Appendix B

A Report Investigating Impacts of Aquifer Pumping Limits on Flow of Comal Springs and San Marcos Springs

Submitted to

Hicks & Company

For

Edwards Aquifer Authority Habitat Conservation Plan

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Introduction

LBG-Guyton Associates was contracted by Hicks Environmental to do a series of model runs with the Edwards Aquifer model (in GWSIM-IV) to determine the impact on Comal and San Marcos springflows of various pumpage reduction strategies. This investigation is part of the Habitat Conservation Plan (HCP) study being conducted for the Edwards Aquifer Authority (EAA). This work was conducted under project number 99227.

Several different scenarios were modeled to determine the impact of reductions of different types of pumpage on springflows. The scenarios modeled included:

1. Equal pumpage reductions across the model area
2. Reduction of irrigation pumpage only
3. Reduction of municipal and industrial pumpage only
4. Reduction of irrigation pumpage in Medina County only
5. Reduction of irrigation pumpage in Uvalde County only

This report details the methodology used to make the model simulations, the assumptions used, and gives the results of the simulations and a discussion on the meaning of these results.

Methodology

All of the model simulations run for this investigation used the latest version of the "official" Edwards model. The original Edwards Aquifer model was developed by the Texas Water Development Board (TWDB) in the early 1970's. The Edwards model uses the GWSIM-IV code, and was originally calibrated to data for the 1947 to 1971 time period using annual time steps (Klemt and others, 1979). It is a one-layer groundwater model, and assumes no movement of water into the modeled area from the Glen Rose Formation, from the other side of the "bad water" line, or the underlying or overlying formations, except in the vicinity of Leona Springs, where some water is allowed to leak out. Figure 1 shows the model area and grid used. Figure 1 also shows some of the significant features in the model. All springflows given in the results for this investigation are produced by the Edwards model.

In the early 1990's, the TWDB recalibrated the model and converted it from annual time steps to monthly time steps (Thorkildsen and McElhaney, 1992). This recalibration was based on simulations for the 1947 to 1959 time period and verified with simulations from the 1978 to 1989 time period.

In 1999 the model was again revised by the TWDB to include new management strategies that could not be handled by the previous versions of the model. Specifically, the Edward Aquifer Authority's critical period management rules were incorporated into the model, which required the separation of the pumpage inputs into type and county location. The pumpage types included in the newest version of the model include irrigation pumpage, industrial pumpage, municipal pumpage, domestic and stock pumpage, and a "winter base" pumpage. These pumpage types were divided by county, and also separated out the San Antonio Water System (SAWS) pumpage into a separate file. The "winter base" pumpage is a pumpage data set for use specifically with the critical period management rules. The 1999 revision of the Edwards model did not alter any of the basic model assumptions and was not a recalibration of the model. This effort only altered the way pumpage was input into the model so that the EAA's critical period rules could be modeled. However, for the current investigation the critical period management rules were turned off in the model. This allowed for an appropriate evaluation of each option without other variables changing in the model run due to the critical period rules.

Each simulation was 63 years in length, running with monthly time steps. The model uses the following inputs for stresses to the system:

1. Recharge- Historic recharge values for 1934-1996 were used for all of the model runs. This recharge data set includes all of the drought of record (1951-56) as well as numerous shorter duration, high intensity droughts that have occurred since that time.
2. Domestic and Stock Pumpage- Historic estimates for domestic and stock pumpage for 1934-1996 were used.
3. Irrigation Pumpage- All of the annual irrigation pumpage used in the model were based on the initially proposed permitted pumpage data sets put together by the TWDB based on the initially proposed permits by the EAA.
4. Municipal Pumpage- All of the annual municipal pumpage used in the model were based on the initially proposed permitted pumpage data sets put together by the TWDB based on the initially proposed permits by the EAA.
5. Industrial Pumpage- All of the annual industrial pumpage used in the model were based on the initially proposed permitted pumpage data sets put together by the TWDB based on the initially proposed permits by the EAA.
6. Winter Base Pumpage- Winter base pumpage is used only with the critical period management rules that are built into the model. Although these files are required to run the model, they were not used by the model during the simulations run for this investigation.

The irrigation, municipal, and industrial pumpage values used in each model run were based on the proposed permitted amount for a single year. This amount, or a variation of this proposed amount, was used annually and did not vary from year to year during the model run, i.e. the same annual pumpage was used for every year during the simulation.

The initial pumpage data sets were created by the TWDB. The TWDB obtained information on permits issued by the EAA, which included annual permitted pumpage amounts and the physical location of each permit. The TWDB then determined the physical location of each permit within the model, and assigned each permit to a model cell to create an annual distribution of pumpage.

In order to construct monthly data sets of pumpage, it was necessary to divide the annual permitted pumpage amount into monthly pumpage estimates. In order to do this, the TWDB had to make assumptions on how the pumpage varied through a typical year. Tables 1 and 2 show the breakdown on how the TWDB divided up the irrigation and municipal/industrial pumpage from month to month to create the estimated monthly pumpage data sets.

These values were then used by the TWDB to construct monthly pumpage data sets. These data sets have a total permitted pumpage of 498,777 acre-feet for a single year, and were used as the basis for all model runs. Of the total, 484,803 acre-feet/year was from permitted pumpage types in the data sets used for this investigation. The remaining pumpage is unpermitted pumpage which is not regulated by the EAA.

The TWDB pumpage data sets had some initial problems with the distribution of the pumpage, and had to be changed to correctly distribute the pumpage. Table 3 shows the final distribution of the pumpage by county and pumpage type. Tables 4-8 list pumpage totals and factors used to determine the pumpage distribution.

Baseline Results

A baseline simulation for 1978 to 1989 historic conditions (recharge and pumping) was run to illustrate the accuracy of the Edwards model. This time period includes two very dry periods (1983-84 and 1988-89), as well as many "normal" years. Figures 2 to 4 show the results of this run compared to actual measure values for J-17 water levels, and Comal and San Marcos springflows, respectively. Water levels for the San Antonio index well (J-17) are shown in Figure 2. The trend in modeled water levels generally follows actual water levels, although the model tends to overestimate summer declines in normal years, and in most winters. Comal springflows are shown in Figure 3. This figure indicates that the model tends to overestimate springflows during times of extremely high springflow, but generally follows the same trend as actual springflow. Figure 4 shows San Marcos springflow. This figure indicates that the model tends to underestimate San Marcos springflow most of the time.

Scenario Descriptions

Five different scenarios were modeled during this investigation. These include equal pumpage reductions, reductions to irrigation pumpage only, reductions to municipal and industrial pumpage only, reductions to Medina County irrigation pumpage only, and reductions to Uvalde County irrigation pumpage only. Each of these are described below.

Scenario 1- Equal Pumpage Reductions- For the first scenario, the pumpage of each of the three types of permitted pumpage (irrigation, municipal, and industrial) were equally reduced to obtain a desired total permitted pumpage. Table 4 details the factors that were used and the resulting total pumpage for each type of pumpage, and the total pumpage. Pumpage totals for these simulations ranged from 0 acre-feet/year to 484,803 acre-feet/year.

Scenario 2- Irrigation Pumpage Reductions Only- In this scenario, the permitted pumpage was reduced by reducing only irrigation pumpage. Because the initial amount of irrigation pumpage in the initially proposed permitted pumpage total was 236,520 acre-feet/year, the total pumpage could only be reduced to 248,243 acre-feet/year, which is the amount of municipal and industrial pumpage in the initial pumpage total. Table 5 details the factors that were used to reduce the irrigation pumpage and the resulting total for each type of pumpage, and the total pumpage.

Scenario 3- Municipal and Industrial Pumpage Reductions Only- In this scenario, the permitted pumpage was reduced by reducing only municipal and industrial pumpage. Because the initial amount of municipal and industrial pumpage in the initially proposed permitted pumpage total was 248,243 acre-feet/year, the total pumpage could only be reduced to 236,520 acre-feet/year, which is the amount of irrigation pumpage in the initial pumpage total. Table 6 details the factors that were used to reduce the municipal and industrial pumpage and the resulting total for each type of pumpage, and the total pumpage.

Scenario 4- Medina County Irrigation Pumpage Reductions Only- In this scenario, the permitted pumpage was reduced by reducing only irrigation pumpage from Medina County. Because the initial amount of irrigation pumpage in Medina County in the initially proposed permitted pumpage total was 87,259 acre-feet/year, the total pumpage could only be reduced to 397,544 acre-feet/year, which is the amount of irrigation pumpage outside of Medina County plus municipal and industrial pumpage in the initial pumpage total. Table 7 details the factors that were used to reduce the irrigation pumpage in Medina County and the resulting total for each type of pumpage, and the total pumpage.

Scenario 5- Uvalde County Irrigation Pumpage Reductions Only- In this scenario, the permitted pumpage was reduced by reducing only irrigation pumpage from Uvalde County. Because the initial amount of irrigation pumpage in Uvalde County in the initially proposed permitted pumpage total was 112,606 acre-feet/year, the total pumpage could only be reduced to 372,197 acre-feet/year, which is the amount of irrigation pumpage outside of Uvalde County plus the municipal and industrial pumpage in the initial pumpage total. Table 8 details the factors that were used to reduce the irrigation pumpage in Uvalde County and the resulting total for each type of pumpage, and the total pumpage.

How to Interpret The Results

The results for each scenario are shown in figures for both Comal and San Marcos springflows compared to the total permitted pumpage. An example of the springflows output from the model is shown in Figure 5. This figure shows the modeled springflow for a run with a total pumpage of 350,000 acre-feet/year. In this figure, the yearly variation can be seen in the springflow, with lows occurring every summer and highs occurring every winter, and the entire period of record is shown in the figure. However, for the purposes of this investigation, where numerous variations of pumpage will be compared to each other, it was necessary to present the results in a different format. For this investigation, the results will be shown in figures with up to four lines, one each representing the absolute minimum springflow (springflow met 100% of the time), and springflow being met 95%, 90%, and 75% of the time for each of the runs. These are each described below.

<u>Absolute minimum springflow (springflow met 100% of the time)</u>- The lowest of the four lines in the results figures is the absolute minimum springflow from the model results for the scenario being tested. This line indicates the minimum springflow from any single month during each of the simulations. All of the springflows output from each of the 756 monthly time steps were examined, and the single lowest value constituted the minimum value. This line shows the minimum springflow predicted by the model during the lowest point of the drought of record, because in all runs, the minimum springflow occurs in July or August, 1956. This line can therefore be used to estimate the total permitted pumpage for any desired minimum springflow between 0 and 276 cfs, which is the minimum springflow that is predicted by the model if all permitted pumpage is turned off.

<u>Springflow met 95% of the time</u>- The springflow results from the model for the 756 months were sorted in ascending order. The value for the 38th lowest value ((756 months-38 months)/756 months = 95%) represents the 95% value. This means that 95% of the springflows output from the simulation are greater than this value, and that 5% of the values are less than this value.

<u>Springflow met 90% and 75% of the time</u>- The springflow values for these lines were calculated in an identical fashion as the 95% line, however the 90% and 75% values were identified instead of the 95% value. The 75% line is the highest line on each chart.

