Evaluation of the Aquifer and Springflow Impacts Associated with the Cibolo Creek Transfer Rules

prepared for

The Edwards Aquifer Authority

by

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Executive Summary

The Edwards Aquifer Authority has promulgated rules that regulate the usage of ground water within the Edwards Aquifer. This includes 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 to use available data and the EAA MODFLOW groundwater model to assess the impact of Cibolo transfers on aquifer water levels and springflow.

An evaluation of current permits and transfers show that 58 percent of the transfers originate in Bexar County, followed by Medina (26%) and Uvalde (16%). Transfers make 0.51 percent of total permits. 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. Based on the modeling methodology used for this study, it is clear that Cibolo transfers impact springflow from San Marcos and Comal Springs.

The model results indicate 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. 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. Model results indicate that on average, San Marcos springflow may be decreased from 0 to 92% of the transfer volume. In seasonally high summer pumping, San Marcos springflow may be decreased from 4 to 313% of the transfer volume. Model results indicate that on average, the impact to Comal springflow ranges from a 51% increase to a 35% decrease of the transfer volume. During peak summer pumping, the maximum impact to Comal springflow ranges from an increase of 7 percent to a decrease of 203 percent of the transfer volume.

Water levels in the Bexar County index well (J-17) increase slightly due to transfers, suggesting that CP/DM triggers for the San Antonio pool would be reached slightly later during any particular dry period then they would have prior to the transfer.

1.0 Introduction

The Edwards Aquifer Authority has promulgated rules that regulate the usage of ground water within the Edwards Aquifer. This includes 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 ground-water 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.

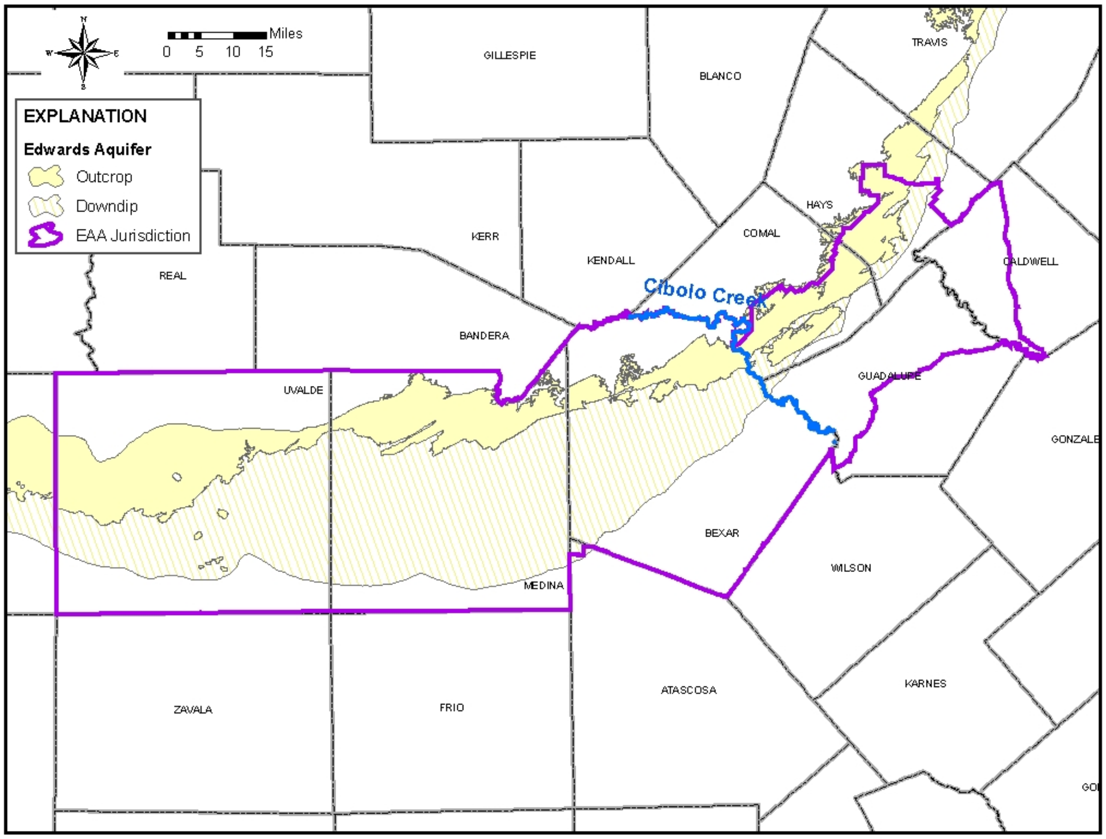

Figure 1.1 Location of Cibolo Creek, Edwards Aquifer, and EAA Jurisdiction

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 proposed project. How well the model works on a local (county or smaller) basis was evaluated. Two areas of the model were tested:

a. How spring flow is simulated within the model should be evaluated in detail. For example, the LBG-Guyton Associates' (2004) report has developed new 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. For previous modeling efforts of the Edwards, the bench testing 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 needs to be 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 insure that the proposed model runs to test the impact of pumping within 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. Geographic Location: 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/Drought Management Rules: The management module for MODFLOW-2000 that simulates the Critical Period Demand Management Rules (CP/DM) was not available for this study. Thus, the effect of a Cibolo transfer was evaluated in qualitative terms by assessing water levels at the Bexar County index well (J-17).
5. Overall Impact: These 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.

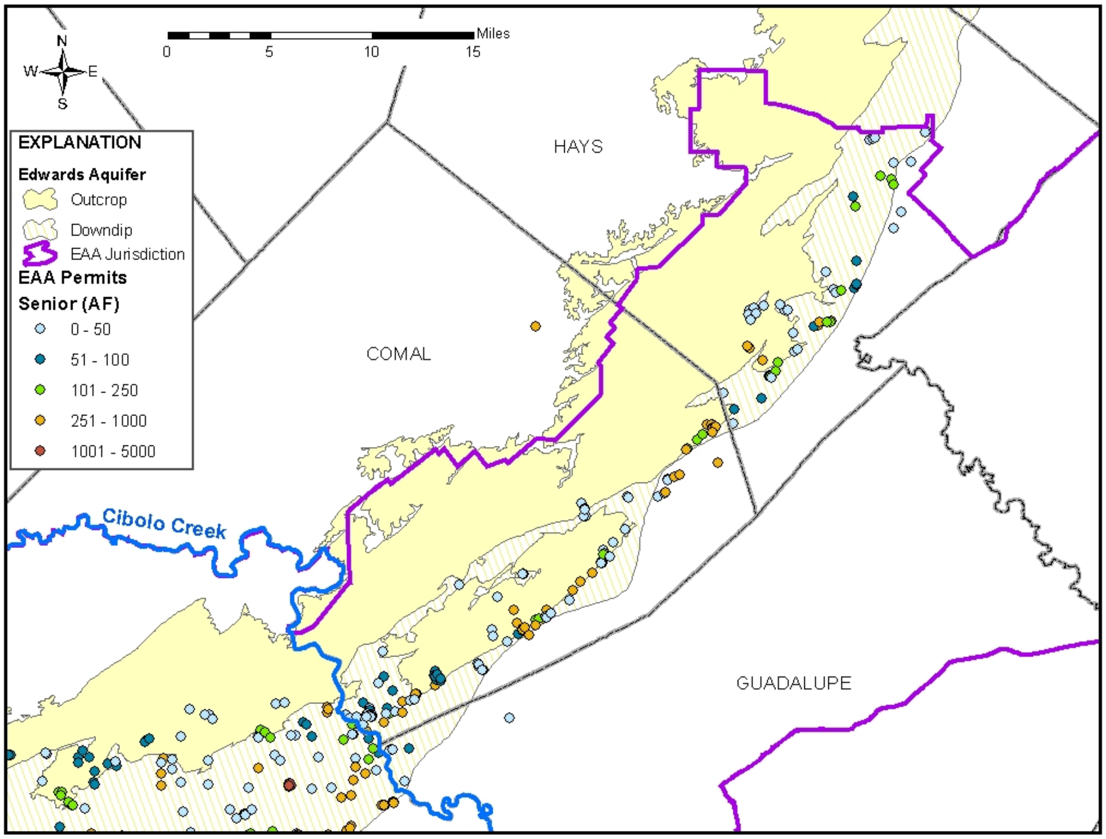

Figure 2.1 Location and Size of Permits in Comal and Hays Counties

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 30,857 acre-feet per year. The total senior permits east of Cibolo Creek equal 27,613 acre-feet per year, leaving 3,244 acre-feet per year available as junior rights.

Table 2.1 lists the current (2005) Cibolo transfers. The total transfers from west of Cibolo Creek to the east of Cibolo Creek total about 2,791.5 acre-feet.

Table 2.1 Listing of Transfers as of 2005

Docket #	Purpose	Transfer Amount
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
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
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 east of the Cibolo to west. The graph shows that 58 percent of the transfers originate in Bexar County, followed by Medina (26%) and Uvalde (16%).

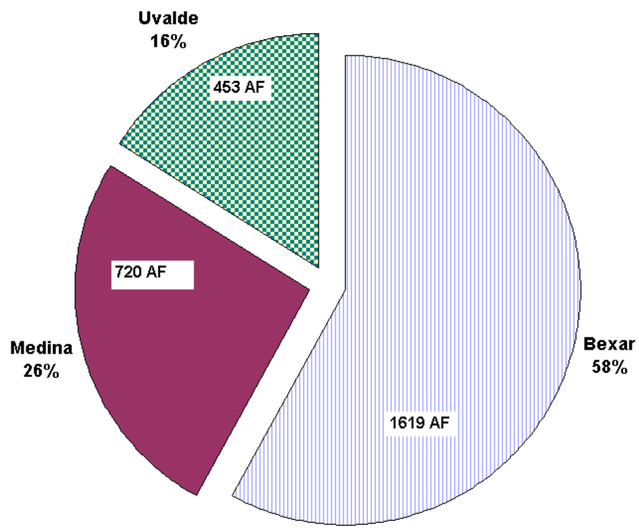

Figure 2.2 Cibolo Transfers (west to east) by County as of 2005

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 (550,000 acre-feet per year). The transferred permits equal 0.51 percent of total permits.

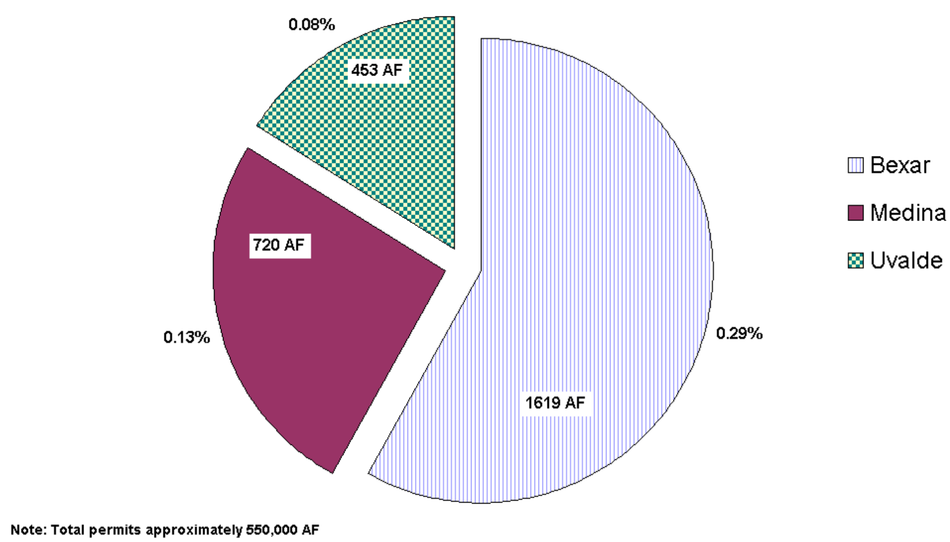

Figure 2.3 Cibolo Transfers by County (west to east) as Percent of Total Permits (as of 2005)

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

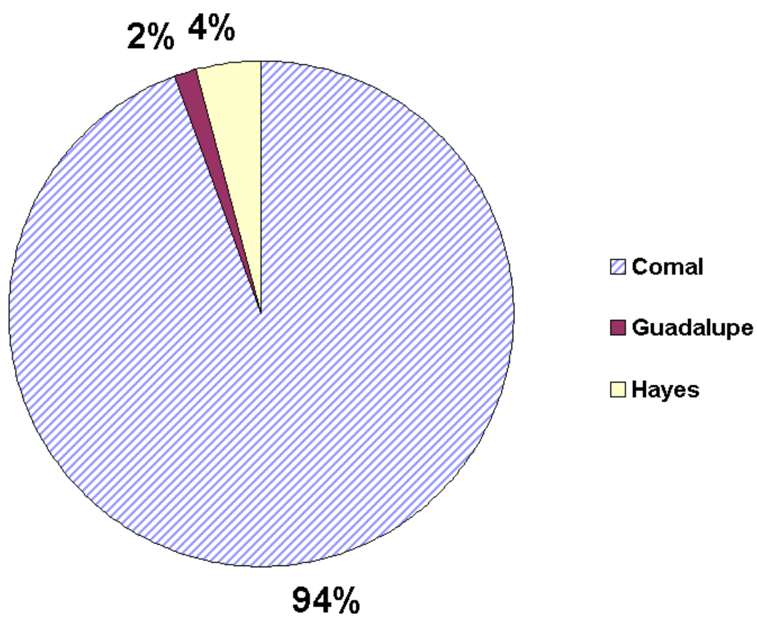

Figure 2.4 Volume of Cibolo Transfers for Receiving County

3.0 Assessment of MODFLOW Model

The anisotropic 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 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 and simulated fault locations was compared. 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 fault 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.

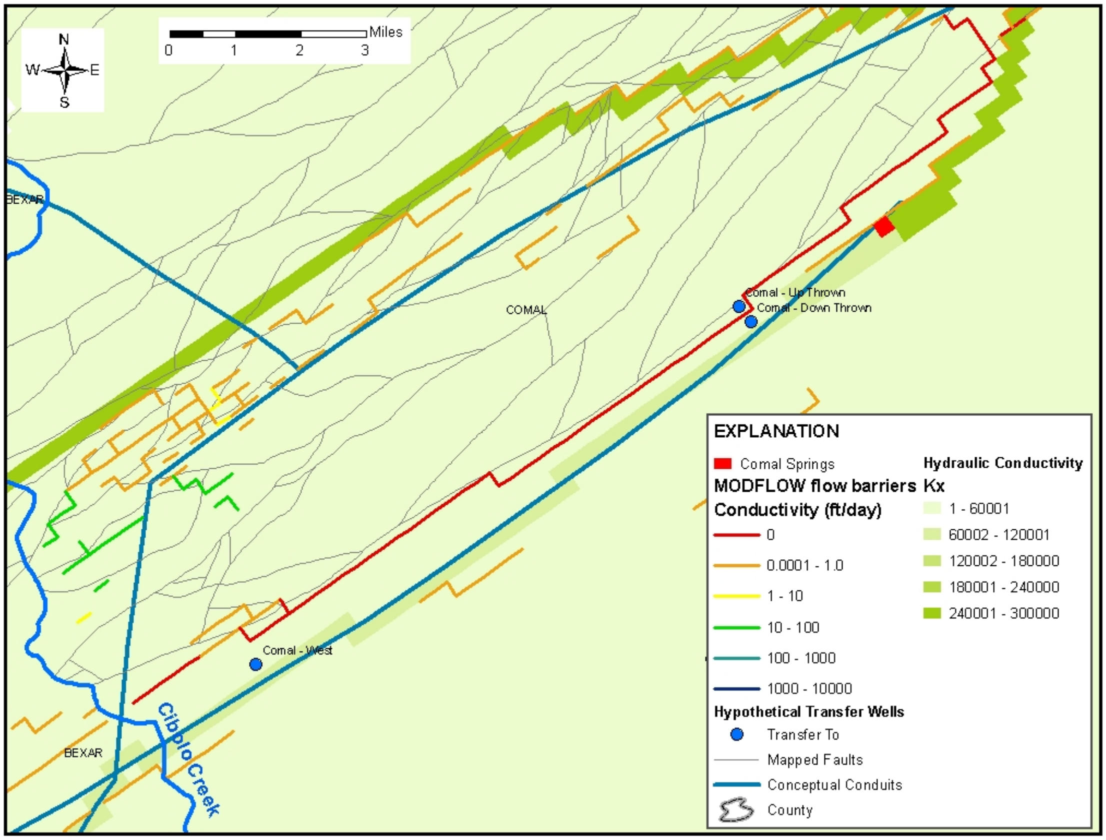

Figure 3.1 Location of Actual and Simulated Faults near Comal Springs

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 than 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.

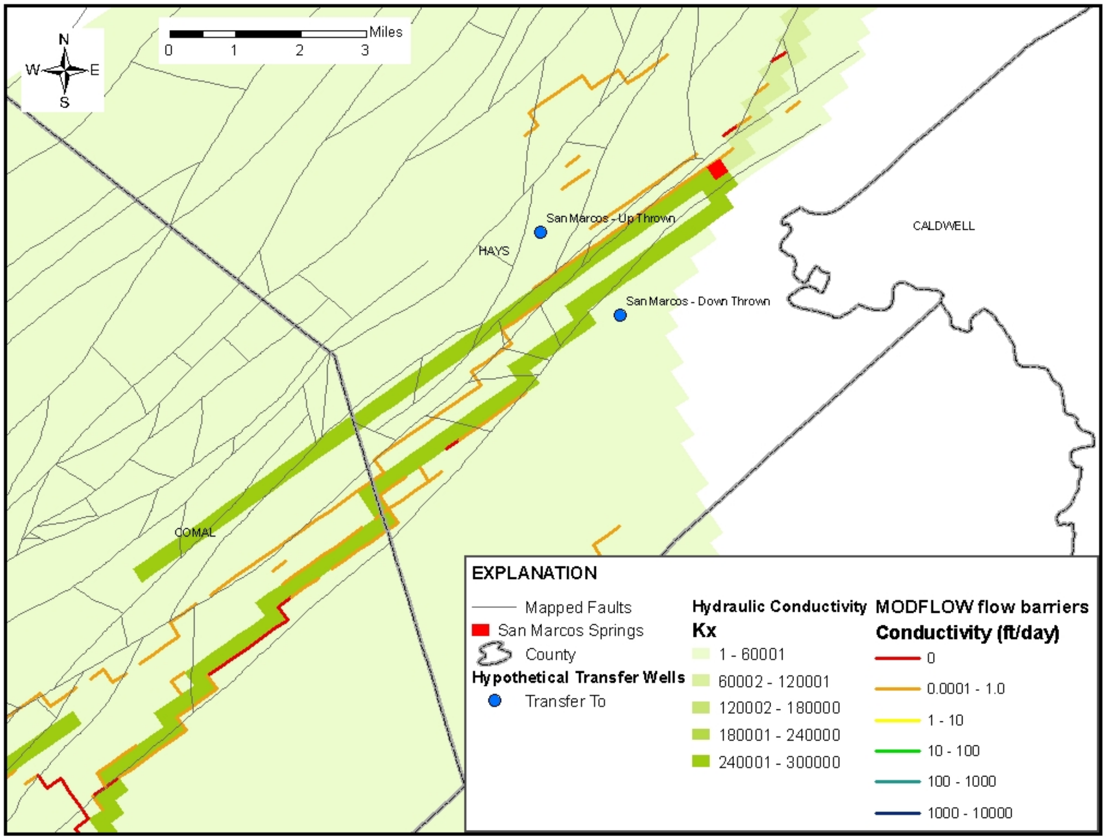

Figure 3.2 Location of Actual and Simulated Faults near San Marcos Springs

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.

