Phase 6 Model Calibration
RGDSS Memorandum
Final

To: File
From: Dr. Willem A. Schreüder, Principia Mathematica
Subject: Phase 6 Model Calibration
Date: June 8, 2016

Model Calibration

The RGDSS Groundwater Model (the "Model") was calibrated to heads and fluxes. Since one of the major purposes of the Model is to predict impacts to stream flows, it is important that the Model should be calibrated to stream flows. The RGDSS Peer Review Team (PRT) concluded that the calibration of the Model was sufficiently good that the Model is reliable for the purposes to which it was being applied.

The Model calibration adjusted aquifer properties, primarily the horizontal and vertical hydraulic conductivity of the aquifer materials, and the stream bed conductance of streams. The PEST program was used to perform the calibration. The calibration was done using transient model runs. The process of setting up the PEST calibration is described in detail in the Phase 6 memorandum entitled RGDSS_P6_MOD_ModelSet.pdf. This document presents the results of the calibration.

Head Calibration

Figures 1 and **2** display the Median Absolute Head Residual for the confined and unconfined aquifer for different phases of the Model development. These graphs are a global summary of the quality of the calibration of the transient head calibration of the model and have been presented during each legal proceeding in which the Model was used. The median absolute residual is defined as the median value of the absolute difference between the observed and model predicted value calculated using all the calibration targets for each well. **Figure 1a** shows the number of wells falling in each range of absolute mean residuals.

For the unconfined aquifer, the testimony at the Rules Trial[1] was that excellent agreement was <5 feet, 5-10 feet was good, 10-20 feet was fair. As can be seen in this figure in each successive iteration of the model, more wells are classified as having a better matches and fewer wells have poorer matches. In subsequent phases more wells were available to calculate these matches, so **Figure 1b** expresses the number of wells in each category as a percentage of the total number of unconfined well used as calibration targets. This shows improvements in the calibration in successive phases of the modeling effort from model versions 4P13 through 6P98 The difference between model version 6P97 and 6P98 shows the minor incremental improvement in calibration between model versions achieved at the end of Phase 6.

[1] Case No. 04CW24 as part of the Confined Aquifer New Use Rules for Division 3 which was upheld by the Colorado Supreme Court in Case No. 07SA42.

Figures 2a and **2b** similarly evaluates the calibration for the confined aquifer in terms of the absolute number of wells and percentage of the wells. The testimony during the Rules Trial was that in a confined aquifer, a match better than 20 feet was an excellent match, while 20-40 feet was good, and 40-100 feet was fair. For the 6P35 evaluation, a number of water level observations from well permits were included in this analysis, and showed very good agreement between model predictions and observations. However, in subsequent phases, the PRT determined that since these observations are generally of lower quality, they should be used as targets in the model calibration, but not included in the Median Residual statistic. When viewed as a percentage of the confined aquifer monitor wells, the percentage of better matches increase over time while the percentage of poorer matches decrease over time.

Figures 3a and **3b** and **4a** and **4b** repeat the analysis for each of the zones. These figures demonstrate that the calibrations for all the zones are properly calibrated, except for the Costilla Zone where the calibration is unacceptable.

Figure 5 shows the monthly average head residual by layer. At each black dot shown in the figures, the average residual is calculated. In order to display the difference, the residuals are spatially interpreted and displayed as color bands. It is important to note that the residuals are only calculated at the points shown, and that the color bands are for display purposes only. Where green-red colors appear, the model predicted heads are too high, while blue-purple colors show where the model predictions are too low.

Figure 6 shows the head calibration as a cross plot. The horizontal axis represents the observed value while the vertical axis represents the predicted value. A perfect calibration would fall on the 45 degree line. In **Figure 6** all the observations are shown, which means that there are about a quarter million data points in **Figure 6**. Colors are used to represent the spatial location if the wells.

There are 1565 individual well hydrographs are provided in **Appendix A** (RGDSS_P6_MOD_AppendixACalibrationWells.zip). These hydrographs may also be viewed through at least the next year using the online model viewer at http://www.prinmath.com/cgi-bin/slvp/doq.pl. **Figure 7** is an example hydrograph (RG-37) that can be accessed from this site. **Figure 7** shows the observed water levels as blue dots, while the model predictions are shown as solid red line. The prediction by previous model versions are shown as dashed red lines. **Figure 7** also shows a map with the well location.

Based on a review of the information presented in this section, the PRT concluded that the Model is a reasonable and reliable representation of the groundwater flow system and replicates observed water levels to a reasonable degree.

Flux Calibration

The Model was calibrated to the fluxes between the surface water and groundwater systems. In particular, the Model was calibrated to stream gains on major streams and McIntyre Springs. In order to determine the gain or loss from groundwater, a baseflow separation must be performed if the stream flow in a reach cannot be entirely attributed to groundwater as in the case of McIntyre Springs.

Figure 8 shows the long term average gain for four reaches of the Rio Grande, two reaches of the Conejos River and the single reach of the Rio San Antonio that were determined from the baseflow separation and the model predicted average gain in cubic feet per second (cfs).

Figure 9 shows the measured and predicted monthly average flow at McIntyre Springs. Since McIntyre Springs is a groundwater discharge the measured flow is compared directly to the discharge predicted by the model.

Figures 10a through **10f** show the seasonal average gain estimated form the baseflow separation and the model predicted seasonal average flows for the four Rio Grande reaches, the Conejos River and the Rio San Antonio. For the Rio Grande and Conejos, the seasonal periods are April to October and November to March. For the Rio San Antonio the seasonal periods are March to October and November to February because the runoff starts earlier.

Figure 11 shows the estimated and predicted Norton Drain discharge at the Rio Grande and at the gage at the southern gaging station on an annual average basis. Although the Norton drain supply is primarily the capture of groundwater, overland flow may be included in the Norton drain flow which the groundwater model does not consider.

For the many streams that run onto the valley floor, an implicit gain/loss estimate can be derived by subtracting diversions from the estimate of flow at the model boundary. This estimate is complicated when tail water from some diversions return to the stream and is re-diverted by downstream users. A further complication on smaller streams are that the runoff peaks may be for periods of time much shorter than the monthly stress periods simulated in the model.

Figure 12 shows the amount of diversions simulated in the groundwater model, and the recorded diversions for these smaller stream reaches. An orange bar shows the simulated diversions, while a red extension to the bar shows the difference between the observed and simulated diversions. The simulated diversions are limited to the observed diversions, so the simulated diversions can never exceed the observed diversions. The goal in the calibration is to have the observed and simulated diversions match.

For some figures in **Figure 12** blue bars may appear above the horizontal axis. For these streams water commissioner interviews indicated that t a diversion would sweep the stream and there should be no flow beyond the last diversion on the stream. Any simulated flow pass that point is shown as a light blue bar. Similarly, dark blue bars are used to show where water commissioner interviews indicated that the stream is generally dry below a point during the winter months.

Figure 13 shows the calibration on San Luis Creek. On San Luis Creek there are three dry-up points along the creek, depicted by blue and green bars above the axis.

For canals modeled as streams, **Figure 14** shows the comparison of the estimated and simulated ditch leakage.

The goal of the calibration is to minimizing the red, blue and green bars shown in **Figures 12**, **13** and **14**. The PRT evaluated the differences between the observed and simulated fluxes taking into consideration the time scales, flow volumes and uncertainty associated with the records, and concluded that the model predictions to these streams are sufficiently reliable to generate response functions.

Conclusions

Based on a review of the calibration results presented above, a review of the model input data sets and the predicted responses from the Model, the PRT concluded that the Model calibration is sufficiently reliable that the model can be used to generate response functions for groundwater withdrawals in each of the response zones to streams. The fact that the model was calibrated to both heads and fluxes gave the PRT confidence in the results predicted by the Model. However, the PRT also concluded that it would be inappropriate to apply the model to areas smaller than the response zones, or at time and spatial scales smaller than what was used in the calibration.

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14a – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) on the Rio Grande Canal

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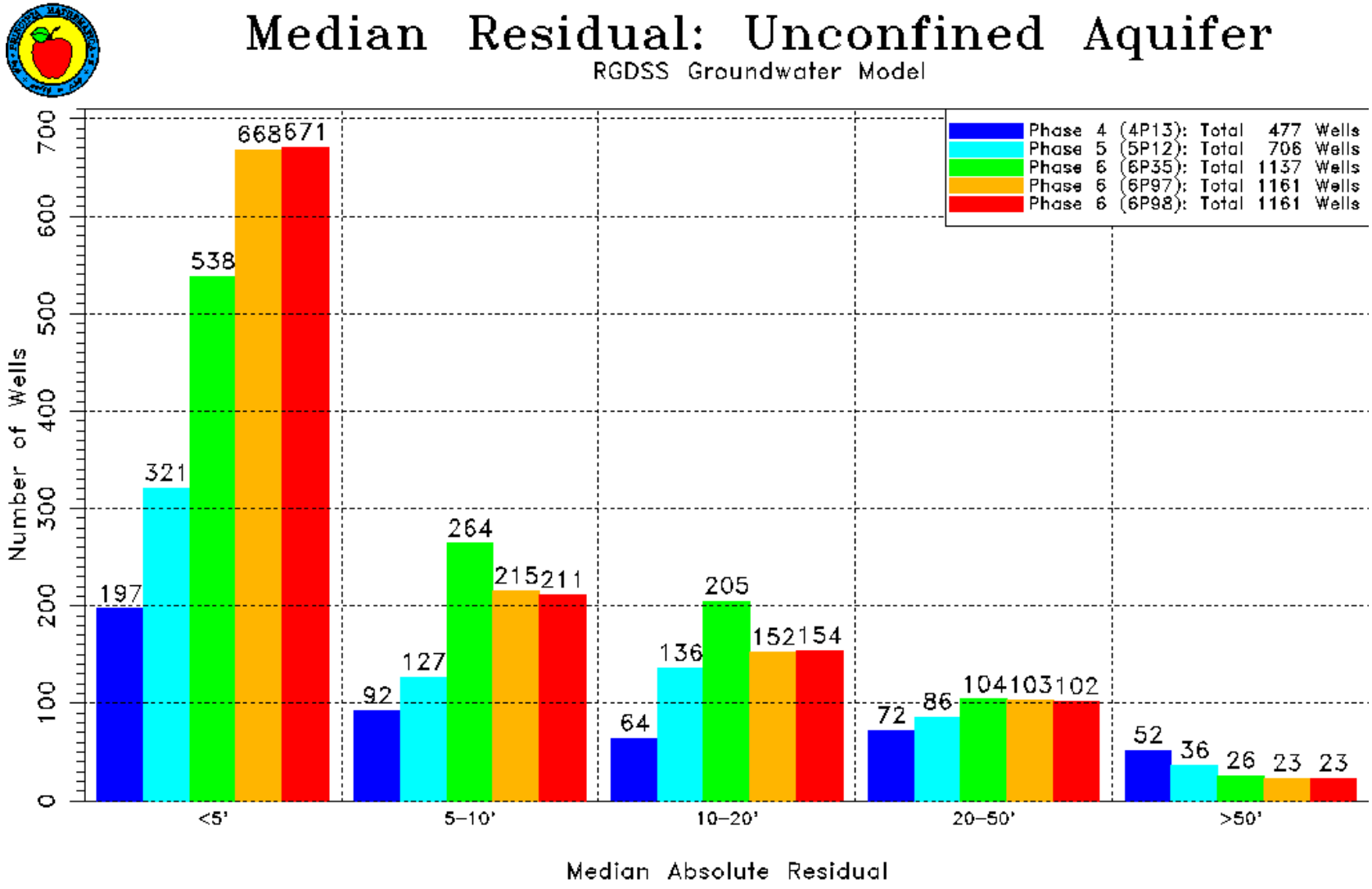


Figure 1a – Median Head Residual: Unconfined Aquifer Based on the Number of Wells

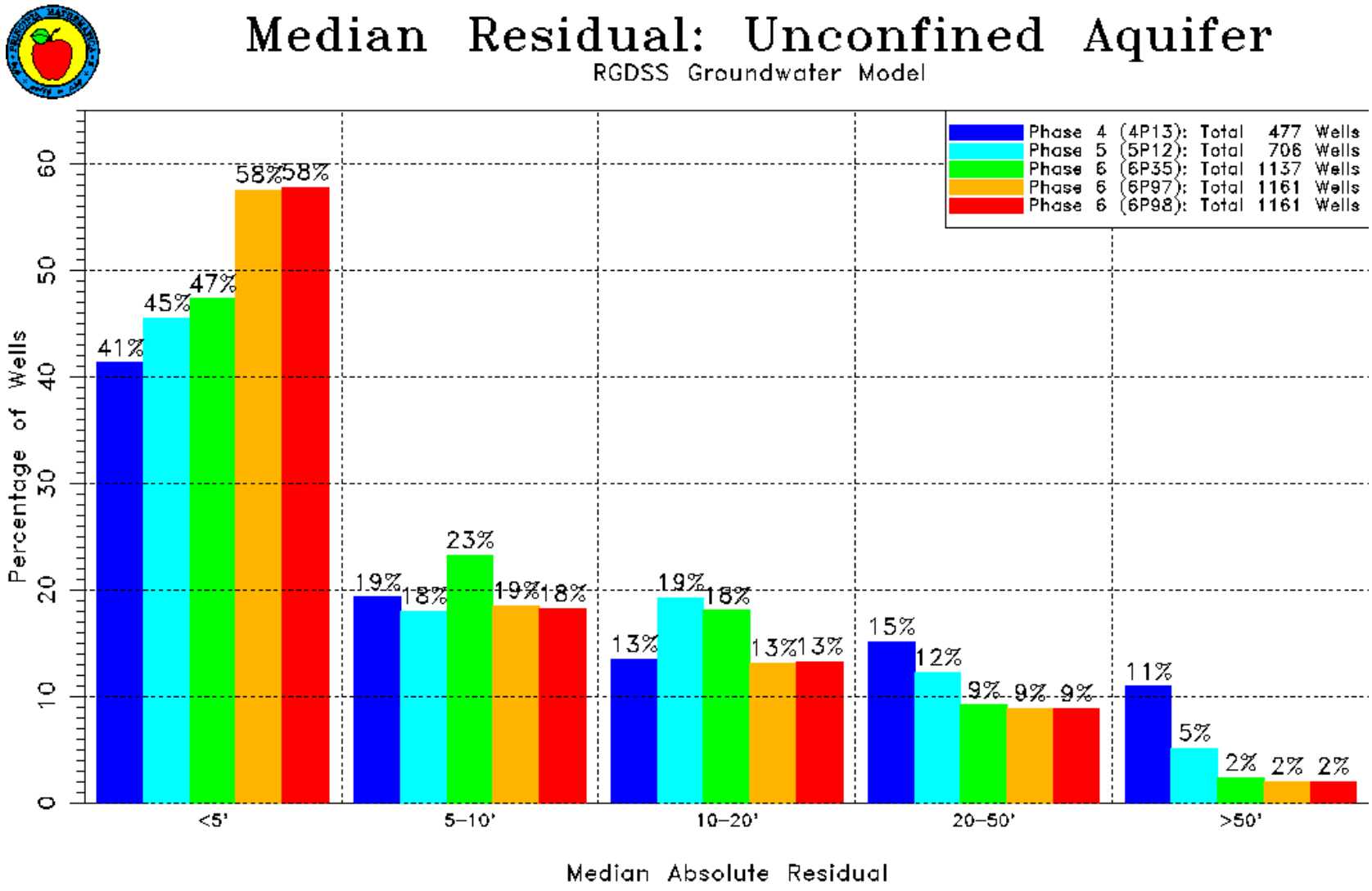


Figure 1b – Median Head Residual: Unconfined Aquifer Based on the Percentage of Wells.

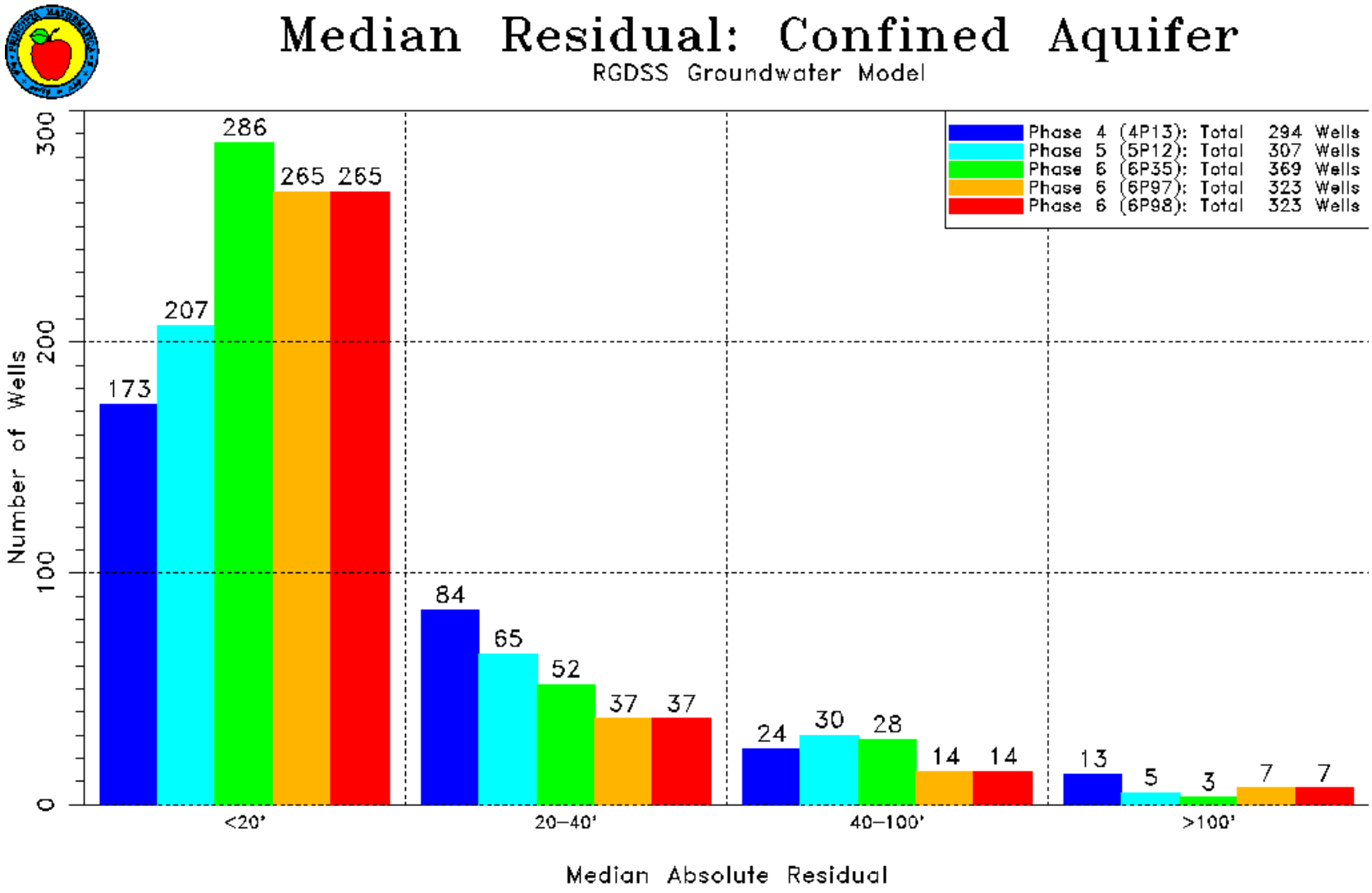


Figure 2a – Median Head Residual: Confined Aquifer Based on the Number of Wells

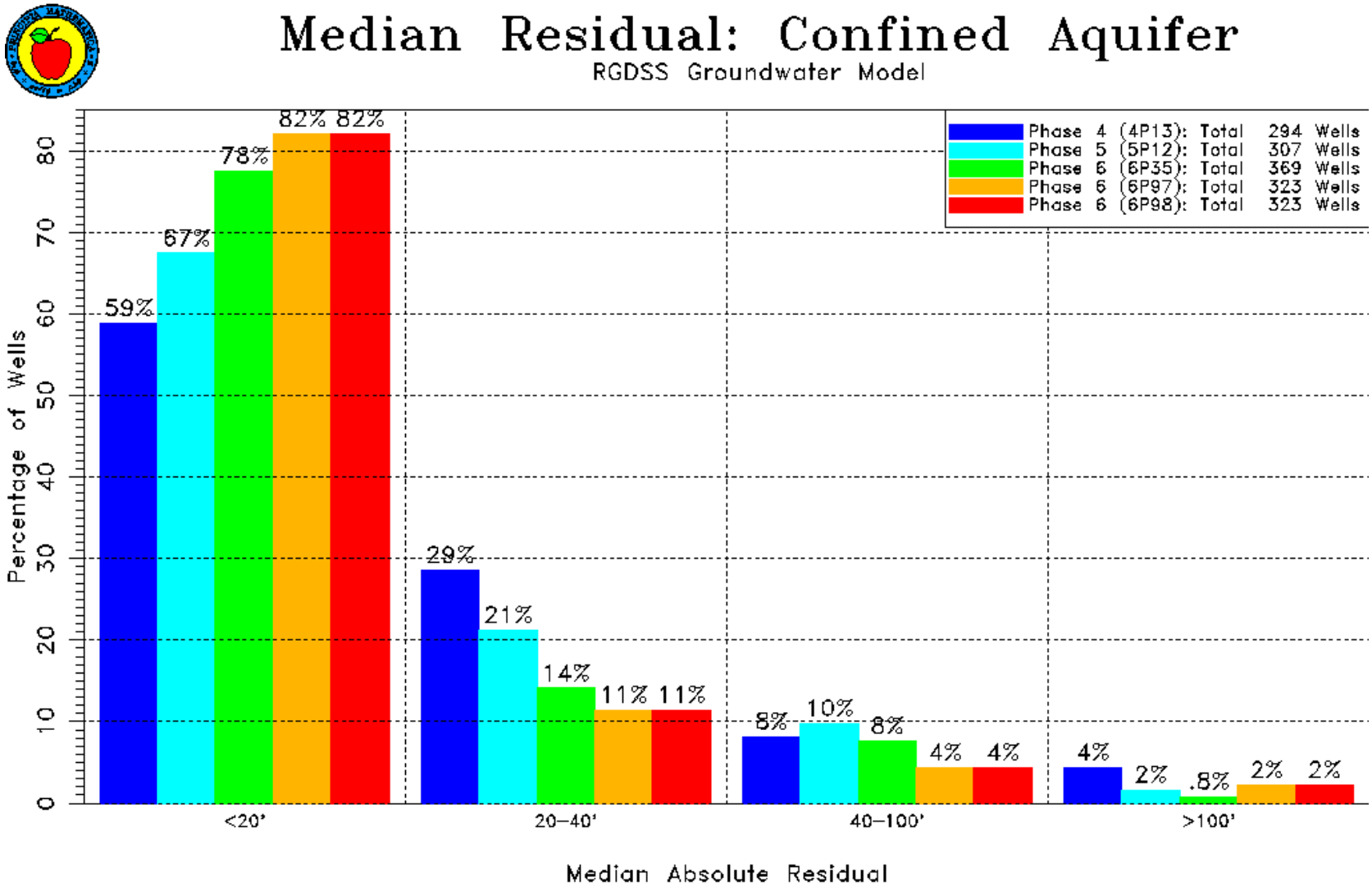


Figure 2b – Median Head Residual: Confined Aquifer Based on the Percentage of Wells.

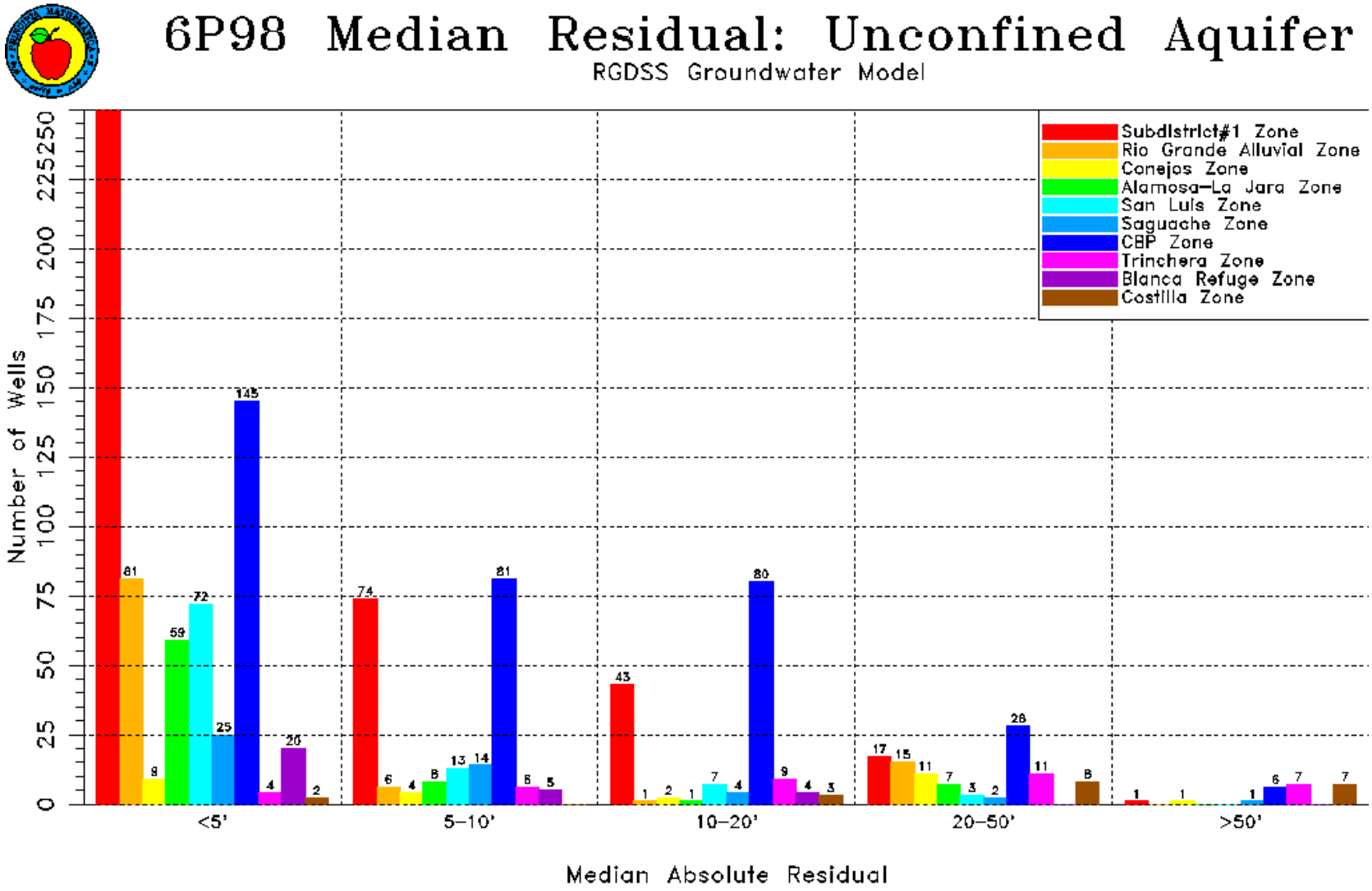


Figure 3a – Median Head Residual by Response Area Zone: Unconfined Aquifer Based on the Number of Wells

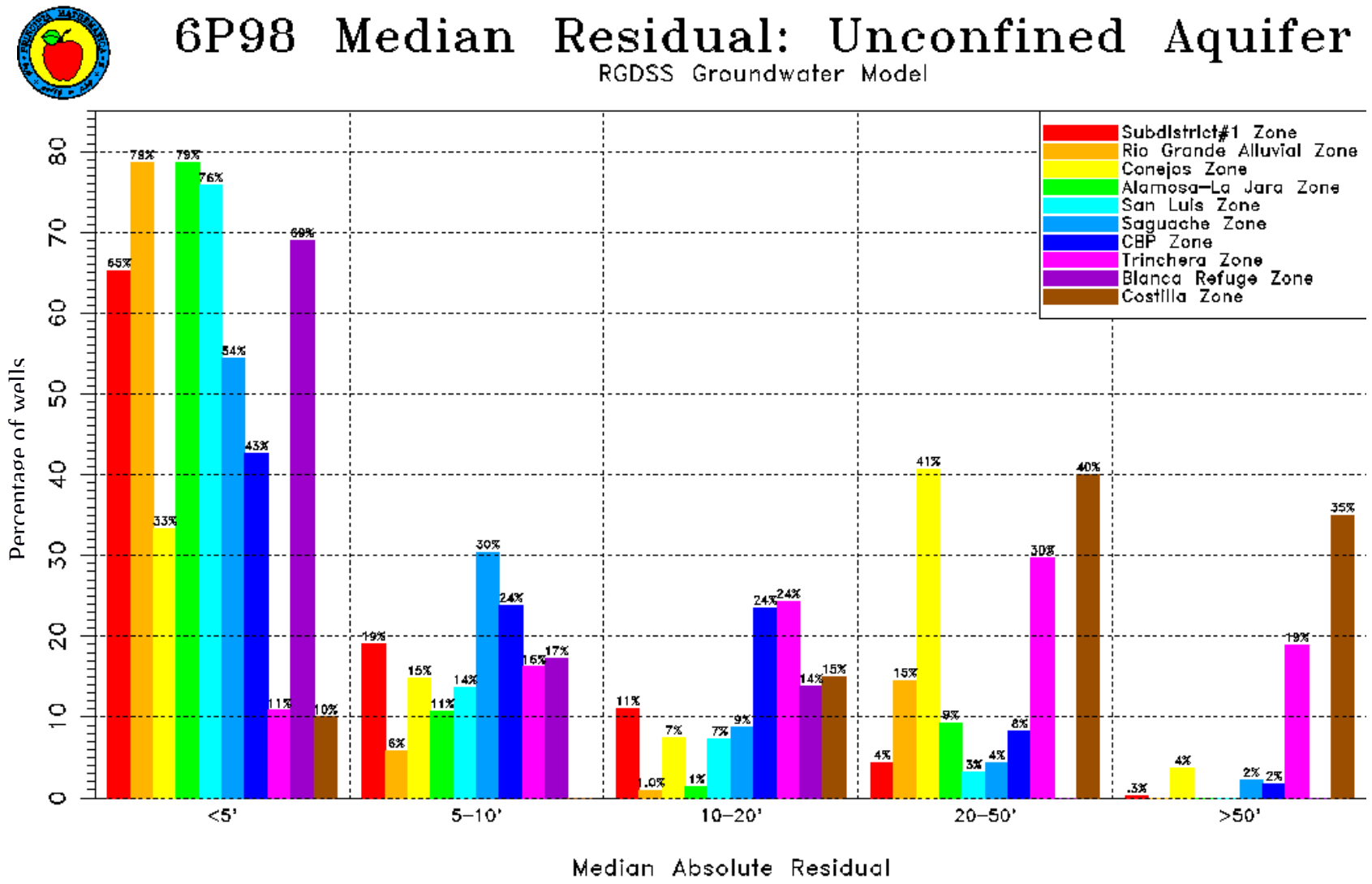


Figure 3b – Median Head Residual by Response Area Zone: Unconfined Aquifer Based on the Percentage of Wells

