GAM Run 08-24

by Mr. Wade Oliver
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Groundwater Availability Modeling Section
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EXECUTIVE SUMMARY:

We ran the groundwater availability model for the Igneous and parts of the West Texas Bolsons aquifers, adjusting annual pumpage to produce average drawdowns of 10, 20, 30, 40, and 50 feet, respectively, after a 50-year (2001 to 2050) predictive simulation using average recharge as requested by Groundwater Management Area 4. These model runs result in the following:

- For the 10-foot average drawdown scenario, pumping of 16,200 acre-feet per year in the Wild Horse Flat, Michigan Flat, Ryan Flat, and Lobo Flat portions of the West Texas Bolsons Aquifer results in drawdowns from 0 to 30 feet. For the Igneous Aquifer, pumping of 10,200 acre-feet per year results in water-level changes from an increase of 50 feet to a drawdown of 60 feet.

- For the 20-foot average drawdown scenario, pumping of 22,000 acre-feet per year in the Wild Horse Flat, Michigan Flat, Ryan Flat, and Lobo Flat portions of the West Texas Bolsons Aquifer results in drawdowns from 0 to 55 feet. For the Igneous Aquifer, pumping of 17,800 acre-feet per year results in water-level changes from an increase of 30 feet to a drawdown of 70 feet.

- For the 30-foot average drawdown scenario, pumping of 27,600 acre-feet per year in the Wild Horse Flat, Michigan Flat, Ryan Flat, and Lobo Flat portions of the West Texas Bolsons Aquifer results in drawdowns from 5 to 80 feet. For the Igneous Aquifer, pumping of 25,200 acre-feet per year results in water-level changes from an increase of 20 feet to a drawdown of 80 feet.

- For the 40-foot average drawdown scenario, pumping of 33,800 acre-feet per year in the Wild Horse Flat, Michigan Flat, Ryan Flat, and Lobo Flat portions of the West Texas Bolsons Aquifer results in drawdowns from 10 to 100 feet. For the Igneous Aquifer, pumping of 32,700 acre-feet per year results in water-level changes from an increase of 10 feet to a drawdown of 90 feet.

- For the 50-foot average drawdown scenario, pumping of 40,400 acre-feet per year in the Wild Horse Flat, Michigan Flat, Ryan Flat, and Lobo Flat portions of the West Texas Bolsons Aquifer results in drawdowns from 15 to 115 feet. For the Igneous Aquifer, pumping of 40,000 acre-feet per year results in drawdowns from 0 to 110 feet.

REQUESTOR:

Ms. Janet Adams of Jeff Davis County Underground Water Conservation District and Presidio County Underground Water Conservation District (on behalf of Groundwater Management Area 4).

DESCRIPTION OF REQUEST:

Ms. Janet Adams asked us to perform a series of model runs that result in average drawdowns of 10, 20, 30, 40, and 50 feet for the West Texas Bolsons and Igneous aquifers using the groundwater availability model for the Igneous and parts of the West Texas Bolsons (Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat) aquifers over a 50-year simulation period.

METHODS:

In order to determine the pumping required to achieve the drawdowns requested above, we used the groundwater availability model for the Igneous and parts of the West Texas Bolsons aquifers. It should be noted that the parts of the West Texas Bolsons Aquifer in the groundwater availability model (Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat) are referred to in the model report (Beach and others, 2004) collectively as the Salt Basin Bolson Aquifer.

The simulation was set up using average recharge (Beach and others, 2004). The pumping specified in the model was determined iteratively by adjusting the pumping values in each aquifer to obtain the requested drawdowns, as described in the pumpage section below. Simulated water levels and water-level declines were then evaluated and are described in the results section below.

PARAMETERS AND ASSUMPTIONS:

The parameters and assumptions for the model run using the groundwater availability model for the Igneous and parts of the West Texas Bolsons aquifers are described below:

- We used Version 1.01 of the groundwater availability model for the Igneous and parts of the West Texas Bolsons aquifers. See Beach and others (2004) for assumptions and limitations of the model.

- We used Groundwater Vistas version 5 (Environmental Simulations, Inc., 2007) as the interface to process model output.

- The model includes three layers representing the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer (Layer 1), the Igneous Aquifer (Layer 2), and the underlying Cretaceous and Permian units (Layer 3).

- The Igneous Aquifer boundary used in the groundwater availability model run was the boundary around which the model was developed. This boundary is a both a generalized (or smoothed) and slightly smaller version of the official boundary of the Igneous Aquifer according to the 2007 State Water Plan. A comparison of these two boundaries, as well as the boundary for the Wild Horse Flat, Michigan Flat, Ryan Flat, and Lobo Flat portions of the West Texas Bolsons Aquifer, are shown in Figure 1.

- The mean absolute error (a measure of the difference between simulated and actual water levels during model calibration) of the entire model for the period of 1990 to 2000 is 64 feet, or four percent of the range of measured water levels (Beach and others, 2004).

- The pumpage used for each of the 2001 to 2050 predictive simulations was determined iteratively to match drawdown scenarios requested by members of Groundwater Management Area 4. Details on this pumpage are given below. It is important to note that the pumping required to achieve a particular drawdown in an aquifer is not necessarily unique. The water levels in one aquifer also depend on the water levels in neighboring aquifers. The results presented here reflect scenarios with matching drawdowns in both the Igneous and West Texas Bolsons aquifers.

Pumpage

The pumpage values in the groundwater availability model for each aquifer for the requested drawdown scenarios were determined using an iterative process. The pumpage in the model for the year 2000 was adjusted up or down and applied to all years of the predictive model run (2001 to 2050). After running the model, the average drop in water levels (drawdown) between the beginning and end of the predictive simulation for each aquifer, within the boundaries described above, was then calculated. This process was repeated until a pumping value for each aquifer was determined for the five drawdown scenarios. It is important to note that dry cells, described in the results section below, were not considered when calculating the average drawdown in each aquifer.

For scenarios in which a decrease in pumping was required, the pumpage value for each cell in the model was decreased by a uniform factor to preserve the year 2000 pumpage distribution. For scenarios in which an increase in pumping was required, pumping was uniformly increased over all model cells that contained pumping in the year 2000. The pumpage specified in the model for each drawdown scenario is shown in Table 1.

Table 1. Pumpage input into the groundwater availability model to yield drawdowns requested by Groundwater Management Area 4. All pumpage is reported in acre-feet per year.

Drawdown Scenario (ft)	Aquifer	County				Total
		Brewster	Culberson	Jeff Davis	Presidio	
10	West Texas Bolsons	NA	15,700	68	420	16,200
20	West Texas Bolsons	NA	21,300	92	569	22,000
30	West Texas Bolsons	NA	26,800	115	715	27,600
40	West Texas Bolsons	NA	31,400	926	1,480	33,800
50	West Texas Bolsons	NA	34,700	2,710	3,000	40,400
10	Igneous	2,910	NA	2,510	4,750	10,200
20	Igneous	4,160	NA	4,800	8,790	17,800
30	Igneous	5,400	NA	7,070	12,800	25,200
40	Igneous	6,620	NA	9,310	16,700	32,700
50	Igneous	7,840	NA	11,500	20,600	40,000

RESULTS:

Included in Appendix A are estimates of the water budgets after running the model for 50 years (2001 to 2050) by county for the Igneous Aquifer and the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer for each of the drawdown scenarios requested by Groundwater Management Area 4. The components of the water budget are described below.

- Recharge—simulates areally distributed recharge due to precipitation falling on the outcrop (where the aquifer is exposed at land surface) areas of aquifers as well as inflow to the aquifer from alluvial fans and stream beds as described in Beach and others (2004). Recharge is always shown as "Inflow" into the water budget. Recharge is modeled using the MODFLOW Recharge package.

- Evapotranspiration—water that flows out of an aquifer due to direct evaporation and plant transpiration. This component of the budget will always be shown as "Outflow". Evapotranspiration is modeled using the MODFLOW Evapotranspiration (EVT) package.

- Wells—water produced from wells in each aquifer. This component is always shown as "Outflow" from the water budget, because all wells included in the model produce (rather than inject) water. Wells are simulated in the model using the MODFLOW Well package. It is important to note that values in Appendix A for wells in the water budget may not precisely match the pumpage amounts shown in Table 1 because of dry cells, as described below.

- Streams and Springs—water that naturally discharges from an aquifer when water levels rise above the elevation of the stream or spring. This component is always shown as "Outflow," or discharge, in the water budget. Stream and spring outflows are simulated in the model using the MODFLOW Drain package. Stream inflow was modeled using the MODFLOW Recharge package and is included in the recharge values described above.

- Change in Storage—changes in the water stored in the aquifer. The storage component that is included in "Inflow" is water that is removed from storage in the aquifer (that is, water levels decline). The storage component that is included in "Outflow" is water that is added back into storage in the aquifer (that is, water levels increase). This component of the budget is often seen as water both going into and out of the aquifer because water levels will decline in some areas (water is being removed from storage) and will rise in others (water is being added to storage).

- Lateral flow—describes lateral flow within an aquifer between a county and adjacent counties.

- Vertical leakage (upward or downward)—describes the vertical flow, or leakage, between two aquifers. This flow is controlled by the water levels in each aquifer and aquifer properties that define the amount of leakage that can occur. In this model, the West Texas Bolsons Aquifer is not always underlain by the Igneous Aquifer and the Igneous Aquifer is not always overlain by the West Texas Bolsons Aquifer. For this reason, the amount of water exiting the West Texas Bolsons Aquifer may not equal the amount of water entering the Igneous Aquifer.

The results of the model run are described for the two aquifers in the model area: the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer (Layer 1 in the model) and the Igneous Aquifer (Layer 2).

Initial water levels (those from the end of the transient calibration period – the end of 2000) for the West Texas Bolsons and Igneous aquifers are shown in Figures 2 and 3, respectively. These figures show the starting water levels for the 50-year predictive model run. For the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer, water levels generally decrease from south to north with the highest water levels found in the extreme southeast portion of the aquifer in northern Presidio County. For the Igneous Aquifer, water levels are highest in the Davis Mountains in central Jeff Davis County and drop radially from this high. The lowest initial water levels in the Igneous Aquifer are found in the southernmost portion of the aquifer in southern Presidio County.

Water-level trends for the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer and the Igneous Aquifer for each of the requested drawdown scenarios are similar to those described for the initial water levels above. These water levels are shown in Figures 4, 5, 6, 7, and 8 for the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer for the 10-, 20-, 30-, 40-, and 50-foot average drawdown scenarios, respectively. The water levels for the Igneous Aquifer are shown in Figures 9, 10, 11, 12, and 13 for the same drawdown scenarios.

Because differences between initial water levels and water levels after 50 years are sometimes difficult to quantify in the above figures, maps of predicted drawdown were made. Drawdown refers to a drop in water levels over a period of time – in this case between the end of 2000 and the end of 2050. Table 2 shows the average predicted drawdown, and the pumping required to achieve the drawdown, by county and groundwater conservation district between 2001 and 2050 for each of the drawdown scenarios. Figures 14, 15, 16, 17, and 18 show the predicted drawdowns for the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer for the 10-, 20-, 30-, 40-, and 50-foot average drawdown scenarios, respectively. Figures 19, 20, 21, 22, and 23 show the predicted drawdowns for the Igneous Aquifer for the same drawdown scenarios.

Drawdowns over the 50-year predictive portion of the model simulation for the 10-foot drawdown scenario are shown in Figures 14 and 19 for the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer and the Igneous Aquifer, respectively. For the West Texas Bolsons Aquifer, drawdown is highest in southwestern Culberson County along a narrower portion of the aquifer. Water levels are predicted to drop in this area between 25 and 30 feet under this scenario. The lowest drawdowns are in the northern and southernmost portions of the aquifer between 0 and 5 feet. For the Igneous Aquifer, the highest drawdowns are in a localized area in northwestern Brewster County with a predicted drop in water levels up to 60 feet. Under this scenario, an increase in water levels (negative drawdown) by as much as 50 feet is also predicted in south-central Jeff Davis County. With the exception of these two areas, drawdowns over the rest of the Igneous Aquifer for the 10-foot average drawdown scenario are generally between 0 and 20 feet.

Drawdowns for the 20-foot drawdown scenario are shown in Figures 15 and 20 for the two aquifers in the model. For the West Texas Bolsons Aquifer, the drawdown trend is similar to that of the 10-foot scenario described above. The highest predicted drawdowns are between 50 and 55 feet and occur in southern Culberson County. The lowest predicted drawdowns occur in the extreme southeastern portions of the aquifer in southern Jeff Davis and northern Presidio counties. For the Igneous Aquifer, the highest drawdowns, up to 70 feet, occur in northwestern Brewster County. An area in the northwestern portion of the aquifer in Culberson County also shows drawdowns up to 50 feet. The lowest drawdowns are in the same area described above in south-central Jeff Davis County with an increase in water levels by as much as 30 feet. Over the remaining areas of the aquifer, drawdowns are generally between 0 and 30 feet.

Drawdowns for the 30-foot drawdown scenario are shown in Figures 16 and 21 for the two aquifers in the model. For the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer, the drawdown trend is similar to that of the two scenarios above with drawdowns between 5 and 80 feet. For the Igneous Aquifer, drawdowns by as much as 80 feet are predicted in southern

Culberson County and northwestern Brewster County. The lowest drawdowns are in south-central Jeff Dais County with a predicted increase in water levels by as much as 20 feet. Over the remaining areas of the aquifer, drawdowns are generally between 10 and 40 feet.

Drawdowns for the 40-foot drawdown scenario are shown in Figures 17 and 22 for the two aquifers in the model. For the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer, the drawdown trend is again similar to the those of the scenarios above, ranging from 10 to 100 feet. For the Igneous Aquifer, predicted drawdowns range from 90 ft in southern Culberson County and northerwestern Brewster County to an increase in water levels by up to 10 feet. Over the remaining areas of the aquifer, drawdowns are generally between 20 and 50 feet.

Drawdowns for the 50-foot drawdown scenario are shown in Figures 18 and 23 for the two aquifers in the model. For the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer, the drawdown trend is the same as those in the above scenarios with a maximum drawdown between 110 and 115 feet occuring in southwestern Culberson County and a minimum between 15 and 20 feet occurring in north-central Presidio County. For the Igneous Aquifer, drawdowns as high as 110 feet are predicted to occur in southern Culberson County and northwestern Brewster County. The lowest drawdowns are predicted to occur along the northeastern edge of the aquifer. Under this drawdown scenario, no areas are expected to exhibit increases in water levels from 2001 to 2050.

