STUDY REPORT W&AR-02
PROJECT OPERATIONS/WATER BALANCE MODEL

ATTACHMENT A

TUOLUMNE RIVER DAILY OPERATIONS MODEL

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1.0 INTRODUCTION

The Turlock Irrigation District (TID) and Modesto Irrigation District (MID) (collectively, the Districts) have developed a computerized Project Operations Model (Model) to assist in evaluating the relicensing of the Don Pedro Project (Project) (FERC Project 2299). On November 22, 2011, in accordance with the Integrated Licensing Process schedule for the relicensing of the Don Pedro Project, the Districts filed their Revised Study Plan containing 35 proposed studies with the Federal Energy Regulatory Commission (FERC) and relicensing participants. On December 22, 2011, FERC issued its Study Plan Determination approving, with modifications, the proposed studies, including Study Plan W&AR-2: Project Operations /Water Balance Model Study Plan. Consistent with the FERC-approved study plan, the objective of the Model is to provide a tool to compare current and potential future operations of the Project. Due to the fact that the geographic scope of the Model extends from the City and County of San Francisco's (CCSF) Hetch Hetchy system in the upper part of the watershed to the confluence of the Tuolumne and San Joaquin rivers, the Model is now entitled the Tuolumne River Daily Operations Model (Model).

In accordance with the study plan, the Districts have prepared a Model Development Report filed with FERC in January 2013 (W&AR-02 Study Plan, page 7). This Model Hydrology Report is an attachment to the Model Development Report and provides information concerning the development of the hydrology for the Model. Section 2.0 describes the development of the unimpaired flow of the Tuolumne River Basin, subcomponents of unimpaired flow and other components of flow needed by the Model. Section 3.0 describes the analysis used to estimate accretion flow in the Tuolumne River below La Grange Dam and the Modesto Gage in the Tuolumne River, and the estimated flow of Dry Creek.

2.0 TUOLUMNE RIVER UNIMPAIRED AND COMPUTED FLOW

Included in the Model are numerous user-controlled parameters that allow the simulation of alternative Project operations, such as the prescription of lower Tuolumne River minimum flow requirements. The Model performs a simulation of Project operations for a sequential period of years that covers a range of historical hydrologic conditions. The period of hydrologic record selected for the Model is Water Year[1] 1971 through Water Year 2009, which includes extreme years of hydrology (1977 dry and 1983 wet) and multi-year periods of challenging water supply conditions such as 1976-1977, 1987-1992, and 2001-2004.

Underlying Project operations and water supply in the Tuolumne River Basin is the unimpaired flow of the river and its tributaries. "Unimpaired flow" is surface water that is available for management and use. The California Department of Water Resources (DWR) provides a definition of unimpaired flow as "… runoff that would have occurred had water flow remained unaltered in rivers and streams instead of stored in reservoirs, imported, exported, or diverted. The data is a measure of the total water supply available for all uses after removing the impacts of most upstream alterations as they occurred over the years." By computing the unimpaired flow one acquires the record of flow at a location, had no physical (e.g., dams and diversions) facilities been developed upstream of the location. At times, this record is fundamental to modeling the operations of a project as it provides a record of inflow to a facility. At other times, this record is needed to identify the total available water supply of the stream for purposes of division or allocation, which would not be known by simple measurement of the stream at a location that is below controlling facilities.

The unimpaired flow of the Tuolumne River has been computed for various locations within the basin for decades. From a water project development perspective, this information was important during project planning in understanding water availability within the basin. Today, it plays directly into Project and basin operations as a key factor in establishing annual water deliveries and the provision of flows to the lower Tuolumne River. The Districts and CCSF have used unimpaired flow computations to comply with Raker Act and Fourth Agreement provisions, and for the operational and planning needs of their respective projects. Further, unimpaired flow data, along with other data is provided by the Districts to the DWR for incorporation into Statewide water management efforts.

The Model requires several records of unimpaired flow. Three primary records are: 1) unimpaired flow (inflow) at Hetch Hetchy Reservoir, 2) unimpaired flow (inflow) at Lake Lloyd Reservoir and Eleanor Reservoirs, and 3) unimpaired flow at La Grange. Unimpaired flows at each of these locations must be calculated from flows measured from other locations. The Model utilizes a unique fourth component of unimpaired flow which depicts the runoff entering Don Pedro Reservoir that is not affected by upstream CCSF facilities. This runoff concerns runoff from tributaries and streams such as the South and North Forks of the Tuolumne River.

An unimpaired record of flow at a location requires an identification of the flow occurring at that location and the alterations of flow occurring upstream of that point. If no man-made alterations

[1] In California the Water Year is defined as the period of time between and inclusive of October 1 of a year and September 30 of the following year. Water Year 1971 begins October 1, 1970 and ends September 30, 1971.

are occurring upstream of a point of interest the measured flow at that location can be considered the unimpaired flow at the location. When storage reservoirs and diversions occur upstream of the point of interest the effect on the flow due to these alterations of a freely flowing stream must be taken into consideration. The general form of equation to compute unimpaired flow follows:

$$\text{Inflow}_t\ (\text{unimpaired}) = \text{Outflow}_t\ (\text{measured}) + \text{Storage}_t - \text{Storage}_{t-1} + \text{Reservoir Evaporation}_t + \text{Diversions}$$

Where, inflow is the unimpaired flow computed at a specific location for a specified time period (the Model utilizes a daily time step). Outflow is the measured flow at the location, which has been altered by upstream activity. The change in storage recognizes the amount of stream flow that has been reduced from or added to the measured flow due to upstream reservoir operation. The reservoir evaporation term recognizes that the measured flow would also be affected by a loss of flow equal to the amount of evaporation caused by the surface area of upstream reservoirs. The diversion term recognizes flow being removed (and not returned) from the stream upstream of the point of interest.

As indicated above three primary records are developed: unimpaired flow (inflow) at Hetch Hetchy Reservoir, unimpaired flow (inflow) at Lake Lloyd Reservoir and Eleanor Reservoirs, and unimpaired flow at La Grange. Unimpaired flows at each of these locations must be calculated from flows measured from other locations. Figure 2.1-1 illustrates hydrologic measurement and computation points within the Tuolumne River basin and other flow parameters of interest.

The following Section 2.1 provides a narrative description of the computation of unimpaired flow for several components of flow needed by the Operations Model. Accompanying this appendix is a workbook entitled “Don Pedro unimpaired and other flow data Version 2.xlsx” (Hydrology Workbook) with the data used to compute these components.[2] Also described are other components of flow computed from this information that was used for Model result comparison and validation purposes. Following the columnar description is a description and documentation of an adjustment of the historical unregulated component of inflow to Don Pedro Reservoir that is used in Project modeling (Section 2.2) and a discussion (Section 2.3) of other hydrologic information pertaining to the modeling. Also presented (Section 2.4) is an analysis that compares the results of the unimpaired flow computation method used by the Districts (mass balance approach) to an alternative method of flow computation that uses a watershed comparison approach.

2.1 Worksheet Columnar Description

Each section and column of the Hydrology Workbook is described below.

[2] An earlier version of the Hydrology Workbook was presented to RPs during the W&AR-2 Workshop No. 1 held on April 9, 2012. The workbook contained hydrologic records for the Period WY1971 through WY2010. Due to the needs of Don Pedro Reservoir and Tuolumne River temperature modeling validation and calibration processes preliminary hydrologic data and computations have been extended in the workbook through December 18, 2012.

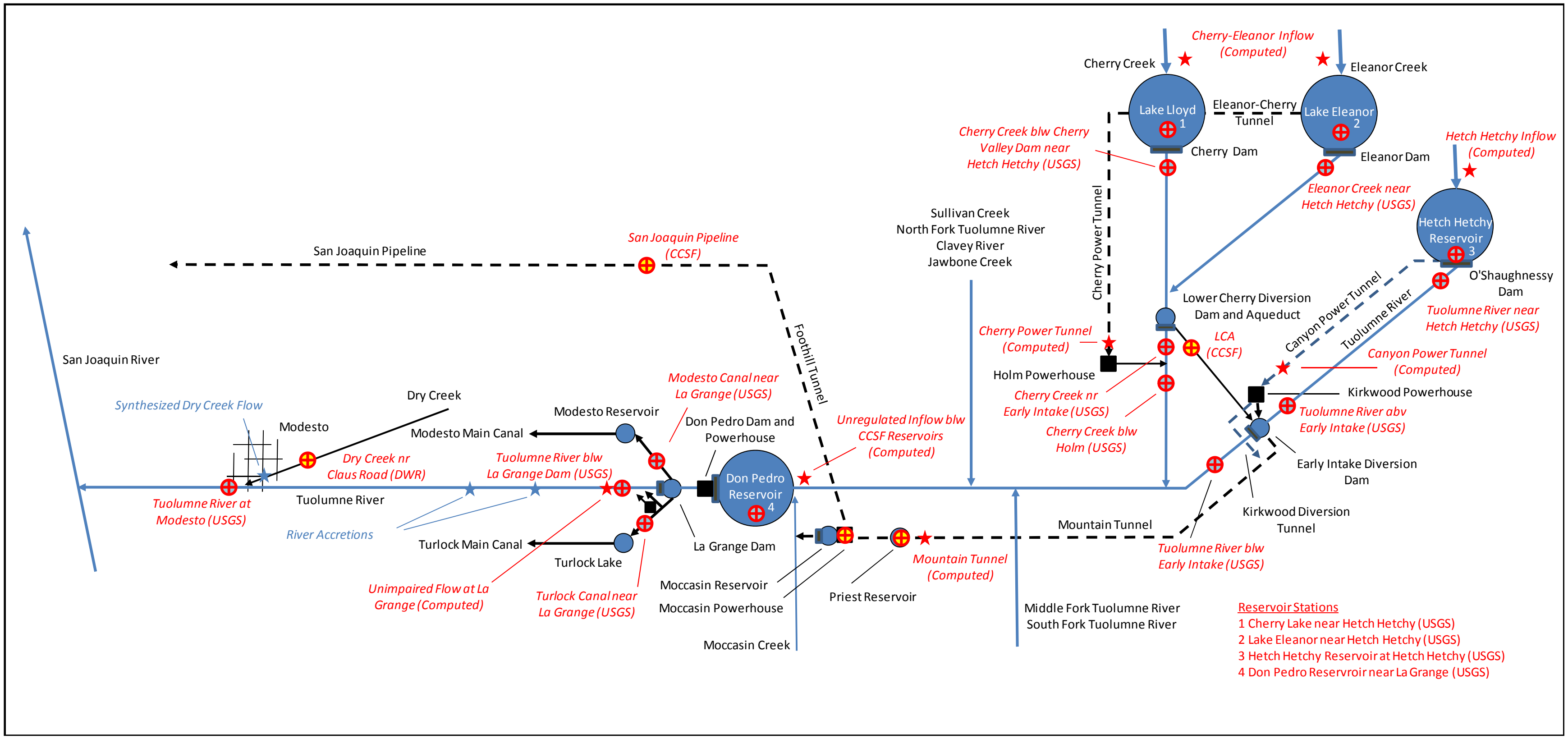


Figure 2.1-1. Tuolumne River Basin hydrologic measurement and computation points.

Date Indices Columns A, B and C
The numeric and alphanumeric values identifying the date of applicable record. These values are also used for data assemblage purposes. All records reported by date represent either end-of-day status (e.g., storage ending at midnight, in acre-feet (ac-ft)) or average daily flow (e.g., average flow occurring throughout the day, in cubic feet per second (cfs)).

Reservoir Storage Columns D, G, J, and M
Reservoir storage reported by USGS:

- 11275500 Hetch Hetchy Reservoir at Hetch Hetchy, CA, Column D
- 11277200 Cherry Lake near Hetch Hetchy, CA, Column G
- 11277500 Lake Eleanor near Hetch Hetchy, CA, Column J
- 11287500 Don Pedro Reservoir near La Grange, CA, Column M

The record is reported in units of ac-ft.

Change in Storage Columns E, H, K, and N
The algebraic difference of the previous day storage record and the current day storage record. The value provides the storage change from the previous day, and is converted from ac-ft to cfs by multiplying by a conversion constant of 0.504167.

- Hetch Hetchy Reservoir, Column E
- Lake Lloyd Reservoir, Column H
- Lake Eleanor, Column K
- Don Pedro Reservoir, Column N

The record is reported in units of cfs.

Reservoir Evaporation Columns F, I, L, and O
Daily evaporation in a reservoir, estimated by determining the surface area of a reservoir from reservoir storage applied to area rating tables and multiplying the surface area by the evaporation factor (tables) for the month involved.

- Hetch Hetchy Reservoir, Column F
- Lake Lloyd Reservoir, Column I
- Lake Eleanor, Column L
- Don Pedro Reservoir, Column O

For CCSF reservoirs an estimate of monthly net depth of evaporation is applied. These factors were developed from the mean of monthly observed depths of evaporation and precipitation readings taken at Lake Eleanor from 1909 to 1933. These factors are shown in the Table 2.1-1 below.

The same daily reservoir evaporation value for each of its reservoirs is used for the applicable month based on the ending storage of the previous month. The factor shown in the table is multiplied by the area, with the result being in units of cfs.

Table 2.1-1. CCSF Reservoir Daily Evaporation Factors.

Month	Daily Factor	Month	Daily Factor
January	-0.00325269	July	0.00975807
February	-0.00360119	August	0.00975807
March	0.00000000	September	0.00672222
April	0.00000000	October	0.00325269
May	0.00325269	November	0.00000000
June	0.00672222	December	0.00000000

For Don Pedro Reservoir, monthly evaporation factors were also derived from monthly averages from historical experience. These factors, converted to apply as a daily factor multiplied by the surface area of Don Pedro Reservoir are shown in the Table 2.1-2 below.

Table 2.1-2. Don Pedro Reservoir Daily Evaporation Factors.

Month	Daily Factor	Month	Daily Factor
January	-0.00088458	July	0.01397570
February	-0.00025777	August	0.01410893
March	0.00113491	September	0.01072018
April	0.00308124	October	0.00639480
May	0.00796822	November	0.00178105
June	0.01094715	December	-0.00013449

Don Pedro Reservoir evaporation is computed for every day, and results are in units of cfs.

The storage to surface area rating tables used for the estimated evaporation loss calculation are included in the Hydrology Workbook within the worksheet labeled “Reservoir”.

<u>Measured Flow</u> Columns P, Q, R, S, T, U, V, W, X, Y, Z, AA, AB, AC, and AD
Several measured flow components are needed to compute unimpaired flow at the three primary locations. To compute unimpaired flow at La Grange, the following measured flow records are needed:

- CCSF[3] San Joaquin Pipelines (SJPL), Column Z
- 11289000 Modesto Canal near La Grange, CA, Column AA
- 11289500 Turlock Canal near La Grange, CA, Column AB
- 11289650 Tuolumne River below La Grange Dam, near La Grange, CA, Column AC

[3] CCSF gage locations are shown Figure 2.1-1.

The diversion to the SJPL, measured in million gallons per day (mgd) at the Oakdale Meters, is multiplied by a conversion constant of 1.547229 and reported by CCSF in units of cfs. The other three records are reported by USGS, also in units of cfs.

The other records of measured flow pertain to the computation of unimpaired flow at Hetch Hetchy Reservoir and Lake Lloyd Reservoir and Eleanor Lake. With little or no impairment upstream of these reservoirs, the computation of unimpaired inflow at these locations also represents the inflow to these reservoirs. The records provided are:

- 11276500 Tuolumne River near Hetch Hetchy, CA, Column P
- 11276600 Tuolumne River above Early Intake, near Mather, CA, Column Q
- 11276900 Tuolumne River below Early Intake, near Mather, CA, Column R
- 11278000 Eleanor Creek near Hetch Hetchy, CA, Column S
- 11277300 Cherry Creek below Cherry Valley Dam, near Hetch Hetchy, CA, Column T
- 11278300 Cherry Creek near Early Intake, CA, Column U
- 11278400 Cherry Creek below Dion R. Holm Powerplant, near Mather, CA, Column V
- CCSF Lower Cherry Aqueduct, Column W
- CCSF Mountain Tunnel, Column X
- CCSF Holm Powerhouse, Column Y

The use of these records within computation procedures is described in the next section. Column AD “Total Release Don Pedro Dam” is for informational purposes and is the summation of Columns AA, AB and AC, in cfs.

<u>Computed Unimpaired Flow</u> Columns AE, AF, AG, and AH

As described earlier, unimpaired flow is computed by removing the effects that upstream storage and diversions have upon the flow in the stream. In a developed basin such as the Tuolumne River the procedures involve the recognition of the physical impairments that happen along the course of the stream.

There is no gage to measure inflow to Hetch Hetchy Reservoir. Hence, the computation of unimpaired flow into Hetch Hetchy Reservoir (Column AE), which is accepted as the inflow to Hetch Hetchy Reservoir, is calculated for a time period, *t*, using recorded historical storage, outflow and reservoir evaporation data using the following equation. The equation is of a form that recognizes all flow entering and exiting a reservoir must balance.

$$\text{Inflow}_t = \text{Ouflow}_t + \text{Storage}_t - \text{Storage}_{t\text{-}1} + \text{Reservoir Evaporation}_t$$

The storage and reservoir evaporation components of the equation have already been defined or computed for Hetch Hetchy Reservoir by Column D (Hetch Hetchy Reservoir storage) computed as a change in storage expressed as average daily flow (Column E), and Column F (reservoir evaporation) expressed as average daily flow. Outflow from Hetch Hetchy Reservoir is the summation of water released to the stream below O'Shaunessy Dam and to Canyon Power Tunnel.

Releases from Hetch Hetchy Reservoir to the stream below O'Shaunessy Dam are measured at the USGS gaging station below the dam (USGS gage 11276500; Column P). Releases to Canyon Power Tunnel are computed by accounting for the flow through Mountain Tunnel (Column X) and the flow that is released back to the Tuolumne River from Kirkwood Powerhouse. The release back to the Tuolumne River from Kirkwood Powerhouse is estimated by measuring the flow in the Tuolumne River upstream of the release (USGS gage 11276600; Column Q) and downstream of the release (USGS gage; 11276900; Column R), and adjusting the difference in flow by amount of flow that occurs to the reach from the Lower Cherry Aqueduct (Column W).

By substituting the recorded values into the equation, the following computation results. Results are shown in Column AE.

Unimpaired Flow (inflow) at Hetch Hetchy Reservoir

Inflow $_t$ = Column P $_t$ (flow below dam) + Column X $_t$ (Mountain Tunnel) - Column Q $_t$ (above Early Intake) + Column R $_t$ (below Early Intake) - Column W $_t$ (Lower Cherry Aqueduct) + Column E $_t$ (change in storage) + Column F $_t$ (reservoir evaporation)

For the computation of unimpaired flow of Cherry Creek and Eleanor Creek into Lake Lloyd Reservoir and Lake Eleanor (combined) (Column AF) the same basic reservoir equation is used. The change in storage and reservoir evaporation components of the equation have already been computed for Lake Lloyd Reservoir and Lake Eleanor by Column H and Column K (Lake Lloyd Reservoir storage change and Lake Eleanor storage change) computed as a change in storage expressed as average daily flow, and Column I and Column L (reservoir evaporation, respectively for Lake Lloyd Reservoir and Lake Eleanor) expressed as average daily flow. Outflow from Lake Lloyd Reservoir and Lake Eleanor is the summation of water released to the streams below Cherry Valley Dam and Eleanor Dam, and to Cherry Power Tunnel.

Releases from Cherry Valley Dam and Eleanor Dam to the streams are measured at USGS gaging stations below the dams (USGS gage 11277300, Column T, and USGS gage 11278000, Column S). Flow diverted to Cherry Power Tunnel from Lake Lloyd Reservoir and released back to Cherry Creek is estimated by measuring the flow in Cherry Creek above Holm Powerhouse (USGS gage 11278300, Column U) and below Holm Powerhouse (USGS gage 11278400, Column V), and computing the difference between measurements.

By substituting the recorded values into the equation, the following computation results. Results are shown in Column AF.

Unimpaired Flow (inflow) at Lake Lloyd Reservoir and Lake Eleanor (combined)

Inflow $_t$ = Column T $_t$ (flow below Cherry Valley Dam) + Column S $_t$ (flow below Eleanor Dam) + Column V $_t$ (flow below Holm Powerhouse) - Column U $_t$ (flow above Holm Powerhouse) + Column H $_t$ (change in Lake Lloyd Reservoir storage) +

Column K_t (change in Lake Eleanor storage) + Column I_t (Lake Lloyd Reservoir evaporation) + Column L_t (Lake Eleanor evaporation)

For the computation of unimpaired flow at La Grange, the basic inflow equation again applies, only in this instance the combined effects of both CCSF and District diversions and storage (above La Grange) are incorporated. For this computation the storage effects of Don Pedro Reservoir, Hetch Hetchy Reservoir, Lake Lloyd Reservoir and Lake Eleanor affect flow in the Tuolumne River. Regarding diversions from the river above La Grange that affect the computation, CCSF's SJPL diversion and the Districts' two canal diversions at La Grange Dam are incorporated. The other diversions described previously for CCSF operations remain within the basin and are assumed to be diverted and returned to the river instantaneously. The regulated release to the Tuolumne River below La Grange Dam is treated as an outflow in the equation.

By substituting the recorded values into the equation below the following computation results. Results are shown in Column AG.

Unimpaired Flow at La Grange

Unimpaired $Flow_t$ = Column AC_t (flow at La Grange) + Column Z_t (CCSF SJPL) + Column AA_t (MID Canal) + Column AB_t (TID Canal) + Column N_t (change in Don Pedro Reservoir storage) + Column E_t (change in Hetch Hetchy Reservoir storage) + Column H_t (change in Lake Lloyd Reservoir storage) + Column K_t (change in Lake Eleanor storage) + Column O_t (Don Pedro Reservoir evaporation) + Column F_t (Hetch Hetchy Reservoir evaporation) + Column I_t (Lake Lloyd Reservoir evaporation) + Column L_t (Lake Eleanor evaporation)

The Model incorporates two components of inflow to Don Pedro Reservoir, a component of regulated inflow through CCSF facilities and a component of inflow (considered unimpaired) not affected by CCSF facilities. This second component of inflow was described previously and concerns runoff from tributaries and streams such as the South and North Forks of the Tuolumne River. A computation of this component of flow is provided in Column AH and is the algebraic difference between the total unimpaired flow computed at La Grange (Column AG) and the two components of unimpaired flow (inflow) to Hetch Hetchy Reservoir (Column AE, calculated above) and Lake Lloyd Reservoir and Lake Eleanor (Column AF, calculated above).

