Simulated Impacts Associated with the Cibolo Creek Transfers Using MODFLOW-NR and Senate Bill 3 Assumptions

prepared for

The Edwards Aquifer Authority

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AUTHORITY

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Appendix

Appendix A – Graphical Results of Simulations

Executive Summary

The Edwards Aquifer Authority has promulgated rules that regulate the usage of ground water within the Edwards Aquifer. These include the approach by which a water producer can acquire additional water rights by purchase or by lease from other water right holders. Water right transfers from Bexar County and west into Comal and Hays Counties are referred to as "Cibolo transfers" because Cibolo Creek is the geographic feature between the two areas. This study was designed by using available data and the EAA MODFLOW groundwater model to assess the impact of Cibolo transfers on aquifer water levels and springflow.

An evaluation of permits and transfers (based on 2005 permit database) show that 58 percent of the Cibolo transfers originate in Bexar County, followed by Medina (26%) and Uvalde (16%). Groundwater rights associated with Cibolo transfers represent 0.51 percent of total permitted rights. Comal County receives the largest portion of transfers (94%) followed by Hays (4%), and Guadalupe (2%).

Assessment of the faults and springs in the MODFLOW model indicates that the model is generally consistent with the current conceptual model of the aquifer. Previous studies by LBG-Guyton Associates (2006) determined that a modeling evaluation using MODFLOW-2000 was limited because of dry cell problems with the USGS version of the MODFLOW-2000 code. This assessment implemented a version of MODFLOW (SwRI, 2007) that handles the dry cell problem more robustly even under assumptions of large pumping.

The approach was to simulate the impact of transferred permits (i.e., production) from western Bexar County to five different locations east of Cibolo Creek. In addition, four different production scenarios (i.e., permit amounts) ranging from 78 to 4,743 acre-feet per year were simulated. Maximum permitted aquifer production was 572,000 acre feet per year and Senate Bill 3 (80^{th} Session, 2007) critical period rules were applied.

Modeling results provide the following general insights into Cibolo transfers:

- Permits transferred farther east have more impact on San Marcos springflow.
- Permits transferred farther east result in slightly higher water levels in J-17 because pumping is shifted downgradient of J-17.
- The location of the new pumping for transfers are a factor in determining the impact to Comal springflow due to the flow dynamics resulting from faults.
- The average change in Comal springflow as a percent of the transfer volume ranges from -16% reduction to a 42% increase, depending on the "transfer to" location. The average reduction in San Marcos springflow as a percent of the transfer volume ranges from about -78 to -1 percent. As shown in Table 4.31 and 4.32, the variation is caused by the changes in the "transfer to" location.

- During heavy summer pumping, the monthly impact can be over 200 percent (of annual transfer volume) because (1) of the proximity of the well to the spring, and (2) the larger proportion of pumping that occurs during the summer months. See Section 4.2.4 for more explanation.
- Smaller transfers (78 and 782 af/yr) do not tend to impact Stage 4 statistics in J-17 and Comal Springs or Stage 2 statistics in San Marcos Springs. Larger transfers (2,353 and 4,743 af/yr) do tend to have some impact on these stages.
- Dry periods were assessed by counting the number of months (out of 96) from 1950-1957 that water levels and springflow were at various critical period stages with and without transfers. Because springflow from Comal and San Marcos are generally lower during the 1950's drought, the reduction in springflow represents a larger portion of the total springflow during dry times.
- There is no measurable impact on San Pedro and San Antonio Springs because there is almost never flow from these springs when the permitted pumping of 572,000 acre-feet per year in implemented in the model.
- In the model, the reduction in springflow from Comal Springs and San Marcos Springs caused by transferred production is balanced by an increase in springflow from other springs represented in the model (Los Moras, Barton, and Leona Springs).

1.0 Introduction

The Edwards Aquifer Authority has promulgated rules that regulate the usage of ground water within the Edwards Aquifer. These include the approach by which a water producer can acquire additional water rights by purchase or by lease from other water right holders. These water rights can be acquired in one geographic area of the aquifer and transferred to another location for pumping. Chapter 711, Subchapter L of the Authority's Rules defines the transfer process and addresses the issue of whether water rights can be transferred from Bexar County and west to Comal and Hays Counties to the east. Cibolo Creek is the geographic feature between the two areas and the process of transferring water rights is often referred to as a Cibolo Transfer. Figure 1.1 shows the location of Cibolo Creek in relation to the Edwards aquifer and the EAA Jurisdiction boundary.

A request for a "Cibolo Transfer" may be reduced or denied by the Authority if it is determined that a potential increase in production east of Cibolo Creek, with a subsequent equal reduction west of Cibolo Creek, either a) does not protect aquatic and wildlife habitat, b) does not protect threatened and endangered species in the springs, c) does not effect spring flow at Comal and San Marcos Springs during critical low-flow periods, or d) does not ensure continuous minimum spring flow at both springs to protect endangered and threatened species as required by federal law. (The Edwards Aquifer Rules, p. 182-183). Historically the Authority has had requests to transfer water rights from west of Cibolo Creek to Comal County.

A recent study (LBG-Guyton Associates, 2004) concluded that pumpage of Edwards ground water close to either Comal or San Marcos Springs might have a significant impact on spring flow at either of these springs, particularly during low-flow conditions. A question raised by this observation is how far from the springs does groundwater pumping have a significant impact on spring flow and under what flow conditions? Is the influence of pumping strictly local to the springs or should the larger area of Comal and Hays County be considered? This technical issue is the essence of the Cibolo Transfer Rule, that is, will additional pumpage east of Cibolo Creek have a negative impact on spring flow at Comal and San Marcos Springs? One approach to evaluating this issue is by running a number of different pumping scenarios with the new Edwards MODFLOW ground-water flow model and comparing them to spring flow for Comal and San Marcos Springs and to the hydrogeologic setting of the Edwards in Comal and Hays Counties.

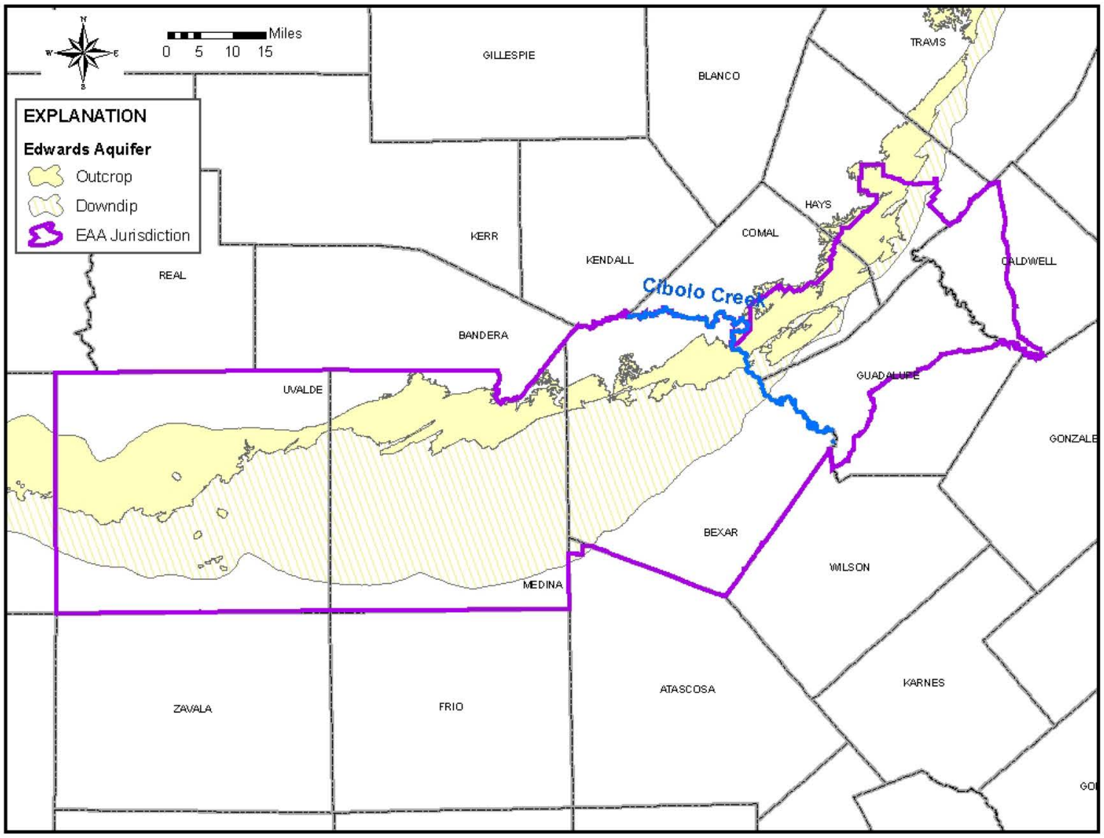

Figure 1.1 Location of Cibolo Creek, Edwards Aquifer, and EAA Jurisdiction

1.1 Objectives of Study

- **Task 1.** Map the location of current permit holders, the amount of their permit, and the type of permit (Industrial, Municipal or Irrigation) within Comal and Hays Counties. The volume of water that is already permitted in the two-county area was determined to properly assess the impact of additional pumpage in the area. In addition, the location of pumpage in Comal and Hays Counties within the new Edwards model was evaluated and compared to the latest distribution of permit holders in these counties.
- **Task 2.** Evaluate the accuracy of the new MODFLOW modeled spring flow estimates at Comal and San Marcos Springs under different historic pumping conditions as a way of judging the appropriateness of using the model in assessing the Cibolo Transfer question. The MODFLOW Edwards model is considered to accurately simulate water levels over the period of record over the entire modeled area. However, the accuracy of the model over short periods of time was evaluated in greater detail than was done during the development of the model in order to quantify

the model estimates of spring flow for this project. How well the model works on a local (county or smaller) basis was evaluated. Two main issues were assessed:

a. How spring flow is simulated within the model. For example, the LBG-Guyton Associates (2004) report has developed interpretations of the hydrogeology of Comal and San Marcos Springs. Ground-water discharge at Comal Springs is now considered to be from discrete flow paths in the upthrown and downthrown blocks of the Edwards. At low-flow conditions discharge is strictly from the downthrown block. "Regional" ground-water flow to San Marcos Springs appears to be solely in the upthrown block as it flows past Comal Springs. The MODFLOW model was reviewed to determine how the model interprets the hydrogeology in Comal and Hays Counties and whether the new interpretation of the hydrogeology of the springs significantly alters the simulations of spring flow.

b. Various hydrologic conditions were simulated. This modeling effort included simulation of water level and spring flow data to modeled simulations often only compared the general shape of the simulated curves to measured spring flow curves over time. In the context of drought conditions, comparisons at low-flow periods are far more important than comparison of high-flow conditions. The MODFLOW model was run to develop a detailed quantitative evaluation of spring flow during low-flow conditions and include the drought of record and other short duration, high intensity droughts (e.g. 1983-1984, 1988-1989, and 1995-1996). Validation of the model over these low-flow periods helps ensure that the proposed model runs to test the impact of pumping in Comal and Hays Counties on spring flow are realistic at low-flow conditions.

1.2 Approach and Methodology

LBG-Guyton Associates evaluated the impact of ground-water pumpage as it relates to the Cibolo Transfer Rule. The evaluation entailed assessing five factors that may affect transfers.

1. <u>Geographic Location:</u> These simulations considered increased pumping both up and down gradient from Comal and San Marcos Springs to determine the importance of the new withdrawal location for the transfer. Five scenarios were run to determine the importance of proximity to the springs. The scenarios assessed the effect of pumping from the upthrown and downthrown side of the Comal Springs Fault and the fault near San Marcos Springs. Pumpage was reduced by an equal amount in Bexar County to simulate the transfer process.

2. Aquifer Conditions: The simulations incorporated high recharge periods and drought periods (1947-1973).

3. Pumping Rate: The simulations incorporated different pumping rates to determine the importance of the size of the transfer.

4. Critical Period Rules: Maximum permitted aquifer production was 572,000 acre-feet per year and Senate Bill 3 (80th Session, 2007) critical period rules were applied. The Critical Period withdrawal reduction stages for the San Antonio and Uvalde Pool are shown in Tables 1.1 and 1.2.

Table 1.1 Critical Period Withdrawal Reduction Stages for the San Antonio Pool

Comal Springs Flow (cfs)	San Marcos Springs Flow (cfs)	Index Well J-17 Level (MSL)	Critical Period Stage	Withdrawal Reduction- San Antonio Pool
<225	<96	<660	I	20%
<200	<80	<650	II	30%
<150	N/A	<640	III	35%
<100	N/A	<630	IV	40%

Table 1.2 Critical Period Withdrawal Reduction Stages for the Uvalde Pool

Withdrawal Reduction- Uvalde Pool	Index Well J-27 Level (MSL)	Critical Period Stage
N/A	----	I
5%	<850	II
20%	<845	III
35%	<842	IV

5. Overall Impact: The simulated springflow for different scenarios were compared to assess the overall impact of Cibolo transfers.

2.0 EAA Permits in Comal and Hays Counties

The permit database was obtained from the Authority and evaluated in an effort to document the approximate amount, type, and location of production permits in Comal and Hays Counties. Figure 2.1 shows the location and size of all permits in Comal and Hays Counties.

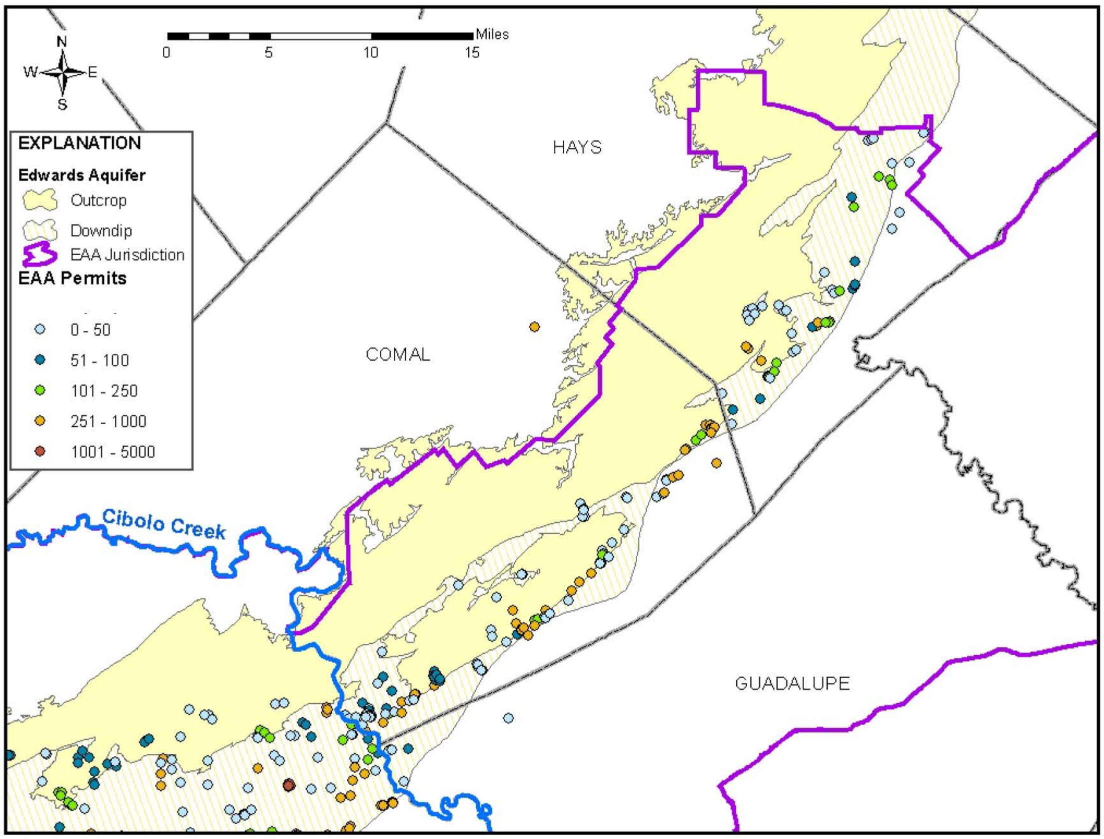

Figure 2.1 Location and Size of Permits in Comal and Hays Counties

As of October 2005, there were 190 permits east of the Cibolo. The permit amounts range from 0.14 – 900 acre-feet per year. The total authorized withdrawal east of the Cibolo is 30,522 acre-feet per year. Table 2.1 lists the Cibolo transfers as of 2005. The total transfers from west of Cibolo Creek to the east of Cibolo Creek total about 2,792 acre-feet.

Table 2.1 Listing of Transfers as of 2005

County	Docket #	Purpose	Transfer Amount (acre-feet/year)
Bexar	BE00081AD	Municipal	309.0
	BE00081AE	Municipal	62.0
	BE00081L1L1	Municipal	60.0
	BE00081L1L2	Municipal	150.0
	BE00090A	Industrial	8.0
	BE00090B	Industrial	35.0
	BE00094A	Industrial	900.0
	BE00109I	Municipal	2.0
	BE00181A	Industrial	24.2
	BE00182A	Industrial	18.3
	BE00195CAA	Irrigation	5.0
	BE00269L2	Industrial	45.0
Medina	ME00307L1L4	Municipal	2.0
	ME00307L1L6	Municipal	35.0
	ME00307L1L7	Municipal	21.0
	ME00339A	Irrigation	1.0
	ME00345L1L4	Municipal	43.0
	ME00349L2L1	Irrigation	200.0
	ME00365B	Irrigation	1.0
	ME00417D	Irrigation	4.0
	ME00438L2L2	Irrigation	63.7
	ME00442A	Irrigation	2.0
	ME00449A	Irrigation	5.0
	ME00468A	Irrigation	2.0
	ME00479I	Irrigation	4.0
	ME00493AE	Irrigation	3.0
	ME00534B	Irrigation	1.0
	ME00535L5L1	Municipal	75.0
	ME00599L1	Irrigation	21.0
	ME00607L1L1	Irrigation	236.3
Uvalde	UV00427AM	Irrigation	78.0
	UV00437I	Irrigation	2.0
	UV00461I	Irrigation	4.0
	UV00469L2L1	Irrigation	46.0
	UV00478I	Irrigation	2.0
	UV00531L1L1L1	Irrigation	10.0
	UV00533L1L3	Irrigation	13.0
	UV00537H	Irrigation	2.0
	UV00576I	Irrigation	14.0
	UV00589L1L2	Municipal	45.0
	UV00629L1	Irrigation	35.0
	UV00629L2	Irrigation	200.0
	UV00630G	Irrigation	2.0

Figure 2.2 shows the county of origin and total volume of transfers from west of the Cibolo to east. The graph shows that 58 percent of the transfers originate in Bexar County, followed by Medina (26%) and Uvalde (16%).

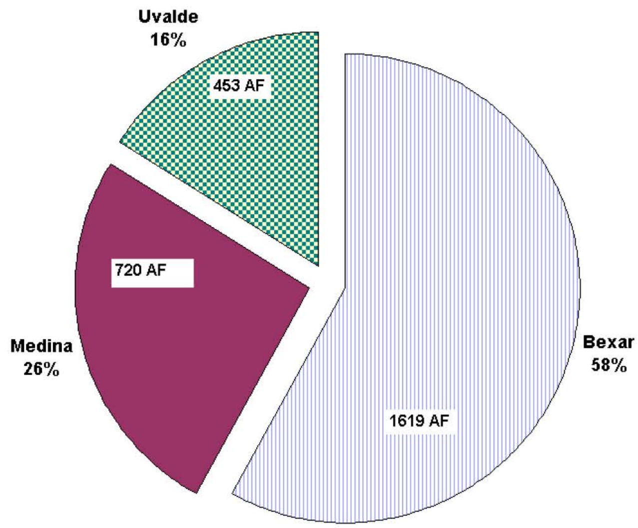

Figure 2.2 Cibolo Transfers (west to east) by County as of 2005

Figure 2.3 shows the same information as Figure 2.2, but also includes the transferred permits shown as a percent of the total permits by the Authority (572,000 acre-feet per year). The transferred rights equal 0.51 percent of total permitted rights.

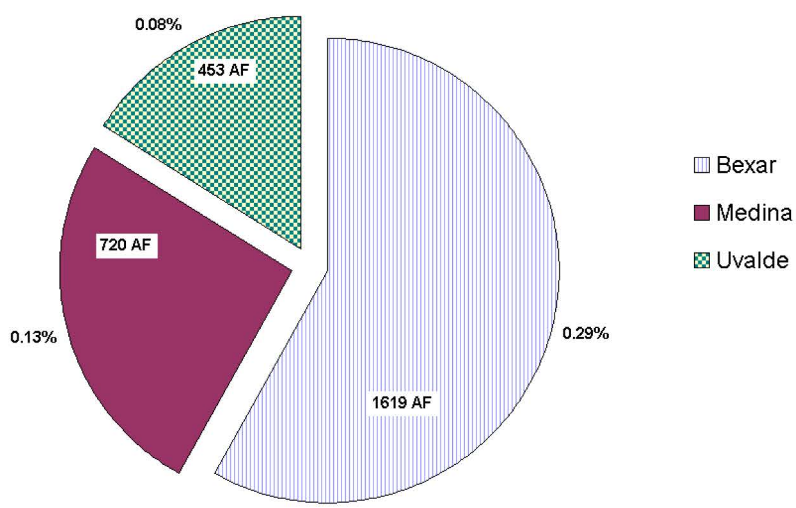

Figure 2.3 Cibolo Transfers by County (west to east) as Percent of Total Permits (as of 2005)

Figure 2.4 shows the volume (as a percent of total transfers) for the receiving counties. The figure clearly indicates that Comal County receives the largest volume of Cibolo transfers as of 2005.

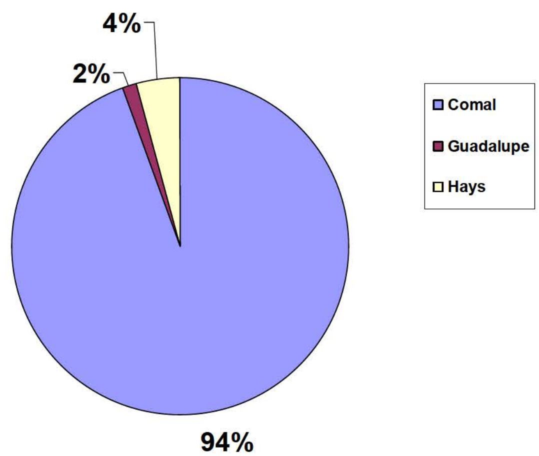

Figure 2.4 Volume of Cibolo Transfers for Receiving County

3.0 Assessment of MODFLOW Model

The effects of faults were incorporated in the model using the MODFLOW horizontal-flow barrier package (Lindgren and others, 2004). The horizontal-flow barrier (HFB) package simulates thin, vertical low permeability geologic features that impede the horizontal flow of ground water. These geologic features are approximated as a series of horizontal-flow barriers conceptually situated on the boundaries between pairs of adjacent cells in the finite difference model grid. The width of the barrier is assumed to be negligibly small relative to the horizontal dimensions of the cells in the grid, and the barrier is assumed to have zero storage capacity. Its sole function is to lower the horizontal conductance between the two cells that it separates. Lindgren and others (2004), indicate that the placement of horizontal-flow barriers in the model grid was determined by overlaying the model grid on an areal map of faults. Horizontal-flow barriers (HFB) were placed at the boundaries of cells crossed by the trace of a fault. Lindgren and others (2004) discuss the assumptions regarding the hydraulic characteristics of the faults implemented into the MODFLOW model.

3.1 Springs and Faults

To assess springs and faults in MODLOW, the location of mapped faults were compared to the location of simulated faults. Figure 3.1 shows the location of mapped faults and faults that have been implemented into the MODFLOW model near Comal Springs. The color of the HFB faults indicates the horizontal hydraulic conductivity of the fault between two MODFLOW gridblocks. Red faults indicate zero hydraulic conductivity, and result in no flow across the gridblocks. Orange and yellow HFB faults indicate successively higher hydraulic conductivity perpendicular to the fault. The faults implemented near Comal Springs (indicated by the red line) allow very little flow from north to south near the springs. Model results indicate that simulated springflow and heads can vary on either side of this no-flow barrier based on the location of the pumping.

Figure 3.1 also shows the hydraulic conductivity of the Edwards aquifer as simulated in the model. The location of the simulated conduits is evident in the darker colored zones. The location and hydraulic conductivity of these conduits also has an impact on transfers based on the location of the transferred pumpage.

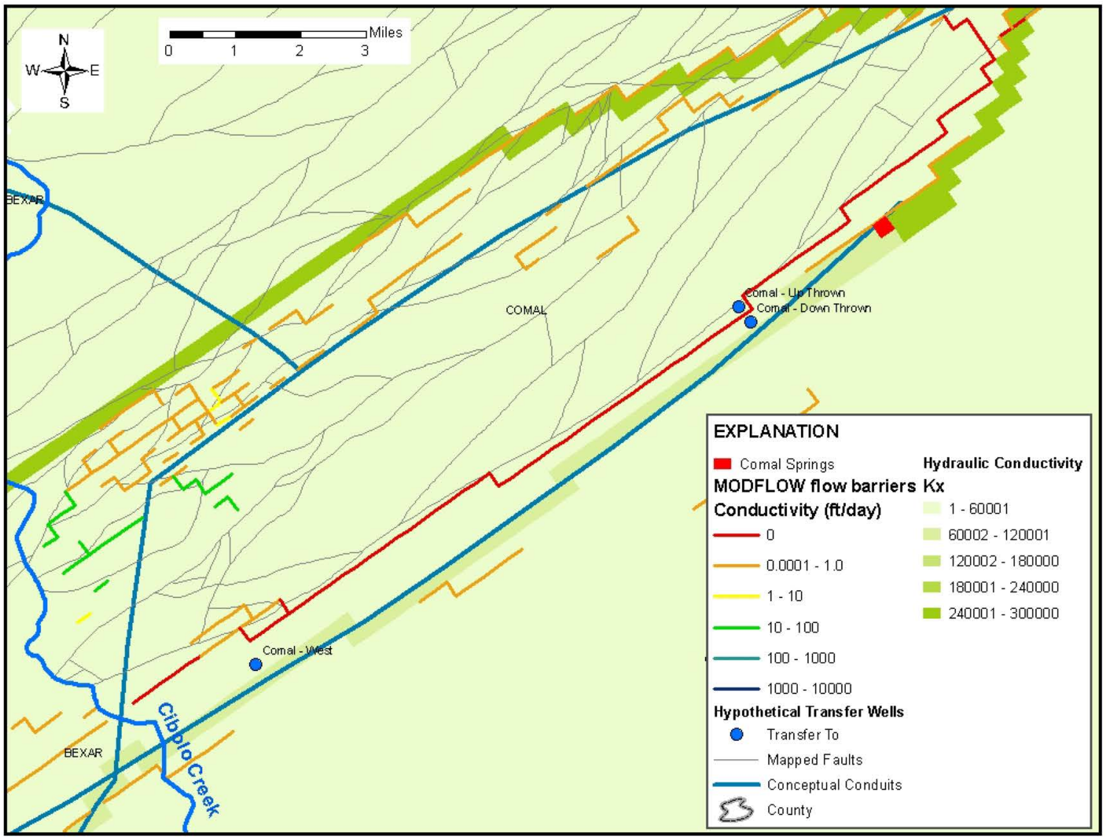

Figure 3.1 Location of Actual and Simulated Faults near Comal Springs

Figure 3.2 shows the location of mapped faults and HFB faults that have been implemented into the MODFLOW model near San Marcos Springs. The faults implemented near San Marcos Springs (indicated by the orange and red lines) allow more water movement from north to south near the HFB faults near Comal Springs. The implementation of the HFB faults produces a significant anisotropy along the mapped faults by greatly reducing the hydraulic conductivity in the downdip direction.

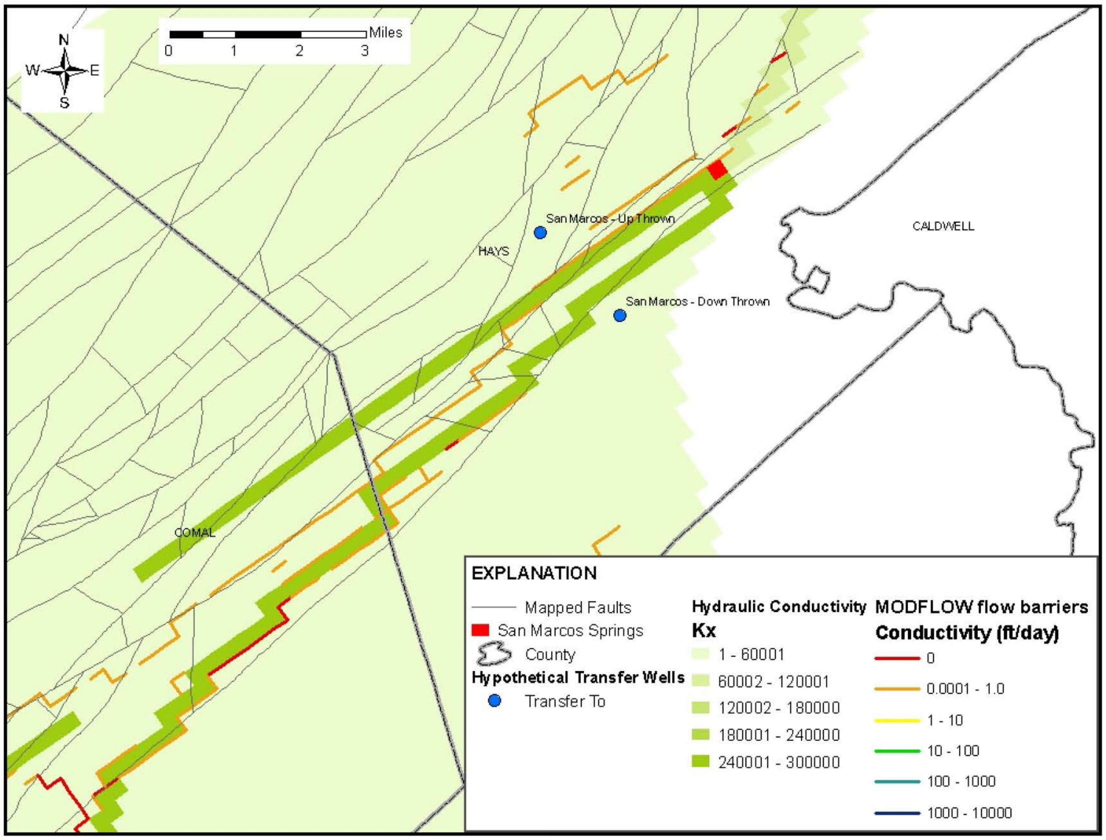

Figure 3.2 Location of Actual and Simulated Faults near San Marcos Springs

Figure 3.3 shows the connection between Comal and San Marcos Springs in the model. This figure helps illustrate in general how groundwater moves from west to east in the Edwards aquifer and how various model characteristics might impact the outcome of simulated transfer scenarios.

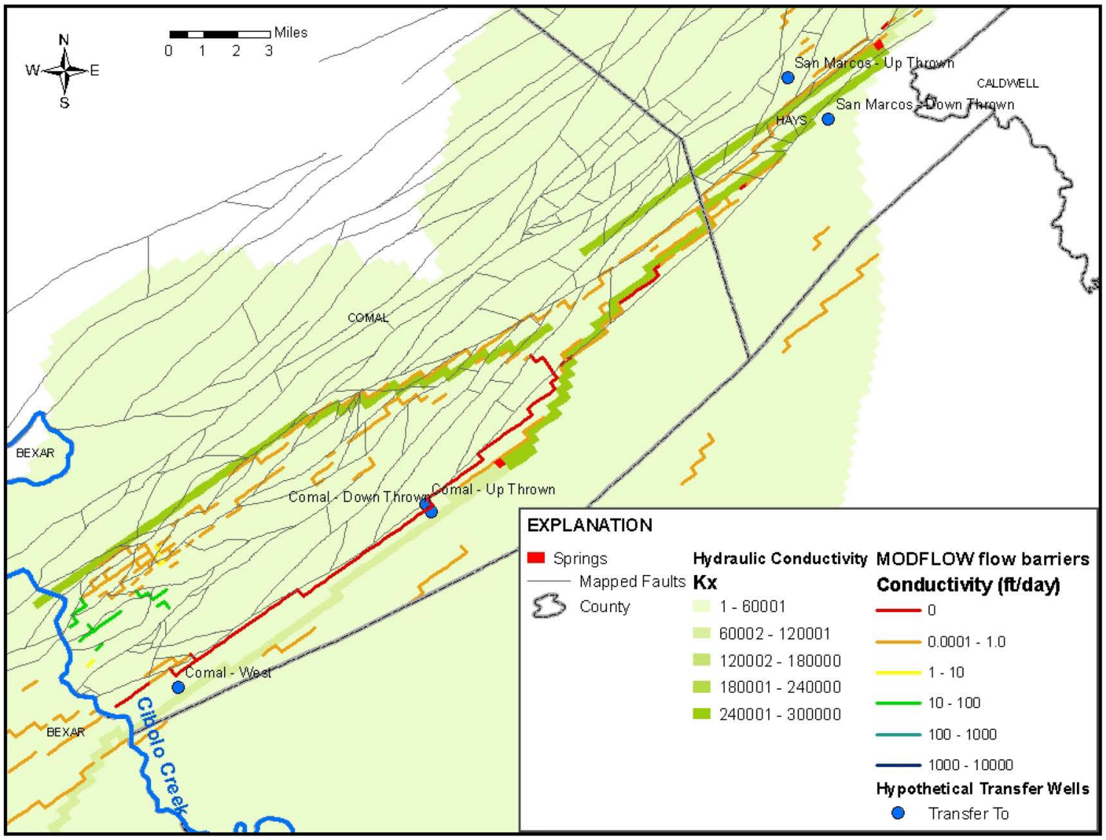

Figure 3.3 Location of Actual and Simulated Faults in Comal and Hays Counties

3.2 Quantity and Location of Pumping in MODFLOW Model

Table 3.1 compares the volume of permits that exist east of Cibolo Creek.