Although springflow graphs for each of the scenarios will be presented for both Comal and San Marcos Springs, the discussion of the results below will focus entirely on Comal Springs. The reason for this are shown in Figures 6 and 7, which show estimated Comal and San Marcos Springs springflow compared to permitted pumpage for equal reductions to all of the permitted pumpage types. The springflow curves for Comal Springs in Figure 6 show a good correlation to the decrease in pumpage. However, the springflow curves for San Marcos Springs in Figure 7 are very flat, especially the minimum springflow curve from a permitted pumpage of 0 acre-feet/year to 410,000 acre-feet/year. The difference in the minimum modeled San Marcos springflow over this range of pumpage is only a little over 3 cfs. The reason for this appears to be because the large majority of the pumpage reductions occur to the west of Comal Springs. Because Comal Springs drains such a large amount of water from the system, and is at a higher elevation and therefore upgradient from San Marcos Springs, all of the impact of the pumpage reductions are seen at Comal Springs. Comal essentially "dampens" the effect of the pumpage reductions at San Marcos Springs. It is only after Comal Springs goes dry, and is therefore no longer able to dampen the effects of the pumpage changes to the west, that an impact is observed at San Marcos. Comal Springs goes dry at approximately 350,000 acre-feet/year, and a sharp decline in minimum springflow at San Marcos is observed starting at about 410,000 acre-feet/year. The lag is due to the distance between the two springs, and an additional 60,000 acre-feet/year of pumpage is required to move the effects of the pumpage the additional distance to San Marcos. Because of this, the focus of the results in this report will be on Comal springflows.

Results

The results of each of the five scenarios are described below.

Scenario 1- Equal Pumpage Reductions- Figures 6 and 7 show Comal and San Marcos springflows predicted by the model compared to the total permitted pumpage used in each of the simulations as the total permitted pumpage is reduced equally between irrigation, municipal, and industrial pumpage. Table 9 lists predicted springflows for specified aquifer pumping limits calculated from GWSIM IV model runs using equal reductions irrigation, municipal and industrial pumping. In Figures 6 and 7, the minimum springflow curve indicates the cutbacks in permitted pumpage that would be required to meet an absolute minimum springflow during the model runs. An important comparison to this curve is the 95% springflow curve. This curve indicates that if a minimum springflow is only required to be met 95% of the time, the model predicts that pumpage reductions would need to be 75,000 to 100,000 acre-feet/year less than if an absolute minimum springflow had to be met. This illustrates the large impact that meeting absolute minimum springflows has on the overall management of the aquifer. For example, in order to meet a springflow of 150 cfs at Comal Springs, the total permitted pumpage would have to be cut back to approximately 175,000 acre-feet/year, producing a predicted springflow of 154 cfs. (Table 9). However, if a springflow of 150 cfs or greater at Comal Springs is required only 95% of the time, then the permitted pumpage needs only to be cut down to approximately 265,000 acre-feet/year, a difference of 90,000 acre-feet/year. In addition, Figure 6 shows that when 150 cfs is met 95% of the time at Comal Springs (i.e. at a total pumpage of 265,000 acre-feet/year), a minimum springflow of about 60 cfs is obtained.

Scenario 2- Irrigation Pumpage Reductions Only- Figures 8 and 9 show Comal and San Marcos springflows predicted by the model compared to the total permitted pumpage used in each of the simulations as the total permitted pumpage is reduced by reducing only the irrigation pumpage. Figure 8 indicates that even if all irrigation pumpage is removed from the model, a springflow of less than 60 cfs is the highest minimum springflow that is predicted at Comal Springs. In fact, 150 cfs at Comal Springs is not predicted to occur even 95% of the time by the reduction of irrigation pumpage alone, based on these model results.

Scenario 3- Municipal and Industrial Pumpage Reductions Only- Figures 10 and 11 show Comal and San Marcos springflows predicted by the model compared to the total permitted pumpage used in each of the simulations as the total permitted pumpage is reduced by reducing only municipal and industrial pumpage. Figure 10 indicates that even if all of the municipal and industrial pumpage is removed from the model, a springflow of just over 100 cfs is the highest minimum springflow that is predicted at Comal Springs.

Scenario 4- Medina County Irrigation Pumpage Reductions Only- Figures 12 and 13 show Comal and San Marcos springflows predicted by the model compared to the total permitted pumpage used in each of the simulations as the total permitted pumpage is reduced by reducing only irrigation pumpage in Medina County. Figure 12 indicates that even if all irrigation pumpage in Medina County is eliminated, the minimum springflow during the model run will still be zero at Comal Springs. In fact, a springflow of only approximately 17 cfs at Comal Springs or greater is predicted to occur 95% of the time if all of the Medina County irrigation pumpage is eliminated.

Scenario 5- Uvalde County Irrigation Pumpage Reductions Only- Figures 14 and 15 show Comal and San Marcos springflows predicted by the model compared to the total permitted pumpage used in each of the simulations as the total permitted pumpage is reduced by reducing only irrigation pumpage in Uvalde County. Figure 14 indicates that even if all irrigation pumpage in Uvalde County is eliminated, the minimum springflow during the model run will still be zero at Comal Springs. In fact, a springflow of only approximately 10 cfs at Comal Springs or greater is predicted to occur 95% of the time even if all of the irrigation pumpage in Uvalde County is eliminated.

Discussion

The results of the five scenarios modeled show several important points, in particular regarding the impact of one type of pumpage reduction compared to another. Although these model results should not be taken as a quantitative projection of springflows, they can be used to get some general ideas on how the aquifer may react to different stresses, and can certainly be used to assess the effectiveness of one pumpage reduction strategy compared to another.

A comparison of Scenario 2 (irrigation reductions) to Scenario 3 (municipal and industrial reductions) for the minimum springflow curve is shown in Figure 16. This figure indicates that even though the total amount of irrigation pumpage in the initially proposed permitted pumpage data set is almost equal to the amount of municipal and industrial pumpage, there is more benefit to Comal Springs when municipal and industrial pumpage is reduced. If the total pumpage is reduced to 250,000 acre-feet/year, reductions in only the municipal and industrial pumpage will result in more than 50 cfs higher minimum springflow at Comal Springs than if only the irrigation pumpage was reduced. The reason for this is that the majority of the irrigation pumpage is located in the western parts of the model area, farther away from the springs. Most of the municipal and industrial pumpage is located in Bexar County, which is much closer to both Comal Springs and San Marcos Springs than most of the irrigation pumpage. If irrigation pumpage alone is targeted as a source of pumpage reductions, the best minimum springflow at Comal Springs that can be obtained is less than 60 cfs. The best minimum springflow at Comal Springs that is predicted if only the municipal and industrial pumpage is reduced is more than 120 cfs. Therefore, targeting one type of pumpage (irrigation or municipal and industrial) will not meet a minimum springflow requirement of 150 cfs at Comal Springs.

Figure 17 shows the 75% curves for the Scenario 2 (irrigation pumpage reductions), Scenario 4 (Medina County irrigation pumpage reductions), and Scenario 5 (Uvalde County irrigation pumpage reductions). The 75% springflow curve is used for comparison in this figure because the other three curves (minimum, 95%, and 90%) are much shorter (or non-existent) in this figure, and therefore do not allow for a good comparison. This figure shows that the farther west the irrigation pumpage reductions occur (Scenario 5- Uvalde County), the less the benefit to Comal Springs. Figure 17 shows that reducing the total pumpage to 400,000 acre-feet/year has more than a 20 cfs difference at Comal Springs for reductions in Medina County compared to Uvalde County. As with the irrigation reductions compared to municipal and industrial reductions described above, this difference occurs because Medina County is located east of Uvalde County, and is therefore closer to both Comal and San Marcos Springs that Uvalde County. Therefore, reductions in pumpage in Medina County will have more impact on springflows at Comal and San Marcos than reductions in Uvalde County.

As noted above, the minimum springflow for most or all of the model runs occurs in either July or August, 1956. Therefore, the drought of record conditions "drives" the minimum springflow curve. In addition, all of the lowest 5% months from the model runs also occur during the drought of record, and therefore the drought of record also "drives" the 95% curve. It is not until we examine the 90% data set that some springflows from outside of the drought of record are factored in. Springflows from 1963 and 1964 do fall into the 90% to 95% range, although this category is also dominated by the drought of record.

It is important to note that this approach for evaluating the effectiveness of different types of pumpage reduction scenarios only assesses the low springflow conditions at Comal and San Marcos Springs. The impact these pumpage reductions have on springflows during normal and high flow conditions are not included in the analysis, and the pumpage reductions in the model simulations are implemented 100% of the time, regardless of whether or not the springflow conditions require that pumpage reductions are necessary.

Conclusions

The Edwards model was used to evaluate the effectiveness of several different pumpage reduction strategies, including equal pumpage reductions, irrigation pumpage reductions, municipal and industrial pumpage reductions, Medina County irrigation pumpage reductions, and Uvalde County irrigation pumpage reductions. Several conclusions about these pumpage reduction strategies can be drawn from these model runs.

The results of the model runs are shown in graphs of total permitted pumpage versus springflow at Comal and San Marcos Springs. These graphs show the minimum predicted springflow, as well as springflow that is predicted to occur 95%, 90%, and 75% of the months in the model run. All of the evaluations of the effectiveness of different pumpage reduction strategies are compared to Comal Springs springflow. This is because the springflow curves for San Marcos Springs are fairly flat except at very high total pumpage. The reason for this is that most of the pumpage in the model occurs to the west of Comal Springs, and all of the effect of changes to this pumpage is "absorbed" by Comal Springs. In essence, Comal Springs "dampens" any changes in pumpage to San Marcos Springs, and it is not until Comal Springs goes dry at higher pumpages that an impact in springflows at San Marcos is observed in the model runs.

The results of the model runs indicate that if all of the permitted pumpage is removed in the model, a minimum springflow at Comal Springs of 276 cfs is predicted by the model. The additional pumpage reductions required to meet a minimum springflow compared to only meeting that springflow 95% of the time is between 75,000 and 100,000 acre-feet/year. This indicates that meeting a minimum springflow in drought of record conditions will require large pumpage reductions over the long term. These large pumpage reductions are not needed for most of the simulation, but are always in effect for these simulations.

If only irrigation pumpage is reduced, a minimum springflow of less than 60 cfs at Comal Springs is predicted by the model. This much lower minimum springflow is caused by two factors. First, there is only 236,520 acre-feet/year of irrigation pumpage in the model, and therefore the total annual permitted pumpage can only be reduced to 248,283 acre-feet/year, which is the amount of municipal and industrial pumpage in the model. In addition, this pumpage is mostly located farther to the west, where it has a smaller impact on springflows in the eastern portions of the model area.

If only municipal and industrial pumpage is reduced, a minimum springflow of more than 120 cfs at Comal Springs is predicted. This minimum springflow is much higher than the minimum springflow predicted with only irrigation reductions because the pumpage is slightly higher than the irrigation total in the model, but more importantly, the municipal and industrial pumpage is mainly located in Bexar County, which is closer to the springs than most of the irrigation pumpage, and therefore it has a greater impact on these springflows.

A comparison of the reduction of Uvalde County irrigation pumpage to Medina County irrigation pumpage shows a similar result. Irrigation pumpage reductions in Medina County results in more springflow in Comal Springs than the same amount of irrigation pumpage reductions in Uvalde County.

This is because Medina County is located to the east of Uvalde County, and is closer to the springs, and therefore has more of an impact than changes in pumpage farther to the west.