Also computed from the information used to develop the unimpaired flow records is the computed historical record of total inflow to Don Pedro Reservoir. Although unnecessary for scenario modeling since inflow to Don Pedro Reservoir will be the result of modeling assumptions, the computed historical record of inflow serves as a benchmark for Model validation. Computed inflow to Don Pedro Reservoir is derived from the basic mass balance equation:

$$Inflow_t = Ouflow_t + Storage_t - Storage_{t-1} + Reservoir\ Evaporation_t$$

Where, outflow is the total release from Don Pedro Reservoir which is the combined measured flow at La Grange (Column AC) plus diversions to Modesto Canal (Column AA) plus diversions to Turlock Canal (Column AB). The result of the computation is provided in Column AU noted as “Inflow to Don Pedro”.

For reservoir temperature modeling calibration and validation purposes, both the regulated and unregulated components of computed historical inflow to Don Pedro Reservoir were needed. The unregulated inflow and total inflow to Don Pedro Reservoir have been described above. The computed historical regulated component of inflow to Don Pedro Reservoir is the difference between the total inflow and unregulated inflow, and is reported in Column AV.

2.2 Adjustment of Historical Inflow to Don Pedro Reservoir

Although not directly used by the Model, unimpaired flow at La Grange is needed to develop a unique component of unimpaired flow which depicts the runoff entering Don Pedro Reservoir that is not affected by upstream CCSF facilities. This runoff concerns runoff from tributaries and streams such as the South and North Forks of the Tuolumne River. This component of runoff is referred to as unregulated inflow to Don Pedro Reservoir. It is computed as the difference between the unimpaired flow at La Grange and the unimpaired flows entering Hetch Hetchy Reservoir, Lake Lloyd and Lake Eleanor.

Due to computational procedures, gage accuracy, and reporting errors there can be on occasion a reporting of a “negative” flow associated with one or more of the just described unimpaired flow components. These computed negative flows are typically the result of applying a computational mass balancing of several flows and changes in storage components, which may result in an occasional computed negative value for flow. These occurrences are considered anomalies in the day to day record, which tend to occur during low flow periods when a small misinterpretation of reservoir stage can overwhelm the determination of a small flow value. These anomalies in daily values will normally self-correct over several days of record. Within the modeling of CCSF facilities, the unimpaired flow data that will be used consists solely of the inflows to Hetch Hetchy Reservoir and Lake Lloyd and Lake Eleanor. This daily record, potentially inclusive of intermittent negative daily flows, will be absorbed by reservoir operations (storage in Hetch Hetchy Reservoir up to 360,000 acre-feet and storage in Lake Lloyd and Lake Eleanor up to 295,000 acre-feet). Within the model, an anomaly in inflows such as a negative flow one day and a compensating overestimation of inflow the next will be correctly accounted for, but the precise day-to-day fluctuation will be "lost" within the operation of the reservoir and not cause a decisional effect to simulated operations.

The release from CCSF facilities, components from Hetch Hetchy Reservoir and components from Lake Lloyd and Lake Eleanor, is added to the unregulated inflow to Don Pedro Reservoir which becomes the total inflow to Don Pedro Reservoir. Due to the same data challenges as described above for the computation of inflow to CCSF reservoirs and the unimpaired flow at La Grange, there are occurrences of "negative flows" within the record of the mathematically derived unregulated inflow to Don Pedro Reservoir. From a perspective of modeling the operations of Don Pedro Reservoir, the intermittent occurrence of negative flows for the unregulated component of total Don Pedro Reservoir inflow is also not problematic. In many instances the computed negative unregulated flows will be overwhelmed by the positive regulated flow being released from CCSF facilities. However, even if there remained a net negative inflow Don Pedro Reservoir storage would absorb negative inflows as an adjustment to reservoir storage and not affect operation decisions which rely on greater-than-daily hydrology.

That all said, a need to refine (adjust) the negative flow values for unregulated inflow to Don Pedro Reservoir occurs due to modeling needs of the Don Pedro Reservoir temperature model. Inflow is modeled as two distinct components as described above, with separate temperature characteristics associated with each component. With this approach, negative inflow values associated with a component of inflow is not acceptable for reservoir temperature modeling. Therefore, the daily unregulated inflow component must be adjusted through data smoothing techniques to remove the occurrence of negative values.

The following provides documentation of the procedures and results of performing adjustments to hydrology used for modeling purposes.

Procedures for Adjusting Historical Unregulated Inflow to Don Pedro Reservoir

This component of hydrology is derived as the mathematical difference between the computed unimpaired flow at La Grange and the computed unimpaired flow entering Hetch Hetchy Reservoir, Lake Lloyd and Lake Eleanor (CCSF facilities). This component of flow is a fact of the computed historical record and is unaffected by CCSF facility operation. The daily-varying values will be consistent among all scenario studies and calibration-validation studies. The procedures employed to remedy negative values were guided by the following steps:

For each month in a year:

- Isolated negative values were replaced by a 3-day (or other short duration) average when possible, preserving the volume of the three days (or other duration). This form of adjustment was typically applied during non-summer or fall months. These instances appeared to occur from isolated day-to-day anomalies in the data. The shortness of the averaging period preserved adjacent period flow fluctuations including storm events.
- During chronic extended periods of anomalies (typically summer and fall months), a month was split into 1/3 periods and averaged during each period, preserving the period's volume. Within a month the values were sometimes averaged over longer or shorter periods to preserve the hydrology of apparent storms. Monthly volumes were preserved when possible.
- Values within a month were sometimes averaged over longer periods to eliminate sub-month period negative averages.
- When a month average was less than zero, the entire period was set as 1 cfs. This form of adjustment does not maintain the annual volume of runoff but was relatively small when compared to the annual volume. Some sub-month period 1 cfs adjustments were made.

Procedures for Adjusting Historical Regulated Inflow to Don Pedro Reservoir

This component of historical hydrology is not germane to scenario modeling. Within scenario modeling the regulated inflow to Don Pedro Reservoir will be determined by Model logic and assumptions, and may be unique to each study. However, for Don Pedro Reservoir temperature model calibration-validation and analysis, the historical computed record of the regulated inflow component of Don Pedro Reservoir must also be absent of negative values. The regulated inflow component is the mathematical difference between the computed inflow to Don Pedro Reservoir and the computed unregulated component of inflow. Due to the far fewer number of instances of occurrence and the limited use of this data set for temperature model calibration-validation and analysis a more simple approach of adjustment was employed. All negative values were replaced with a positive 1 cfs value.

Results

The computation and results of adjustments to the computed unregulated and regulated components of historical Don Pedro Reservoir inflow are shown in the Hydrology Workbook in Column AP through Column AY. A summary of annual computed historical hydrology and the adjustments is shown in Table 2.2-1 below. Reported “adjustments” represent the difference in volume of water associated with replacing a computed negative flow value with a 1 cfs flow assumption. This circumstance only occurs when the computed average flow in a month was less than zero.

Table 2.2-1. Summary of adjustments to computed historical inflow (annual).

	Before Adjustment			After Adjustment					
CY	Don Pedro Inflow AF	Regulated Inflow AF	Unregulated Inflow AF	Regulated Inflow AF	Regulated Adjustment AF	Unregulated Inflow AF	Unregulated Adjustment AF	Total Adjustment AF	Percent Adjustment %
1971	1,452,671	950,336	502,335	950,336	0	502,335	0	0	0.0
1972	994,994	628,774	366,220	628,774	0	366,220	0	0	0.0
1973	1,792,297	939,056	853,240	939,056	0	853,240	0	0	0.0
1974	1,846,644	1,163,328	683,316	1,163,328	0	683,316	0	0	0.0
1975	1,854,713	1,065,222	789,491	1,065,222	0	789,491	0	0	0.0
1976	440,985	303,132	137,852	303,132	0	145,444	7,592	7,592	1.7
1977	172,395	87,011	85,384	87,358	348	92,329	6,945	7,292	4.2
1978	2,574,771	1,497,986	1,076,785	1,497,986	0	1,076,785	0	0	0.0
1979	1,764,273	1,030,030	734,243	1,030,030	0	734,243	0	0	0.0
1980	2,712,898	1,582,413	1,130,485	1,582,413	0	1,130,485	0	0	0.0
1981	1,081,994	631,448	450,546	631,448	0	450,546	0	0	0.0
1982	3,712,941	1,946,427	1,766,513	1,946,427	0	1,766,513	0	0	0.0
1983	4,609,612	2,450,196	2,159,416	2,450,196	0	2,159,416	0	0	0.0
1984	1,918,102	1,322,120	595,983	1,322,120	0	595,983	0	0	0.0
1985	1,013,642	645,960	367,682	645,960	0	367,682	0	0	0.0
1986	2,582,309	1,536,733	1,045,576	1,536,733	0	1,045,576	0	0	0.0
1987	354,807	189,168	165,639	190,182	1,014	167,231	1,591	2,605	0.7
1988	722,606	507,453	215,153	507,453	0	215,153	0	0	0.0
1989	957,854	670,506	287,349	670,506	0	296,119	8,770	8,770	0.9
1990	725,340	550,191	175,149	550,191	0	184,956	9,807	9,807	1.4
1991	811,674	475,624	336,051	475,776	152	336,051	0	152	0.0
1992	720,161	462,794	257,368	462,794	0	257,368	0	0	0.0
1993	1,961,791	1,030,845	930,946	1,030,986	141	930,946	0	141	0.0
1994	856,778	604,162	252,616	608,056	3,894	258,434	5,818	9,712	1.1
1995	3,449,475	1,920,640	1,528,835	1,920,640	0	1,531,139	2,304	2,304	0.1
1996	2,601,289	1,541,146	1,060,143	1,541,146	0	1,060,143	0	0	0.0
1997	2,553,789	1,575,350	978,439	1,575,512	163	978,439	0	163	0.0
1998	3,002,931	1,547,432	1,455,500	1,547,855	423	1,455,500	0	423	0.0
1999	1,851,119	1,094,397	756,722	1,094,508	111	756,722	0	111	0.0
2000	1,861,233	1,082,329	778,904	1,083,865	1,536	778,904	0	1,536	0.1
2001	833,845	470,290	363,555	470,464	175	363,555	0	175	0.0
2002	1,137,527	760,735	376,792	760,735	0	384,724	7,932	7,932	0.7
2003	1,302,788	929,971	372,817	929,971	0	374,967	2,149	2,149	0.2
2004	1,098,453	790,920	307,532	790,936	16	307,532	0	16	0.0
2005	2,793,607	1,659,349	1,134,258	1,659,349	0	1,134,258	0	0	0.0
2006	2,897,316	1,737,130	1,160,186	1,737,130	0	1,160,186	0	0	0.0
2007	720,006	542,423	177,582	542,628	205	179,629	2,047	2,251	0.3
2008	810,433	509,554	300,879	509,554	0	300,879	0	0	0.0
2009	1,403,951	965,427	438,523	965,427	0	438,523	0	0	0.0

The following graphs illustrate the daily computed historical hydrology for total inflow to Don Pedro Reservoir and its regulated and unregulated inflow components, and the computed unimpaired runoff at La Grange for each year of the 1971 through 2009 modeling period. The data labeled "Adj Unregulated Inflow to Don Pedro" is the adjusted unregulated inflow to Don Pedro Reservoir and is shown as the solid red line. It lays over the original unregulated value which is shown as the solid royal blue line. During a significant amount of time there is no adjustment.

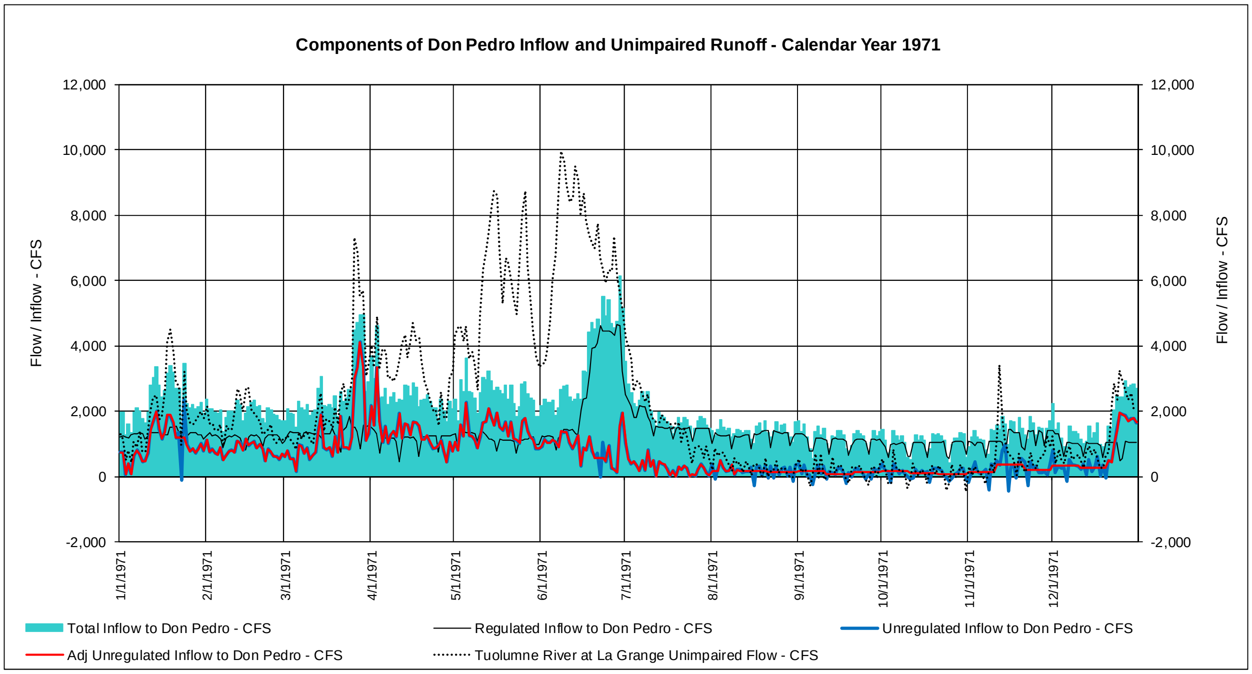


Figure 2.2-1. Calendar Year 1971.

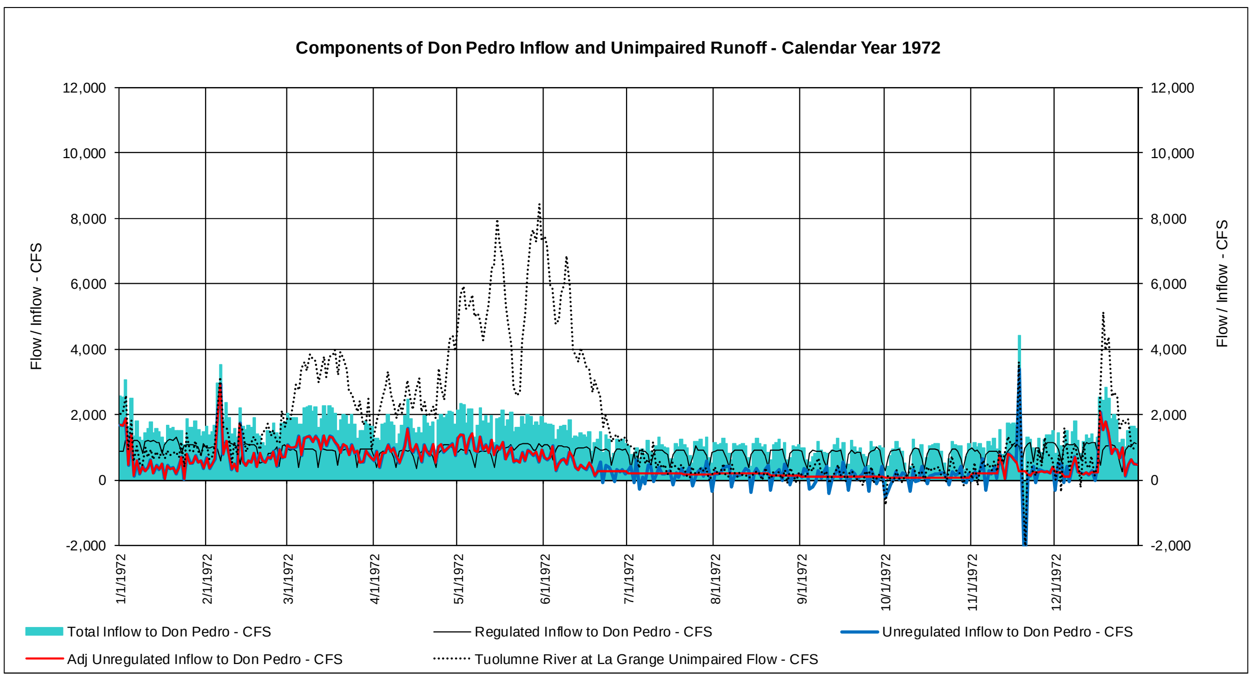


Figure 2.2-2. Calendar Year 1972.

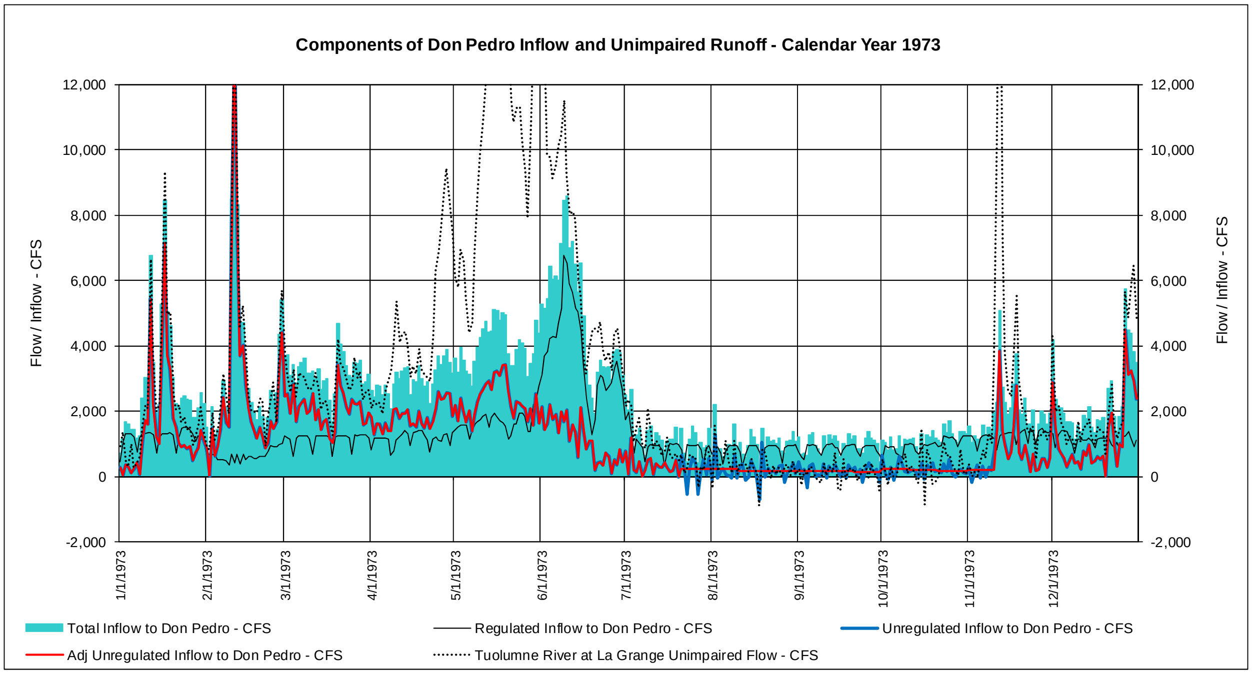


Figure 2.2-3. Calendar Year 1973.

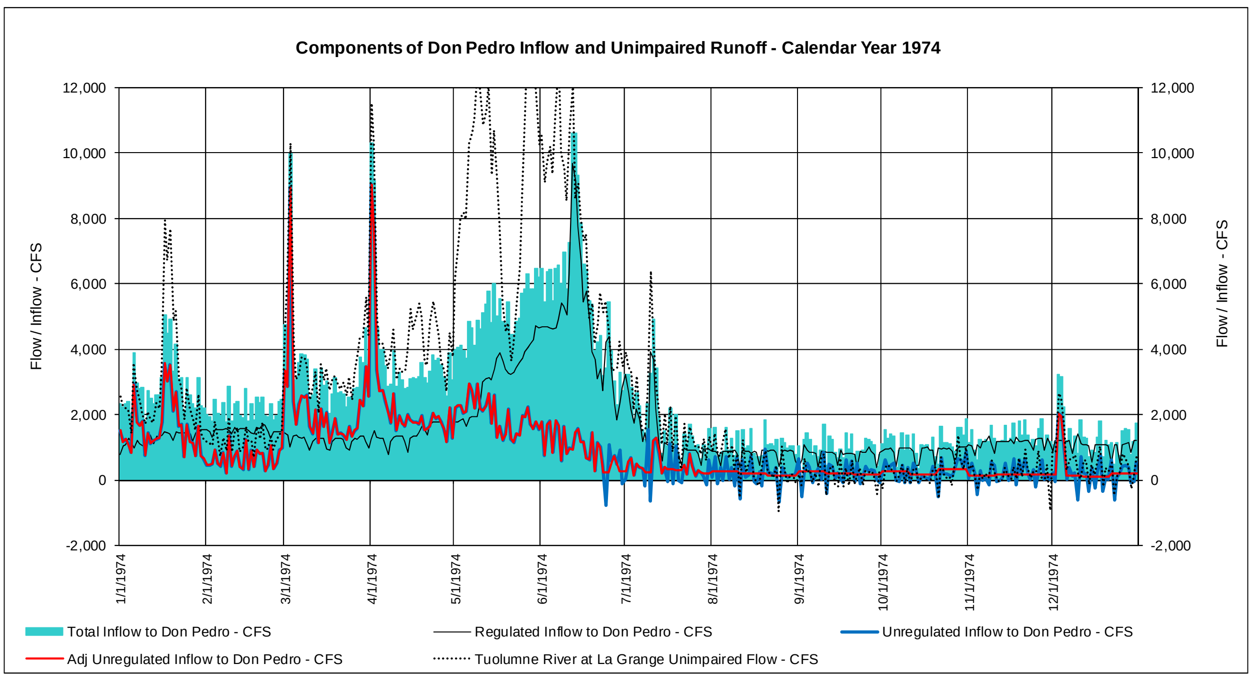


Figure 2.2-4. Calendar Year 1974.

