GAM Run 06-16

by Andrew C. A. Donnelly, P.G.
Texas Water Development Board
Groundwater Availability Modeling Section
(512) 463-3132
February 2, 2007

EXECUTIVE SUMMARY:

The groundwater availability model (GAM) for the Edwards-Trinity (Plateau) Aquifer was used to evaluate the impact of additional pumpage in Terrell and Val Verde counties on discharge to the Rio Grande, Pecos River, and Devils River. Pumpage was increased in the Edwards Aquifer and Trinity Aquifer layers of the GAM in Terrell and Val Verde counties individually. The model runs indicated that the amount of pumpage required to reduce the discharge to the rivers by 50 percent varied from 12,000 to 160,000 acre-feet per year depending on which river, aquifer, and county was being evaluated. In general the effect was restricted to the aquifer being pumped in the county where the pumpage occurred, with much smaller effects being observed in other river reaches.

REQUESTOR:

Mr. Jeff Bennett from the National Park Service, sponsored by Mr. Conrad Arriola from the Brewster County Groundwater Conservation District (GCD).

DESCRIPTION OF REQUEST:

Mr. Bennett requested a GAM run to evaluate the effect of additional pumpage in Terrell and Val Verde counties on discharge from the Edwards-Trinity (Plateau) Aquifer to the Rio Grande, Pecos River, and Devils River. Mr. Bennett desired to know how much additional pumpage distributed evenly across the county was required to result in a 15, 30, and 50 percent decline in groundwater discharge to these rivers under average recharge conditions.

METHODS:

To determine the effect on discharge to rivers in Terrell and Val Verde counties, we used the GAM for the Edwards-Trinity (Plateau) Aquifer. We ran the GAM using 2000 estimated pumpage as the basis for each year of 50-year predictive simulations. To this baseline pumpage we added pumpage in either the Edwards Aquifer layer or the Trinity Aquifer layer in either Terrell County or Val Verde County. Pumpage was added equally to all active cells in the county. Pumpage was increased until the net discharge into rivers (net discharge is the total discharge from the aquifer to rivers minus the discharge from rivers to the aquifer) was decreased by at least 50 percent.

PARAMETERS AND ASSUMPTIONS:

- See Anaya and Jones (2004) for assumptions and limitations of the GAM.

- The root mean squared error (a measure of the difference between simulated and actual water levels during model calibration) in the entire Edwards-Trinity (Plateau) and Cenozoic Pecos Alluvium GAM for the period of 1990 to 2000 is 143 feet, or six percent of the range of measured water levels (Anaya and Jones, 2004).

- The model includes two layers, representing the Edwards and associated limestones (Layer 1) and undifferentiated Trinity units (Layer 2).

- We used estimated historic recharge and pumpage included in the transient calibration simulation.

- Pumpage for each year of the predictive portion of the model run was based on the 2000 historic spatial distribution and amount of estimated pumpage. Additional pumpage was then added to this baseline pumpage set in Terrell or Val Verde counties. Additional pumpage was added to each layer in each county individually (to the Edwards Aquifer in Terrell County, to the Trinity Aquifer in Terrell County, to the Edwards Aquifer in Val Verde County, or to the Trinity Aquifer in Val Verde County). The additional pumpage was distributed evenly to all active cells in each county per aquifer layer. Pumpage was added equally to each cell.

- The GAM uses drains to simulate discharge to springs and seeps mostly along the northern and eastern margins of the aquifer, as well as along the Rio Grande in Brewster County. Drains are not used in lieu of stream cells for the Rio Grande, but are used in addition to the streams cells to represent springs along the river. Drain package parameters used in the model are from the calibrated model.

- Recharge was distributed in the GAM based on a percent of annual precipitation and aquifer outcrop (surface geology).

- The GAM uses streams to simulate the interaction between the aquifer(s) and major streams and rivers flowing in the region. Flow both from the stream to the aquifer and from the aquifer to the stream is allowed, and the direction of flow is determined by the water levels in the aquifer and stream during each stress period in the simulation. Major rivers included in the GAM in Terrell and Val Verde counties include the Rio Grande, Pecos River, and Devils River (Figure 1). The Stream package parameters, including streambed conductance and initial flow values, used in the model are from the calibrated model.

- A constant head boundary is used to simulate Amistad Reservoir in Val Verde County, with a constant head of 1,081 feet. This restricts the water level changes in cells in the vicinity of the reservoir.

- The GAM uses general head boundary (GHB) cells to simulate cross-formational groundwater flow between the Edwards-Trinity (Plateau) and Cenozoic Pecos Alluvium aquifers and adjacent aquifers, the Ogallala and Edwards (Balcones Fault Zone) aquifers. Parameters assigned to the GHB cells were from the calibrated model.

RESULTS:

A baseline model run was done to estimate the discharge to each river in the two counties of interest. This baseline model run used the estimated historic 2000 pumpage for each year of a 50-year predictive simulation. Water levels in the Edwards and Trinity Aquifers from the GAM after 50 years of pumpage using 2000 pumping rates are shown in Figures 2 and 3, respectively. In general, the model indicates that groundwater in the Edwards Aquifer (Figure 2) flows to the south and east towards the Rio Grande, and groundwater in the Trinity Aquifer (Figure 3) generally flows to the south. Table 1 shows the budgets for each of the rivers in Terrell and Val Verde counties at the end of the 50-year predictive model run. As shown in Table 1, several of the rivers are connected to both the Edwards Aquifer (Layer 1) and Trinity Aquifer (Layer 2) layers within each county. Also shown in Table 1 is a value for "Recharge", "Discharge", and "Net Discharge". Because the GAM includes water moving from the rivers to the aquifer (recharge) and from the aquifer to the river (discharge) in different areas within each county, a "net discharge" value was calculated from the water budgets. The net discharge was calculated using the following equation:

$$Net\ Discharge = Discharge - Recharge$$

where:

Discharge = Water leaving the water budget and discharging to the rivers (where the river is "gaining" or "effluent")

Recharge = Water entering the water budget from the rivers (where the river is "losing" or "influent")

In other words, the amount of water being discharged to the river was reduced by the amount that the river recharged to the aquifer elsewhere in the county.

Table 1. Summary of annual stream package water budgets for the baseline run at the end of a 50-year predictive model run. All values are reported in acre-feet per year.

River	County	Layer 1- Edwards Aquifer			Layer 2- Trinity Aquifer		
		Recharge	Discharge	Net Discharge	Recharge	Discharge	Net Discharge
Rio Grande	Brewster	NA	NA	NA	1,463	13,148	11,685
Rio Grande	Terrell	167	34,644	34,477	0	10,154	10,154
Rio Grande	Val Verde	11,313	36,949	25,636	NA	NA	NA
Pecos	Terrell	NA	NA	NA	283	14,420	14,137
Pecos	Val Verde	5,524	56,301	50,778	1	1,947	1,946
Devils	Val Verde	8,082	38,747	30,665	NA	NA	NA

NA = Not applicable. The river is not present in this layer in this county.