The minimum springflows in the model runs all occur in the drought of record, usually in July or August, 1956. All of the springflows in the lower 5% of the months also occur in the drought of record. Therefore the drought of record is the main "driving force" in the results of these simulations.

Literature Cited

Klemt, W.B., Knowles, T.R., Elder, G.R., and Sieh, T.W., 1979, Ground-water resources and model applications for the Edwards (Balcones fault zone) Aquifer in the San Antonio region, Texas: Texas Department of Water Resources Report 239, 88pp.

Thorkildsen, David, and McElhaney, Paul D., 1992, Model Refinement and Applications for the Edwards (Balcones Fault Zone) Aquifer in the San Antonio Region, Texas: Texas Water Development Board Report 340, 33pp.

Table 1 - Monthly Distribution of Municipal and Industrial Pumpage (values in percent of annual pumpage)

County	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bexar	6.7	6.3	7.3	8.1	8.4	9.1	11.2	11.4	9.1	8.3	7.1	6.9
Comal	7.1	6.5	7.2	8.2	8.4	8.9	10.4	11.2	8.9	8.5	7.5	7.2
Hays	6.9	6.8	7.4	8.1	8.2	8.6	10.1	10.7	9.6	8.8	7.7	7.1
Kinney	6.8	6.5	7.7	8.4	8.6	9.2	10.8	11.2	9.3	8.0	6.9	6.6
Medina	5.8	5.6	6.8	8.2	8.9	10.3	12.1	12.1	9.6	8.2	6.4	6.1
Uvalde	5.7	5.7	8.2	9.7	8.9	9.5	11.4	11.5	9.5	8.0	6.3	5.6

Table 2- Monthly Distribution of Irrigation Pumpage (values in percent of annual pumpage)

County	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bexar	4.0	2.0	6.0	7.3	9.9	15.1	13.9	18.0	10.6	8.3	3.0	2.0
Comal	0	0	10.0	0	0	25.0	25.0	25.0	15.0	0	0	0
Hays	0	0	10.0	0	0	25.0	25.0	25.0	15.0	0	0	0
Kinney	4.0	2.0	8.3	7.0	6.0	13.2	17.8	15.3	13.0	8.4	3.0	0
Medina	4.0	2.0	6.0	7.2	11.0	14.4	13.2	18.2	10.8	8.2	3.0	2.0
Uvalde	4.0	2.0	8.2	7.4	6.5	15.1	18.7	14.4	10.8	8.0	3.0	2.0

Table 3 - Pumpage File Annual Totals by County (in acre-feet/year)

Area	Industrial	Irrigation	Municipal	Total
Bexar	26,300[1]	36,655[1]	45,214	108,169
Comal	0	0	9,873	9,873
Hays	0	0	6,588	6,588
Medina	1,221	87,259	4,896	93,376
Uvalde	1,581	112,606	4,389	118,576
SAWS	40,019	0	108,202	148,221
Total	69,121	236,520	179,162	484,803

[1]Comal and Hays County irrigation and industrial pumpage are included in the Bexar County data set for the model.

Table 4 - Pumpage Totals and Factors Used for Equal Pumpage Reduction Runs

Permitted Pumpage	All Pumpage Factor	Pumpage (acre-feet/year)		
		Municipal	Industrial	Irrigation
484,803	1.00000	179,162	69,121	236,520
475,000	0.97978	175,539	67,723	231,737
450,000	0.92821	166,300	64,159	219,541
425,000	0.87664	157,061	60,595	207,344
410,000	0.84570	151,518	58,456	200,026
400,000	0.82508	147,823	57,030	195,147
375,000	0.77351	138,584	53,466	182,951
350,000	0.72194	129,345	49,901	170,754
332,000	0.68481	122,693	47,335	161,972
325,000	0.67038	120,106	46,337	158,557
300,000	0.61881	110,867	42,773	146,360
275,000	0.56724	101,628	39,208	134,164
250,000	0.51567	92,389	35,644	121,967
225,000	0.46411	83,150	32,079	109,770
200,000	0.41254	73,911	28,515	97,574
175,000	0.36097	64,672	24,951	85,377
150,000	0.30940	55,433	21,386	73,180
125,000	0.25784	46,195	17,822	60,984
100,000	0.20627	36,956	14,258	48,787
75,000	0.15470	27,717	10,693	36,590
50,000	0.10313	18,478	7,129	24,393
25,000	0.05157	9,239	3,564	12,197
0	0.00000	0	0	0

Table 5 - Pumpage Totals and Factors Used for Irrigation Pumpage Reduction Runs

Permitted Pumpage	Irrigation Pumpage Factor	Pumpage (acre-feet/year) Municipal	Industrial	Irrigation
484,803	1.00000	179,162	69,121	236,520
475,000	0.95855	179,162	69,121	226,717
450,000	0.85285	179,162	69,121	201,717
425,000	0.74715	179,162	69,121	176,717
400,000	0.64146	179,162	69,121	151,717
375,000	0.53576	179,162	69,121	126,717
350,000	0.43006	179,162	69,121	101,717
325,000	0.32436	179,162	69,121	76,717
300,000	0.21866	179,162	69,121	51,717
275,000	0.11296	179,162	69,121	26,717
250,000	0.00726	179,162	69,121	1,717
248,283	0.00000	179,162	69,121	0

Table 6 - Pumpage Totals and Factors Used for Municipal and Industrial Pumpage Reduction Runs

Total Pumpage	Municipal and Industrial Pumpage Factor	Pumpage (acre-feet/year) Municipal	Industrial	Irrigation
484,803	1.00000	179,162	69,121	236,520
475,000	0.96052	172,088	66,392	236,520
450,000	0.85983	154,048	59,432	236,520
425,000	0.75913	136,008	52,472	236,520
400,000	0.65844	117,968	45,512	236,520
375,000	0.55775	99,928	38,552	236,520
350,000	0.45706	81,888	31,592	236,520
325,000	0.35637	63,848	24,632	236,520
300,000	0.25568	45,807	17,673	236,520
275,000	0.15498	27,767	10,713	236,520
250,000	0.05429	9,727	3,753	236,520
236,520	0.00000	0	0	236,520

Table 7 - Pumpage Totals and Factors Used for Medina County Irrigation Pumpage Reduction Runs

Total Pumpage	Medina County Irrigation Pumpage Factor	Pumpage (acre-feet/year) Medina County Irrigation	Total Irrigation	Municipal Pumpage	Industrial Pumpage
484,803	1.00000	87,259	236,520	179,162	69,121
475,000	0.88766	77,456	226,717	179,162	69,121
450,000	0.60115	52,456	201,717	179,162	69,121
444,000	0.53239	46,456	195,717	179,162	69,121
440,000	0.48655	42,456	191,717	179,162	69,121
435,000	0.42925	37,456	186,717	179,162	69,121
425,000	0.31465	27,456	176,717	179,162	69,121
410,000	0.14275	12,456	161,717	179,162	69,121
405,000	0.08545	7,456	156,717	179,162	69,121
400,000	0.02815	2,456	151,717	179,162	69,121
397,544	0.00000	0	149,261	179,162	69,121

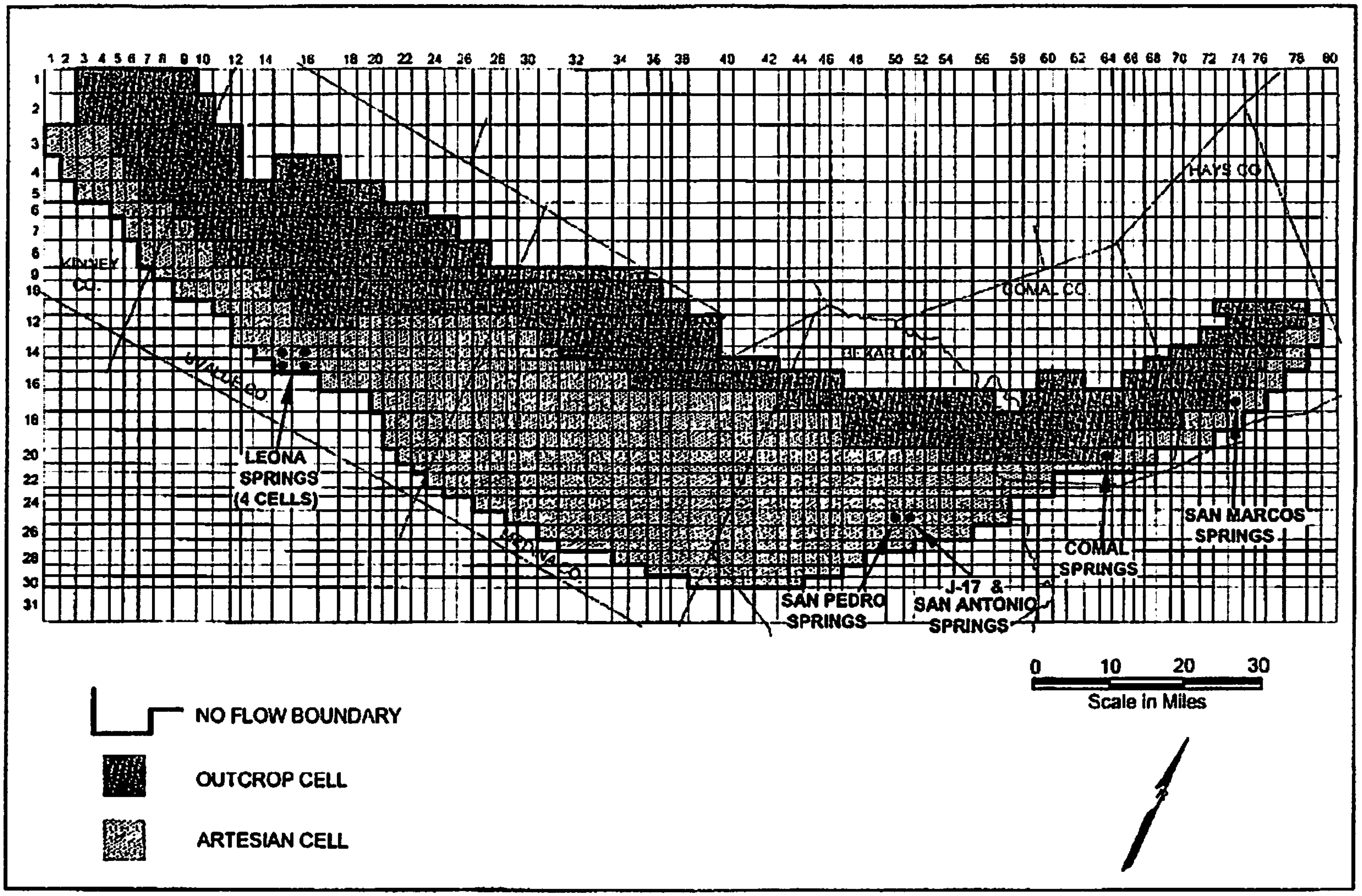
Table 8- Pumpage Totals and Factors Used for Uvalde County Irrigation Pumpage Reduction Runs

Total Pumpage	Uvalde County Irrigation Pumpage Factor	Pumpage (acre-feet/year) Uvalde County Irrigation	Total Irrigation	Municipal	Industrial
484,803	1.00000	112,606	236,520	179,162	69,121
475,000	0.91294	102,803	226,717	179,162	69,121
450,000	0.69093	77,803	201,717	179,162	69,121
425,000	0.46892	52,803	176,717	179,162	69,121
400,000	0.24691	27,803	151,717	179,162	69,121
375,000	0.02489	2,803	126,717	179,162	69,121
372,197	0.00000	0	123,914	179,162	69,121