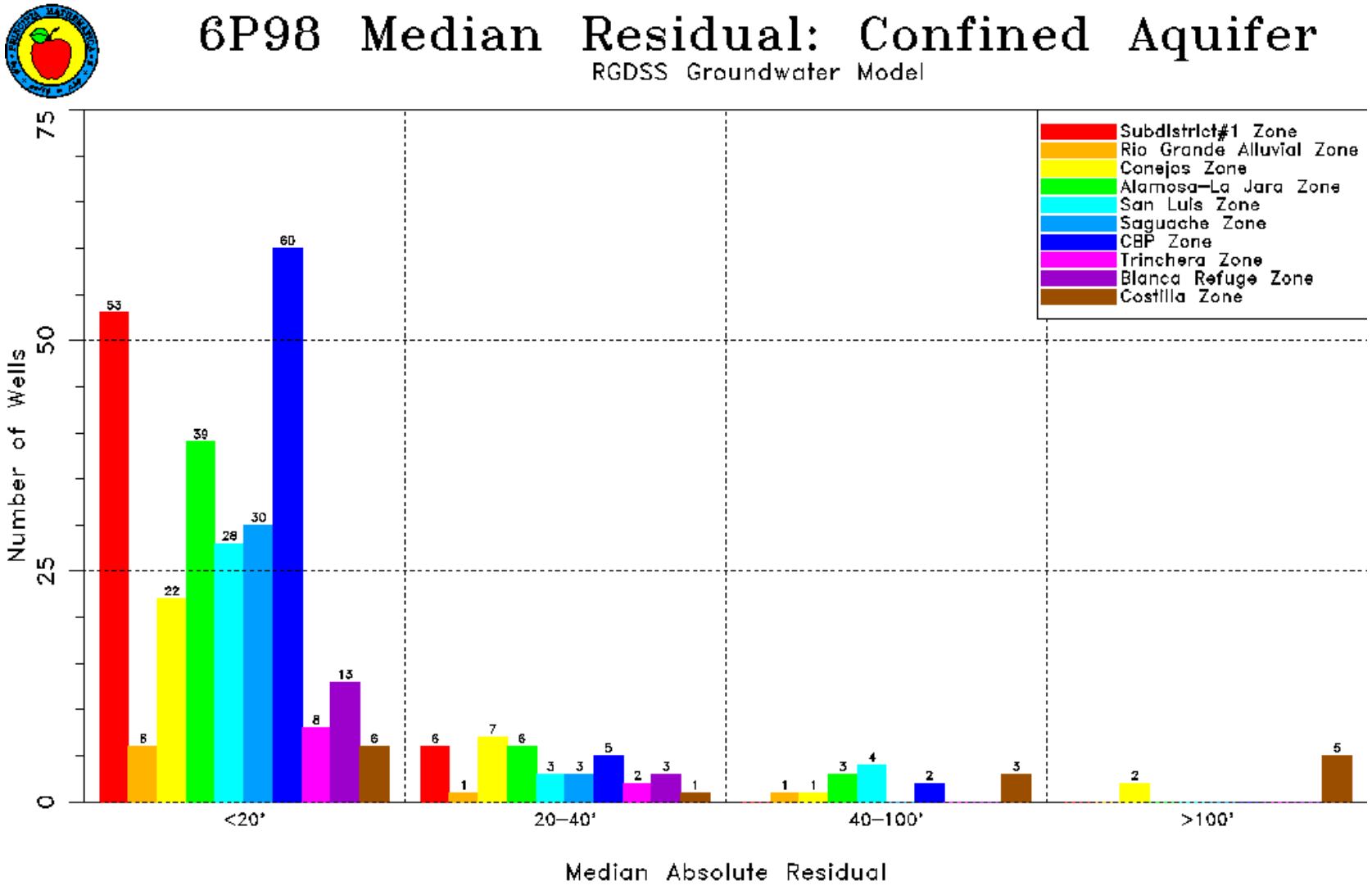


Figure 4a – Median Head Residual by Response Area Zone: Confined Aquifer Based on the Number of Wells

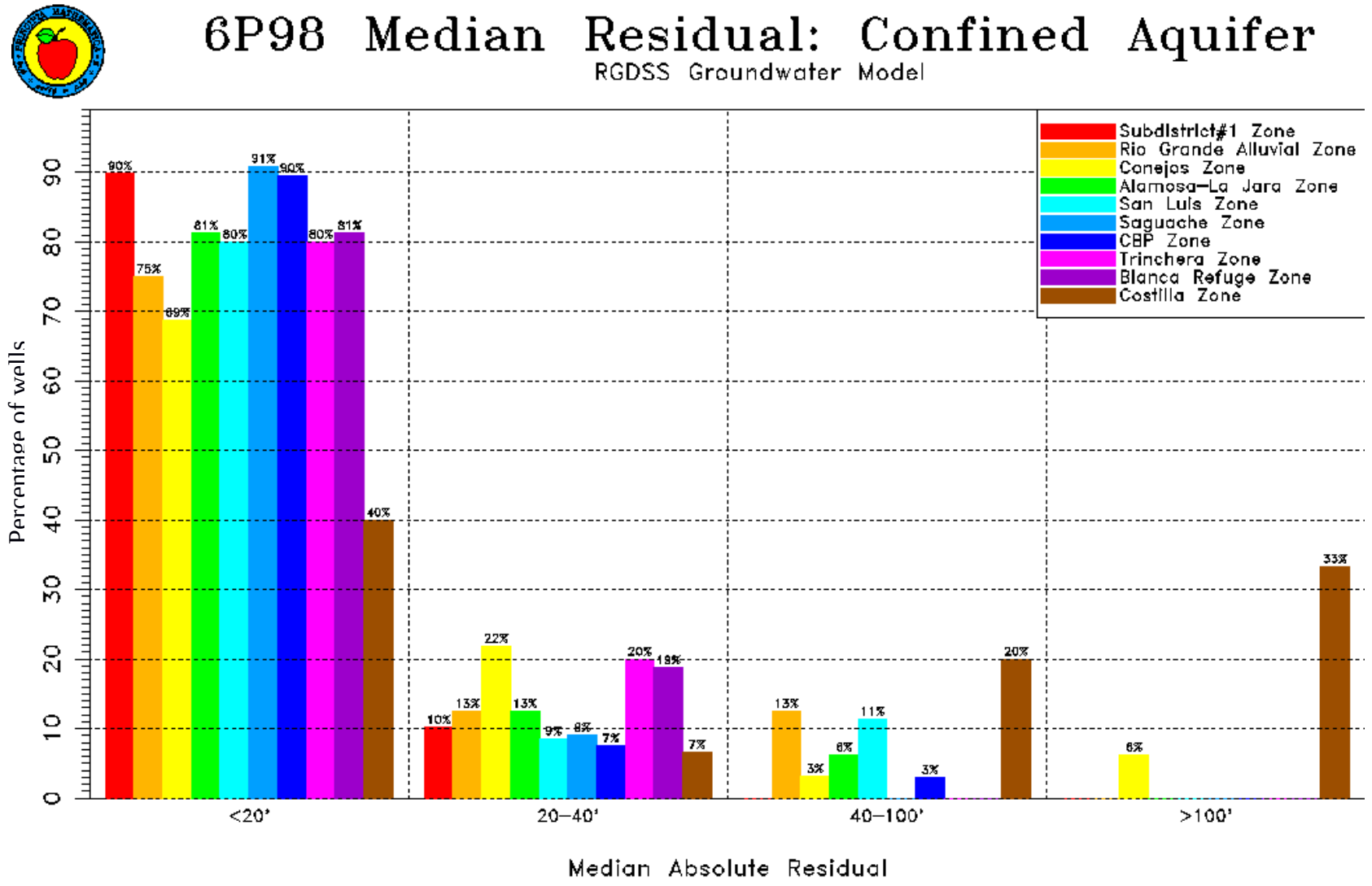


Figure 4b – Median Head Residual by Response Area Zone: Confined Aquifer Based on the Percentage of Wells

