Report 340

Model Refinement and Applications for the Edwards (Balcones Fault Zone) Aquifer in the San Antonio Region, Texas

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July 1992

Texas Water Development Board

Published and Distributed
by the
Texas Water Development Board
P.O. Box 13231
Austin, Texas 78711-3231

ABSTRACT

The Edwards (Balcones Fault Zone) Aquifer is an important water resource in the San Antonio region of Texas. It supplies water for irrigation, industrial, and municipal purposes, as well as to major spring systems. The purpose of this project was to refine the Texas Water Development Board's existing Edwards (BFZ) flow model to improve aquifer simulation. Ultimately the model can be used as a tool to predict aquifer response to potential stress conditions and in evaluating management plans for the region. An additional use will be to develop ground-water availability figures for incorporation into the Texas Water Plan.

The basic scope of the project involved development of monthly recharge and pumpage data sets in order to provide a realistic annual distribution of these parameters and evaluation and incorporation of any new or additional existing data on the Edwards to improve aquifer simulation. This second task was directed primarily toward modeling work by the U.S. Geological Survey that focused on concepts such as the effects of barrier faults on flow direction, water levels, springflow, and aquifer storage.

A total of 139 transient simulations were made during model calibration. Calibration used the 1947-1959 monthly recharge and pumpage sequence. Model parameters including transmissivity, storage coefficients, and anisotropy were adjusted until the model acceptably reproduced measured regional water levels and springflows for that period. Calibrated parameters were verified with the application of a different set of monthly recharge and pumpage data covering the period 1978-1989. Simulated water levels and springflows for the verification run also acceptably reproduced measured values for that period. Therefore, the model was believed to be a reasonable representation of the Edwards (BFZ) aquifer regional flow system.

A variety of model applications were made including: 1) runs with various amounts of constant regional pumpage applied to the recharge period of record (1934-1990); 2) runs with reduced pumpage in certain areas of the region; and 3) application of management plans for the Edwards proposed by the Texas Water Commission. Conclusions drawn from results of the simulations are: 1) maintaining springflows at Comal Springs at 100 cfs or greater would require large reductions in total regional pumpage. The maximum amount for all uses would be approximately 165,000 ac-ft/yr; 2) pumpage reductions in the western part of the San Antonio region would result in increased springflows in the east. However, the increase would be only 34% to 67% of the total amount of pumpage reduced; 3) based on the 1934-1990 period of record, implementation of the Texas Water Commission's proposed management plan for the Edwards would result in continual springflow at San Marcos Springs under all conditions. Comal Springs would also flow under all but the severest drought conditions. Flows at Comal Springs of 100 cfs or greater would occur from 74% to 79% of the time depending on whether a mandatory demand curtailment with a "dry year" option for irrigation use is applied or a mandatory demand curtailment for all uses option is applied; 4) although the Water Development Board's flow model, as designed, will not adequately address certain site-specific questions concerning the aquifer, it is a useful tool for regional aquifer simulation and management evaluation.

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Figures (*cont'd..*)

INTRODUCTION

Purpose and Scope

The Edwards (Balcones Fault Zone) Aquifer is an important water resource in the San Antonio region of Texas supplying water for irrigation, to major spring systems, and to numerous industries and municipalities, including the City of San Antonio (Figure 1). The purpose of this project was to reevaluate the Texas Water Development Board's (T.W.D.B.) existing Edwards aquifer flow model (Klemt and others, 1979) and refine the simulation of water levels and springflows in the San Antonio region. Ultimately the model will be used as a tool to predict the aquifer's response to potential stress conditions and to help evaluate the impacts of any type of regional management plan which might be developed for the aquifer. It will also be used to derive ground-water availability figures for use in the Texas Water Plan.

The general scope of this project consisted of several objectives. These objectives involved: 1) organization and evaluation of any previously compiled geologic and hydrologic data from the original model development; 2) collection and analysis of any new or additional pertinent data and incorporation into the model in order to improve model capabilities; 3) calibration of the model to acceptably reproduce measured aquifer response to historical stress conditions (recharge and pumpage); 4) application of the model to various potential future stress conditions or management plans; and 5) preparation of a report providing a general discussion of the project objectives, methodologies, and results.

Model Simulation Capabilities and Limitations

The refined version of the Board's Edwards Aquifer model simulates water levels and springflows based on the hydrogeological parameters that define the flow system and on the recharge and pumpage rates applied. Simulations operate on a monthly time step in order to show the considerable annual variation in water levels and springflows that can occur in the aquifer. The model is able to store voluminous complex hydrogeologic data and rapidly analyze many different combinations of imposed stress conditions.

When making applications of the model it is important to realize that there are limitations which must be considered. Water levels are simulated at the center of each cell based on the hydrogeological parameters of the cell and of all other cells in the aquifer model grid (Figure 2). Since each cell represents a large land area, the value for each parameter must represent the average or composite value for the entire area. Pumpage and recharge are assumed to be spread uniformly across the cell. There are no point sources (recharge wells) or point sinks (pumping wells) in the model. Each square foot of the cell is assumed to have its portion of pumpage and recharge. These facts require that the water level simulated by the model be considered as the representative value for the water level for the entire cell. Therefore, the simulated water levels represent regional values and do not represent water levels in a producing well. This limitation in no way restricts the use of the model in evaluating the long term effects of pumpage and recharge on the aquifer.

Several assumptions concerning water quality made for the original model development and earlier revisions are also used in the current refined version. One is that the "bad-water" line, with the exception of a small area in southeast Uvalde County, can be treated as an impermeable aquifer boundary. Another is that the spatial distribution of water quality will not change due to changes in pumpage patterns and amounts.

Recharge in the model is based on estimates made by the U. S. Geological Survey (U.S.G.S.) for the different basins crossing the aquifer outcrop or recharge zone. The model does not consider any additional recharge entering the system as cross-formational flow from the underlying Glen Rose Formation or inflow across other prescribed aquifer boundaries. Also, previous studies have suggested that there may be some additional recharge entering the system from the Guadalupe River (Guyton, 1979). In recent modeling work, Maclay and Land (1988) state that this additional recharge, along with inflow from the Glen Rose Formation, in that area approximately equals discharge from Hueco Springs. Therefore, this component is not included in the model.

It is important to understand that this project is regional in nature and the model was designed accordingly. Modeling certain aspects of the Edwards Aquifer discussed in this section, such as inflow from the Glen Rose Formation or recharge from the Guadalupe River, will require a more site-specific approach. However, in conjunction with sound geologic and hydrologic techniques, the model can be a useful tool in formulating and evaluating sound management decisions, especially about conjunctive use of surface and ground water, aquifer recharge, and alternative patterns of development and pumpage rates. As more information about the aquifer becomes available and model accuracy is improved, limitations can hopefully be minimized.

Acknowledgements

Part of the scope of the Edwards model refinement was to collect and analyze new and pertinent data for incorporation into the existing model in order to improve model capabilities. Therefore, the Texas Water Development Board wishes to extend acknowledgement and thanks to the staff of the U.S. Geological Survey in Austin and San Antonio who graciously provided important hydrogeological information on the Edwards Aquifer and technical advice during the calibration and verification phases of this project. Data and support were also made available to the Board by W.F. Guyton and Associates and personnel of the Edwards Underground Water District. This assistance is acknowledged and greatly appreciated.

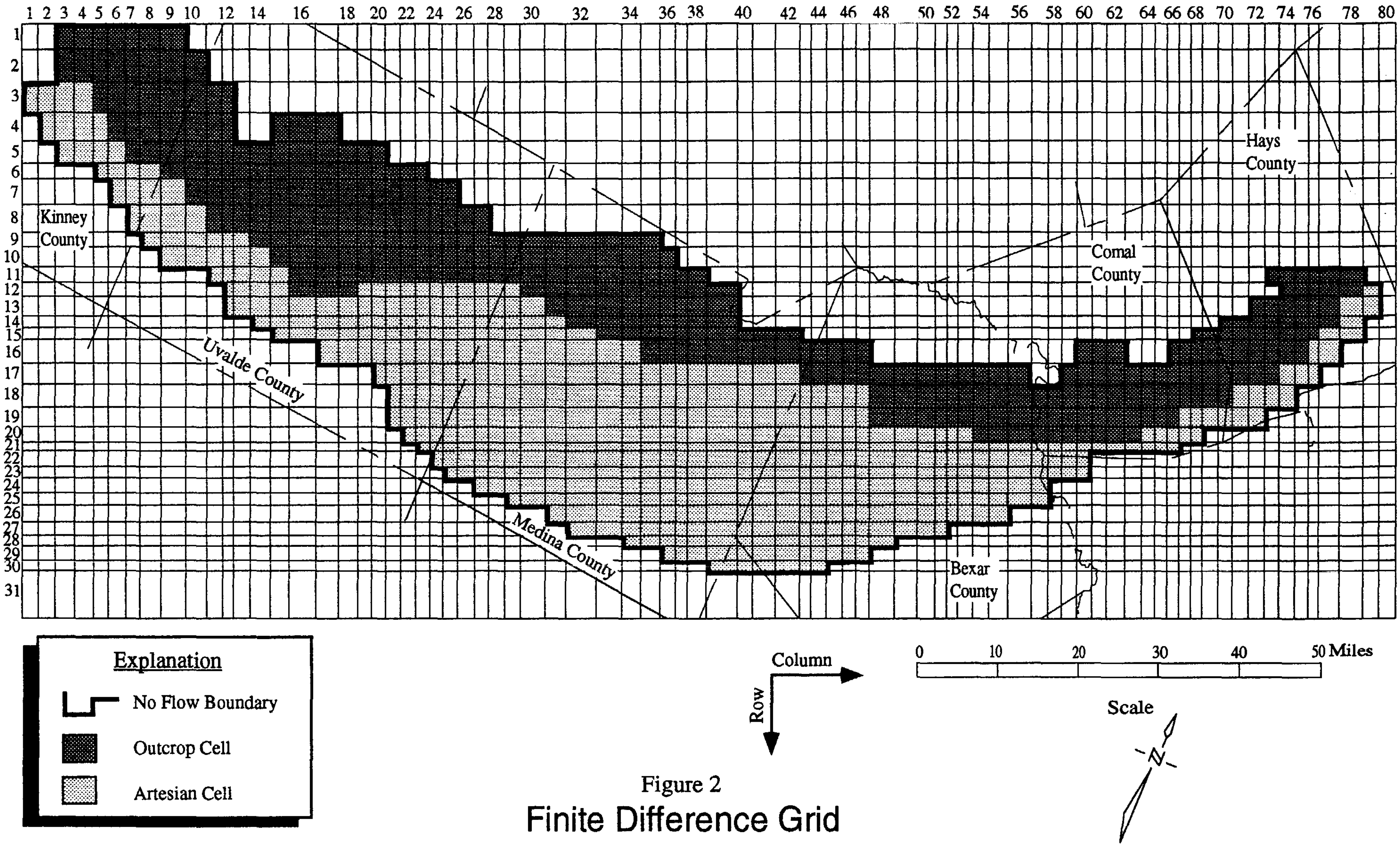


Figure 2
Finite Difference Grid

MODEL CALIBRATION AND APPLICATION

Modeling of the Edwards Aquifer involved several phases each of which had its own goal or objective, methodology, and results. A general discussion of each phase follows:

Phase One - Drought Sequence Calibration

Objective

The objective of Phase One was to build and calibrate the model to simulate water levels and springflows for the period 1947-1959 using a monthly time step. This time period included the extreme drought that occurred in Texas from 1947-1956 as well as the recovery years that followed and continued through 1959. It was believed that this period of extreme stress conditions provided a good test for the parameters in the model.

Methodology

Development of the model for Phase One included using data from the original model runs (Klemt and others, 1979), U.S.G.S. recharge and pumpage data, and data from the Board's hydrology refinement study on the Edwards in order to calculate recharge and pumpage on a monthly basis. This provided a realistic annual distribution of these parameters and allowed for simulations using monthly instead of annual time steps (stress periods). Pumpage distribution was the same as used in the original model runs. Domestic and stock pumpage was adjusted in order to equal totals published by the Edwards Underground Water District (E.U.W.D.). Recharge totals were equal to totals estimated by the U.S.G.S. for the different recharge basins. Distribution in the model was the same as used in the original model with the exception of the Blanco River Basin. Forty-three percent of the total basin recharge for the Blanco River Basin was assigned directly to the spring cell representing San Marcos Springs to better simulate the local component of flow from the outcrop area. This percentage was believed to be reasonable based on the work by Puente (1976) in which he concludes that, on a monthly basis, the underflow component ranges from 40 to 100 percent of the total springflow at San Marcos Springs. Therefore, the local component would range from 0 to 60 percent on a monthly basis.

