Conservation District provided a well point dataset for their entire district (North Plains Groundwater Conservation District, 2024a), which included 19,013 wells. Wells drilled after 2019 were removed and wells that had a status of being plugged, capped, canceled, or recent application were removed. Monitoring, auxiliary, and geothermal wells were also removed. The final well dataset resulted in a total of 13,123 wells with irrigation wells being the main water use category followed by livestock and domestic (Table 2-7). There is a total of 10,119 permitted wells and 3,004 wells exempt from permitting.

The Original Model Ogallala Aquifer wells and the new Texas Submitted Drillers Report Database Ogallala Aquifer wells were replaced with this new North Plains Groundwater Conservation District dataset. North Plains Groundwater Conservation District provided metered data that was distributed to four classes of permitted wells based on pumping capacity (Table 2-8) as described in Section 3.6. Figure 2-7 shows the final distribution of the North Plains Groundwater Conservation District wells and Figure 2-6 shows the final distribution of the Ogallala Aquifer irrigation wells.

Table 2-7 Well counts for North Plains Groundwater Conservation District by use.

County	Domestic	Livestock	Irrigation	Public supply	Industrial	Mining	Total
Dallam	273	399	2,383	16	11	0	**3,082**
Hansford	105	175	842	7	33	29	**1,191**
Hartley	151	210	2,362	14	27	6	**2,770**
Hutchinson	42	69	360	11	20	4	**506**
Lipscomb	94	149	266	10	7	210	**736**
Moore	203	155	1,210	24	57	3	**1,652**
Ochiltree	142	126	452	16	66	168	**970**
Sherman	108	181	1,861	6	58	2	**2,216**
Total	**1,118**	**1,464**	**9,736**	**104**	**279**	**422**	**13,123**

Table 2-8 Well counts for North Plains Groundwater Conservation District by class.

County	Class A (18 to 100 gallons per minute)	Class B (101 to 400 gallons per minute)	Class C (401 to 800 gallons per minute)	Class D (greater than 801 gallons per minute)	Exempt (0 to 17 gallons per minute)
Dallam	29	296	1,304	780	673
Hansford	18	42	156	664	311
Hartley	14	259	1,281	850	366
Hutchinson	5	19	115	250	117
Lipscomb	11	19	100	157	449
Moore	15	219	495	560	363
Ochiltree	23	62	102	346	437
Sherman	49	311	729	839	288
Total	**164**	**1,227**	**4,282**	**4,446**	**3,004**

2.5 Oklahoma wells

No new wells were added in Oklahoma.

2.6 Kansas wells

No new wells were added in Kansas.

2.7 New Mexico wells

The Original Model New Mexico well dataset was developed from various sources including previous groundwater models for the four aquifers (Deeds and others, 2015). For the Model Extension, the Original Model well dataset was replaced with groundwater permit locations from the New Mexico Office of the State Engineer points of diversion geodatabase (New Mexico Office of the State Engineer, 2023).

First, the New Mexico points of diversion database was filtered to include only groundwater points of diversion (permits). To assign an aquifer to each of the New Mexico groundwater permits, the well location and depth were intersected with the model framework. The well latitude, longitude, and depth from the database were used to intersect the permit wells with the model framework and model grid attributes were added to the permit database. Initially aquifers were assigned to wells by comparing the well depth to the top and bottom elevation of the model layers. However, a relatively large fraction of wells was identified as upper Dockum unit (Layer 3) and the distribution was inconsistent with the distribution of upper Dockum unit wells in the Original Model.

A number of permit wells that were originally classified as upper Dockum unit were reassigned in two steps. First, to account for uncertainty in the aquifer framework a 30 feet buffer below the base of Layer 1 was used in areas where the Rita Blanca or Edwards-Trinity (High Plains) aquifers were not present. Permitted wells within 30 feet below the base of Layer 1 were reassigned as Ogallala Aquifer wells. In areas where the Rita Blanca or Edwards-Trinity (High Plains) aquifers were present, a buffer of 20 feet below the base of Layer 2 was used. Permit wells within 20 feet below the base of Layer 2 were reassigned as either Rita Blanca Aquifer or Edwards-Trinity (High Plains) Aquifer wells depending on their location.

The number of wells assigned as upper Dockum unit still appeared to be relatively large, so the definition of the base of the Ogallala Aquifer (in areas where the Rita Blanca or Edwards-Trinity [High Plains] aquifers were not present) was further expanded. In the aquifer code field of the New Mexico permit database, 48 permit wells categorized as upper Dockum unit based on the model framework (well depth more than 30 feet below base of Layer 1) are labeled as “Ogallala”. The deepest of those wells is 538 feet. To further account for uncertainty in the model framework and knowing that most wells in the model area are located in the Ogallala Aquifer, all upper Dockum unit wells within the Ogallala Aquifer boundary (excluding areas of the Rita Blanca and Edwards-Trinity [High Plains] aquifers) less than 538 feet deep were reclassified as Ogallala Aquifer wells.

Preliminary model runs and subsequent review of well distribution for the Model Extension suggested that too few wells were assigned to the Rita Blanca Aquifer in Union County. As a remedy, all irrigation permit wells initially assigned as upper Dockum unit or having no assignment (because of no depth) were assigned to the Rita Blanca Aquifer (Layer 2). This increased the Union County irrigation well count from 80 to 455 and improved distribution.

For the purposes of developing a post-2012 MODFLOW pumping file, the New Mexico permit database was filtered on permitted wells completed before the end of 2013 (the first year of the Model Extension period) and either not plugged before 2020 or never plugged and assigned as Ogallala, Rita Blanca, Edwards-Trinity (High Plains), upper Dockum, or lower Dockum.

2.8 Model extension well dataset

The filtered Original Model active well point dataset; filtered Original Model additional irrigated land cells, redistributed pumping cells, and additional adjacent cells dataset; and new Texas Submitted Drillers Report Database final 2013 through 2020 dataset were merged into one dataset. Then, the New Mexico and the North Plains Groundwater Conservation District wells were replaced with the datasets described in Sections 2.4 and 2.7 to create a final well dataset (Tables 2-9 and 2-10; Figure 2-7).

Table 2-9 Number of 2020 Texas wells by aquifer and water use category.

Use	Ogallala	Rita Blanca	Edwards-Trinity (High Plains)	Dockum
Domestic	14,339	10	1,384	2,030
Livestock	4,126	20	59	458
Irrigation	54,306	174	2,181	1,432
Public Supply	1,201	3	7	224
Industrial	921	0	37	268
Rig Supply and Fracking Supply	5,222	0	12	1,996
Total	**80,115**	**207**	**3,680**	**6,408**

Table 2-10 Number of 2020 wells by aquifer and state.

Aquifer	Layer	Texas	New Mexico	Oklahoma	Kansas
Ogallala	1	80,115	16,222	1,849	377
Rita Blanca	2	207	638	0	0
Edwards-Trinity (High Plains)	2	3,680	-	0	0
Upper Dockum	3	209	-	0	0
Lower Dockum	4	6,199	417	0	0
Total		**90,410**	**17,277**	**1,849**	**377**

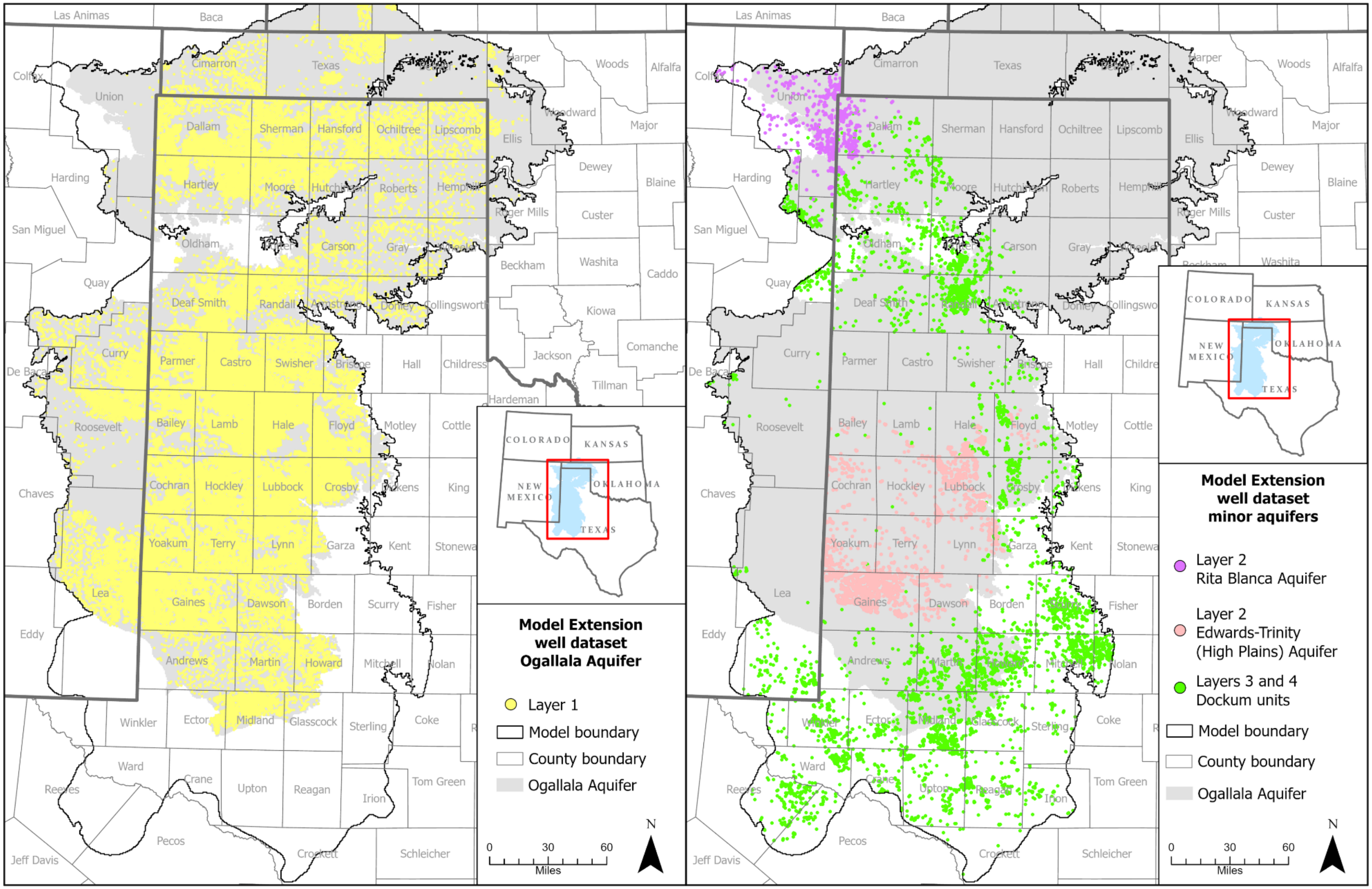

Figure 2-7 Distribution of the final Model Extension well point dataset for the Ogallala Aquifer (left) and minor aquifers (right).

3 Pumping distribution

The Original Model well package includes variable annual pumping rates from 1930 through 2012. For the Model Extension, 2013 through 2020 annual pumping estimates were gathered from the TWDB Water Use Survey (TWDB, 2023c), New Mexico Office of the State Engineer (2024), and local groundwater conservation districts for multiple water use categories. The pumping estimates were distributed to the well dataset described in Section 2 and then to each corresponding 1/2 mile by 1/2 mile model cell. This section describes the different methodologies used for distributing the pumping depending on a well's water use category, aquifer, and geographic location. Appendix A includes pumping graphs comparing the Original Model and Model Extension pumping estimates per county and Appendix B includes tables with county pumping from 2013 through 2020 distributed to the model grid for each county.

3.1 TWDB Water Use Survey

The TWDB Water Use Survey (TWDB, 2023c) was used as the source for all 2013 through 2020 Texas pumping estimates except for non-exempt wells (permit required by groundwater conservation district) in North Plains Groundwater Conservation District and Panhandle Groundwater Conservation District as described in Sections 3.5 and 3.6.

The Original Model's iterative and manual process of redistributing Ogallala Aquifer irrigation pumping to areas of higher saturated thickness as described in Sections 2.3 and 5.3 of this report was not followed for the Model Extension. A different approach was taken to distribute Ogallala Aquifer county-level irrigation pumping equally to all irrigation wells in a county. However, as described in Section 2.3, most of the additional irrigated land cells, redistributed pumping cells, and additional adjacent cells were carried forward as Ogallala Aquifer irrigation well points for the Model Extension (Table 2-6; Figure 2-6). Additionally, there were 8,165 new Ogallala Aquifer irrigation wells added for the Model Extension, with 86 percent of those in areas with more than 30 feet of saturated thickness (discussed further in Section 5.3). This increased confidence that irrigation pumping is being distributed to areas of higher saturated thickness using the new Model Extension methodology.

Rural domestic, livestock, and irrigation county-level groundwater use estimates for each aquifer were equally distributed to wells with the same use within a county. The TWDB Water Use Survey includes pumping estimates for these categories for all counties overlapping the Ogallala Aquifer but does not include pumping estimates for all counties overlapping the minor aquifers. Thus, if a county had irrigation, rural domestic, or livestock wells for a minor aquifer but there was no corresponding county pumping estimate, then no pumping was distributed to those wells.

For some counties in the southern Ogallala Aquifer area, the Original Model applied irrigation scaling factors to the Ogallala Aquifer pumping estimates in the TWDB Water Use Survey (Table 3-1) in order to be consistent with the pumping magnitudes in the appendix B report (Amosson and others, 2003) of the groundwater availability model for the Southern Ogallala. The TWDB Water Use Survey irrigation estimates for 2013 through 2020 were multiplied by these factors for consistency with the Original Model.

Municipal, industrial, power, and manufacturing water users annually report pumping by aquifer and county to the TWDB for inclusion in the TWDB Water Use Survey (TWDB, 2023c). Well owner names were matched to system names included in the TWDB Water Use Survey. The total county pumping reported by a system for an aquifer was distributed equally to all system wells assigned to that aquifer within that county. For example, if a system had 10 wells for the Ogallala Aquifer in a county, then the reported Ogallala Aquifer pumping for that county was distributed equally to those 10 wells. There were some municipal well systems with different wells screened in multiple aquifers, but water use reported to the TWDB Water Use Survey was only for one aquifer. For these situations, pumping was only distributed to the wells that matched the aquifer for which use was reported.

The TWDB Water Use Survey includes 2013 through 2020 non-surveyed pumping estimates for mining use per county (TWDB, 2023c). For the Model Extension, these estimates were split into pumping amounts per aquifer using Equation 3. New 2013 through 2020 Texas Submitted Drillers Report Database wells with proposed uses of either fracking supply or rig supply were selected and assigned aquifers using the methodology described in Section 2.1 (Figure 3-1). For each county, an aquifer split ratio of the total new rig and fracking supply wells with that aquifer assignment to the total new rig and fracking supply wells for all aquifers in the entire county was calculated. Not every county is fully within the model area, so a county weighting factor was calculated by dividing the total area of the county overlapping the active model area by the entire county area. The total mining non-surveyed pumping for an aquifer was calculated by multiplying the TWDB Water Use Survey pumping estimate by the aquifer ratio and county weighting factor. Table 3-2 includes the county aquifer splits and Appendix B includes the total non-surveyed mining pumping distributed to the model grid split per county.

$$PUMP_{aq} = PUMP_{wus} * \left(\frac{SDR_{aq}}{SDR_{tot}}\right) * \left(\frac{MOD_{area}}{CNTY_{area}}\right) \qquad \textbf{(Equation 3)}$$

Where:

$PUMP_{aq}$ = Aquifer non-surveyed mining pumping estimate.

$PUMP_{wus}$ = County non-surveyed mining pumping estimate (TWDB, 2023c).

SDR_{aq} = Aquifer total number of 2013 through 2020 rig and fracking supply wells.

SDR_{tot} = County total number of 2013 through 2020 rig and fracking supply wells.

MOD_{area} = County area overlapping the active model area.

$CNTY_{area}$ = County area.

Table 3-1 Original Model irrigation scaling factors for the Ogallala Aquifer. These values were not included in the Original Model report but were derived from Original Model data for applying to this Model Extension.

County	Ratio
Andrews	0.69
Armstrong	0.90
Bailey	0.53
Borden	1.18
Briscoe	1.28
Castro	0.46
Cochran	0.64
Crosby	1.04
Dawson	0.74
Deaf Smith	0.70
Dickens	3.94
Ector	0.29
Floyd	0.77
Gaines	0.65
Garza	1.66
Glasscock	0.71
Hale	0.75
Hockley	0.99
Howard	2.36
Lamb	0.76
Lubbock	0.82
Lynn	0.97
Martin	1.00
Midland	0.22
Motley	1.18
Oldham	2.41
Parmer	0.62
Swisher	0.81
Terry	1.05
Yoakum	0.89

Table 3-2 Aquifer assignments for 2013 through 2020 Submitted Drillers Report Database wells with a proposed use of either rig or fracking supply. The values in this table were used to split TWDB Water Use Survey non-surveyed mining pumping estimates by aquifer (Appendix B).

County	2013 through 2020 wells	Ogallala (percent)	Dockum (percent)	Edwards-Trinity (High Plains) (percent)	Other (percent)	County area within model (percent)
Andrews	83	53	43	-	4	100
Borden	30	33	67	-	-	100
Cochran	3	100	-	-	-	100
Crane	27	-	70	-	30	72
Crockett	124	-	2	-	98	26
Dawson	171	94	4	3	-	100
Donley	1	100	-	-	-	64
Ector	104	35	24	-	41	100
Gaines	14	71	14	14	-	100
Glasscock	693	4	10	-	85	100
Gray	1	100	-	-	-	97
Hansford	9	78	-	-	22	100
Hartley	5	40	60	-	-	100
Hemphill	60	95	-	-	5	99
Hockley	10	80	-	20	-	100
Howard	2,650	78	21	-	-	100
Hutchinson	6	100	-	-	-	78
Irion	208	-	22	-	78	63
Lamb	1	-	100	-	-	100
Lipscomb	71	94	-	-	6	100
Loving	11	-	45	-	55	35
Martin	1,856	82	14	-	4	100
Midland	1,318	43	23	-	34	100
Mitchell	14	-	100	-	-	88
Nolan	1	-	100	-	-	29
Ochiltree	50	94	-	-	6	100
Oldham	1	-	100	-	-	97
Pecos	97	-	35	-	65	14
Potter	27	-	100	-	-	85
Reagan	1,169	-	12	-	88	100
Reeves	321	-	43	-	57	31
Roberts	24	88	-	-	13	99
Scurry	7	-	100	-	-	87
Sterling	20	-	35	-	65	98
Terry	1	100	-	-	-	100
Tom Green	3	-	67	-	33	3
Upton	772	-	18	-	82	99
Ward	200	-	29	-	72	96
Wheeler	13	77	-	-	23	63
Winkler	77	-	53	-	47	100
Yoakum	35	86	6	9	0	100

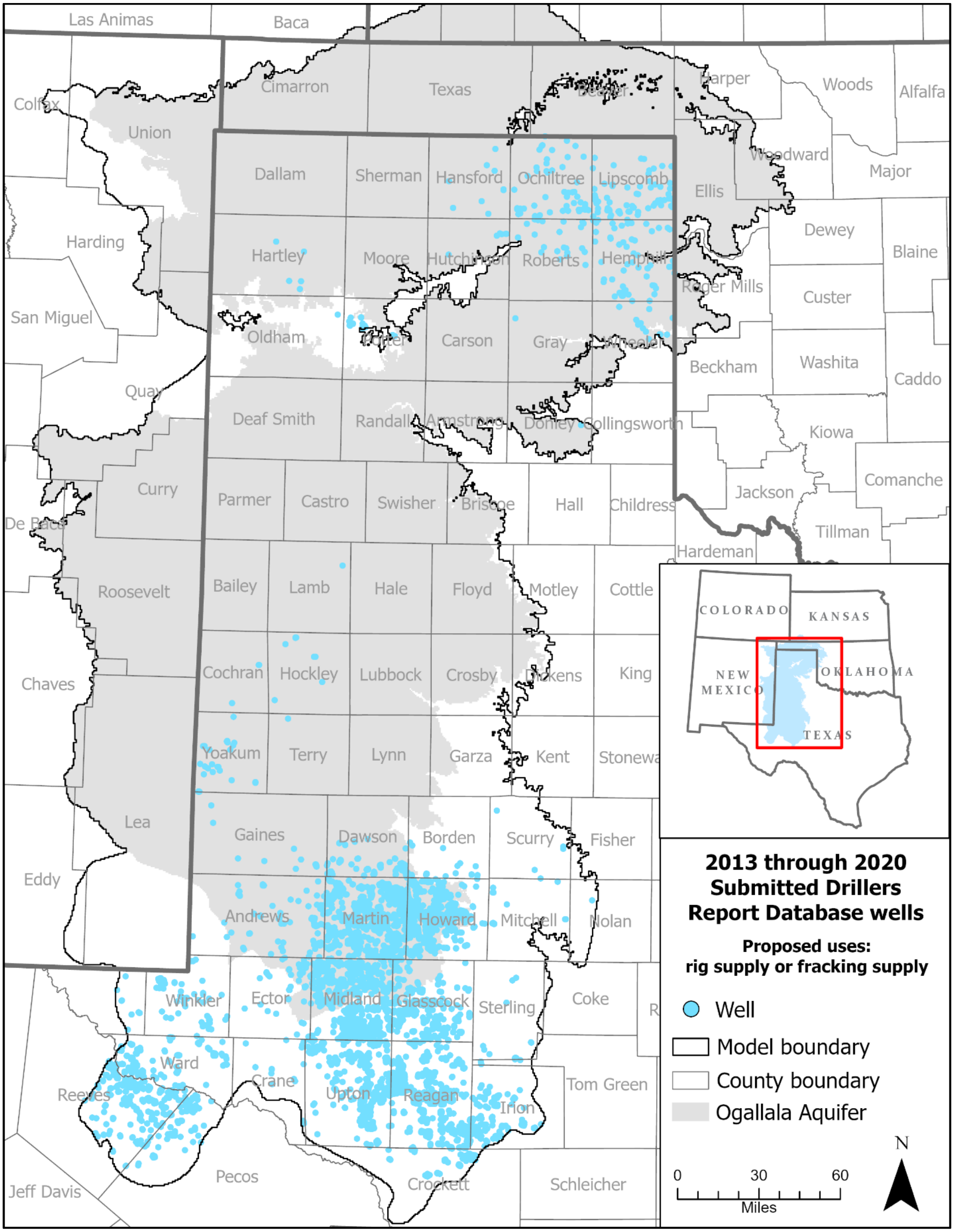

Figure 3-1 **Distribution of Texas Submitted Drillers Report Database wells with either a rig or fracking supply proposed use between 2013 and 2020.**

3.2 Oklahoma pumping

We used the Original Model 2012 pumping for 2013 through 2020.

3.3 Kansas pumping

We used the Original Model 2012 pumping for 2013 through 2020.

3.4 New Mexico pumping

We based pumping rates in New Mexico for the model verification update on New Mexico county water use data available from the New Mexico Office of the State Engineer (New Mexico Office of the State Engineer, 2024). The data are semi-decadal, and 2015 data were available for the Model Extension period, but 2020 data were not available. Therefore, we used 2015 data for each year of the Model Extension period and assigned pumping rates to permitted wells uniformly by county and water use type. The water use data represented all groundwater use in the county with no aquifer designation. Therefore, we distributed the pumping to modeled aquifers based on the fraction of wells assigned to a particular aquifer in that county. For example, if 90 percent of irrigation wells in the county were assigned to the Ogallala Aquifer, 90 percent of the irrigation water use was assigned to Ogallala Aquifer irrigation wells.

The New Mexico counties within the model area have less than 100 percent of their area inside the active model area, but the water use data is for the entire county. The permit database includes a field with information on the water use type for the permit. We used the permit use type information to count as a starting point to scale the water use data for that county. However, the use types listed in the permit database were not always a direct match with the eight use categories of the water use data. The permit database use field had a total of 58 possible descriptions of use. We recategorized each of the 58 permit use descriptions into one of the 8 water use data types to scale the water use data. For each county and use category, we calculated a ratio of the number of permits with that use type in the model area to the total number of permits for that use in the county. The scaled groundwater use for each category was equal to the use-ratio multiplied by the water use for that category in the county.

As in the Original Model, pumping was not included for the Edwards-Trinity (High Plains) Aquifer and upper Dockum unit in New Mexico.

Table 3-3 New Mexico water use codes recategorized for use in the Model Extension.

New Mexico code value	New Mexico code description	Model Extension water use category
AGR	Agriculture other than irrigation	commercial
AUG	Augmentation well	other
BPW	Brine production well	mining
CEM	Cemetery	irrigation
CLS	Closed file	other
COM	Commercial	commercial
CON	Construction	commercial
CPS	Cathodic protection well	other
DAI	Dairy operation	commercial
DCN	Domestic construction	commercial
DEW	Dewatering well	mining
DOL	72-12-1 domestic and livestock watering	domestic
DOM	72-12-1 domestic one household	domestic
EXP	Exploration	mining
FCD	Flood control	other
FGP	Fish and game propogation	commercial
FPO	Feed pen operation	commercial
GEO	Geothermal boreholes	other
HWY	Highway construction	commercial
IND	Industrial	industrial
INJ	Injection	other
IRR	Irrigation	irrigation
MDW	Community type use - mdwca, private or commercial supplied	public water supply
MFG	Manufacturing	commercial
MIL	Military - military installations	public water supply
MIN	Mining or milling or oil	mining
MOB	Mobile home parks	public water supply
MON	Monitoring well	other
MPP	Meat packing plant	commercial
MUL	72-12-1 multiple domestic households	public water supply
MUN	Municipal - city or county supplied water	public water supply
N07	No pre-1907 water right exists on this land	other
NON	Non-profit organizational use	other
NOT	No use of right or POD	other
NRT	No right	other
OBS	Observation	other
OFM	Oil field maintenance	mining
OIL	Oil production	mining
PDL	Non 72-12-1 domestic and livestock watering	domestic
PDM	Non 72-12-1 domestic one household	domestic
PLS	Non 72-12-1 livestock watering	livestock
PMH	Non 72-12-1 multiple domestic households	public water supply
POL	Pollution control well	other
POU	Poultry and egg operation	commercial
PPP	Petroleum processing plant	industrial

Table 3-3 continued

New Mexico code value	New Mexico code description	Model Extension water use category
PRO	72-12-1 Prospecting or development of natural resource	mining
PUB	72-12-1 Construction of public works	commercial
REC	Recreation	commercial
SAN	72-12-1 Sanitary in conjunction with a commercial use	commercial
SCH	School use - public, private, parochial, & universities	public water supply
SRO	Secondary recovery of oil	mining
STK	72-12-1 livestock watering	livestock
STO	Storage	other
STR	Strategic water reserve	other
SUB	Subdivision	public water supply
SWR	Stacked water right	other
TBD	To be determined	other
UTL	Public utility	public water supply

3.5 Panhandle Groundwater Conservation District pumping

The Panhandle Groundwater Conservation District provided county-level pumping estimates for irrigation, industrial, and public supply water uses in the Ogallala and Dockum aquifers (Panhandle Groundwater Conservation District, 2023). The estimates for irrigation and industrial uses were used instead of the TWDB Water Use Survey for counties that were completely within the Panhandle Groundwater Conservation District. Additionally, the pumping was distributed according to the process detailed in Section 3.1.

3.6 North Plains Groundwater Conservation District pumping

North Plains Groundwater Conservation District provided metered data from 2013 through 2018 for the entire district (North Plains Groundwater Conservation District, 2024b). The metered data is not reported by well but by groundwater production unit, which is a polygon boundary that contains multiple wells. A table of pumping per groundwater production unit was provided for 2013 through 2018, which included the latitude and longitude for the center of each unit.

Groundwater production unit boundaries can sometimes change so it was necessary to relate the 2013 through 2018 unit centers to the 2018 unit polygons. For each year from 2013 through 2018 the polygon unit centers were intersected with the 2018 polygon units and all the unit groundwater production for that year was assigned to the 2018 polygon unit. If a unit was not split, merged, or redrawn between 2013 through 2018 then the unit center for all years would be the same as the unit center in 2018. If unit boundaries were split, merged, or redrawn sometime during this period then there could be more or less unit centers in 2018. The total annual pumping that was assigned to each unit polygon was then distributed equally to all North Plains Groundwater

Conservation District Class A, B, C, and D wells that intersected the unit polygon. The pumping was then assigned to the model grid cell it intersected. Figure 3-2 shows a diagram of the process.

The final 2018 pumping distribution was carried forward for 2019 and 2020. Pumping for wells exempt from permitting (rural domestic, livestock, and non-surveyed mining) was distributed following the procedures described in Section 3.1.

3.7 Model extension pumping distribution

Pumping estimates for 2013 through 2020 by water use category (Figures 3-3 through 3-6) were distributed to the well points and corresponding model grid cells (Figures 3-7 through 3-11) as described in Sections 3.1 through 3.6.

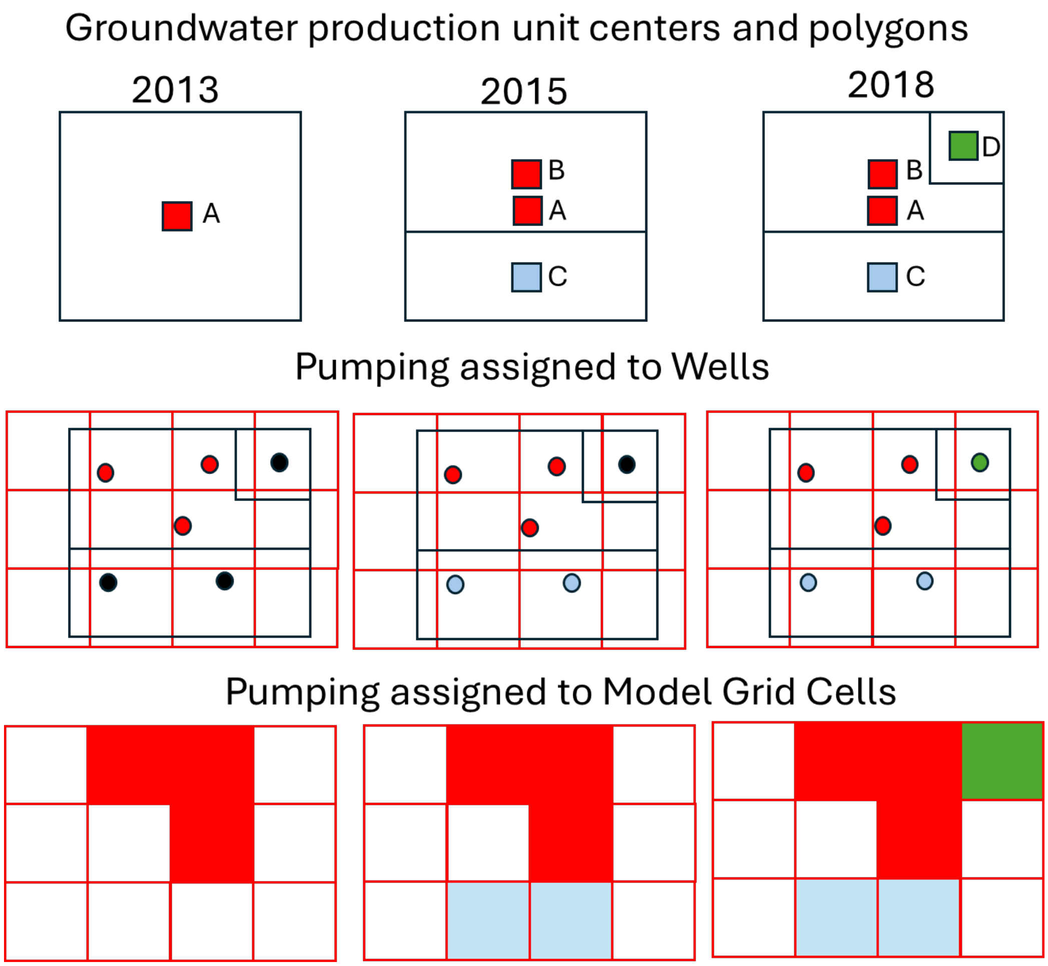

Figure 3-2 Example of how North Plains Groundwater Conservation District groundwater production unit pumping was distributed to the model grid. In the top row, hypothetical groundwater production unit centers for 2013, 2015, and 2018 are shown as squares A, B, C, and D. In the second row, pumping is assigned to wells (circles) with the same color as the groundwater production unit centers in the first row. Black circles represent wells with no pumping assigned. In the third row, model grid cells are assigned pumping from groundwater production unit centers of the same color.

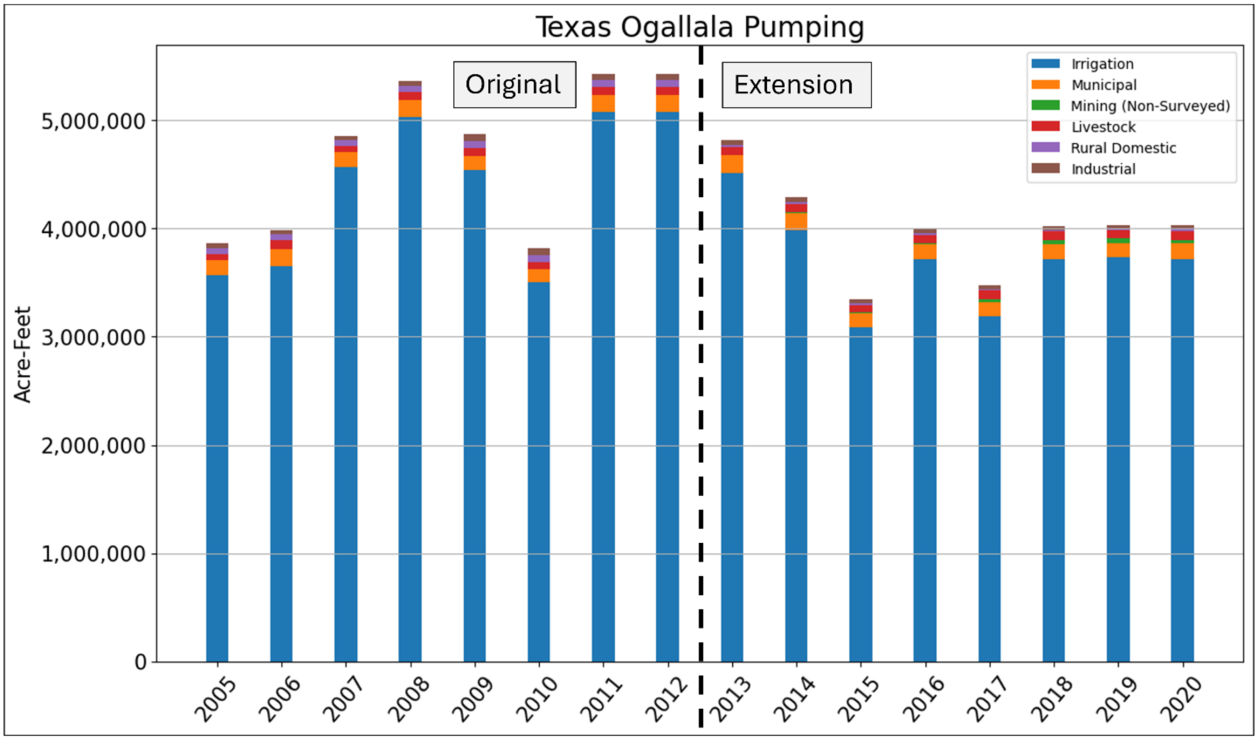

Figure 3-3 Ogallala Aquifer pumping in Texas between 2005 and 2020.

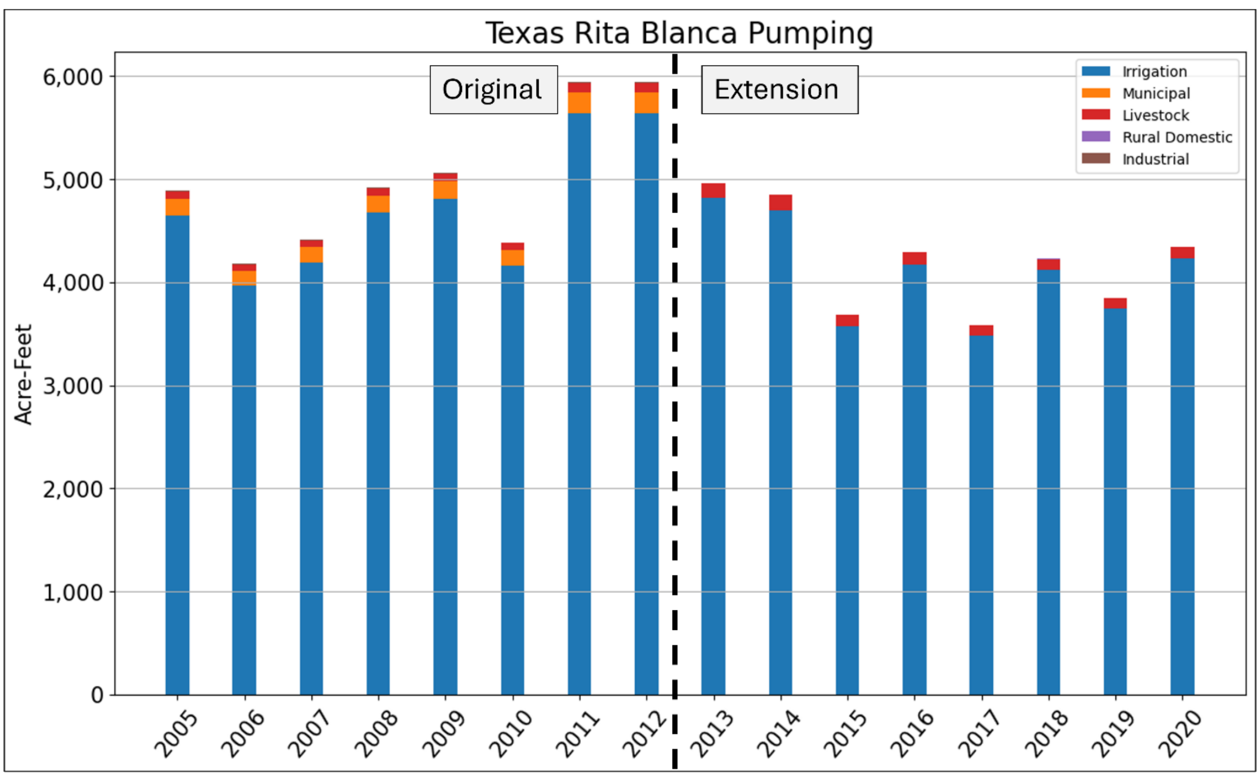

Figure 3-4 Rita Blanca Aquifer pumping in Texas between 2005 and 2020.

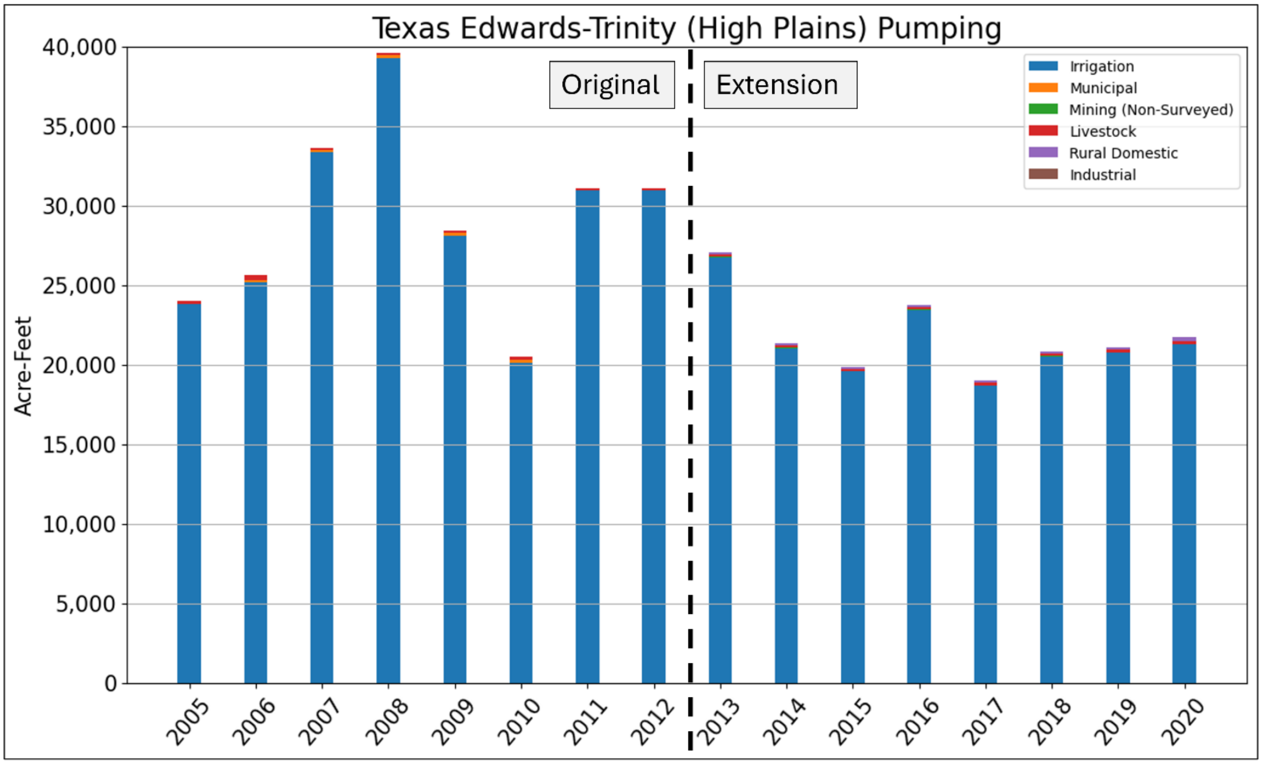

Figure 3-5 Edwards-Trinity (High Plains) Aquifer pumping in Texas between 2005 and 2020.

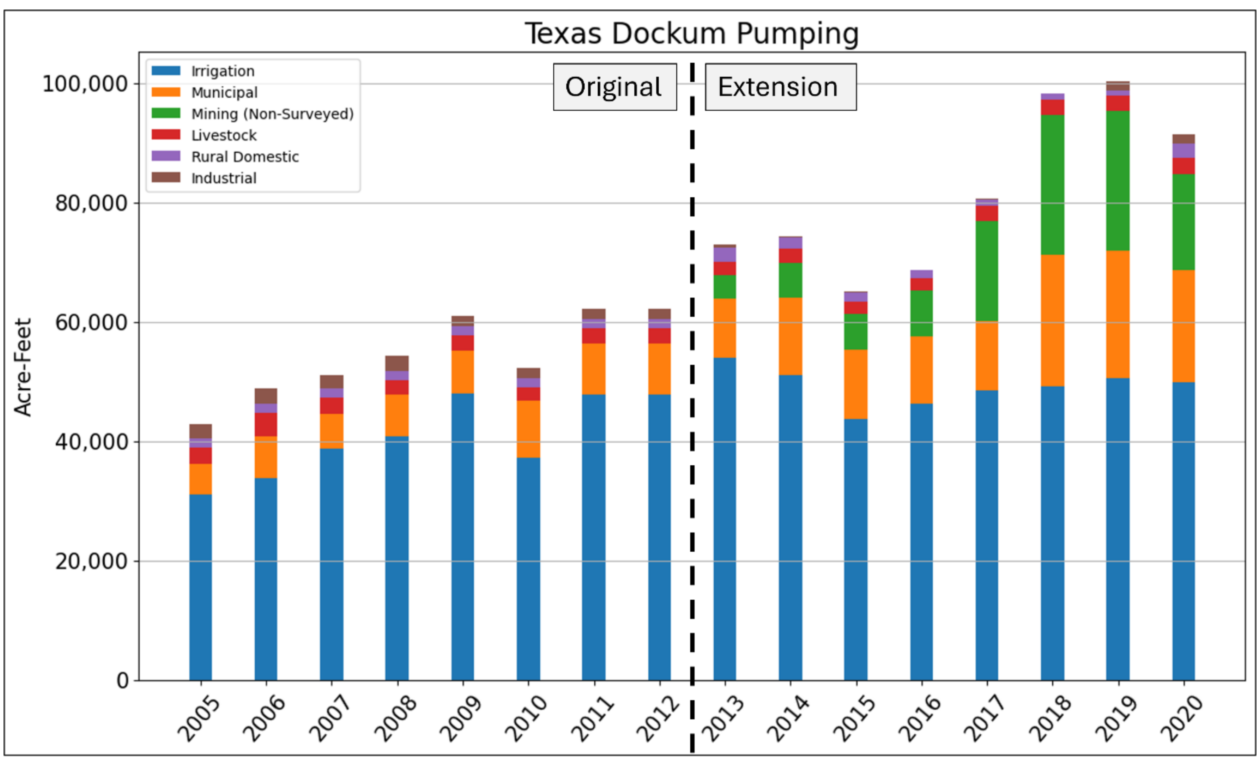

Figure 3-6 Dockum units pumping in Texas between 2005 and 2020.

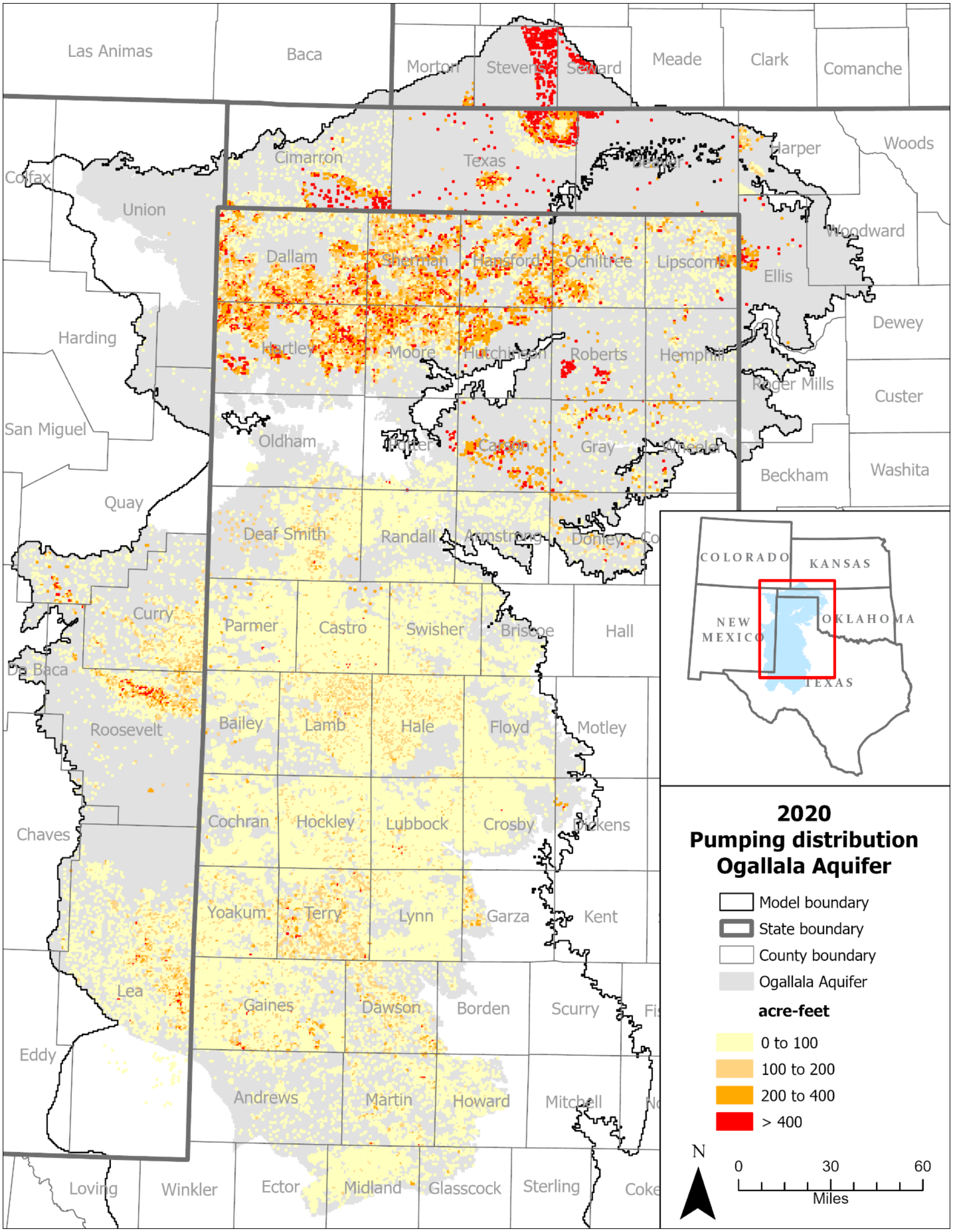

Figure 3-7 Ogallala Aquifer pumping distribution in 2020.

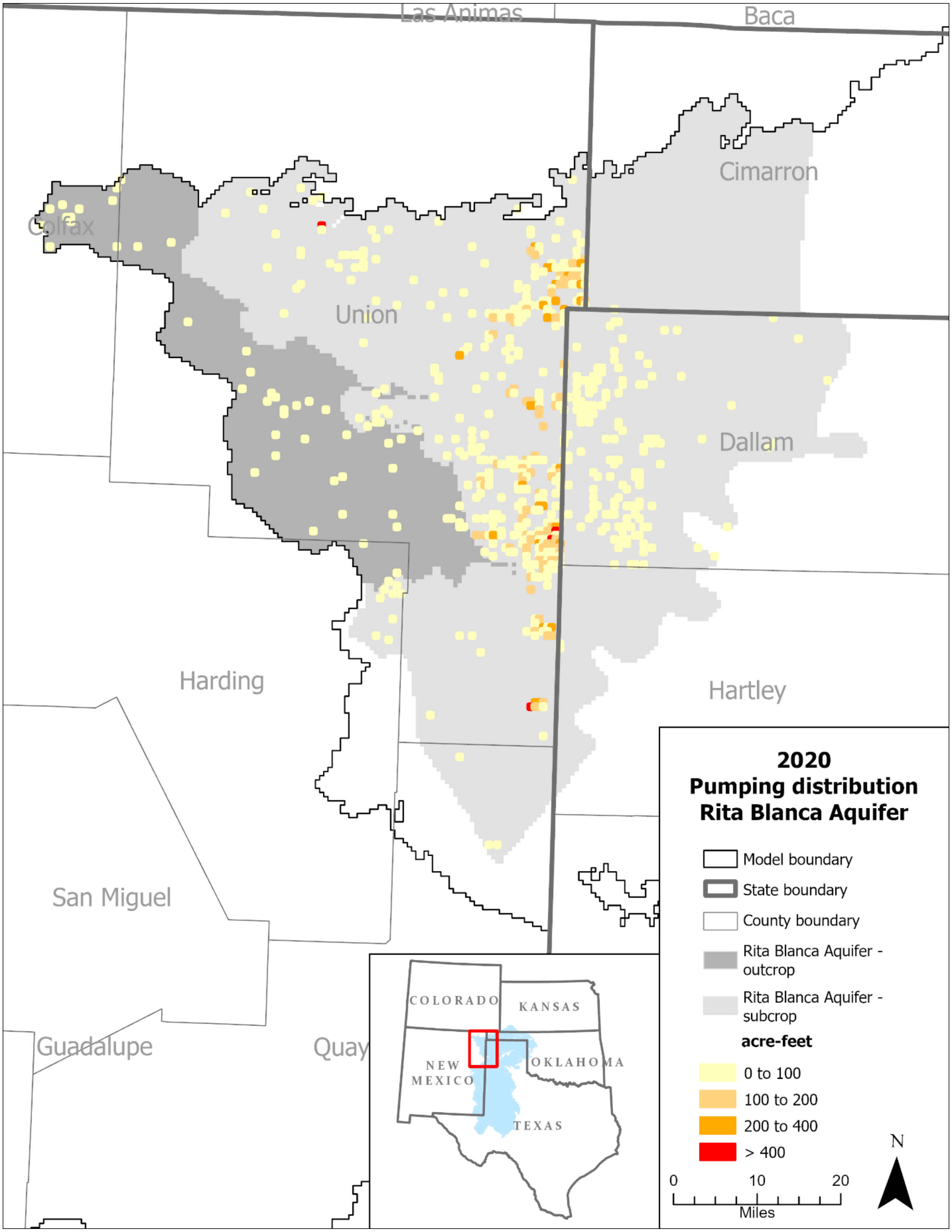

Figure 3-8 Rita Blanca Aquifer pumping distribution in 2020.