To estimate the effect of increasing pumpage on discharge to the rivers in each county, pumpage was added to each aquifer in each county individually, until the original net discharge to all rivers in the county from the aquifer being pumped was decreased at least 50 percent. Therefore, four sets of model runs were done, individually increasing pumpage in the Edwards and Trinity aquifers in Terrell and Val Verde counties. Each of these is described separately below.

Increasing Pumpage in the Edwards Aquifer in Terrell County

The Rio Grande is the only river directly connected to the Edwards Aquifer layer in Terrell County. Figure 4 and Table 2 show the effect on the Rio Grande in those cells where it is connected to the Edwards layer in the GAM. This figure shows that the addition of approximately 80,000 acre-feet per year of pumpage evenly in Terrell County to the Edwards Aquifer (Layer 1 in the GAM) decreases net discharge from the aquifer to the Rio Grande in Layer 1 by approximately 50 percent. The addition of this amount of pumpage also reduces the discharge in the Rio Grande in Brewster County from the Trinity Aquifer by approximately 9 percent (Figure 5).

Table 2. Percent decrease in net discharge to rivers in Terrell and Val Verde counties when pumpage is increased in the Edwards Aquifer in Terrell County.

Additional Pumpage (acre-feet/year)	Percent Decrease in Original Net Discharge to Rivers							
	Brewster County	Terrell County			Val Verde County			
	Rio Grande-Layer 2	Rio Grande-Layer 1	Rio Grande-Layer 2	Pecos-Layer 2	Rio Grande-Layer 1	Pecos-Layer 1	Pecos-Layer 2	Devil's-Layer 1
20,000	1.8	12.4	2.1	7.2	2.2	4.0	6.1	0.0
40,000	3.6	24.7	4.2	14.1	4.3	7.9	12.0	0.0
60,000	5.3	37.0	6.3	20.7	6.5	11.8	17.8	0.1
80,000	7.2	49.4	8.4	27.4	8.7	15.8	23.8	0.1
100,000	8.9	61.7	10.5	33.9	10.9	19.7	29.6	0.1

Table 2 shows the effect of increasing pumpage in the Edwards Aquifer (Layer 1) in Terrell County on all of the rivers in Terrell and Val Verde counties. This table indicates that even though water is only pumped from the Edwards Aquifer in Terrell County, discharge to the Rio Grande and Pecos River from the Trinity layer in the GAM is also affected, and discharge to both of these rivers from both the Edwards and Trinity layers in Val Verde County is also affected. Flow in the Devils River, which does not flow through Terrell County, is virtually unaffected by the increase in pumpage in Terrell County.

Increasing Pumpage in the Trinity Aquifer in Terrell County

Both the Rio Grande and the Pecos River are directly connected to the Trinity Aquifer layer in Terrell County. Figures 6 and 7 and Table 3 show the effect on the Rio Grande and Pecos River in those cells where they are connected to the Edwards layer in the GAM. These figures show that the addition of 30,000 acre-feet per year of pumpage evenly in Terrell County to the Trinity Aquifer (Layer 2) decreases net discharge from the aquifer to the Rio Grande in Layer 2 by approximately 55 percent and the addition of 50,000 acre-feet per year decreases the net discharge to the Pecos River by approximately 56 percent. The addition of this amount of pumpage also reduces the discharge in the Rio Grande in Brewster County from the Trinity Aquifer by approximately 41 percent (Figure 8).

Table 3 shows the effect of increasing pumpage in the Trinity Aquifer (Layer 2) in Terrell County on all of the rivers in Terrell and Val Verde counties. This table indicates

that when pumpage is only increased in the Trinity layer in Terrell County, only those portions of rivers directly connected to the Trinity Aquifer in the GAM are affected. The portions of all rivers in both counties connected to the Edwards aquifer (Layer 1) are virtually unaffected by the increase in pumpage in the Trinity aquifer.

Table 3. Percent decrease in net discharge to rivers in Terrell and Val Verde counties when pumpage is increased in the Trinity Aquifer in Terrell County.

Additional Pumpage (acre-feet/year)	Percent Decrease in Original Net Discharge to Rivers							
	Brewster County	Terrell County			Val Verde County			
	Rio Grande-Layer 2	Rio Grande-Layer 1	Rio Grande-Layer 2	Pecos-Layer 2	Rio Grande-Layer 1	Pecos-Layer 1	Pecos-Layer 2	Devil's-Layer 1
10,000	8.0	0.4	18.2	11.2	0.2	0.3	32.9	0.2
20,000	16.1	0.7	36.4	22.4	0.4	0.6	65.8	0.4
30,000	24.3	1.0	54.6	33.7	0.6	0.9	98.6	0.6
40,000	32.4	1.3	72.7	44.8	0.8	1.1	131.0	0.8
50,000	40.7	1.6	91.0	56.0	1.0	1.4	163.2	1.1

Increasing Pumpage in the Edwards Aquifer in Val Verde County

All three rivers (Rio Grande, Pecos, Devils) are directly connected to the Edwards Aquifer layer in Val Verde County. Figures 9, 10, and 11 and Table 4 show the affect on the Rio Grande, Pecos River, and Devils River in those cells where they are connected to the Edwards layer in the GAM. These figures show that the addition of 160,000 acre-feet per year of pumpage evenly in Val Verde County to the Edwards aquifer (Layer 1) decreases net discharge from the aquifer to the Rio Grande in Layer 1 by approximately 50 percent, but that only 100,000 and 50,000 acre-feet per year of pumpage are required to reduce discharge to the Pecos and Devils Rivers, respectively, by the same amount. The addition of this amount of pumpage only does not significantly change the discharge in the Rio Grande in Brewster County.

Table 4. Percent decrease in net discharge to rivers in Terrell and Val Verde counties when pumpage is increased in the Edwards Aquifer in Val Verde County.

Additional Pumpage (acre-feet/year)	Percent Decrease in Original Net Discharge to Rivers							
	Brewster County	Terrell County			Val Verde County			
	Rio Grande-Layer 2	Rio Grande-Layer 1	Rio Grande-Layer 2	Pecos-Layer 2	Rio Grande-Layer 1	Pecos-Layer 1	Pecos-Layer 2	Devil's-Layer 1
40,000	0.0	2.0	0.3	0.9	12.6	19.2	3.1	41.1
80,000	0.1	4.1	0.6	1.9	25.3	38.6	6.3	81.6
120,000	0.1	6.2	0.9	2.8	38.0	58.3	9.5	120.9
160,000	0.2	8.2	1.3	3.8	51.0	79.1	13.0	156.8

Table 4 shows the affect of increasing pumpage in the Edwards Aquifer (Layer 1) in Val Verde County on all of the rivers in Terrell and Val Verde counties. This table indicates that when pumpage is only increased from the Edwards layer in Val Verde County, discharge to all three rivers connected to the Edwards (Layer 1) is affected. However,

discharge to the Pecos River from the Trinity Aquifer (Layer 2) is virtually unaffected, and discharge to all rivers in Terrell County is minimally affected as well. This may be because all of the rivers flow through Terrell County before Val Verde County and, therefore, decreases in streamflow will not impact the portions of these rivers in Val Verde County.