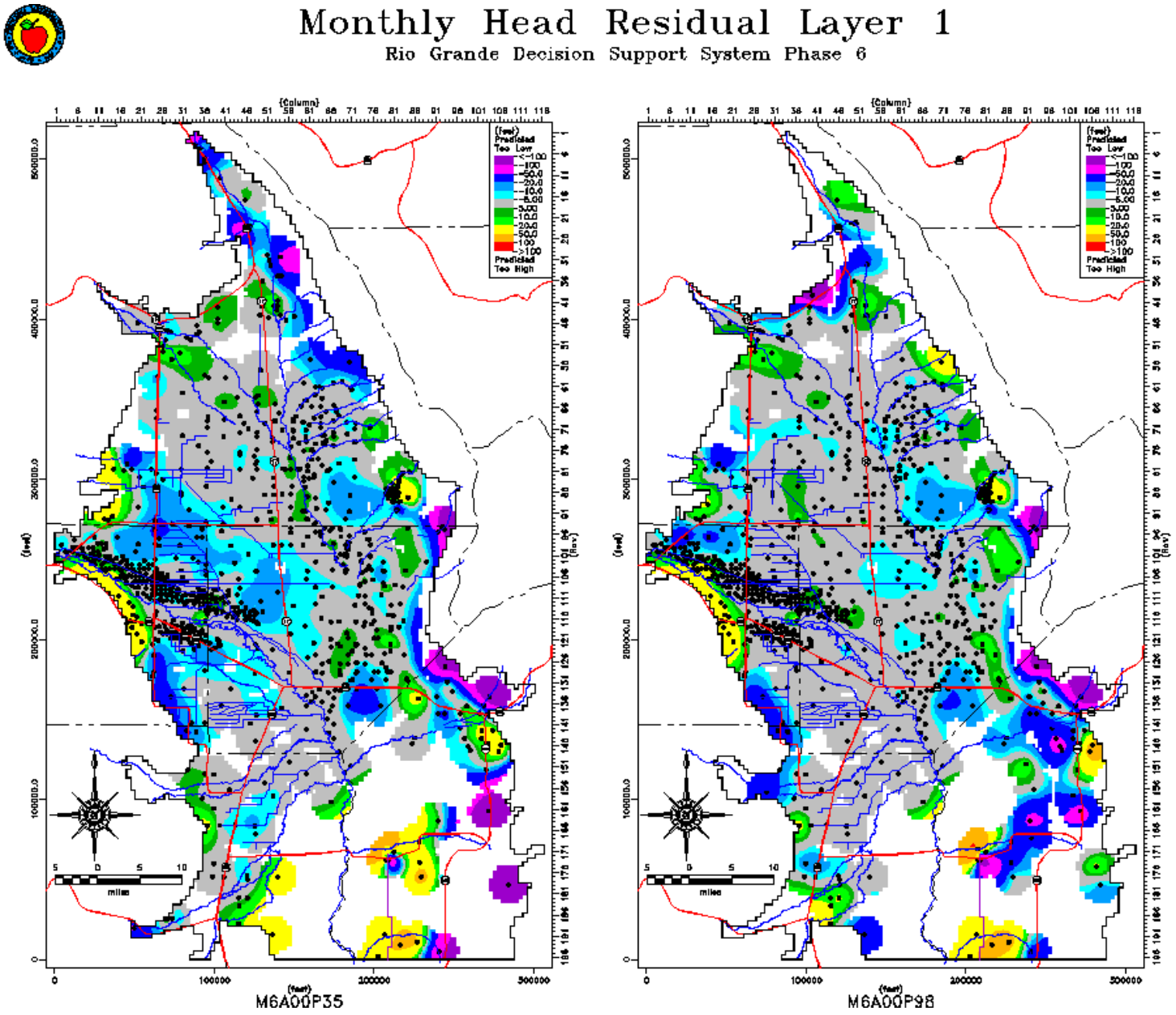


Figure 5a – Monthly Head Residual Maps for Layer 1

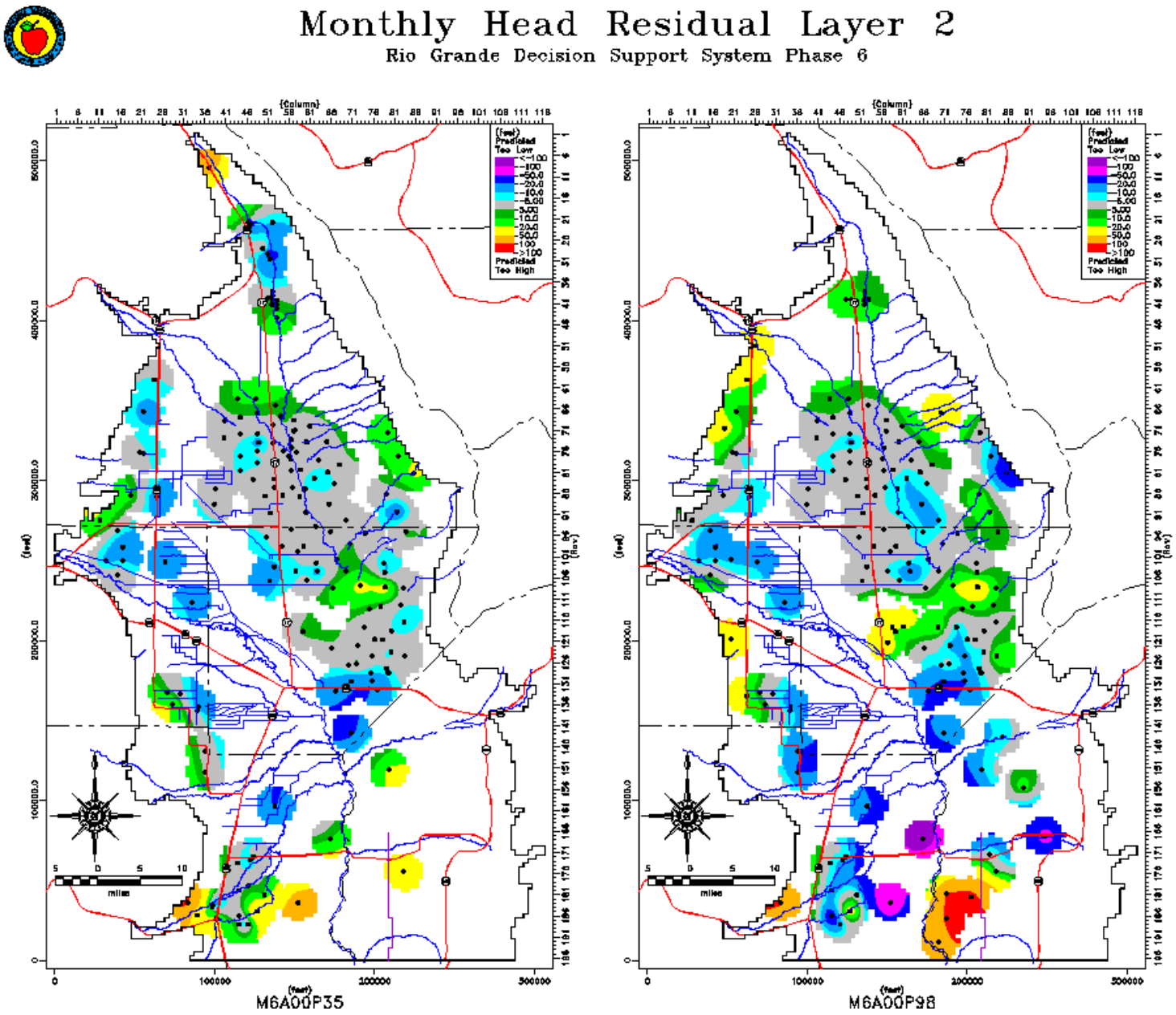


Figure 5b – Monthly Head Residual Maps for Layer 2

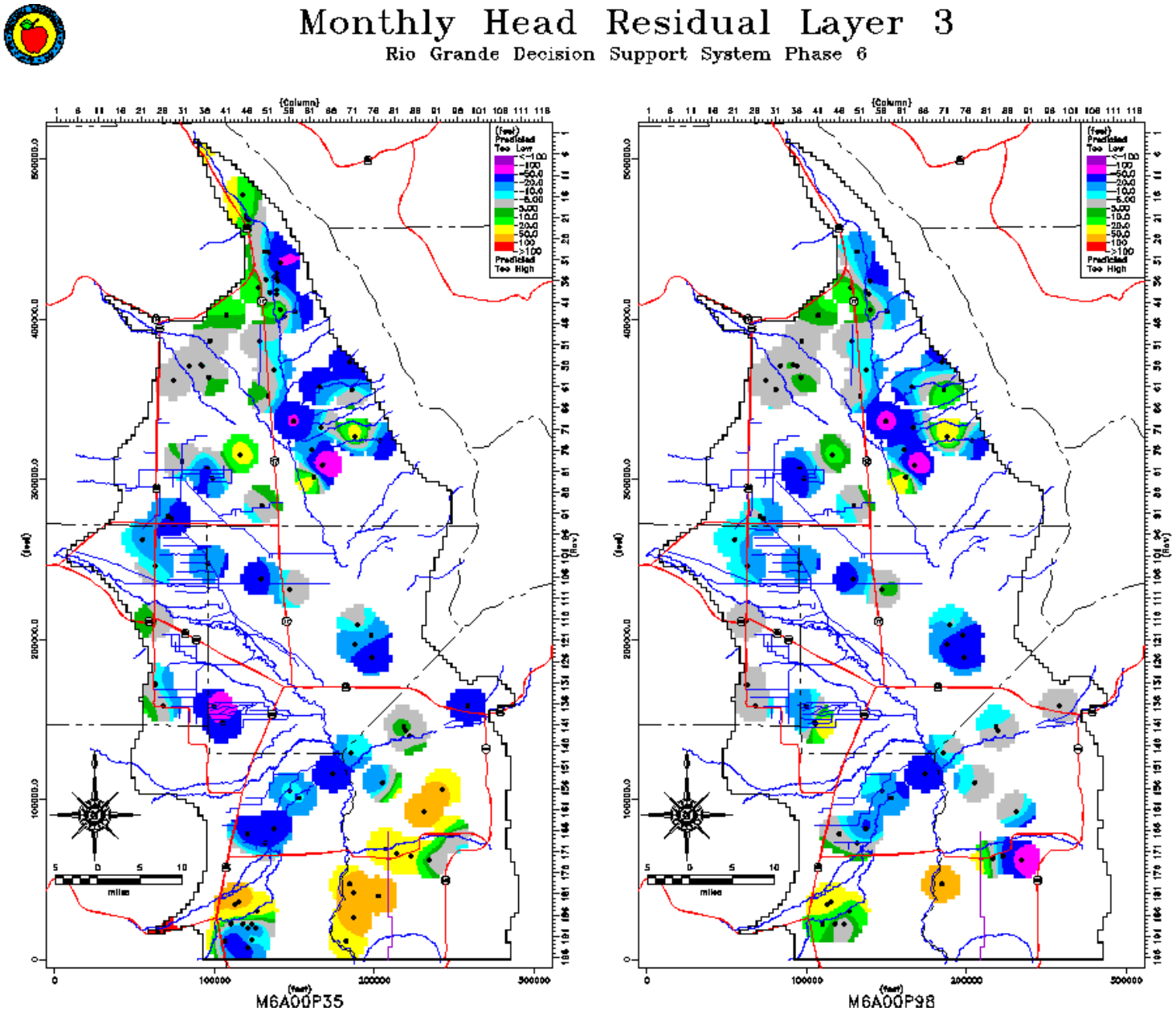


Figure 5c – Monthly Head Residual Maps for Layer 3

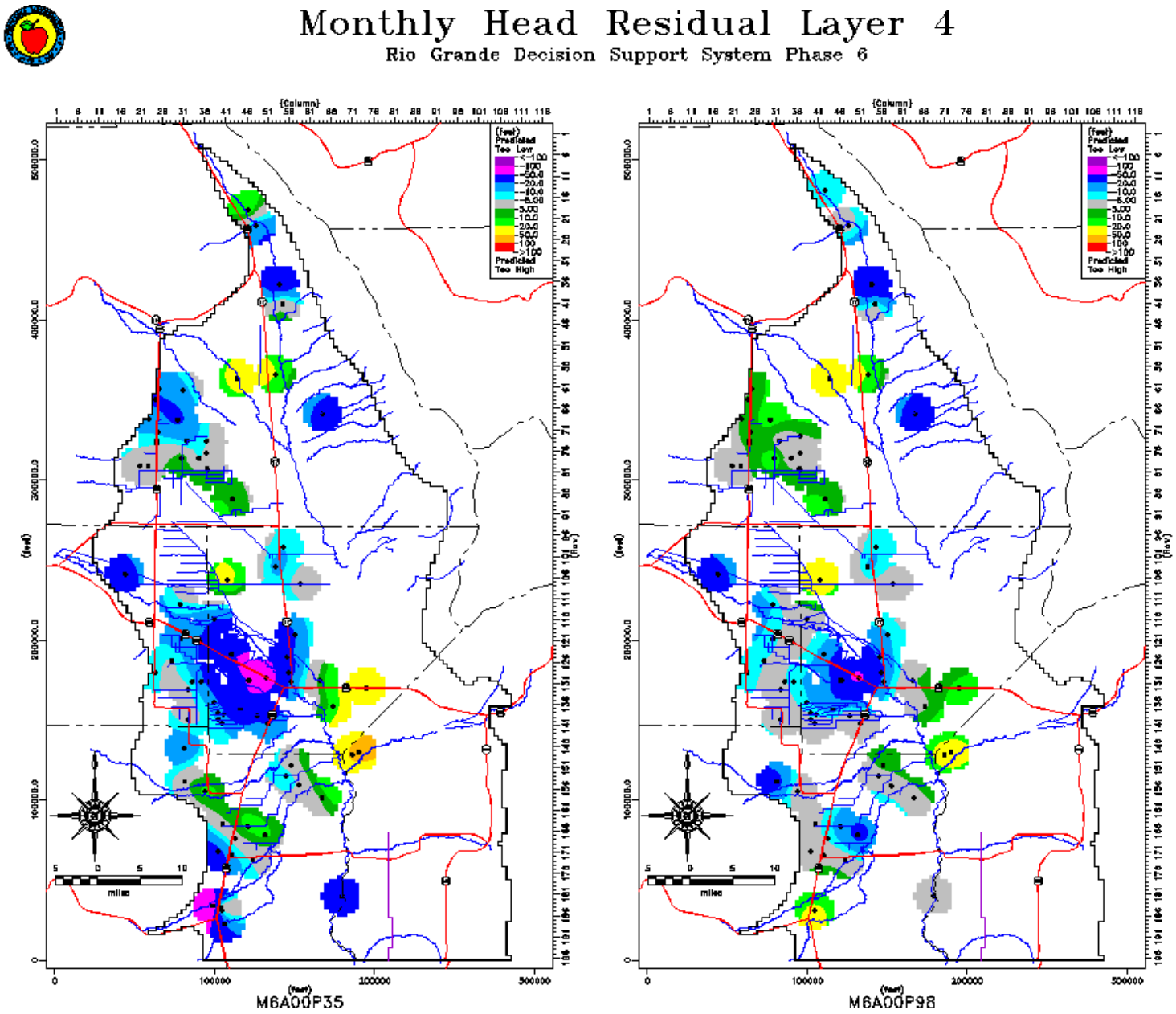


Figure 5d – Monthly Head Residual Maps for Layer 4

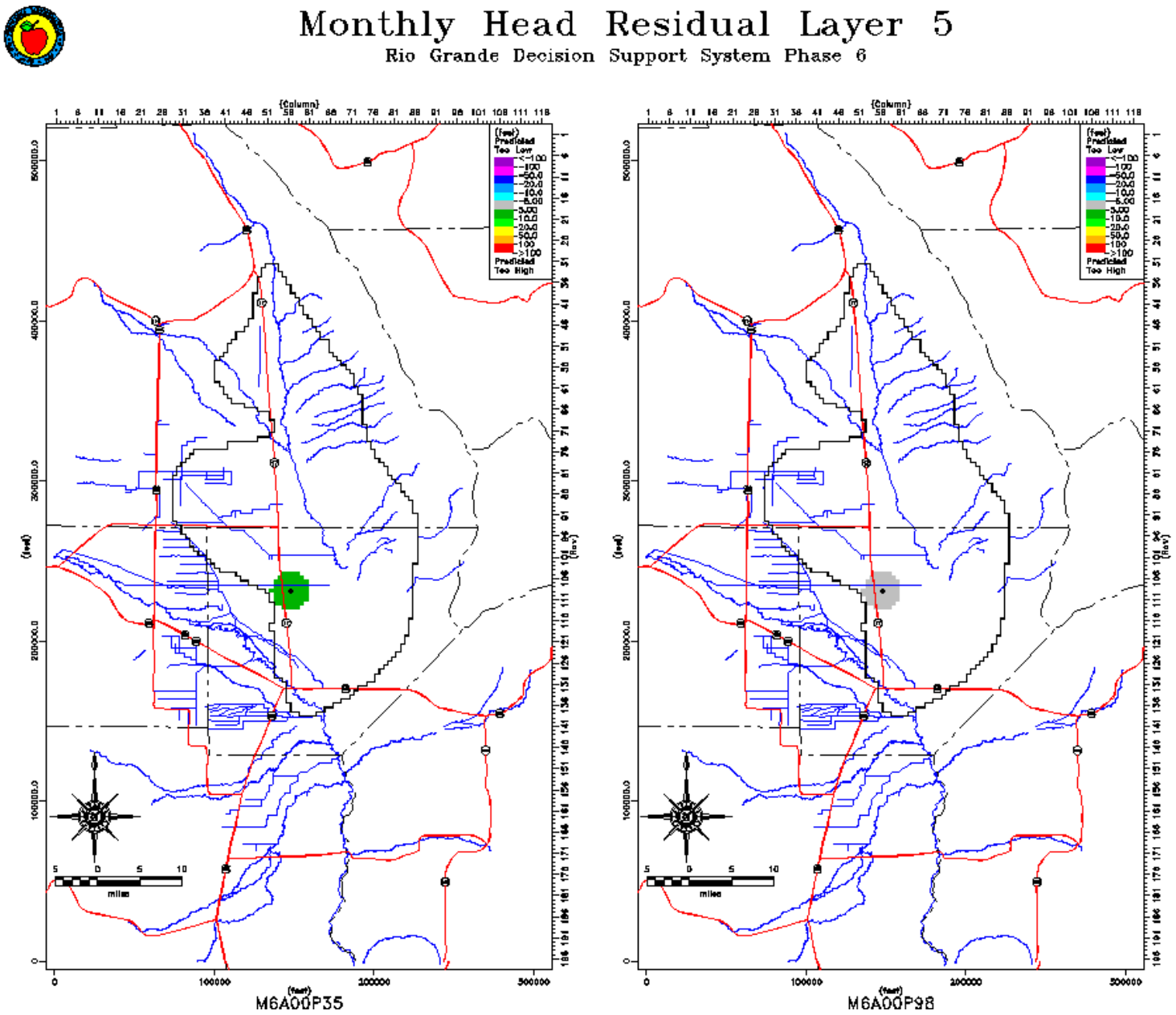


Figure 5e – Monthly Head Residual Maps for Layer 5

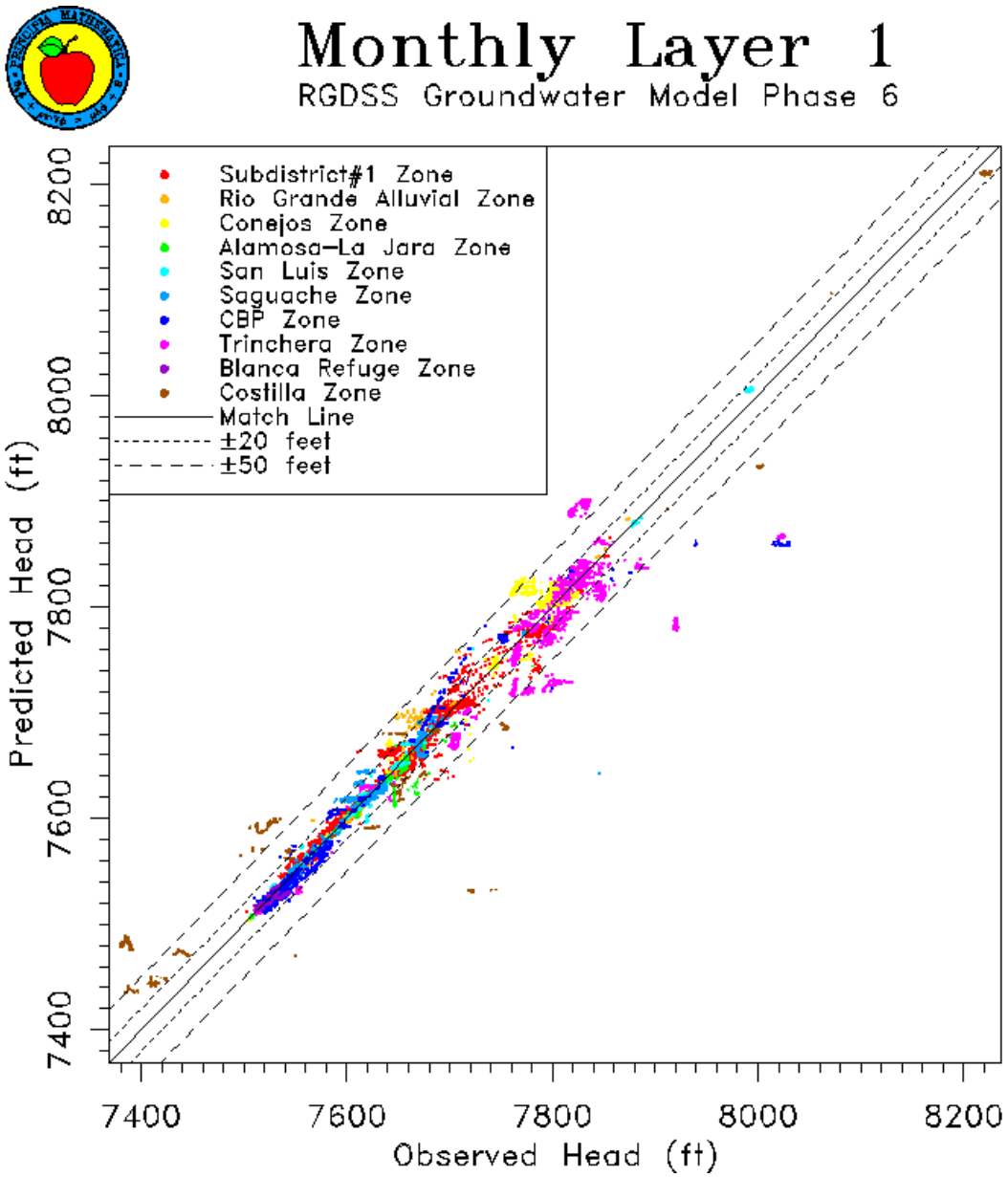


Figure 6a – Predicted Versus Observed Head Cross-Plot Graph for Layer 1

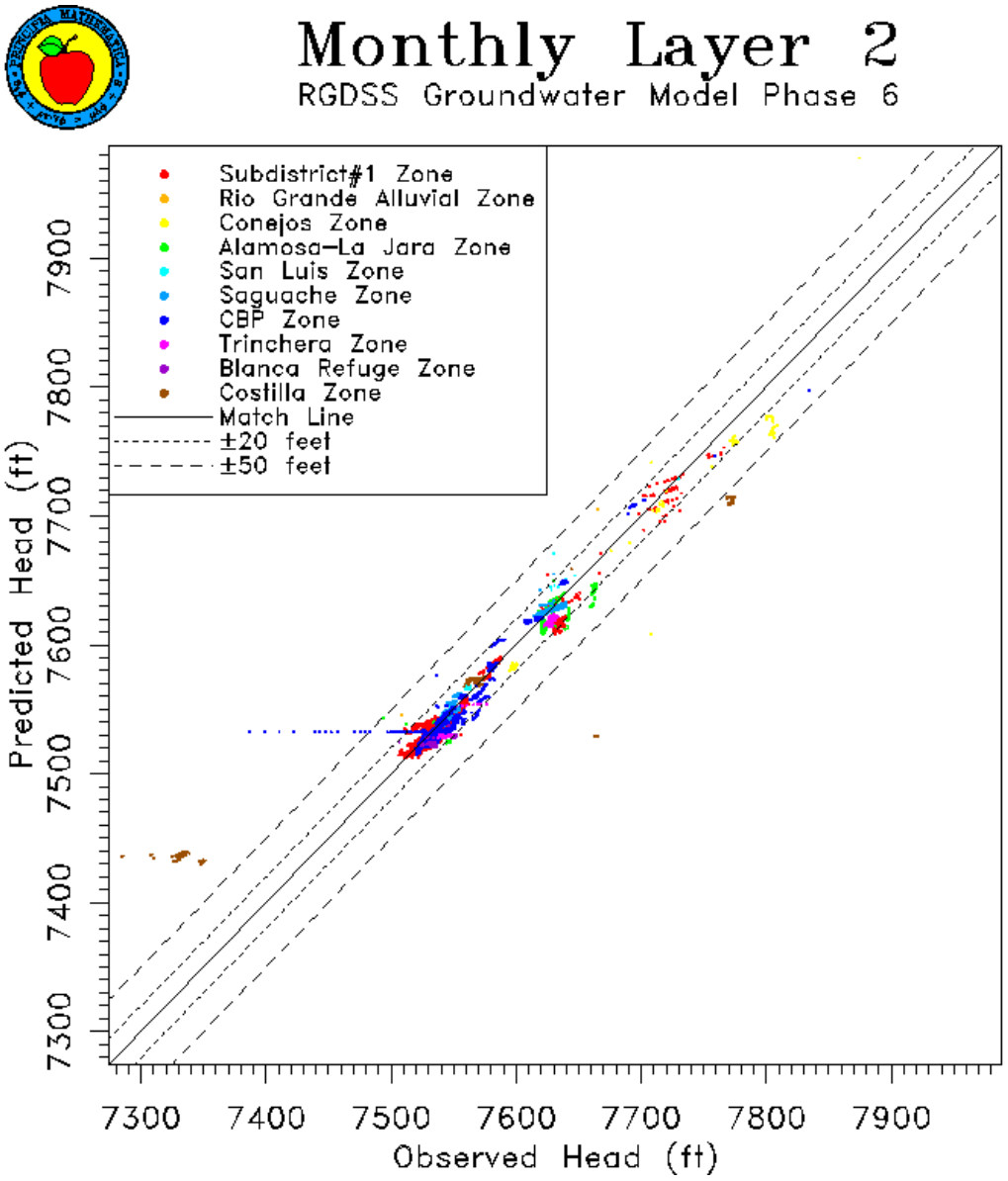


Figure 6b – Predicted Versus Observed Head Cross-Plot Graph for Layer 2

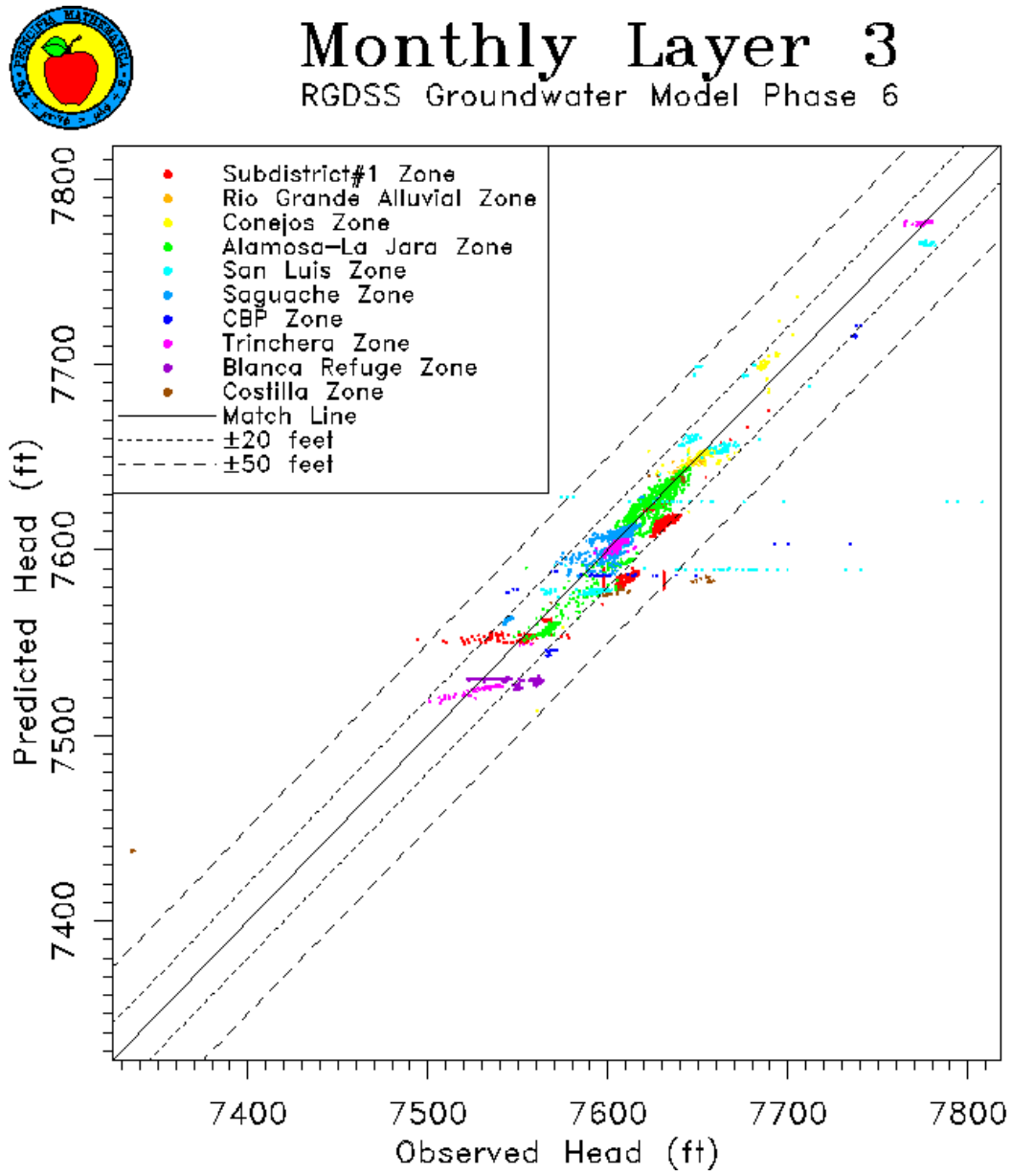


Figure 6c – Predicted Versus Observed Head Cross-Plot Graph for Layer 3

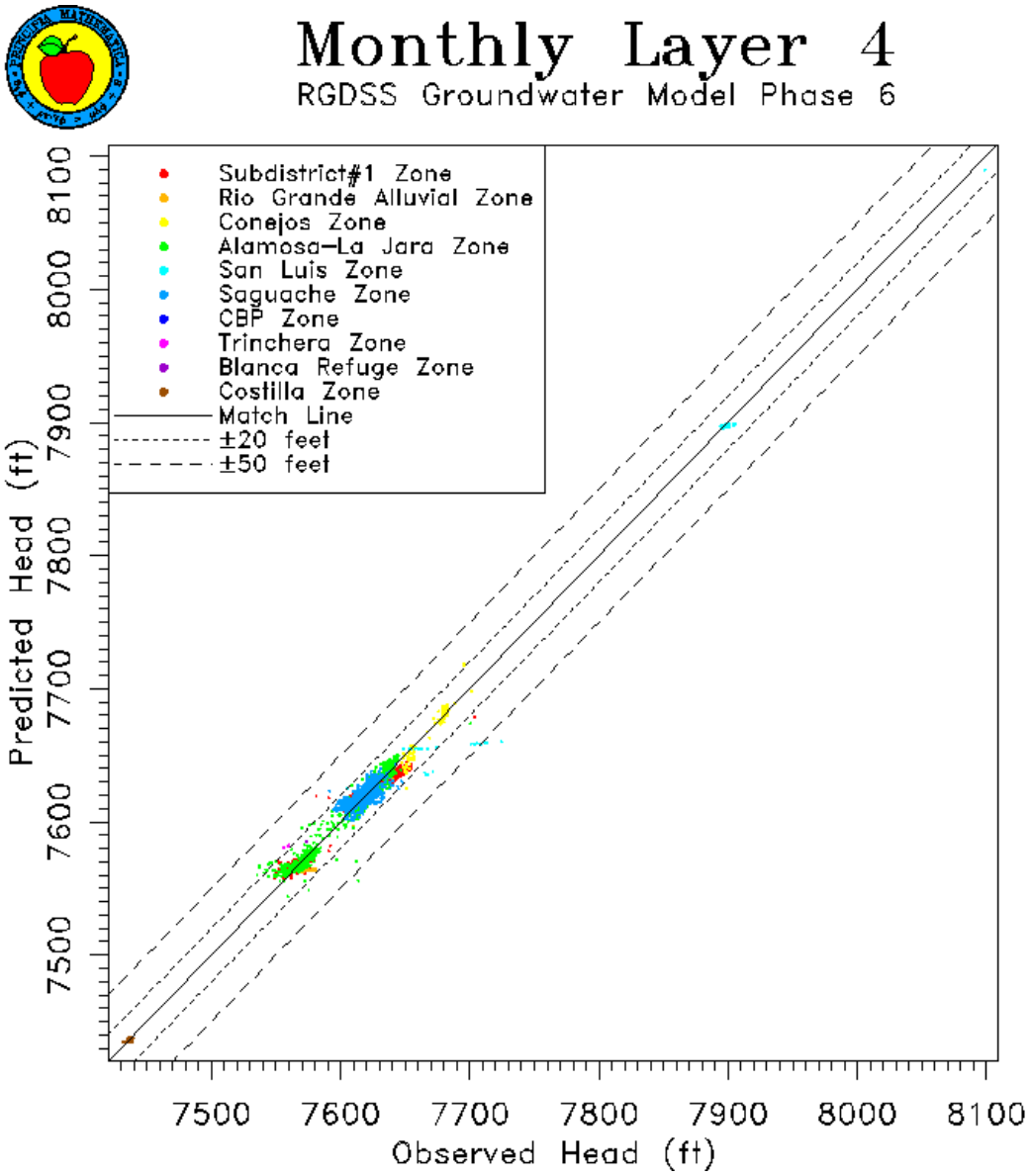


Figure 6d – Predicted Versus Observed Head Cross-Plot Graph for Layer 4

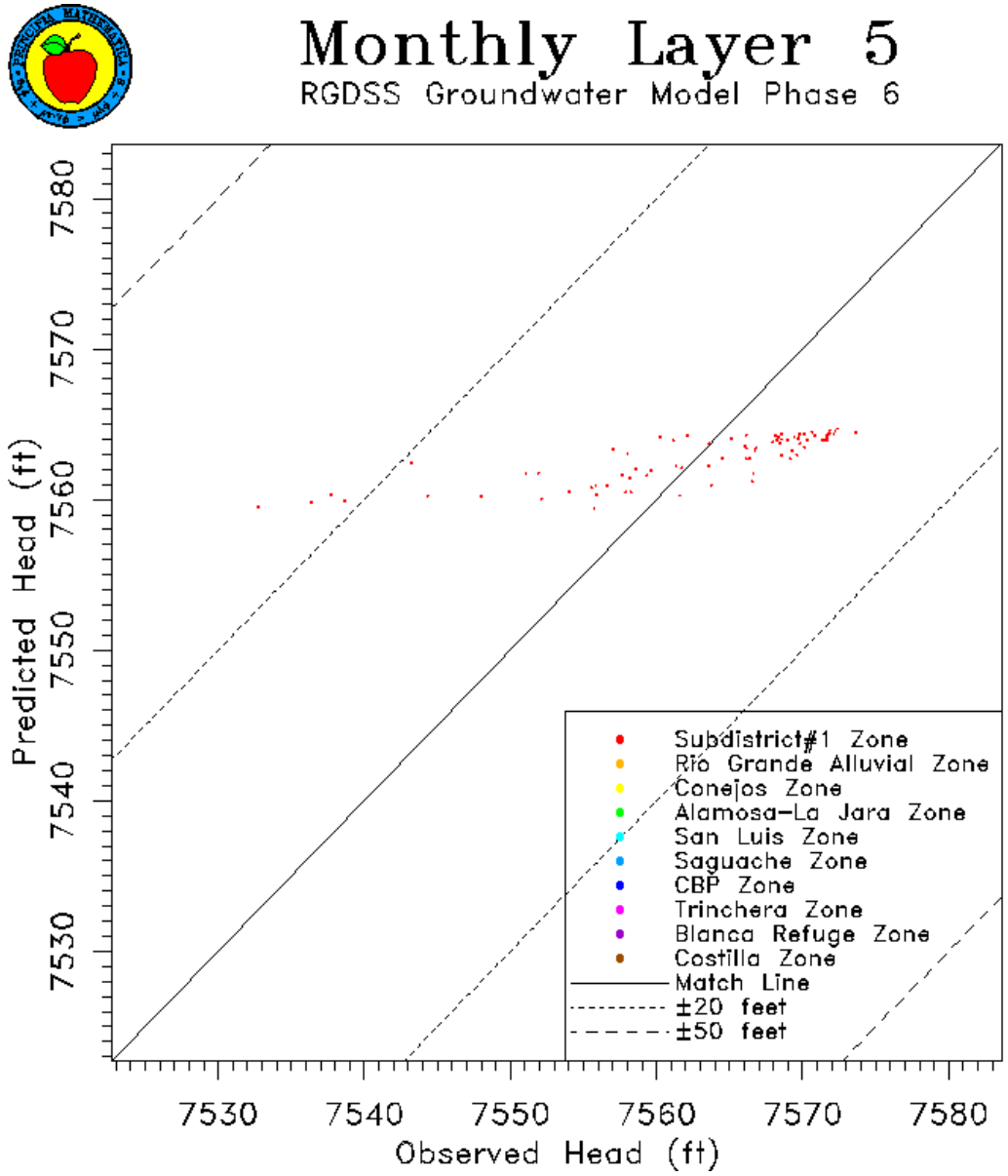


Figure 6e – Predicted Versus Observed Head Cross-Plot Graph for Layer 5

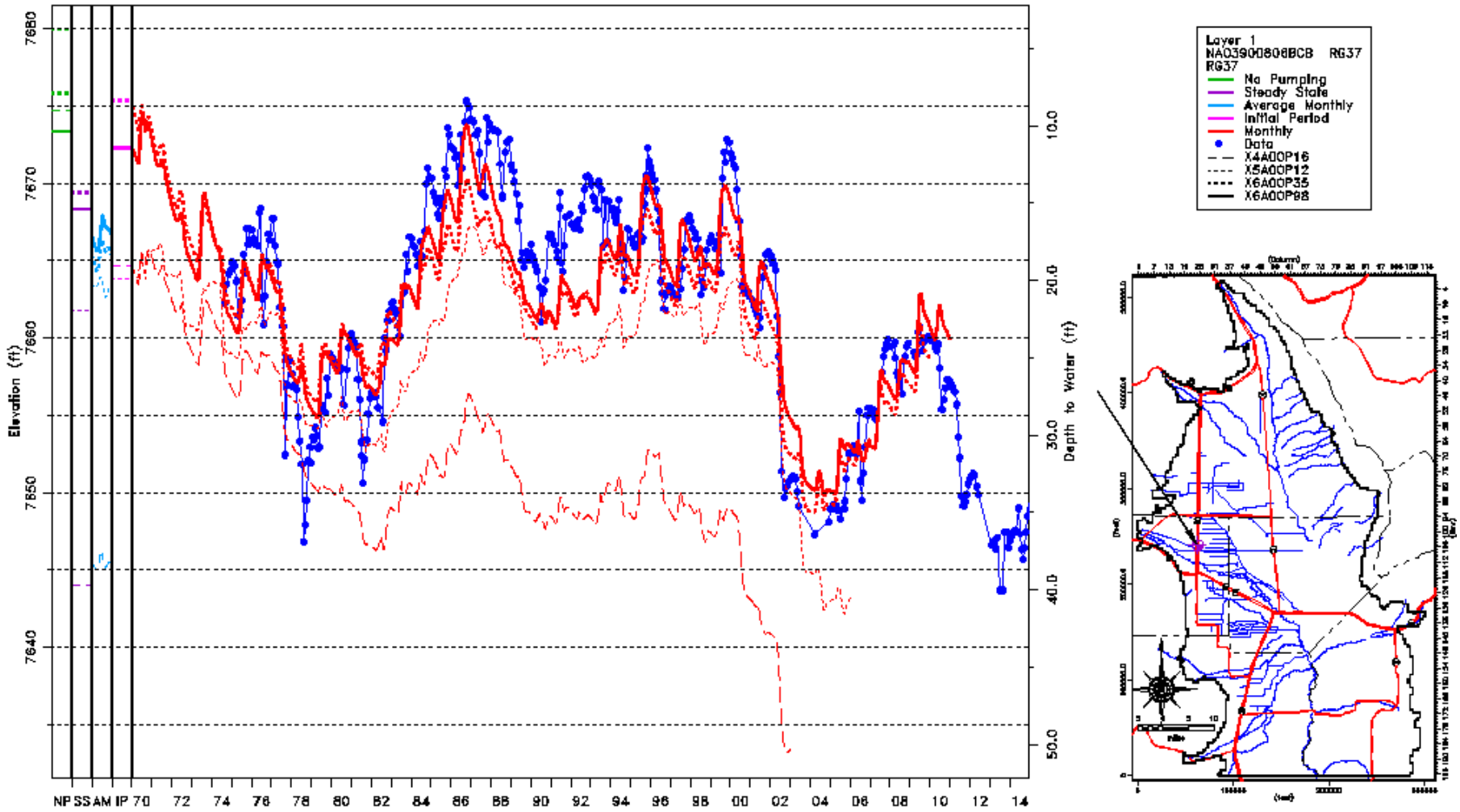


Figure 7 – Example Predicted Versus Observed Hydrograph for Observation Well RG37

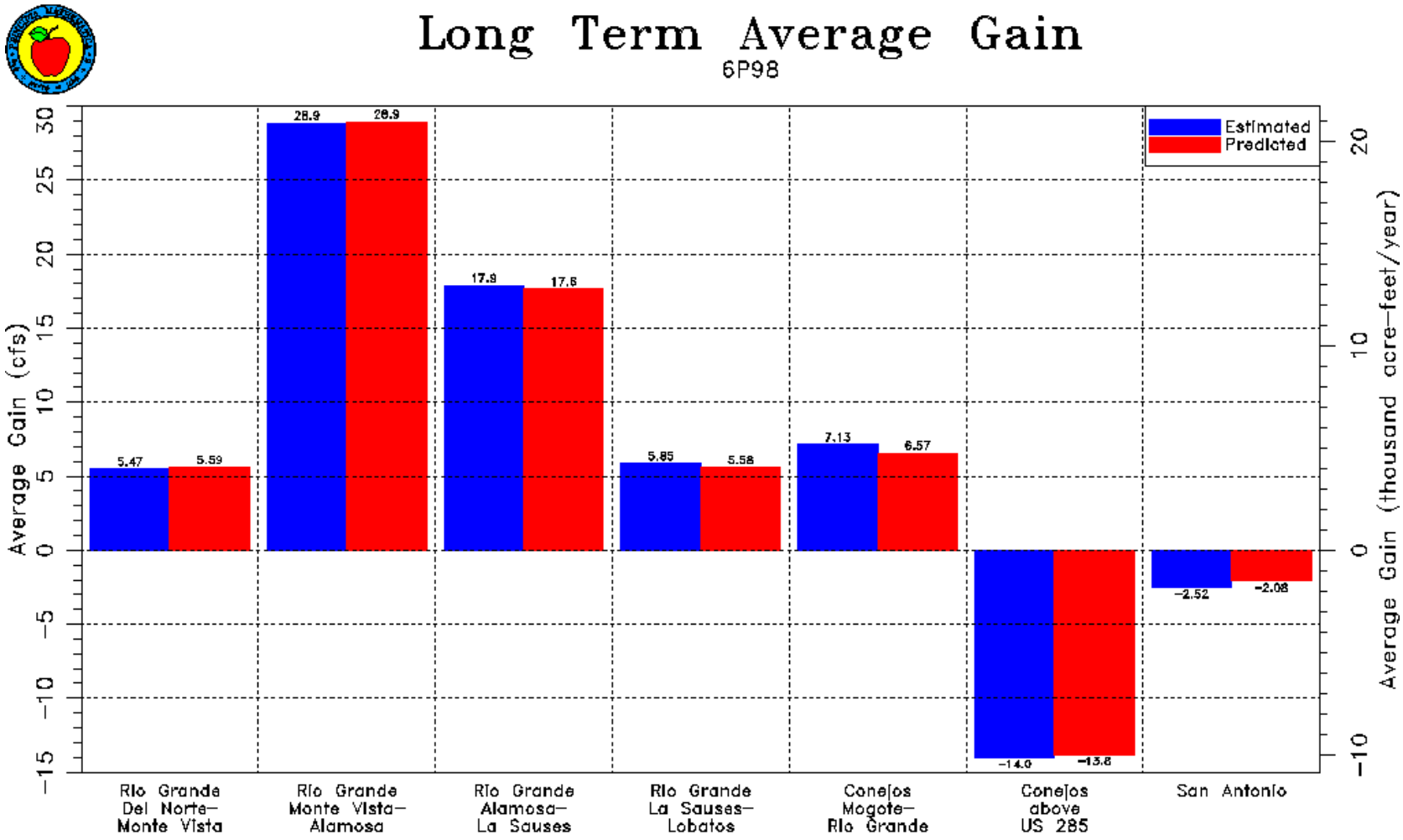


Figure 8 – Predicted and Estimated Long Term Average Stream Gain for Major Modeled Streams

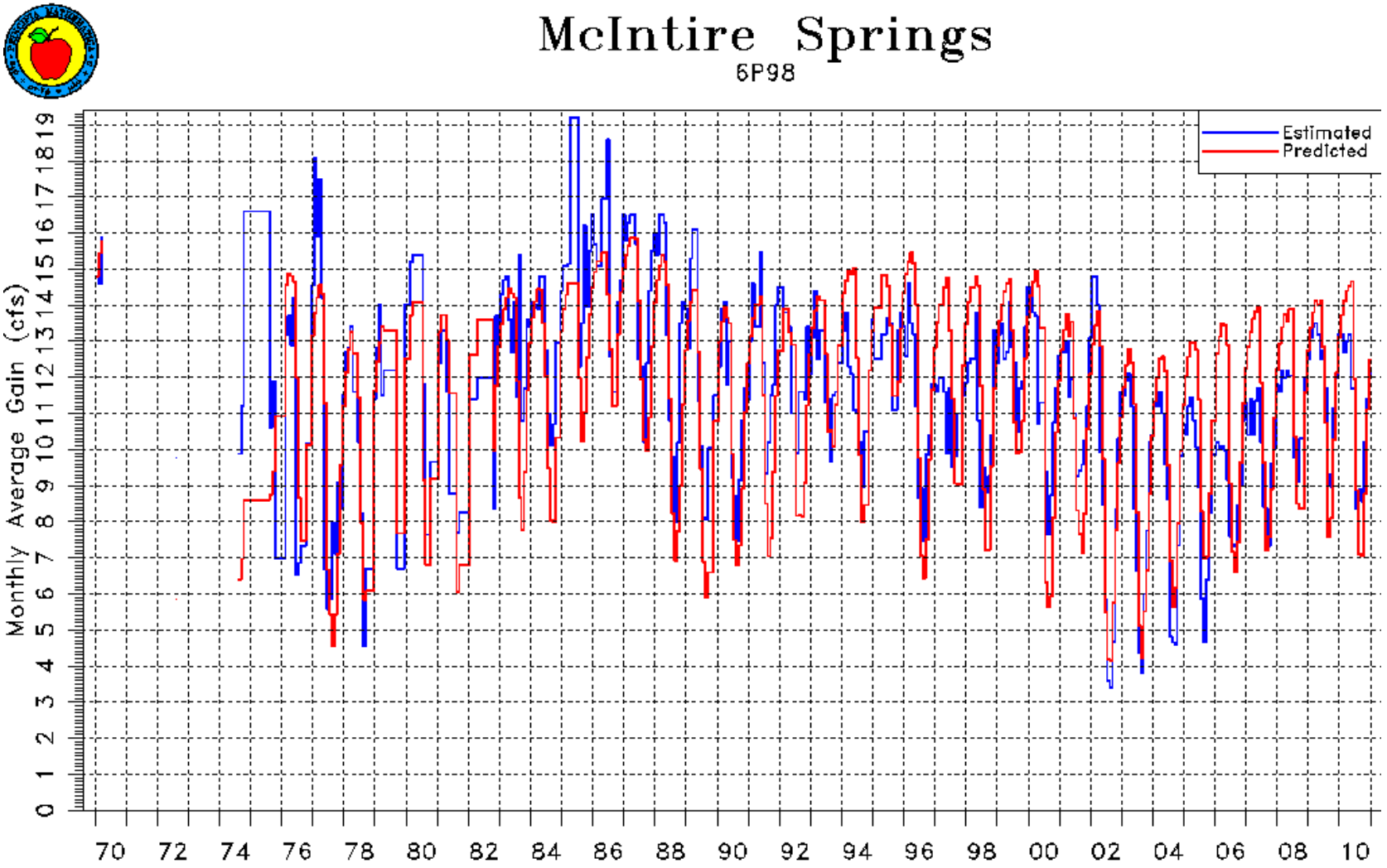


Figure 9 – Predicted and Estimated Average Monthly Gain at McIntire Springs

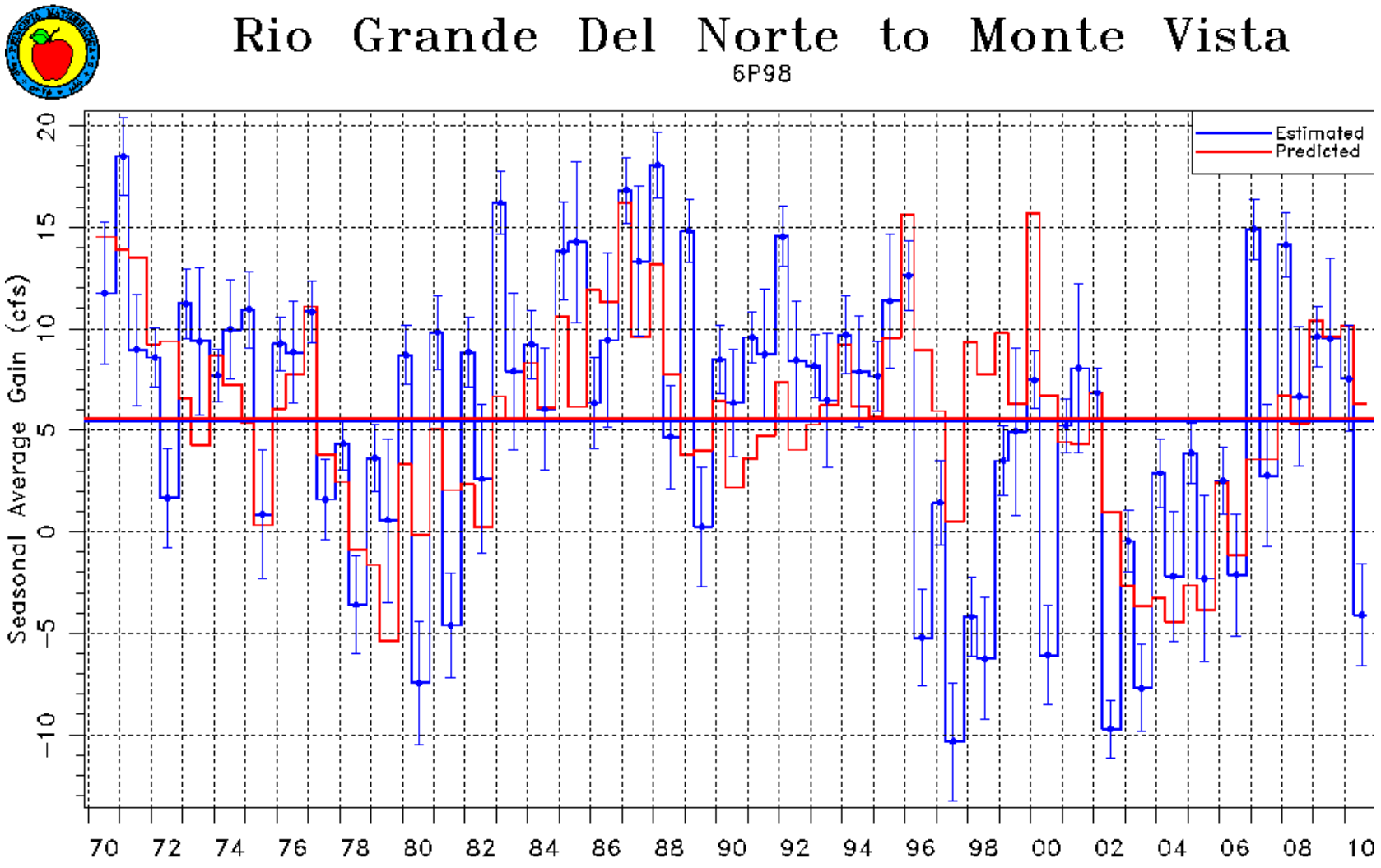


Figure 10a – Predicted and Estimated Seasonal Average Gain on the Rio Grande from Del Norte to Monte Vista