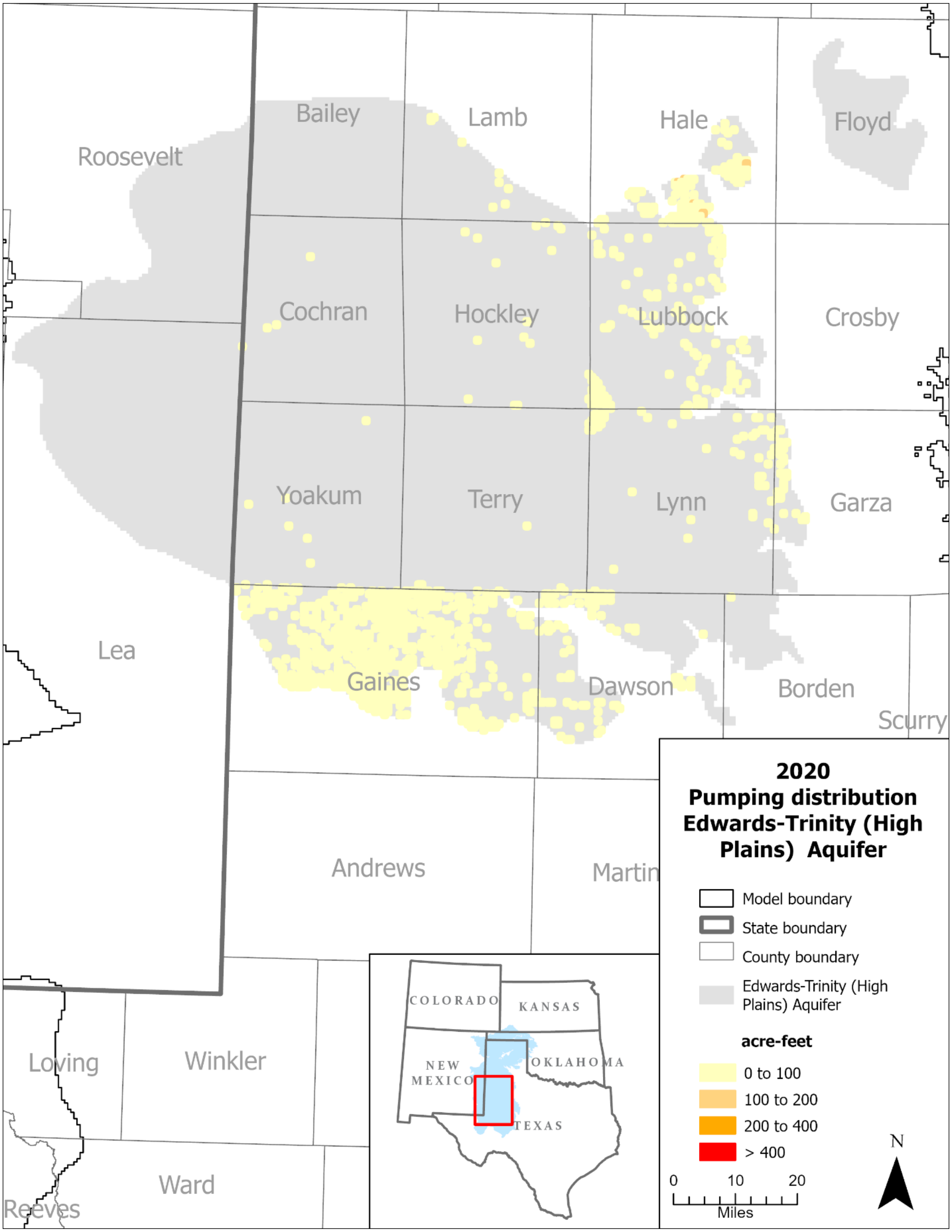

Figure 3-9 Edwards-Trinity (High Plains) Aquifer pumping distribution in 2020.

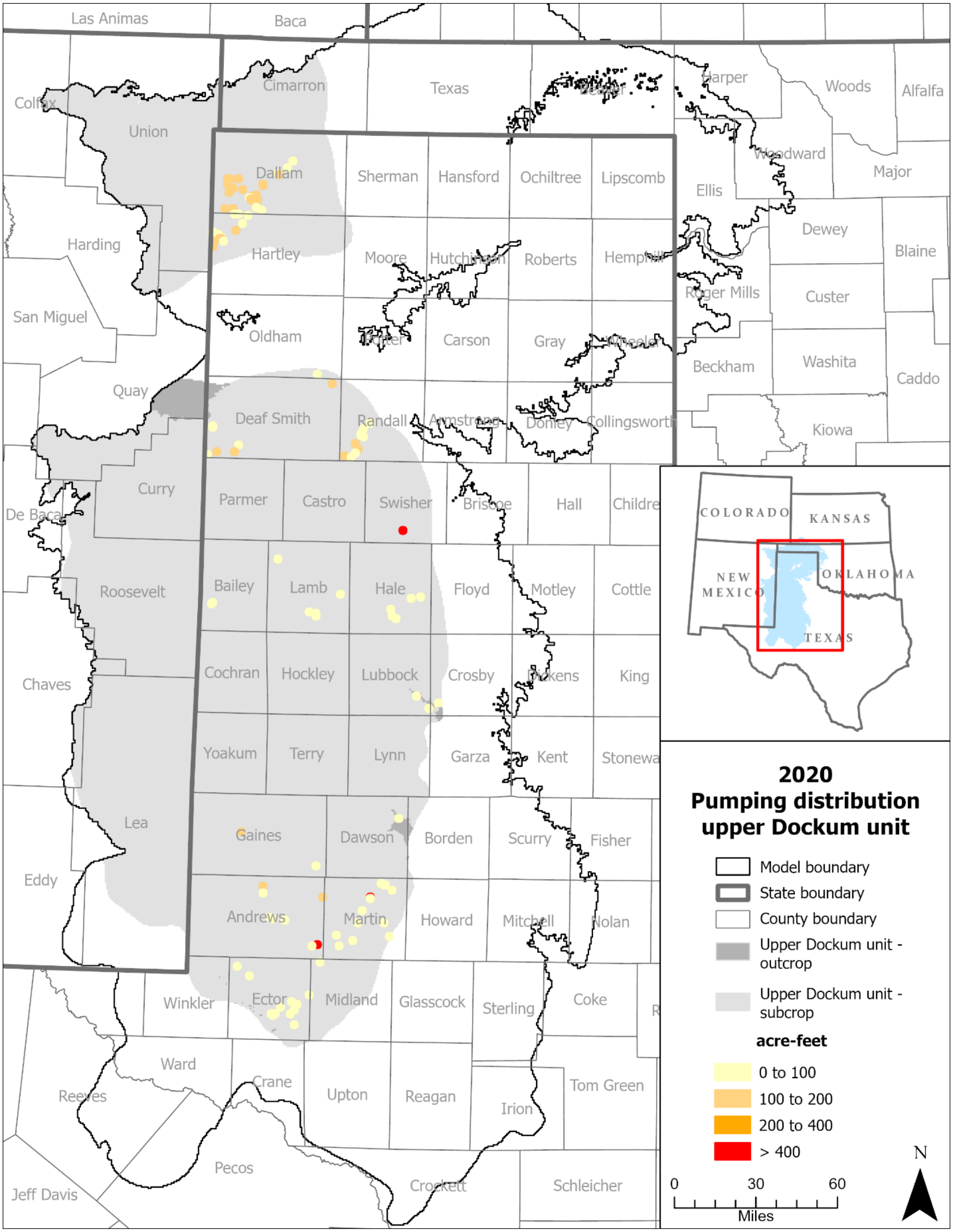

Figure 3-10 Upper Dockum unit pumping distribution in 2020.

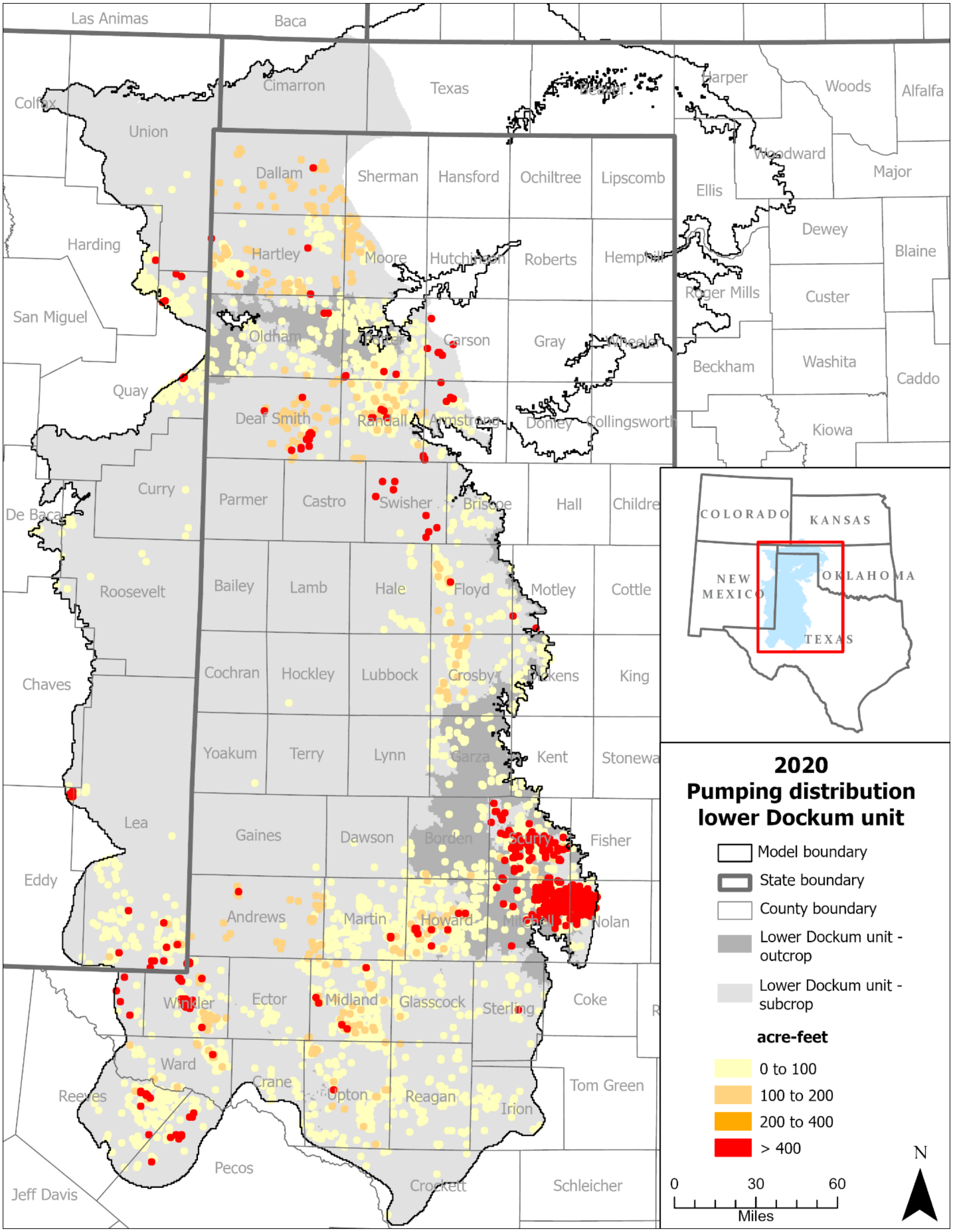

Figure 3-11 Lower Dockum unit pumping distribution in 2020.

4 Recharge package update

The Groundwater Management Area 2 explanatory report for the third round of joint planning identified groundwater availability model limitations related to recharge in Howard County (Hutchison, 2021). Increased recharge in the modern period (post 1982) resulted in almost no drawdown in the predictive simulations and budget diagrams for storage change in Howard County showed unusual behavior indicating rising water levels in the predictive period (Hutchison, 2021). Significant county-wide rising water levels during the predictive period do not occur in any other counties. To investigate and possibly remedy the model limitations for Howard County we reviewed the conceptual model of recharge for the Original Model and conducted model sensitivity analyses of recharge focusing on Howard County.

4.1 Original model recharge

In the conceptual model for the Ogallala Aquifer, predevelopment recharge for the northern portion of the model was based on chloride data (chloride mass balance method). For the southern portion of the model, predevelopment recharge rates were extrapolated from the northern estimates (Deeds and others, 2015). Post development recharge in the northern model area was the same as predevelopment because of an impermeable layer limiting the effect of land cultivation. The limited effect of land development in the northern portion of the model was supported by nitrate data (Deeds and others, 2015). The 500 milligram/liter total dissolved solids isoline was used to divide increased post-development recharge areas from zero-increase recharge areas. In the southern portion of the model area, recharge was enhanced due to conversion of land to cultivated agriculture and the recharge distribution was based on land use (Deeds and others, 2015). Where there was no agriculture, recharge was unchanged from predevelopment. Nitrate data were used to estimate breakthrough times (by county) for enhanced agriculture related recharge (Deeds and others, 2015).

In the numerical model, predevelopment steady-state recharge was based on the conceptual model and adjusted as part of calibration (Deeds and Jigmond, 2015). The post-development distribution in the northern part of the model was unchanged from predevelopment (Deeds and Jigmond, 2015). For the southern part of the model, post-development recharge was based on land use. Cultivated areas received greater post-development recharge (Deeds and Jigmond, 2015). Recharge estimates based on unsaturated zone chloride mass balance profiles in the southern part of the model supported increased recharge in cultivated areas. The onset of the ten-year transition time from pre to post development recharge was based on county nitrate breakthrough and breakthrough times were smoothed across the southern part of the model to avoid abrupt changes in timing across county boundaries (Deeds and Jigmond, 2015).

4.2 Howard County recharge

Post development recharge in the southern part of the groundwater availability model for the High Plains Aquifer System increases linearly over a transition period based on county nitrate breakthrough data (Deeds and Jigmond, 2015). For Howard County, the recharge increased from 1960 to 1980 and leveled out after 1980 (Figure 4-1). In addition to the rising predictive water levels, the water budget for Howard County shows multiple cross-overs between the pumping flux and change in storage during the historical period. These budget cross-overs are not seen in the budgets for any other counties and suggest that, in the model, the post development recharge rather than aquifer storage is supplying water for pumping in Howard County. In Andrews County, for example, pumping and change in storage are almost equal and opposite and do not cross over (Figure 4-2). For all other counties in the model area the pattern is similar to the pattern in Andrews County.

We investigated the effect of post development recharge in Howard County by conducting a sensitivity analysis. For the analysis, four model simulations were run with recharge capped at a year prior to 1980 (1970, 1967, 1965, and 1963) and the effect on the simulated change in aquifer storage in Howard County was examined. Capping recharge for Howard County in 1965 (model stress period 37) produced the best results. The pumping flux and change in storage during the historical period showed little cross-over and water levels did not rise during the predictive period (change in storage remains negative; Figure 4-3).

The model-wide target residual statistics were calculated for a model run using the modified recharge package. The target water levels were the same targets submitted with the Original Model. The target statistics using the modified recharge package (Howard County recharge capped at 1965) produced slightly better target statistics. The mean residual for Ogallala Aquifer water levels is -0.92 feet using the modified recharge package, compared to -0.95 feet in the Original Model.

For the Model Extension, we used the modified recharge package with Howard County recharge capped at 1965 rates and recharge in all other counties remained unchanged from the Original Model. Recharge from 2012 was extended from 2013 through 2020.

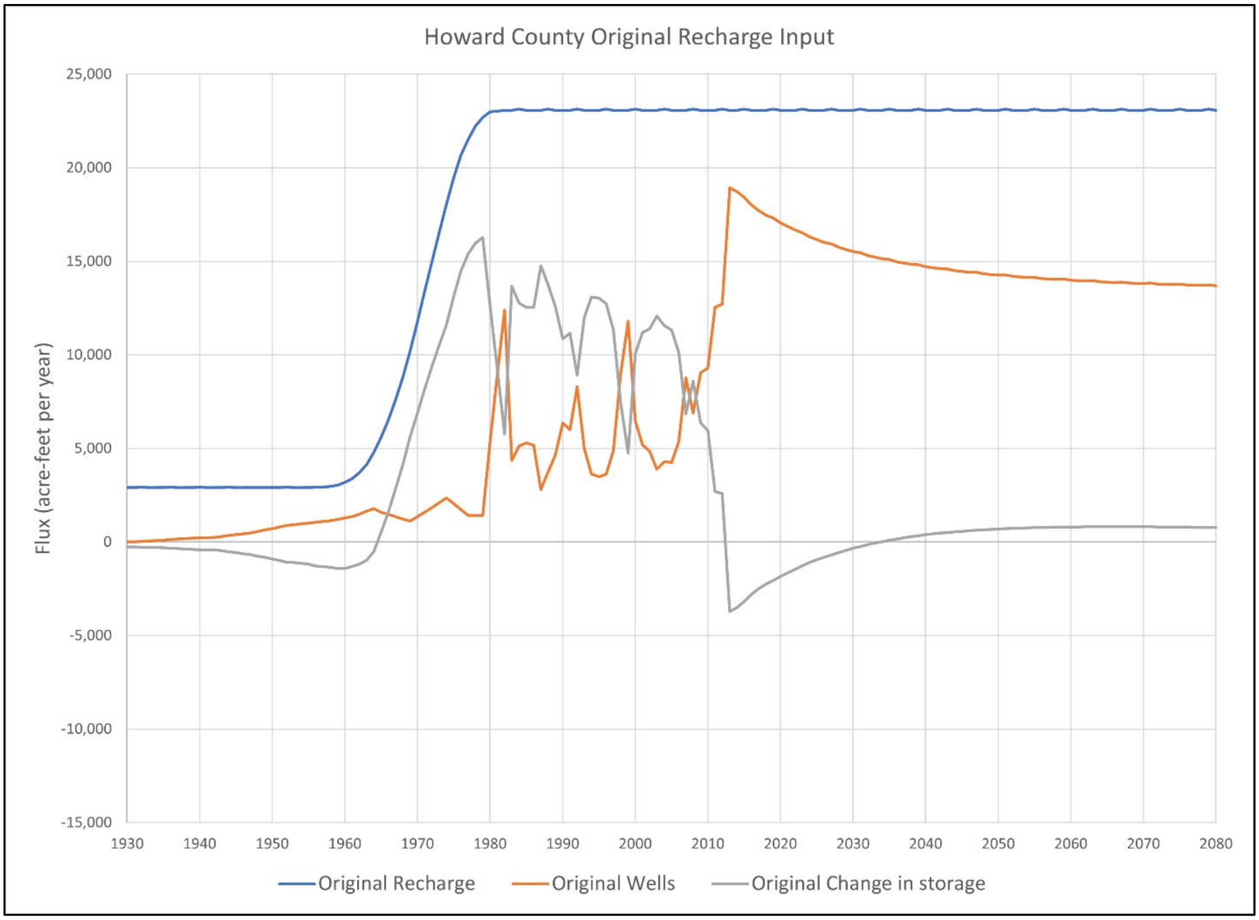

Figure 4-1 Water budget terms for recharge, pumping, and change in storage for the historical and predictive modeling periods in Howard County in the Original Model. Positive changes in storage indicate rising water levels after 2030.

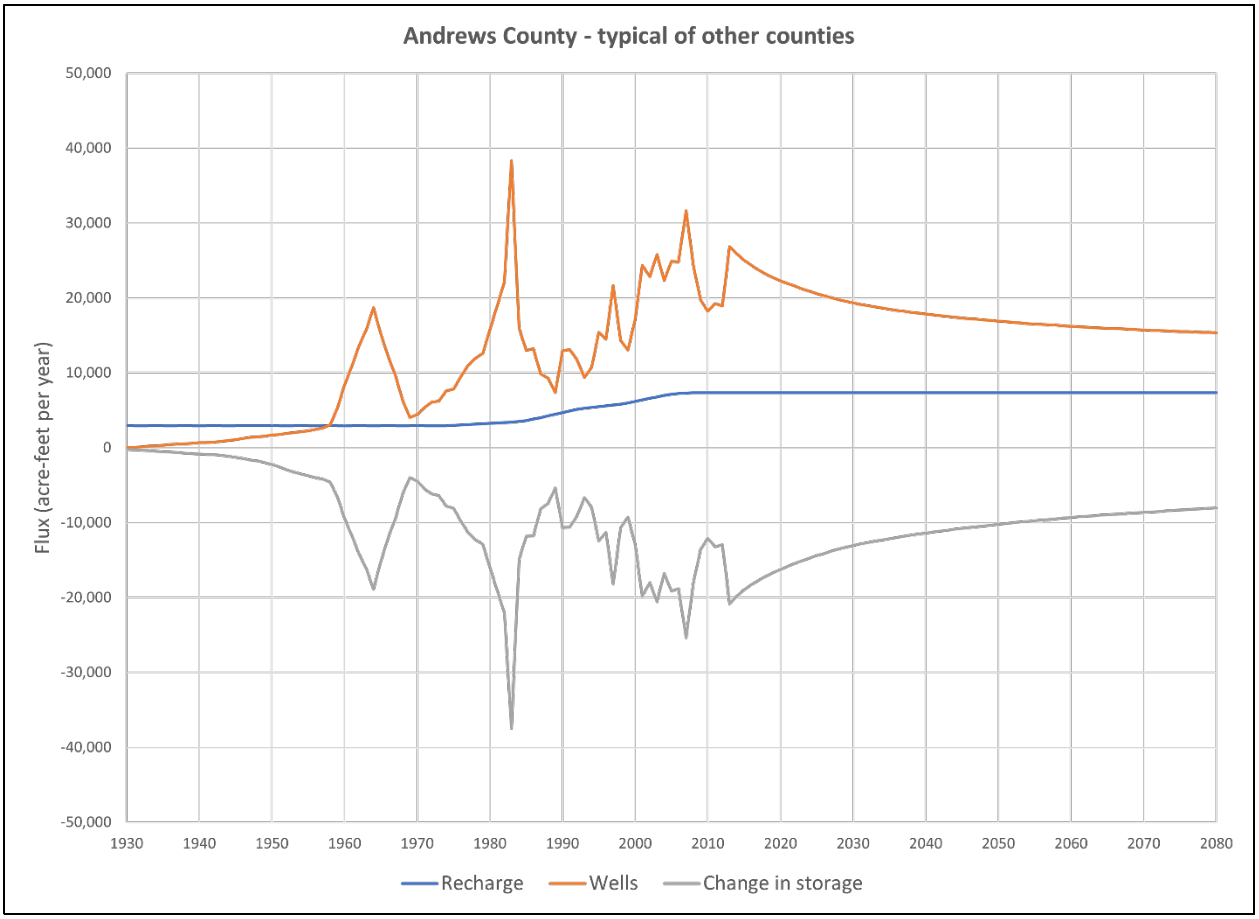

Figure 4-2 Water budget terms for recharge, pumping, and change in storage for the historical and predictive modeling periods in Andrews County in the Original Model and Model Extension. The change in storage begins to level out but never rises above zero.

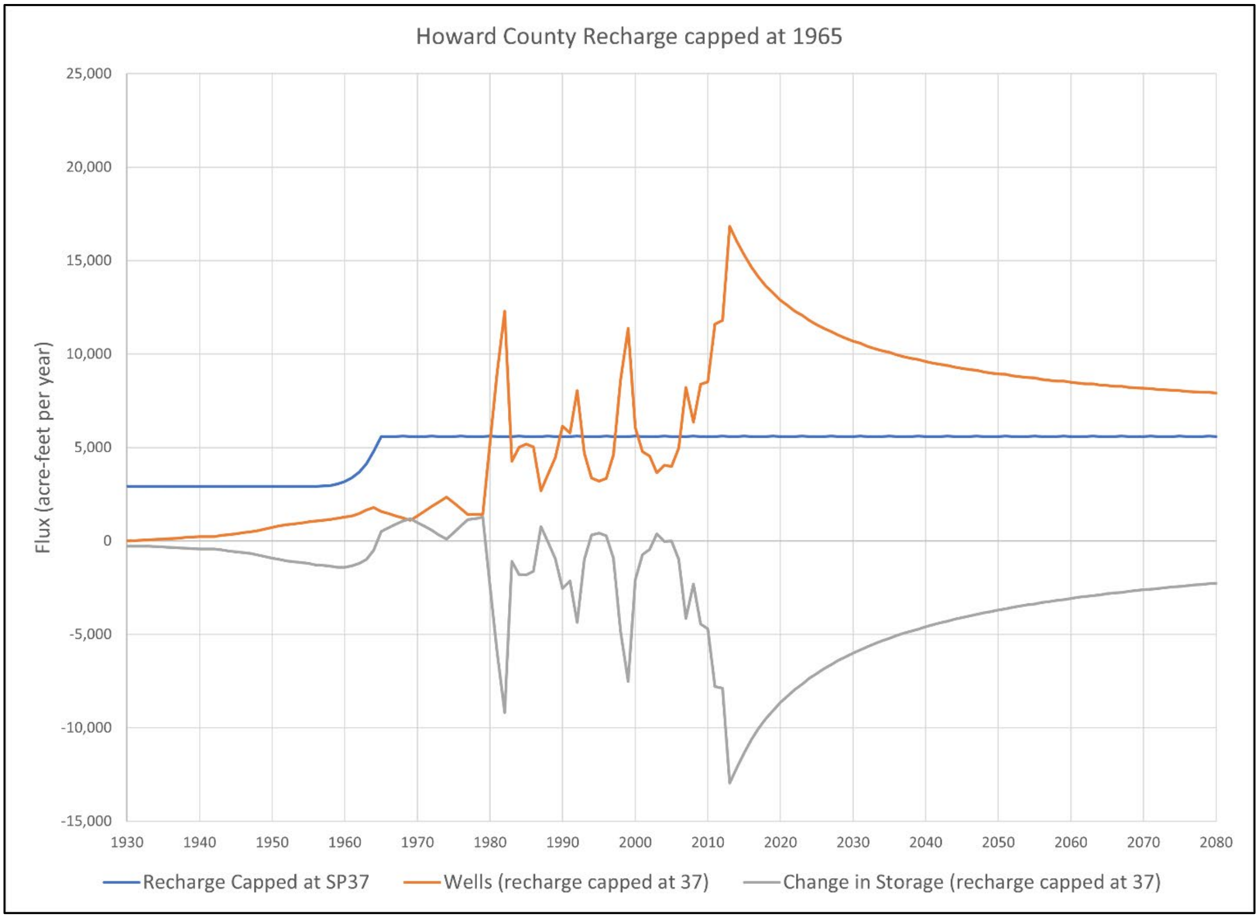

Figure 4-3 **Water budget terms for recharge, pumping, and change in storage for the historical and predictive modeling periods with recharge capped at 1965 rates in Howard County in the Model Extension. Pumping flux and change in storage cross-over only slightly in about 1968 and water levels do not rise at any time during the predictive period.**

5 Model performance and results

A successful Model Extension would have simulated heads (water levels) from 2013 through 2020 that reasonably match field observations at selected target wells. Specifically, the Model Extension error summary statistics for each aquifer should meet the TWDB Groundwater Modeling standards (TWDB, 2023a) and the original goals of the model (Deeds and Jigmond, 2015). Comparison of the Model Extension performance statistics, hydrographs, reduced pumping amounts, and groundwater budgets to the Original Model results show that the Model Extension performs about the same as the calibrated period.

5.1 Head targets

The TWDB Groundwater Modeling standards (TWDB, 2023a) specify the mean absolute error or root mean squared error between observed heads and simulated heads should be less than 10 percent of the range in observed heads across the model area for each model layer. For example, if the range in observed heads for an aquifer is 100 to 200 feet, an acceptable mean absolute error or root mean squared error would be less than 10. Deeds and Jigmond (2015) calculated summary statistics for the Original Model for the pre-development period, 1930 through 1979, and 1980 through 2012 (Table 5-1). The Original Model set additional calibration goals of a mean absolute error of no more than 30 feet for the Ogallala Aquifer and 50 feet for the minor aquifers (Deeds and Jigmond, 2015). For the 1980 through 2012 period these goals were met for each aquifer except the lower Dockum unit (Table 5-1).

The same target wells used for the Original Model were used for the Model Extension if there was at least one head measurement from 2013 through 2020. Heads from 2013 through 2020 were downloaded from the TWDB Groundwater Database (TWDB, 2023d) and the U.S. Geological Survey National Water Information System (2023) and prepared for statistical analysis. To prevent bias, the mean annual head was calculated for wells with multiple head measurements in a single year. TWDB Groundwater Database measurements that had measurement status codes of N (Non-Publishable), Q (Questionable), or X (No Measurement) and U.S. Geological Survey National Water Information System measurements with water qualifier codes of AD (Dry), AP (Pumping), AO (Obstructed), P3 (True value is above reported value), or PP (Pumping) were removed from the dataset. Only measurements from October through April were used to minimize the seasonal effects of pumping during the growing season.

The Original Model used the PEST: Model-Independent Parameter Estimation executable MOD2OBS (Watermark Numerical Computing, 2024) to interpolate model-simulated heads to the same times and locations as target well observations. This same MOD2OBS executable was applied to the Model Extension 2013 through 2020 target well dataset and residual error was calculated.

Residual error is the difference between a target's observed and simulated values. A negative residual indicates the simulated head is above the observed value and a positive value indicates the simulated head is below the observed head. The residuals were used to calculate the mean error and mean absolute error for each of the aquifers (Table 5-2). The Model Extension's 2013 through 2020 mean absolute error for the Ogallala Aquifer, Edwards-Trinity (High Plains) Aquifer, and lower Dockum unit slightly improved when compared to 1980 through 2012. The mean absolute error for the upper Dockum unit slightly increased and the mean absolute error for the Rita Blanca Aquifer increased significantly. All aquifers meet the TWDB Groundwater Modeling standards since the mean absolute error divided by the range in heads is less than 10 percent (Table 5-2).

The observed heads versus the simulated heads are generally plotted along a line with a slope of one for all aquifers (Figures 5-1 through 5-4). Residuals for each target well were averaged for all observations from 2013 through 2020 and plotted on a map to evaluate any spatial bias (Figures 5-5 through 5-9). Points with cool colors indicate negative residuals less than -30 feet and warmer colors indicate positive residuals greater than 30 feet. Points with no color indicate a residual between -30 and 30 feet.

Hydrographs were developed for all target wells plotting observed versus simulated heads. Some of these hydrographs are presented in this section (Figures 5-10 through 5-24) and the rest are presented in Appendix F. The selected hydrograph figures include a map of simulated drawdown from 2012 through 2020 to assist with interpretation of the head trends. Some model cells show acceptable agreement with observed water levels while others appear to diverge or have no correlation. Simulated heads and observed heads often differ by several feet since the model is a coarse representation of reality (cell size of 1/2 mile by 1/2 mile).

5.2 Simulated heads

The overall trend in 2020 simulated heads for all aquifers is one of a west to east gradient, generally following regional topographic trends (Figures 5-25 through 5-29). The Ogallala Aquifer and minor aquifer 2020 head contours show some localized effects of drawdown including some areas of bent or closed contours. The Edwards-Trinity (High Plains) Aquifer shows the least effects of drawdown (Figure 5-27). The 2020 saturated thickness map for the Ogallala Aquifer shows a majority of the aquifer with a saturated thickness below 100 feet and a large area of higher saturated thickness in the northeast (Figure 5-30).

Table 5-1 Original Model calibration statistics for 1980 through 2012 target wells (From Deeds and Jigmond, 2015).

Aquifer	Mean error (feet)	Mean absolute error (feet)	Range (feet)	Mean absolute error/range (percent)	Number of head measurements
Ogallala	1.5	28.4	3,529	0.8	91,805
Rita Blanca	-24.0	42.6	2,841	1.5	1,078
Edwards-Trinity (High Plains)	-19.4	29.7	1,327	2.2	1,945
Upper Dockum	-27.4	33.2	2,125	1.6	671
Lower Dockum	-15.6	53.3	3,465	1.5	4,744

Table 5-2 Model Extension performance statistics for 2013 through 2020 target wells.

Aquifer	Mean error (feet)	Mean absolute error (feet)	Range (feet)	Mean absolute error/range (percent)	Number of head measurements
Ogallala	5.5	26.6	3,065	0.9	12,824
Rita Blanca	-30.3	59.2	2,744	2.2	130
Edwards-Trinity (High Plains)	-20.7	27.2	1,085	2.5	159
Upper Dockum	-14.0	34.4	1,745	2.0	159
Lower Dockum	-16.3	45.9	3,056	1.5	960

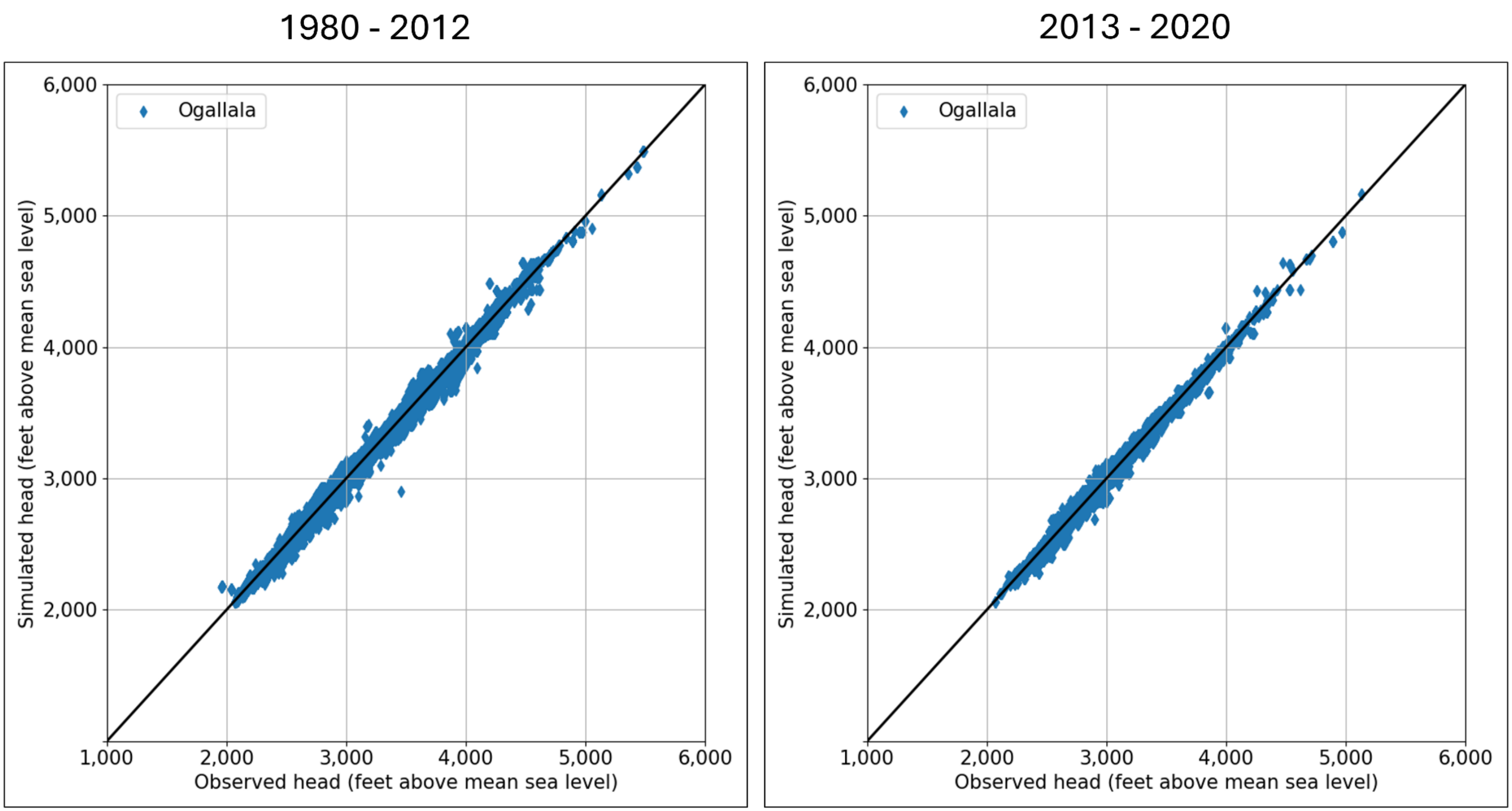

Figure 5-1 Observed versus simulated heads for the Ogallala Aquifer. Points above the line indicate that the simulated head is above the observed head and points below the line indicate simulated head is below the observed head.

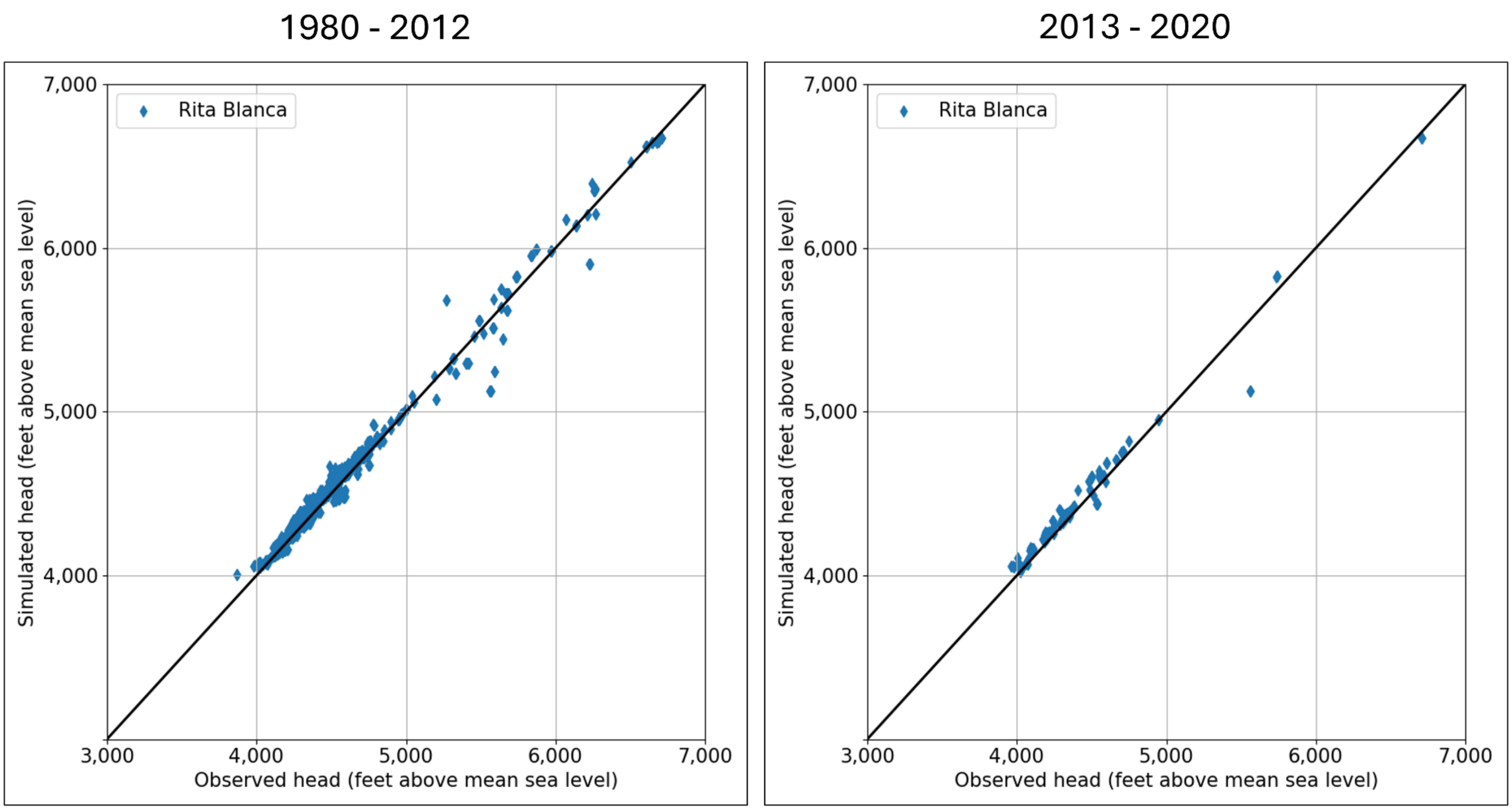

Figure 5-2 Observed versus simulated heads for the Rita Blanca Aquifer. Points above the line indicate that the simulated head is above the observed head and points below the line indicate simulated head is below the observed head.

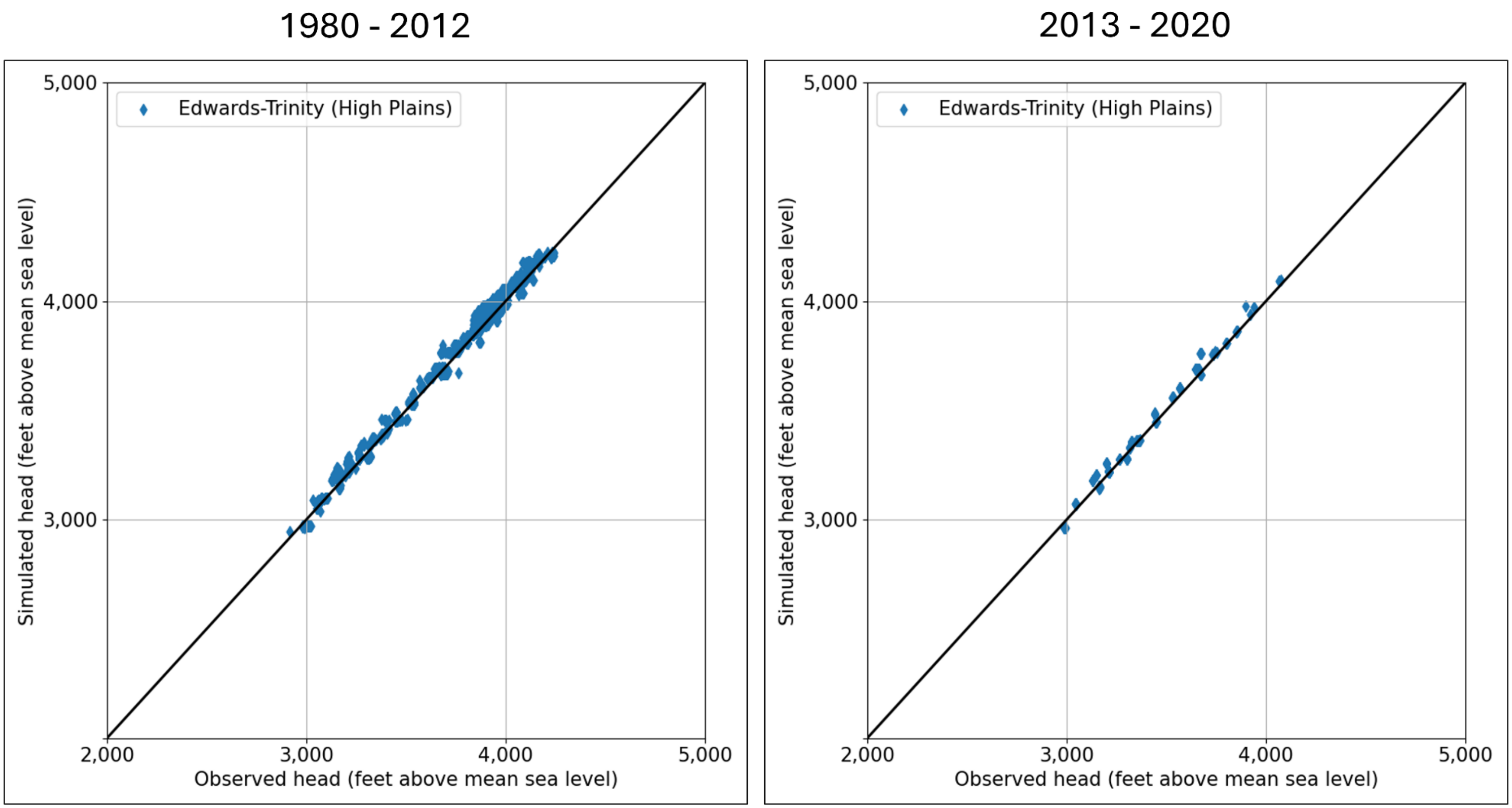

Figure 5-3 Observed versus simulated heads for the Edwards-Trinity (High Plains) Aquifer. Points above the line indicate that the simulated head is above the observed head and points below the line indicate simulated head is below the observed head.

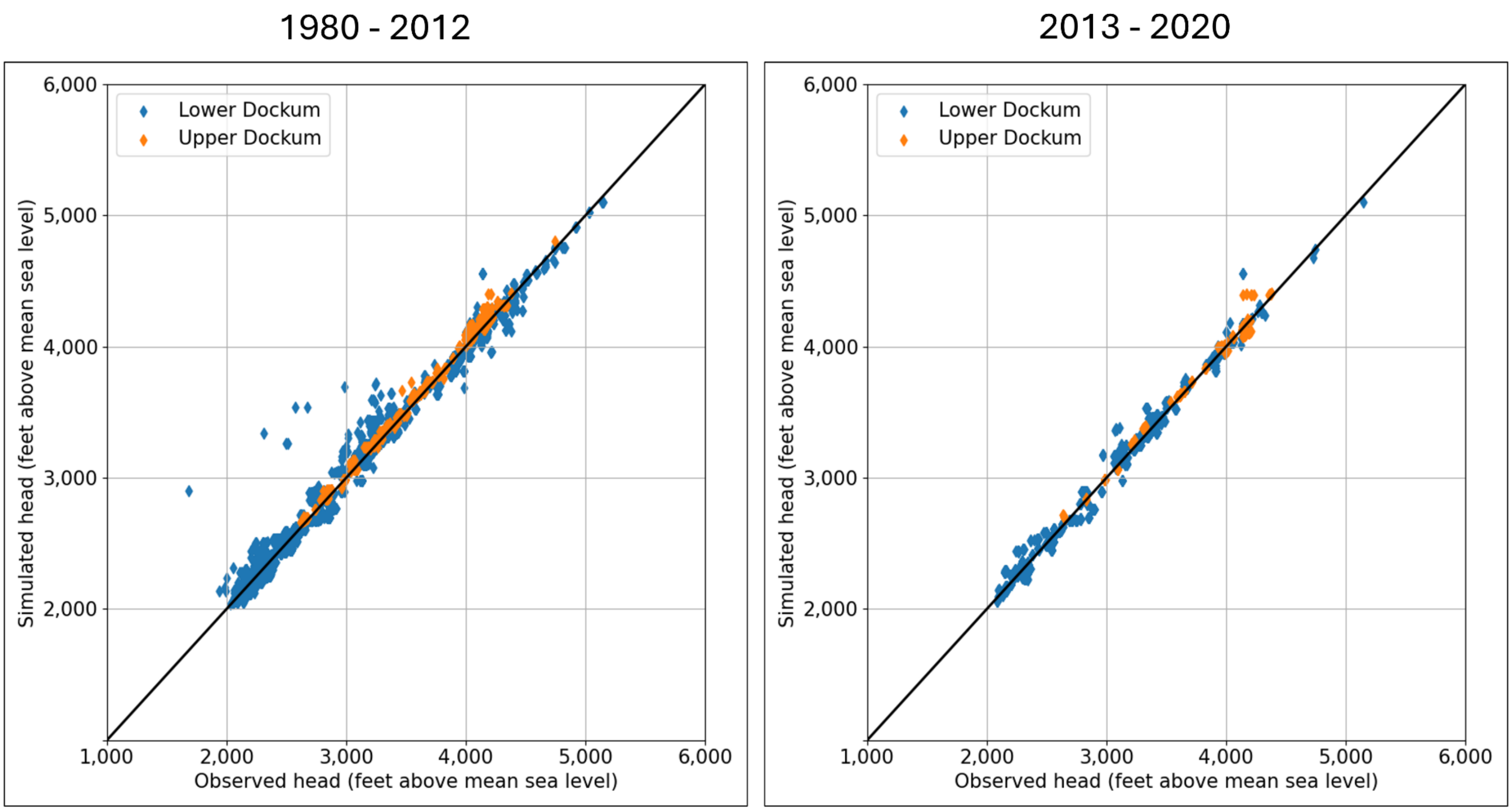

Figure 5-4 Observed versus simulated heads for the Dockum units. Points above the line indicate that the simulated head is above the observed head and points below the line indicate simulated head is below the observed head.

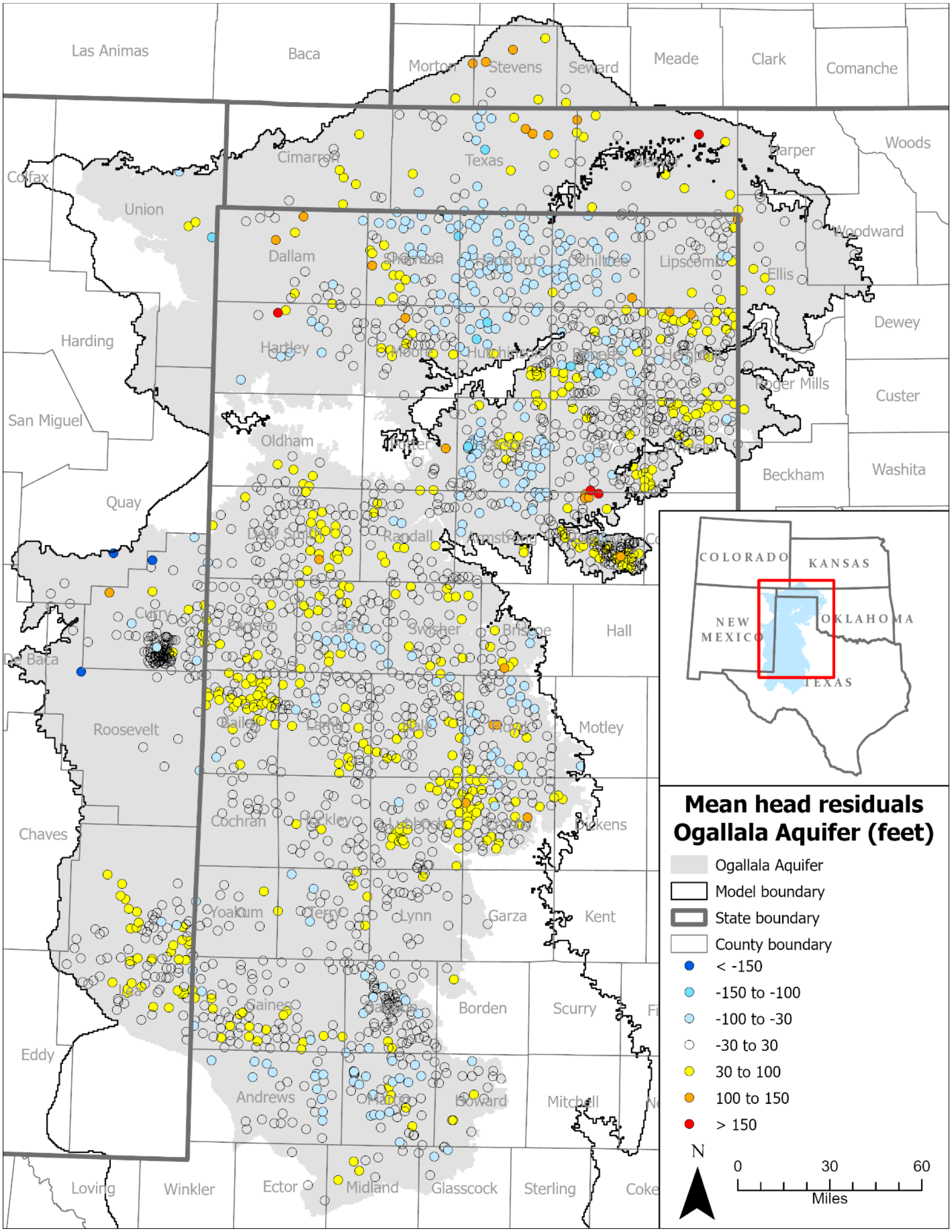

Figure 5-5 Mean head residual distribution between 2013 and 2020 for the Ogallala Aquifer.

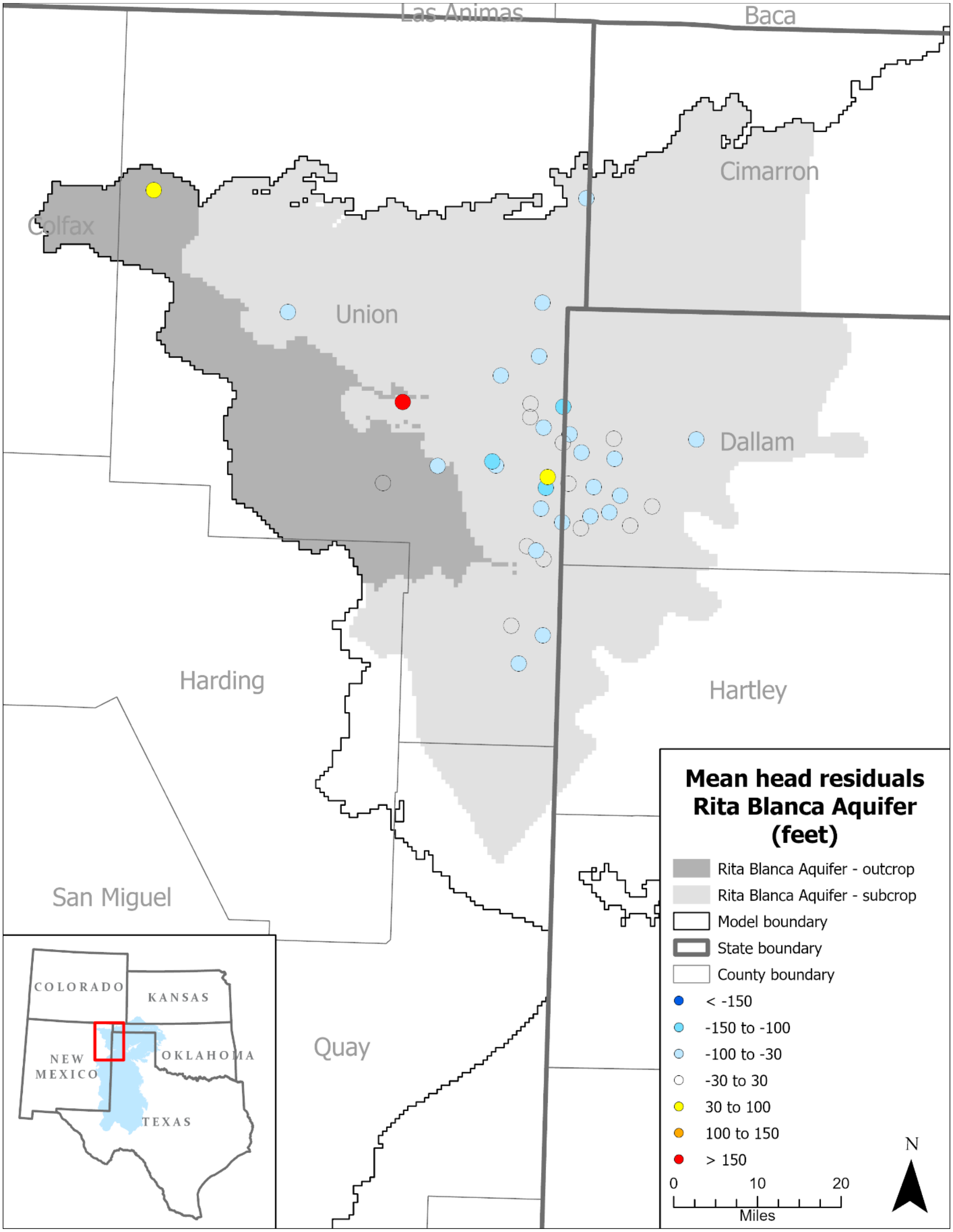

Figure 5-6 Mean head residual distribution between 2013 and 2020 for the Rita Blanca Aquifer.