Table 3.1 County Comparison of Pumping in Permit Database

County	Permit Volume (acre-feet/year)
Comal	21,853
Hays	8,669

3.3 Using MODFLOW to Evaluate Cibolo Transfers

Assessment of the faults and springs in the MODFLOW model indicates that the model is generally consistent with the current conceptual model of the aquifer. Previous studies by LBG-Guyton Associates (2006) determined that a modeling evaluation using the standard version of the USGS MODFLOW-2000 code was limited because of dry cell problems. For that reason, LBG-Guyton Associates (2006) limited total pumping to 100,000 af/yr to perform an assessment of Cibolo transfers. The assessment documented herein has implemented a new version of MODFLOW known as MODFLOW-NR (SwRI, 2007) that handles the dry cell problem more robustly, and thus allows increased pumping (572,000 af/yr). With the exception of implementing the Newton-Raphson solver, the MODFLOW model input files developed for the Edwards Aquifer Authority (Lindgren and others, 2004) were used for this evaluation.

3.4 Model and Study Limitations

Lindgren (2004) documents the model limitations in detail. In general, Lindgren identifies three main types of limitations, including:

1. assumptions for conceptual and numerical models,
2. limitations of input data, and
3. scale of application.

All of those limitations are applicable to this study and should be considered when assessing the results of this study. Several other assumptions and limitations specific to this study should be noted.

First, only one well was used to transfer production from, and that well was located in western Bexar County. This study did not consider how the results might be affected if the production was transferred from a different location in the model, such as Medina or Uvalde County.

The production that was transferred in this study was an agricultural irrigation well. Therefore, production from the well was seasonally adjusted according to the assumed seasonal distribution for all irrigation wells in the model. The seasonal irrigation adjustment was used in the non-transfer and transfer simulations so that only one variable (location) was modified in the comparitive runs. This avoids the confusion of trying to sort out the impact of multiple variables in the comparative simulations.

The average mass balance error in these runs was ±20 af/yr. Therefore, it is not recommended that the model be used to assess transfers less than 50 af/yr. The smallest transfer simulated in this study was 78 af/yr, and the general results of this scenario were consistent with larger transfers. Therefore, we feel the results of that simulation are appropriate.

4.0 Assessment of Cibolo Transfers

Assessment of each hypothetical transfer requires two simulations. The first simulation is a baseline run to determine springflow and heads with the production at the original location. The second simulation simply moved the hypothetical permit to a new location for pumping. The change in springflow and heads resulting from the transfer were then calculated based on the difference between the simulations. For the evaluation herein, five new locations were considered, and thus five scenarios were run and compared to the baseline results.

4.1 Evaluation of Impact

Model simulations focused on addressing the impact of water rights transferred from west of Cibolo Creek to east of Cibolo Creek. The results of the simulations were evaluated to determine the impact of transfers on:

- J-17 water levels
- Springflow from Comal and San Marcos Springs
- Number of months in each critical period stage for J17, Comal and San Marcos Springs.

All scenarios were run using the MODFLOW model that simulates the recharge conditions from 1947 through 1973. During this 26-year period, the hydrologic conditions vary significantly and include the drought from 1950-1956 and several wet periods. All simulations were completed with a total aquifer withdrawal of 572,000 acre-feet per year of permitted production and a domestic (unpermitted) demand of 13,300 acre-feet per year, for a total annual average of 585,300 acre-feet per year. The actual location of the transferred permit is in western Bexar County, as shown in Figure 4.1. To assess the impact of Cibolo transfers, the following variables were considered:

1) new production locations ("transfer to"), including
   i) Two sites near San Marcos Springs (one in the up-thrown block and one in the down-thrown block)
   ii) Two sites near Comal Springs (one in the up-thrown block and one in the down-thrown block)
   iii) Western Comal County
2) permit amounts, including
   i) 782 acre-feet/year (Scenario 1)
   ii) 78 acre-feet/year (Scenario 2)
   iii) 2,353 acre-feet/year (Scenario 3)
   iv) 4,743 acre-feet/year (Scenario 4)

Scenario 1, with a transfer volume of 782 acre-feet per year, was selected because it is an actual permit volume in western Bexar County. Scenario 2 represents a transfer volume equal to 10% of Scenario 1. The transfer volume in Scenarios 3 and 4 was roughly equal to about three and six times the amount in Scenario 1.

All scenarios incorporated a seasonal adjustment for permits as shown in Table 4.1. The table shows the percent of the yearly total that is pumped in each month in each category. The seasonal adjustment was incorporated because it is more realistic than pumping the wells at a constant level throughout the year and provides insight into the maximum impact that could be expected during the heaviest summer pumping. Because both municipal and irrigation pumping are heavier during the summer months and these types of pumping account for most of the production, there is a significantly higher amount of pumping in summer than during winter months. The resulting monthly pumpage is illustrated in Figure 4.2. The seasonal adjustment was incorporated in all production estimates, including the permits for 30,522 acre-feet per year east of Cibolo Creek.

Table 4.1 Percent of Yearly Pumping Implemented for each Month for Each Pumping Category in the Seasonally Adjusted Runs

Month	Municipal	Industrial	Agricultural
January	6.9	8.33	1.1
February	6.4	8.33	1.5
March	7.5	8.33	2.6
April	8.0	8.33	5.7
May	8.4	8.33	19.0
June	9.1	8.33	29.0
July	11.0	8.33	16.1
August	11.1	8.33	9.9
September	9.0	8.33	4.7
October	8.4	8.33	5.2
November	7.1	8.33	3.8
December	7.1	8.33	1.4

Figure 4.1 also shows the hypothetical transfer locations east of Cibolo Creek. The transfer permit was selected at random from those located in western Bexar County. The range of permit amounts was selected to assess the impact of different transfer volumes.

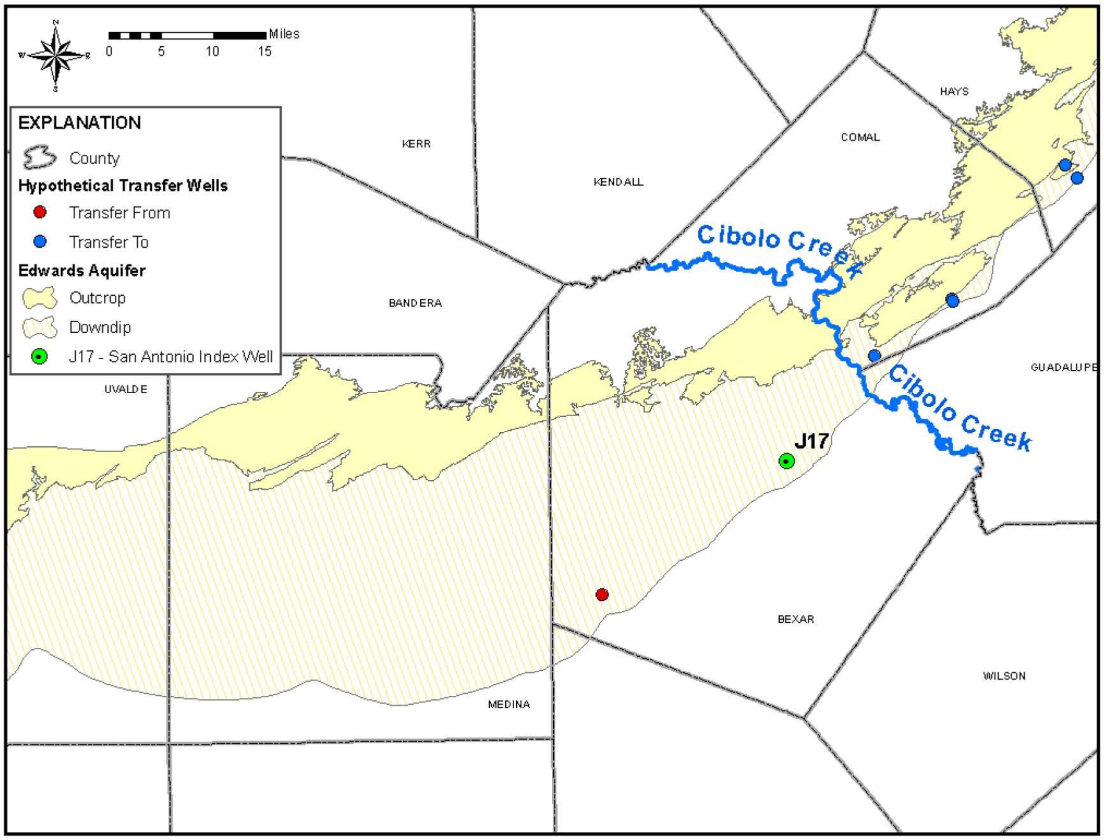

Figure 4.1 Location of Hypothetical Transferred Permits

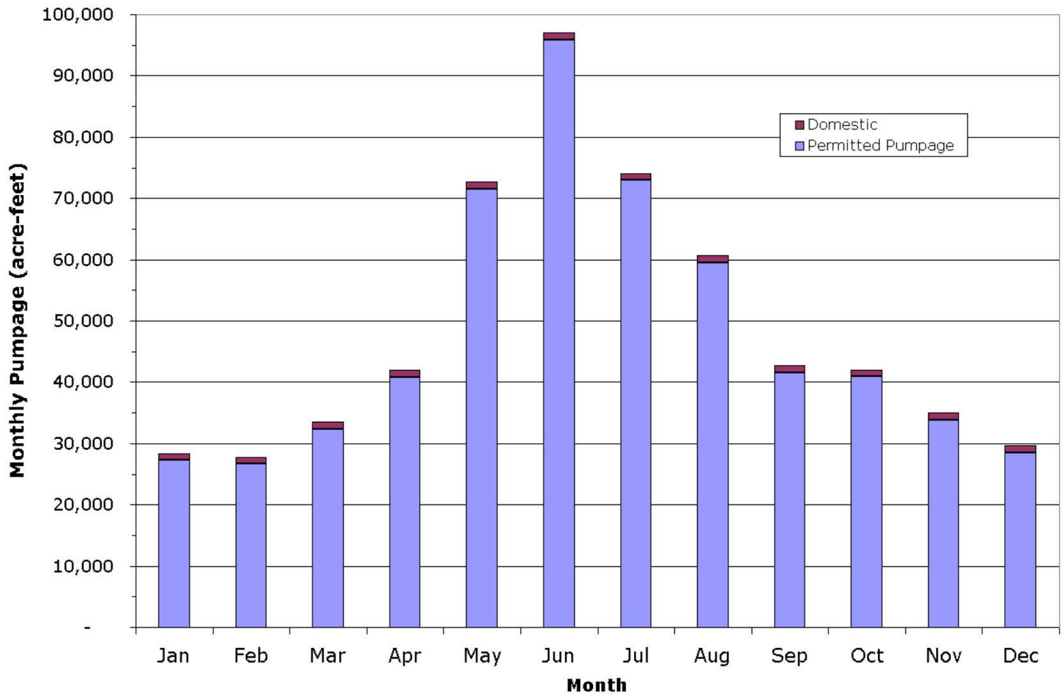

Figure 4.2 Monthly distribution of pumpage in the model assuming 572,000 acre-feet/year permitted pumping.

4.2 Results from Cibolo Transfer Scenarios

4.2.1 782 af/yr Transfer – Scenario 1

Scenario 1 was completed to simulate the impact of transferring 782 acre-feet per year from the original location in western Bexar County to the 5 new locations east of Cibolo Creek. The transfer volume of 782 acre-feet per year was selected because it is an actual permit volume in western Bexar County. Figure 4.3 illustrates the simulated J-17 water level for the baseline and five transfer scenarios. Figure 4.3 contains 6 lines that overlap most of the time, indicating that the overall changes in J-17 water levels are relatively small. A better way to observe the effect of the transfers is to compare the baseline simulation (with production in the original location) to the transfer simulation (with production shifted to the new location). There are many graphs associated with the analysis, and therefore, they have been included in Appendix A and are discussed in the following paragraphs.

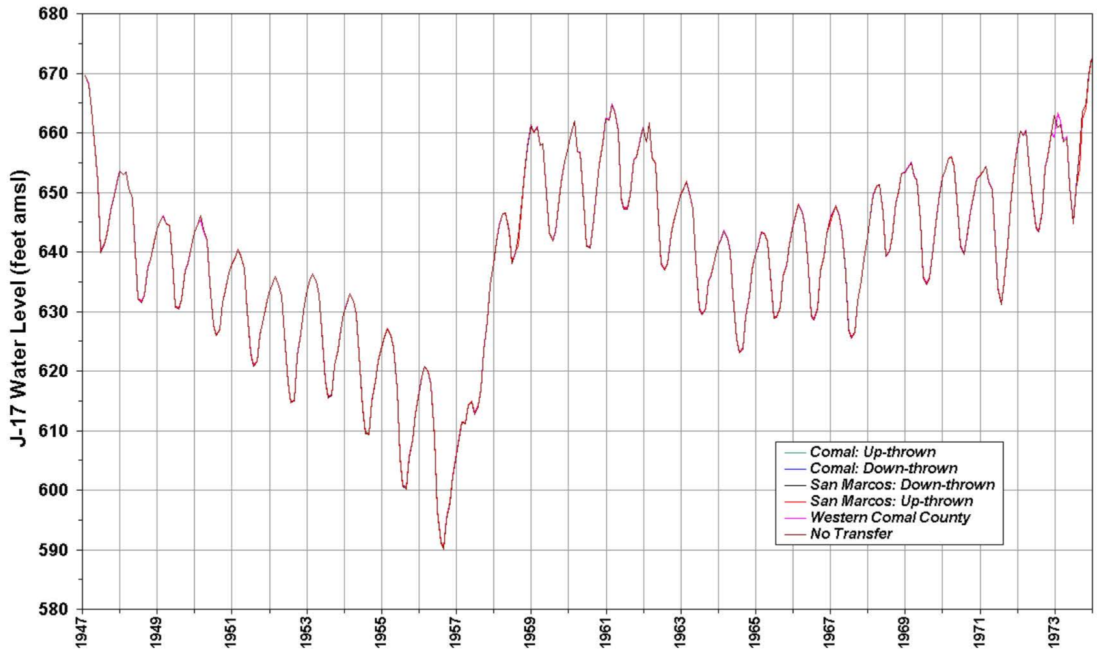

Figure 4.3 Simulated Water Level Elevation in J-17 for the No Transfer and Five Transfer Scenarios from Bexar County (782 af/yr)

Appendix A contains a series of graphs that illustrate the differences between the baseline run and transfer scenarios of the different scenarios. Figures A1 through A11 show the results of transferring the original 782 acre-feet per year from western Bexar County to five different locations east of Cibolo Creek. Results indicate the impact of the seasonal production increase during summer. Figure A1 shows the change in springflow and J-17 water level after transferring 782 af/yr to near Comal Springs (up-thrown block). Figure A2 shows the change in springflow and J-17 water level after transferring 782 af/yr to near Comal Springs (down-thrown block).

Figure A3 shows the change in springflow and J-17 water level after transferring 782 af/yr to near San Marcos Springs (down-thrown block). Figure A4 shows the change in springflow and J-17 water level after transferring 782 af/yr to near San Marcos Springs (up-thrown block). Figure A5 shows the change in springflow and J-17 water level after transferring 782 af/yr to the western part of Comal County (near the county line).

Figures A6 through A9 provide the same information as Figures A1 through A5, except that each plot compares a particular response (springflow or J-17 water level) for all five scenarios, each containing a different withdrawal location. Figure A6 compares Comal springflow after transferring 782 af/yr from western Bexar County to the five locations east of Cibolo Creek. Likewise, Figures A7 through A9 show responses in San Marcos springflow, total springflow, and J-17 water levels, respectively, from transferring production to five different locations.

Figure A10 illustrates why there are significant spikes in the results shown in Figures A1 through A9. For example, as shown in Figure A10, during November of 1972, the simulated water levels and springflow for all the scenarios is very similar. However, close inspection indicates that the water level in J-17 for the baseline scenario (no transfer) is slightly below 660 feet amsl (Stage I) and the other five scenarios estimate the J-17 water level to be slightly above 660 feet amsl. The simulated water level at J-17 is slightly lower in the baseline run because production in the original location is upgradient from J-17, as opposed to being significantly downgradient in the other scenarios. Therefore, in the baseline simulation with no transfer, the critical period withdrawal reductions are implemented, but this is not the case for the five transfer scenarios in which the withdrawal reduction is not implemented during that month. That is why there is a significant spike in the change in water level and springflow in the following months when comparing the five transfer scenarios to the baseline. Figure A10 also indicates that the difference in J-17 for the baseline and the transfer runs because of this irregularity do diminish after about four months. Although not evaluated in this study, it is likely that the distance of the original permit from Cibolo Creek would affect the magnitude of impact on water levels and springflow east of Cibolo Creek.

Figures 4.4 and 4.5 illustrate the simulated spring discharge for Comal and San Marcos springs, respectively, for the baseline and five transfer scenarios. As indicated by the overlapping lines in the graph, the overall changes in spring discharge are relatively small when compared to the total springflow. The model indicates that under the production rate assumed for these simulations, Comal Springs does stop flowing for 29 months during the 27-year period but San Marcos Springs does not go dry.

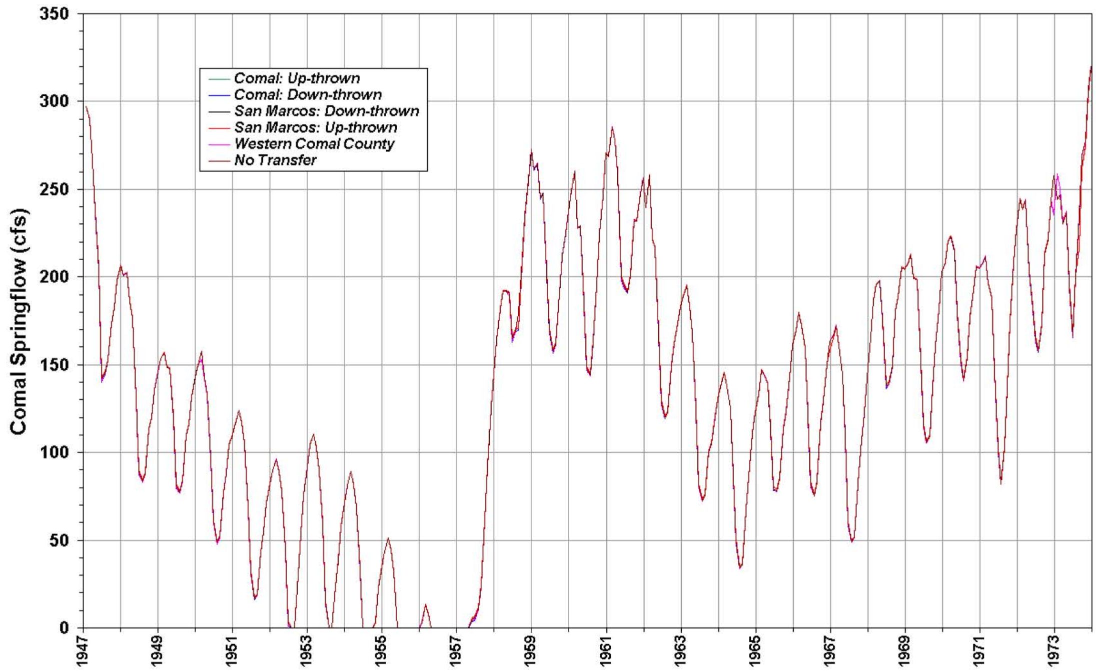

Figure 4.4 Simulated Comal Springflow for the No Transfer and Five Transfer Scenarios from Bexar County (782 af/yr)

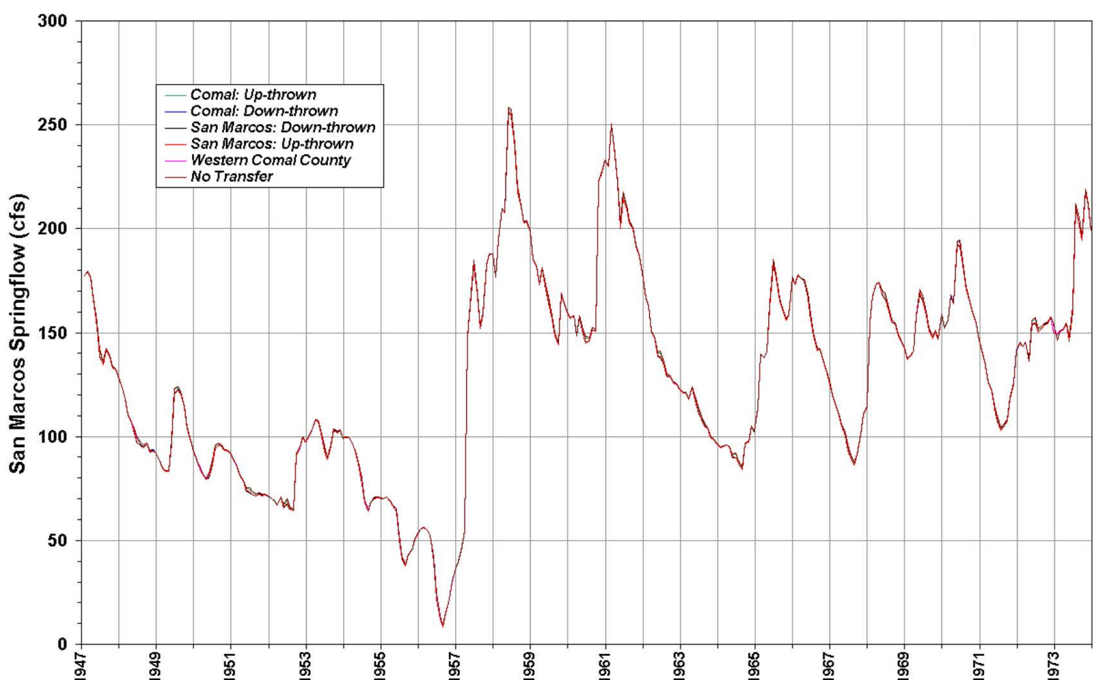

Figure 4.5 Simulated San Marcos Springflow for the No Transfer and Five Transfer Scenarios from Bexar County (782 af/yr)

Table 4.2 summarizes the average impact to springflow and J-17 water level over the 27-year simulation period (1947-1973). The table shows the average value of the change for the 324 monthly stress periods. The total springflow is the sum of Comal, San Marcos, San Pedro and San Antonio springflow. Negative values indicate that on average, the springflow or water level decreases due to the transfer to that location. Positive values indicate that the springflow or water level increases due to the transfer to that location.

Table 4.2 Average Change in Springflow and Water Level from Bexar County Transfer (782 af/yr)

Transfer from Bexar County to	Average Change in Springflow or Water Level (1947-1973)					
	Comal Springflow (cfs)	San Marcos Springflow (cfs)	San Pedro Springflow (cfs)	San Antonio Springflow (cfs)	Total Springflow (cfs)	J17 Water Level (feet)
Comal: Up-thrown block	0.10	-0.50	0.00	0.00	-0.41	0.08
Comal: Down-thrown block	-0.28	-0.02	0.00	0.00	-0.30	0.09
San Marcos: Down-thrown block	0.35	-0.85	0.00	0.00	-0.51	0.10
San Marcos: Up-thrown block	0.35	-0.85	0.00	0.00	-0.50	0.10
Western Comal County	-0.14	-0.02	0.00	0.00	-0.15	0.05

Table 4.2 indicates that Comal and San Marcos Springs react differently depending on the new location of the transfer withdrawal. At Comal Springs, springflow actually increases if production is transferred to the up-thrown block near Comal Springs or the up-thrown block or down-thrown block near San Marcos Springs. Springflow from Comal Springs is decreased (on average) if production is transferred to the down-thrown block near Comal Springs or to western Comal County. By contrast, San Marcos springflow and total springflow is decreased regardless of the transfer location, although the reduction is more significant when the production is transferred to the up-thrown block near Comal Springs, or either the up-thrown block or down-thrown block near San Marcos Springs. The average water level in J-17 increases slightly, which is logical because the production is occurring further downgradient in the flow system from J-17 and therefore, the same amount of pumping does not have as much impact on the J-17. As expected, J-17 water levels increase the most when the production is transferred farther east (i.e., near San Marcos Springs), and increase the least if the production is transferred to western Comal County.

Table 4.3 shows the same information as Table 4.2, except that the change in springflow is presented as a percent of the transferred volume. For example, a value of -46% is calculated by dividing the average change in springflow at San Marcos Springs due to a transfer to the up-thrown block near Comal Springs (-0.50 cfs from Table 4.2) by the total volume of the transfer (1.08 cfs). This is only one way to represent the change. Another approach might be to calculate the change as a percent of the total springflow. However, the values of total springflow vary significantly throughout the simulation. If evaluated that way, the impact of any particular transfer will become a larger portion of the total springflow as total production from the aquifer increases.

Table 4.3 Average Change in Springflow from Bexar County Transfer (782 af/yr) as a Percent of the Transfer Amount

Transfer from Bexar County to	Average Change in Springflow (1947-1973)				
	Comal Springflow	San Marcos Springflow	San Pedro Springflow	San Antonio Springflow	Total Springflow
Comal: Up-thrown block	9%	-46%	0%	0%	-38%
Comal: Down-thrown block	-26%	-2%	0%	0%	-27%
San Marcos: Down-thrown block	32%	-79%	0%	0%	-47%
San Marcos: Up-thrown block	33%	-79%	0%	0%	-47%
Western Comal County	-13%	-1%	0%	0%	-14%

Another way to measure the impact of Cibolo transfers is to compare how often critical period stages (springflow or J-17 water levels) are simulated with and without the transfer. For these simulations, there are 324 monthly stress periods for which a water level and springflow are simulated. These monthly values represent an average condition for the month. Table 4.4 tabulates the number of months (out of 324) that the J-17 index well in San Antonio is in various critical period stages with and without the transfer (782 af/yr) to various locations.

Table 4.4 Number of Months (out of 324) that J-17 Index Well is in Critical Period Stages from 1947-1973 with Bexar County Transfer (782 af/yr)

Transfer from Bexar County to	Stage 1 (<660 feet amsl)	Stage 2 (<650 feet amsl)	Stage 3 (<640 feet amsl)	Stage 4 (<630 feet amsl)
No Transfer	301	242	151	77
Comal: Up-thrown block	301	240	148	77
Comal: Down-thrown block	301	240	148	77
San Marcos: Down-thrown block	301	240	148	77
San Marcos: Up-thrown block	301	240	148	77
Western Comal County	301	241	150	77

Table 4.4 indicates that the model results show no change in the number of months that J-17 is in Stage 1 or Stage 4, regardless of transfer location. If production is transferred to near Comal Springs or San Marcos Springs:

- the number of months that J-17 is in Stage 2 is reduced by 2 months (0.62% of time)
- the number of months that J-17 is in Stage 3 is reduced by 3 months (0.93% of time).

If production is transferred to near western Comal County:

- the number of months that J-17 is in Stage 2 is reduced by 1 month (0.31% of time)
- the number of months that J-17 is in Stage 3 is reduced by 1 month (0.31% of time).

This result indicates that in some cases, Cibolo transfers would extend the period of time that Stage 2 and 3 restrictions would not be in place based on J-17 criteria, but only very slightly. It is important to remember that CP/DM criteria are based on J-17 water level and springflow from Comal Springs and San Marcos Springs. Therefore, both criteria must be considered.

To assess potential changes during drier periods, such as the drought of the 1950s, Table 4.5 was created. Table 4.5 tabulates the number of months (out of 96 months from 1950-1957) that the J-17 index well in San Antonio is in various critical period stages with and without the transfer (782 af/yr) to various locations. Based on this metric, the model indicates that the transfer does not impact the number of months that the J-17 index well is in the various critical period stages during dry periods.

Table 4.5 Number of Months (out of 96) that J-17 Index Well is in Critical Period Stages from 1950-1957 with Bexar County Transfer (782 af/yr)

Transfer from Bexar County to	Stage 1 (<660 feet amsl)	Stage 2 (<650 feet amsl)	Stage 3 (<640 feet amsl)	Stage 4 (<630 feet amsl)
No Transfer	96	96	90	65
Comal: Up-thrown block	96	96	90	65
Comal: Down-thrown block	96	96	90	65
San Marcos: Down-thrown block	96	96	90	65
San Marcos: Up-thrown block	96	96	90	65
Western Comal County	96	96	90	65

Table 4.6 tabulates the number of months (out of 324) that springflow from Comal Springs is in various critical period stages with the Bexar county transfer (782 af/yr) to various locations. Simulation results indicate that the impact on Comal Springs is mixed, but transfers to near San Marcos Springs generally slightly decreases the number of months that Comal Springs is in Stage 1, 2 and 3. For J-17 and Comal Springs, a transfer

does not impact the number of months in Stage 4. A transfer does not affect the number of months that Comal Springs is dry.

Table 4.6 Number of Months (out of 324) that Comal Springs is in Critical Period Stages from 1947-1973 with Bexar County Transfer (782 af/yr)

Transfer from Bexar County to	Stage 1 (<225 cfs)	Stage 2 (<200 cfs)	Stage 3 (<150 cfs)	Stage 4 (<100 cfs)	Dry (0 cfs)
No Transfer	281	252	181	107	29
Comal: Up-thrown block	282	250	180	107	29
Comal: Down-thrown block	281	252	180	107	29
San Marcos: Down-thrown block	280	250	179	107	29
San Marcos: Up-thrown block	280	250	179	107	29
Western Comal County	281	252	180	107	29

Table 4.7 tabulates the number of months (out of 96 months between 1950-1957) that the Comal Springs is in various critical period stages with and without the transfer (782 af/yr). Similar to the results summarized in Table 4.5, the model indicates that the transfer does not impact the number of months that Comal springflow is in the various critical period stages during dry periods.

Table 4.7 Number of Months (out of 96) that Comal Springs is in Critical Period Stages from 1950-1957 with Bexar County Transfer (782 af/yr)

Transfer from Bexar County to	Stage 1 (<225 cfs)	Stage 2 (<200 cfs)	Stage 3 (<150 cfs)	Stage 4 (<100 cfs)	Dry (0 cfs)
No Transfer	96	96	95	81	29
Comal: Up-thrown block	96	96	94	81	29
Comal: Down-thrown block	96	96	94	81	29
San Marcos: Down-thrown block	96	96	94	81	29
San Marcos: Up-thrown block	96	96	94	81	29
Western Comal County	96	96	94	81	29

Table 4.8 tabulates the number of months (out of 324) that springflow from San Marcos Springs is in critical period stages with the Bexar county transfer (782 af/yr) to various locations. Simulation results indicate that the impact on San Marcos Springs is mixed, but transfers to near San Marcos Springs generally slightly increases the number of months that San Marcos Springs is in Stage 1. Transfers do not impact the number of months in Stage 2. San Marcos Springs does not go dry in any of the simulations.

Table 4.8 Number of Months (out of 324) that San Marcos Springs is in Critical Period Stages from 1947-1973 with Bexar County Transfer (782 af/yr)

Transfer from Bexar County to	Stage 1 (<96 cfs)	Stage 2 (<80 cfs)	Dry (0 cfs)
No Transfer	92	52	0
Comal: Up-thrown block	93	52	0
Comal: Down-thrown block	92	52	0
San Marcos: Down-thrown block	95	52	0
San Marcos: Up-thrown block	95	52	0
Western Comal County	92	52	0

Table 4.9 tabulates the number of months (out of 96 months between 1950-1957) that the San Marcos Springs is in various critical period stages with and without the transfer (782 af/yr). Similar to the results summarized in Tables 4.5 and 4.7, the model indicates that the transfer does not impact the number of months that San Marcos springflow is in the various critical period stages during dry periods.