Increasing Pumpage in the Trinity Aquifer in Val Verde County

Only the Pecos River is directly connected to the Trinity Aquifer layer in Val Verde County. Figure 12 and Table 5 show the effect on the Pecos River in those cells where it is connected to the Trinity layer in the GAM. These figures show that the addition of only 12,000 acre-feet per year of pumpage evenly in Val Verde County to the Trinity Aquifer (Layer 1) decreases net discharge from the aquifer to the Rio Grande in Layer 1 by approximately 51 percent. The addition of this amount of pumpage reduces the discharge in the Rio Grande in Brewster County by less than one percent.

Table 5 shows the effect of increasing pumpage in the Trinity Aquifer (Layer 2) in Val Verde County on all of the rivers in Terrell and Val Verde counties. This table indicates that when pumpage is only increased from the Trinity layer in Val Verde County, discharge to all three rivers connected to the Edwards (Layer 1) is virtually unaffected. A small effect is also noted in discharges to the Rio Grande and Pecos River in Terrell County where they are directly connected to the Trinity Aquifer; however, the effect is small because the increase in pumpage is very small.

Table 5. Percent decrease in net discharge to rivers in Terrell and Val Verde counties when pumpage is increased in the Trinity Aquifer in Val Verde County.

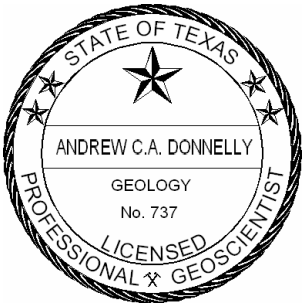
Additional Pumpage (acre-feet/year)	Percent Decrease in Original Net Discharge to Rivers							
	Brewster County	Terrell County			Val Verde County			
	Rio Grande-Layer 2	Rio Grande-Layer 1	Rio Grande-Layer 2	Pecos-Layer 2	Rio Grande-Layer 1	Pecos-Layer 1	Pecos-Layer 2	Devil's-Layer 1
2,500	0.2	0.1	1.4	0.5	0.1	0.3	10.8	0.8
5,000	0.3	0.1	2.8	1.1	0.3	0.5	21.5	1.6
7,500	0.5	0.2	4.2	1.6	0.4	0.8	32.2	2.4
10,000	0.7	0.2	5.5	2.1	0.6	1.1	42.8	3.2
12,000	0.8	0.3	6.7	2.5	0.7	1.3	51.3	3.8

Summary

Effect on rivers is largely restricted to the aquifer being pumped in the county where the pumpage is added. The main exception to this is when downstream reaches in Val Verde County are affected by reductions in flow in Terrell County. The amounts of pumpage required to reduce the net discharge to the rivers by 50 percent varies from only 12,000 acre-feet per year required to reduce discharge to the Pecos River from the Trinity Aquifer in Val Verde County to 160,000 acre-feet per year required to reduce discharge to the Rio Grande from the Edwards Aquifer in Val Verde County. However, the effect of constant head cells to model Amistad Reservoir on discharge to the Rio Grande is unknown.

REFERENCES:

Anaya, R., and Jones, I., 2004, Groundwater availability model for the Edwards-Trinity (Plateau) and Cenozoic Pecos Alluvium aquifer systems, Texas: Texas Water Development Board, GAM Report, 208 p.



The seal appearing on this document was authorized by Andrew C.A. Donnelly, P.G. 737, on February 2, 2007.

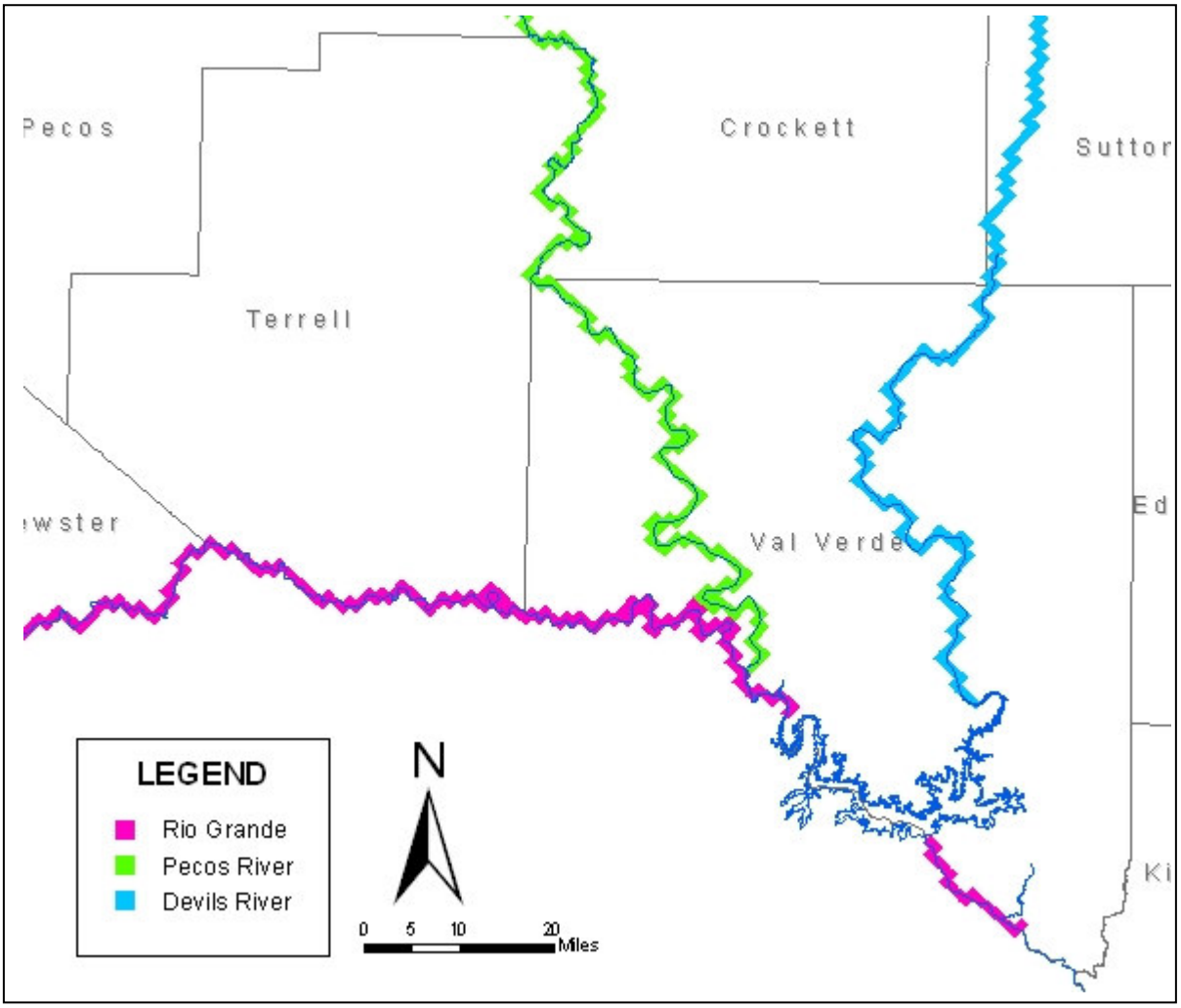


Figure 1. Cells included in the GAM that represent the Rio Grande, Pecos River, and Devils River.