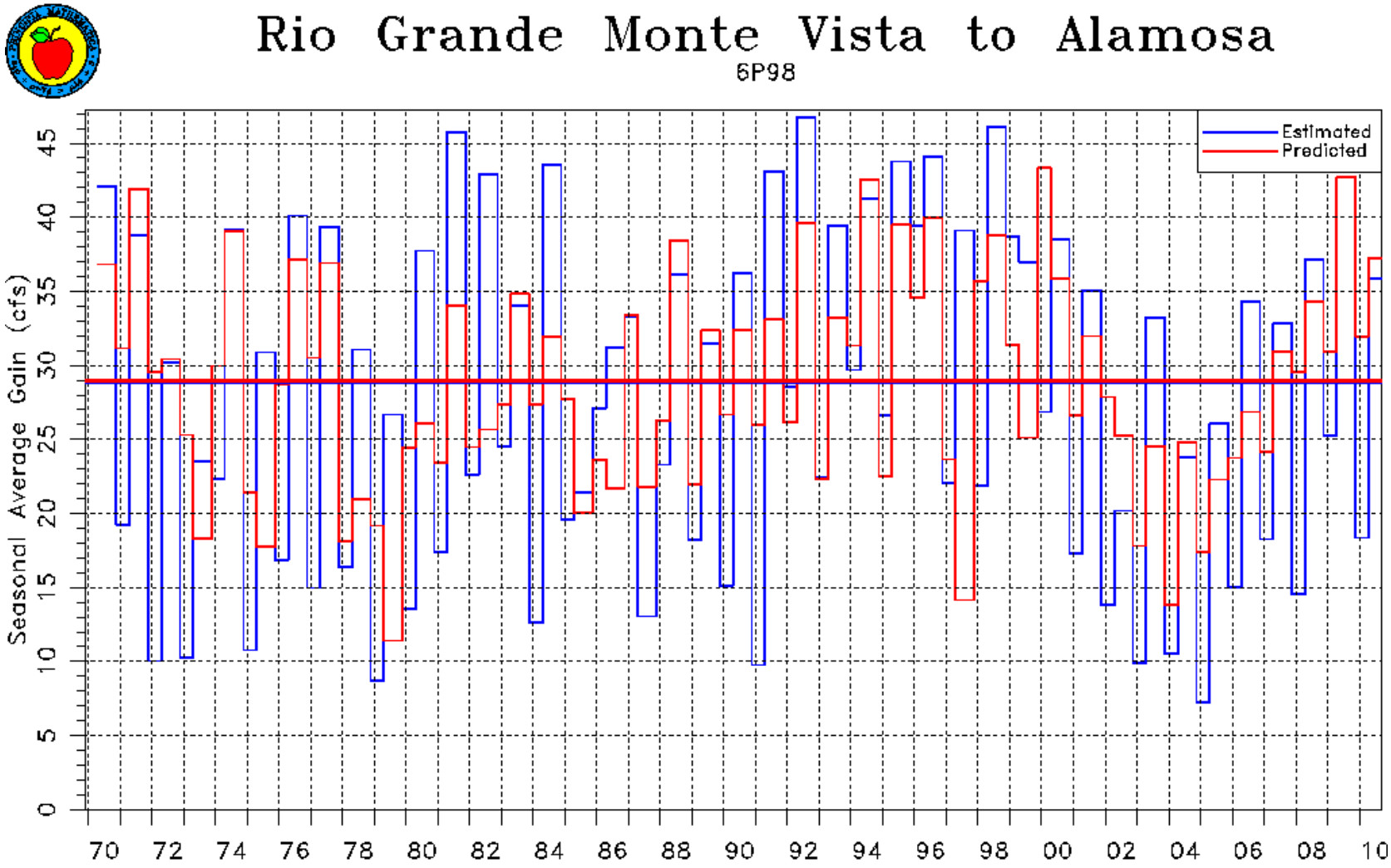


Figure 10b – Predicted and Estimated Seasonal Average Gain on the Rio Grande from Monte Vista to Alamosa

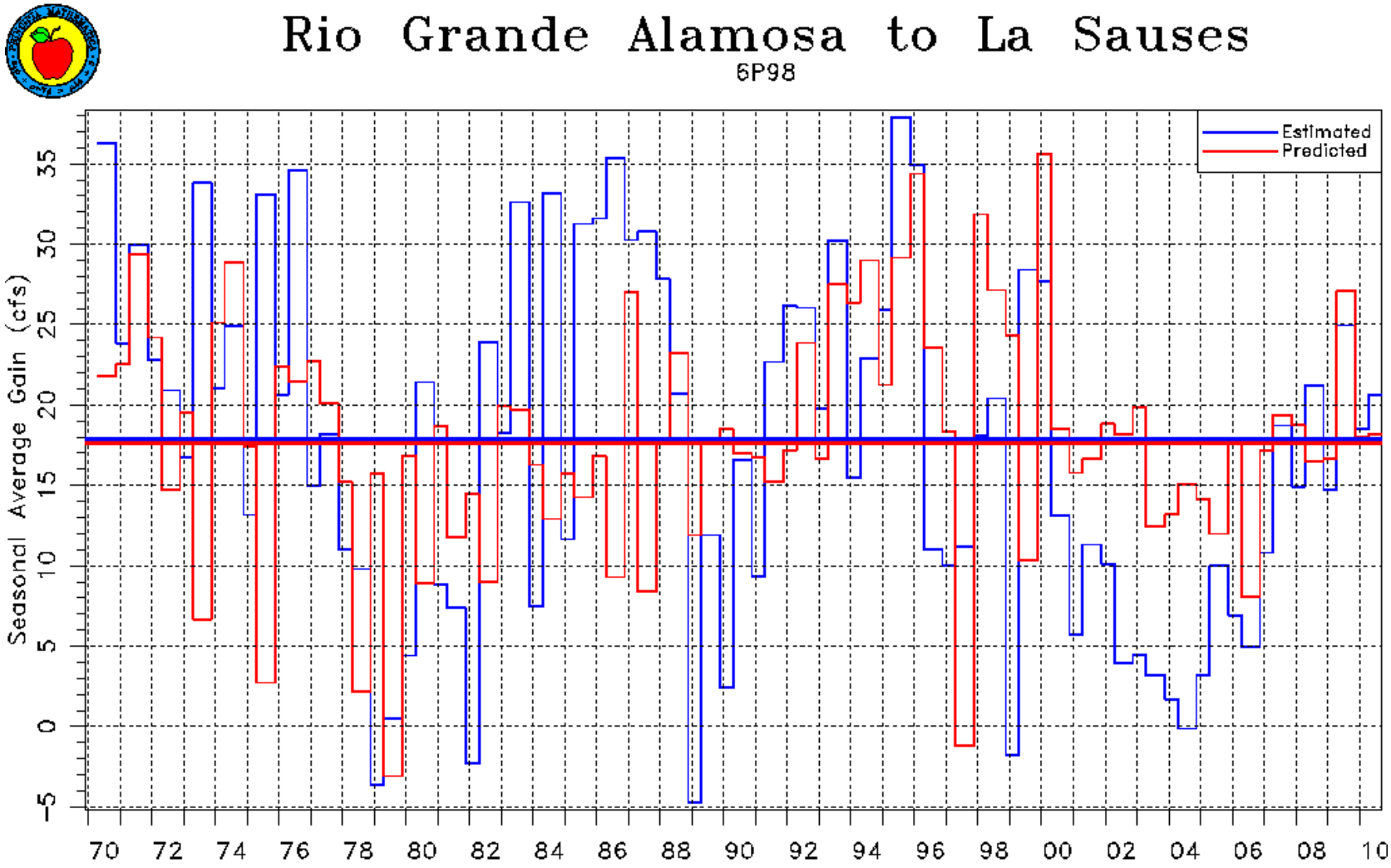


Figure 10c – Predicted and Estimated Seansonal Average Gain on the Rio Grande from Alamosa to La Sauses

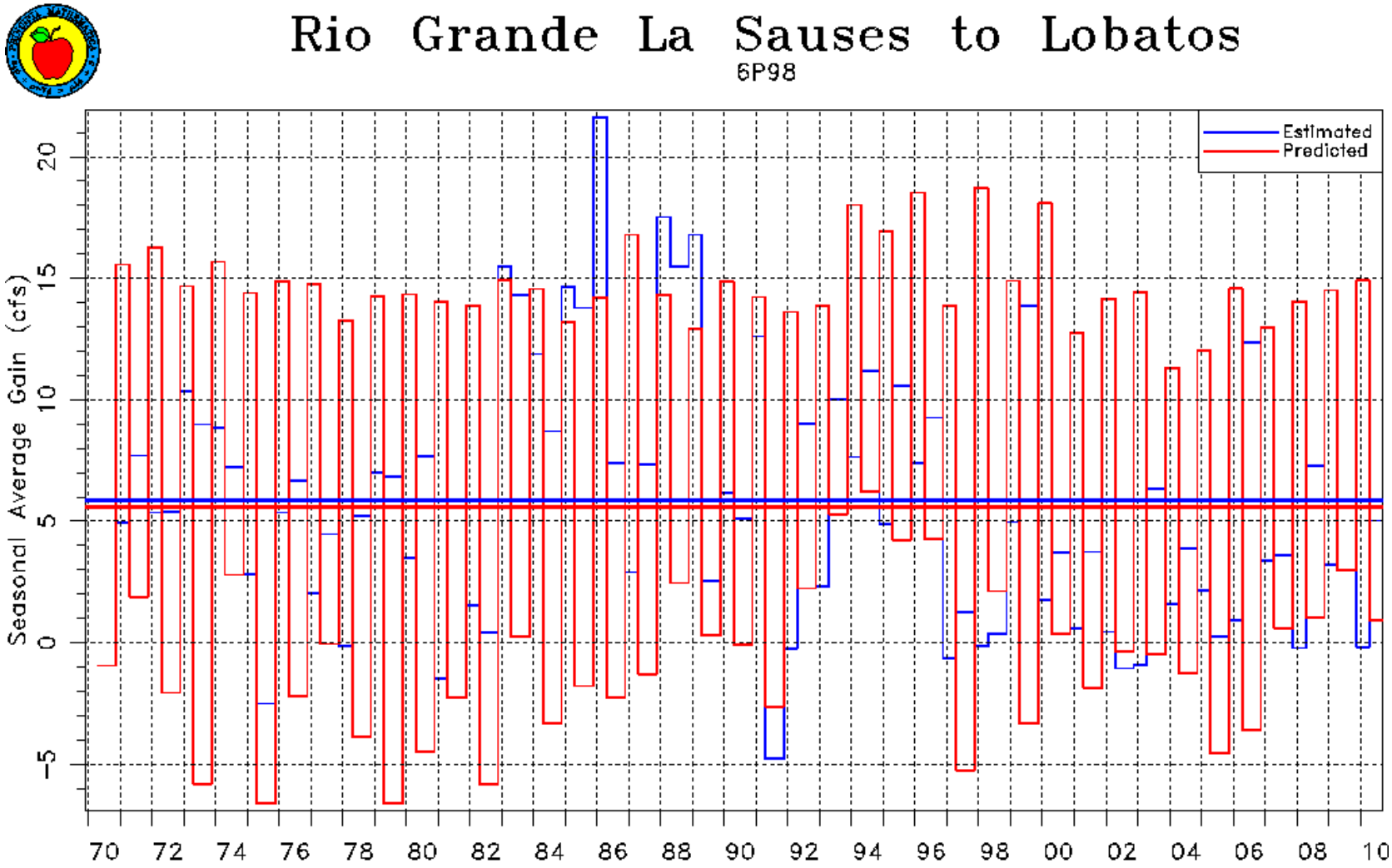


Figure 10d – Predicted and Estimated Seasonal Average Gain on the Rio Grande from La Sauses to Lobatos

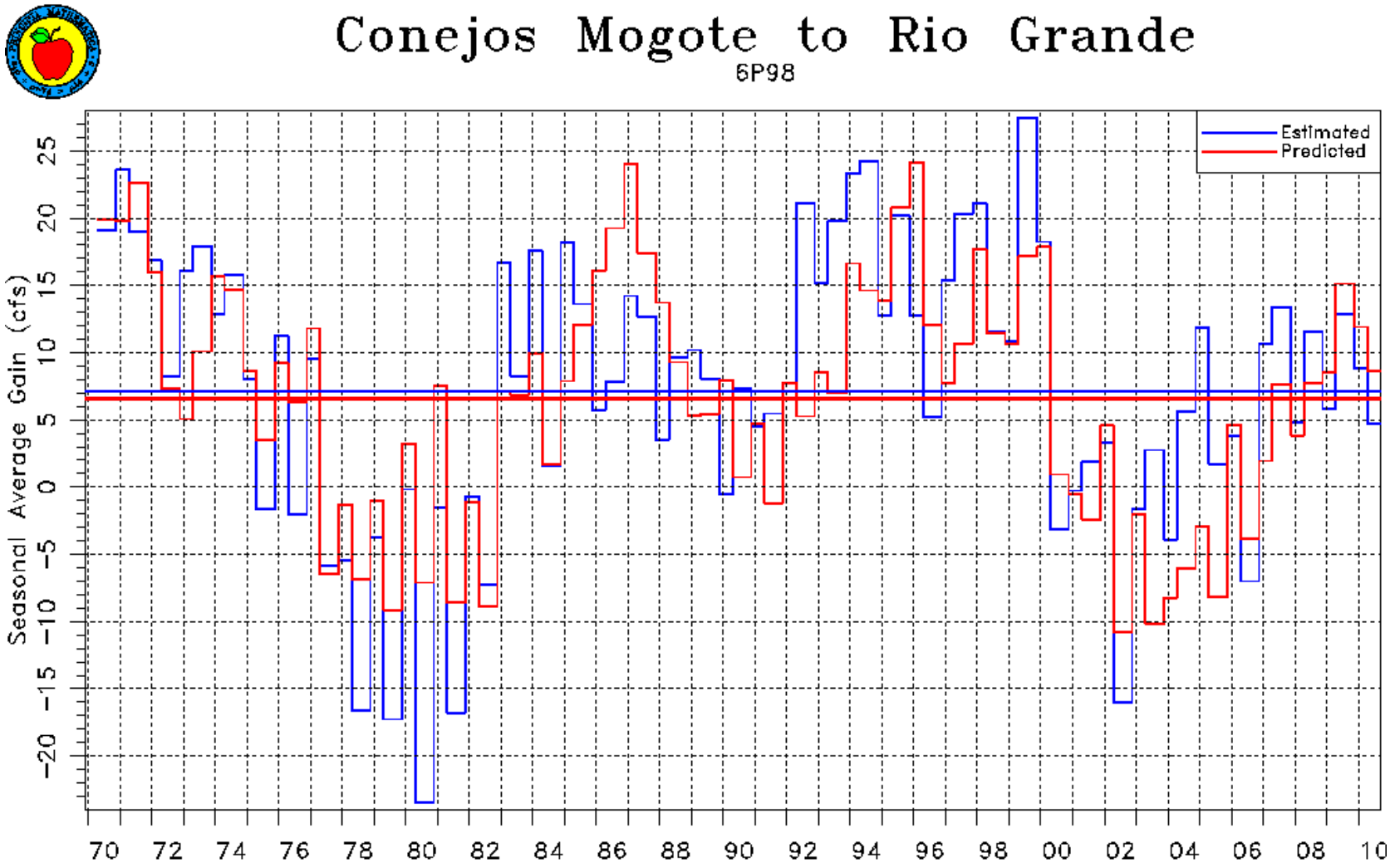


Figure 10e Predicted and Estimated Seasonal Average Gain on the Conejos River from Mogote to the Rio Grande

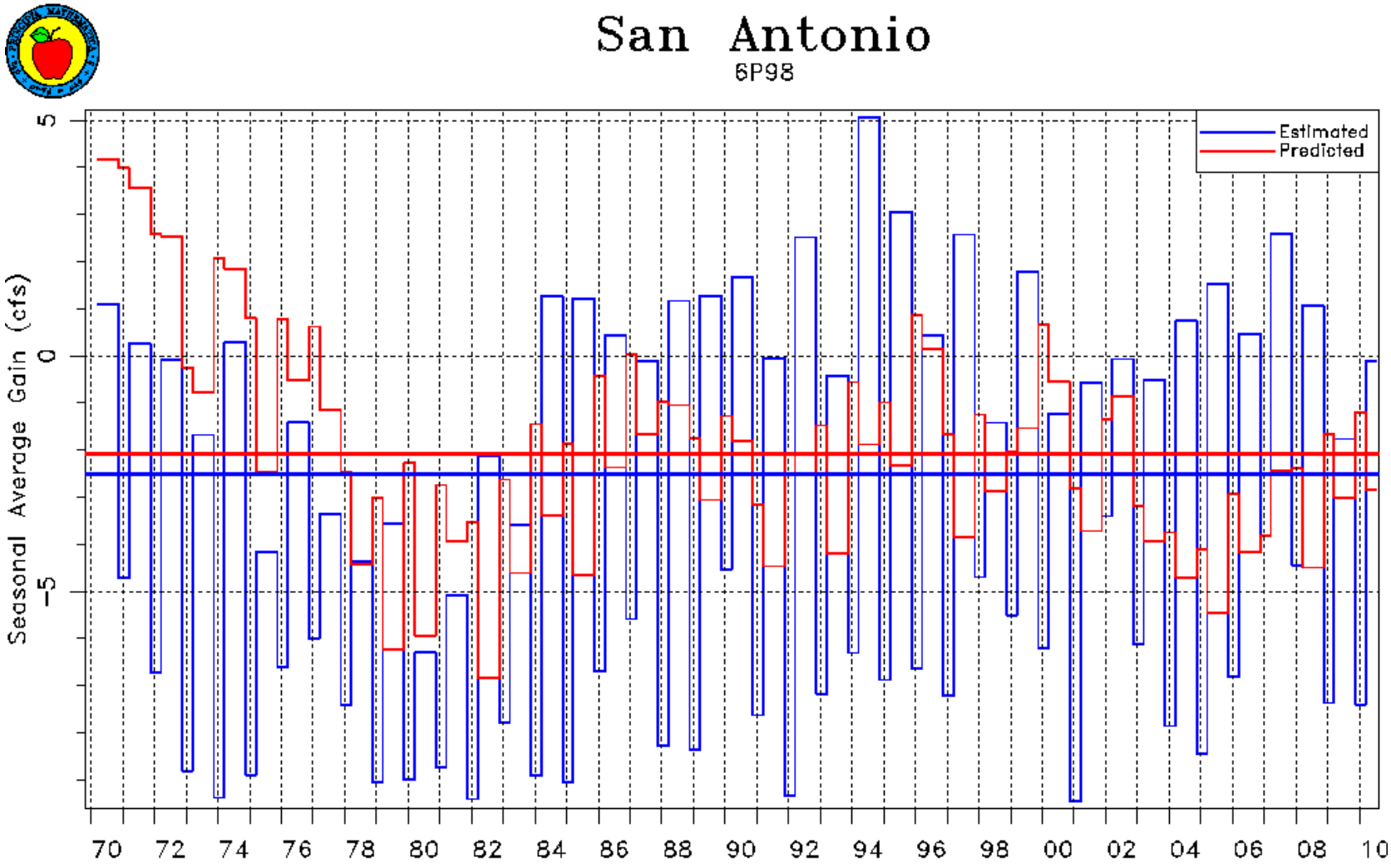


Figure 10f – Predicted and Estimated Seasonal Average Gain on the San Antonio River

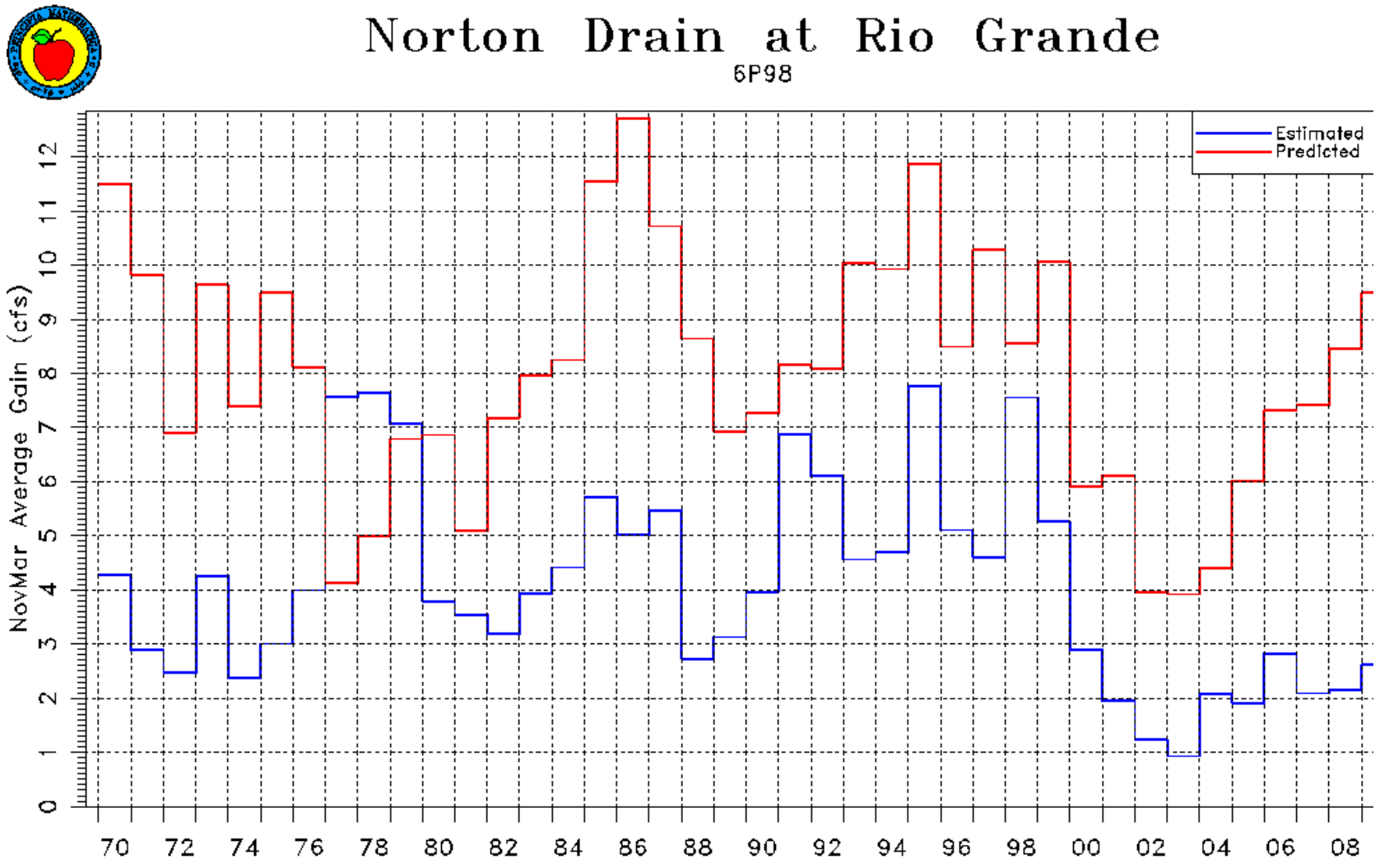


Figure 11a – Predicted and Estimated November Through March Average Norton Drain Discharge to the Rio Grande

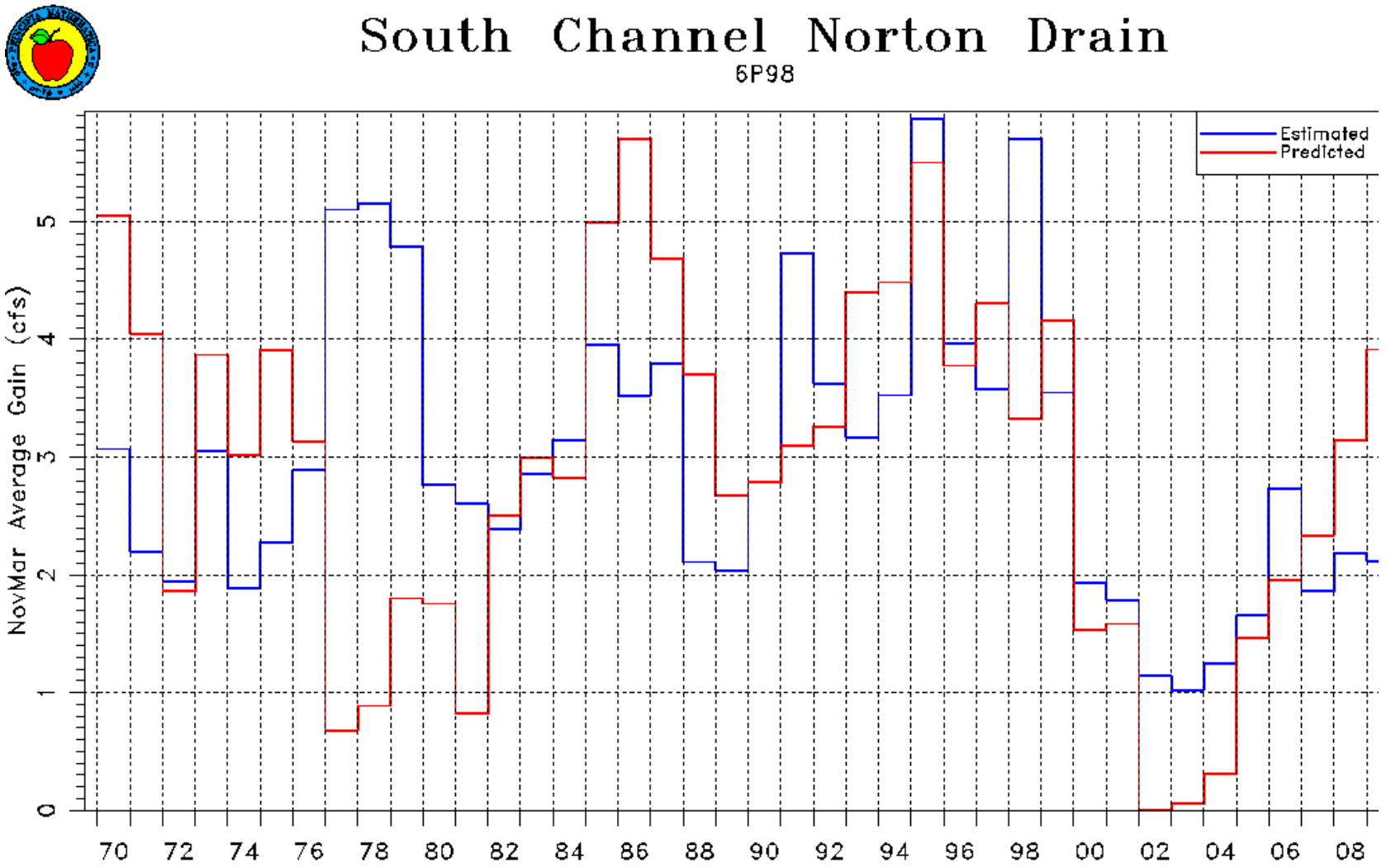


Figure 11b – Predicted and Estimated November Through March Average Gain for the South Channel of the Norton Drain