Some of the pumping totals (Wells) listed in Appendix A differ from the pumping amounts listed in Tables 1 and 2. The primary reason for this difference is the occurrence of dry cells. When the water level in a cell drops below the bottom of the aquifer in a cell, the cell goes dry and pumping can no longer occur. The total county pumpage is, therefore, reduced. For the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portion of the West Texas Bolsons Aquifer, 674 cells out of 3,104 active cells within the aquifer boundary were dry at the beginning of the predictive model run (the end of 2000). The total number of dry cells in the model after 50 years for the 10-, 20-, 30-, 40-, and 50-foot drawdown scenarios is 685, 703, 718, 730, and 743 cells, respectively. For the Igneous Aquifer, 1,827 cells out of 21,679 active cells within the aquifer boundary were dry at the beginning of the predictive model run. The total number of dry cells in the model after 50 years for the 10-, 20-, 30-, 40-, and 50-foot drawdown scenarios for the Igneous Aquifer is 1,834, 1,841, 1,854, 1,879, 1,892 cells, respectively. If high pumpage is the primary factor for a cell going dry, the model is indicating that the pumping may be too great for the aquifer in this area.

It is important to note that sub-regional water budgets are not exact. This is due to the size of the model cells and the approach used to extract data from the model. To avoid double accounting, a model cell that straddles a county boundary is assigned to one side of the boundary based on the location of the centroid of the model cell. For example, if a cell contains two counties, the cell is assigned to the county where the centroid of the cell is located.

Table 2. Average drawdown and pumping for each drawdown scenario and aquifer by county and groundwater conservation district. All water-level changes are reported in feet. All pumping values are reported in acre-feet per year. Positive drawdown values indicate an average water-level decrease.

Drawdown Scenario (ft)	Aquifer	Term	Brewster	Culberson	Jeff Davis	Presidio			Grand Total
			Brewster County GCD	Culberson County GCD	Jeff Davis County UWCD	Jeff Davis County UWCD	Presidio County UWCD	Total	
10	West Texas Bolsons	Pumping	0	15,700	68	3	417	420	16,200
		Drawdown	0.0	11.4	12.6	10.3	4.4	4.7	10.0
	Igneous	Pumping	2,910	0	2,510	5	4,750	4,750	10,200
		Drawdown	11.7	19.7	8.0	14.4	10.3	10.3	10.0
20	West Texas Bolsons	Pumping	0	21,300	92	5	565	569	22,000
		Drawdown	0.0	29.1	17.3	11.9	5.5	5.8	20.0
	Igneous	Pumping	4,160	0	4,800	13	8,780	8,790	17,800
		Drawdown	22.6	31.6	16.7	23.9	21.0	21.0	20.0
30	West Texas Bolsons	Pumping	0	26,800	115	6	709	715	27,600
		Drawdown	0.0	47.0	21.9	13.5	6.5	6.9	30.0
	Igneous	Pumping	5,400	0	7,070	21	12,800	12,800	25,200
		Drawdown	33.5	43.6	25.4	33.2	31.6	31.6	30.0
40	West Texas Bolsons	Pumping	0	31,400	926	43	1,430	1,480	33,800
		Drawdown	0.0	61.0	29.3	18.8	12.1	12.5	40.0
	Igneous	Pumping	6,620	0	9,310	28	16,700	16,700	32,700
		Drawdown	44.4	53.2	34.2	43.5	42.3	42.3	40.0
50	West Texas Bolsons	Pumping	0	34,700	2,710	125	2,870	3,000	40,400
		Drawdown	0.0	69.7	40.3	29.8	23.4	23.7	50.0
	Igneous	Pumping	7,840	0	11,500	36	20,600	20,600	40,000
		Drawdown	55.3	59.6	43.1	54.1	53.1	53.1	50.0

REFERENCES:

Beach, J.A., Ashworth, J.B., Finch, Jr., S.T., Chastain-Howley, A., Calhoun, K., Urbanczyk, K.M., Sharp, J.M., and Olson, J., 2004, Groundwater availability model for the Igneous and parts of the West Texas Bolsons (Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat) aquifers: contract report to the Texas Water Development Board, 208 p.

Donnelly, A., 2006, GAM run 06-32: Texas Water Development Board, GAM Run 06-32 Report, 13 p.

Environmental Simulations, Inc., 2007, Guide to Using Groundwater Vistas Version 5, 381 p.

Cynthia K. Ridgeway is Manager of the Groundwater Availability Modeling Section and is responsible for oversight of work performed by employees under her direct supervision. The seal appearing on this document was authorized by Cynthia K. Ridgeway, P.G., on December 19, 2008.

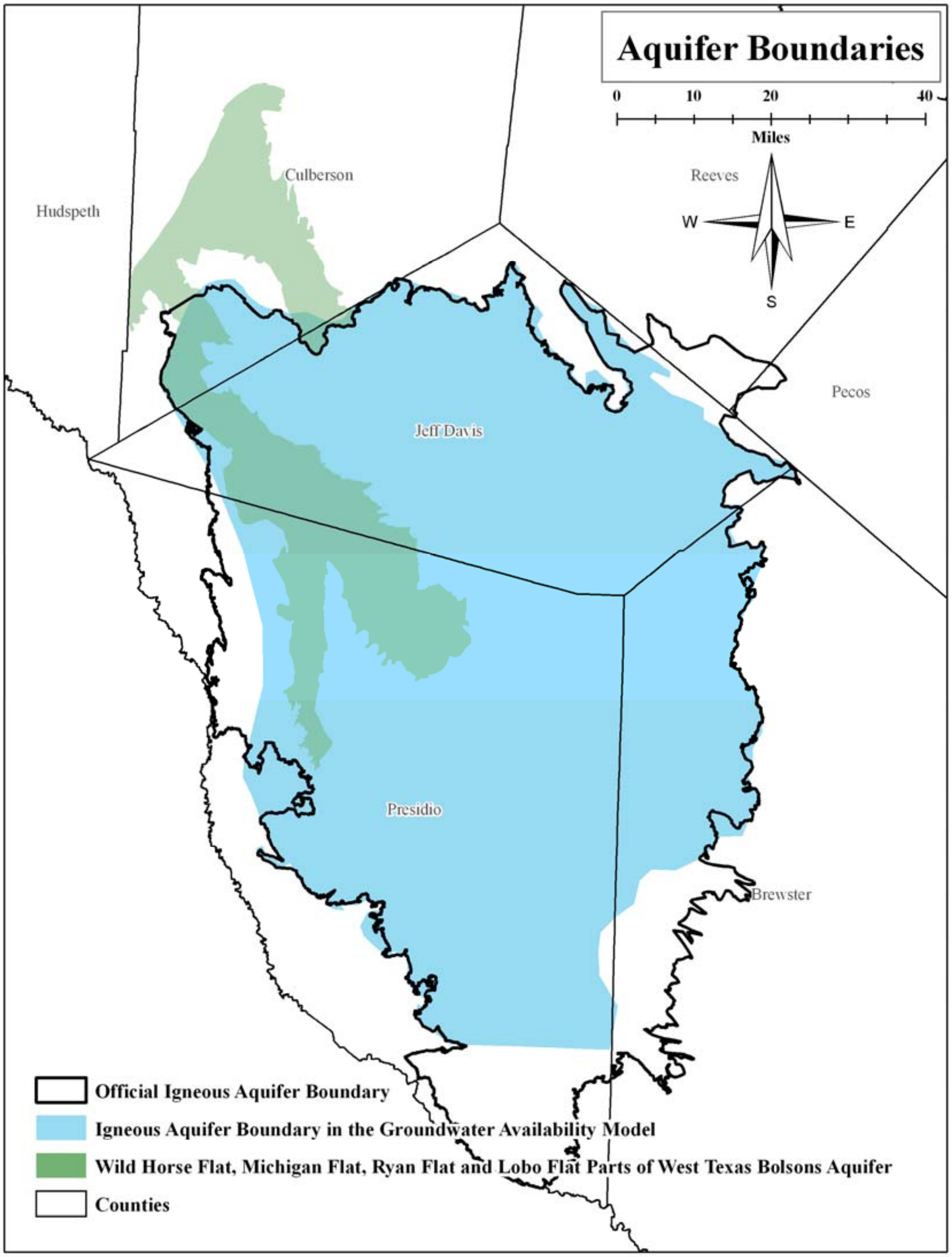

Figure 1. Aquifer boundaries used in the groundwater availability model run. The official boundary of the Igneous Aquifer is also included for comparison purposes. The official boundary of the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer are identical to the model boundary shown which was used during model development.

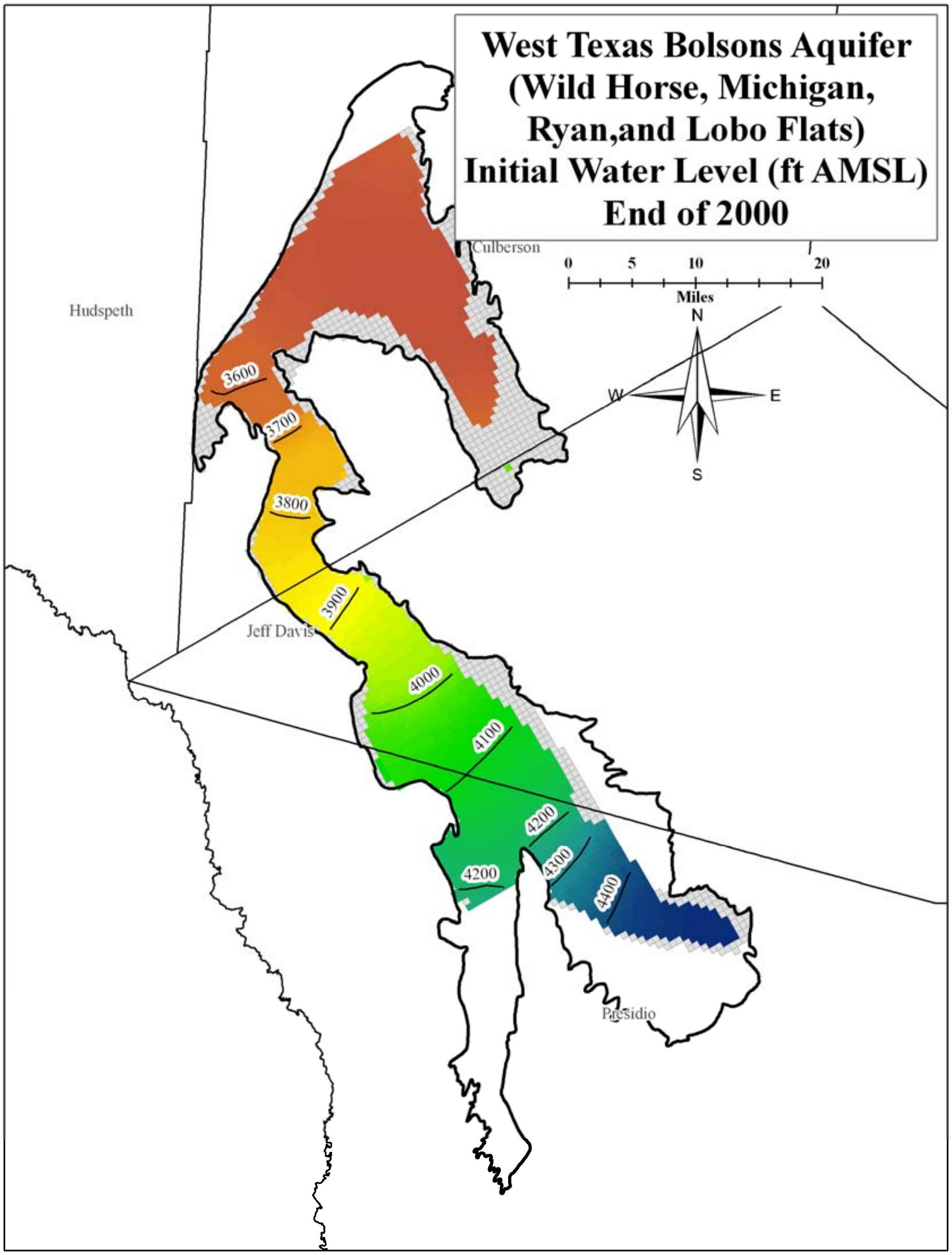

Figure 2. Initial water-level elevations for the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer for the predictive groundwater availability model run. Water-level elevations are in feet above mean sea level (ft AMSL). The contour interval is 100 feet. Grey areas indicate model grid cells that are dry. The black border indicates the boundary of the aquifer used during model development.

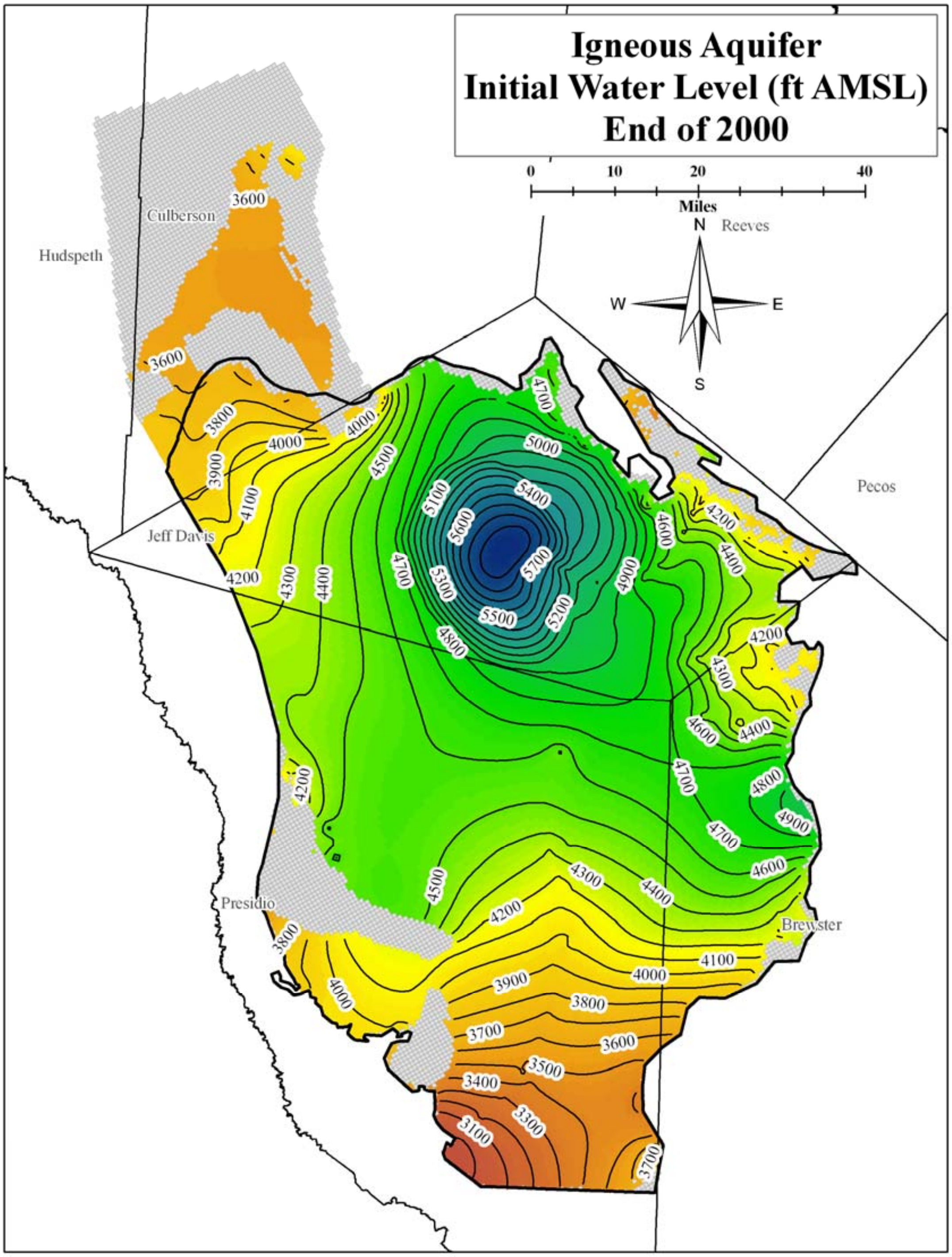

Figure 3. Initial water-level elevations for the Igneous Aquifer for the predictive groundwater availability model run. Water-level elevations are in feet above mean sea level (ft AMSL). The contour interval is 100 feet. Grey areas indicate model grid cells that are dry. Black border indicates the boundary of the aquifer used during model development.