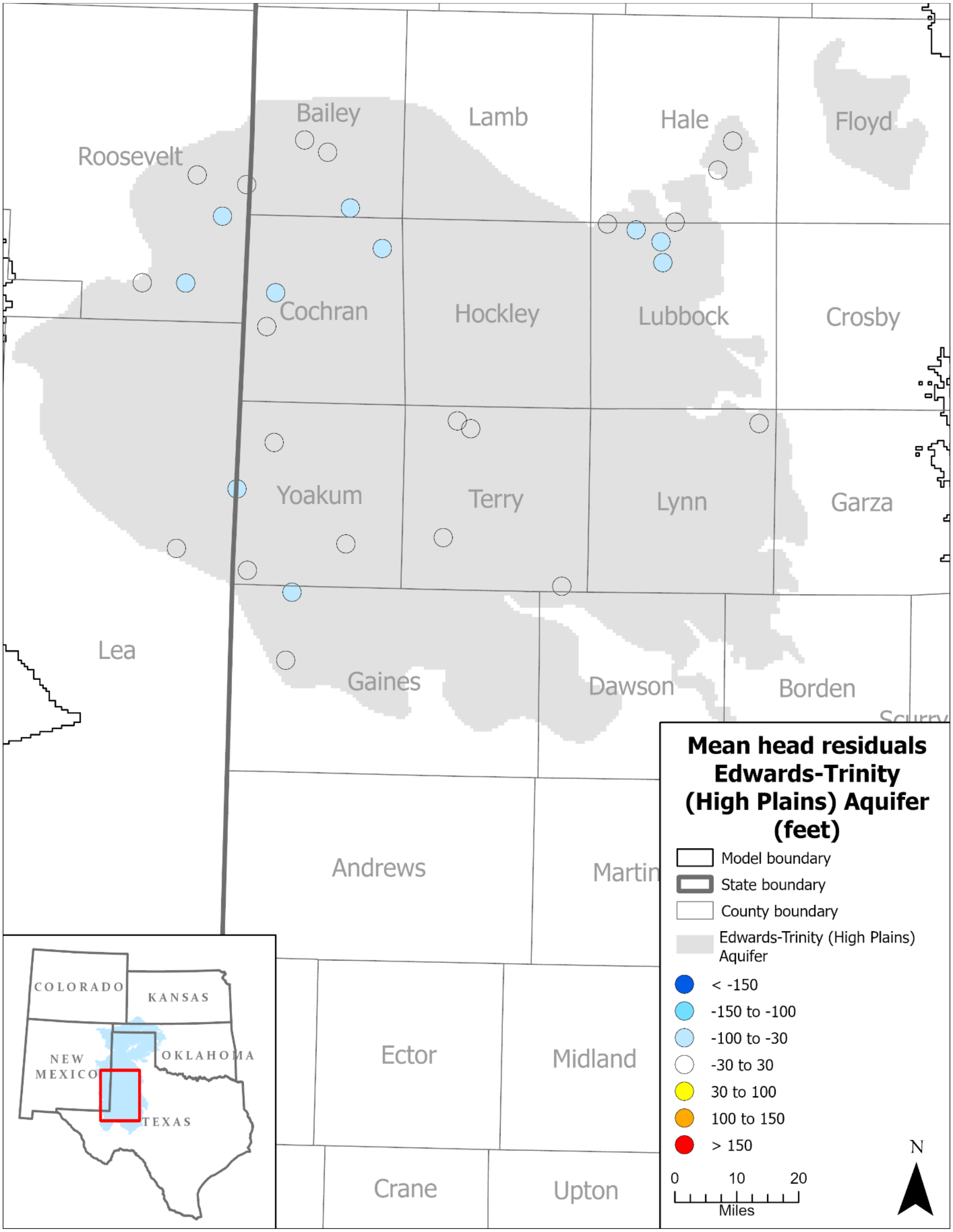

Figure 5-7 **Mean head residual distribution between 2013 and 2020 Edwards-Trinity (High Plains) Aquifer.**

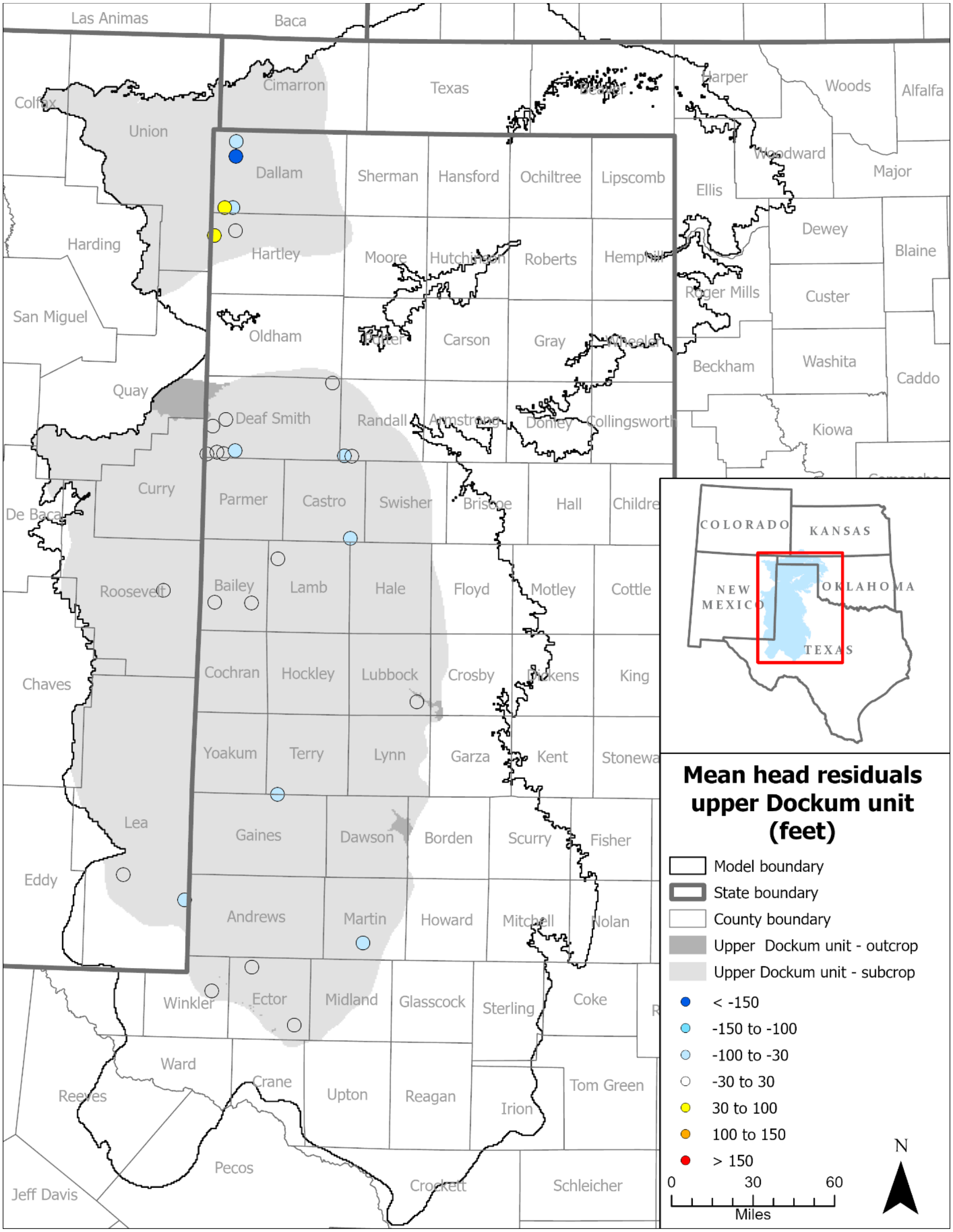

Figure 5-8 Mean head residual distribution between 2013 and 2020 for the upper Dockum unit.

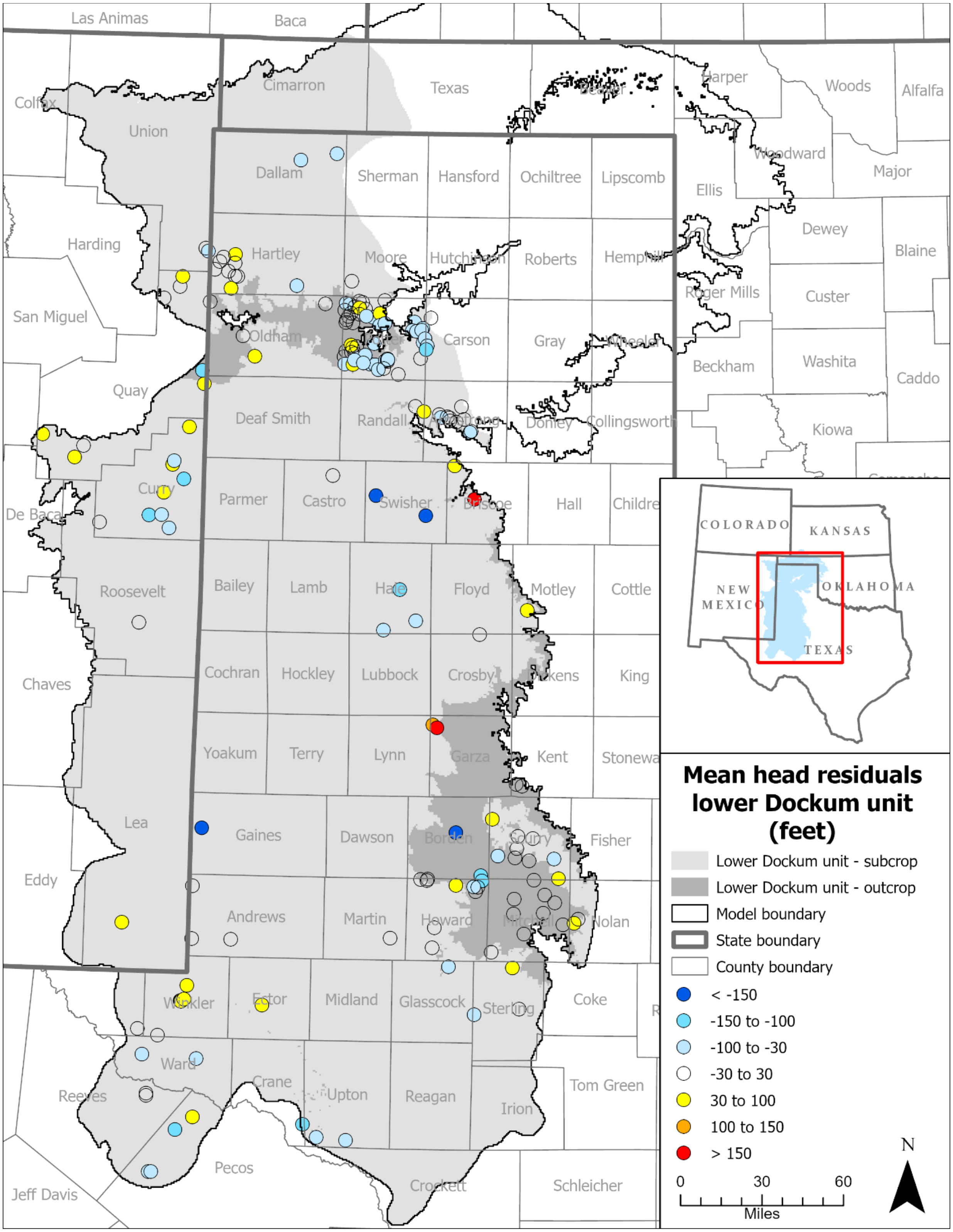

Figure 5-9 Mean head residual distribution between 2013 and 2020 for the lower Dockum unit.

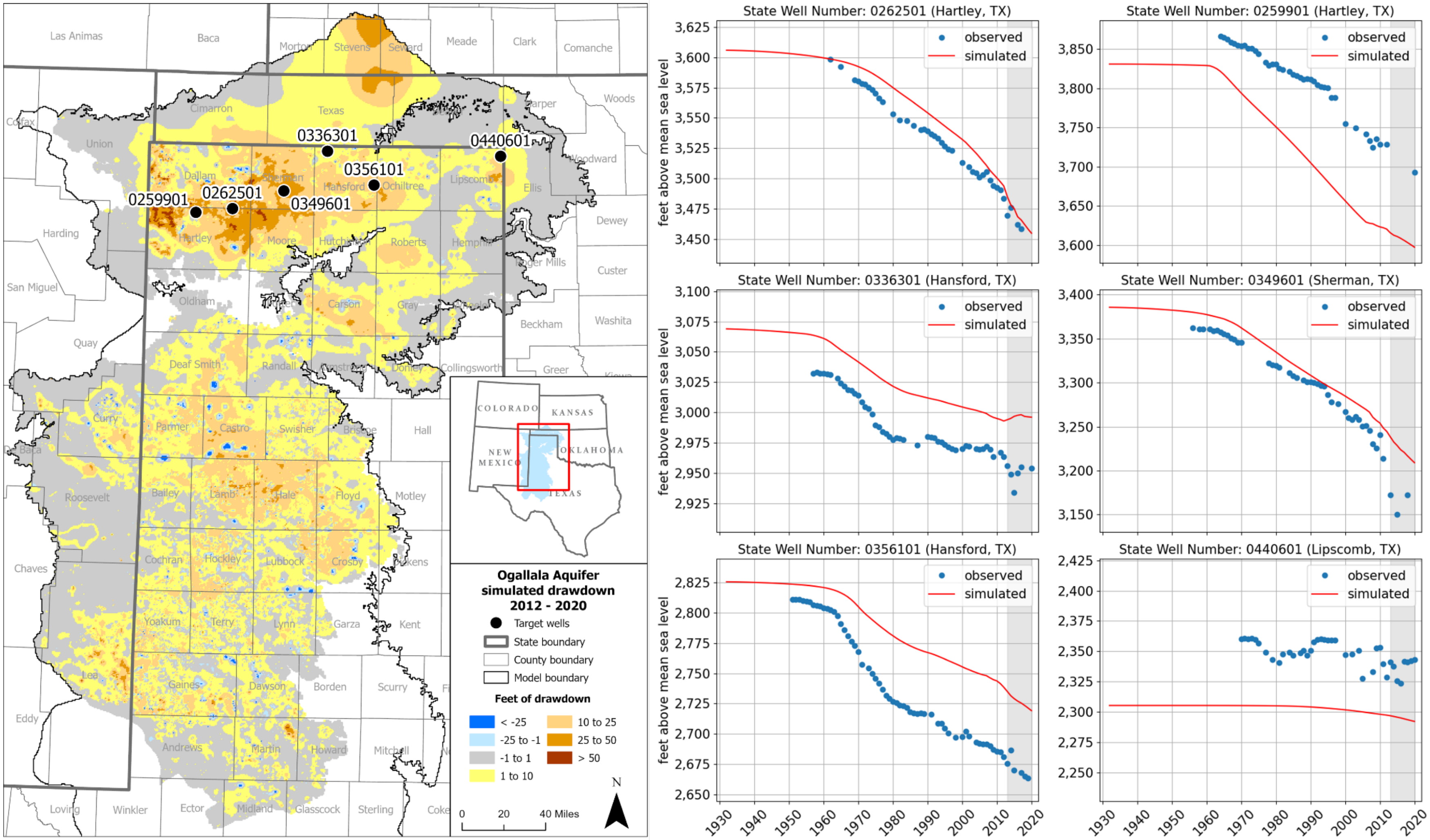

Figure 5-10 Ogallala Aquifer hydrographs in Hartley, Hansford, Sherman, and Lipscomb counties.

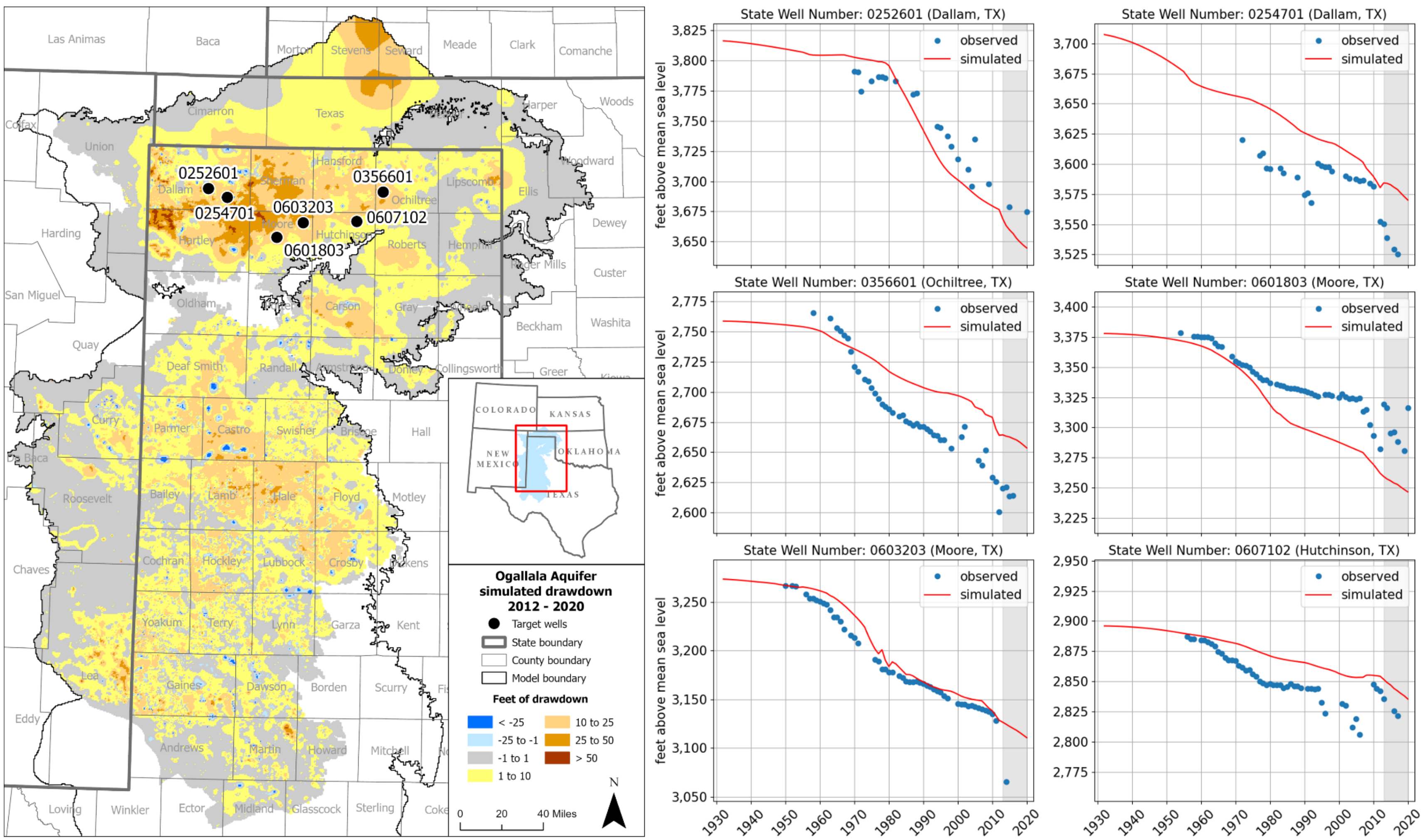

Figure 5-11 Ogallala Aquifer hydrographs in Dallam, Ochiltree, Moore, and Hutchinson counties.

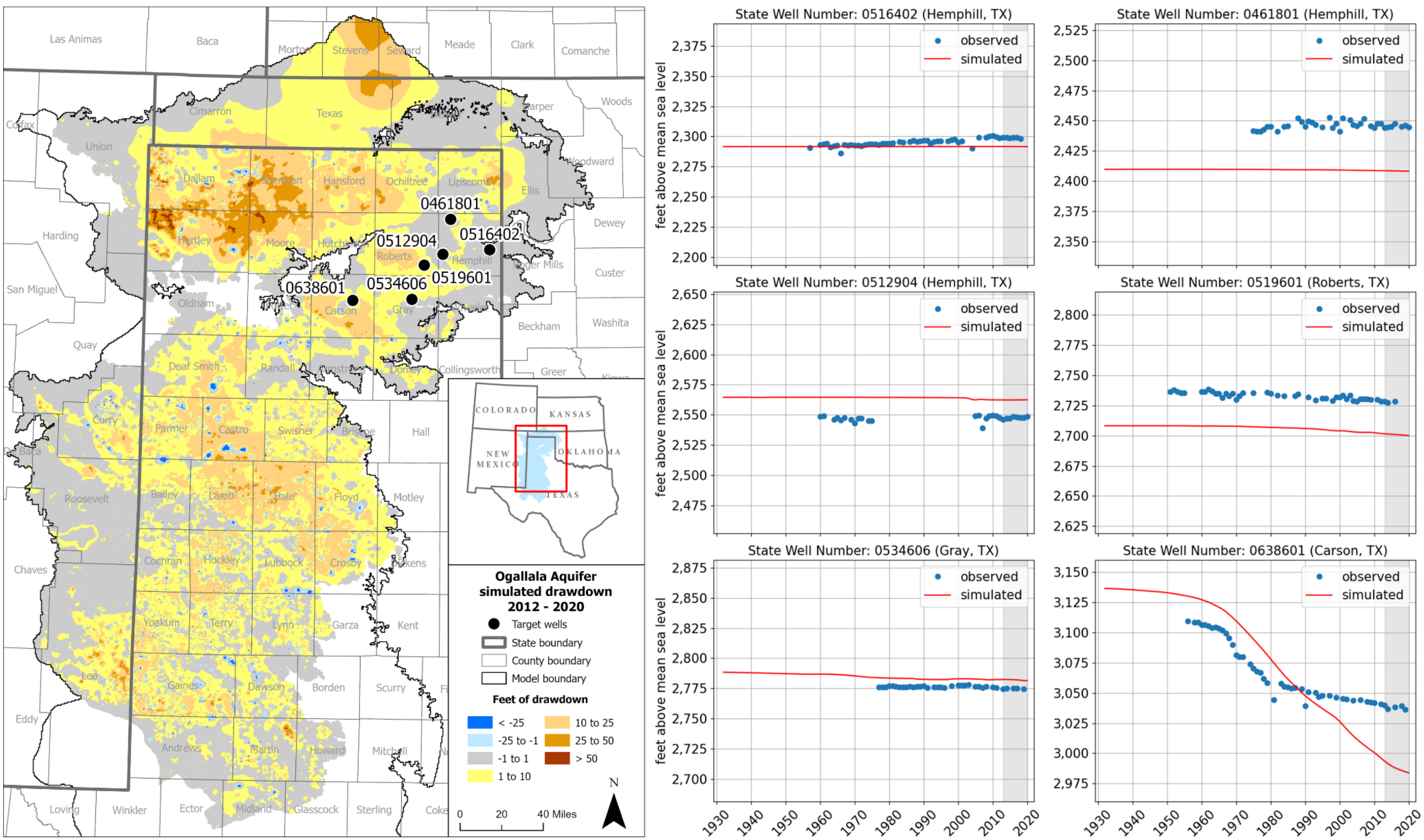

Figure 5-12 Ogallala Aquifer hydrographs in Hemphill, Roberts, Gray, and Carson counties.

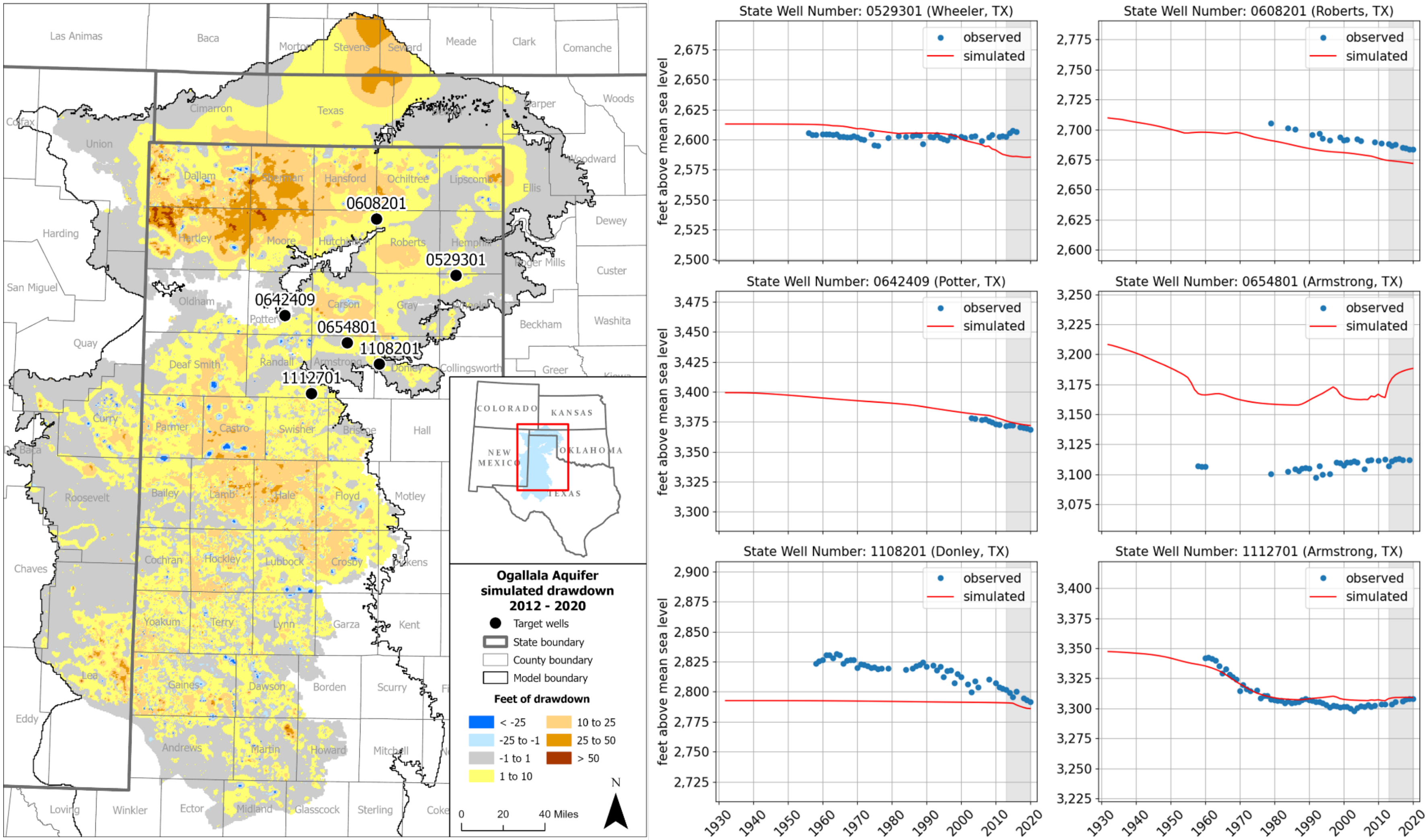

Figure 5-13 Ogallala Aquifer hydrographs in Wheeler, Roberts, Potter, Armstrong, and Donley counties.

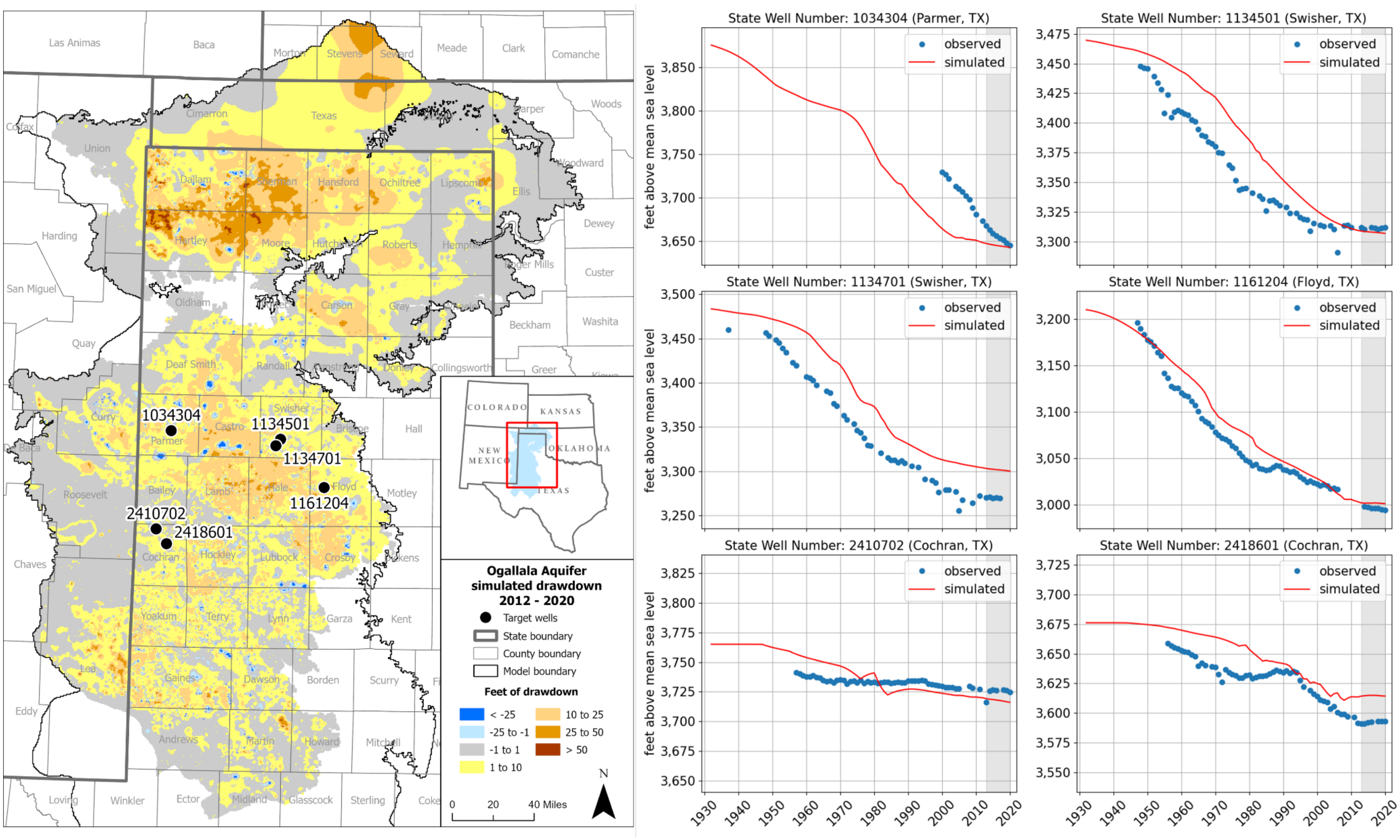

Figure 5-14 Ogallala Aquifer hydrographs in Parmer, Swisher, Floyd, and Cochran counties.

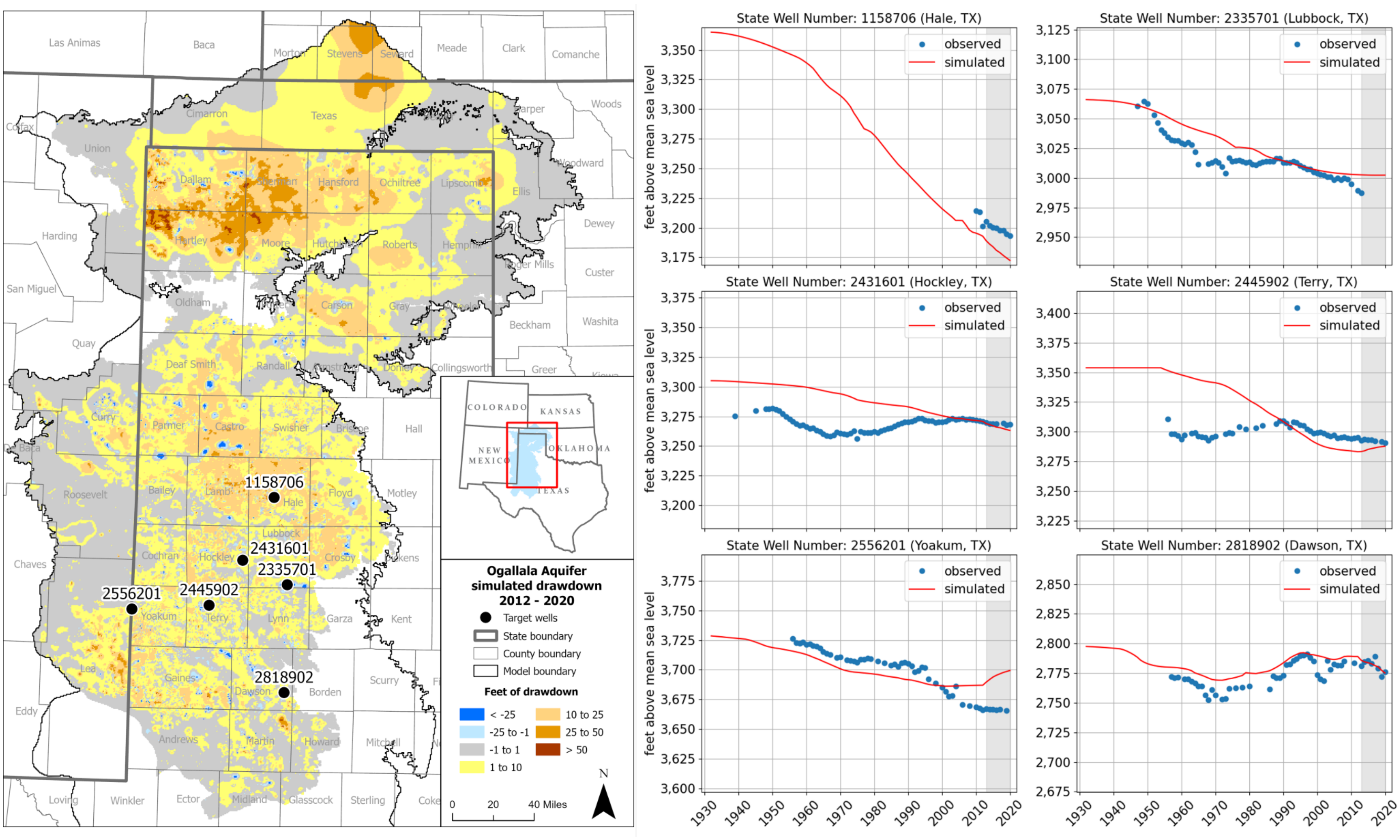

Figure 5-15 Ogallala Aquifer hydrographs in Hale, Lubbock, Hockley, Terry, Yoakum, and Dawson counties.

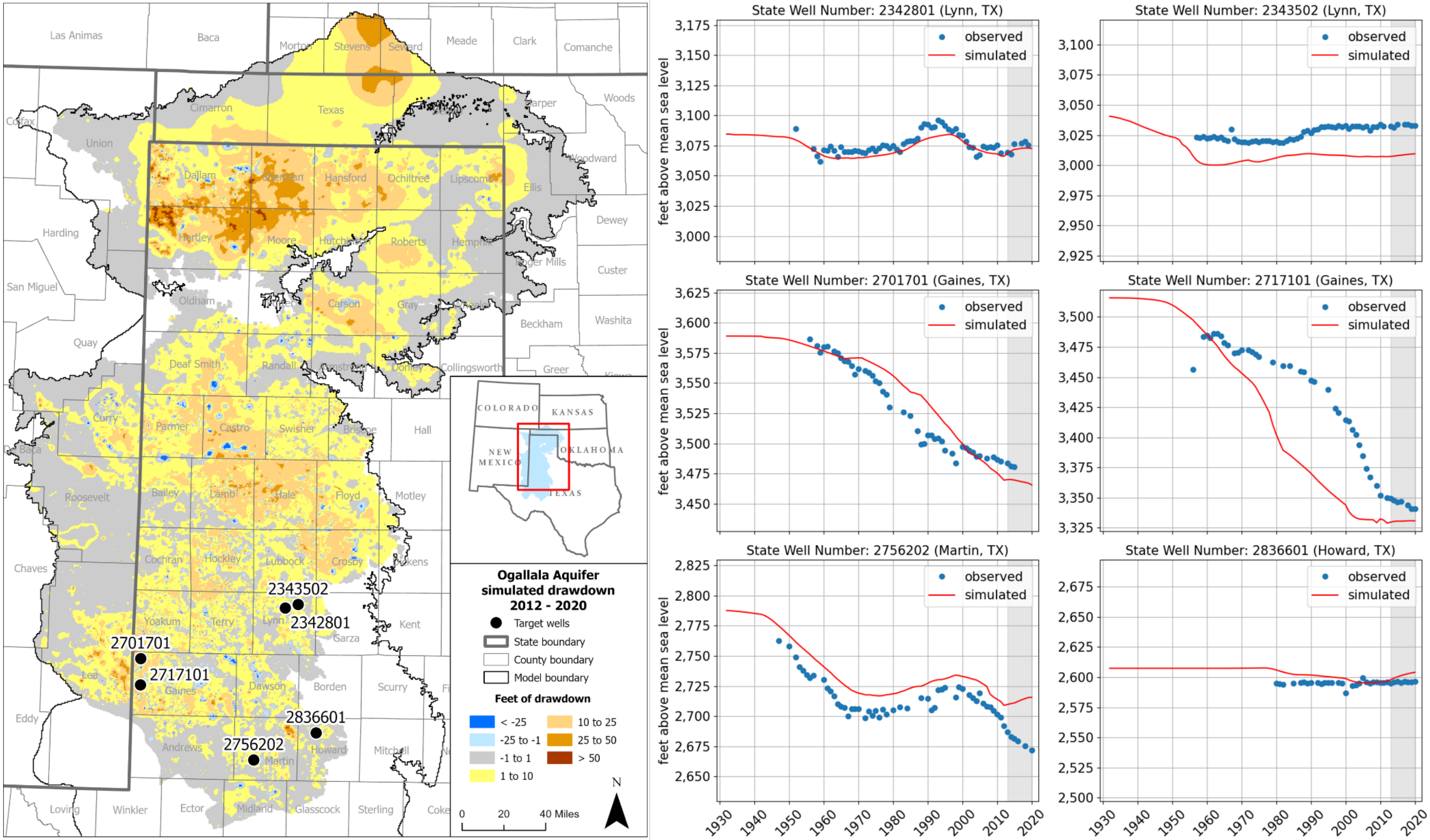

Figure 5-16 Ogallala Aquifer hydrographs in Lynn, Gaines, Martin, and Howard counties.

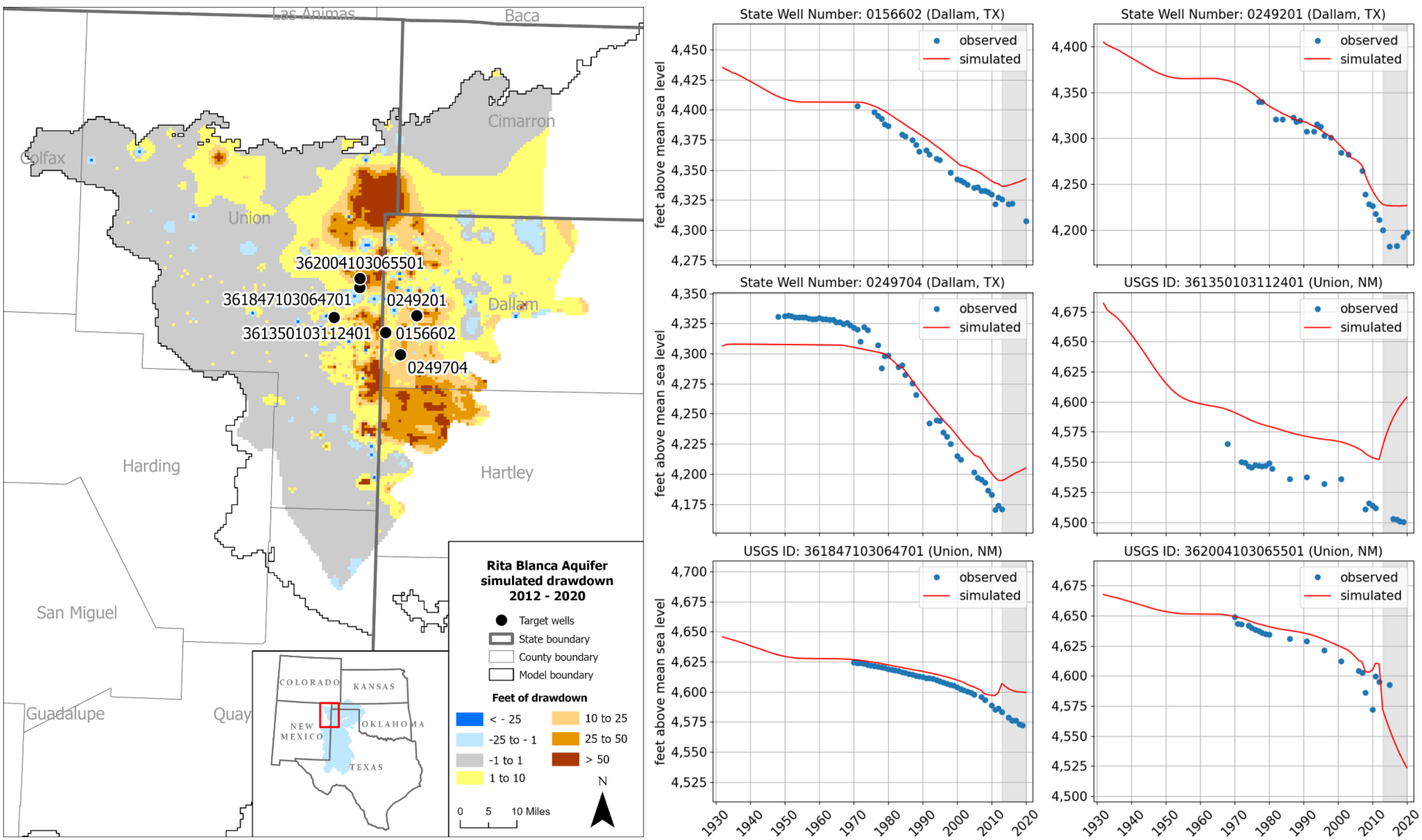

Figure 5-17 Rita Blanca Aquifer hydrographs in Dallam County, Texas and Union County, New Mexico.

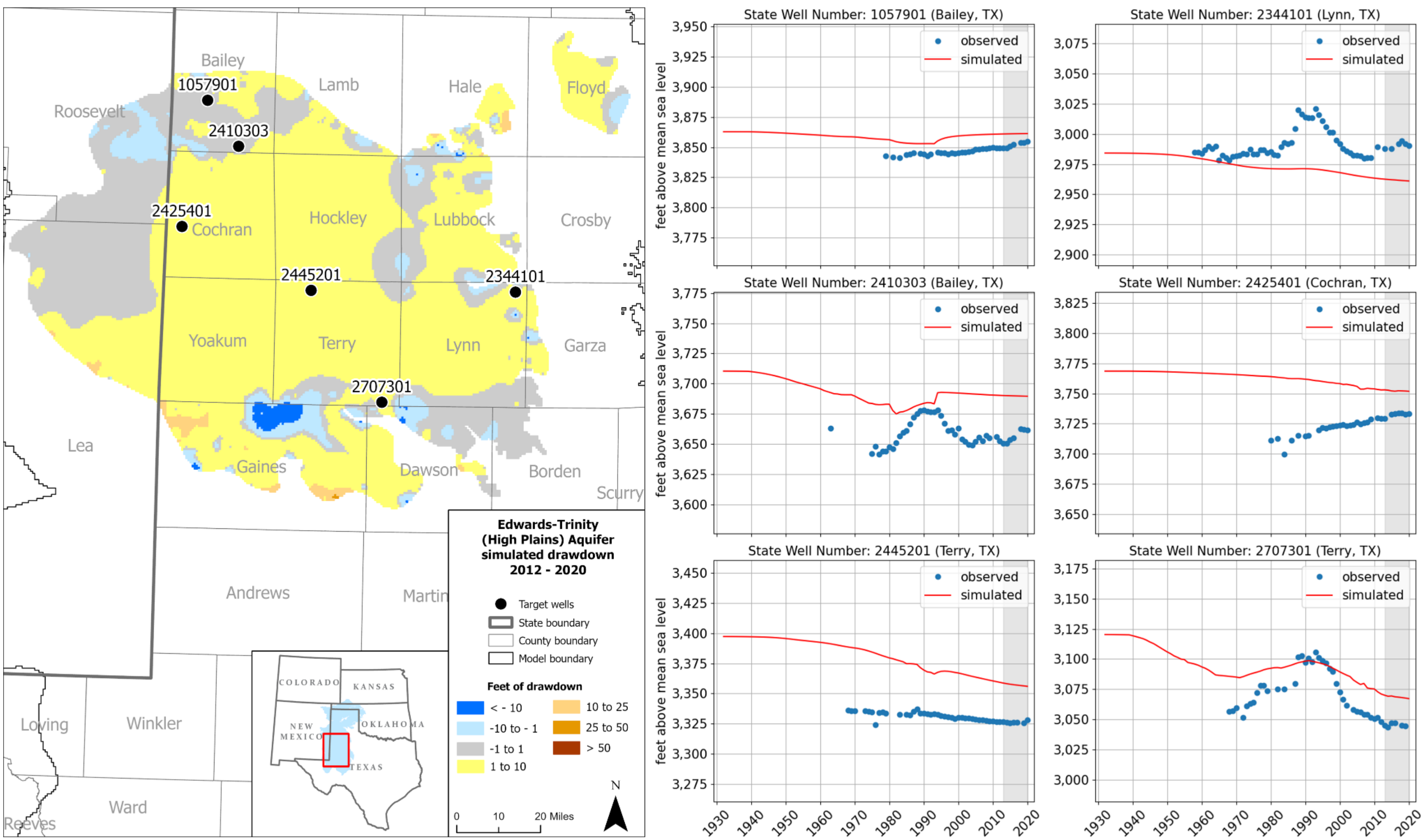

Figure 5-18 Edwards-Trinity (High Plains) Aquifer hydrographs in Bailey, Lynn, Cochran, and Terry counties.

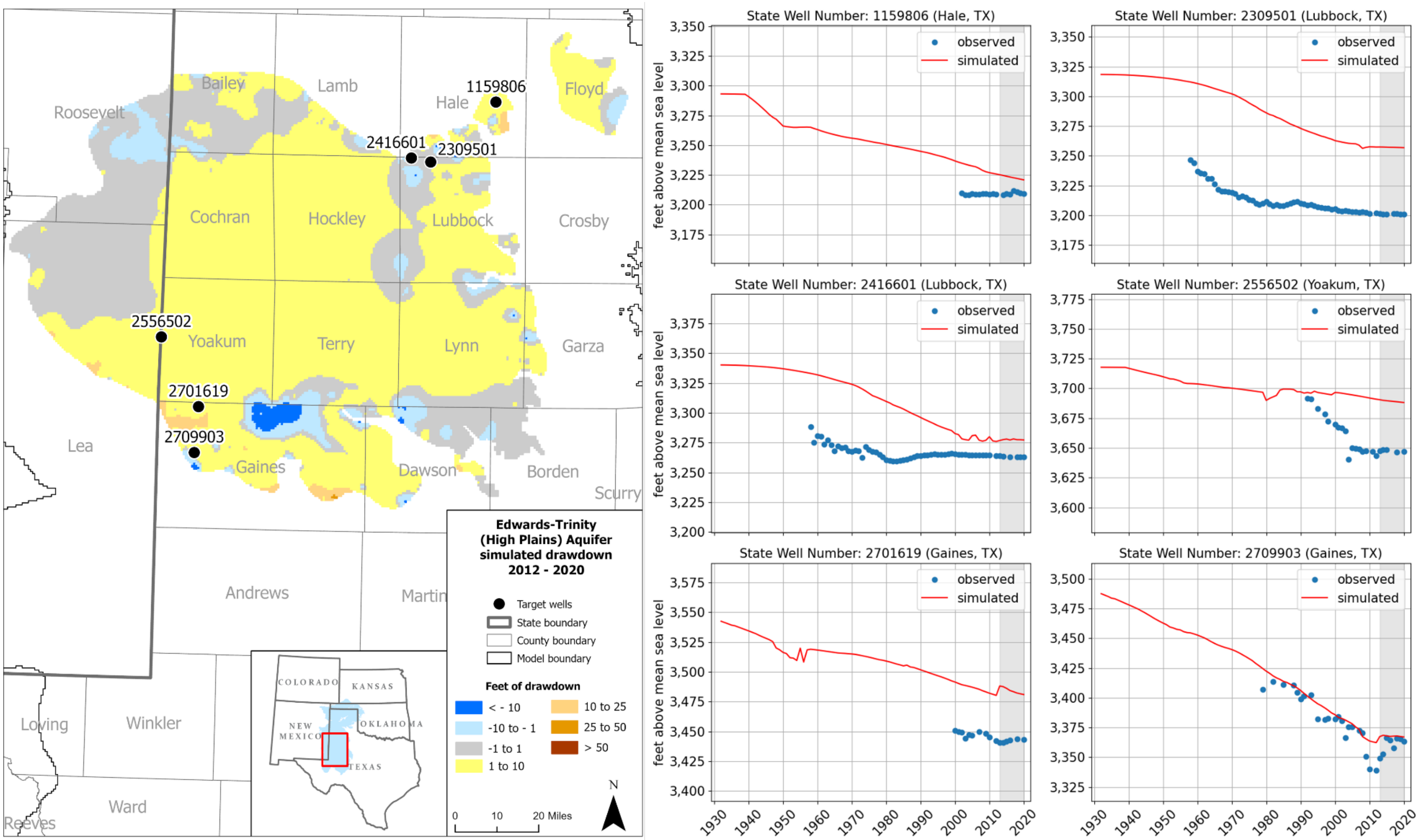

Figure 5-19 Edwards-Trinity (High Plains) Aquifer hydrographs in Hale, Lubbock, Yoakum, and Gaines counties.

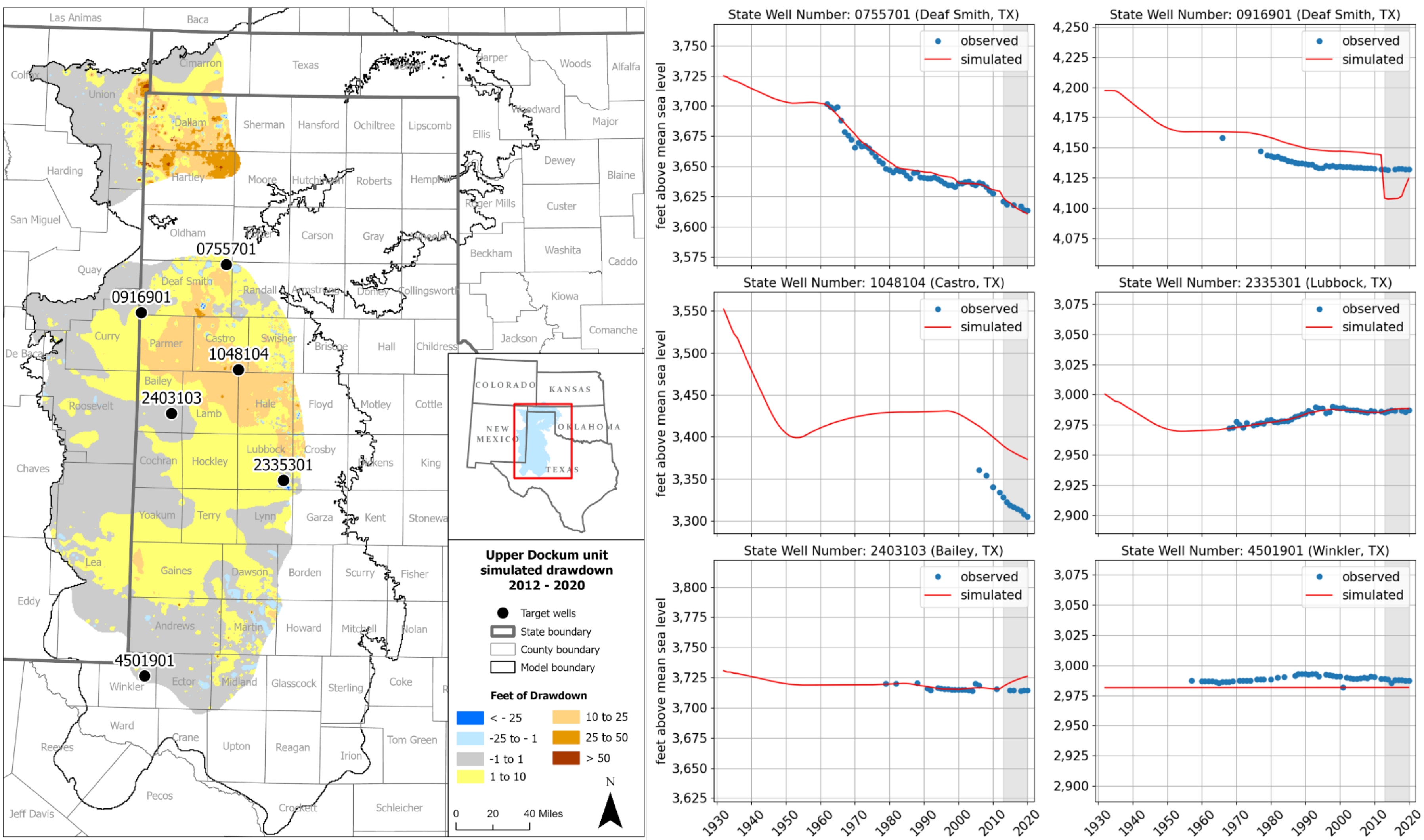

Figure 5-20 Upper Dockum unit hydrographs in Deaf Smith, Castro, Lubbock, Bailey, and Winkler counties.