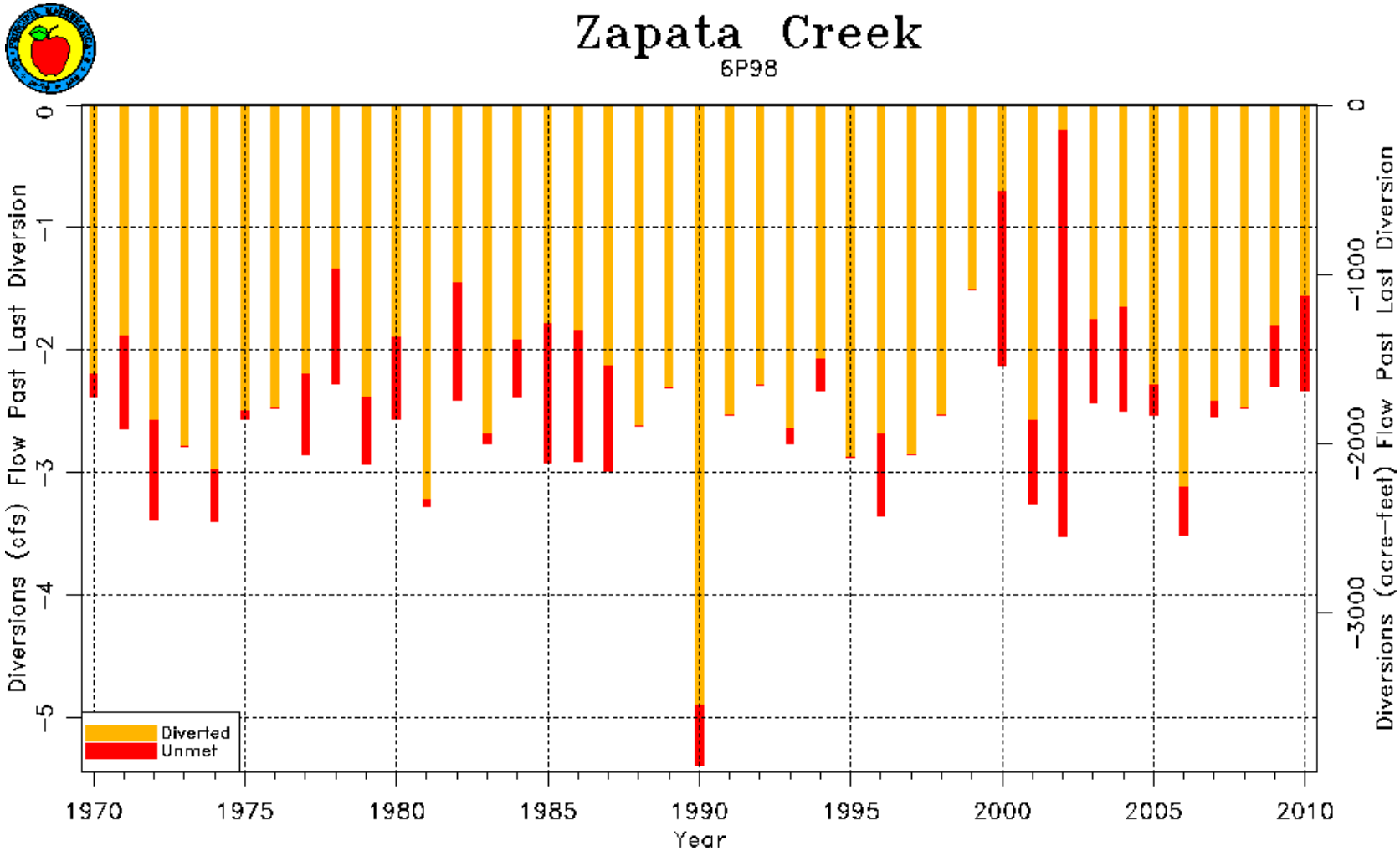


Figure 12a – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Zapata Creek

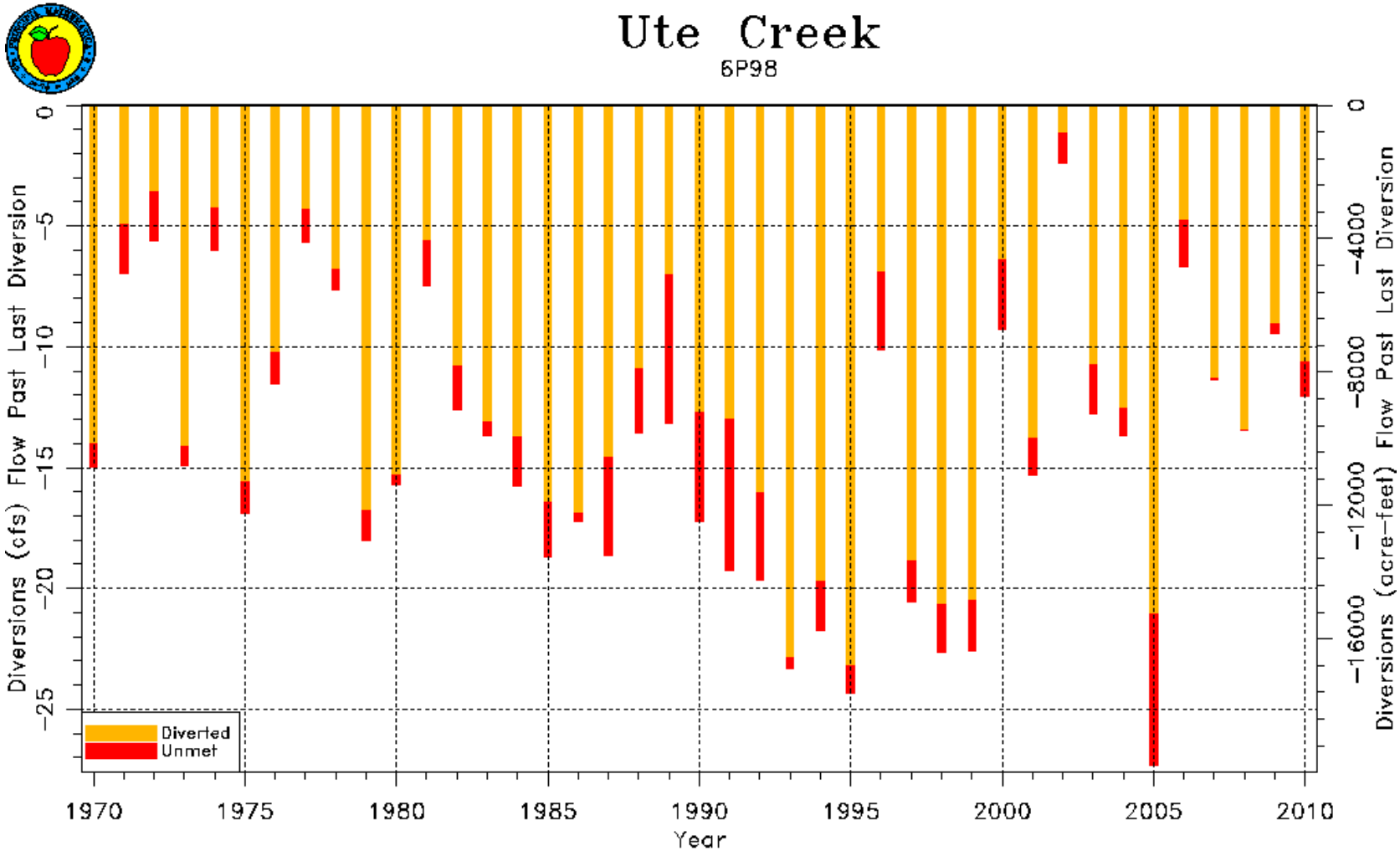


Figure 12b – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Ute Creek

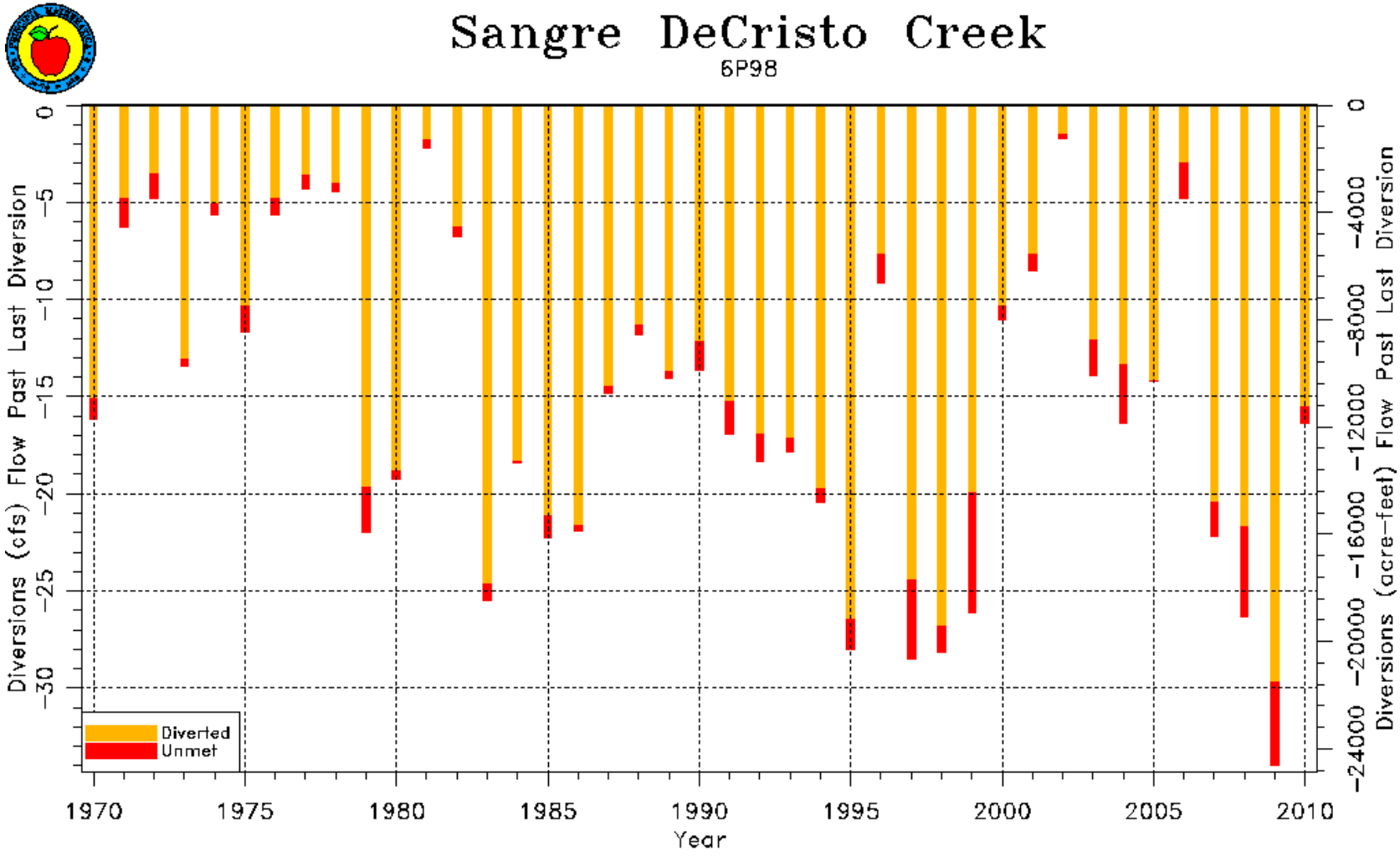


Figure 12c – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Sangre de Cristo Creek

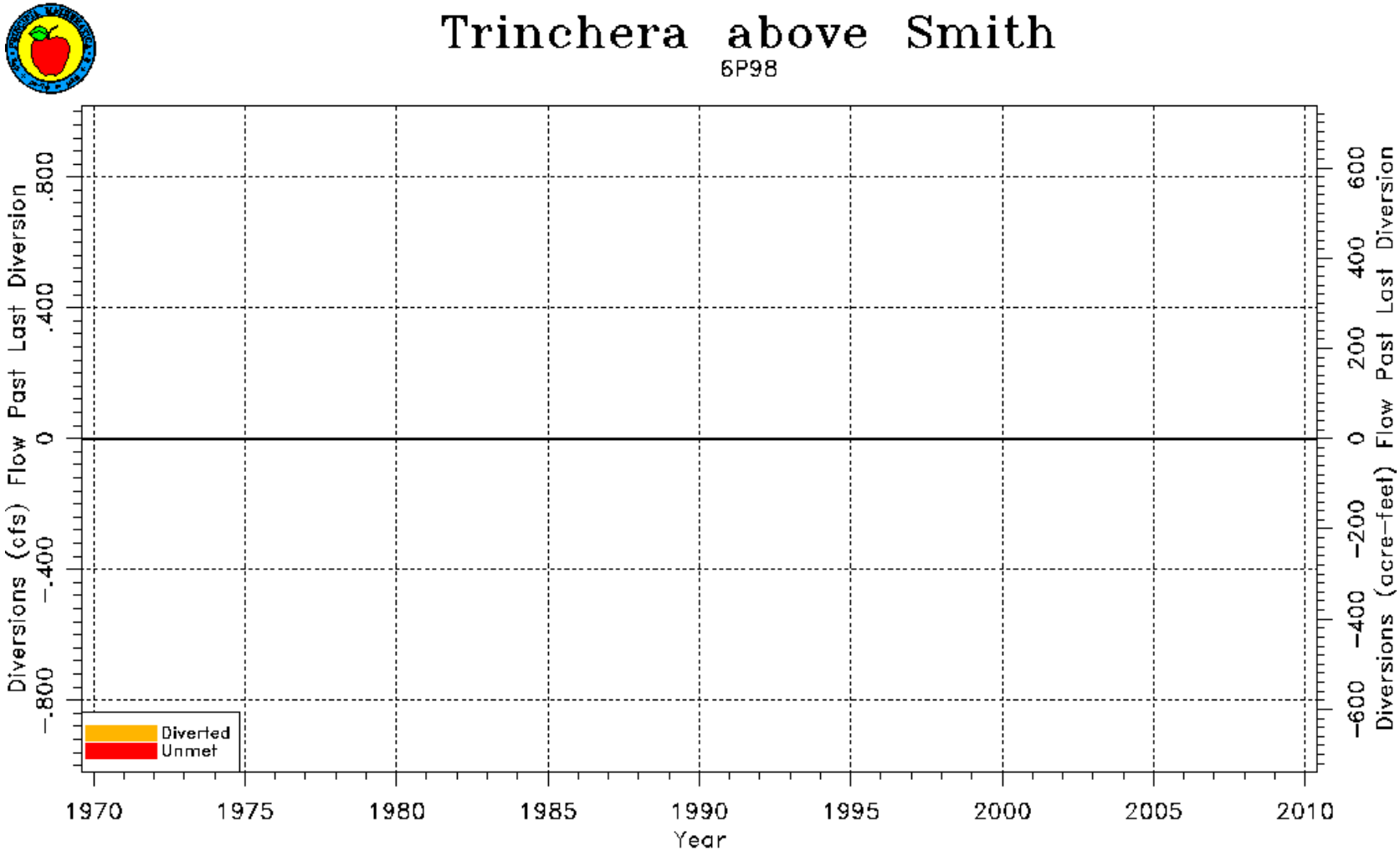


Figure 12d – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Trinchera Creek above Smith

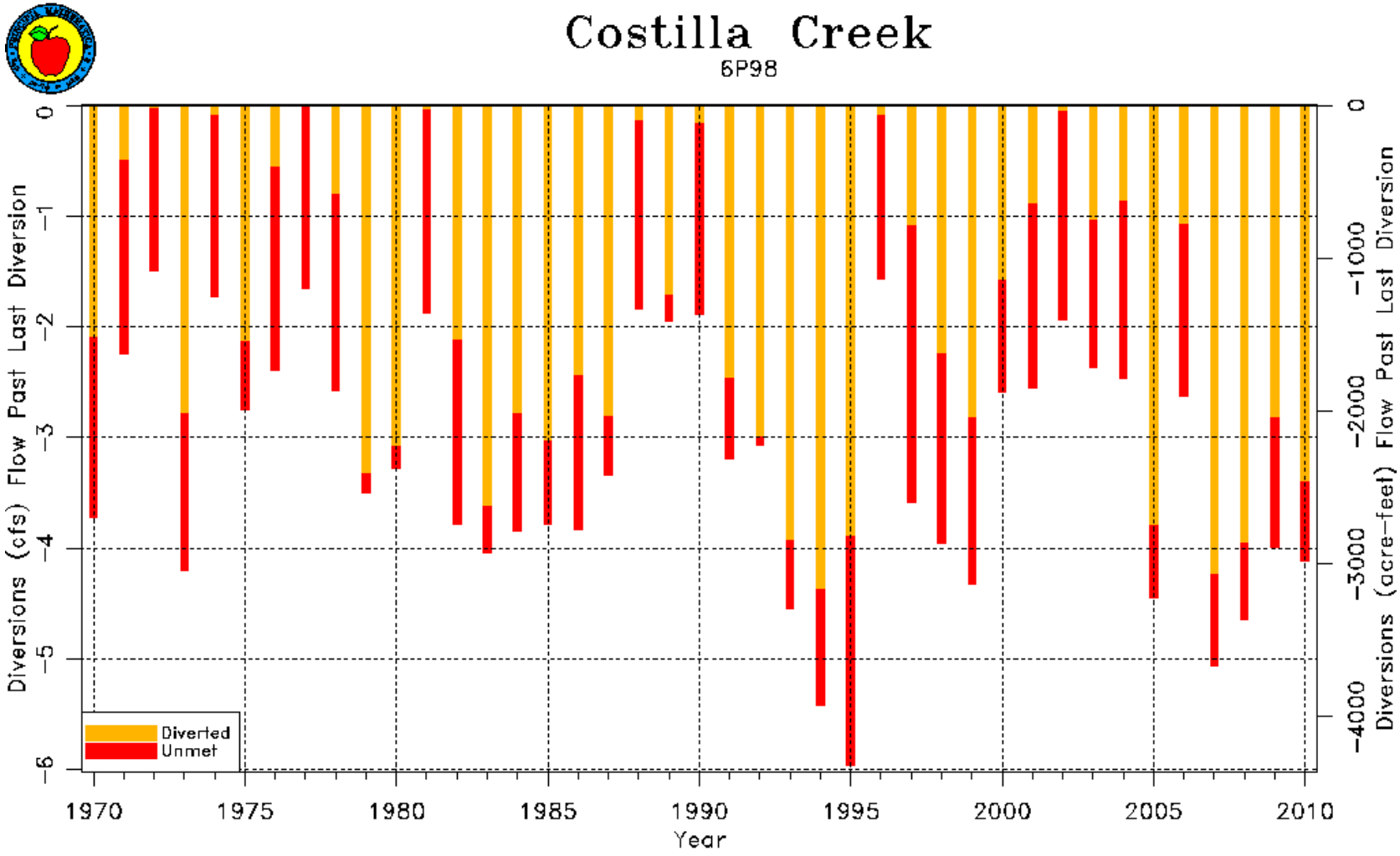


Figure 12e – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Costilla Creek

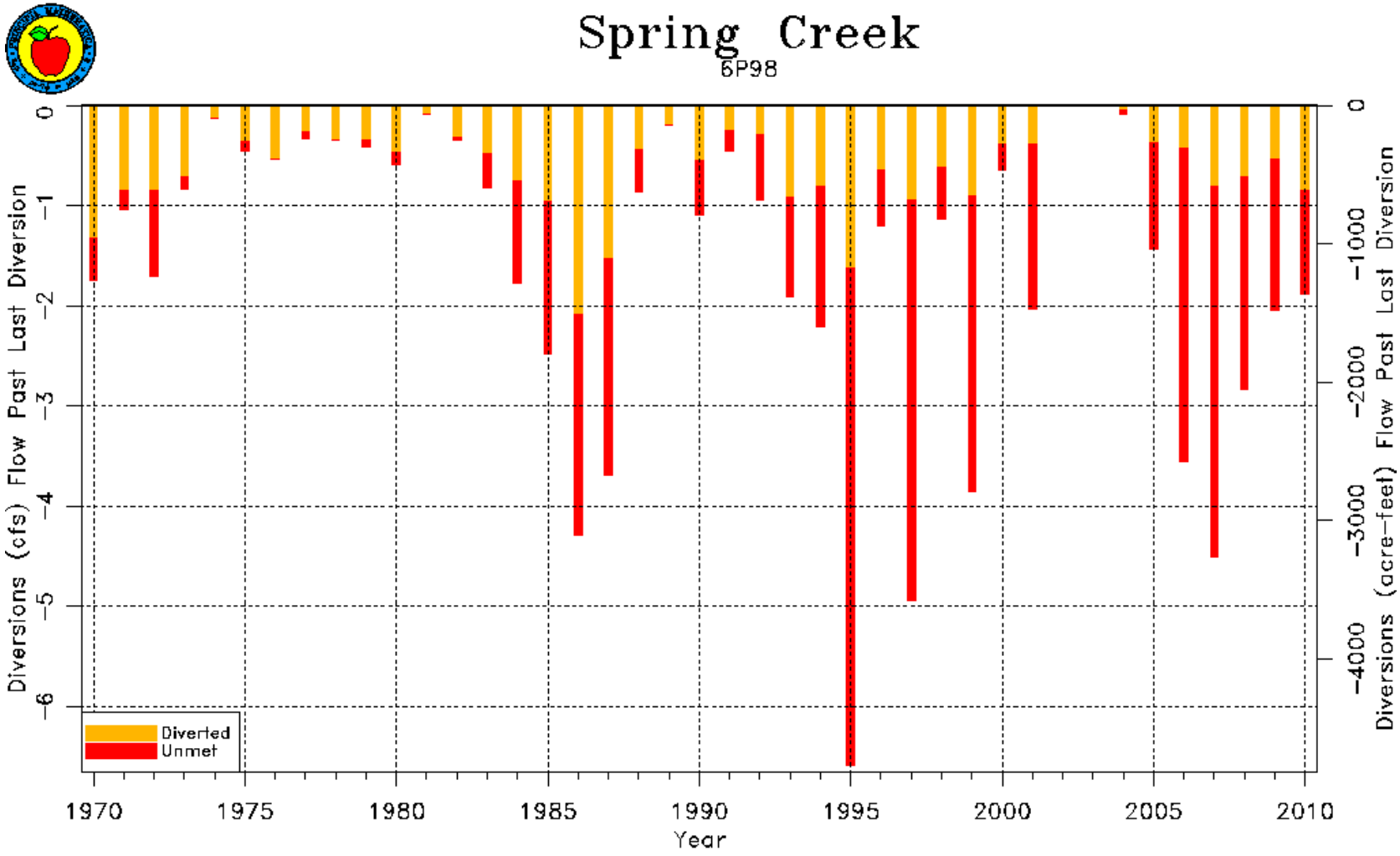


Figure 12f – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Spring Creek

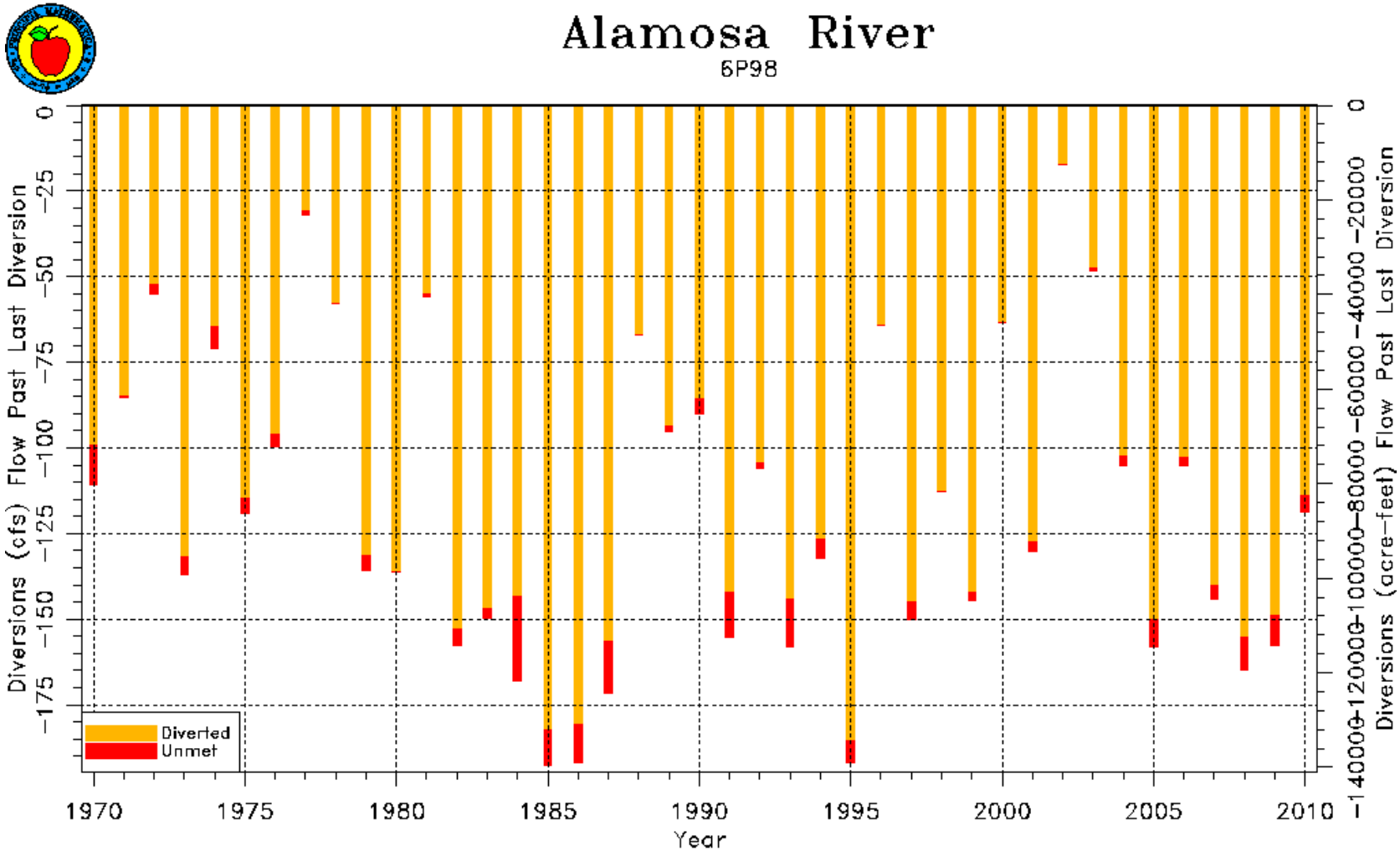


Figure 12g – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Alamosa River

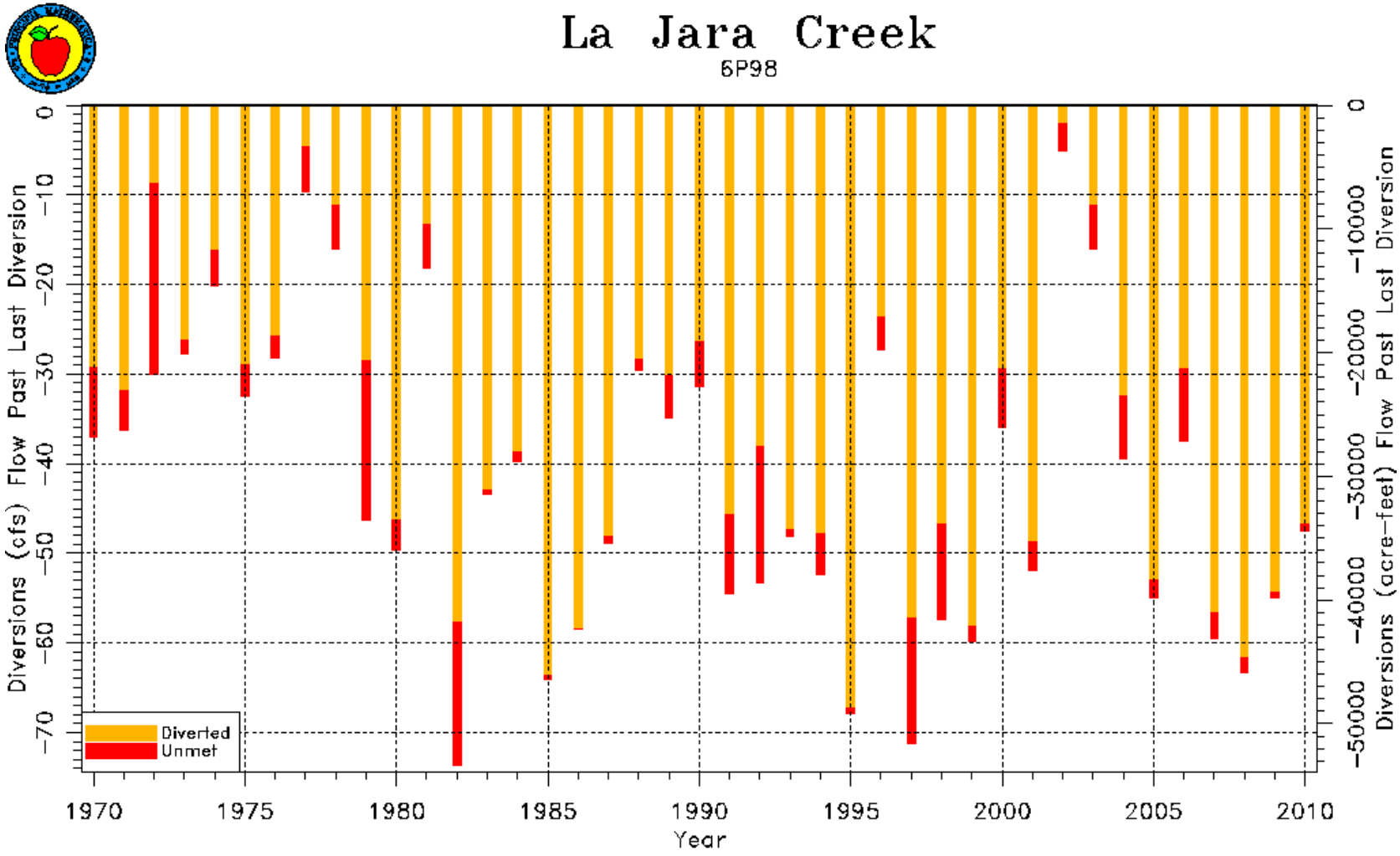


Figure 12h – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for La Jara Creek

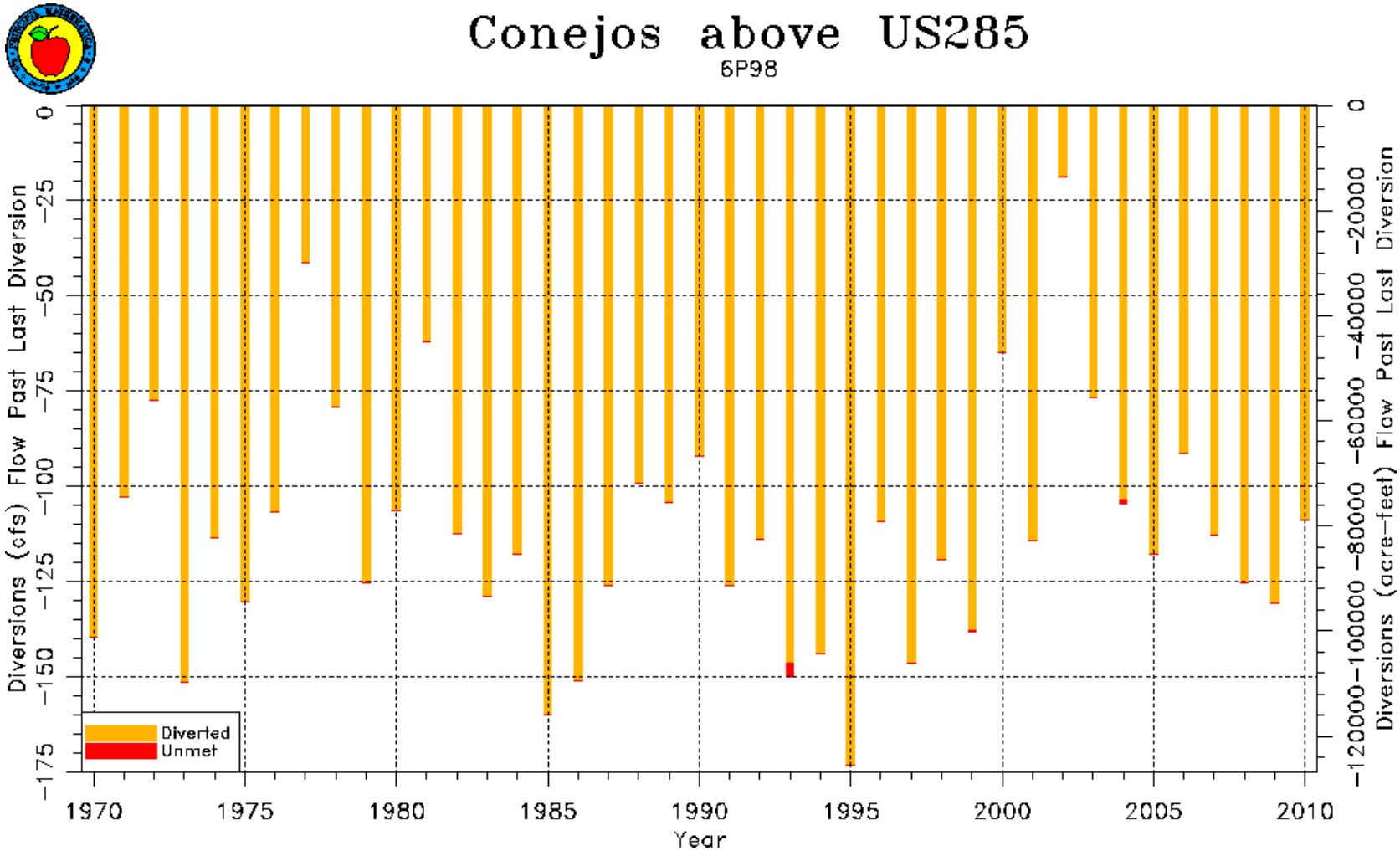


Figure 12i – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Conejos River Above US285