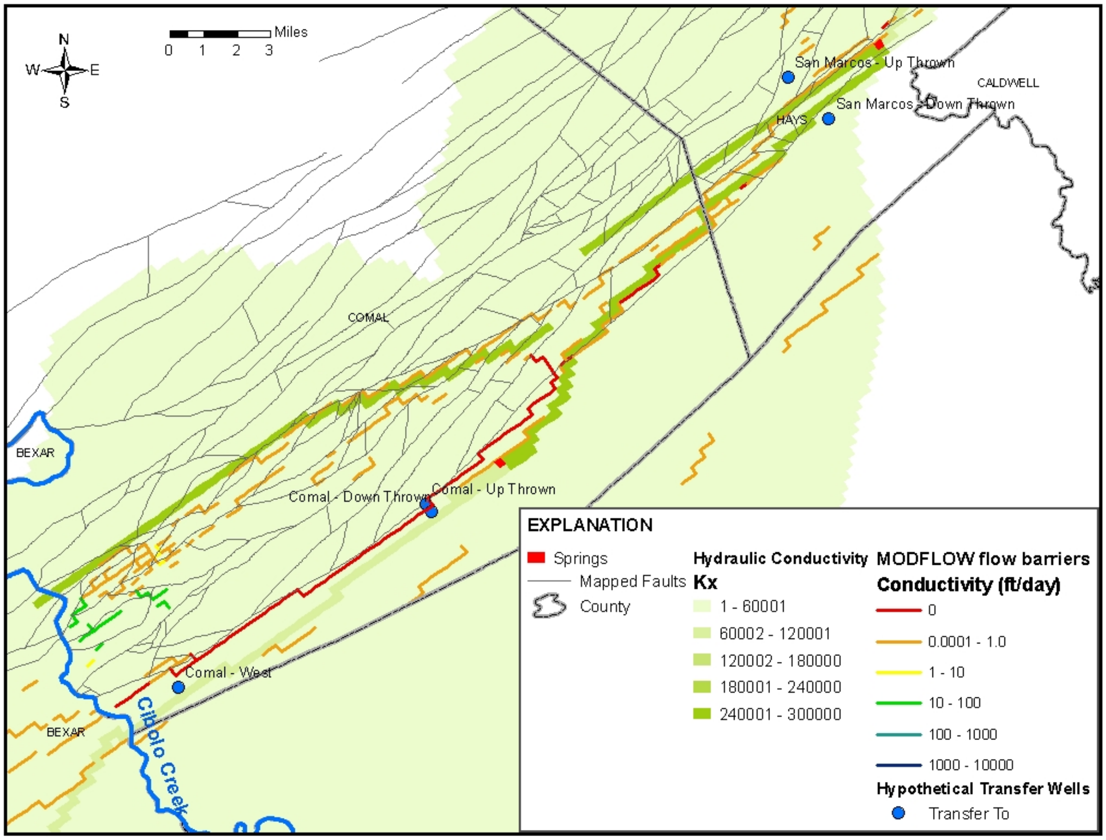

Figure 3.3 Location of Actual and Simulated Faults in Comal and Hays Counties

3.2 Quantity and Location of Pumping in MODFLOW Model

Table 3.1 compares the volume and type (senior/junior) of permits that exist east of Cibolo Creek.

Table 3.1 County Comparison of Pumping in Model and Permit Database

County	Senior	Junior	Total
Comal	19889	1964	21853
Hays	7433	1236	8669

3.3 Using MODFLOW to Evaluate Cibolo Transfers

Bench testing of the MODFLOW model was completed to assess the ability of the model to evaluate transfers. Essentially, assessment of a hypothetical transfer entails two simulations. The first simulation is a baseline to determine springflow and heads with the pumping at the original location. The second simulation simply moves the hypothetical permit to a new location for pumping. The change in springflow and heads for the transfer can then be calculated based on the difference between the simulated results.

Initially, simulations were performed which incorporated production from wells at permitted locations equal to the full senior permit amount. The mass balance errors in the model are very small (0.03 % error) and initially, the model appeared to be a good tool for assessing Cibolo transfer issues. However, after evaluating the budgets of these simulations, it was evident that under high production conditions, the volume of recharge that was simulated in the baseline run was slightly different than in the transfer run. Inspection of the model results indicated that the recharge was different in each simulation because the number and location of dry cells was different in each run. Dry cells occur in MODFLOW when the simulated water level in a cell drops below the bottom of the cell. Cells can go dry for several reasons. First, the water level may actually be below the bottom of the cell. Second, iterative solvers may oscillate such that the intermediate solution for the head in a cell may be below the bottom of the cell, in which case the cell would be inactivated and become a no-flow cell. In either of these cases, the recharge assigned to that cell is eliminated from the model.

In some cases, a MODFLOW option known as cell rewetting can be used to rewet dry cells. However, it is not always successful, and due to the iterative nature of the solution process, it can be somewhat erratic in determining which cells should be dry and which should be active. Lindgren and others (2004, page 51) discuss how the simulated base of the Edwards was lowered in the recharge zone in an effort to avoid "drying out" of cells during the calibration simulation. Although there were some dry cells (and thus loss of intended recharge), the approach worked relatively well for the calibration simulation because the pumping withdrawals increased slowly through the calibration period (for the MODFLOW model, 1947-2000). However, for the simulations that incorporate a relatively high level of pumping for the entire period of record (1947-2000), more dry cells occur, resulting in a decreased recharge that was intended to enter these cells during the course of the simulation.

This is not an issue unless different cells dry up (i.e., different recharge is thus simulated) for runs that are meant to be directly comparable. For example, to assess transfers from western Bexar County to Comal County, two simulations are completed. The baseline simulation simulates pumping in the original location, and the "control" simulation simulates pumping in a new hypothetical location in Comal County. All other variable remain unchanged for the simulation. However, by shifting the pumping from western Bexar County, there is slightly less drawdown, and therefore, fewer dry cells than occur in the baseline simulation. Therefore, overall recharge in the model is greater, and thus there is an change in springflow simply because of this increased recharge. Deciphering what portion of the changed springflow is due to increased recharge and what portion is due to the transfer is difficult.

Our approach to circumvent this problem was to lower the pumping withdrawal for the scenarios to a level that limits the impact of the dry cells and lost recharge. For the simulations completed for this study, the total production from wells was adjusted downward to 100,000 acre-feet per year. Another option might be to artificially move the recharge downdip (generally to the south or southeast) into gridblocks that have sufficient thickness such that they do not go dry during simulations that the Authority will typically be running.

We are currently using the calibrated MODFLOW model without incorporating Critical Period/Demand Management (CP/DM) rules. This is because the GMG solver must be used to obtain good mass balance for this study, but it is only available in MODFLOW-2000. However, the EAA MODFLOW Management Module (MMM) is currently only available for MODFLOW-96. EAA has a contractor working on a MODFLOW-2000 version of the MMM, but it is not available yet. We do not feel that this is a limitation for the study because the general impact of Cibolo transfers on CP/DM can be assessed by looking at J-17 water levels from the current model.

4.0 Assessment of Cibolo Transfers

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

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. As discussed in Section 3, all simulations were completed with a total aquifer withdrawal of 100,000 acre-feet per year and the original location of the transferred permit was in western Bexar County. To assess the impact of Cibolo transfers, the following factors were considered:

1) New pumping location
    - 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 Amount
    - i) 1,600 acre-feet/year
    - ii) 4,800 acre-feet/year

Figure 4.1 shows the location of the original permit in western Bexar County, as well as the hypothetical transfer locations east of Cibolo Creek.

4.2 Results from Cibolo Transfer Scenarios

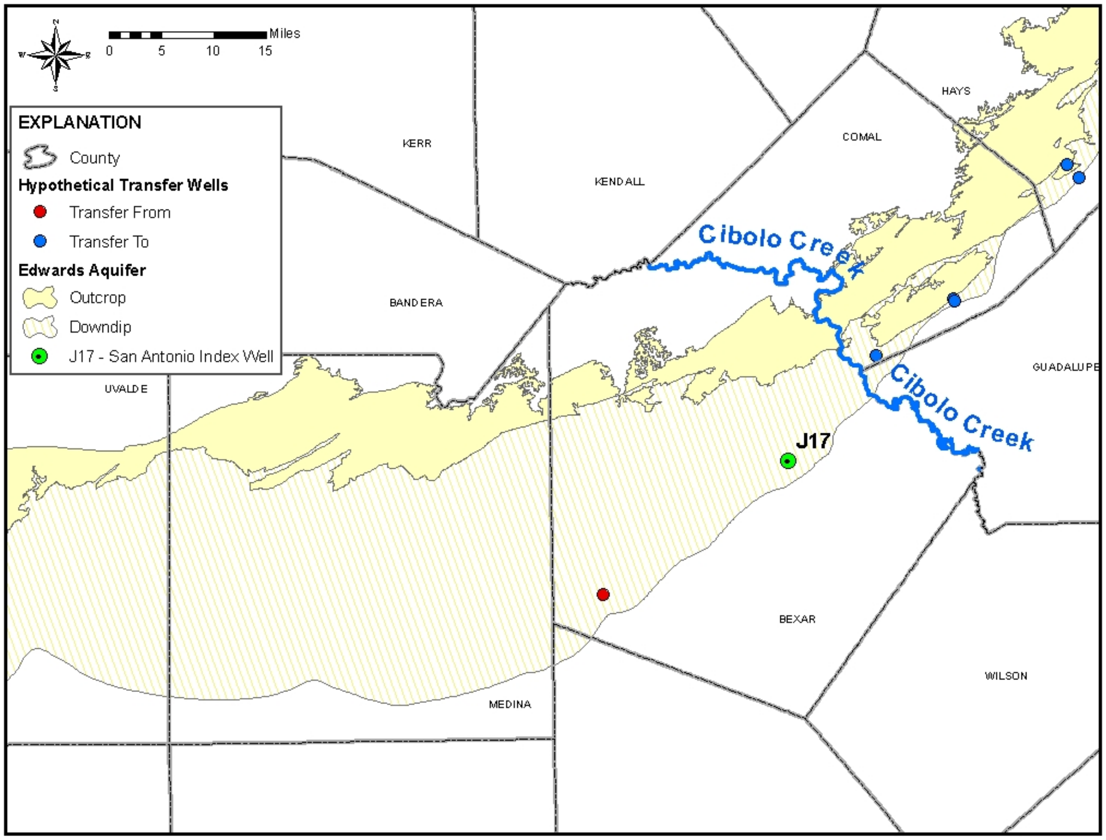

Figure 4.1 Location of Hypothetical Transferred Permits

4.2.1 1,600 af/yr Transfer (No Seasonal Adjustment)

Model runs were completed to determine the impact of transferring production from the original location in western Bexar County to the 5 new locations east of Cibolo Creek. Appendix A contains a series of graphs that illustrate the results of the different scenarios. Figures A1 through A9 show the results of transferring 1600 acre-feet per year from western Bexar County to five different locations east of Cibolo Creek. In this simulation, a seasonal adjustment was not incorporated into the pumping. In other words, the 100,000 acre-feet per year production was evenly divided into 8,333 acre-feet per month. The transfer amount was also equally divided.

Figure A1 shows the change in springflow and J-17 water level after transferring 1,600 af/yr (constant) to near Comal Springs (up-thrown block). These modeling results indicate that this transfer affects Comal and San Marcos Springs differently. Figure A1 illustrates that Comal springflow actually increases when the production is transferred to the up-thrown block near Comal Springs. Comal springflow increases in this scenario because of the no-flow HFB that is present in the model between the up-thrown and down-thrown blocks as discussed in Section 3. Comal springflow increases because most of the produced water at this pumping location is preferentially taken from the up-thrown block, leaving more water to flow into the down-thrown block. Pumping in the up-thrown block does not decrease Comal springflow because most of the flow for Comal Springs originates from the down-thrown block, which is hydraulically separated from the up-thrown block in the model.

San Marcos springflow decreases because the well takes water from the up-thrown block, which is a major artery for groundwater flow to San Marcos Springs. Because the pumping occurs east of Cibolo instead of in Bexar County, J-17 water levels increase about 0.20 feet on average, which increases springflow in San Pedro and San Antonio springs. Total springflow decreases slightly because the water levels in western Bexar County are slightly higher after the transfer, and thus the gradients toward San Antonio are slightly less, resulting in slightly higher spring flow from Leona and Los Moras springs in Uvalde and Kinney counties, respectively. Figure A1 also shows the impact of the 1950's drought on the springflow.

Table 4.1 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 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 decreases due to the transfer to that location. Positive values indicate that the springflow increases due to the transfer to that location. Table 4.2 shows the same information as Table 4.1, except that the change is presented as a percent of the transferred volume. For example, a value of -53% 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 (-1.17 cfs) by the total volume of the transfer (2.2 cfs). Obviously, there are other ways represent the change, such as a percent of the total springflow. However, these values vary significantly throughout the simulation period due to the wide range of springflow. As total production from the aquifer increases so that the total springflow decreases to CP/DM trigger levels, the impact of any particular transfer will become a larger portion of the total springflow.

Table 4.2 indicates that transfers from western Bexar County to east of Cibolo can either increase or decrease Comal springflow from –32% to 54% of the transferred volume. However, San Marcos springflow is never increased with the transfers. The impact on San Marcos springflow ranges from 0% to 91% of the transferred volume on average. San Pedro and San Antonio springflow increases in all cases because the water levels near San Antonio increase, thus increasing springflow. This is confirmed by looking at the right-hand column in Table 4.1, which shows that J-17 water levels increase for each transfer. The consistent increase in J-17 water levels due to transfers suggests that CP/DM 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. As shown in Table 4.1, the further east the Bexar county production is shifted, the more J-17 increases and in theory, the triggers would be reached slightly later in the dry period. From a practical standpoint, the later triggering caused by transfers may not be significant.

We did not perform simulations that transferred production from Uvalde to east of the Cibolo. However, the results of these simulations suggests that transfers from Uvalde (especially those near the Uvalde pool index well J-27), would have some impact on the times at which the Uvalde pool trigger levels were reached during dry periods or during the irrigation season. For the Uvalde pool, later triggering could have a significant impact on total production, especially during the irrigation season. This increase in production from the Uvalde pool might have a delayed impact on the triggering (and thus production) in the San Antonio pool.

As mentioned above, total springflow (from Comal, San Marcos, San Pedro and San Antonio springs) decreases slightly because the water levels in western Bexar County are slightly higher after the transfer, possibly resulting in higher spring flow from Leona and Los Moras springs in Uvalde and Kinney counties, respectively. Although we could not use the model to simulate relatively higher total production (350,000 to 550,000 acre-feet per year), it is expected that springflow from San Pedro and San Antonio springs would cease at those production levels. Therefore, there would be no impact to those springs from transfers because there would be no flow from those springs under that production. However, there would still be a change in J-17 water levels.

Table 4.1 Average Change in Springflow and Water Level from Bexar County Transfer (2.2 cfs or 1,600 af/yr Constant) to Various Locations in Comal and Hays County

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	0.43	-1.17	0.40	0.08	-0.26	0.20
Comal: Down-thrown block	-0.71	0.00	0.41	0.08	-0.23	0.20
San Marcos: Down-thrown block	1.18	-2.01	0.48	0.09	-0.26	0.24
San Marcos: Up-thrown block	1.20	-2.02	0.48	0.09	-0.25	0.24
Western Comal County	-0.44	-0.02	0.25	0.05	-0.17	0.11

Table 4.2 Average Change in Springflow from Bexar County Transfer (2.2 cfs or 1,600 af/yr Constant) to Various Locations in Comal and Hays County 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	19%	-53%	18%	3%	-12%
Comal: Down-thrown block	-32%	0%	18%	3%	-10%
San Marcos: Down-thrown block	53%	-91%	22%	4%	-12%
San Marcos: Up-thrown block	54%	-91%	22%	4%	-11%
Western Comal County	-20%	-1%	11%	2%	-8%

Figure A2 shows the change in springflow and J-17 water level after transferring 1,600 af/yr from western Bexar County to near Comal Springs in the down-thrown block. For this transfer location, San Marcos springflow is not impacted. However, because the withdrawal location is relatively close to Comal Springs and located in the same flowpath that supplies much of Comal Springs flow, the transferred production has an impact on Comal Springs. On average (1947-1973), the decrease in flow from Comal Springs was 0.71 cfs or 32% of the transferred amount.

Figure A3 illustrates the change in springflow and J-17 water level after transferring 1,600 af/yr from western Bexar County to the down-thrown block near San Marcos Springs. The model indicates that this transfer has a positive impact on Comal Springs and negative impact on San Marcos springflow. On average (1947-1973), the increase in flow from Comal Springs was 53% of the transferred amount, and the decrease in springflow from San Marcos was -91% of the transferred amount.

Figure A4 shows the change in springflow and J-17 water level after transferring 1,600 af/yr from western Bexar County to the up-thrown block near San Marcos Springs. As in Figure A3, the model indicates that this transfer has a positive impact on Comal Springs and negative impact on San Marcos springflow. In fact, the average impact (1947-1973) is almost identical, with the increase in flow from Comal Springs equal to 54% of the transferred amount, and the decrease in springflow from San Marcos equal to 91% of the transferred amount.

Figure A5 shows the change in springflow and J-17 water level after transferring 1,600 af/yr from western Bexar County to western Comal County. The withdrawal location for this transfer is closer to Cibolo Creek than any of the other transfers shown in Figures A1 through A4. The withdrawal location is also in the down-thrown block, although there is a relatively greater hydrologic connection between the up-thrown and down-thrown blocks in this area because it is closer to the western extent of the horizontal flow barriers (HFBs) used to simulate the fault. For this transfer location, San Marcos springflow is not impacted significantly. However, because the withdrawal location is relatively close to Comal Springs and located in the same flowpath that supplies much of Comal Springs flow, the transferred production has an impact on Comal Springs. On average, the decrease in flow from Comal Springs was 0.44 cfs or 20% of the transferred amount.

Observing the results of all five simulations provides the following general insights into Cibolo transfers.

- Permits transferred farther east have more impact on San Marcos springflow.
- Permits transferred farther east result in a 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.

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 1,600 af/yr from western Bexar County to the five locations east of Cibolo Creek. Likewise, Figures A7 through A9 compare responses in San Marcos springflow, total springflow, and J-17 water levels, respectively.

4.2.2 1,600 af/yr Transfer (With Seasonal Adjustment)

Figures A10 through A18 show the results of transferring 1,600 af/yr (seasonally adjusted) from western Bexar County to five different locations east of Cibolo Creek. This set of runs is identical to those discussed in Section 4.2.1 and shown in Figures A1 through A9, except that a seasonal adjustment was incorporated into the pumping. Table 4.3 shows the percent of the yearly total that is pumped in each month in each of the categories. The seasonal adjustment was incorporated because it is more realistic and provides insight into the maximum impact that could be expected during the heaviest summer pumping.