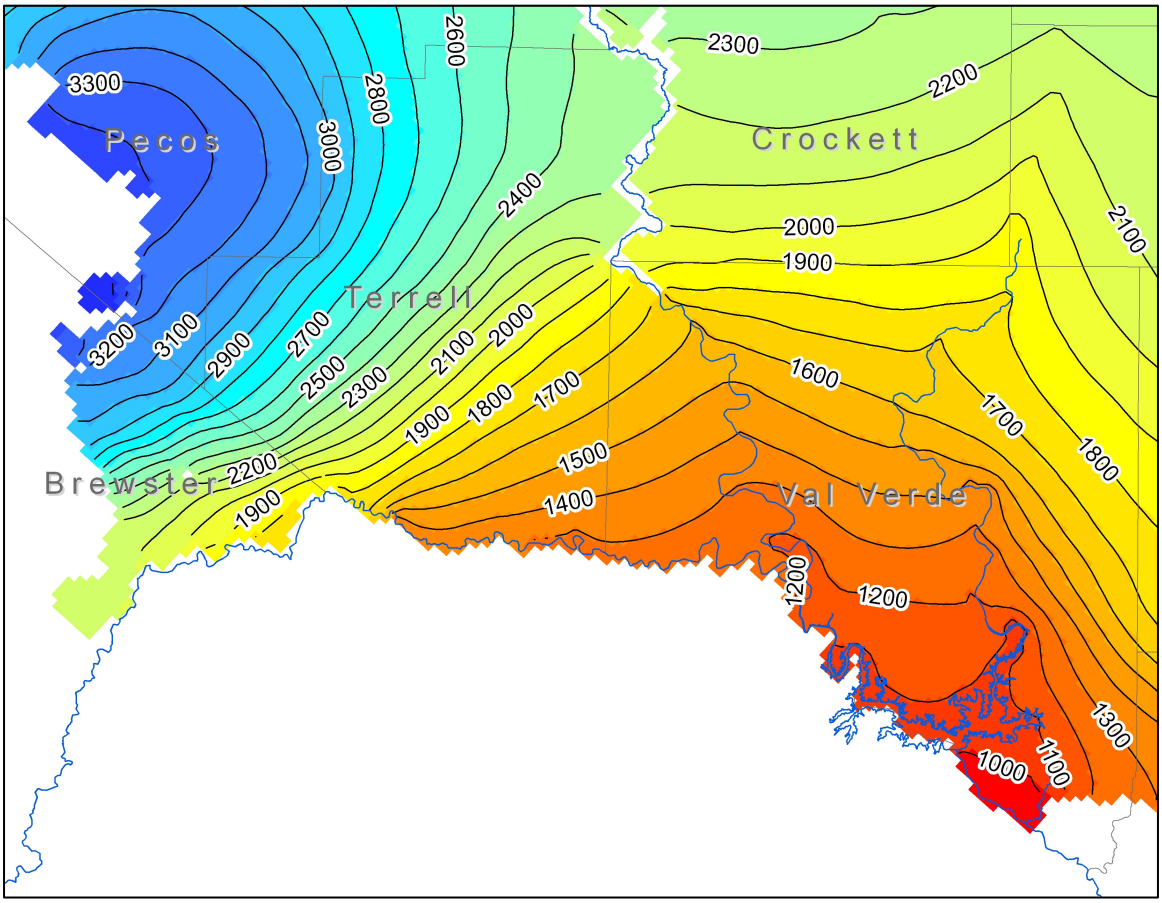


Figure 2. Water levels (in feet above MSL) in the Edwards Aquifer (Layer 1) after 50 years of pumping at 2000 pumping rates. Contour interval is 100 feet.

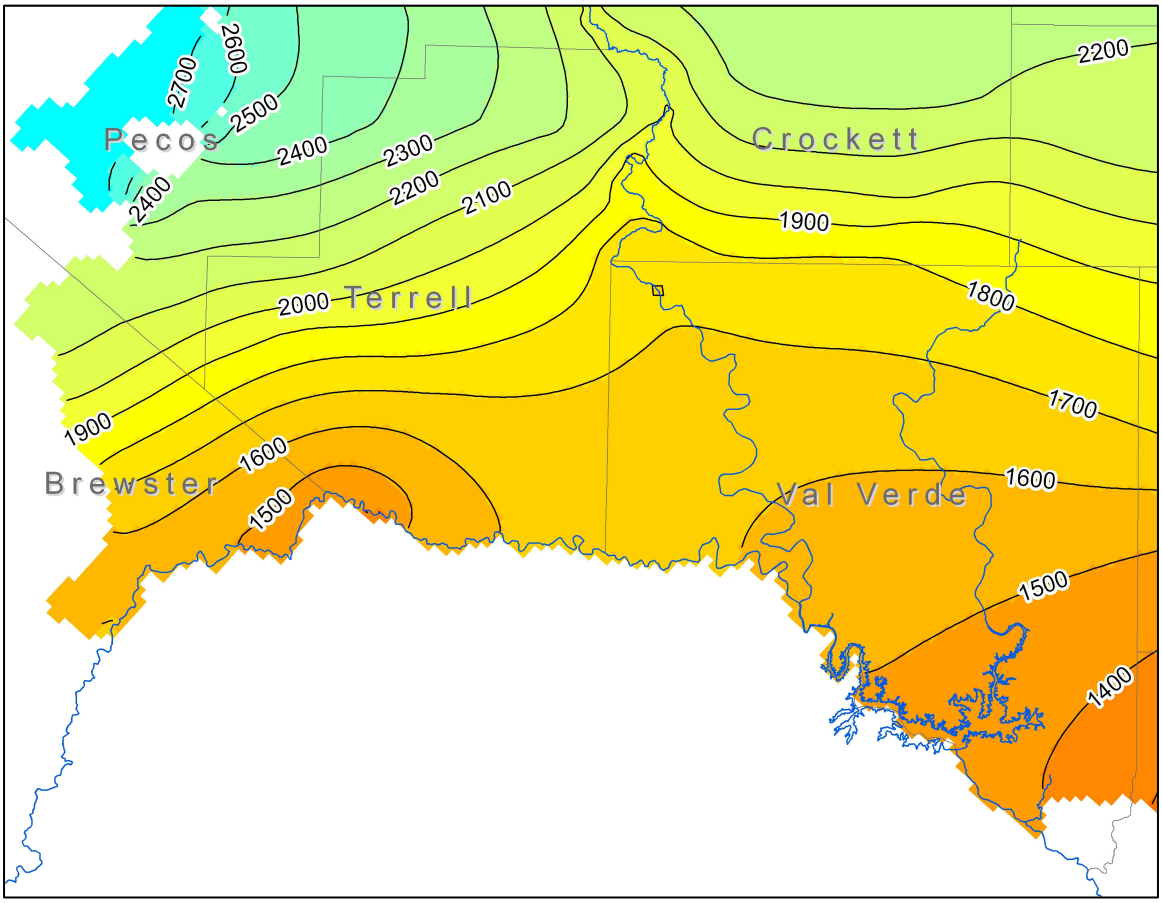


Figure 3. Water levels (in feet above MSL) in the Trinity Aquifer (Layer 2) after 50 years of pumping at 2000 pumping rates. Contour interval is 100 feet.