Table 9. Predicted Springflows for Specified Aquifer Pumping Limits Calculated from GWSIM IV Model Runs Using Equal Reductions in Irrigation, Municipal and Industrial Pumping*

	Comal				San Marcos			
Pumpage	Minimum	95%	90%	75%	Minimum	95%	90%	75%
484,803				16.61	45.71	72.58	82.22	98.27
475,000				29.43	48.82	73.98	83.65	99.27
450,000			0	63.79	55.78	77.13	86.45	101.73
425,000			22.56	91.46	61.56	79.81	88.21	103.78
410,000		1.79	38.27	108	64.52	81.1	89.41	104.84
400,000		12.24	48.15	119.28	64.62	81.83	90.19	105.72
375,000		39.38	72.93	146.19	64.82	83.56	91.67	107.22
350,000		66.14	98.09	171.65	65.02	85.25	92.88	108.98
332,000	3.93	83.23	116.05	189.45	65.16	86.35	93.74	110.02
325,000	10.12	90.14	122.92	197	65.22	86.77	94.14	110.39
300,000	34.53	114.72	146.83	220.12	65.42	87.98	95.49	111.56
275,000	59.19	139.13	170.13	242.43	65.62	89.17	96.8	112.31
250,000	83.84	164.3	191.51	262.04	65.82	90.45	97.81	113.07
225,000	108.13	189.08	213.77	279.34	66.02	91.39	98.79	113.95
200,000	131.62	210.64	233.31	296.18	66.22	92.19	99.85	114.96
175,000	154.39	229.47	252.23	310.16	66.42	93.11	100.74	115.79
150,000	176.61	247.05	269.83	320.93	66.62	93.88	101.54	116.7
125,000	197.88	265.25	286.1	331.58	66.82	94.62	102.33	117.58
100,000	217.85	279.99	297.3	342.1	67.02	95.45	103.1	118.46
75,000	236.29	289.91	308.5	352.16	67.22	96.22	103.95	119.32
50,000	252.78	299.84	319.23	362.03	67.42	97.02	104.81	120.17
25,000	264.78	308.68	330.01	372.32	67.62	97.84	105.67	120.97
0	275.83	317.61	340.95	383.08	67.82	98.66	106.53	121.7

*Predicted springflows are at or above values listed for each frequency column.



EDWARDS AQUIFER MODEL GRID AND SIGNIFICANT FEATURES INCLUDED IN THE MODEL

FIGURE 1

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Figure 2 - Comparison of Modeled Water Levels to Average Monthly Water Levels for J-17 for 1978 to 1989

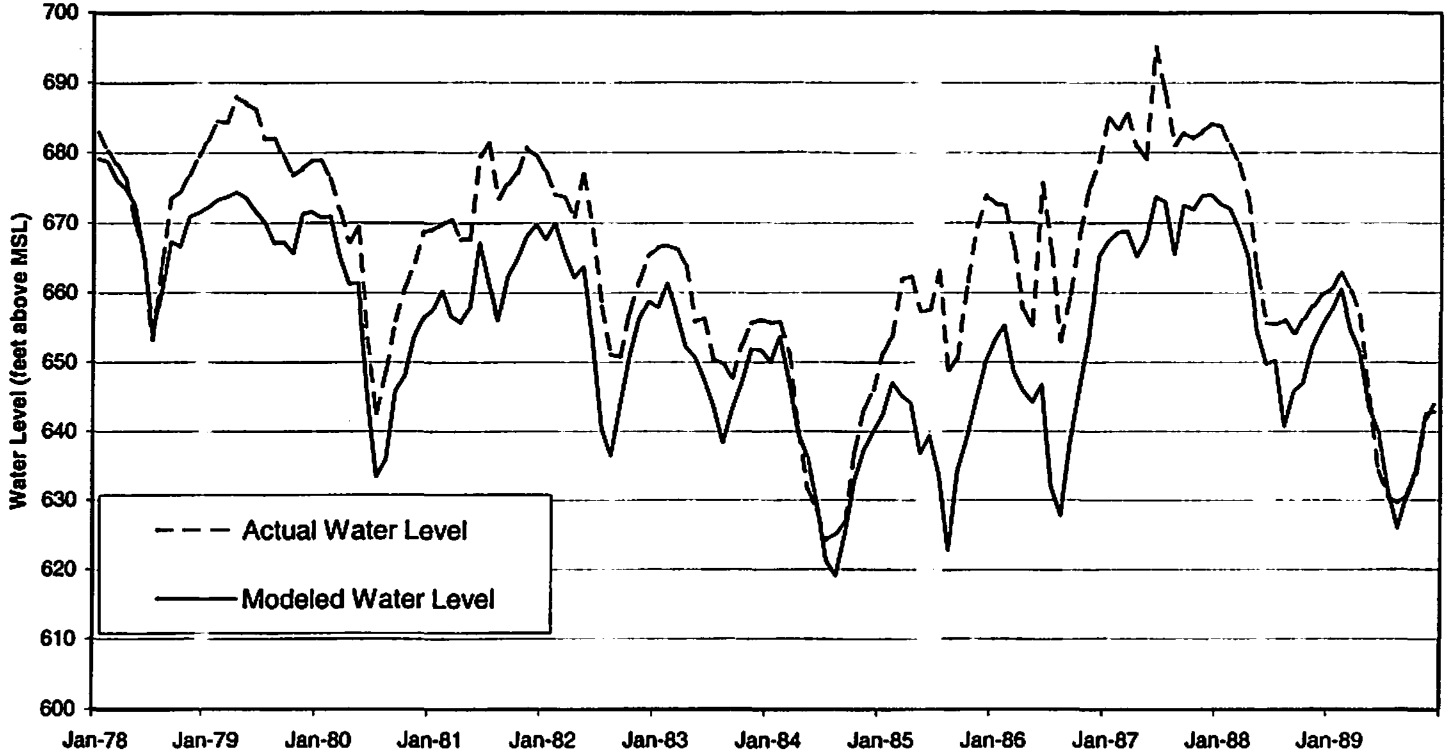

Figure 3 - Comparison of Modeled Springflows to Average Monthly Springflows for Comal Springs for 1978 to 1989

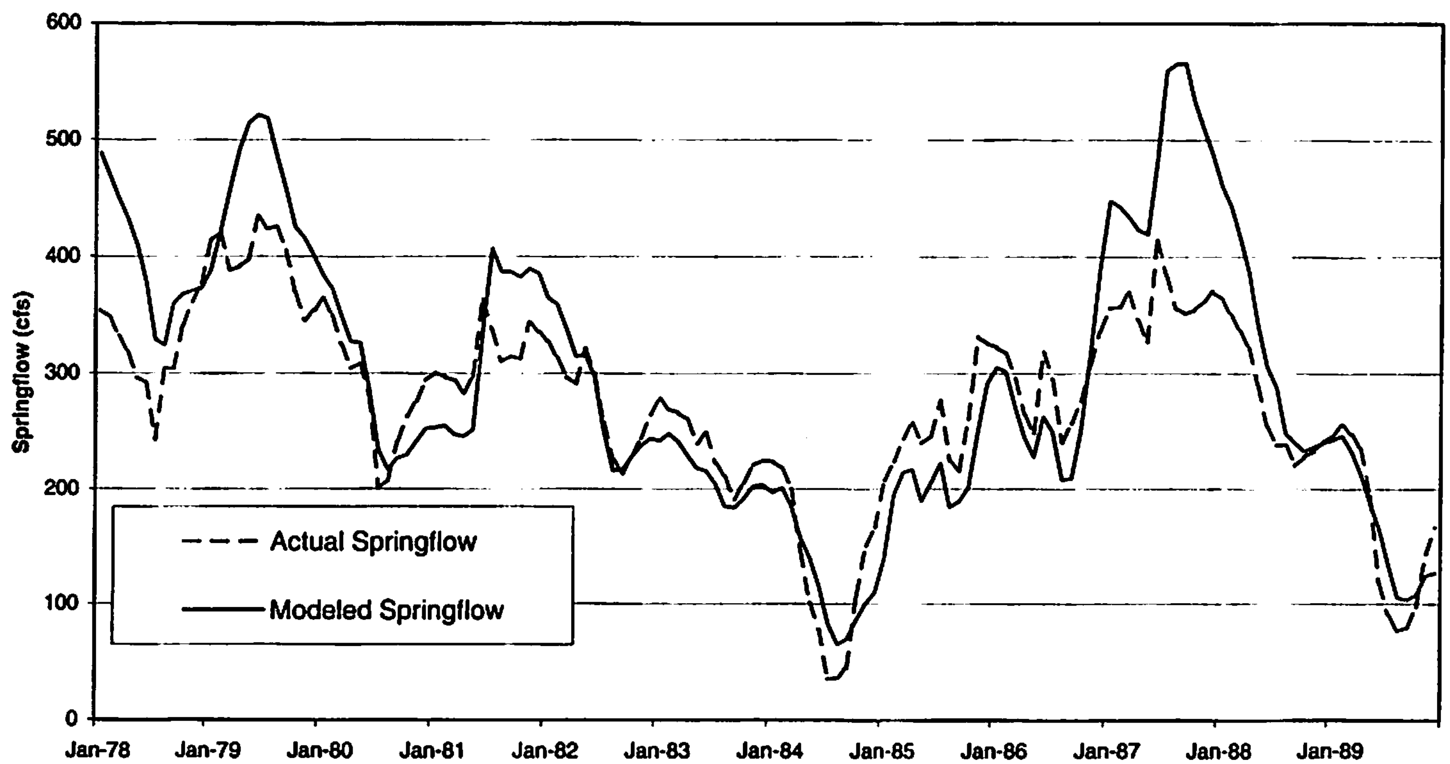

Figure 4 - Comparison of Modeled Springflows to Average Monthly Springflows for San Marcos Springs for 1978 to 1989