Table 4.3 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

Table 4.4 summarizes the average impact to springflow and J-17 water level over the 27-year simulation period (1947-1973) for a 1600 acre-feet per year transfer when the aquifer production is seasonally adjusted. The table shows the average value for the 324 monthly stress periods. As in Table 4.1, negative values indicate that on average, the springflow decreases due to the transfer to that location and positive values indicate that the springflow increases due to the transfer to that location. Table 4.5 contains the same information as Table 4.2, except that it contains results for the seasonally adjusted runs.

Figures A9 through A18 and Table 4.5 indicate that the average results for the seasonally adjusted runs are very similar to the runs that are not constant (not seasonally adjusted). Figures A9 through A18 show that the seasonal variation in pumpage does result in larger seasonal (summer) impacts in springflow. A more thorough discussion of the maximum summer impacts is contained in Section 4.2.3.

Table 4.4 Average Change in Springflow and Water Level from Bexar County Transfer (2.2 cfs or 1,600 af/yr Adjusted Seasonally) to Various Locations in Comal and Hays County

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	0.42	-1.13	0.39	0.07	-0.25	0.19
Comal: Down-thrown block	-0.77	-0.01	0.39	0.07	-0.31	0.19
San Marcos: Down-thrown block	1.12	-2.01	0.46	0.09	-0.35	0.23
San Marcos: Up-thrown block	1.13	-2.02	0.46	0.09	-0.34	0.23
Western Comal County	-0.48	-0.02	0.23	0.05	-0.22	0.10

Table 4.5 Average Change in Springflow from Bexar County Transfer (2.2 cfs or 1,600 af/yr Adjusted Seasonally) to Various Locations in Comal and Hays County 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	19%	-51%	17%	3%	-11%
Comal: Down-thrown block	-35%	0%	18%	3%	-14%
San Marcos: Down-thrown block	50%	-91%	21%	4%	-16%
San Marcos: Up-thrown block	51%	-91%	21%	4%	-15%
Western Comal County	-22%	-1%	10%	2%	-10%

4.2.3 4,800 af/yr Transfer (With Seasonal Adjustment)

The final set of simulations was completed to determine the affects of a 4,800 acre-feet per year transfer. This set of runs incorporated a seasonal adjustment for in the aquifer withdrawals. Figures A19 through A27 show the results of transferring 4,800 af/yr from western Bexar County to five different locations east of Cibolo Creek. This set of runs is identical to those discussed in Section 4.2.2 and shown in Figures A9 through A18, except that the transfer volume is 4,800 instead of 1600 acre-feet per year. The seasonal adjustment was incorporated because it is more realistic and provides insight into the maximum impact that could be expected during the heaviest summer pumping.

Table 4.6 summarizes the average impact to springflow and J-17 water level over the 27-year simulation period (1947-1973) for a 4,800 acre-feet per year transfer when the aquifer production is seasonally adjusted. The table shows the average value for the 324 monthly stress periods. Table 4.7 contains the average change in springflow and water level as a percent of the transfer volume.

Figures A19 through A27 and Table 4.7 indicate that the average results for the seasonally adjusted runs with the 4,800 acre-feet per year transfer are very similar to the previous runs shown in Tables 4.2 and 4.5. As for the 1,600 acre-feet per year transfer, Figures A19 through A27 again shows that the seasonal variation in pumpage does result in larger seasonal (summer) impacts in springflow.

Table 4.6 Average Change in Springflow and Water Level from Bexar County Transfer (6.6 cfs or 4,800 af/yr Adjusted Seasonally) to Various Locations in Comal and Hays County

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	1.26	-3.40	1.17	0.22	-0.74	0.57
Comal: Down-thrown block	-2.31	-0.02	1.17	0.22	-0.94	0.57
San Marcos: Down-thrown block	3.37	-6.06	1.39	0.26	-1.04	0.68
San Marcos: Up-thrown block	3.41	-6.08	1.39	0.26	-1.01	0.68
Western Comal County	-1.45	-0.06	0.70	0.14	-0.67	0.32

Table 4.7 Average Change in Springflow from Bexar County Transfer (6.6 cfs or 4,800 af/yr Adjusted Seasonally) to Various Locations in Comal and Hays County 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	19%	-51%	18%	3%	-11%
Comal: Down-thrown block	-35%	0%	18%	3%	-14%
San Marcos: Down-thrown block	51%	-91%	21%	4%	-16%
San Marcos: Up-thrown block	51%	-92%	21%	4%	-15%
Western Comal County	-22%	-1%	11%	2%	-10%

To gain insight into the maximum impact from transfers during the summer months, Tables 4.8 and 4.9 were developed. These tables calculate the maximum impact during the simulation period in any month due to the 4,800 acre-feet per year seasonally adjusted transfer. In other words, the values and percentages shown in Tables 4.8 and 4.9 respectively represent the maximum decrease in springflow during the simulation period and the maximum increase in J-17 water level.

Table 4.9 indicates that the maximum change in Comal springflow ranges from an increase of 7 to a decrease of 203 percent of the transfer volume. San Marcos springflow always decreases, and decreases from 4 to 313 percent of the transfer volume. The maximum impact to springflow is based on maximum monthly change due to the transfer, and because the seasonal pumping concentrates withdrawals in the summer months, the monthly change during those months can be greater than the 100 percent for the month. However, based on a calendar year average, the impact is less than 100 percent. This result indicates that the impact of transfers is amplified during the summer months of heavy pumping and is less pronounced in the winter months.

The total springflow always decreases, and ranges from 36 to 192 percent. For example, in San Marcos Springs, this means that a 6.6 cfs (4,800 acre-feet per year) transfer from western Bexar County to the down-thrown block near San Marcos Springs results in one summer month where the San Marcos springflow decreases 20.8 cfs, or 313% of the transferred volume.

Table 4.8 Maximum Monthly Change in Springflow and Water Level from Bexar County Transfer (6.6 cfs or 4,800 af/yr Adjusted Seasonally) to Various Locations in Comal and Hays County

Transfer from Bexar County to	Maximum 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	-0.05	-5.88	0.00	0.00	-2.38	1.63
Comal: Down-thrown block	-13.47	-0.42	0.00	0.00	-11.73	1.44
San Marcos: Down-thrown block	0.43	-20.80	0.00	0.00	-12.75	1.77
San Marcos: Up-thrown block	0.44	-17.71	0.00	0.00	-9.26	1.77
Western Comal County	-8.50	-0.29	0.00	0.00	-7.58	0.70

Table 4.9 Maximum Monthly in Springflow from Bexar County Transfer (6.6 cfs or 4,800 af/yr Adjusted Seasonally) to Various Locations in Comal and Hays County as a Percent of the Transfer Amount

Transfer from Bexar County to	Maximum Change in Springflow (1947-1973)				
	Comal Springflow	San Marcos Springflow	San Pedro Springflow	San Antonio Springflow	Total Springflow
Comal: Up-thrown block	-1%	-89%	0%	0%	-36%
Comal: Down-thrown block	-203%	-6%	0%	0%	-177%
San Marcos: Down-thrown block	6%	-313%	0%	0%	-192%
San Marcos: Up-thrown block	7%	-267%	0%	0%	-139%
Western Comal County	-128%	-4%	0%	0%	-114%

5.0 Conclusions and Recommendation

5.1 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 CP/DM 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. Model results indicate that on average, San Marcos springflow may be decreased from 0 to 92% of the transfer volume. In summer months, San Marcos springflow may be decreased from 4 to 313% of the transfer volume.

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. Model results indicate that on average, the impact to Comal springflow ranges from a 51% increase to a 35% decrease of the transfer volume. In summer months however, the maximum impact to Comal springflow ranges from an increase of 7 percent to a decrease of 203 percent of the transfer volume.

5.2 Recommendations

We did not perform simulations that transferred production from Uvalde to east of the Cibolo. However, the results of these simulations suggests that transfers from Uvalde (especially those near the Uvalde pool index well J-27), would have some impact on the times at which the Uvalde pool trigger levels were reached during dry periods or during the irrigation season. For the Uvalde pool, later triggering could have a significant impact on total production, especially during the irrigation season. This increase in production from the Uvalde pool might have a delayed impact on the triggering (and thus production) in the San Antonio pool. Therefore, it is suggested that a more thorough assessment of transfers from Medina and Uvalde Counties be completed.

Because of the limitations of the MODFLOW model, we did not complete simulations with production greater than 100,000 acre-feet per year. It is recommended that the

MODFLOW model be enhanced to resolve these limitations so that runs can be completed with higher total production to determine the impact of Cibolo transfers under those conditions.

In addition, because of the limitations of modeling the CP/DM triggers with the current version of MODFLOW-96, we did not evaluate the impact of the drought triggers on Cibolo transfers. It is recommended that these simulations be completed after the MODFLOW-2000 version of the EAA MODFLOW Management Module is completed. With the MODFLOW-2000 enhancements, it should be possible to determine the impact of Cibolo transfers under high pumping conditions and to determine the effect of transfers on CP/DM rules.

6.0 References

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

Appendix A

Results of MODFLOW Simulations

Appendix A – List of Figures

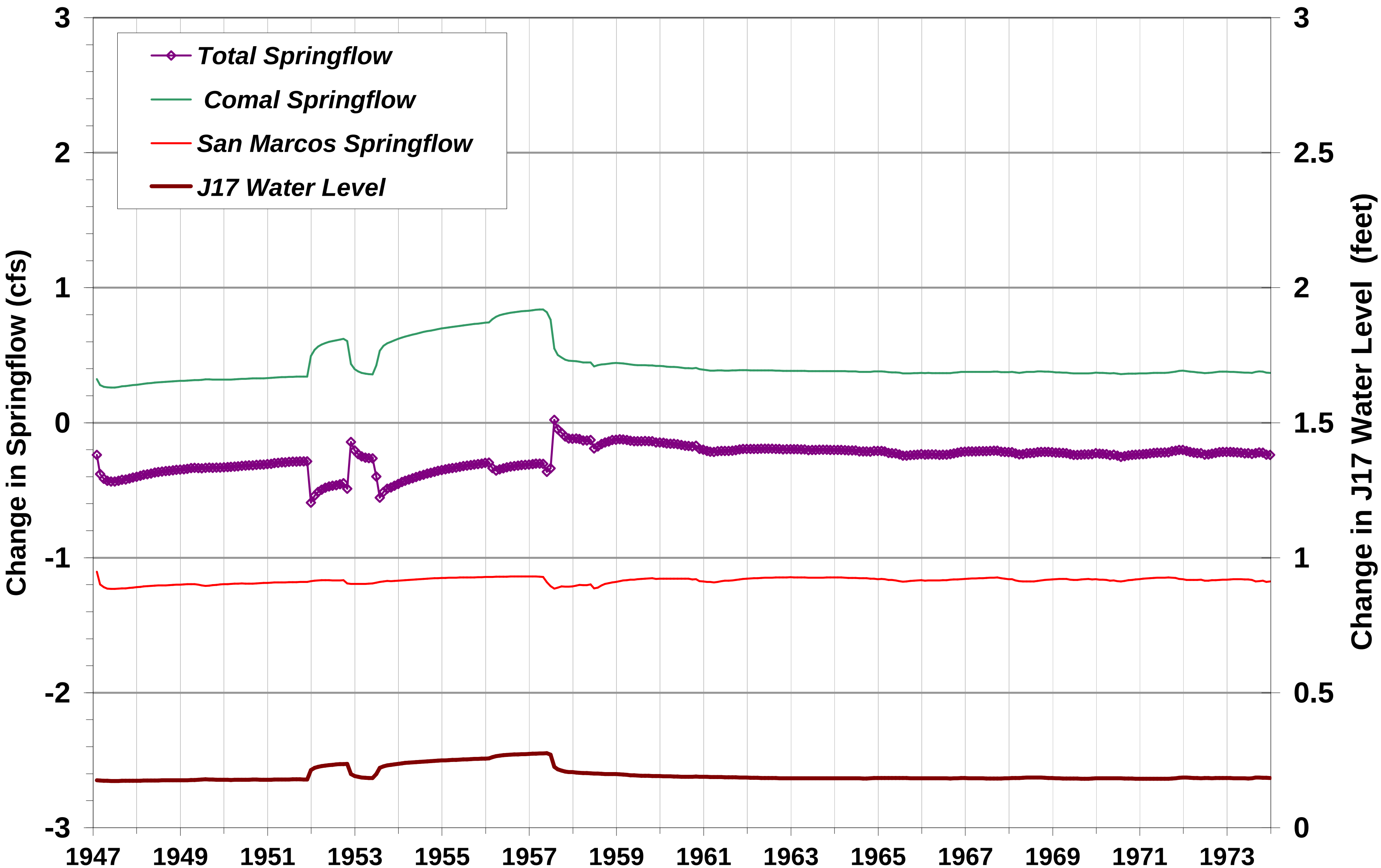

Figure A1. Change in Springflow and J-17 Water Level After Transferring 1,600 af/yr (Constant) from Western Bexar County to near Comal Springs (Up-thrown block)

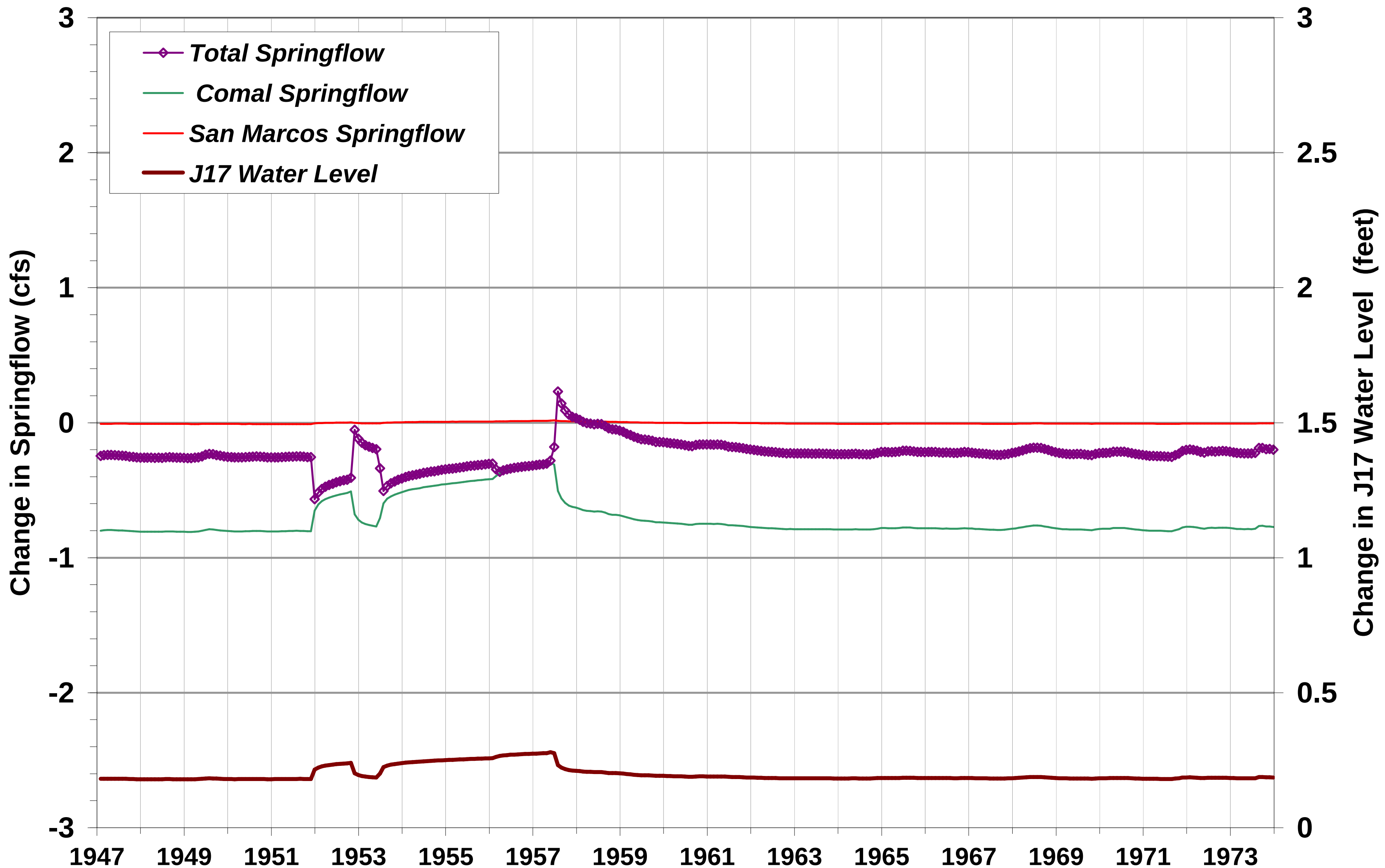

Figure A2. Change in Springflow and J-17 Water Level After Transferring 1,600 af/yr (Constant) from Western Bexar County to near Comal Springs (Down-thrown block)

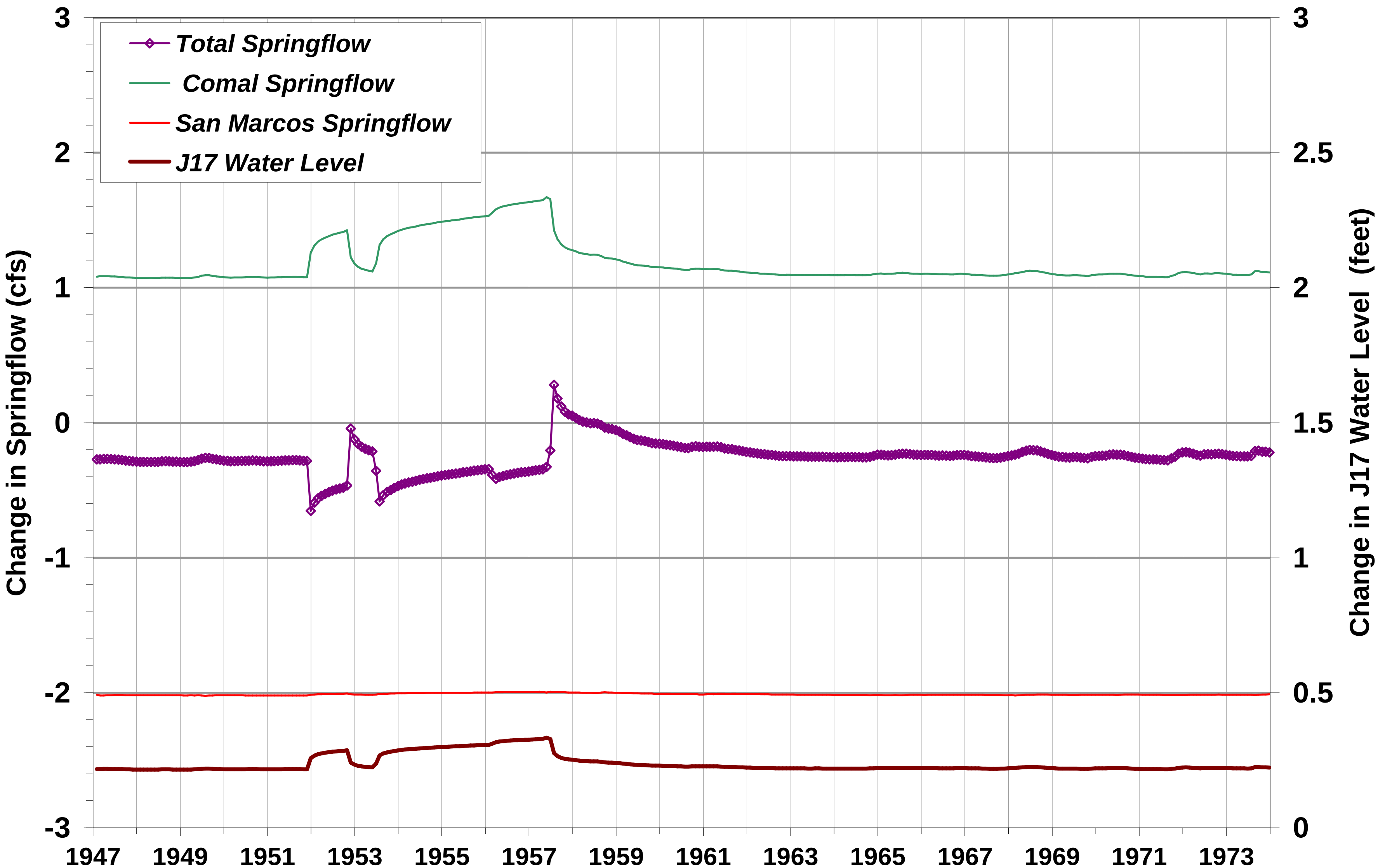

Figure A3. Change in Springflow and J-17 Water Level After Transferring 1,600 af/yr (Constant) from Western Bexar County to near San Marcos Springs (Down-thrown block)