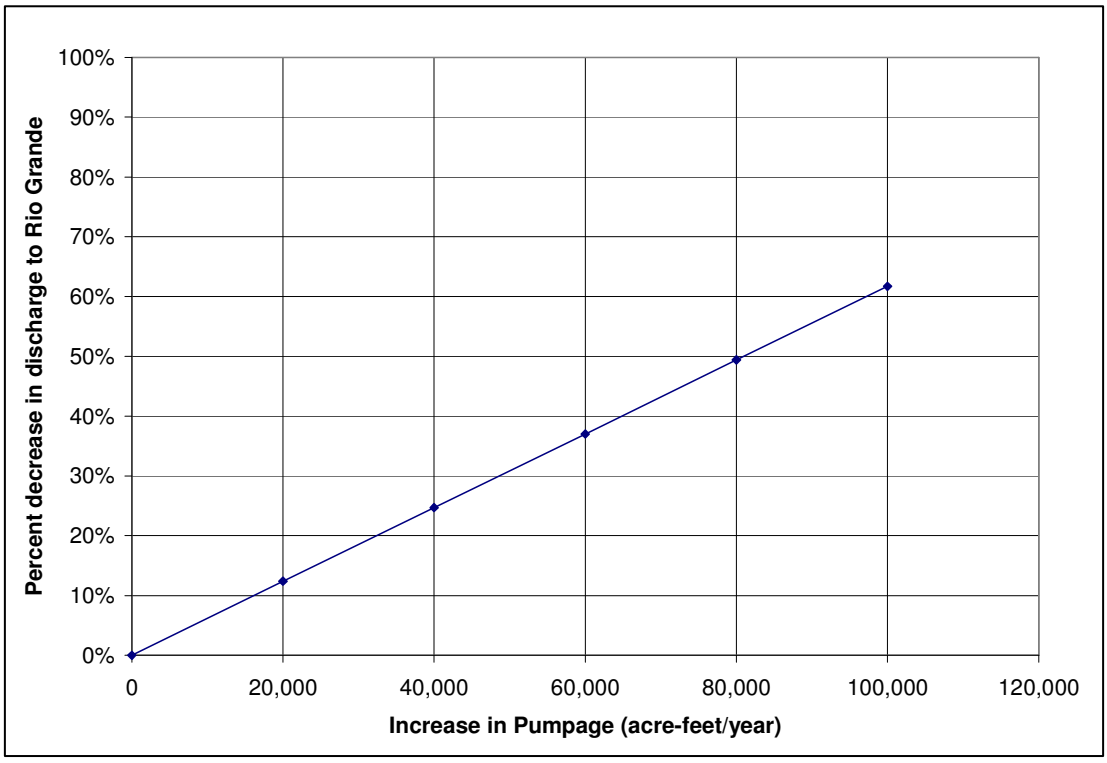


Figure 4. Percent decrease in original net discharge to the Rio Grande from the Edwards Aquifer layer in the GAM (Layer 1) in Terrell County with increasing pumpage in the Edwards Aquifer layer in Terrell County.

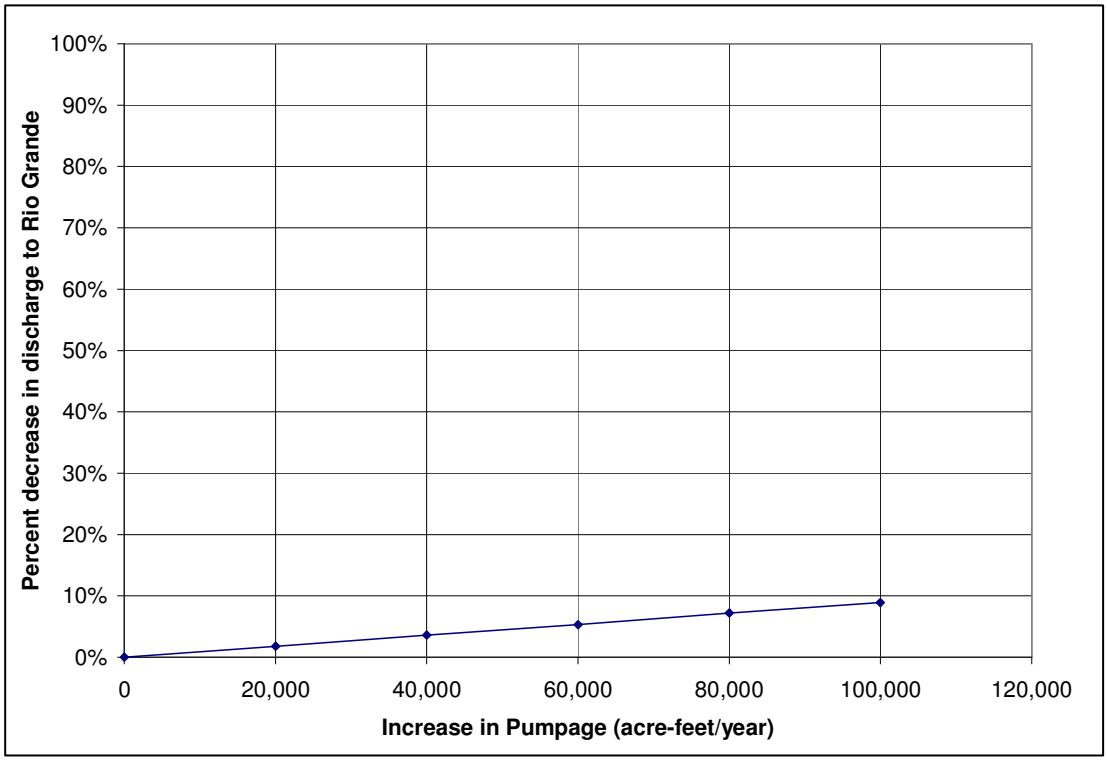


Figure 5. Percent decrease in original net discharge to the Rio Grande from the Trinity Aquifer layer in the GAM (Layer 2) in Terrell County with increasing pumpage in the Edwards Aquifer layer in Terrell County.