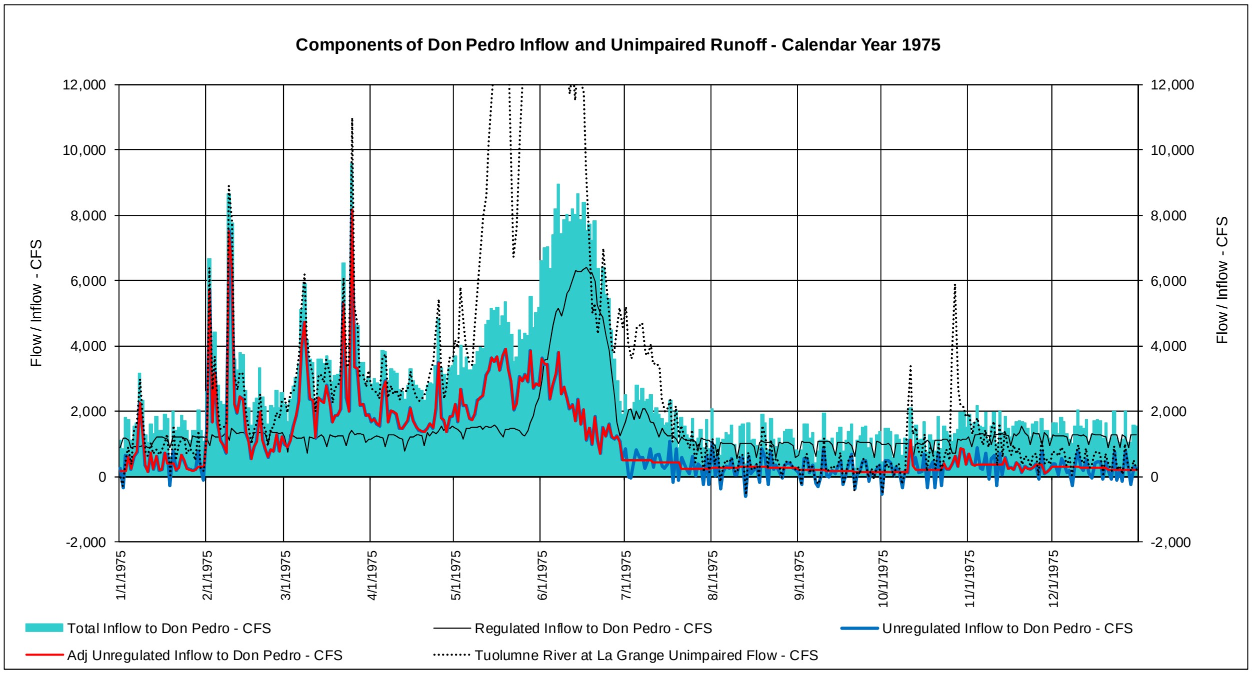


Figure 2.2-5. Calendar Year 1975

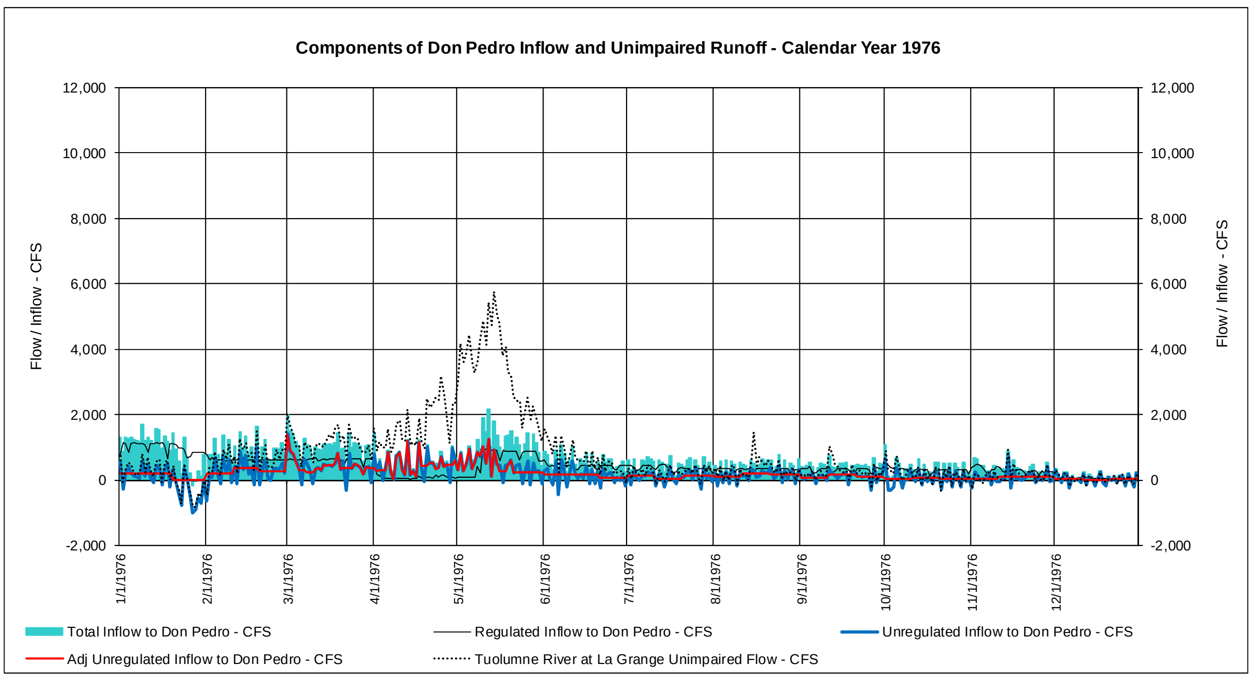


Figure 2.2-6. Calendar Year 1976.

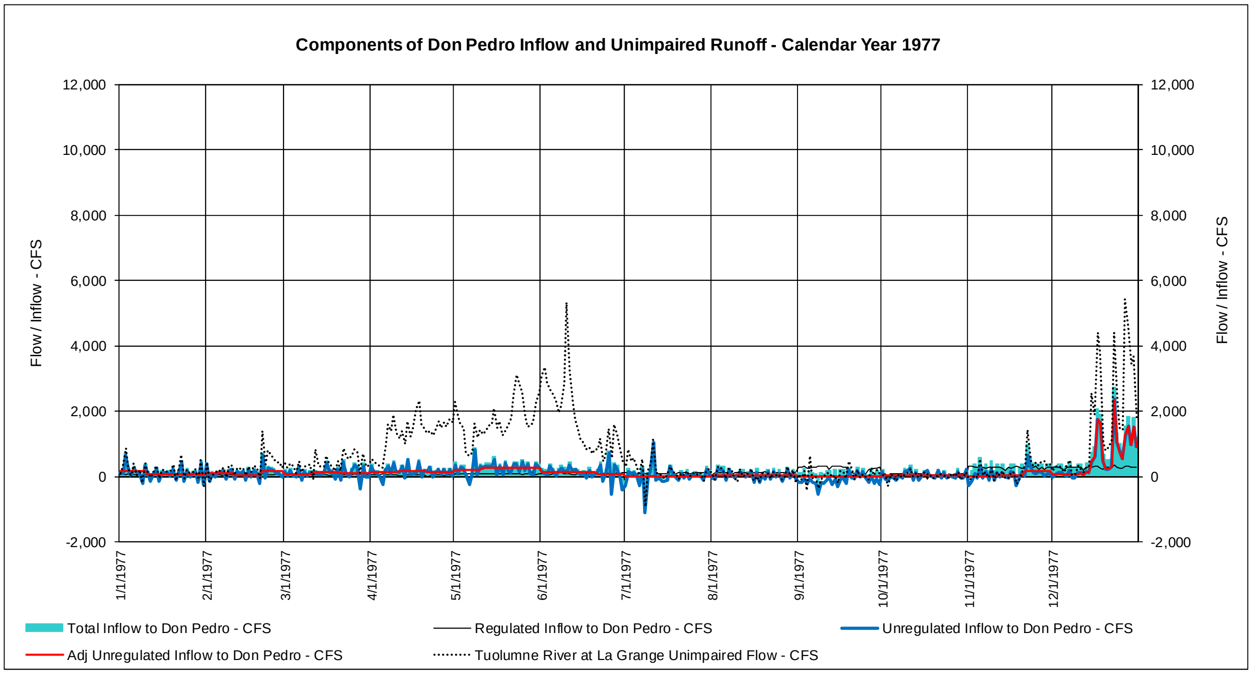


Figure 2.2-7. Calendar Year 1977.

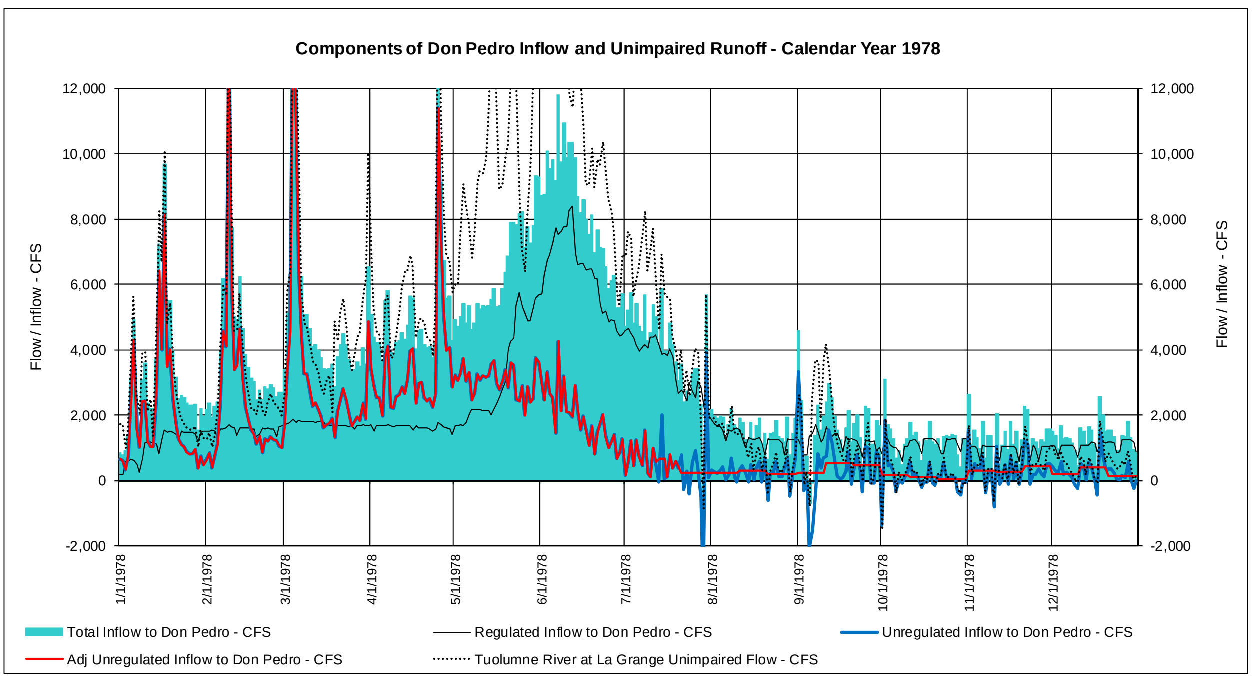


Figure 2.2-8. Calendar Year 1978.

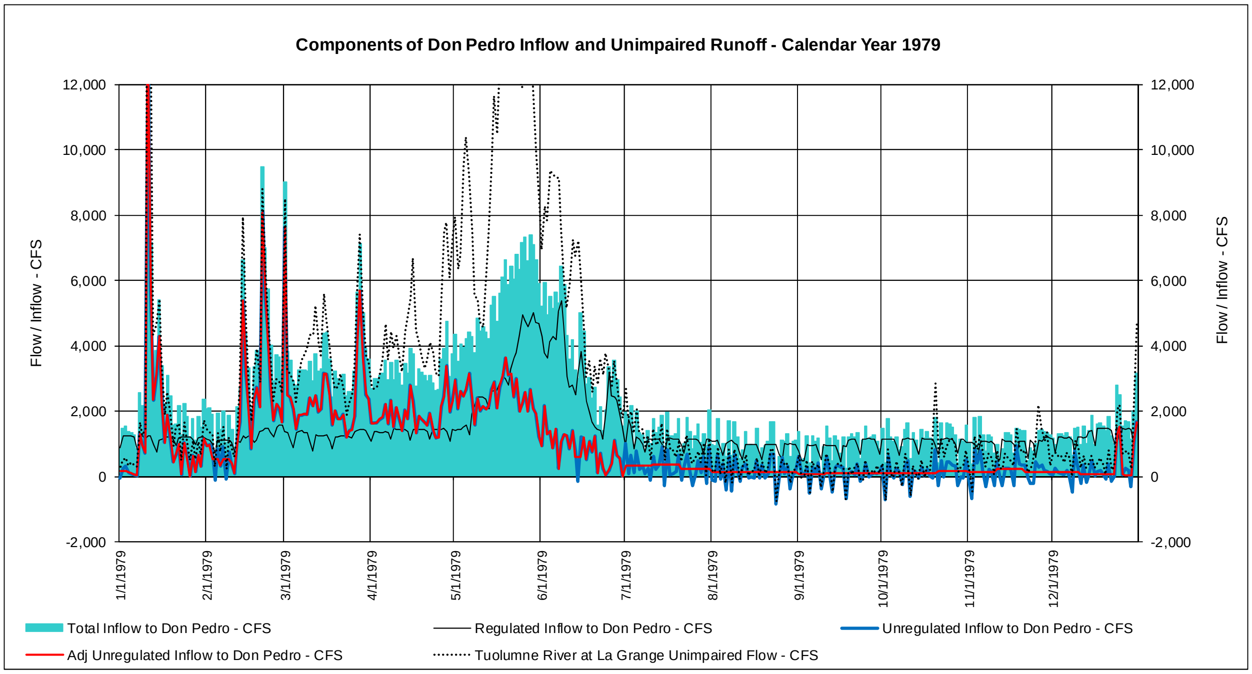


Figure 2.2-9. Calendar Year 1979.

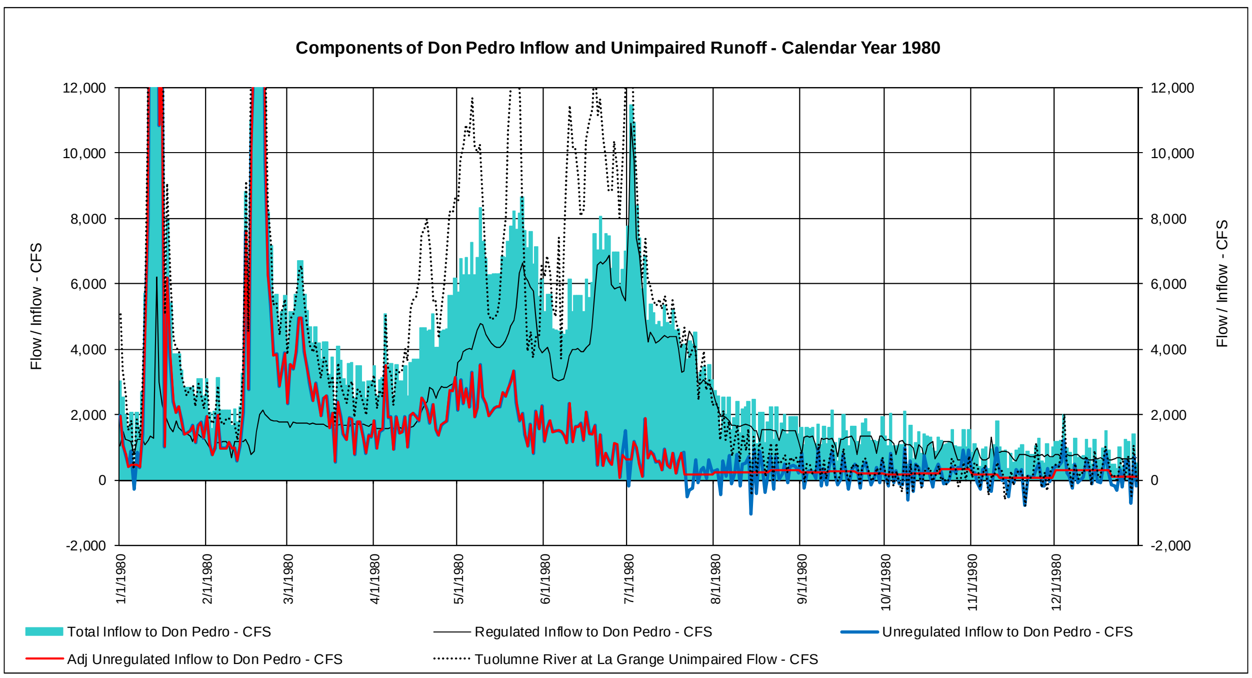


Figure 2.2-10. Calendar Year 1980.

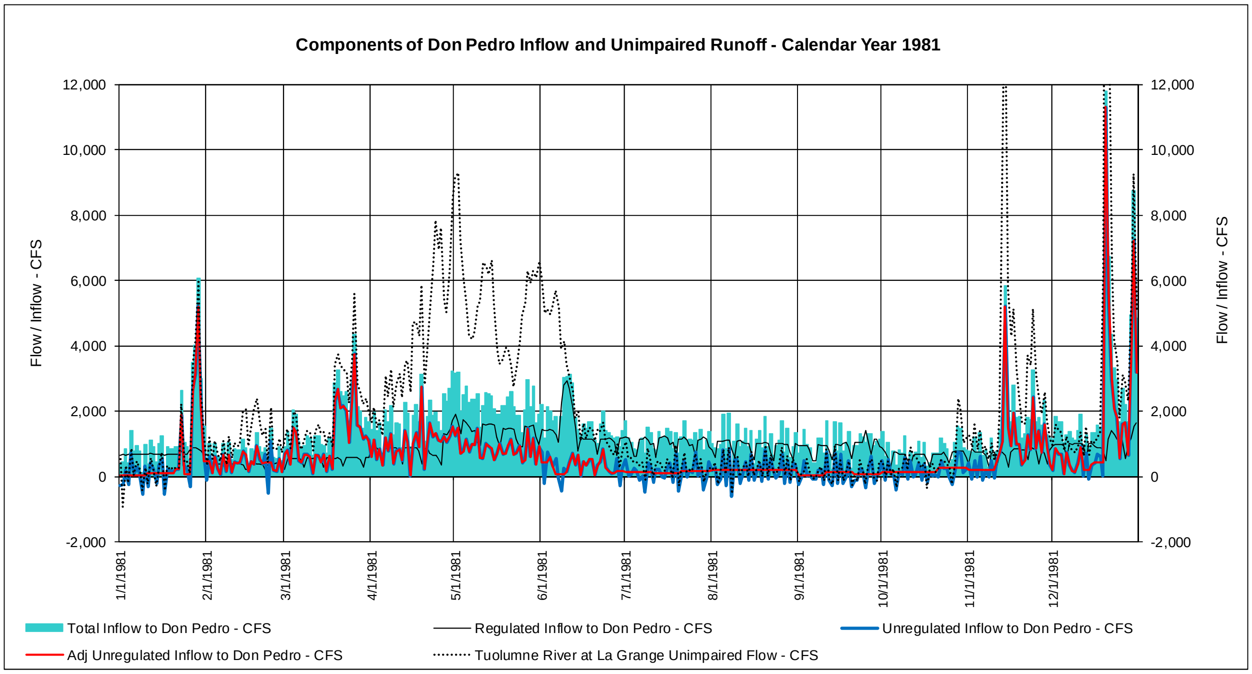
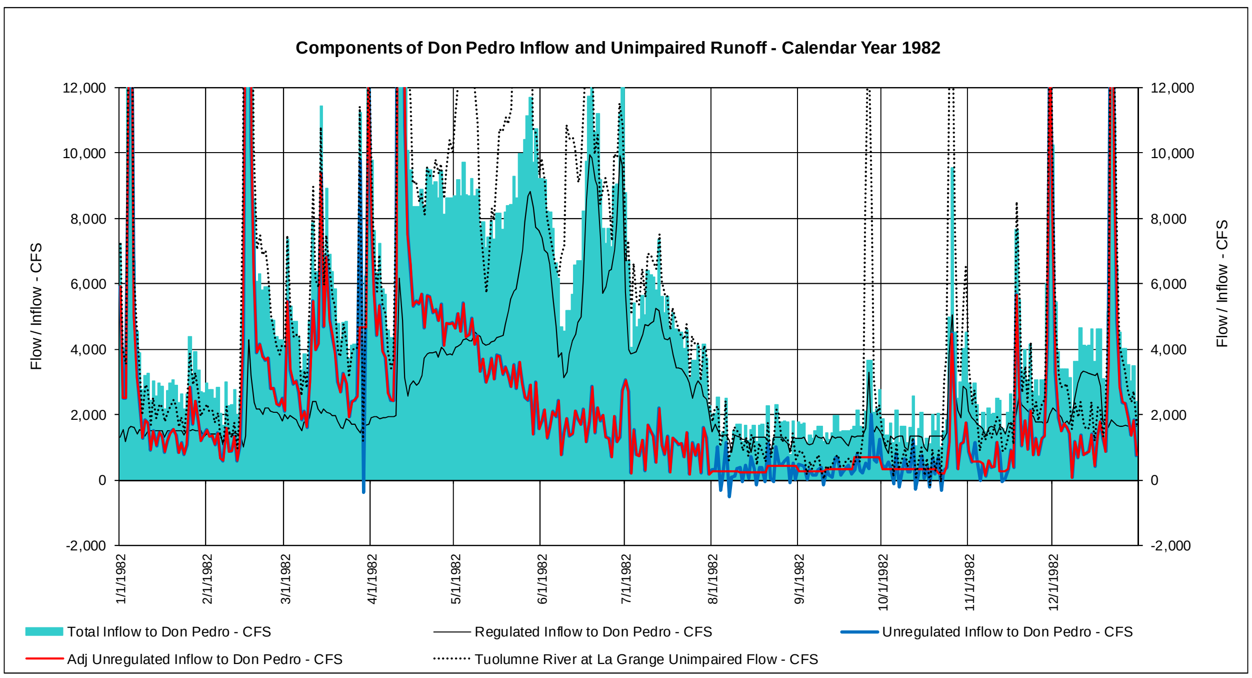


Figure 2.2-11. Calendar Year 1981.