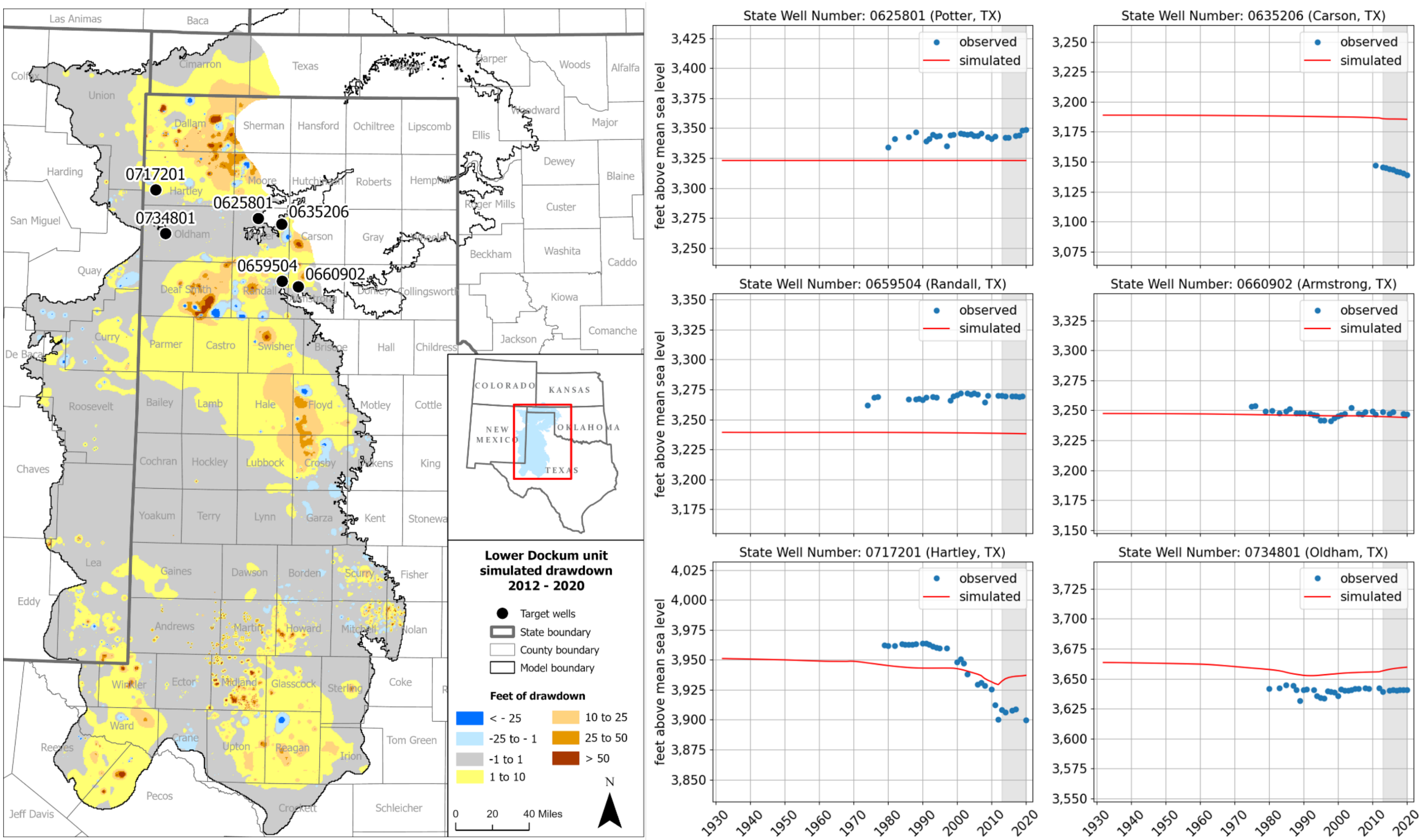

Figure 5-21 Lower Dockum unit hydrographs in Potter, Carson, Randall, Armstrong, Hartley, and Oldham counties.

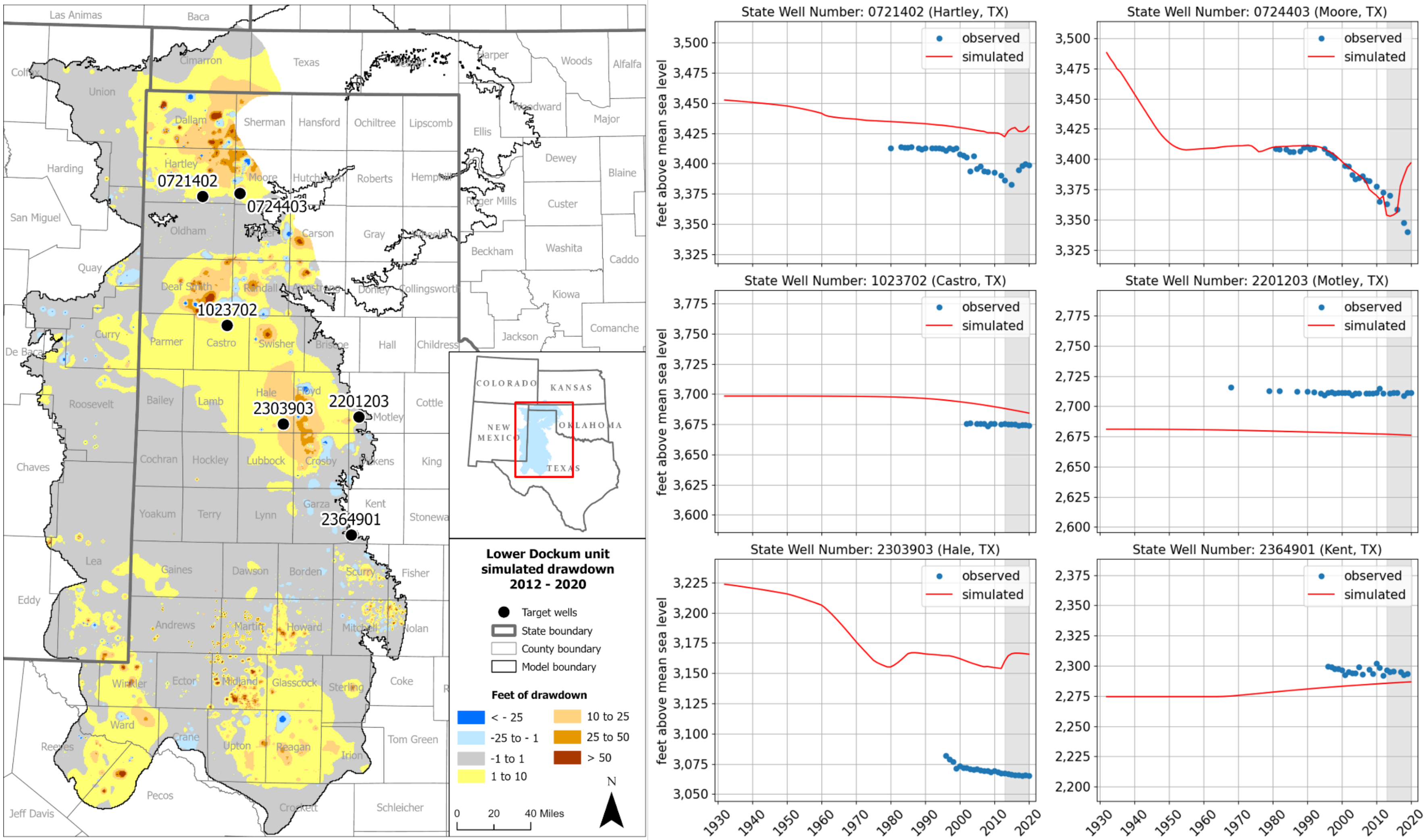

Figure 5-22 Lower Dockum unit hydrographs in Hartley, Moore, Castro, Motley, Hale, and Kent counties.

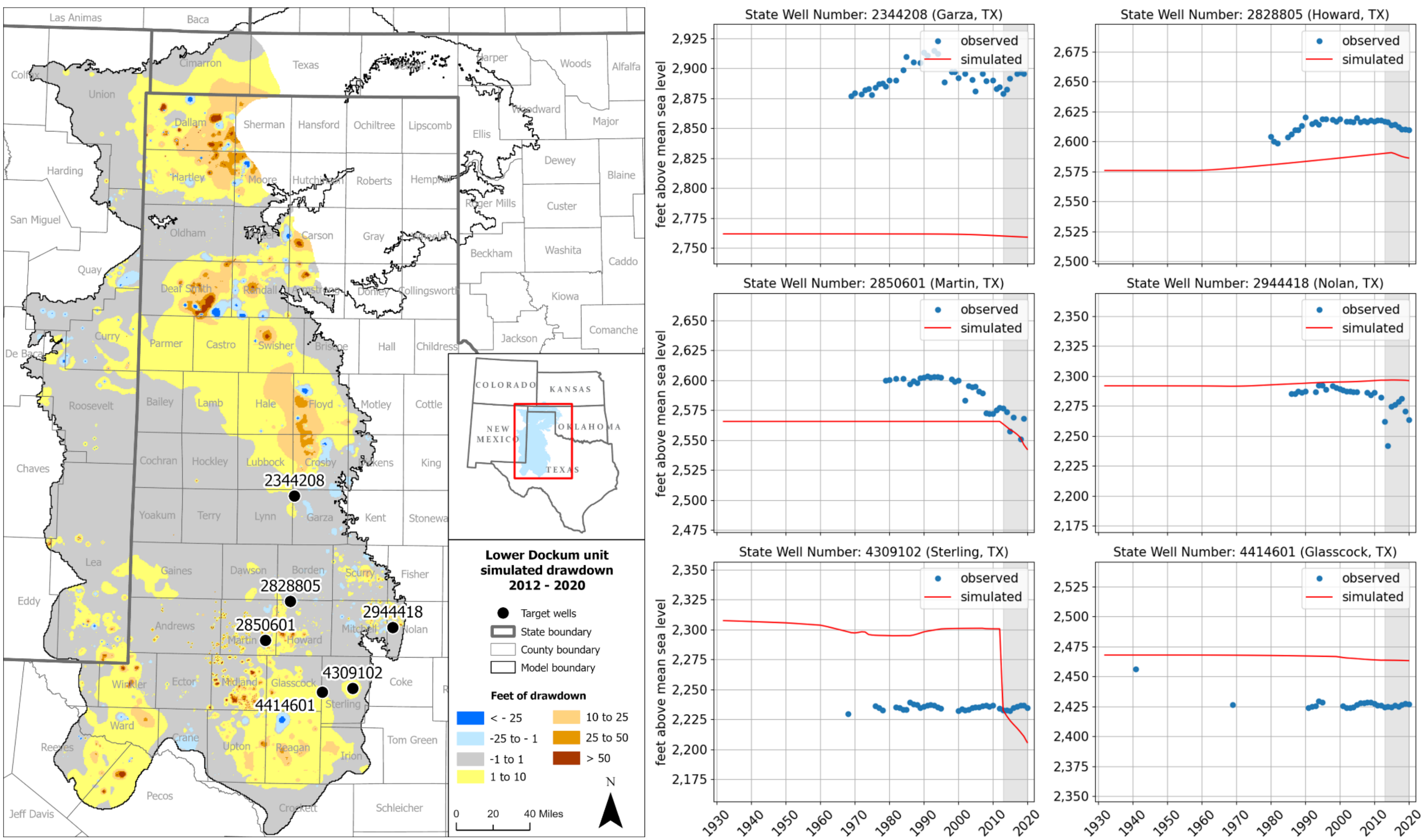

Figure 5-23 Lower Dockum unit hydrographs in Garza, Howard, Martin, Nolan, Sterling, and Glasscock counties.

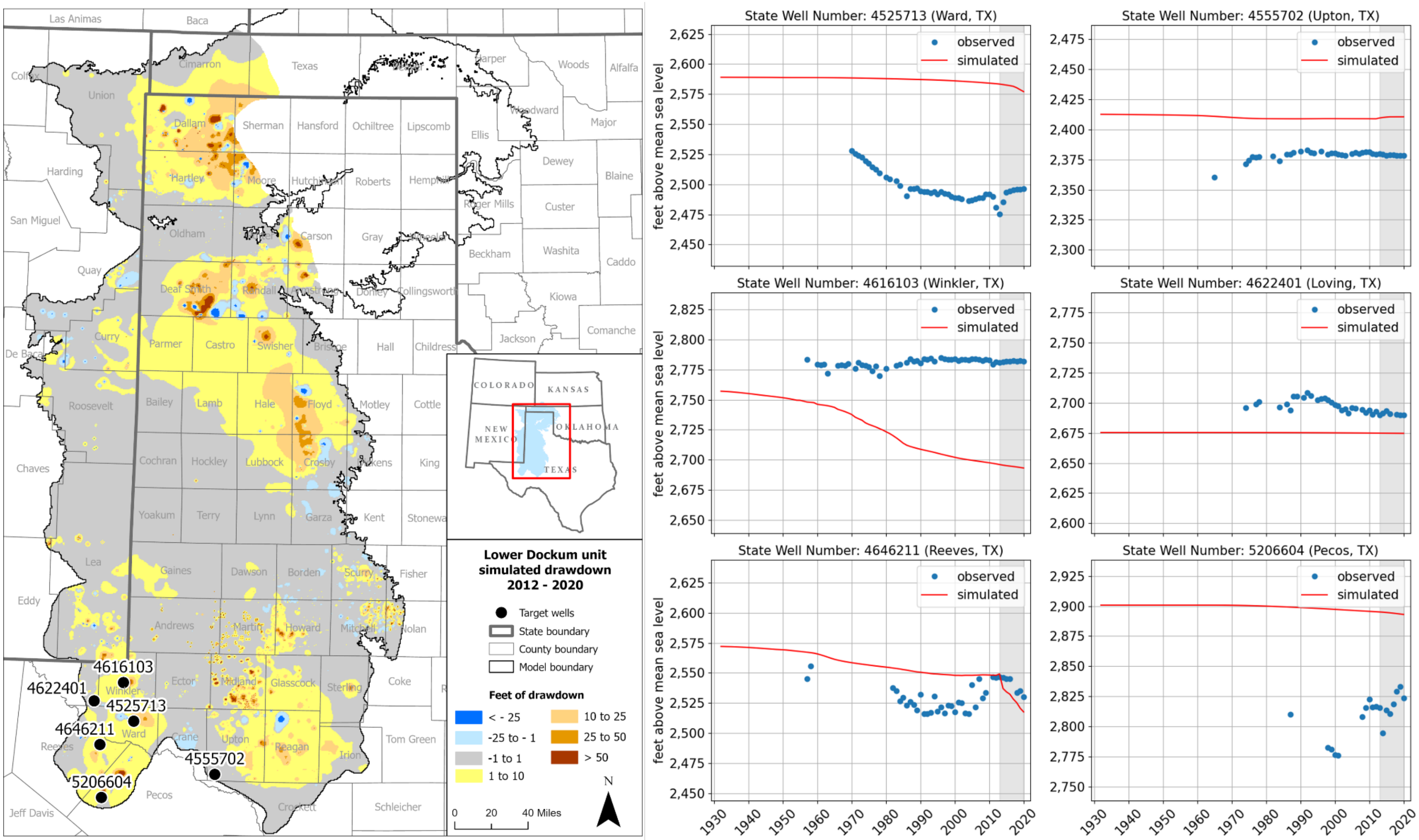

Figure 5-24 Lower Dockum unit hydrographs in Ward, Upton, Winkler, Loving, Reeves, and Pecos counties.

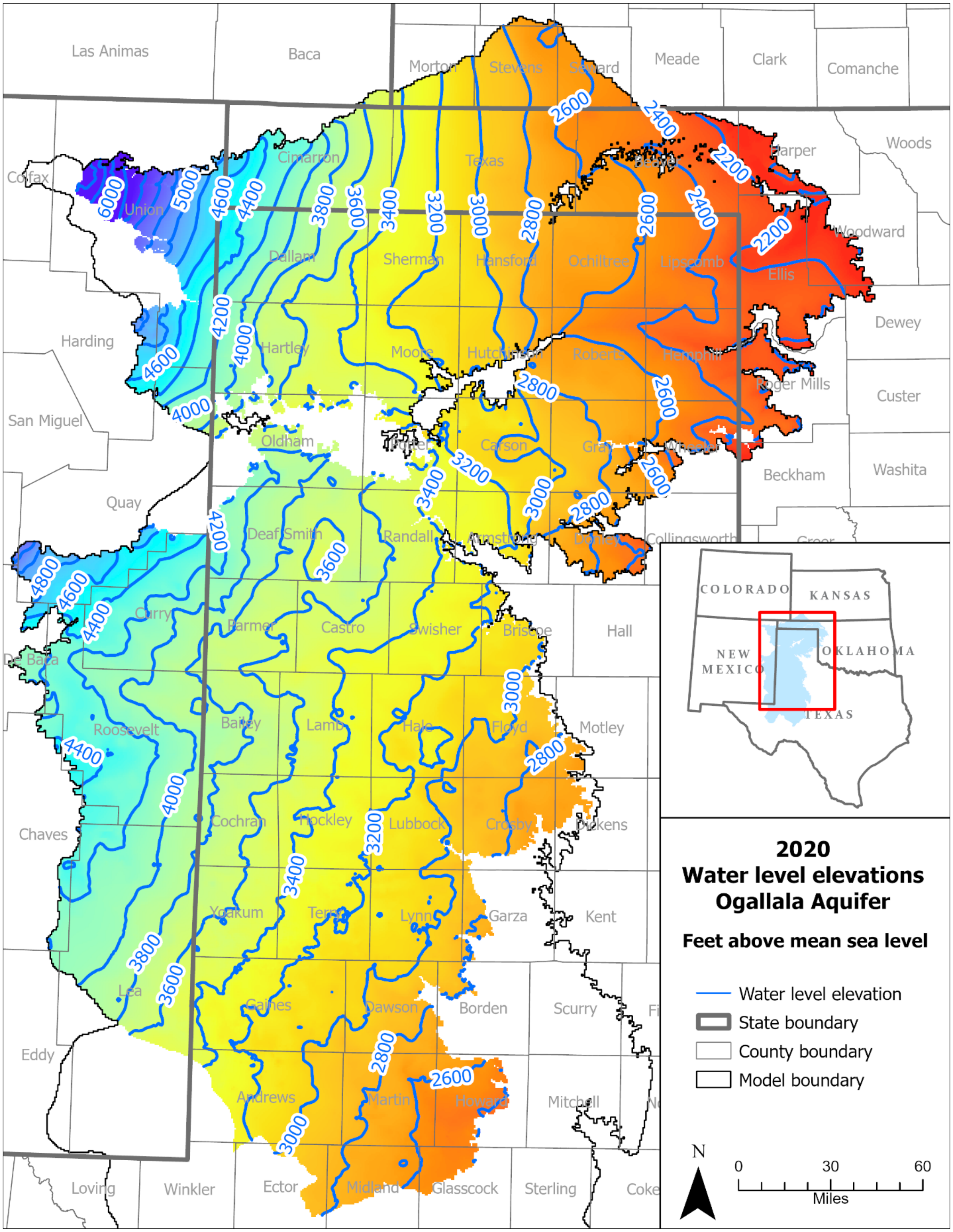

Figure 5-25 Ogallala Aquifer simulated heads in 2020.

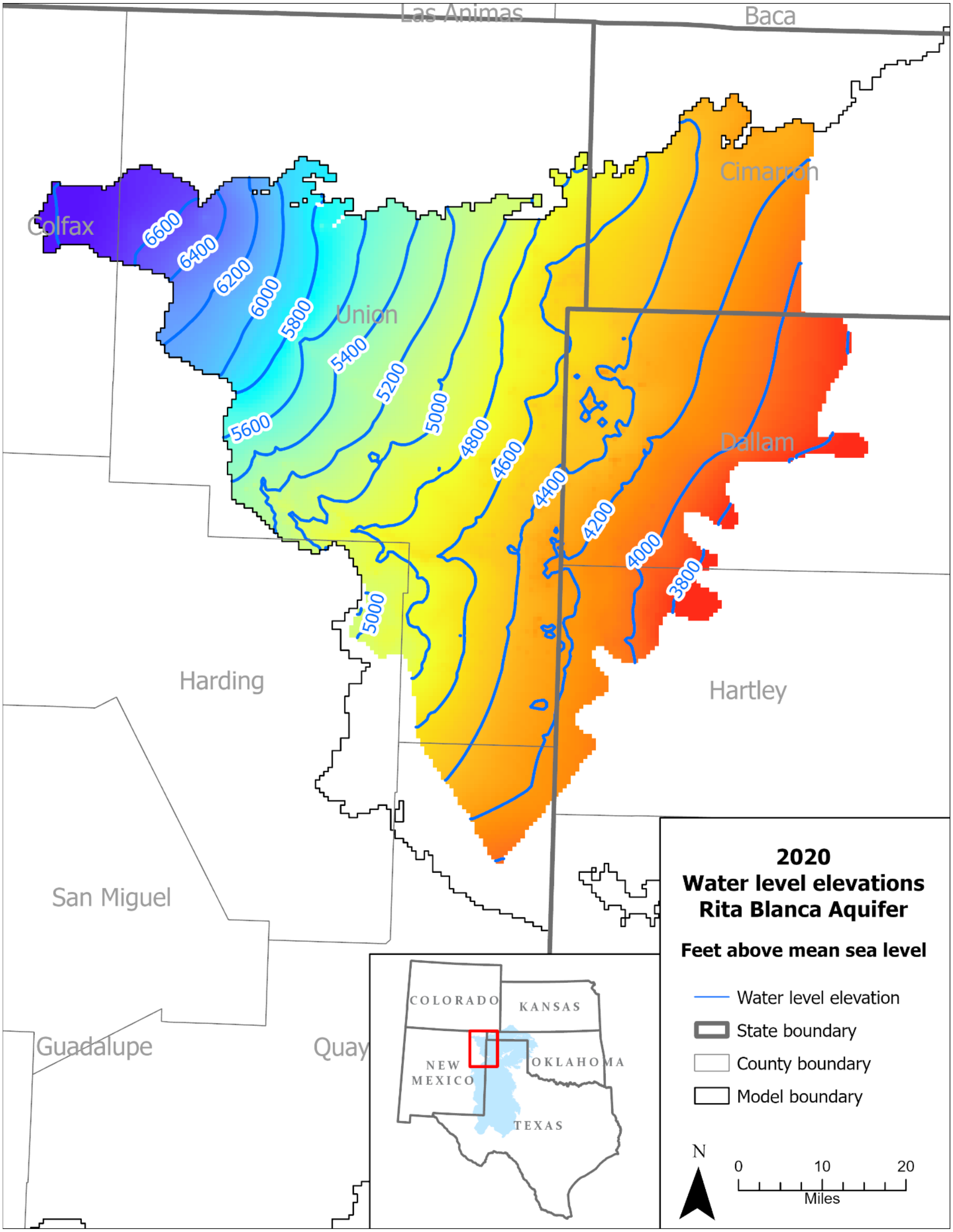

Figure 5-26 Rita Blanca Aquifer simulated heads in 2020.

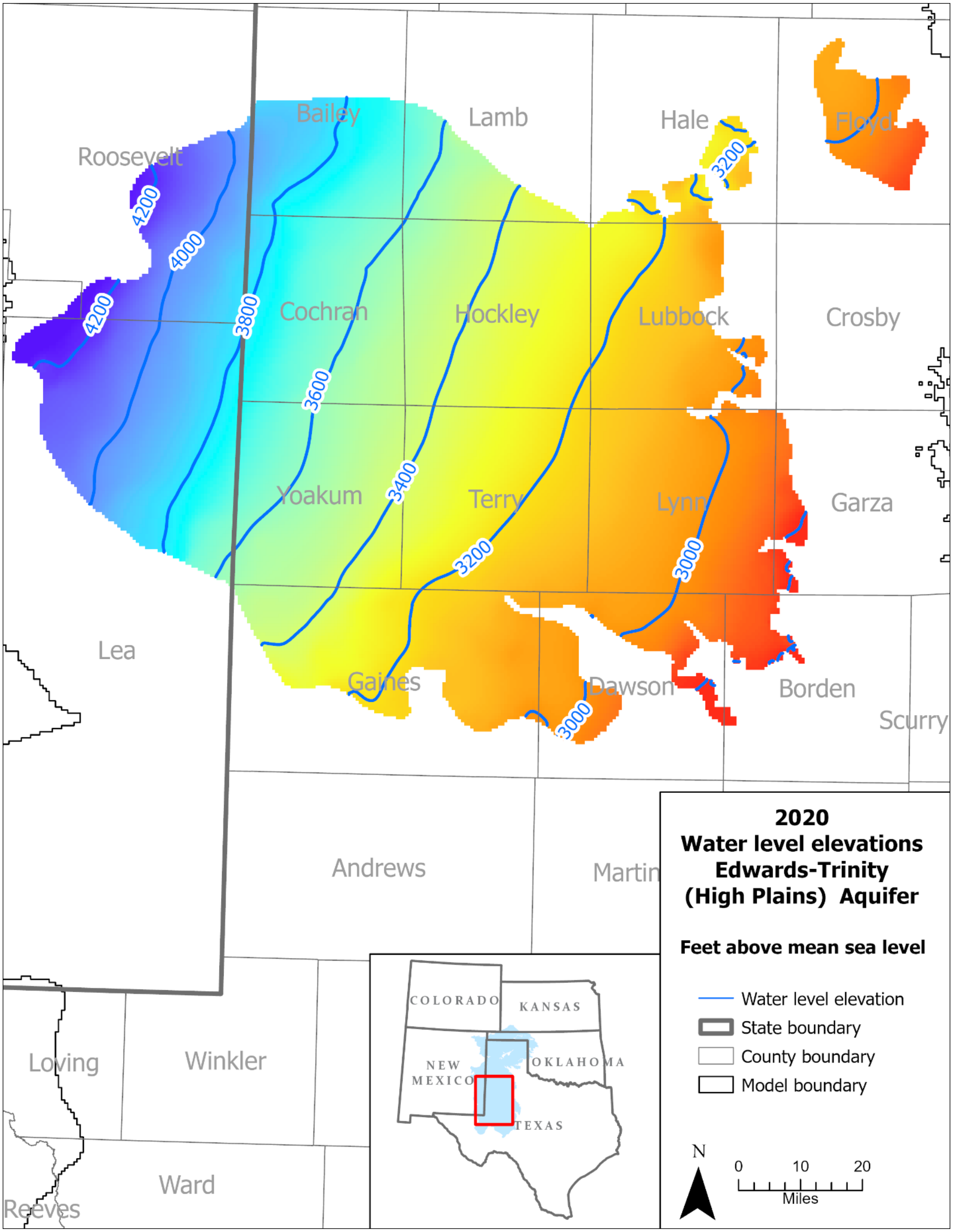

Figure 5-27 Edwards-Trinity (High Plains) Aquifer simulated heads in 2020.

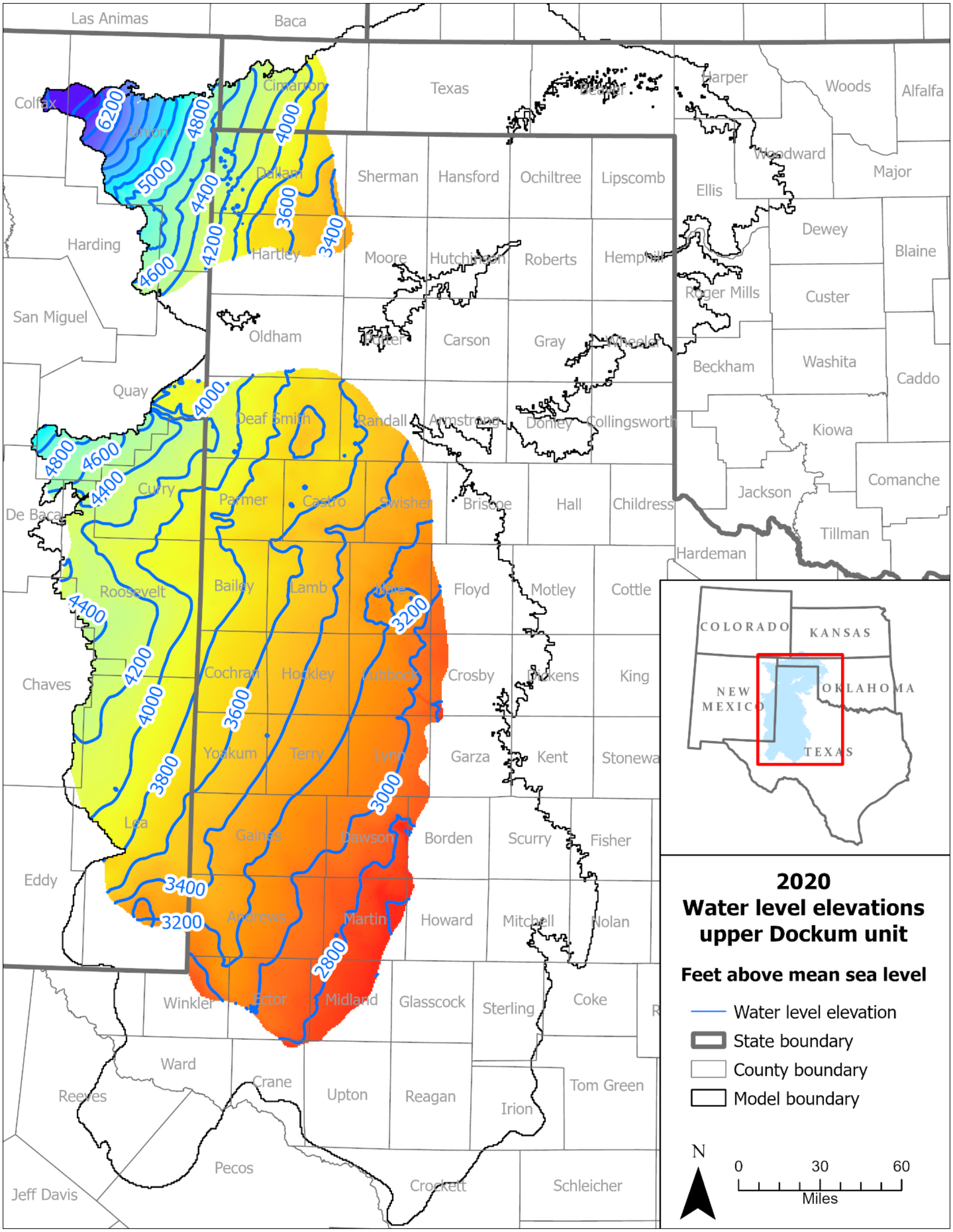

Figure 5-28 Upper Dockum unit simulated heads in 2020.

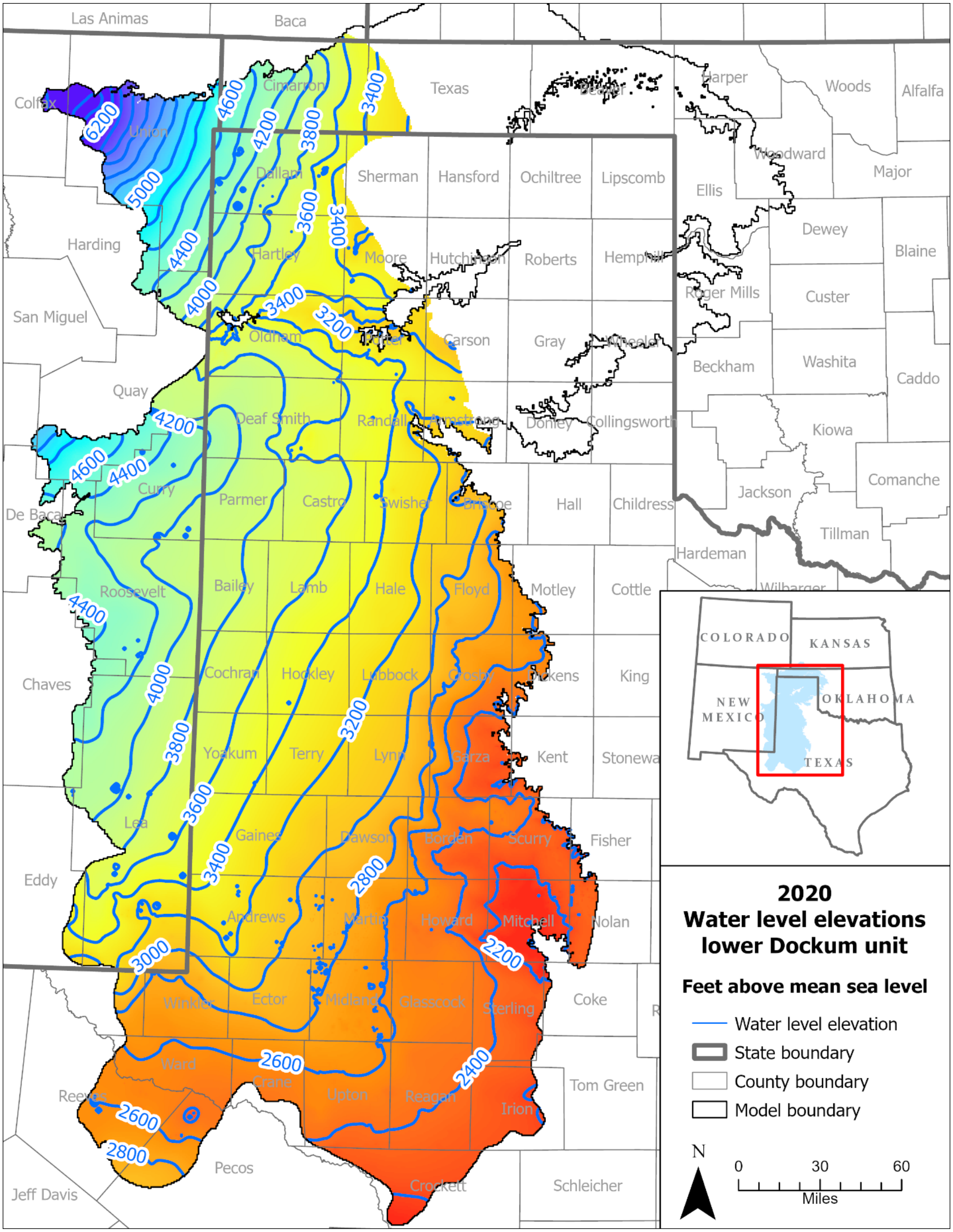

Figure 5-29 Lower Dockum unit simulated heads in 2020.

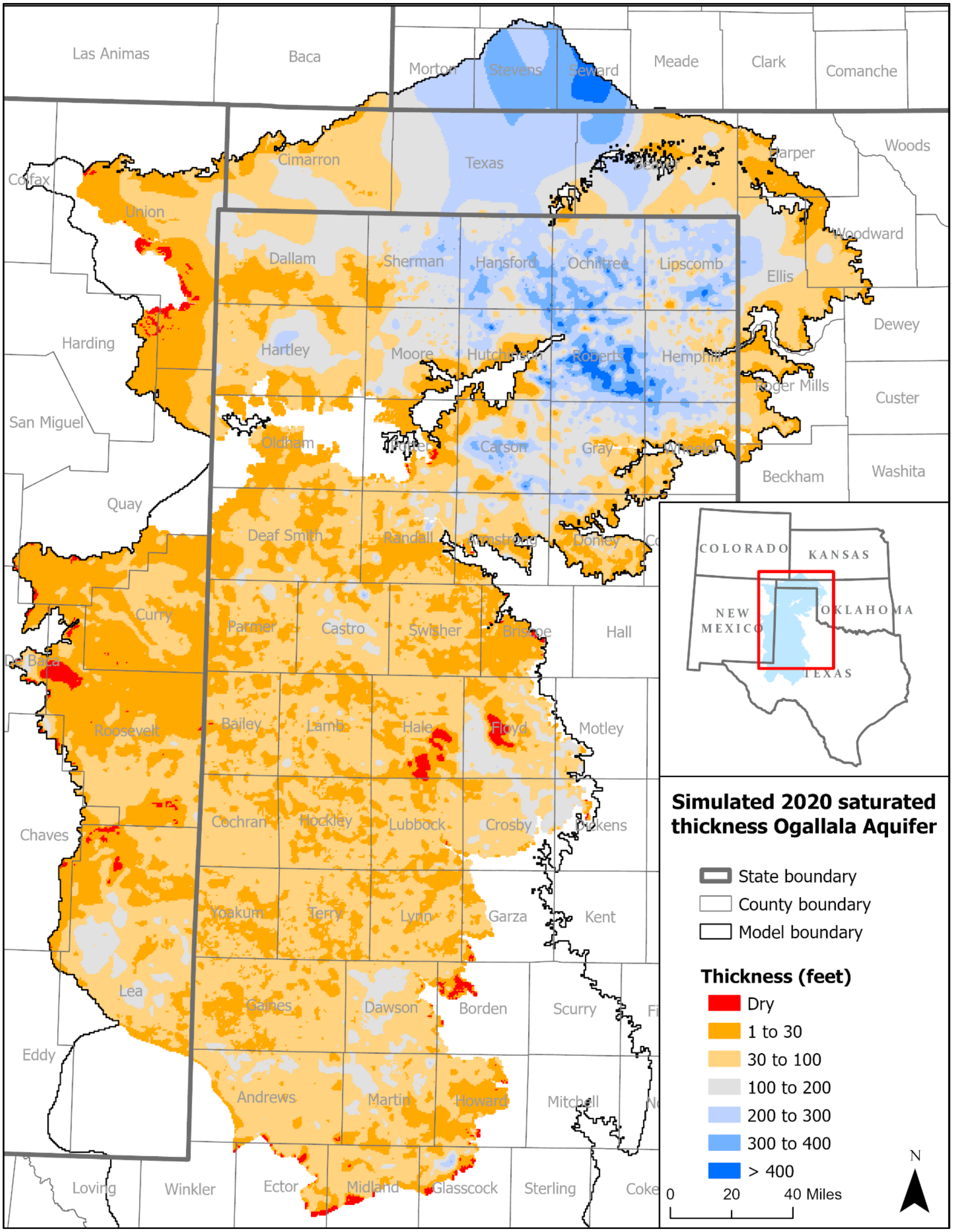

Figure 5-30 Ogallala Aquifer simulated saturated thickness in 2020.

5.3 Reduced pumping

MODFLOW-NWT includes the option to automatically scale back pumping if the saturated thickness of a cell drops below some threshold thickness. Originally the threshold was specified as a fraction of the starting saturated thickness. During development of the Original Model, the MODFLOW-NWT executable source code was slightly modified to allow the threshold to be specified as an absolute minimum thickness (in units of length). The value was set at a minimum thickness of 30 feet (Deeds and Jigmond, 2015). The pumping reductions simulate a decline in production that occurs in many cases when saturated thickness declines and is consistent with the minimum saturated thickness specified in Brune (1969) for which irrigation production is likely to decline significantly. Figure 5-31 shows the simulated 2020 saturated thickness compared to the areas with 2020 model reduced pumping.

In the Original Model, attempts were made to redistribute the reduced pumping to cells of higher saturated thickness within the same county through an iterative process. This process is difficult to replicate because it involves running and rerunning the model multiple times. After each model run, the amount of reduced pumping for each county was evaluated and then redistributed to areas of higher saturated thickness with the goal of minimizing lost pumping as much as possible. The Original Model includes the following description of the process on page 7-1 (Deeds and Jigmond, 2015).

> *As water levels decline, producers respond to decreasing per-well production by drilling additional wells, or increasing activity in areas where saturated thickness is more favorable. During model calibration, this process was emulated by iteratively distributing pumping to other wells in a county when MODFLOW-NWT limited the well production due to small saturated thickness. Iteratively meant running and rerunning the model multiple times.*

For the Model Extension, we used a different approach of evenly distributing county-level pumping estimates for irrigation, rural domestic, livestock, and non-surveyed mining. This approach takes less time, is more transparent, and is reproducible for future extensions.

The Model Extension significantly increases the total Ogallala Aquifer well points in Texas by adding 23,932 new wells from 2013 through 2020 with reports in the Texas Submitted Drillers Report Database. For the Ogallala Aquifer, irrigation is the dominant use and most affected by saturated thickness levels due to the high pumping capacity needed. In total, 8,165 new irrigation wells were drilled between 2013 and 2020 and 86 percent are drilled in areas where the Original Model 2012 saturated thickness is greater than 30 feet (Table 5-3 and Figure 5-32). This helped ensure that adequate model-simulated saturated thickness is available for most of these new irrigation wells.

The years 2010 and 2020 were chosen to compare how updating the Original Model pumping distribution starting in 2013 (Figure 5-33) may affect the reduced pumping.

These years were chosen because they have similar Ogallala Aquifer pumping amounts of 3,251,874 acre-feet (2010) and 3,615,725 acre-feet (2020). The reduced pumping cells and their corresponding amounts were extracted from the output pumping rate reduction files (Table 1-2) for both the Original Model and Model Extensions, summarized by state and counties (Tables 5-4 and 5-5), and plotted on a map for comparison (Figure 5-34). Overall, there was about a two percent increase in reduced pumping between 2010 and 2020 (Table 5-4) with some counties showing an increase and others a decrease (Table 5-5). This small difference is encouraging given that the new pumping distribution methodology is more reproducible and easier to replicate for future model extensions.

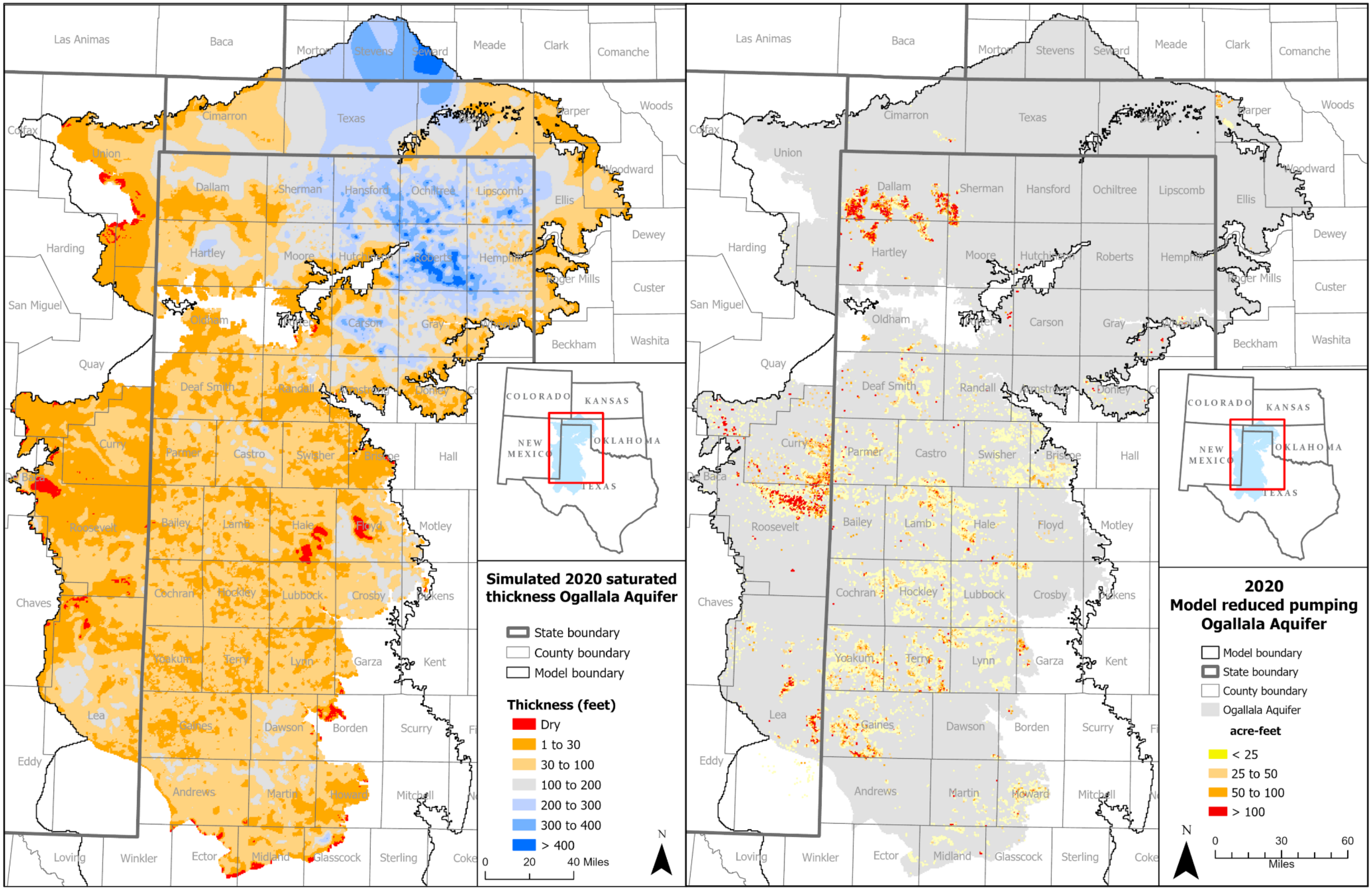

Figure 5-31 Ogallala Aquifer simulated saturated thickness (left) and model reduced pumping distribution (right) in 2020.

Table 5-3 New 2013 through 2020 Texas Submitted Drillers Report Database irrigation wells and model cell 2012 saturated thickness.

2012 saturated thickness (feet)	Irrigation wells	Percent	Multi-aquifer wells
Less than 30	1,117	14	95
30 to 50	2,028	25	76
50 to 100	3,372	41	69
Greater than 100	1,648	20	18
Total	**8,165**	**100**	**258**

Table 5-4 Original Model (2010) reduced pumping compared to Model Extension (2020) reduced pumping by state. Pumping units are in acre-feet.

State	2010 pumping	2020 pumping	2010 reduced pumping	2020 reduced pumping	Percent reduction (2010)	Percent reduction (2020)
Texas	3,251,874	3,615,725	136,519	233,831	4	6
New Mexico	302,536	341,506	78,438	96,847	26	28
Oklahoma	155,603	155,835	1,927	3,121	1	2

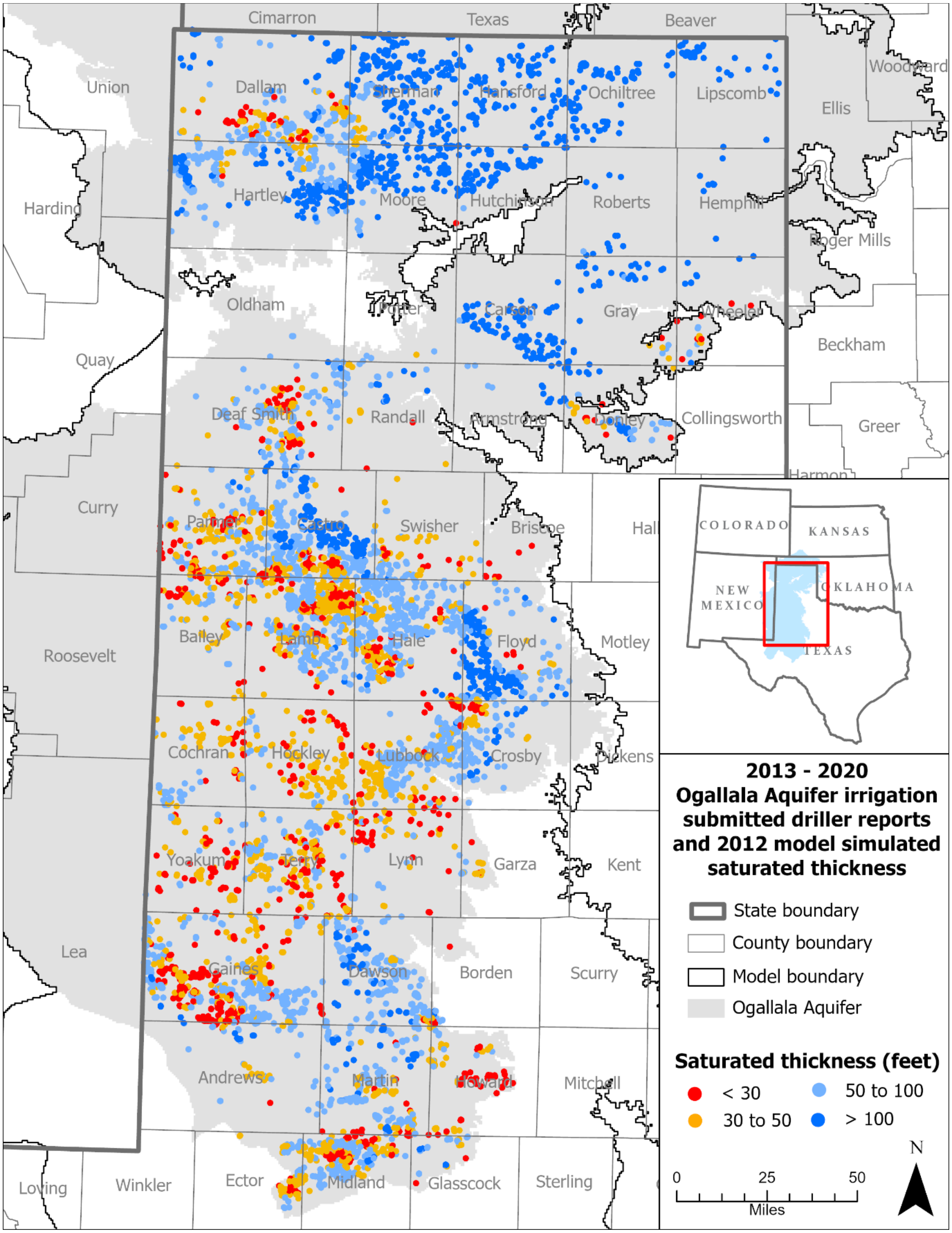

Figure 5-32 **Ogallala Aquifer irrigation wells added from the Texas Submitted Drillers Report Database for 2013 through 2020. Wells are symbolized by the 2012 model-simulated saturated thickness of the model cell the well intersects.**

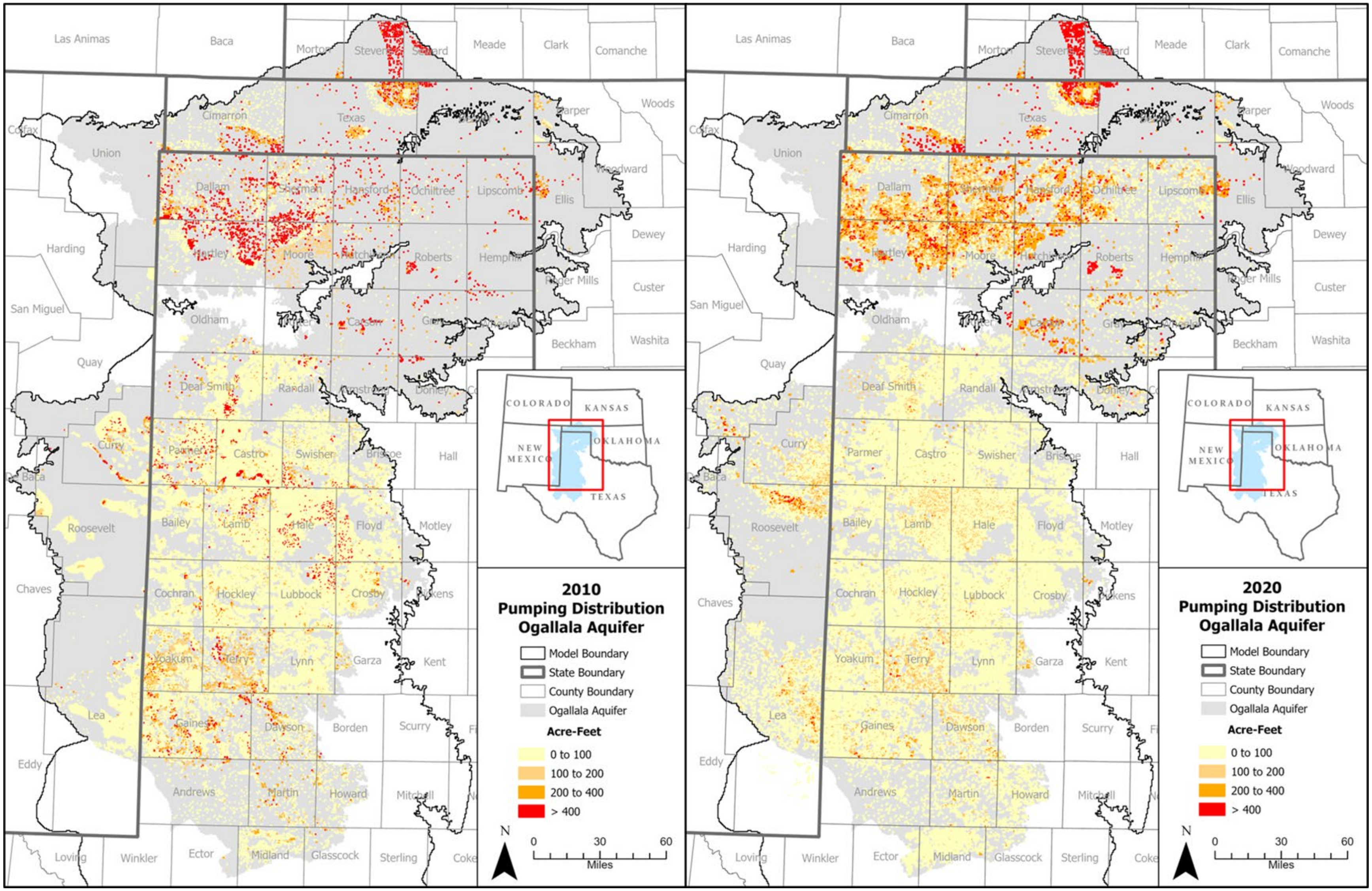

Figure 5-33 Comparison of 2010 (left) to 2020 (right) pumping distribution for the Ogallala Aquifer.

Table 5-5 Original Model (2010) reduced pumping compared to Model Extension (2020) reduced pumping by county. Pumping units are in acre-feet.