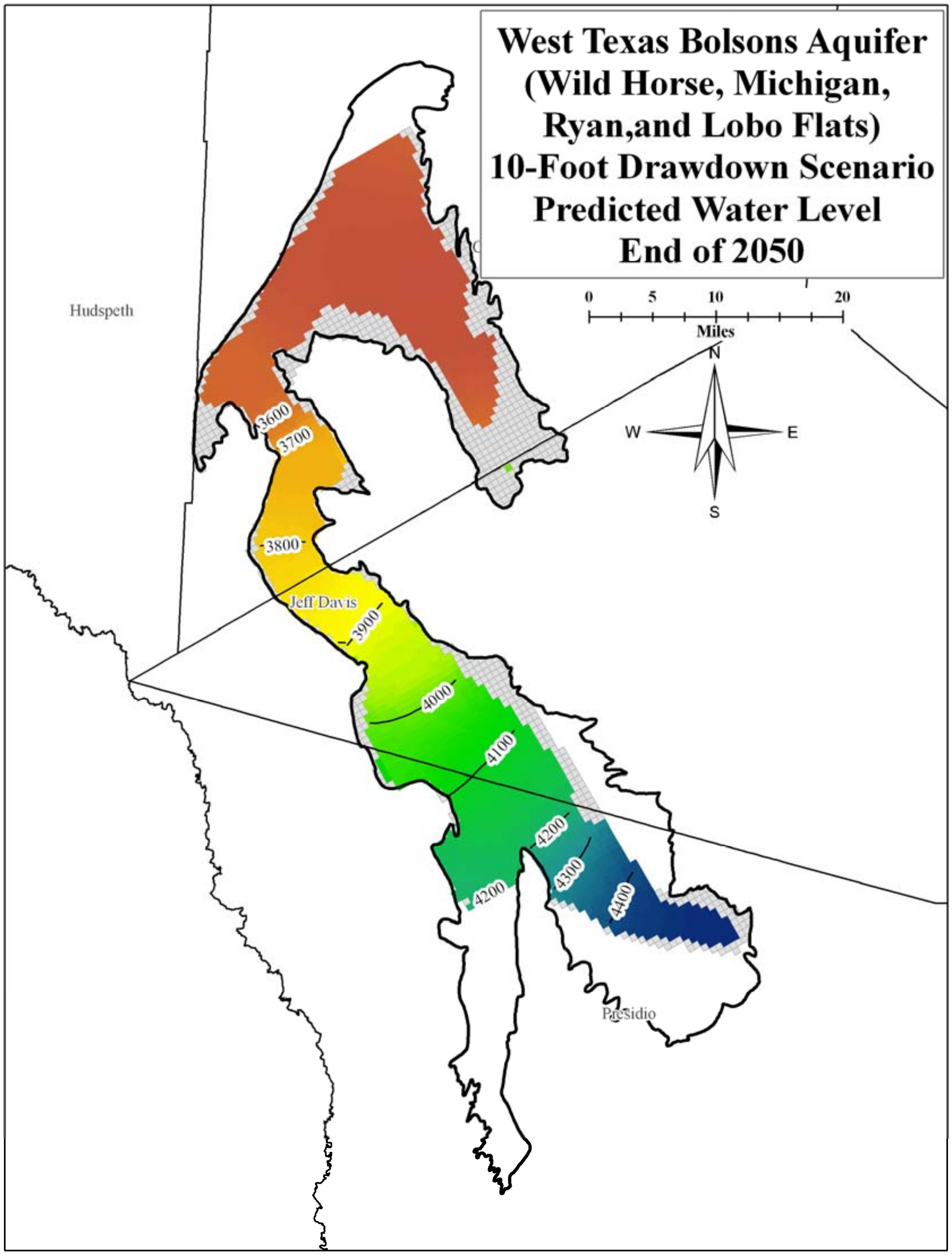

Figure 4. Water-level elevations for the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer at the end of 2050 for the 10-foot drawdown scenario predictive model run. Water-level elevations are in feet above mean sea level (ft AMSL). Contour interval is 100 feet. Grey areas indicate model grid cells that are dry. Black border indicates the boundary of the aquifer used during model development.

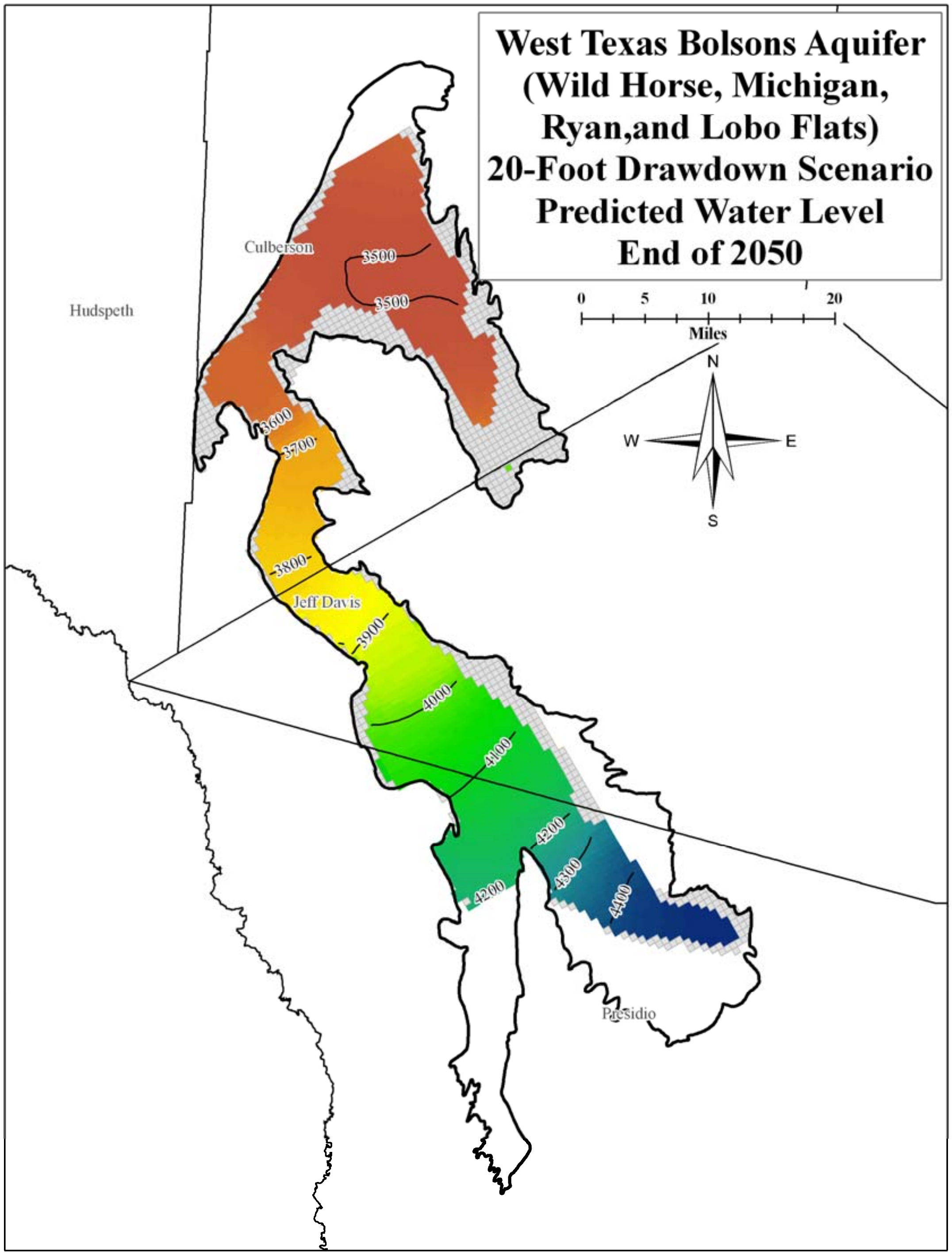

Figure 5. Water-level elevations for the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer at the end of 2050 for the 20-foot drawdown scenario predictive model run. Water-level elevations are in feet above mean sea level (ft AMSL). Contour interval is 100 feet. Grey areas indicate model grid cells that are dry. Black border indicates the boundary of the aquifer used during model development.

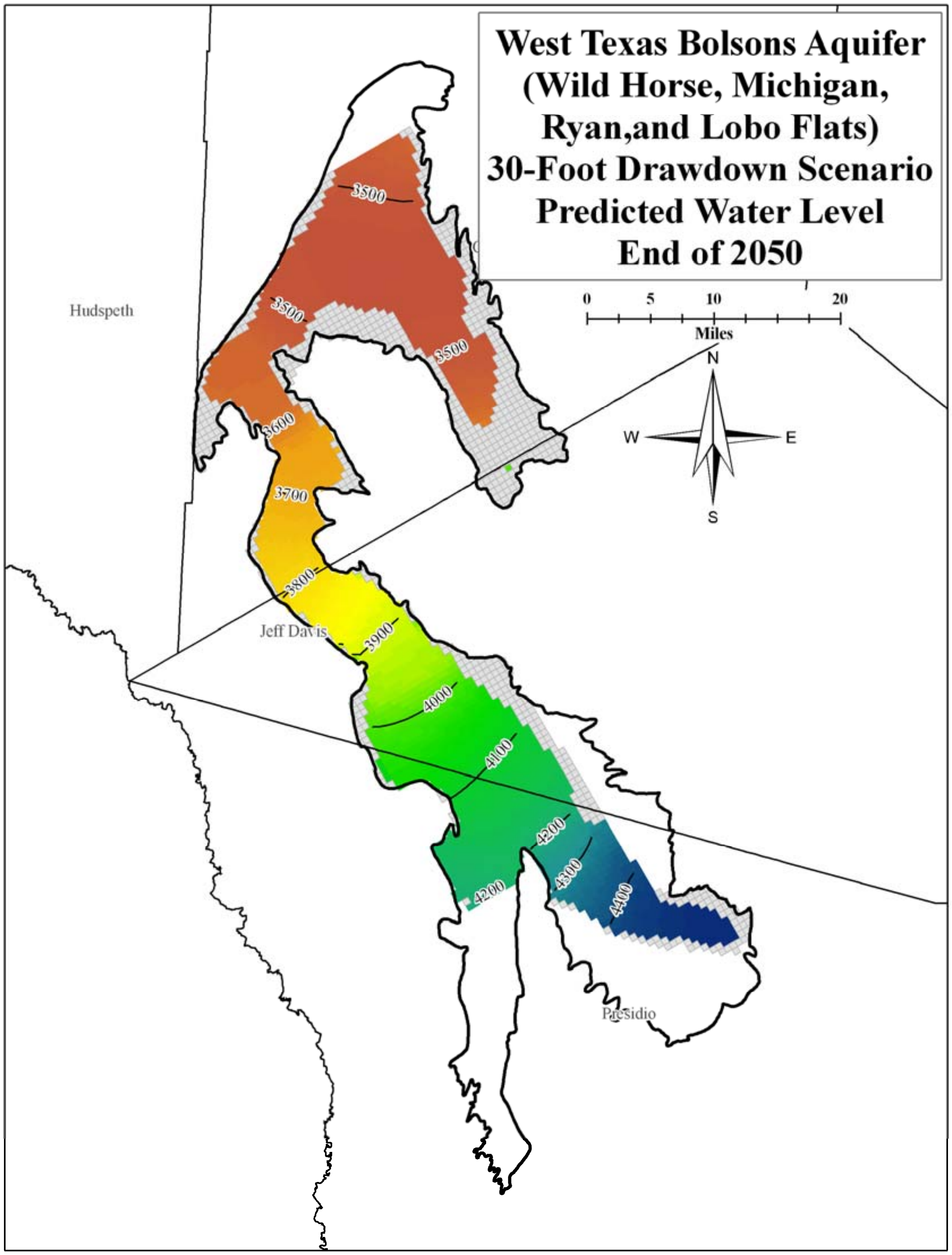

Figure 6. Water-level elevations for the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer at the end of 2050 for the 30-foot drawdown scenario predictive model run. Water-level elevations are in feet above mean sea level (ft AMSL). Contour interval is 100 feet. Grey areas indicate model grid cells that are dry. Black border indicates the boundary of the aquifer used during model development.