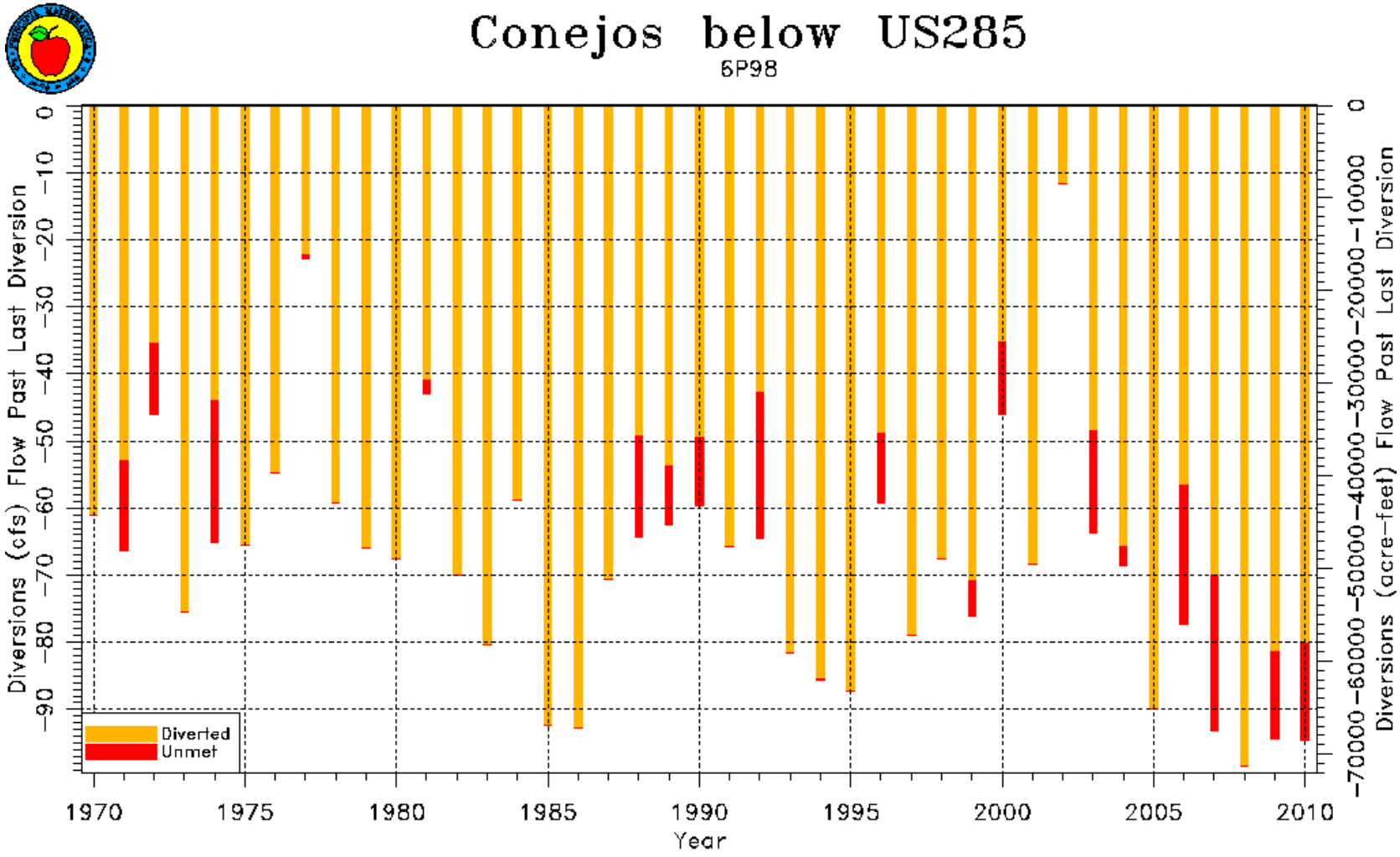


Figure 12j – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Conejos River Below US285

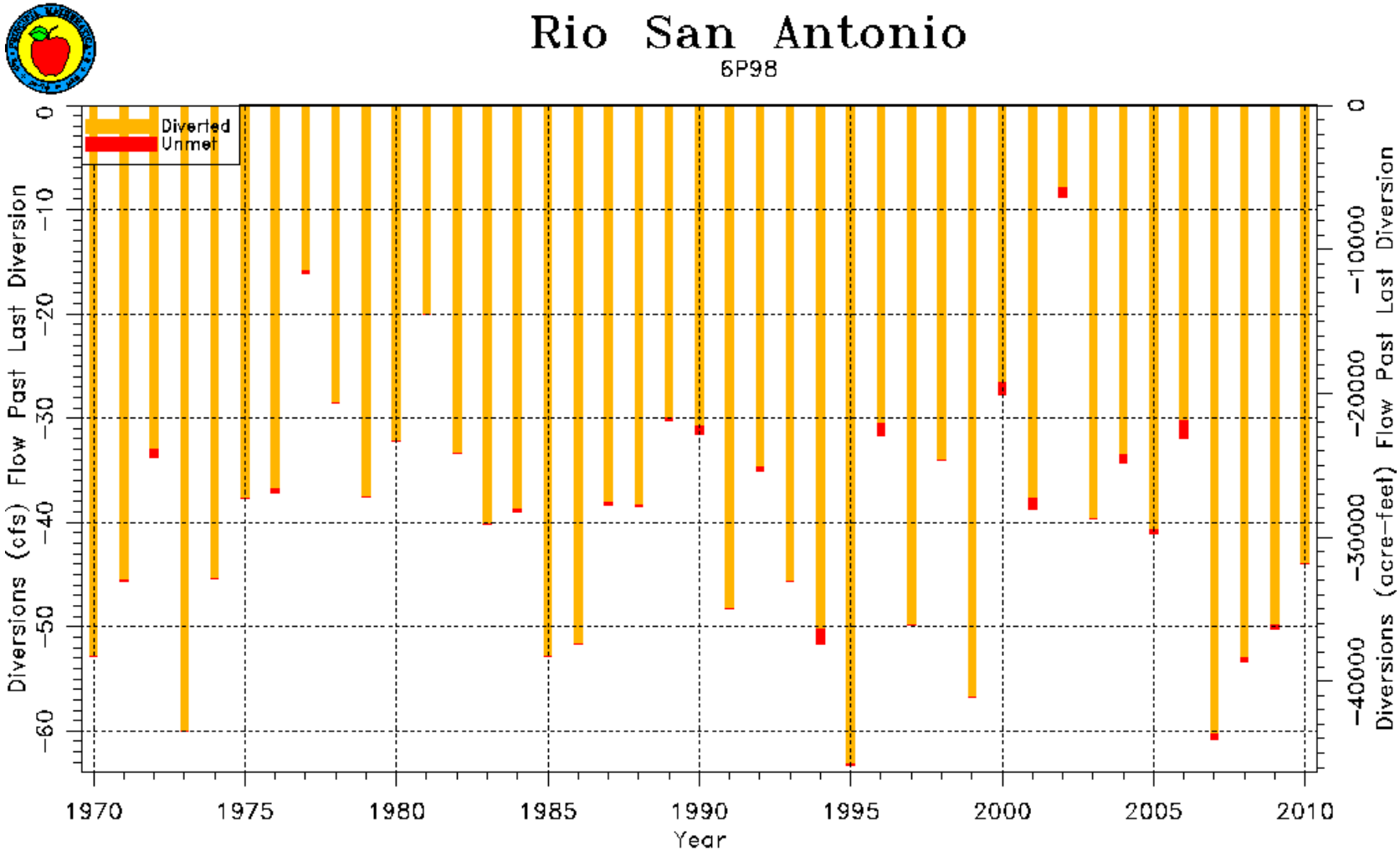


Figure 12k – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Rio San Antonio

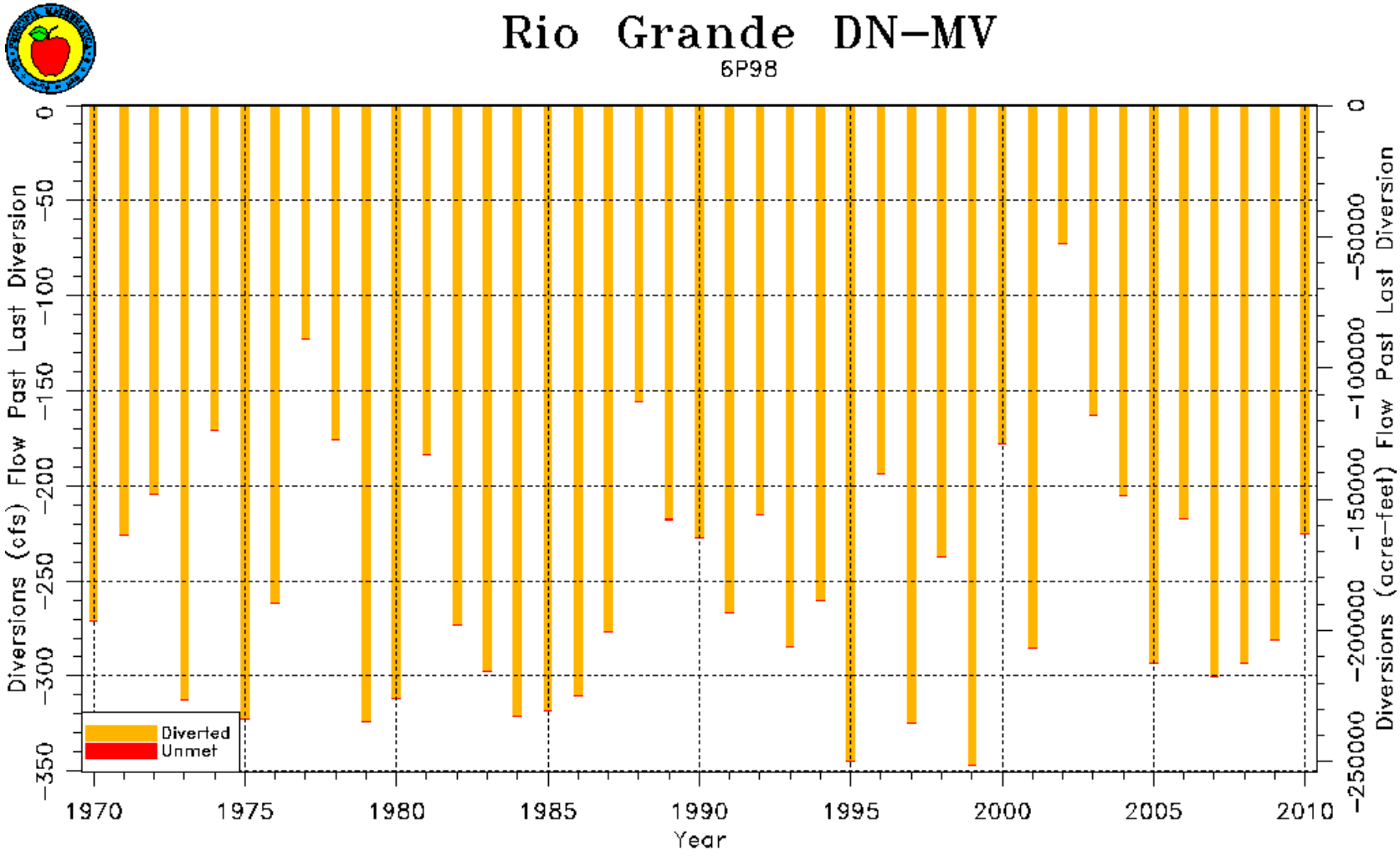


Figure 12l – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Rio Grande from Del Norte to Monte Vista

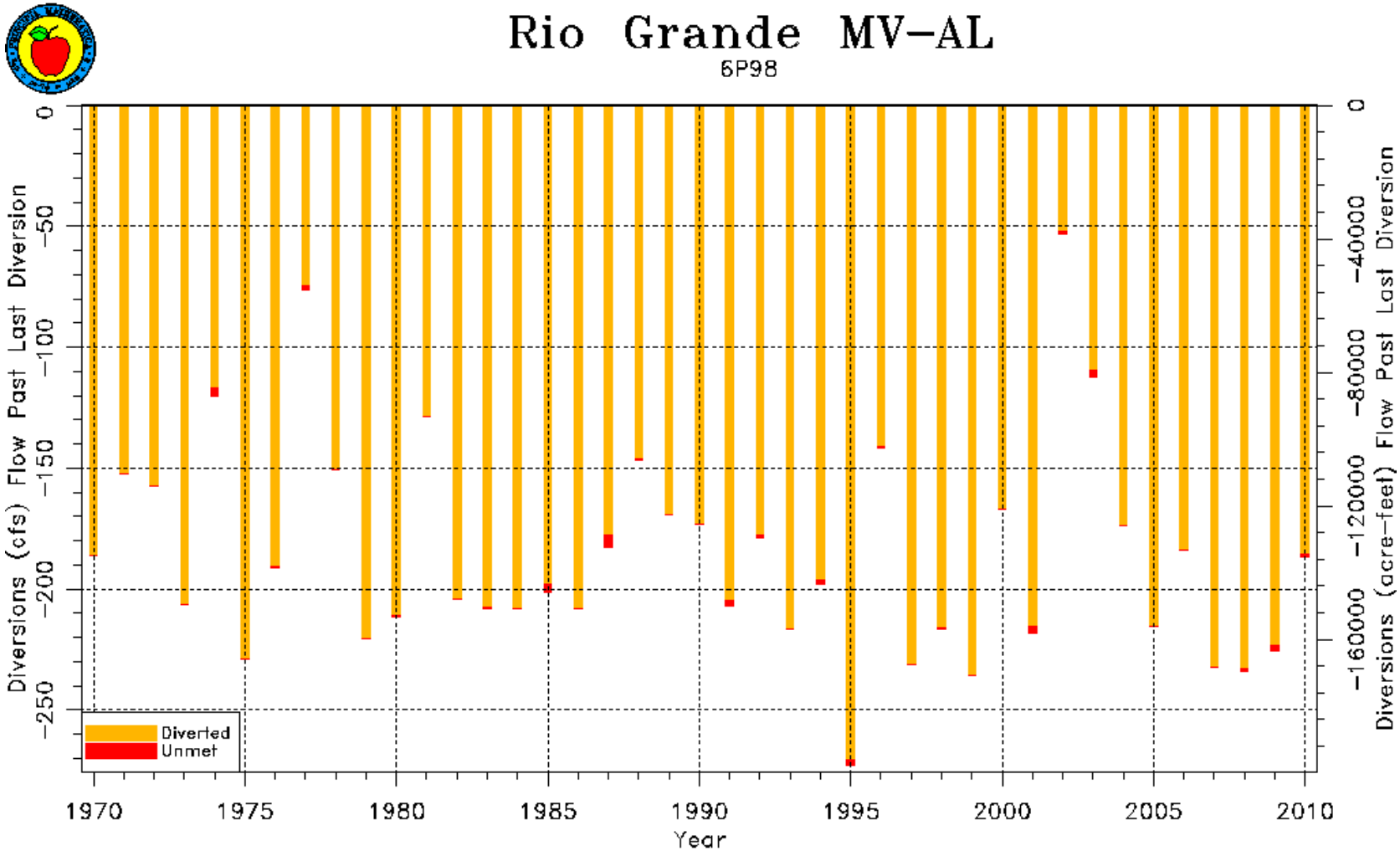


Figure 12m – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Rio Grande from Monte Vista to Alamosa

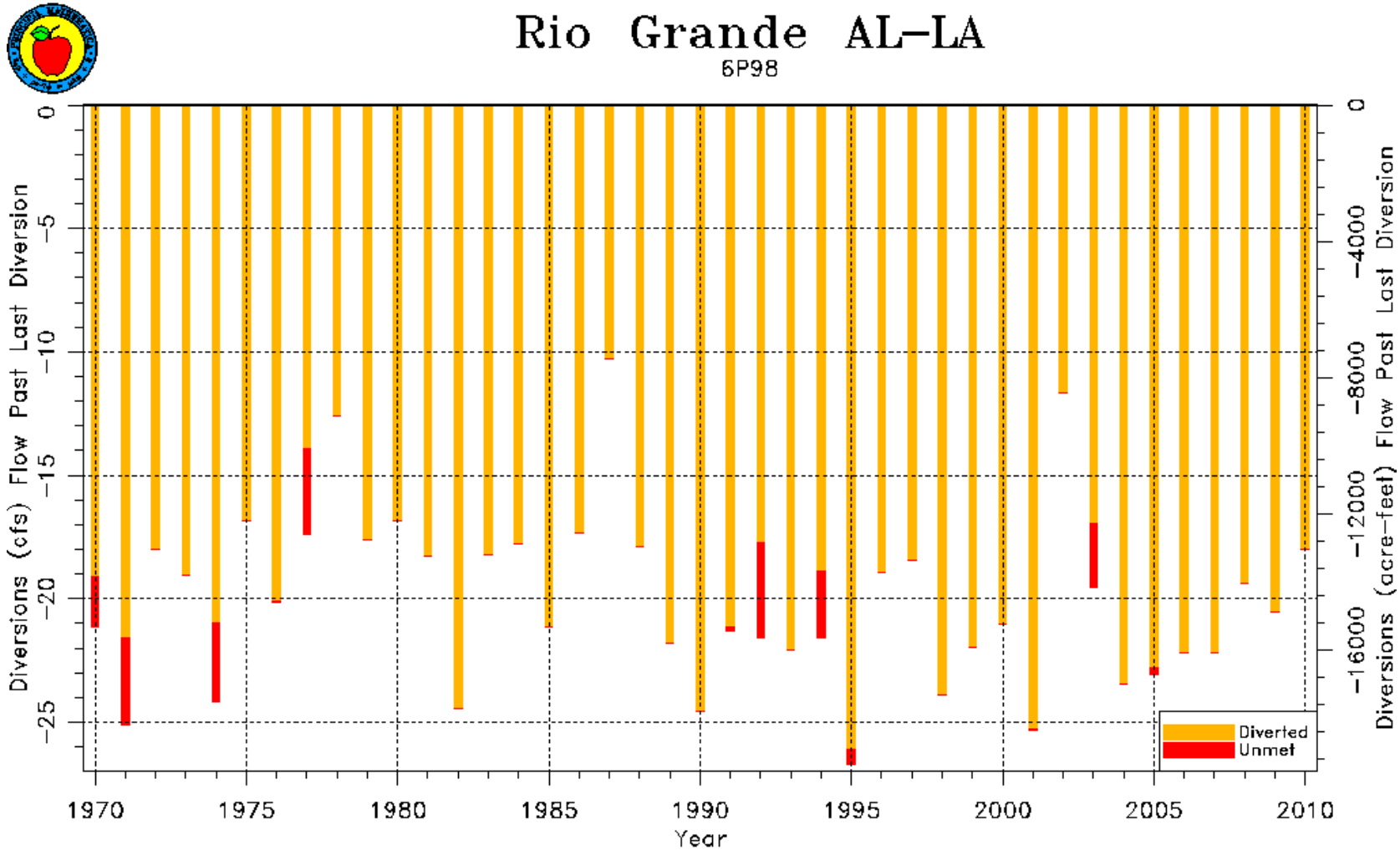


Figure 12n – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Rio Grande from Alamosa to La Sauses

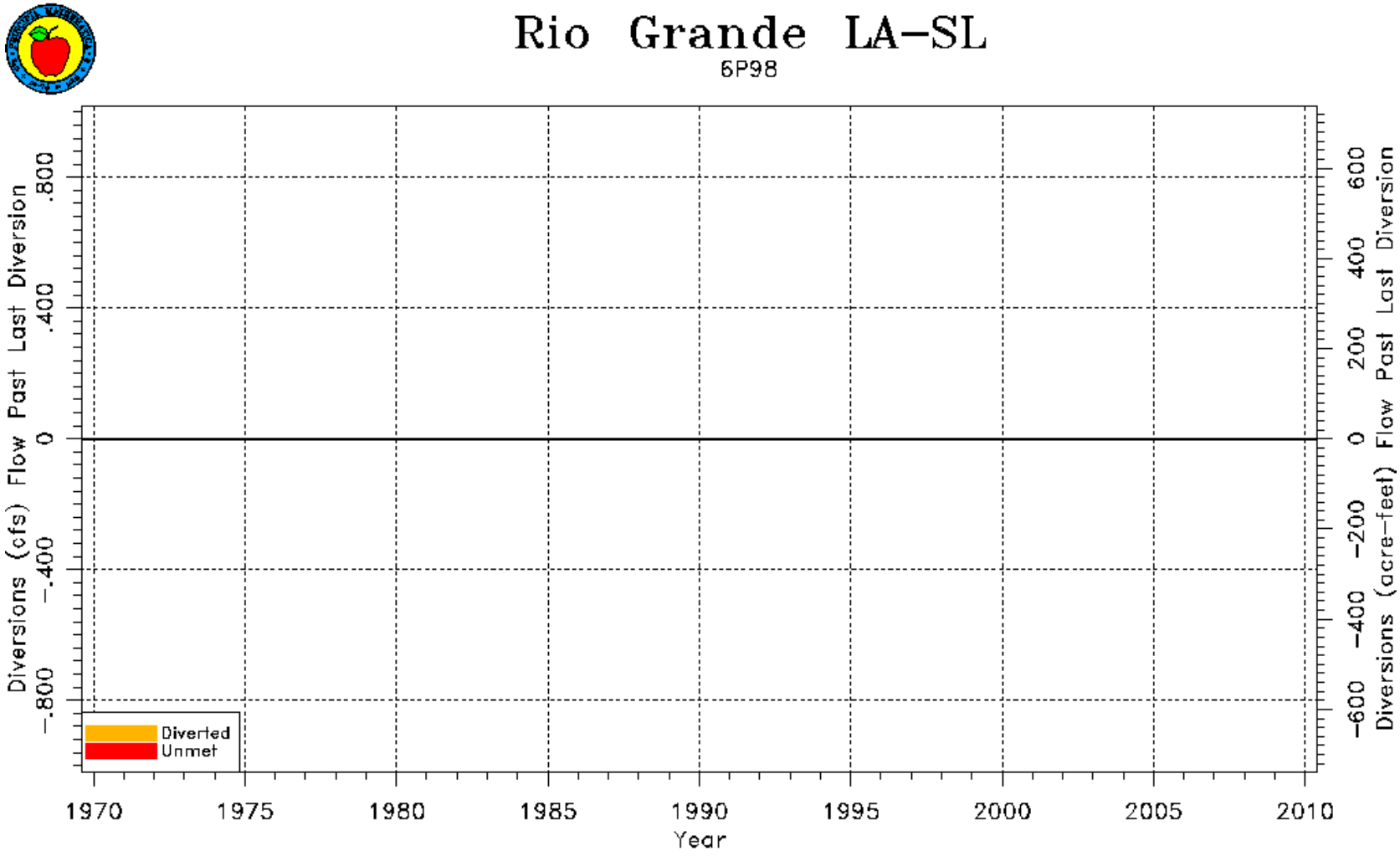


Figure 12o – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Rio Grande from La Sauses to the State Line