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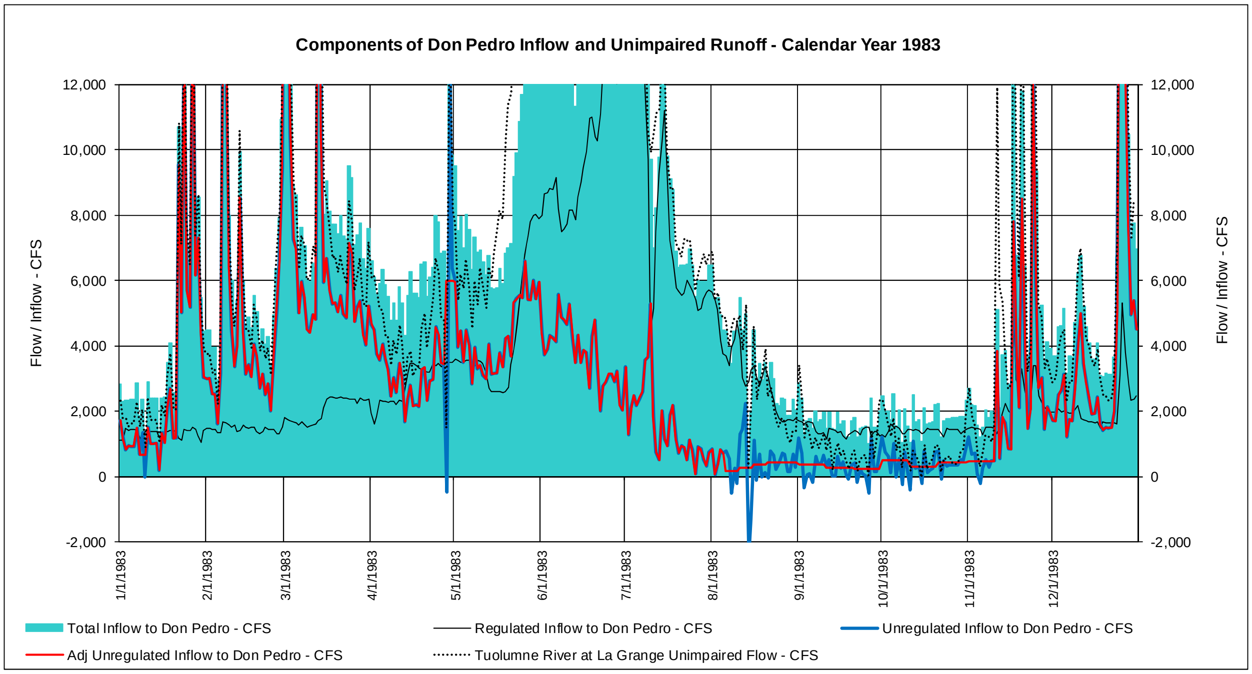


Figure 2.2-13. Calendar Year 1983.

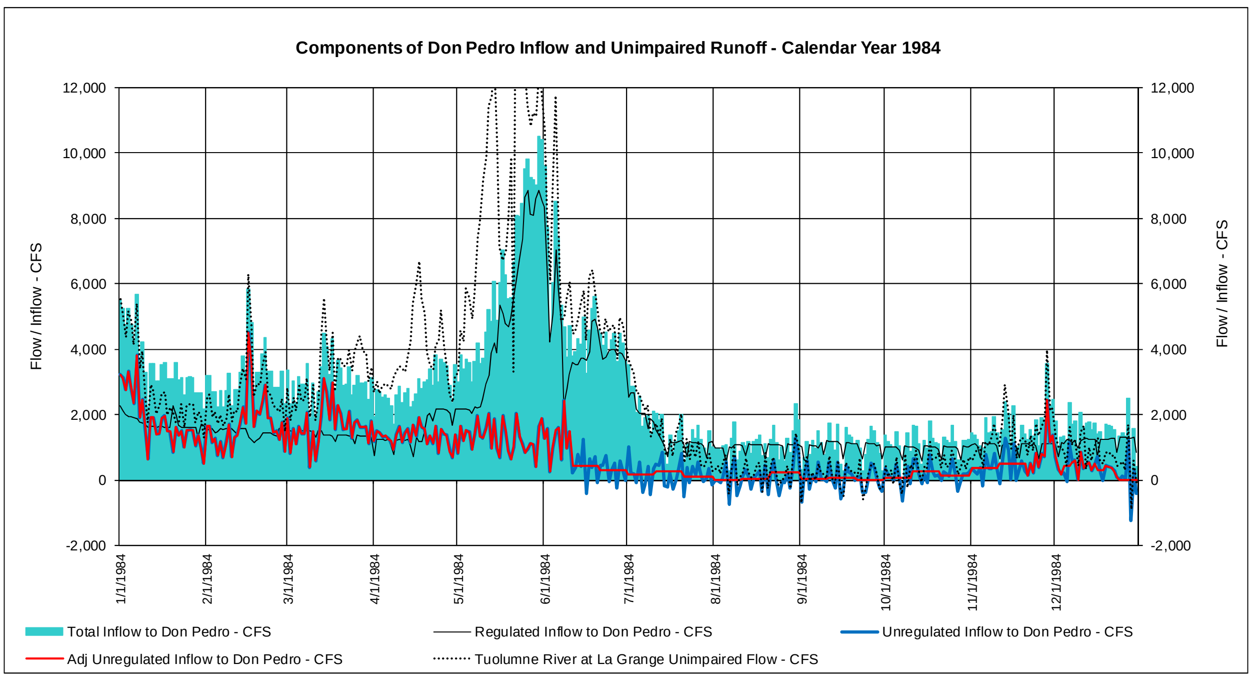
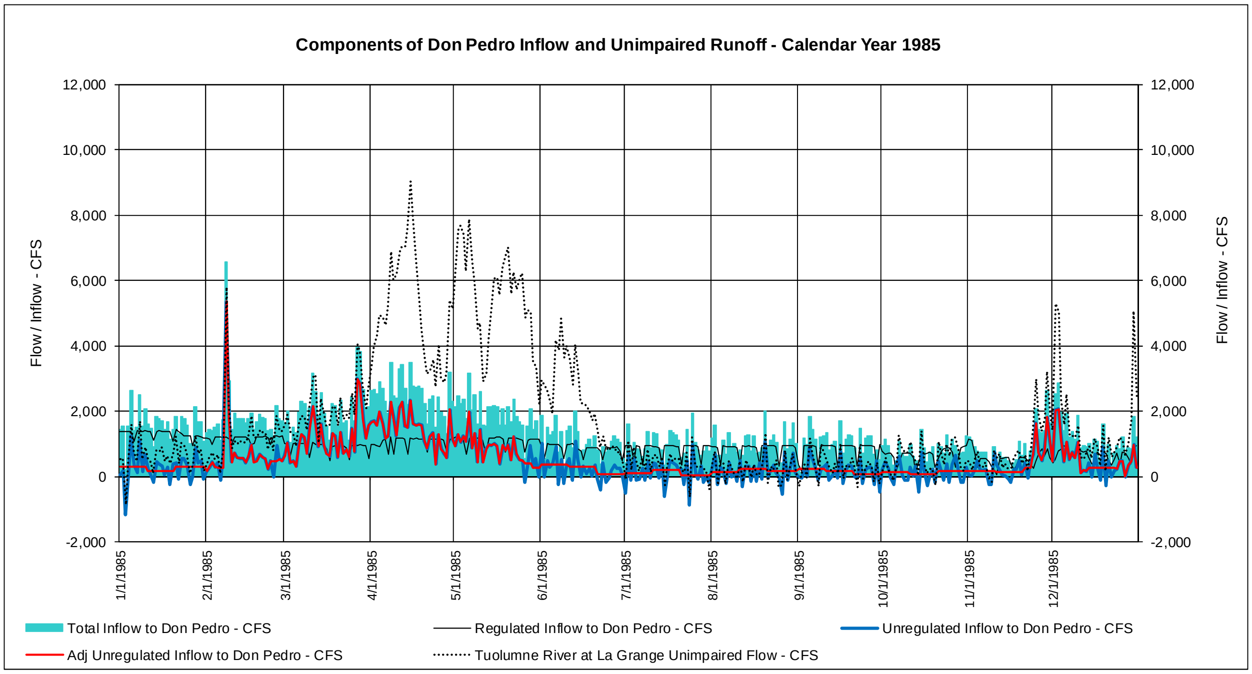


Figure 2.2-14. Calendar Year 1984.



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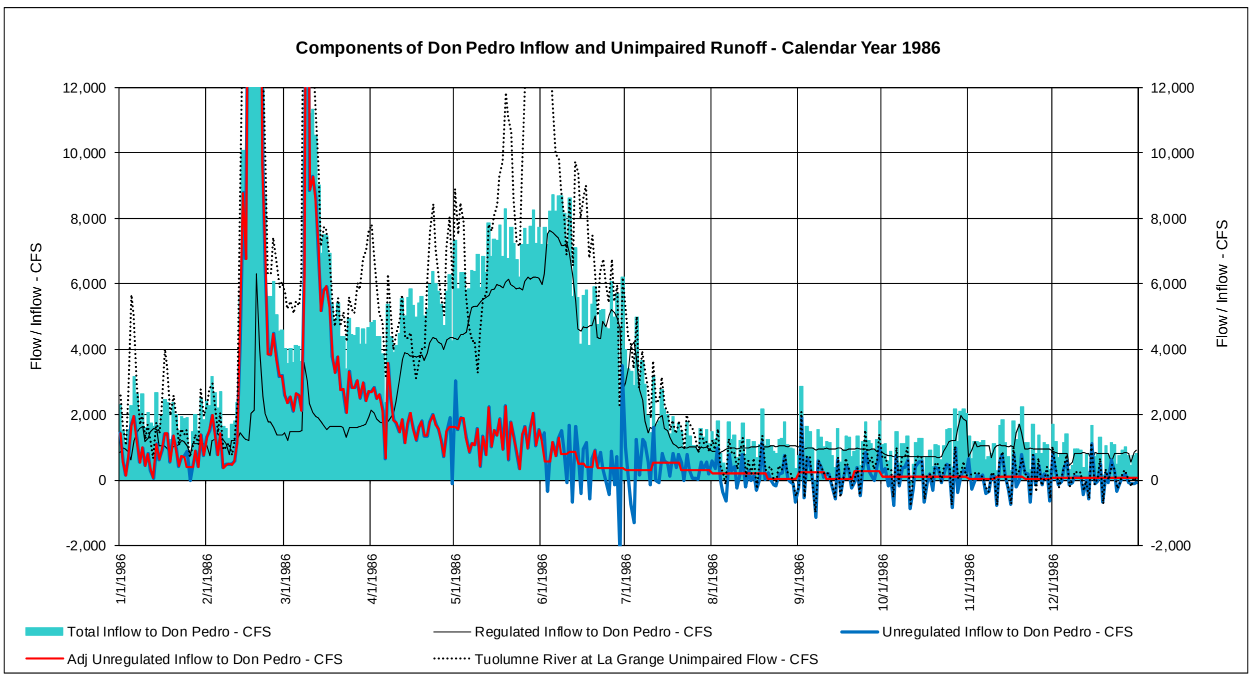

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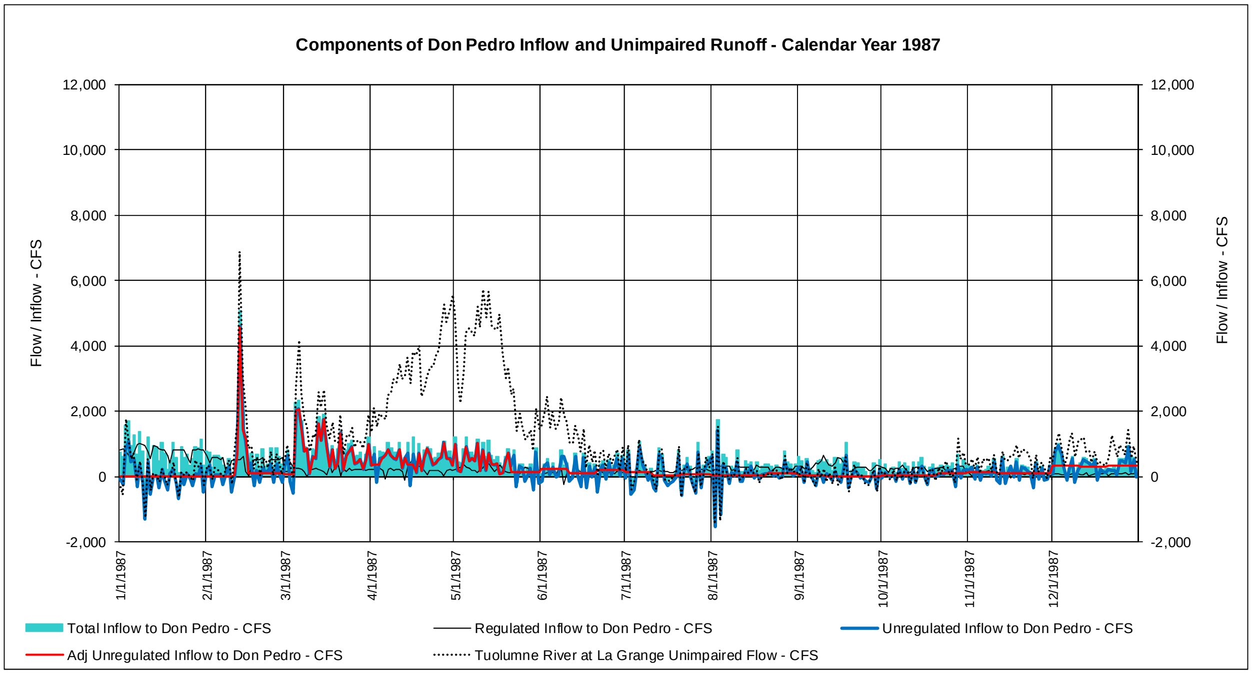

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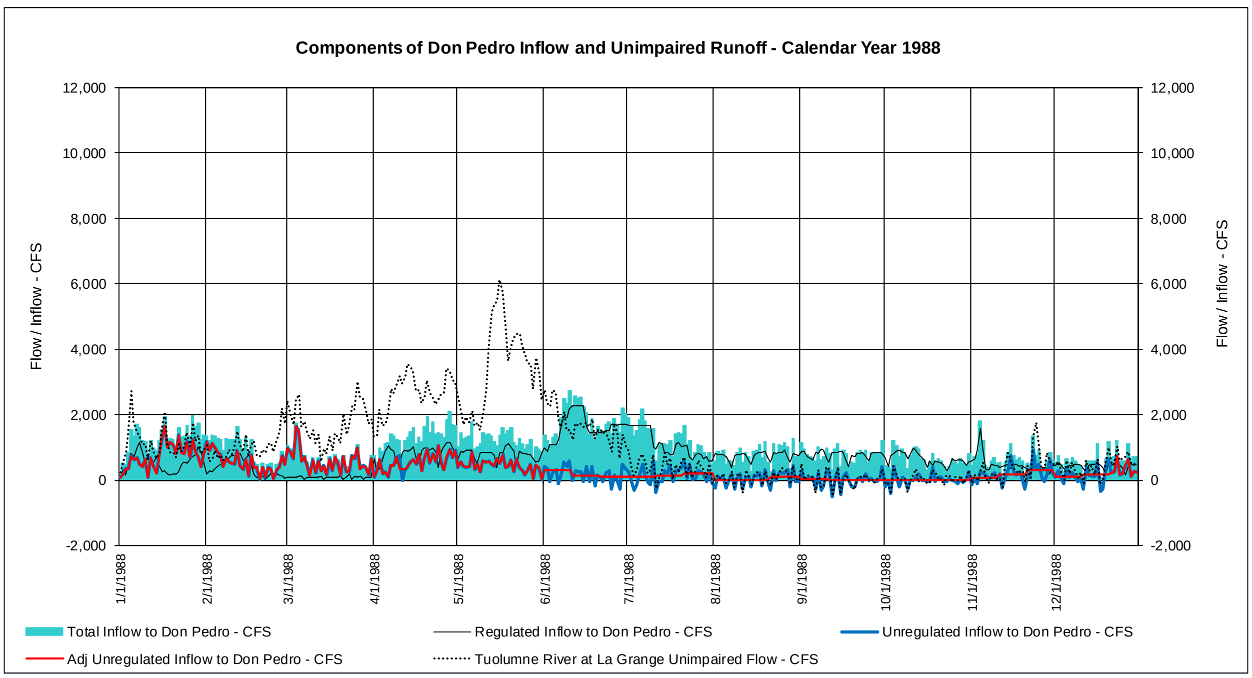


Figure 2.2-18. Calendar Year 1988.

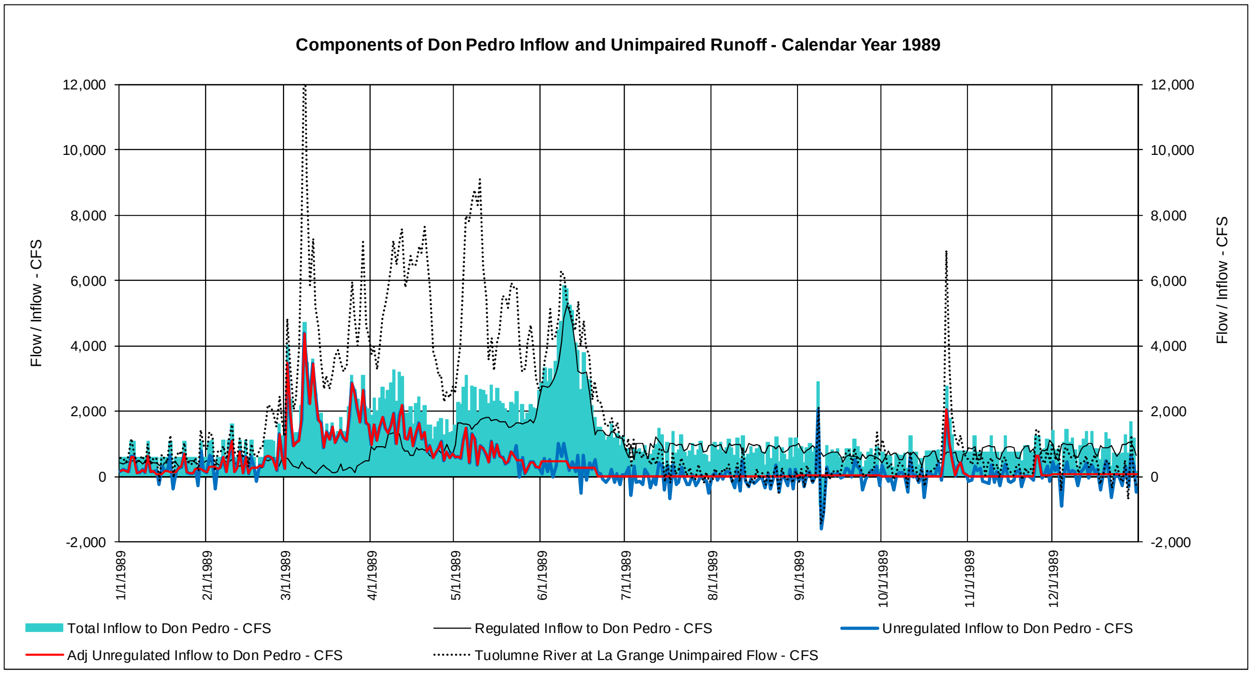


Figure 2.2-19. Calendar Year 1989.

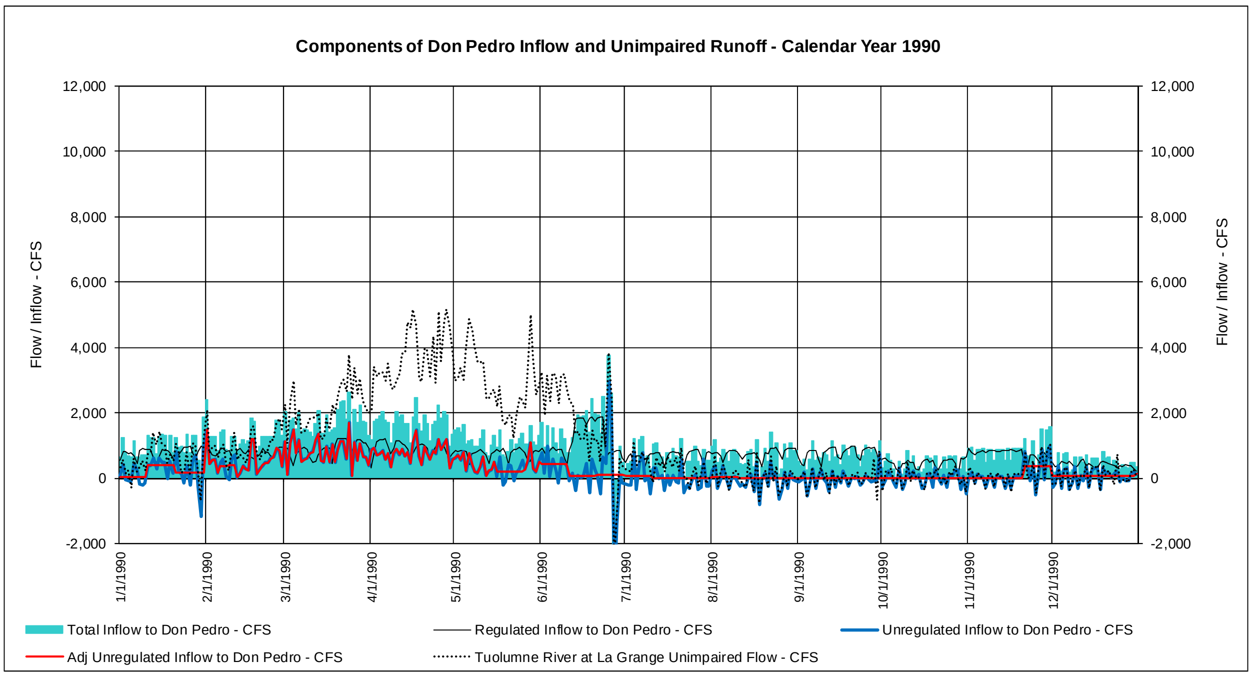


Figure 2.2-20. Calendar Year 1990.