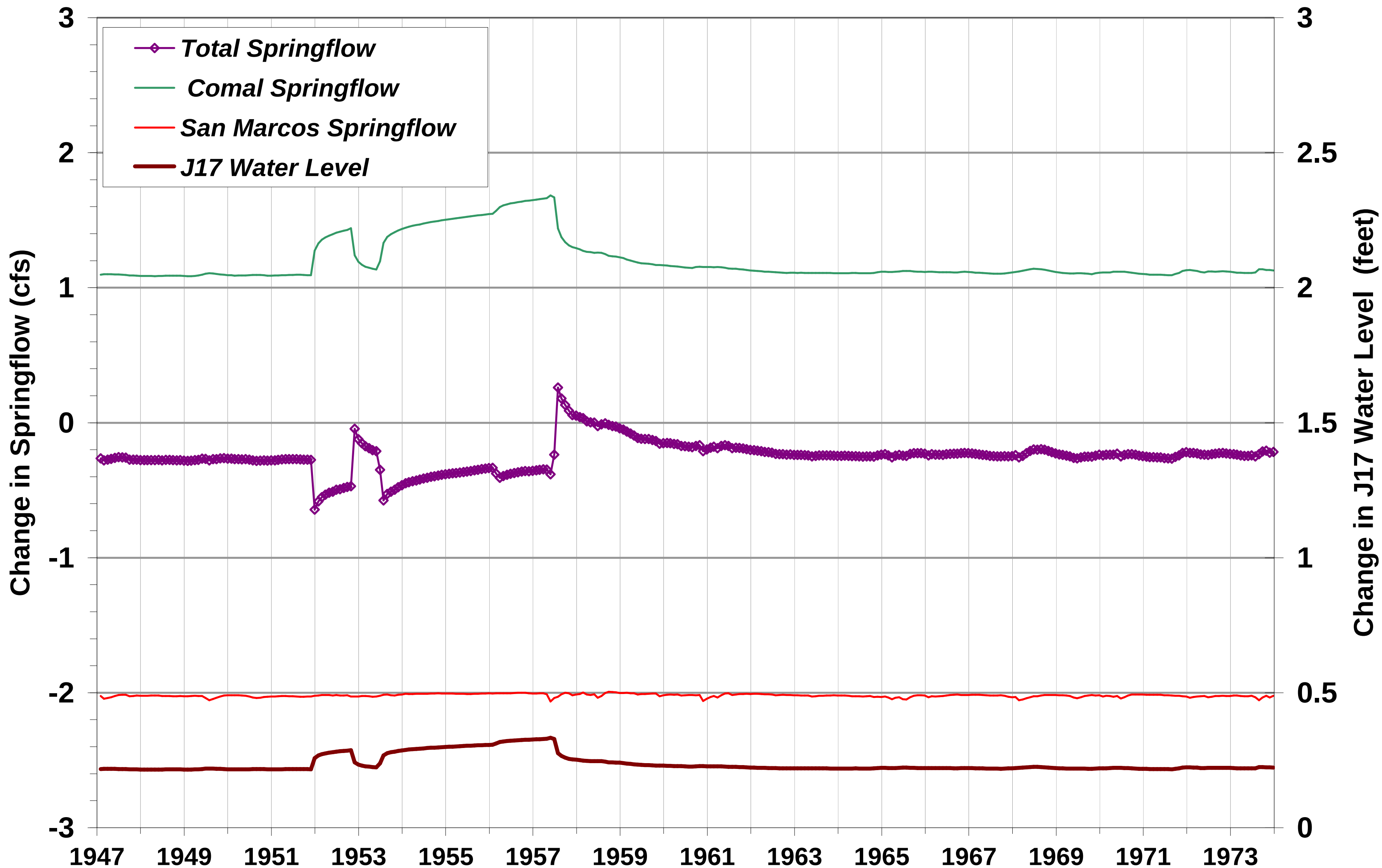

Figure A4. Change in Springflow and J-17 Water Level After Transferring 1,600 af/yr (Constant) from Western Bexar County to near San Marcos Springs (Up-thrown block)

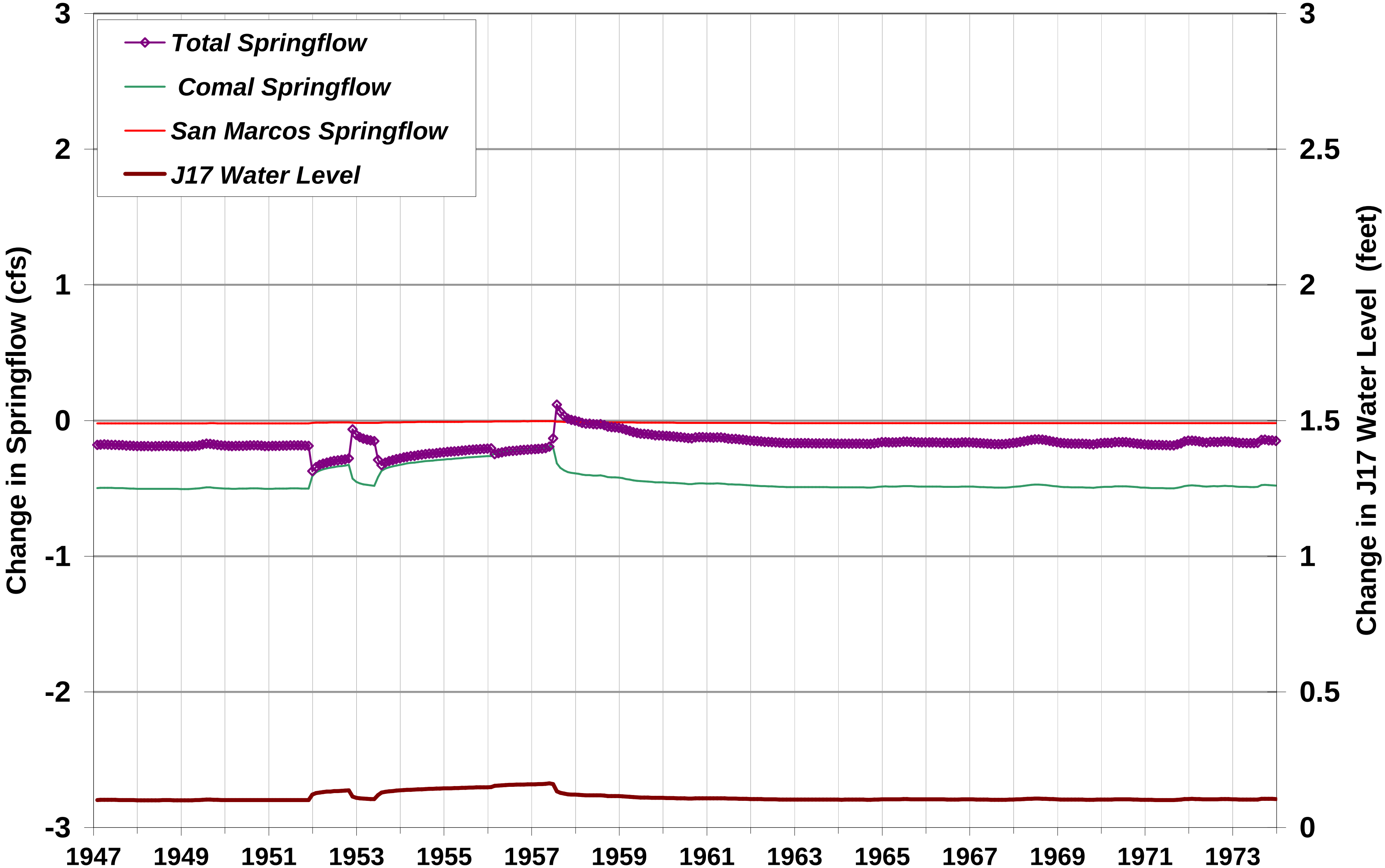

Figure A5. Change in Springflow and J-17 Water Level After Transferring 1,600 af/yr (Constant) from Western Bexar County to Western Comal County

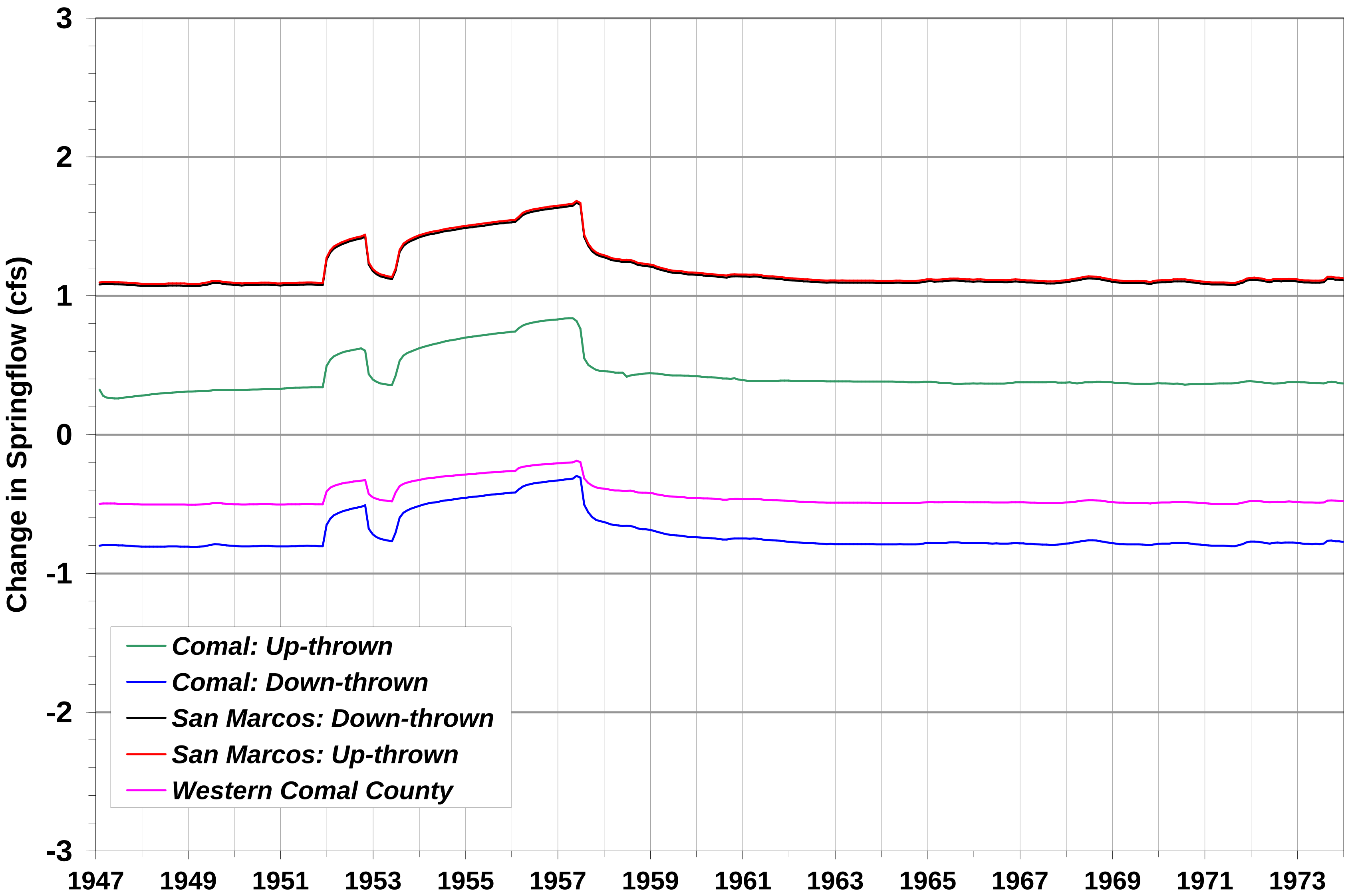

Figure A6. Comparison of Change in Comal Springflow After Transferring 1,600 af/yr (Constant) from Western Bexar County to Five Locations East of Cibolo Creek

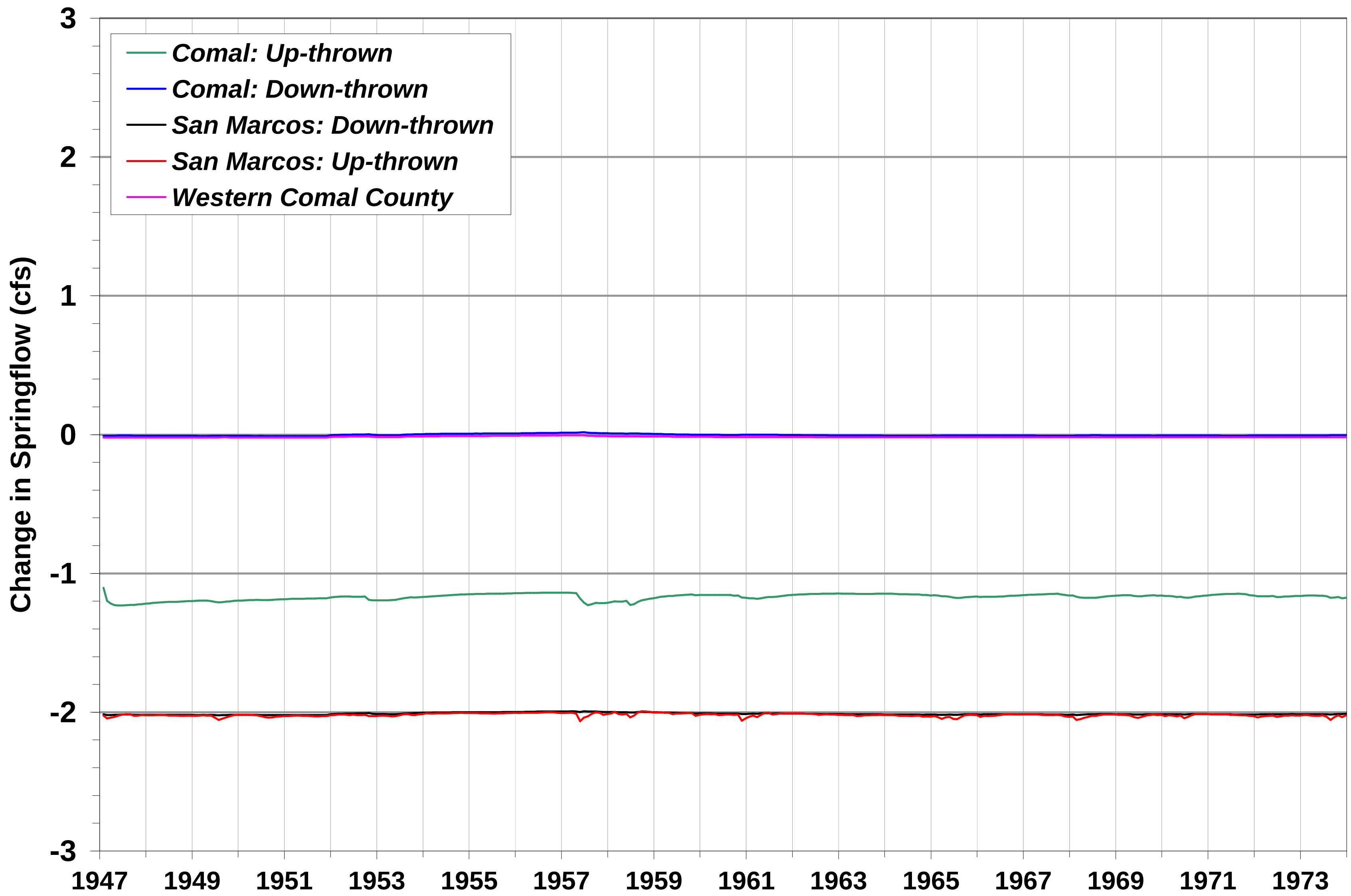

Figure A7. Comparison of Change in San Marcos Springflow After Transferring 1,600 af/yr (Constant) from Western Bexar County to Five Locations East of Cibolo Creek

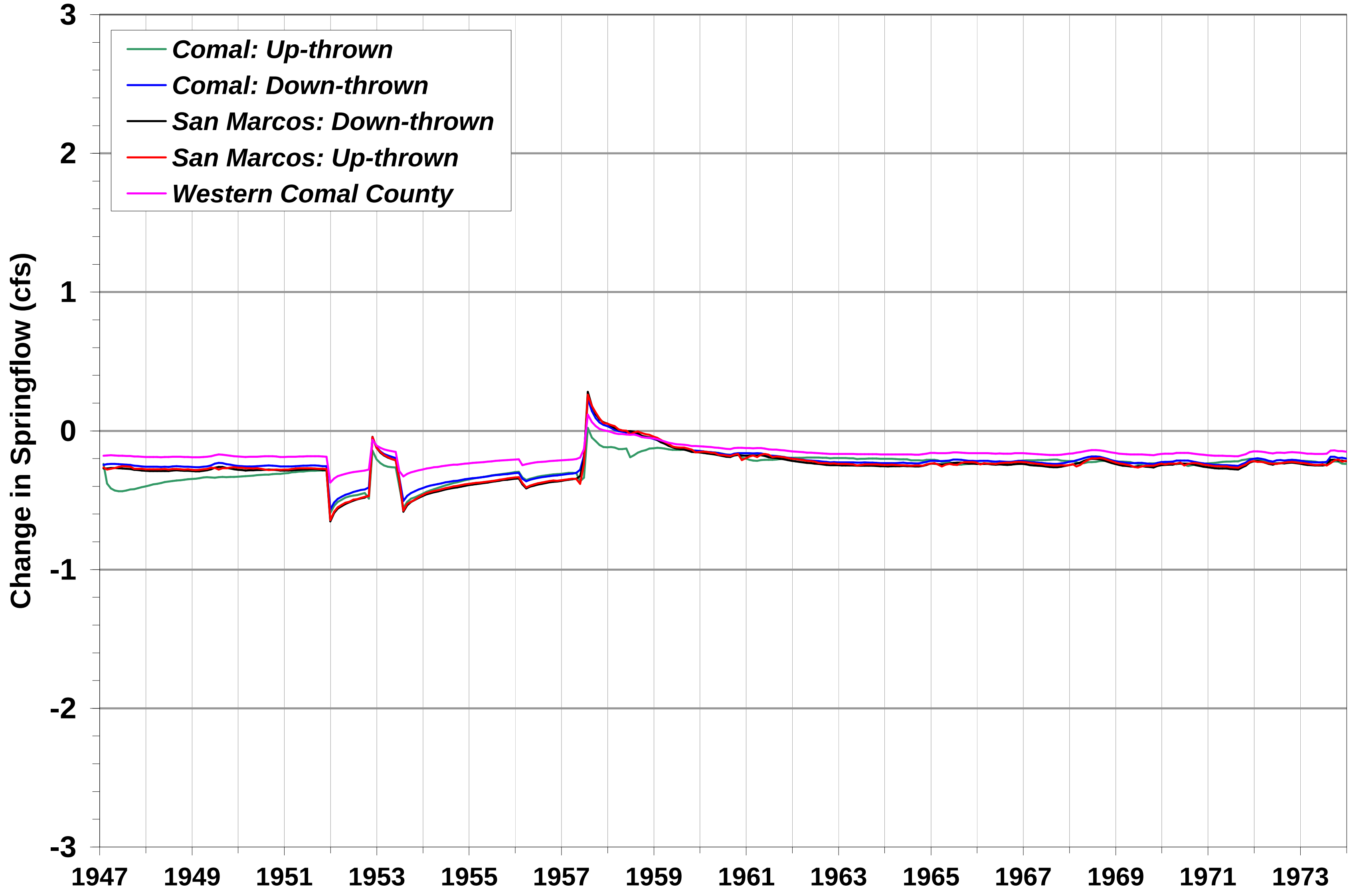

Figure A8. Comparison of Change in Total Springflow After Transferring 1,600 af/yr (Constant) from Western Bexar County to Five Locations East of Cibolo Creek