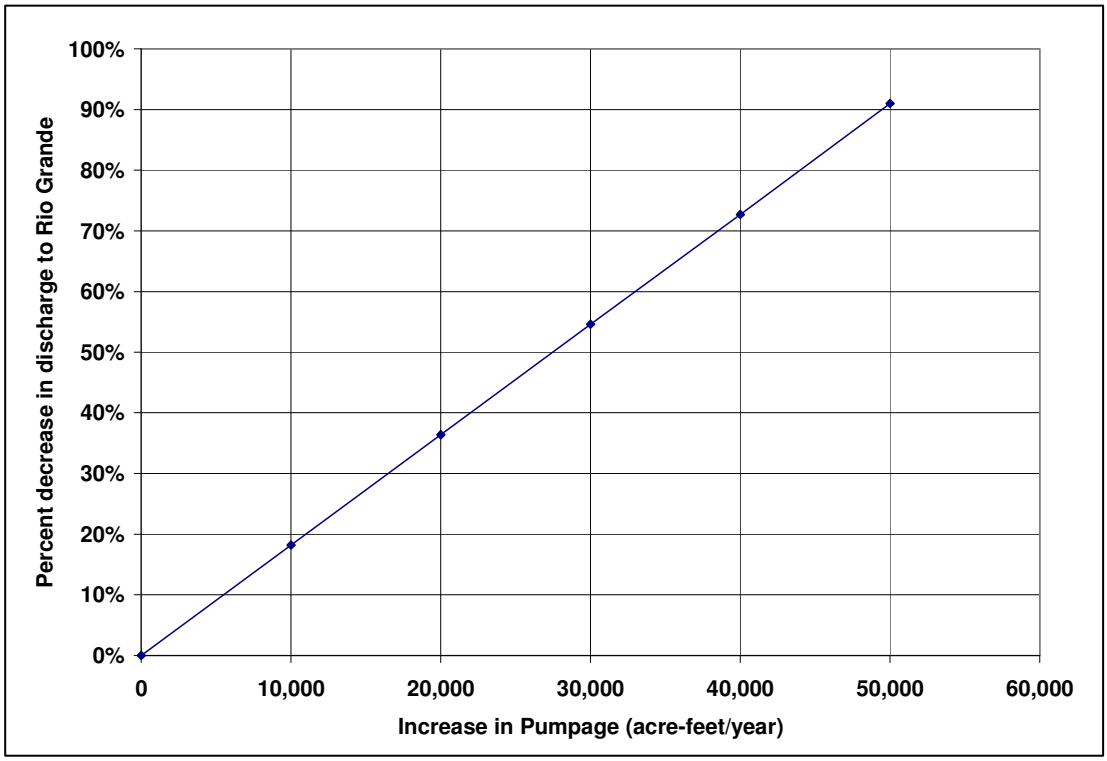


Figure 6. Percent decrease in original net discharge to the Rio Grande from the Trinity Aquifer layer in the GAM (Layer 2) in Terrell County with increasing pumpage in the Trinity Aquifer layer in Terrell County.

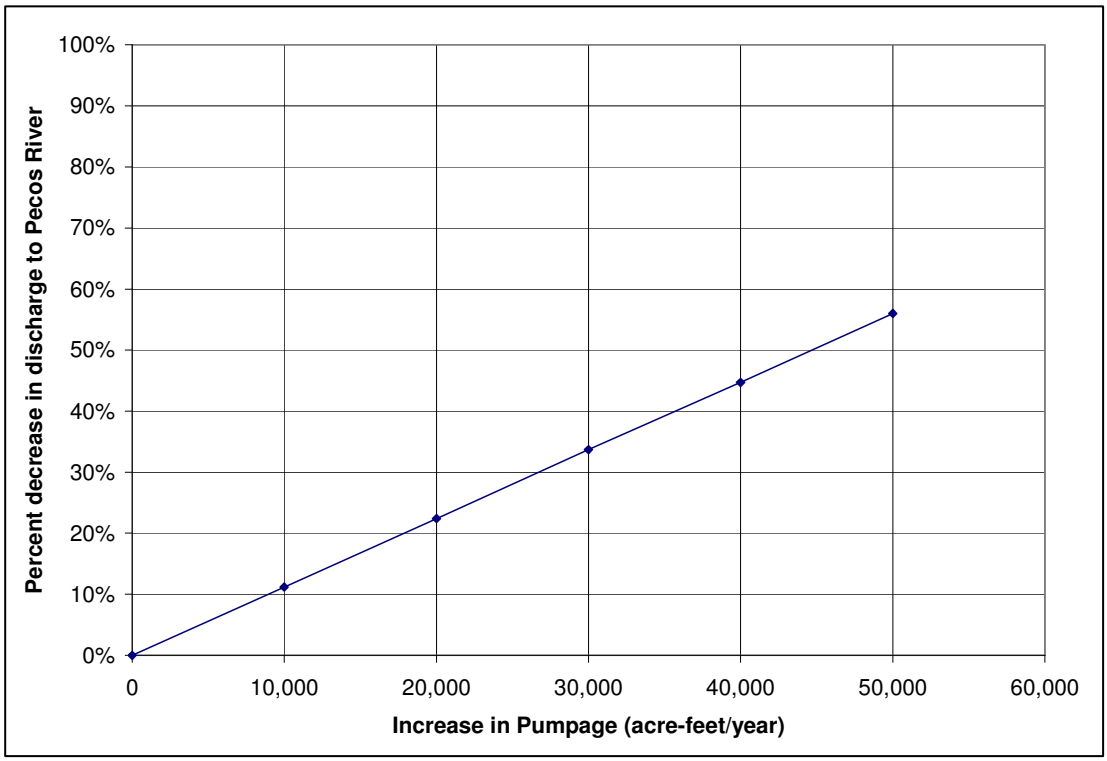


Figure 7. Percent decrease in original net discharge to the Pecos River from the Trinity Aquifer layer in the GAM (Layer 2) in Terrell County with increasing pumpage in the Trinity Aquifer layer in Terrell County.