A steady-state simulation was made incorporating average values of pumpage and recharge for the three years prior to 1947. Values of transmissivity were adjusted so that the model adequately simulated spring 1947 water levels. Simulated heads for spring 1947 were used as the starting heads for the transient calibration runs. Using steady-state heads for starting heads would hopefully eliminate any errors due to the use of starting heads derived from contour maps of measured water levels.

In years since the Board's original model was developed the U.S.G.S. has continued to expand the testing of hydrological concepts for the Edwards by using mathematical simulations (Maclay and Land, 1988). This study has focused on concepts such as the effects of barrier faults on flow direction, water levels, springflow, and storage within the aquifer. As part of this project, all new aquifer data on the Edwards was analyzed and some parameters (including transmissivity, storage coefficient, and aquifer anisotropy) derived from the most current modeling efforts of the U.S.G.S. were incorporated to better represent the flow system and improve model simulation.

Once monthly recharge and pumpage files were developed and new hydrogeologic data was incorporated into the physical data set, model calibration runs were made and parameters were adjusted until simulated heads and springflows acceptably reproduced measured values for the 1947-1959 time period. A total of 139 transient simulations were made during Phase One. Figures 3 and 4 show the final distribution of transmissivity and anisotropy ratios used in the model. Measured values of springflow and water levels used for comparison were obtained from the U.S.G.S.

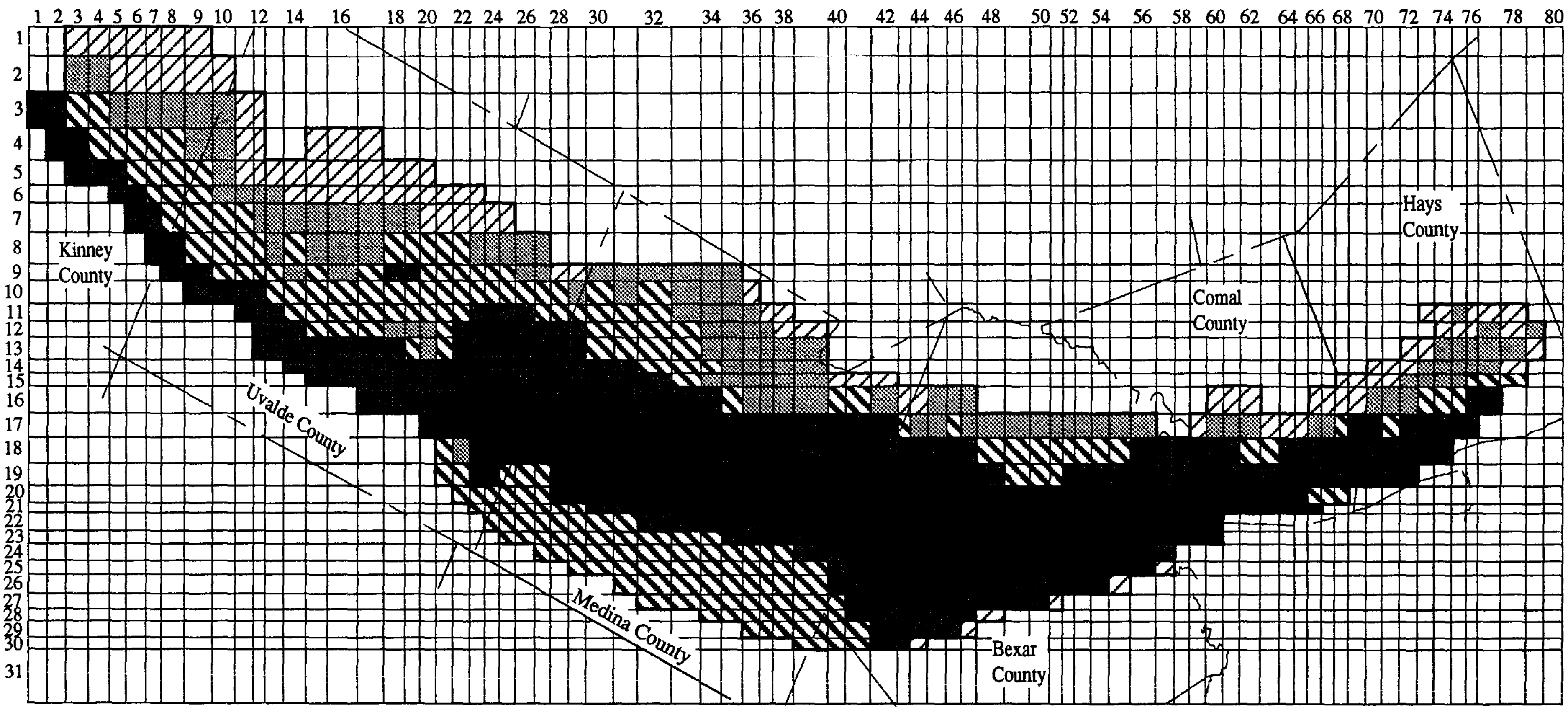
Results

Springflow simulation at Comal Springs was very reasonable as was water level simulation at the model cell which represents the area around the index well CY-26 in San Antonio (Figures 5 and 6). In May, 1956, well J-17 replaced CY-26 as the index well for the San Antonio area. At San Marcos Springs simulated springflows were generally lower than measured amounts (Figure 7), although water-level simulation was reasonable when compared to actual measured water levels. The difference between minimum simulated and measured monthly springflow was very small. Moving a percentage of total basin recharge directly to the spring cell did improve simulated flows to a certain degree, however, there is still a component of springflow that was not totally simulated. This component could be from underflow from the Glen Rose Formation, from areas farther west of the springs, or from recharge in the Guadalupe River basin, none of which are considered in the current model. Overall model results for Phase One are considered acceptable and as accurate as the current design of the model and knowledge of the flow system will produce.

The difference between simulated and monthly measured minimum springflow for San Marcos Springs was 81 acre-feet. For 1956, the year with the lowest springflow, total simulated flow was 42,590 acre-feet and the total measured flow was 47,564 acre-feet. For the entire 1947-1959 period, simulated springflow had a mean difference of 2,034 ac-ft/month less flow than was measured. The simulated median difference was 1,676 ac-ft/month less than measured flows.

For Comal Springs, the minimum monthly simulated and measured flow was zero. During 1956, the total simulated flow was 9,738 acre-feet and the measured flow was 22,336 acre-feet. The model simulated no flow during July through November of 1956 which compares well with measured values showing no flow during July through October. For the entire 1947-1959 period, simulated springflow had a mean difference of 428 acre-feet/month less flow than was measured. The simulated median difference was 1,433 acre-feet/month less than measured flows.

A comparison of water levels indicates that the minimum simulated level was 605 feet (msl) in August 1956 for the area around well CY-26. The corresponding measured value is 619 feet (msl). The mean and median difference between simulated and measured water levels for the entire simulation showed simulated water levels six feet lower than measured levels.



Transmissivities
(gallons per day per foot)
- < 10,000
- 10,000 - < 100,000
- 100,000 - < 1,000,000
- 1,000,000 - < 10,000,000
- > 10,000,000

Areas with a constant or range of maximum transmissivity. Direction dependant upon aquifer anisotropy - refer to Figure 4.