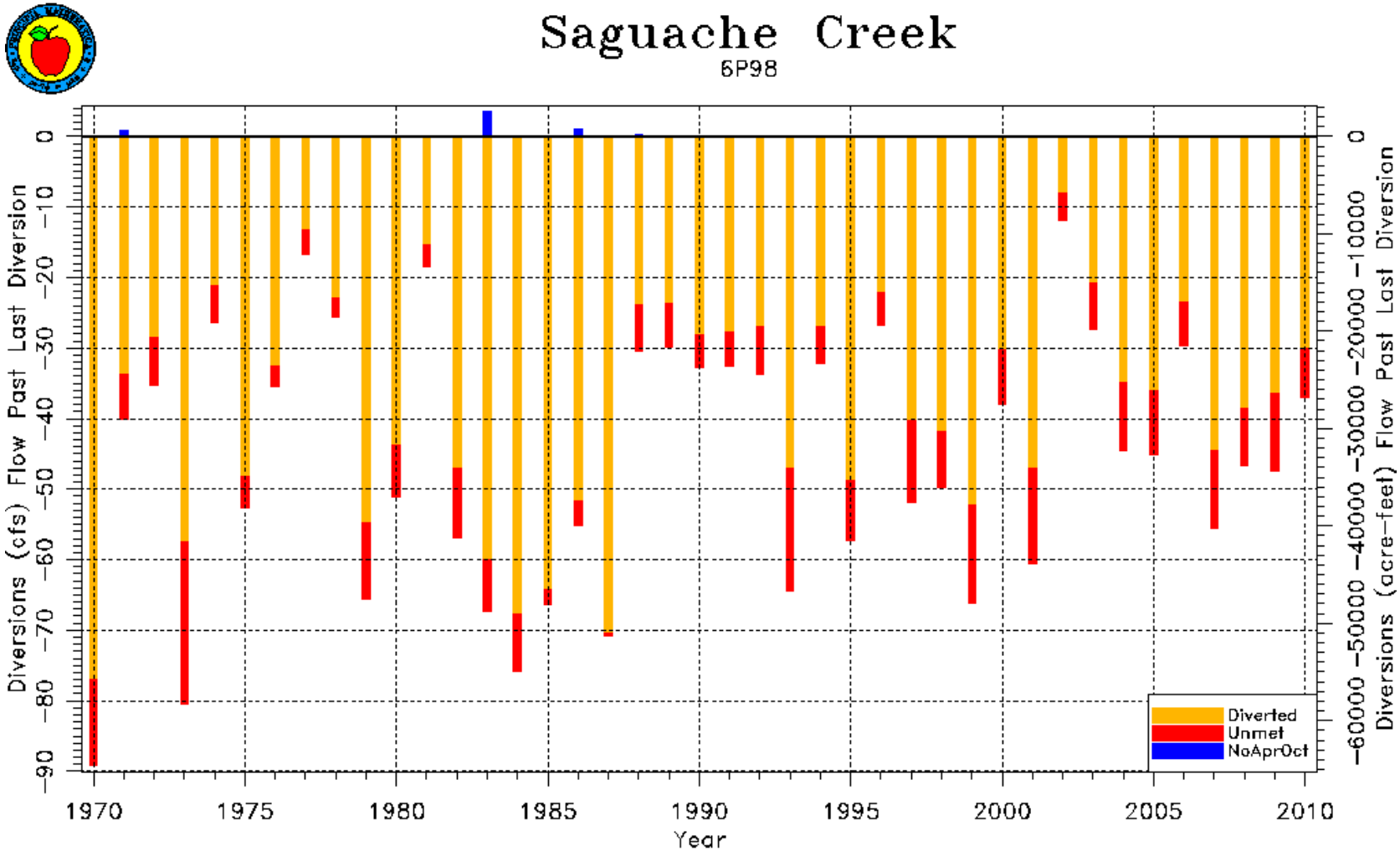


Figure 12p – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Saguache Creek

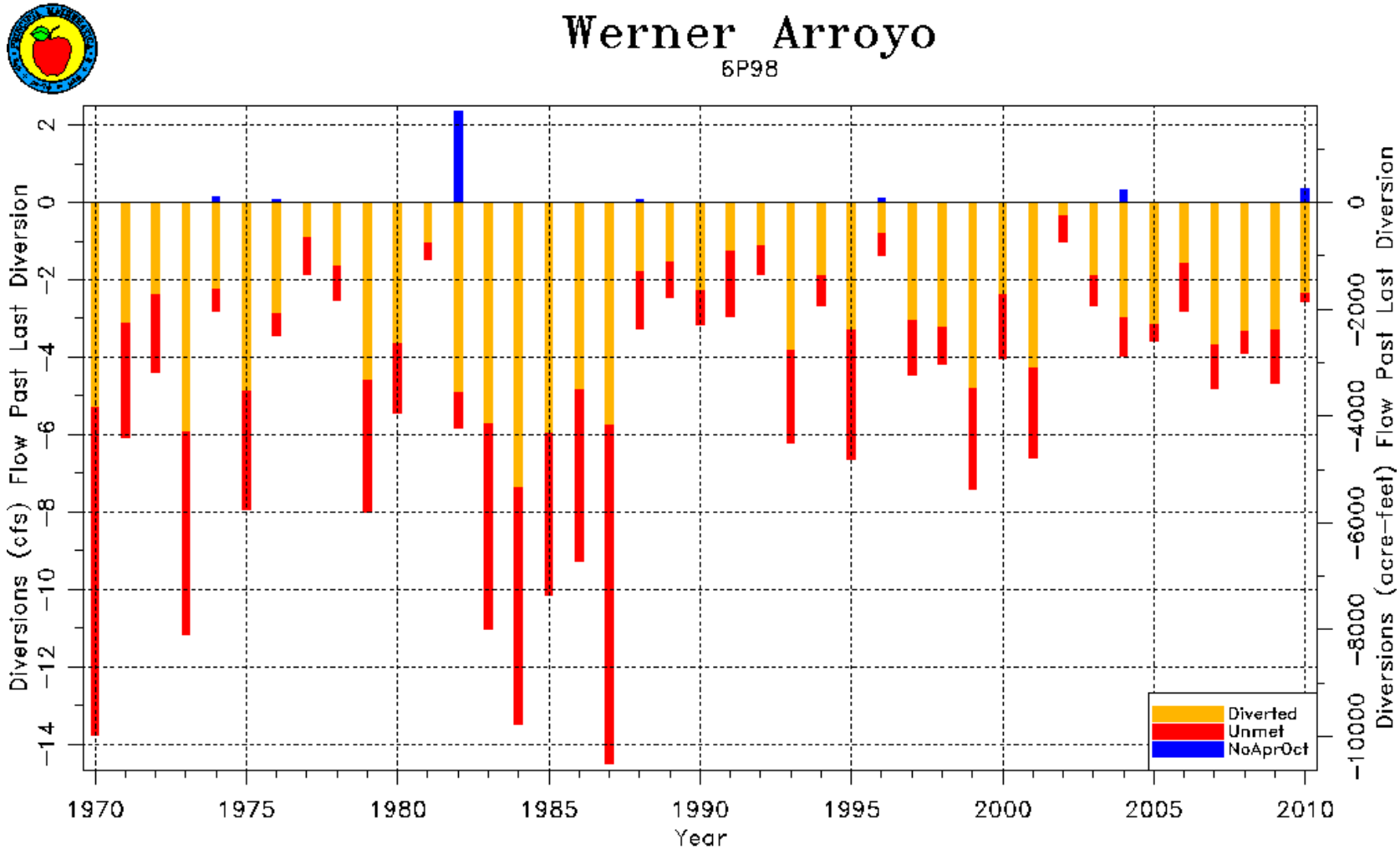


Figure 12q – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Werner Arroyo

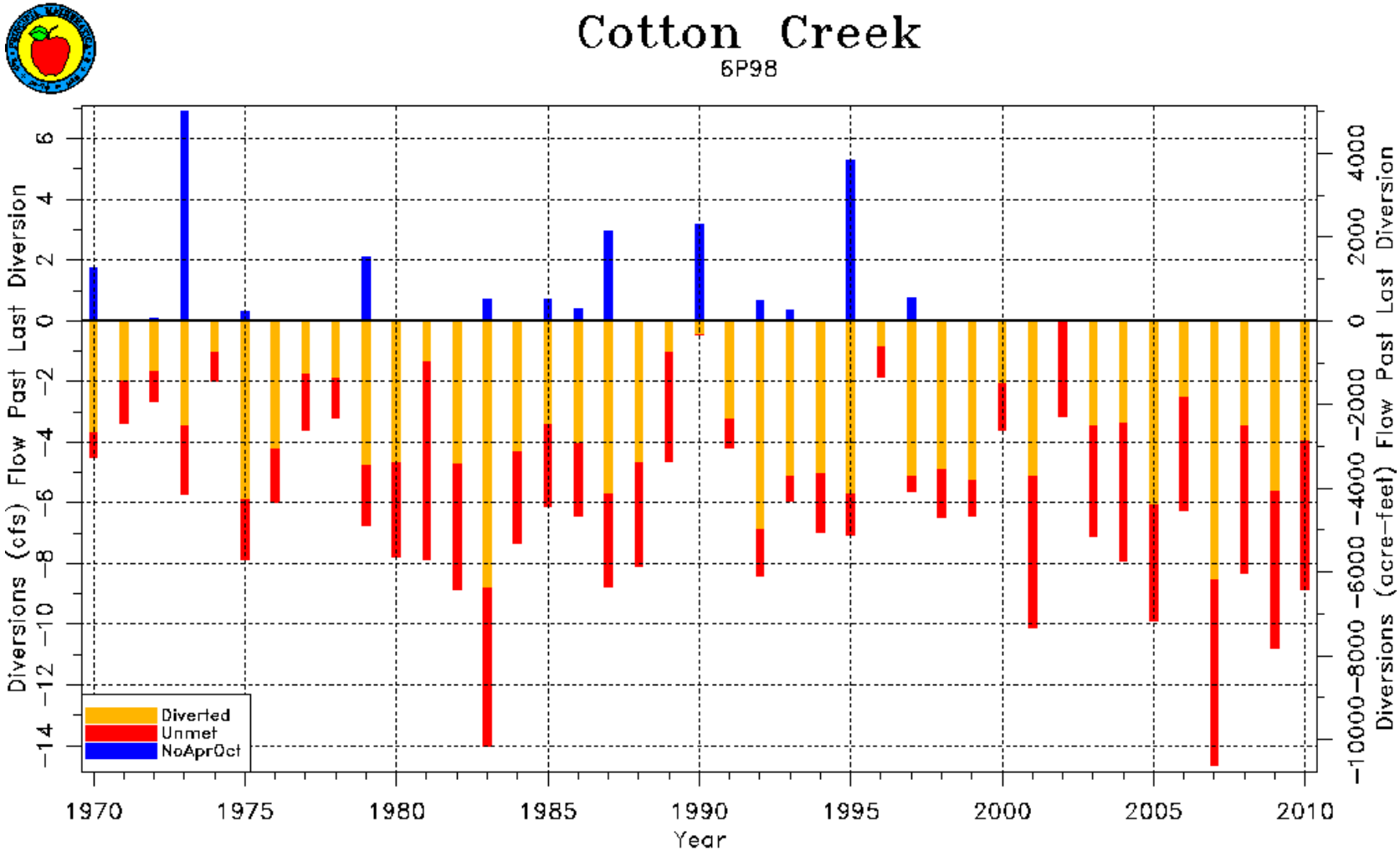


Figure 12r – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Cotton Creek

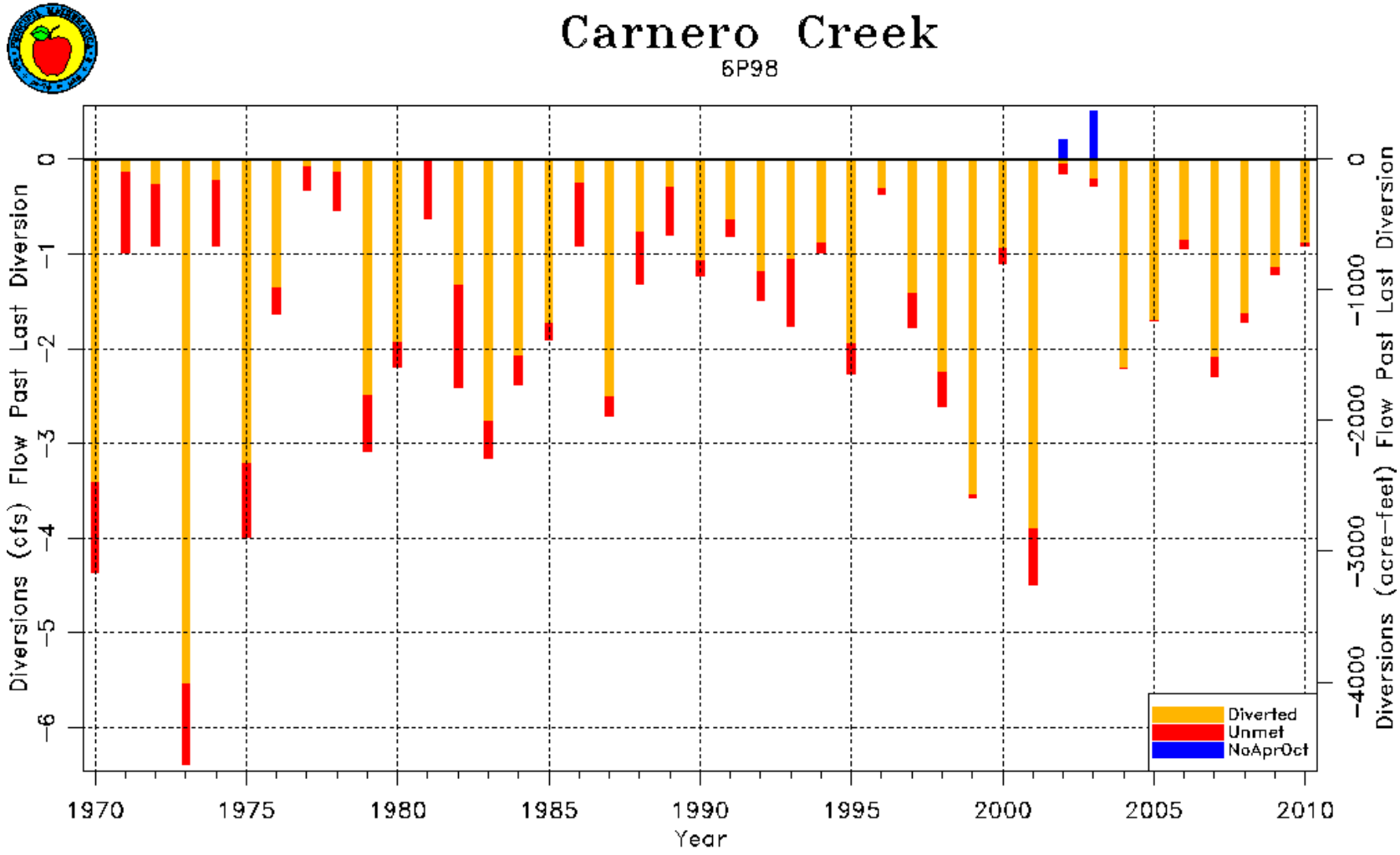


Figure 12s – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Carnero Creek

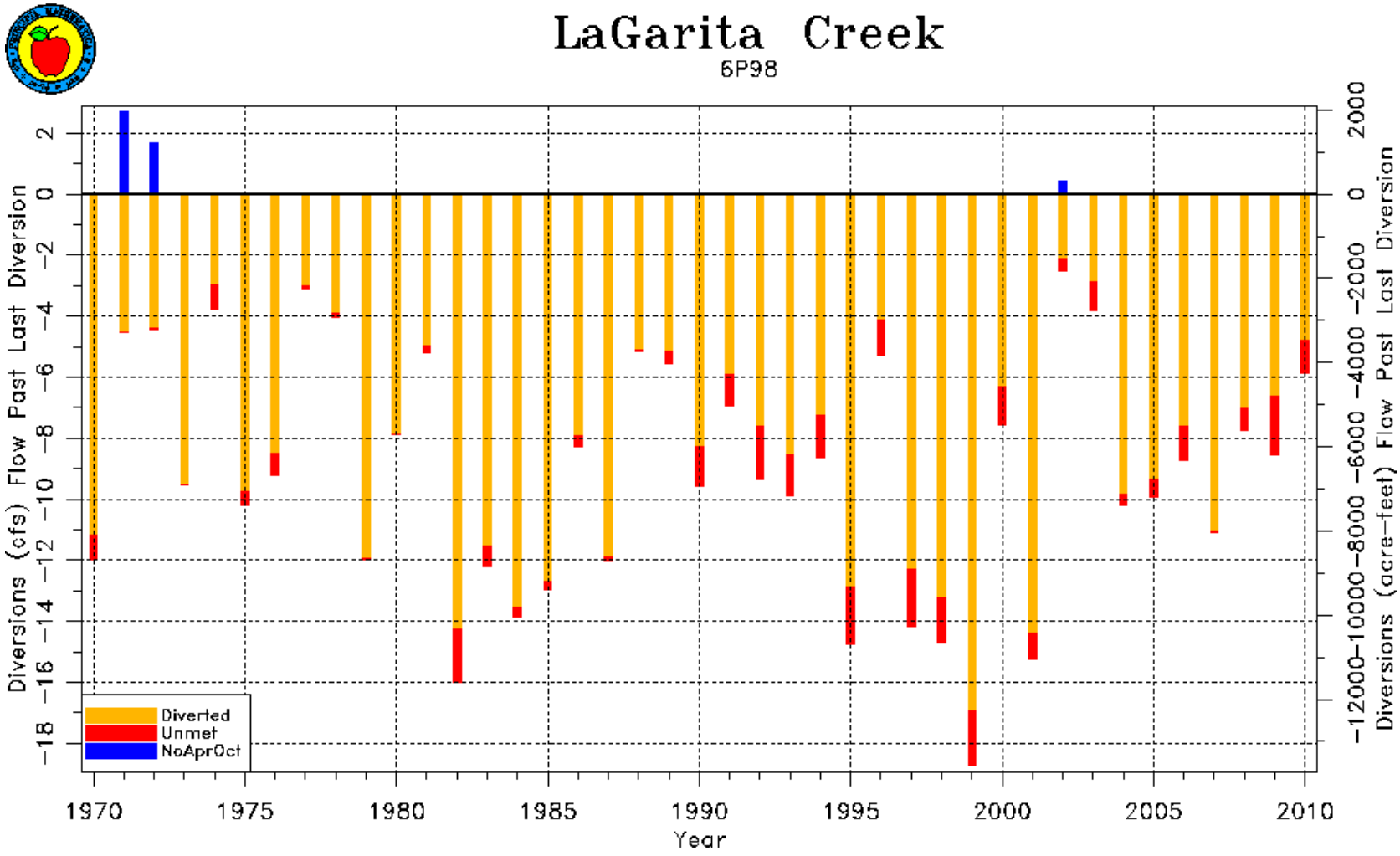


Figure 12t – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for La Garita Creek

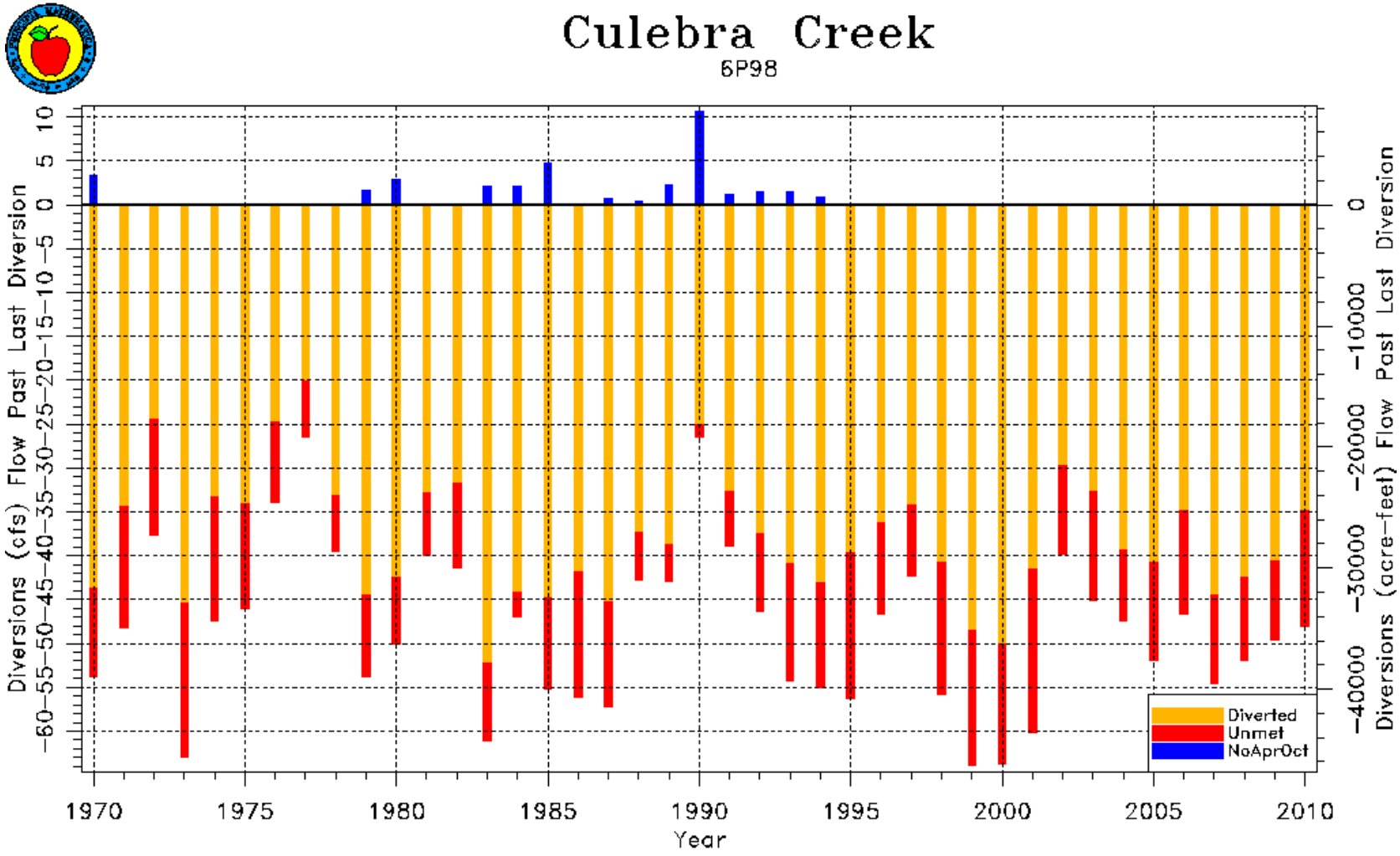


Figure 12u – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Culebra Creek

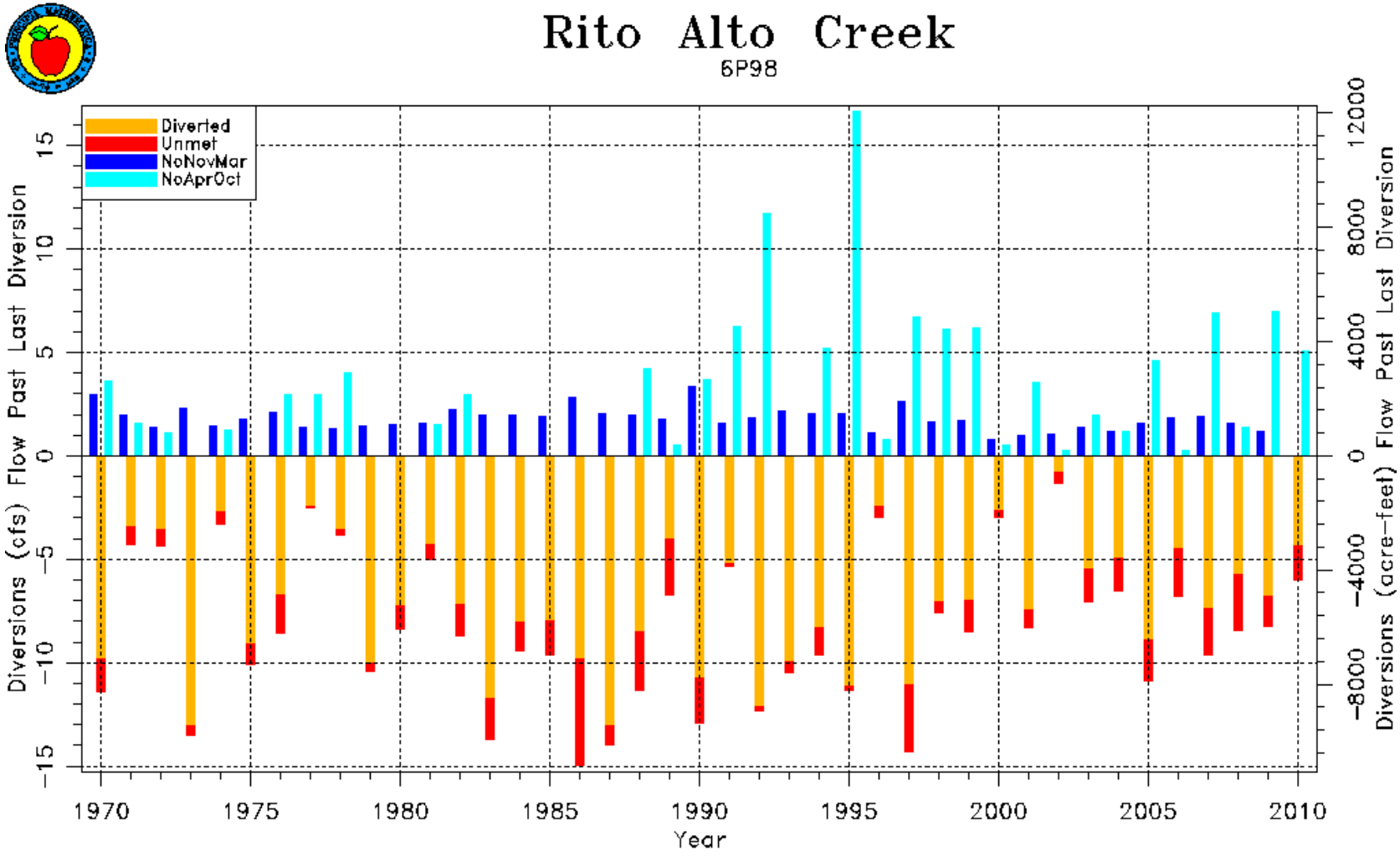


Figure 12v – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Rio Alto Creek

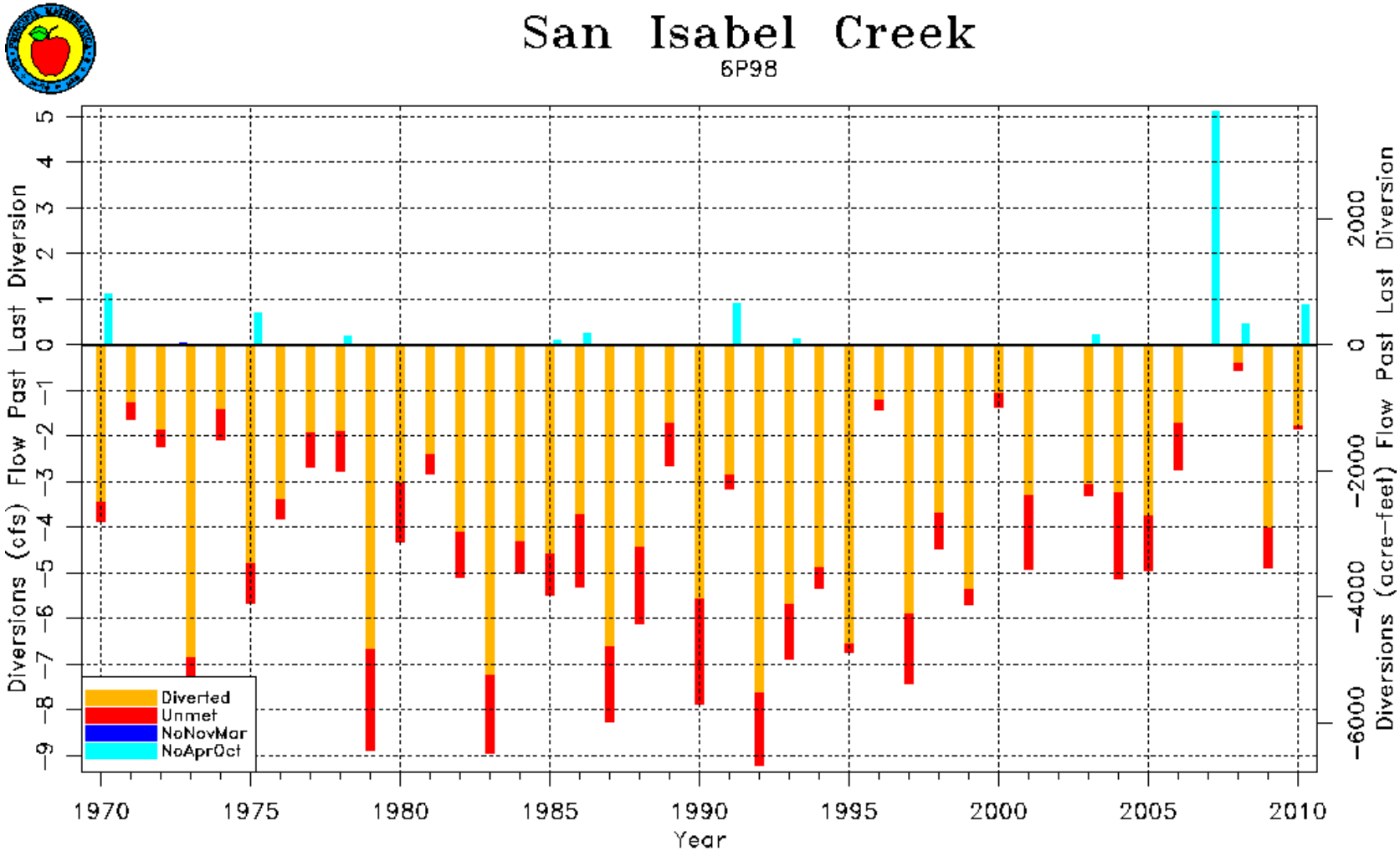


Figure 12w – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for San Isabel Creek

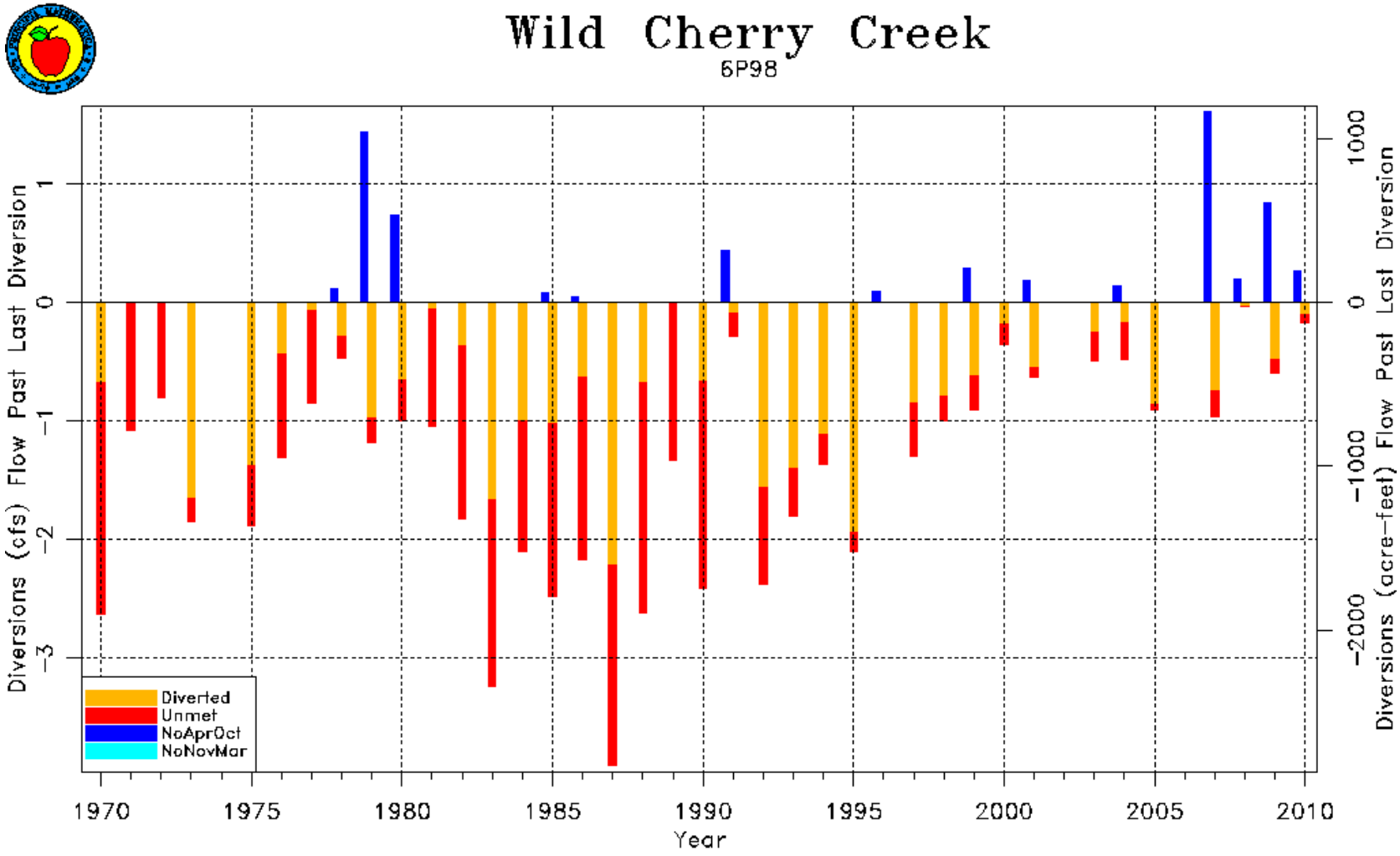


Figure 12x – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Wild Cherry Creek