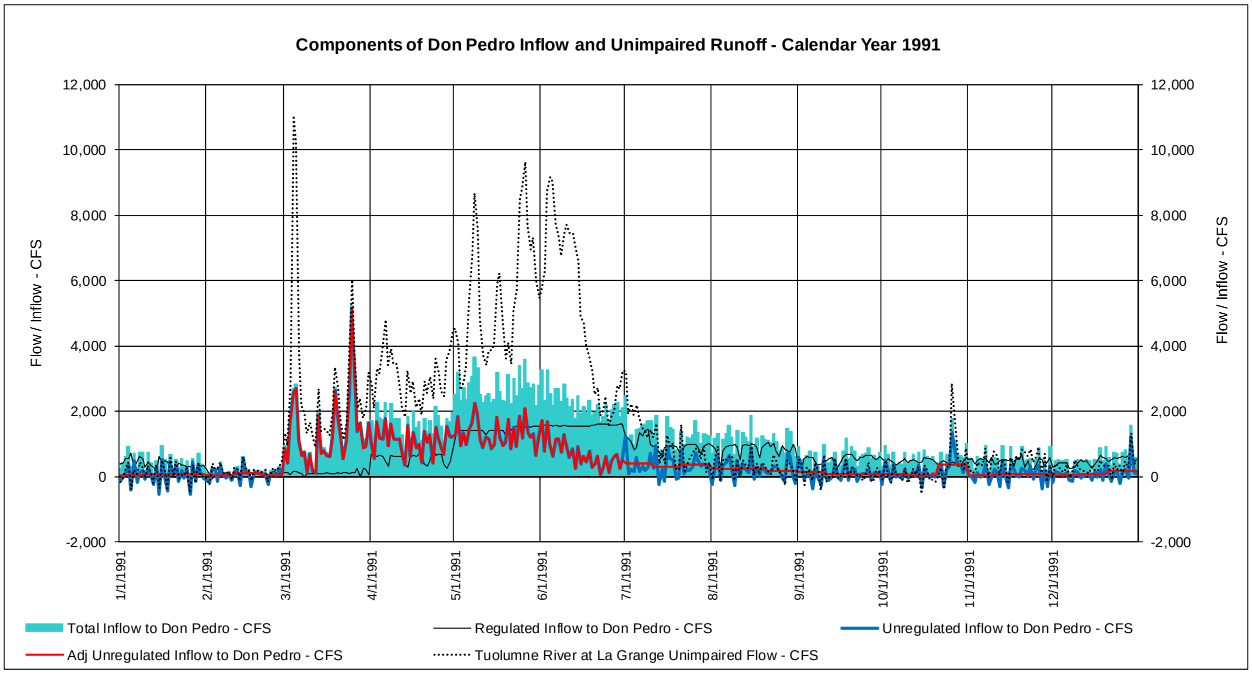


Figure 2.2-21. Calendar Year 1991.

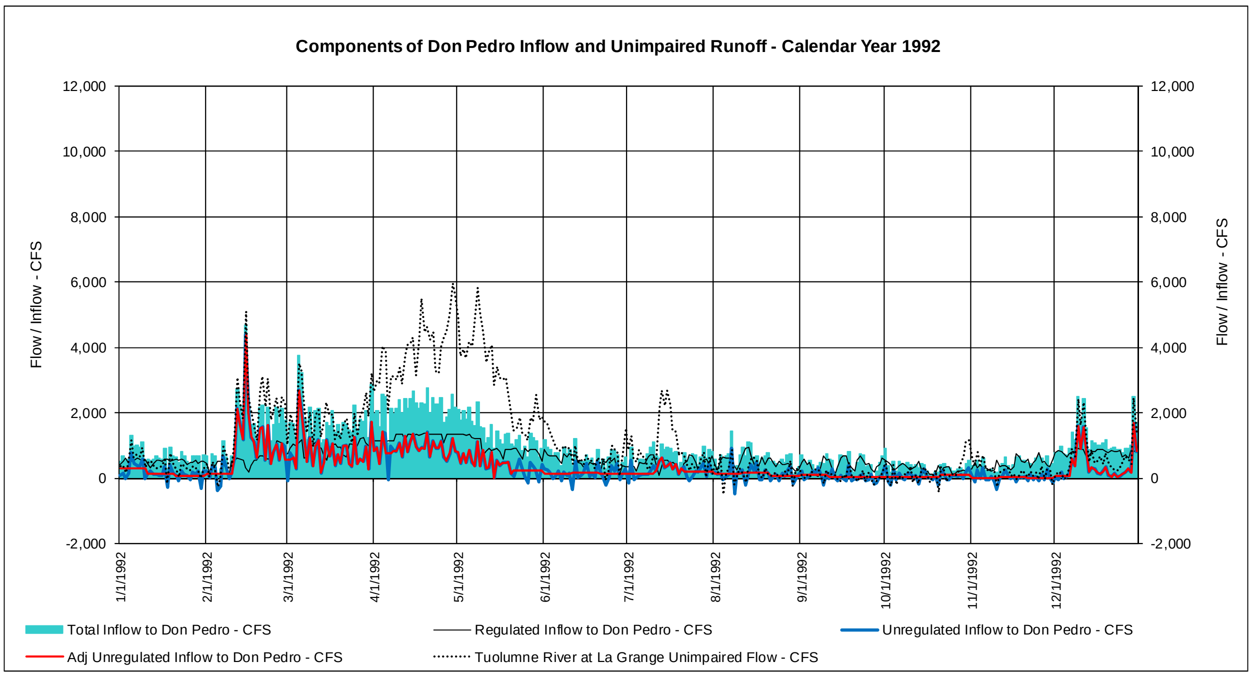


Figure 2.2-22. Calendar Year 1992.

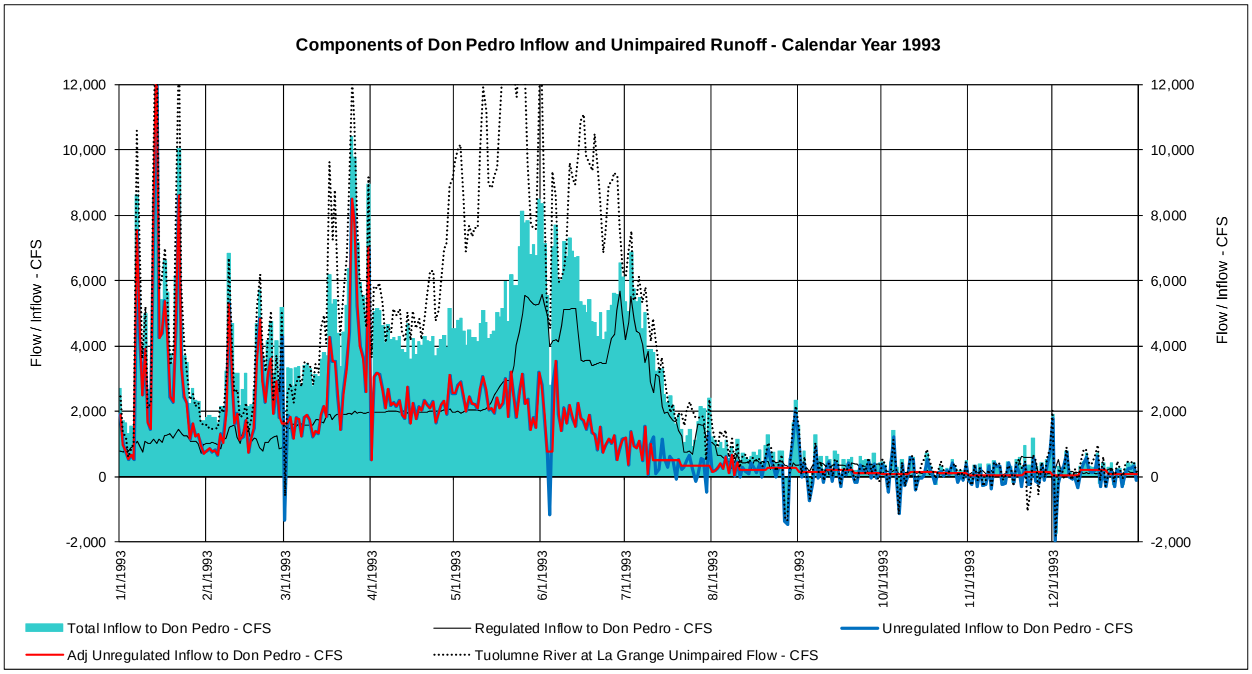


Figure 2.2-23. Calendar Year 1993.

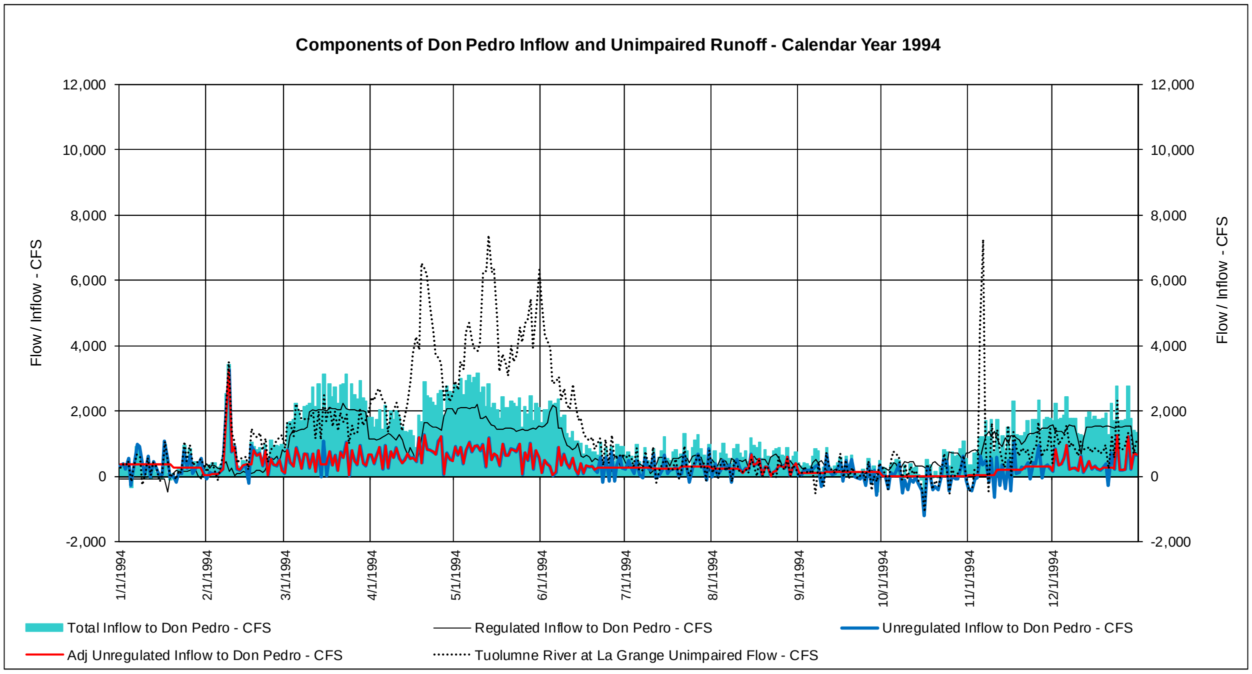


Figure 2.2-24. Calendar Year 1994.

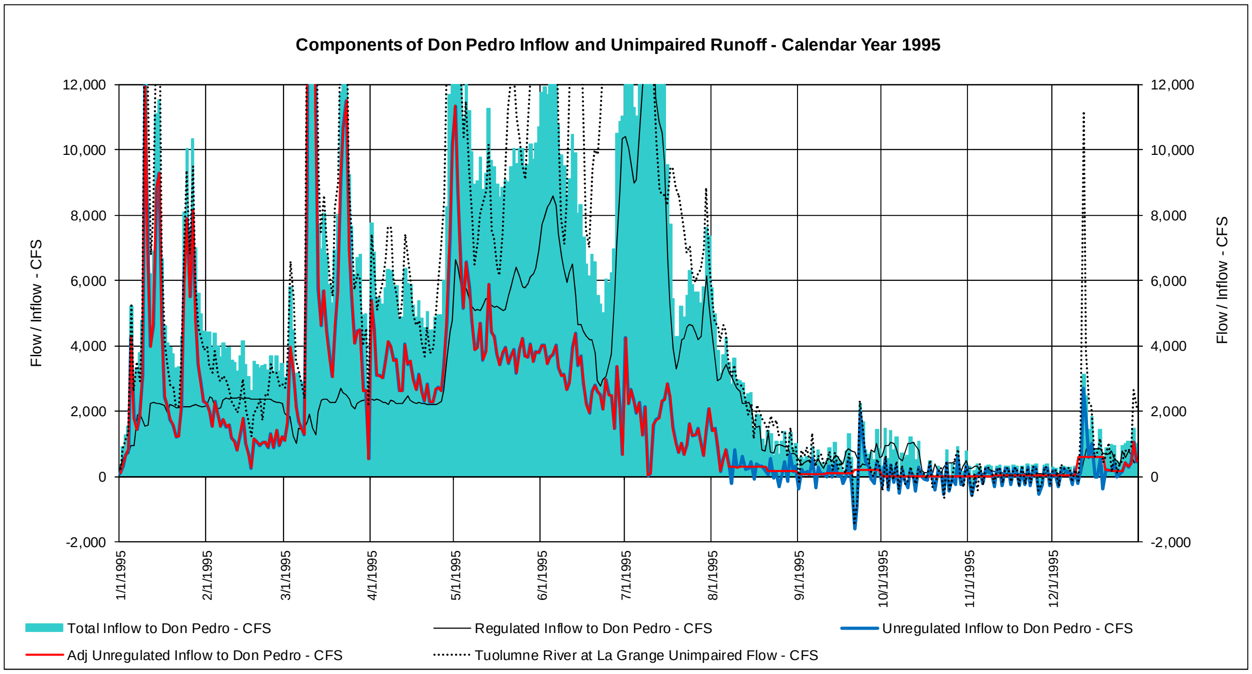
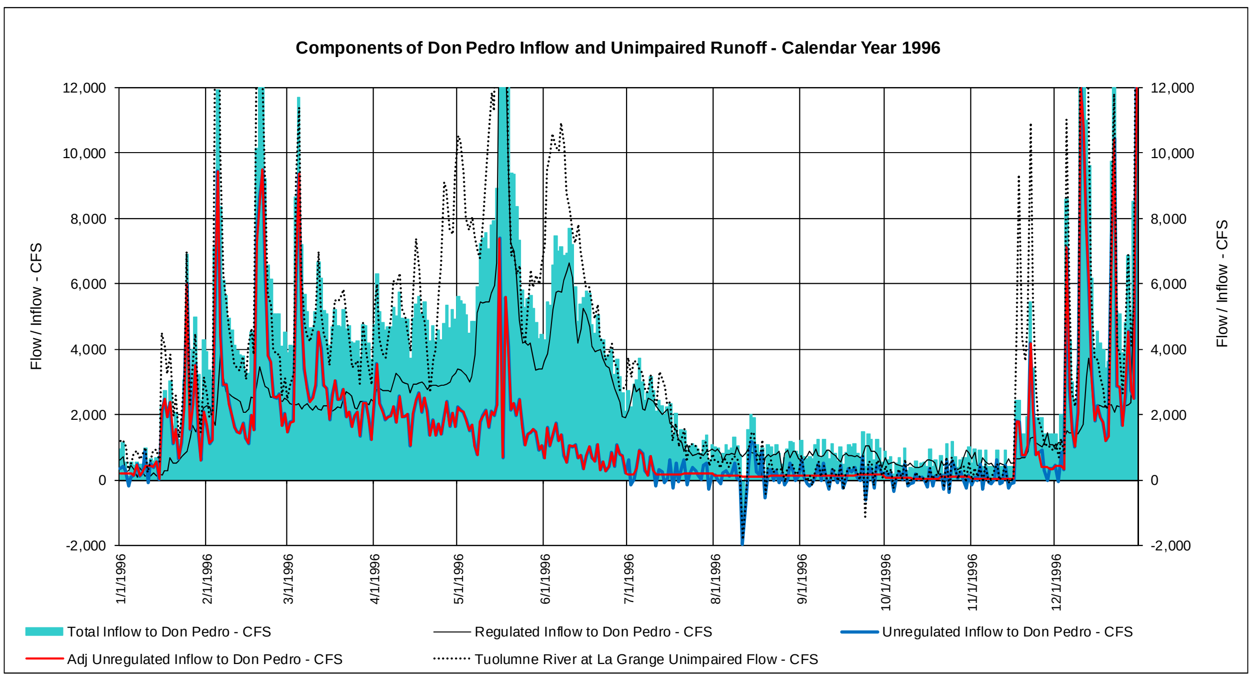


Figure 2.2-25. Calendar Year 1995.



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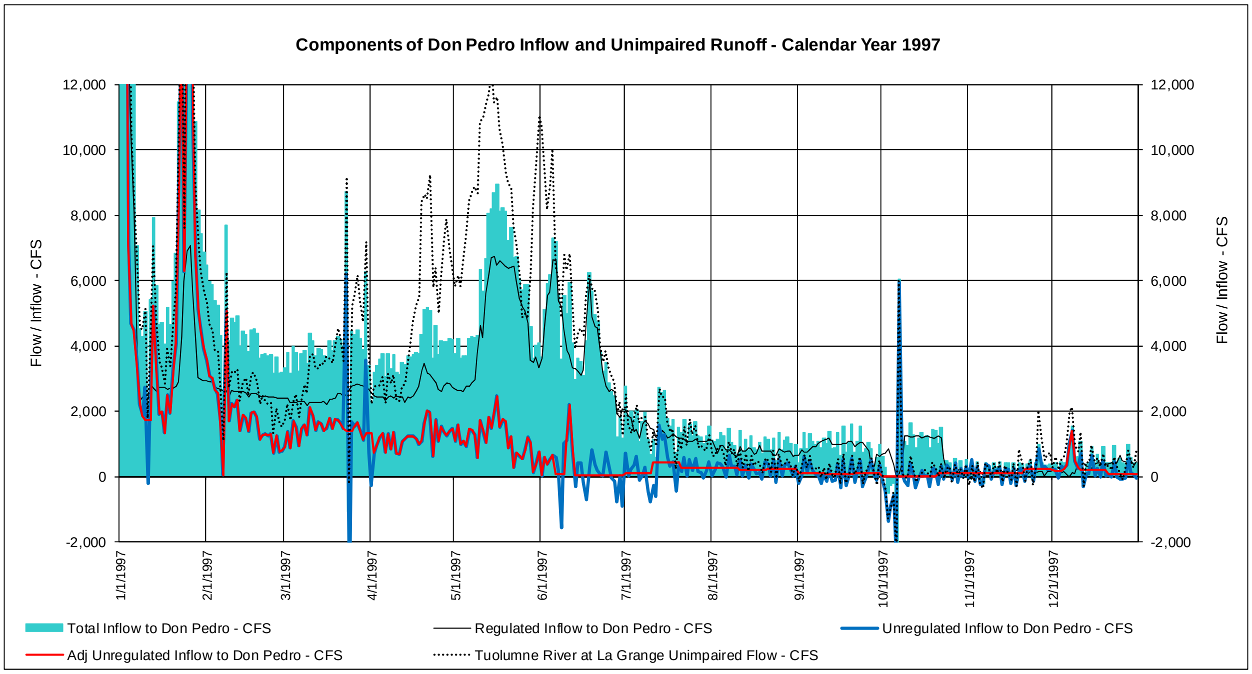

Figure 2.2-27. Calendar Year 1997.

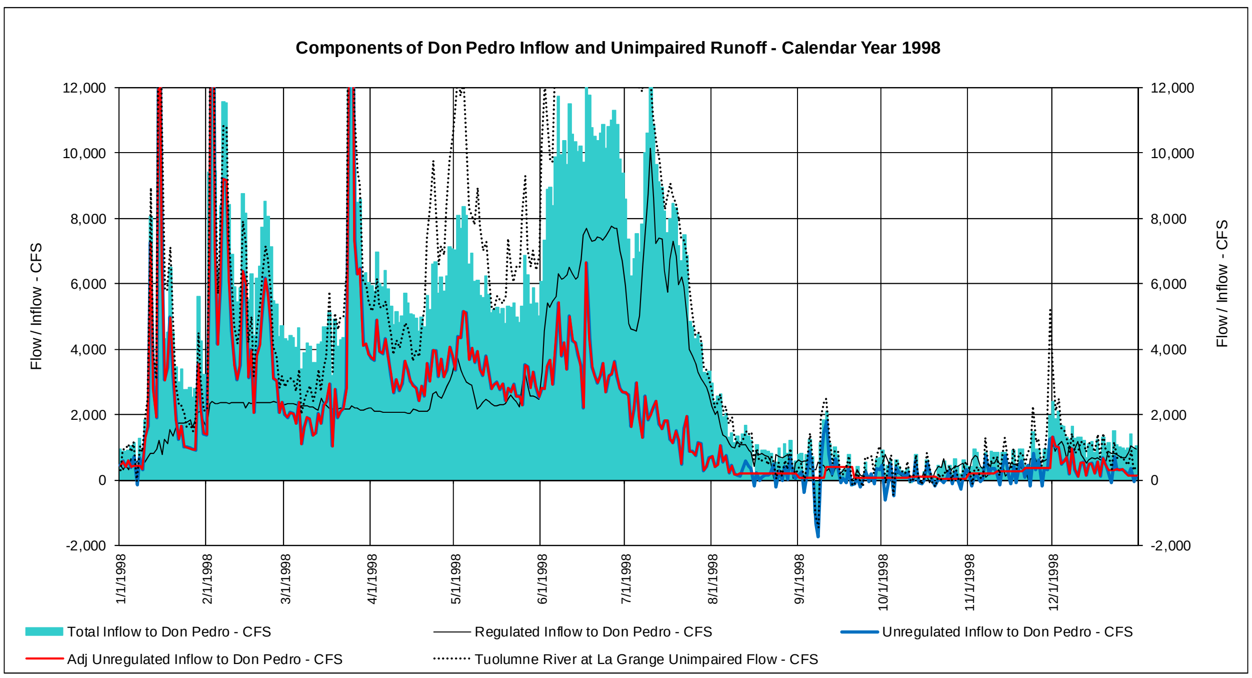

Figure 2.2-28. Calendar Year 1998.