Column → Row ↓

Scale: 0 10 20 30 40 50 Miles

N

Figure 3
Distribution of Transmissivity in the Model

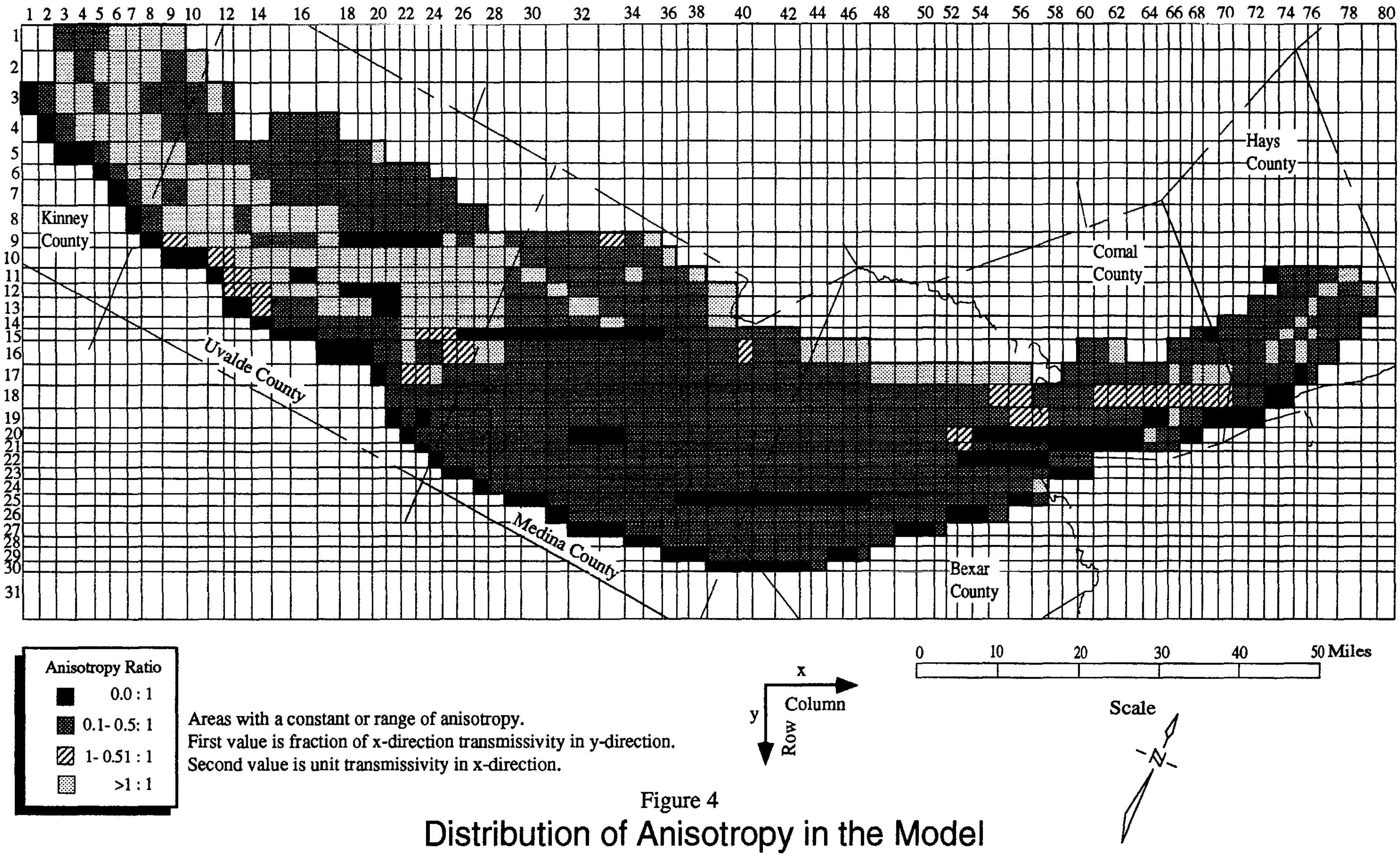


Figure 4
Distribution of Anisotropy in the Model

Comal Springs - Phase 1
Measured vs. Simulated

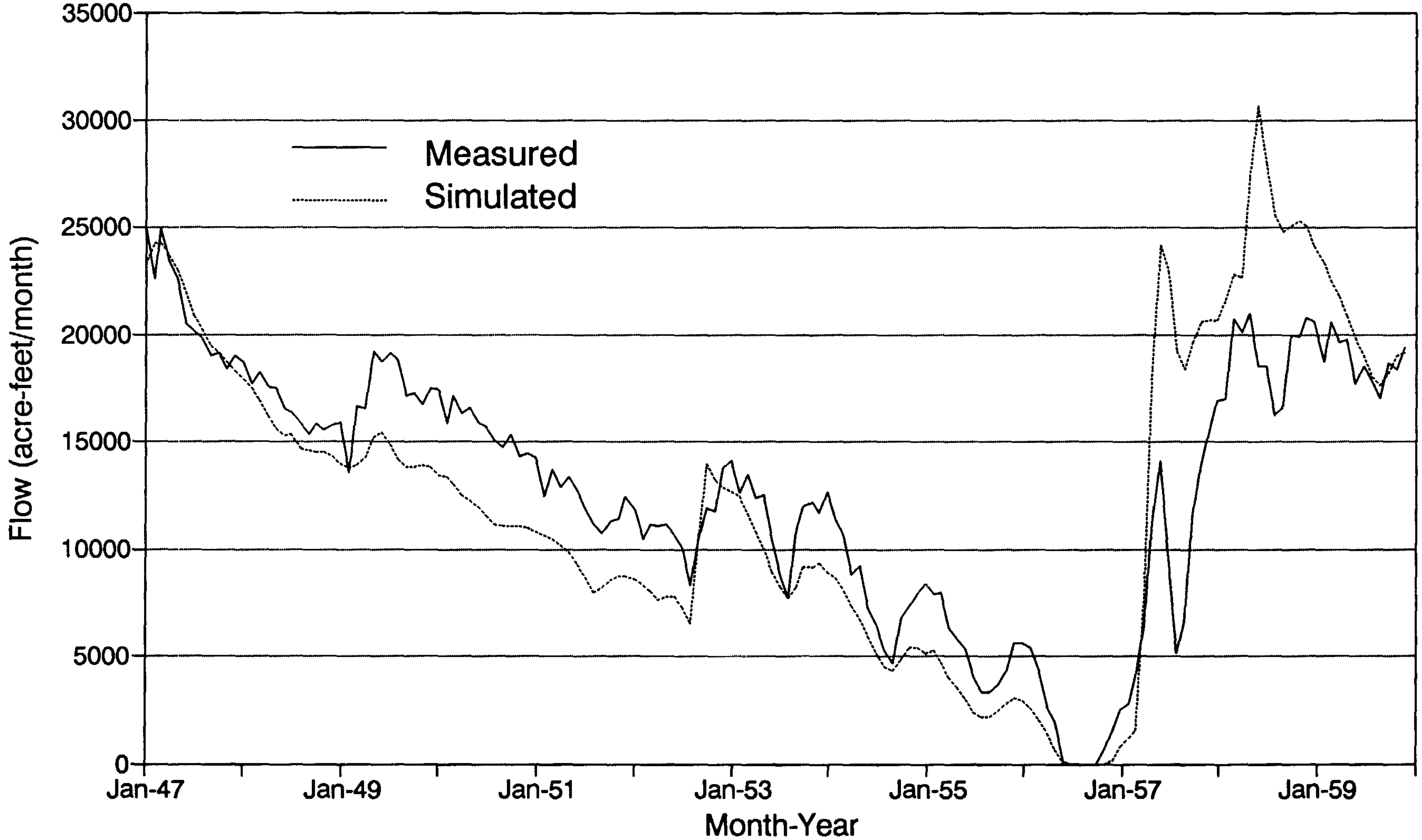


Figure 5

CY-26 (68-37-204) - Phase 1
Measured vs. Simulated

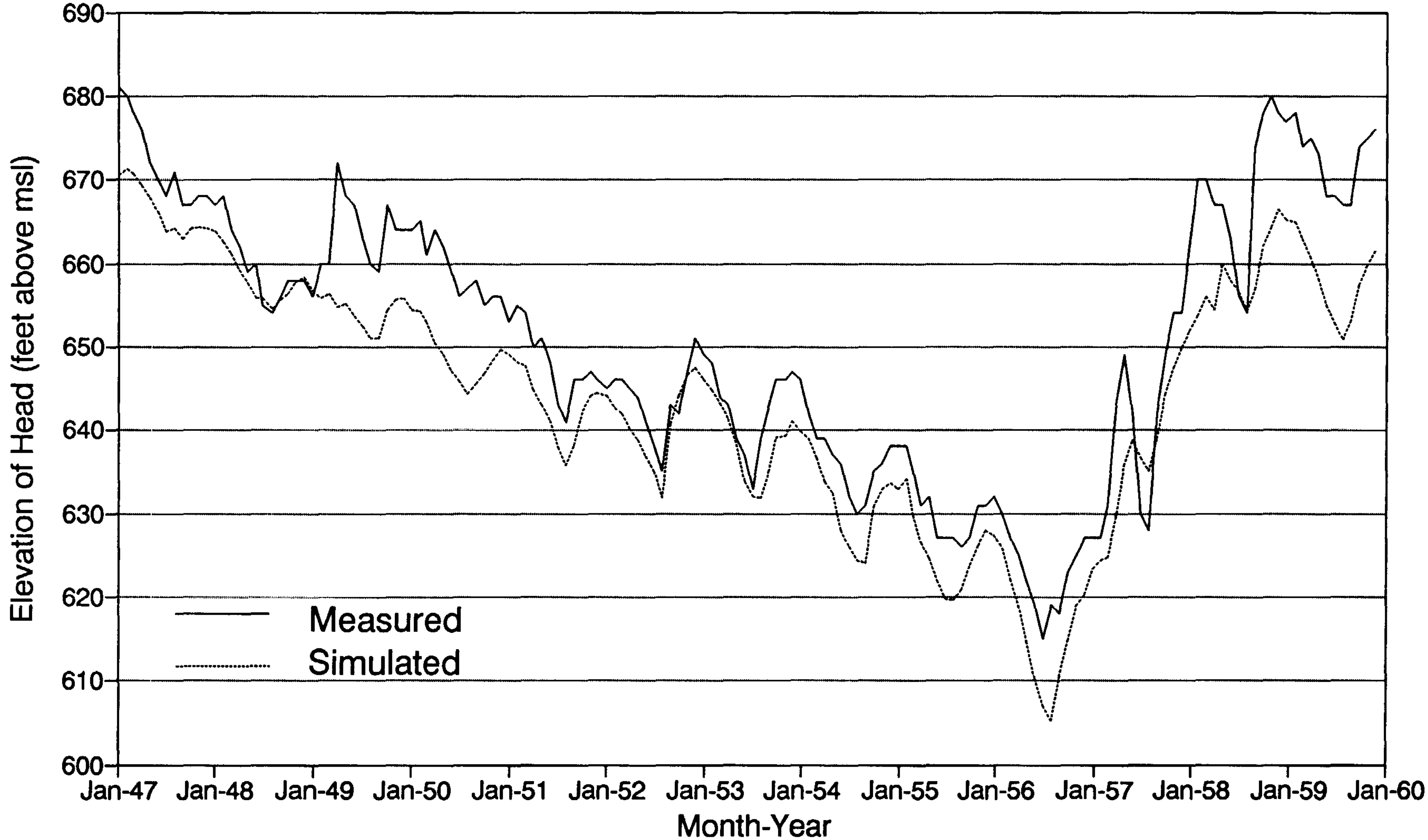


Figure 6

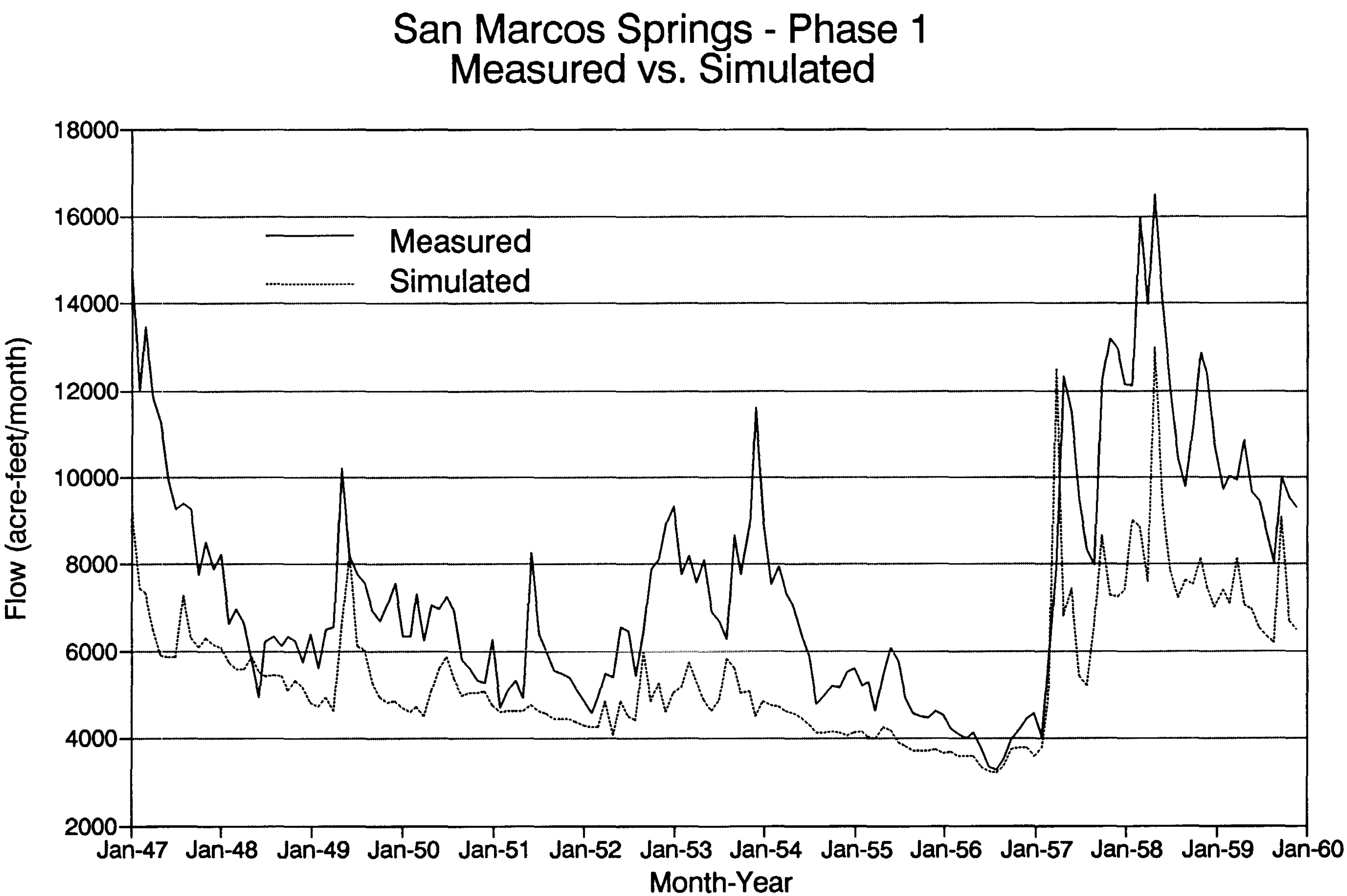

San Marcos Springs - Phase 1
Measured vs. Simulated
Measured
Simulated
Flow (acre-feet/month)
18000
16000
14000
12000
10000
8000
6000
4000
2000
Jan-47
Jan-48
Jan-49
Jan-50
Jan-51
Jan-52
Jan-53
Jan-54
Jan-55
Jan-56
Jan-57
Jan-58
Jan-59
Jan-60
Month-Year

Figure 7

Phase Two - Drought Sequence with Constant Pumpage

Objective

The objective of Phase Two was to simulate aquifer response to several constant pumpage scenarios under recharge conditions of the drought and recovery sequence (years 1947-1959). Comparison of pumpage and simulated spring flows could give an indication of some maximum amount of constant withdrawal that could occur and still maintain some level of flows at either or both springs during a drought event similar to that of the 1950's.

Methodology

The 1959 pumpage distribution was used and the data set adjusted equally so the total pumpage equaled the 1984 total reported pumpage (529,800 acre-feet). Spring 1947 water levels derived from steady-state simulation were used as starting water levels (same as Phase One). Additional runs were made with systematic reductions in the pumpage total (20%, 40%, 50%, 55%, 60%). Plots were made of pumpage versus minimum monthly springflow.