Table 4.9 Number of Months (out of 96) that San Marcos Springs is in Critical Period Stages from 1950-1957 with Bexar County Transfer (782 af/yr)

Transfer from Bexar County to	Stage 1 (<96 cfs)	Stage 2 (<80 cfs)	Dry (0 cfs)
No Transfer	73	52	0
Comal: Up-thrown block	73	52	0
Comal: Down-thrown block	73	52	0
San Marcos: Down-thrown block	74	52	0
San Marcos: Up-thrown block	74	52	0
Western Comal County	73	52	0

Observing the results of all six simulations provides the following general insights into Cibolo transfers of 782 acre-feet per year.

- Permits transferred farther east have more impact on San Marcos springflow.
- Permits transferred farther east result in a slightly higher water level in J-17.
- New withdrawal locations for transfers are a factor in determining the impact to Comal springflow due to the flow dynamics resulting from faults.
- For J-17 and Comal Springs, a transfer does not impact the number of months in Stage 4. A transfer does not affect the number of months that Comal Springs is dry.
- For San Marcos Springs, a transfer does not impact the number of months in Stage 2.

➢ There is no measurable impact on San Pedro and San Antonio Springs because there is almost never flow from these springs when permitted pumping is 572,000 acre-feet per year.

Figure 4.6 illustrates the global mass balance error in the MODFLOW model results for each of the six scenarios. The mass balance error is almost identical for each simulation, and is usually less than 50 acre-feet per year (about 4.2 acre-feet per month) in most stress periods except during the drought in 1955 and 1956. This indicates that the model results are appropriate for simulating springflow changes for transfers of this magnitude.

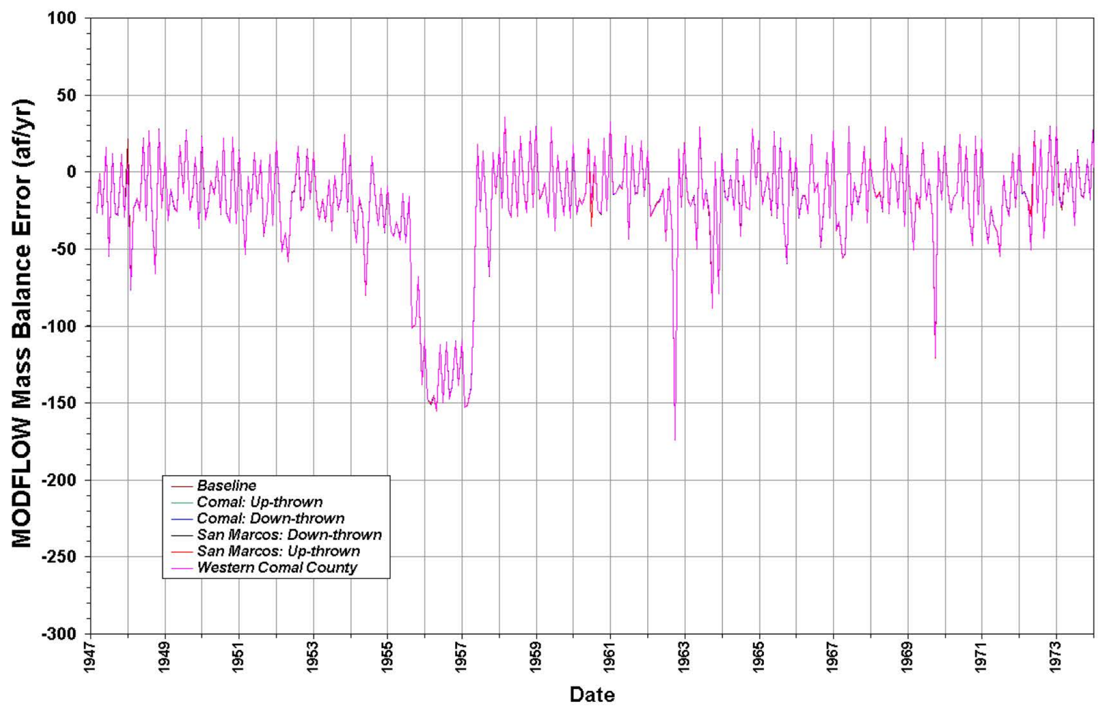

Figure 4.6 MODFLOW Global Mass Balance Errors for 782 af/yr Transfer Scenario

4.2.2 78 af/yr Transfer – Scenario 2

Scenario 2 simulates the impacts of smaller transfers; the transfer amount of 782 acre-feet per year was reduced by a factor of ten to 78 acre-feet per year. Figures A11 through A19 show the results of transferring 78 af/yr from western Bexar County to five different locations east of Cibolo Creek. These figures indicate that very little change in springflow and water levels occurs due to the transfer except for November of 1972, when the baseline run J-17 head is slightly less than Stage 1 and the transfer runs result in a J-17 head that is slightly greater than Stage 1. In this case, the simulated baseline head in November was 659.99, which is 0.01 feet less than Stage 1 and the simulated head in the transfer runs were 660 feet or slightly higher. Therefore, production from wells is reduced in the baseline run according to Stage 1 reductions, but the transfer runs do not implement a production cutback during that month, which leads about 3.7 feet head difference at J-17 in December 1972 when comparing the baseline run to the transfer runs. This is the spike that is evident in Figures A11 through A19.

Table 4.10 summarizes the average impact to springflow and J-17 water level over the 27-year simulation period (1947-1973). Table 4.11 shows the same information as Table 4.10, except that the change in springflow is presented as a percent of the transferred volume. Overall, the percentage change in springflow show the same direction (negative or positive) of impact as was simulated for the transfer that was ten times larger in Scenario 1. The magnitude of the average change for San Marcos Springs is roughly 10 times smaller than for Scenario 1, but the percentages are similar to Scenario 1. The percentage of change for Comal Springs and total springflow is generally more positive (less negative) than for Scenario 1.

Table 4.10 Average Change in Springflow and Water Level from Bexar County Transfer (78 af/yr)

Transfer from Bexar County to	Average Change in Springflow or Water Level (1947-1973)					
	Comal Springflow (cfs)	San Marcos Springflow (cfs)	San Pedro Springflow (cfs)	San Antonio Springflow (cfs)	Total Springflow (cfs)	J17 Water Level (feet)
Comal: Up-thrown block	0.03	-0.05	0.00	0.00	-0.02	0.01
Comal: Down-thrown block	-0.02	0.00	0.00	0.00	-0.02	0.01
San Marcos: Down-thrown block	0.06	-0.08	0.00	0.00	-0.02	0.01
San Marcos: Up-thrown block	0.06	-0.08	0.00	0.00	-0.02	0.01
Western Comal County	-0.01	0.00	0.00	0.00	-0.01	0.01

Table 4.11 Average Change in Springflow from Bexar County Transfer (78 af/yr) as a Percent of the Transfer Amount

Transfer from Bexar County to	Average Change in Springflow (1947-1973)				
	Comal Springflow	San Marcos Springflow	San Pedro Springflow	San Antonio Springflow	Total Springflow
Comal: Up-thrown block	28%	-44%	0%	0%	-16%
Comal: Down-thrown block	-16%	-1%	0%	0%	-17%
San Marcos: Down-thrown block	57%	-76%	0%	0%	-19%
San Marcos: Up-thrown block	57%	-76%	0%	0%	-19%
Western Comal County	-12%	-1%	0%	0%	-13%

Table 4.12 tabulates the number of months (out of 324) that the J-17 index well in San Antonio is in critical period stages with the Bexar county transfer (78 af/yr) to various locations. The table indicates very little change in the number of months that J-17 is in critical Stages 1 through 4 because the transfer volume (78 af/yr) is relatively small as compared to Scenario 1. The period between 1950 and 1957 are not summarized here because the transfer volume was smaller than in Scenario 1, and comparison of the results indicated that no change in the number of months occurred when 78 af/yr was transferred.

Table 4.12 Number of Months (out of 324) that J-17 Index Well is in Critical Period Stages with Bexar County Transfer (78 af/yr)

Transfer from Bexar County to	Stage 1 (<660 feet amsl)	Stage 2 (<650 feet amsl)	Stage 3 (<640 feet amsl)	Stage 4 (<630 feet amsl)
No Transfer	301	242	150	77
Comal: Up-thrown block	301	242	149	77
Comal: Down-thrown block	301	242	149	77
San Marcos: Down-thrown block	301	242	149	77
San Marcos: Up-thrown block	301	242	149	77
Western Comal County	301	242	150	77

Tables 4.13 and 4.14 tabulate the number of months (out of 324) that springflow from Comal Springs and San Marcos Springs respectively are in critical period stages with the Bexar county transfer (78 af/yr) to various locations. As with the J-17 water levels, the relatively small transfer volume does not significantly affect the percentage of time that the springs are in each critical stage.

Table 4.13 Number of Months (out of 324) that Comal Springs is in Critical Period Stages with Bexar County Transfer (78 af/yr)

Transfer from Bexar County to	Stage 1 (<225 cfs)	Stage 2 (<200 cfs)	Stage 3 (<150 cfs)	Stage 4 (<100 cfs)	Dry (0 cfs)
No Transfer	282	250	181	107	29
Comal: Up-thrown block	282	250	181	107	29
Comal: Down-thrown block	282	251	181	107	29
San Marcos: Down-thrown block	282	250	181	107	29
San Marcos: Up-thrown block	282	250	181	107	29
Western Comal County	282	250	181	107	29

Table 4.14 Number of Months (out of 324) that San Marcos Springs is in Critical Period Stages with Bexar County Transfer (78 af/yr)

Transfer from Bexar County to	Stage 1 (<96 cfs)	Stage 2 (<80 cfs)	Dry (0 cfs)
No Transfer	92	51	0
Comal: Up-thrown block	92	51	0
Comal: Down-thrown block	92	51	0
San Marcos: Down-thrown block	92	52	0
San Marcos: Up-thrown block	92	52	0
Western Comal County	92	51	0

4.2.3 2,353 af/yr Transfer – Scenario 3

Scenario 3 transferred 2,353 acre-feet per year (3.25 cfs), a volume about three times greater than that of Scenario 1. Figures A20 through A28 show the results of transferring 2,353 af/yr from western Bexar County to five different locations east of Cibolo Creek. As expected, the figures indicate a larger impact because of the larger transfer volume.

As shown in Figure A20, with few exceptions, J-17 and Comal Springs are consistently higher when the transfer is made to the up-thrown block near Comal Springs. On the other hand, San Marcos Spring and total springflow are almost always lower with this transfer. As with Scenario 1, transfers to near San Marcos Springs result in an increase in over 30 percent (as a percent of transfer volume) in Comal Springs and a decrease of almost 80 percent in San Marcos Springs. There are several large spikes in the change plots shown in Figure A20 through A24, which are caused by the modeling anomalies described in the previous sections for Scenarios 1 and 2.

Figure A25 indicates that transfers, depending on the location, can impact Comal Springs either positively or negatively throughout the year. Figure A26 indicates that transfers, regardless of location, almost always negatively impact San Marcos Springs.

Table 4.15 summarizes the average impact to springflow and J-17 water level over the 27-year simulation period (1947-1973) for a 2,353 acre-feet per year transfer when the aquifer production is seasonally adjusted. Table 4.16 contains the average change in springflow as a percent of the transfer volume. Average impacts shown in Table 4.16 are similar to those for Scenario 1. The decrease in total springflow (as a percent of the transfer volume) ranges from 2 to 38 percent depending on the transfer location.

Table 4.15 Average Change in Springflow and Water Level from Bexar County Transfer (2,353 af/yr)

Transfer from Bexar County to	Average Change in Springflow or Water Level (1947-1973)					
	Comal Springflow (cfs)	San Marcos Springflow (cfs)	San Pedro Springflow (cfs)	San Antonio Springflow (cfs)	Total Springflow (cfs)	J17 Water Level (feet)
Comal: Up-thrown block	0.60	-1.44	0.00	0.00	-0.84	0.30
Comal: Down-thrown block	-0.30	0.00	0.01	0.00	-0.29	0.35
San Marcos: Down-thrown block	1.26	-2.52	0.01	0.00	-1.25	0.34
San Marcos: Up-thrown block	1.28	-2.52	0.01	0.00	-1.24	0.34
Western Comal County	-0.08	-0.01	0.01	0.00	-0.07	0.22

Table 4.16 Average Change in Springflow from Bexar County Transfer (2,353 af/yr) as a Percent of the Transfer Amount

Transfer from Bexar County to	Average Change in Springflow (1947-1973)				
	Comal Springflow	San Marcos Springflow	San Pedro Springflow	San Antonio Springflow	Total Springflow
Comal: Up-thrown block	18%	-44%	0%	0%	-26%
Comal: Down-thrown block	-9%	0%	0%	0%	-9%
San Marcos: Down-thrown block	39%	-77%	0%	0%	-38%
San Marcos: Up-thrown block	39%	-78%	0%	0%	-38%
Western Comal County	-2%	0%	0%	0%	-2%

Table 4.17 tabulates the number of months (out of 324) that the J-17 index well in San Antonio is in critical period stages with the Bexar county transfer (2,353 af/yr) to various locations. Table 4.17 indicates that the transfer results in only small changes in the number of months that J-17 is in different stages, and that it is dependent on transfer location. Table 4.18 summarizes the impact from 1950-1957, and indicates that the number of months in a J-17 critical period do not change during the dry period except for

Stage 4. In this case, the transfer puts J-17 in Stage 4 for 65 months, instead of the 66 months without the transfer.

Table 4.17 Number of Months (out of 324) that J-17 Index Well is in Critical Period Stages from 1947-1973 with Bexar County Transfer (2,353 af/yr)

Transfer from Bexar County to	Stage 1 (<660 feet amsl)	Stage 2 (<650 feet amsl)	Stage 3 (<640 feet amsl)	Stage 4 (<630 feet amsl)
No Transfer	300	241	151	78
Comal: Up-thrown block	301	240	149	77
Comal: Down-thrown block	301	239	147	77
San Marcos: Down-thrown block	301	240	150	77
San Marcos: Up-thrown block	301	240	150	77
Western Comal County	301	240	149	77

Table 4.18 Number of Months (out of 96) that J-17 Index Well is in Critical Period Stages from 1950-1957 with Bexar County Transfer (2,353 af/yr)

Transfer from Bexar County to	Stage 1 (<660 feet amsl)	Stage 2 (<650 feet amsl)	Stage 3 (<640 feet amsl)	Stage 4 (<630 feet amsl)
No Transfer	96	96	90	66
Comal: Up-thrown block	96	96	90	65
Comal: Down-thrown block	96	96	90	65
San Marcos: Down-thrown block	96	96	90	65
San Marcos: Up-thrown block	96	96	90	65
Western Comal County	96	96	90	65

Tables 4.19 and 4.20 tabulate the number of months that Comal springflow is in critical period stages with the Bexar county transfer (2,353 af/yr) to various locations. As with the J-17 water levels, the transfer does not significantly affect the percentage of time that the Comal Springs are in each critical stage. Transfers to the down-thrown Comal block and to western Comal County dry up Comal Springs for one month longer (30 months) than does the no transfer scenario (29 months).

Table 4.19 Number of Months (out of 324) that Comal Springs is in Critical Period Stages from 1947-1973 with Bexar County Transfer (2,353 af/yr)

Transfer from Bexar County to	Stage 1 (<225 cfs)	Stage 2 (<200 cfs)	Stage 3 (<150 cfs)	Stage 4 (<100 cfs)	Dry (0 cfs)
No Transfer	281	253	180	107	29
Comal: Up-thrown block	281	250	179	107	29
Comal: Down-thrown block	280	254	180	108	30
San Marcos: Down-thrown block	280	249	176	107	29
San Marcos: Up-thrown block	280	249	176	107	29
Western Comal County	279	253	180	108	30

Table 4.20 Number of Months (out of 96) that Comal Springs is in Critical Period Stages from 1950-1957 with Bexar County Transfer (2,353 af/yr)

Transfer from Bexar County to	Stage 1 (<225 cfs)	Stage 2 (<200 cfs)	Stage 3 (<150 cfs)	Stage 4 (<100 cfs)	Dry (0 cfs)
No Transfer	96	96	94	81	29
Comal: Up-thrown block	96	96	94	81	29
Comal: Down-thrown block	96	96	94	81	30
San Marcos: Down-thrown block	96	96	94	81	29
San Marcos: Up-thrown block	96	96	94	81	29
Western Comal County	96	96	94	81	30

Tables 4.21 and 4.22 tabulate the number of months that San Marcos springflow is in critical period stages with the Bexar county transfer (2,353 af/yr) to various locations.

San Marcos Springs is impacted mainly in regards to the number of months in Stage 1, and is impacted most by the transfers close to San Marcos Springs and to the up-thrown block of Comal Springs. For example, if production is shifted to the up-thrown block near San Marcos Springs, there are 9 more months of the 324 months when San Marcos Springs is below Stage 1.

Table 4.21 Number of Months (out of 324) that San Marcos Springs is in Critical Period Stages from 1947-1973 with Bexar County Transfer (2,353 af/yr)

Transfer from Bexar County to	Stage 1 (<96 cfs)	Stage 2 (<80 cfs)	Dry (0 cfs)
No Transfer	92	52	0
Comal: Up-thrown block	99	52	0
Comal: Down-thrown block	92	52	0
San Marcos: Down-thrown block	100	53	0
San Marcos: Up-thrown block	101	53	0
Western Comal County	92	52	0

Table 4.22 Number of Months (out of 96) that San Marcos Springs is in Critical Period Stages from 1950-1957 with Bexar County Transfer (2,353 af/yr)

Transfer from Bexar County to	Stage 1 (<96 cfs)	Stage 2 (<80 cfs)	Dry (0 cfs)
No Transfer	73	52	0
Comal: Up-thrown block	75	52	0
Comal: Down-thrown block	73	52	0
San Marcos: Down-thrown block	75	53	0
San Marcos: Up-thrown block	75	53	0
Western Comal County	73	52	0

4.2.4 4,743 af/yr Transfer – Scenario 4

Scenario 4 transfers 4,743 acre-feet per year (6.6 cfs) east of Cibolo, which is about six times the volume of Scenario 1. Like all the other scenarios, these runs incorporated a seasonal adjustment for the aquifer withdrawals. Figures A29 through A37 show the results of transferring 4,743 af/yr from western Bexar County to five different locations east of Cibolo Creek. Figures A29 through A33 illustrate the same general trends seen in the other results except that the magnitude of the changes are larger.

Figure A34 shows that transfers to the up-thrown block near San Marcos Springs or Comal Springs positively affects Comal Springs flow, as do transfers to the down-thrown block near San Marcos Springs. As with Scenarios 1 through 3, Figure A35 indicates that San Marcos Springs discharge is almost always reduced with a transfer.

Figure A36 indicates that total springflow is usually reduced and is reduced the most during the summer months. Figure A37 shows that J-17 water level is almost always higher with transfers.

In the summer season, when production is greatest, the decrease in discharge from San Marcos Springs can be up to 15 cfs. This represents a change of over 200% when compared to average annual production rate (4,743 af/yr or 6.6 cfs) of the transfer. There are two reasons why this occurs. First, there is the seasonal increase in pumping during the summer as illustrated in Figure 4.7. Although the averaged annual production is 6.6 cfs, the monthly pumping in May, June, and July is almost 17 cfs due to the seasonal increase during the summer.

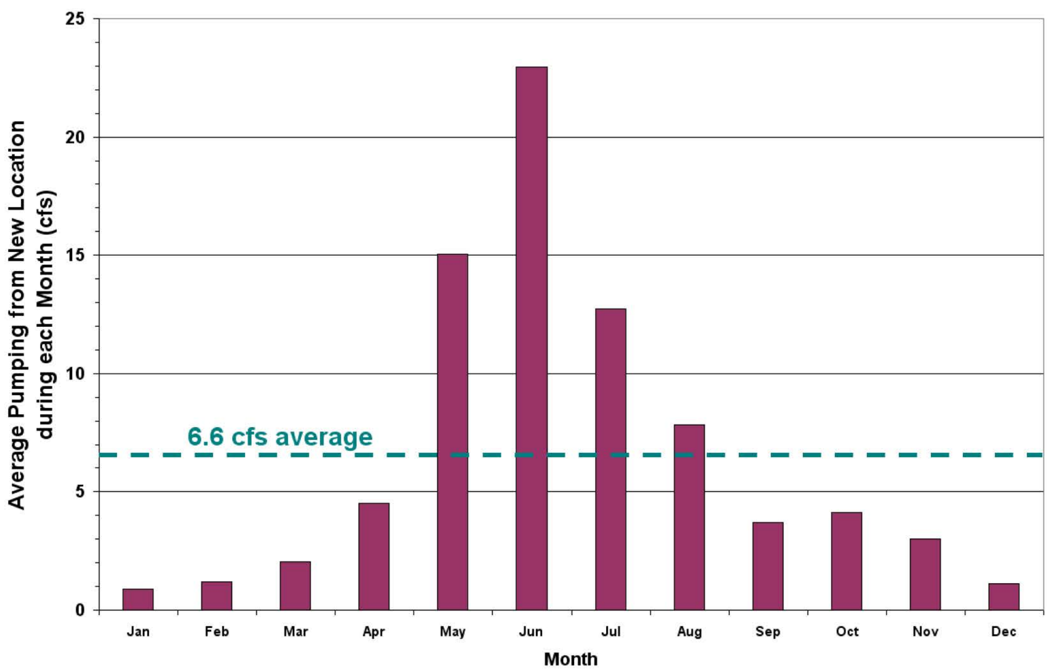

Figure 4.7 Monthly pumpage for Scenario 4.

Second, because the production has been moved closer to the springs, the relative decrease in water level from the same amount of pumping is greater. Figure 4.8 illustrates this well-accepted response of water level at different distances from a production well. The cone of depression, as it commonly referred to, shows the greatest water level decline near the production well and that the water level decline at distance is always less. Water level declines from a pumping well near the spring (e.g., when the permit is transferred) will therefore cause greater spring flow declines than the same production located a greater distance from the spring.

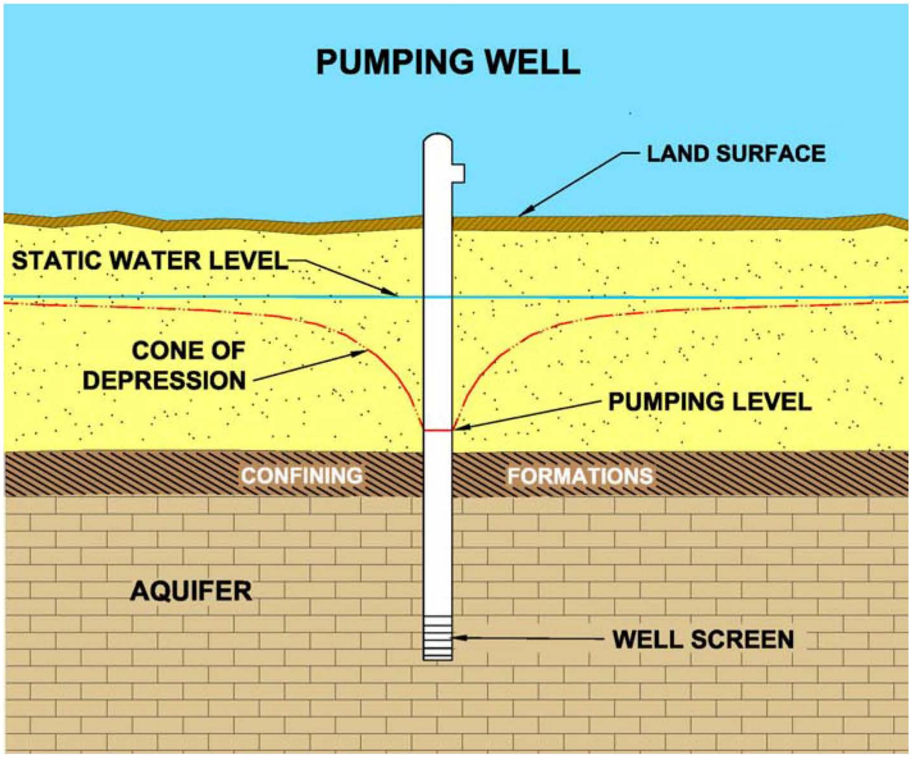

Figure 4.8 Schematic diagram showing water level depression around a production well

Table 4.23 summarizes the average impact to springflow and J-17 water level over the 27-year simulation period (1947-1973) for a 4,743 acre-feet per year transfer when the aquifer production is seasonally adjusted. Table 4.24 contains the average change in springflow as a percent of the transfer volume.

Table 4.23 Average Change in Springflow and Water Level from Bexar County Transfer (4,743 af/yr)

Transfer from Bexar County to	Average Change in Springflow or Water Level (1947-1973)					
	Comal Springflow (cfs)	San Marcos Springflow (cfs)	San Pedro Springflow (cfs)	San Antonio Springflow (cfs)	Total Springflow (cfs)	J17 Water Level (feet)
Comal: Up-thrown block	1.07	-2.92	0.01	0.00	-1.84	0.57
Comal: Down-thrown block	-0.96	-0.06	0.02	0.01	-1.00	0.63
San Marcos: Down-thrown block	2.51	-5.07	0.01	0.00	-2.54	0.67
San Marcos: Up-thrown block	2.48	-5.09	0.01	0.00	-2.61	0.66
Western Comal County	-0.47	-0.06	0.01	0.00	-0.51	0.39

Table 4.24 Average Change in Springflow from Bexar County Transfer (4,743 af/yr) as a Percent of the Transfer Amount

Transfer from Bexar County to	Average Change in Springflow (1947-1973)				
	Comal Springflow	San Marcos Springflow	San Pedro Springflow	San Antonio Springflow	Total Springflow
Comal: Up-thrown block	16%	-45%	0%	0%	-28%
Comal: Down-thrown block	-15%	-1%	0%	0%	-15%
San Marcos: Down-thrown block	38%	-77%	0%	0%	-39%
San Marcos: Up-thrown block	38%	-78%	0%	0%	-40%
Western Comal County	-7%	-1%	0%	0%	-8%

Table 4.25 tabulates the number of months (out of 324) that the J-17 index well in San Antonio is in critical period stages with the Bexar county transfer (4,743 af/yr) to various locations. Likewise, Table 4.26 tabulates the number of months (out of 96) during 1950 through 1957 that the J-17 index well is in various stages.

Table 4.25 Number of Months (out of 324) that J-17 Index Well is in Critical Period Stages from 1947-1973 with Bexar County Transfer (4,743 af/yr)

Transfer from Bexar County to	Stage 1 (<660 feet amsl)	Stage 2 (<650 feet amsl)	Stage 3 (<640 feet amsl)	Stage 4 (<630 feet amsl)
No Transfer	301	243	151	79
Comal: Up-thrown block	301	237	147	74
Comal: Down-thrown block	300	236	147	75
San Marcos: Down-thrown block	300	237	147	73
San Marcos: Up-thrown block	300	237	147	73
Western Comal County	301	239	147	77

Table 4.26 Number of Months (out of 96) that J-17 Index Well is in Critical Period Stages from 1950-1957 with Bexar County Transfer (4,743 af/yr)

Transfer from Bexar County to	Stage 1 (<660 feet amsl)	Stage 2 (<650 feet amsl)	Stage 3 (<640 feet amsl)	Stage 4 (<630 feet amsl)
No Transfer	96	96	90	66
Comal: Up-thrown block	96	96	90	64
Comal: Down-thrown block	96	96	90	64
San Marcos: Down-thrown block	96	96	90	63
San Marcos: Up-thrown block	96	96	90	63
Western Comal County	96	96	90	65

Figure 4.9 plots J-17 water level against the change in J-17 water level for Scenario 4 (4,743 af/yr transfer). Monthly results are shown for each of the five transfer locations. This plot indicates that transfers generally increase the water level in J-17 under most hydrologic conditions (i.e., high and low water levels). As discussed previously, the largest positive and negative changes in J-17 indicated by the outliers are related to the anomalies of the simulations wherein the no-transfer and transfer simulations hit management triggers (and therefore production cutbacks) one month apart, resulting in spikes in water level during those months.

Figure 4.10 plots Comal springflow against the change in Comal springflow for Scenario 4 (4,743 af/yr transfer). Monthly results are shown for each of the five transfer locations. This plot indicates that the transfers near San Marcos generally have a positive impact (increase discharge) from Comal Springs. Transfers to western Comal County or near Comal Springs generally decrease Comal discharge or do not greatly impact it.

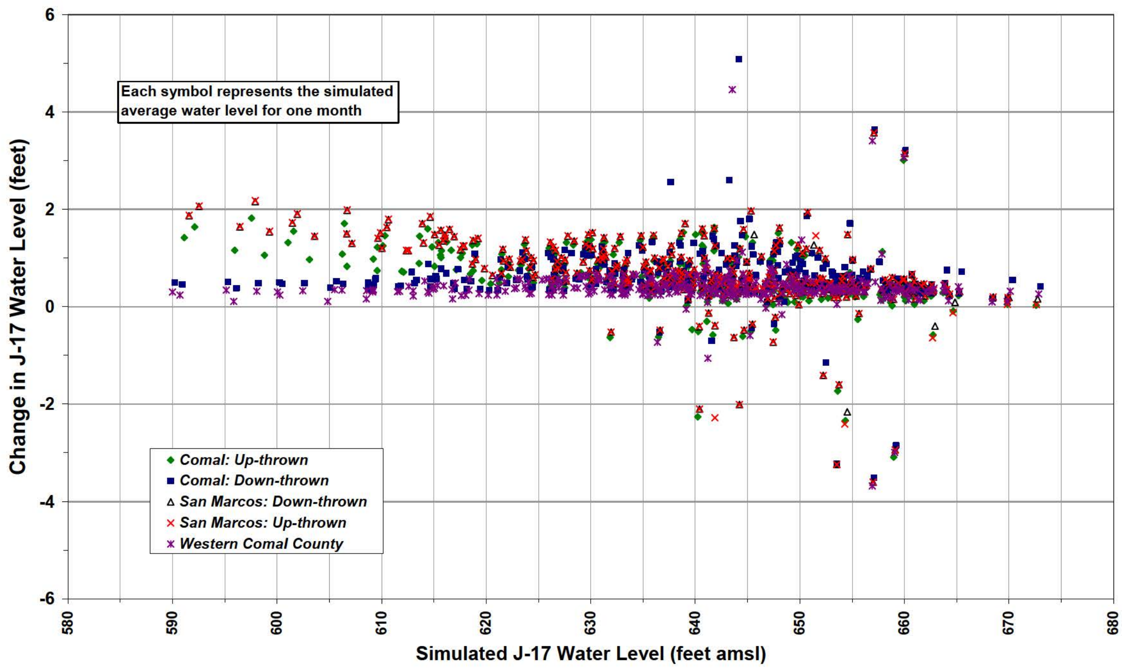

Figure 4.9 Change in J17 Water Level Plotted Against J17 Water Level After Transferring 4,743 af/yr (6.6 cfs)

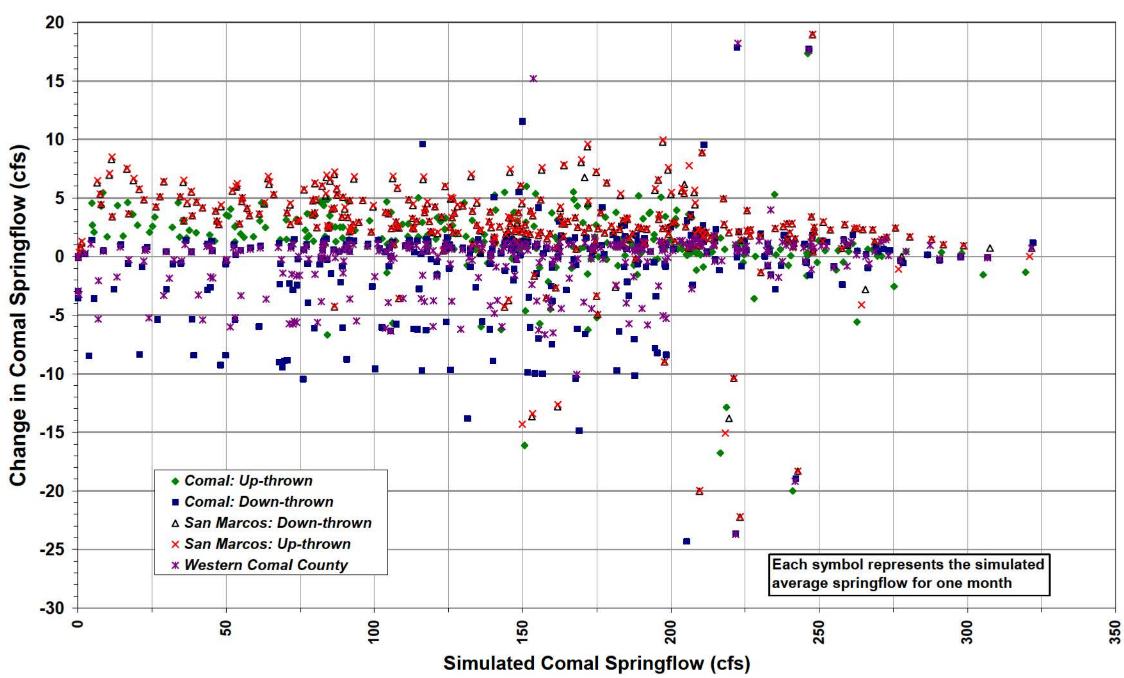

Figure 4.10 Change in Comal Springflow Plotted Against Comal Springflow After Transferring 4,743 af/yr (6.6 cfs)

Figure 4.9 plots San Marcos springflow against the change in San Marcos springflow for Scenario 4 (4,743 af/yr transfer). Monthly results are shown for each of the five transfer locations. This plot indicates that transfers to any location generally have a negative impact (decrease discharge) from San Marcos Springs. Transfers to near San Marcos Springs decrease San Marcos springflow the most.