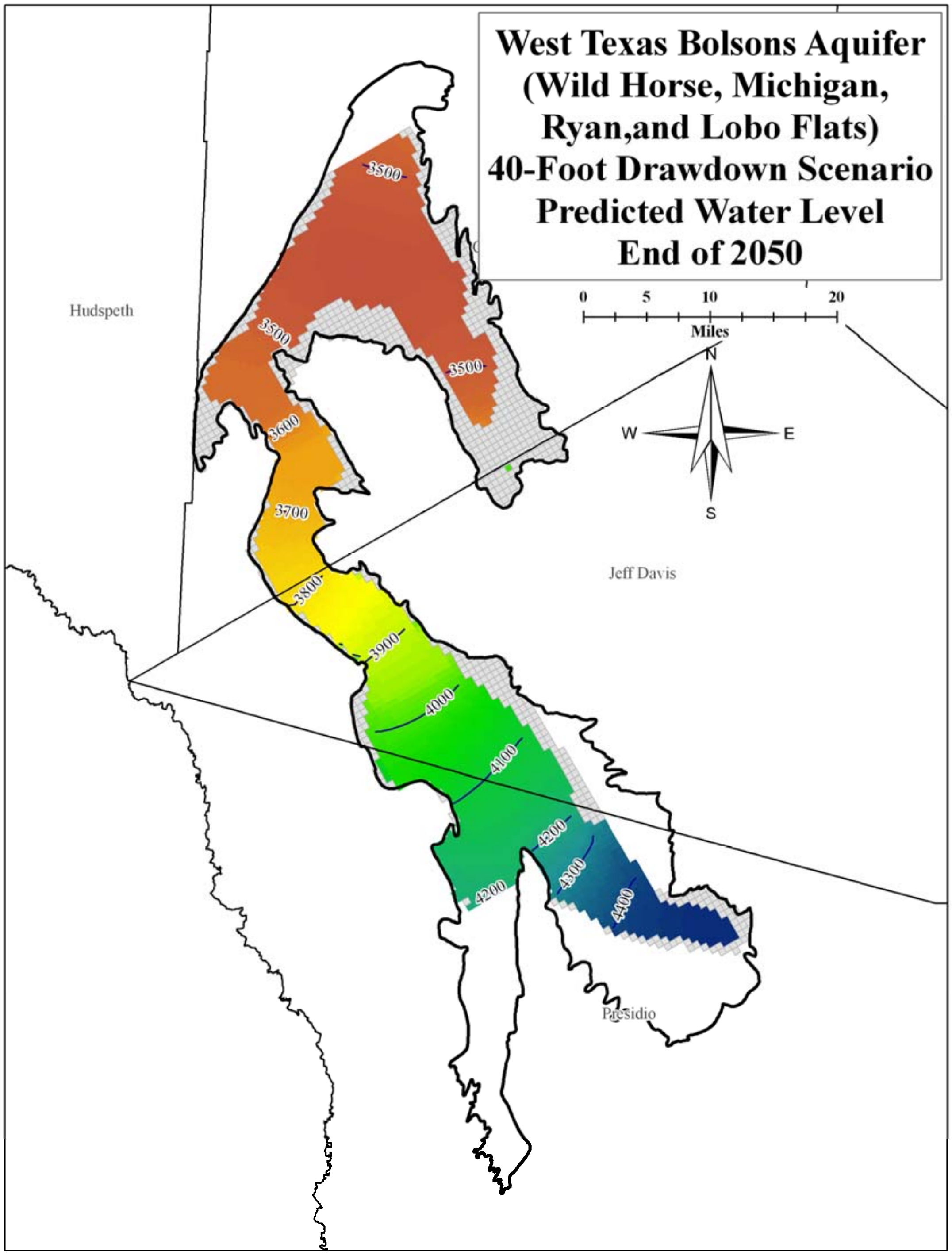

Figure 7. Water-level elevations for the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer at the end of 2050 for the 40-foot drawdown scenario predictive model run. Water-level elevations are in feet above mean sea level (ft AMSL). Contour interval is 100 feet. Grey areas indicate model grid cells that are dry. Black border indicates the boundary of the aquifer used during model development.

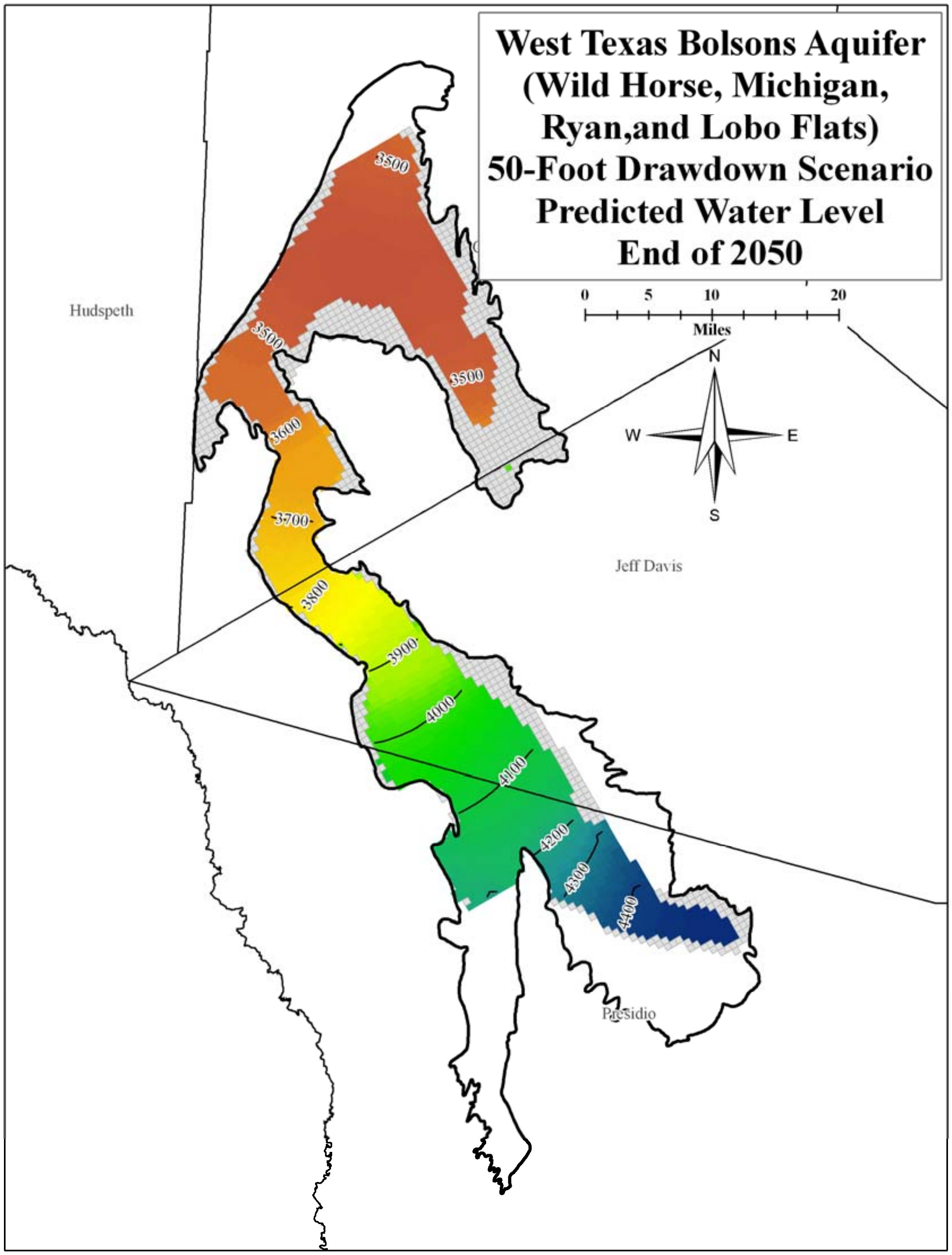

Figure 8. Water-level elevations for the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer at the end of 2050 for the 50-foot drawdown scenario predictive model run. Water-level elevations are in feet above mean sea level (ft AMSL). Contour interval is 100 feet. Grey areas indicate model grid cells that are dry. Black border indicates the boundary of the aquifer used during model development.

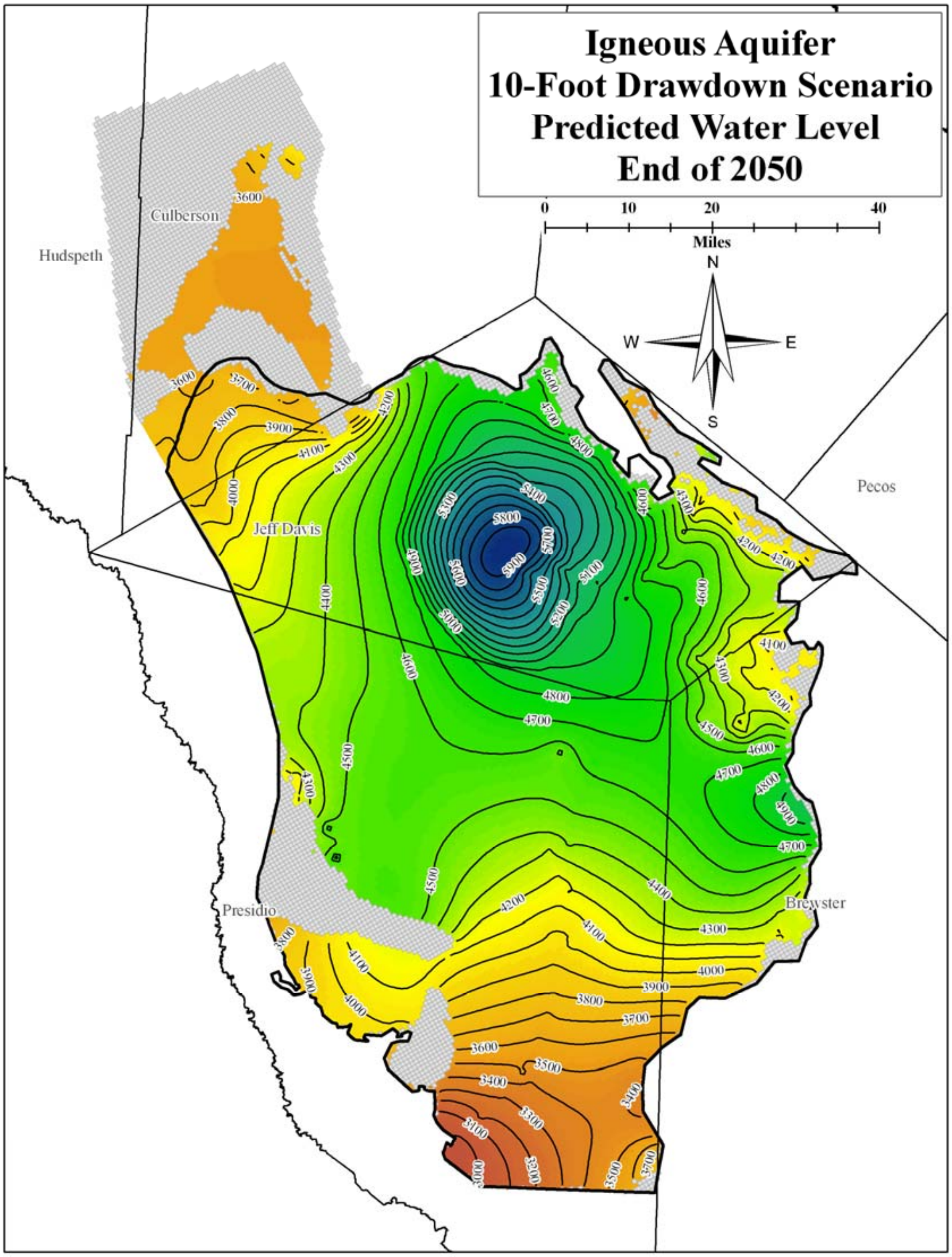

Figure 9. Water-level elevations for the Igneous Aquifer at the end of 2050 for the 10-foot drawdown scenario predictive model run. Water-level elevations are in feet above mean sea level (ft AMSL). Contour interval is 100 feet. Grey areas indicate model grid cells that are dry. Black border indicates the boundary of the aquifer used during model development.

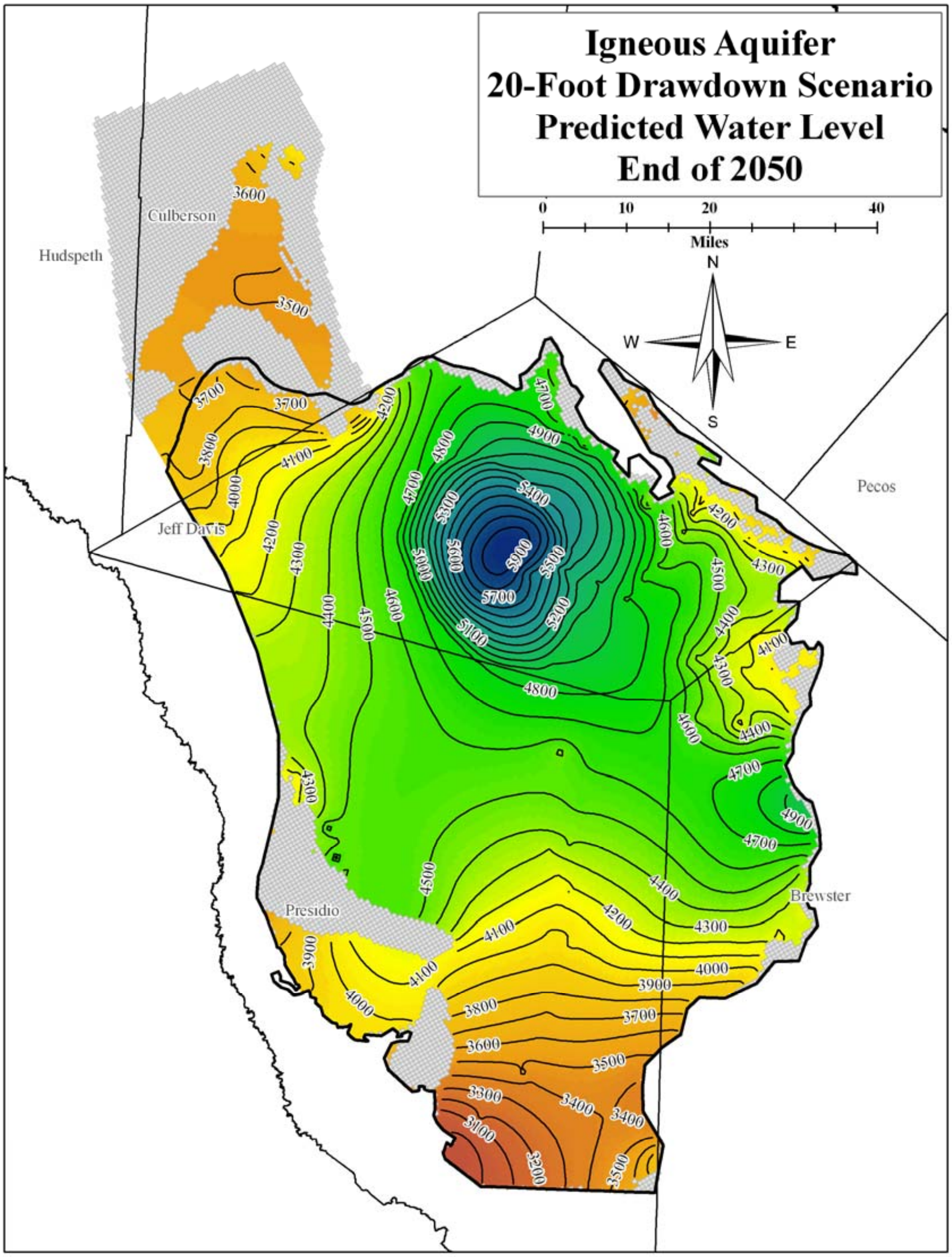

Figure 10. Water-level elevations for the Igneous Aquifer at the end of 2050 for the 20-foot drawdown scenario predictive model run. Water-level elevations are in feet above mean sea level (ft AMSL). Contour interval is 100 feet. Grey areas indicate model grid cells that are dry. Black border indicates the boundary of the aquifer used during model development.