Results

Results of Phase Two runs indicate that large pumpage reductions would be necessary in order to insure minimum springflows in the 40 to 50 cfs range at both San Marcos and Comal Springs. Total pumpage would be in the range of 225,000 to 250,000 acre-feet per year for the entire San Antonio Region for 50 cfs or greater to be maintained at Comal Springs (Figure 8).

Phase Three - Verification

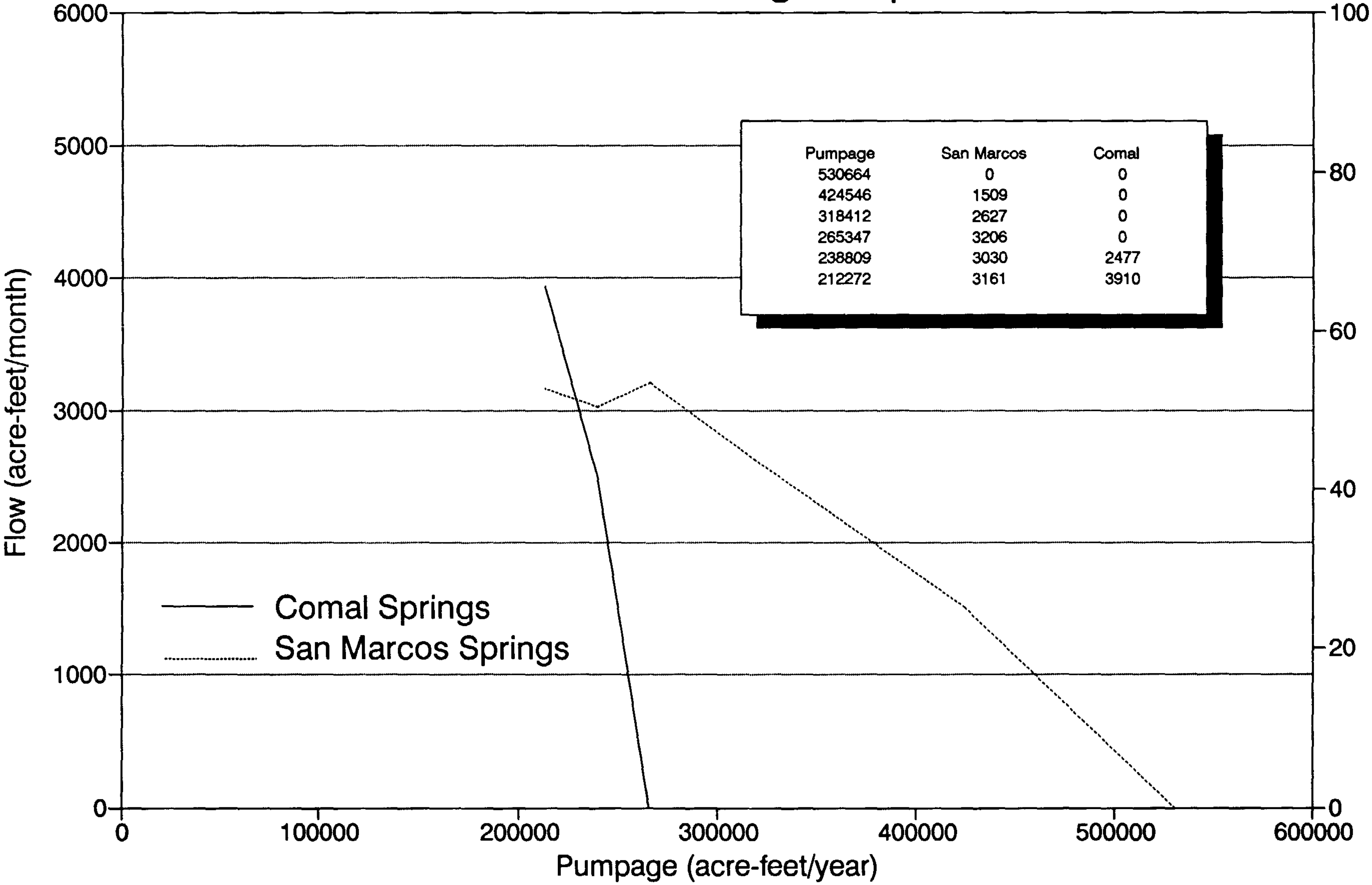
Objective

The objective of Phase Three was to construct a new monthly pumpage and recharge data set covering the years 1978-1989 in order to verify the aquifer parameters developed for the drought sequence calibration runs.

Methodology

Monthly recharge values were obtained from the U.S.G.S. San Antonio office. Municipal and industrial pumpage was obtained from the T.W.D.B. Uses and Projections Section and distributed according to the most recent well data available. Irrigation totals were taken from the E.U.W.D. Bulletins and distributed according to T.W.D.B. irrigated acreage maps. County totals were compared to E.U.W.D. published totals and any difference was considered to be domestic and stock pumpage and adjusted, when necessary, so that county totals matched E.U.W.D. published totals. The final physical data set developed for the Phase One calibration runs was used with spring 1978 water levels substituted as starting water levels.

Pumpage vs. Simulated Minimum Monthly Springflow - Phase 2
1947-1959 Recharge Sequence



Pumpage	San Marcos	Comal
530664	0	0
424546	1509	0
318412	2627	0
265347	3206	0
238809	3030	2477
212272	3161	3910

Figure 8

Results

Phase Three simulation results compared favorably to the results achieved in Phase One. As in Phase One, the best match between measured and simulated springflows occurred at Comal Springs (Figure 9). Total simulated flow for the entire simulation was 2,563,681 acre-feet and the measured flow was 2,392,307 acre-feet. Average monthly simulated flow was 17,803 acre-feet as compared to 16,613 acre-feet average measured flow. During 1984, the year with the lowest springflow, simulated flows totaled 90,801 acre-feet and measured flows totaled 91,088 acre-feet. Simulated monthly average Comal springflow was 7,567 acre-feet and measured monthly average flow was 7,591 acre-feet for 1984. For the entire simulation, simulated springflows had a mean difference of 1,190 ac-ft/month more flow than measured amounts. The median difference was 546 ac-ft/month more flow than was measured.

Results of simulated springflows at San Marcos Springs also compare well with the results achieved in Phase One (Figure 10). In this area there is still a component of flow that does not totally simulate. For the entire 1978-1989 time period, total simulated flow was 912,160 acre-feet and total measured flow was 1,375,940 acre-feet. Average monthly simulated flow was 6,334 acre-feet as compared to 9,555 acre-feet average measured flow, a mean difference of 3,221 acre-feet/month for the entire simulation. The median difference showed simulated flows at 2,378 acre-feet/month less flow than was measured. The best match of measured and simulated flows was achieved for 1989, which was a low-recharge year. For this year, total simulated flow was 62,124 acre-feet and total measured flow was 72,520 acre-feet. Average monthly simulated flow for 1989 was 5,177 acre-feet and average monthly measured flow was 6,043 acre-feet.

The lowest simulated monthly water levels for the area around the index well J-17 during the two driest years, 1984 and 1989, were 619 (August 1984) and 626 (August 1989) feet (msl). The corresponding measured values were 624 and 628 feet (msl), respectively (Figure 11). The mean and median amount of difference between measured and simulated water levels for the entire simulation showed simulated values that were 10 feet below measured values.

Based on the good reproduction of springflows and water levels, especially the minimum levels for Phase One and Phase Three, it was concluded that the model design and parameters provided an acceptable representation of the Edwards (BFZ) Aquifer regional flow system. It could then be used to evaluate alternative management plans for the aquifer.

Phase Four - Reduced Regional Pumpage

Objective

The objective of Phase Four was to determine the effect of reduced pumpage in the western part of the region (Uvalde and Medina Counties) on water levels and springflows in the eastern part (Bexar, Comal, and Hays Counties). The objective also involved an increase in pumpage in Bexar county by the same amount as the decrease in Uvalde and Medina Counties. These increases were initiated in 0, 1, 3, and 6 month delayed intervals.

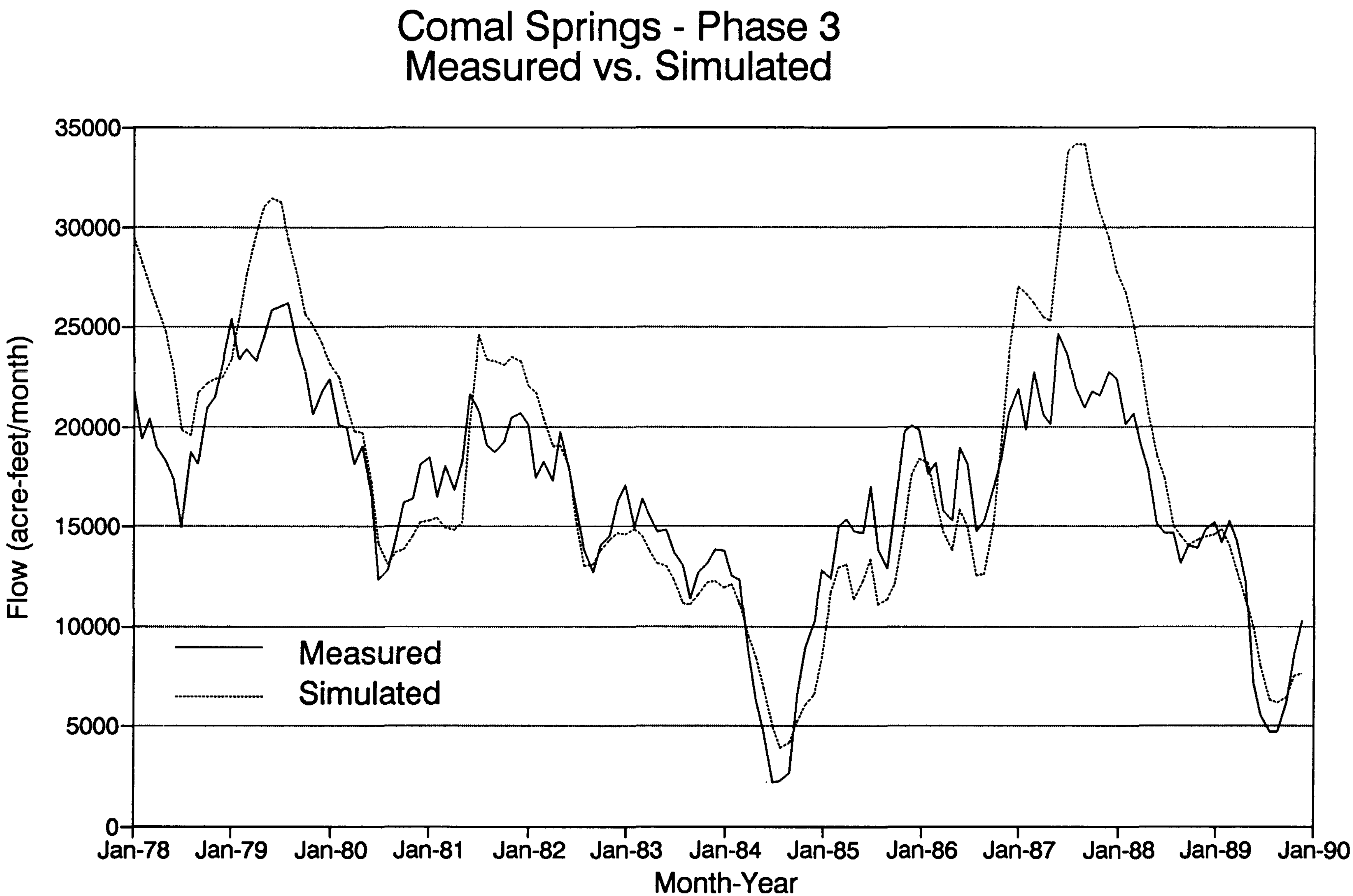

Comal Springs - Phase 3
Measured vs. Simulated
Flow (acre-feet/month)
35000
30000
25000
20000
15000
10000
5000
0
Measured
Simulated
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Month-Year