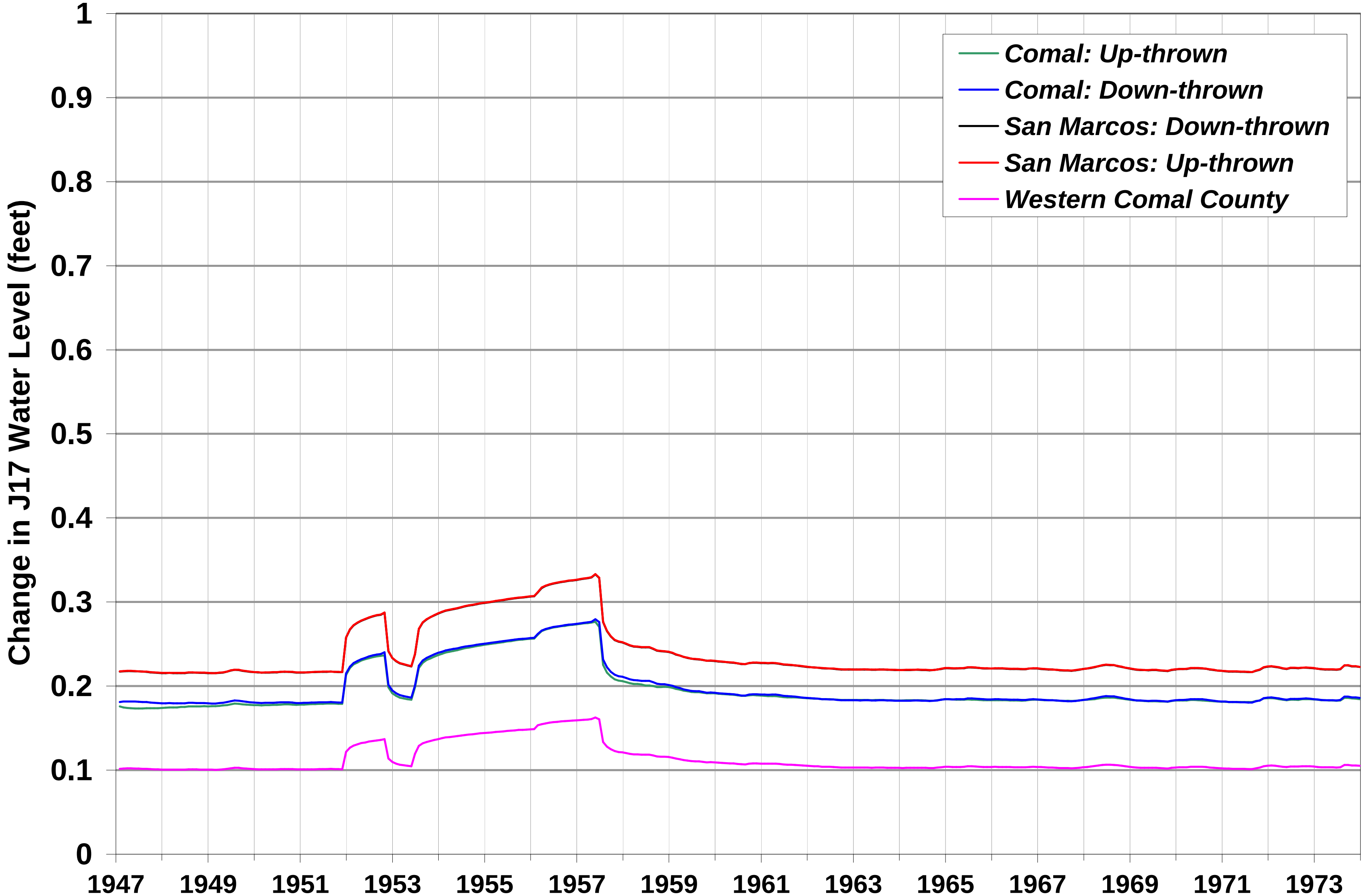

Figure A9. Comparison of Change in J-17 Water Level After Transferring 1,600 af/yr (Constant) from Western Bexar County to Five Locations East of Cibolo Creek

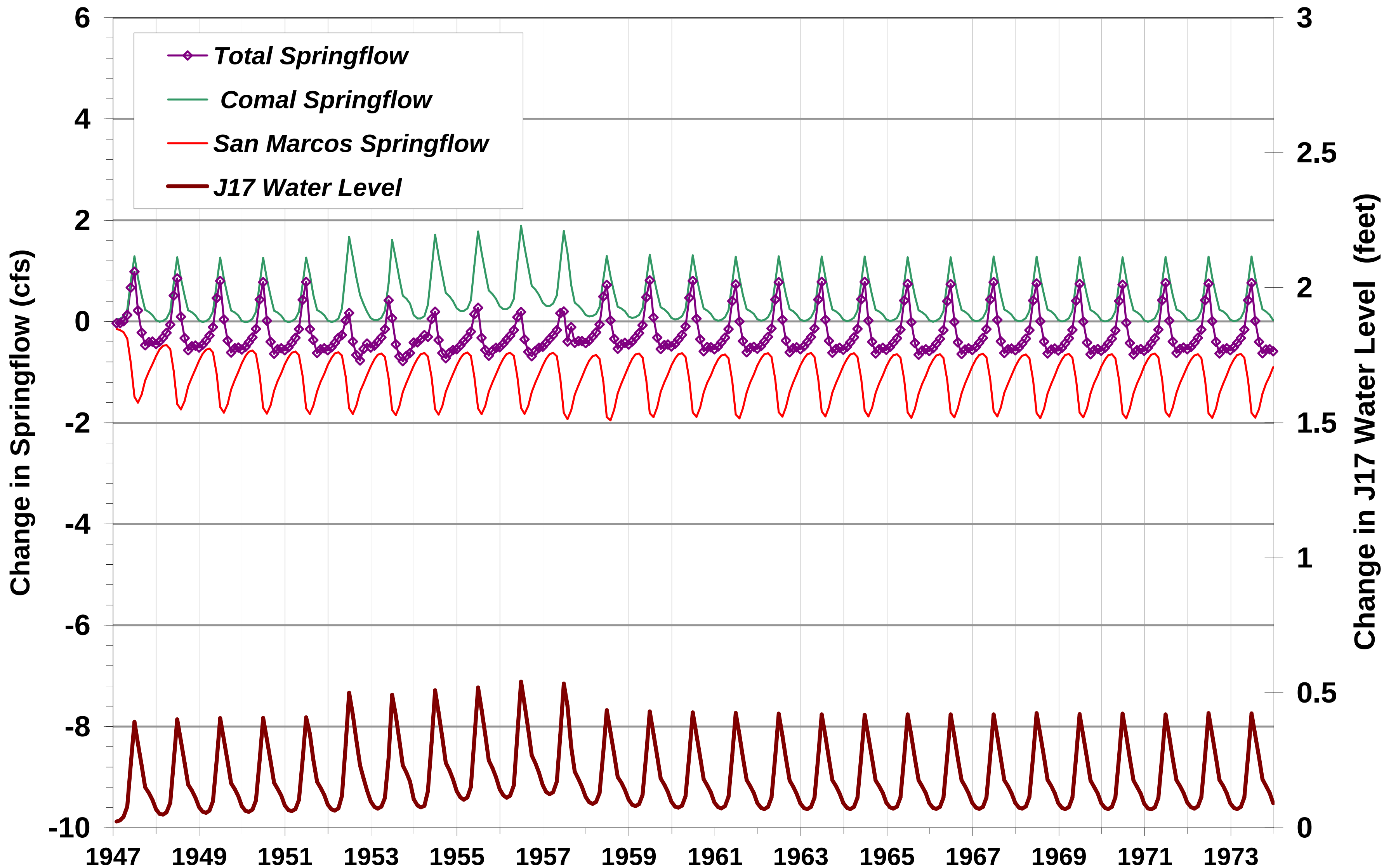

Figure A10. Change in Springflow and J-17 Water Level After Transferring 1,600 af/yr (Adjusted Seasonally) from Western Bexar County to near Comal Springs (Up-thrown block)

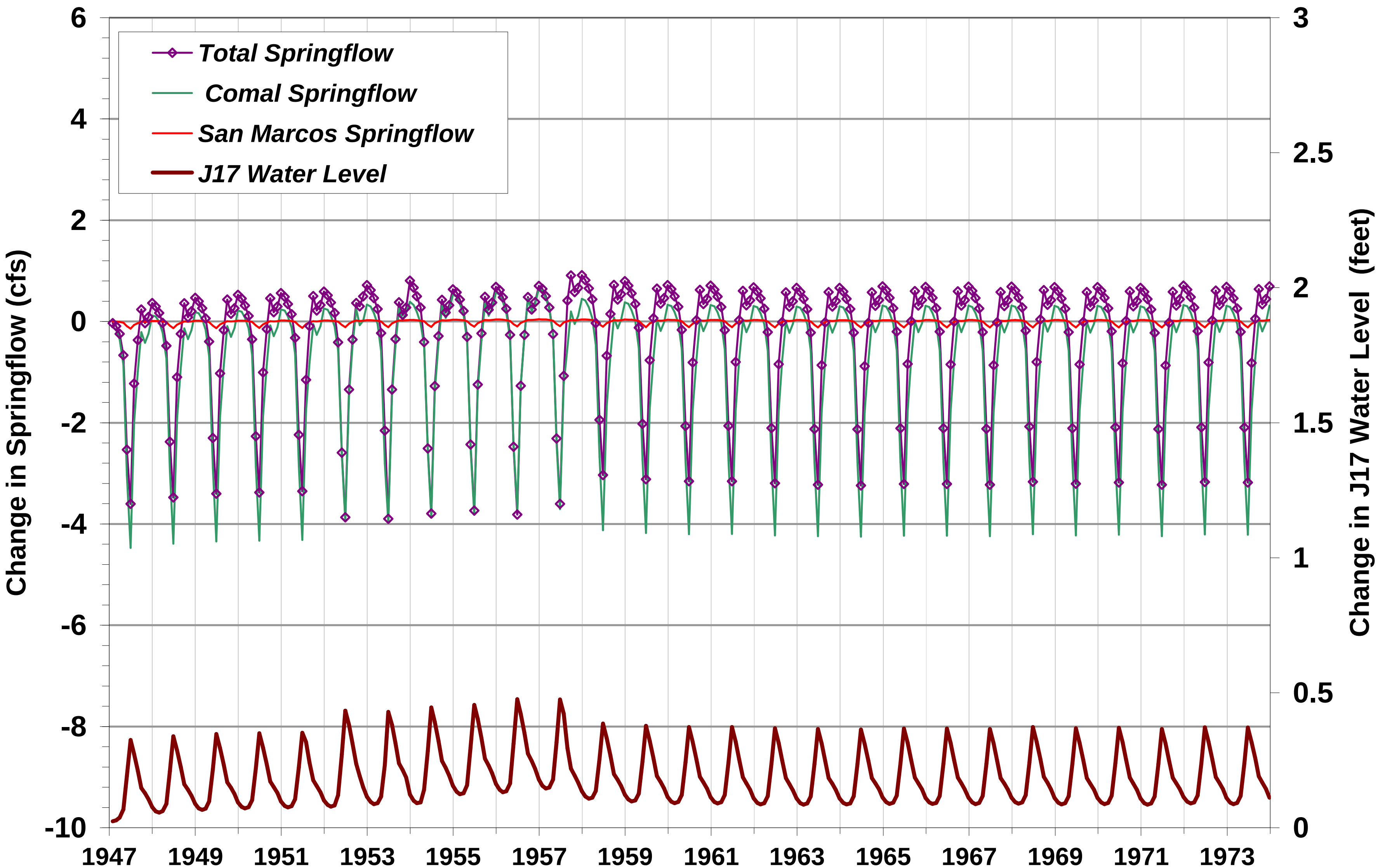

Figure A11. Change in Springflow and J-17 Water Level After Transferring 1,600 af/yr (Adjusted Seasonally) from Western Bexar County to near Comal Springs (Down-thrown block)

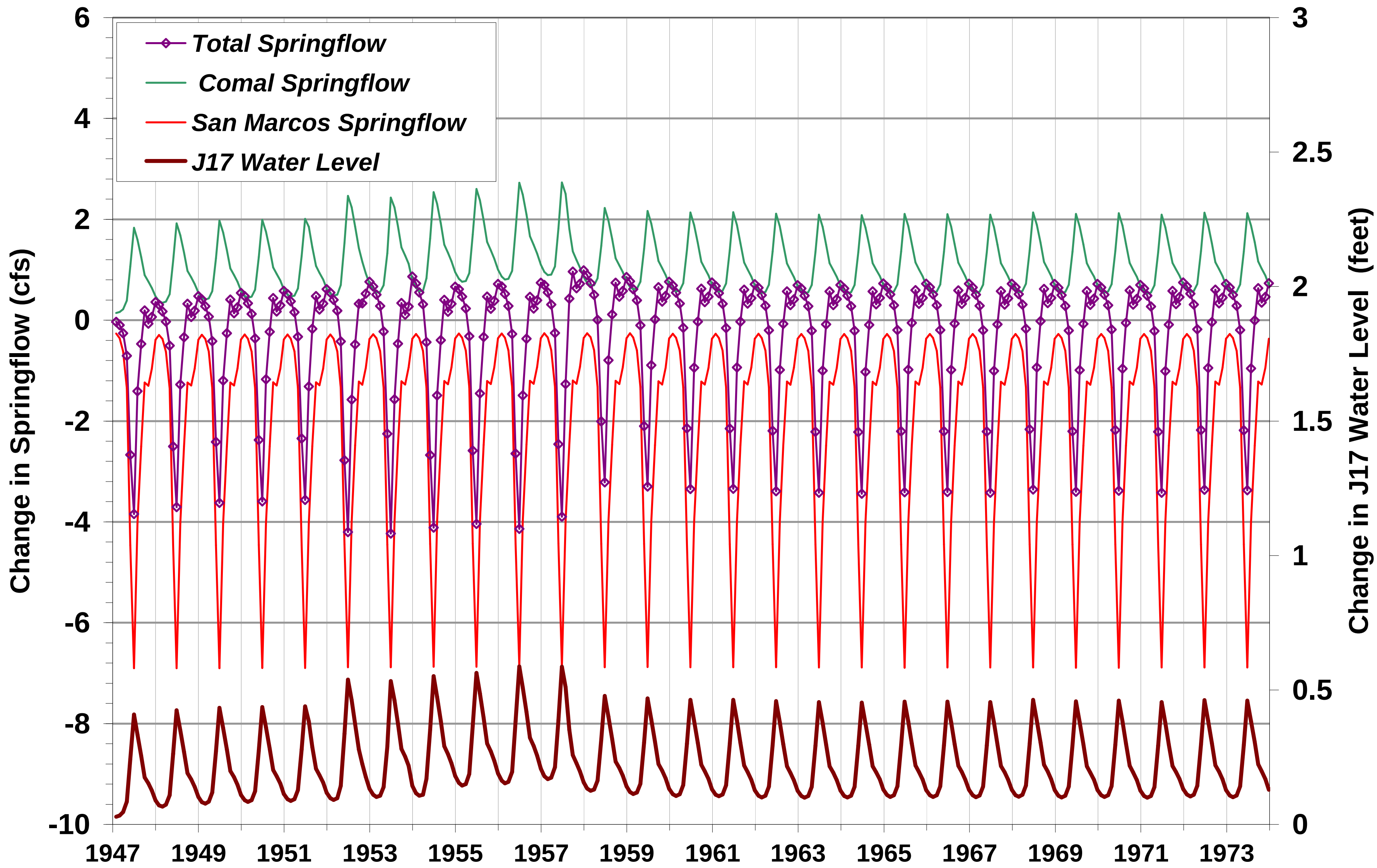

Figure A12. Change in Springflow and J-17 Water Level After Transferring 1,600 af/yr (Adjusted Seasonally) from Western Bexar County to near San Marcos Springs (Down-thrown block)