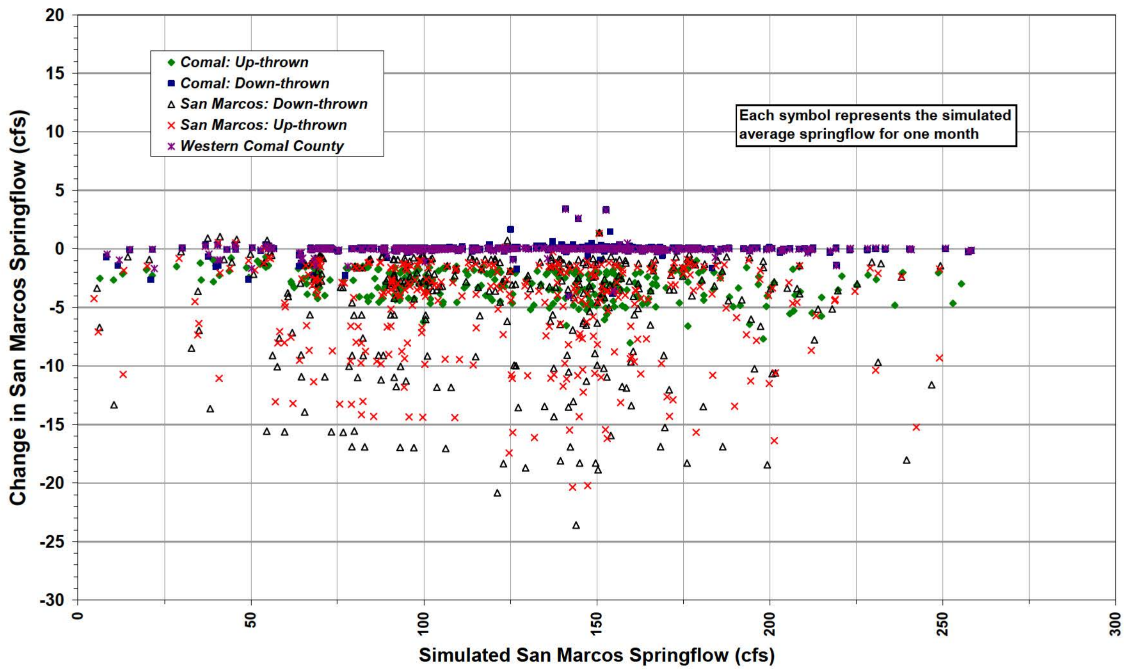

Figure 4.11 Change in San Marcos Springflow Plotted Against San Marcos Springflow After Transferring 4,743 af/yr

Tables 4.27 and 4.28 tabulate the number of months that Comal springflow is in critical period stages with the Bexar county transfer (4,743 af/yr) to various locations. As in previous scenarios, the model indicates that water level in J-17 is slightly less likely to reach critical stages when production is transferred to some locations. For Comal Springs, the number of dry months is decreased slightly if production is transferred to near San Marcos Springs.

Table 4.28 indicates that transfers have little impact on the number of months that Comal springflow is in various stages during the dry period from 1950-1957. It is important to remember that while the metric of "months in each stage" is a quantitative measure, it is sensitive to several factors. One important factor is the initial water level at the start of a particular period of evaluation, which is impacted by the overall production from the aquifer. If total permitted production from the aquifer was assumed to be less than

572,000 af/yr, slightly different values may result because of different conditions in the aquifer in 1950.

Table 4.27 Number of Months (out of 324) that Comal Springs is in Critical Period Stages from 1947-1973 with Bexar County Transfer (4,743 af/yr)

Transfer from Bexar County to	Stage 1 (<225 cfs)	Stage 2 (<200 cfs)	Stage 3 (<150 cfs)	Stage 4 (<100 cfs)	Dry (0 cfs)
No Transfer	281	252	181	109	29
Comal: Up-thrown block	283	249	176	107	29
Comal: Down-thrown block	282	254	179	109	32
San Marcos: Down-thrown block	280	248	176	107	25
San Marcos: Up-thrown block	280	247	177	107	25
Western Comal County	280	254	179	108	31

Table 4.28 Number of Months (out of 96) that Comal Springs is in Critical Period Stages from 1950-1957 with Bexar County Transfer (4,743 af/yr)

Transfer from Bexar County to	Stage 1 (<225 cfs)	Stage 2 (<200 cfs)	Stage 3 (<150 cfs)	Stage 4 (<100 cfs)	Dry (0 cfs)
No Transfer	96	96	94	81	29
Comal: Up-thrown block	96	96	94	81	29
Comal: Down-thrown block	96	96	94	81	32
San Marcos: Down-thrown block	96	96	94	81	25
San Marcos: Up-thrown block	96	96	94	81	25
Western Comal County	96	96	94	81	31

Tables 4.29 and 4.30 tabulate the number of months that springflow from San Marcos Springs is in critical period stages with the Bexar county transfer (4,743 af/yr) to various locations. As with Scenario 3, the model indicates that San Marcos discharge is more likely to reach critical stages when a transfer occurs to the up-thrown block at either spring or the down-thrown block at San Marcos Springs.

As with Comal Springs, the higher volume transfer in Scenario 4 also has a greater impact on Stage 2 (increased months in Stage 2) then did lower volume transfers. San Marcos Springs was not dry during any month of the simulation, regardless of the transfer.

Table 4.29 Number of Months (out of 324) that San Marcos Springs is in Critical Period Stages from 1947-1973 with Bexar County Transfer (4,743 af/yr)

Transfer from Bexar County to	Stage 1 (<96 cfs)	Stage 2 (<80 cfs)	Dry (0 cfs)
No Transfer	90	52	0
Comal: Up-thrown block	103	53	0
Comal: Down-thrown block	90	52	0
San Marcos: Down-thrown block	108	61	0
San Marcos: Up-thrown block	109	58	0
Western Comal County	91	52	0

Table 4.30 Number of Months (out of 96) that San Marcos Springs is in Critical Period Stages from 1950-1957 with Bexar County Transfer (4,743 af/yr)

Transfer from Bexar County to	Stage 1 (<96 cfs)	Stage 2 (<80 cfs)	Dry (0 cfs)
No Transfer	73	52	0
Comal: Up-thrown block	76	53	0
Comal: Down-thrown block	72	52	0
San Marcos: Down-thrown block	76	56	0
San Marcos: Up-thrown block	76	54	0
Western Comal County	73	52	0

4.2.5 Summary of Scenarios

Table 4.31 summarizes the impact to Comal springflow over the 27-year simulation period for all four transfer scenarios and also shows the average impact in the rightmost column. Figure 4.10 illustrates the same data but does not include the average data. Table 4.31 indicates that to varying degrees, transferring permits east of Cibolo Creek reduces the total springflow. The simulated percent change in springflow for transfer volumes of different sizes does vary. This may be due in part to small mass balance errors, especially for Scenario 2 (78 af/yr). In addition, the percentages may vary in part because of the significant spikes that can occur in the change in springflow due to different scenarios causing different critical period reductions at different times based on very small head differences between scenarios.

Overall, the average reduction in Comal springflow (as a percent of the transfer volume) ranges from about –16 to 42 percent. The increase in springflow at Comal Springs when production is shifted to San Marcos Springs is shown in Figure 4.10. This occurs because the water is produced further downgradient in the system, and thus has less impact on Comal Springs. In the model, the reduction in springflow from Comal

Springs and San Marcos Springs is balanced by an increase in springflow from other springs represented in the model.

Table 4.32 summarizes the impact to San Marcos springflow over the 27-year simulation period for all four transfer scenarios and also shows the average impact in the rightmost column. Figure 4.11 illustrates the same data but does not include the average data. Table 4.32 indicates that to varying degrees, transferring production east of Cibolo Creek reduces the discharge from San Marcos Springs. The most impact (reduced springflow) is simulated when production is moved to near San Marcos Springs.

Table 4.31 Summary of Change in Comal Springflow as a Percent of the Transfer Amount for Various Transfer Volumes

Transfer from Bexar County to	Average Change in Springflow (1947-1973) as Percent of Transfer Volume				
	78 af/yr	782 af/yr	2,353 af/yr	4,743 af/yr	Average
Comal: Up-thrown block	28%	9%	18%	16%	18%
Comal: Down-thrown block	-16%	-26%	-9%	-15%	-16%
San Marcos: Down-thrown block	57%	32%	39%	38%	41%
San Marcos: Up-thrown block	57%	33%	39%	38%	42%
Western Comal County	-12%	-13%	-2%	-7%	-9%

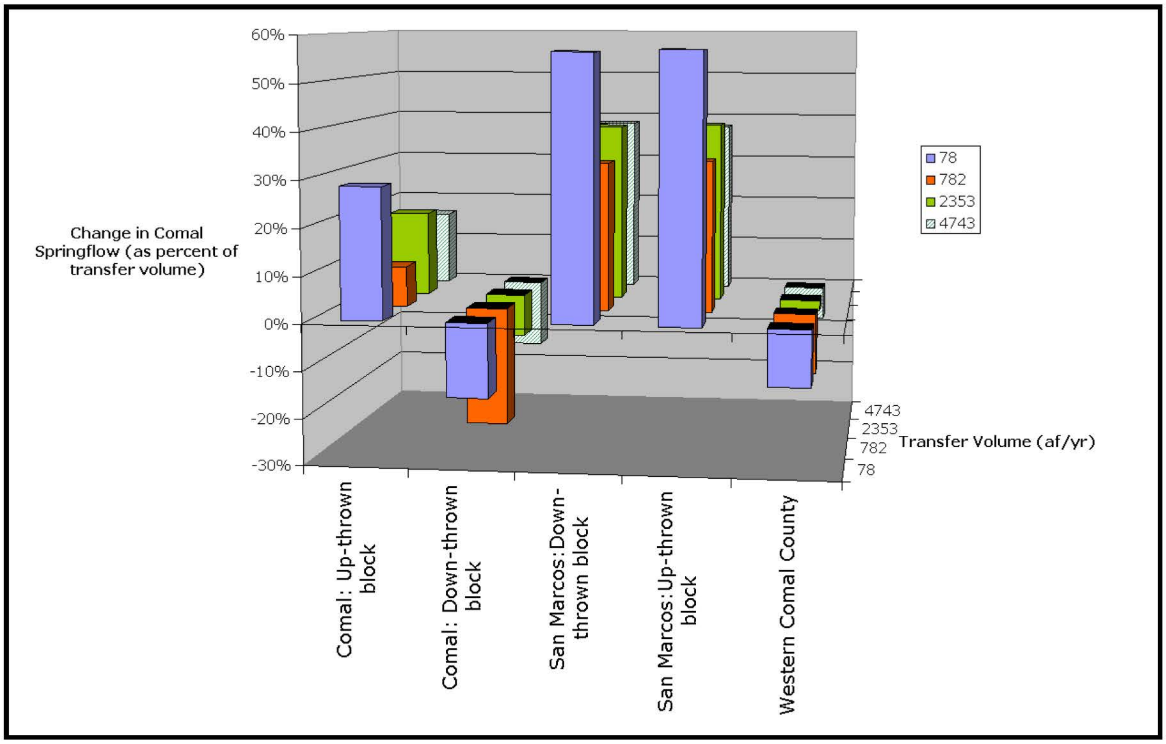

Figure 4.12 Summary of Cibolo transfer impact on Comal springflow.

Table 4.32 Summary of Change in San Marcos Springflow as a Percent of the Transfer Amount for Various Transfer Volumes

Transfer from Bexar County to	Average Change in Springflow (1947-1973) as Percent of Transfer Volume				
	78 af/yr	**782 af/yr**	**2,353 af/yr**	**4,743 af/yr**	**Average**
Comal: Up-thrown block	-44%	-46%	-44%	-45%	-45%
Comal: Down-thrown block	-1%	-2%	0%	-1%	-1%
San Marcos: Down-thrown block	-76%	-79%	-77%	-77%	-77%
San Marcos: Up-thrown block	-76%	-79%	-78%	-78%	-78%
Western Comal County	-1%	-1%	0%	-1%	-1%

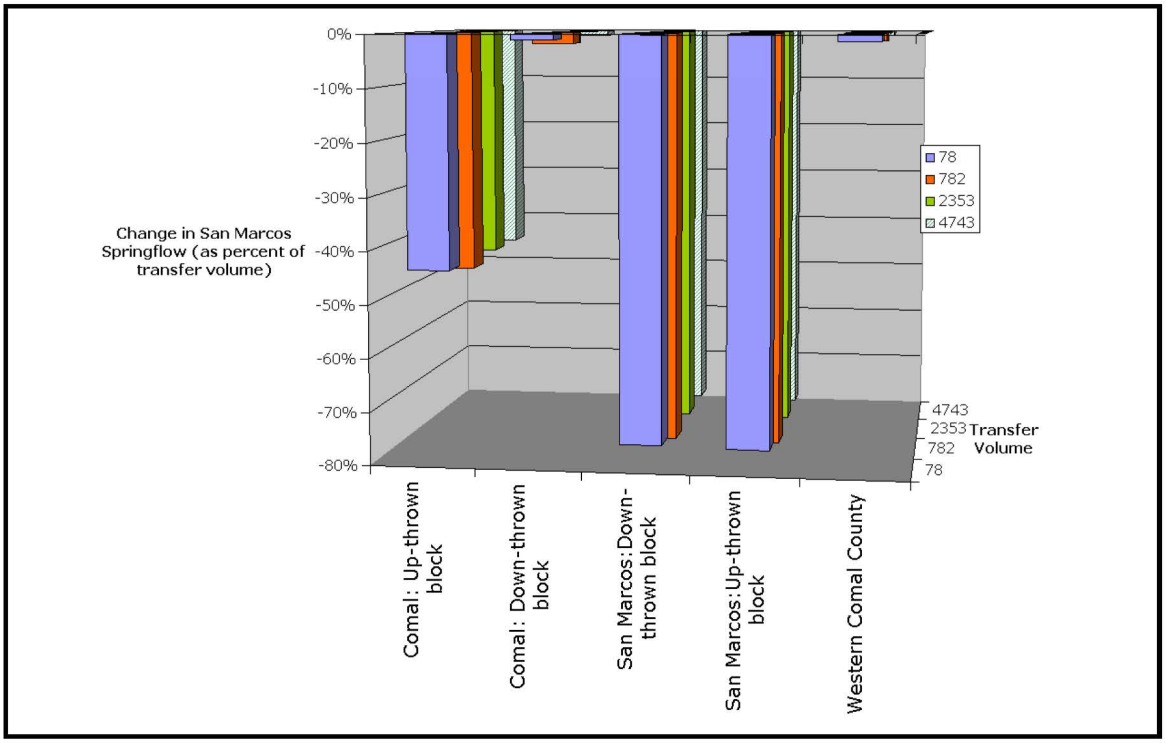

Figure 4.13 Summary of Cibolo transfer impact on San Marcos springflow.

5.0 Conclusions

Based on the modeling methodology used for this study, it is clear that Cibolo transfers impact springflow from San Marcos and Comal Springs. The MODFLOW model, which is generally consistent with the best available science for the aquifer, also indicates that the withdrawal location of the transfer can affect the amount of impact that the transfer has on flow from individual springs and on the total springflow. The consistent increase in J-17 water levels due to transfers suggests that critical period triggers for the San Antonio pool (based on J-17) would be reached slightly later in any particular dry period then they would have prior to the transfer. Based on this study, it cannot be determined whether the later triggering caused by transfers would be significant from a practical perspective.

Cibolo transfers generally have a negative affect on San Marcos springflow because San Marcos Springs are located at the end of the flow system, and thus are generally affected by upgradient withdrawals.

This study indicates that the location of the transfer plays a role in determining the impact to Comal Springs due to the significant flow barrier between the up-thrown and down-thrown block caused by faulting near Comal Springs.

Modeling results provide the following general insights into Cibolo transfers:

- Permits transferred farther east have more impact on San Marcos springflow.
- Permits transferred farther east result in slightly higher water levels in J-17 because pumping is shifted downgradient of J-17.
- The location of the new pumping for transfers are a factor in determining the impact to Comal springflow due to the flow dynamics resulting from faults.
- The average change in Comal springflow as a percent of the transfer volume ranges from -16% reduction to a 42% increase, depending on the "transfer to" location. The average reduction in San Marcos springflow as a percent of the transfer volume ranges from about -78 to -1 percent. As shown in Table 4.31 and 4.32, the variation is caused by the changes in the "transfer to" location.
- During heavy summer pumping, the monthly impact can be over 200 percent of the annual average transfer volume because (1) of the proximity of the well to the spring, and (2) the larger proportion of pumping that occurs during the summer months. See Section 4.2.4 for more explanation.
- Smaller transfers (78 and 782 af/yr) do not tend to impact Stage 4 statistics in J-17 and Comal Springs or Stage 2 statistics in San Marcos Springs. Larger transfers (2,353 and 4,743 af/yr) do tend to have some impact on these stages.

- Dry periods were assessed by counting the number of months (out of 96) from 1950-1957 that water levels and springflow were at various critical period stages with and without transfers. Because springflow from Comal and San Marcos are generally lower during the 1950's drought, the reduction in springflow represents a larger portion of the total springflow during this dry period.
- There is no measurable impact on San Pedro and San Antonio Springs because there is almost never flow from these springs when the permitted pumping of 572,000 acre-feet per year in implemented in the model.
- In the model, the reduction in springflow from Comal Springs and San Marcos Springs caused by transferred production is balanced by an increase in springflow from other springs represented in the model (Los Moras, Barton, and Leona Springs).

6.0 References

LBG-Guyton Associates, 2006. Evaluation of the Aquifer and Springflow Impacts Associated with the Cibolo Creek Transfer Rules. Contract Report prepared for Edwards Aquifer Authority.

Lindgren, R.J., A.R. Dutton, S.D. Hovorka, S.R.H. Worthington, and Scott Painter, 2004. Conceptualization and Simulation of the Edwards Aquifer, San Antonio Region, Texas. Scientific Investigations Report 2004–5277

Southwest Research Institute, 2007. Robust Representation of Dry Cells in MODFLOW. Contract Report prepared for Edwards Aquifer Authority. SwRI Project 20-13003.

APPENDIX A

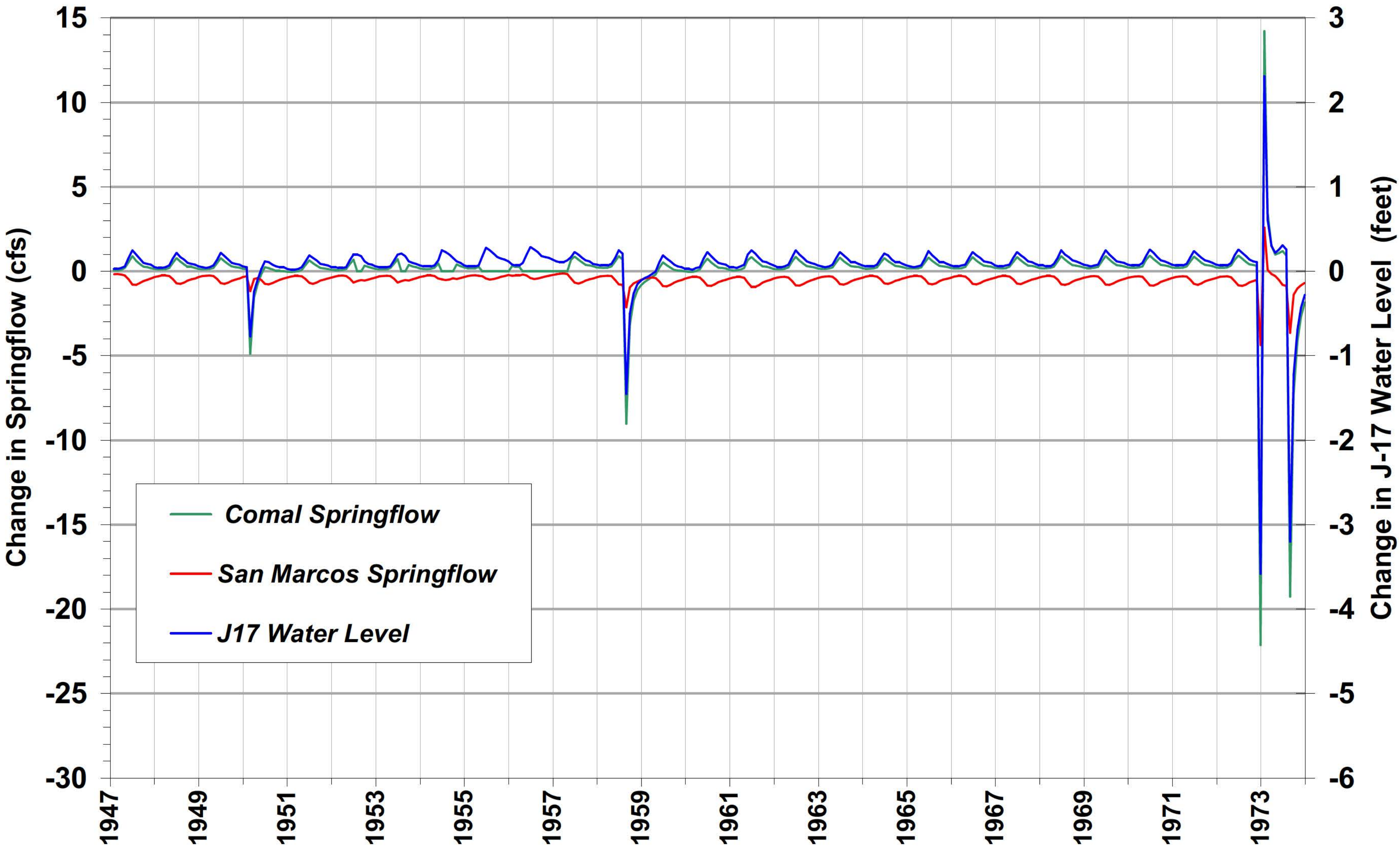

Figure A1. Change in Springflow and J-17 Water Level After Transferring 782 af/yr from Western Bexar County to near Comal Springs (Up-thrown block)

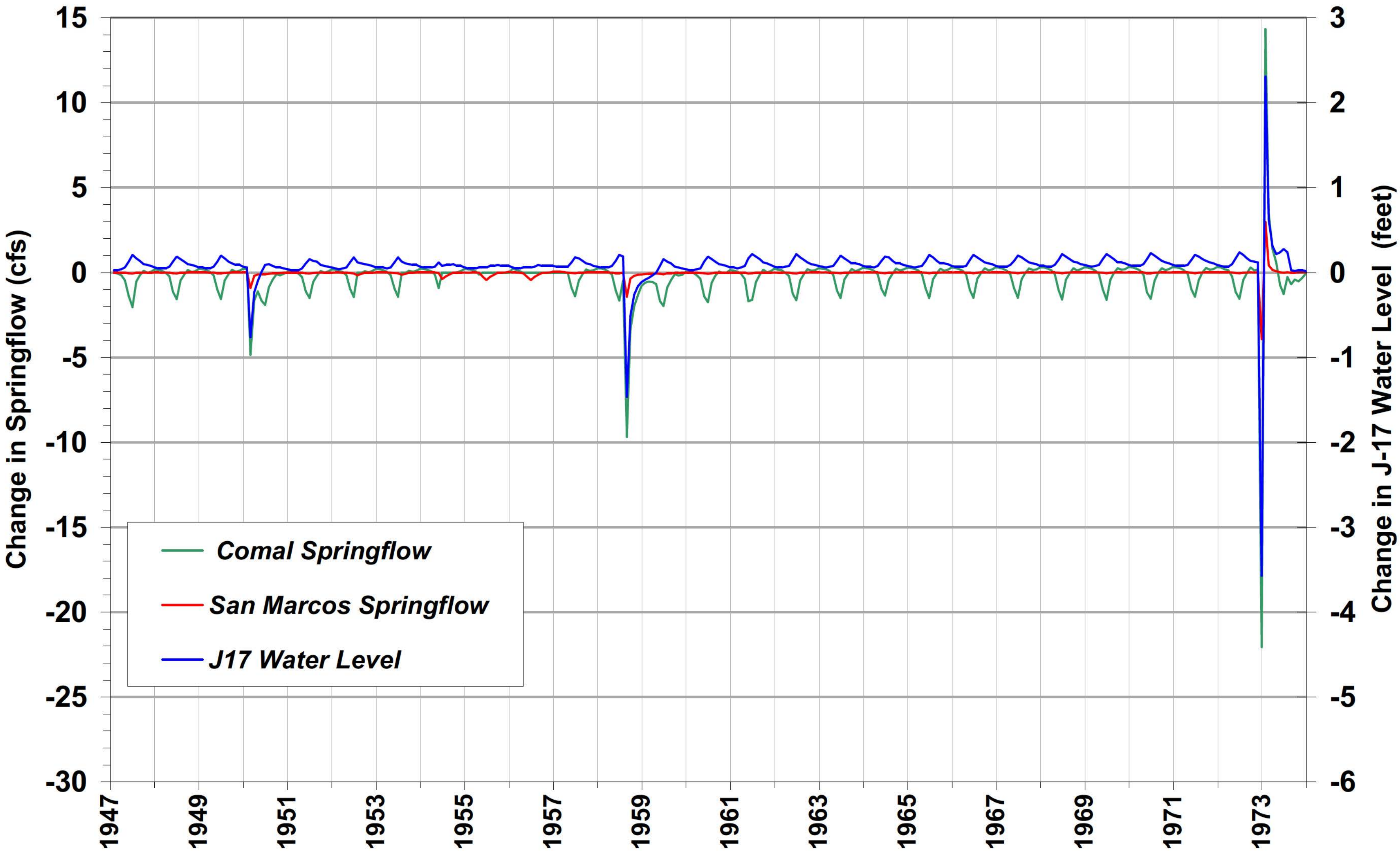

Figure A2. Change in Springflow and J-17 Water Level After Transferring 782 af/yr from Western Bexar County to near Comal Springs (Down-thrown block)

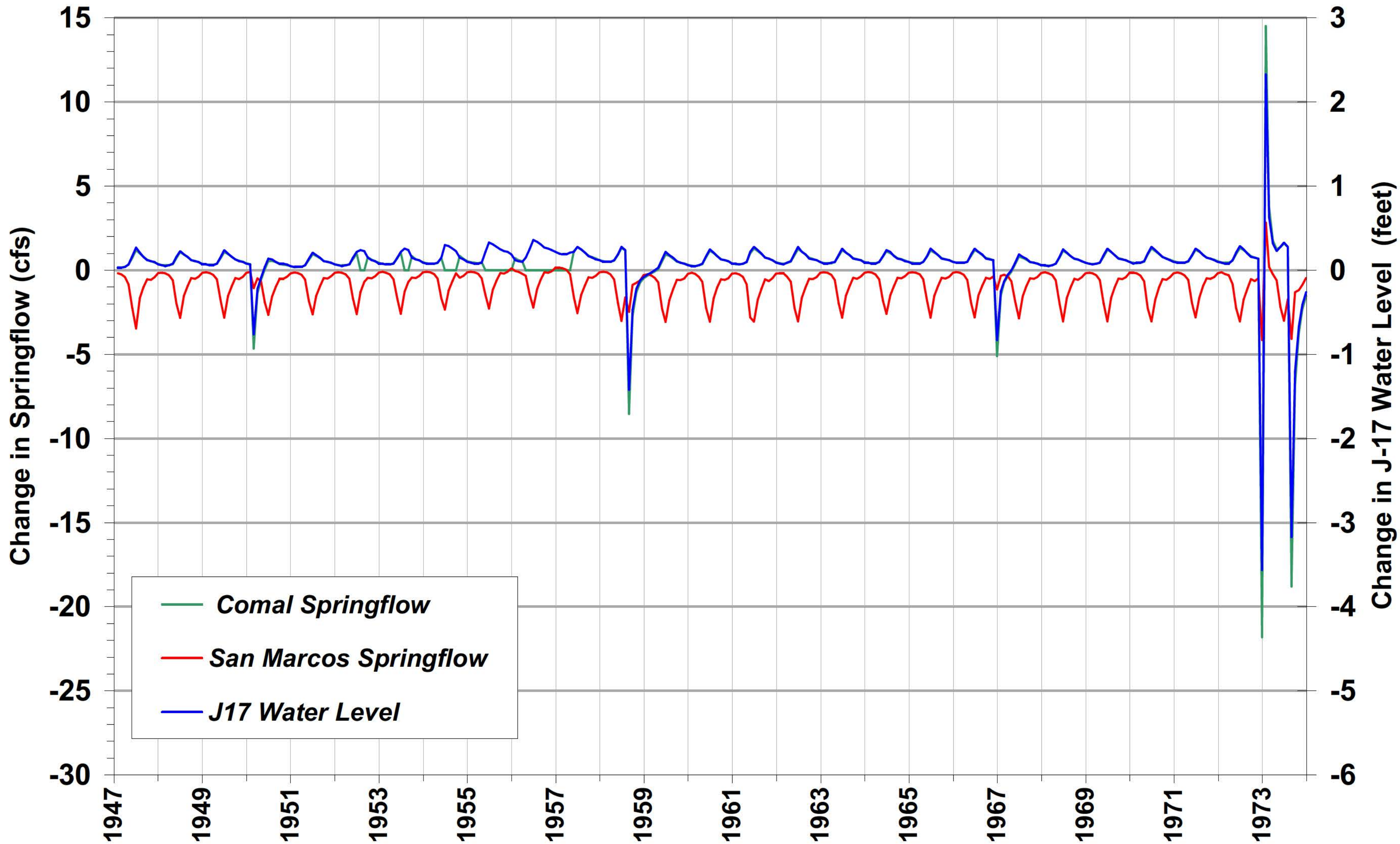

Figure A3. Change in Springflow and J-17 Water Level After Transferring 782 af/yr from Western Bexar County to near San Marcos Springs (Down-thrown block)