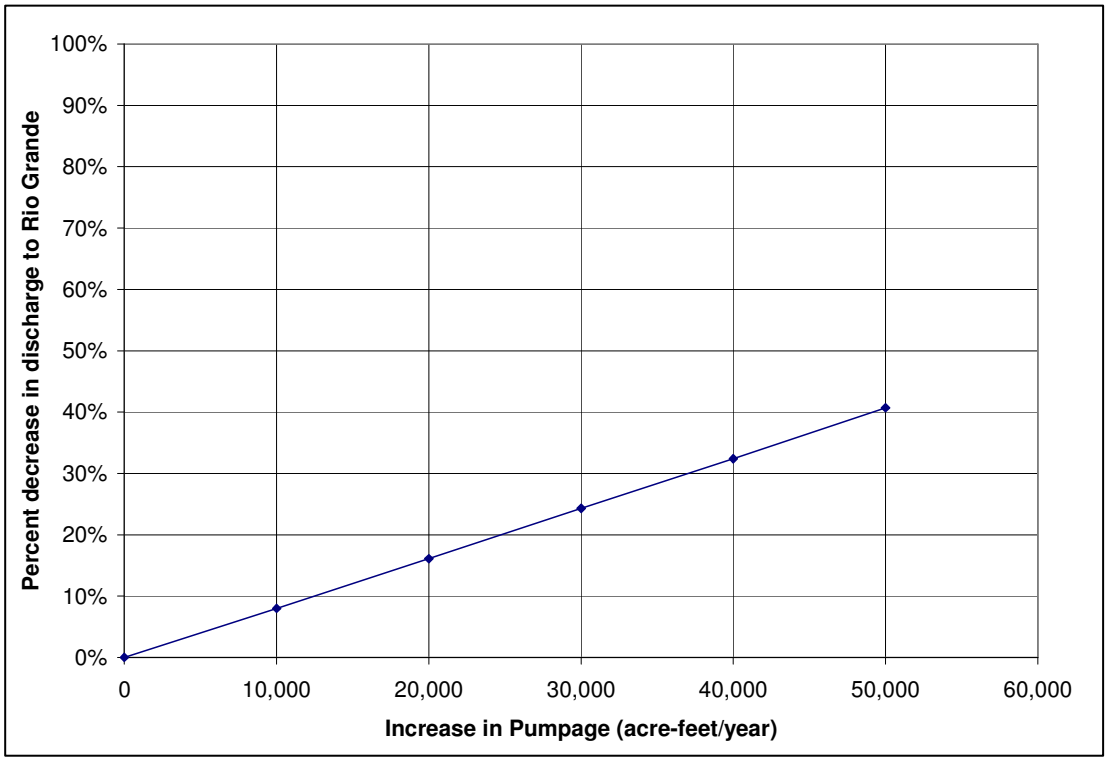


Figure 8. Percent decrease in original net discharge to the Rio Grande from the Trinity Aquifer layer in the GAM (Layer 2) in Terrell County with increasing pumpage in the Trinity Aquifer layer in Terrell County.

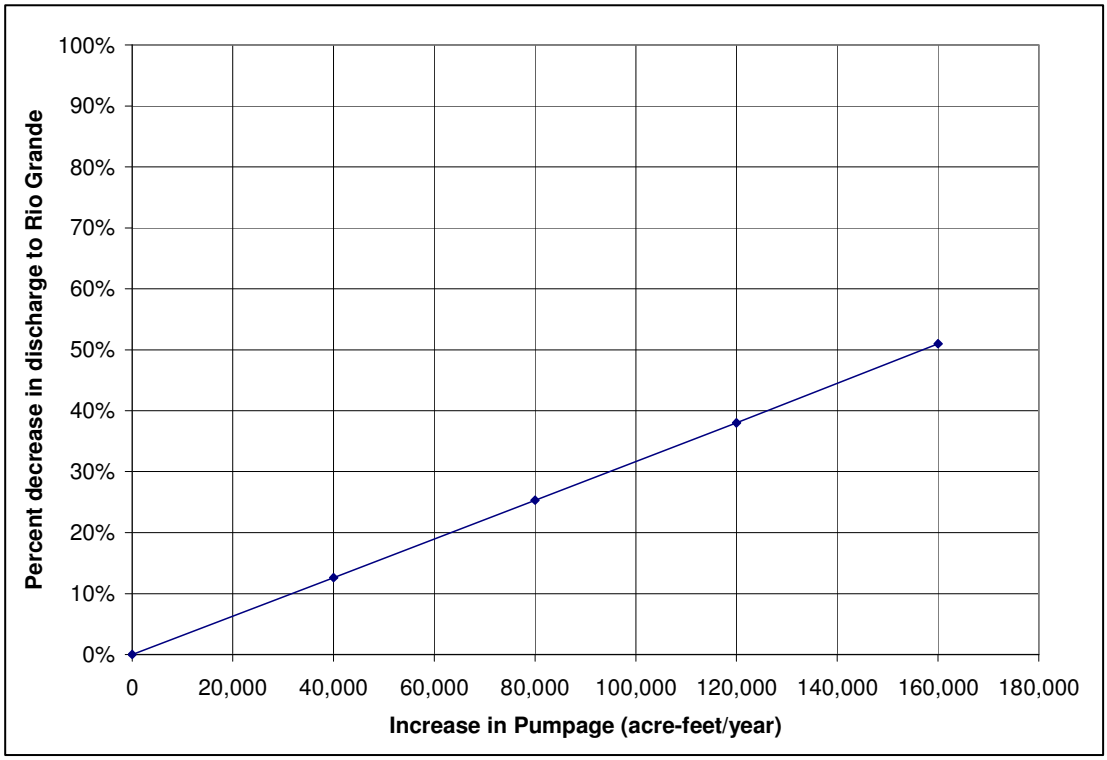


Figure 9. Percent decrease in original net discharge to the Rio Grande from the Edwards Aquifer layer in the GAM (Layer 1) in Val Verde County with increasing pumpage in the Edwards Aquifer layer in Val Verde County.

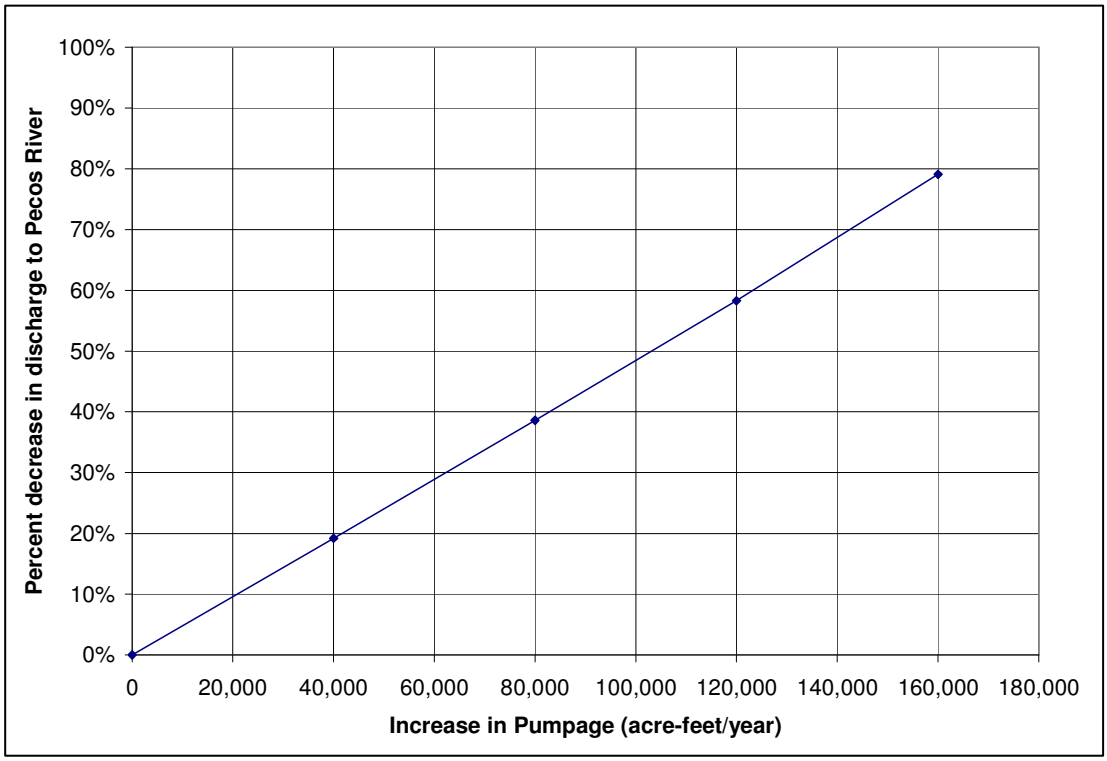


Figure 10. Percent decrease in original net discharge to the Pecos River from the Edwards Aquifer layer in the GAM (Layer 1) in Val Verde County with increasing pumpage in the Edwards Aquifer layer in Val Verde County.