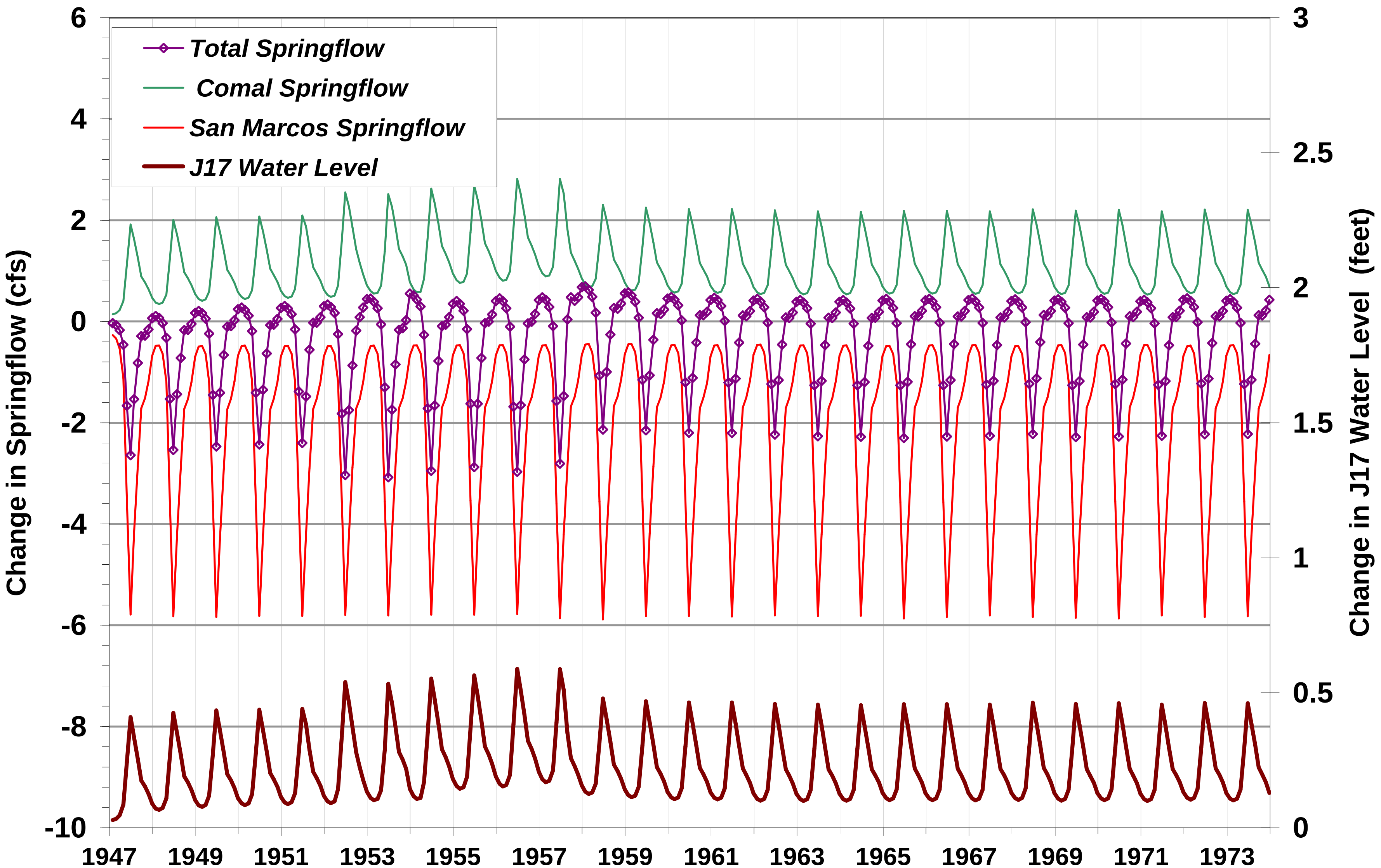

Figure A13. Change in Springflow and J-17 Water Level After Transferring 1,600 af/yr (Adjusted Seasonally) from Western Bexar County to near San Marcos Springs (Up-thrown block)

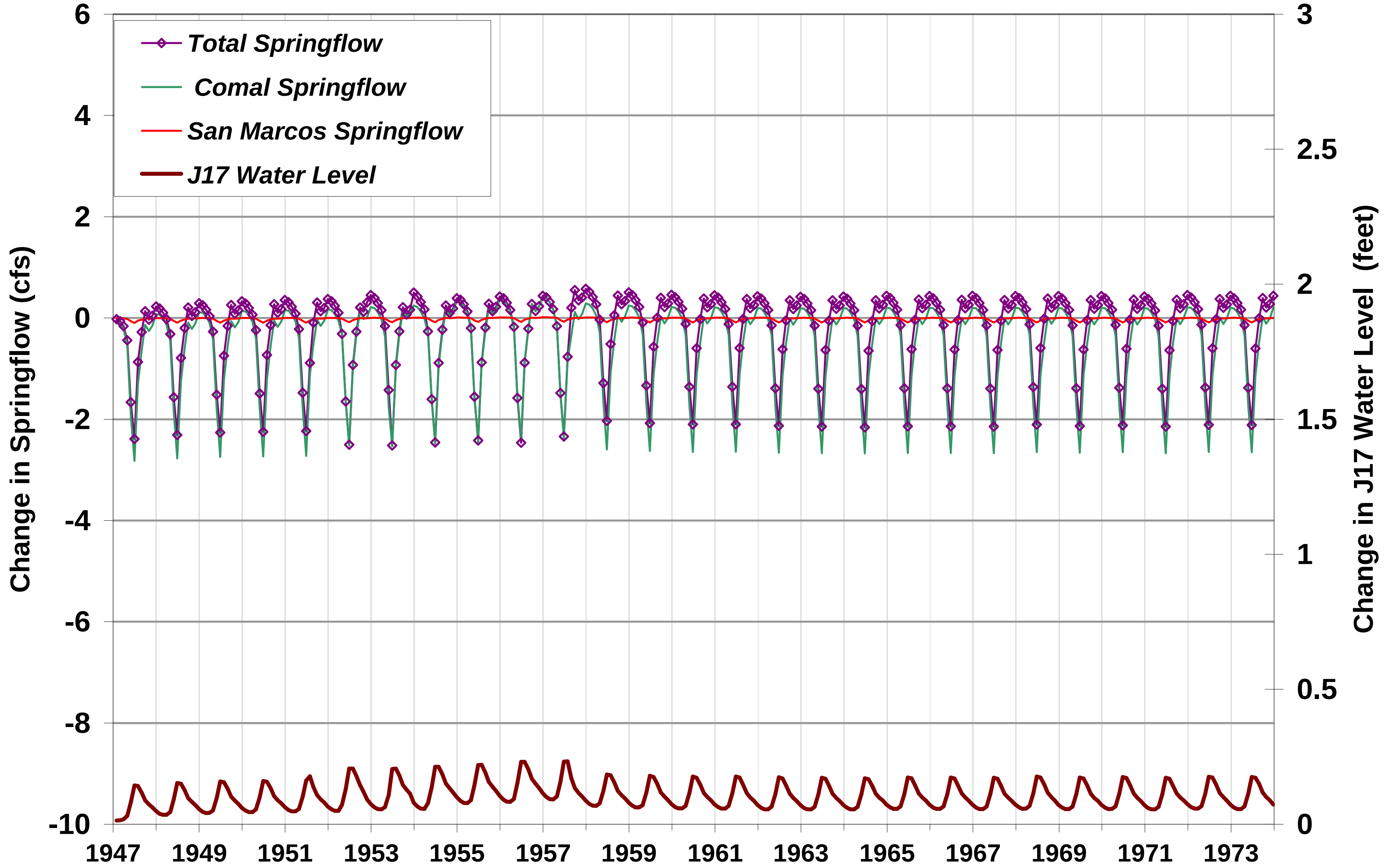

Figure A14. Change in Springflow and J-17 Water Level After Transferring 1,600 af/yr (Adjusted Seasonally) from Western Bexar County to Western Comal County

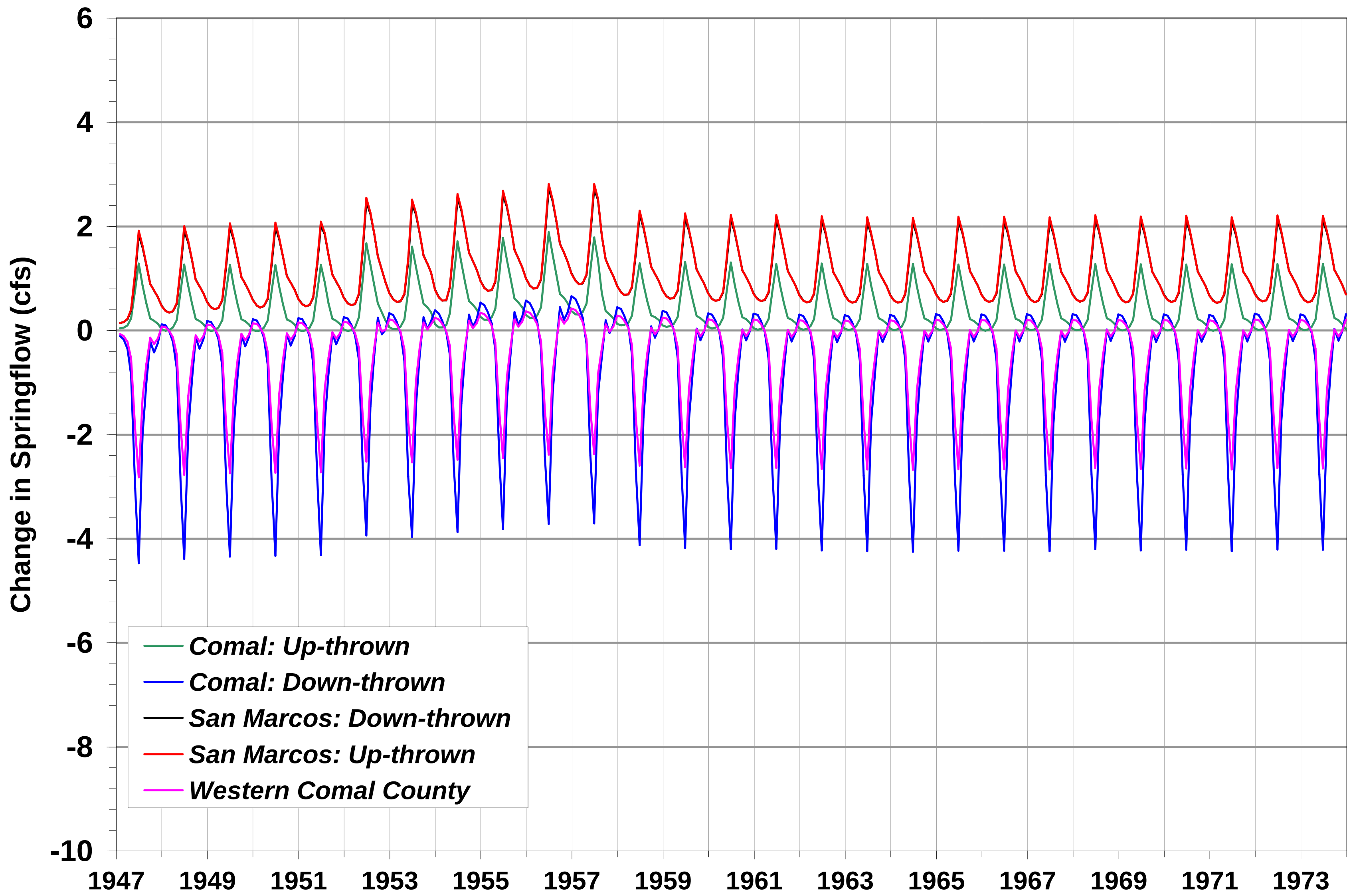

Figure A15. Comparison of Change in Comal Springflow After Transferring 1,600 af/yr (Adjusted Seasonally) from Western Bexar County to Five Locations East of Cibolo Creek

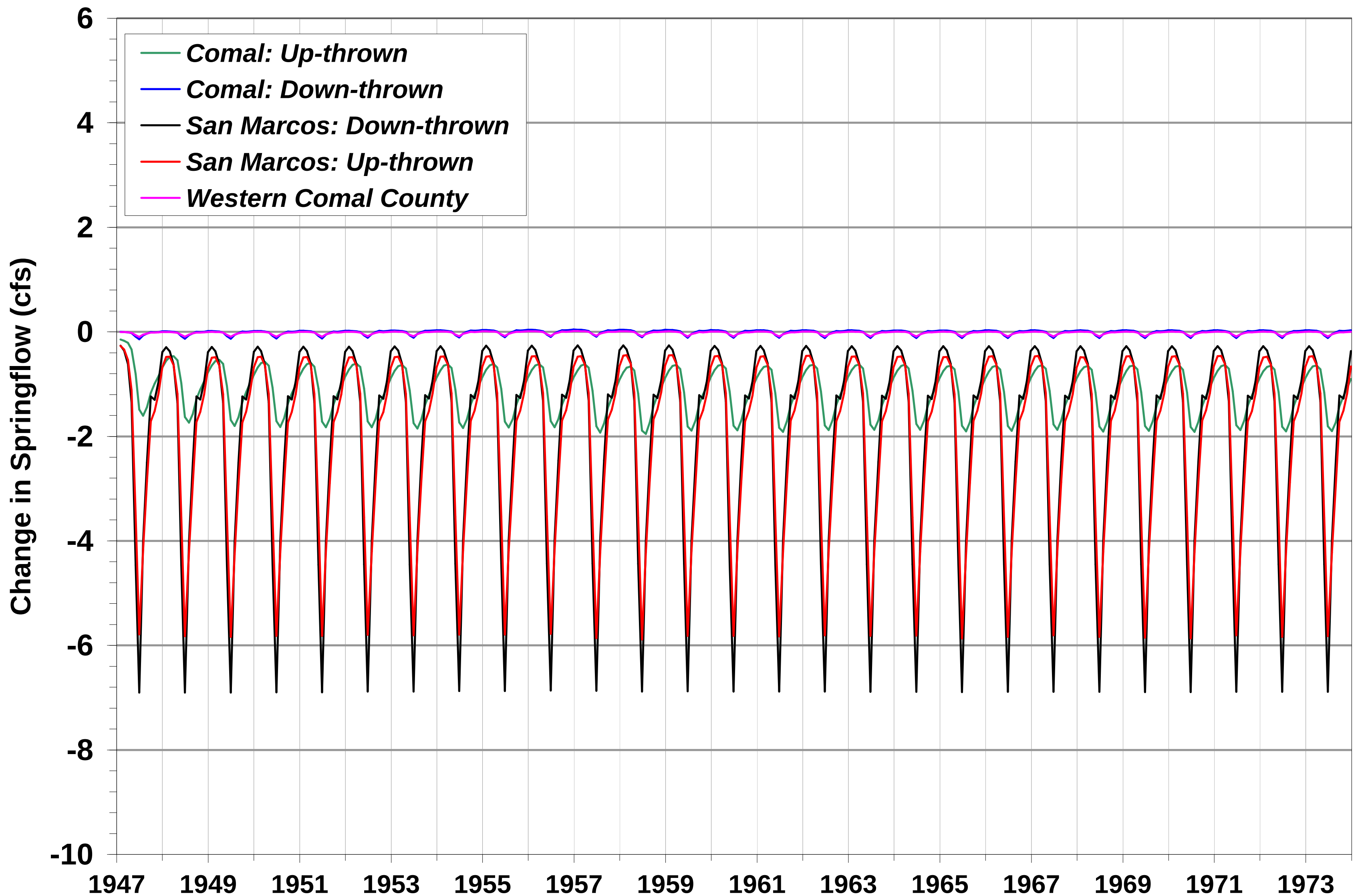

Figure A16. Comparison of Change in San Marcos Springflow After Transferring 1,600 af/yr (Adjusted Seasonally) from Western Bexar County to Five Locations East of Cibolo Creek

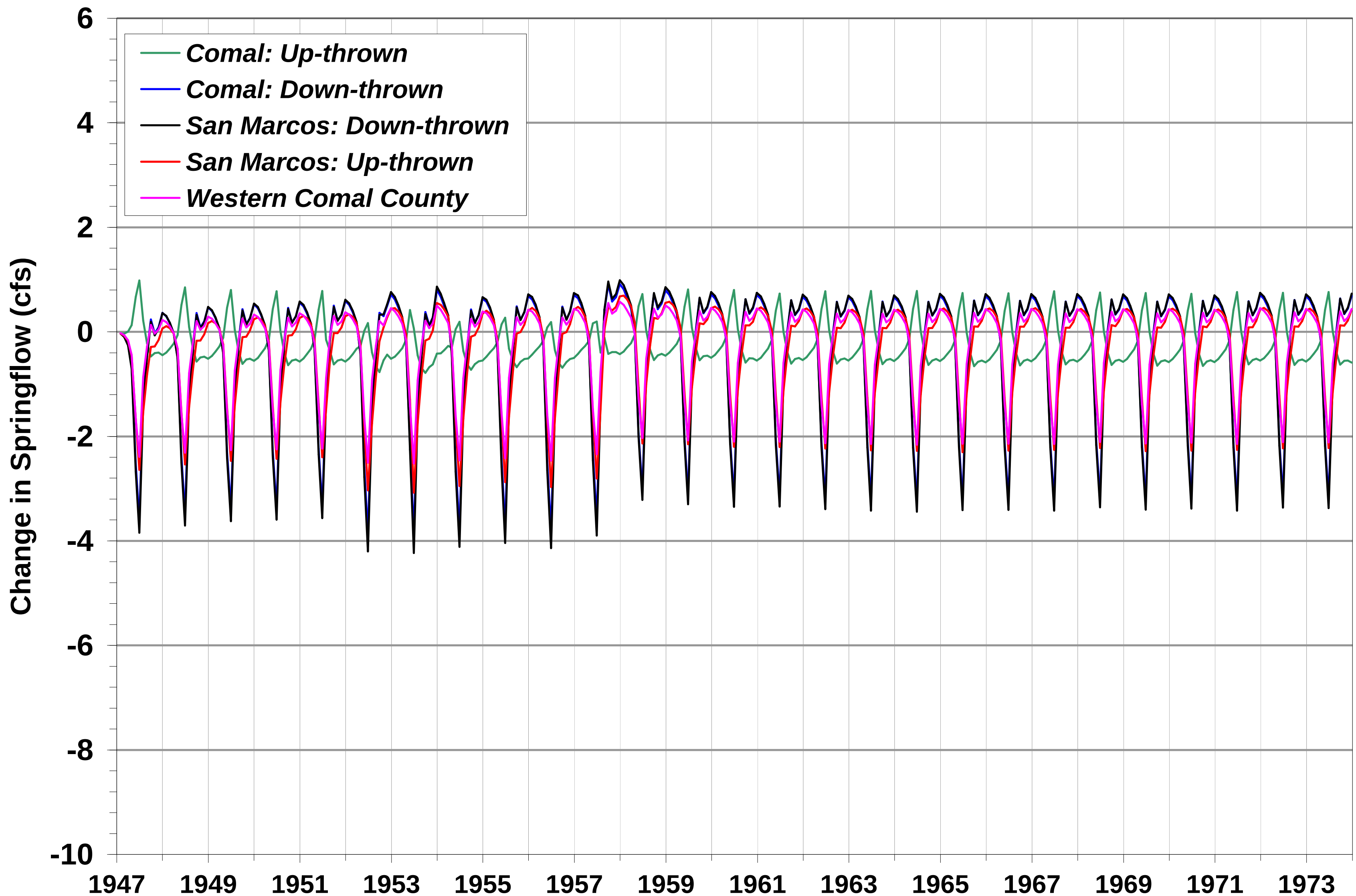

Figure A17. Comparison of Change in Total Springflow After Transferring 1,600 af/yr (Adjusted Seasonally) from Western Bexar County to Five Locations East of Cibolo Creek