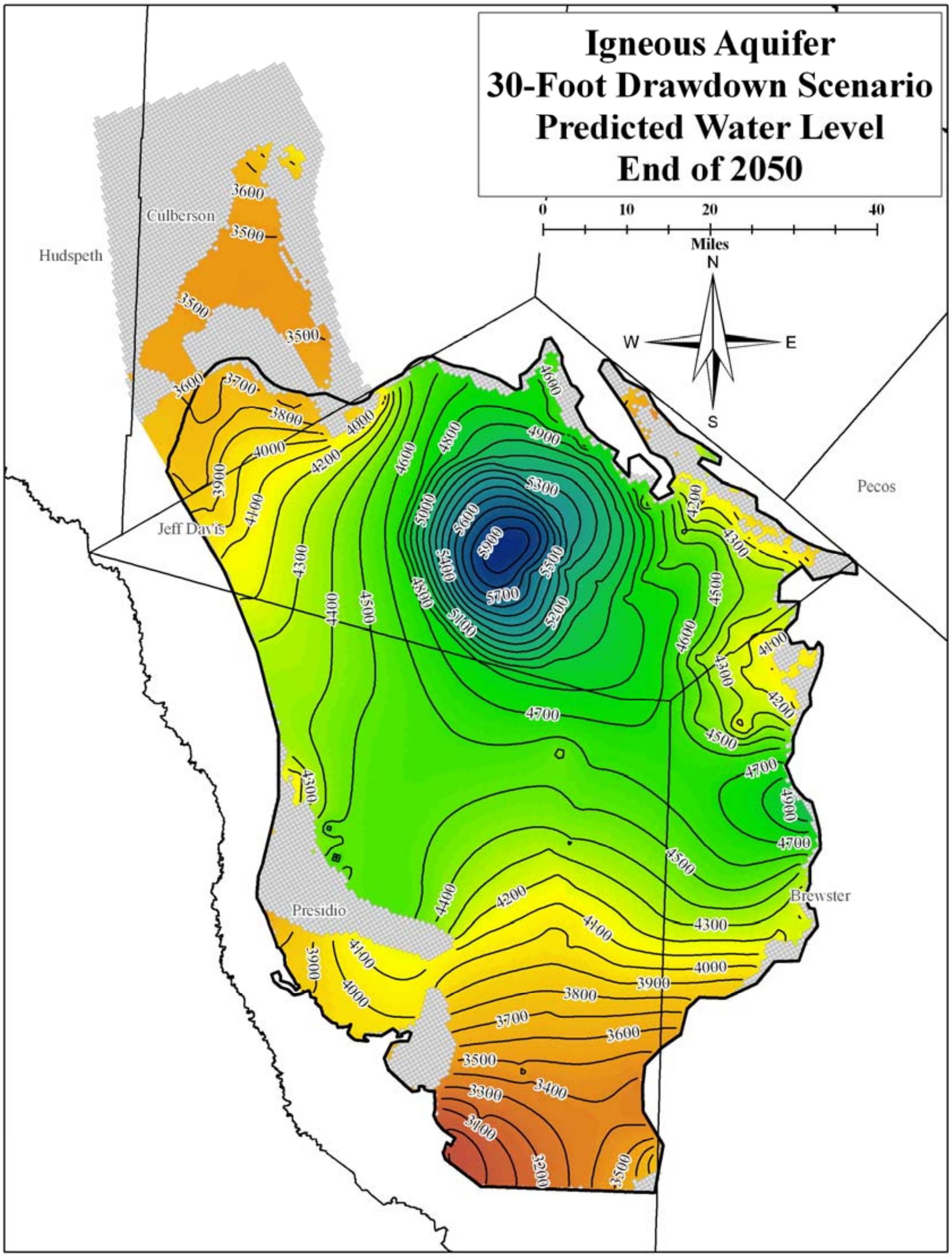

Figure 11. Water-level elevations for the Igneous Aquifer at the end of 2050 for the 30-foot drawdown scenario predictive model run. Water-level elevations are in feet above mean sea level (ft AMSL). Contour interval is 100 feet. Grey areas indicate model grid cells that are dry. Black border indicates the boundary of the aquifer used during model development.

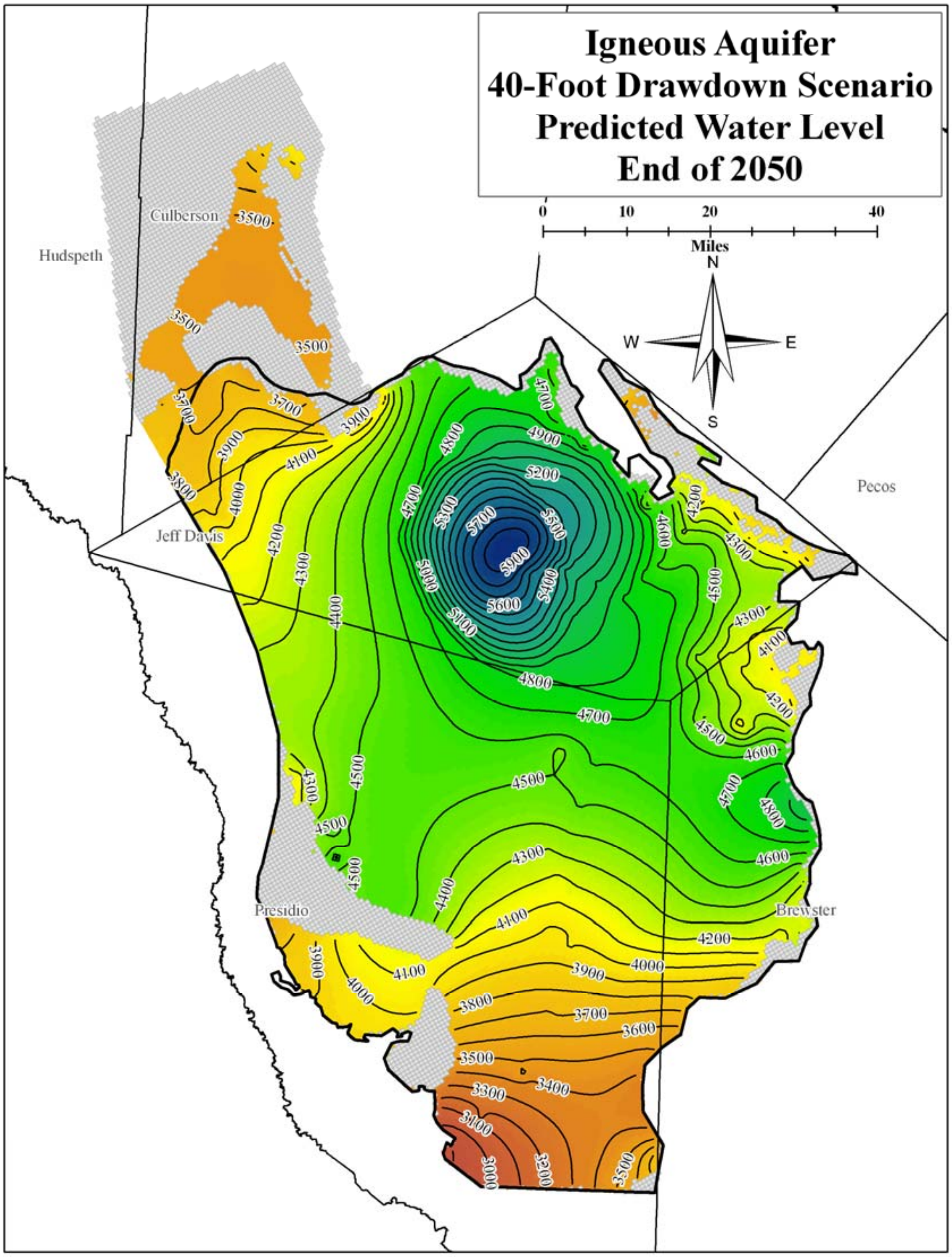

Figure 12. Water-level elevations for the Igneous Aquifer at the end of 2050 for the 40-foot drawdown scenario predictive model run. Water-level elevations are in feet above mean sea level (ft AMSL). Contour interval is 100 feet. Grey areas indicate model grid cells that are dry. Black border indicates the boundary of the aquifer used during model development.

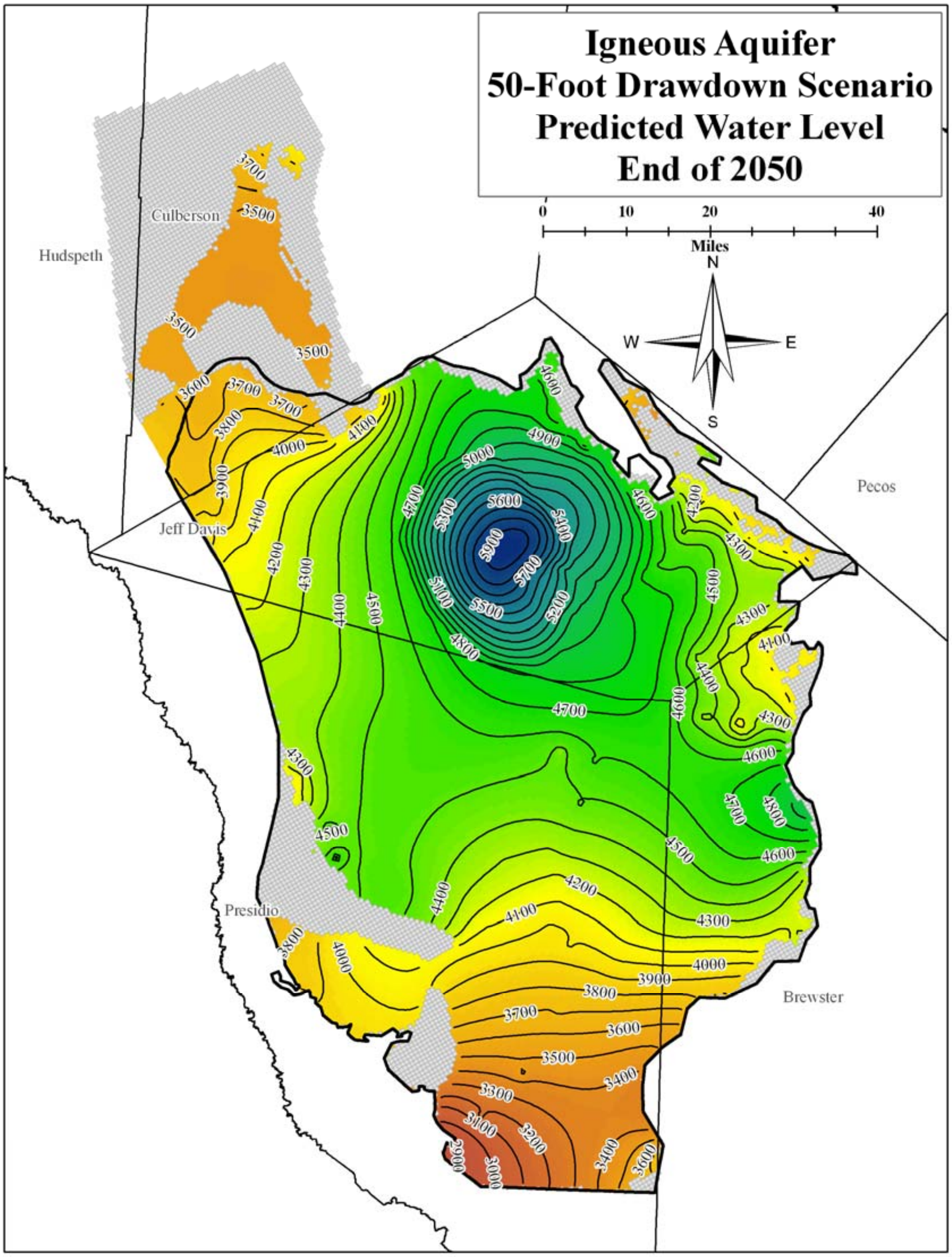

Figure 13. Water-level elevations for the Igneous Aquifer at the end of 2050 for the 50-foot drawdown scenario predictive model run. Water-level elevations are in feet above mean sea level (ft AMSL). Contour interval is 100 feet. Grey areas indicate model grid cells that are dry. Black border indicates the boundary of the aquifer used during model development.

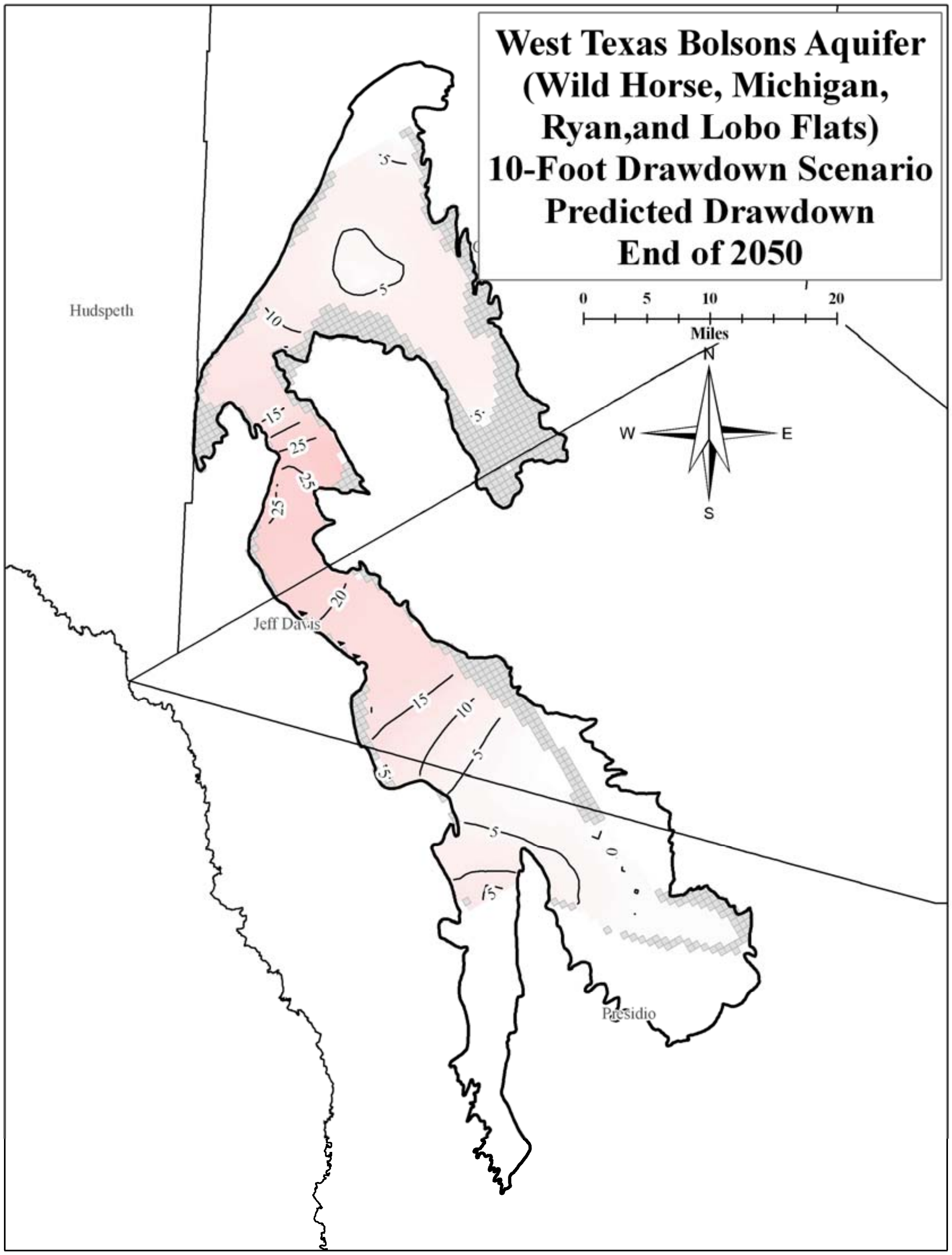

Figure 14. Drawdown (drop in water level) in the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer after 50 years for the 10-foot drawdown scenario. Changes in water levels are in feet (ft). Contour interval is 5 feet. Areas highlighted in red indicate a decrease in water levels. Areas highlighted in blue indicate an increase in water levels. Grey areas indicate model grid cells that are dry.