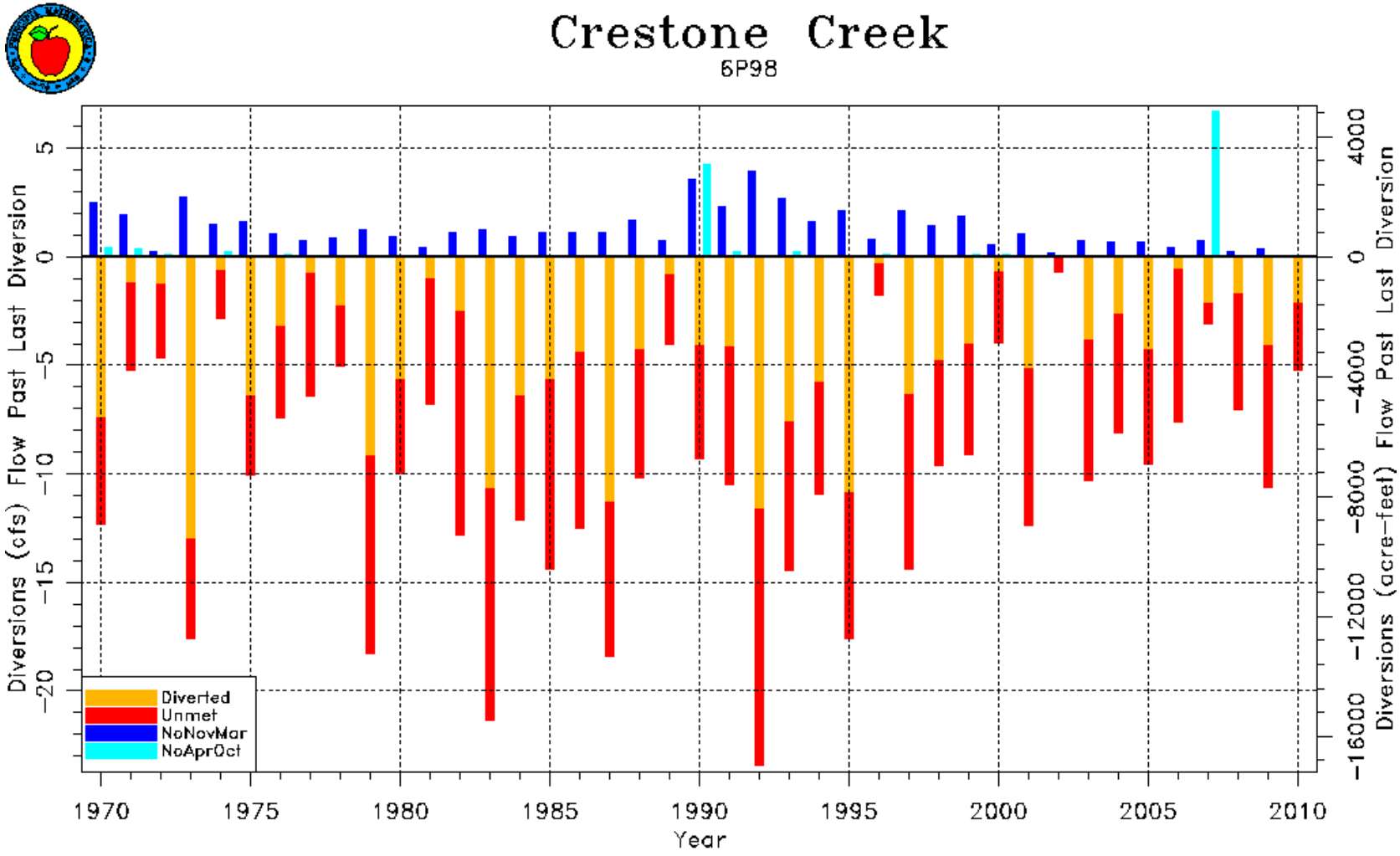


Figure 12y – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Crestone Creek

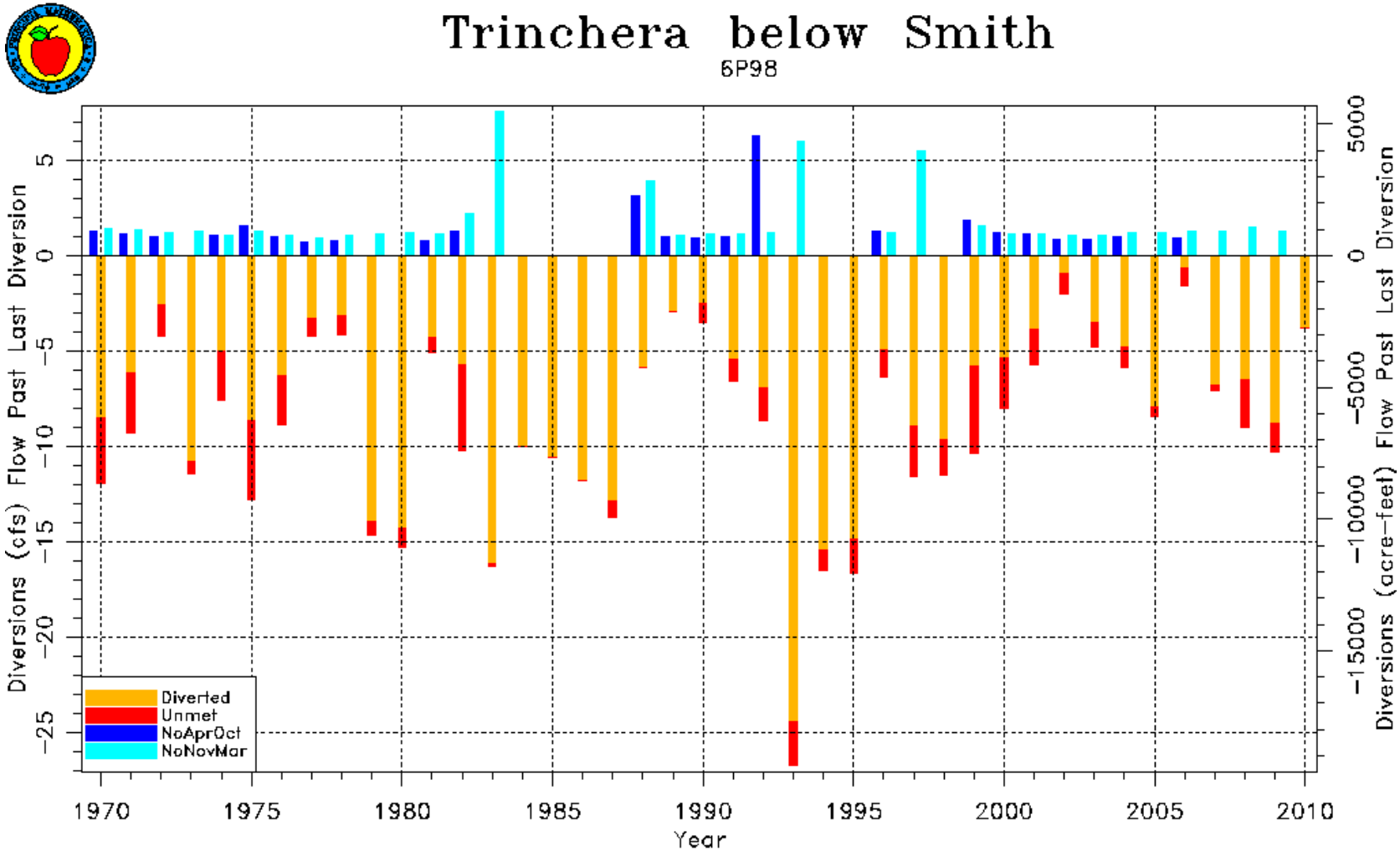


Figure 12z – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) for Trinchera Creek Below Smith

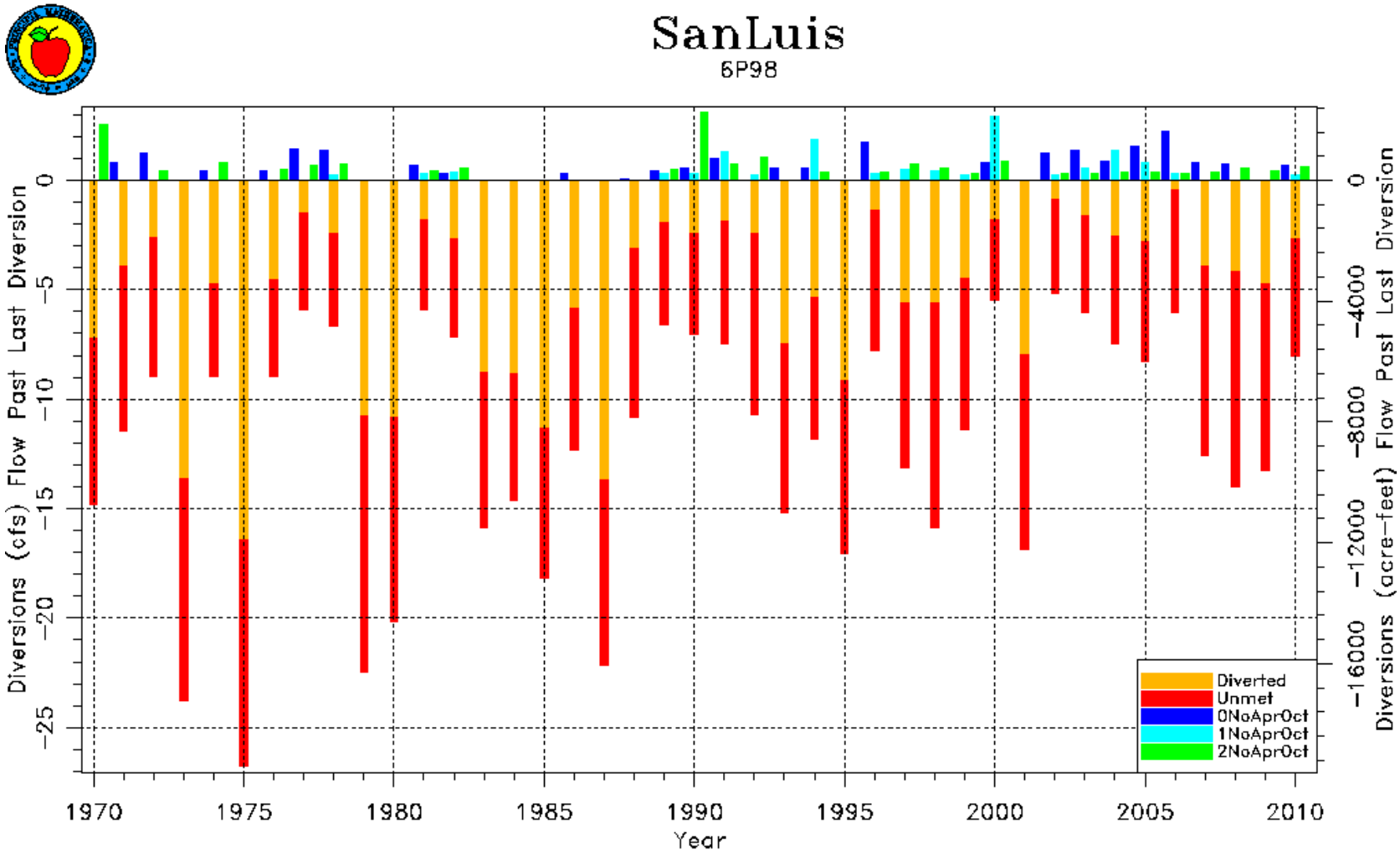


Figure 13 – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) on San Luis Creek

Note, there are three dry-up points along the creek, depicted by the dark blue, light blue and green bars above the axis.

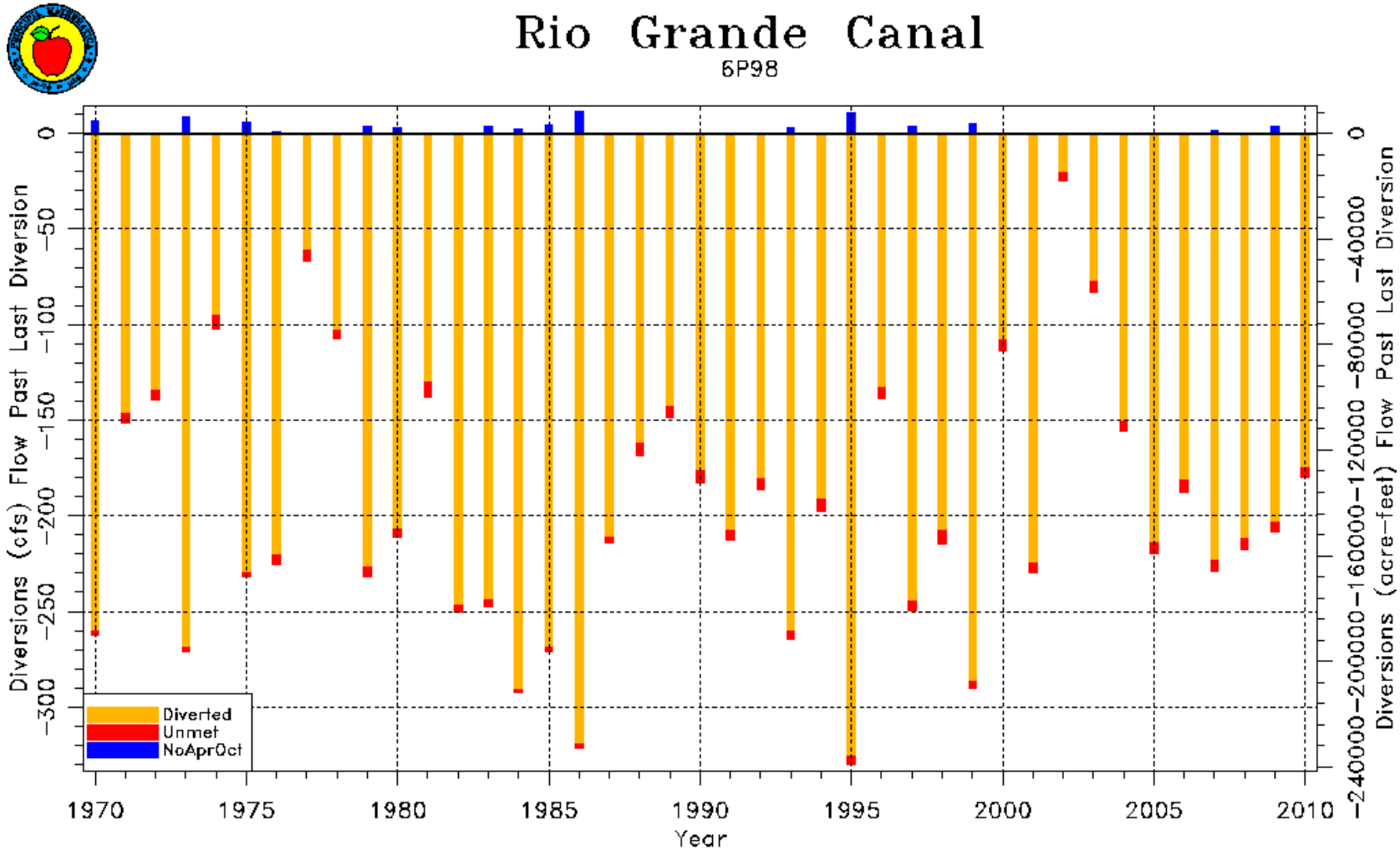


Figure 14a – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) on the Rio Grande Canal

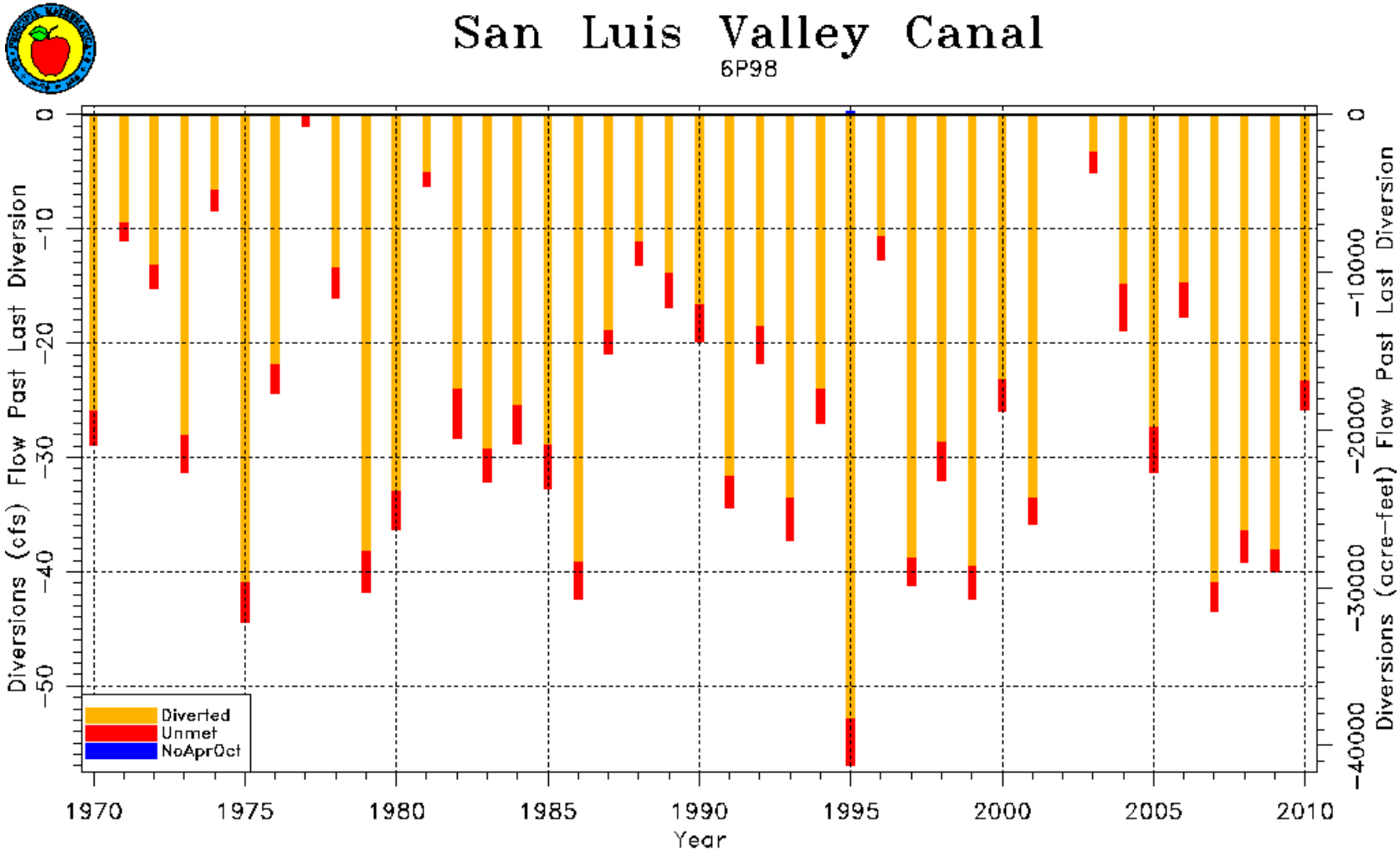


Figure 14b – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) on the San Luis Valley Canal

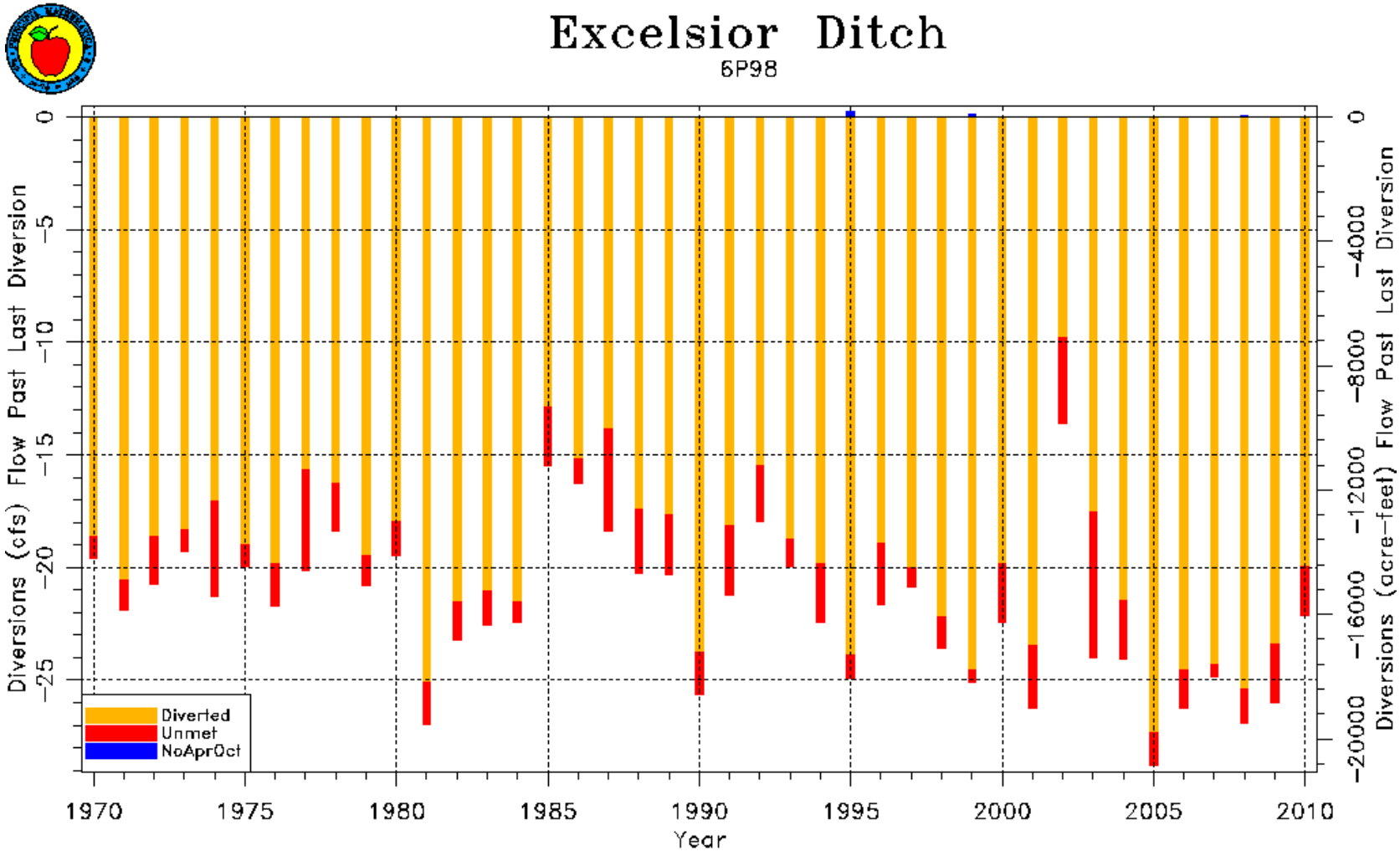


Figure 14c – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) on the Excelsior Ditch

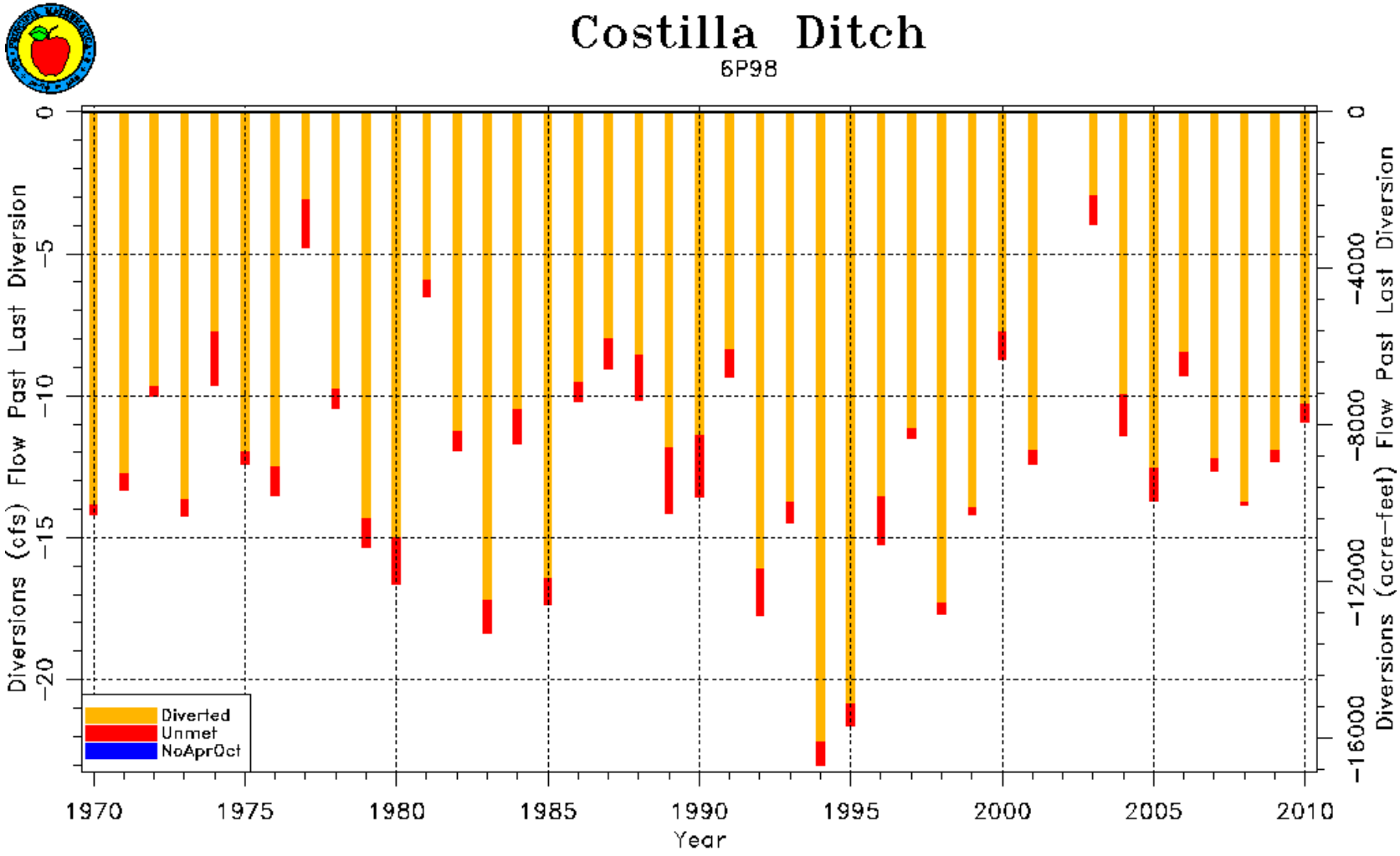


Figure 14d – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) on the Costilla Ditch

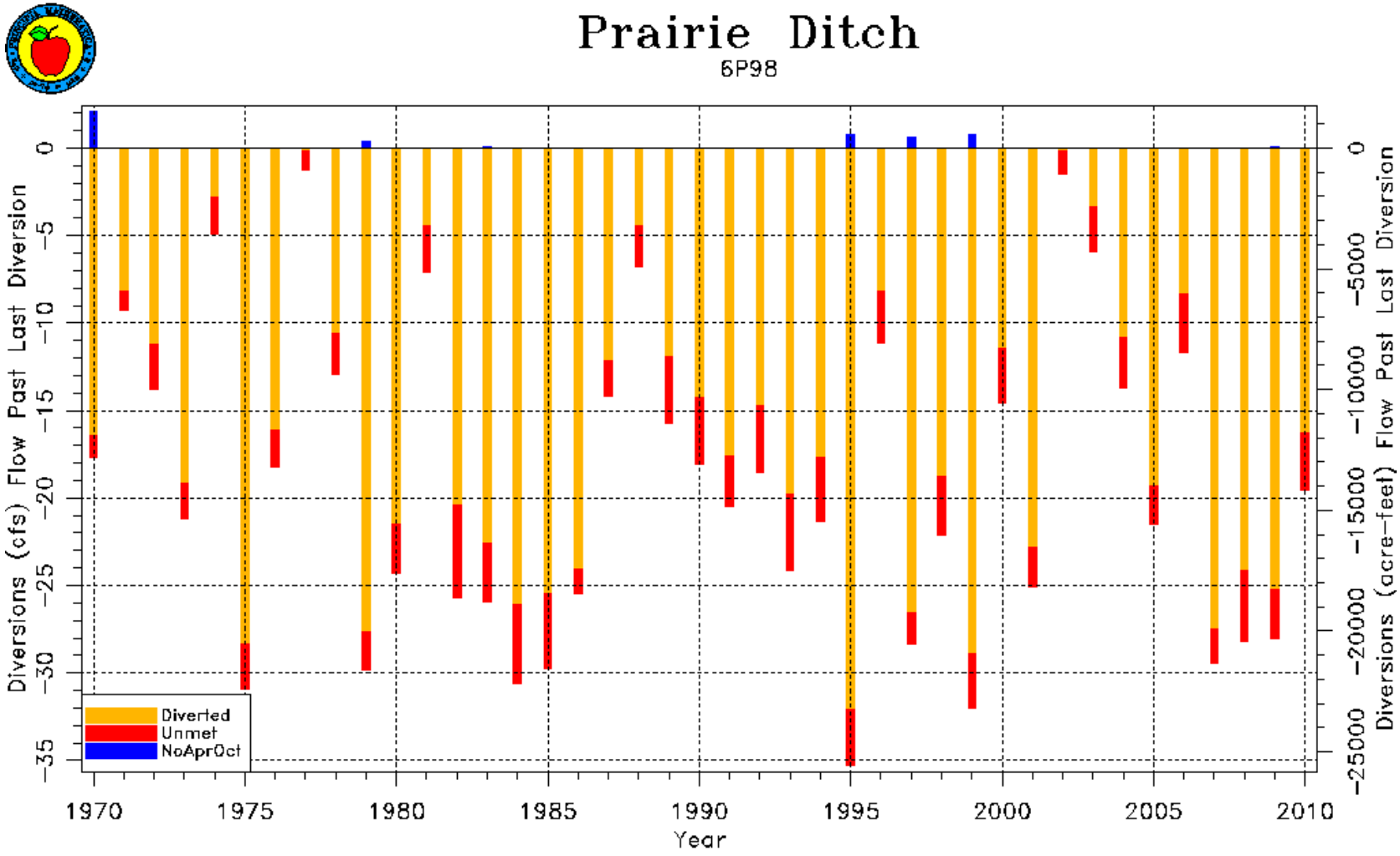


Figure 14e – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) on the Prairie Ditch

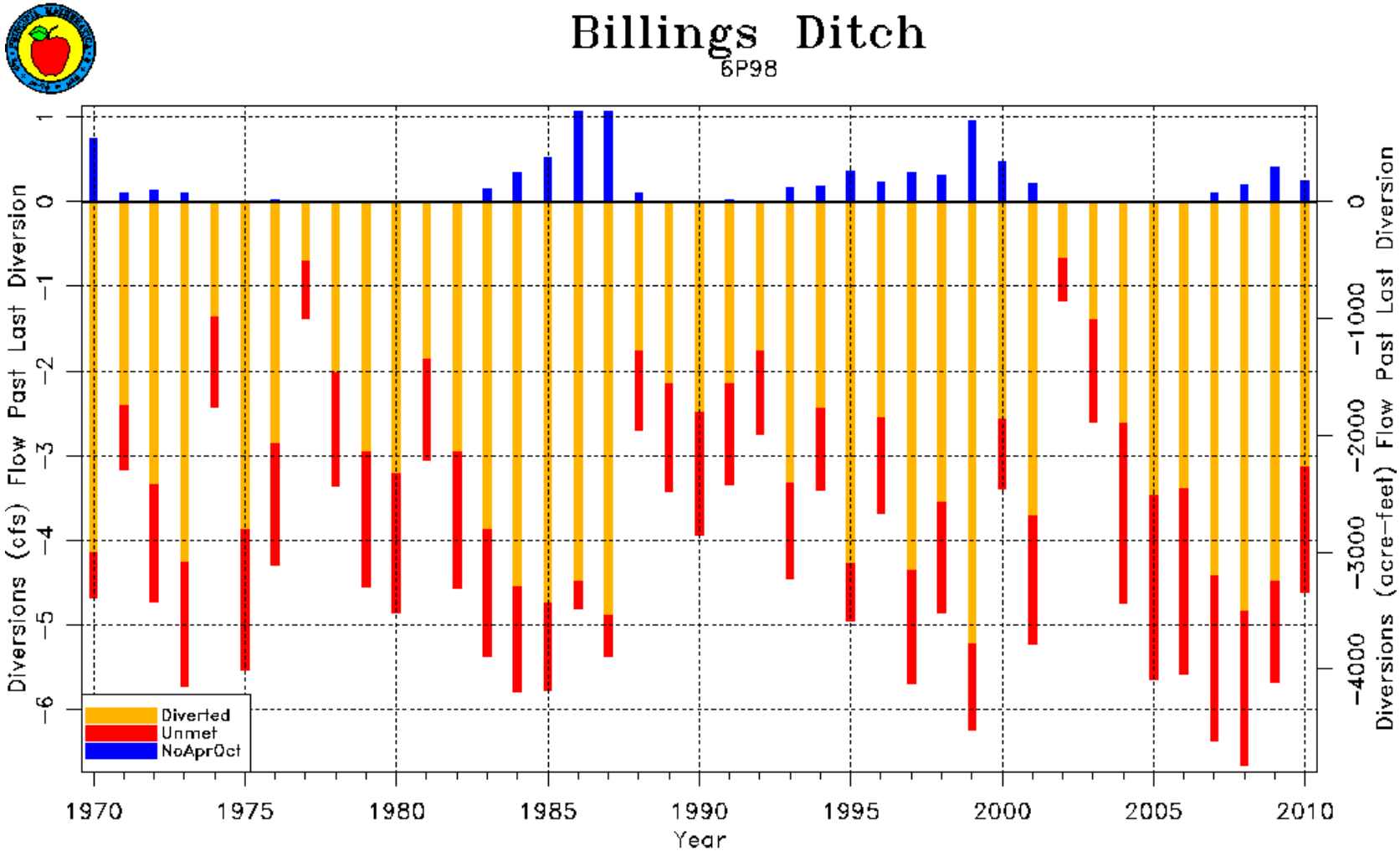


Figure 14f – Simulated Diversions and Unmet Diversions (difference between the observed and simulated diversions) on the Billings Ditch