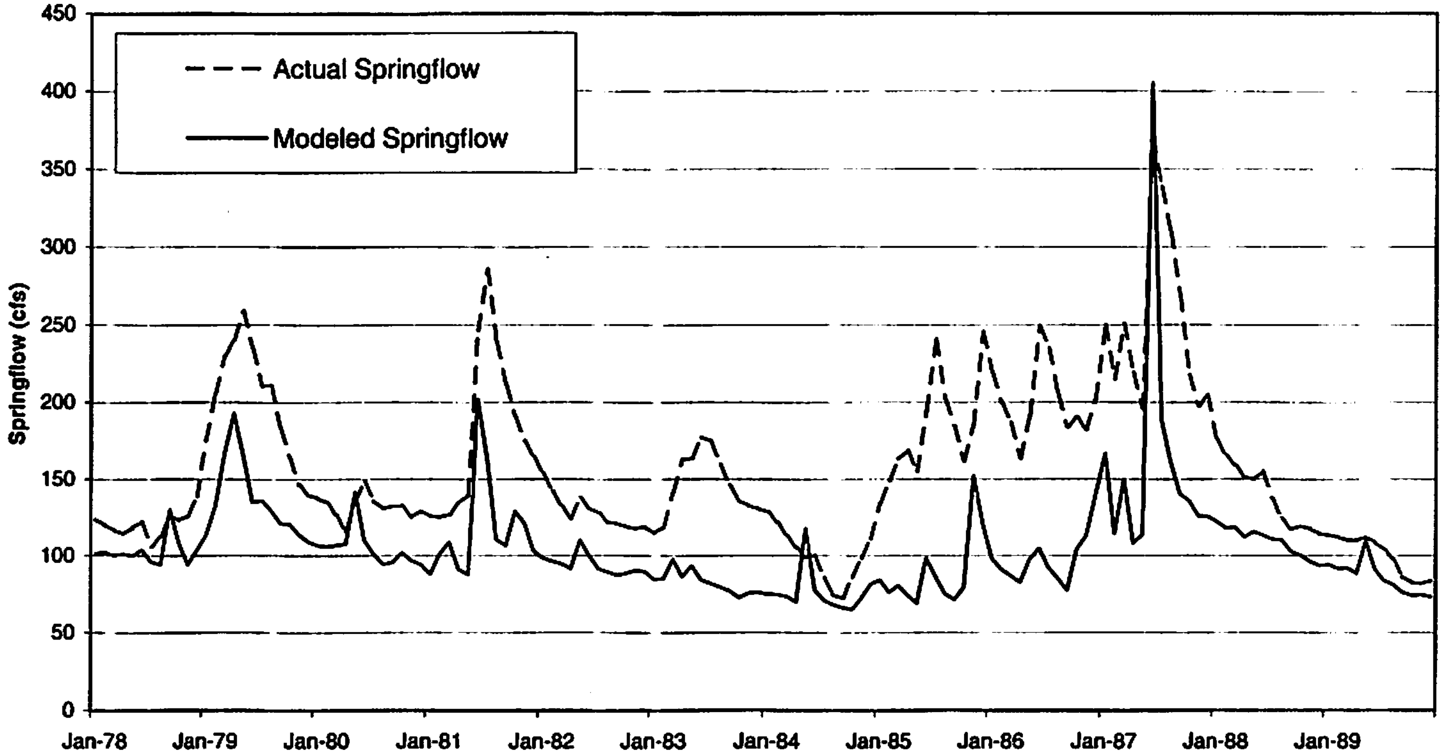

Figure 5 - Comal Springflow for Entire Period of Record Using 350,000 acre-feet/year of Pumpage