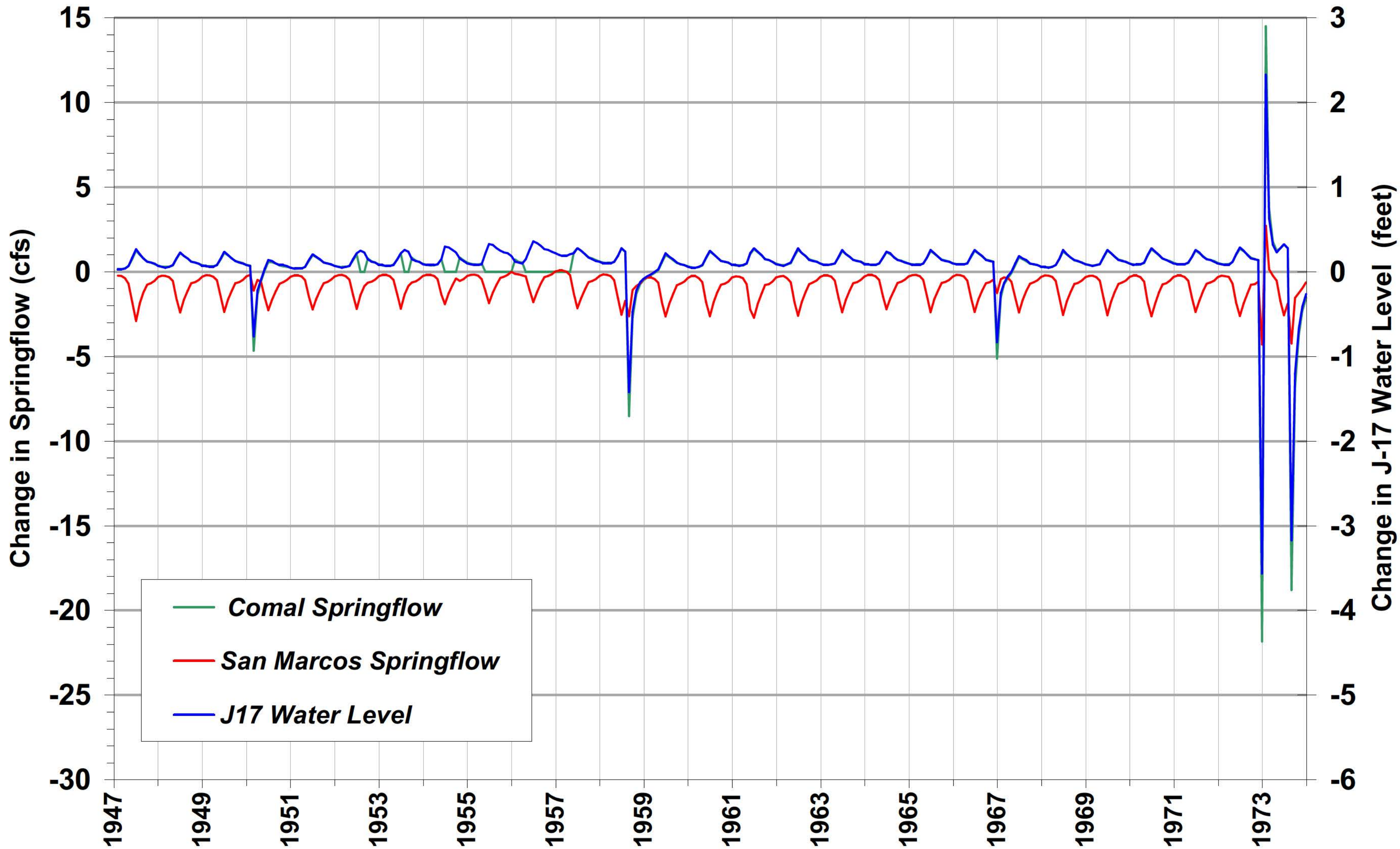

Figure A4. Change in Springflow and J-17 Water Level After Transferring 782 af/yr from Western Bexar County to near San Marcos Springs (Up-thrown block)

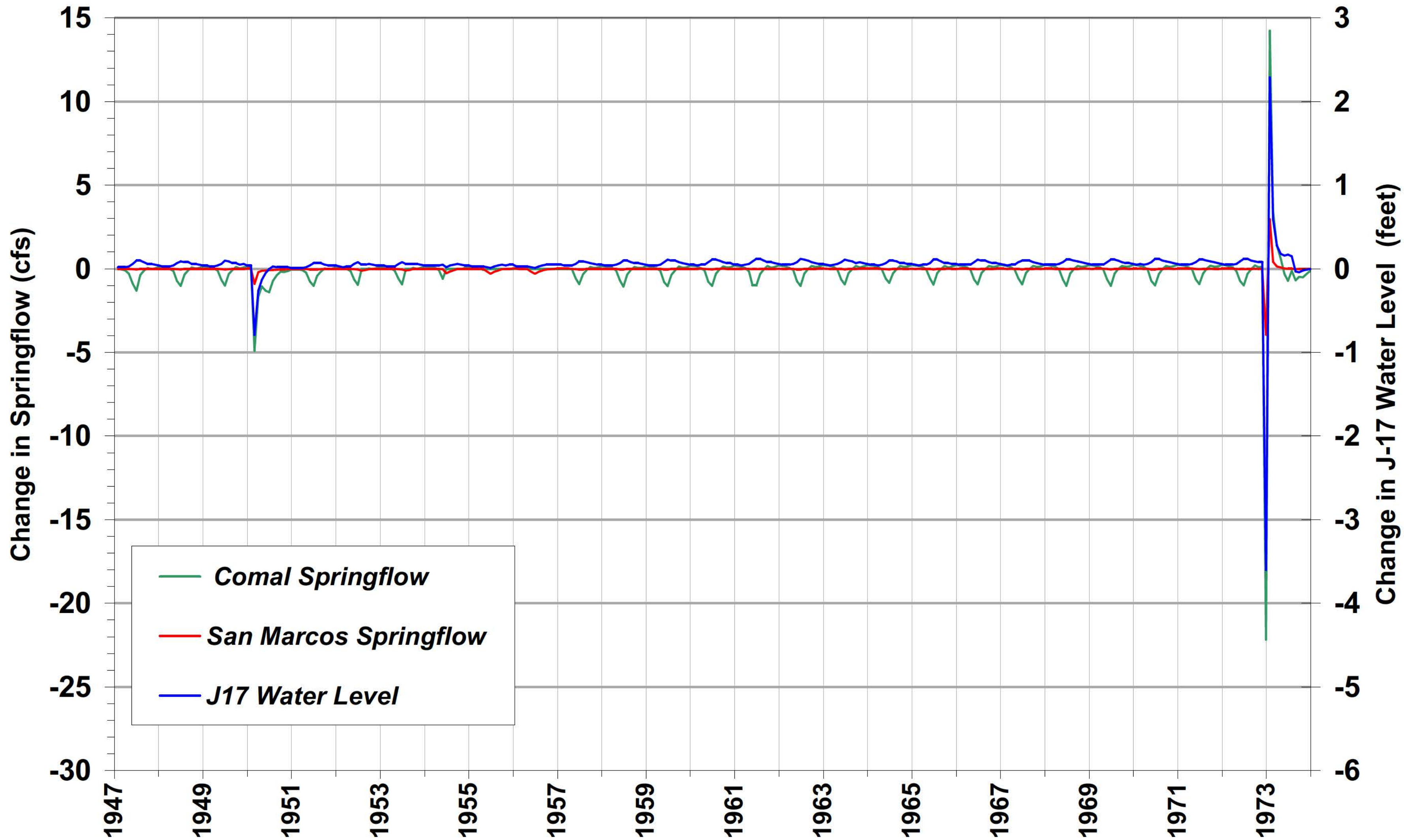

Figure A5. Change in Springflow and J-17 Water Level After Transferring 782 af/yr from Western Bexar County to Western Comal County

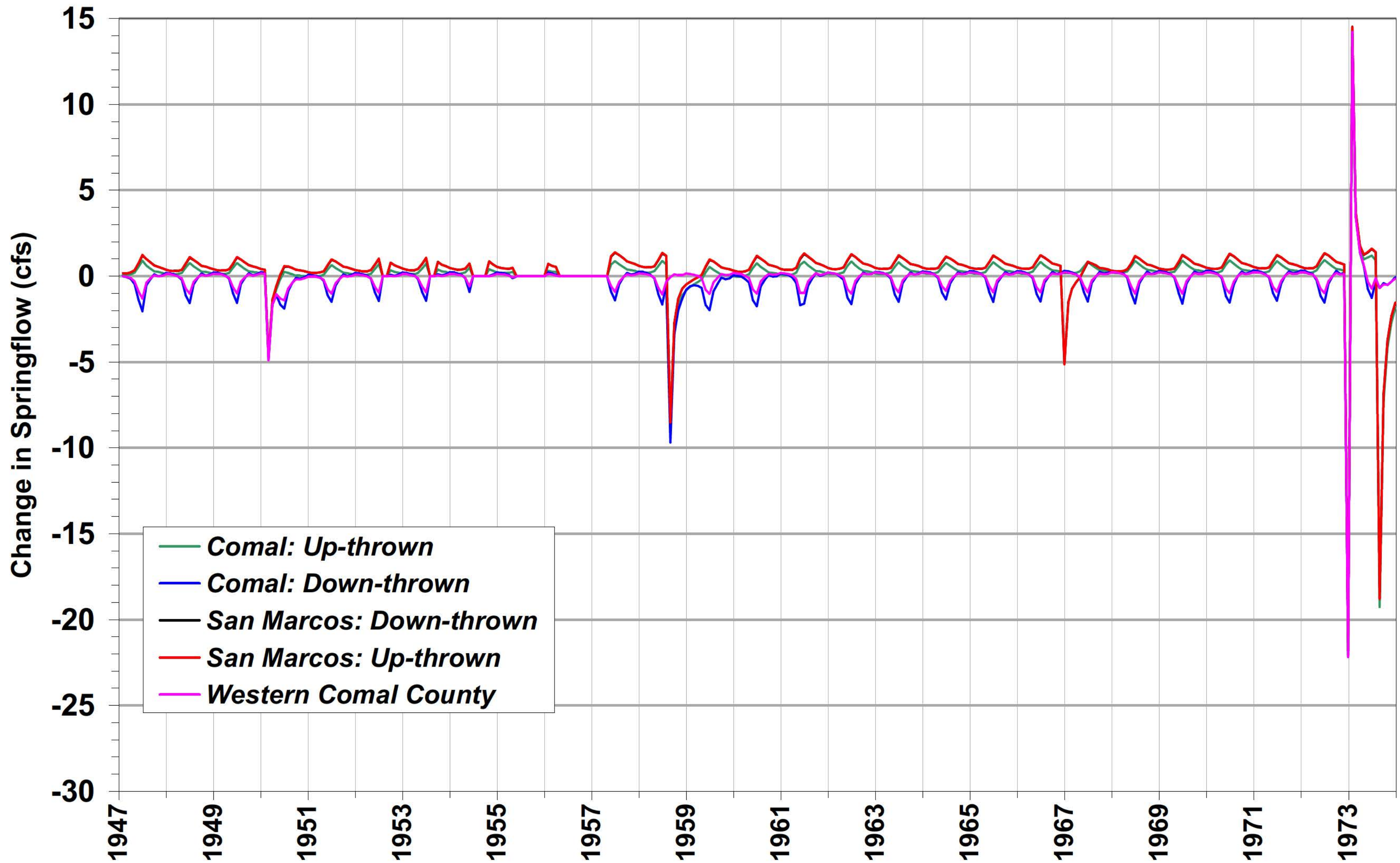

Figure A6. Comparison of Change in Comal Springflow After Transferring 782 af/yr from Western Bexar County to Five Locations East of Cibolo Creek

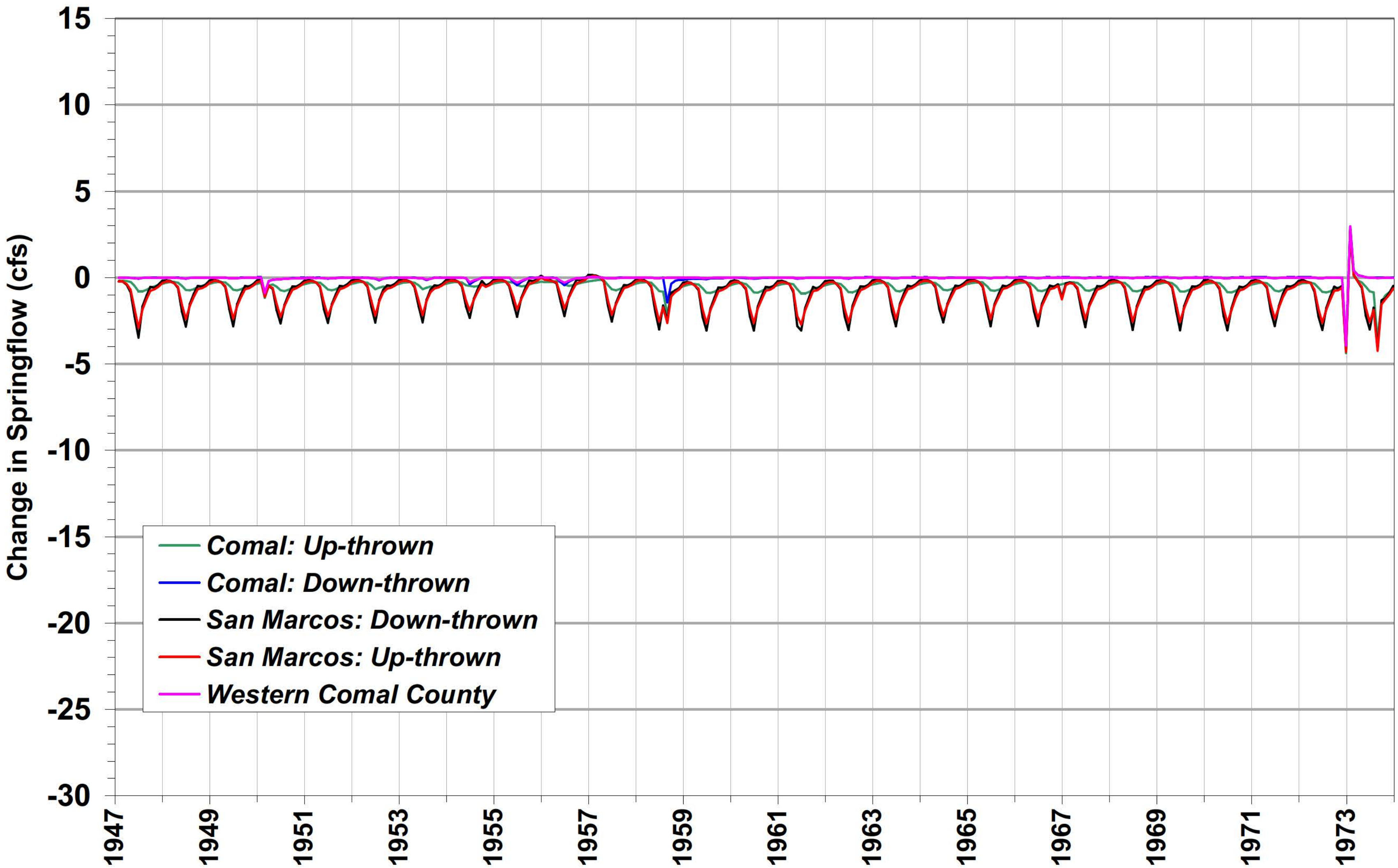

Figure A7. Comparison of Change in San Marcos Springflow After Transferring 782 af/yr from Western Bexar County to Five Locations East of Cibolo Creek

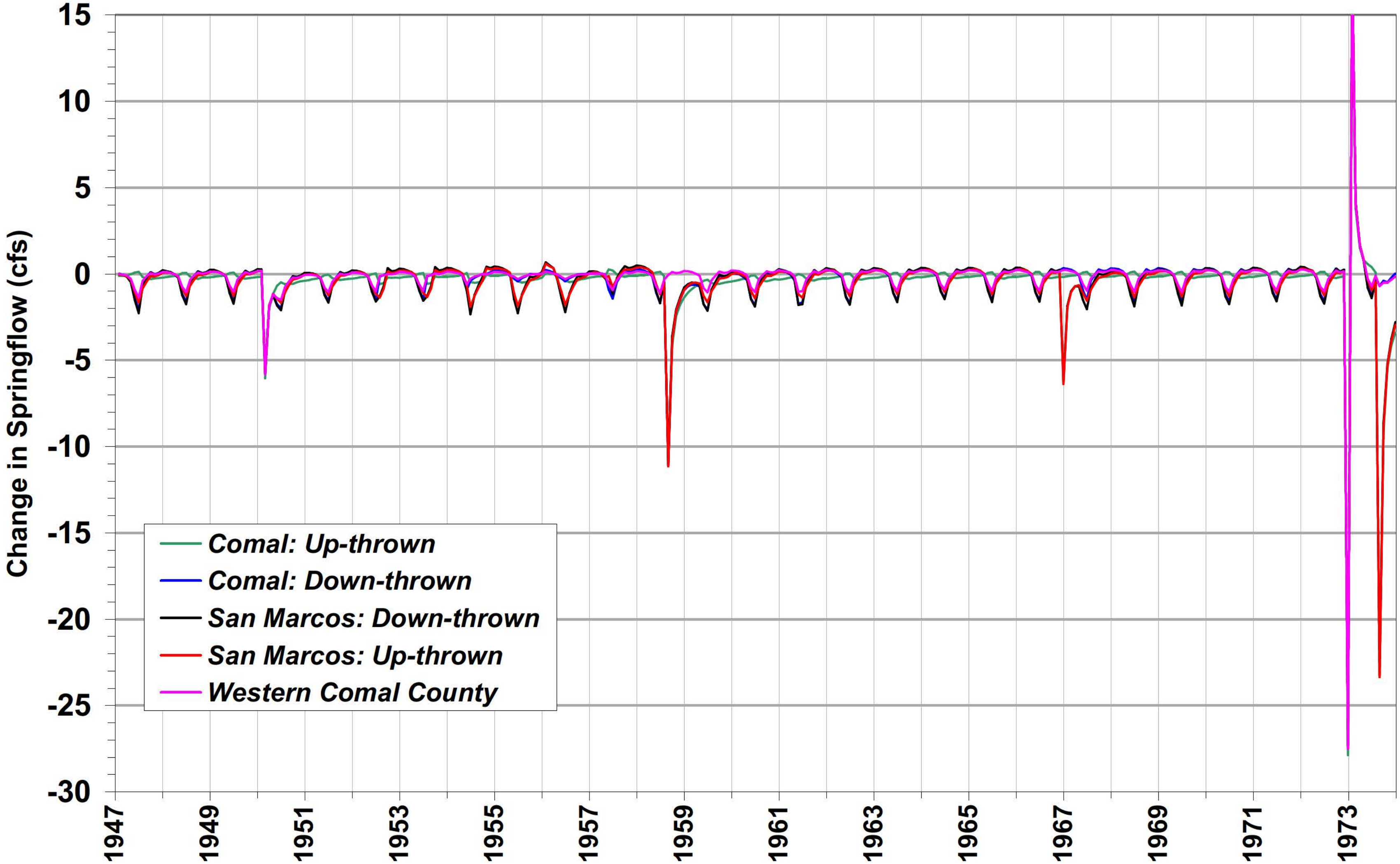

Figure A8. Comparison of Change in Total Springflow After Transferring 782 af/yr from Western Bexar County to Five Locations East of Cibolo Creek

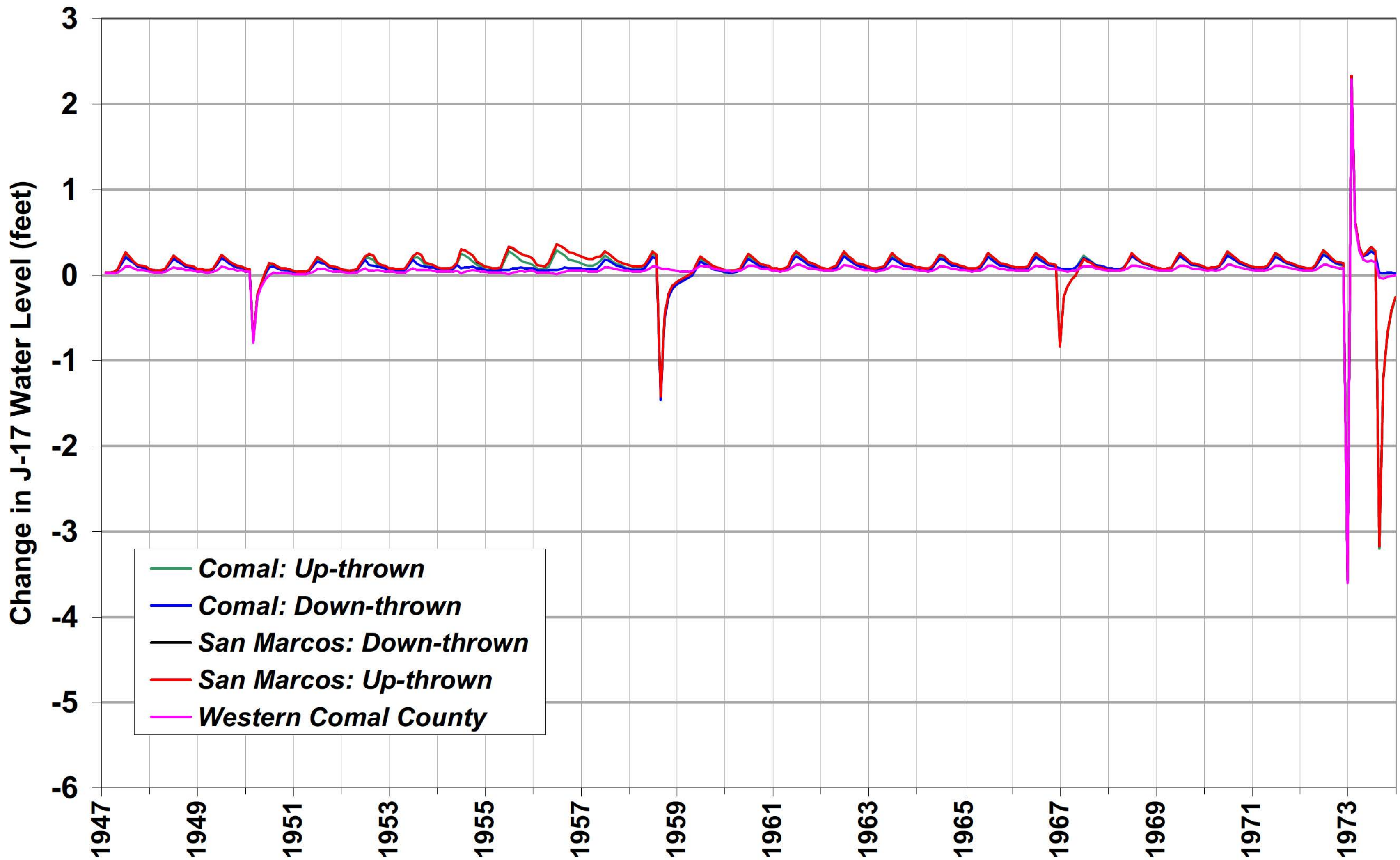

Figure A9. Comparison of Change in J-17 Water Level After Transferring 782 af/yr from Western Bexar County to Five Locations East of Cibolo Creek

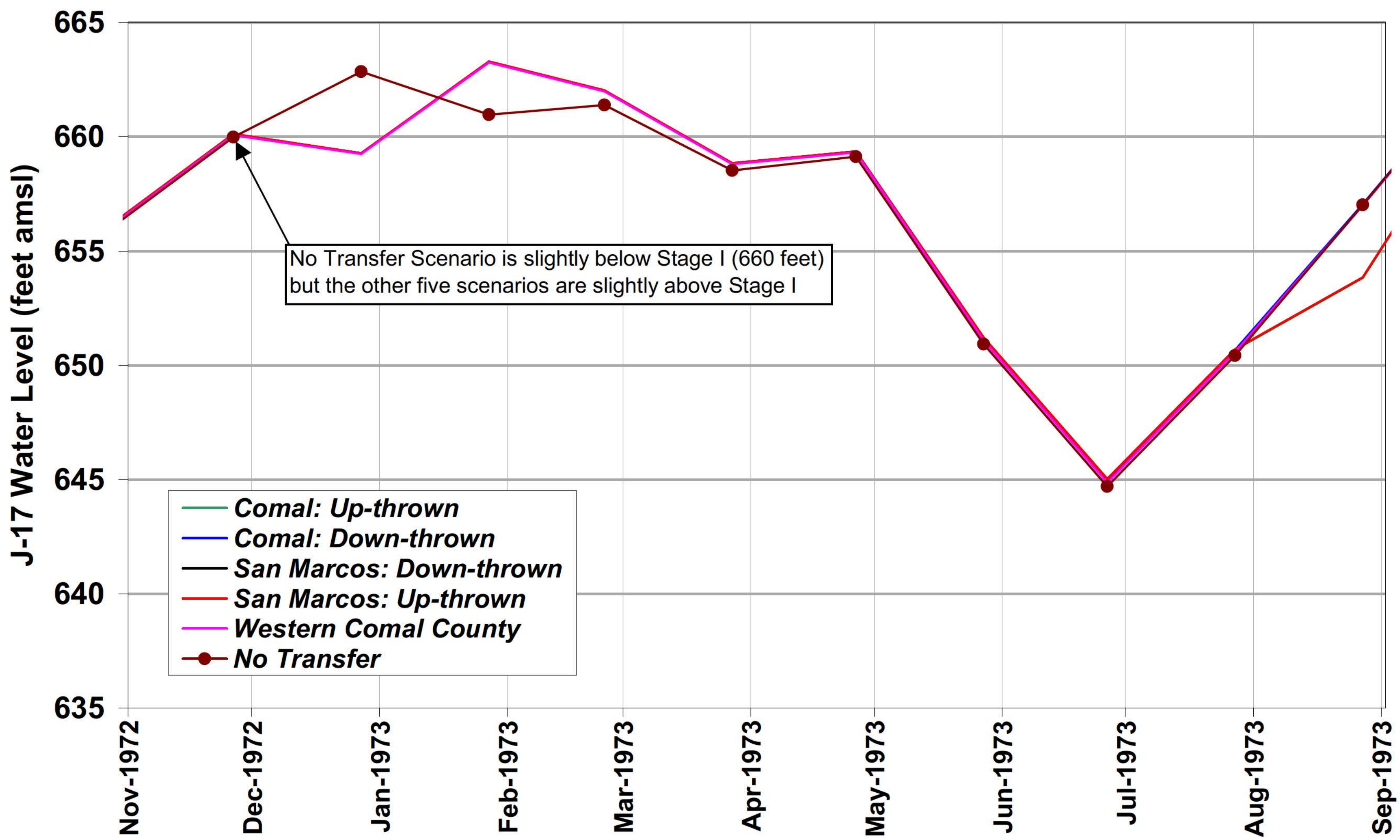

Figure A10. Comparison of Change in J-17 Water Level during 1972 After Transferring 782 af/yr from Western Bexar County to Five Locations East of Cibolo Creek

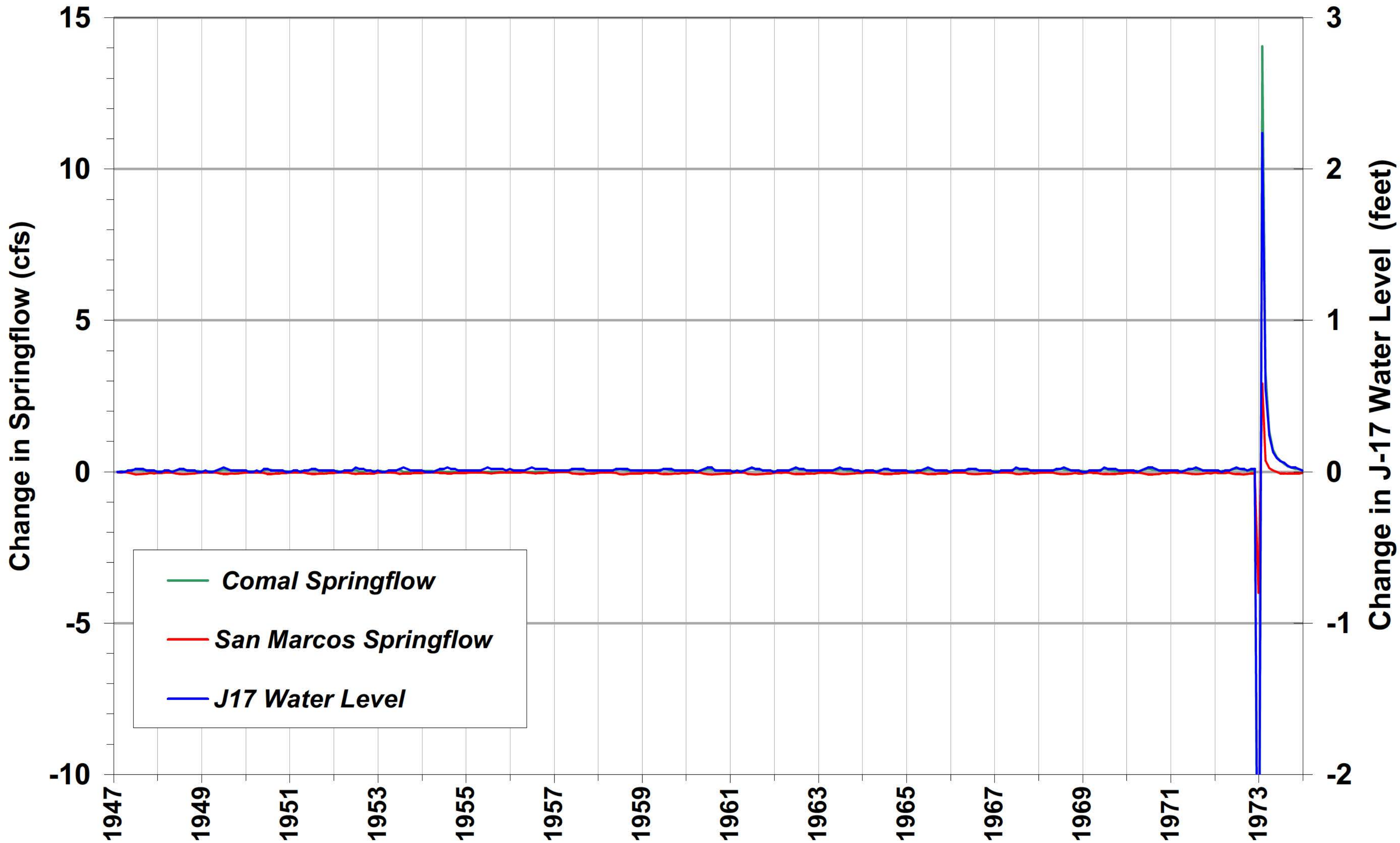

Figure A11. Change in Springflow and J-17 Water Level After Transferring 78 af/yr from Western Bexar County to near Comal Springs (Up-thrown block)

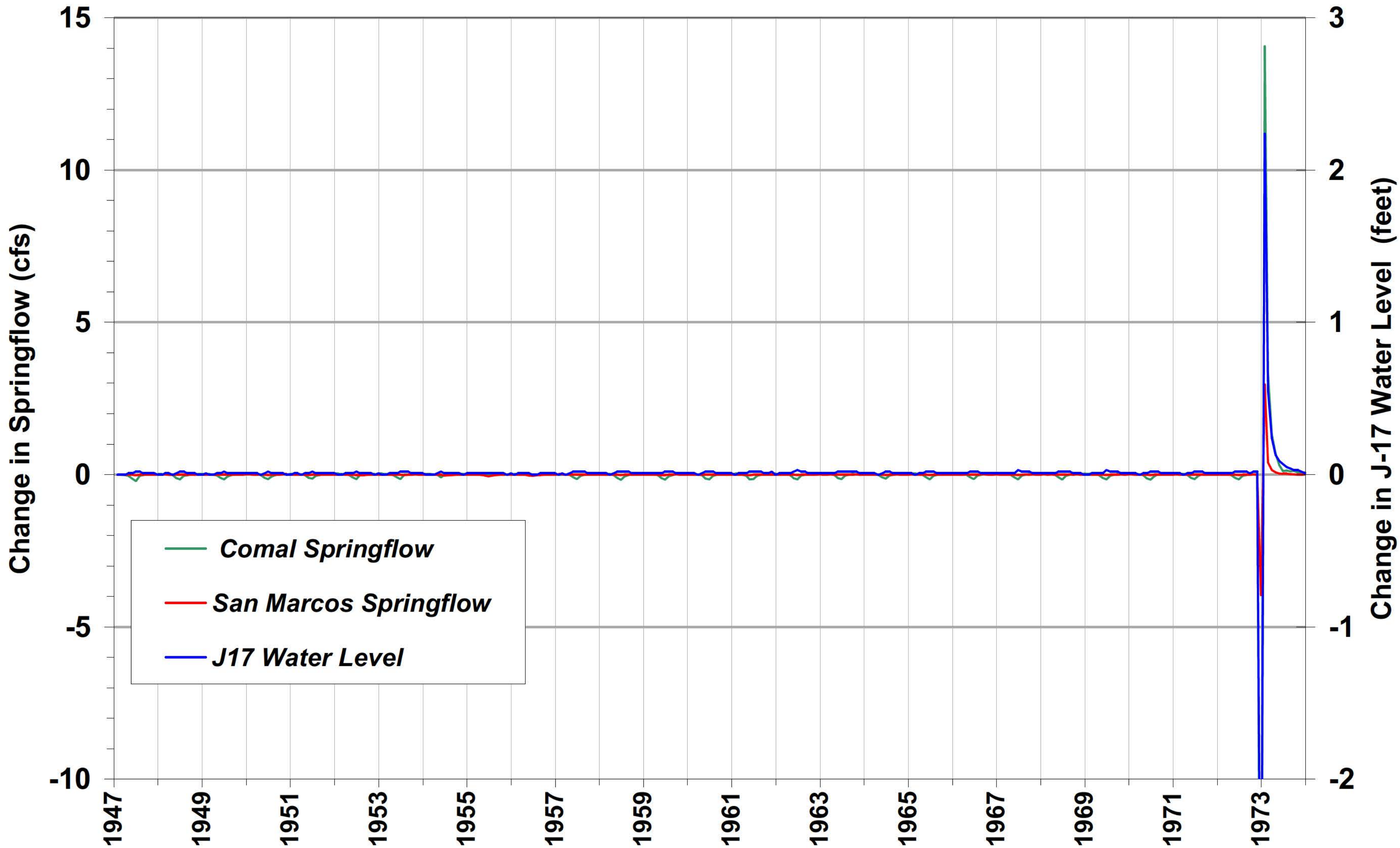

Figure A12. Change in Springflow and J-17 Water Level After Transferring 78 af/yr from Western Bexar County to near Comal Springs (Down-thrown block)

