Adjustment of Parameters to Improve the Calibration of the Og-n Model of the Ogallala Aquifer, Panhandle Water Planning Area

Prepared for

Freese and Nichols, Inc.

and

Panhandle Water Planning Group

by

Alan Dutton
Texas Professional Geologist (#900)

Bureau of Economic Geology
Scott W. Tinker, Director
John A. and Katherine G. Jackson School of Geosciences
The University of Texas at Austin
University Station Box X
Austin, TX 78713

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SUMMARY

This study adjusted parameters within a model of the Ogallala aquifer in the northern part of the Texas Panhandle and adjacent parts of New Mexico, Oklahoma, and Kansas. The model is known as the “Ogll-n” GAM (Groundwater Availability Model) model or Panhandle Water Planning Area (PWPA) model. The model was developed in 2000, updated in 2001 for the Panhandle Water Planning Group, and is one of the GAM models adopted by the Texas Water Development Board (TWDB). Major adjustments included:

- elevation of the base of the Ogallala aquifer assigned to selected model cells,
- recharge rate applied to parts of the aquifer in the model on the basis of soil properties, and
- parameters of the MODFLOW Drain and GHB (general head boundary) packages used to simulate the flow of groundwater at the edge of the aquifer.

The steady-state (predevelopment) model error (RMSE or root mean square error) was reduced by more than 3 ft to 32 ft, which is less than 2 percent of the change in hydraulic head in monitoring wells across the model area. The RMSE error in all counties was lowered to less than 10 percent. The RMSE error for Roberts County, for example, was lowered from about 26 to 22 ft, which is less than 5 percent of the hydraulic-head change across the county. The transient model RMSE error was reduced by about 6 ft to 53 ft, which is about 2 percent of the hydraulic-head change across the model area. The transient-model RMSE for Roberts County, for example, was reduced from 51 to 45 ft, which is about 6 percent of hydraulic-head change across the county. The transient-model

RMSE for 10 of the 17 counties with monitoring well data is less than 10 percent. The largest RMSE (17 percent) was for Randall County where model-edge boundary conditions highly impact simulation results.

INTRODUCTION

This study adjusted selected parameters within a model of the Ogallala aquifer in the northern part of the Texas Panhandle and adjacent parts of New Mexico, Oklahoma, and Kansas. The model is known as the “Ogll-n” GAM (Groundwater Availability Model) model or Panhandle Water Planning Area (PWPA) model. The model was developed in 2000, updated in 2001 for the Panhandle Water Planning Group (PWPG), and is one of the GAM models (http://www.twdb.state.tx.us/gam/ogll_n/ogll_n.htm) adopted by the Texas Water Development Board (TWDB).

The purpose of the adjustment for the Panhandle Water Planning Group was to improve calibration of the model compared to the previous version (Dutton and others, 2001), for example, in the Roberts County area. Model revision is one of the activities involved in preparing the 2005 Panhandle (Region A) Regional Water Plan. The revised model will be used to simulate the hydrologic effect of updated water demand projections for 2005 through 2060 for analysis in the regional water plan.

Adjustments included how the base of the aquifer and recharge are represented in the model. Additional changes included parameters in the MODFLOW Drain and GHB packages and minor, local changes in hydraulic conductivity. This work was supported by a grant from the TWDB to the Panhandle Regional Planning Commission (PRPC), on behalf of the PWPG, and performed by the Bureau of Economic Geology under a subcontract with Freese and Nichols, Inc.

This report should be read as a supplement to the report documenting the PWPA model (Dutton and others, 2001). This report summarizes the adjustments to the previous model and recalculates model calibration statistics. Tables and other illustrations are compiled at the end of the report. In addition, a data model was prepared and submitted on a CD to the TWDB, PRPC, and Freese and Nichols, Inc.

MODEL ADJUSTMENTS

Base of Aquifer

In the previous model (Dutton and others, 2001), the base of the aquifer had been mapped mainly on the basis of depth of water wells in the Internet-based data base of the Texas Water Development Board. These data were contoured using spatial analysis features in ArcView GIS software and assigned to model grid cells.

Results of new drilling information, collected since construction began on the model in 1999, indicated that at some Roberts County locations the base of the Ogallala aquifer may be deeper and the thickness of the aquifer may be greater than as represented in the model. These features might reflect the effect of salt dissolution on deposition of sediments making up the Ogallala Formation (Gustavson and Finley, 1985). Change in how the model represents the base of the aquifer can improve how well simulation results match saturated thickness.

The Panhandle Groundwater Conservation District (PGCD) and Hemphill County Underground Water Conservation District (HCWD) provided a new data base listing the top of “red beds” from a review of approximately 1,530 drillers and geophysical logs (fig. 1). The accuracy of the estimates of depth to the red beds or base of the Ogallala aquifer might be approximately ±~20 ft. Most of the uncertainty comes from the difficulty in defining the contact on the basis of drill cuttings.

The wells included in the data base fall within 1,263 of the 1-square-mile cells of the model. Average elevation of the top of red beds was calculated for those model cells with more than one well record. The revised elevation was lower than or equal to the previous estimate for 549 model cells or 43 percent of the 1,263 comparisons (fig. 1). The revised elevation was within ±30 ft of the previous estimate for about 70 percent of the model cells and within ±50 ft for about 80 percent of the model cells.

The revised elevations were substituted into the model on a cell-by-cell basis. Honoring all revised elevations in model cells that were greatly thinned, however, was found to result in the simulation of some model cells dewatering or going dry. No thinning of model cells, therefore, was included. Not decreasing the thickness of model cells might be justified by the uncertainty in the red-bed elevation data. Layer thickness was increased in more than 500 model cells but not decreased in any (fig. 2). Additional parameter adjustment beyond the scope of this work would be needed to compensate for “thinning” of model cell thicknesses.

Recharge

In the previous model (Dutton and others, 2001), recharge was assigned on the basis of precipitation and three groups of soil texture. GIS polygons of soil types had been downloaded from http://www.ftw.nrcs.usda.gov/stat_data:html, the U.S.

Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) Internet data base. The numerous soil types first had been joined into eight groups on the basis of soil texture information. Three of the soil groups mainly have loamy soils such as those developed on the Ogallala Formation and on alluvium in the Canadian River Breaks. Some of the alluvium may have been derived from the Ogallala Formation. Four of the groups mainly have loamy surface and clayey subsurface soils and correspond to the Blackwater Draw Formation. Another soil group consisted of windblown sands.

The initial set of eight soil-texture groups were combined into three groups for the purpose of assigning recharge in the model (Dutton and others, 2001). Weighting factors were derived by trial-and-error to optimize model calibration by assigning more recharge to soils developed on alluvium and the Ogallala Formation than to those developed on the Blackwater Draw Formation. Soils on windblown sand were given the greatest recharge weighting factor. The three combined soil-texture groups break out major trends in recharge patterns, following the approach of Mullican and others (1977), but do not break out how recharge might vary locally with respect to soil properties.