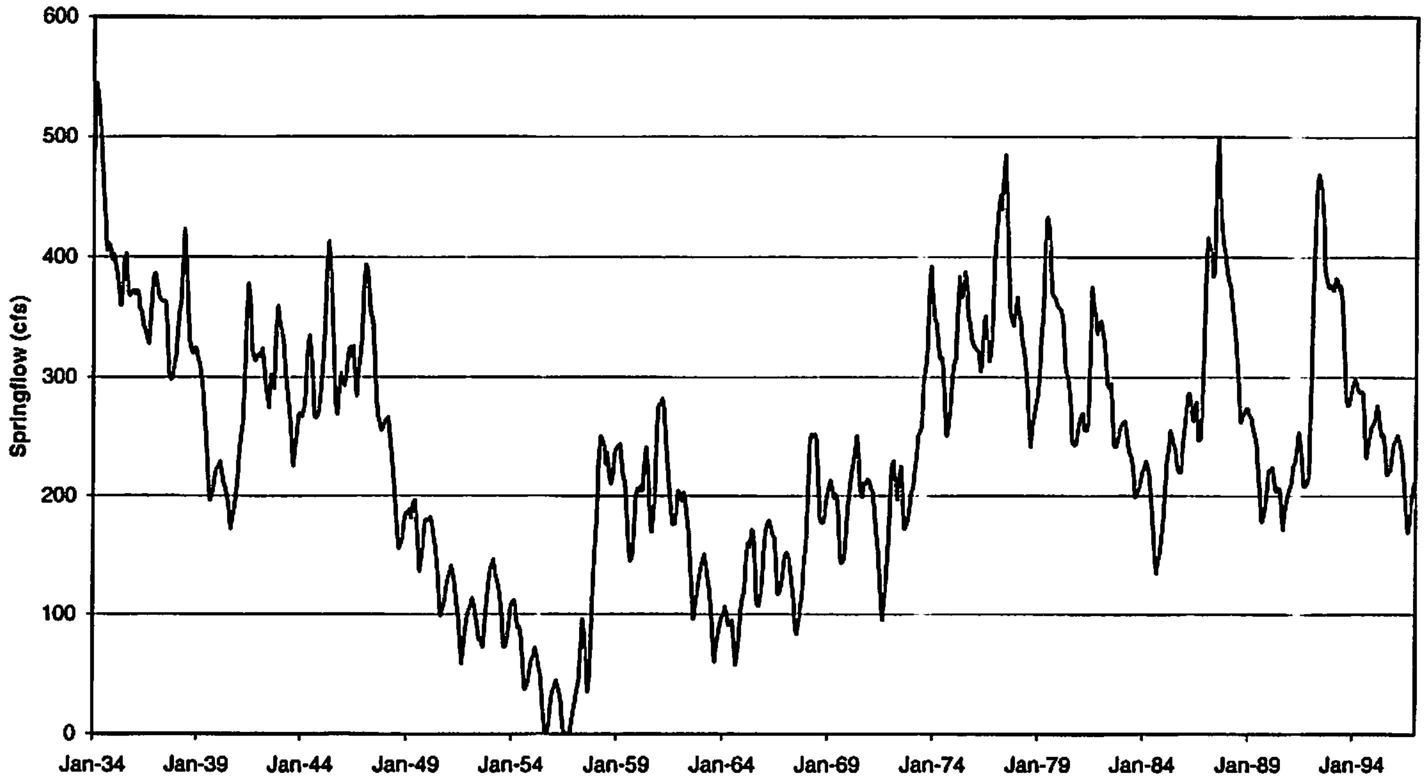

Figure 6 - Comal Springflows with Equal Pumpage Reductions

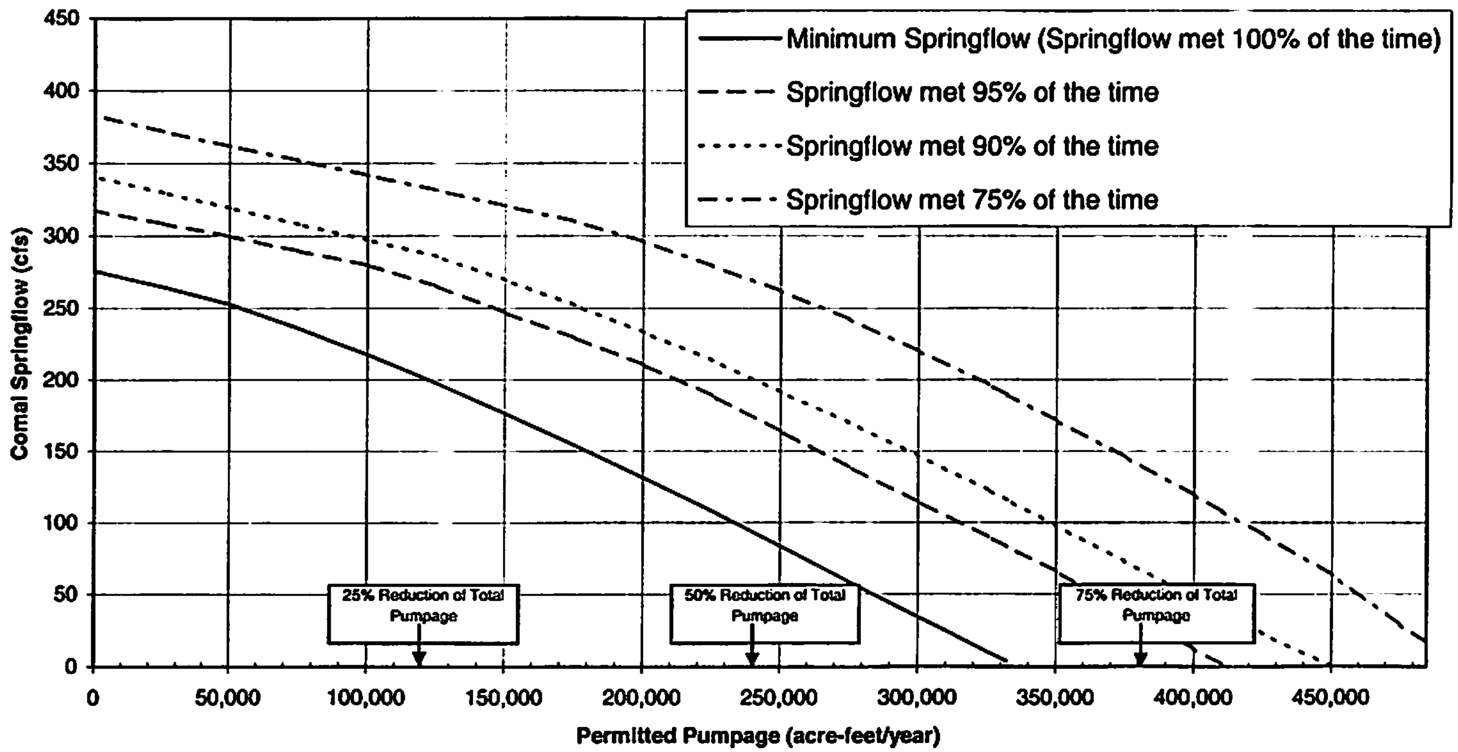

Figure 7 - San Marcos Springflows with Equal Pumpage Reductions

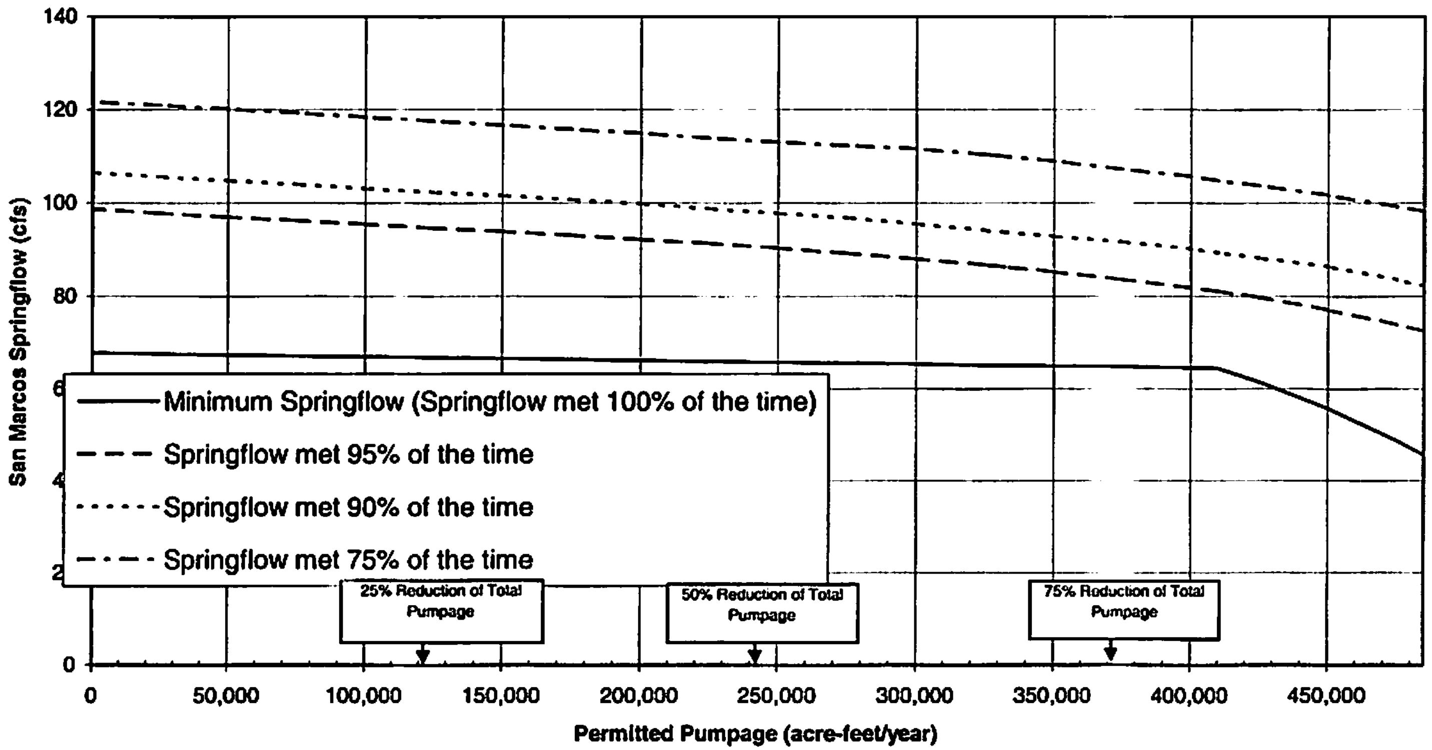

Figure 8 - Comal Springflows with Irrigation Pumpage Reductions Only

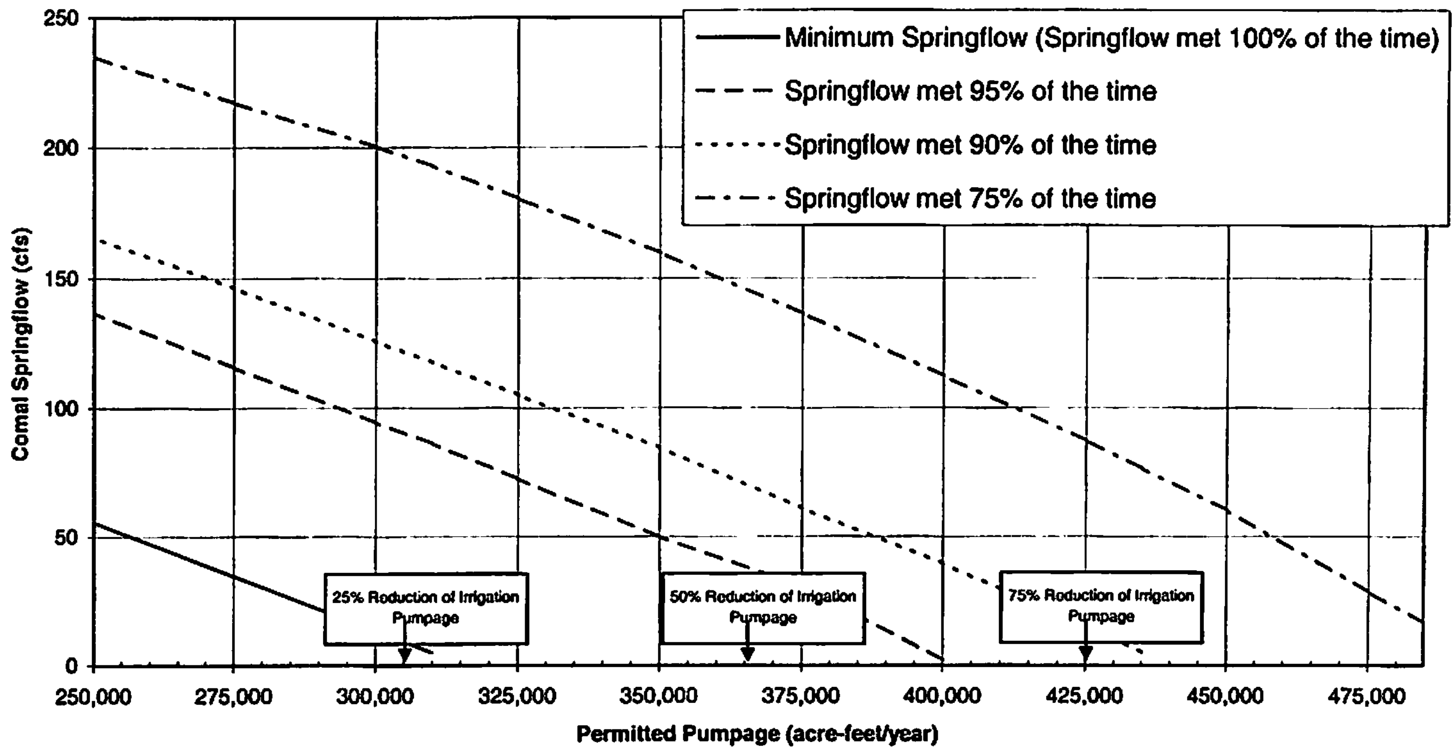

Figure 9 - San Marcos Springflows with Irrigation Pumpage Reductions Only

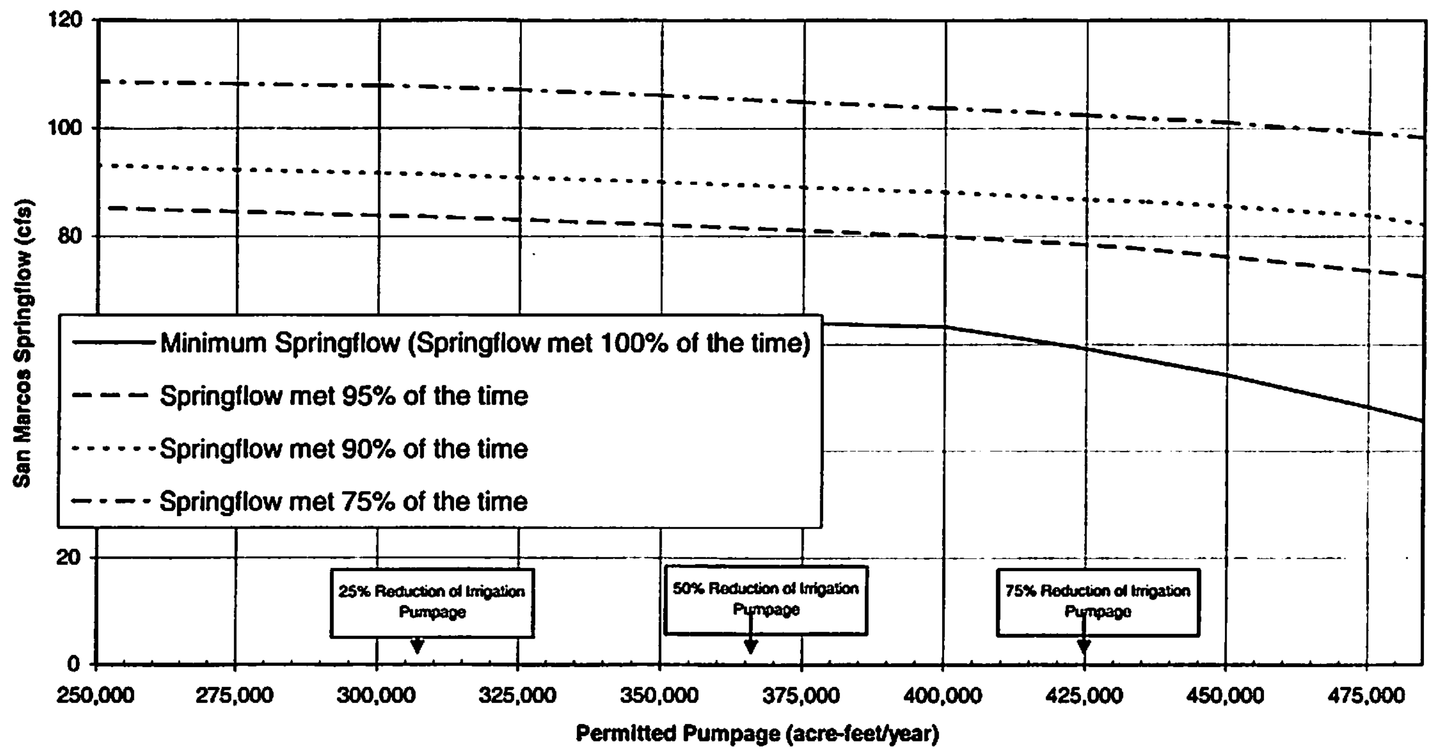

Figure 10 - Comal Springflows with Municipal and Industrial Pumpage Reductions Only

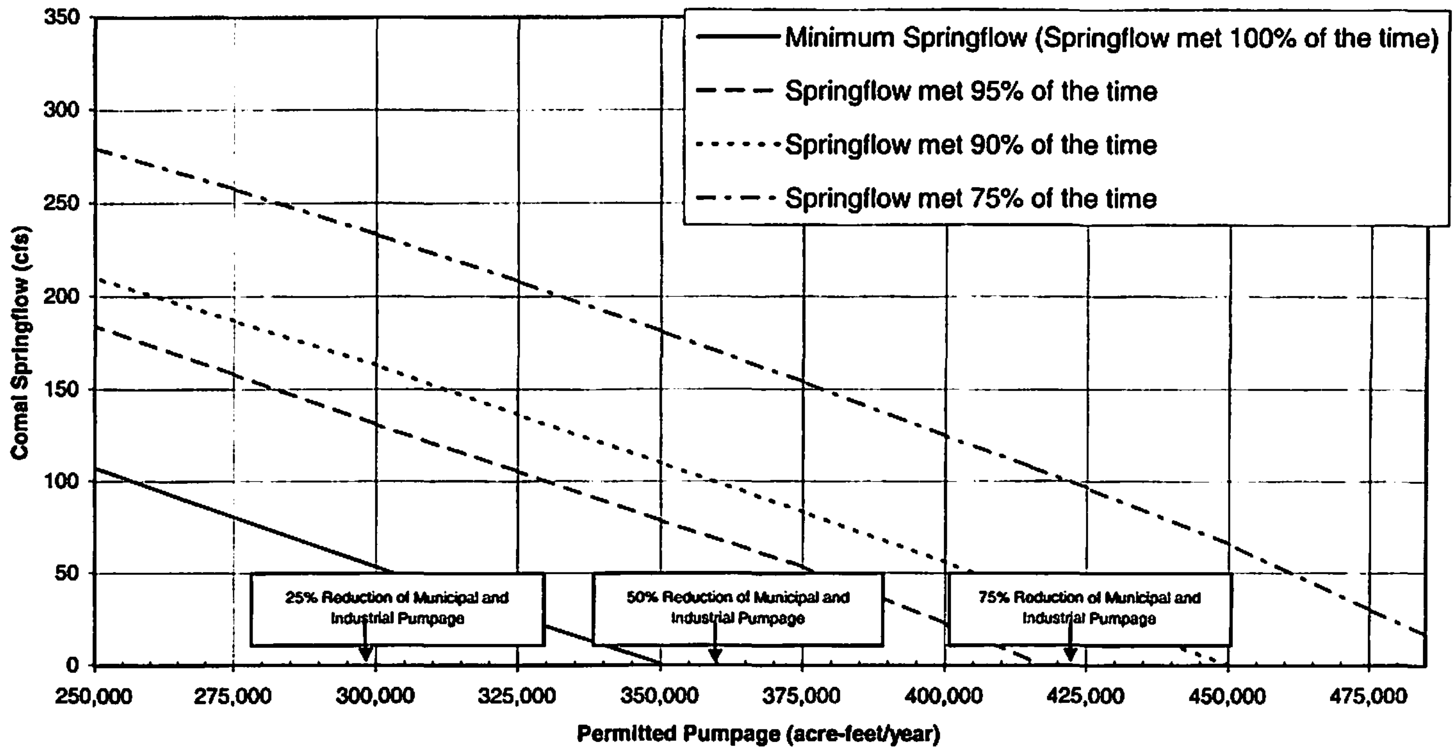

Figure 11 - San Marcos Springflows with Municipal and Industrial Pumpage Reductions Only