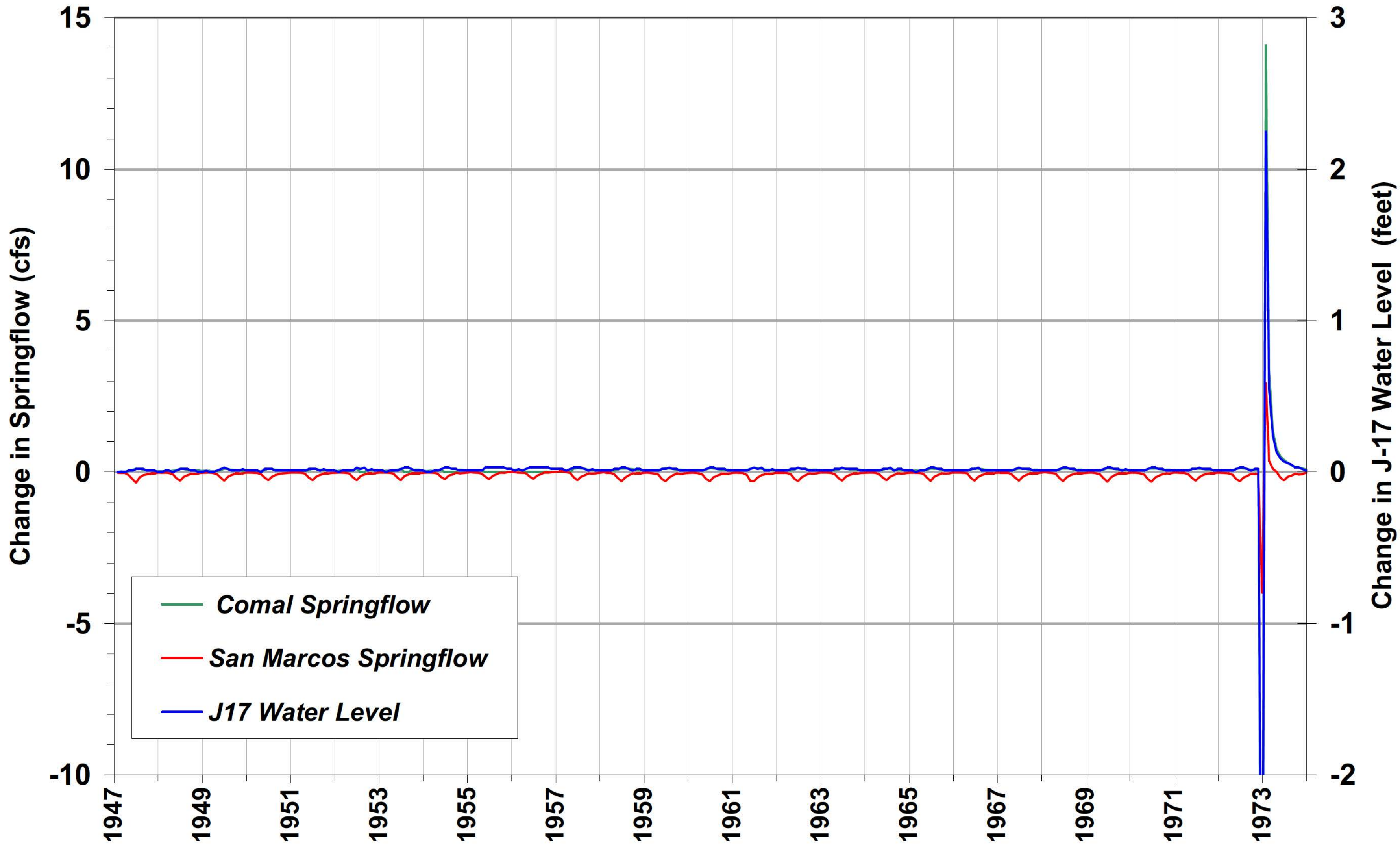

Figure A13. Change in Springflow and J-17 Water Level After Transferring 78 af/yr from Western Bexar County to near San Marcos Springs (Down-thrown block)

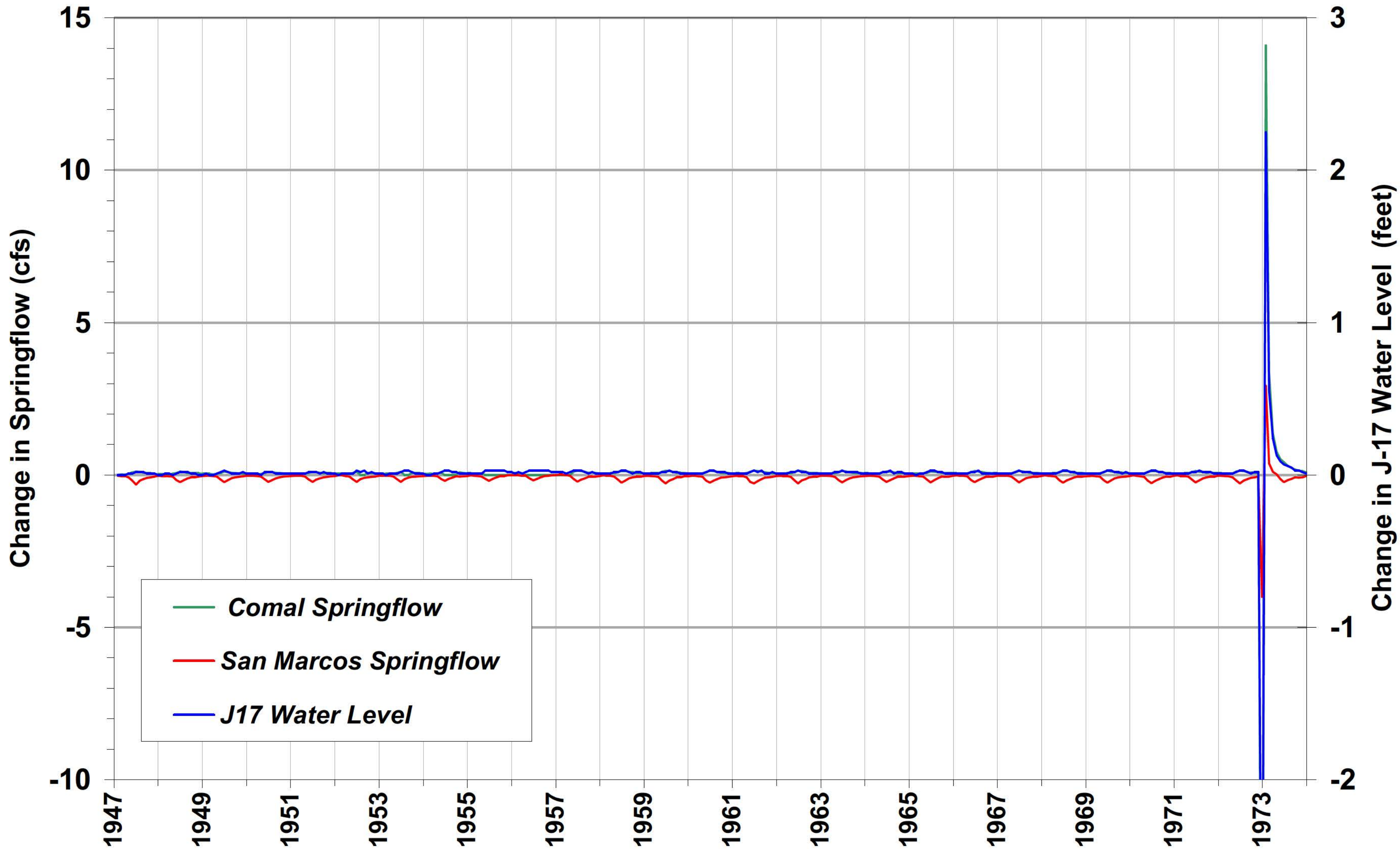

Figure A14. Change in Springflow and J-17 Water Level After Transferring 78 af/yr from Western Bexar County to near San Marcos Springs (Up-thrown block)

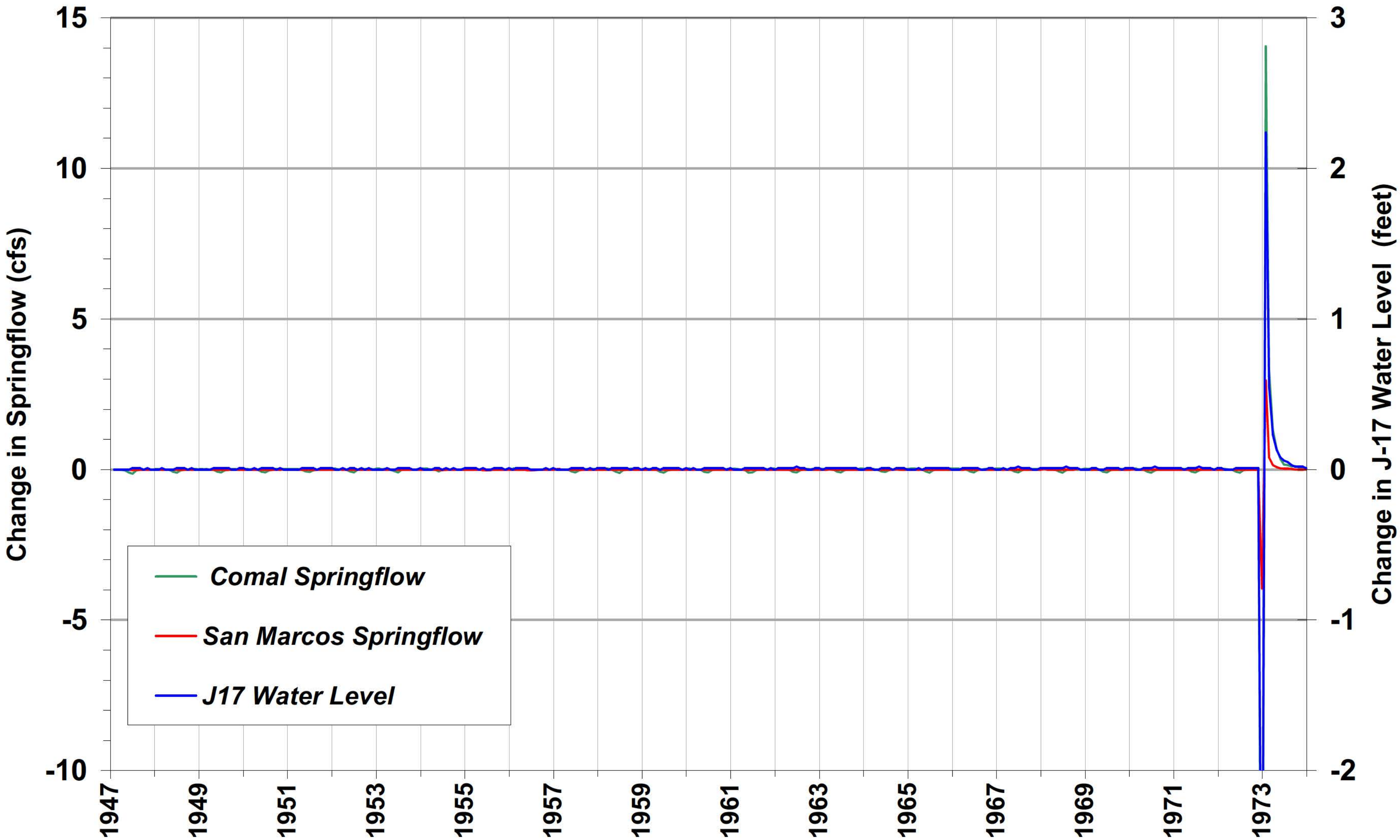

Figure A15. Change in Springflow and J-17 Water Level After Transferring 78 af/yr from Western Bexar County to Western Comal County

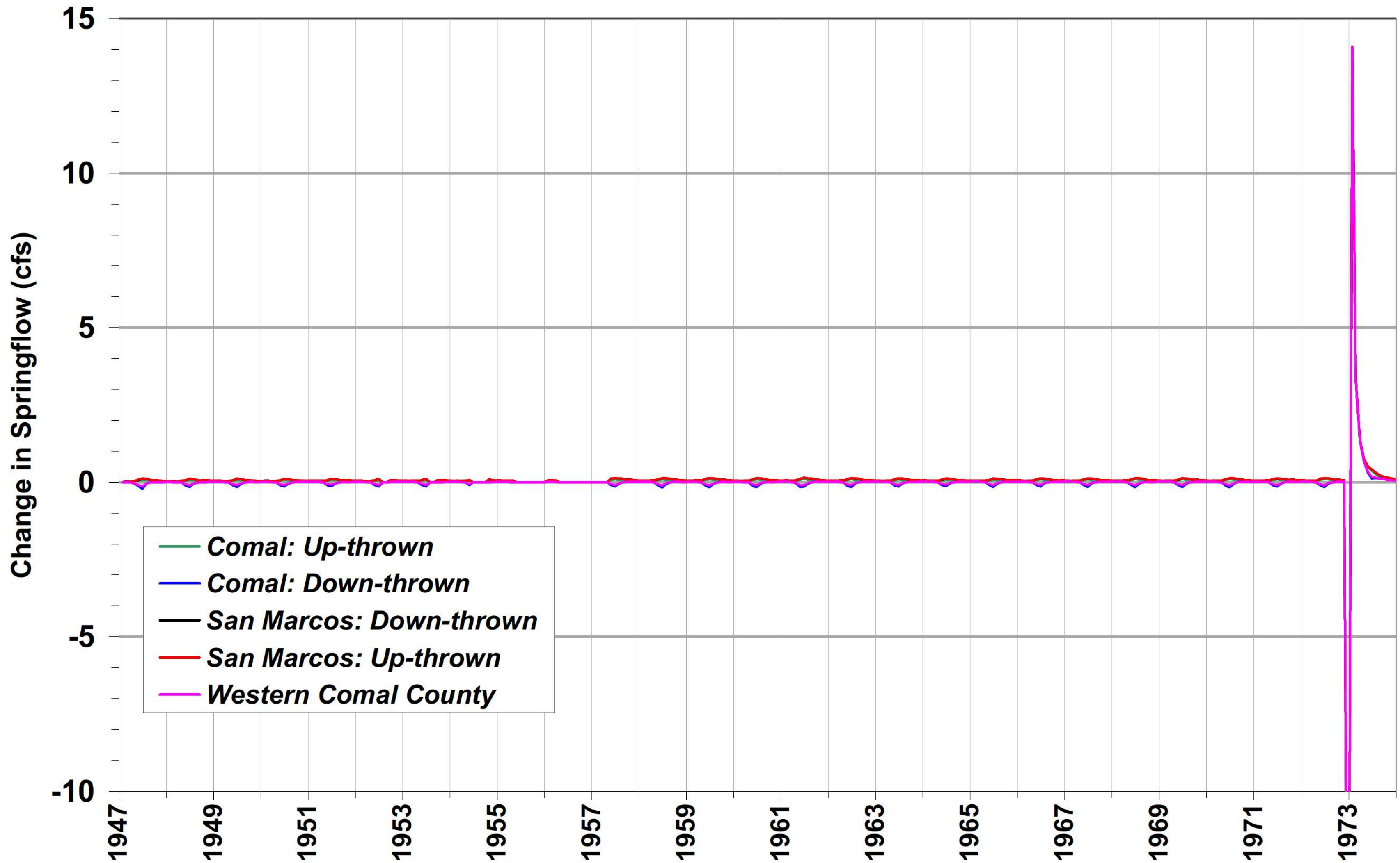

Figure A16. Comparison of Change in Comal Springflow After Transferring 78 af/yr from Western Bexar County to Five Locations East of Cibolo Creek

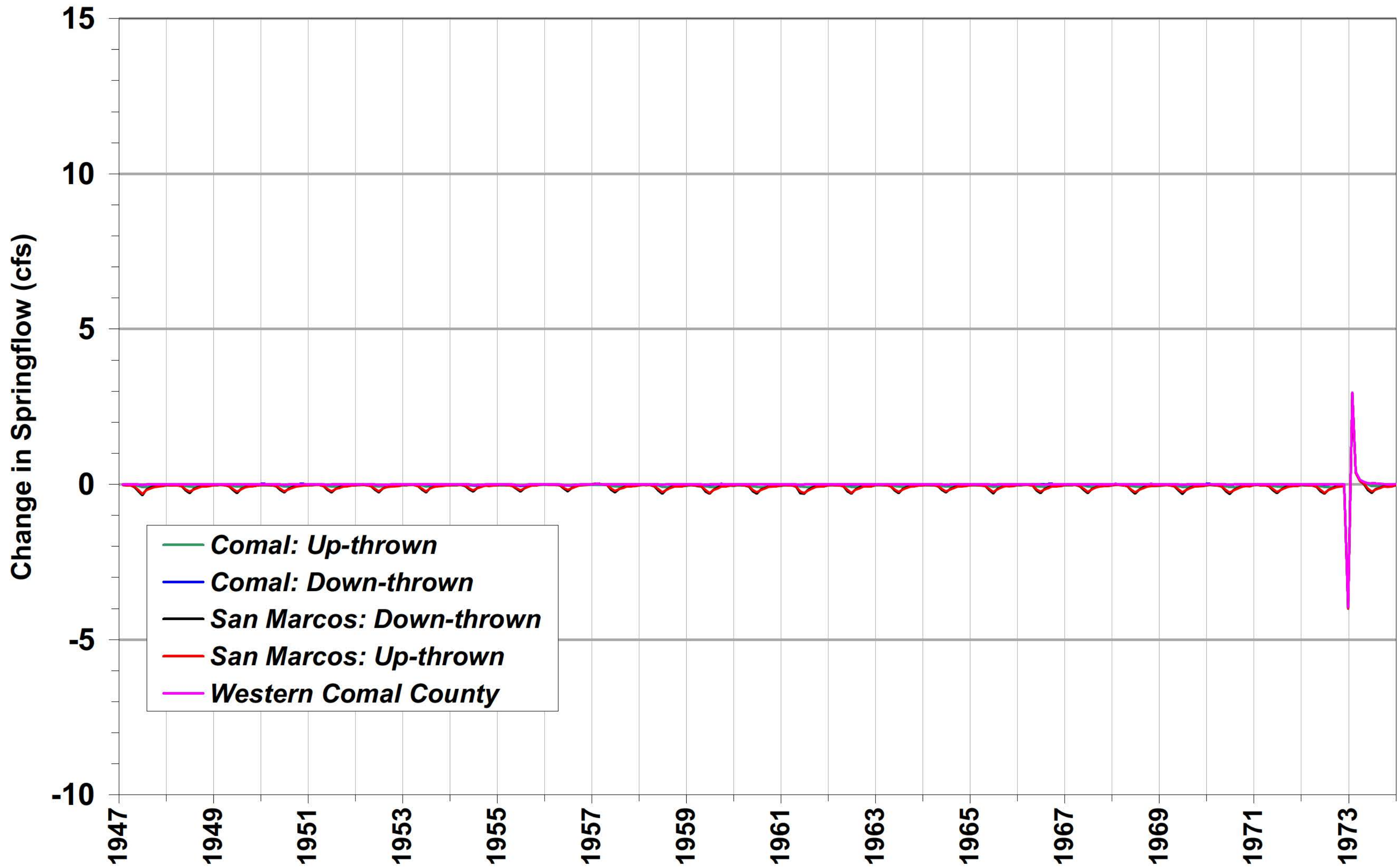

Figure A17. Comparison of Change in San Marcos Springflow After Transferring 78 af/yr from Western Bexar County to Five Locations East of Cibolo Creek

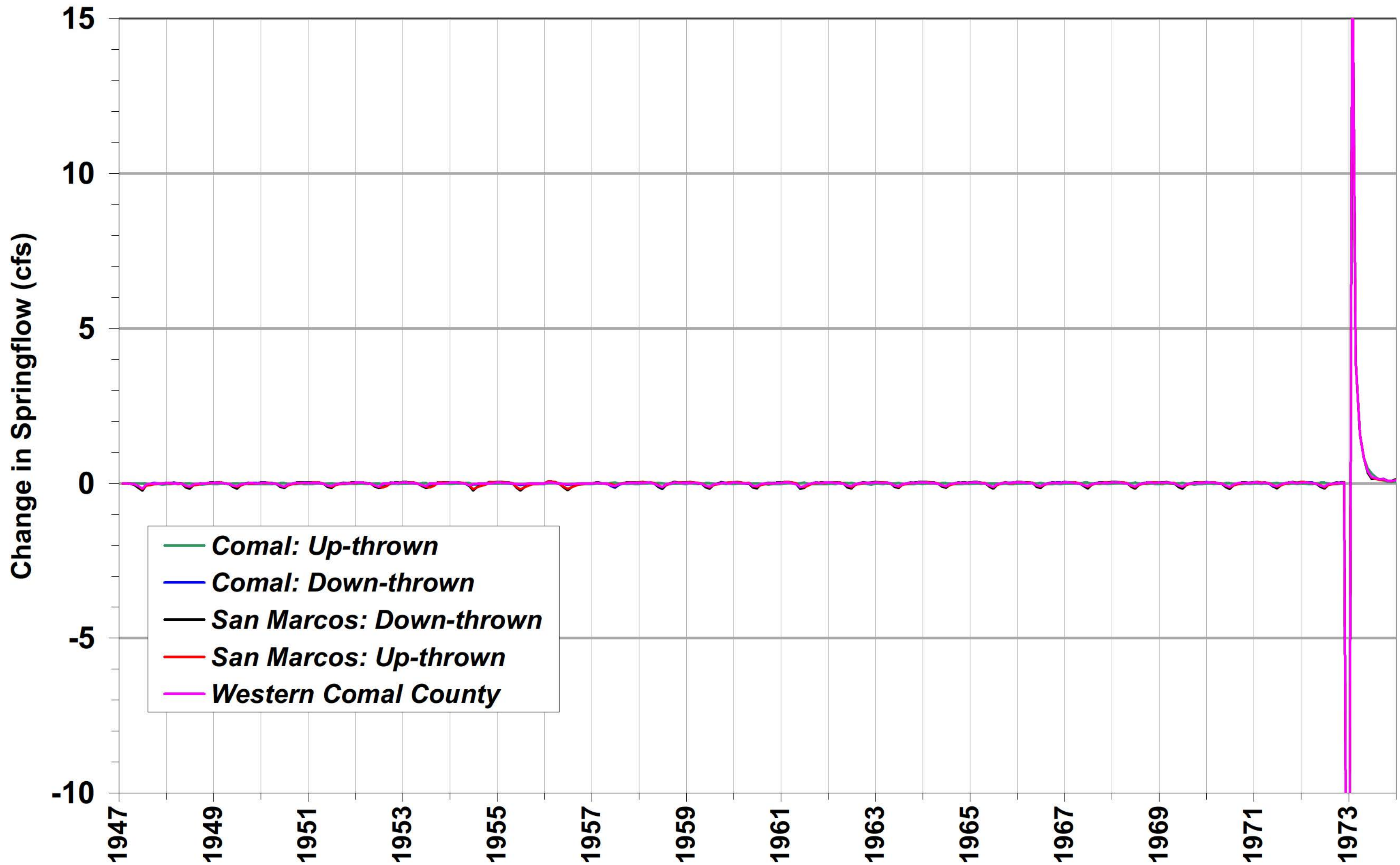

Figure A18. Comparison of Change in Total Springflow After Transferring 78 af/yr from Western Bexar County to Five Locations East of Cibolo Creek

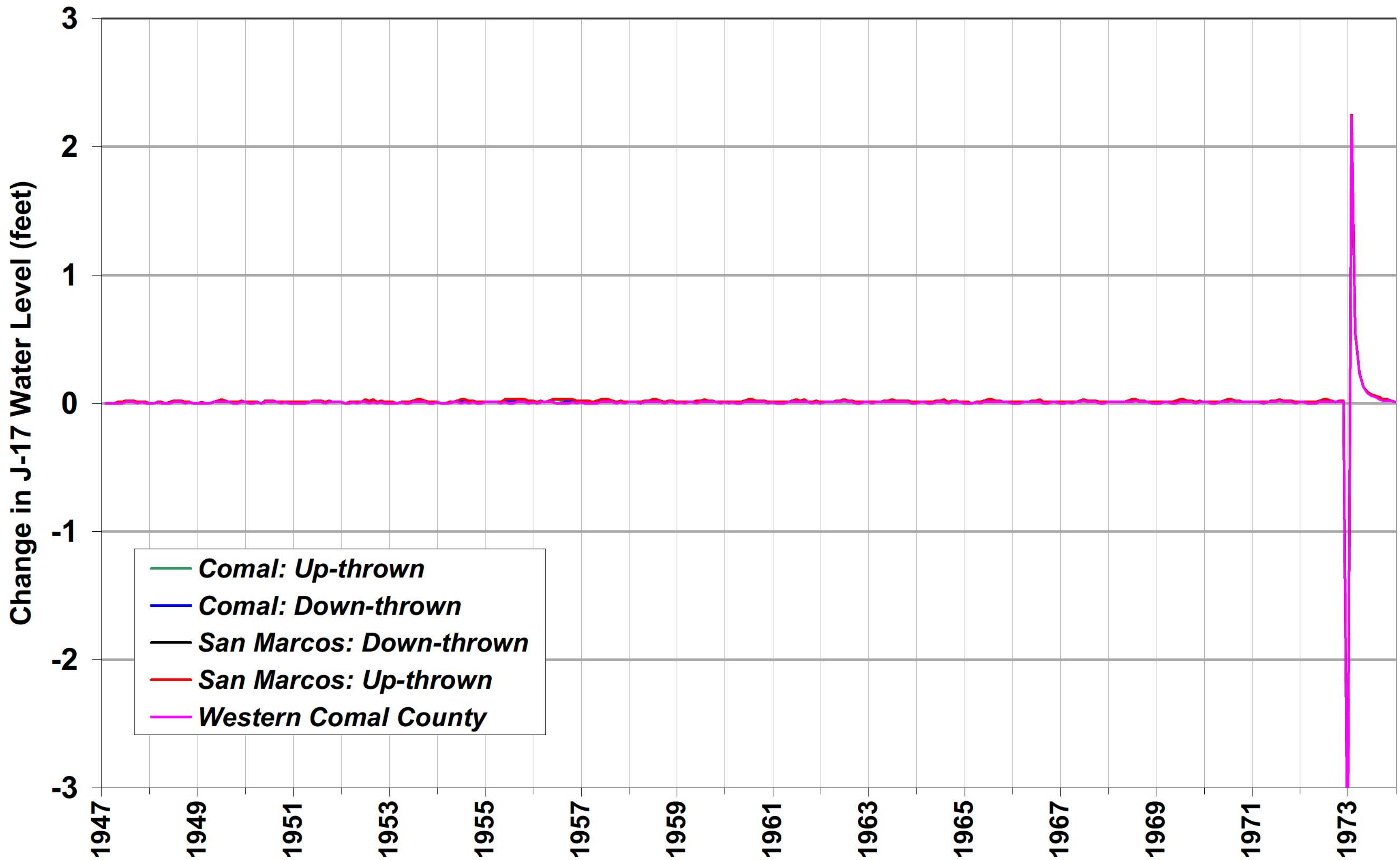

Figure A19. Comparison of Change in J-17 Water Level After Transferring 78 af/yr from Western Bexar County to Five Locations East of Cibolo Creek

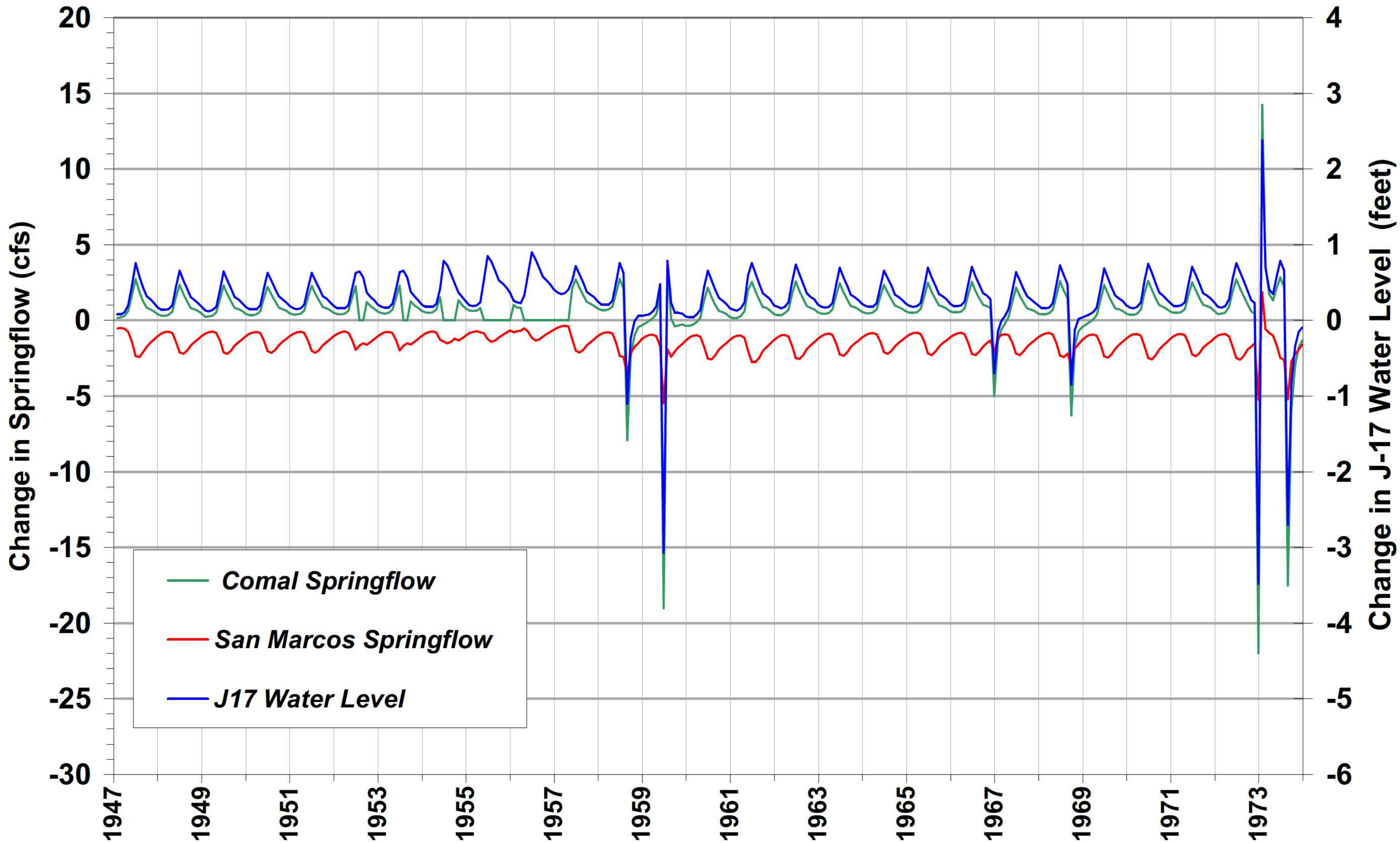

Figure A20. Change in Springflow and J-17 Water Level After Transferring 2353 af/yr from Western Bexar County to near Comal Springs (Up-thrown block)