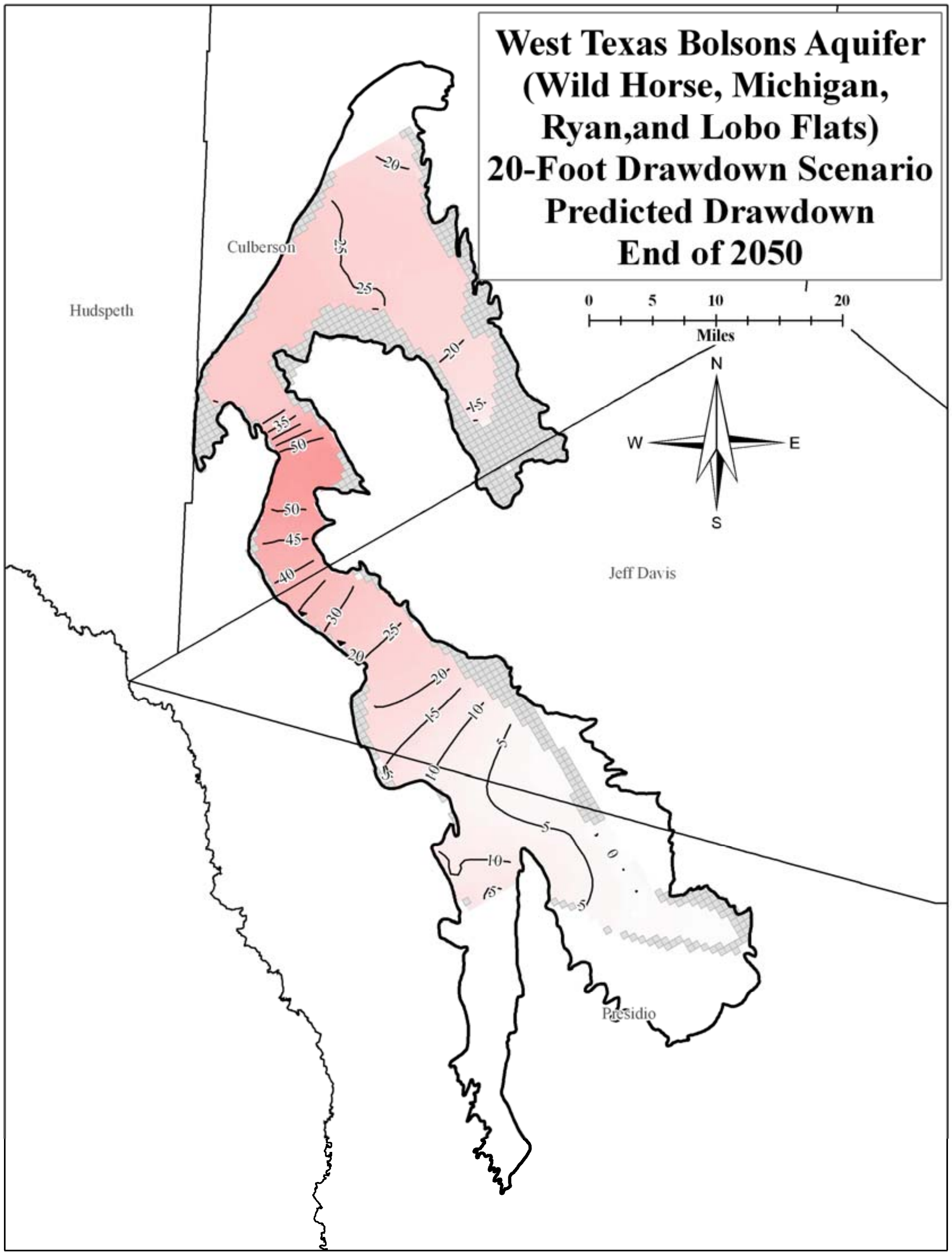

Figure 15. Drawdown (drop in water level) in the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer after 50 years for the 20-foot drawdown scenario. Changes in water levels are in feet (ft). Contour interval is 5 feet. Areas highlighted in red indicate a decrease in water levels. Areas highlighted in blue indicate an increase in water levels. Grey areas indicate model grid cells that are dry.

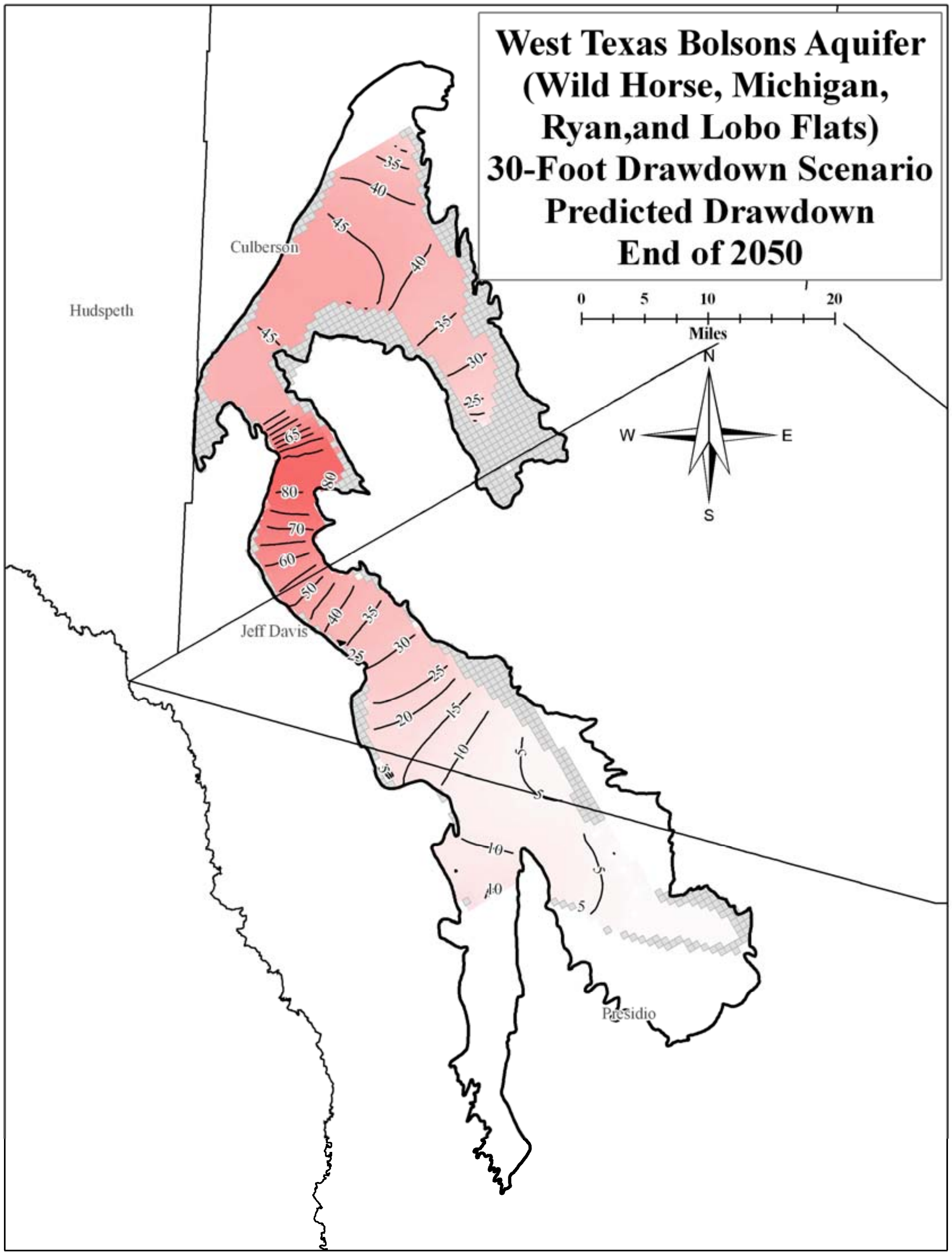

Figure 16. Drawdown (drop in water level) in the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer after 50 years for the 30-foot drawdown scenario. Changes in water levels are in feet (ft). Contour interval is 5 feet. Areas highlighted in red indicate a decrease in water levels. Areas highlighted in blue indicate an increase in water levels. Grey areas indicate model grid cells that are dry.

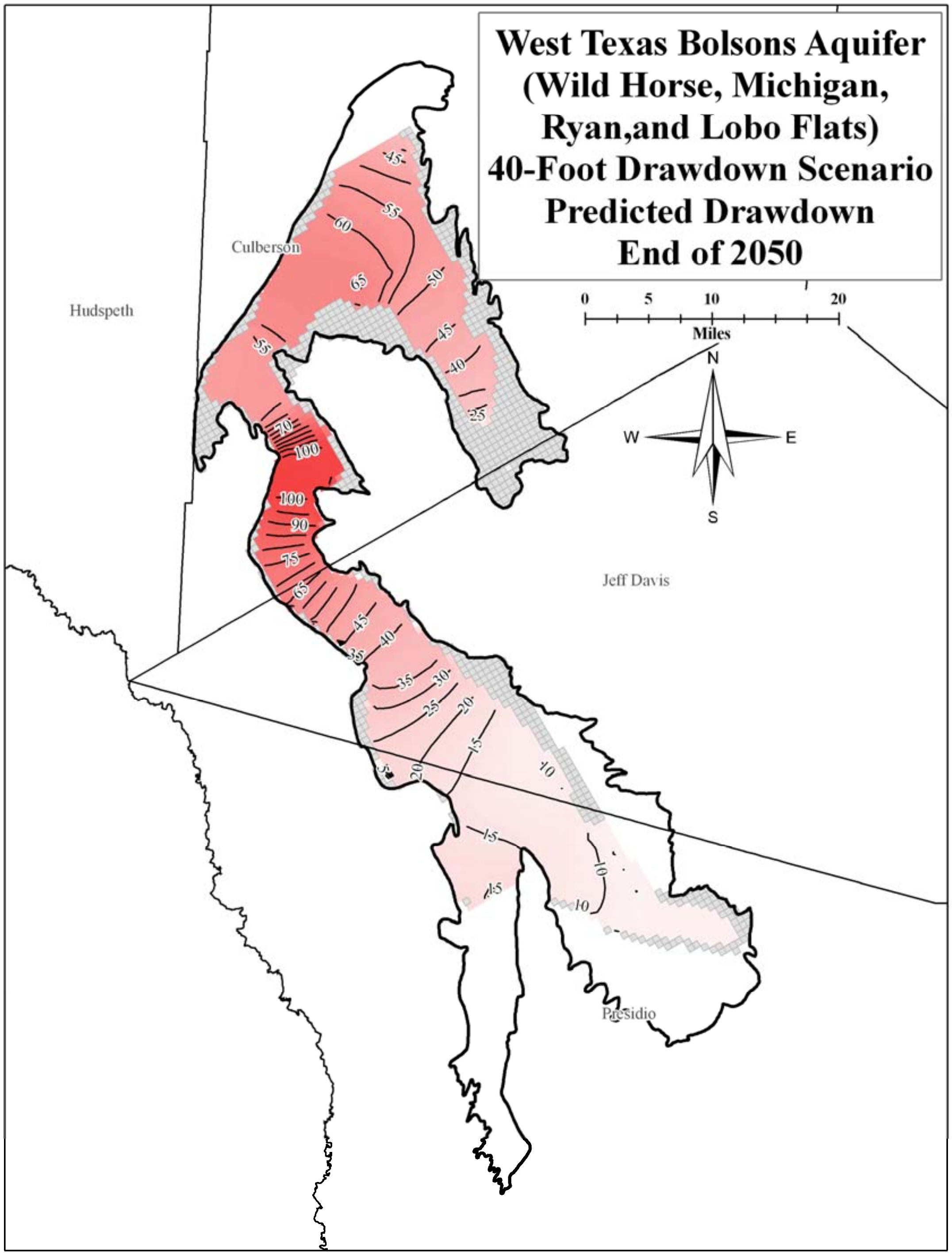

Figure 17. Drawdown (drop in water level) in the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer after 50 years for the 40-foot drawdown scenario. Changes in water levels are in feet (ft). Contour interval is 5 feet. Areas highlighted in red indicate a decrease in water levels. Areas highlighted in blue indicate an increase in water levels. Grey areas indicate model grid cells that are dry.