The revised model superposes additional local variations in soil weighting factors to take into account soil permeability. There are several areas in the 2001 model (Dutton and others, 2001) where positive or negative residuals are clustered within regional trends in soil type or soil permeability. The approach to adjusting recharge was to (1) select soil-permeability zones using ArcView mapping tools, then (2) specify adjustment factors for each soil zone to increase or decrease recharge relative to the previous model to reduce the residual (fig. 3). The amount of adjustment was varied by trial and error to result in an improved model calibration. Changes were made in this manner to ten areas of the model (table 1, fig. 4). Table 1 compares the simple average, minimum, and maximum recharge rate between the previous (Dutton and others, 2001) and revised models for each of the ten adjustment zones and for the whole model. Figure 5 shows the revised distribution of recharge rates in the model area. The revised model redistributes recharge and results in a greater range in recharge rates, from 0.06 to 2.31 inches/yr, compared to the range in the previous model, 0.1 to 1.68 inches/yr (table 1). Table 2 summarizes the county-average recharge rates applied to the Ogallala aquifer. Counties with a large area of recharge-adjustment zone 3 (fig. 4), for example, have a reduced recharge rate applied in the revised model. Counties with recharge-adjustment zone 1 in the Canadian River Breaks (fig. 4), for example, have an increased recharge rate applied in the revised model (table 2).

MODFLOW Drain and GHB Packages

Boundary conditions assigned around the perimeter of the model influence simulated results near the model boundary. The MODFLOW Drain and GHB (general head boundary) packages are the main controls used in the model to account for the flow of water at the edge of the aquifer.

The main adjustment to the Drain Package was to reset its hydraulic-head parameter within the saturated column of the aquifer. Decreasing the hydraulic-head value in a Drain cell simulates greater groundwater discharge and lowers the calculated hydraulic head in the vicinity of the Drain cell. Hydraulic head of Drain cells were adjusted in four areas where clusters of positive residuals in the previous model signify overestimation of water levels in the aquifer (fig. 6).

The GHB Package was applied to the area in Randall and southern Potter Counties where the Ogallala aquifer is narrow between the Canadian River Breaks and the Prairie Dog Town Fork of the Red River (fig. 6). Positive residuals in hydraulic head indicated that the previous model was overestimating hydraulic head in the vicinity of the GHB cells. Decreasing the recharge rate applied to zone 3 (fig. 4) somewhat reduced the positive residual in Randall County. Decreasing hydraulic head and hydraulic conductance assigned to the GHB cells further improved model calibration in that area.

Other Adjustments

Three monitoring wells in the northwest corner of Collingsworth County lie within a few miles of the model boundary. In the previous model, the average calibration (root mean square) error for these three wells was 45 ft, which was 68 percent of the 65-ft difference in water level between these wells. Change in the hydraulic-head and hydraulic-conductance parameters of the Drain package did not significantly reduce the calibration error. To increase the effect of the Drain package on the model cells representing those monitoring wells, hydraulic conductivity of six intervening cells was increased from approximately2 to 5 ft/d. The slightly greater hydraulic conductivity allows more water to move to the Drain cells and results in an improved calibration by decreasing simulated water levels at the calibration wells.

RECALIBRATION RESULTS

The overall RMSE (root mean square) error for the steady state model was reduced from 36 to 32 ft (table 3). The RMSE error for each county was reduced to less than 10 percent of the range in calibration water levels across each county. This makes the overall RMSE error less than 2 percent of the 2,360-ft change in calibration water levels across the model (fig. 7). The residuals between simulated and measured water levels are more uniformly distributed (fig. 3) than in the previous model. The calibration (RMSE) error for Roberts County was reduced from 26 to 22 ft, or less than 5 percent of the range of calibration water levels in the county (table 3). Figure 8 shows the steady-state residuals for calibration wells in Roberts and eastern Hutchinson Counties.

The RMSE error for the transient model representing December 1998 was reduced from 58 to 53 ft, which is less than 3 percent of the calibration range (table 4, fig. 9). The RMSE error for 10 of the 17 counties with calibration data is less than 10 percent of the calibration range for each county. The transient-model RMSE error for Roberts County was reduced from 51 to 45 ft, or about 6 percent of the range of calibration water levels in the county (table 4). Randall County had the largest RMSE (17 percent) in the transient model.

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Mullican, W. F., III, Johns, N. D., and Fryar, A. E., 1997, Playas and recharge of the Ogallala aquifer on the southern High Plains of Texas—an examination using numerical techniques: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 242, 72 p.

Table 1. Comparison of mean, minimum, and maximum recharge rates applied in the previous (Dutton and others, 2001) and revised models. Zones are shown in figure 4.

Zone	Substrate	Location or County	Change	No. of model cells	Previous mean	New mean	Previous minimum	New minimum	Previous maximum	New maximum
1	Sandy soils in Canadian River Breaks	Roberts, Hutchinson, Carson	Increase	226	0.34	1.53	0.29	0.88	0.47	2.31
2	Sandy soils in Canadian River Breaks	Roberts, Carson, Potter	Increase	621	0.32	0.36	0.12	0.18	0.52	0.57
3	Soils on Blackwater Draw Formation south of Canadian River	multiple	Decrease	1,596	0.16	0.09	0.12	0.06	0.30	0.16
4	Sandy soils	Gray, Wheeler	Decrease	402	0.83	0.71	0.19	0.18	1.51	1.37
5	Sandy soils	Donley	Increase	164	0.42	0.63	0.17	0.26	0.51	0.88
6	Soils on Ogallala Formation	Dallam, Hartley, New Mexico	Increase	1,362	0.20	0.35	0.20	0.34	0.20	0.40
7	Low-permeability soils north of Canadian River	various	Increase	1,321	0.12	0.14	0.10	0.12	0.24	0.29
8	Low-permeability soils north of Canadian River	Sherman, Hansford	Increase	800	0.10	0.13	0.10	0.13	0.11	0.15
9	Low-permeability soils north of Canadian River	Sherman	Increase	104	0.10	0.12	0.10	0.11	0.20	0.22
10	Low-permeability soils north of Canadian River	Ochiltree	Decrease	235	0.13	0.11	0.12	0.10	0.30	0.24
All				24,550	0.30	0.32	0.10	0.06	1.68	2.31

Table 2. Comparison of county-average recharge rates for the Ogallala aquifer between the previous (Dutton and others, 2001) and revised models.