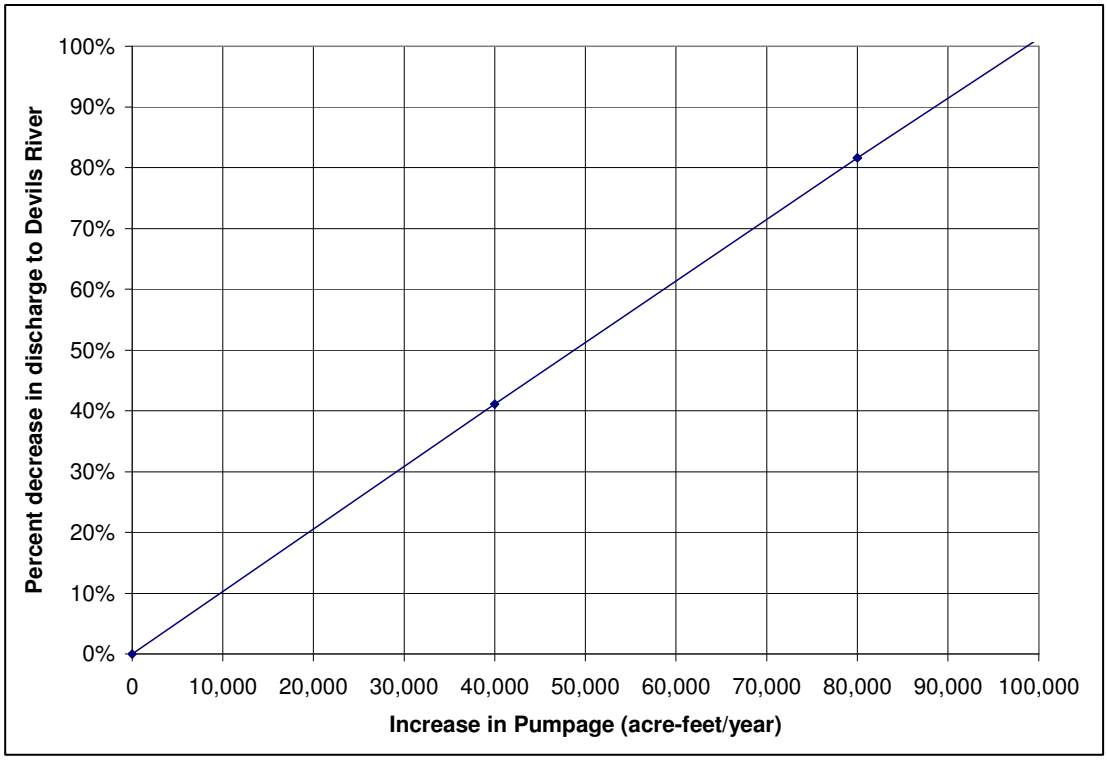


Figure 11. Percent decrease in original net discharge to the Devils River from the Edwards Aquifer layer in the GAM (Layer 1) in Val Verde County with increasing pumpage in the Edwards Aquifer layer in Val Verde County.

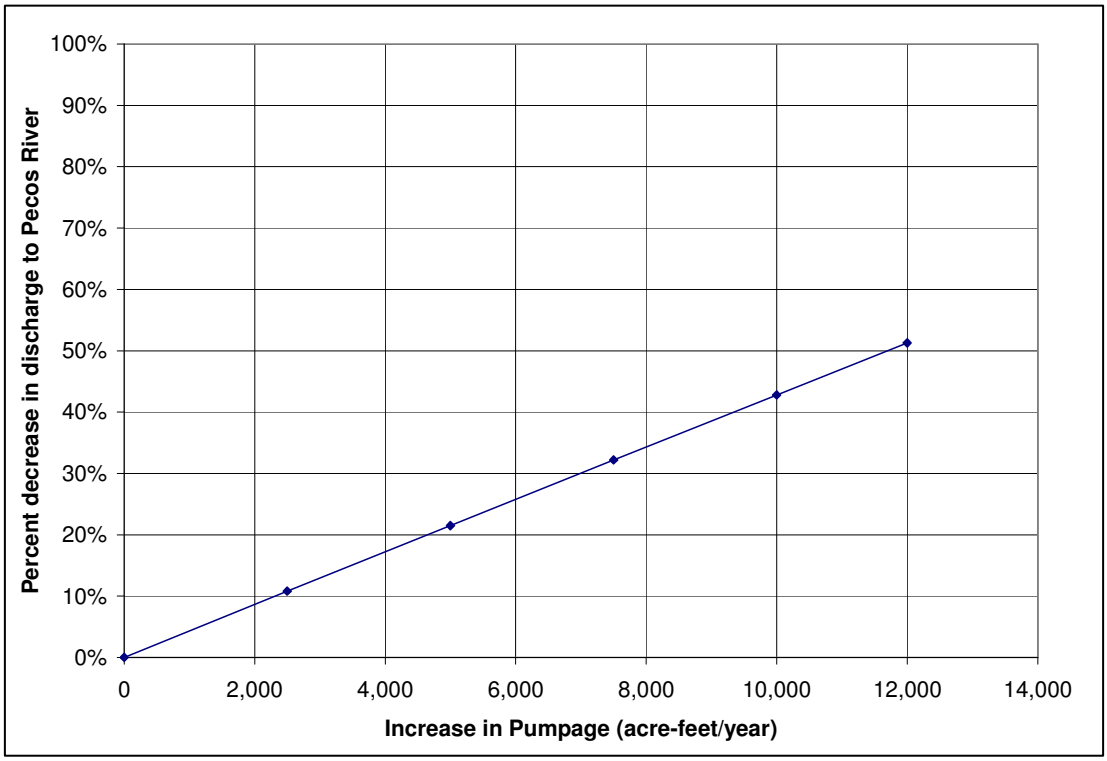


Figure 12. Percent decrease in original net discharge to the Pecos River from the Trinity Aquifer layer in the GAM (Layer 2) in Val Verde County with increasing pumpage in the Trinity Aquifer layer in Val Verde County.