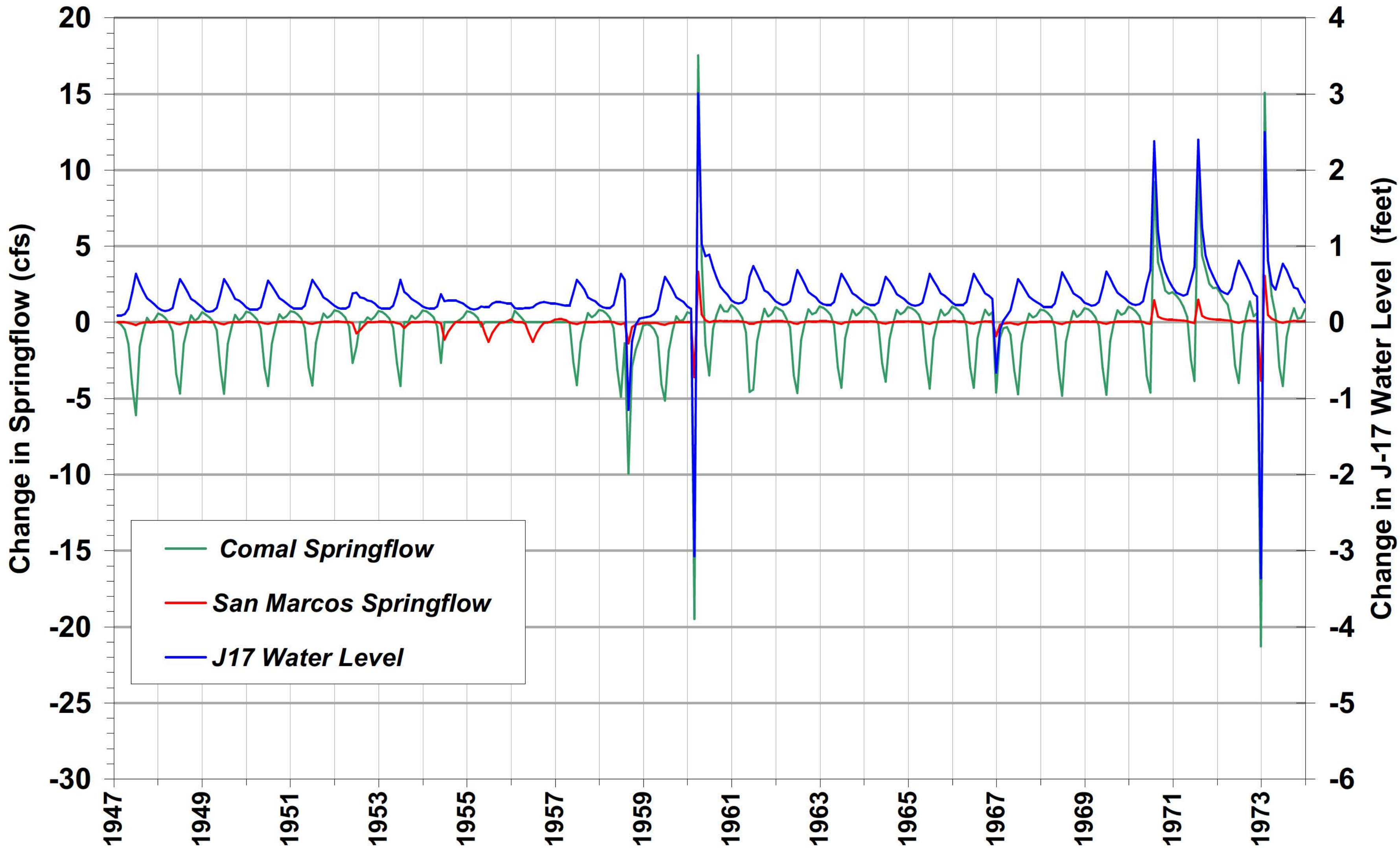

Figure A21. Change in Springflow and J-17 Water Level After Transferring 2353 af/yr from Western Bexar County to near Comal Springs (Down-thrown block)

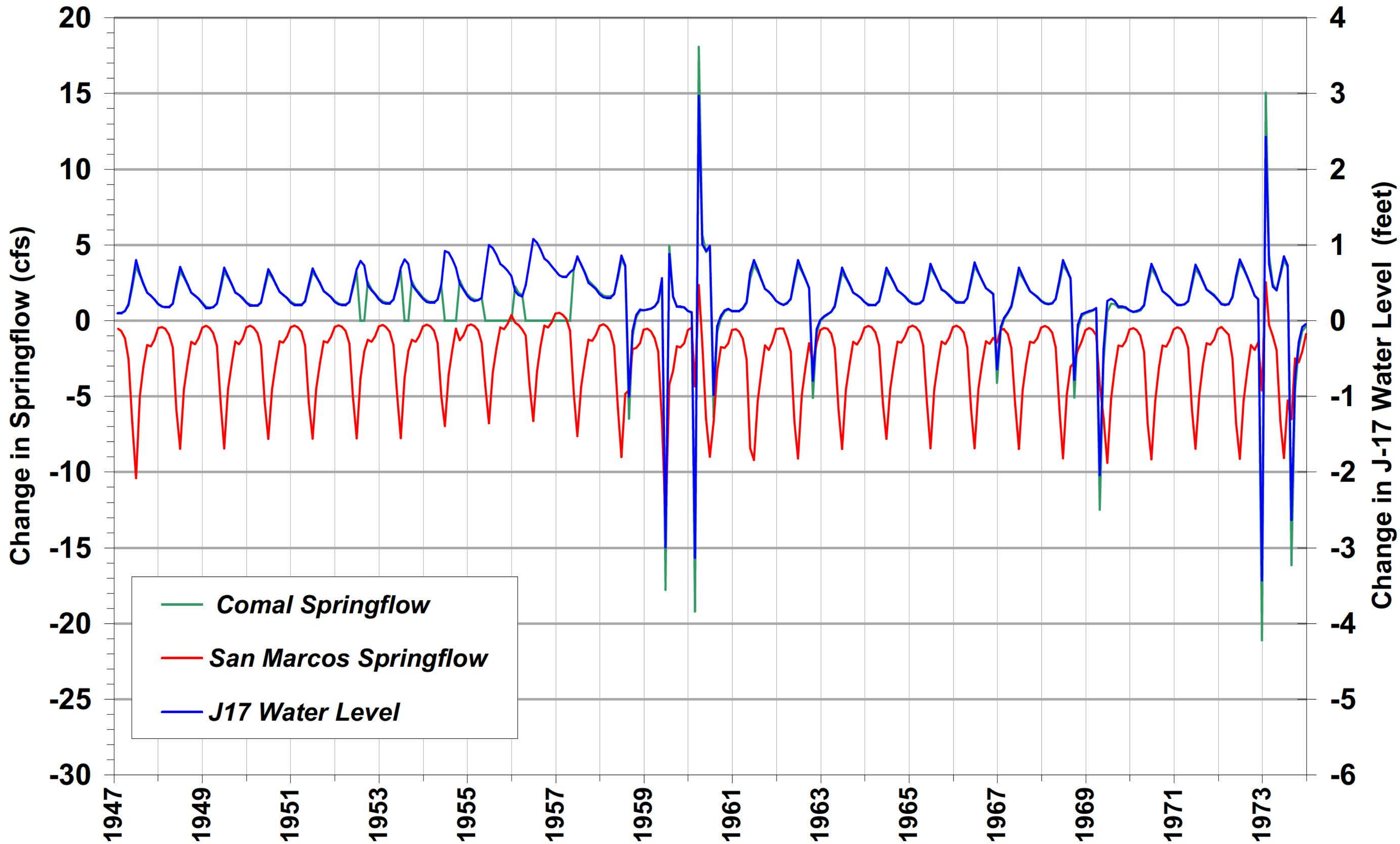

Figure A22. Change in Springflow and J-17 Water Level After Transferring 2353 af/yr from Western Bexar County to near San Marcos Springs (Down-thrown block)

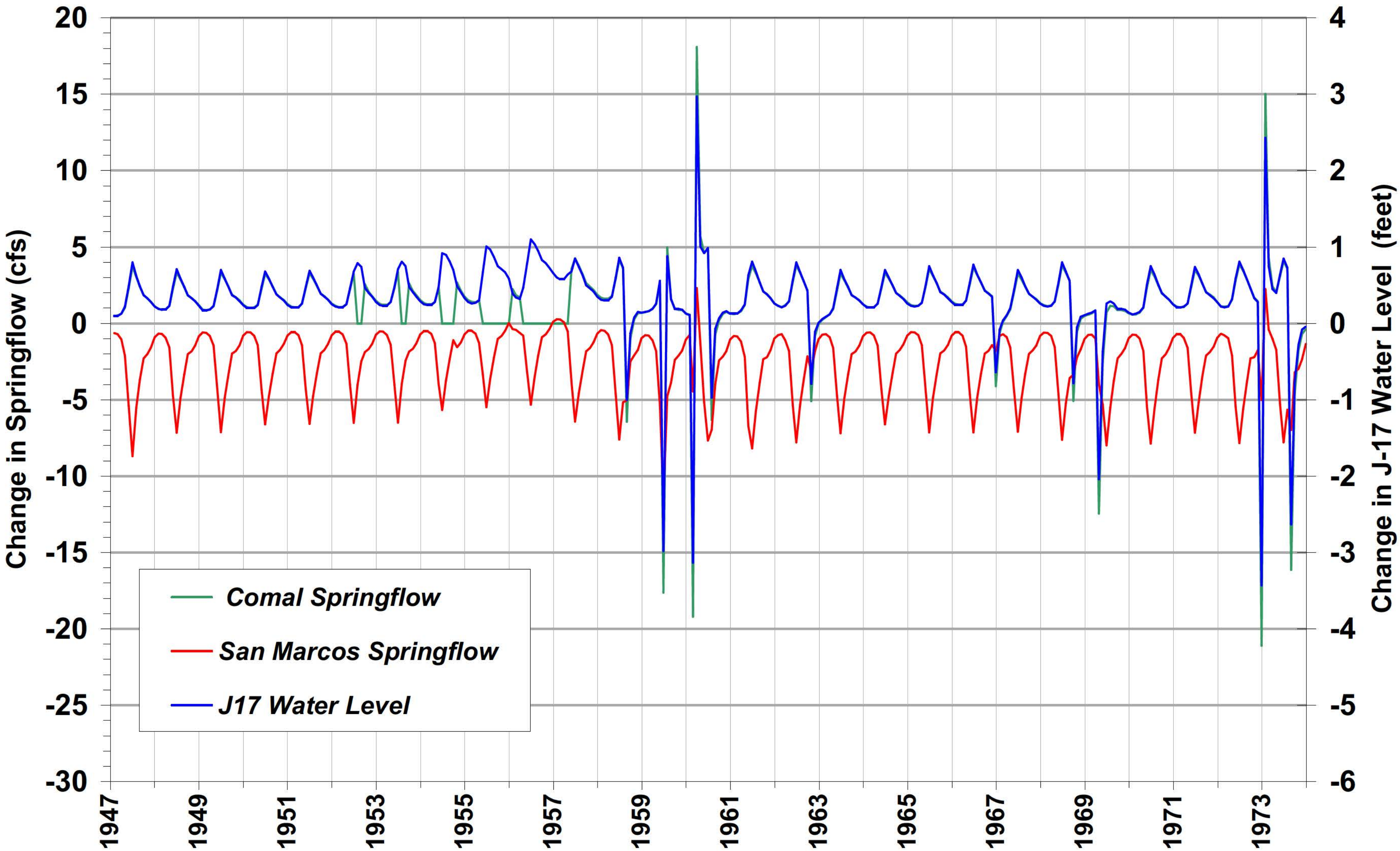

Figure A23. Change in Springflow and J-17 Water Level After Transferring 2353 af/yr from Western Bexar County to near San Marcos Springs (Up-thrown block)

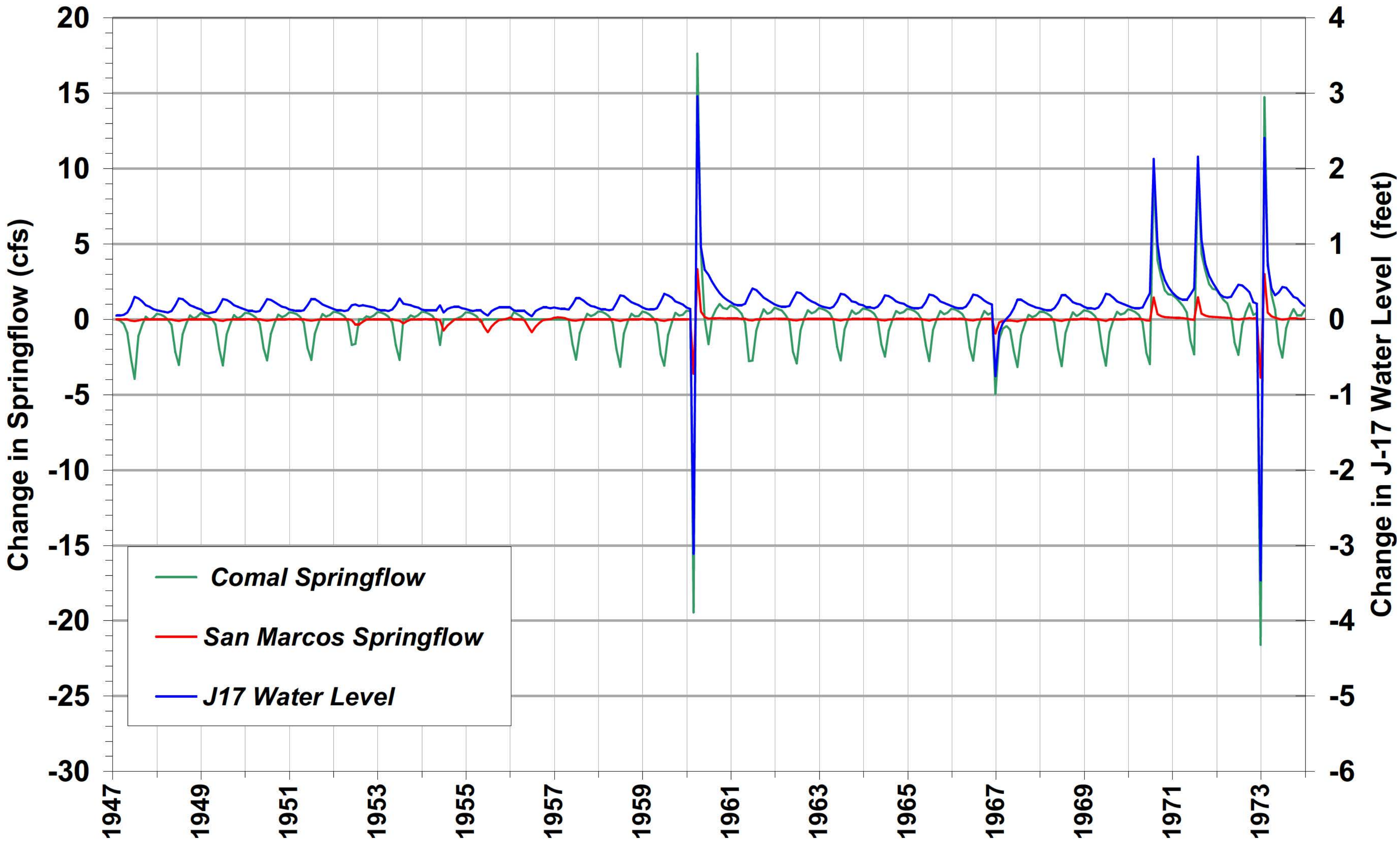

Figure A24. Change in Springflow and J-17 Water Level After Transferring 2353 af/yr from Western Bexar County to Western Comal County

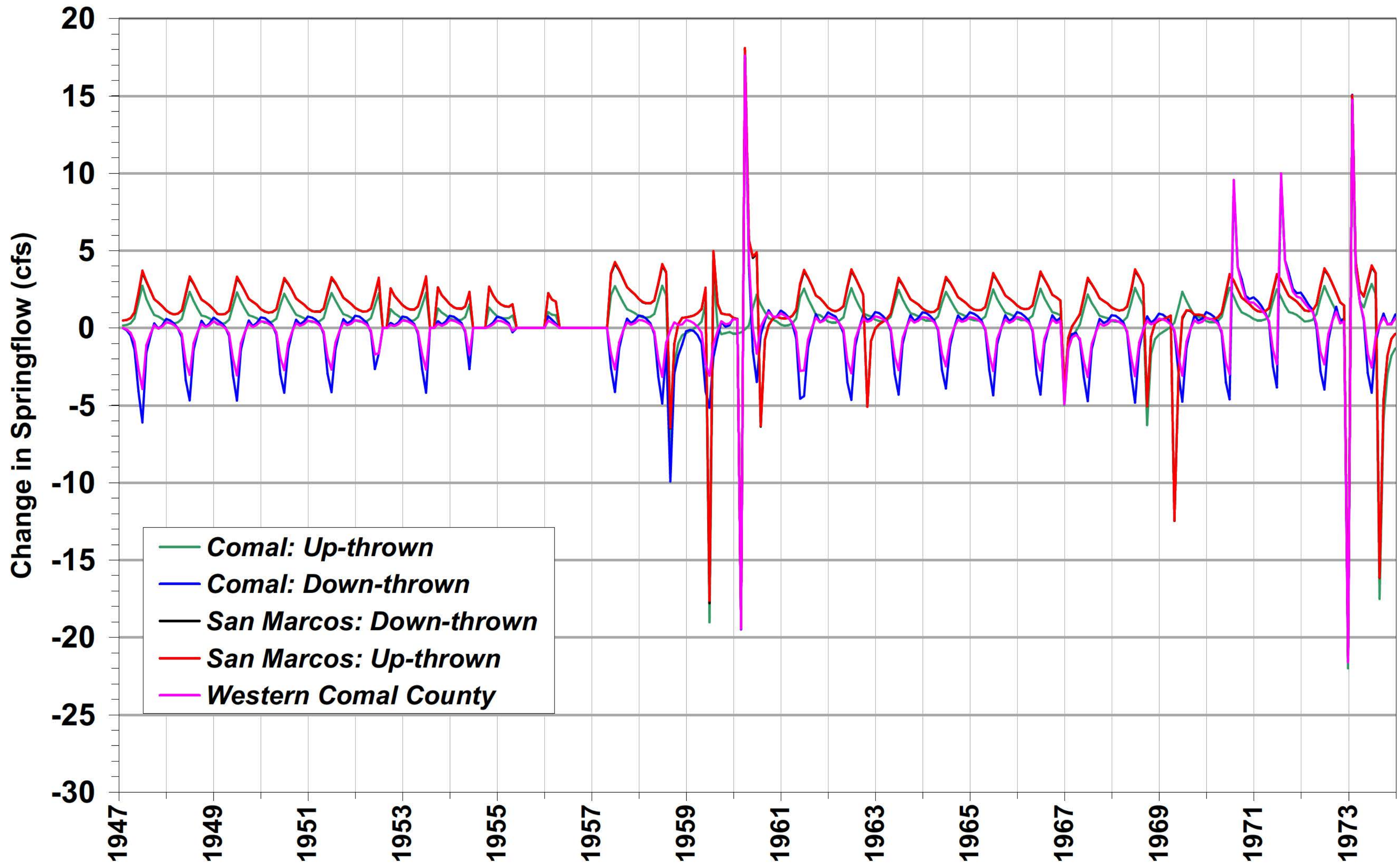

Figure A25. Comparison of Change in Comal Springflow After Transferring 2353 af/yr from Western Bexar County to Five Locations East of Cibolo Creek

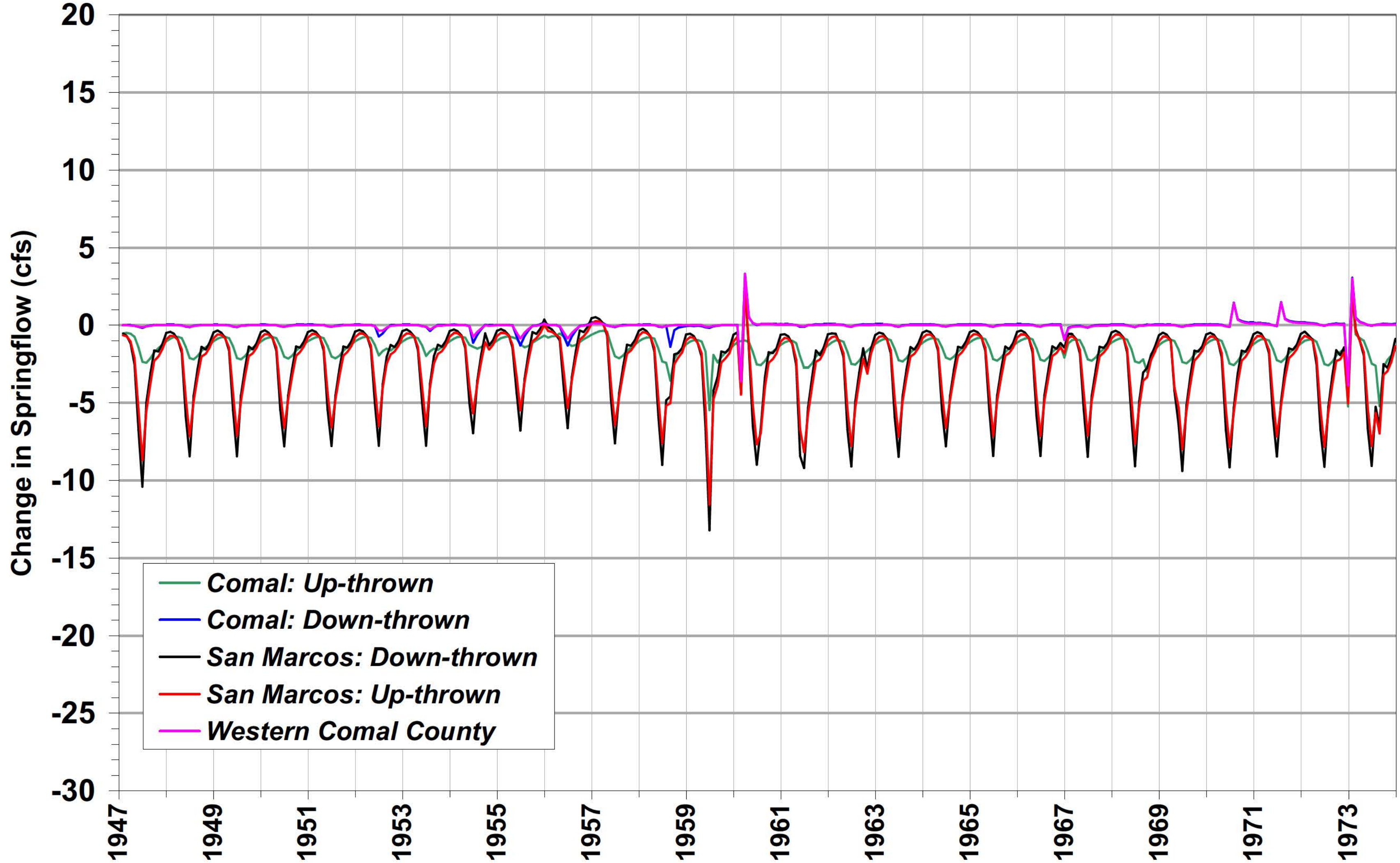

Figure A26. Comparison of Change in San Marcos Springflow After Transferring 2353 af/yr from Western Bexar County to Five Locations East of Cibolo Creek

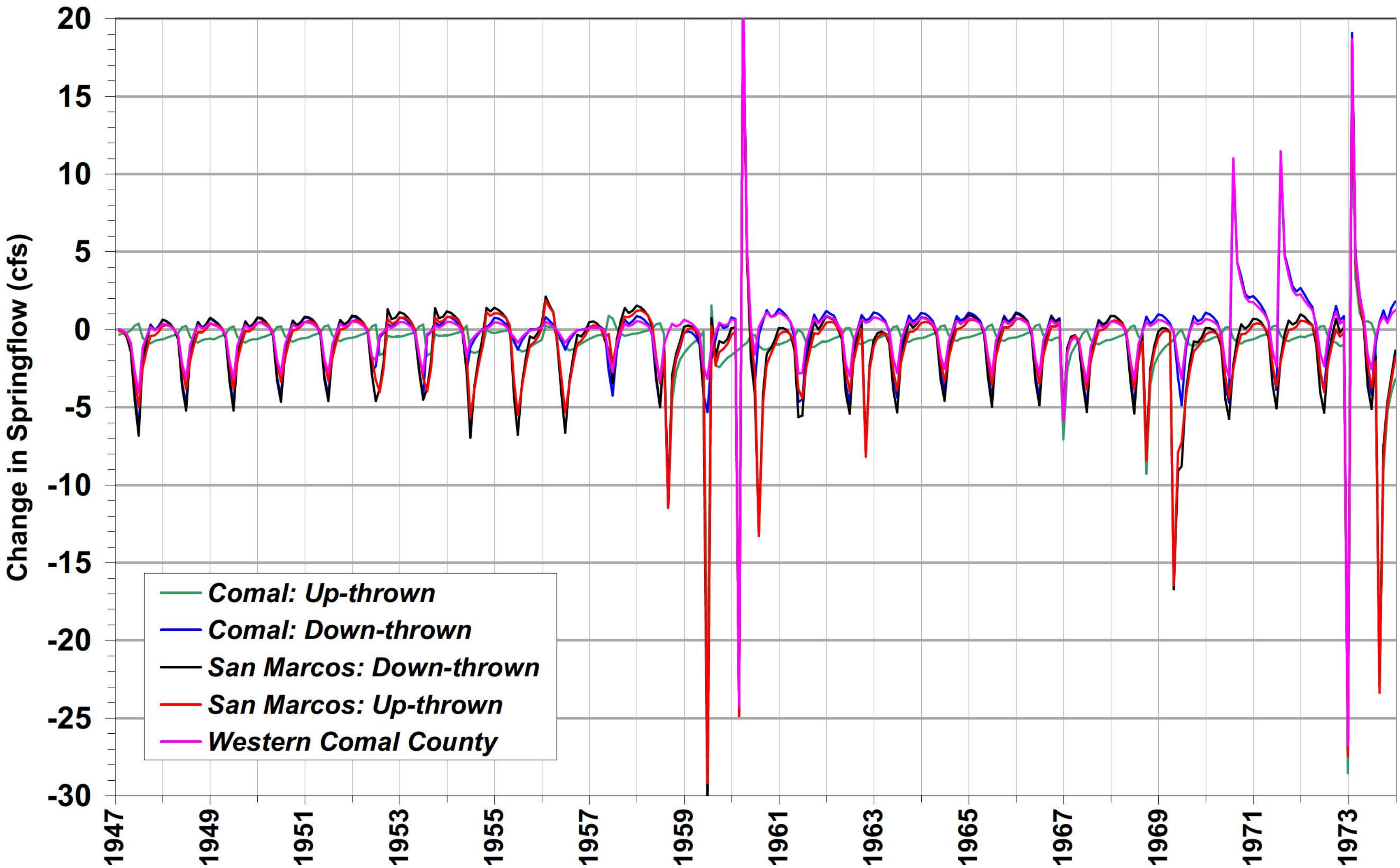

Figure A27. Comparison of Change in Total Springflow After Transferring 2353 af/yr from Western Bexar County to Five Locations East of Cibolo Creek

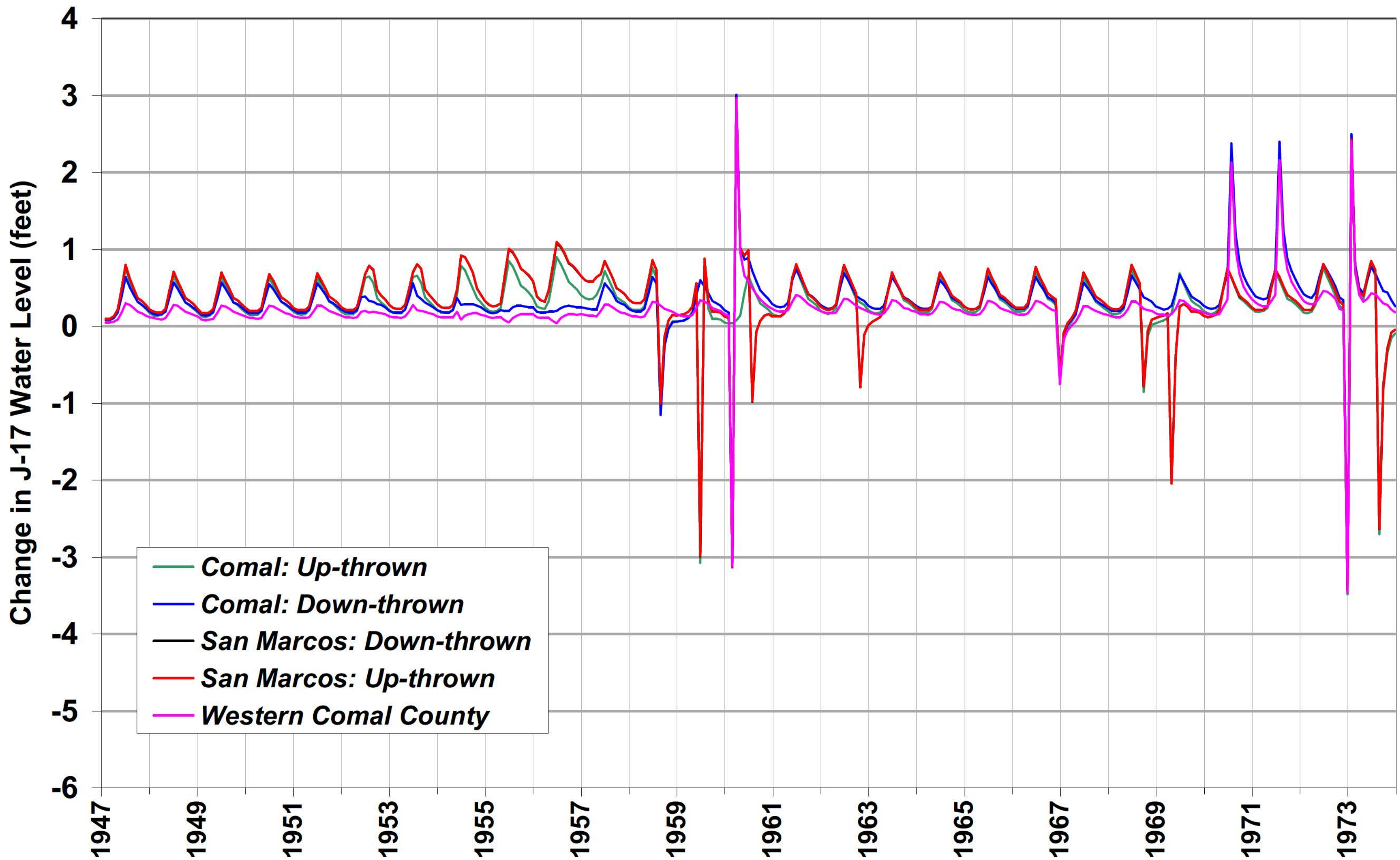

Figure A28. Comparison of Change in J-17 Water Level After Transferring 2353 af/yr from Western Bexar County to Five Locations East of Cibolo Creek

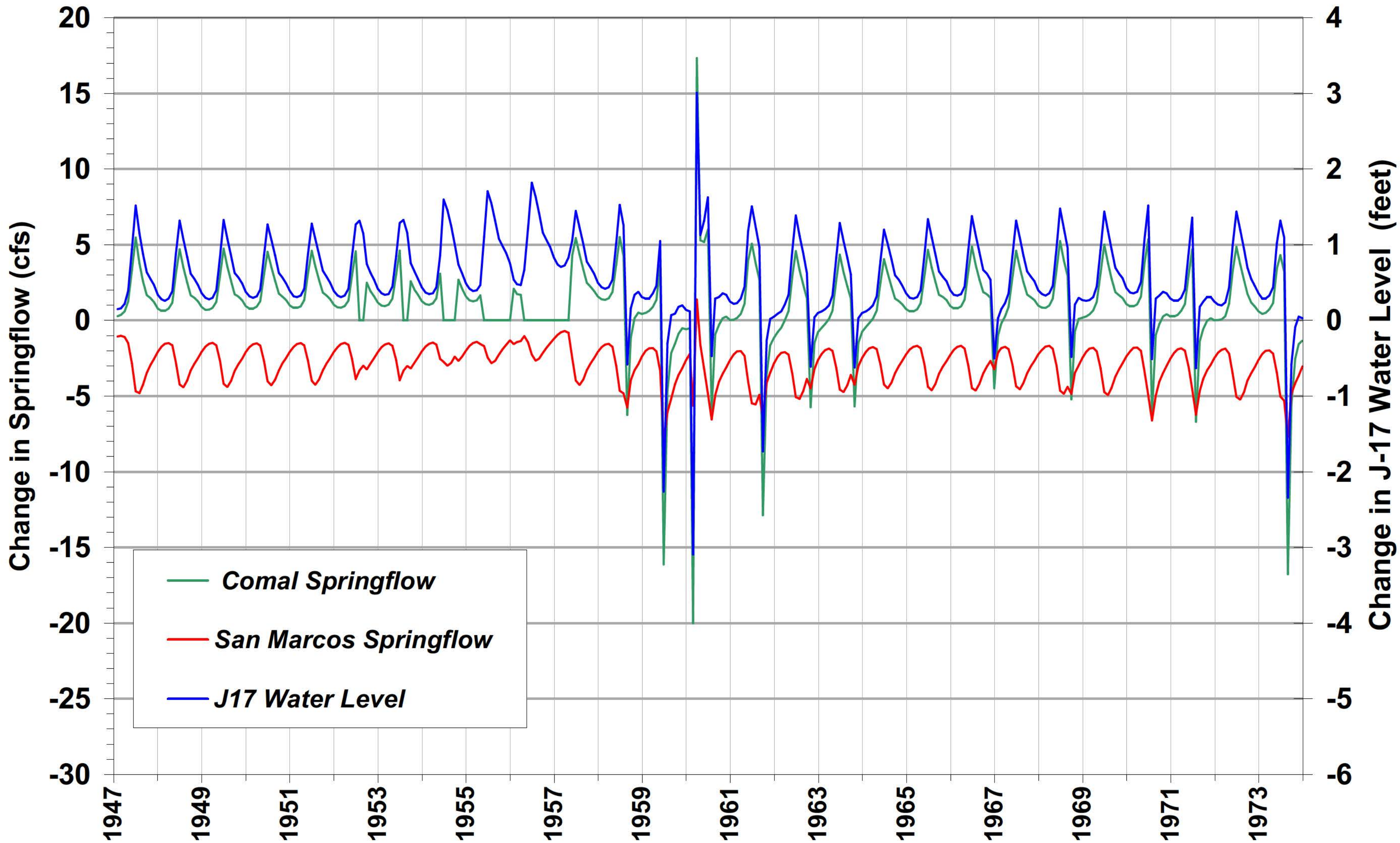

Figure A29. Change in Springflow and J-17 Water Level After Transferring 4743 af/yr from Western Bexar County to near Comal Springs (Up-thrown block)