County	2010 pumping	2020 pumping	2010 reduced pumping	2020 reduced pumping	Percent reduction (2010)	Percent reduction (2020)
Andrews	19,574	13,656	1,615	992	8	7
Armstrong	4,735	5,912	119	267	3	5
Bailey	43,665	48,038	1,991	2,038	5	4
Borden	3,645	2,694	253	526	7	20
Briscoe	33,456	23,790	7,103	6,919	21	29
Carson	89,291	82,183	185	745	0	1
Castro	173,502	153,433	2,307	4,048	1	3
Cochran	49,843	63,614	2,358	3,331	5	5
Crosby	78,202	75,569	1,941	1,720	2	2
Dallam	336,684	343,425	11,558	41,848	3	12
Dawson	61,114	63,961	2	356	0	1
Deaf Smith	138,671	122,132	6,608	7,285	5	6
Donley	26,277	20,740	10	14	0	0
Ector	712	471	119	1	17	0
Floyd	73,658	72,825	8	612	0	1
Gaines	230,353	203,564	26,017	24,234	11	12
Garza	10,824	16,712	1,394	4,411	13	26
Glasscock	5,240	3,898	1	67	0	2
Gray	0	25,561	0	21	0	0
Hale	166,304	180,511	5,735	9,524	3	5
Hartley	346,449	429,468	875	15,868	0	4
Hockley	101,261	116,890	4,423	8,859	4	8
Howard	10,807	15,622	1,962	2,299	18	15
Hutchinson	63,416	87,417	711	7,117	1	8
Lamb	158,134	172,139	4,450	15,996	3	9
Lubbock	100,371	118,535	9,046	5,298	9	4
Lynn	51,716	84,227	8,150	5,661	16	7
Martin	37,190	44,651	273	1,392	1	3
Midland	16,269	11,443	424	20	3	0
Moore	173,866	203,005	29	2,713	0	1
Oldham	12,463	11,134	1,362	2,741	11	25
Parmer	169,872	109,955	14,363	7,027	8	6
Potter	0	15,226	0	2,524	0	17
Randall	32,389	23,304	209	359	1	2
Sherman	0	315,112	0	6,021	0	2
Swisher	94,323	74,490	3,916	3,537	4	5
Terry	145,191	141,835	8,919	17,316	6	12
Wheeler	11,678	11,840	123	519	1	4
Yoakum	180,729	106,743	7,960	19,605	4	18

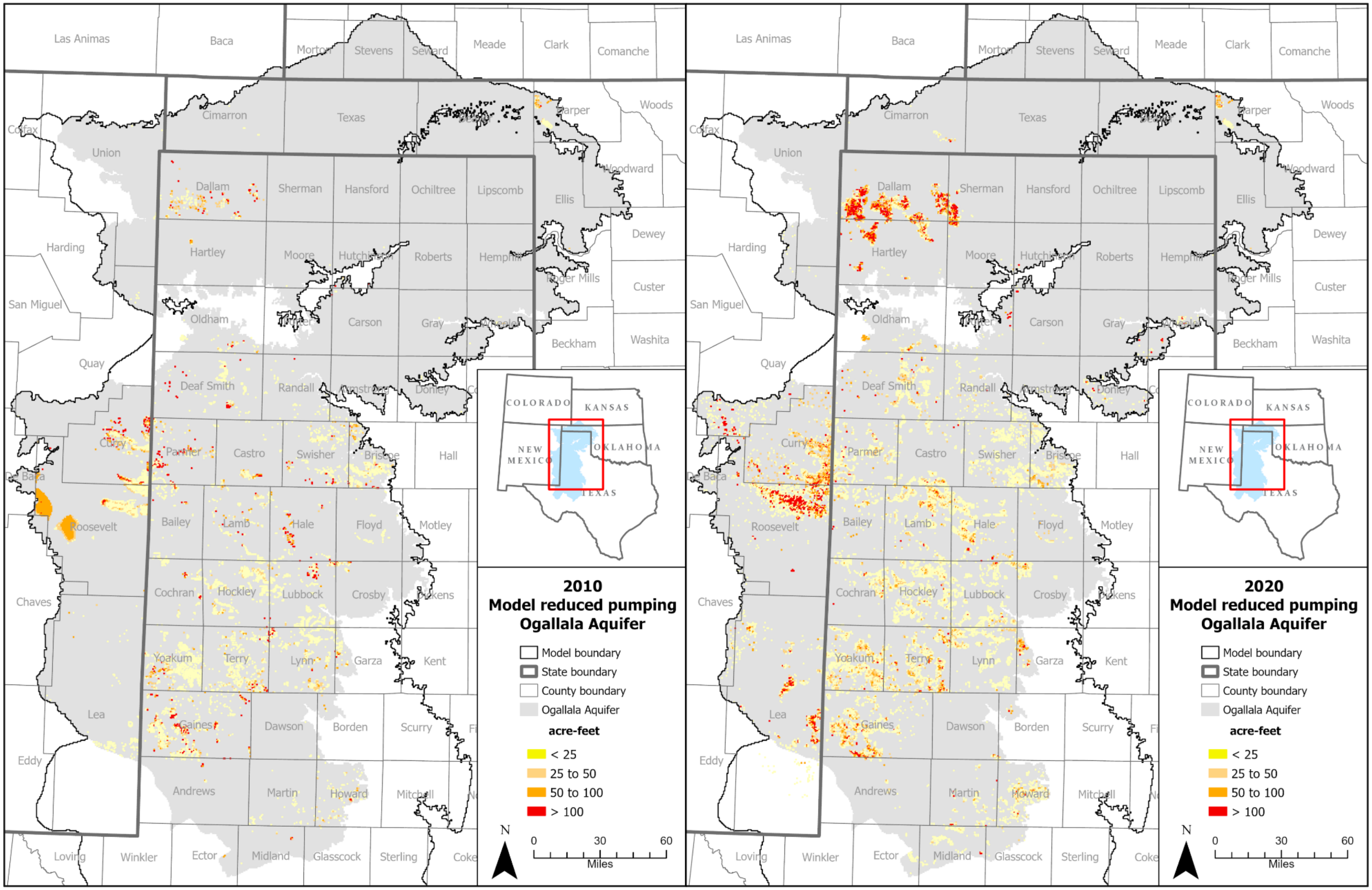

Figure 5-34 Comparison of 2010 (left) to 2020 (right) model reduced pumping distribution for the Ogallala Aquifer.

5.4 Model-simulated water budgets

Overall groundwater budgets for 2010 and 2020 (Tables 5-6 through 5-9) were extracted from the groundwater model cell-by-cell output with ZONEBUDGET Version 3.01 (Harbaugh, 2009). The years 2010 and 2020 were chosen to compare the Original Model to the Model Extension because both years include similar input pumping. The budgets include the following components: recharge, rivers, drains, evapotranspiration, pumping, vertical leakage, lateral flow; and storage change. In addition, overall annual budgets from 2005 through 2020 were plotted for each of the aquifers (Figure 5-35 through 5-38).

Table 5-6 and Figure 5-35 show the water budget for the Ogallala Aquifer. Pumping dominates outflow from the aquifer and storage shows large depletions for all years. There does not appear to be a significant difference between 2010 and 2020.

Table 5-7 and Figure 5-36 show the water budget for the Rita Blanca Aquifer. Pumping and storage remain fairly steady from 2000 through 2020. However, during the Model Extension period there is a slight increase in storage due to increased inflow from the overlying Ogallala Aquifer because of an increased vertical gradient due to drawdown in the Rita Blanca Aquifer.

Table 5-8 and Figure 5-37 show the water budget for the Edwards-Trinity (High Plains) Aquifer. Pumping trends mirror the Ogallala Aquifer trends and there are a few periods of increased pumping from 2000 through 2020 that induced inflow from the overlying Ogallala Aquifer.

Table 5-9 and Figure 5-38 show the combined layers 3 and 4 water budget for the Dockum units. From 2000 through 2005 there is a trend of increased pumping for the Dockum units and a corresponding decline in storage. The increase in pumping for the Model Extension period shows a corresponding increase in inflow from the overlying aquifers due to declining heads in the Dockum units.

Appendices C and D provide 2020 simulated water budgets by county and groundwater conservation district to assist in local groundwater planning. Budgets were split into official and unofficial aquifer based on the whether the center of a model cell fell within the official TWDB boundary of the aquifer.

Table 5-6 Ogallala Aquifer groundwater budgets in Texas for 2010 and 2020.

Flow component	2010 (acre-feet)	2020 (acre-feet)
Recharge Inflow	1,001,504	1,004,248
River Leakage Inflow	248,410	256,000
Upper Vertical Leakage Inflow	0	0
Lower Vertical Leakage Inflow	84,873	77,629
Lateral Inflow	66,739	65,766
Storage Inflow	3,227,957	2,963,354
Total Inflow	4,629,483	4,366,997
Wells	3,704,487	3,710,856
Evapotranspiration Outflow	82,876	77,311
Drain Outflow	109,327	102,877
River Leakage Outflow	180,569	163,072
Upper Vertical Leakage Outflow	0	0
Lower Vertical Leakage Inflow	88,516	86,045
Lateral Outflow	45,836	37,801
Storage Outflow	417,870	189,035
Total Outflow	4,629,481	4,366,997
Total Inflow – Total Outflow	2	0
Storage Change	-2,810,087	-2,774,319

Table 5-7 Rita Blanca Aquifer groundwater budgets in Texas for 2010 and 2020.

Flow component	2010 (acre-feet)	2020 (acre-feet)
Recharge Inflow	0	0
River Leakage Inflow	0	0
Upper Vertical Leakage Inflow	4,461	5,326
Lower Vertical Leakage Inflow	1,076	1,461
Lateral Inflow	978	626
Storage Inflow	2,235	1,856
Total Inflow	8,750	9,270
Wells	4,640	4,483
Evapotranspiration Outflow	0	0
Drain Outflow	0	0
River Leakage Outflow	0	0
Upper Vertical Leakage Outflow	1,759	1,642
Lower Vertical Leakage Inflow	307	386
Lateral Outflow	238	832
Storage Outflow	1,806	1,927
Total Outflow	8,750	9,270
Total Inflow – Total Outflow	0	0
Storage Change	-429	71

Table 5-8 Edwards-Trinity (High Plains) Aquifer groundwater budgets in Texas for 2010 and 2020.

Flow component	2010 (acre-feet)	2020 (acre-feet)
Recharge Inflow	0	0
River Leakage Inflow	0	0
Upper Vertical Leakage Inflow	51,056	48,230
Lower Vertical Leakage Inflow	4,570	4,518
Lateral Inflow	7,528	7,759
Storage Inflow	14,975	11,701
Total Inflow	78,129	72,209
Wells	16,905	18,338
Evapotranspiration Outflow	0	0
Drain Outflow	0	0
River Leakage Outflow	0	0
Upper Vertical Leakage Outflow	49,919	44,392
Lower Vertical Leakage Inflow	1,370	1,397
Lateral Outflow	5,863	5,557
Storage Outflow	4,072	2,525
Total Outflow	78,129	72,209
Total Inflow – Total Outflow	0	0
Storage Change	-10,903	-9,176

Table 5-9 Dockum units groundwater budgets in Texas for 2010 and 2020. The upper and lower Dockum aquifers are combined.

Flow component	2010 (acre-feet)	2020 (acre-feet)
Recharge Inflow	61,282	61,450
River Leakage Inflow	25,472	26,635
Upper Vertical Leakage Inflow	45,266	46,237
Lower Vertical Leakage Inflow	0	0
Lateral Inflow	2,761	2,829
Storage Inflow	88,664	119,348
Total Inflow	223,445	256,499
Wells	50,615	90,649
Evapotranspiration Outflow	17,980	17,510
Drain Outflow	19,354	19,596
River Leakage Outflow	71,775	71,192
Upper Vertical Leakage Outflow	38,856	37,010
Lower Vertical Leakage Inflow	0	0
Lateral Outflow	558	539
Storage Outflow	24,311	20,011
Total Outflow	223,449	256,507
Total Inflow – Total Outflow	-4	-8
Storage Change	-64,353	-99,337

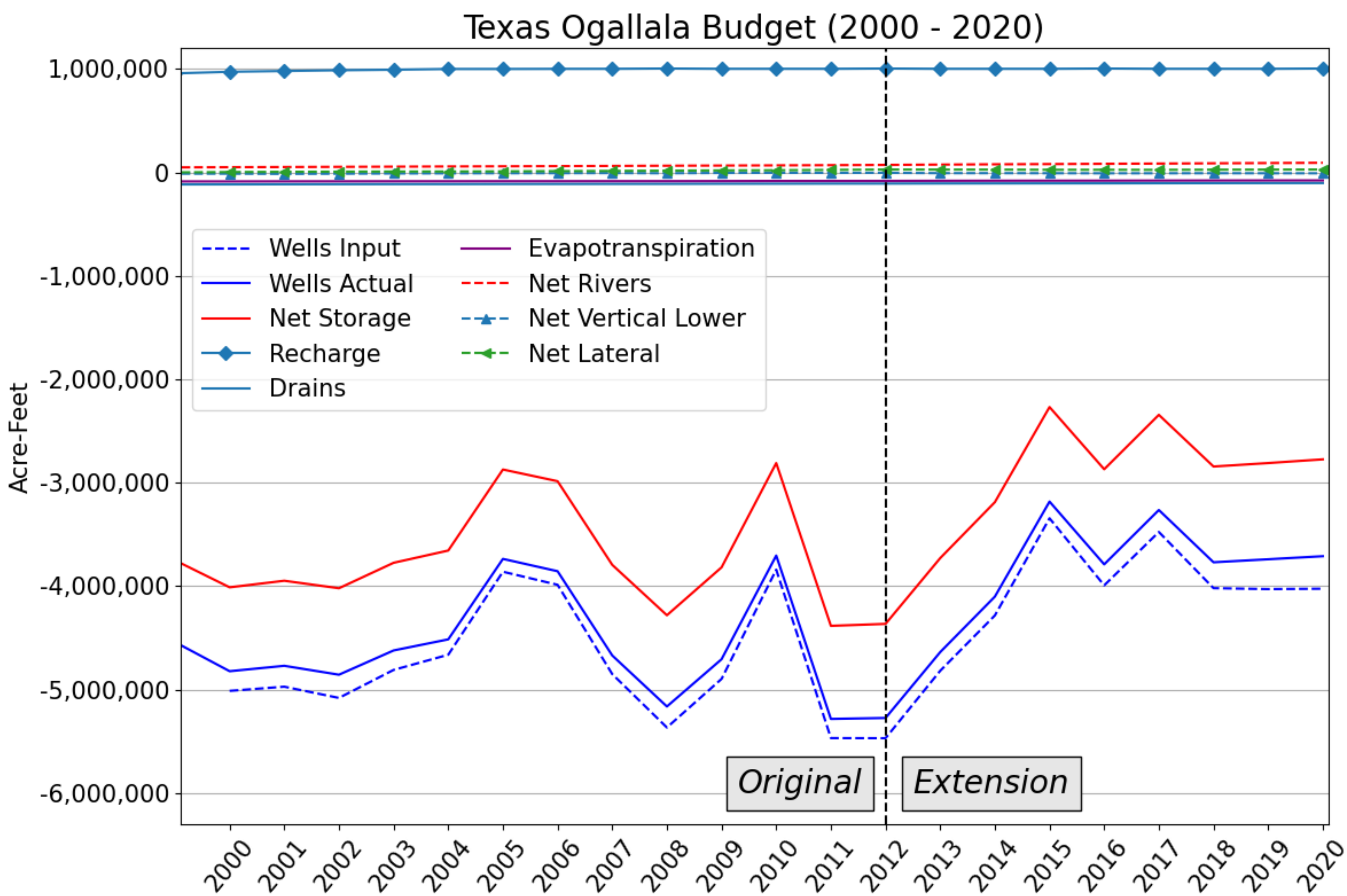

Figure 5-35 Ogallala Aquifer groundwater budget in Texas between 2000 and 2020. The blue dashed line indicates total input pumping, and the solid blue line indicates total output pumping (input pumping minus model reduced pumping).

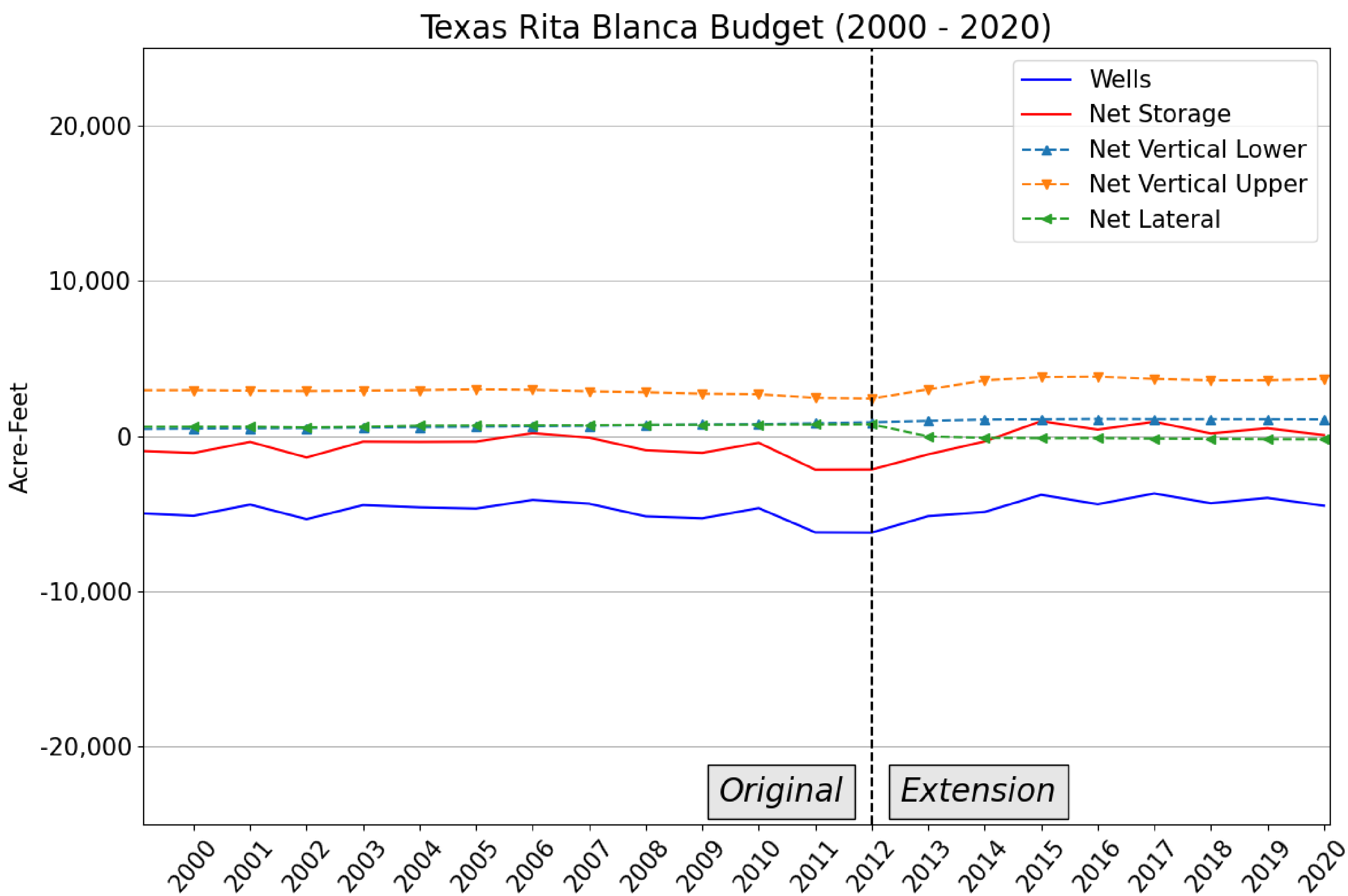

Figure 5-36 Rita Blanca Aquifer groundwater budget in Texas between 2000 and 2020.

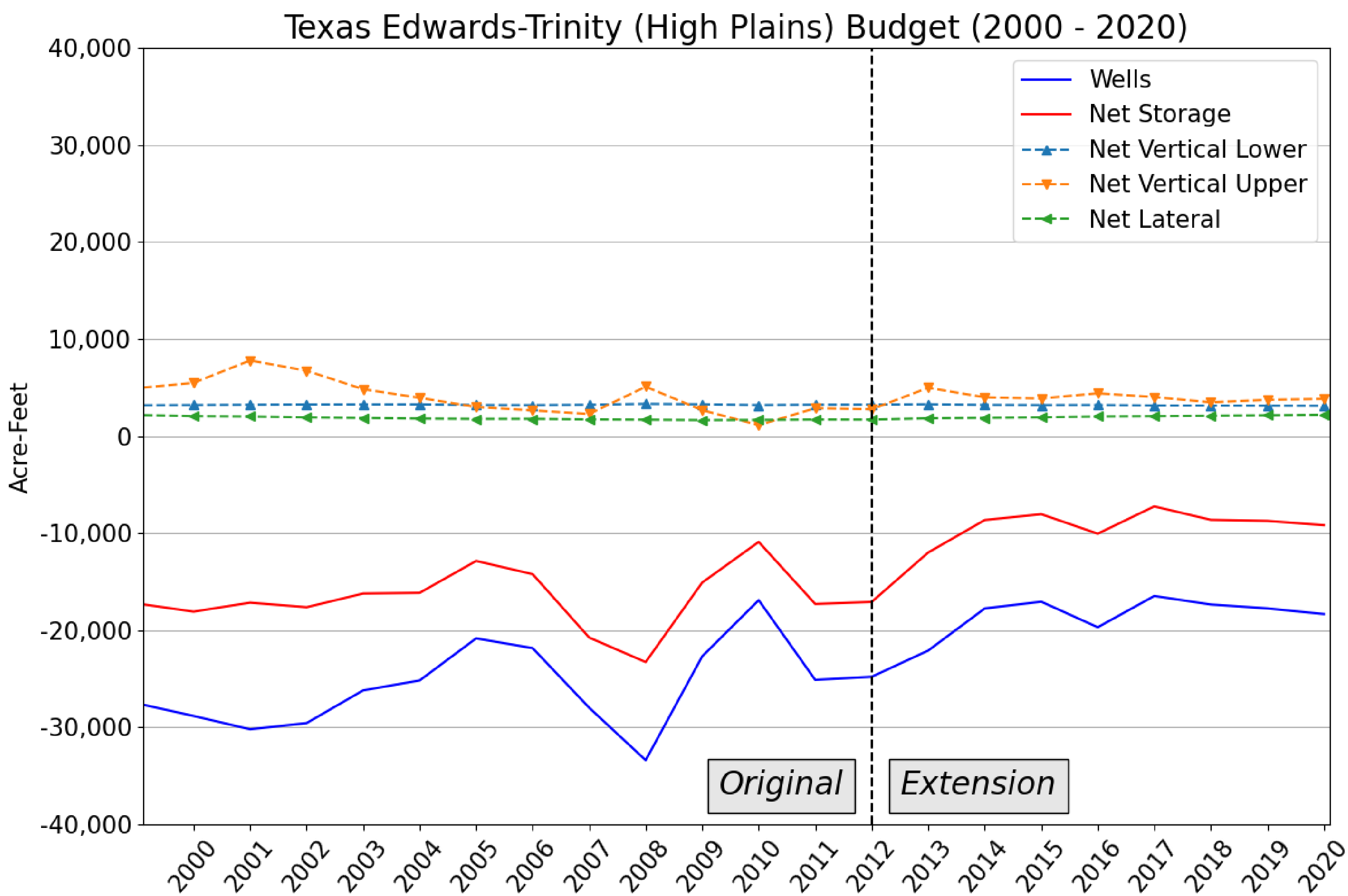

Figure 5-37 Edwards-Trinity (High Plains) Aquifer groundwater budget in Texas between 2000 and 2020.

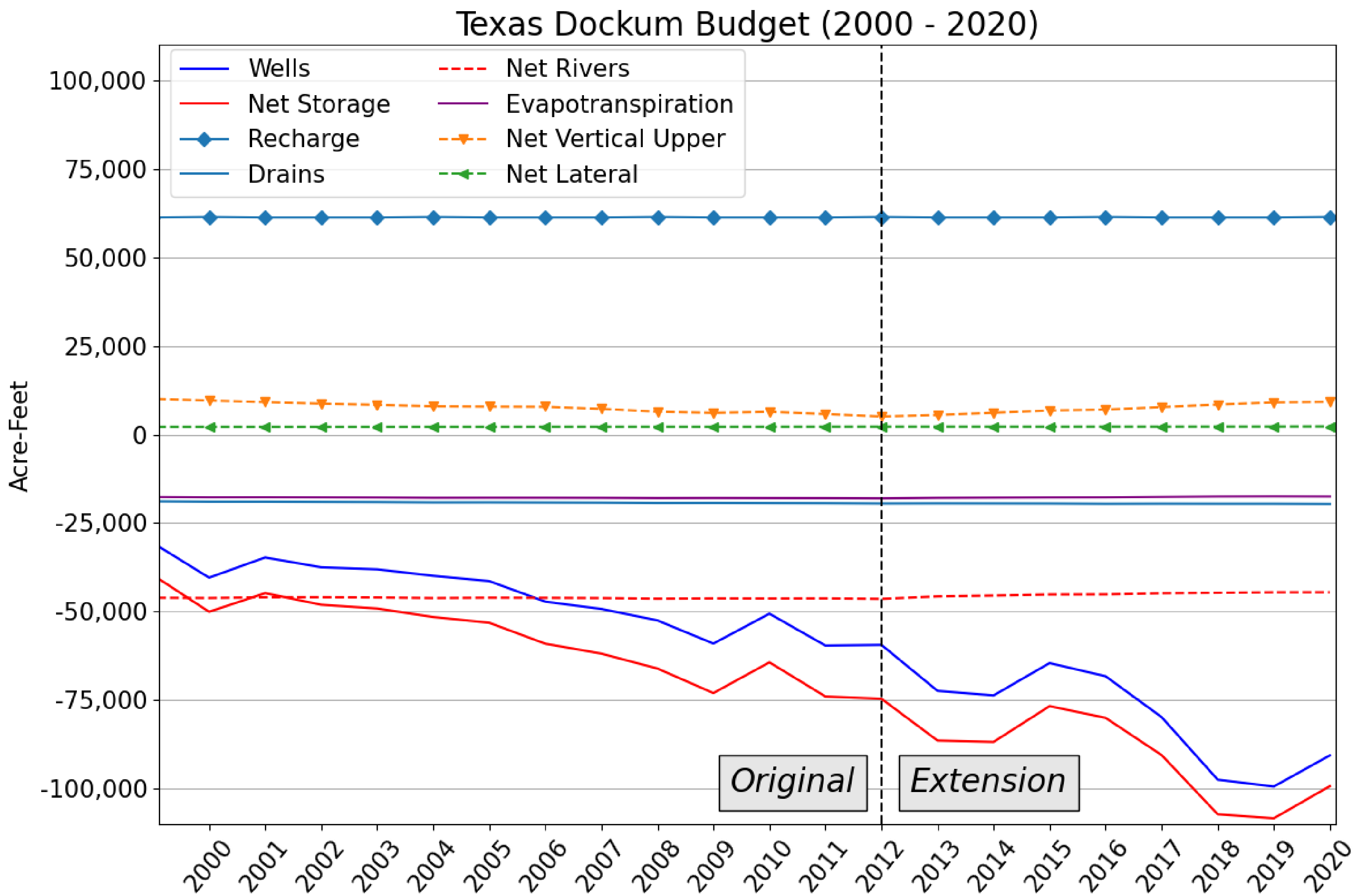

Figure 5-38 **Dockum units groundwater budget in Texas between 2000 and 2020 (upper and lower Dockum units are combined).**

6 Predictive scenario

One of the primary objectives of the groundwater availability model for the High Plains Aquifer System is to estimate groundwater availability based on predictive pumping scenarios. A predictive model was developed from 2021 through 2080 and one pumping scenario was simulated. The heads from the last stress period of the Model Extension were used as the 2021 starting heads and the Model Extension 2020 pumping rates and distribution were extended through 2080.

Average drawdown from 2021 through 2080 by county, groundwater conservation district, and groundwater management area were calculated (Tables 6-1 through 6-3), and simulated drawdown maps were developed (Figures 6-1 through 6-5). This analysis does not account for TWDB official aquifer boundaries. If a cell was dry in 2021 it was removed from the analysis.

Comparing the Ogallala Aquifer drawdown map (Figure 6-1) to the minor aquifer drawdown maps (Figures 6-2 through 6-5), it is evident that most of the minor aquifers are experiencing areas of drawdown because of pumping in the overlying Ogallala Aquifer. For example, Parmer County has no wells pumping in the upper Dockum unit (Layer 3; Figure 3-10) but is experiencing 47.9 feet of drawdown from 2021 through 2080 (Table 6-1). The Dockum units water budget for Parmer County in 2020 shows a net of 3,031 acre-feet flowing to the overlying Ogallala Aquifer (Appendix D). This cross-formational flow is likely due to the declining heads in the Ogallala Aquifer.

The percentage of Ogallala Aquifer cells below 30 feet of saturated thickness increased from 26 percent in 2021 to 44 percent in 2080 (Figure 6-6). Total model reduced pumping for the Ogallala Aquifer in Texas increases from 259,021 acre-feet in 2020 to 1,385,813 acre-feet in 2080.

In the southern portion of the Ogallala Aquifer, there are some small areas where rebound (increase in heads) occurs in the predictive model. Some of these areas of rebound correspond to areas where the Original Model included higher concentration of pumping but the pumping in the Model Extension was distributed more evenly throughout a county because of the change in methodology (See Sections 3 and 5.3). It should be noted that these areas of rebound in Texas correspond to the counties (Gaines, Lubbock, Terry, Lynn, Dawson, and Hockley counties) with the highest post-development recharge applied in the Original Model. See Section 4.1 of this report for more information on post-development recharge in the southern portion of the Ogallala Aquifer.

Even though some of these counties may show small areas of rebound, the overall trend for the county is drawdown (Table 6-1). For example, Gaines County has a small area of rebound (Figure 6-1) from 2021 through 2080 but the overall county-wide drawdown is 14.6 feet (Table 6-1).

Table 6-1 Average simulated drawdown (in feet) by county between 2021 and 2080. If an aquifer cell was dry in 2021 it was not included in the average. Input pumping from 2021 through 2080 the same as 2020.

County	Ogallala	Rita Blanca	Edwards-Trinity (High Plains)	Upper Dockum	Lower Dockum
Andrews	2.3	--	--	3.8	7.8
Armstrong	7.5	--	--	--	5.2
Bailey	8.6	--	3.7	15.9	5.1
Borden	-0.2	--	-1.7	-0.2	-1.0
Briscoe	9.2	--	--	--	3.7
Carson	38.5	--	--	--	34.9
Castro	49.0	--	--	59.3	42.5
Cochran	13.4	--	11.9	6.5	0.9
Collingsworth	2.6	--	--	--	--
Crane	--	--	--	0.6	0.0
Crockett	--	--	--	--	0.7
Crosby	34.5	--	--	36.5	19.0
Dallam	31.1	24.9	--	36.9	47.5
Dawson	6.1	--	5.9	7.1	2.7
Deaf Smith	19.7	--	--	23.2	36.3
Dickens	12.6	--	--	--	3.1
Donley	7.3	--	--	--	--
Ector	-0.7	--	--	0.4	1.9
Fisher	--	--	--	--	-0.2
Floyd	36.3	--	21.7	71.1	33.0
Gaines	14.6	--	6.3	25.1	6.4
Garza	4.1	--	4.5	-4.2	-1.2
Glasscock	-0.8	--	--	--	10.7
Gray	13.5	--	--	--	--
Hale	33.3	--	12.5	41.8	58.1
Hansford	94.8	--	--	--	--
Hartley	43.5	34.9	--	57.1	43.5
Hemphill	2.9	--	--	--	--
Hockley	12.9	--	9.6	11.8	2.9
Howard	3.7	--	--	5.7	9.7
Hutchinson	53.7	--	--	--	0.8
Irion	--	--	--	--	-0.4
Kent	--	--	--	--	-1.0
Lamb	21.2	--	6.4	39.7	20.6
Lipscomb	17.9	--	--	--	--
Loving	--	--	--	--	2.3

Table 6-1 continued

County	Ogallala	Rita Blanca	Edwards-Trinity (High Plains)	Upper Dockum	Lower Dockum
Lubbock	11.0	--	5.8	14.8	20.9
Lynn	5.6	--	7.0	5.8	2.1
Martin	5.3	--	--	8.6	20.2
Midland	2.5	--	--	6.2	43.5
Mitchell	--	--	--	--	4.3
Moore	65.9	--	--	42.6	25.8
Motley	14.7	--	--	--	5.5
Nolan	--	--	--	--	18.8
Ochiltree	47.9	--	--	--	--
Oldham	3.6	--	--	12.3	1.0
Parmer	23.8	--	--	47.9	28.7
Pecos	--	--	--	--	14.7
Potter	7.7	--	--	30.7	3.7
Randall	8.0	--	--	11.5	15.0
Reagan	--	--	--	--	5.3
Reeves	--	--	--	--	8.2
Roberts	28.8	--	--	--	--
Scurry	--	--	--	--	4.0
Sherman	105.5	--	--	10.2	70.8
Sterling	--	--	--	--	1.3
Swisher	22.0	--	--	27.2	32.1
Taylor	--	--	--	--	--
Terry	10.5	--	5.5	9.6	1.7
Tom Green	--	--	--	--	0.6
Upton	--	--	--	1.4	10.8
Ward	--	--	--	--	7.9
Wheeler	2.9	--	--	--	--
Winkler	2.3	--	--	1.0	15.0
Yoakum	11.9	--	11.6	10.4	1.8

Table 6-2 Average simulated drawdown (in feet) by groundwater conservation district between 2021 and 2080. If an aquifer cell was dry in 2021 it was not included in the average. GCD = groundwater conservation district, UWCD = underground water conservation district, and WCD = water conservation district. Input pumping from 2021 through 2080 the same as 2020.

Groundwater conservation district	Ogallala	Rita Blanca	Edwards-Trinity (High Plains)	Upper Dockum	Lower Dockum
Clear Fork GCD	--	--	--	--	-0.2
Coke County UWCD	--	--	--	--	0.0
Crockett County GCD	--	--	--	--	0.7
Garza County UWCD	4.1	--	4.5	-4.2	-1.2
Gateway GCD	14.7	--	--	--	5.5
Glasscock GCD	-0.8	--	--	--	10.2
Hemphill County UWCD	2.9	--	--	--	--
High Plains UWCD No. 1	22.5	--	8.8	28.8	26.1
Irion County WCD	--	--	--	--	-0.4
Llano Estacado UWCD	14.6	--	6.3	25.1	6.4
Lone Wolf GCD	--	--	--	--	4.3
Mesa UWCD	6.1	--	5.9	7.1	2.7
Mesquite GCD	2.6	--	--	--	--
Middle Pecos GCD	--	--	--	--	14.7
North Plains GCD	58.6	27.3	--	43.9	47.8
Panhandle GCD	17.8	--	--	--	9.0
Permian Basin UWCD	4.8	--	--	8.6	15.0
Reeves County GCD	--	--	--	--	8.2
Sandy Land UWCD	11.9	--	11.6	10.4	1.8
Santa Rita UWCD	--	--	--	--	5.3
South Plains UWCD	11.0	--	5.5	9.6	1.7
Sterling County UWCD	--	--	--	--	1.3
Wes-Tex GCD	--	--	--	--	18.8

Table 6-3 Average simulated drawdown (in feet) by groundwater management area between 2021 and 2080. If an aquifer cell was dry in 2021 it was not included in the average. Input pumping from 2021 through 2080 the same as 2020.

Groundwater management area	Ogallala	Rita Blanca	Edwards-Trinity (High Plains)	Upper Dockum	Lower Dockum
1	35.0	27.1	--	37.0	24.9
2	16.9	--	8.1	21.5	16.2
3	2.3	--	--	1.0	9.0
6	12.7	--	--	--	2.9
7	1.1	--	--	2.8	9.0

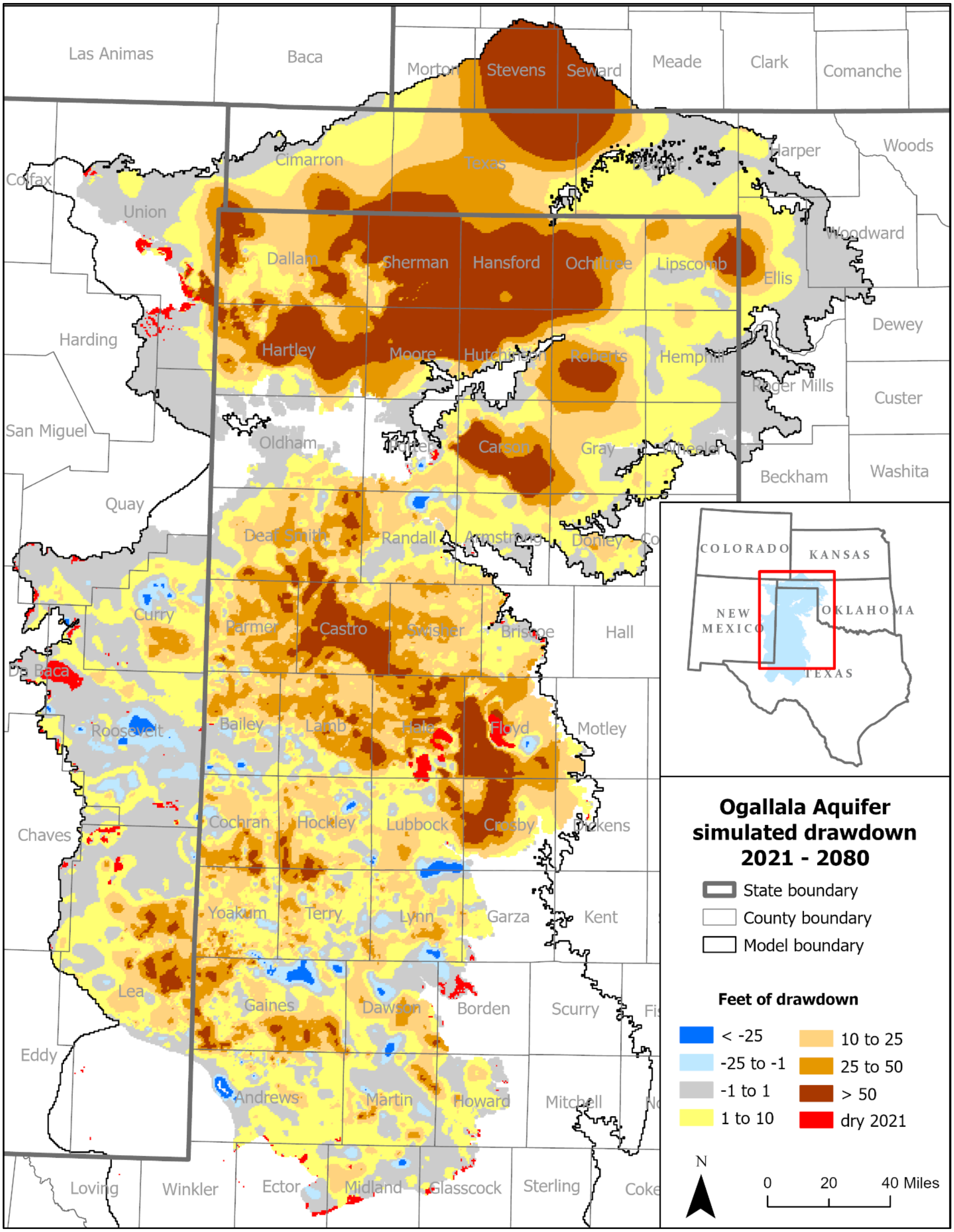

Figure 6-1 Ogallala Aquifer simulated drawdown between 2021 and 2080. Input pumping from 2021 through 2080 the same as 2020.

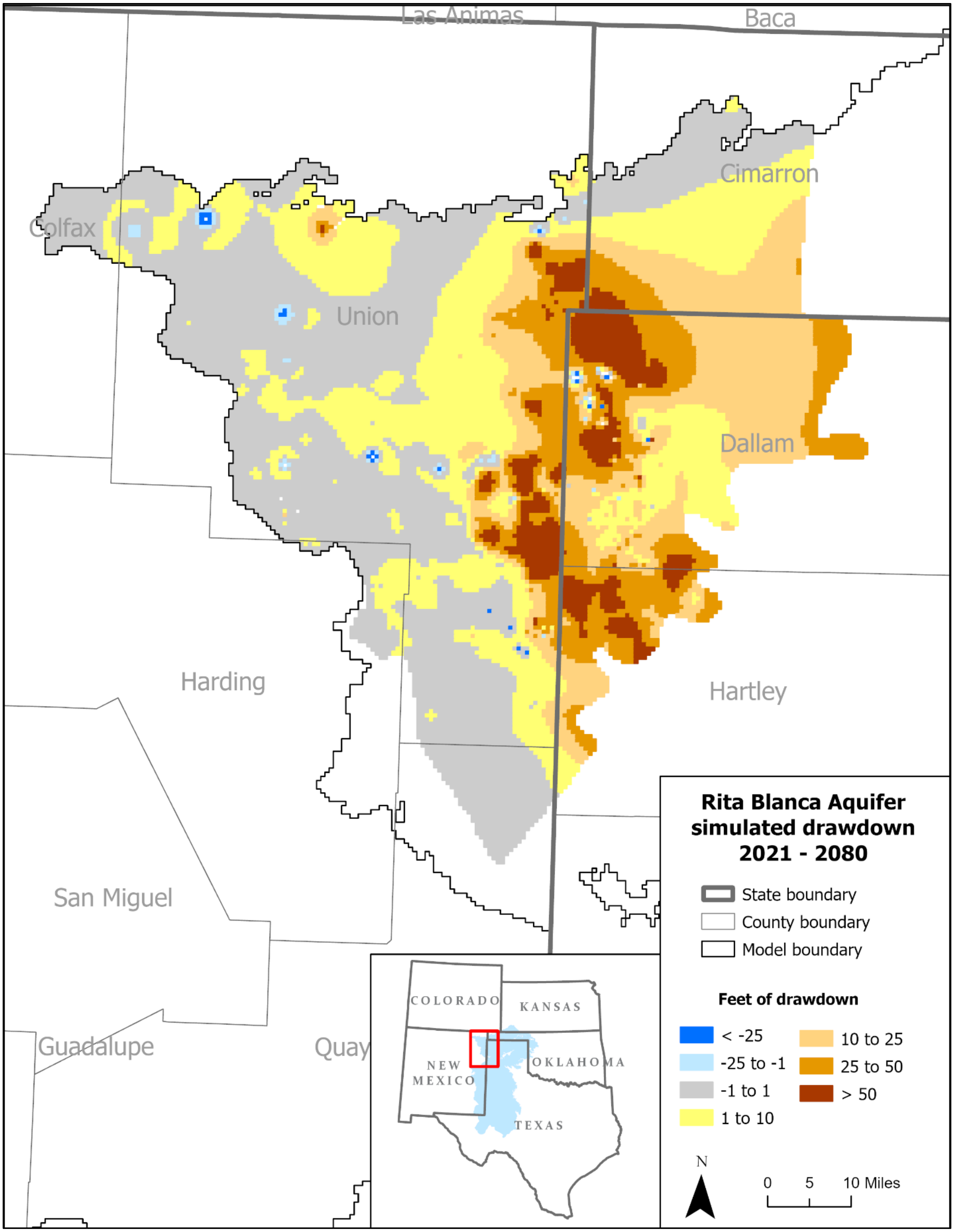

Figure 6-2 Rita Blanca Aquifer simulated drawdown between 2021 and 2080. Input pumping from 2021 through 2080 the same as 2020.

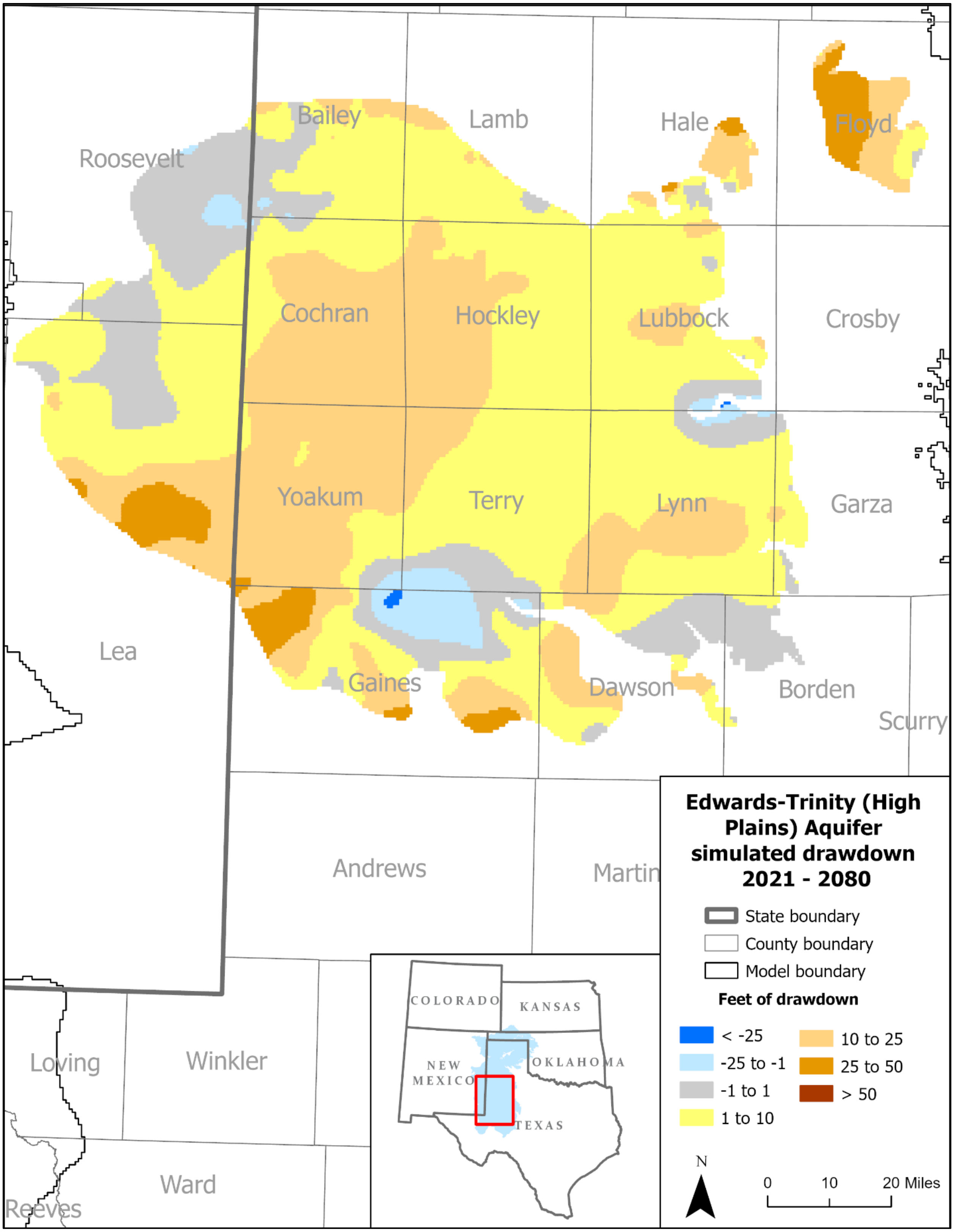

Figure 6-3 **Edwards-Trinity (High Plains) Aquifer simulated drawdown between 2021 and 2080. Input pumping from 2021 through 2080 the same as 2020.**

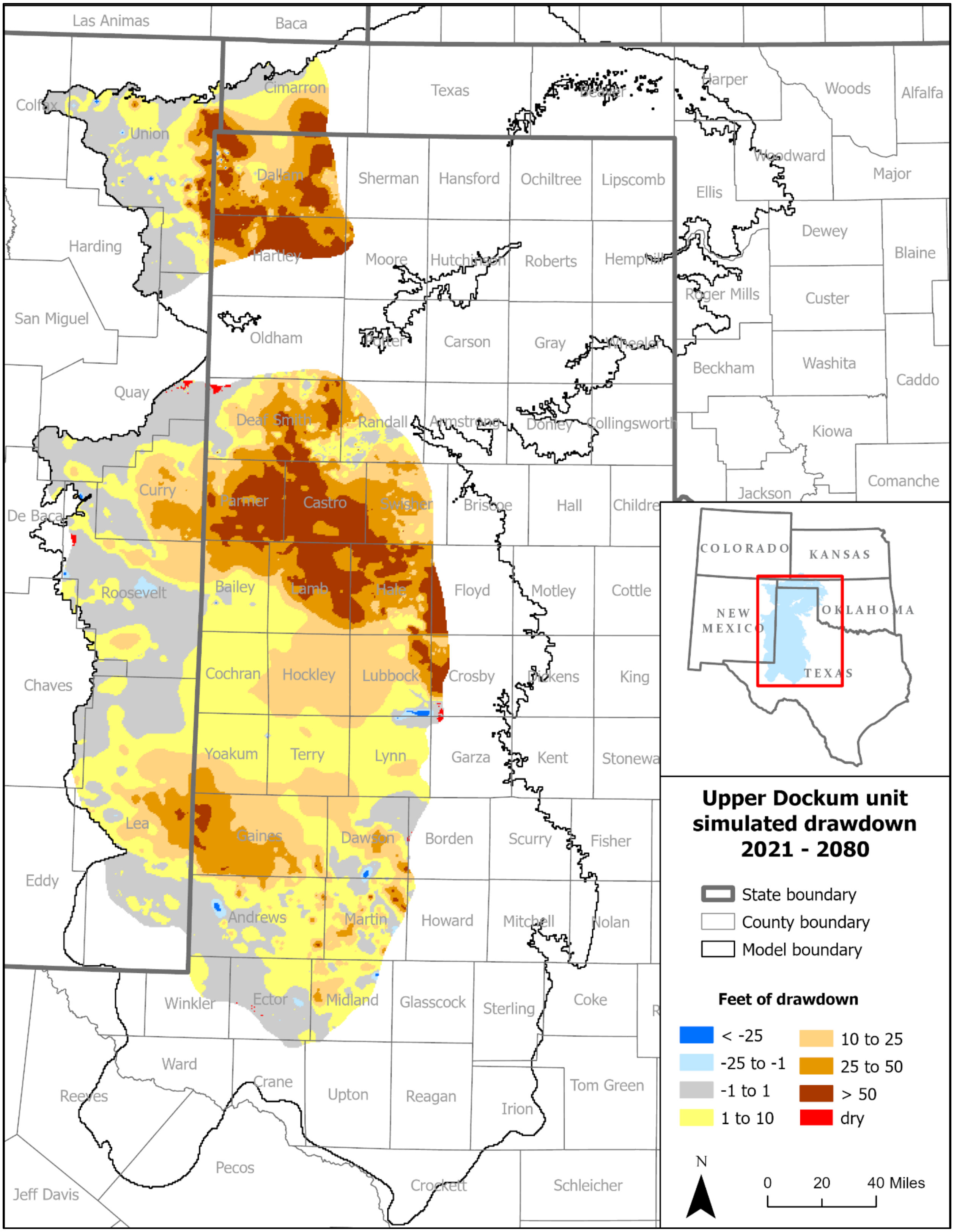

Figure 6-4 Upper Dockum unit simulated drawdown between 2021 and 2080. Input pumping from 2021 through 2080 the same as 2020.