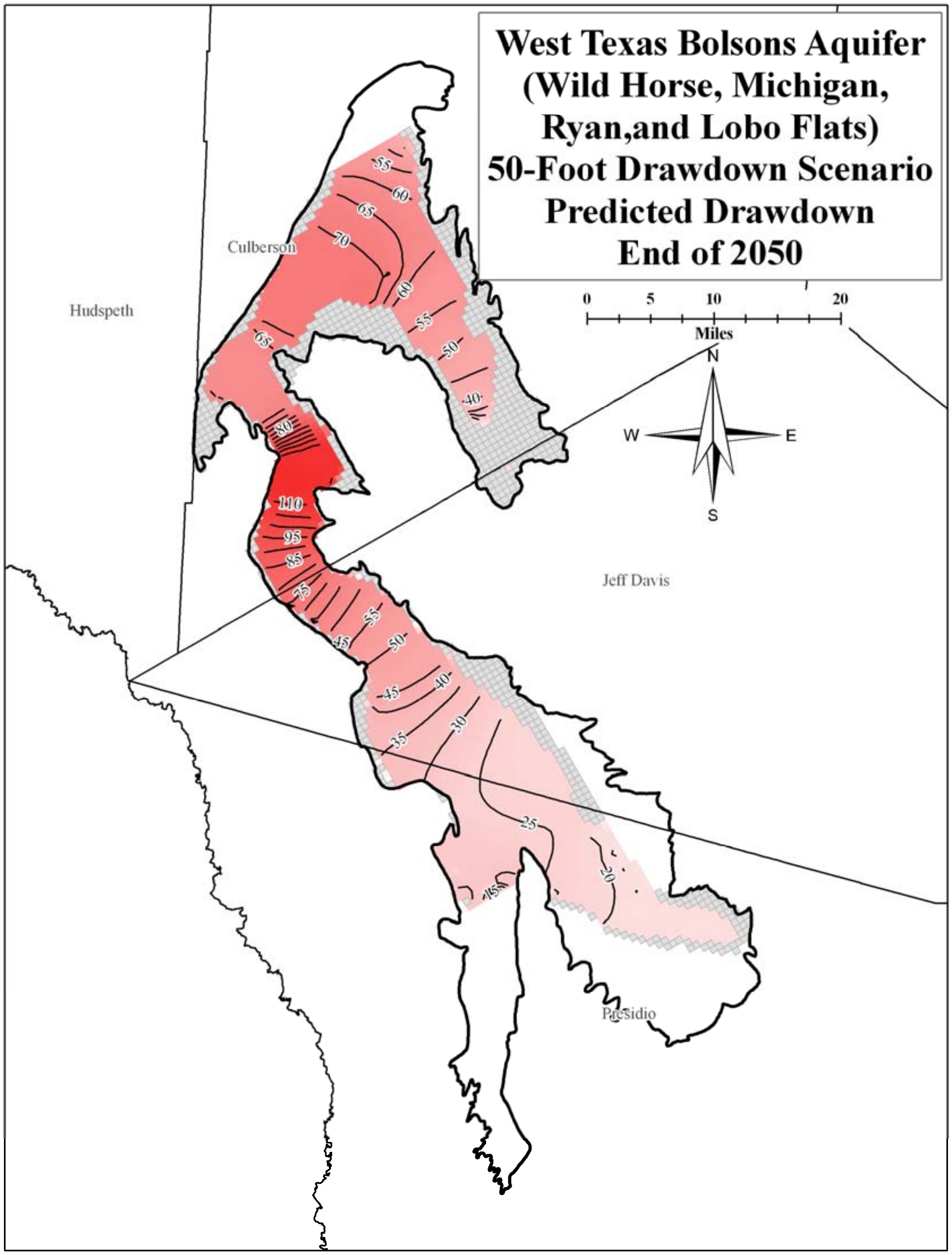

Figure 18. Drawdown (drop in water level) in the Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat portions of the West Texas Bolsons Aquifer after 50 years for the 50-foot drawdown scenario. Changes in water levels are in feet (ft). Contour interval is 5 feet. Areas highlighted in red indicate a decrease in water levels. Areas highlighted in blue indicate an increase in water levels. Grey areas indicate model grid cells that are dry.

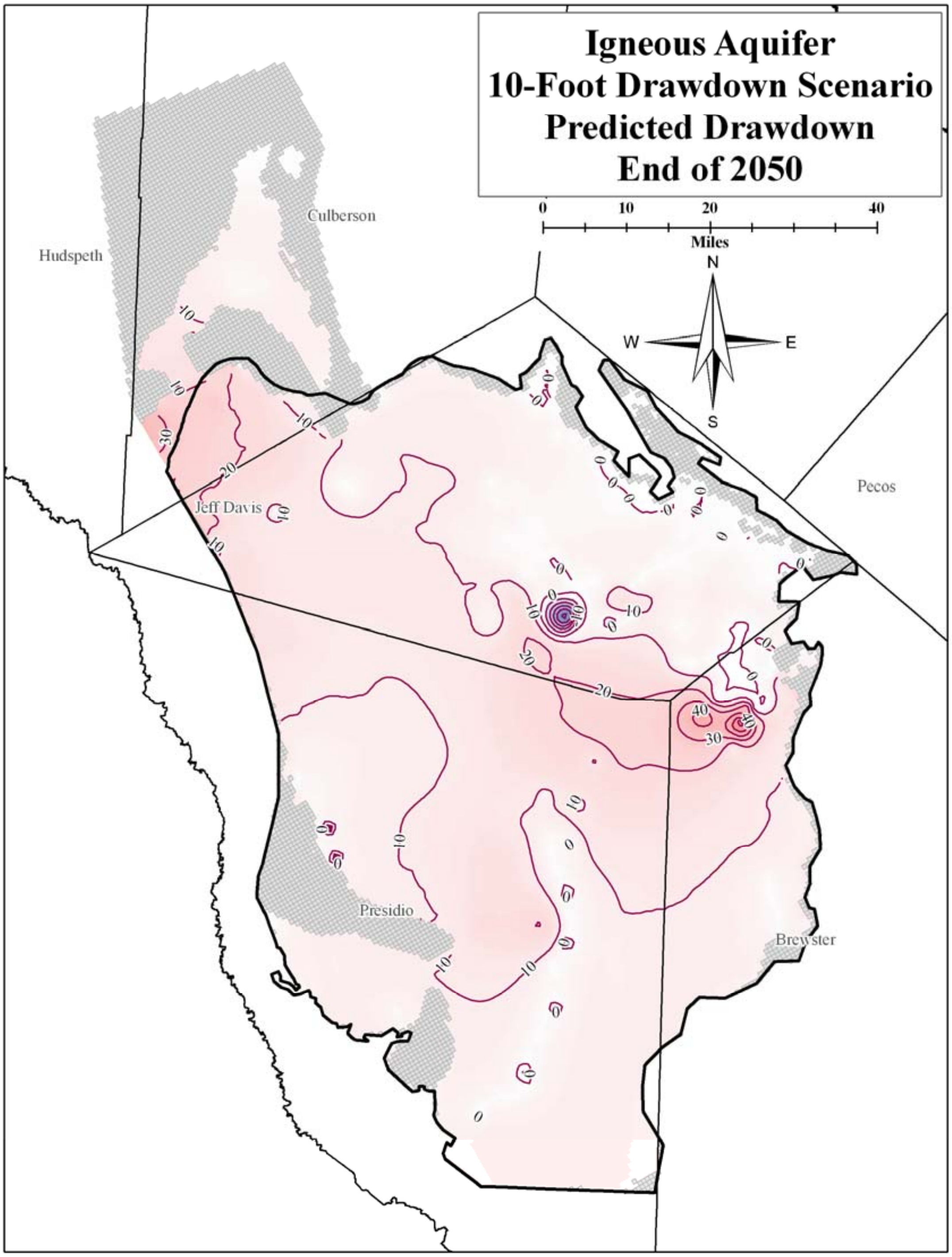

Figure 19. Drawdown (drop in water level) in the Igneous Aquifer after 50 years for the 10-foot drawdown scenario. Changes in water levels are in feet (ft). Contour interval is 10 feet. Areas highlighted in red indicate a decrease in water levels. Areas highlighted in blue indicate an increase in water levels. Grey areas indicate model grid cells that are dry.

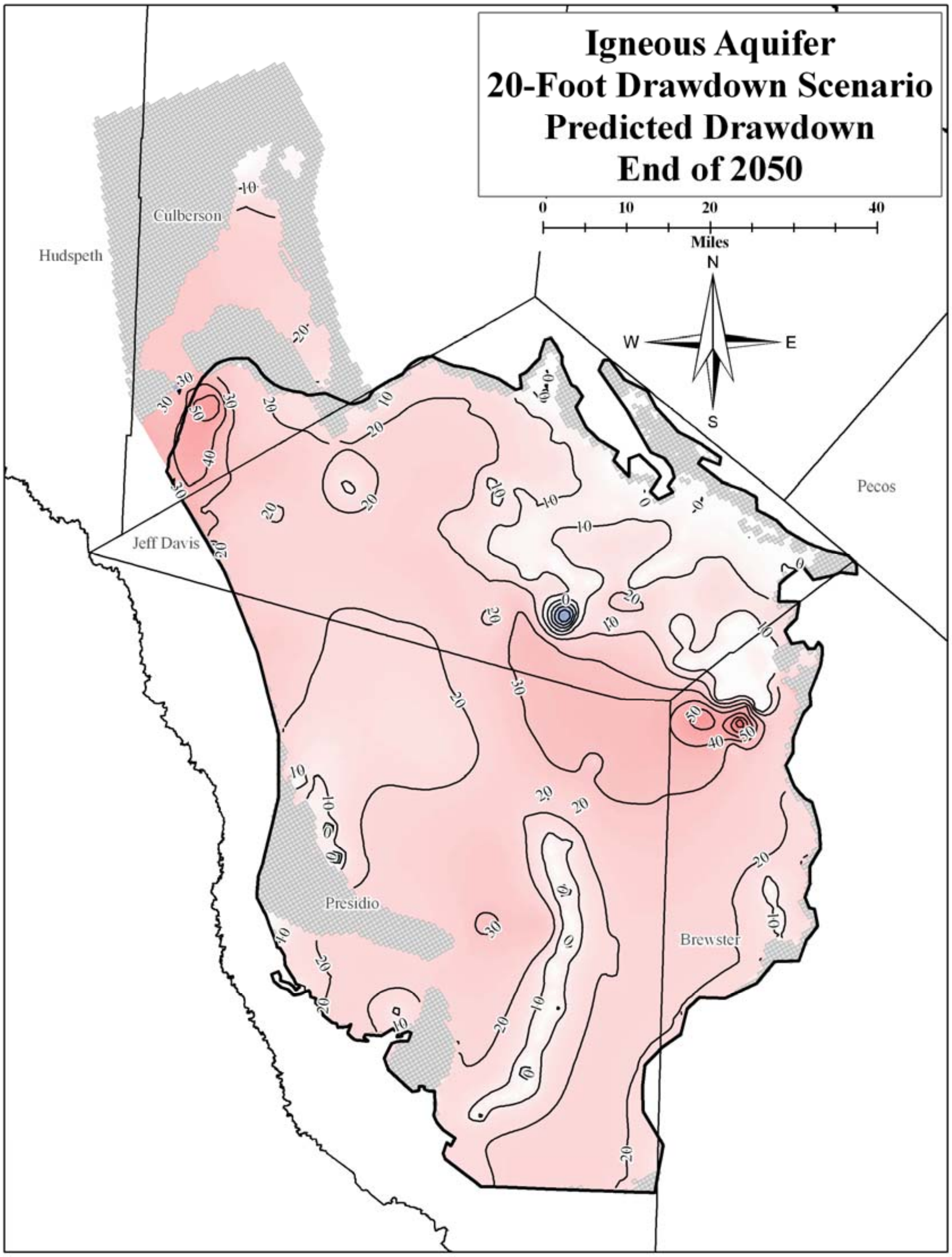

Figure 20. Drawdown (drop in water level) in the Igneous Aquifer after 50 years for the 20-foot drawdown scenario. Changes in water levels are in feet (ft). Contour interval is 10 feet. Areas highlighted in red indicate a decrease in water levels. Areas highlighted in blue indicate an increase in water levels. Grey areas indicate model grid cells that are dry.

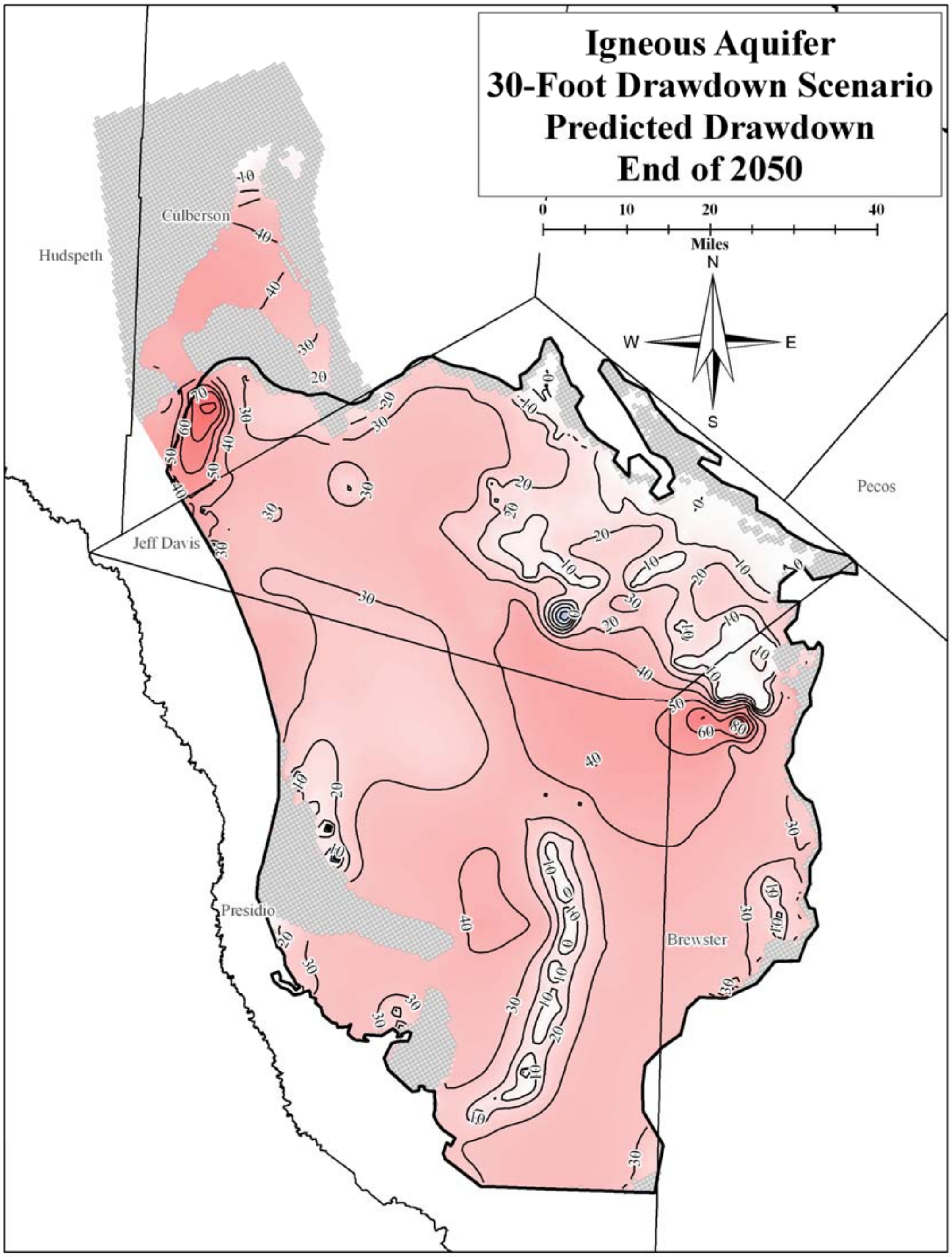

Figure 21. Drawdown (drop in water level) in the Igneous Aquifer after 50 years for the 30-foot drawdown scenario. Changes in water levels are in feet (ft). Contour interval is 10 feet. Areas highlighted in red indicate a decrease in water levels. Areas highlighted in blue indicate an increase in water levels. Grey areas indicate model grid cells that are dry.