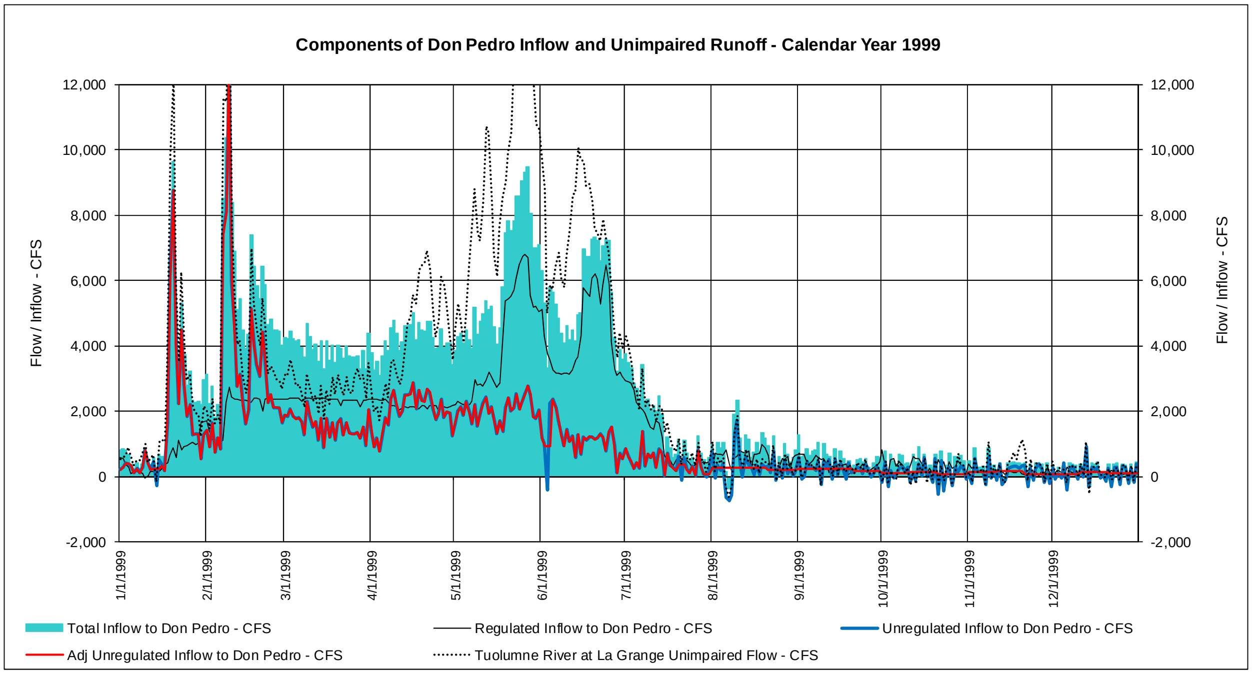

Figure 2.2-29. Calendar Year 1999.

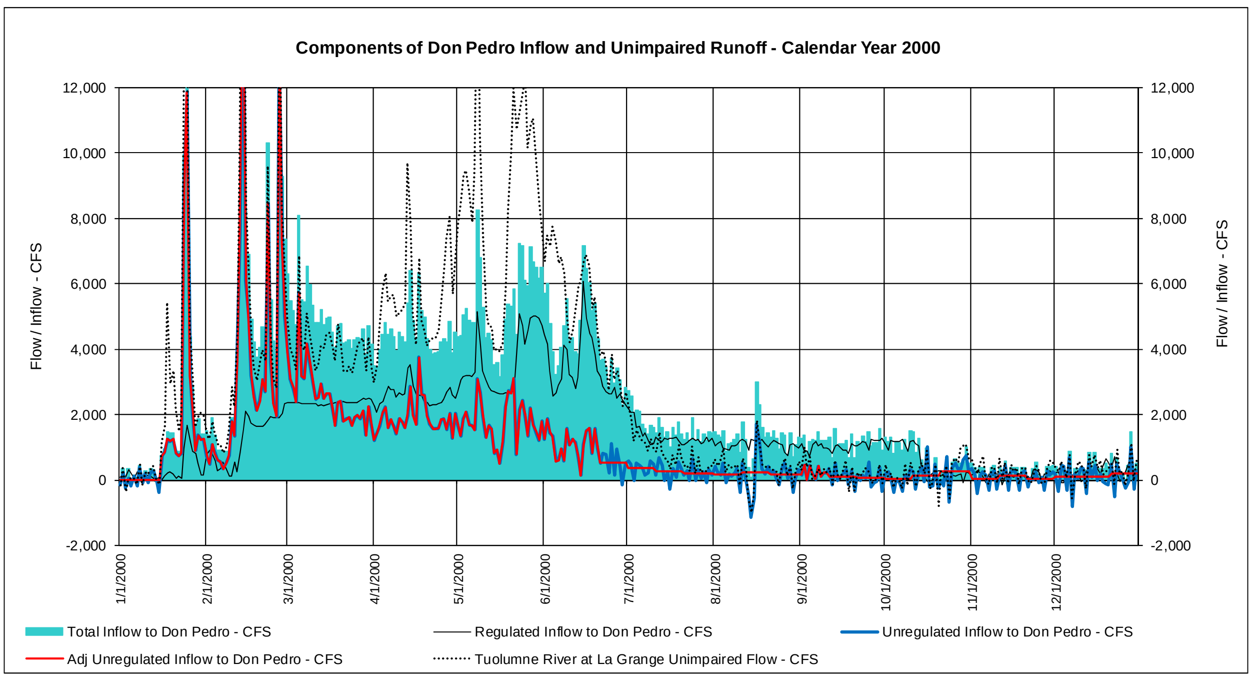

Figure 2.2-30. Calendar Year 2000.

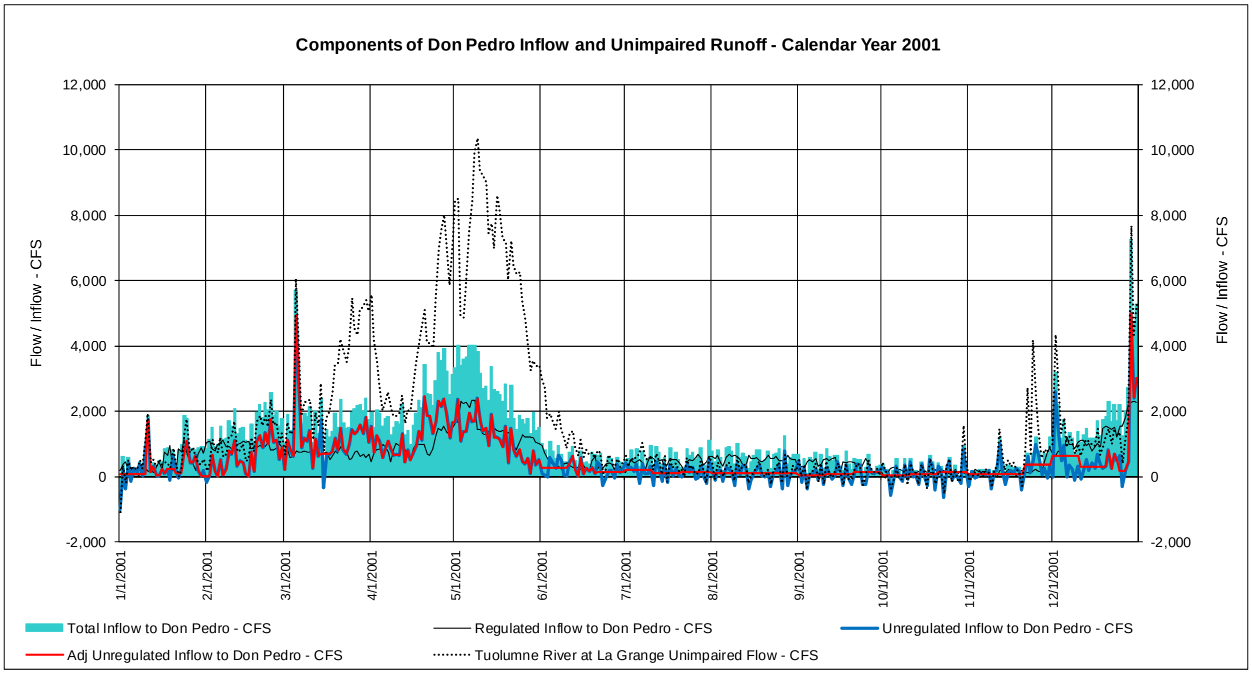

Figure 2.2-31. Calendar Year 2001.

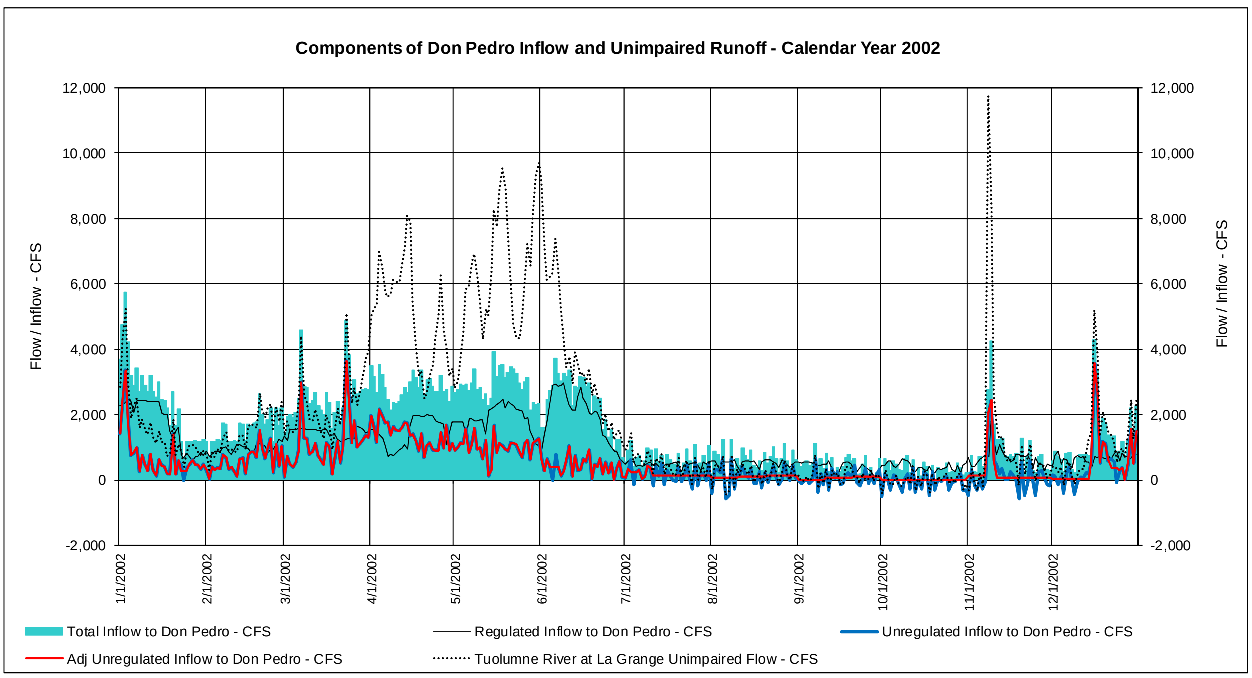

Figure 2.2-32. Calendar Year 2002.

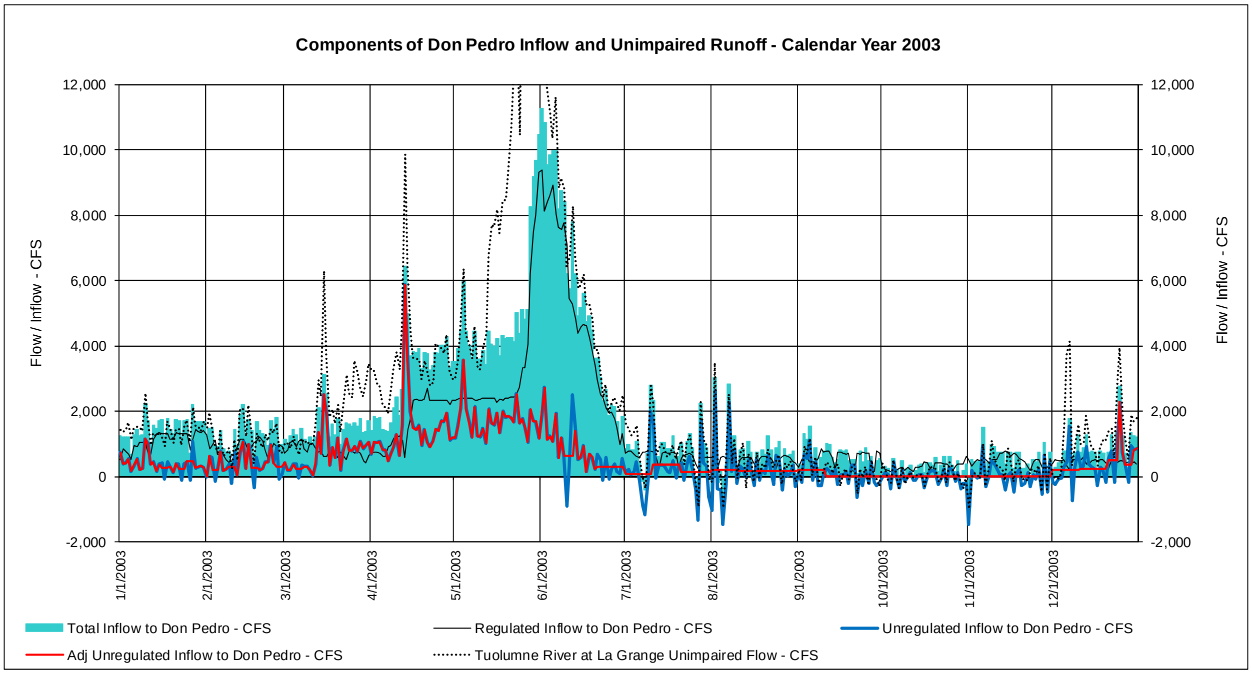

Figure 2.2-33. Calendar Year 2003.

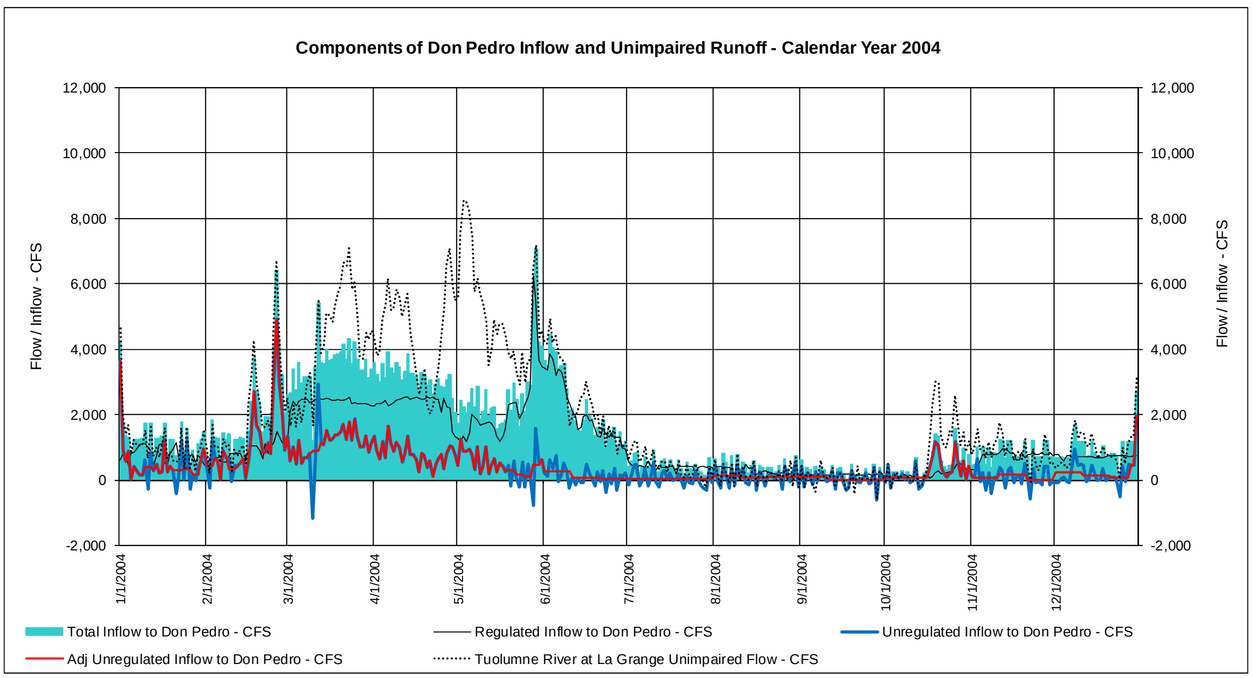

Figure 2.2-34. Calendar Year 2004.

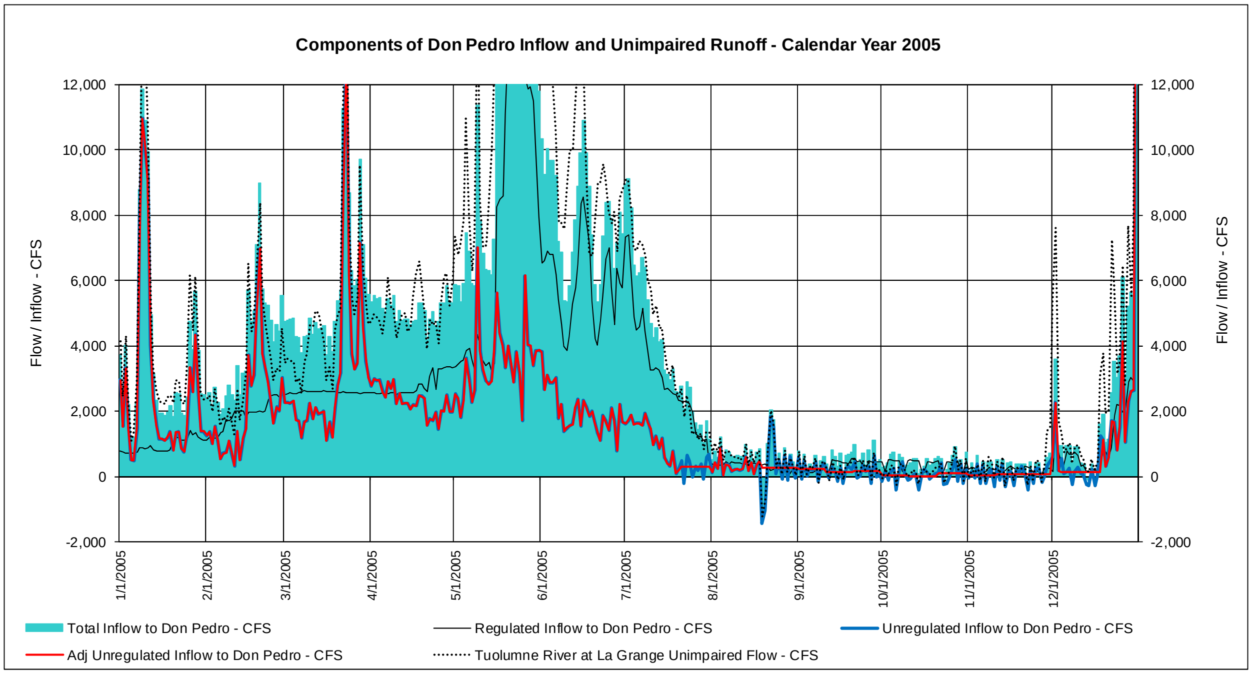

Figure 2.2-35. Calendar Year 2005.

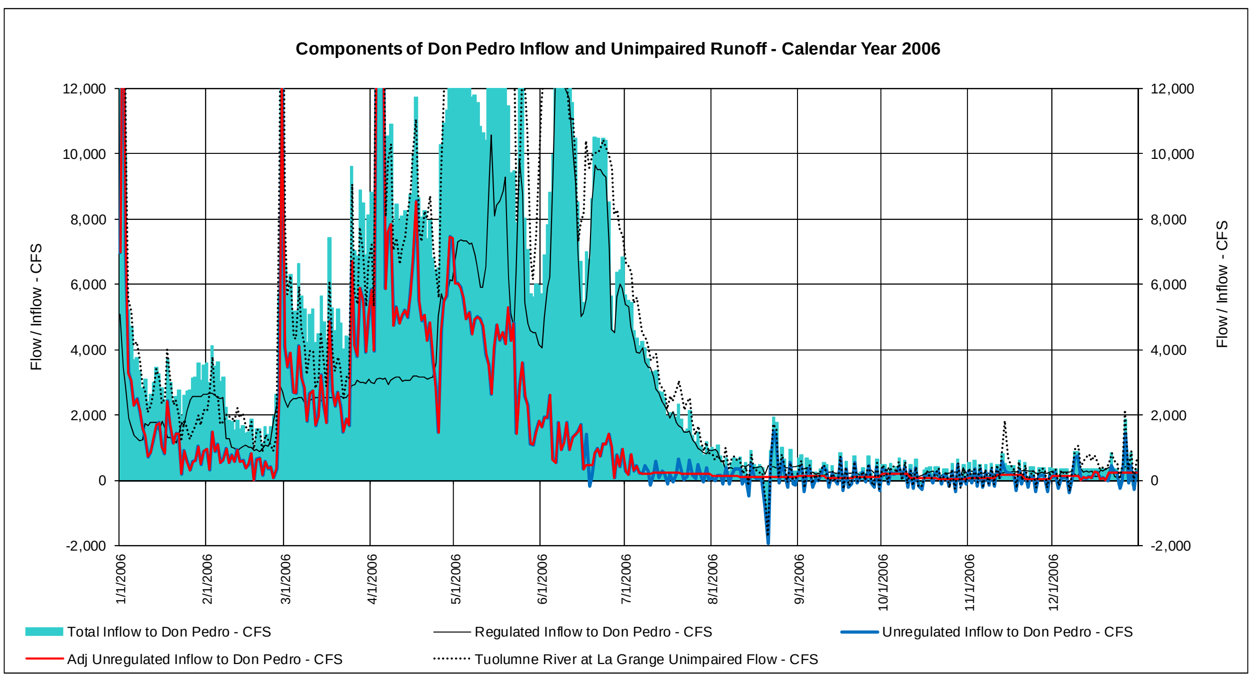

Figure 2.2-36. Calendar Year 2006.