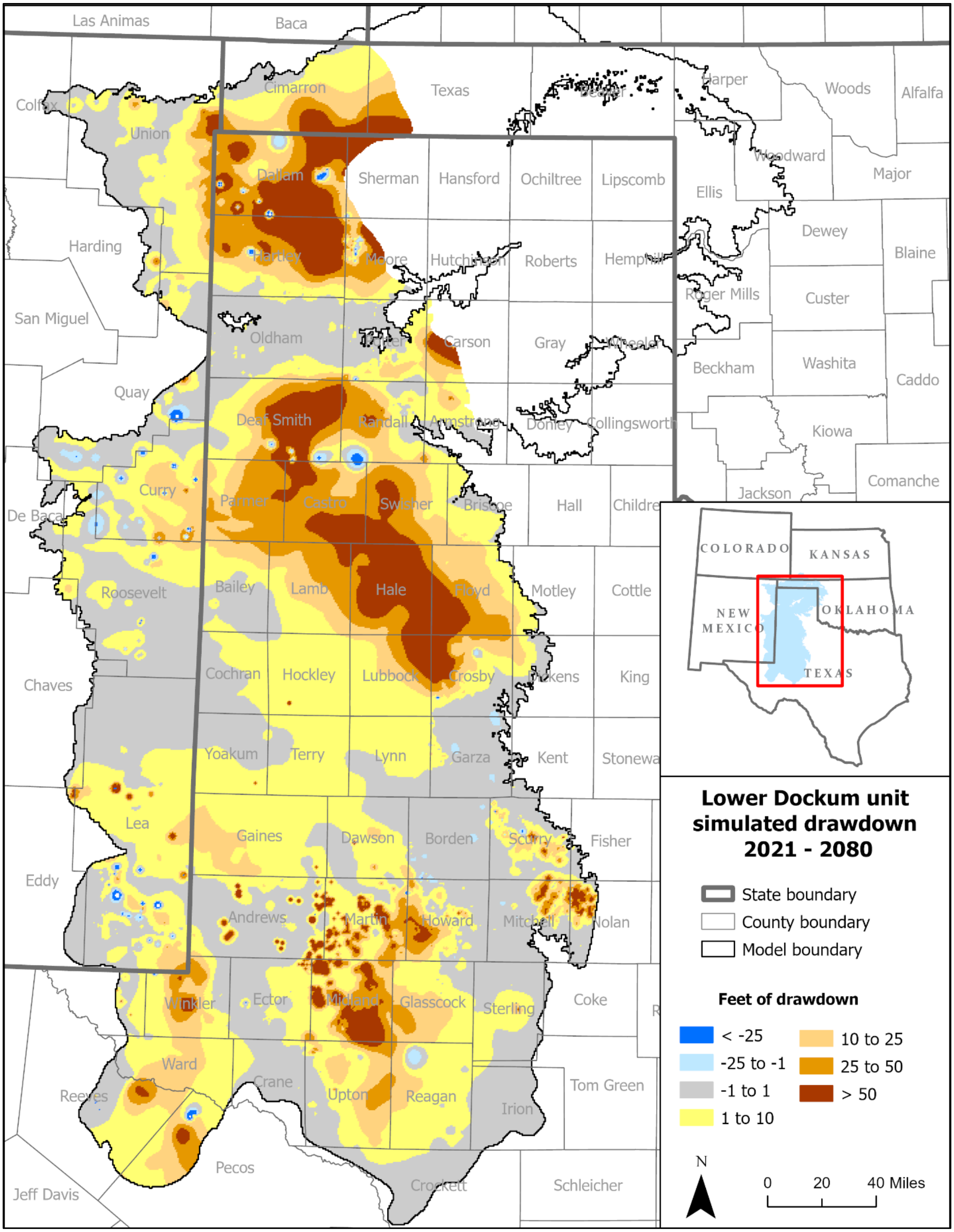

Figure 6-5 **Lower Dockum unit simulated drawdown between 2021 and 2080. Input pumping from 2021 through 2080 the same as 2020.**

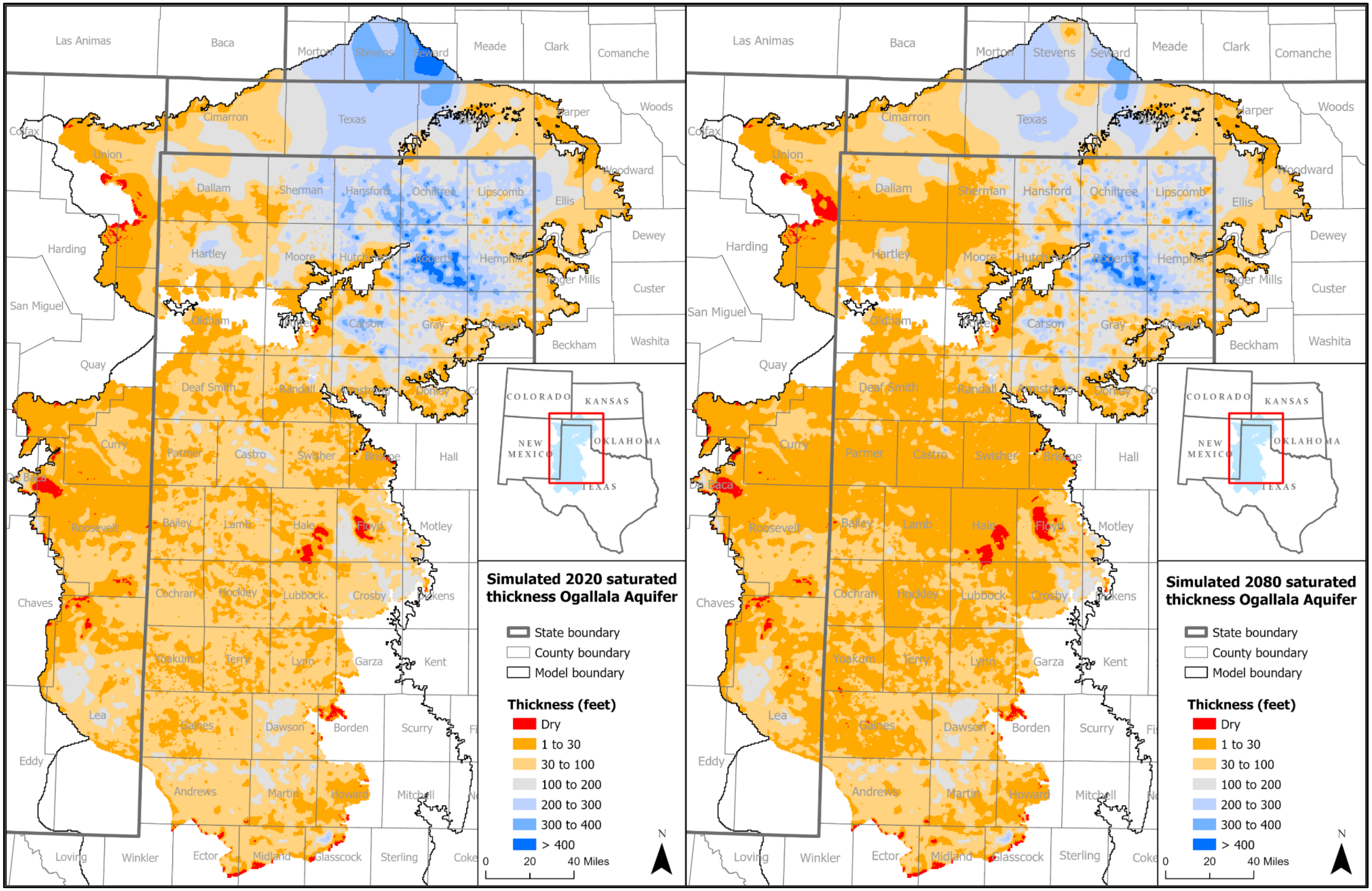

Figure 6-6 Ogallala Aquifer simulated saturated thickness in 2020 (left) compared to simulated saturated thickness in 2080 (right). Input pumping from 2021 through 2080 the same as 2020.

7 Model limitations

Numerical groundwater flow models are simplified representations of aquifer systems (Anderson and Woessner, 1992) and, as such, have limitations. These limitations are usually associated with (1) the purpose for the groundwater flow model, (2) the extent of the understanding of the aquifer(s), (3) the quantity and quality of data used to constrain parameters in the groundwater flow model, and (4) assumptions made during model development. Models are best viewed as tools to help form decisions rather than as machines to generate truth or make decisions. The National Research Council (2007) concluded that scientific advances will never make it possible to build a perfect model that accounts for every aspect of reality or be able to prove that a given model is correct in all respects for a particular application.

The purpose of the TWDB Groundwater Modeling program is the development of models to determine how regional groundwater availability is impacted by different factors, such as pumping and recharge. While the current model uses a half-mile square grid, its applicability is representative at a larger scale, such as tens of miles. The model should not be used to predict drawdown at a particular well. The model may be applicable at the scale of a large wellfield, depending on the data availability in that area of the model.

The mean absolute error of the model-simulated to observed heads ranged from approximately 30 feet to 60 feet. This means that, on average, simulated heads deviate from observed heads by this amount. However, the model performs better in some areas and worse in others, so care must be taken in using the model to estimate absolute head elevation. As a predictive tool, the model will be better at predicting changes in heads due to changes in stresses than absolute head values.

Many of the model limitations described in the Original Model report (Deeds and Jigmond, 2015) are still applicable and are included below.

> *The High Plains Aquifer System groundwater availability model should be used to estimate water availability for the Ogallala Aquifer, the Rita Blanca Aquifer, the Edwards-Trinity (High Plains) Aquifer, and the portion of the Dockum Aquifer that is represented in the model. Do not use the High Plains Aquifer System groundwater availability model for estimating water availability in the Pecos Valley or Edwards-Trinity (Plateau) aquifers. Portions of the Pecos Valley and Edwards-Trinity (Plateau) aquifers are represented as layers in the model. Although they are represented as layers, head-dependent flow boundary conditions were placed in the layers to emulate the historical response of these aquifers. Because realistic fixed flux boundaries (recharge and pumping, for example) were not used, the model is not appropriate for simulating water availability in the portions of these two aquifers represented in the model.*

MODFLOW-NWT does not account for density-dependent flow. Therefore, the higher density of the groundwater in the high total dissolved solids portion of the Dockum Aquifer and, to a lesser extent, the other portions of the aquifer which exhibit relatively high total dissolved solids concentrations are not accounted for in the governing flow equations of the model. Currently, little recharge and pumping occurs within this region of the aquifer and therefore, this shortcoming likely has little impact. However, potential future predictive simulations involving development of the high total dissolved solids portions of the Dockum Aquifer could be impacted by this limitation.

Pumping, which is by far the largest source of discharge from the model, is uncertain because estimates of pumping are dependent on secondary sources, such as crop areas and application rates, which are themselves uncertain. Although some metering or more direct use reporting has occurred in recent years (for example, North Plains Groundwater Conservation District), the lack of historical data results in the pumping being revised during calibration. This occurred both in previous modeling efforts for the Ogallala Aquifer and in the current study.

The primary type of calibration target used in most models, including this groundwater availability model, is hydraulic head. Wells in the Rita Blanca and Edwards-Trinity (High Plains) aquifers are often screened at least partially in the Ogallala Aquifer, which may impact the applicability of water level measurements in describing actual water levels in those aquifers. Although development of the Dockum Aquifer is increasing, the available head data in many areas is sparse or has little temporal consistency.

8 Summary and conclusions

This project was initiated to extend the groundwater availability model for the High Plains Aquifer System (Deeds and Jigmond, 2015) from 2012 through 2020. Ultimately, the Model Extension performs as well as the Original Model. Model statistics did not degrade, hydrographs generally maintained trends, and groundwater budgets were in agreement. The updated groundwater availability model meets the TWDB Groundwater Modeling standards (TWDB, 2023a), and can be used as a tool to assist in groundwater management and planning efforts. A list of improvements for any future model updates are included in Section 8.1.

8.1 Future improvements

Groundwater availability models are considered ‘living tools’. In other words, they are subject to periodic updates to improve model results and to make the models better groundwater management tools. Below is a discussion of possible model improvements that may be incorporated into future updates to this model.

As discussed in Sections 2.1 and 2.7, using the model framework to assign aquifers to new Texas Submitted Drillers Report Database wells and New Mexico wells initially resulted in excessive wells being assigned to the upper Dockum unit (Layer 3) unit, which is highly saline and considered an aquitard. This was especially the case from roughly Yoakum and Terry counties in the north to Ector and Midland counties in the south. Driller logs in this area were examined to compare the elevation for the top of the Dockum units with the model framework. For many logs, the top of the upper Dockum unit was referred to as “red beds” and it was usually below the elevation top of the Dockum for the corresponding model cell. For future model updates, an assessment of the current model framework could provide possible refinements to some areas to delineate the top of the upper Dockum unit.

In recent years there has been significant advancement in the automation of mapping center pivot systems and irrigated lands using machine learning techniques. These methods have been successfully tested for mapping center pivots in the High Plains Aquifer System area (Cooley and others, 2021; Fagin and others, 2024). Using these automation methods or datasets developed by these methods could greatly reduce the time needed to manually map irrigated lands or to merge multiple groundwater conservation district datasets. These methods could be used to identify annual changes to irrigated lands and provide much greater temporal coverage than a single dataset snapshot provides.

At the beginning of this effort, we attempted to update the model from MODFLOW-NWT to MODFLOW 6. This was unsuccessful because the Original Model MODFLOW-NWT executable was customized to have model-reduced pumping start at a minimum absolute thickness of 30 feet rather than a percentage of saturated thickness. If this customization to the MODFLOW-NWT source code is going to be included in a future High Plains Aquifer System model update to MODFLOW 6, then the MODFLOW 6 source code will need to be customized.

The Rita Blanca Aquifer was the one aquifer for which the mean absolute error increased substantially from the Original Model. The Rita Blanca has limited model-wide influence since it only covers two Texas counties. However, it may be useful to further investigate and refine this aquifer for modeling purposes.

In addition to the above recommendations from the Model Extension, the Original Model report (Deeds and others, 2015) included the following recommendations:

> *As water levels decline, producers respond to decreasing per-well production by drilling additional wells, or increasing activity in areas where saturated thickness is more favorable. During model calibration, this process was emulated by iteratively distributing pumping to other wells in a county when MODFLOW-NWT limited the well production due to small saturated thickness. Iteratively meant running and rerunning the model multiple times. A relatively simple improvement would be to change the*

well package so that after each stress period, the code would assess which wells were going to be limited in pumping due to saturated thickness limits, and reallocate that pumping to other wells with better capacity. This would greatly streamline the calibration process.

Analysis of the model water budget indicated that a relatively small rate of flux occurs between the Ogallala Aquifer and the minor aquifers it overlays. However, in the case of the upper Dockum Aquifer and portions of the Edwards-Trinity (High Plains) and lower Dockum aquifers, even this small amount of flux could bring highly saline water into water lying at the base of the Ogallala Aquifer. Performing some basic transport calculations and estimating the impact on Ogallala Aquifer water quality would help constrain the model estimated flux rates.

A large portion of the modeled Dockum Group exhibits total dissolved solids concentrations in excess of 5,000 milligrams per liter. The greater density of this water is not accounted for in the governing equations of groundwater flow used in MODFLOW. If predictive simulations are going to include development of the aquifer within the high total dissolved solids region, use of a simulator with the capability of simulating density-dependent flow (for example, SEAWAT) may be warranted. It would be useful just to use SEAWAT with the current model to perform sensitivity analyses and answer the question of whether density dependence is even important for availability in the Dockum Aquifer.

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Appendix A: County pumping graphs

Figure A-1 County graphs for Texas comparing 2005 through 2020 model input pumping for the Ogallala Aquifer to various sources of pumping.

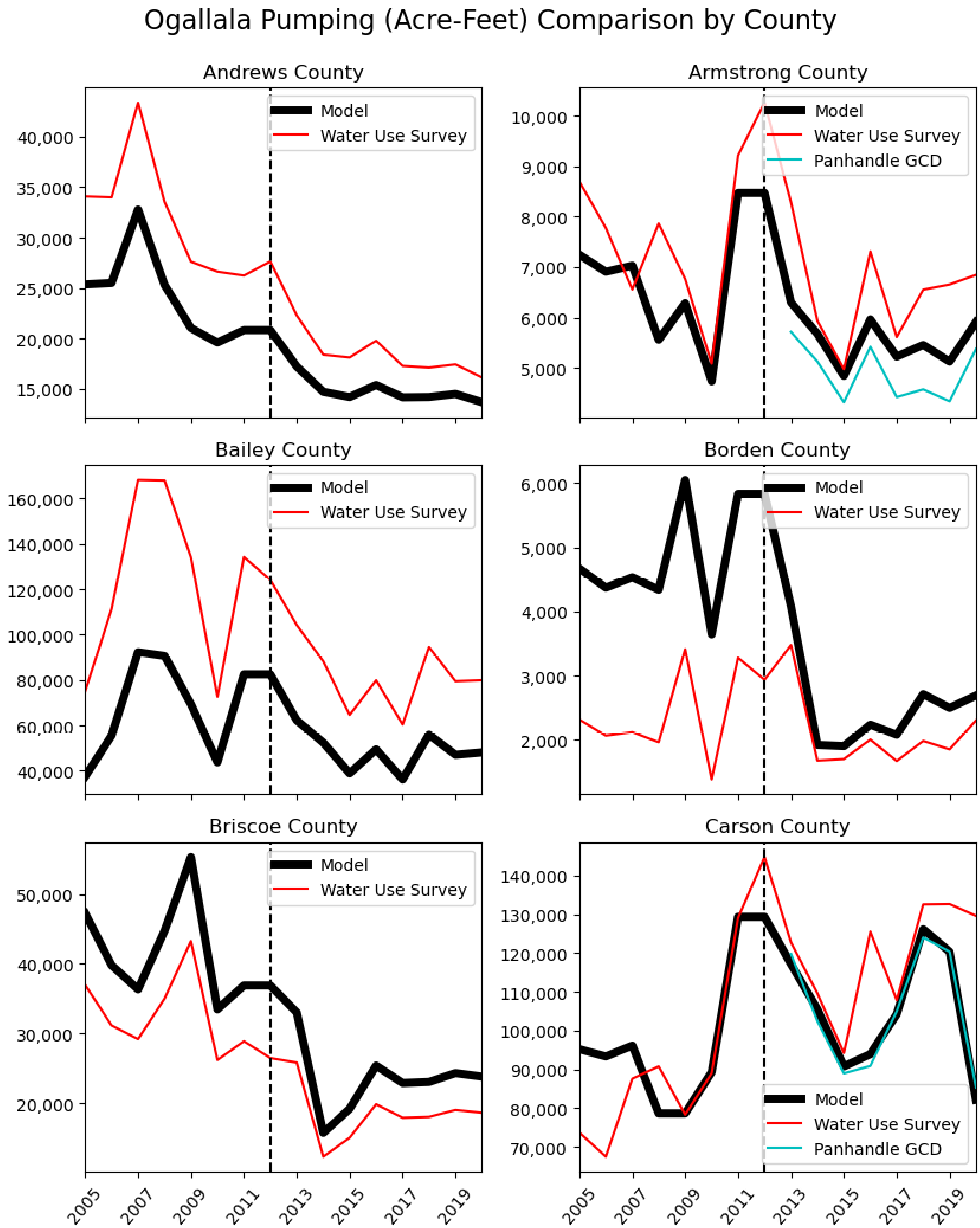


Figure A-1 continued

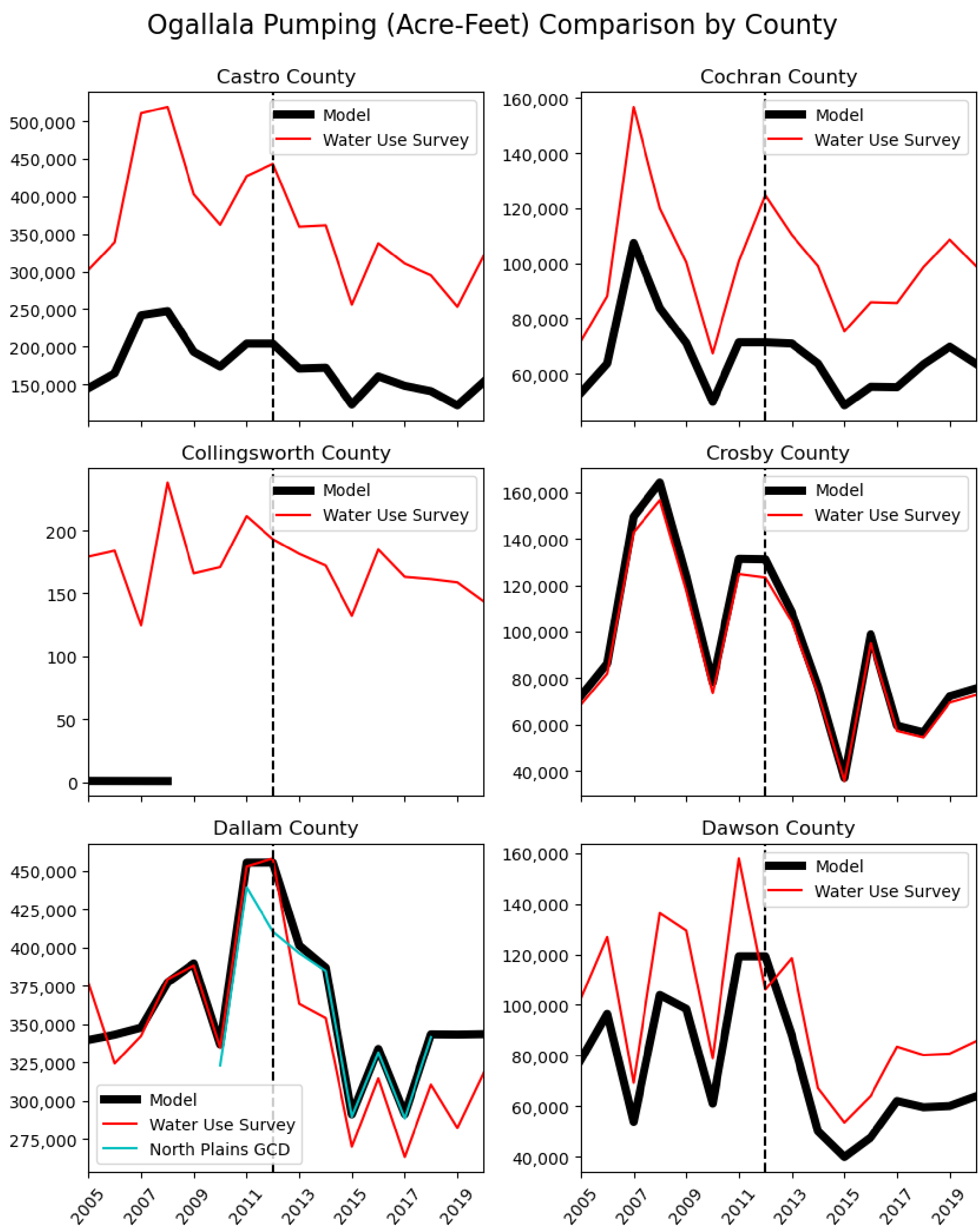


Figure A-1 continued

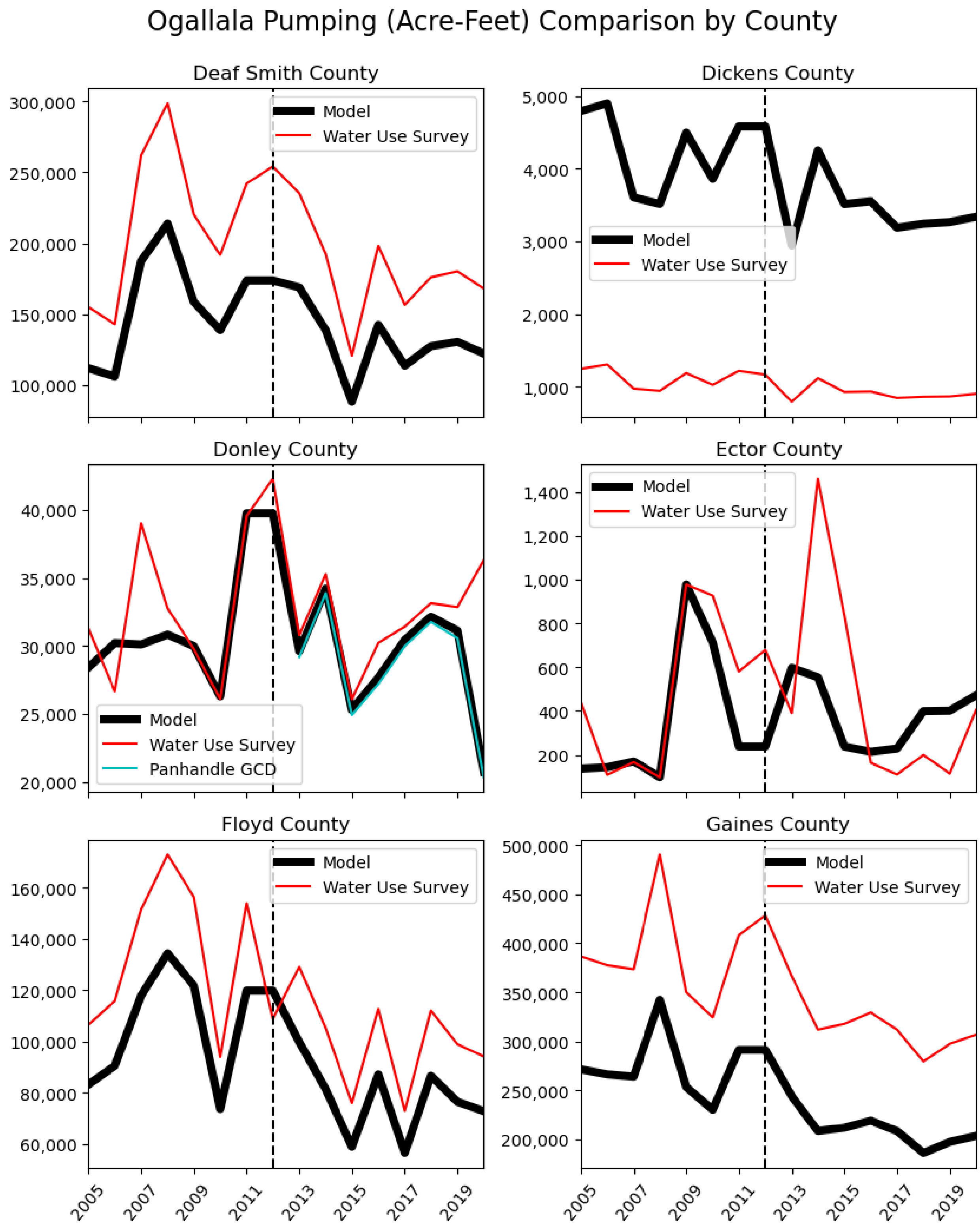


Figure A-1 continued

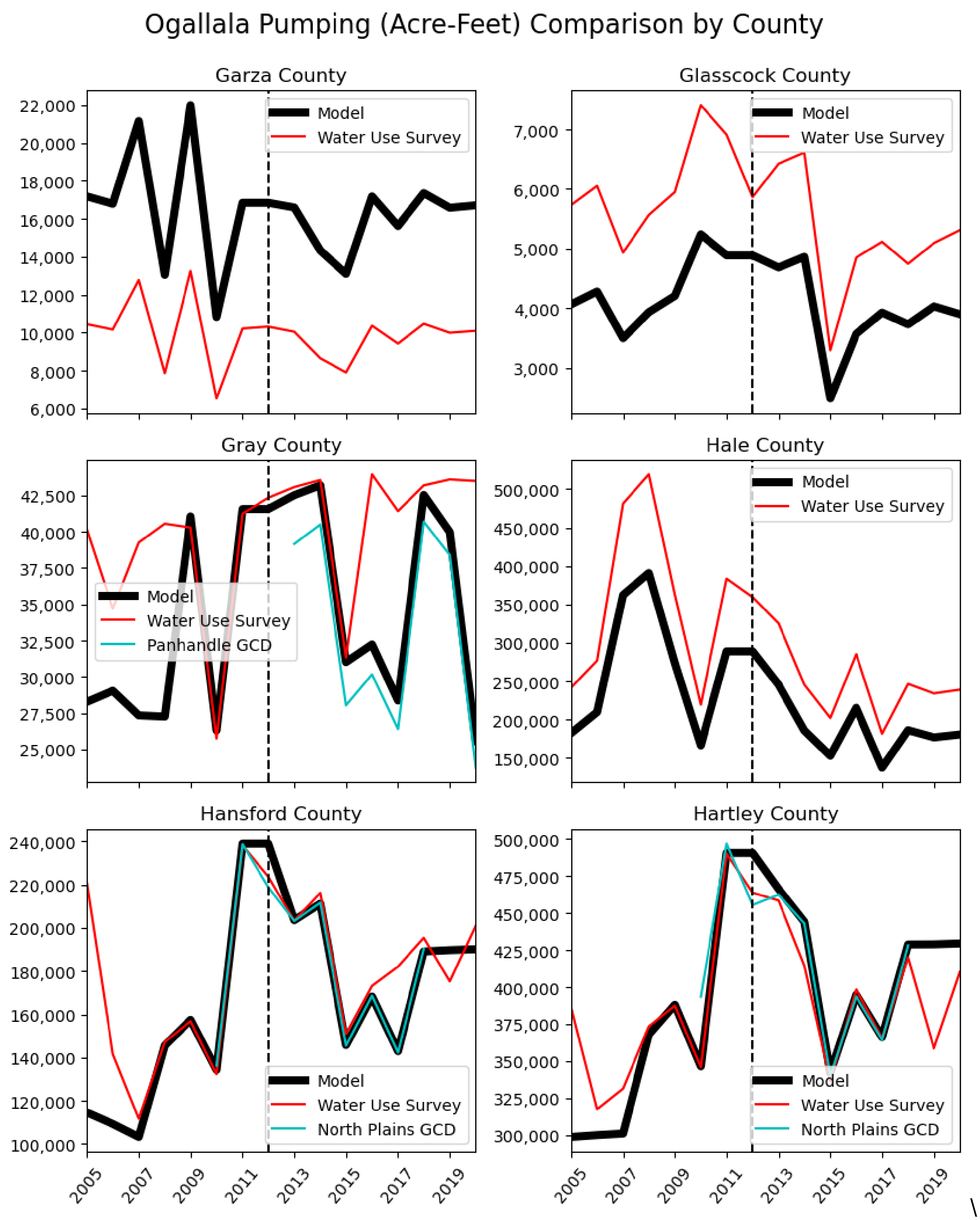


Figure A-1 continued

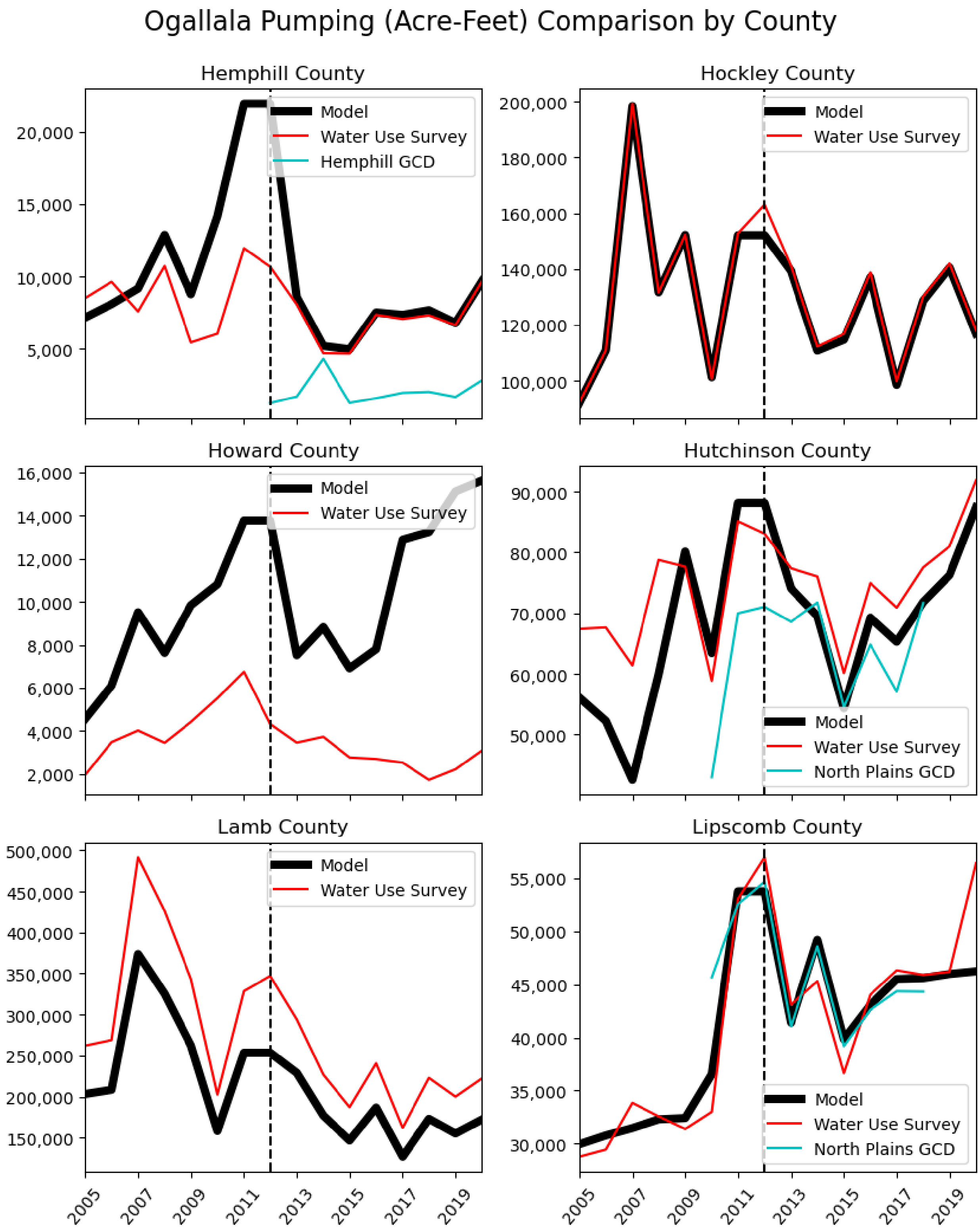


Figure A-1 continued

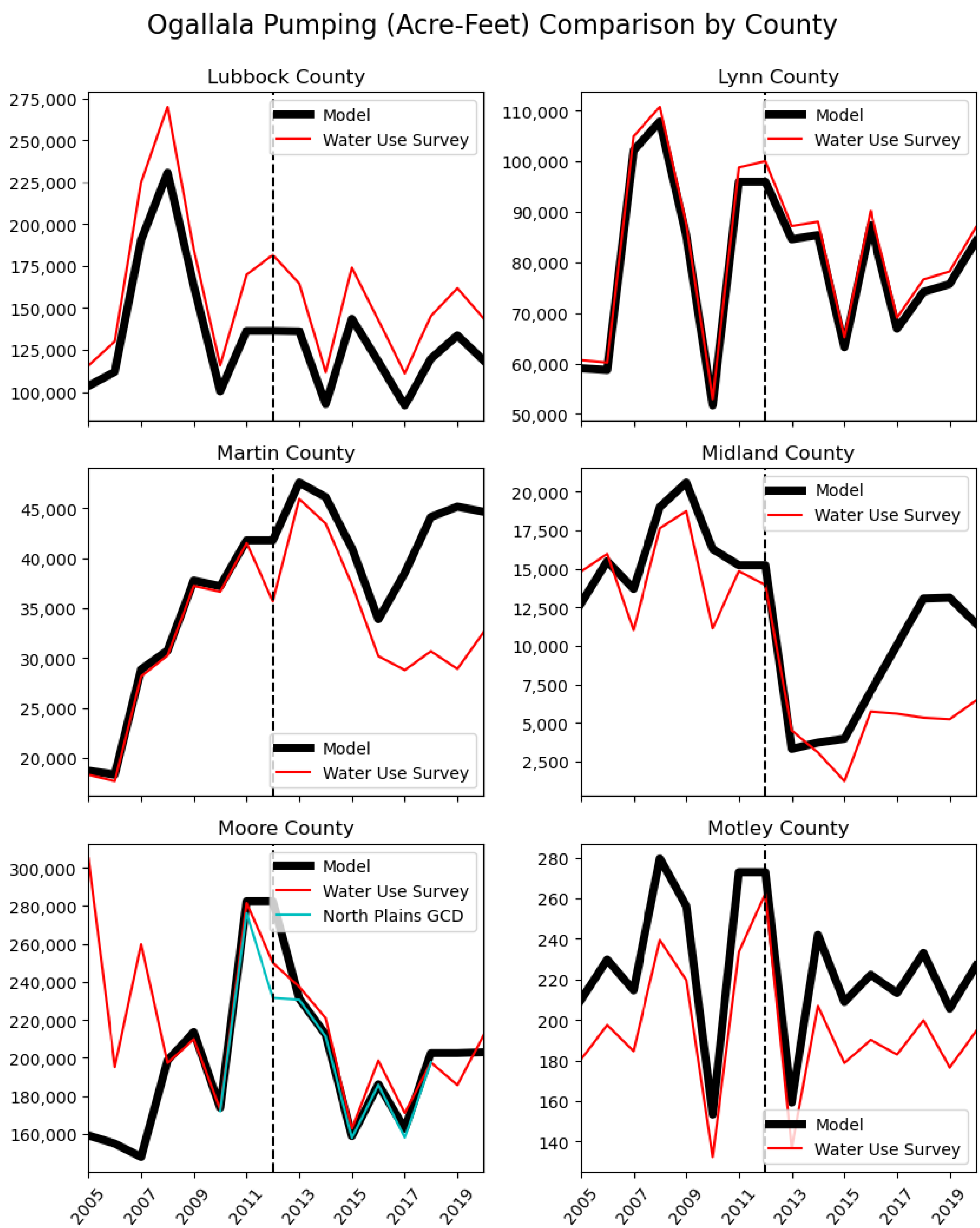


Figure A-1 continued

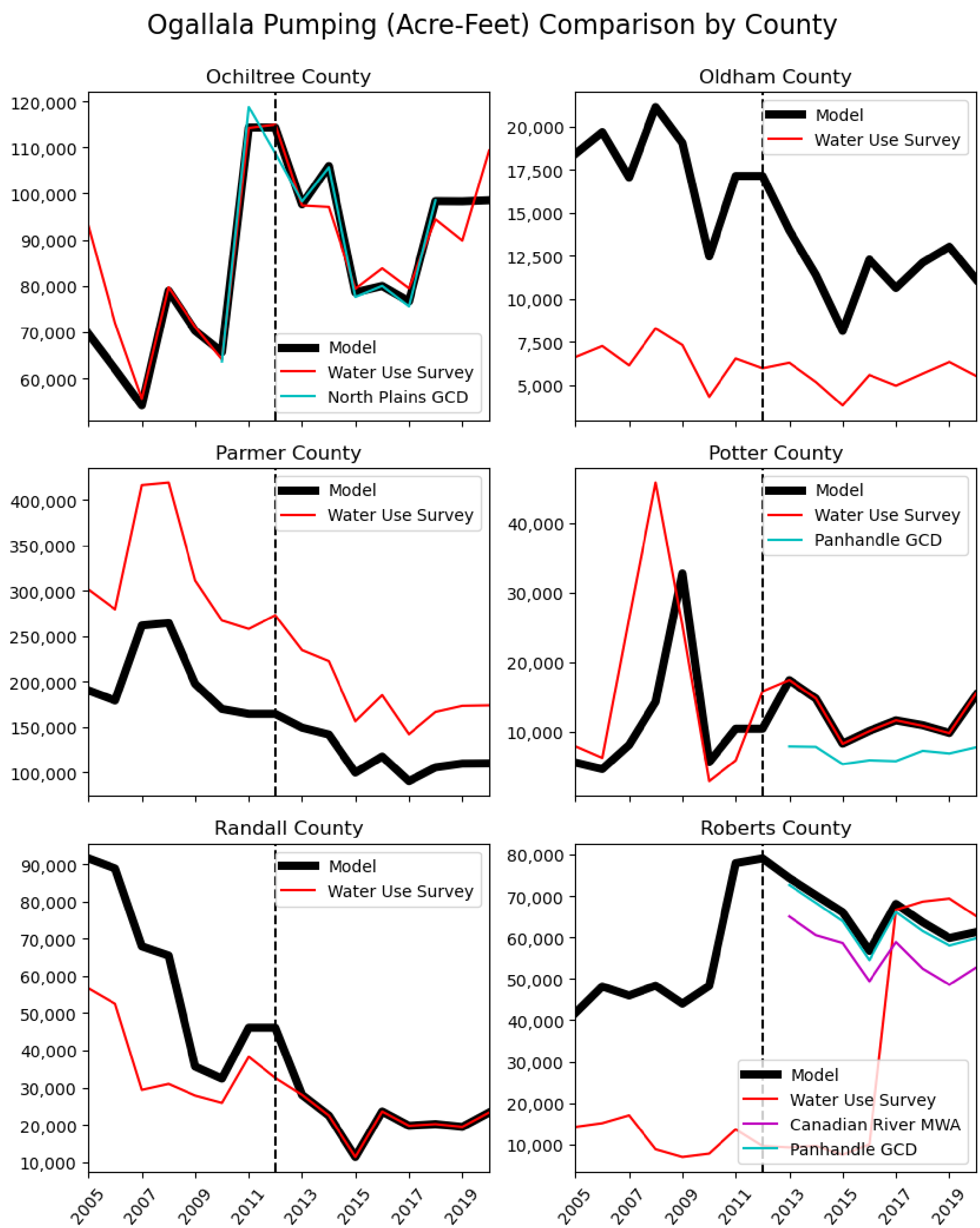


Figure A-1 continued

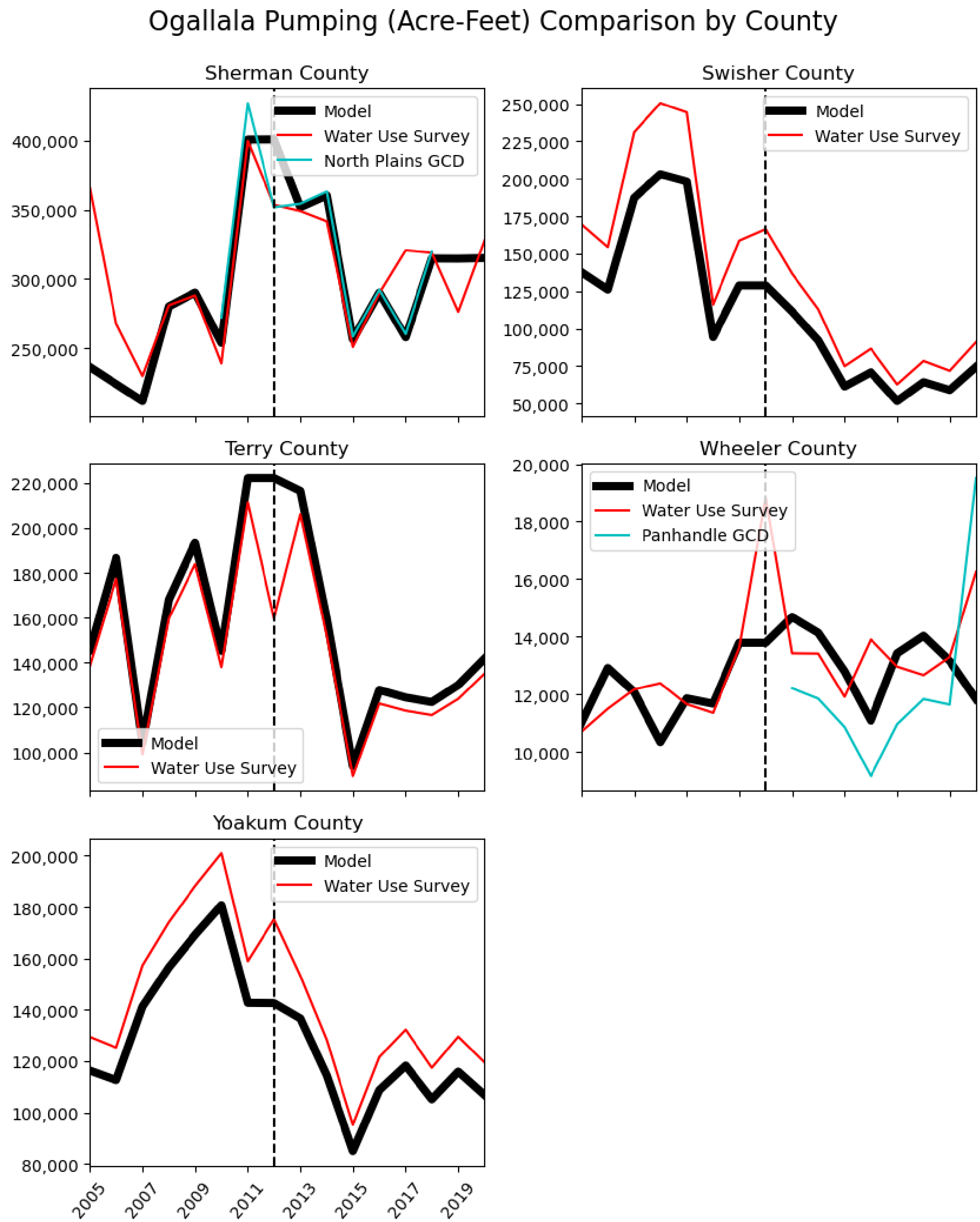


Figure A-2 County graphs for Texas comparing 2005 through 2020 model input pumping for the Rita Blanca Aquifer to various sources of pumping.

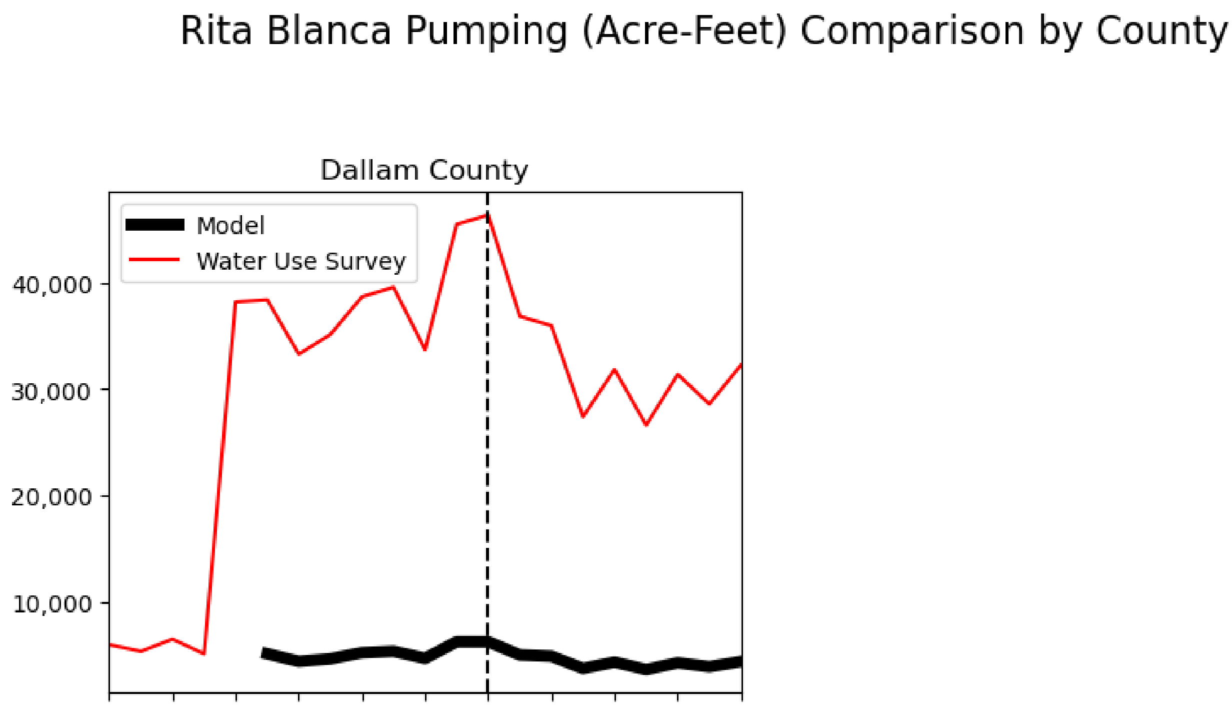


Figure A-3 County graphs for Texas comparing 2005 through 2020 model input pumping for the Edwards-Trinity (High Plains) Aquifer to various sources of pumping.

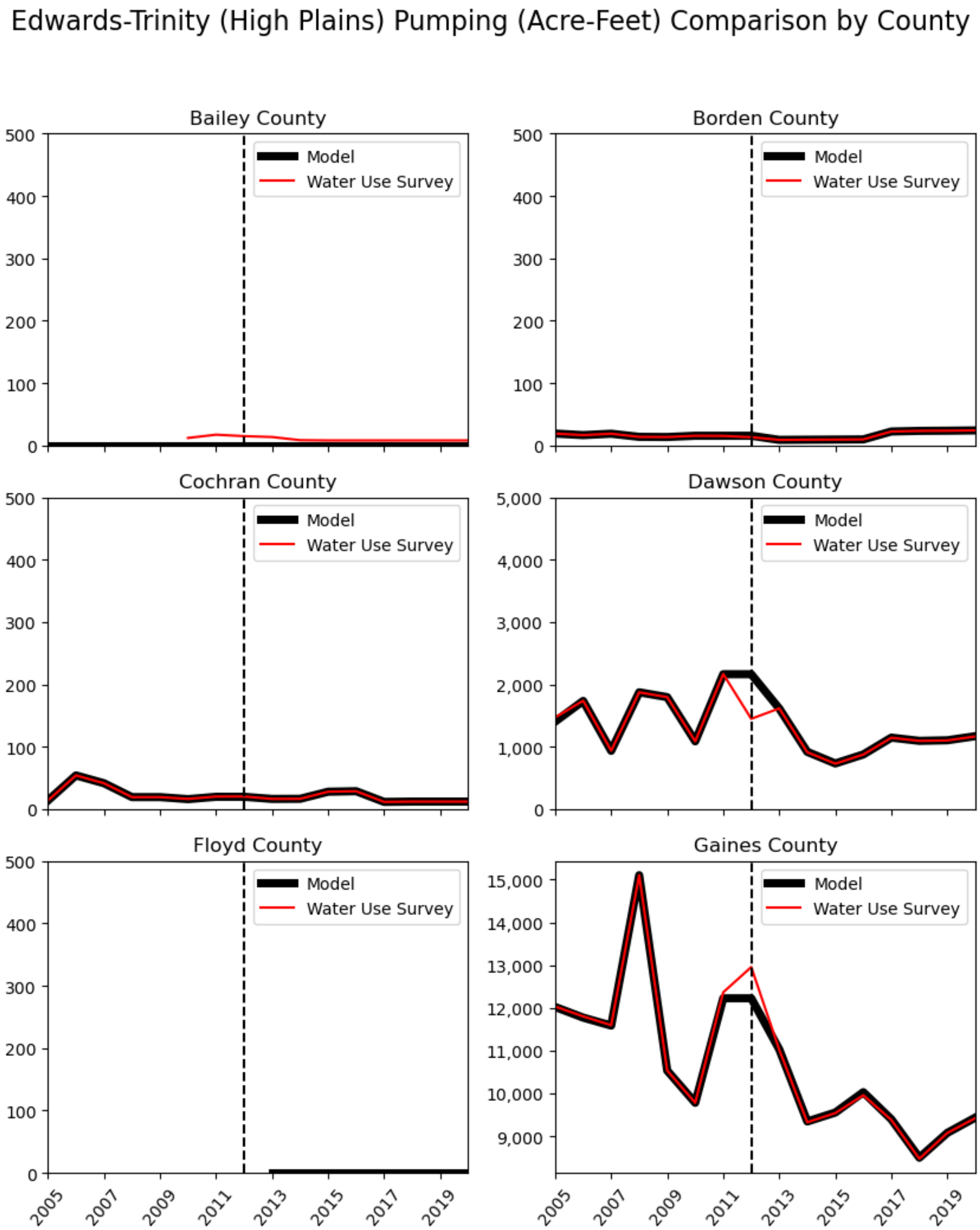


Figure A-3 continued

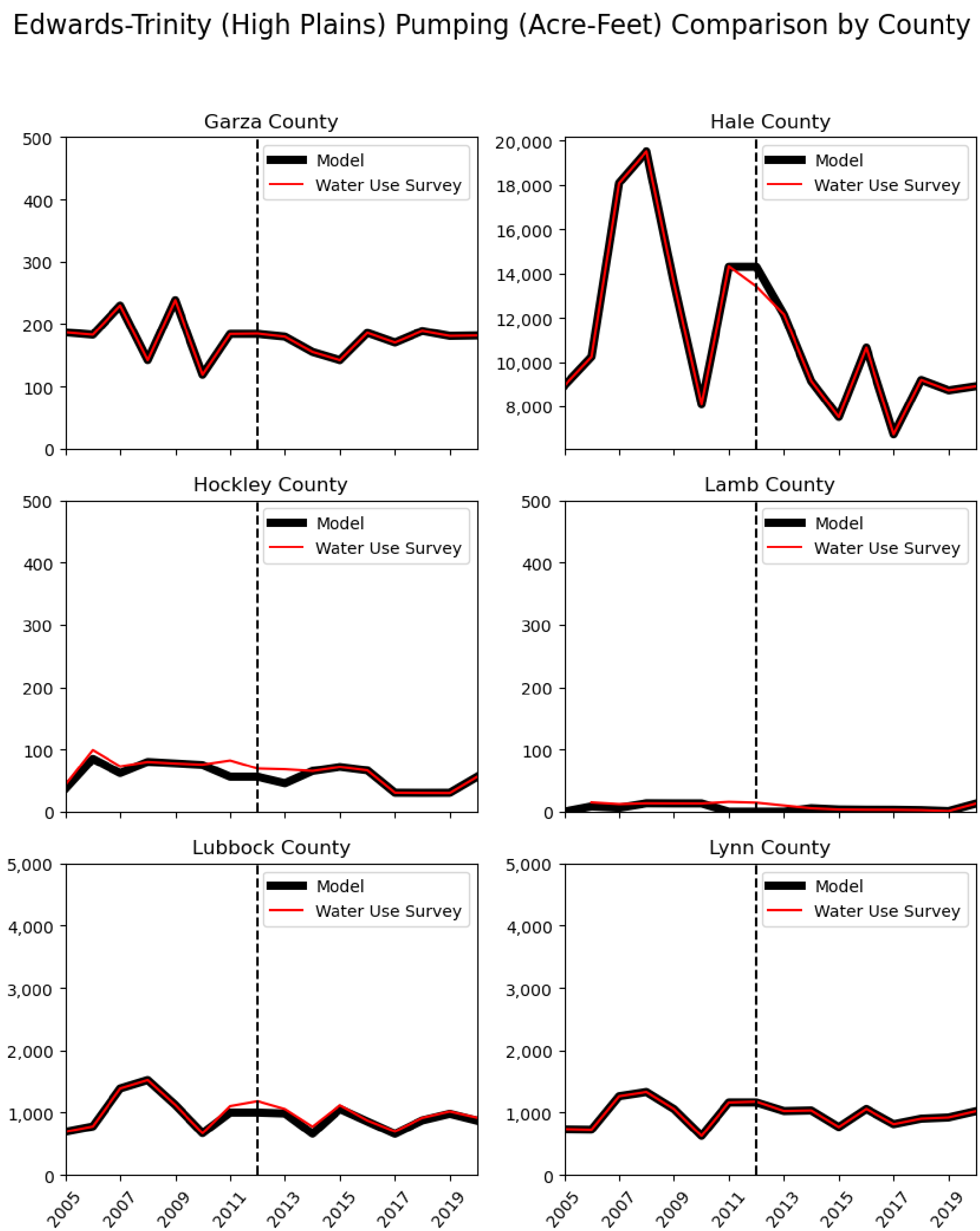


Figure A-3 continued

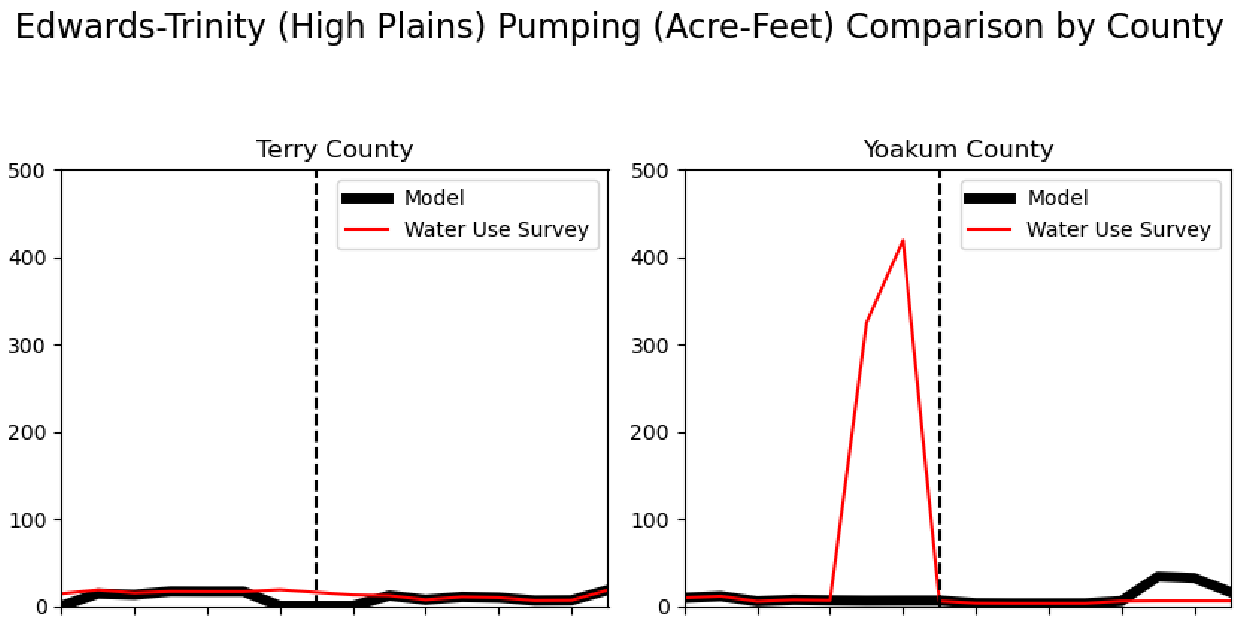


Figure A-4 County graphs for Texas comparing 2005 through 2020 model input pumping for the Dockum units to various sources of pumping.