		Previous model		Revised model	
County	Area in model (1000 acres)	Average recharge (inches/yr)	Total recharge (acre-feet/year)	Average recharge (inches/yr)	Total recharge (acre-feet/year)
Armstrong	332	0.208	5,748	0.166	4,579
Carson	583	0.202	9,815	0.173	8,394
Collingsworth	5	0.556	233	0.523	219
Dallam	954	0.194	15,459	0.269	21,403
Donley	343	0.430	12,294	0.492	14,051
Gray	566	0.398	18,775	0.356	16,782
Hansford	588	0.144	7,048	0.161	7,867
Hartley	902	0.189	14,222	0.228	17,162
Hemphill	576	0.650	31,184	0.654	31,347
Hutchinson	420	0.229	8,013	0.447	15,645
Lipscomb	597	0.414	20,578	0.414	20,578
Moore	530	0.156	6,906	0.169	7,473
Ochiltree	585	0.185	9,050	0.183	8,922
Oldham*	58	0.199	969	0.199	969
Potter*	222	0.196	3,616	0.184	3,408
Randall*	133	0.133	1,478	0.081	898
Roberts	587	0.359	17,575	0.503	24,622
Sherman	591	0.146	7,176	0.158	7,798
Wheeler	336	0.946	26,528	0.865	24,262

* Not all of the Ogallala aquifer in the county is included in the model

Table 3. Comparison of RMSE error estimates between the previous and revised steady-state models.

			2001 Model		*Revised*	
COUNTY	No.	Range	RMSE (ft)	RMSE %	RMSE (ft)	RMSE %
Armstrong	37	505	46.0	9.1%	22.5	4.5%
Carson	79	413	50.6	12.2%	20.1	4.9%
Collingsworth	3	66	45.0	68.4%	6.0	9.1%
Dallam	74	1037	47.9	4.6%	64.9	6.3%
Donley	116	727	37.4	5.1%	39.0	5.4%
Gray	117	458	27.2	5.9%	24.0	5.2%
Hansford	89	492	19.7	4.0%	20.8	4.2%
Hartley	58	840	36.0	4.3%	34.1	4.1%
Hemphill	90	385	29.0	7.5%	30.6	8.0%
Hutchinson	57	469	33.5	7.1%	25.3	5.4%
Lipscomb	45	369	24.9	6.7%	26.0	7.0%
Moore	91	404	25.6	6.3%	25.5	6.3%
Ochiltree	49	254	18.3	7.2%	18.1	7.1%
Potter	6	305	50.6	16.6%	27.2	8.9%
Randall	25	189	43.4	23.0%	18.0	9.5%
Roberts	47	480	25.7	5.4%	21.9	4.6%
Sherman	89	365	41.2	11.3%	32.3	8.9%
Wheeler	208	413	39.4	9.5%	35.2	8.5%
Net mean error (ft)			0.1		-10.3	
Net mean absolute error (ft)			27.2		23.0	
Net RMSE		2360	35.6	1.5%	32.2	1.4%

Table 4. Comparison of RMSE error estimates between the previous and revised transient (1998) models.

	2001 Model			*Revised*		
COUNTY	Range	RMSE (ft)	RMSE %	Range	RMSE (ft)	RMSE %
Armstrong	558	61.5	11.0%	492	26.4	5.4%
Carson	629	63.5	10.1%	421	28.4	6.7%
Dallam	962	47.3	4.9%	998	70.3	7.0%
Donley	585	63.7	10.9%	701	59.0	8.4%
Gray	468	49.3	10.5%	467	31.7	6.8%
Hansford	465	62.0	13.3%	622	67.5	10.8%
Hartley	676	44.1	6.5%	669	36.1	5.4%
Hemphill	298	39.1	13.1%	420	50.8	12.1%
Hutchinson	437	40.2	9.2%	496	48.2	9.7%
Lipscomb	382	54.7	14.3%	423	67.5	15.9%
Moore	484	52.7	10.9%	461	62.0	13.4%
Ochiltree	966	87.2	9.0%	671	87.6	13.0%
Potter	254	51.2	20.1%	378	20.3	5.4%
Randall	228	76.6	33.6%	179	30.9	17.3%
Roberts	425	50.8	12.0%	752	45.2	6.0%
Sherman	415	65.7	15.8%	367	38.6	10.5%
Wheeler	292	39.0	13.3%	425	39.2	9.2%
Net mean error (ft)		16.3			-10.9	
Net mean absolute error (ft)		50.12			35.8	
Net RMSE	2191	58.8	2.7%	2328	52.8	2.2%