Figure 9

San Marcos Springs - Phase 3
Measured vs. Simulated

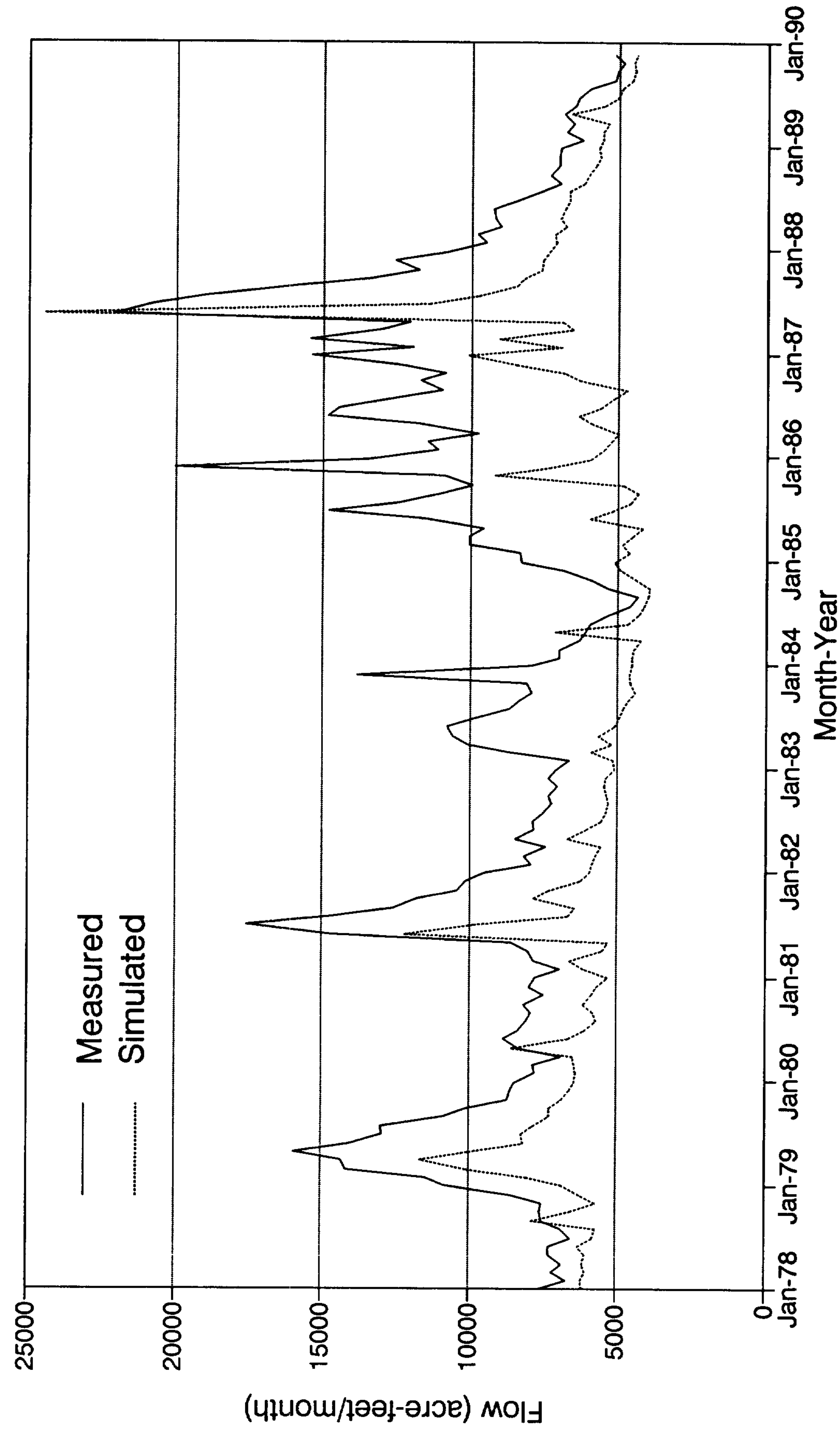


Figure 10

J-17 (68-37-203) - Phase 3
Measured vs. Simulated

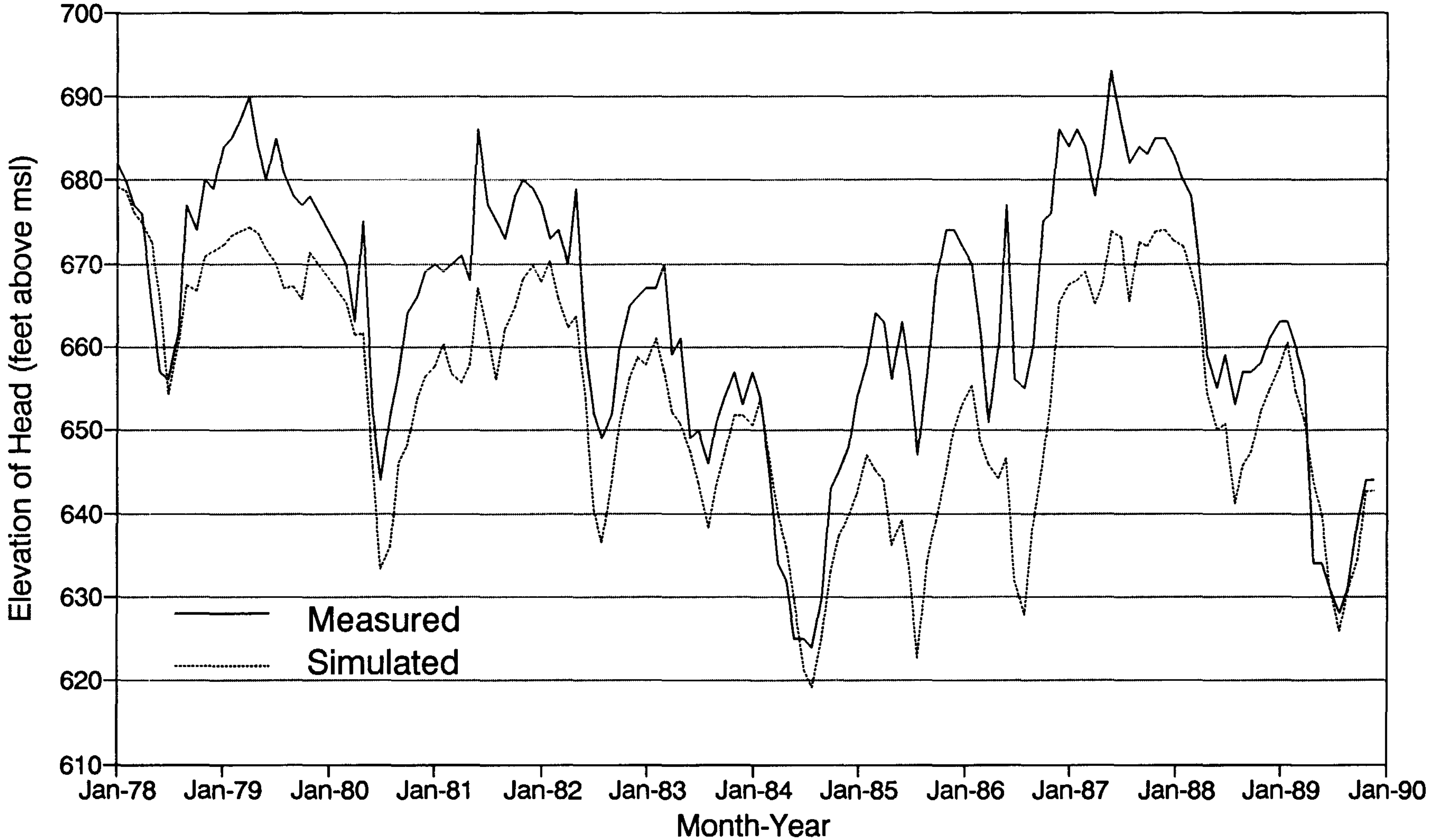


Figure 11

Methodology

A base run was first made with constant recharge (July 1985) and pumpage (October 1985) from the 1978-1989 data set. These two months are average amounts for the time interval. This base run was then made covering a time period of 12 years. With constant recharge and pumpage the model approached steady state conditions, therefore, the final heads were used as starting heads for another 12 year run to check for consistency of results.

Two additional runs were made with the same starting conditions as in the base run, but after three years the pumpage in Uvalde County was reduced by 25% (2,784 acre-feet/month) and 50% (5,567 acre-feet/month). The percentage reductions were distributed to all cells in the county. Two additional runs were then made, but the pumpage reductions were moved to Medina County (25% = 1,197 acre-feet/month and 50% = 2,394 acre-feet/month).

One additional set of runs was made with constant pumpage (October 1985) run through the 1978-1989 recharge record. Pumpage reductions were made as in the previous runs, but pumpage in Bexar County was increased by the same amount (not %) as the reductions in Uvalde County. This increase was delayed by 0, 1, 3, and 6 month intervals in four separate runs. This increased pumpage was distributed in Bexar County based on the percent of the total county pumpage that each cell was already receiving (if a cell was receiving 10% of the total pumpage prior to the increase, it received 10% of the total to be increased).

Results

Runs with reduced pumpage in Uvalde County indicated that significant rises in water levels (.5 ft to >1 ft) could be expected in the San Antonio area (Well J-17) in 12 to 15 days with a 25% reduction in pumpage and in 9 to 12 days with a 50% reduction in pumpage. Total simulated springflow at Comal springs was increased by 245 acre-feet in the next month following the 25% pumpage reduction and by 297 acre-feet following the 50% reduction. After nine years of constant recharge and pumpage the additional simulated springflow had increased by 910 acre-feet/month with a 25% pumpage reduction and by 1,759 acre-feet/month with a 50% pumpage reduction.

When the reductions are moved to Medina County, model results indicate the same kinds of water level rises in the San Antonio area (Well J-17) in 7 to 9 days with a 25% reduction in pumpage and in 5 to 7 days with a 50% reduction. Total simulated springflow at Comal Springs was increased by 268 acre-feet in the next month following the 25% pumpage reduction and by 408 acre-feet following the 50% reduction. After nine years of constant recharge and pumpage the additional simulated springflow had increased by 787 acre-feet/month with a 25% pumpage reduction and by 1,482 acre-feet/month with a 50% pumpage reduction.

When pumpage was increased in Bexar County by the same amount as the reductions in Uvalde County, water levels immediately dropped four to seven feet in the San Antonio area (Well J-17). Delaying the pumpage from one to three months did not make any significant difference in the declines. When the pumpage was delayed six months, however, there was actually a water level rise with the 25% pumpage reduction and a decline of less than one foot with the 50% pumpage reduction. What caused this decrease in the water level declines was not the six month delay, but the fact that recharge was higher during that month than the previous months. If the same amount of recharge had occurred during the previous months the water level declines would probably have been much less and some water level rises may have occurred.

One significant result of the Phase Four simulations was that a decrease in pumpage in the western part of the region did not result in an equal increase in springflows in the eastern part on the region. While a decrease in pumpage in Uvalde County did show a corresponding increase in flows at Comal and San Marcos Springs, it amounted to approximately 34% of the total decrease in pumpage after nine years. The largest effect was seen in the west as an increase in aquifer storage, increased interformational flow from the model, and renewed flow at the cells that represent Leona Springs.

Similar results were seen when the reductions were made in Medina County. In this case, however, the majority of the reduced pumpage was seen as increased flows at Comal and San Marcos Springs (approx. 67% of the decreased pumpage) after nine years. As with the other run, the model also indicated an increase in aquifer storage and interformational flow from the model. In this case there was no flow at Leona Springs.

Phase Five - Texas Water Commission - Edwards Aquifer Management Plan

Objective

The objective of Phase Five was to complete development of the 1934-1990 monthly recharge sequence and then make model runs of various management scenarios proposed by the Texas Water Commission (TWC) for the Edwards (BFZ) Aquifer in the San Antonio region (Texas Water Commission, 1992).

Methodology

As with previous data sets, the 1934-1946, 1960-1977, and 1990 monthly recharge figures were obtained from the U.S.G.S. San Antonio office. A pumpage data set was created with constant pumpage totaling 538,000 acre-feet/year which included 15,000 acre-feet/year pumpage at a catfish farm in southwest Bexar County. The 1989 monthly pumpage distribution (most recent) was adjusted, by county, so that the totals used by the TWC were obtained.