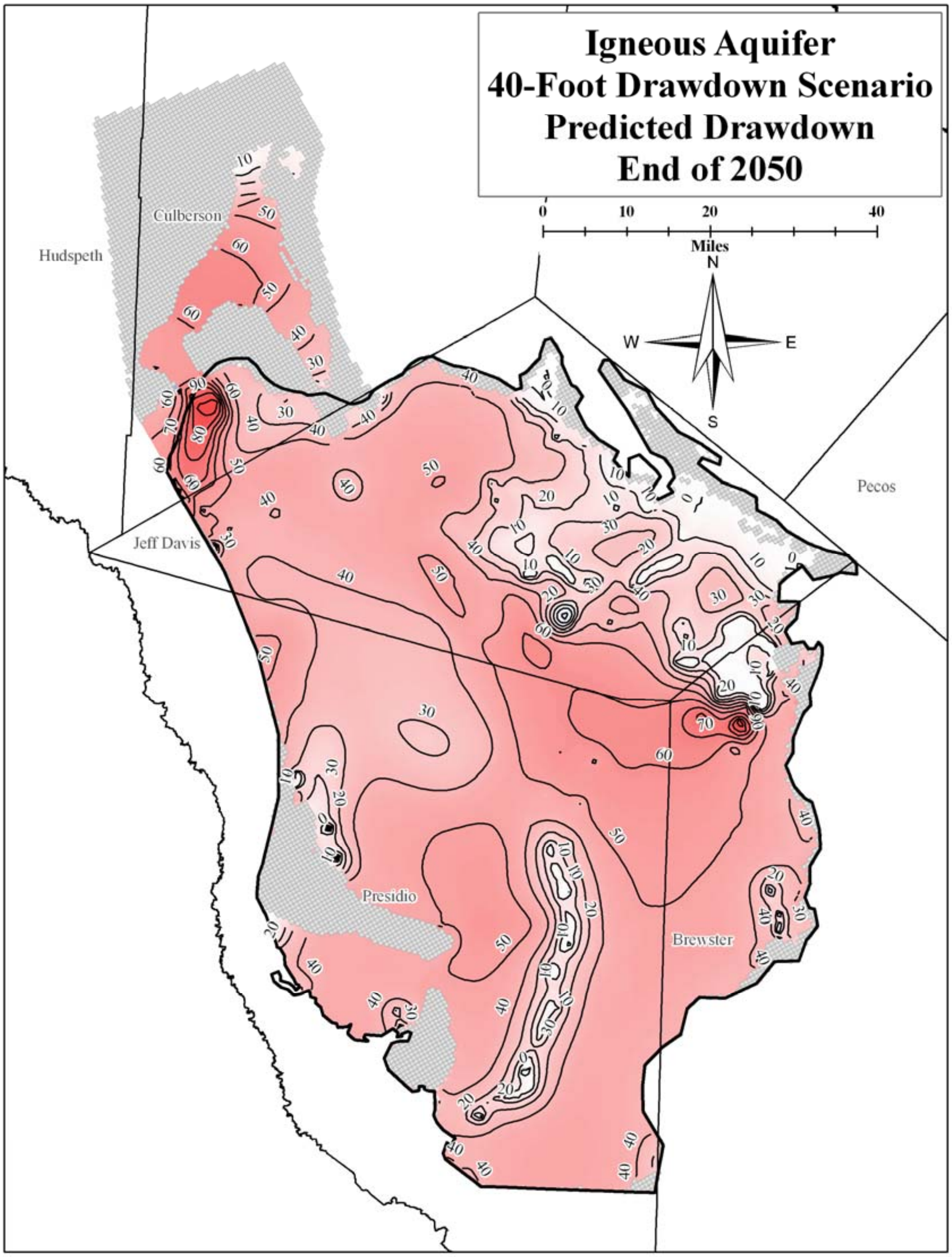

Figure 22. Drawdown (drop in water level) in the Igneous Aquifer after 50 years for the 40-foot drawdown scenario. Changes in water levels are in feet (ft). Contour interval is 10 feet. Areas highlighted in red indicate a decrease in water levels. Areas highlighted in blue indicate an increase in water levels. Grey areas indicate model grid cells that are dry.

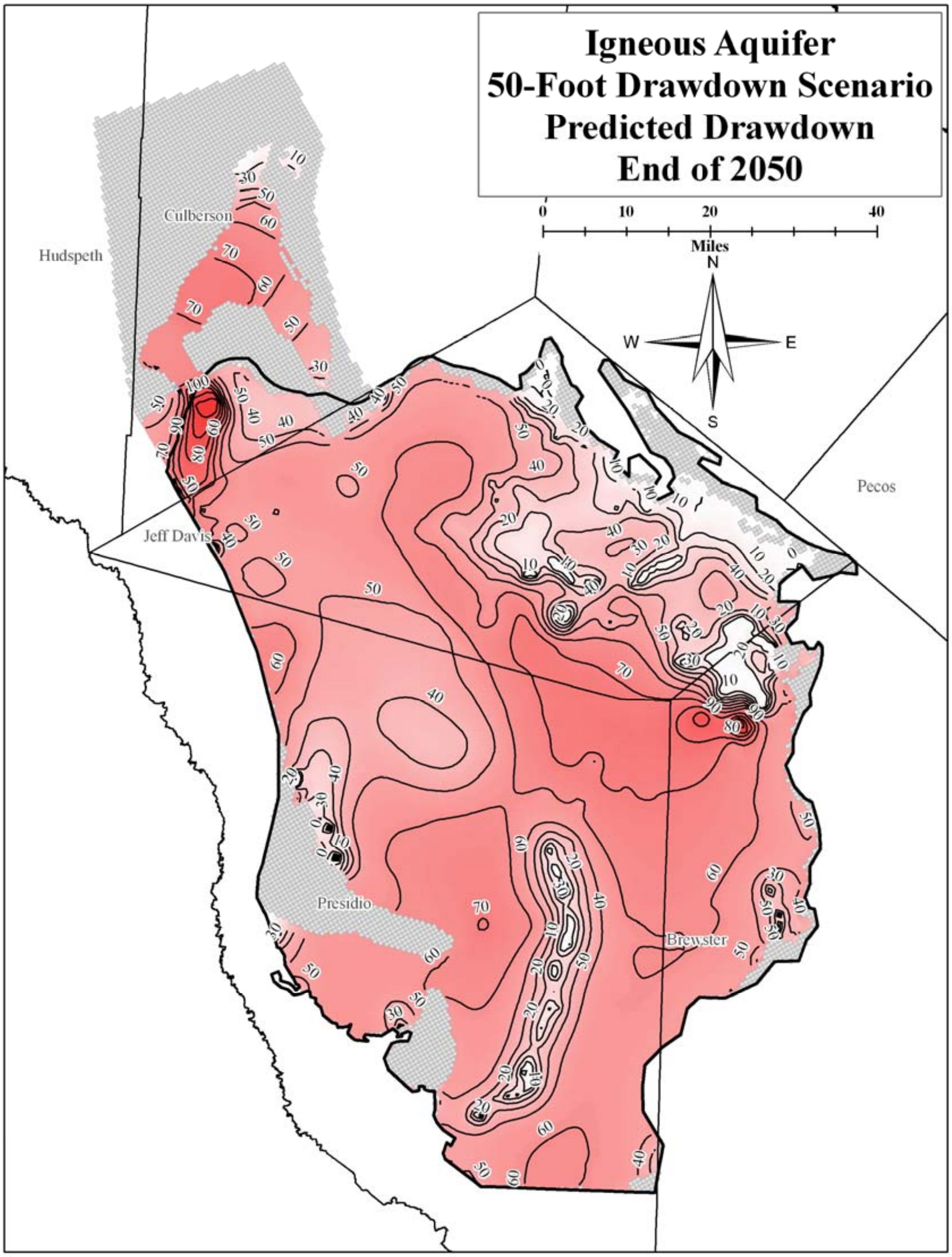

Figure 23. Drawdown (drop in water level) in the Igneous Aquifer after 50 years for the 50-foot drawdown scenario. Changes in water levels are in feet (ft). Contour interval is 10 feet. Areas highlighted in red indicate a decrease in water levels. Areas highlighted in blue indicate an increase in water levels. Grey areas indicate model grid cells that are dry.

Appendix A

Summary of Budgets
After Predictive Model Run
2050

Table A-1. Annual water budgets for each county in Groundwater Management Area 4 at the end of the 50-year predictive model run for the five requested drawdown scenarios. A comparison of the waterbudget values of baseline GAM run 06-32 are also provided (Donnelly, 2006). Values are reported in acre-feet per year.

		Brewster						Culberson					
		GAM 06-32	10ft	20ft	30ft	40ft	50ft	GAM 06-32	10ft	20ft	30ft	40ft	50ft
West Texas Bolson													
Storage	**In**	-	-	-	-	-	-	9,648	2,274	5,473	8,610	11,110	12,723
	Out	-	-	-	-	-	-	0	0	0	0	0	0
Streams and Springs	**In**	-	-	-	-	-	-	0	0	0	0	0	0
	Out	-	-	-	-	-	-	0	10	0	0	0	0
Wells	**In**	-	-	-	-	-	-	0	0	0	0	0	0
	Out	-	-	-	-	-	-	30,278	15,728	21,306	26,765	30,856	33,144
Recharge	**In**	-	-	-	-	-	-	2,096	2,096	2,096	2,096	2,096	2,096
	Out	-	-	-	-	-	-	0	0	0	0	0	0
Evapotranspiration	**In**	-	-	-	-	-	-	0	0	0	0	0	0
	Out	-	-	-	-	-	-	0	0	0	0	0	0
Lateral Flow	**In**	-	-	-	-	-	-	8,180	6,985	7,640	8,235	8,473	8,261
	Out	-	-	-	-	-	-	0	658	747	828	863	843
Vertical Leakage Downward	**In**	-	-	-	-	-	-	15,817	12,262	13,424	14,679	15,629	16,125
	Out	-	-	-	-	-	-	5,464	7,222	6,587	6,037	5,590	5,220
Igneous Aquifer													
Storage	**In**	243	771	1,535	2,298	3,052	3,832	583	180	305	428	530	611
	Out	2	0	0	0	0	0	0	0	0	0	0	0
Streams and Springs	**In**	0	0	0	0	0	0	0	0	0	0	0	0
	Out	136	97	61	31	7	2	0	0	0	0	0	0
Wells	**In**	0	0	0	0	0	0	0	0	0	0	0	0
	Out	2,031	2,822	3,972	5,100	6,196	7,292	0	0	0	0	0	0
Recharge	**In**	6,525	6,569	6,569	6,565	6,560	6,558	885	627	627	627	627	627
	Out	0	0	0	0	0	0	0	0	0	0	0	0
Evapotranspiration	**In**	0	0	0	0	0	0	0	0	0	0	0	0
	Out	1,050	972	829	697	578	471	67	0	0	0	0	0
Vertical Leakage Upward	**In**	-	-	-	-	-	-	5,464	38	23	12	7	6
	Out	-	-	-	-	-	-	15,817	474	584	697	783	832
Lateral Flow	**In**	1,147	1,117	1,108	1,098	1,090	1,083	909	907	905	906	900	879
	Out	1,216	1,226	1,217	1,208	1,199	1,191	0	10	5	4	3	3
Vertical Leakage Downward	**In**	460	483	495	509	526	546	15,250	135	155	179	198	208
	Out	3,936	3,819	3,625	3,433	3,246	3,064	7,207	1,403	1,425	1,451	1,475	1,495

Table A-1. (continued)

		Jeff Davis						Presidio					
		GAM 06-32	10ft	20ft	30ft	40ft	50ft	GAM 06-32	10ft	20ft	30ft	40ft	50ft
West Texas Bolson													
Storage	**In**	3,196	1,523	2,253	2,956	3,914	5,204	881	575	741	906	1,561	2,816
	Out	0	0	0	0	0	0	0	0	0	0	0	0
Streams and Springs	**In**	0	0	0	0	0	0	0	0	0	0	0	0
	Out	0	0	0	0	0	0	0	0	0	0	0	0
Wells	**In**	0	0	0	0	0	0	0	0	0	0	0	0
	Out	117	62	84	105	742	2,136	795	419	568	714	1,401	2,737
Recharge	**In**	154	154	154	154	154	154	1,457	1,457	1,457	1,457	1,457	1,457
	Out	0	0	0	0	0	0	0	0	0	0	0	0
Evapotranspiration	**In**	0	0	0	0	0	0	0	0	0	0	0	0
	Out	0	0	0	0	0	0	0	0	0	0	0	0
Lateral Flow	**In**	4,191	4,179	4,162	4,145	4,091	3,992	1,036	1,150	1,165	1,181	1,183	1,167
	Out	9,215	7,520	8,184	8,814	9,063	8,857	4,191	4,336	4,321	4,304	4,249	4,147
Vertical Leakage Downward	**In**	1,819	1,727	1,697	1,663	1,646	1,642	1,611	1,575	1,524	1,475	1,450	1,444
	Out	0	0	0	0	0	0	0	0	0	0	0	0
Igneous Aquifer													
Storage	**In**	520	1,284	2,804	4,348	5,914	7,478	704	2,506	5,171	7,869	10,612	13,441
	Out	28	7	0	0	0	0	1	0	0	0	0	0
Streams and Springs	**In**	0	0	0	0	0	0	0	0	0	0	0	0
	Out	2,402	2,269	2,066	1,872	1,687	1,500	2,681	2,282	1,731	1,249	836	520
Wells	**In**	0	0	0	0	0	0	0	0	0	0	0	0
	Out	931	2,483	4,749	6,983	9,194	11,389	1,973	4,461	8,089	11,662	15,183	18,675
Recharge	**In**	25,912	25,881	25,881	25,881	25,881	25,881	9,393	9,383	9,383	9,382	9,381	9,381
	Out	0	0	0	0	0	0	0	0	0	0	0	0
Evapotranspiration	**In**	0	0	0	0	0	0	0	0	0	0	0	0
	Out	3,011	2,766	2,503	2,286	2,096	1,915	680	630	554	498	443	394
Vertical Leakage Upward	**In**	0	0	0	0	0	0	0	0	0	0	0	0
	Out	1,819	1,727	1,697	1,663	1,646	1,642	1,611	1,577	1,527	1,477	1,452	1,446
Lateral Flow	**In**	552	545	542	541	540	539	4,203	4,195	4,169	4,144	4,123	4,105
	Out	6,061	4,147	4,102	4,056	4,015	3,973	1,352	1,335	1,323	1,313	1,304	1,295
Vertical Leakage Downward	**In**	254	234	232	228	226	224	744	767	829	902	980	1,063
	Out	14,804	14,546	14,339	14,133	13,921	13,698	6,736	6,557	6,319	6,092	5,872	5,659