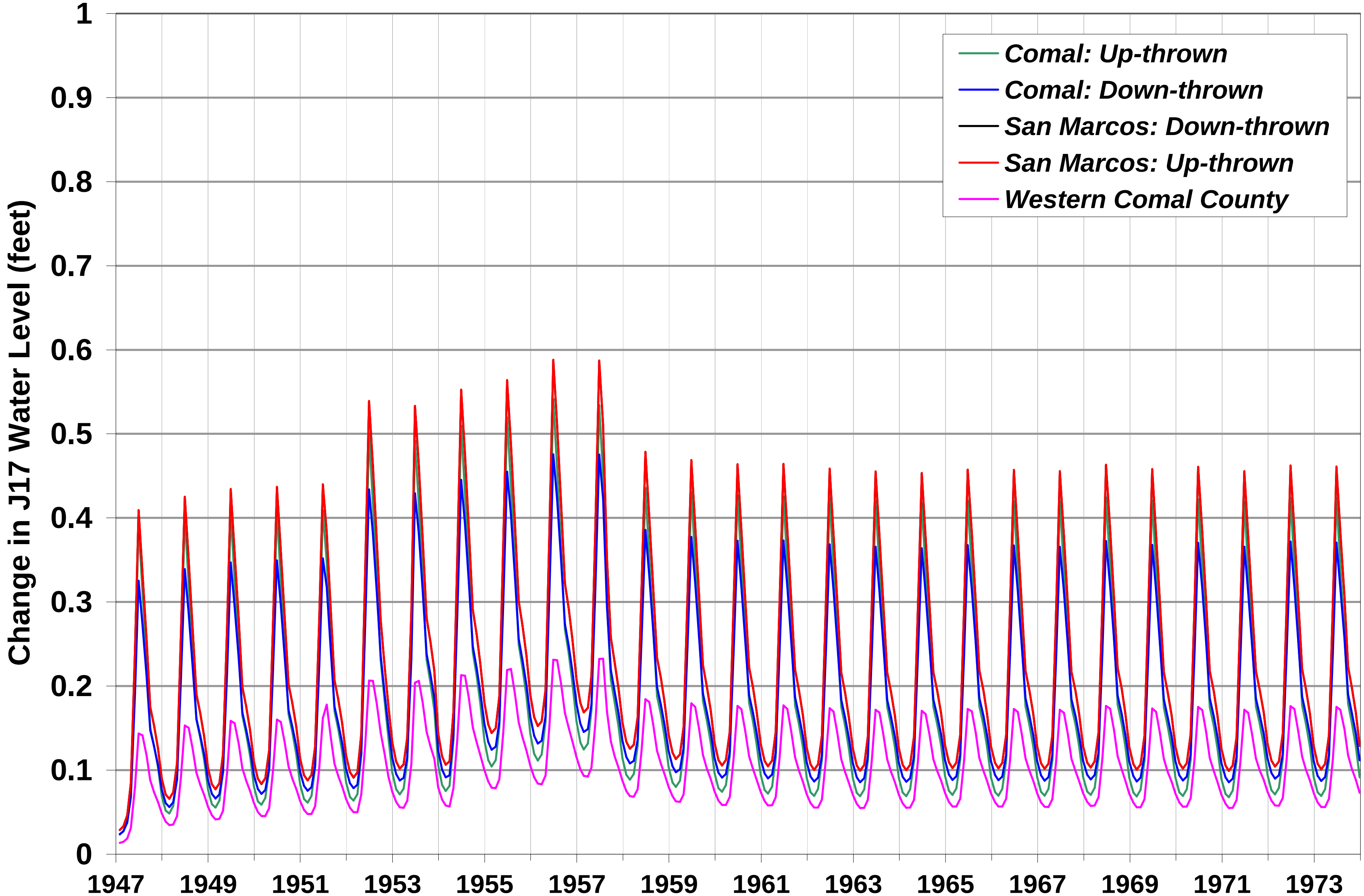

Figure A18. Comparison of Change in J-17 Water Level After Transferring 1,600 af/yr (Adjusted Seasonally) from Western Bexar County to Five Locations East of Cibolo Creek

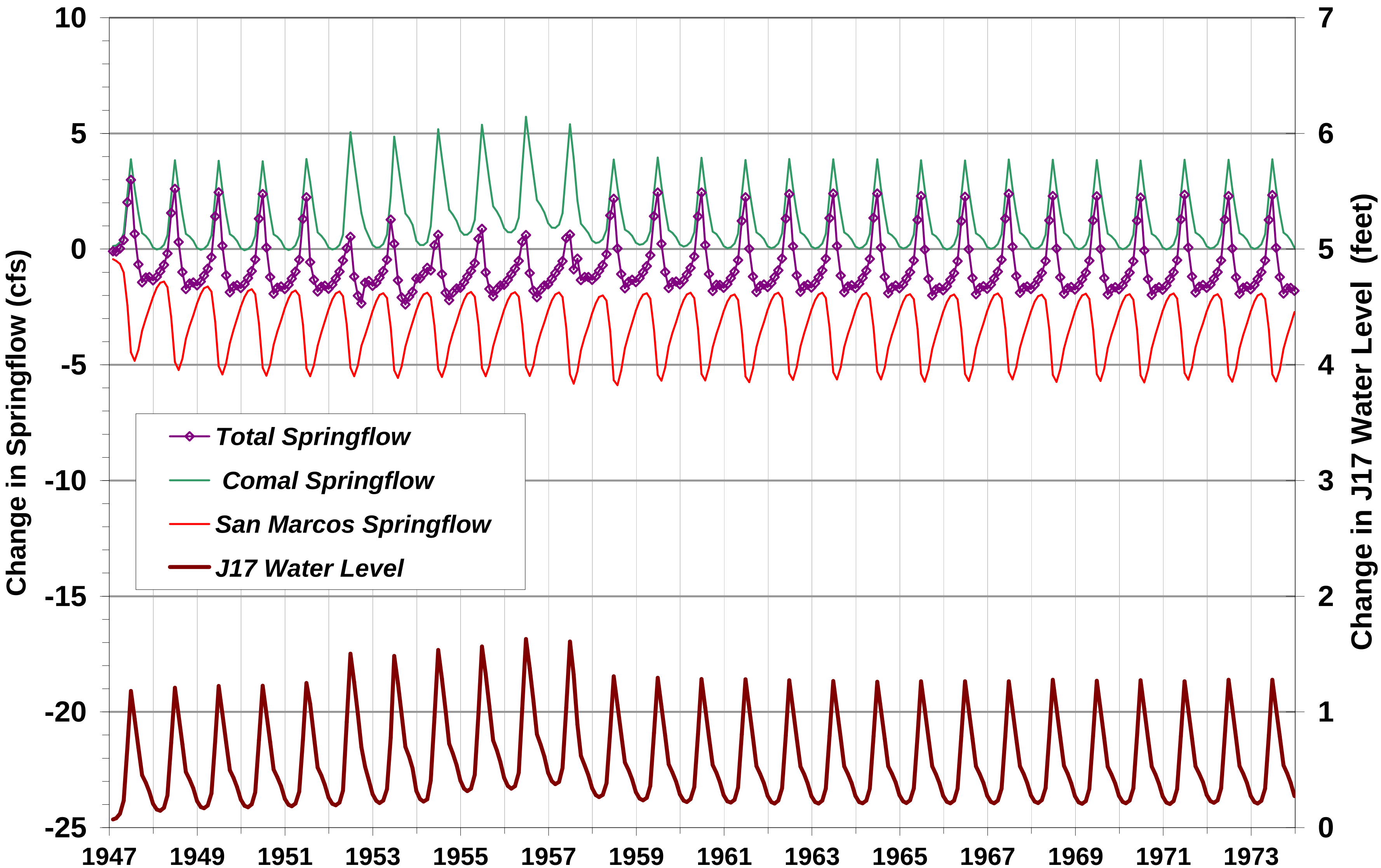

Figure A19. Change in Springflow and J-17 Water Level After Transferring (6.6 cfs or 4,800 af/yr Adjusted Seasonally) from Western Bexar County to near Comal Springs (Up-thrown block)

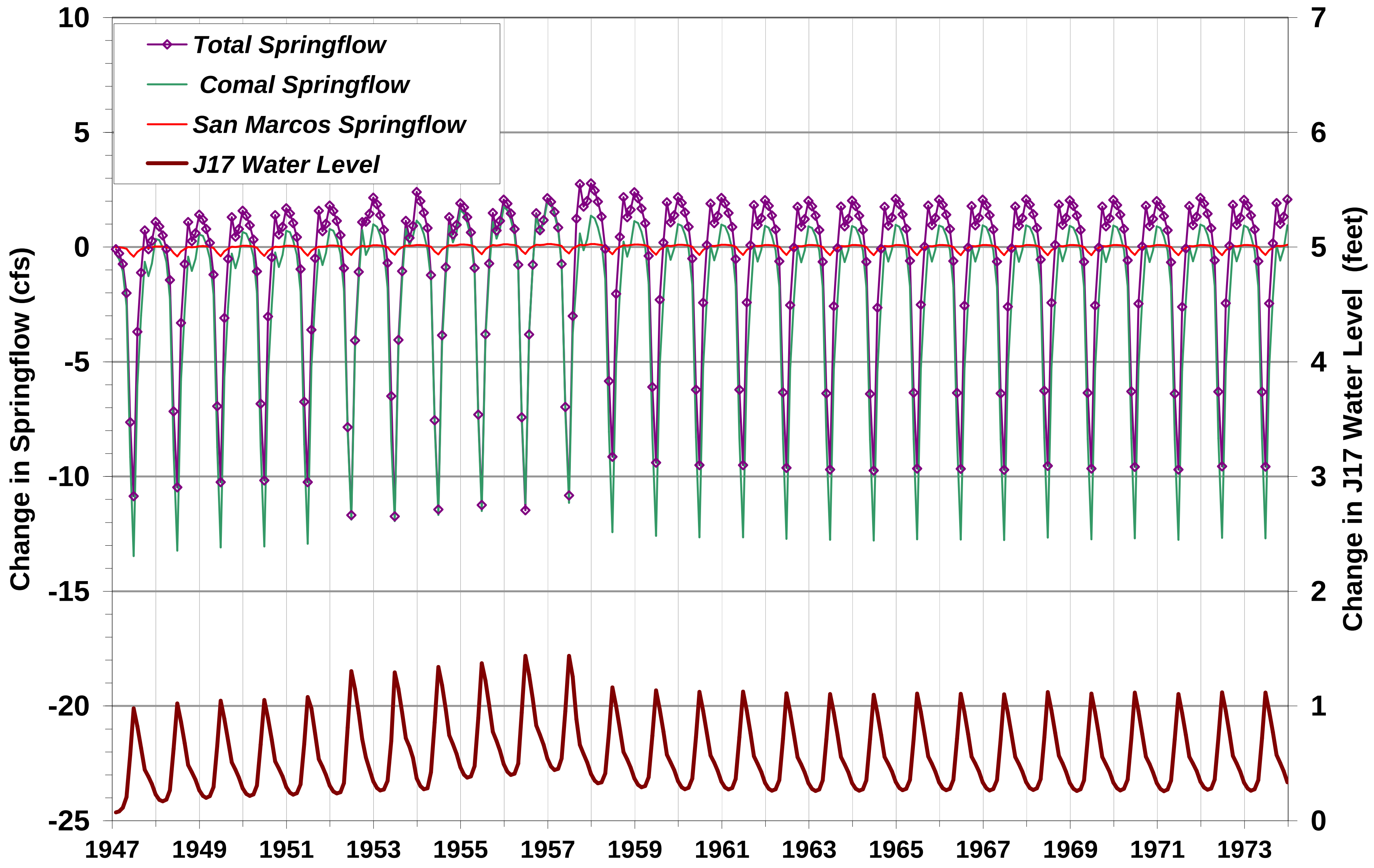

Figure A20. Change in Springflow and J-17 Water Level After Transferring (6.6 cfs or 4,800 af/yr Adjusted Seasonally) from Western Bexar County to near Comal Springs (Down-thrown block)

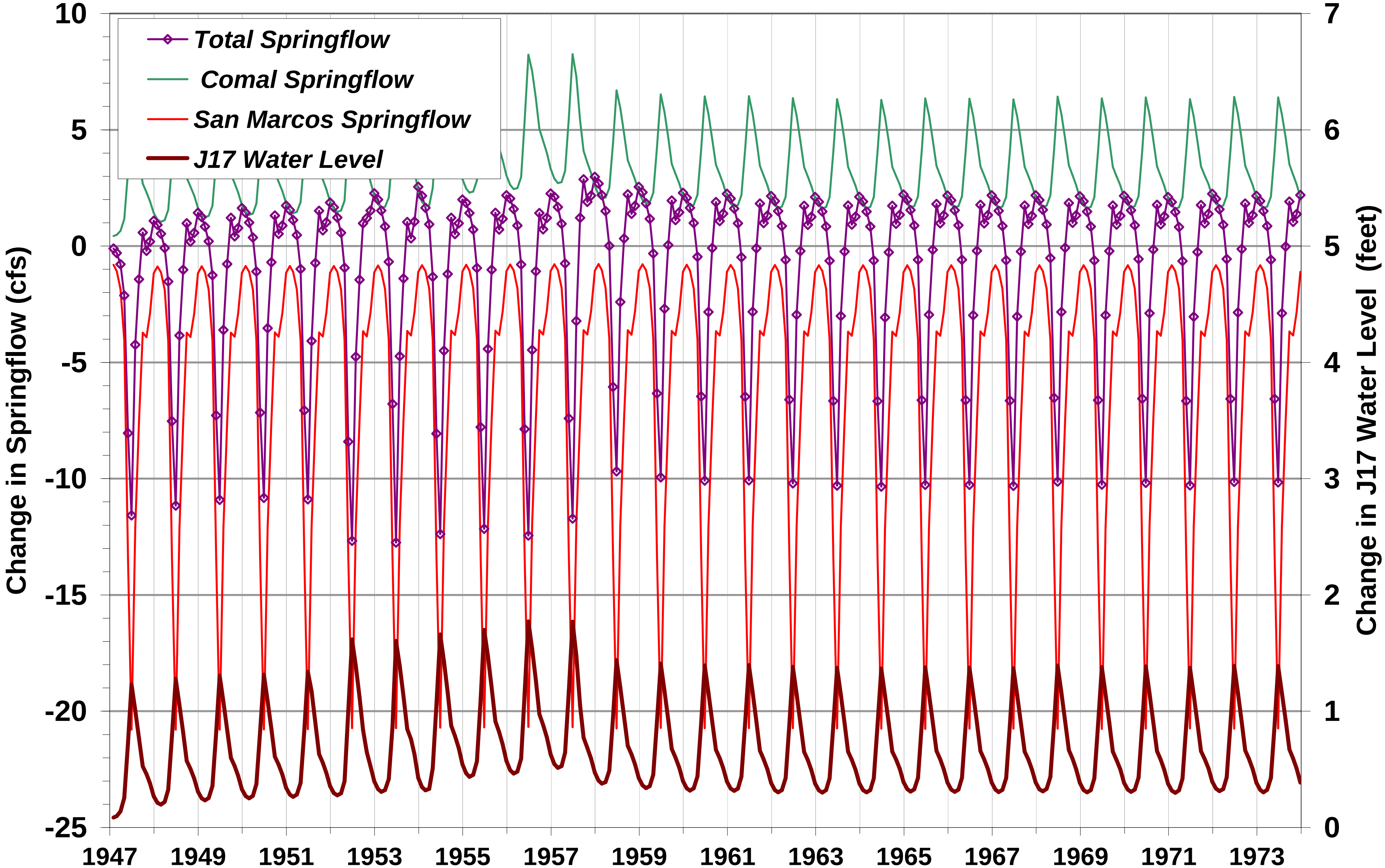

Figure A21. Change in Springflow and J-17 Water Level After Transferring (6.6 cfs or 4,800 af/yr Adjusted Seasonally) from Western Bexar County to near San Marcos Springs (Down-thrown block)

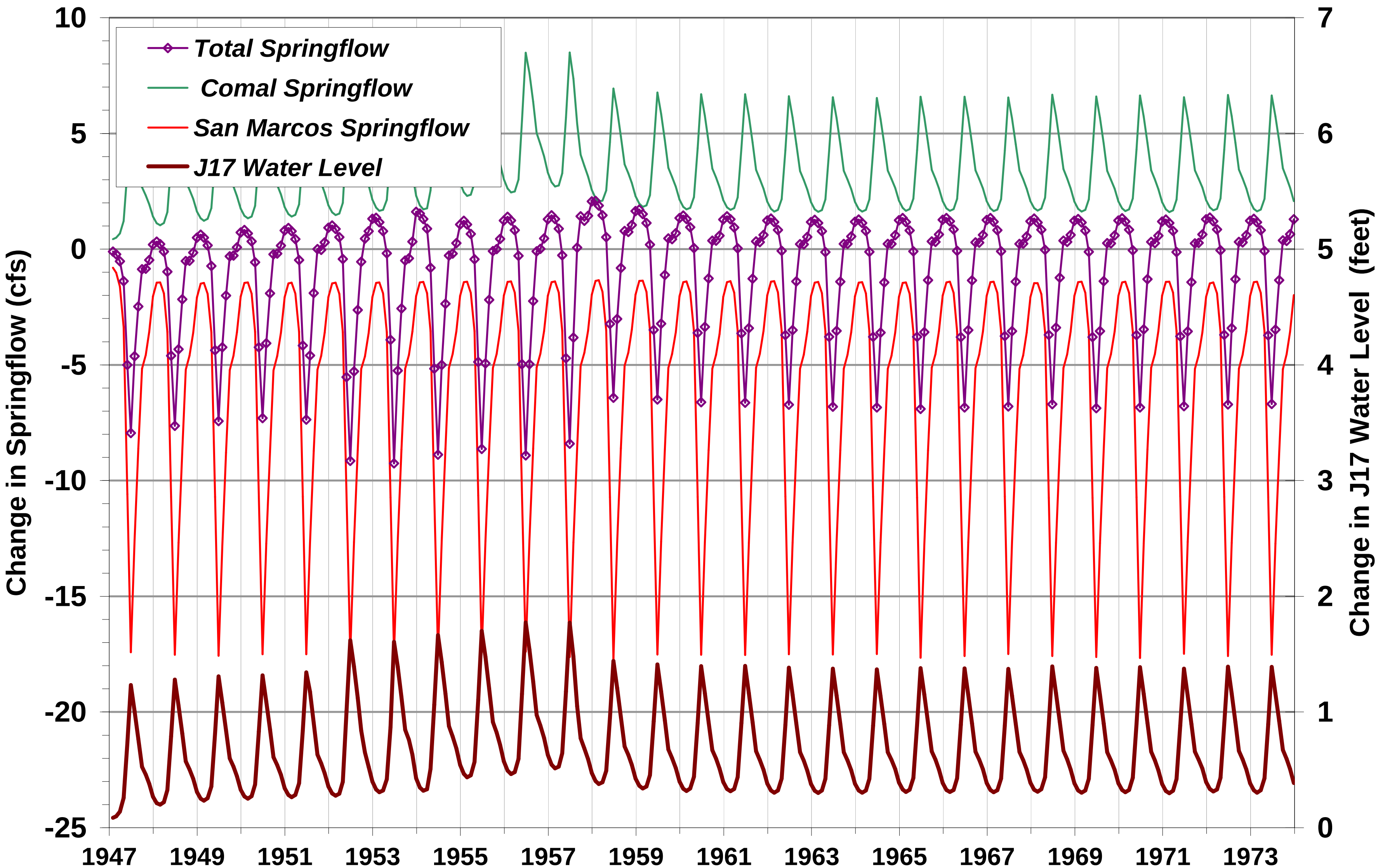

Figure A22. Change in Springflow and J-17 Water Level After Transferring (6.6 cfs or 4,800 af/yr Adjusted Seasonally) from Western Bexar County to near San Marcos Springs (Up-thrown block)