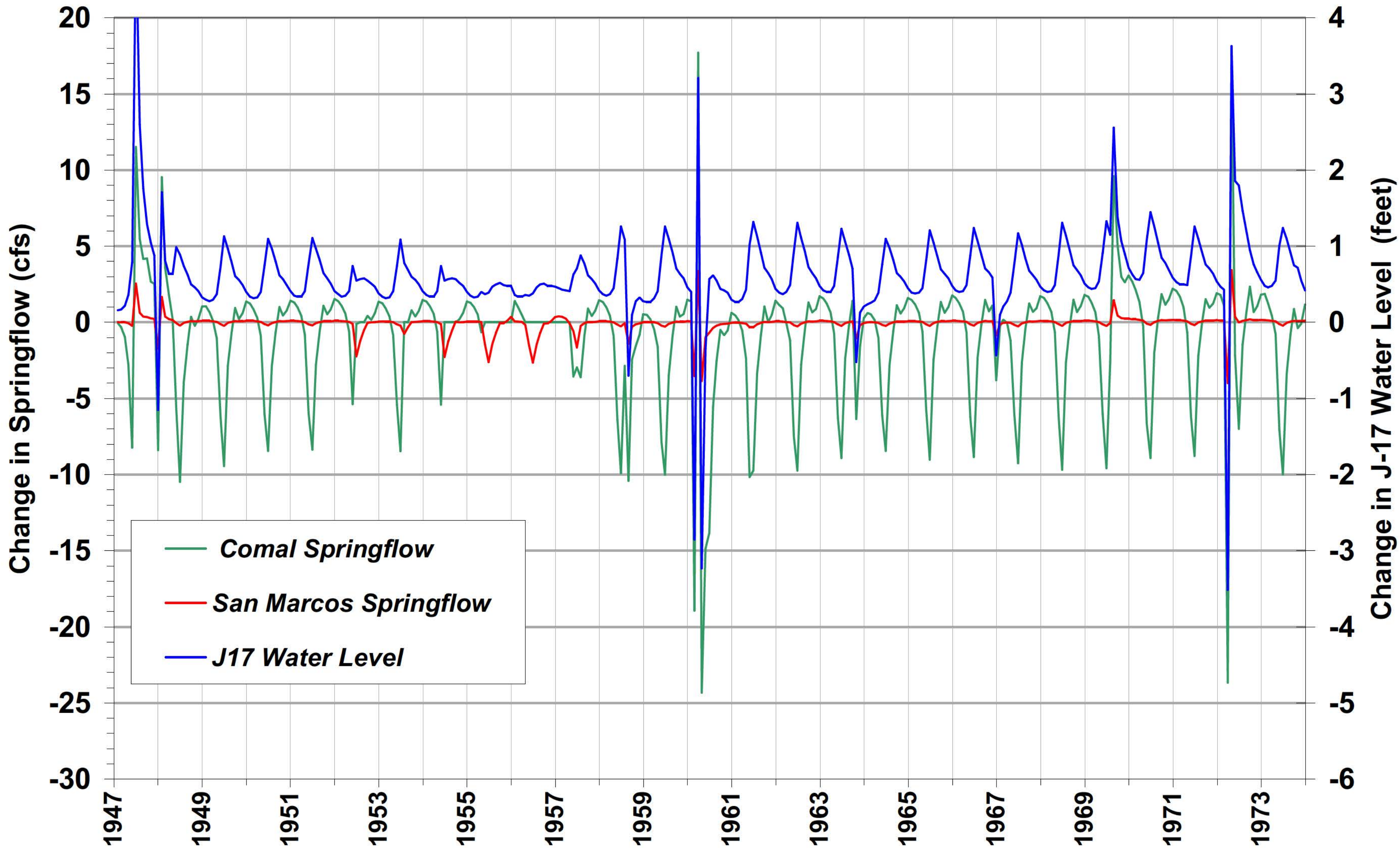

Figure A30. Change in Springflow and J-17 Water Level After Transferring 4743 af/yr from Western Bexar County to near Comal Springs (Down-thrown block)

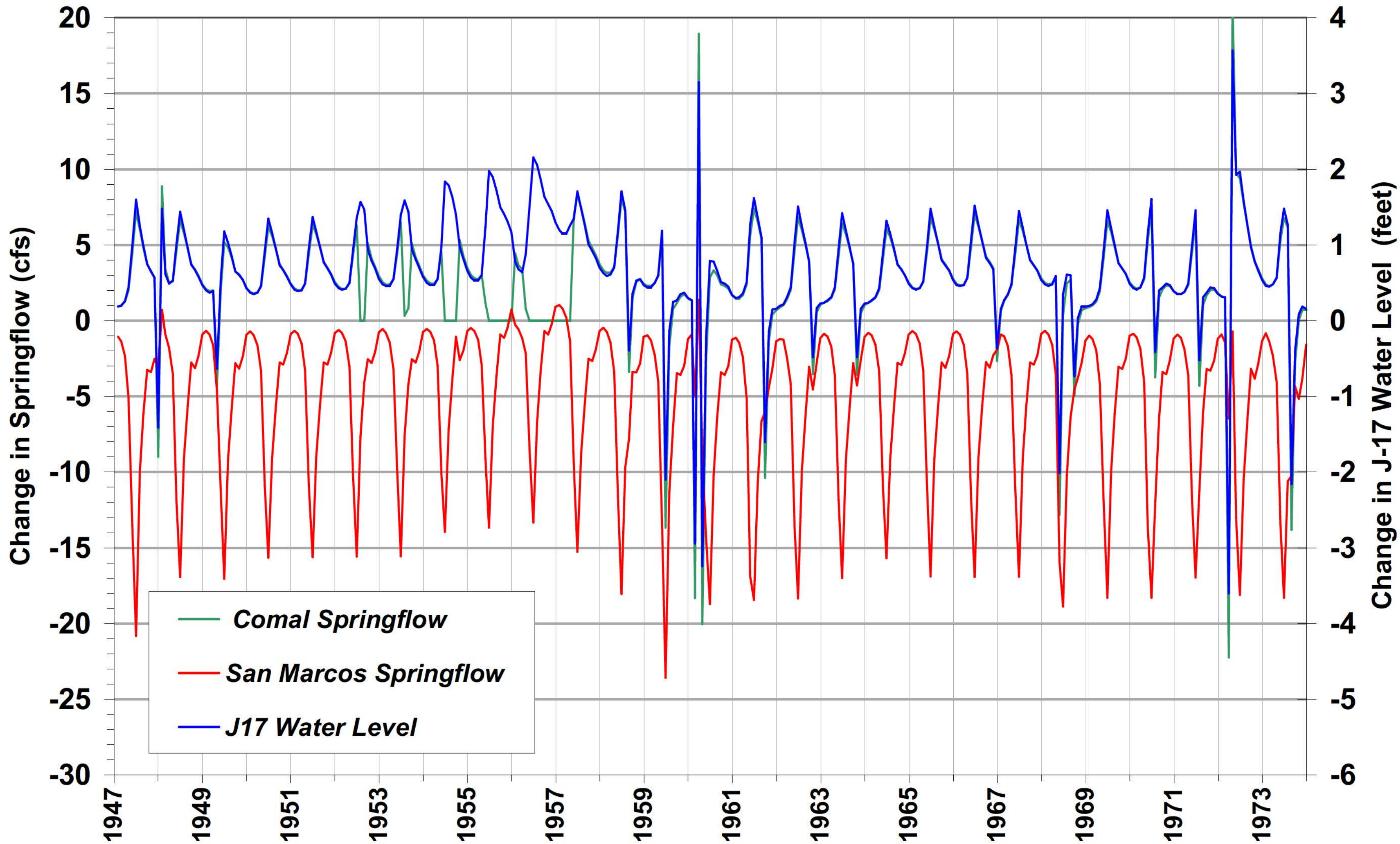

Figure A31. Change in Springflow and J-17 Water Level After Transferring 4743 af/yr from Western Bexar County to near San Marcos Springs (Down-thrown block)

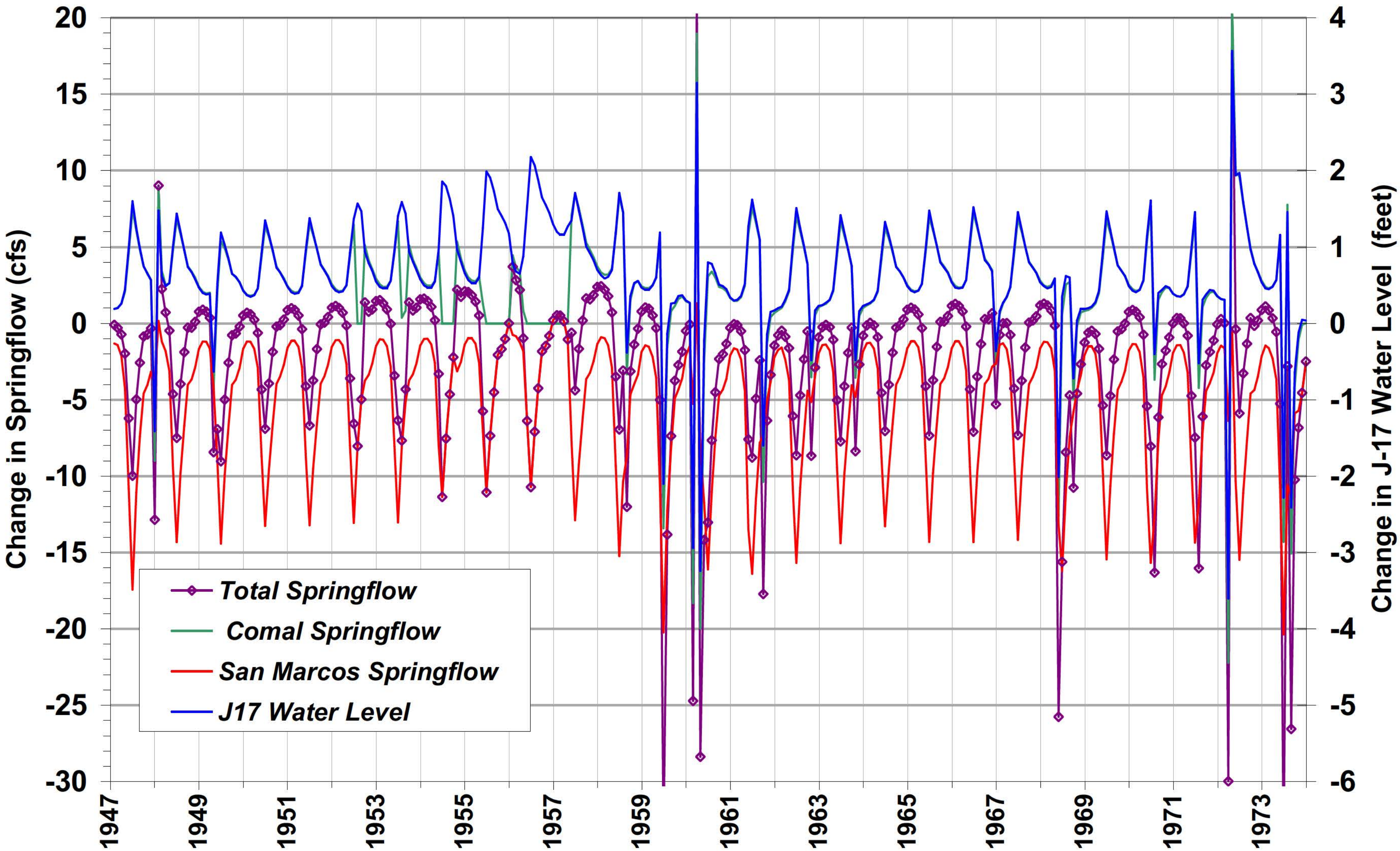

Figure A32. Change in Springflow and J-17 Water Level After Transferring 4743 af/yr from Western Bexar County to near San Marcos Springs (Up-thrown block)

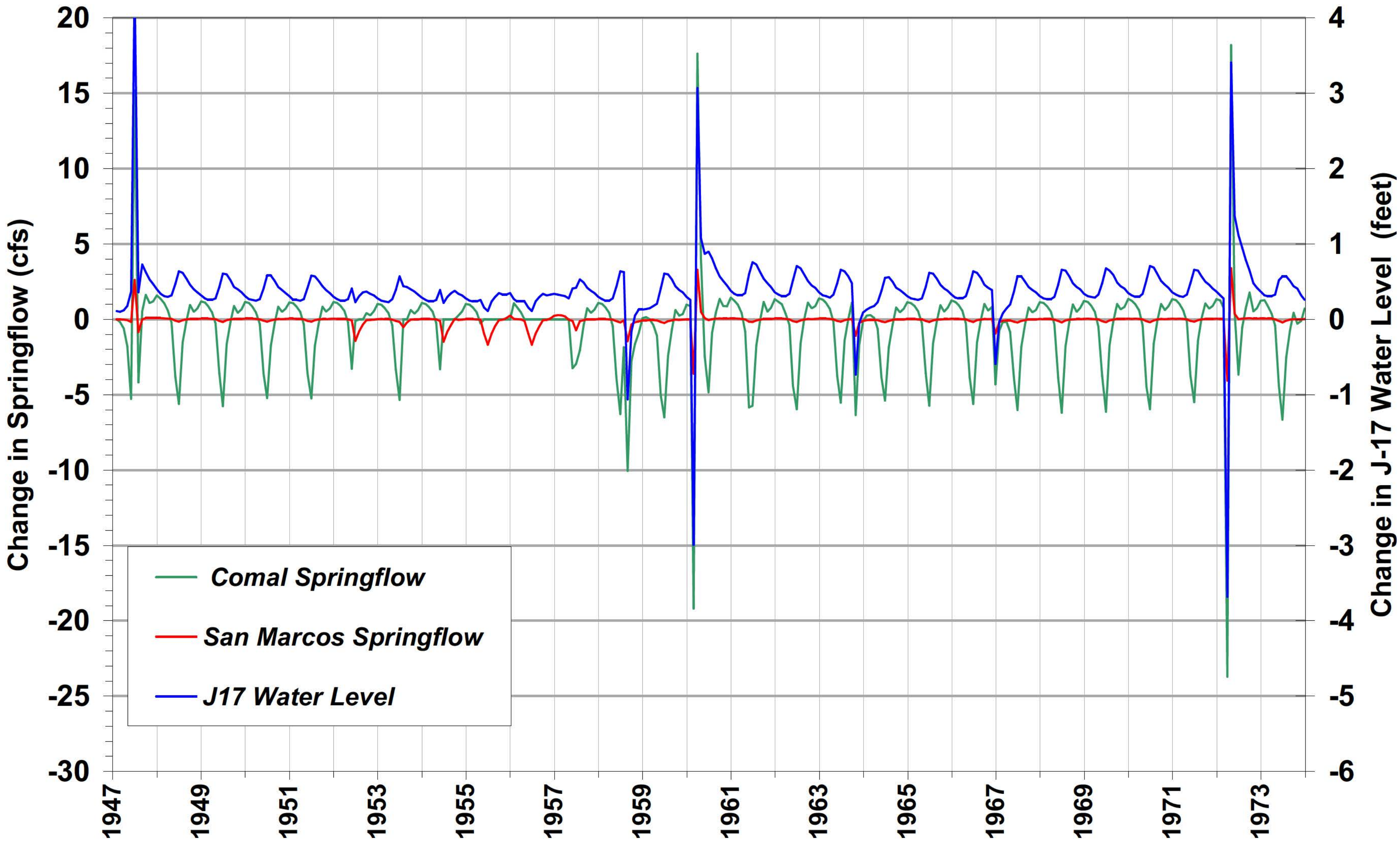

Figure A33. Change in Springflow and J-17 Water Level After Transferring 4743 af/yr from Western Bexar County to Western Comal County

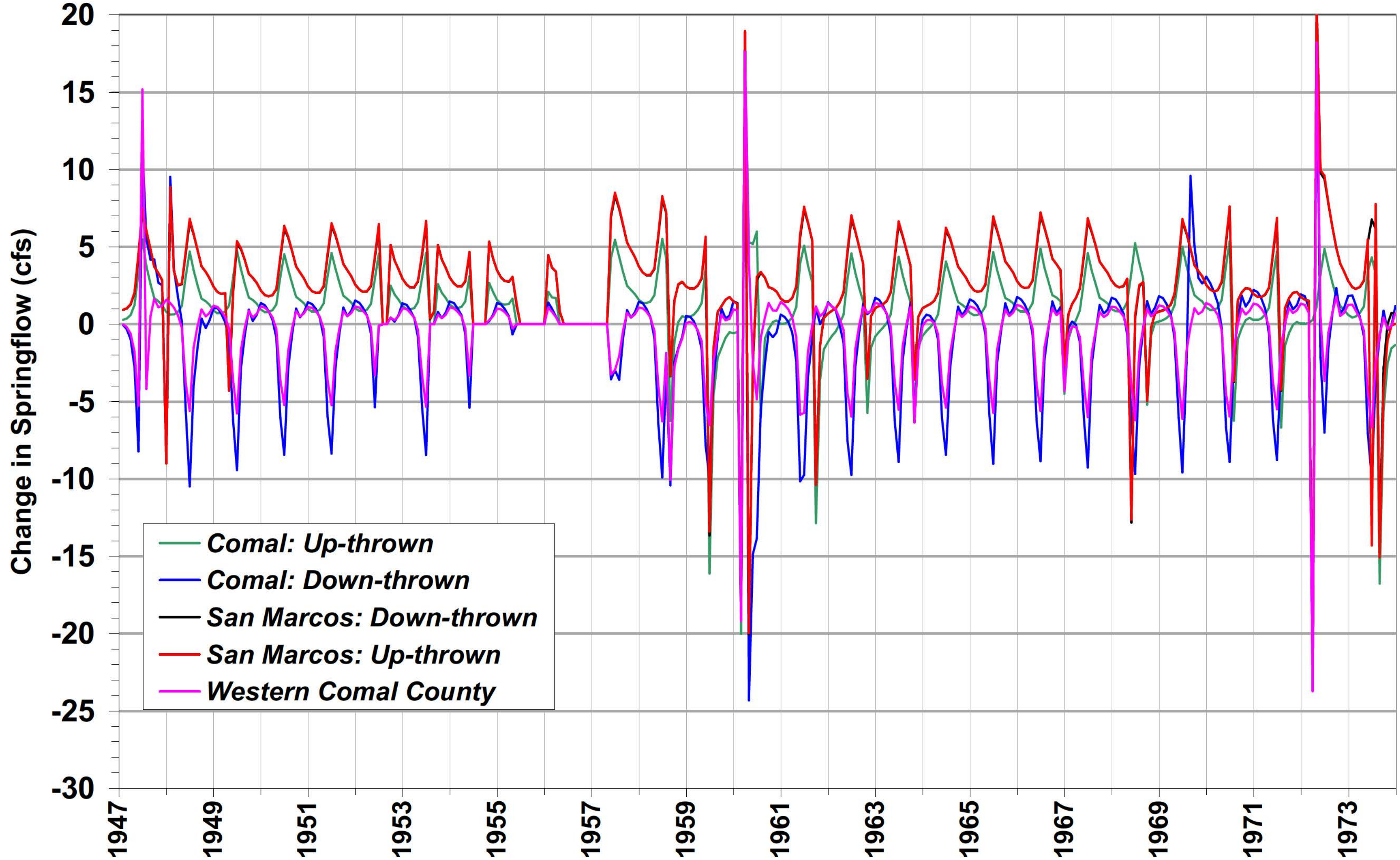

Figure A34. Comparison of Change in Comal Springflow After Transferring 4743 af/yr from Western Bexar County to Five Locations East of Cibolo Creek

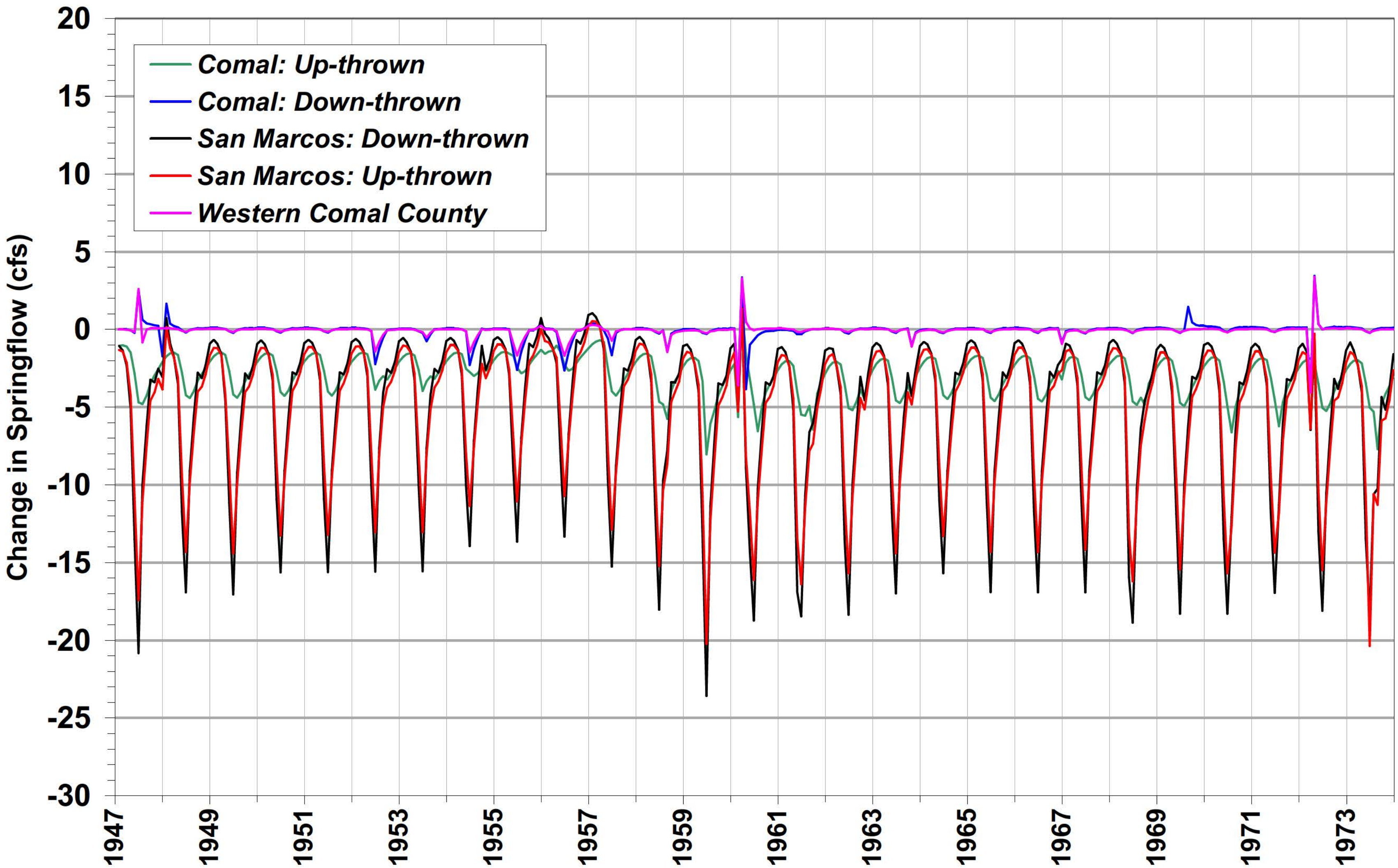

Figure A35. Comparison of Change in San Marcos Springflow After Transferring 4743 af/yr from Western Bexar County to Five Locations East of Cibolo Creek

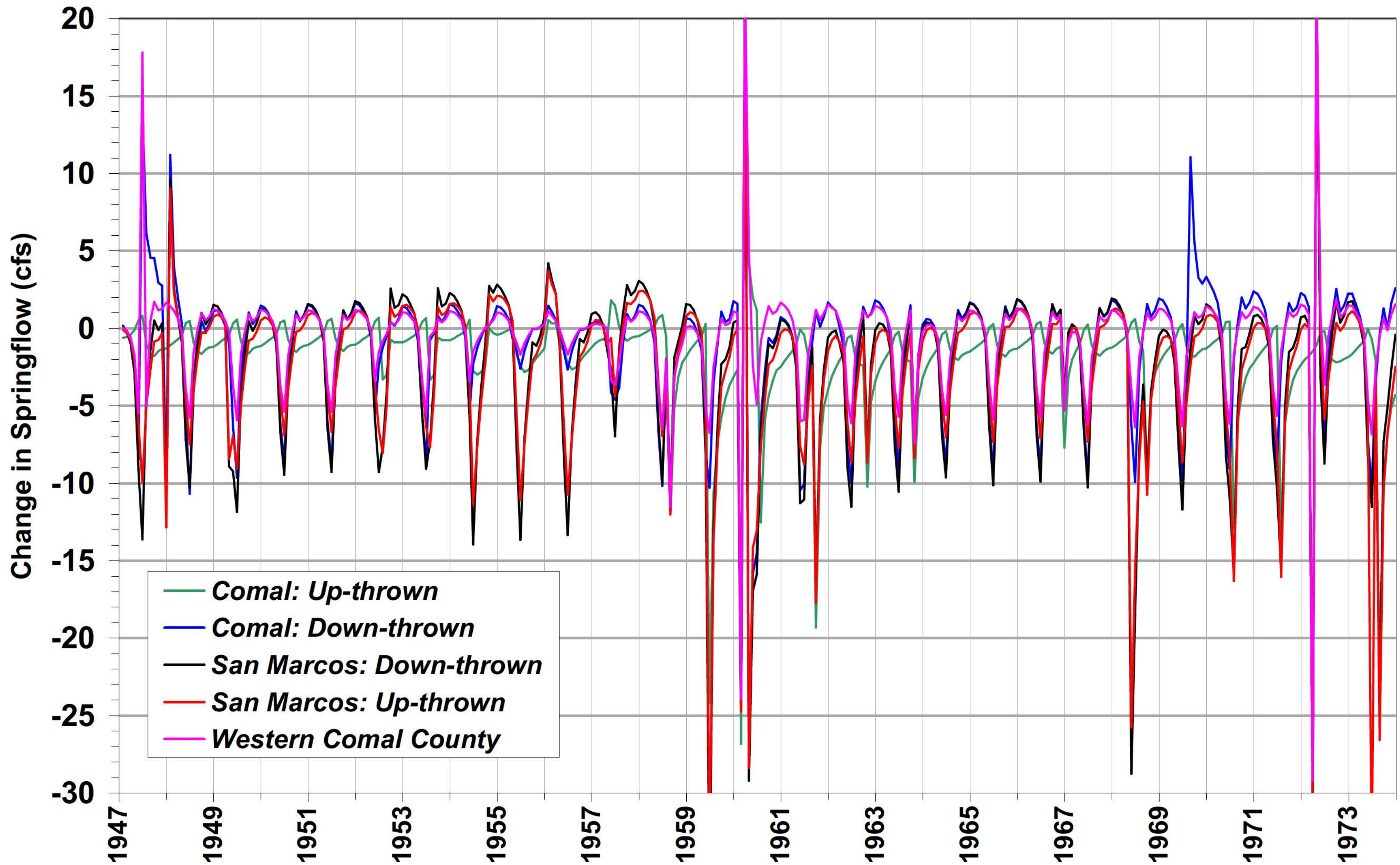

Figure A36. Comparison of Change in Total Springflow After Transferring 4743 af/yr from Western Bexar County to Five Locations East of Cibolo Creek

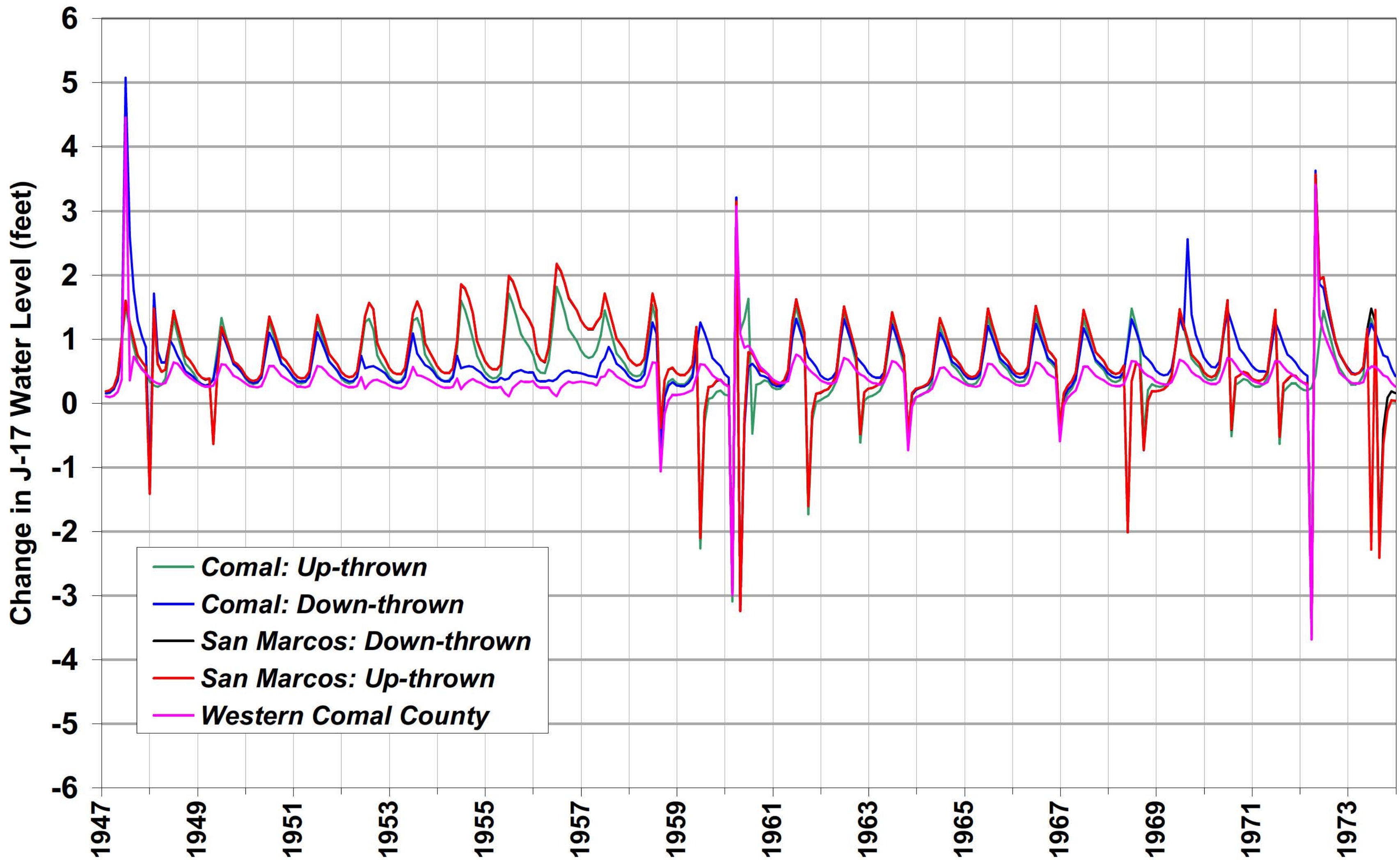

Figure A37. Comparison of Change in J-17 Water Level After Transferring 4743 af/yr from Western Bexar County to Five Locations East of Cibolo Creek