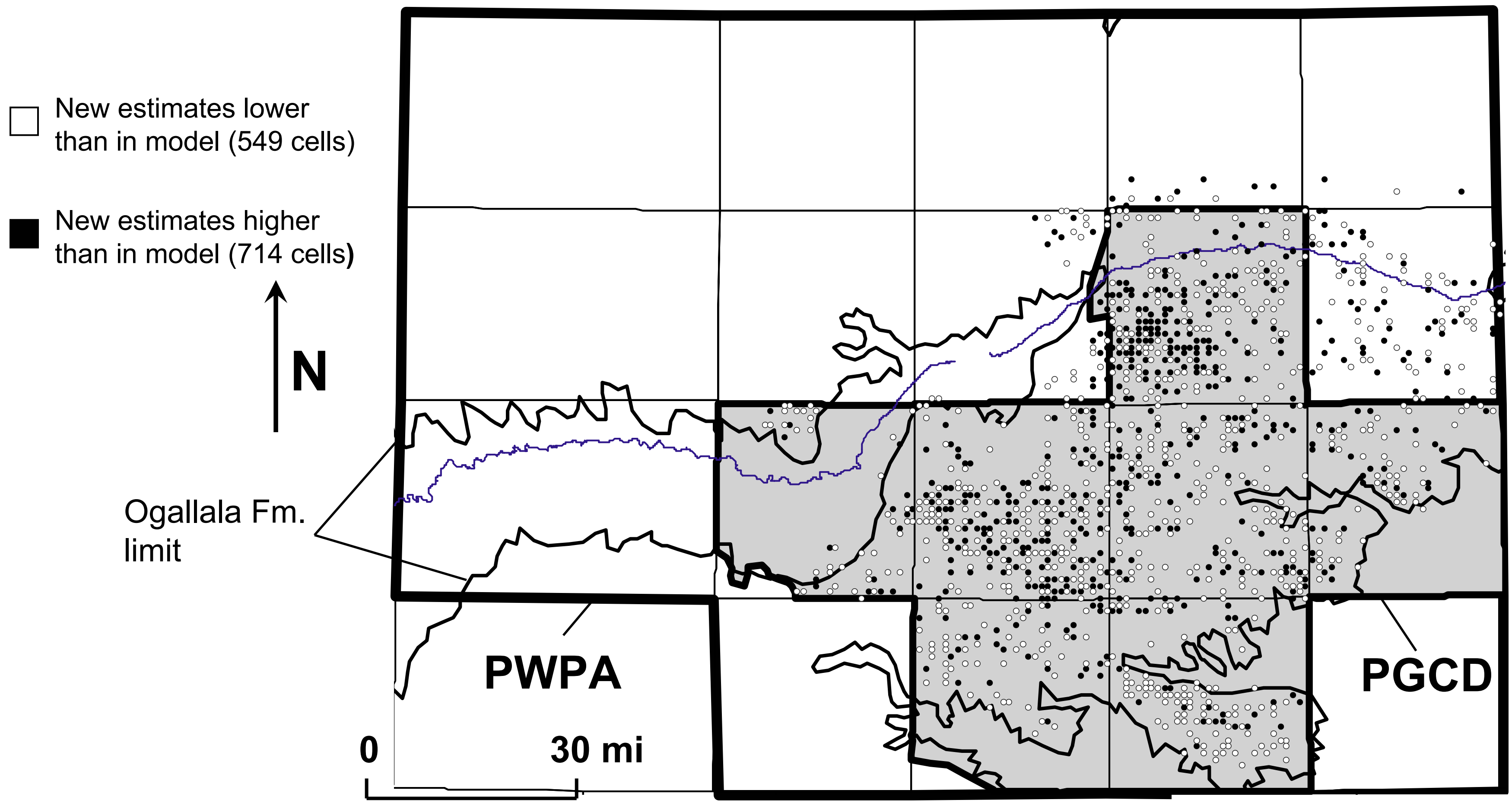

Figure 1. Map of model cells for which data on new base-of-aquifer estimates were provided by PGCD.

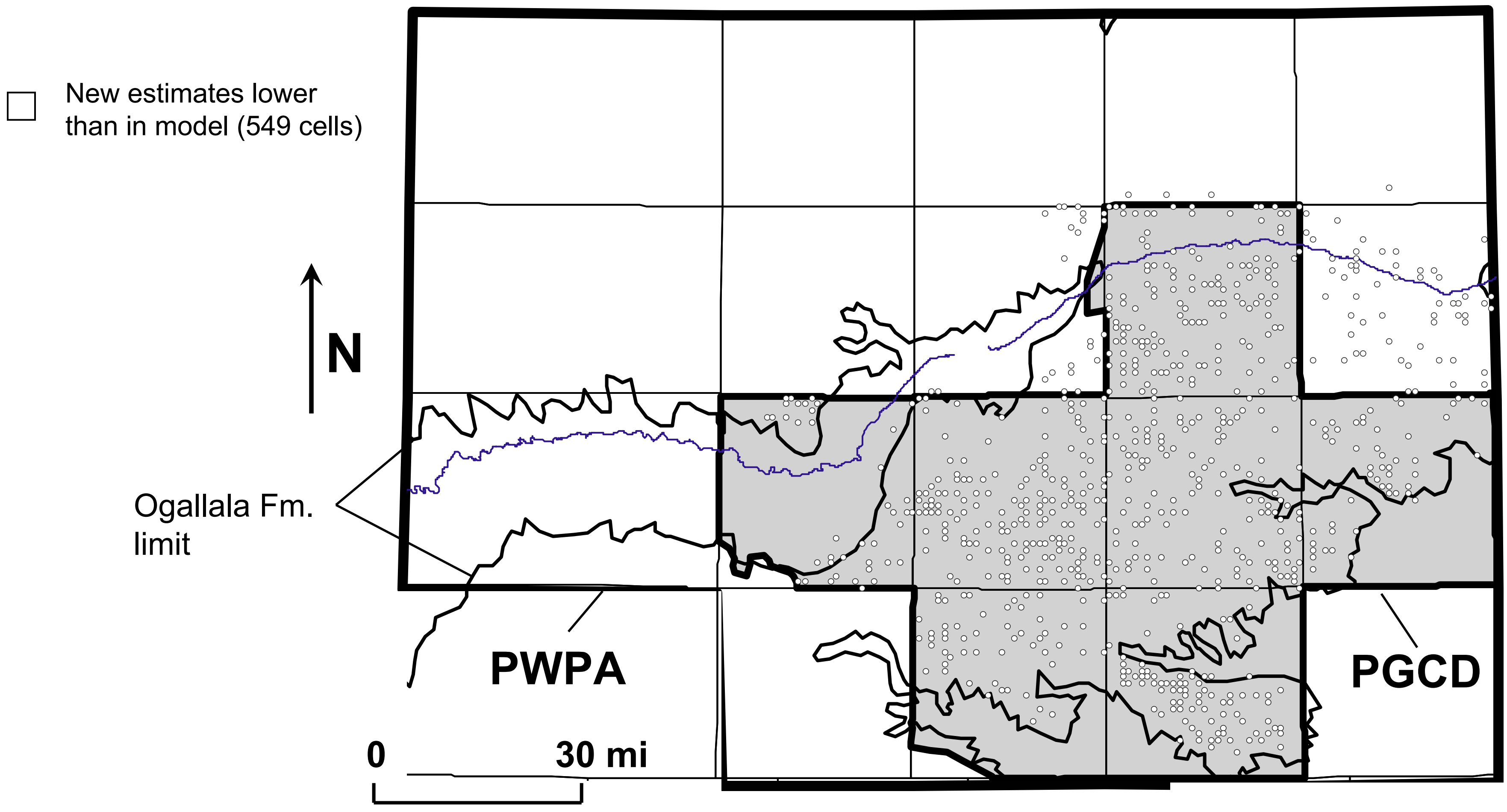

Figure 2. Map of model cells at which the base of aquifer was lowered on the basis of data provided by PGCD.