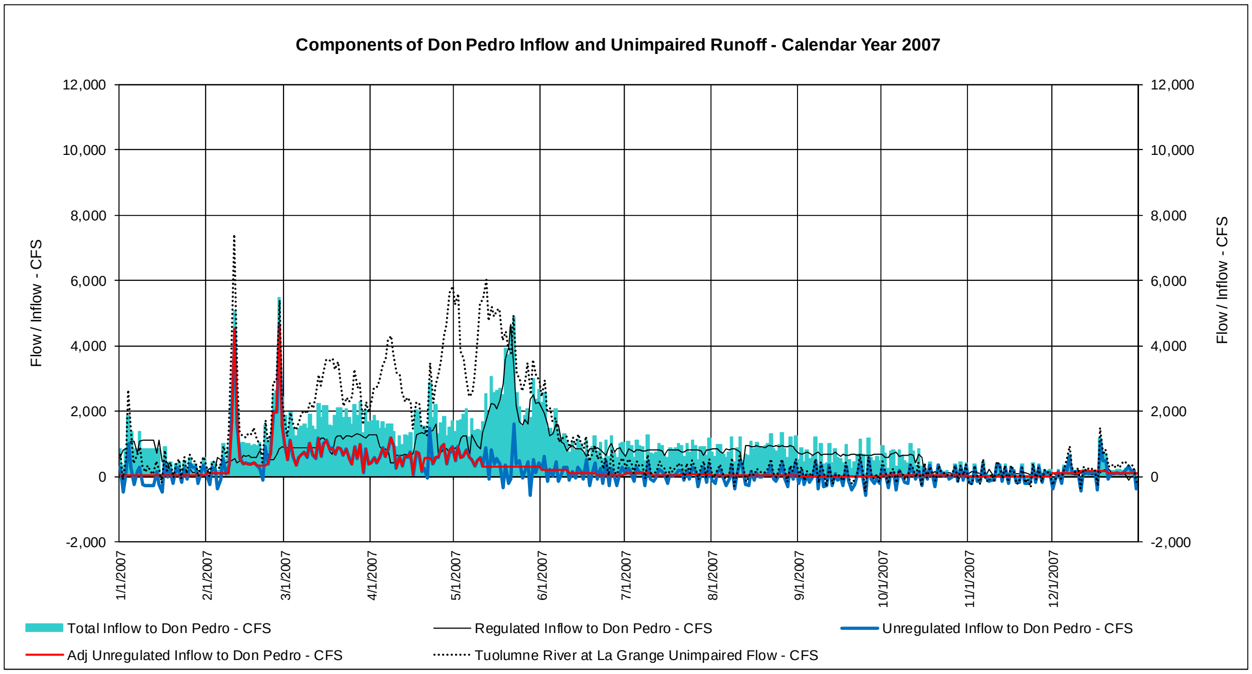

Figure 2.2-37. Calendar Year 2007.

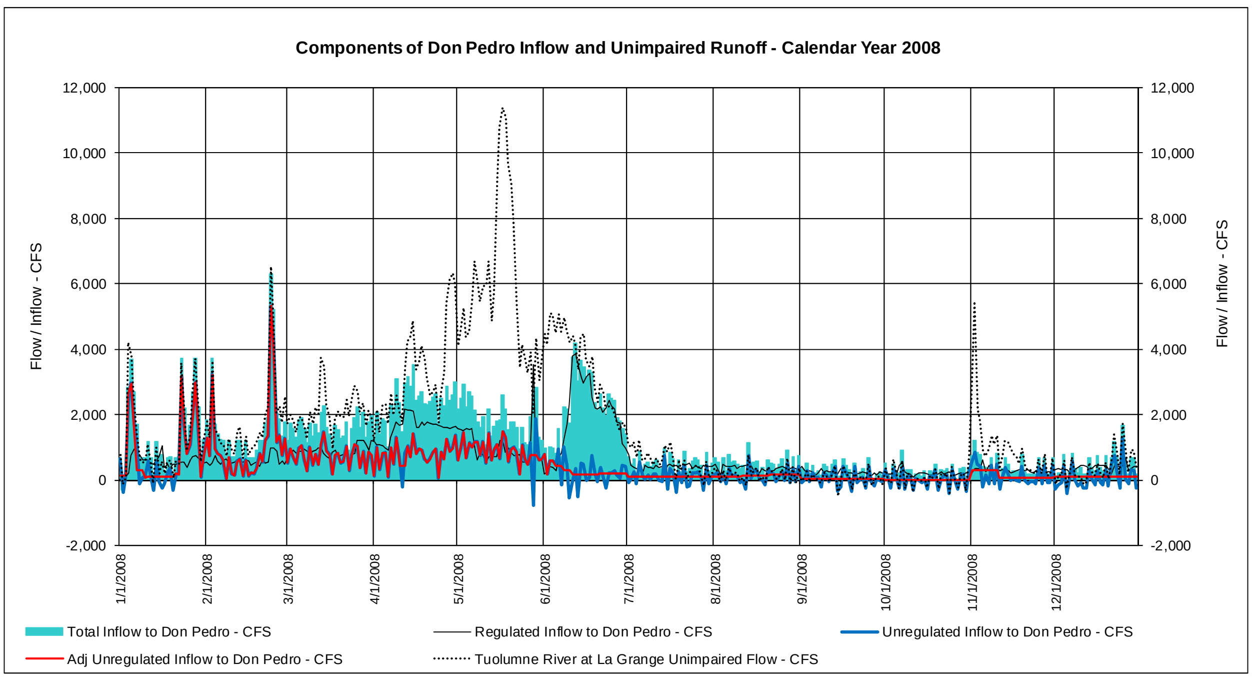

Figure 2.2-38. Calendar Year 2008.

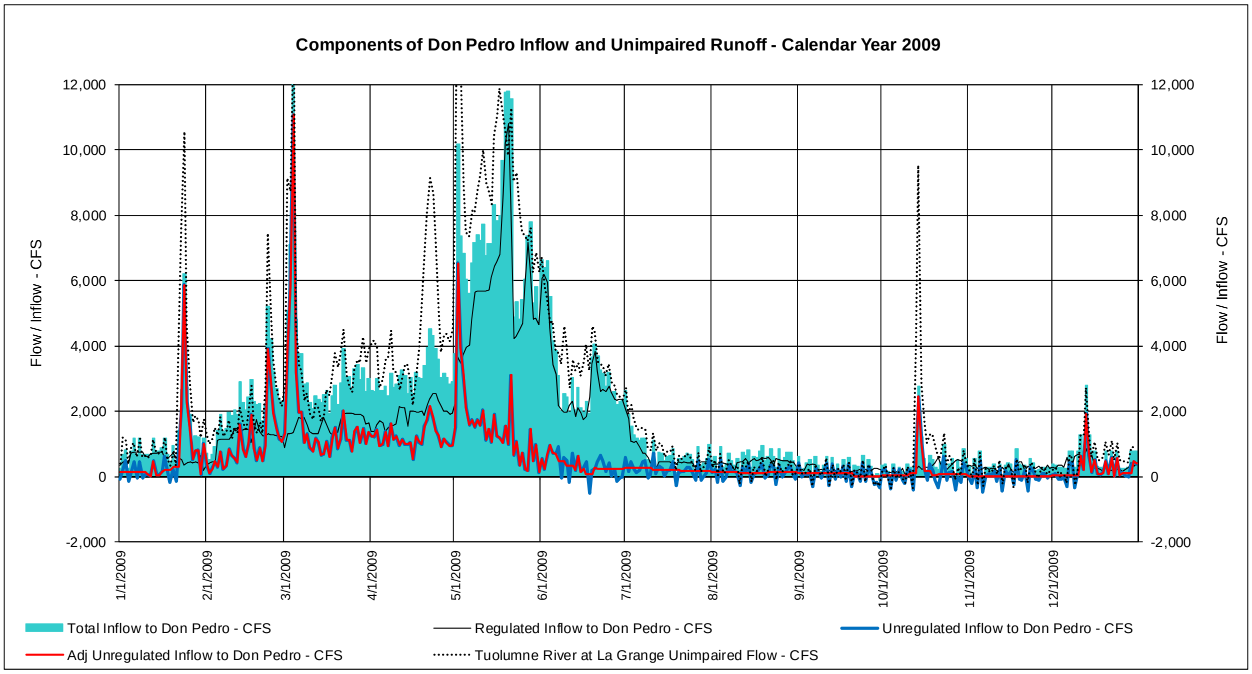

Figure 2.2-39. Calendar Year 2009.

2.3 Additional Flow Information

The Hydrology Workbook also lists a long-term record of computed unimpaired flow of the Tuolumne River at La Grange as reported by the DWR. The record is a mixture of values (1921 through 2003) published by DWR as planning estimates, and more recent records acquired through the DWR CDEC data system which are considered preliminary. The overlapping record of DWR's data and the detailed daily data provided by the Districts in the worksheet at times illustrate differences. To the best of the Districts' knowledge, current DWR procedures accept the Districts' computation of unimpaired flow as being the record. Differences that exist might be explained as a change in DWR protocols for the record or the absence on the part of DWR of incorporating revised records. Nonetheless, the differences are small and the Districts will use its computation of unimpaired flow for the FERC analysis. The extended DWR record is provided to provide context of the 1971-2009 period of record used for the Model within the perspective of the longer hydrologic record.

2.4 Alternative Method of Estimating Tuolumne River Unimpaired Flow

The California Department of Fish and Game suggested that the Districts consider using a "gage proration methodology" to estimate unimpaired flows, using several reference gages of the watershed or other watersheds for use in a "prorated gauge synthesis". Using historical gage data, the Districts developed an estimate of unimpaired hydrology for the Tuolumne River below La Grange Dam (La Grange), and compared the resulting dataset to the mass balance approach previously described. The complete analysis performed by the Districts is included as Appendix A to this Attachment. The following is a discussion of results and conclusions.

Due to a lack of available gage records for employment in the prorated gage synthesis, the comparison was limited to the WY 1971 to 1983 period. The magnitude and shape of the hydrographs for the examined period compared quite well between the two approaches. The cumulative volume for the full thirteen-year analysis is 9.5% less using the gage proration approach when compared to the mass balance approach. The type of deviation between the two approaches suggests a relatively consistent difference in volumes that occurs each year, rather than a difference caused by a small number of discrete flow events.

While individual storm and runoff events appear to have consistently good agreement between the two approaches, there are periods of significant discrepancy, likely resulting from poor basin representation by the reference gages. There appears to be a chronic underestimation of the late season snowmelt by the gauge proration approach. This can be explained by the lack of reference gage representation within the higher elevation portions of the basin, where much of the remaining snowmelt runoff is likely occurring during the early summer.

The mass balance approach provides a consistent, defensible, long-term approach to the development of the unimpaired hydrology at La Grange, in particular the estimation of seasonal and annual volumes of watershed runoff. The main drawback to the approach is the uncertainty (including negative values) that occurs during the low flow portion of the year (i.e., late summer and fall months). As described previously, these below zero values are primarily due to inaccuracies in the stage readings of the reservoirs used; any remaining uncertainty may be an artifact of indirect evaporation estimates from Don Pedro Reservoir and upstream impoundments. The anomalies (negative flows) in the daily dataset have been addressed through the adjustment procedures described in Section 2.2 above.

3.0 LOWER TUOLUMNE RIVER ACCRETION FLOW AND DRY CREEK FLOW

Additional flow data is needed for construction of the Model. These data include flows that are not technically “unimpaired” but are representative of flows that affect the depiction of flow within the lower Tuolumne River, and may contribute to conditions that affect Project operations. Such a flow component is the flow from Dry Creek which enters the Tuolumne River near Modesto. The flow from Dry Creek at times can influence flood control operations at Don Pedro Reservoir. The flow can also influence the temperature of flow in the Tuolumne River at and below the Dry Creek confluence. This flow information is included in the Hydrology Workbook.

Column AK lists a synthesized estimate of the flow that enters the Tuolumne River from Dry Creek for the modeling period. The synthesized record is representative of current circumstances that affect flow. Surface runoff was estimated for Dry Creek manually using base flow separation techniques. The entire period of record of the gage was examined graphically to determine if the flows recorded were likely to be surface runoff, base flow, or return flow from irrigation canals. The synthetic base flow values were then used to fill in all hydrograph values judged to be base flow, or return flow. Also included in the Hydrology Workbook (Column AJ) is the record of flow as measured by the DWR station Dry Creek near Modesto (Station BO4016), located upstream of the City of Modesto near Claus Road.

Column AL presents an estimate of lower Tuolumne River accretions to be used in modeling. These accretions represent the net flow change between the La Grange gage and the Modesto gage, and will be added to the regulated releases of the Project to the lower Tuolumne River. The sum of the regulated Project release plus the accretion flow plus the flow from Dry Creek will represent the modeled flow occurring at the Modesto gage location.

The analysis supporting the Dry Creek and lower Tuolumne River accretion estimates is included at Appendix B of this Attachment.

The Districts collected accretion measurements at the locations, and using the methods proposed by the Districts on June 6, 2012 (memorandum included in Appendix C of this Attachment). The measurements were conducted on June 25, 2012 and the results are presented in Appendix C. A second set of measurements were acquired during October 2012. These data are also presented in Appendix C.

TUOLUMNE RIVER DAILY OPERATIONS MODEL

APPENDIX A

EXAMINATION OF A GAUGE PRORATION METHOD FOR TUOLUMNE RIVER UNIMPAIRED HYDROLOGY DEVELOPMENT

Examination of a Gauge Proration Method for Tuolumne River Unimpaired Hydrology Development

November 12, 2012 – prepared by Rob Sherrick and Rick Jones, HDR

Objective

Using historical gauge data, develop an estimate of unimpaired hydrology for the Tuolumne River below La Grange Dam (La Grange), and compare the resulting dataset to a mass balance approach previously developed by Modesto Irrigation District and Turlock Irrigation District (Districts). Assess the option of using a guage proration methodology.

Background

By letter dated September 10, 2012, Mr. Jeffrey R. Single, Regional Manager for the California Department of Fish & Game (CDFG), provided comments to the State Water Resources Control Board (SWRCB) related to the unimpaired hydrology for the operations/water balance model being developed for the Don Pedro Project relicensing. In summary, CDFG states that it is concerned "that the Districts' proposed method of estimating unimpaired hydrology is not appropriate for the purpose of the state of California's environmental review process required for a new license."

In its letter, the CDFG suggests that the Districts consider using a "gauge proration methodology" to estimate unimpaired flows. The CDFG recommends the evaluation of several reference gauges for use in a "prorated gauge synthesis". The specific gauges that were referenced for consideration are shown in Table 1.

Table 1. List of potential reference gauges identified by CDFG in September 10, 2012 letter to SWRCB.

Gauge and Description	Drainage Area / Elevation	Period of Record	USGS Remarks
USGS 11281000 SF Tuolumne R near Oakland Recreation Camp	87.0 sq. mi. El. 2,800 ft.	4/1/1923 to 9/30/2002 1/26/2009 to present (excluding WY 1997)	Records good. No storage or diversion above station.
USGS 11282000 M Tuolumne R at Oakland Recreation Camp	73.5 sq. mi. El. 2,800 ft.	10/1/1916 to 9/30/2002 1/26/2009 to present (excluding WY 1997)	Records good. No regulation; small diversion above station for irrigation.
USGS 11283500 Clavey R near Buck Meadows	144 sq. mi. El. 2,374 ft.	10/1/1959 to 6/13/1995 12/7/2009 to present (excluding WY 1984-1986)	Records excellent. No storage or diversion above station.
USGS 11284700 NF Tuolumne R near Long Barn	23.1 sq. mi. El. 4,650 ft.	9/1/1962 to 9/30/1986	Records good. No storage or diversion above station.

In addition to these gauges, HDR has identified five additional locations that are potentially useful for the development of unimpaired hydrology at La Grange. It should be noted that, even with the additionally identified gauges, the period of record with adequate data coverage only spans the period of Water Year 1971-1983. While this duration is insufficient for the development of a long-term unimpaired estimate at La Grange or an inflow dataset for use in the water balance/operations model, it is adequate for the purposes of comparison with the aforementioned mass balance approach. At least eight out of nine of the identified gauges have continuous data for the thirteen-year period. Table 2 presents the complete list of gauges and date range used in this analysis. Figure 1 presents a map of the Tuolumne River watershed with the location of each of the gauged basins specified.

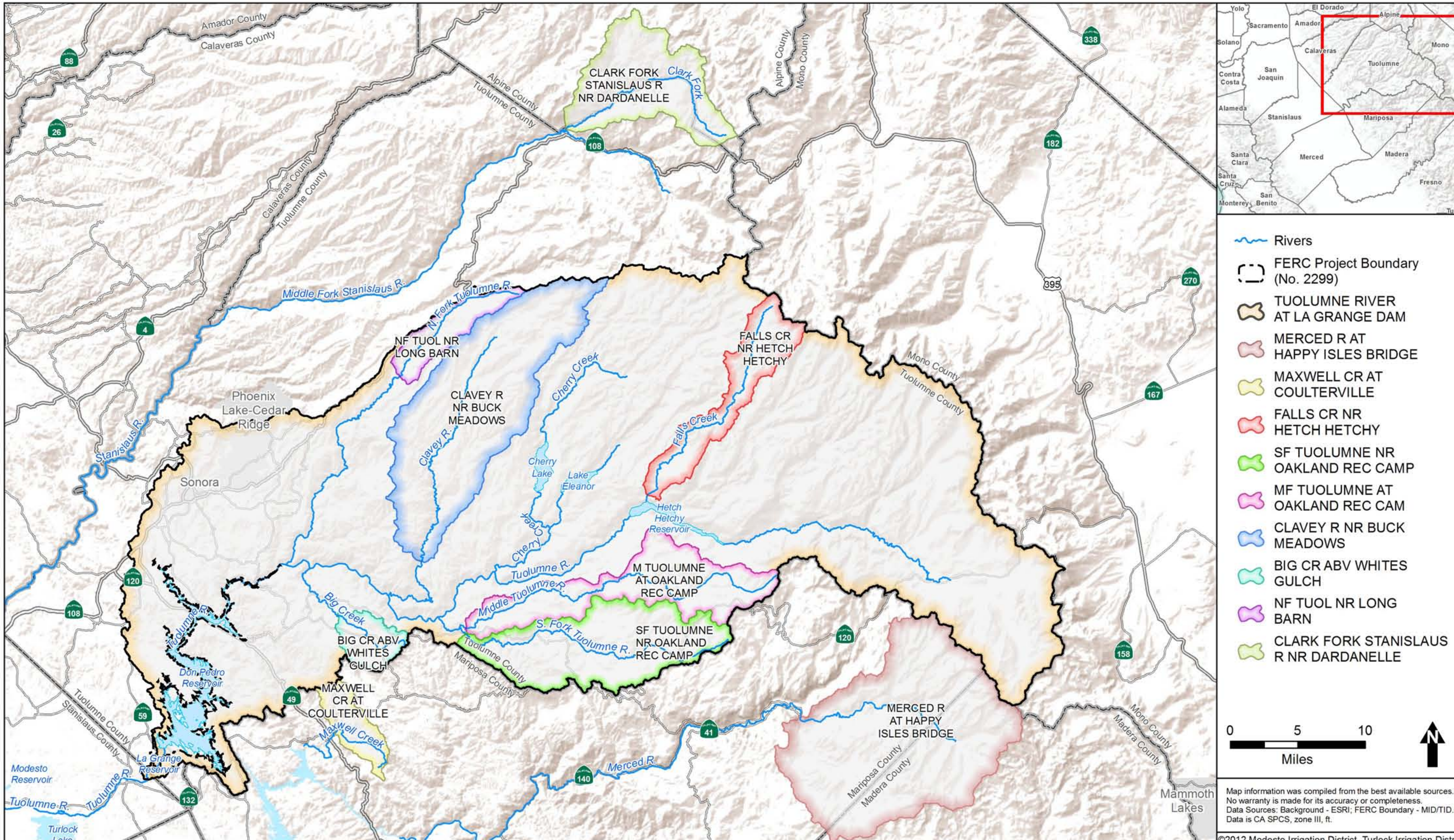

Figure 1. Map of gauges used in proration method for unimpaired hydrology

Table 2. List of gauges used for development of prorated unimpaired hydrology at La Grange

USGS No.	Gage Name	Drainage Area (mi²)	Date Range Used
11281000	SF TUOLUMNE NR OAKLAND REC CAMP	87	WY 1971 - 1983
11282000	MF TUOLUMNE AT OAKLAND REC CAMP	73.5	WY 1971 - 1983
11283500	CLAVEY R NR BUCK MEADOWS	144	WY 1971 - 1983
11284700	NF TUOL NR LONG BARN	23.1	WY 1971 - 1983
11284400	BIG CR ABV WHITES GULCH	16.4	WY 1971 - 1983
11275000	FALLS CR NR HETCH HETCHY	46	WY 1971 - 1983
11292500	CLARK FORK STANISLAUS R NR DARDANELLE	67.5	WY 1971 - 1983
11264500	MERCED R AT HAPPY ISLES BRIDGE	181	WY 1971 - 1983
11269300	MAXWELL CR AT COULTERVILLE	17	WY '71-'74, '76-'80

The last three gauges in Table 2 are not within the Tuolumne River basin, but were added to provide representation for elevation ranges that were not well represented by gauged data within the Tuolumne River basin.

Methods

In order to prorate the gauged data to a larger ungauged area, three physical variables were considered – elevation, drainage area, and average annual precipitation (precipitation). Each gauged basin, along with the full basin (La Grange), was divided into 100-foot "elevation bands" for its entire drainage area. This was done using USGS National Elevation Dataset, 1/3 arc-second (USGS, 2009), which equates to about a 30 foot pixel size. Each elevation band for each gauge had attributes added for the drainage area within this band (e.g., the number of square miles of the Tuolumne River drainage that exists between elevation 500 and 600 feet) and precipitation (e.g. the average annual precipitation for the drainage area between elevation 500 and 600 feet).