A run was then made based on the TWC's mandatory water curtailment plan for municipal, industrial, and aquaculture users and a "dry year" option for agriculture users in Bexar, Medina, and Uvalde Counties. Under this alternative, pumpage for municipal, industrial, and aquaculture was adjusted (decreased or increased) on a monthly basis based on the simulated water level at the cell representing the area around the index well J-17 and held constant for the entire month. Irrigation pumpage under the "dry year" option was adjusted on an annual basis also using the simulated water level at the J-17 cell. These conditions were run through the 1934-1990 recharge sequence using the physical data set developed during model calibration and verification.

Pumpage adjustments were made as follows:

Stage	J-17 Level	Reductions
1	>649	no reductions
2	649-633	15% reduction of municipal, industrial, and aquaculture pumpage (monthly option) and 30% reduction of irrigation pumpage (annual "dry year" option).
3	<633	30% reduction of municipal, industrial, and aquaculture pumpage (monthly option) and 50% reduction of irrigation pumpage (annual "dry year" option).

A similar run was then made, but with across-the-board mandatory monthly water demand curtailment for all uses depending on the simulated water level at the cell representing the area around the index well J-17 as follows:

Stage	J-17 Level	Reductions
1	>666	no reduction
2	666-650	10%
3	649-633	20%
4	<633	40%

Results

Under conditions of the "dry year" option, which greatly limits irrigation pumpage in Bexar, Medina, and Uvalde Counties, San Marcos Springs flowed during the entire recharge sequence. Comal Springs also maintained flows during all but the severest of drought conditions. The model simulated no flow at Comal Springs for three months from August through October 1954 and for a longer period (22 months) from June 1955 through March 1957. Under this option Comal Springs would flow at 100 cfs or greater 74% of the time based on the 1934-1990 period of record (Figures 12, 13, and 14). Model results also indicate that, based on the 1934-1990 period of record, municipal, industrial, and aquaculture pumpage would require Stage 1 reductions 18% of the time, Stage 2 reductions 54% of the time, and Stage 3 reductions 28% of the time. Irrigation pumpage under the "dry year" option would require no reductions 19% of the time, a 30% reduction 58% of the time, and a 50% reduction 23% of the time.

Under conditions of mandatory monthly water demand curtailment with across-the-board pumpage reductions for all uses based on water levels at the J-17 cell, model results indicate springflows can be maintained at San Marcos Springs indefinitely and during all but the most severe drought conditions at Comal Springs. Under this alternative, results indicate that Comal Springs would flow at 100 cfs or greater 79% of the time based on the 1934-1990 period of record (Figures 15, 16, and 17). Results also indicate that, based on the 1934-1990 period of record, no mandatory pumpage reductions would be needed 2% of the time. Mandatory pumpage reductions for all uses would be required 23% of the time under Stage 2, 51% of the time under Stage 3, and 24% of the time under Stage 4.

Simulated Comal Springflow - Phase 5
Curtailment and Dry-Year Option, Based on J-17 Water Levels

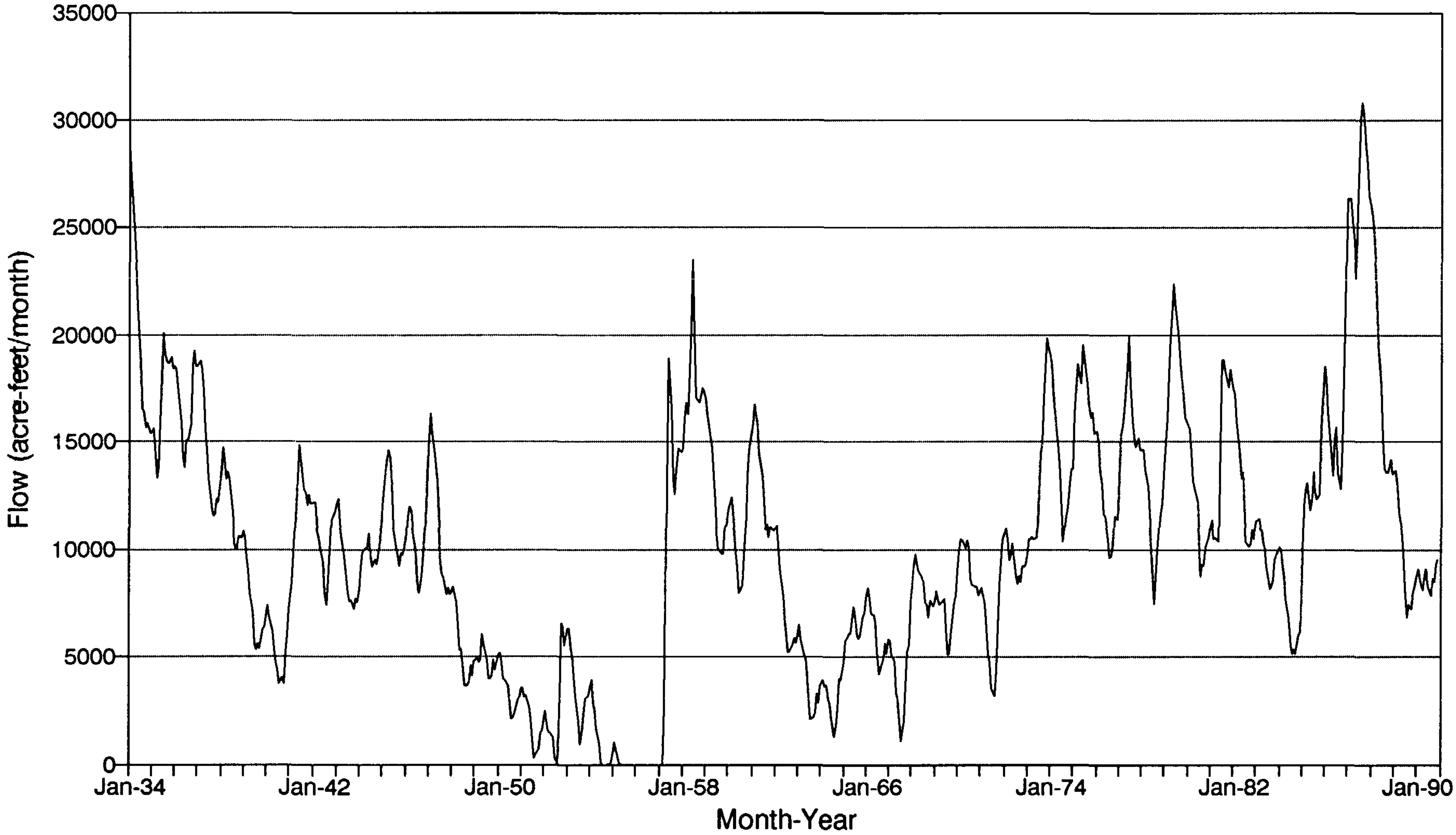


Figure 12

Simulated San Marcos Springflow - Phase 5
Curtailment and Dry-Year Option, Based on J-17 Water Levels

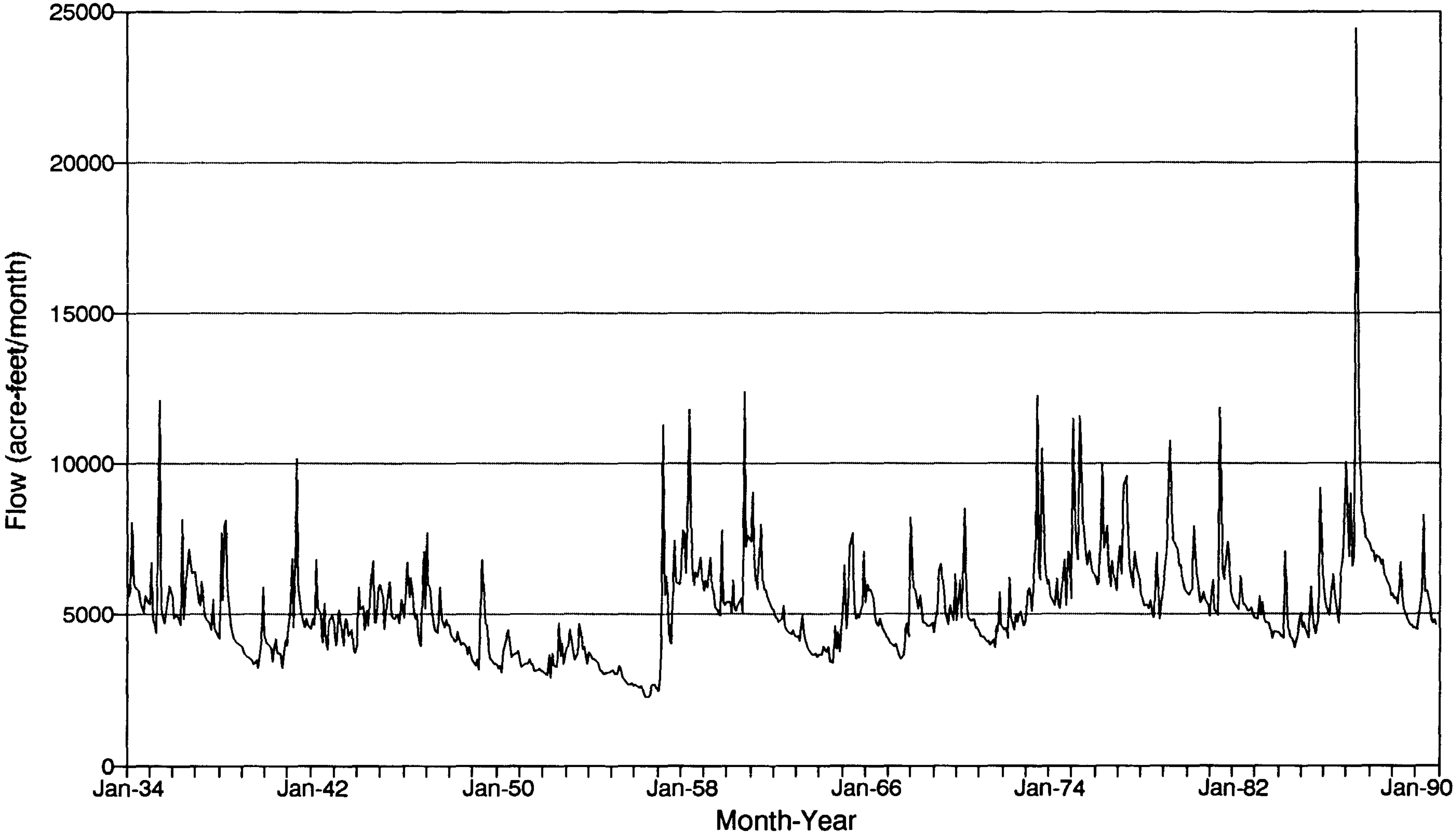


Figure 13

Simulation of Heads at J-17 - Phase 5
Curtailment and Dry-Year Option, Based on J-17 Water Levels