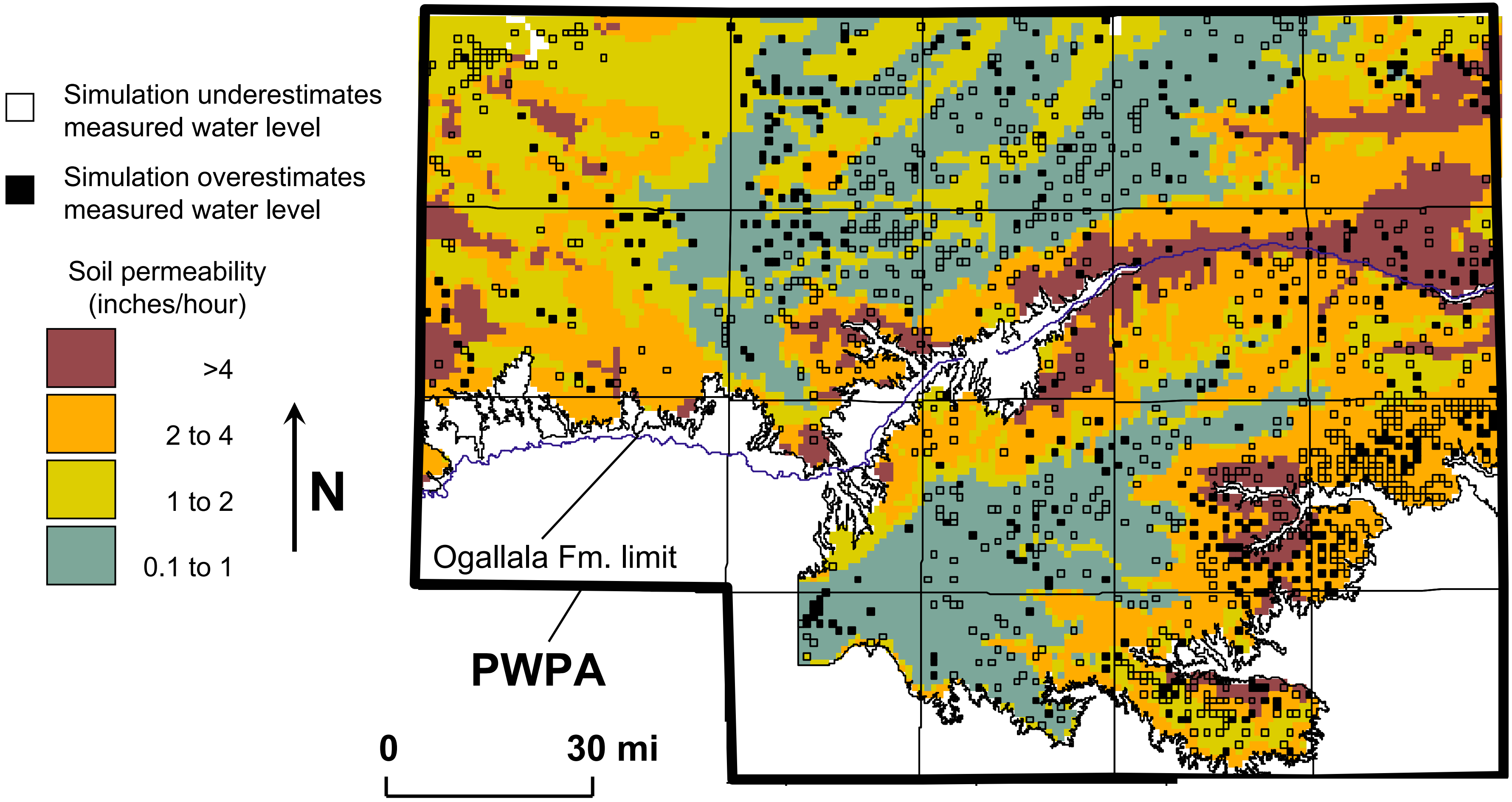

Figure 3. Map comparing revised model residuals (simulated minus measured water levels) to values of soil permeability mapped on the basis of STATSGO data.

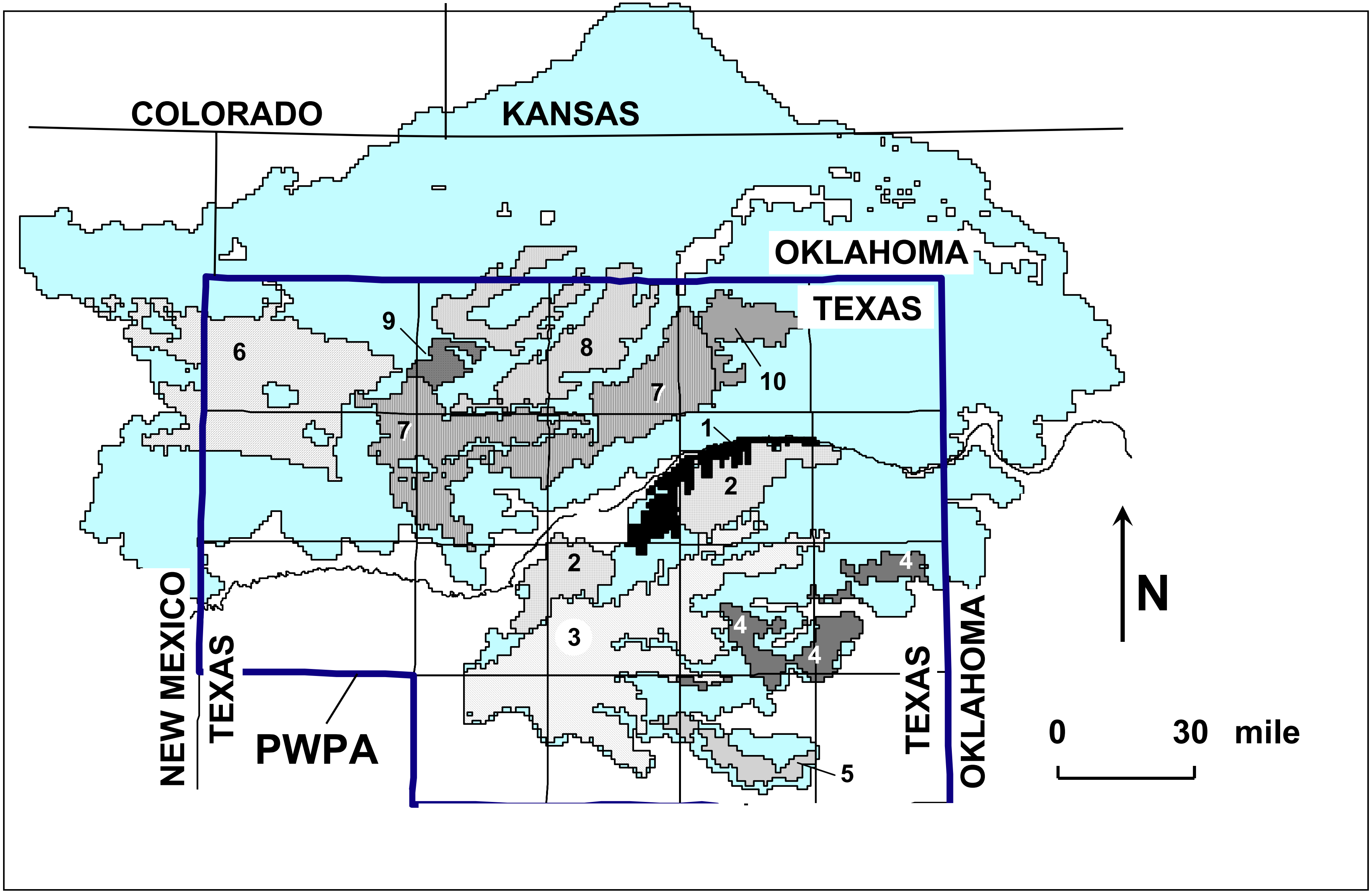

Figure 4. Map showing 10 zones in which recharge was adjusted in the revised model. See table 1.