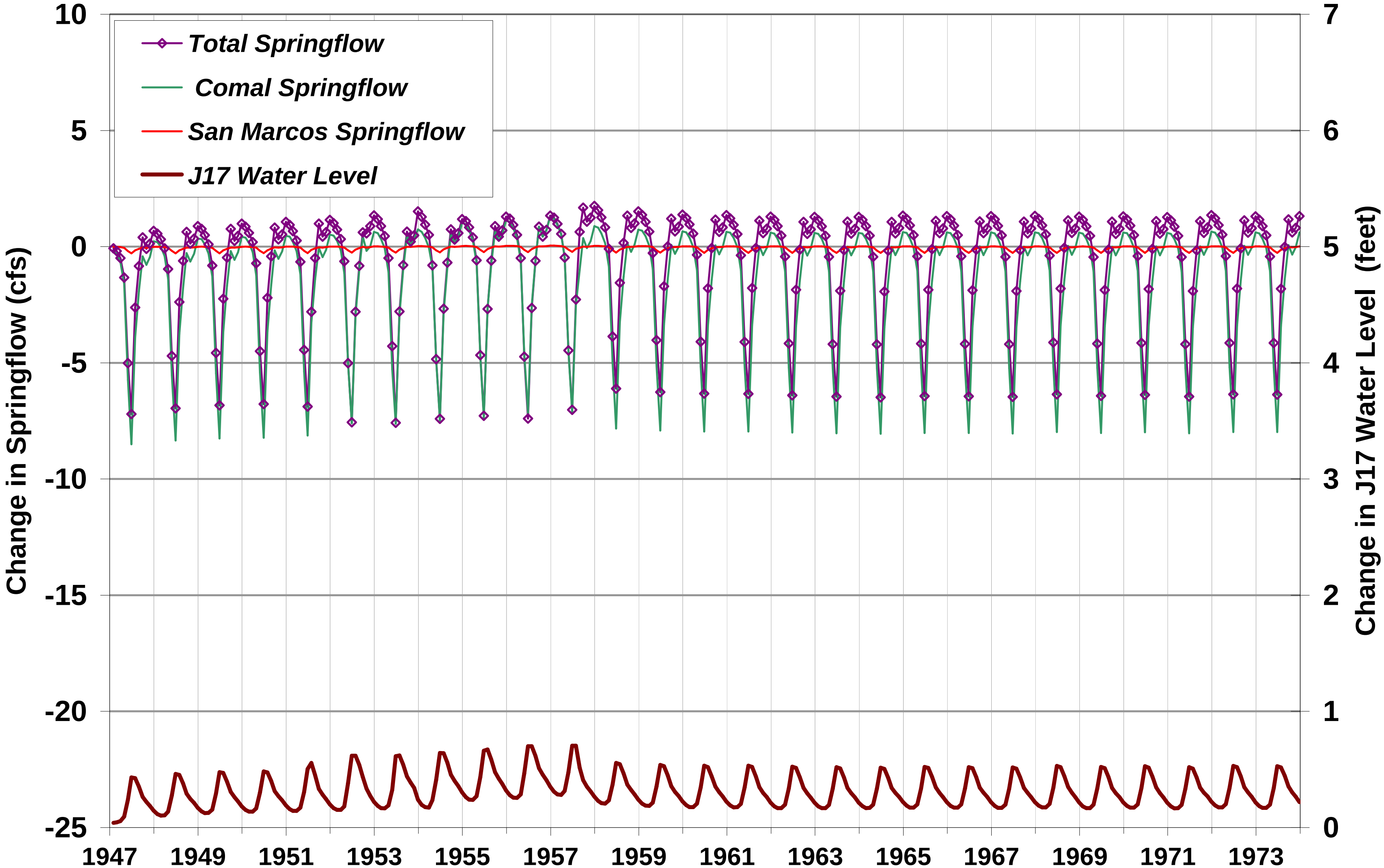

Figure A23. Change in Springflow and J-17 Water Level After Transferring (6.6 cfs or 4,800 af/yr Adjusted Seasonally) from Western Bexar County to Western Comal County

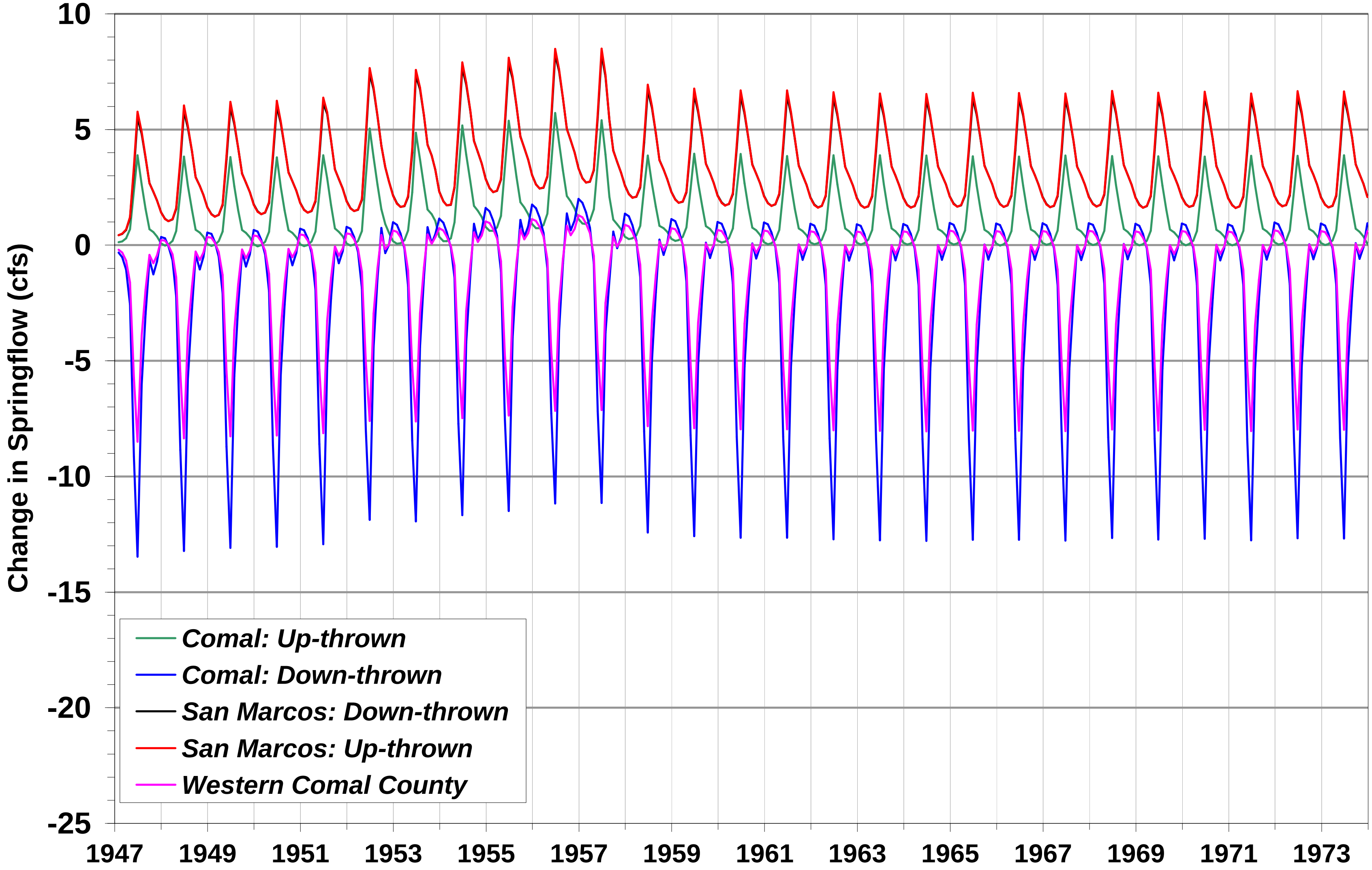

Figure A24. Comparison of Change in Comal Springflow After Transferring 4,800 af/yr (Adjusted Seasonally) from Western Bexar County to Five Locations East of Cibolo Creek

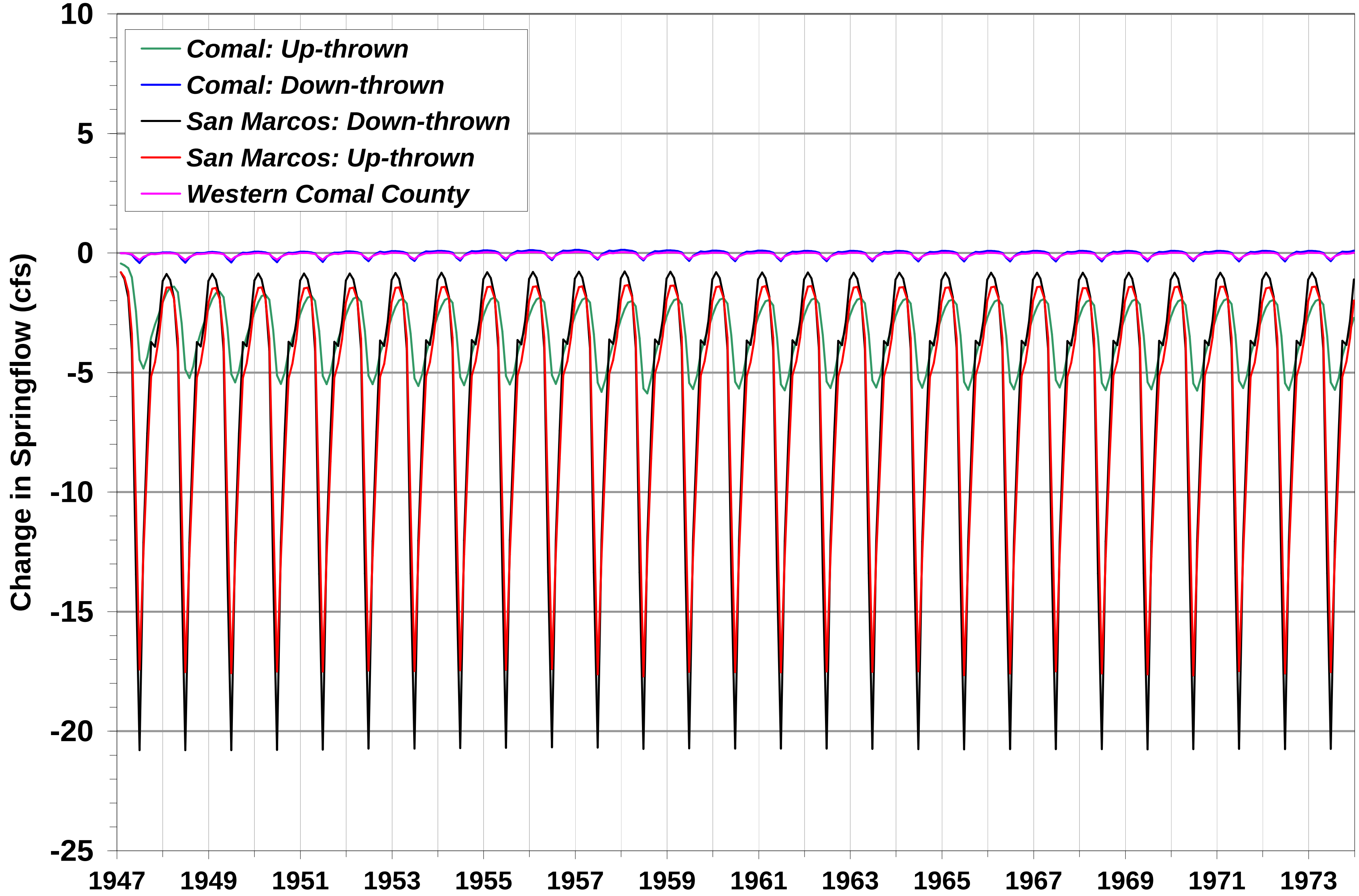

Figure A25. Comparison of Change in San Marcos Springflow After Transferring 4,800 af/yr (Adjusted Seasonally) from Western Bexar County to Five Locations East of Cibolo Creek

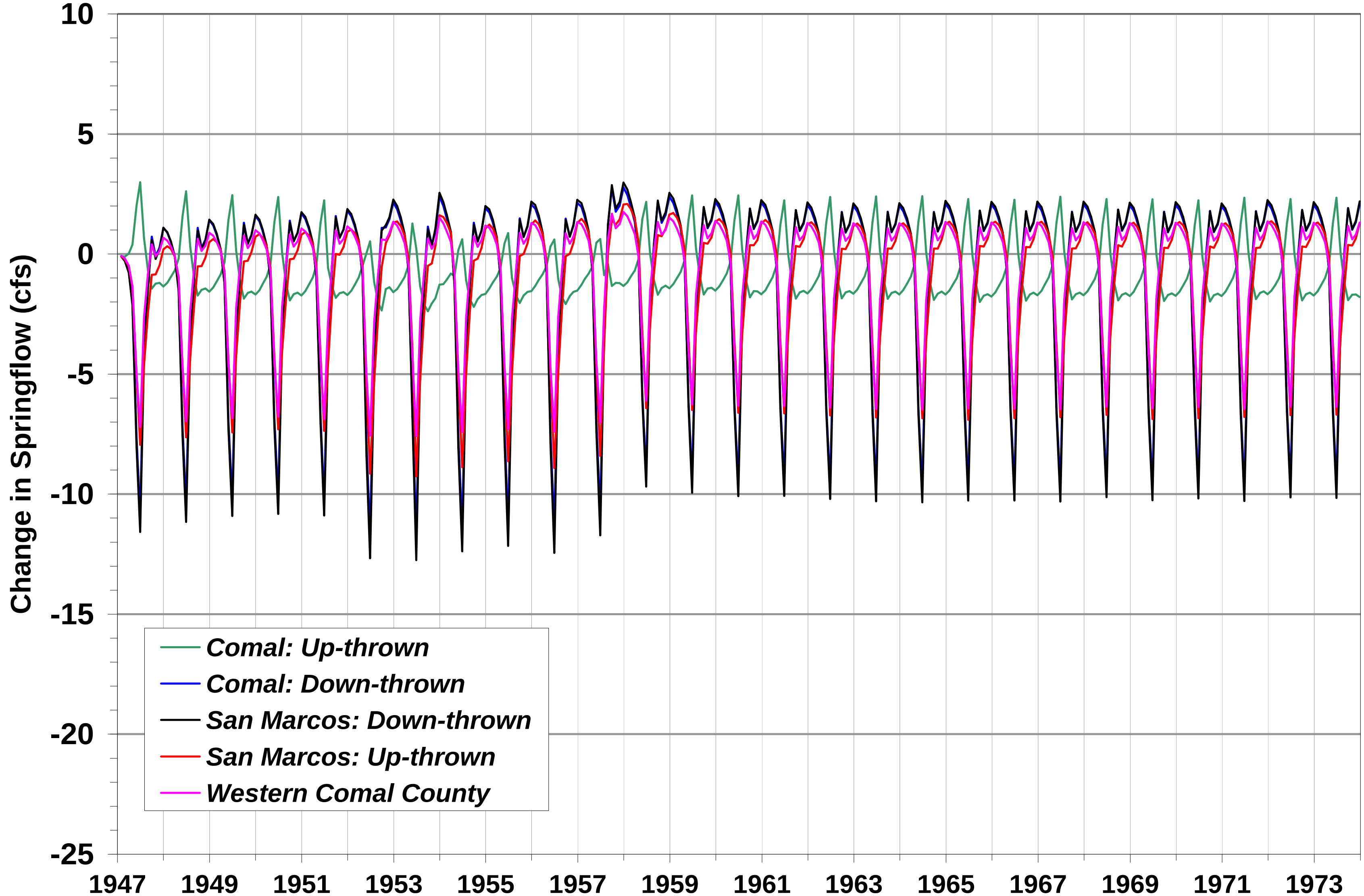

Figure A26. Comparison of Change in Total Springflow After Transferring 4,800 af/yr (Adjusted Seasonally) from Western Bexar County to Five Locations East of Cibolo Creek

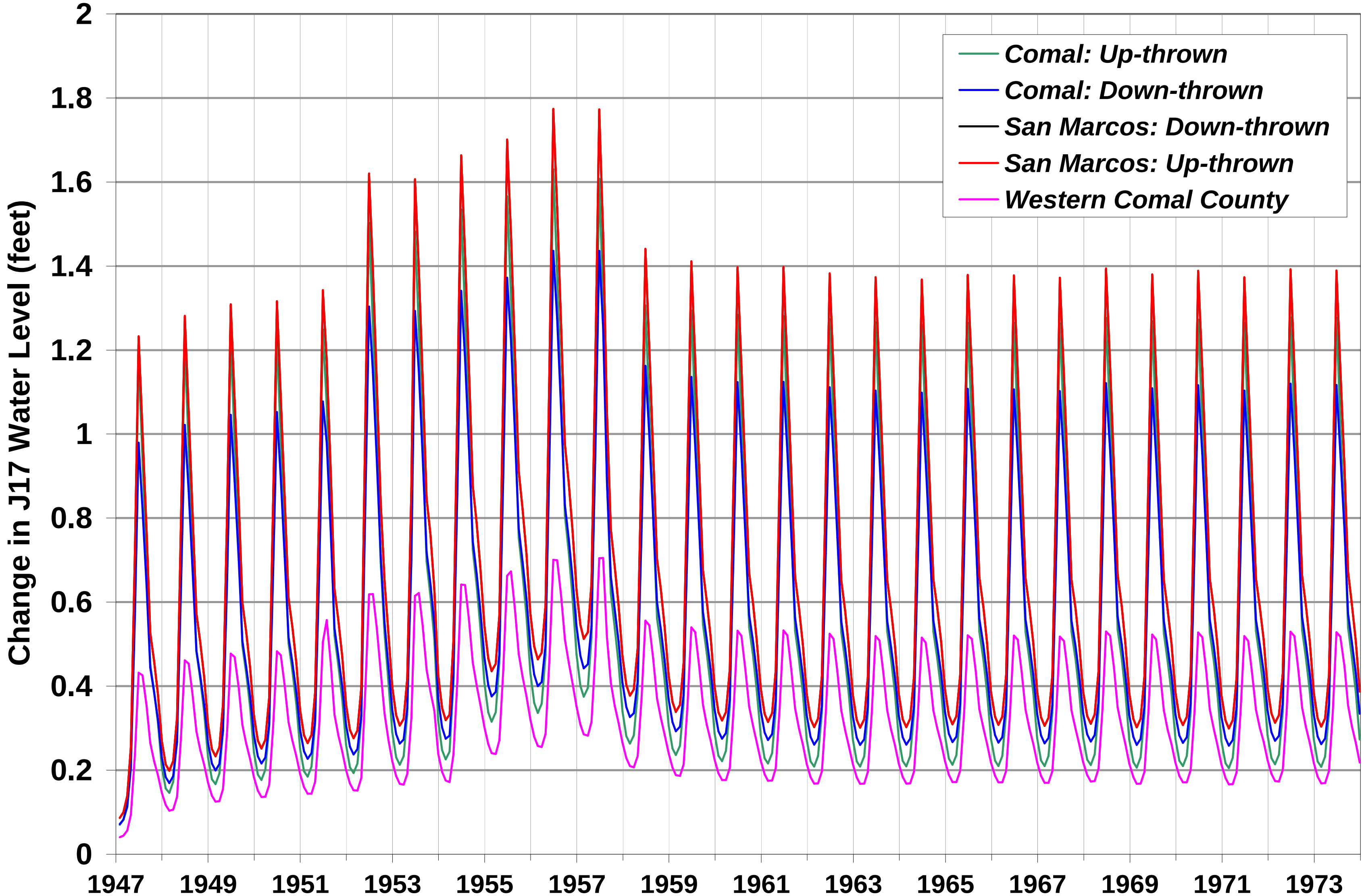

Figure A27. Comparison of Change in J-17 Water Level After Transferring 4,800 af/yr (Adjusted Seasonally) from Western Bexar County to Five Locations East of Cibolo Creek