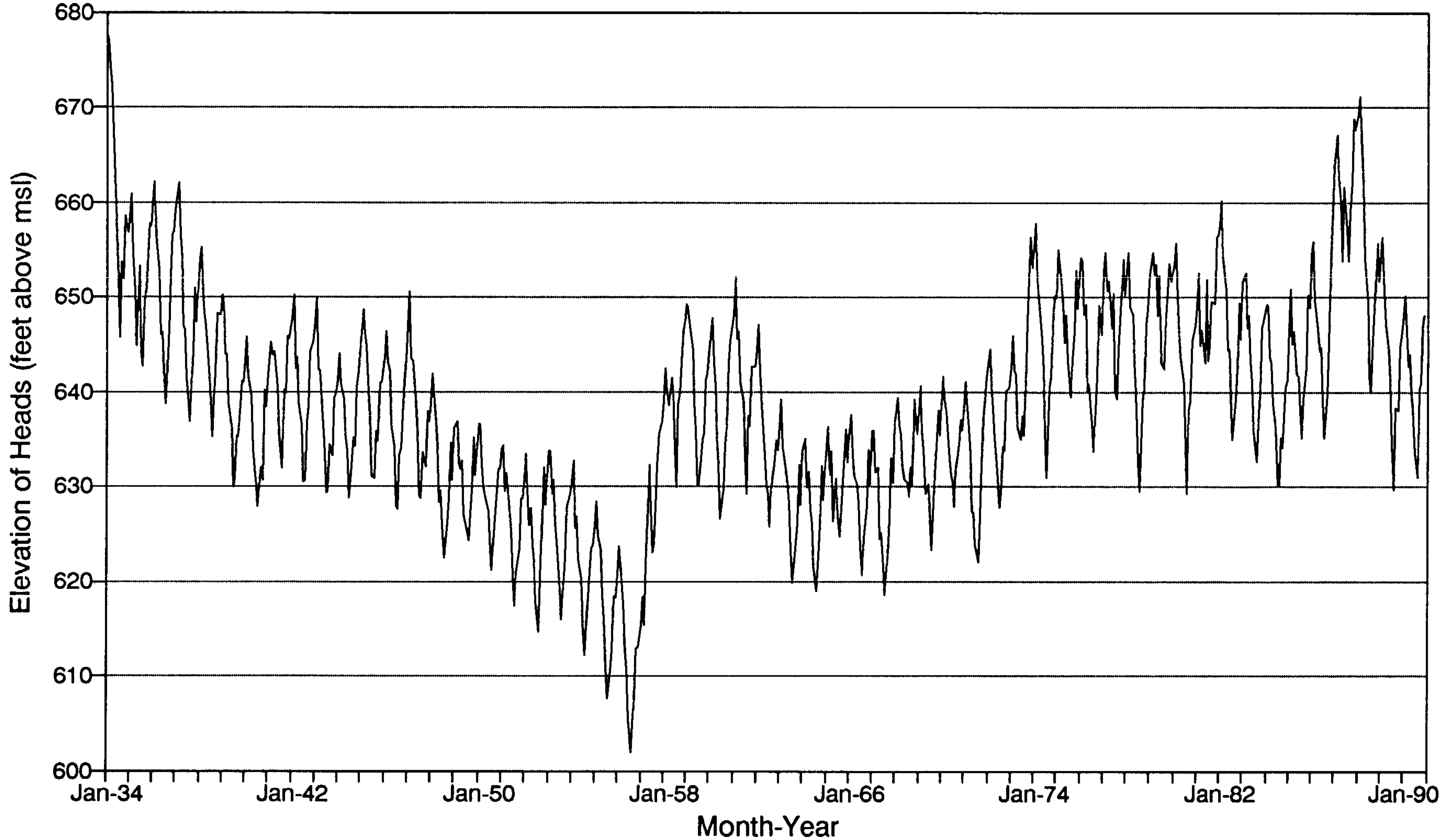


Figure 14

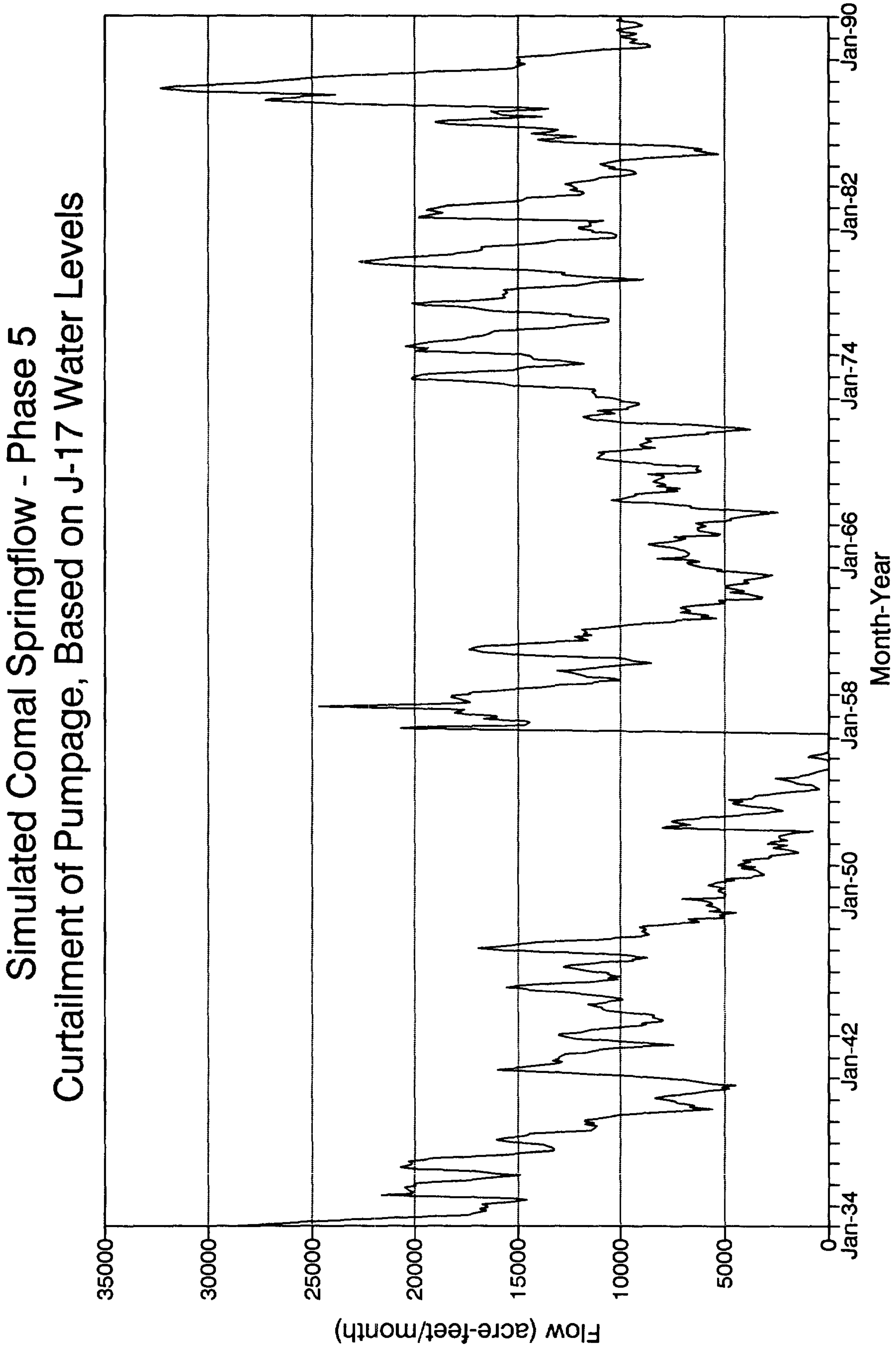

Simulated Comal Springflow - Phase 5
Curtailment of Pumpage, Based on J-17 Water Levels
Flow (acre-feet/month)
35000
30000
25000
20000
15000
10000
5000
0
Jan-34
Jan-42
Jan-50
Jan-58
Jan-66
Jan-74
Jan-82
Jan-90
Month-Year

Figure 15

Simulated San Marcos Springflow - Phase 5
Curtailment of Pumpage, Based on J-17 Water Levels

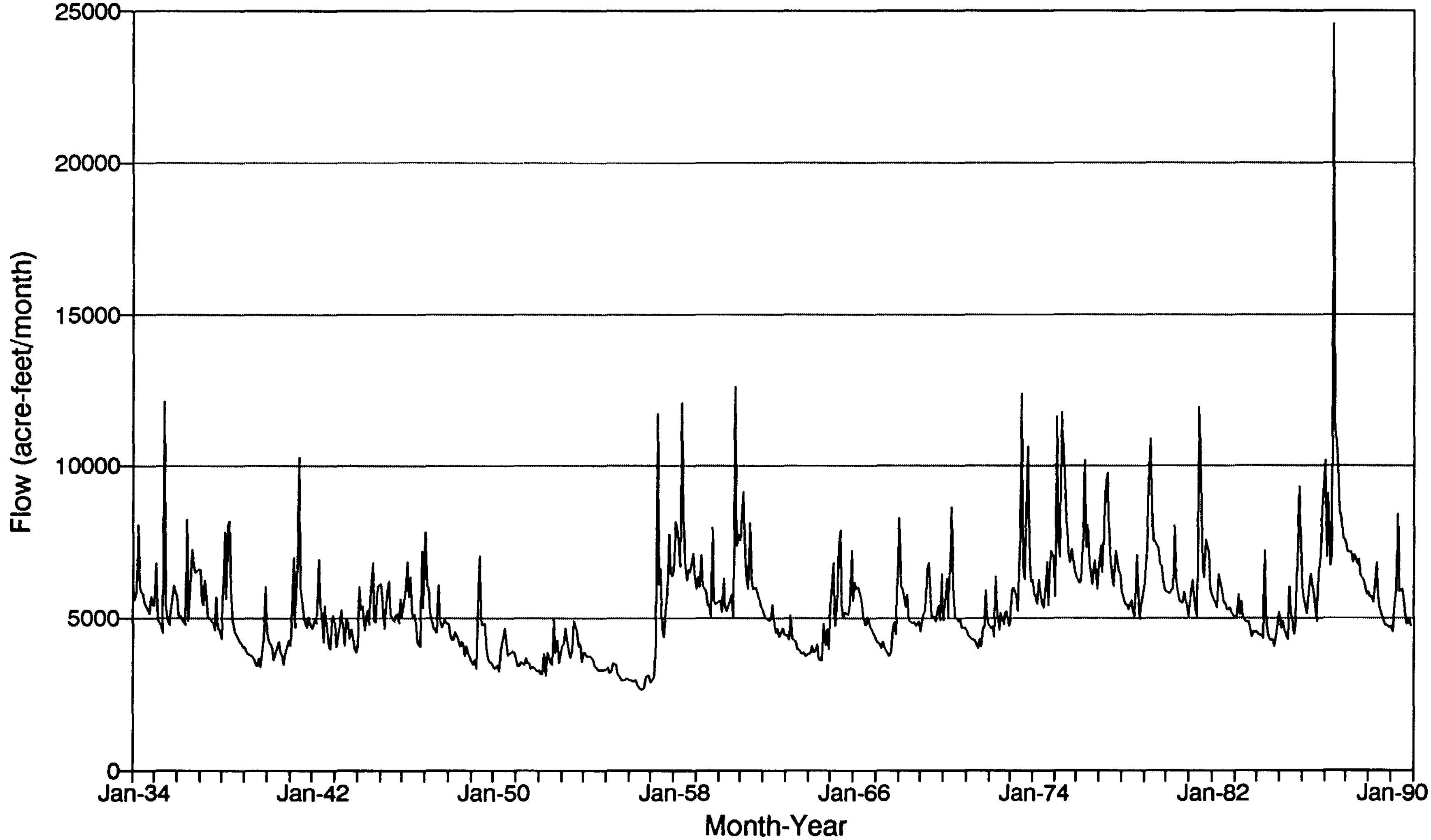


Figure 16

Simulation of Heads at J-17 - Phase 5
Curtailment of Pumpage, Based on J-17 Water Levels