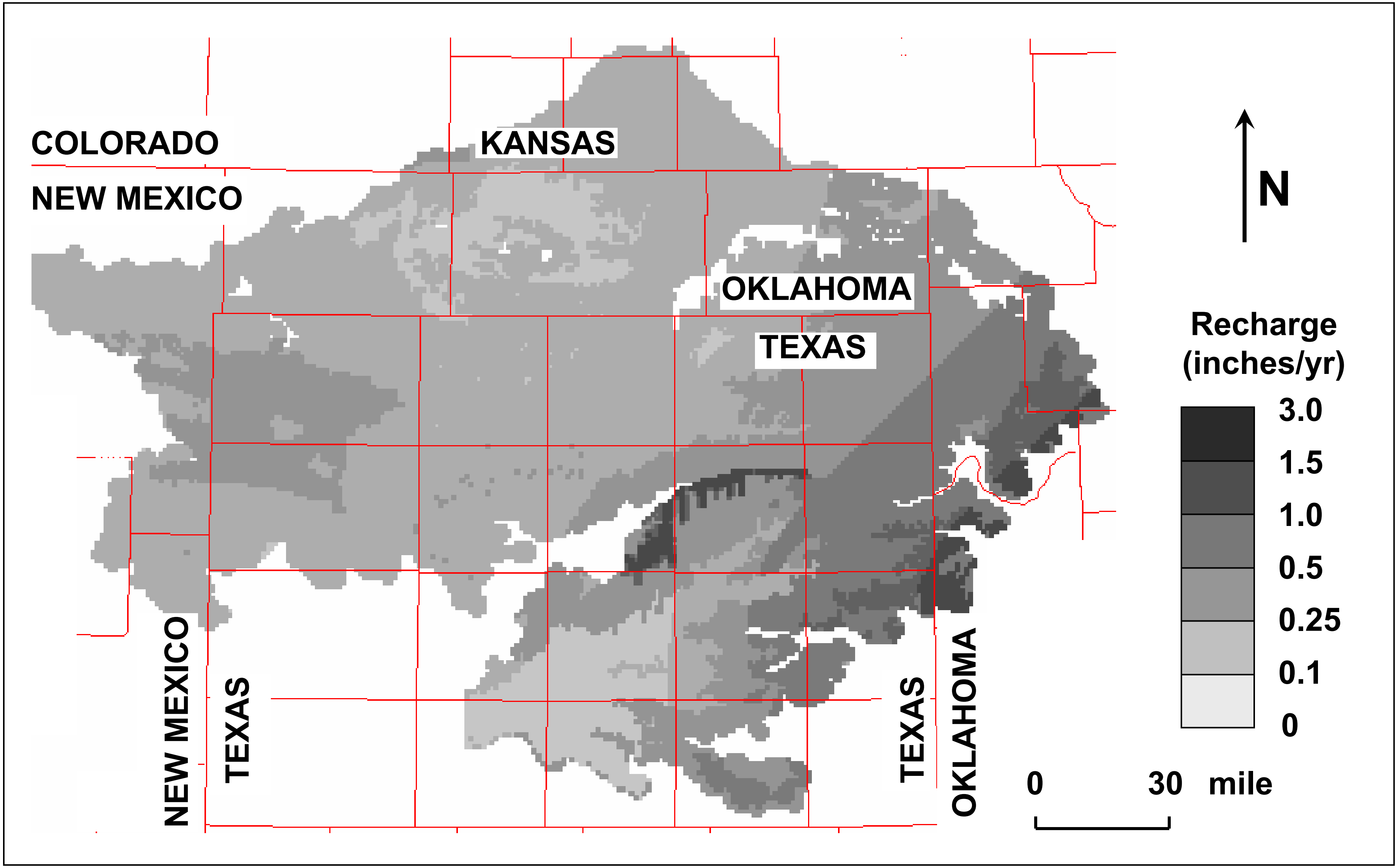

Figure 5. Distribution of recharge applied in the revised model.