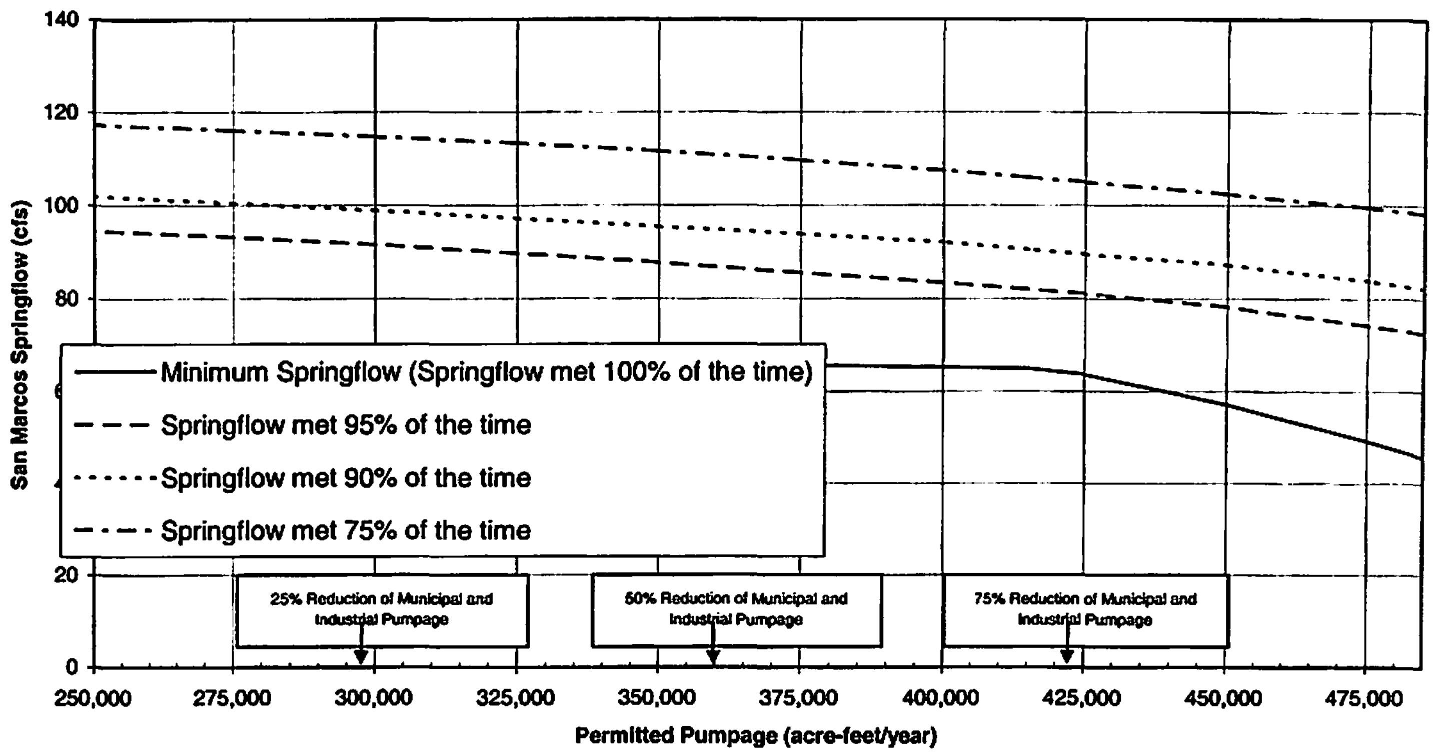

Figure 12 - Comal Springflows with Medina Irrigation Pumpage Reductions Only

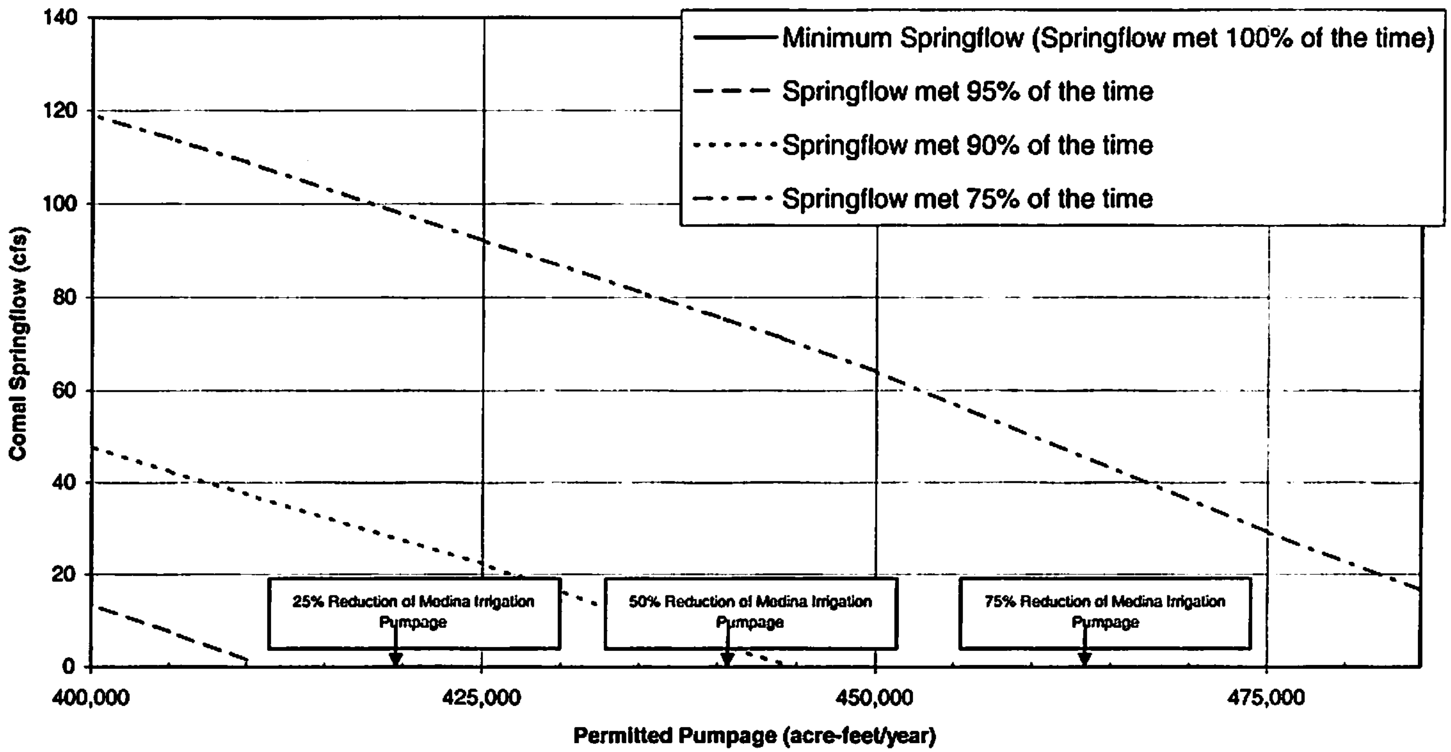

Figure 13 - San Marcos Springflows with Medina Irrigation Pumpage Reductions Only