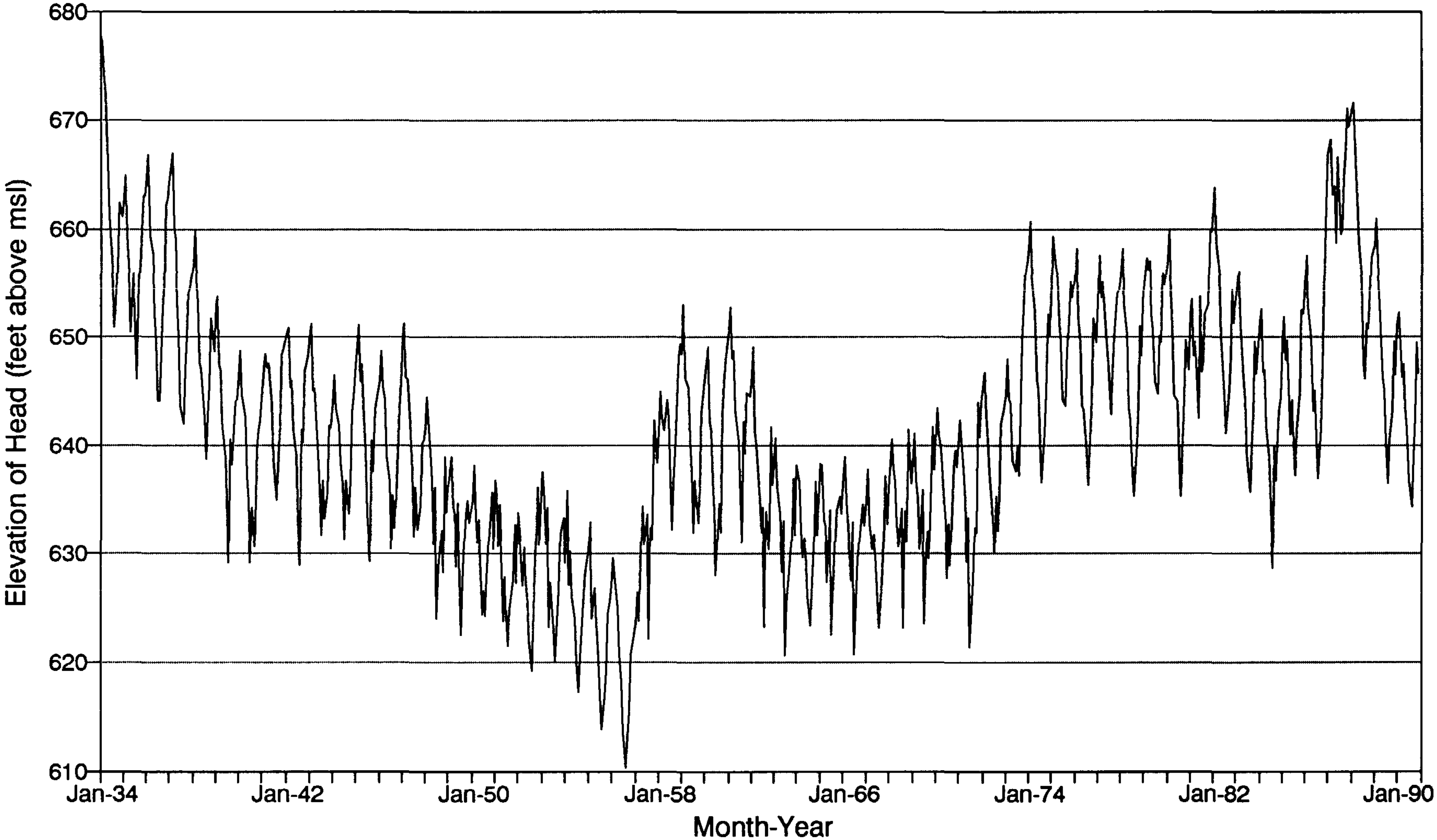


Figure 17

Phase Six - Constant Pumpage over the Drought and Recovery Period of Record

Objective

The objective of Phase six was to simulate aquifer response to several constant pumpage scenarios under recharge conditions covering the drought and recovery period of record (1947-1959). By comparing pumpage to simulated springflows an indication can be made of some maximum amount of constant withdrawal that could occur and still maintain some level of flows at either or both springs during the different recharge conditions that have occurred over the period of record. This objective is virtually the same as the Phase Two objective but with some changes in methodology.

Methodology

The 1989 pumpage distribution was used (our most recent) which totaled 543,700 acre-feet. Pumpage totals* by county are:

Bexar	293,000 acre-feet
Comal	27,800 acre-feet
Hays	13,000 acre-feet
Kinney	2,600 acre-feet
Medina	70,500 acre-feet
Uvalde	136,800 acre-feet
TOTAL	543,700 acre-feet

* Totals rounded to nearest 100 acre-feet

Spring 1947 water levels derived from steady-state runs were used as starting water levels. Additional runs were made with systematic reductions to the original pumpage total in 10% increments ranging from 0% to 100%. Plots were made of pumpage versus minimum monthly springflow.

Results

The results of Phase Six were similar to those for Phase Two. They indicate that large pumpage reductions would be necessary in order to insure minimum springflows at both San Marcos and Comal Springs at levels of 100 cfs or more. Total pumpage would need to be approximately 165,000 acre-feet/year for the entire San Antonio region (Figure 18). The difference in pumpage distribution between Phase Six and Phase Two did not have any significant impact on model output.

Pumpage vs. Simulated Minimum Monthly Springflow - Phase 6
1947-1959 Recharge Sequence

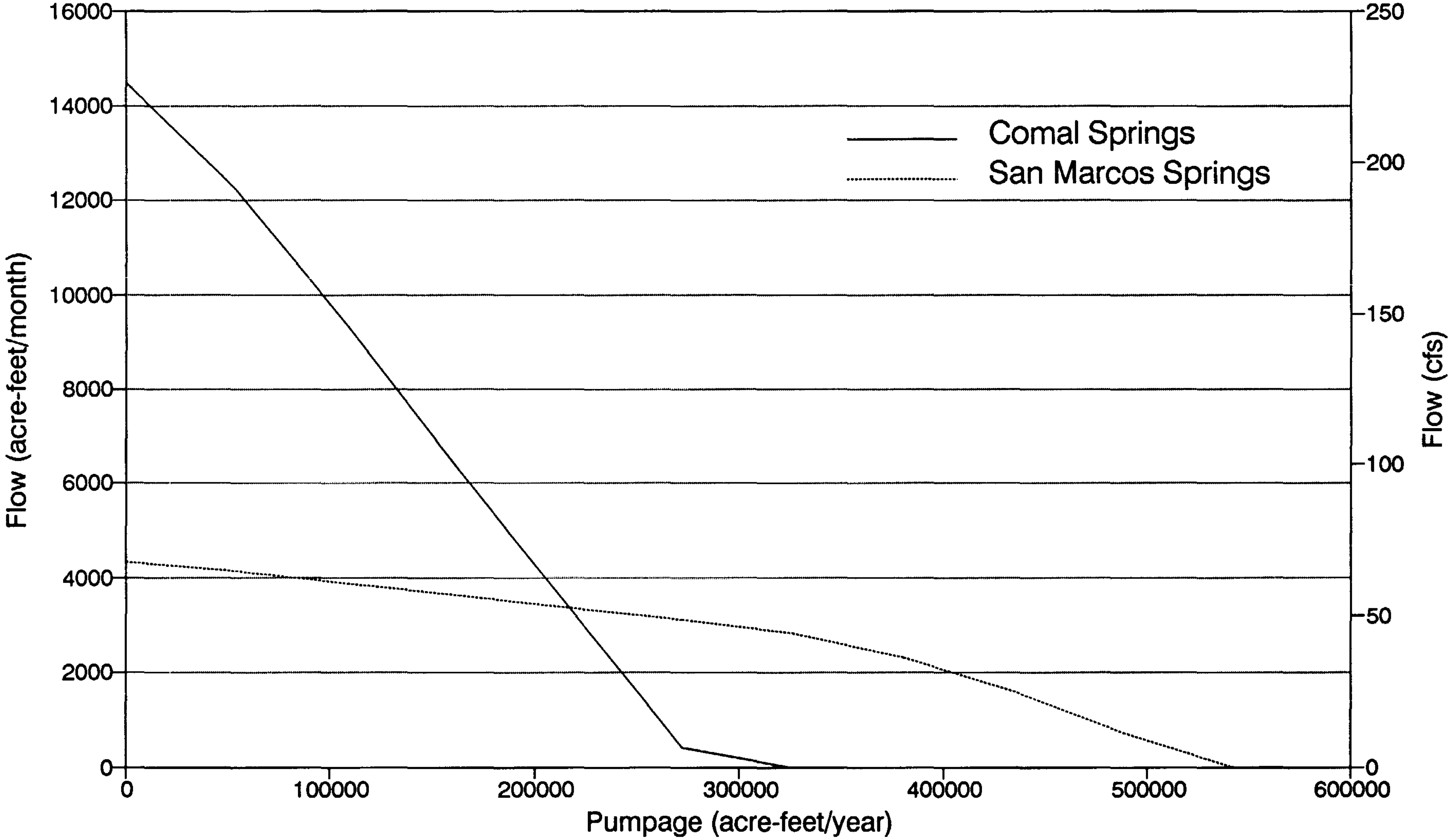


Figure 18

SUMMARY AND CONCLUSIONS

The purpose of this project was to reevaluate the Texas Water Development Board's existing Edwards (BFZ) Aquifer flow model and refine the simulation of water levels and springflows in the San Antonio region of Texas. The refined model will be used as a tool to help predict the aquifer's response to potential future stress conditions and to aid in the evaluation of any type of regional management plan developed for the aquifer. It will also be used to derive ground-water availability figures for use in the Texas Water Plan.

Model refinement consisted primarily of two elements. The first involved converting values of annual recharge and pumpage used in the original model to monthly values. This allowed the model to operate on a monthly time step and provide a realistic annual distribution of aquifer stress (pumpage and recharge) and
simulated aquifer response (water levels and springflows) to that stress. The second concentrated on analyzing and incorporating any new or additional information on the Edwards Aquifer that would improve simulation accuracy. Much of this new information involved refinements to transmissivity and anisotropy derived from recent modeling efforts by the U.S. Geological Survey.

The model was calibrated to the 1947-1959 recharge and pumpage sequence. A total of 139 simulations were made during this phase of the project. Overall simulated water levels and springflows acceptably reproduced measured values for that period, especially during periods of low recharge. To verify the aquifer parameters developed during calibration, new recharge and pumpage data sets covering the period 1978-1989 were constructed and run with the aquifer parameters from the calibration run. Results compared very well with those from the calibration run. Therefore, the model was considered to be a reasonable and usable representation of the Edwards (BFZ) Aquifer regional flow system.

A variety of applications were made in order to get an indication of how the aquifer would respond under differing stress conditions. These runs included: 1) application of differing amounts of constant regional pumpage through the historical drought and recovery recharge sequence; 2) reduction of pumpage in certain areas of the region; and 3) application of Texas Water Commission proposed management plans for the Edwards and the simulated results of such plans.

Conclusions drawn from model results are the following:

1) Large overall reductions in total regional pumpage would be necessary to insure the maintenance of springflows at Comal and San Marcos Springs in the 50 to 100 cfs range under the 1947-1959 period of record. To maintain 50 cfs or greater would require a maximum total pumpage of 225,000 to 250,000 acre-feet/year. To maintain 100 cfs or greater would require a maximum total pumpage of approximately 165,000 acre-feet/year.

2) Reducing pumpage in the western part of the San Antonio region (Uvalde and Medina Counties) results in an increase in springflow at Comal Springs. However, the increase in springflow does not equal the amount of pumpage reduced. Model results indicate that 34% of reduced pumpage in Uvalde County is seen as increased flow at Comal Springs after a nine year period. If the reductions are placed in Medina County, 67% of the reduction is seen as increased springflow at Comal Springs after a nine year period. In both cases the remainder of the reduced pumpage becomes increased aquifer storage, outflow, or springflow in the western area of the San Antonio region.

3) Based on the 1934-1990 period of record, model results indicate that with a maximum of 538,000 acre-feet/year total regional pumpage, implementation of the Texas Water Commission Edwards Aquifer management plan with the "dry year" option for irrigation pumpage in place would result in continual springflow at San Marcos Springs under all conditions. Comal Springs would flow under all but the severest of drought conditions. A flow of 100 cfs or greater at Comal Springs would occur 74% of the time.

   Under identical maximum pumpage and recharge conditions, implementation of mandatory water demand curtailment for all uses would also provide for continual springflow at San Marcos springs under all conditions. Comal Springs would also flow under all but the severest drought conditions. A flow of 100 cfs or greater would occur at Comal Springs 79% of the time.

4) It is important to understand that this project is regional in nature and the model was designed accordingly. Modeling certain aspects of the Edwards aquifer will require a more site-specific approach. However, in conjunction with sound geologic and hydrologic techniques the model developed here can be a useful tool in formulating and evaluating sound management decisions. Hopefully as more information about the aquifer becomes available and model accuracy is improved, limitations can be minimized.

5) Some topics for future study should include:
   a) cross-formational flow between the Edwards and the underlying Glen Rose Limestone;
   b) recharge to the Edwards in the Guadalupe River basin;
   c) flow within the Edwards in the vicinity of the "bad water" line and the effect of pumpage on the position of that line;
   d) more detailed study of the Edwards between Bexar County and the northeastern limit of the aquifer in Hays County, particularly in the artesian portion; and
   e) additional analysis of local and regional flow components contributing to springflow at San Marcos Springs.

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