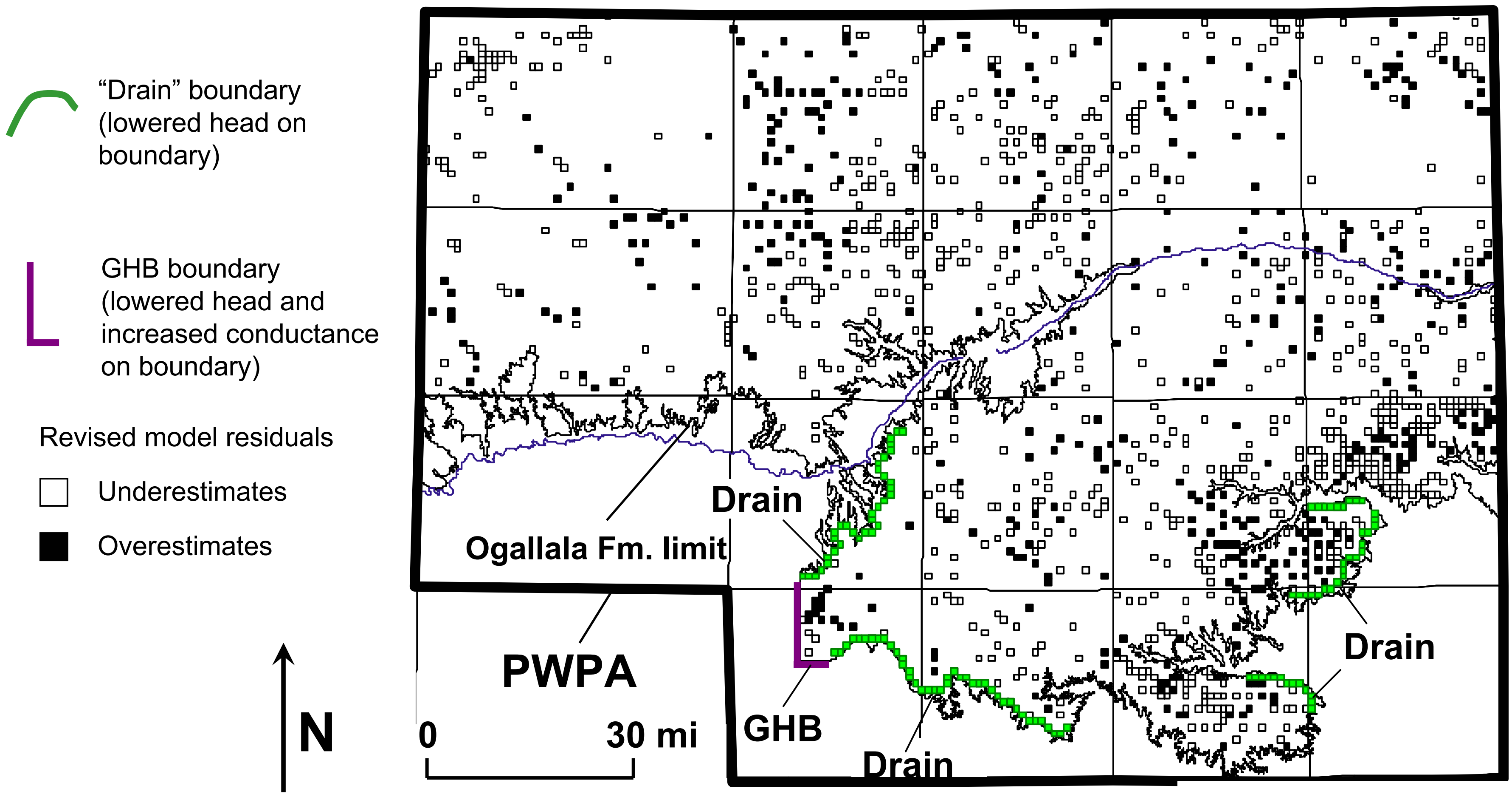

Figure 6. Map showing location of model boundary cells at which parameters were adjusted in the MODFLOW Drain and GHB Packages, in comparison to residual error in simulated water level.

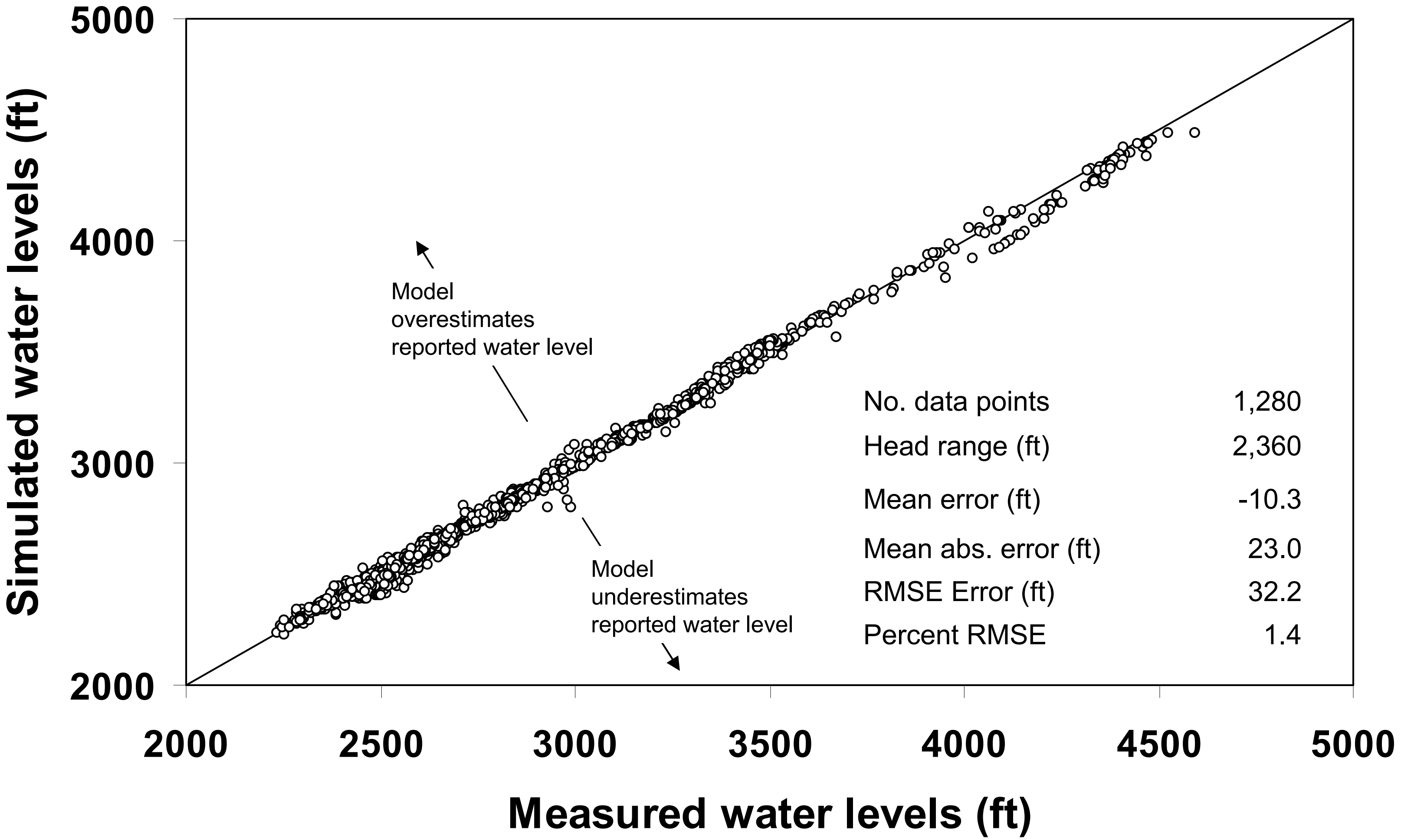

Figure 7. Comparison of simulated and measured water levels in the steady-state OG-n model simulation of the Ogallala aquifer.