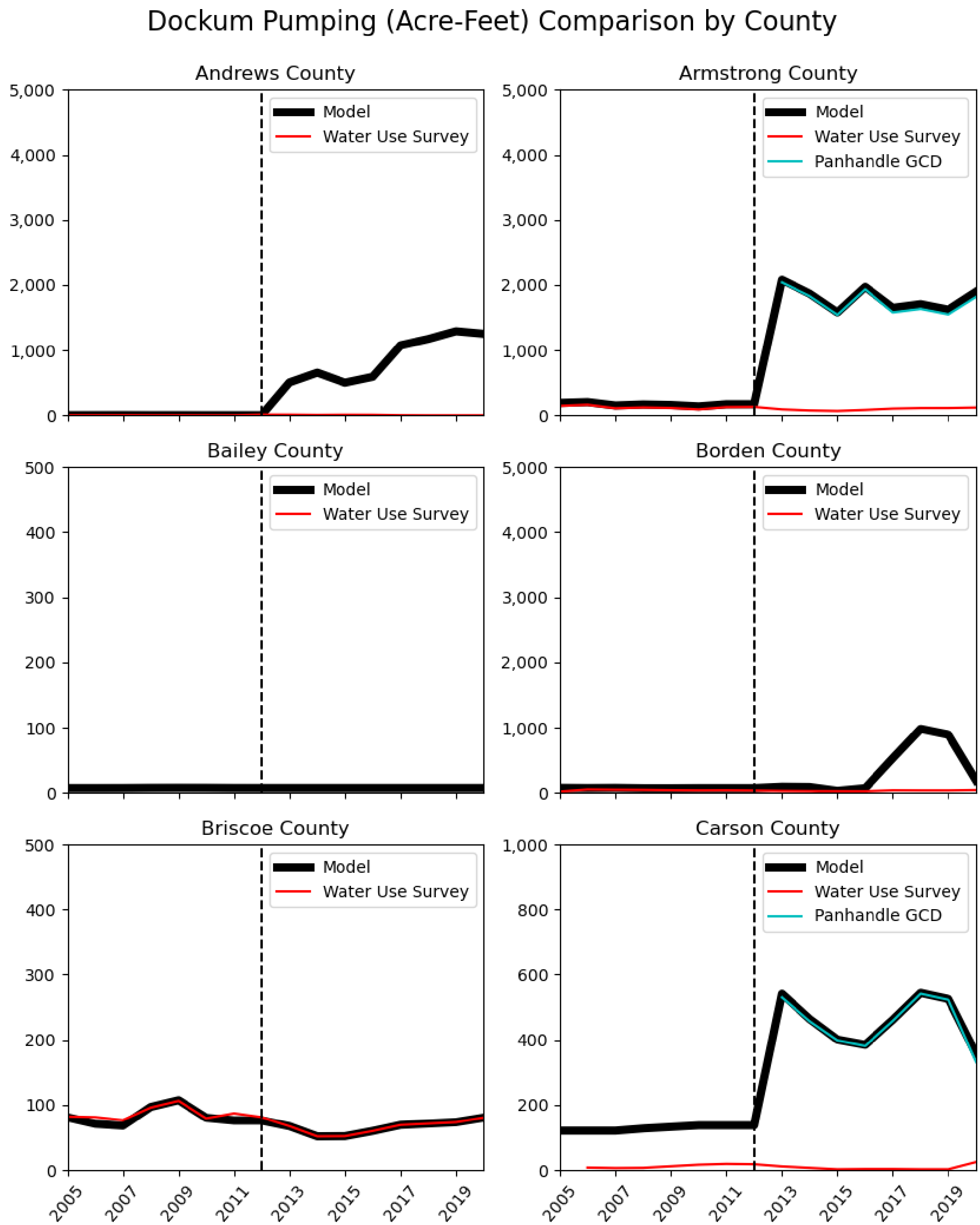
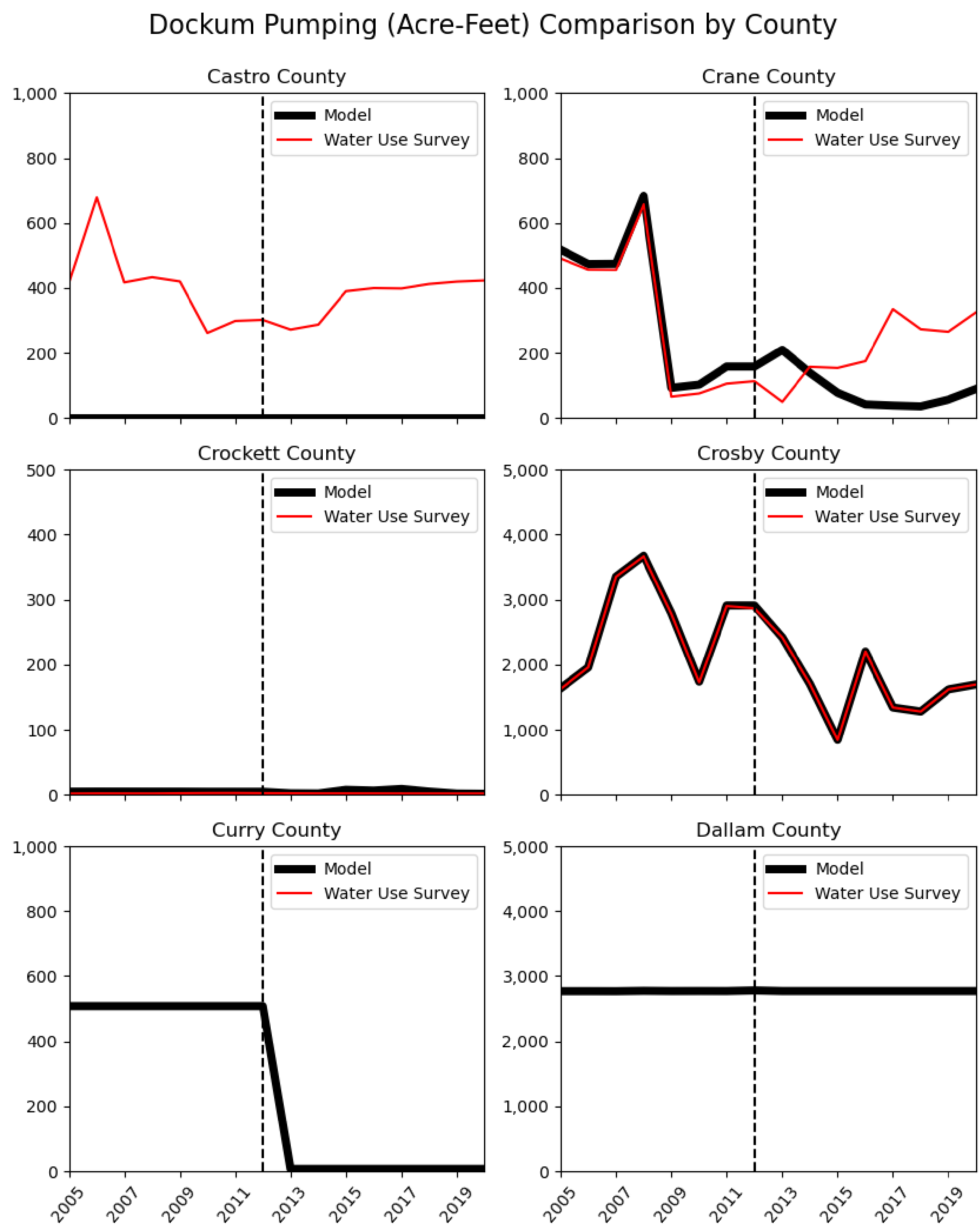


Figure A-4 continued



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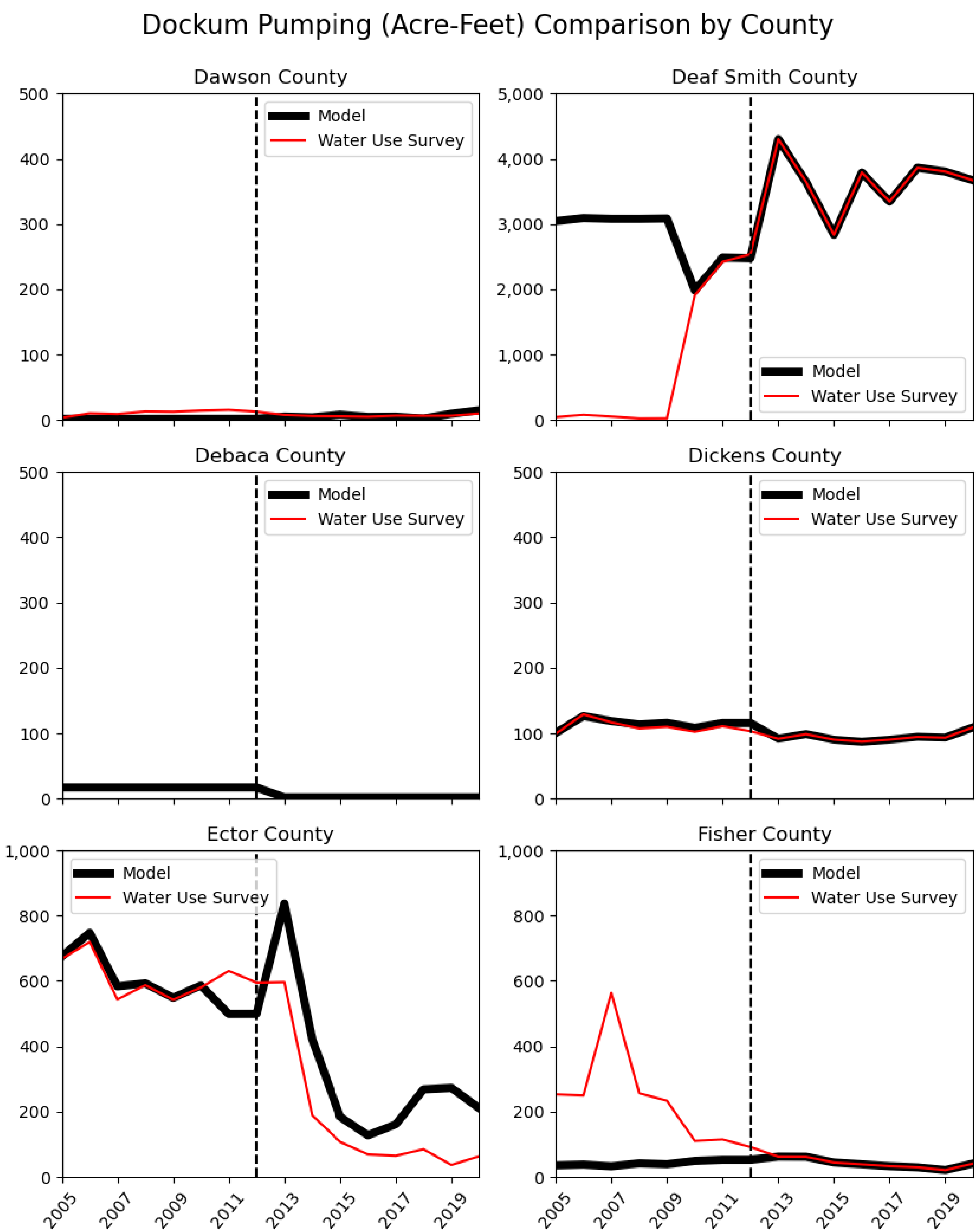

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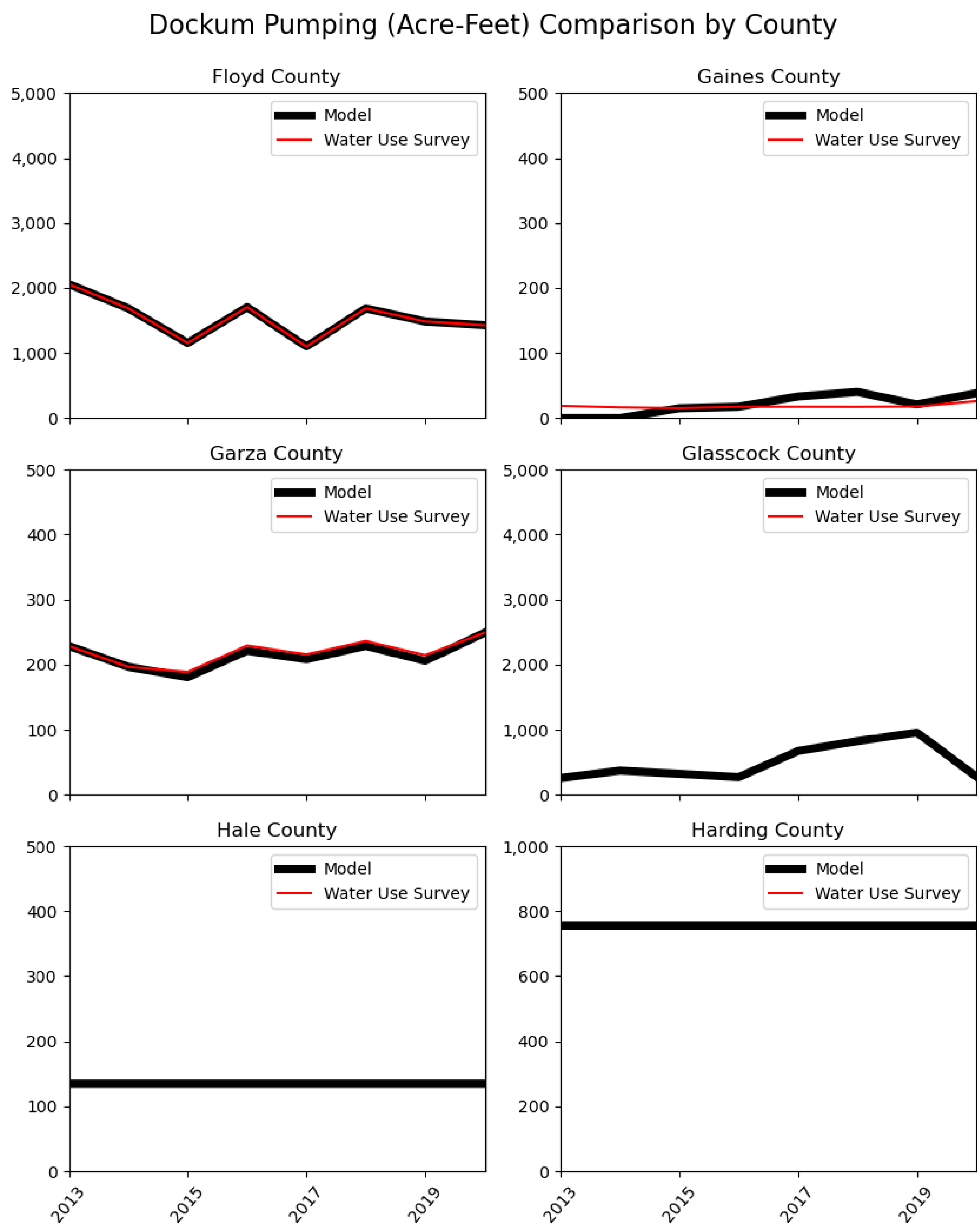


Figure A-4 continued

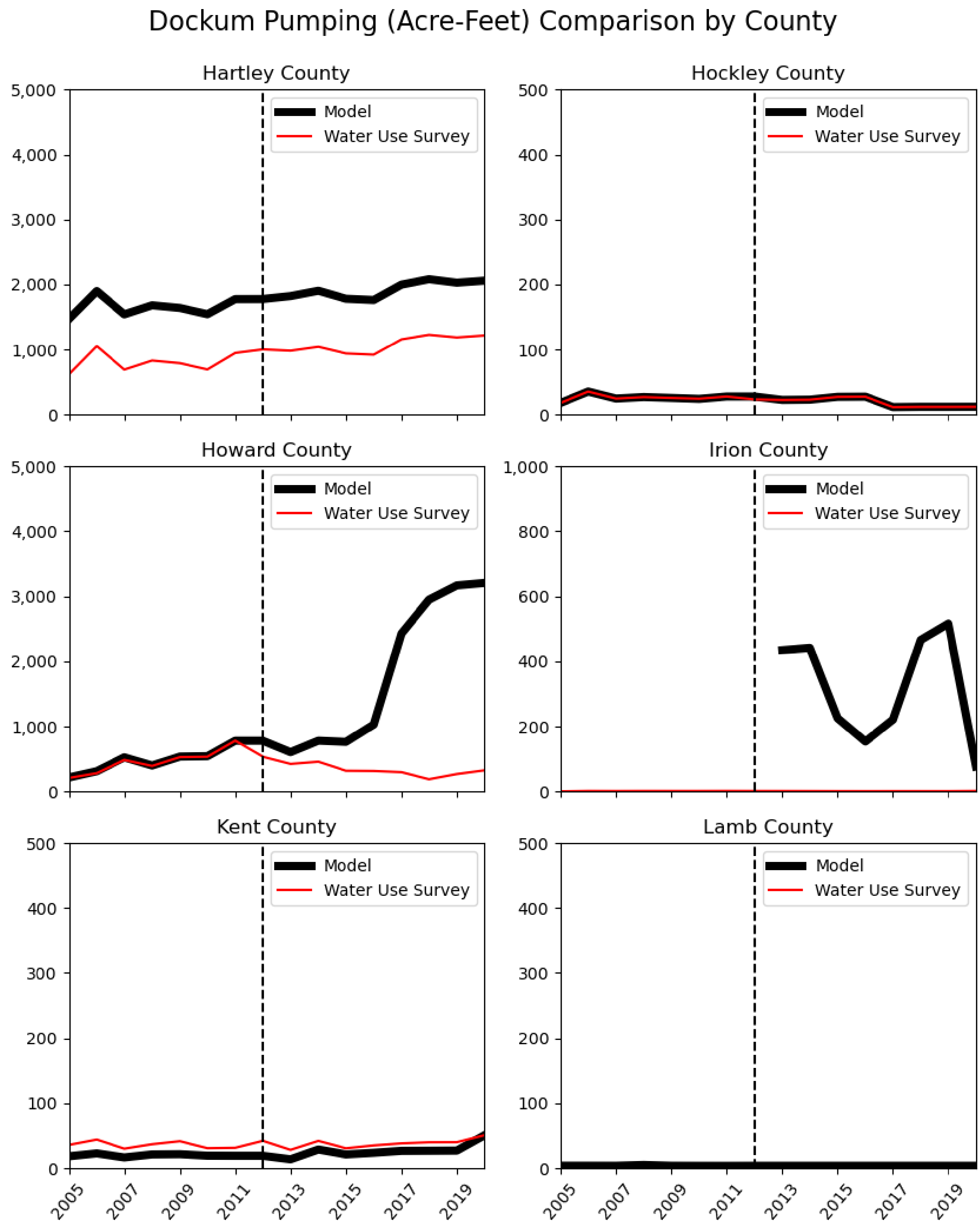


Figure A-4 continued

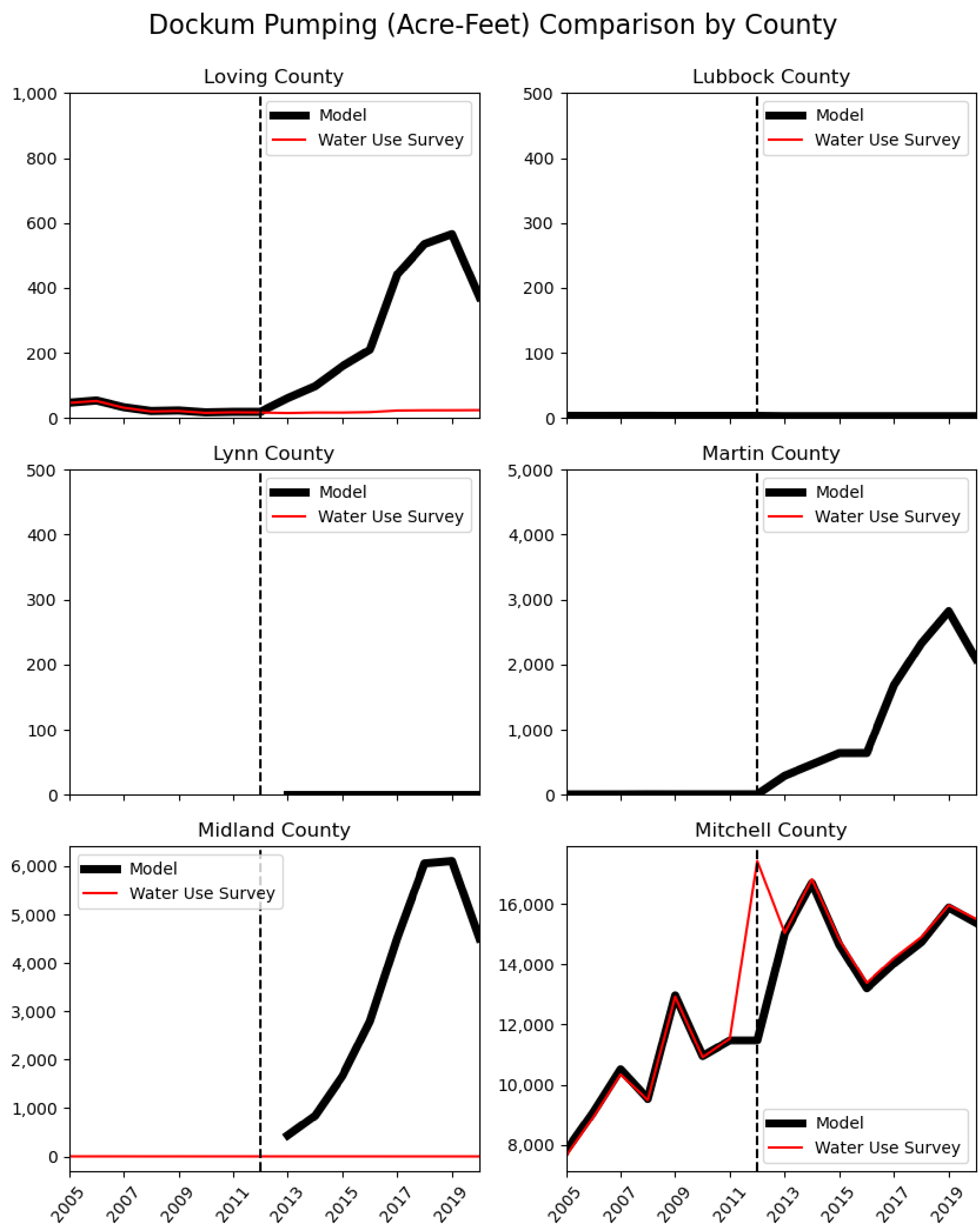


Figure A-4 continued

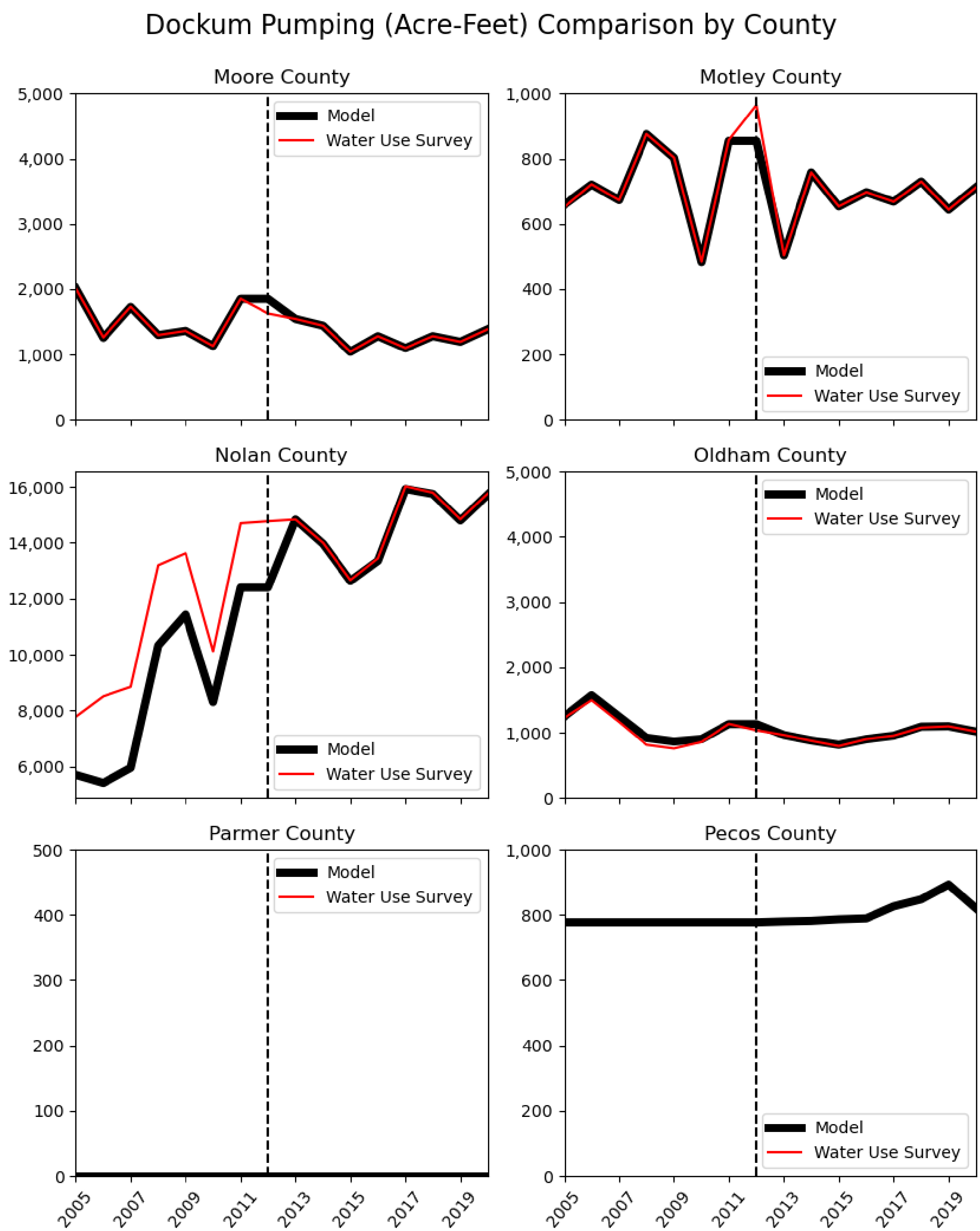


Figure A-4 continued

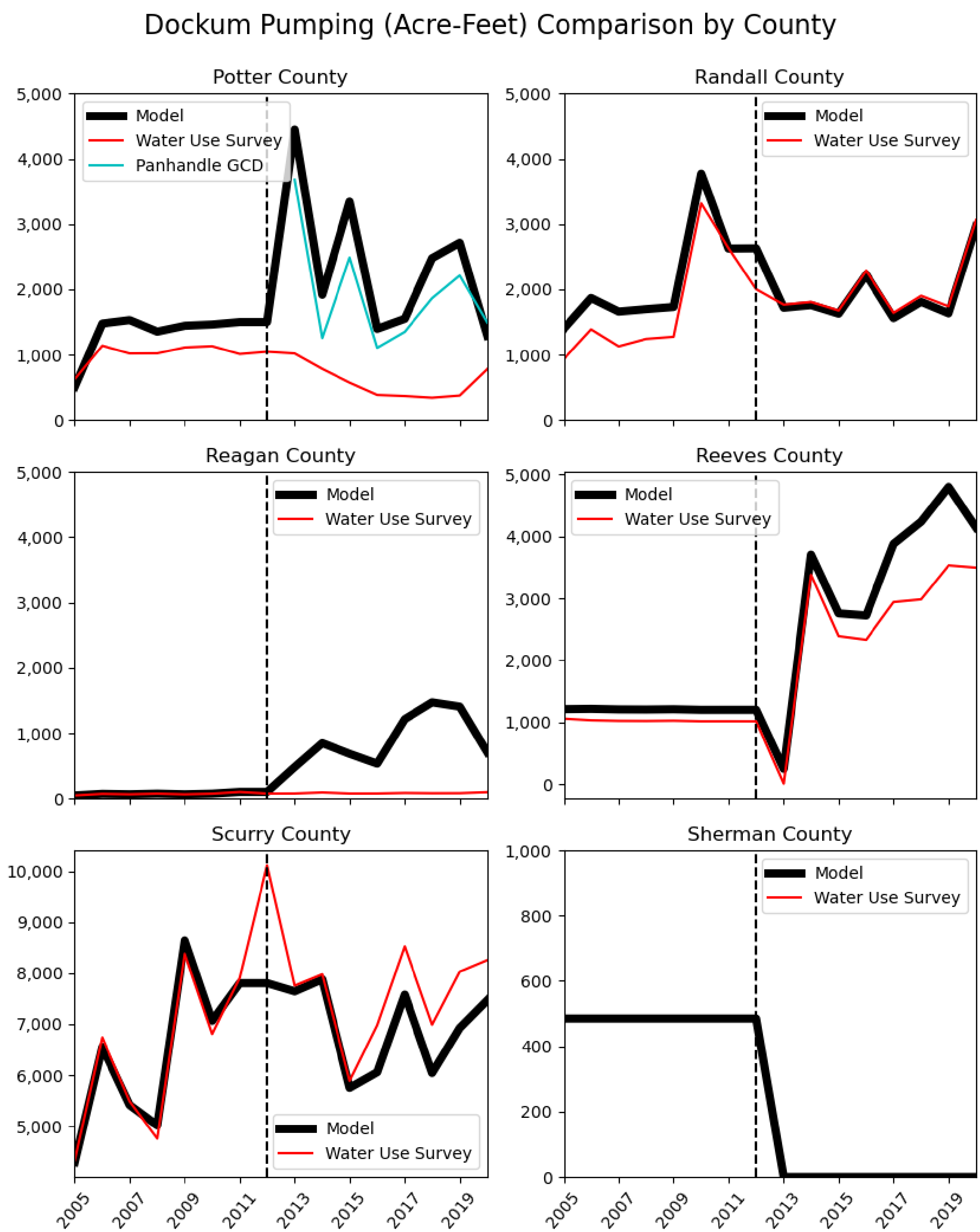
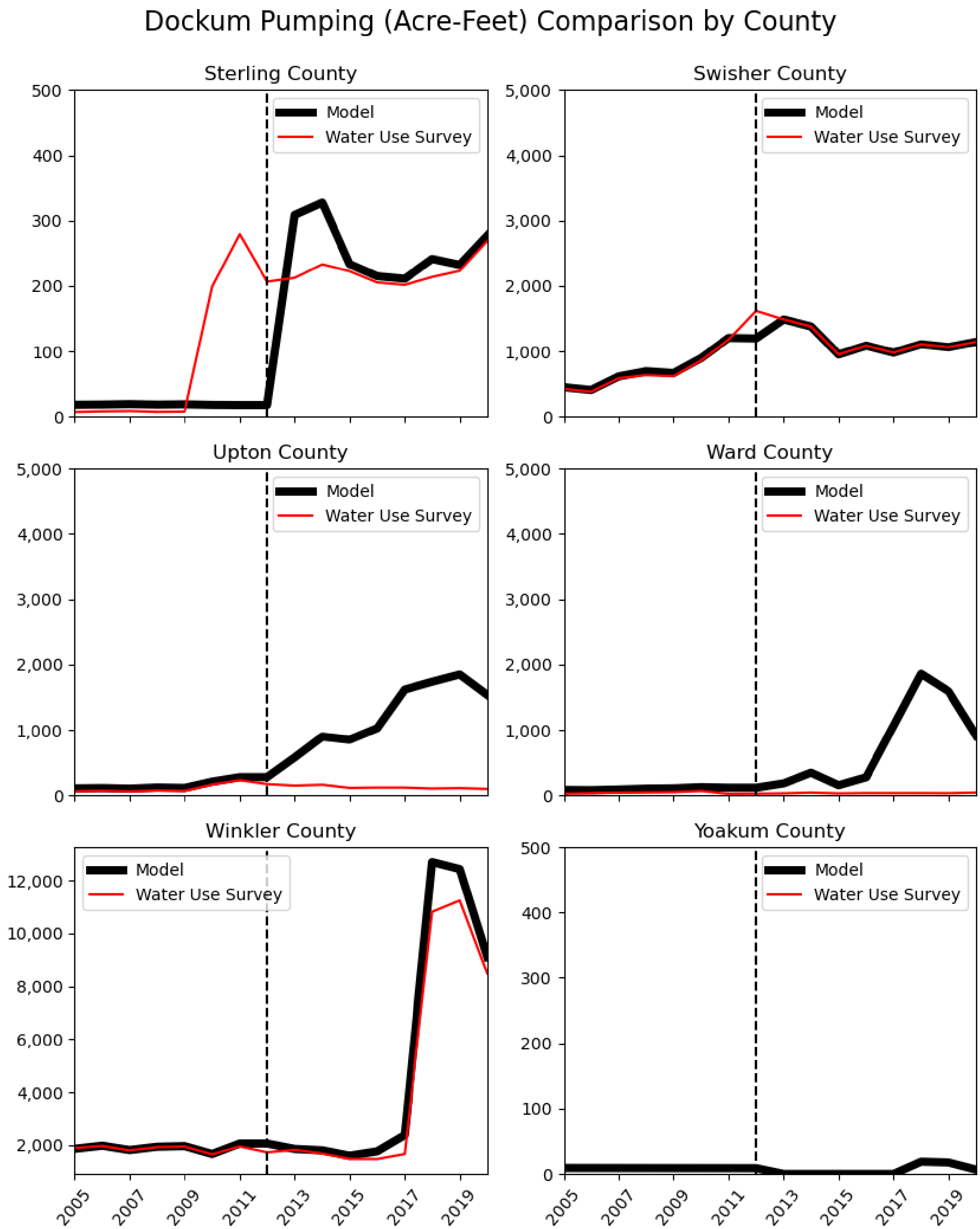


Figure A-4 continued



Appendix B: Model pumping by county

Table B-1 Model Extension pumping by county and water use category from 2013 through 2020 for the Ogallala Aquifer.

Ogallala Aquifer Irrigation All values are reported in acre-feet per year and rounded to the nearest 1 acre-foot.								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Andrews	12,695	9,964	10,083	11,410	9,828	9,649	9,957	8,691
Armstrong	5,717	5,126	4,320	5,419	4,423	4,575	4,338	5,093
Bailey	47,373	40,456	29,125	34,335	27,369	43,538	36,587	35,894
Borden	4,037	1,877	1,889	2,204	1,808	2,215	2,043	2,589
Briscoe	32,904	15,606	19,094	25,279	22,744	22,895	24,167	23,635
Carson	105,523	90,976	79,231	75,874	91,180	107,817	104,070	66,065
Castro	160,640	161,290	113,300	150,810	138,389	131,136	111,804	142,980
Cochran	70,080	62,815	47,699	54,465	54,412	62,733	69,178	62,911
Crosby	108,063	75,639	36,191	98,150	58,816	56,027	71,485	74,682
Dallam	391,522	377,676	283,841	325,448	283,803	335,388	335,219	335,401
Dawson	86,563	48,854	38,951	46,845	61,171	58,496	58,869	62,226
Deaf Smith	154,709	125,303	75,741	129,767	100,068	113,351	115,910	107,152
Dickens	2,885	4,203	3,463	3,507	3,141	3,190	3,216	3,269
Donley	28,638	33,251	24,411	26,818	29,557	31,246	30,194	19,663
Ector	11	12	9	15	11	29	24	26
Floyd	98,100	79,835	57,304	85,505	55,208	85,207	75,141	71,208
Gaines	227,179	192,019	196,771	205,190	192,319	173,321	185,825	191,880
Garza	16,535	14,281	13,049	17,141	15,585	17,317	16,569	16,630
Glasscock	4,534	4,671	2,311	3,418	3,605	3,343	3,588	3,742
Gray	39,168	40,501	28,030	30,166	26,395	40,669	38,060	23,369
Hale	238,134	179,216	147,259	208,852	132,133	180,326	171,136	174,433
Hansford	196,220	203,500	139,647	161,397	134,900	181,253	181,918	182,185
Hartley	456,177	435,046	334,059	385,654	356,080	417,801	417,839	418,245
Hemphill	6,276	2,883	2,987	5,521	5,376	5,739	5,115	8,027
Hockley	136,860	108,823	113,121	135,260	97,533	127,573	139,603	114,928
Howard	5,891	6,784	4,367	4,321	4,425	2,443	3,966	4,069
Hutchinson	68,213	63,546	48,850	63,324	57,997	64,882	67,681	78,500
Lamb	206,388	157,890	128,815	170,628	111,709	158,136	141,958	158,861
Lipscomb	39,467	47,179	37,966	41,042	42,828	42,375	42,867	43,057
Lubbock	127,451	85,285	136,896	110,758	85,063	113,070	126,793	112,409
Lynn	84,163	84,949	62,880	86,964	66,476	73,784	75,352	83,686
Martin	41,967	37,632	35,488	28,245	26,890	29,266	26,984	30,132
Midland	560	253	83	1,077	1,089	957	937	929
Moore	218,046	198,589	145,880	171,799	148,847	188,751	188,670	188,804
Motley	147	230	197	210	198	218	190	211
Ochiltree	93,111	101,485	74,511	76,224	71,585	92,822	92,951	93,160
Oldham	13,377	10,817	7,548	11,682	9,889	11,320	12,250	10,352

Table B-1 continued

Ogallala Aquifer Irrigation All values are reported in acre-feet per year and rounded to the nearest 1 acre-foot.								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Parmer	138,165	130,646	90,222	107,740	81,787	96,832	101,011	101,022
Potter	3,969	2,524	507	1,481	1,189	2,319	3,517	2,485
Randall	20,313	15,453	5,834	17,213	13,718	14,523	13,825	16,846
Roberts	8,868	9,157	7,065	7,040	8,880	10,875	10,962	8,228
Sherman	340,977	348,649	247,770	280,579	248,367	304,553	304,485	304,747
Swisher	107,928	88,653	57,779	67,226	47,650	60,172	54,978	70,261
Terry	215,632	158,761	93,150	126,675	123,823	121,841	129,418	141,134
Wheeler	12,218	11,855	10,865	9,162	10,964	11,836	11,642	9,877
Yoakum	134,753	112,704	83,418	105,655	115,241	101,527	112,354	103,621

Ogallala Aquifer Livestock All values are reported in acre-feet per year and rounded to the nearest 1 acre-foot.								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Andrews	169	152	110	112	118	123	123	122
Armstrong	211	217	220	225	482	502	506	511
Bailey	2,837	2,956	2,585	2,614	3,071	3,180	3,240	3,321
Borden	11	12	10	10	24	25	25	26
Briscoe	76	79	80	81	119	126	126	126
Carson	307	320	297	302	300	316	316	315
Castro	8,796	9,294	8,280	8,482	8,458	8,748	8,902	8,979
Cochran	344	346	338	348	140	146	146	146
Crosby	39	41	40	40	43	45	45	45
Dallam	4,832	5,084	3,791	4,271	3,628	3,694	3,707	3,774
Dawson	51	38	37	37	81	83	83	83
Deaf Smith	9,731	9,759	9,123	9,314	10,596	10,982	11,083	11,128
Dickens	34	36	37	37	45	47	47	47
Donley	477	521	488	492	545	567	567	567
Ector	7	4	2	2	4	4	4	4
Floyd	942	932	1,071	1,085	793	823	823	823
Gaines	98	99	91	92	182	186	189	195
Garza	4	3	3	3	5	6	6	6
Glasscock	22	19	20	20	21	21	21	21
Gray	1,335	1,372	1,394	1,421	1,243	1,286	1,305	1,313
Hale	3,454	3,695	3,284	3,343	2,918	2,980	3,040	3,176
Hansford	3,339	3,487	3,364	3,475	3,742	3,898	3,875	3,923
Hartley	4,141	4,482	4,088	4,156	5,238	5,417	5,497	5,624
Hemphill	963	1,014	1,043	1,053	944	978	978	978
Hockley	263	268	267	269	114	118	118	118

Table B-1 continued

Ogallala Aquifer Livestock All values are reported in acre-feet per year and rounded to the nearest 1 acre-foot.								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Howard	102	98	99	103	85	88	88	89
Hutchinson	229	229	232	238	291	302	303	306
Lamb	4,571	5,178	4,534	4,616	4,483	4,575	4,703	4,868
Lipscomb	571	577	580	604	1,278	1,463	1,446	1,440
Lubbock	561	569	572	582	730	756	756	763
Lynn	60	56	59	60	118	122	122	122
Martin	67	58	58	59	46	49	49	48
Midland	82	90	89	92	48	51	51	50
Moore	2,724	2,836	2,597	2,734	3,516	3,593	3,684	3,866
Motley	12	12	12	12	15	15	15	16
Ochiltree	2,183	2,306	1,868	1,983	3,144	3,318	3,236	3,198
Oldham	272	274	295	298	436	451	451	451
Parmer	8,703	8,821	8,102	8,177	6,941	7,138	7,239	7,435
Potter	423	375	379	389	386	396	396	403
Randall	2,027	2,156	2,218	2,246	2,538	2,648	2,650	2,653
Roberts	270	268	272	281	277	283	283	290
Sherman	4,443	4,807	3,647	3,878	4,524	4,651	4,623	4,695
Swisher	3,072	3,146	3,230	3,270	3,639	3,724	3,724	3,807
Terry	358	375	368	385	335	346	349	356
Wheeler	514	517	533	539	463	476	476	483
Yoakum	82	76	76	77	145	152	152	151

Ogallala Aquifer Rural Domestic All values are reported in acre-feet per year and rounded to the nearest 1 acre-foot.								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Andrews	484	480	473	484	415	441	483	605
Armstrong	61	53	45	41	41	37	30	61
Bailey	232	192	174	190	174	160	152	222
Borden	3	3	3	3	3	3	3	6
Briscoe	21	17	10	10	10	9	9	29
Carson	91	56	20	27	27	20	20	130
Castro	266	195	137	102	119	93	61	291
Cochran	46	50	27	7	7	3	5	73
Crosby	108	85	85	89	77	40	35	106
Dallam	101	92	83	81	86	83	85	132
Dawson	456	362	343	277	238	207	218	485
Deaf Smith	453	396	355	169	163	127	125	532
Dickens	24	13	11	5	2	3	1	21

Table B-1 continued

Ogallala Aquifer Rural Domestic All values are reported in acre-feet per year and rounded to the nearest 1 acre-foot.								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Donley	82	64	49	34	6	6	6	98
Ector	229	201	111	108	68	94	25	222
Floyd	61	30	23	26	13	10	1	122
Gaines	925	812	746	858	857	851	875	1,278
Garza	57	48	43	38	30	33	9	76
Glasscock	18	16	15	15	16	16	16	16
Gray	509	351	262	218	175	111	6	316
Hale	282	242	228	95	28	27	27	440
Hansford	87	50	50	47	12	11	11	125
Hartley	345	403	362	273	312	214	204	260
Hemphill	143	98	81	81	67	39	38	113
Hockley	565	477	424	272	172	143	139	698
Howard	681	526	498	485	282	310	251	753
Hutchinson	255	190	154	130	110	65	31	186
Lamb	232	129	82	73	71	58	22	306
Lipscomb	71	87	48	51	34	16	15	97
Lubbock	6,601	5,340	4,763	5,160	4,562	4,345	4,538	3,662
Lynn	136	137	119	86	92	92	83	241
Martin	225	183	145	174	157	136	137	290
Midland	1,593	1,577	428	444	299	550	509	1,840
Moore	152	180	151	74	72	69	67	201
Ochiltree	411	276	536	250	223	205	162	322
Oldham	67	57	51	54	52	52	49	42
Parmer	284	224	187	198	202	198	145	333
Potter	585	460	363	219	214	173	170	956
Randall	1,875	1,816	1,636	1,779	1,229	1,351	934	2,631
Roberts	22	19	12	8	10	6	0	35
Sherman	222	182	126	132	85	114	115	174
Swisher	200	158	136	137	121	94	86	225
Terry	187	175	105	153	140	92	95	256
Wheeler	98	84	68	58	45	25	16	114
Yoakum	353	316	309	308	311	299	312	170

Ogallala Aquifer Municipal All values are reported in acre-feet per year and rounded to the nearest 1 acre-foot.								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Andrews	3,020	3,039	2,649	2,495	2,383	2,500	2,310	2,713
Armstrong	309	282	257	280	279	342	250	247

Table B-1 continued

Ogallala Aquifer Municipal All values are reported in acre-feet per year and rounded to the nearest 1 acre-foot.								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Bailey	11,781	8,711	6,914	12,241	5,506	9,025	6,997	8,601
Briscoe	1	0	0	0	0	0	0	0
Carson	10,899	13,217	10,068	16,500	11,895	17,057	15,224	15,036
Castro	1,181	1,195	1,189	1,054	961	892	1,031	1,183
Cochran	492	472	451	464	460	446	405	483
Crosby	230	648	642	516	582	487	610	736
Dallam	3,709	3,070	2,559	3,042	2,597	2,831	2,831	2,831
Dawson	941	763	570	493	557	645	745	659
Deaf Smith	3,982	3,230	3,036	3,304	2,881	2,885	3,339	3,320
Donley	411	373	335	328	322	325	345	411
Floyd	683	578	451	516	453	538	532	672
Gaines	10,320	10,188	9,197	7,806	8,720	9,548	9,345	9,645
Gray	1,512	984	1,324	422	545	444	370	497
Hale	2,966	1,908	1,442	2,411	1,569	2,168	1,881	1,859
Hansford	689	969	531	625	609	715	715	715
Hartley	3,057	1,938	1,950	2,227	1,871	2,394	2,377	2,385
Hemphill	680	698	559	697	666	553	502	561
Hockley	1,402	1,008	686	1,029	631	753	677	1,138
Hutchinson	5,378	5,549	5,093	5,565	6,872	6,577	8,259	8,426
Lamb	2,092	2,016	1,719	1,542	1,552	1,688	1,778	2,185
Lipscomb	767	758	734	705	742	787	787	787
Lubbock	1,172	1,176	1,075	1,260	1,221	1,444	1,384	1,628
Lynn	219	254	160	228	185	162	154	178
Martin	3,629	5,556	1,648	1,707	1,695	1,222	1,677	2,132
Midland	271	245	302	284	272	341	324	305
Moore	3,235	3,940	3,746	4,416	3,895	3,605	3,605	3,605
Ochiltree	433	391	334	294	361	409	409	409
Oldham	263	242	242	242	250	280	277	289
Parmer	1,300	1,240	961	1,130	1,049	1,094	996	1,165
Potter	11,568	10,612	6,250	7,260	9,083	7,391	5,003	10,791
Randall	3,810	3,061	1,652	2,334	2,242	1,652	2,030	1,173
Roberts	65,041	60,524	58,628	49,390	58,860	52,436	48,555	52,703
Sherman	533	650	659	642	529	487	487	487
Swisher	243	209	218	209	193	295	120	197
Terry	209	161	189	540	132	106	101	78
Wheeler	1,190	1,346	1,275	1,285	1,866	1,633	1,014	1,361
Yoakum	1,362	1,272	1,082	1,168	1,202	1,267	1,200	1,272

Table B-1 continued

Ogallala Aquifer Non-Surveyed Mining All values are reported in acre-feet per year and rounded to the nearest 1 acre-foot.								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Andrews	612	797	608	720	1,310	1,427	1,574	1,526
Borden	31	31	2	23	246	472	428	73
Cochran	4	42	13	44	161	82	67	0
Dawson	141	176	112	45	65	1	80	135
Ector	350	336	116	88	146	271	347	219
Gaines	54	92	64	358	79	114	16	61
Glasscock	108	156	135	113	283	347	403	118
Hansford	6	9	2	10	19	31	6	0
Hartley	0	14	0	0	0	8	0	0
Hemphill	511	508	297	161	291	359	153	0
Hockley	0	42	14	35	0	1	2	0
Howard	662	1,181	1,623	2,608	7,798	10,093	10,598	10,529
Hutchinson	1	0	2	0	21	5	0	0
Lipscomb	179	254	101	81	104	128	40	25
Martin	1,679	2,680	3,686	3,689	9,729	13,461	16,318	12,049
Midland	802	1,556	3,068	5,152	8,332	11,167	11,258	8,314
Ochiltree	287	306	146	46	90	166	124	26
Roberts	127	201	101	14	54	42	28	0
Terry	22	5	3	4	4	1	0	0
Wheeler	667	337	58	43	87	60	8	4
Yoakum	54	60	38	184	233	280	263	99
Ogallala Aquifer Surveyed Mining, Manufacturing, and Power All values are reported in acre-feet per year and rounded to the nearest 1 acre-foot.								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Andrews	214	262	250	141	91	35	36	0
Carson	322	947	1,118	1,224	792	921	705	638
Dallam	1,045	856	841	953	1,165	1,287	1,287	1,287
Dawson	0	0	0	0	0	235	153	372
Gaines	5,653	5,392	5,076	4,911	6,356	2,175	1,195	506
Gray	0	0	0	0	0	31	243	66
Hale	596	606	608	629	602	610	652	603
Hansford	3,223	3,218	2,144	2,669	3,627	3,185	3,185	3,185
Hartley	2,562	2,242	1,705	2,590	2,671	2,954	2,954	2,954
Hockley	171	171	174	174	67	42	24	6
Howard	184	235	324	281	292	298	206	183
Lamb	15,666	11,760	11,352	9,834	8,824	8,465	6,648	5,919
Lipscomb	337	321	402	572	501	808	808	808

Table B-1 continued

Ogallala Aquifer Surveyed Mining, Manufacturing, and Power All values are reported in acre-feet per year and rounded to the nearest 1 acre-foot.								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Lubbock	249	227	247	254	261	68	74	74
Midland	5	4	4	4	4	3	46	4
Moore	6,963	6,695	6,555	7,088	6,440	6,529	6,529	6,529
Ochiltree	1,222	1,192	1,192	1,164	1,235	1,410	1,410	1,410
Parmer	829	808	273	304	326	327	331	0
Potter	847	776	757	726	718	613	692	592
Sherman	5,525	5,916	4,272	4,923	4,518	5,008	5,008	5,008
Terry	12	12	12	12	12	12	12	12
Wheeler	0	0	0	0	0	3	1	1
Yoakum	0	0	0	1,302	1,113	1,594	1,598	1,430

Table B-2 Model Extension pumping by county and water use category from 2013 through 2020 for the Rita Blanca Aquifer.

Irrigation All values are reported in acre-feet per year and rounded to the nearest 1 acre-foot.								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Dallam	4,819	4,693	3,573	4,167	3,479	4,118	3,742	4,231
Livestock								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Dallam	1	1	1	1	1	1	1	1
Rural Domestic								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Dallam	142	151	113	121	103	107	107	109

Table B-3 Model Extension pumping by county and water use category from 2013 through 2020 for the Edwards-Trinity (High Plains) Aquifer.

Irrigation All values are reported in acre-feet per year and rounded to the nearest 1 acre-foot.								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Dawson	1,608	908	724	870	1,137	1,087	1,094	1,156
Gaines	10,847	9,168	9,395	9,797	9,182	8,275	8,872	9,161
Garza	178	153	140	184	167	186	178	179
Hale	12,134	9,132	7,504	10,642	6,733	9,188	8,720	8,888
Lubbock	985	659	1,058	856	658	874	980	869
Lynn	1,021	1,030	762	1,054	806	895	914	1,015
Livestock								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Borden	9	9	9	10	22	23	24	24
Cochran	16	17	28	29	12	12	12	12
Dawson	4	3	3	3	6	6	6	6
Gaines	39	40	37	37	73	74	76	78
Garza	2	2	2	2	3	3	3	3
Hockley	45	46	55	55	23	24	24	24
Lynn	4	4	4	4	8	9	9	9
Yoakum	3	3	3	3	6	6	6	6
Rural Domestic								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Dawson	0	2	2	2	1	1	1	3
Gaines	132	116	107	123	122	122	125	182
Hale	0	0	10	4	1	1	1	20
Hockley	0	19	17	11	7	6	6	32
Lamb	0	6	3	3	3	2	1	13
Terry	0	12	7	10	10	6	7	18
Non-Surveyed Mining								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Dawson	0	5	4	1	2	0	2	4
Gaines	11	18	13	72	16	23	3	12
Yoakum	0	0	0	0	0	28	26	10

Table B-4 Model Extension pumping by county and water use category from 2013 through 2020 for the upper and lower Dockum units.