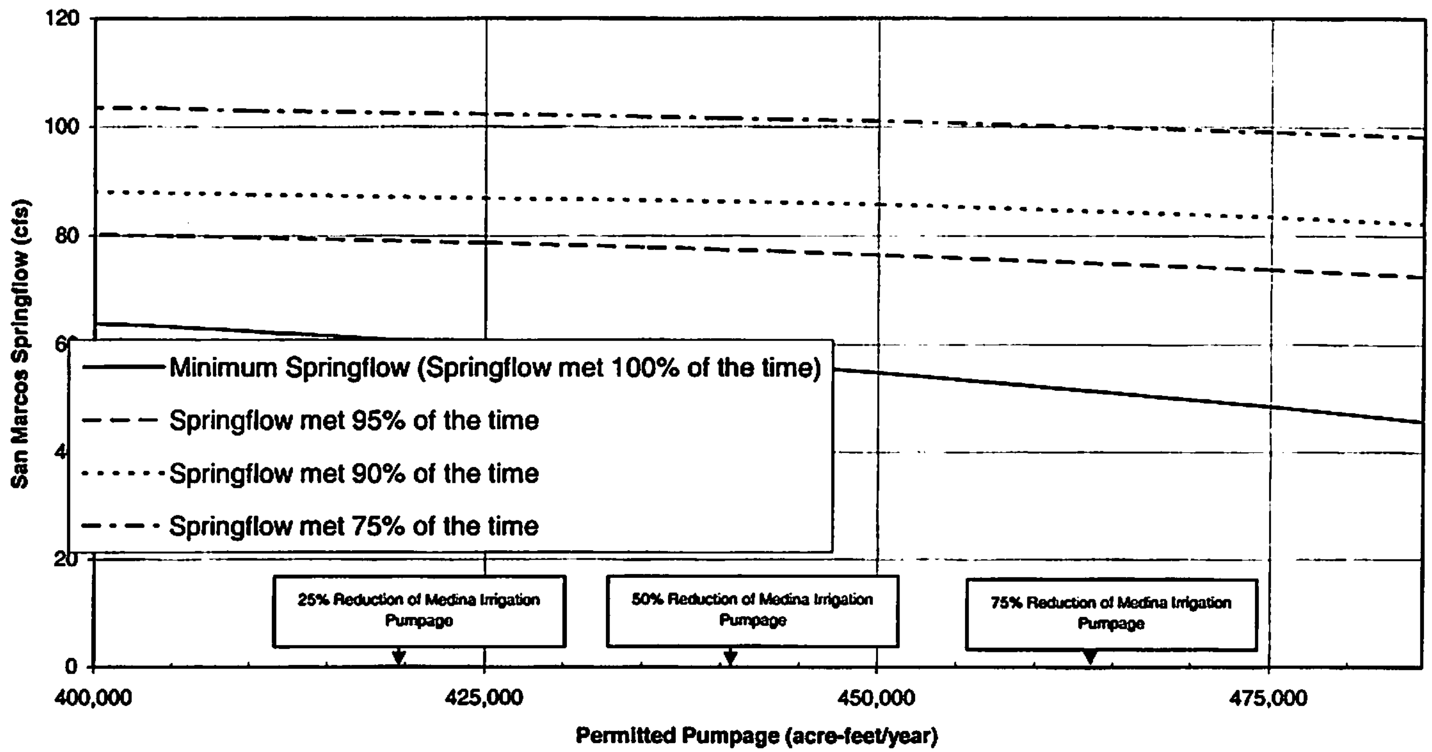

Figure 14 - Comal Springflows with Uvalde Irrigation Pumpage Reductions Only

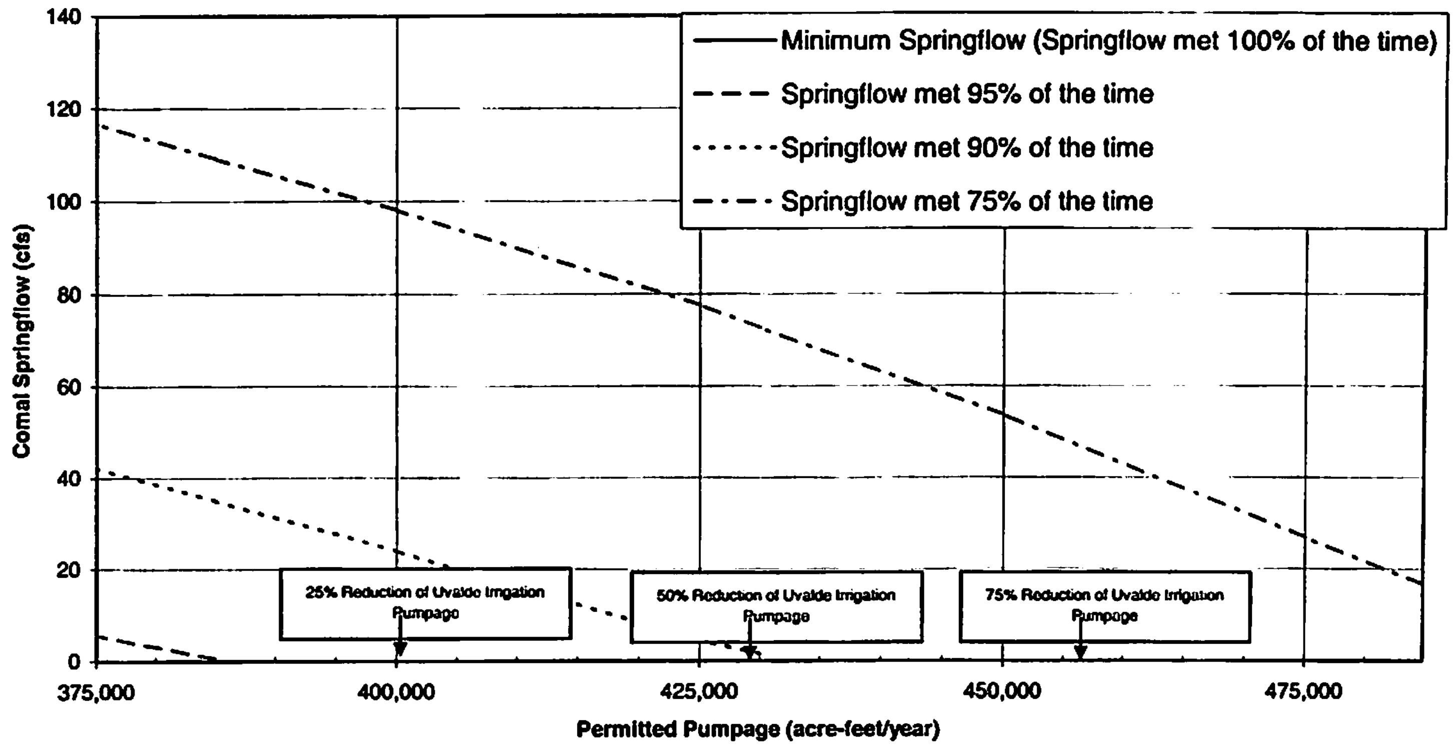

Figure 15 - San Marcos Springflows with Uvalde Irrigation Pumpage Reductions Only

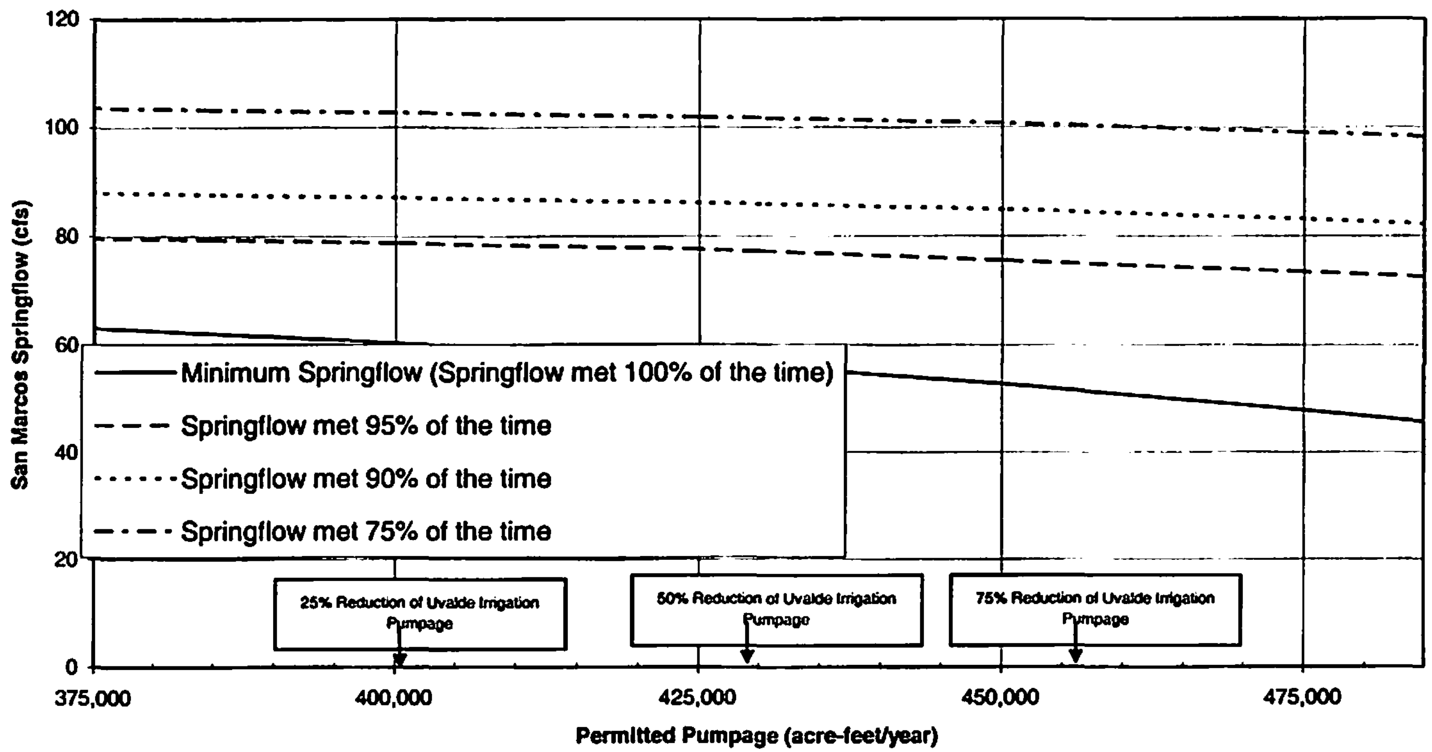

Figure 16 - Comparison of Minimum Comal Springflows (Springflows met 100% of the time)for Equal Pumpage Reductions, Irrigation Reduction Only, and Municipal and Industrial Reductions Only

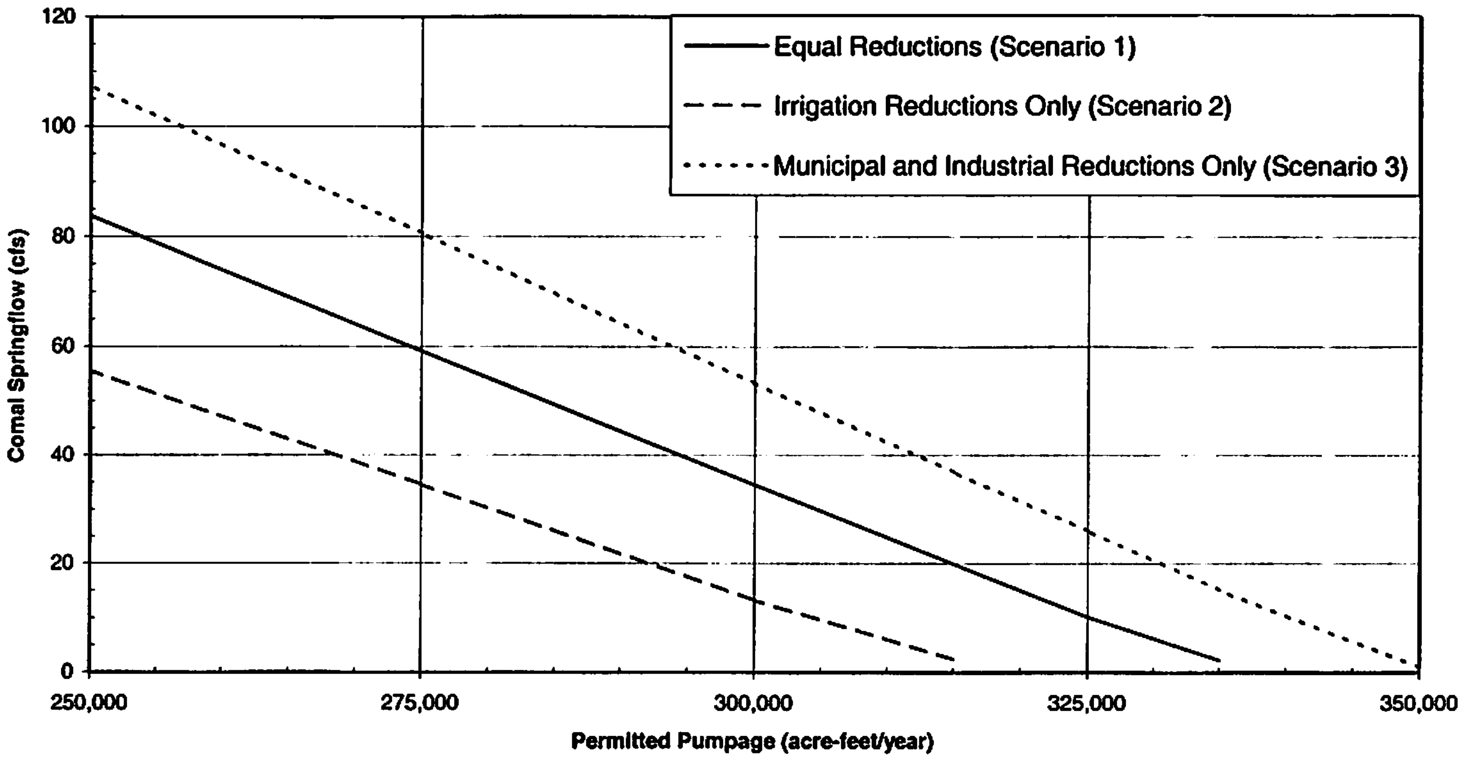

Figure 17 - Comparison of 75% Comal Springflow Curves for All Irrigation Reductions, Medina County Irrigation Reductions, and Uvalde County Irrigation Reductions