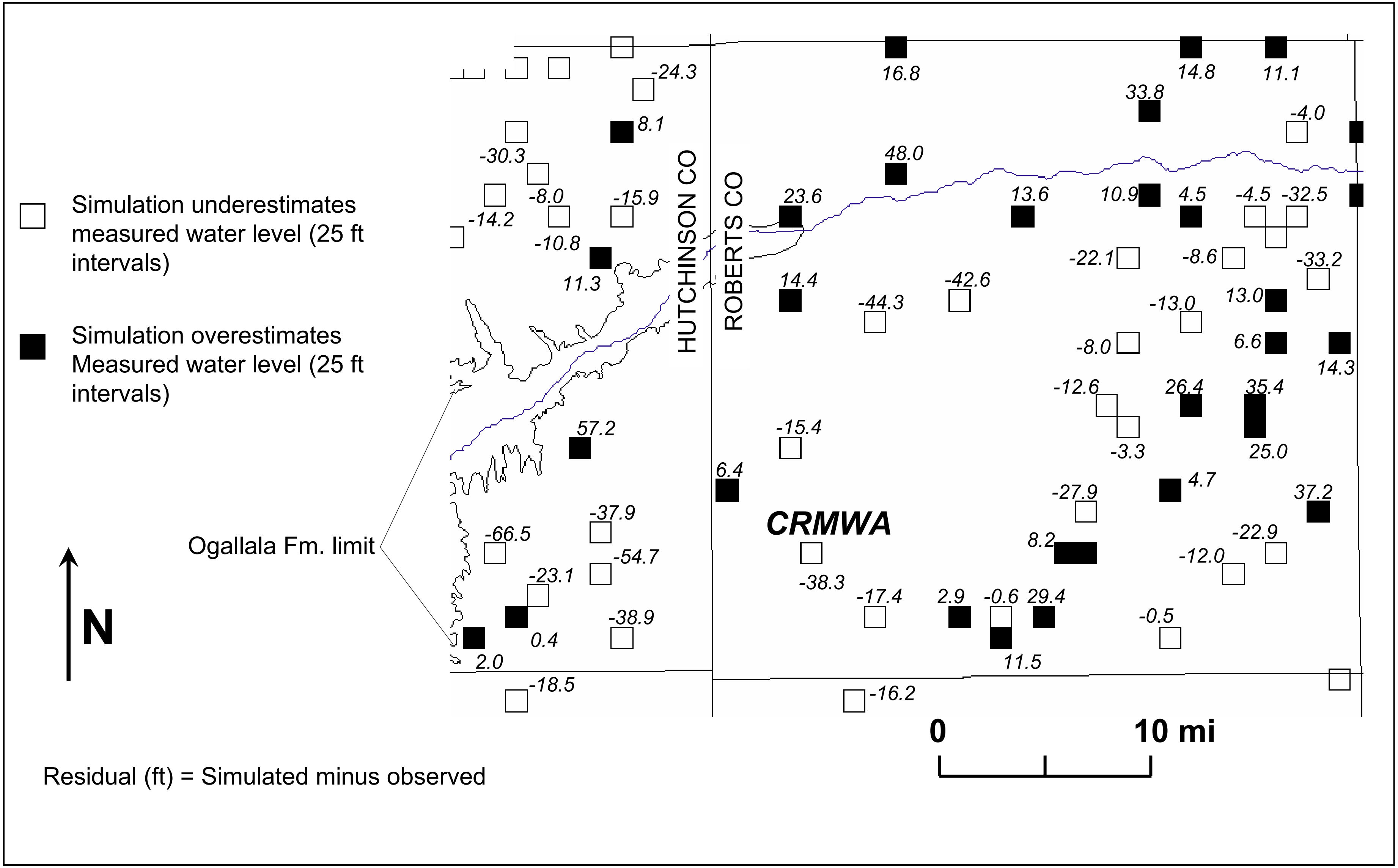

Figure 8. Map of model residuals for Roberts and eastern Hutchinson Counties.

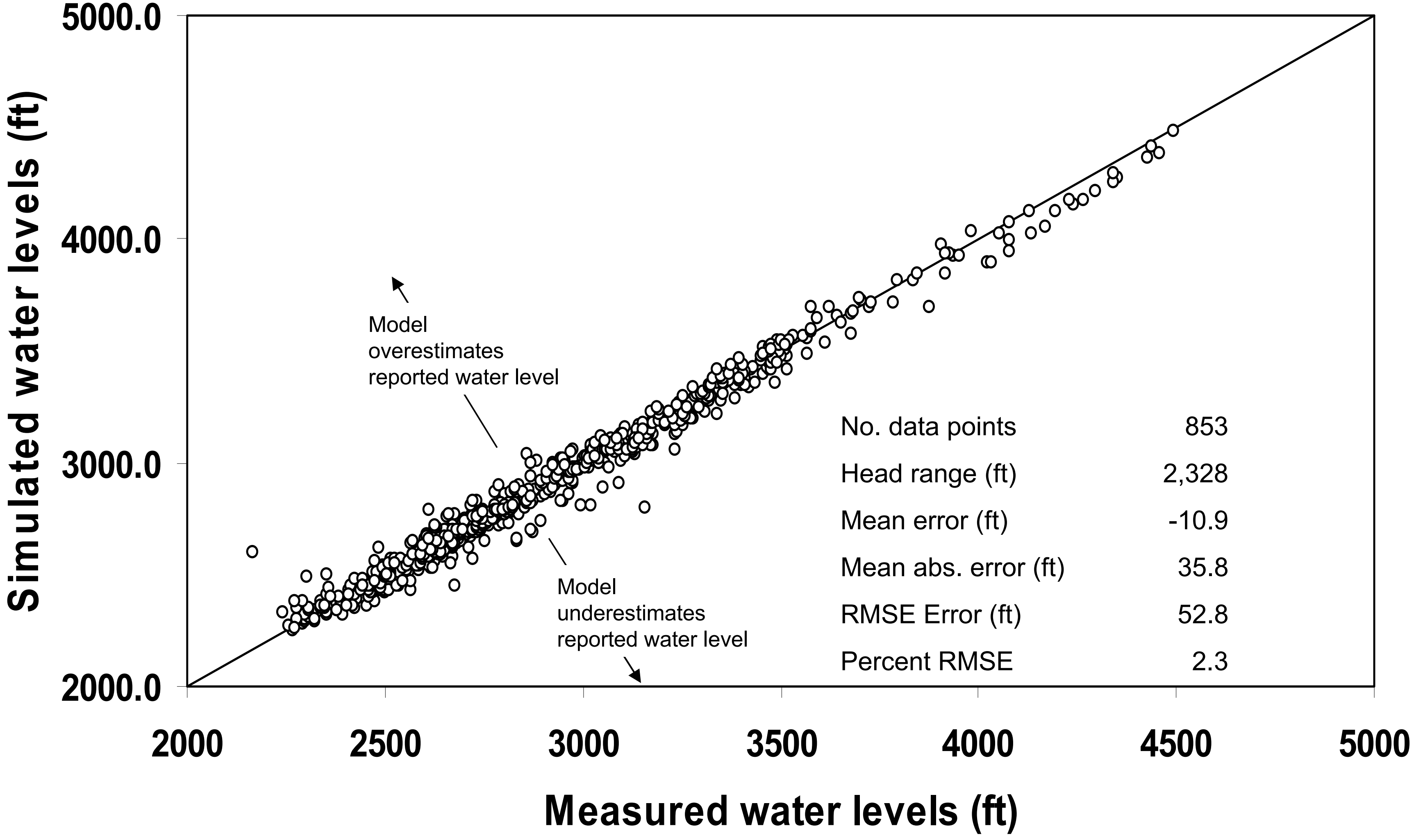

Figure 9. Comparison of simulated and measured water levels in the transient OG-n model simulation of the Ogallala aquifer for December 1998.