Dockum Units Irrigation All values are reported in acre-feet per year and rounded to the nearest 1 acre-foot.								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Armstrong	2,040	1,829	1,542	1,934	1,578	1,633	1,548	1,818
Bailey	7	7	7	7	7	7	7	7
Briscoe	29	14	17	22	20	20	21	20
Carson	530	457	398	381	458	542	523	332
Crosby	2,372	1,661	795	2,155	1,291	1,230	1,569	1,640
Dallam	2,763	2,763	2,763	2,763	2,763	2,763	2,763	2,763
Deaf Smith	2,233	1,809	1,093	1,873	1,445	1,636	1,673	1,547
Dickens	29	43	35	36	32	33	33	33
Floyd	1,910	1,554	1,116	1,665	1,075	1,659	1,463	1,386
Garza	178	153	140	184	167	186	178	179
Hale	135	135	135	135	135	135	135	135
Hartley	840	840	840	840	840	840	840	840
Howard	332	383	246	244	250	138	224	230
Kent	0	0	0	0	0	0	0	13
Lamb	4	4	4	4	4	4	4	4
Mitchell	13,463	15,137	13,236	11,943	12,797	13,385	14,555	13,868
Moore	1,538	1,434	1,036	1,278	1,094	1,278	1,192	1,381
Motley	457	715	614	655	617	677	592	657
Nolan	12,368	11,693	10,493	11,744	13,933	13,664	12,913	13,537
Oldham	304	246	172	266	225	257	279	235
Pecos	772	772	772	772	772	772	772	772
Potter	3,018	723	2,044	420	712	1,450	1,522	590
Randall	418	318	120	354	282	299	285	347
Reagan	77	93	77	77	84	80	81	97
Reeves	180	180	180	180	180	180	180	180
Scurry	6,897	7,175	5,293	5,635	7,197	5,625	6,539	6,492
Sterling	8	8	8	8	8	8	8	8
Swisher	946	777	507	589	418	528	482	616
Upton	137	146	102	104	106	91	98	78
Ward	15	29	16	21	19	20	17	20

Table B-4 continued

Dockum Units Livestock All values are reported in acre-feet per year and rounded to the nearest 1 acre-foot.								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Andrews	3	2	2	2	2	2	2	2
Armstrong	28	29	29	30	64	67	67	68
Borden	9	9	9	10	22	23	24	24
Briscoe	27	28	28	29	43	45	45	45
Crane	21	20	20	21	18	18	18	18
Crockett	1	1	1	1	1	1	1	1
Crosby	38	39	41	41	44	46	46	46
Dallam	8	8	8	8	8	8	8	8
Dawson	0	0	0	0	0	0	4	4
Deaf Smith	93	93	0	0	0	0	0	0
Dickens	43	45	46	47	57	59	59	59
Fisher	21	24	21	21	20	21	21	20
Floyd	122	121	30	30	22	22	22	22
Garza	15	13	13	13	22	22	22	22
Hartley	836	901	819	832	1,051	1,087	1,103	1,128
Hockley	23	23	27	28	12	12	12	12
Howard	21	20	20	21	17	18	18	18
Irion	0	0	0	0	1	1	1	1
Kent	12	12	12	12	16	16	16	16
Loving	15	17	17	18	23	23	23	24
Mitchell	68	81	69	70	57	60	60	60
Motley	38	37	36	37	46	47	47	48
Nolan	36	35	38	38	36	38	38	38
Oldham	310	313	308	312	455	471	471	471
Potter	6	5	4	5	5	5	5	5
Randall	287	306	315	319	360	376	376	376
Reagan	1	1	1	1	2	2	2	2
Reeves	14	13	13	13	6	6	6	6
Scurry	91	92	93	96	113	116	117	118
Sterling	6	6	6	6	6	7	7	7
Upton	9	13	10	11	8	9	9	9
Ward	9	8	8	8	9	10	10	10
Winkler	6	6	6	6	7	7	7	7

Table B-4 continued

Dockum Units Rural Domestic All values are reported in acre-feet per year and rounded to the nearest 1 acre-foot.								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Andrews	1	1	1	1	1	1	1	1
Armstrong	11	10	8	8	8	7	6	11
Borden	20	17	15	14	16	13	13	18
Briscoe	8	6	3	4	4	3	3	11
Carson	11	7	3	3	3	3	3	25
Crane	13	13	9	7	5	5	5	15
Crockett	1	1	1	1	0	0	0	0
Crosby	8	6	6	6	5	3	2	8
Dawson	5	4	4	3	3	3	3	6
Deaf Smith	28	25	22	11	11	9	9	1
Dickens	19	11	9	4	1	3	1	17
Ector	131	115	63	61	39	54	14	46
Fisher	42	37	23	17	13	9	0	20
Floyd	24	12	9	11	6	4	0	20
Gaines	0	0	15	17	17	17	18	26
Garza	36	31	27	24	19	21	6	49
Hartley	18	16	13	10	9	8	7	11
Howard	69	54	51	49	29	32	26	77
Irion	0	1	1	1	1	1	0	1
Kent	2	1	1	1	1	0	0	1
Loving	2	2	2	3	3	3	3	2
Lubbock	3	3	3	3	3	3	3	3
Mitchell	22	19	5	5	5	5	25	94
Moore	6	7	6	3	3	3	3	8
Motley	9	6	5	6	5	5	5	7
Nolan	33	22	9	18	18	15	15	47
Oldham	25	22	19	20	19	19	18	13
Pecos	5	5	5	5	5	5	5	5
Potter	888	698	552	333	326	264	259	696
Randall	454	440	397	431	298	328	226	638
Reeves	4	4	4	4	4	4	4	4
Scurry	416	330	206	174	125	61	60	490
Sterling	1	1	1	1	1	0	0	1
Upton	3	3	2	4	4	4	3	11
Ward	7	7	6	6	6	5	7	13
Winkler	6	5	6	6	5	5	6	9

Table B-4 continued

Dockum Units Municipal All values are reported in acre-feet per year and rounded to the nearest 1 acre-foot.								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Briscoe	4	4	4	6	4	4	5	5
Deaf Smith	1,945	1,721	1,721	1,907	1,888	2,220	2,124	2,124
Hartley	128	125	109	80	98	133	78	79
Kent	0	15	8	10	10	10	10	20
Mitchell	1,343	1,431	1,337	1,188	1,178	1,298	1,255	1,366
Nolan	2,393	2,209	2,092	1,549	1,931	2,023	1,822	2,089
Oldham	322	294	294	301	253	329	329	297
Potter	533	444	685	639	415	692	902	0
Randall	559	695	797	1,124	620	808	746	1,602
Reeves	0	3,366	2,377	2,318	2,934	2,977	3,525	3,489
Scurry	205	233	145	113	114	127	185	97
Sterling	206	226	216	198	195	207	216	262
Swisher	542	603	446	497	562	580	581	528
Winkler	1,758	1,616	1,405	1,430	1,497	10,678	9,687	6,906
Dockum Units Non-Surveyed Mining All values are reported in acre-feet per year and rounded to the nearest 1 acre-foot.								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Andrews	501	652	497	589	1,072	1,168	1,288	1,248
Borden	63	62	5	46	492	943	855	145
Crane	175	107	49	15	16	13	33	56
Crockett	0	0	6	4	7	3	0	0
Dawson	0	0	4	2	2	0	3	5
Ector	243	234	81	61	101	188	241	152
Gaines	0	0	0	0	16	23	3	12
Glasscock	255	368	320	268	670	822	954	280
Hartley	0	22	1	0	0	13	0	0
Howard	181	323	444	713	2,132	2,760	2,898	2,879
Irion	435	441	224	152	220	465	515	75
Loving	44	79	140	189	416	509	540	346
Martin	290	464	638	638	1,683	2,329	2,823	2,085
Midland	435	844	1,664	2,794	4,519	6,057	6,106	4,510
Mitchell	140	47	6	0	1	1	0	0
Nolan	0	0	0	2	0	1	4	10
Oldham	0	5	21	0	0	15	0	0
Pecos	3	4	9	12	49	71	116	43
Potter	0	47	58	0	94	67	26	0
Reagan	404	755	607	456	1,129	1,391	1,325	609

Table B-4 continued

Dockum Units Non-Surveyed Mining All values are reported in acre-feet per year and rounded to the nearest 1 acre-foot.								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Reeves	53	142	183	208	753	1,066	1,081	461
Scurry	33	47	13	38	30	112	23	271
Sterling	88	86	3	2	1	20	1	0
Upton	431	736	738	907	1,499	1,633	1,737	1,437
Ward	152	302	124	240	1,028	1,823	1,557	873
Winkler	36	124	124	292	716	1,886	1,194	635
Yoakum	0	0	0	0	0	19	18	7
Dockum Units Surveyed Mining, Manufacturing, and Power All values are reported in acre-feet per year and rounded to the nearest 1 acre-foot.								
County	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Ector	463	72	41	4	21	26	18	13
Winkler	46	50	58	29	152	125	1,543	1,558

Appendix C: Water budget by groundwater conservation district

Table C-1 Ogallala Aquifer groundwater budgets by groundwater conservation district in 2020.

Ogallala Aquifer 2020 Groundwater Conservation District Water Budgets Flow values are in acre-feet per year. Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.									
Groundwater conservation district	**Net storage**	**Net wells**	**Net drains**	**Net river leakage**	**Net ET**	**Net recharge**	**Net vertical leakage upper**	**Net vertical leakage lower**	**Net lateral flow**
Garza County Official	2,743	-12,159	-2,602	0	0	8,475	0	2,089	1,455
Garza County Unofficial	4	0	-2,255	0	0	64	0	976	1,210
Garza County Total	2,747	-12,159	-4,857	0	0	8,539	0	3,065	--
Gateway Official	2,529	-227	-2,366	-66	0	1,786	0	-2,257	602
Gateway Unofficial	3	0	-141	0	0	5	0	-5	137
Gateway Total	2,532	-227	-2,507	-66	0	1,791	0	-2,262	--
Glasscock Official	-171	-3,758	-95	837	-381	3,301	0	326	-59
Glasscock Unofficial	0	0	0	0	0	1	0	-1	0
Glasscock Total	-171	-3,758	-95	837	-381	3,302	0	325	--
Hemphill County Official	7,955	-9,722	-3,683	-19,547	-24,036	34,420	0	0	14,613
Hemphill County Unofficial	0	0	-223	0	0	17	0	0	205
Hemphill County Total	7,955	-9,722	-3,906	-19,547	-24,036	34,437	0	0	--
High Plains Official	902,688	-1,313,406	-5,181	54,857	-243	348,437	0	10,488	2,360
High Plains Unofficial	12	-35	-1,323	-162	-594	47	0	868	1,187
High Plains Total	902,700	-1,313,441	-6,504	54,695	-837	348,484	0	11,356	--
Llano Estacado Official	73,242	-178,391	-1,100	19,781	-2,332	85,126	0	-2,828	6,502
Llano Estacado Total	73,242	-178,391	-1,100	19,781	-2,332	85,126	0	-2,828	--
Mesa Official	13,479	-63,760	-1,146	5,836	-889	54,401	0	-1,180	-6,742
Mesa Unofficial	1	-4	-4,939	0	0	440	0	970	3,533
Mesa Total	13,480	-63,764	-6,085	5,836	-889	54,841	0	-210	--
Mesquite Official	122	0	-658	0	0	648	0	0	-113
Mesquite Total	122	0	-658	0	0	648	0	0	--

Table C-1 continued

Ogallala Aquifer **2020 Groundwater Conservation District Water Budgets** Flow values are in acre-feet per year. Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.									
Groundwater conservation district	**Net storage**	**Net wells**	**Net drains**	**Net river leakage**	**Net ET**	**Net recharge**	**Net vertical leakage upper**	**Net vertical leakage lower**	**Net lateral flow**
North Plains Official	1,381,451	-1,570,115	0	62,626	-6,978	137,422	0	-2,146	-2,260
North Plains Unofficial	18	0	0	-962	-161	7	0	0	1,097
North Plains Total	1,381,469	-1,570,115	0	61,664	-7,139	137,429	0	-2,146	--
Panhandle Official	191,886	-211,777	-38,782	-25,417	-32,285	114,452	0	-3,269	5,193
Panhandle Unofficial	7	0	-434	0	0	70	0	0	357
Panhandle Total	191,893	-211,777	-39,216	-25,417	-32,285	114,522	0	-3,269	--
Permian Basin Official	19,443	-51,285	-4,066	2,159	-4,046	35,317	0	-228	2,706
Permian Basin Unofficial	2	-3	-55	-2	0	1	0	0	57
Permian Basin Total	19,445	-51,288	-4,121	2,157	-4,046	35,318	0	-228	--
Sandy Land Official	47,663	-86,388	-13	2,526	0	34,652	0	-51	1,611
Sandy Land Total	47,663	-86,388	-13	2,526	0	34,652	0	-51	--
South Plains Official	48,646	-124,949	-307	3,002	0	74,205	0	369	-966
South Plains Total	48,646	-124,949	-307	3,002	0	74,205	0	369	--

Table C-2 Edwards-Trinity (High Plains) Aquifer groundwater budgets by groundwater conservation district in 2020.

Edwards-Trinity (High Plains) Aquifer 2020 Groundwater Conservation District Water Budgets Flow values are in acre-feet per year. Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.									
Groundwater conservation district	**Net storage**	**Net wells**	**Net drains**	**Net river leakage**	**Net ET**	**Net recharge**	**Net vertical leakage upper**	**Net vertical leakage lower**	**Net lateral flow**
Garza County Official	14	-175	0	0	0	0	-2,304	-245	2,710
Garza County Unofficial	0	-4	0	0	0	0	-779	-8	790
Garza County Total	14	-179	0	0	0	0	-3,083	-253	--
High Plains Official	8,284	-7,053	0	0	0	0	1,896	1,374	-4,501
High Plains Unofficial	99	-399	0	0	0	0	-744	50	994
High Plains Total	8,383	-7,452	0	0	0	0	1,152	1,424	--
Llano Estacado Official	-1,334	-9,014	0	0	0	0	6,029	1,121	3,199
Llano Estacado Unofficial	1	-392	0	0	0	0	-775	16	1,150
Llano Estacado Total	-1,333	-9,406	0	0	0	0	5,254	1,137	--
Mesa Official	0	-1,129	0	0	0	0	2,034	-33	-872
Mesa Unofficial	1	-43	0	0	0	0	-909	-16	967
Mesa Total	1	-1,172	0	0	0	0	1,125	-49	--
Sandy Land Official	2,249	-43	0	0	0	0	51	488	-2,744
Sandy Land Total	2,249	-43	0	0	0	0	51	488	--
South Plains Official	37	-63	0	0	0	0	-369	539	-143
South Plains Total	37	-63	0	0	0	0	-369	539	--

Table C-3 Rita Blanca Aquifer groundwater budgets by groundwater conservation district in 2020.

Rita Blanca Aquifer 2020 Groundwater Conservation District Water Budgets Flow values are in acre-feet per year. Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.									
Groundwater conservation district	**Net storage**	**Net wells**	**Net drains**	**Net river leakage**	**Net ET**	**Net recharge**	**Net vertical leakage upper**	**Net vertical leakage lower**	**Net lateral flow**
North Plains Official	-91	-4,471	0	0	0	0	3,710	1,036	-185
North Plains Unofficial	20	-11	0	0	0	0	-98	108	-19
North Plains Total	-71	-4,482	0	0	0	0	3,612	1,144	--

Table C-4 Lower and upper Dockum units groundwater budgets by groundwater conservation district in 2020.

Dockum Units 2020 Groundwater Conservation District Water Budgets Flow values are in acre-feet per year. Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.									
Groundwater conservation district	**Net storage**	**Net wells**	**Net drains**	**Net river leakage**	**Net ET**	**Net recharge**	**Net vertical leakage upper**	**Net vertical leakage lower**	**Net lateral flow**
Clear Fork Official	-33	-40	-644	-140	-126	736	117	0	130
Clear Fork Total	-33	-40	-644	-140	-126	736	117	0	--
Coke County Official	0	0	-264	-21	-11	133	64	0	100
Coke County Unofficial	0	0	-29	-2	0	0	42	0	-10
Coke County Total	0	0	-293	-23	-11	133	106	0	--
Crockett County Official	30	-2	0	0	0	0	-517	0	488
Crockett County Unofficial	0	0	0	0	0	0	-2	0	2
Crockett County Total	30	-2	0	0	0	0	-519	0	--
Garza County Official	-963	-27	-808	-3,881	-2,428	4,298	0	0	3,809
Garza County Unofficial	-1,504	-202	-52	144	-996	2,664	549	0	-604
Garza County Total	-2,467	-229	-860	-3,737	-3,424	6,962	549	0	--
Gateway Official	625	-385	-2,551	-1,785	-6	404	2,262	0	1,436
Gateway Total	625	-385	-2,551	-1,785	-6	404	2,262	0	--
Glasscock Official	24	-8	0	0	0	0	8	0	-23
Glasscock Unofficial	622	-336	0	0	0	2	-297	0	9
Glasscock Total	646	-344	0	0	0	2	-289	0	--
High Plains Official	16,026	-10,596	0	-17	0	15	3,090	0	-8,519
High Plains Unofficial	16,028	-551	0	-75	-3	1	-13,917	0	-1,485
High Plains Total	32,054	-11,147	0	-92	-3	16	-10,827	0	--
Irion County Official	-170	-76	0	0	0	0	125	0	122
Irion County Total	-170	-76	0	0	0	0	125	0	--

Table C-4 continued

Dockum Units
2020 Groundwater Conservation District Water Budgets
Flow values are in acre-feet per year.
Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.

Groundwater conservation district	Net storage	Net wells	Net drains	Net river leakage	Net ET	Net recharge	Net vertical leakage upper	Net vertical leakage lower	Net lateral flow
Llano Estacado Official	2,121	-38	0	0	0	0	-2,100	0	17
Llano Estacado Unofficial	351	0	0	0	0	0	-368	0	17
Llano Estacado Total	2,472	-38	0	0	0	0	-2,468	0	--
Lone Wolf Official	7,706	-15,302	-1,109	-7,418	-4,102	18,141	449	0	1,637
Lone Wolf Unofficial	0	0	0	2	0	0	0	0	-1
Lone Wolf Total	7,706	-15,302	-1,109	-7,416	-4,102	18,141	449	0	--
Mesa Unofficial	346	-30	-22	-49	-7	2	-164	0	-76
Mesa Total	346	-30	-22	-49	-7	2	-164	0	--
Middle Pecos Official	371	-756	0	0	0	0	259	0	125
Middle Pecos Unofficial	21	-4	0	0	0	0	-16	0	-1
Middle Pecos Total	392	-760	0	0	0	0	243	0	--
North Plains Official	8,492	-5,907	0	194	0	49	-2,331	0	-496
North Plains Unofficial	23	0	0	0	0	0	-96	0	73
North Plains Total	8,515	-5,907	0	194	0	49	-2,427	0	--
Panhandle Official	2,047	-2,181	-2,975	-3,876	-1,064	2,439	3,378	0	2,231
Panhandle Unofficial	167	-176	0	0	0	0	-96	0	105
Panhandle Total	2,214	-2,357	-2,975	-3,876	-1,064	2,439	3,282	0	--
Permian Basin Official	78	-351	-16	-1,163	-1,139	3,377	34	0	-820
Permian Basin Unofficial	4,387	-4,739	0	9	0	406	308	0	-376
Permian Basin Total	4,465	-5,090	-16	-1,154	-1,139	3,783	342	0	--
Reeves County Official	3,541	-4,131	0	0	0	0	297	0	293
Reeves County Unofficial	-43	-82	0	0	0	0	56	0	69
Reeves County Total	3,498	-4,213	0	0	0	0	353	0	--

Table C-4 continued

Dockum Units 2020 Groundwater Conservation District Water Budgets Flow values are in acre-feet per year. Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.									
Groundwater conservation district	**Net storage**	**Net wells**	**Net drains**	**Net river leakage**	**Net ET**	**Net recharge**	**Net vertical leakage upper**	**Net vertical leakage lower**	**Net lateral flow**
Sandy Land Unofficial	499	-7	0	0	0	0	-488	0	-4
Sandy Land Total	499	-7	0	0	0	0	-488	0	--
Santa Rita Official	102	-287	0	0	0	0	183	0	2
Santa Rita Unofficial	207	-335	0	0	0	0	122	0	6
Santa Rita Total	309	-622	0	0	0	0	305	0	--
South Plains Unofficial	545	0	0	0	0	0	-539	0	-6
South Plains Total	545	0	0	0	0	0	-539	0	--
Sterling County Official	224	-278	0	-285	-268	458	672	0	-525
Sterling County Total	224	-278	0	-285	-268	458	672	0	--
Wes-Tex Official	9,164	-12,034	-353	-210	-76	1,763	633	0	1,113
Wes-Tex Unofficial	3,164	-3,152	-370	-36	0	0	1,187	0	-794
Wes-Tex Total	12,328	-15,186	-723	-246	-76	1,763	1,820	0	--

Appendix D: Water budget by county

Table D-1 Ogallala Aquifer groundwater budgets by county in 2020.

Ogallala Aquifer 2020 County Water Budgets Flow values are in acre-feet per year. Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.									
County	**Net storage**	**Net wells**	**Net drains**	**Net river leakage**	**Net ET**	**Net rechar ge**	**Net vertical leakage upper**	**Net vertical leakage lower**	**Net lateral flow**
Andrews Official	6,669	-12,971	-278	3,468	-86	7,375	0	-104	-4,074
Andrews Unofficial	-6	0	0	0	0	2	0	0	4
Andrews Total	6,663	-12,971	-278	3,468	-86	7,377	0	-104	--
Armstrong Official	8,689	-6,118	-2,318	-952	0	9,555	0	-2,518	-6,337
Armstrong Total	8,689	-6,118	-2,318	-952	0	9,555	0	-2,518	--
Bailey Official	26,973	-46,313	-226	1,982	0	24,948	0	798	-8,162
Bailey Total	26,973	-46,313	-226	1,982	0	24,948	0	798	--
Borden Official	-184	-2,041	-177	0	0	5,059	0	-2,222	-435
Borden Unofficial	-19	0	-3,617	0	0	295	0	2,797	545
Borden Total	-203	-2,041	-3,794	0	0	5,354	0	575	--
Briscoe Official	12,206	-16,568	-1,665	-581	-16	6,200	0	-2,718	3,141
Briscoe Total	12,206	-16,568	-1,665	-581	-16	6,200	0	-2,718	--
Carson Official	73,086	-81,636	-132	5,704	-311	12,496	0	264	-9,471
Carson Total	73,086	-81,636	-132	5,704	-311	12,496	0	264	--
Castro Official	139,503	-149,059	0	4,116	0	7,356	0	2,814	-4,730
Castro Total	139,503	-149,059	0	4,116	0	7,356	0	2,814	--
Cochran Official	32,016	-60,099	-50	0	0	26,582	0	1,080	470
Cochran Total	32,016	-60,099	-50	0	0	26,582	0	1,080	--
Collingsworth Official	122	0	-658	0	0	648	0	0	-113
Collingsworth Total	122	0	-658	0	0	648	0	0	--
Crosby Official	58,837	-73,607	-4,507	1,722	0	14,817	0	-2,487	5,225
Crosby Unofficial	6	0	0	-337	0	0	0	-2	333
Crosby Total	58,843	-73,607	-4,507	1,385	0	14,817	0	-2,489	--
Dallam Official	214,712	-254,460	0	20,139	0	24,655	0	-3,197	-1,849
Dallam Total	214,712	-254,460	0	20,139	0	24,655	0	-3,197	--

Table D-1 continued

Ogallala Aquifer 2020 County Water Budgets Flow values are in acre-feet per year. Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.									
County	**Net storage**	**Net wells**	**Net drains**	**Net river leakage**	**Net ET**	**Net rechar ge**	**Net vertical leakage upper**	**Net vertical leakage lower**	**Net lateral flow**
Dawson Official	13,479	-63,760	-1,146	5,836	-889	54,401	0	-1,180	-6,742
Dawson Unofficial	1	-4	-4,939	0	0	440	0	970	3,533
Dawson Total	13,480	-63,764	-6,085	5,836	-889	54,841	0	-210	--
Deaf smith Official	89,474	-113,767	-50	9,260	-86	17,447	0	213	-2,492
Deaf smith Total	89,474	-113,767	-50	9,260	-86	17,447	0	213	--
Dickens Official	2,552	-2,744	-161	-404	0	2,168	0	-2,027	616
Dickens Unofficial	4	0	0	0	0	4	0	-9	1
Dickens Total	2,556	-2,744	-161	-404	0	2,172	0	-2,036	--
Donley Official	9,729	-19,460	-7,630	-10,126	-1,608	17,361	0	0	11,734
Donley Unofficial	0	0	-210	0	0	35	0	0	174
Donley Total	9,729	-19,460	-7,840	-10,126	-1,608	17,396	0	0	--
Ector Official	-533	-493	-15	876	-2	504	0	-116	-220
Ector Total	-533	-493	-15	876	-2	504	0	-116	--
Floyd Official	59,034	-73,018	-2,962	3,969	0	14,489	0	517	-2,029
Floyd Total	59,034	-73,018	-2,962	3,969	0	14,489	0	517	--
Gaines Official	73,242	-178,391	-1,100	19,781	-2,332	85,126	0	-2,828	6,502
Gaines Total	73,242	-178,391	-1,100	19,781	-2,332	85,126	0	-2,828	--
Garza Official	2,743	-12,159	-2,602	0	0	8,475	0	2,089	1,455
Garza Unofficial	4	0	-2,255	0	0	64	0	976	1,210
Garza Total	2,747	-12,159	-4,857	0	0	8,539	0	3,065	--
Glasscock Official	-171	-3,758	-95	837	-381	3,301	0	326	-59
Glasscock Unofficial	0	0	0	0	0	1	0	-1	0
Glasscock Total	-171	-3,758	-95	837	-381	3,302	0	325	--
Gray Official	23,028	-25,230	-6,202	-2,703	-736	26,464	0	0	-14,619
Gray Total	23,028	-25,230	-6,202	-2,703	-736	26,464	0	0	--

Table D-1 continued

Ogallala Aquifer 2020 County Water Budgets Flow values are in acre-feet per year. Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.									
County	**Net storage**	**Net wells**	**Net drains**	**Net river leakage**	**Net ET**	**Net rechar ge**	**Net vertical leakage upper**	**Net vertical leakage lower**	**Net lateral flow**
Hale Official	148,023	-170,862	0	8,454	0	12,401	0	-34	2,018
Hale Total	148,023	-170,862	0	8,454	0	12,401	0	-34	--
Hansford Official	172,793	-191,864	0	11,120	-346	11,552	0	0	-3,255
Hansford Unofficial	14	0	0	-261	0	4	0	0	244
Hansford Total	172,807	-191,864	0	10,859	-346	11,556	0	0	--
Hartley Official	372,985	-399,792	-1,549	410	-2,436	29,246	0	1,273	-136
Hartley Total	372,985	-399,792	-1,549	410	-2,436	29,246	0	1,273	--
Hemphill Official	7,955	-9,722	-3,683	-19,547	-24,036	34,420	0	0	14,613
Hemphill Unofficial	0	0	-223	0	0	17	0	0	205
Hemphill Total	7,955	-9,722	-3,906	-19,547	-24,036	34,437	0	0	--
Hockley Official	62,314	-108,442	-77	3,254	-139	43,020	0	254	-183
Hockley Total	62,314	-108,442	-77	3,254	-139	43,020	0	254	--
Howard Official	5,434	-9,759	-2,440	-1,028	-628	5,609	0	162	2,651
Howard Unofficial	3	-3	-55	-2	0	2	0	0	56
Howard Total	5,437	-9,762	-2,495	-1,030	-628	5,611	0	162	--
Hutchinson Official	76,685	-79,711	-7,038	-3,155	-2,003	7,094	0	0	8,127
Hutchinson Unofficial	0	0	0	0	0	3	0	0	-3
Hutchinson Total	76,685	-79,711	-7,038	-3,155	-2,003	7,097	0	0	--
Lamb Official	113,088	-154,989	-577	7,074	0	32,782	0	3,430	-808
Lamb Total	113,088	-154,989	-577	7,074	0	32,782	0	3,430	--
Lipscomb Official	36,370	-48,705	0	2,507	-4,978	29,682	0	0	-14,878
Lipscomb Total	36,370	-48,705	0	2,507	-4,978	29,682	0	0	--
Lubbock Official	35,124	-113,491	-2,435	3,663	0	74,920	0	2,540	-321
Lubbock Unofficial	8	0	-157	-167	0	0	0	14	303
Lubbock Total	35,132	-113,491	-2,592	3,496	0	74,920	0	2,554	--

Table D-1 continued

Ogallala Aquifer 2020 County Water Budgets Flow values are in acre-feet per year. Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.									
County	**Net storage**	**Net wells**	**Net drains**	**Net river leakage**	**Net ET**	**Net rechar ge**	**Net vertical leakage upper**	**Net vertical leakage lower**	**Net lateral flow**
Lynn Official	19,208	-78,363	-1,642	0	-103	68,120	0	-1,971	-5,249
Lynn Unofficial	4	-35	-1,166	5	-594	47	0	855	885
Lynn Total	19,212	-78,398	-2,808	5	-697	68,167	0	-1,116	--
Martin Official	14,084	-41,607	-1,626	2,966	-3,620	29,791	0	-92	104
Martin Total	14,084	-41,607	-1,626	2,966	-3,620	29,791	0	-92	--
Midland Official	3,030	-10,514	-415	3,711	-948	3,865	0	-296	1,566
Midland Total	3,030	-10,514	-415	3,711	-948	3,865	0	-296	--
Moore Official	172,570	-198,600	-1,738	5,992	0	17,472	0	-997	5,301
Moore Total	172,570	-198,600	-1,738	5,992	0	17,472	0	-997	--
Motley Official	2,529	-227	-2,366	-66	0	1,786	0	-2,257	602
Motley Unofficial	3	0	-141	0	0	5	0	-5	137
Motley Total	2,532	-227	-2,507	-66	0	1,791	0	-2,262	--
Ochiltree Official	81,655	-98,490	0	4,278	0	12,401	0	0	157
Ochiltree Unofficial	5	0	0	-700	-161	3	0	0	853
Ochiltree Total	81,660	-98,490	0	3,578	-161	12,404	0	0	--
Oldham Official	6,599	-8,310	-8,854	-8,126	-735	18,511	0	-3,565	4,480
Oldham Unofficial	0	0	0	-295	0	3	0	-2	294
Oldham Total	6,599	-8,310	-8,854	-8,421	-735	18,514	0	-3,567	--
Parmer Official	75,559	-101,660	0	9,834	0	5,389	0	3,036	7,841
Parmer Total	75,559	-101,660	0	9,834	0	5,389	0	3,036	--
Potter Official	13,800	-12,645	-1,912	675	0	7,099	0	-1,558	-5,459
Potter Unofficial	0	0	-23	0	0	6	0	0	16
Potter Total	13,800	-12,645	-1,935	675	0	7,105	0	-1,558	--

Table D-1 continued

Ogallala Aquifer 2020 County Water Budgets Flow values are in acre-feet per year. Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.									
County	**Net storage**	**Net wells**	**Net drains**	**Net river leakage**	**Net ET**	**Net rechar ge**	**Net vertical leakage upper**	**Net vertical leakage lower**	**Net lateral flow**
Randall Official	12,802	-22,389	-993	138	-507	10,186	0	-2,517	3,280
Randall Unofficial	0	0	-220	0	0	4	0	-2	218
Randall Total	12,802	-22,389	-1,213	138	-507	10,190	0	-2,519	--
Roberts Official	61,205	-61,711	-4,004	-10,660	-25,716	13,355	0	0	27,533
Roberts Total	61,205	-61,711	-4,004	-10,660	-25,716	13,355	0	0	--
Sherman Official	281,035	-303,500	0	9,702	0	17,586	0	60	-4,883
Sherman Total	281,035	-303,500	0	9,702	0	17,586	0	60	--
Swisher Official	55,118	-71,182	-102	2,641	0	9,887	0	-505	4,143
Swisher Total	55,118	-71,182	-102	2,641	0	9,887	0	-505	--
Terry Official	46,686	-122,805	-307	3,002	0	74,022	0	381	-980
Terry Total	46,686	-122,805	-307	3,002	0	74,022	0	381	--
Wheeler Official	4,748	-9,432	-15,925	-7,606	-3,914	29,007	0	0	3,121
Wheeler Unofficial	7	0	-202	0	0	28	0	0	166
Wheeler Total	4,755	-9,432	-16,127	-7,606	-3,914	29,035	0	0	--
Winkler Official	13	0	0	0	0	7	0	-4	-16
Winkler Total	13	0	0	0	0	7	0	-4	--
Yoakum Official	47,663	-86,388	-13	2,526	0	34,652	0	-51	1,611
Yoakum Total	47,663	-86,388	-13	2,526	0	34,652	0	-51	--

Table D-2 Edwards-Trinity (High Plains) Aquifer groundwater budgets by county in 2020.

Edwards-Trinity (High Plains) Aquifer
2020 County Water Budgets
Flow values are in acre-feet per year.
Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.

County	Net storage	Net wells	Net drains	Net river leakage	Net ET	Net recharge	Net vertical leakage upper	Net vertical leakage lower	Net lateral flow
Bailey Official	644	0	0	0	0	0	283	84	-1,011
Bailey Unofficial	6	0	0	0	0	0	-115	5	104
Bailey Total	650	0	0	0	0	0	168	89	--
Borden Official	-178	-24	0	0	0	0	1,491	-178	-1,110
Borden Unofficial	-1	0	0	0	0	0	-1,760	-15	1,777
Borden Total	-179	-24	0	0	0	0	-269	-193	--
Cochran Official	246	-12	0	0	0	0	-1,062	294	535
Cochran Unofficial	8	0	0	0	0	0	-18	5	5
Cochran Total	254	-12	0	0	0	0	-1,080	299	--
Dawson Official	0	-1,129	0	0	0	0	2,034	-33	-872
Dawson Unofficial	1	-43	0	0	0	0	-909	-16	967
Dawson Total	1	-1,172	0	0	0	0	1,125	-49	--
Floyd Official	2,518	0	0	0	0	0	-1,193	-515	-810
Floyd Unofficial	5	0	0	0	0	0	-66	-8	69
Floyd Total	2,523	0	0	0	0	0	-1,259	-523	--
Gaines Official	-1,334	-9,014	0	0	0	0	6,029	1,121	3,199
Gaines Unofficial	1	-392	0	0	0	0	-775	16	1,150
Gaines Total	-1,333	-9,406	0	0	0	0	5,254	1,137	--
Garza Official	14	-175	0	0	0	0	-2,304	-245	2,710
Garza Unofficial	0	-4	0	0	0	0	-779	-8	790
Garza Total	14	-179	0	0	0	0	-3,083	-253	--
Hale Official	1,376	-5,104	0	0	0	0	3,357	249	123
Hale Unofficial	78	-397	0	0	0	0	125	22	173
Hale Total	1454	-5501	0	0	0	0	3482	271	--

Table D-2 continued

Edwards-Trinity (High Plains) Aquifer 2020 County Water Budgets Flow values are in acre-feet per year. Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.									
County	**Net storage**	**Net wells**	**Net drains**	**Net river leakage**	**Net ET**	**Net recharge**	**Net vertical leakage upper**	**Net vertical leakage lower**	**Net lateral flow**
Hockley Official	910	-71	0	0	0	0	-289	607	-1,157
Hockley Unofficial	0	0	0	0	0	0	34	2	-36
Hockley Total	910	-71	0	0	0	0	-255	609	--
Lamb Official	347	-11	0	0	0	0	-146	150	-340
Lamb Unofficial	3	-2	0	0	0	0	-347	24	322
Lamb Total	350	-13	0	0	0	0	-493	174	--
Lubbock Official	228	-863	0	0	0	0	-954	630	959
Lubbock Unofficial	0	0	0	0	0	0	-221	2	219
Lubbock Total	228	-863	0	0	0	0	-1,175	632	--
Lynn Official	2,024	-992	0	0	0	0	1,890	-92	-2,830
Lynn Unofficial	0	0	0	0	0	0	-137	-1	138
Lynn Total	2024	-992	0	0	0	0	1753	-93	--
Terry Official	35	-63	0	0	0	0	-381	533	-125
Terry Total	35	-63	0	0	0	0	-381	533	--
Yoakum Official	2,249	-43	0	0	0	0	51	488	-2,744
Yoakum Total	2,249	-43	0	0	0	0	51	488	--

Table D-3 Rita Blanca Aquifer groundwater budgets by county in 2020.

Rita Blanca Aquifer **2020 County Water Budgets** Flow values are in acre-feet per year. Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.									
County	**Net storage**	**Net wells**	**Net drains**	**Net river leakage**	**Net ET**	**Net recharge**	**Net vertical leakage upper**	**Net vertical leakage lower**	**Net lateral flow**
Dallam Official	-397	-4,275	0	0	0	0	4,116	749	-194
Dallam Unofficial	7	-11	0	0	0	0	-89	89	5
Dallam Total	-390	-4,286	0	0	0	0	4,027	838	--
Hartley Official	306	-197	0	0	0	0	-396	277	9
Hartley Unofficial	13	0	0	0	0	0	53	-41	-26
Hartley Total	319	-197	0	0	0	0	-343	236	--

Table D-4 Upper and lower Dockum units groundwater budgets by county in 2020.

Dockum Units 2020 County Water Budgets Flow values are in acre-feet per year. Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.									
County	**Net storage**	**Net wells**	**Net drains**	**Net river leakage**	**Net ET**	**Net recharge**	**Net vertical leakage upper**	**Net vertical leakage lower**	**Net lateral flow**
Andrews Official	1,472	-1,277	0	0	0	0	-62	0	-133
Andrews Total	1,472	-1,277	0	0	0	0	-62	0	--
Armstrong Official	1,268	-1,924	-2,557	-510	0	228	2,525	0	969
Armstrong Total	1,268	-1,924	-2,557	-510	0	228	2,525	0	--
Bailey Unofficial	904	-7	0	0	0	0	-890	0	-7
Bailey Total	904	-7	0	0	0	0	-890	0	--
Borden Official	-225	-81	0	-525	-982	1,708	67	0	37
Borden Unofficial	-1,596	-119	0	-195	-732	2,300	217	0	125
Borden Total	-1,821	-200	0	-720	-1,714	4,008	284	0	--
Briscoe Official	1,565	-78	-2,541	-4,336	-260	282	2,743	0	2,626
Briscoe Total	1,565	-78	-2,541	-4,336	-260	282	2,743	0	--
Carson Official	211	-191	0	0	0	0	36	0	-56
Carson Unofficial	79	-166	0	0	0	0	-295	0	381
Carson Total	290	-357	0	0	0	0	-259	0	--
Castro Official	25	-32	0	0	0	0	27	0	-20
Castro Unofficial	3,290	0	0	0	0	0	-2,839	0	-451
Castro Total	3,315	-32	0	0	0	0	-2,812	0	--
Cochran Unofficial	294	0	0	0	0	0	-299	0	5
Cochran Total	294	0	0	0	0	0	-299	0	--
Coke Official	0	0	-264	-21	-11	133	64	0	100
Coke Unofficial	0	0	-29	-2	0	0	42	0	-10
Coke Total	0	0	-293	-23	-11	133	106	0	--

Table D-4 continued

Dockum Units 2020 County Water Budgets Flow values are in acre-feet per year. Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.									
County	**Net storage**	**Net wells**	**Net drains**	**Net river leakage**	**Net ET**	**Net recharge**	**Net vertical leakage upper**	**Net vertical leakage lower**	**Net lateral flow**
Crane Official	64	-77	0	0	0	0	-802	0	816
Crane Unofficial	36	-20	0	0	0	0	-159	0	143
Crane Total	100	-97	0	0	0	0	-961	0	--
Crockett Official	30	-2	0	0	0	0	-517	0	488
Crockett Unofficial	0	0	0	0	0	0	-2	0	2
Crockett Total	30	-2	0	0	0	0	-519	0	--
Crosby Official	-12	-1,290	-968	-1,886	-262	2,939	2,564	0	-1,084
Crosby Unofficial	641	-413	0	239	0	57	-70	0	-456
Crosby Total	629	-1,703	-968	-1,647	-262	2,996	2,494	0	--
Dallam Official	4,291	-2,777	0	0	0	0	-1,545	0	31
Dallam Total	4,291	-2,777	0	0	0	0	-1,545	0	--
Dawson Unofficial	346	-30	-22	-49	-7	2	-164	0	-76
Dawson Total	346	-30	-22	-49	-7	2	-164	0	--
Deaf Smith Official	4,480	-3,647	0	83	0	202	-212	0	-907
Deaf Smith Total	4,480	-3,647	0	83	0	202	-212	0	--
Dickens Official	-379	-80	-3,721	-1,036	-20	3,611	2,037	0	-412
Dickens Total	-379	-80	-3,721	-1,036	-20	3,611	2,037	0	--
Ector Official	212	-124	0	0	0	0	1,384	0	-1,472
Ector Unofficial	71	-115	0	0	0	0	4	0	40
Ector Total	283	-239	0	0	0	0	1388	0	--
Fisher Official	-33	-40	-644	-140	-126	736	117	0	130
Fisher Total	-33	-40	-644	-140	-126	736	117	0	--

Table D-4 continued

Dockum Units **2020 County Water Budgets** Flow values are in acre-feet per year. Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.									
County	**Net storage**	**Net wells**	**Net drains**	**Net river leakage**	**Net ET**	**Net recharge**	**Net vertical leakage upper**	**Net vertical leakage lower**	**Net lateral flow**
Floyd Official	2,983	-1,432	-283	-2,594	-48	313	2,091	0	-1,030
Floyd Unofficial	78	0	0	-114	0	0	-83	0	119
Floyd Total	3061	-1432	-283	-2708	-48	313	2008	0	--
Gaines Official	2,121	-38	0	0	0	0	-2,100	0	17
Gaines Unofficial	351	0	0	0	0	0	-368	0	17
Gaines Total	2,472	-38	0	0	0	0	-2,468	0	--
Garza Official	-963	-27	-808	-3,881	-2,428	4,298	0	0	3,809
Garza Unofficial	-1,504	-202	-52	144	-996	2,664	549	0	-604
Garza Total	-2467	-229	-860	-3737	-3424	6962	549	0	--
Glasscock Official	24	-8	0	0	0	0	7	0	-23
Glasscock Unofficial	626	-272	0	0	0	2	-301	0	-55
Glasscock Total	650	-280	0	0	0	2	-294	0	--
Hale Official	948	-29	0	0	0	0	-694	0	-225
Hale Unofficial	3,209	-106	0	0	0	0	-2,692	0	-411
Hale Total	4157	-135	0	0	0	0	-3386	0	--
Hartley Official	4,901	-2,206	0	991	-313	205	-1,111	0	-2,467
Hartley Total	4,901	-2,206	0	991	-313	205	-1,111	0	--
Hockley Unofficial	622	-12	0	0	0	0	-609	0	-1
Hockley Total	622	-12	0	0	0	0	-609	0	--
Howard Official	-124	-169	-16	-1,163	-1,139	3,377	54	0	-820
Howard Unofficial	2,562	-3,015	0	9	0	406	396	0	-363
Howard Total	2,438	-3,184	-16	-1,154	-1,139	3,783	450	0	--

Table D-4 continued

Dockum Units **2020 County Water Budgets** Flow values are in acre-feet per year. Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.									
County	**Net storage**	**Net wells**	**Net drains**	**Net river leakage**	**Net ET**	**Net recharge**	**Net vertical leakage upper**	**Net vertical leakage lower**	**Net lateral flow**
Hutchinson Unofficial	0	0	0	0	0	0	0	0	0
Hutchinson Total	0	0	0	0	0	0	0	0	--
Irion Official	-172	-76	0	0	0	0	121	0	128
Irion Total	-172	-76	0	0	0	0	121	0	--
Kent Official	-109	-46	-659	-712	-21	1,302	0	0	245
Kent Total	-109	-46	-659	-712	-21	1,302	0	0	--
Lamb Unofficial	2,802	-4	0	0	0	0	-2,776	0	-22
Lamb Total	2,802	-4	0	0	0	0	-2,776	0	--
Loving Official	363	-374	0	0	0	0	182	0	-171
Loving Unofficial	5	0	0	0	0	0	29	0	-34
Loving Total	368	-374	0	0	0	0	211	0	--
Lubbock Unofficial	1,443	-3	0	-29	-3	0	-1,140	0	-268
Lubbock Total	1,443	-3	0	-29	-3	0	-1,140	0	--
Lynn Unofficial	268	-19	0	-46	0	1	90	0	-294
Lynn Total	268	-19	0	-46	0	1	90	0	--
Martin Official	203	-182	0	0	0	0	-19	0	-2
Martin Unofficial	1,984	-1,884	0	0	0	0	-67	0	-33
Martin Total	2,187	-2,066	0	0	0	0	-86	0	--
Midland Official	525	-500	0	0	0	0	-9	0	-15
Midland Unofficial	4,006	-3,975	0	0	0	0	61	0	-91
Midland Total	4,531	-4,475	0	0	0	0	52	0	--

Table D-4 continued

Dockum Units 2020 County Water Budgets Flow values are in acre-feet per year. Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.									
County	**Net storage**	**Net wells**	**Net drains**	**Net river leakage**	**Net ET**	**Net recharge**	**Net vertical leakage upper**	**Net vertical leakage lower**	**Net lateral flow**
Mitchell Official	7,706	-15,302	-1,109	-7,418	-4,102	18,141	449	0	1,637
Mitchell Unofficial	0	0	0	2	0	0	0	0	-1
Mitchell Total	7,706	-15,302	-1,109	-7,416	-4,102	18,141	449	0	--
Moore Official	171	-1,354	0	-53	0	61	1,204	0	-29
Moore Unofficial	54	0	0	0	0	4	-201	0	144
Moore Total	225	-1354	0	-53	0	65	1003	0	--
Motley Official	625	-385	-2,551	-1,785	-6	404	2,262	0	1,436
Motley Total	625	-385	-2,551	-1,785	-6	404	2,262	0	--
Nolan Official	9,164	-12,034	-353	-210	-76	1,763	633	0	1,113
Nolan Unofficial	3,164	-3,152	-370	-36	0	0	1,187	0	-794
Nolan Total	12328	-15186	-723	-246	-76	1763	1820	0	--
Oldham Official	1,037	-1,002	-120	-9,680	-3,700	5,919	3,567	0	3,978
Oldham Unofficial	0	0	0	-52	0	0	0	0	52
Oldham Total	1,037	-1,002	-120	-9,732	-3,700	5,919	3,567	0	--
Parmer Official	490	0	0	0	0	0	-487	0	-3
Parmer Unofficial	2,555	0	0	0	0	0	-2,544	0	-12
Parmer Total	3,045	0	0	0	0	0	-3,031	0	--
Pecos Official	371	-756	0	0	0	0	259	0	125
Pecos Unofficial	21	-4	0	0	0	0	-16	0	-1
Pecos Total	392	-760	0	0	0	0	243	0	--
Potter Official	1,542	-1,274	-417	-3,366	-1,064	2,222	1,366	0	992
Potter Unofficial	87	-10	0	0	0	0	198	0	-276
Potter Total	1,629	-1,284	-417	-3,366	-1,064	2,222	1,564	0	--

Table D-4 continued

Dockum Units 2020 County Water Budgets Flow values are in acre-feet per year. Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.									
County	**Net storage**	**Net wells**	**Net drains**	**Net river leakage**	**Net ET**	**Net recharge**	**Net vertical leakage upper**	**Net vertical leakage lower**	**Net lateral flow**
Randall Official	3,550	-2,945	-748	-2,250	0	86	2,525	0	-217
Randall Total	3,550	-2,945	-748	-2,250	0	86	2,525	0	--
Reagan Official	102	-287	0	0	0	0	183	0	2
Reagan Unofficial	203	-398	0	0	0	0	125	0	70
Reagan Total	305	-685	0	0	0	0	308	0	--
Reeves Official	3,541	-4,131	0	0	0	0	297	0	293
Reeves Unofficial	-43	-82	0	0	0	0	56	0	69
Reeves Total	3,498	-4,213	0	0	0	0	353	0	--
Scurry Official	5,112	-7,467	-1,364	-3,642	-947	7,626	1,907	0	-1,227
Scurry Total	5,112	-7,467	-1,364	-3,642	-947	7,626	1,907	0	--
Sherman Official	-99	0	0	0	0	0	-36	0	136
Sherman Unofficial	8	0	0	0	0	0	-20	0	12
Sherman Total	-91	0	0	0	0	0	-56	0	--
Sterling Official	224	-278	0	-285	-268	458	686	0	-538
Sterling Total	224	-278	0	-285	-268	458	686	0	--
Swisher Official	3,556	-1,150	0	-17	0	0	552	0	-2,942
Swisher Unofficial	49	0	0	0	0	0	-48	0	-1
Swisher Total	3,605	-1,150	0	-17	0	0	504	0	--
Terry Unofficial	540	0	0	0	0	0	-533	0	-6
Terry Total	540	0	0	0	0	0	-533	0	--
Tom Green Official	2	0	0	0	0	0	-25	0	22
Tom Green Total	2	0	0	0	0	0	-25	0	--

Table D-4 continued

Dockum Units 2020 County Water Budgets Flow values are in acre-feet per year. Positive values represent flows entering the aquifer while negative values represent flows leaving the aquifer.									
County	**Net storage**	**Net wells**	**Net drains**	**Net river leakage**	**Net ET**	**Net recharge**	**Net vertical leakage upper**	**Net vertical leakage lower**	**Net lateral flow**
Upton Official	73	-86	0	0	0	0	-259	0	272
Upton Unofficial	1,497	-1,465	0	8	0	0	978	0	-1,019
Upton Total	1570	-1551	0	8	0	0	719	0	--
Ward Official	251	-765	0	0	0	0	-1,320	0	1,834
Ward Unofficial	664	-154	0	0	0	0	173	0	-684
Ward Total	915	-919	0	0	0	0	-1147	0	--
Winkler Official	8,408	-9,077	0	0	0	0	1,023	0	-354
Winkler Unofficial	28	-15	0	0	0	0	-10	0	-3
Winkler Total	8,436	-9,092	0	0	0	0	1,013	0	--
Yoakum Unofficial	499	-7	0	0	0	0	-488	0	-4
Yoakum Total	499	-7	0	0	0	0	-488	0	--

Appendix E: Stakeholder comments

The TWDB held a stakeholder advisory forum on September 19, 2024. Below are the meeting notes and the stakeholder comments and responses.

High Plains Aquifer System Groundwater Availability Model

Stakeholder Advisory Forum – September 20, 2024

Question 1: Did the Districts besides North Plains review and approve estimates or provide additional information? For example, High Plains? (Cindy Ridgeway)

The TWDB Agriculture Water Conservation Team works with the districts in developing annual irrigation use estimates for the TWDB Water Use Survey. These estimates are sent to the districts for review. We sent out a request for production data to all the Districts on November 20, 2023 and received some data. If the pumping data was comprehensive for an entire county we incorporated it into the model. Districts are welcome to review the pumping data for the model extension and provide feedback. We may still have time for adjustments to the input pumping.

Question 2: Discuss General Head Boundary wells and how much that factors in flow into and out of the model. (Cindy Ridgeway)

In the Original Model, heads from the Edwards-Trinity (Plateau) and Pecos Valley alternative groundwater availability model were used to estimate heads for the layer 1 and 2 general head boundaries implemented in the river package. In the Original Model, the heads were kept constant from 2004 through 2012. For the Model Extension, we kept the head values the same from 2013 through 2020.

Question 3: Do you have a map of actual dry holes in the Ogallala? (Cindy Ridgeway)

We don't have a map of actual dry holes for the Ogallala Aquifer because this was beyond the scope of this project.

Question 4: It should be noted in the report of the model artifact in Gaines and model results should be used with caution in this select area. (Cindy Ridgeway)

We will be sure and use the results with caution in that area.

Question 5: Could you confirm that the Howard County recharge was addressed in this update? (Bill Hutchison)

Yes, the Howard County recharge issue was addressed in this update.

Question 6: I noticed there were some pretty significant changes and assumptions between how different water uses were implemented in each county and how it was distributed among the wells between what was done in the historical GAM and what was done in this extension period. This is the kind of thing that happens when you do an extension, and I do not have any issues with that. It would be good to see an evaluation of the degree to which the model has adjusted to the new pumping distribution so that water level changes picked up at the end of the extension reflect the actual water use that happens after the end of the extension when we're using this in a predictive sense for drought planning versus the model slowly continuing to adjust to a new pumping distribution like you wouldn't want. You know recoveries occurring in an area due to the model adjusting to the extension instead of something happening in the predictive period. When you change the assumptions, the model has to adjust to that change and so having some sort of discussion about the degree to which it has adjusted to the change would be useful. (Wade Oliver)

We will do a predictive model run to evaluate the degree to which the model has adjusted to the new pumping distribution. We will include the results of this analysis in the final report.

Question 7: Need to be clear about what district data was and was not used in the report. (Wade Oliver)

We will document in the final report what district data was and was not used in the report.

Question 8: Can you tell us why you decided to change those assumptions and spread that pumping back out? (Amy Bush)

We were unsuccessful in replicating the Original Model pumping distribution. One of the reasons for this was because the original modeling effort went through an iterative process of running the model and then redistributing pumping within a county from areas of low saturated thickness to areas of higher saturated thickness to reduce the amount of model curtailed pumping. Section 3.1.6 of the Original Numerical Model Report describes this iterative process. We decided to try a different approach of evenly distributing total county pumping estimates for irrigation, rural domestic, livestock, and mining. This approach takes less time, is more transparent, and is able to be replicated for future extensions. The average model curtailed pumping from 2000 through 2012 is 176,853 Acre-Feet compared to an average of 221,497 Acre-Feet from 2013 through 2020 using the new approach. It is also important to note that 7,048 of 8,165 new Submitted Driller Reports from 2013 through 2020 with a proposed use of Irrigation were in areas of 2012 model-simulated saturated thickness greater than 30 feet.

Attendance List

Name	Organization
Christa Perry	Hemphill County Underground Water Conservation District
Jason Coleman	High Plains Underground Water Conservation District
Odell Ward	North Plains Groundwater Conservation District
Janet Guthrie	North Plains Groundwater Conservation District
Ashley Ausbrooks	Panhandle Groundwater Conservation District
Britney Britten	Panhandle Groundwater Conservation District
Amber Blount	Sandy Land Underground Water Conservation District
Adam Foster	Texas Alliance of Groundwater Districts
Michael Chambers	City of Lorenzo
Fabian Heaney	Red River Authority of Texas
Cole Walker	Colorado River Municipal Water District
Paula Jo Lemonds	HDR, Inc.
Wade Oliver	INTERA
John Ellis	INTERA
Alyssa Balzen	KT Groundwater
Philip Webster	KT Groundwater
Bill Hutchison	Consultant
Darrell Peckham	BNP Land LLC
Amy Bush	RMBJ Geo Inc.
Ray Brady	RMBJ Geo Inc.
Larry French	Texas Public Policy Foundation
Cindy Ridgeway	
Zedric Capus	Texas Water Development Board
Sara Sutton	Texas Water Development Board
Heather Rose	Texas Water Development Board
Connie Beniquez	Texas Water Development Board
Jennifer Badhwar	Texas Water Development Board
Ian Jones	Texas Water Development Board
Shirley Wade	Texas Water Development Board
Saheli Majumdar	Texas Water Development Board
Tim Cawthon	Texas Water Development Board
Daryn Hardwick	Texas Water Development Board

Appendix F: Hydrographs

Note: Hydrographs are included in a separate document.