The Oregon Climate Service's PRISM model results were used to estimate average annual precipitation from 1971 – 2000 (PRISM, 2006) for each of the elevation bands represented by the basins being evaluated (elevation beginning 100 to 13,000 feet). PRISM uses the observed precipitation gauge and radar data network, in conjunction with an orographic precipitation and atmospheric model, to develop an estimate of average annual precipitation for the contiguous United States at a pixel size resolution of 2,500 feet. Bi-linear interpolation was used to resample the PRISM values to the same pixel size as the elevation model.

Figure 2 is a suite of "elevation histograms" that shows the amount of area covered by the gauged basins cumulatively (shaded region), as compared to the full area of La Grange to which the gauged data will apply (region with no shading, along with the shaded region). Areas at low elevations and high elevations in the La Grange basin that are poorly represented or not represented at all by the reference gauges were "artificially added" into the elevation distributions of the most representative gauges in order to provide some amount of coverage for those elevation ranges. When artificial areas were added to the gauges, the amount of area added for each gauge was nominally established as one percent of the total La Grange area for that elevation bin. This can be seen graphically in Figure 2 for elevations below 1,800 feet, where the three lowest elevation gauges were artificially augmented to cover three percent of the La Grange area. For precipitation in artificially augmented elevation bands, a multiplier was applied to the La Grange precipitation values equal to the multiplier for the nearest observed elevation band for that gauge. Due to a lack of reference data, the regions where artificial gauge representation were necessary are expected to have the poorest correlation to the La Grange basin overall.

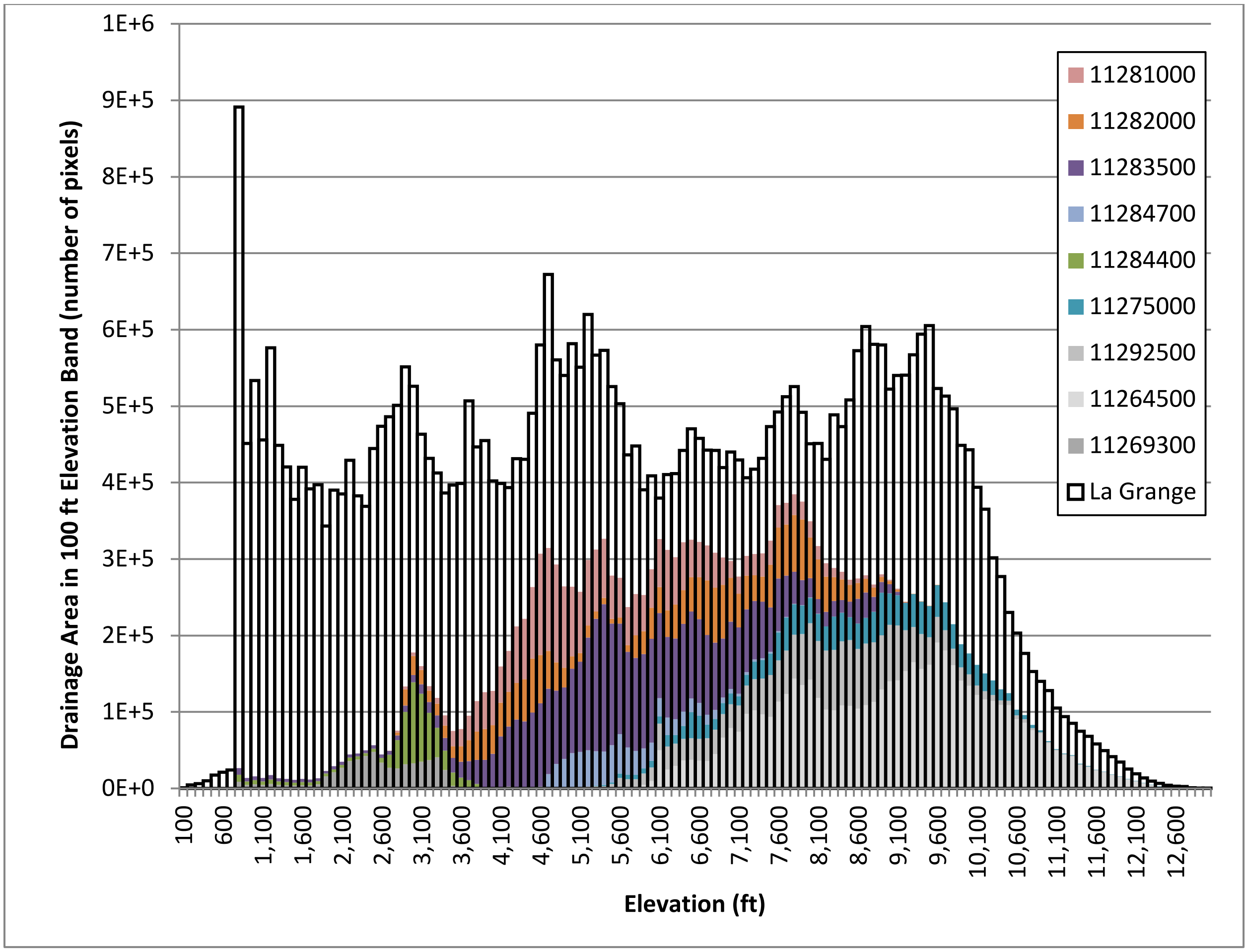

Figure 2. Relative drainage area analysis using elevation histograms for reference gauges used, compared to the watershed above La Grange

The proration calculation includes two main steps. First, the daily flow for a given gauge is divided across the elevation range that the gauge represents, in equal proportion to the drainage area represented within each 100-foot elevation band. Second, the sum of each of the individual "elevation band flows" for each gauge is scaled up to the unimpaired elevation band. Each of these steps includes a scaling factor for both area and precipitation. Equation 1 shows the calculation for prorated flow on a single day, with the first step in the left set of parenthesis, and the second step in the right set of parenthesis (mathematical summation form).

$$q_u = \sum_{e=1}^{130} \sum_{g=1}^{9} q_g \left(\frac{a_{ge} p_{ge}}{\sum_e a_{ge} p_{ge}} \right) \left(\frac{a_{ue} p_{ue}}{\sum_g a_{ge} p_{ge}} \right)$$

Equation 1. Daily unimpaired flow where q is daily average flow, a is area, and p is average annual precipitation. Where $_g$ is each gauged basin, $_u$ is the unimpaired basin, and $_e$ is the lower limit of the 100-foot elevation band divided by 100.

It is worth noting here that a few of the reference gauge basins had facilities that resulted in measurable amounts of stream regulation and/or diversion during the period of data use; no effort was made to modify the observed data to account for these hydrologic effects. However, it is not expected that these water regulation facilities would have a meaningful impact on the results of this analysis.

Results

The methods described above were employed to create an estimate of unimpaired daily flows at La Grange over the WY 1971 to 1983 period. This dataset was then compared to the mass balance methodology developed previously by the Districts, and presented in a prior Hydrology Workshops. The magnitude and shape of the hydrographs for the examined period compare quite well between the two approaches, as seen in Figure 3. The cumulative volume for the full thirteen-year analysis is 9.5% less using the gauge proration approach when compared to the mass balance approach, as seen in Figure 4. The type of deviation between the two approaches (also shown in Figure 4) suggests a relatively consistent difference in volumes that occurs each year, rather than a difference caused by a small number of discrete flow events.

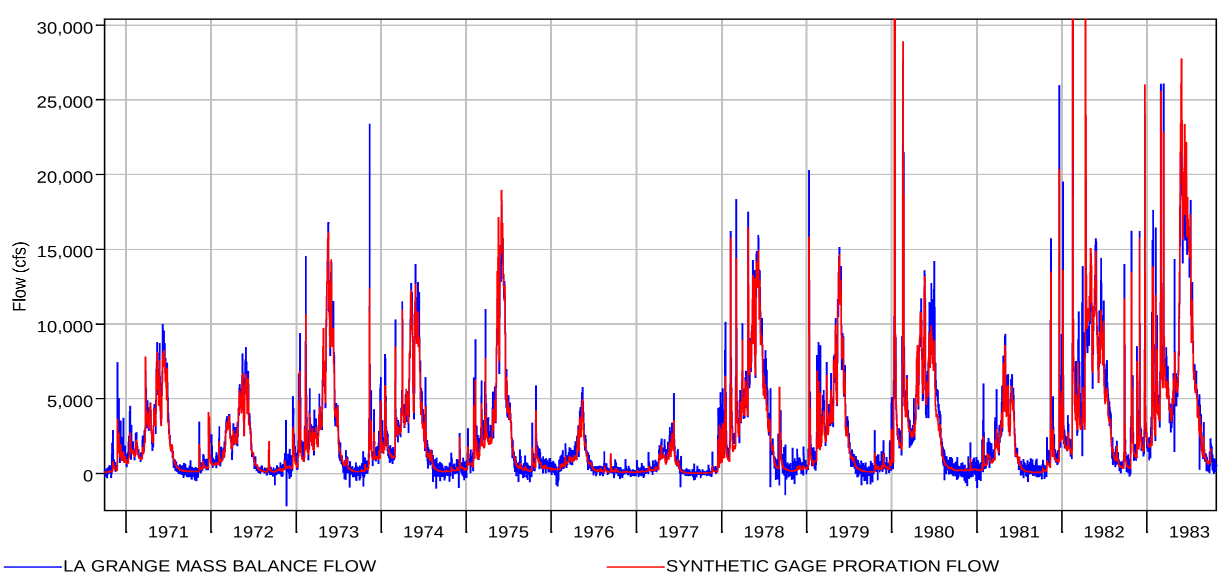

Figure 3. Comparison between mass balance and gauge proration approach, Water Years 1971-1983.

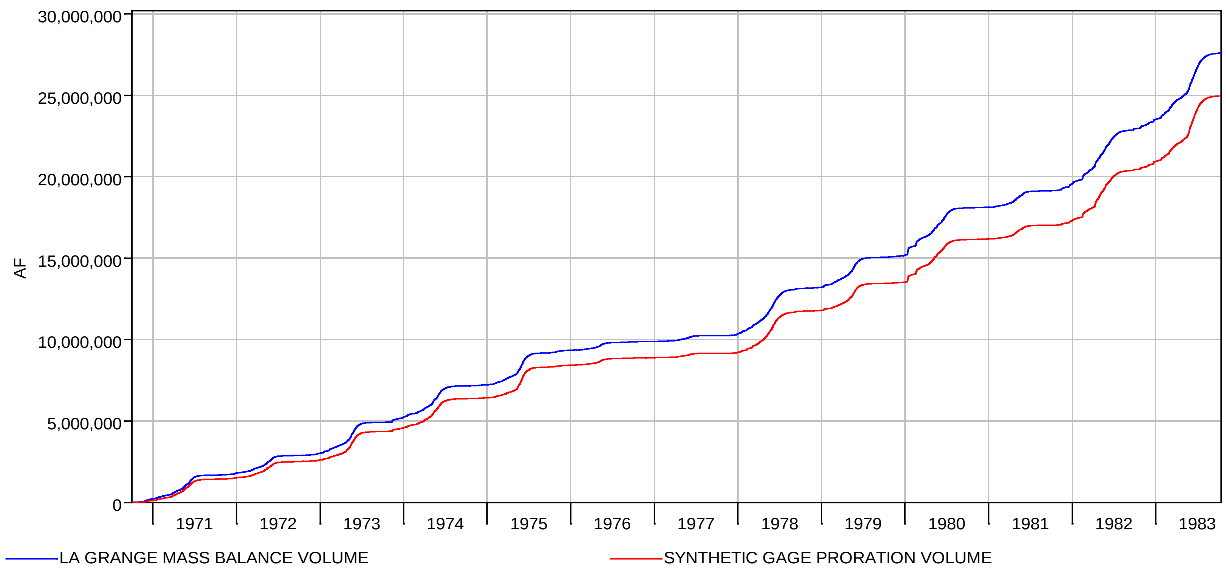

Figure 4. Comparison between mass balance and gauge proration approach, accumulated volume (values in acre-feet).

While individual storm and runoff events appear to have consistently good agreement between the two approaches, closer examination reveals periods of significant discrepancy, likely resulting from poor La Grange basin representation by the reference gauges. Figure 5 shows a chronic underestimation of the late season snowmelt in 1980 by the gauge proration approach. This can be explained by the lack of reference gauge representation within the higher portions of the La Grange basin, where much of the remaining snowmelt runoff is likely occurring during the early summer. Without the inclusion of the Merced River at Happy Isles gauge, the underestimation of the proration approach is even worse due to a complete lack of high elevation gauge coverage in the Tuolumne River.

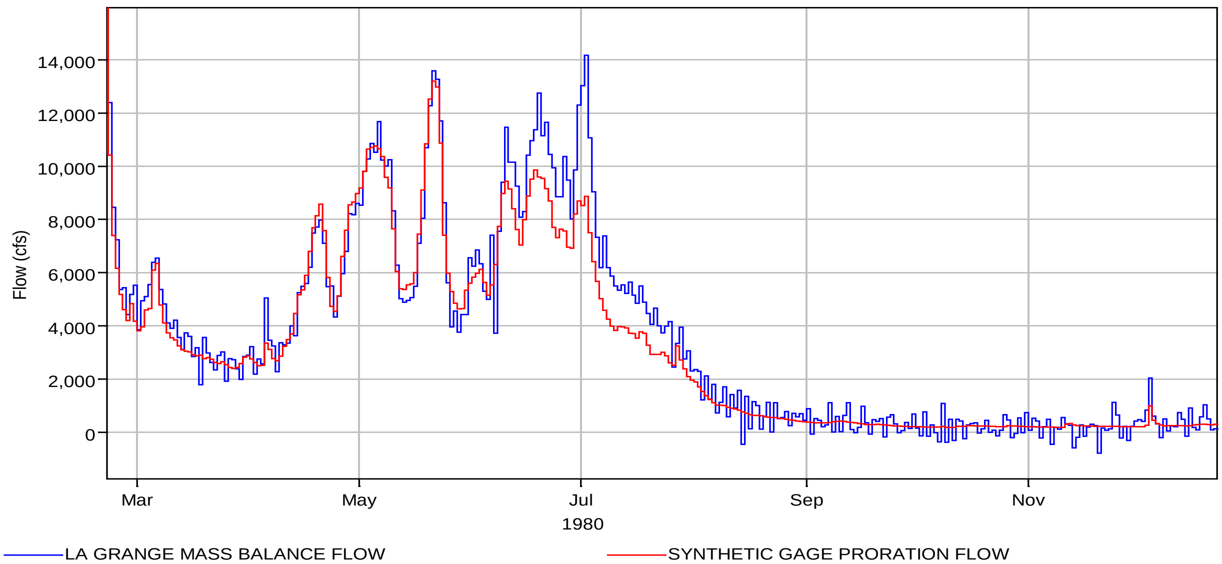

Figure 5. Underestimated late season snowmelt 1980 using gauge proration approach

Figure 6 shows an underestimated rainfall in January of 1972, likely due to a lack of low-elevation reference gauge coverage. Also seen in Figure 6 is another period of underestimated snowmelt in June. A small September storm that occurred only in the Yosemite area (Merced R at Happy Isles),was factored into the gauge proration calculation for the Tuolumne River as an inherent artifact of the approach.

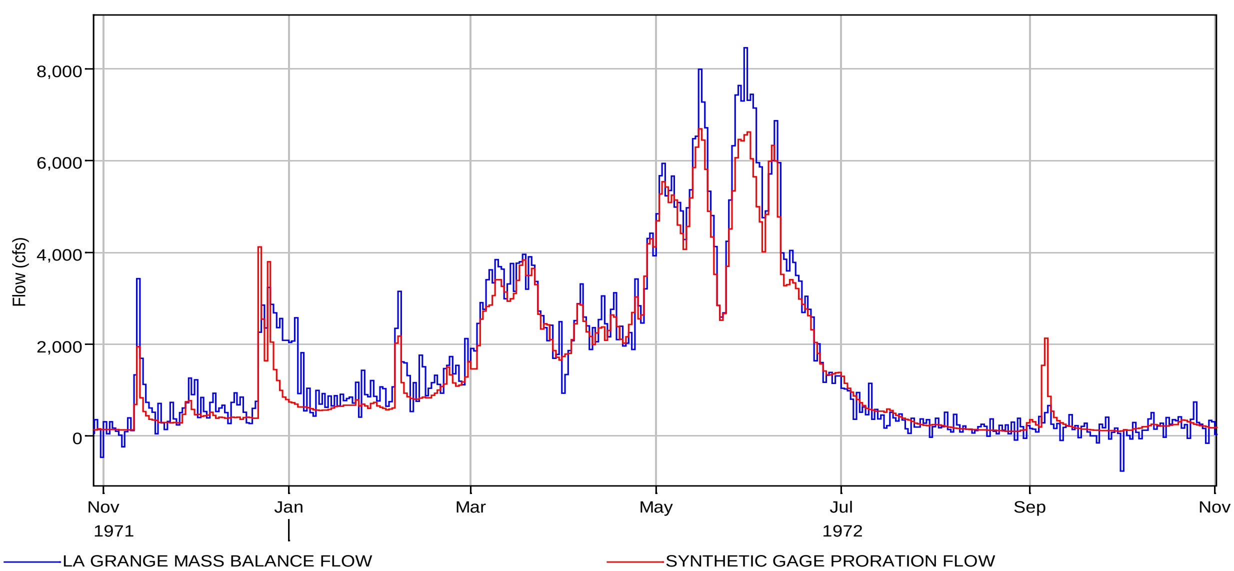

Figure 6. Localized rainfall discrepancies between gauge proration and mass balance approaches

Summer and fall baseflow comparisons are fair between the two approaches, although the mass balance method contains a substantial number of negative flows on a daily basis during low flow periods. It is expected that, with adequate temporal smoothing, the negative values would be adjusted while still retaining the mass balance approach.

Discussion and Conclusion

The period assessed for gauge proration in this report (Water Year 1971 to 1983) has the most complete data coverage of any period covered by the operations model's period of record (Water Year 1971 to 2009). This can therefore be considered a reasonable sample for a comparison of the mass balance and proration methodologies. For the remainder of the period of record, there are intermittent data for at most five of the nine gages. Only two of the nine have continuous records for the whole period of record – Big Creek above White's Gulch and Merced River at Happy Isles Bridge. These two gauges alone are not sufficient for implementation of a gauge proration method for development of a unimpaired flow record at La Grange. If the gauge proration method were to be used when less gauge data are available, the discrepancies and uncertainties will be considerably larger and more frequent.

In terms of the noted discrepancies between the two approaches, the gauge proration method could be more fully "calibrated" to the mass balance approach through the scaling of the prorated data with monthly observed mass balance volumes. This would improve the data comparison where the runoff patterns match well, but it would also potentially amplify errors during discrete events with poor correlation (see Figure 6) and in years where the gauge record is less complete than the period examined in this report.

The mass balance approach provides a consistent, defensible, long-term approach to the development of the unimpaired hydrology at La Grange. The main drawback to the approach is the uncertainty (including negative values) that occurs during the low flow portion of the year (i.e., late summer and fall months). These below zero values are primarily due to inaccuracies in the stage readings of the reservoirs used; any remaining uncertainty may be an artifact of indirect evaporation estimates from Don Pedro Reservoir and upstream impoundments. If a temporal smoothing function was applied to the entire dataset, it would mostly likely degrade the shape of the larger hydrographs, which have been validated by the results of this gauge proration methodology. At higher flows the inflow volumes overwhelm the inaccuracies in the stage readings and evaporation estimates. A selective smoothing function could be used only during the lower flow periods to avoid this side effect. Such a function could be tested against the gauge proration method to ensure it did not degrade the hydrograph correlations across the seasons.

References

PRISM Climate Group, 2006, *United States Average Monthly or Annual Precipitation 1971 – 2000*, <http://prism.oregonstate.edu>, Oregon State University, Created 12 Jun 2006.

United States Geologic Survey (USGS), 2009, *1/3 Arc Second National Elevation Dataset*, <http://seamless.usgs.gov>, USGS Earth Resources Observation & Science (EROS) Center, Sioux Falls, SD, Created 23 March 2009.

TUOLUMNE RIVER DAILY OPERATIONS MODEL

APPENDIX B

LOWER TUOLUMNE RIVER ACCRETION
(LA GRANGE TO MODESTO)

ESTIMATED DAILY FLOWS (1970-2010)
FOR THE OPERATIONS MODEL

Lower Tuolumne River Accretion (La Grange to Modesto)
Estimated daily flows (1970-2010) for the Operations Model
Don Pedro Project Relicensing

1.0 Objective

Using available data, develop a daily time series representing the total accretion and/or depletion flows between La Grange Dam and the Modesto gage on the Tuolumne River. These data will serve as input into the relicensing operations model. Accretion or depletion in this context is defined as the full inflow or outflow, respectively, contributed by or to the local drainage basin, incorporating both groundwater/baseflow and surface runoff considerations.

2.0 Existing Information

As shown in Table 1, there are three permanent flow gages currently installed in the lower Tuolumne River: (1) the Modesto gage, operated by the USGS (USGS 11290000); (2) the gage below La Grange Dam, operated by Turlock Irrigation District and calibrated to USGS standards (USGS 11289650); and (3) the Dry Creek at the Tuolumne River gage, operated by the California Department of Water Resources (DWR; Gage Code DCM on the California Data Exchange Center) on Dry Creek.

Table 1. Historical flow data for the lower Tuolumne River.

River Mile	Location	Gage Identifier	Period of Analysis	Data Quality	Notes
TUOLUMNE RIVER					
51.5	Tuolumne River at La Grange	USGS: 11289650	October 1 1970 – September 30 2010	Records are "good" with expected accuracy to about 5%.[2]	La Grange gage is located 0.5 miles downstream of La Grange Dam.
16.2	Tuolumne River at Modesto	USGS: 11290000	October 1 1970 – September 30 2010	Records are "fair", except for estimated daily discharges which are "poor". About 3% of the daily values since 1970 are estimated.[2]	The flood control flow objective for the lower Tuolumne River is 9,000 cubic feet per second (cfs) at the Modesto Gage (RM 16.2). As Dry Creek confluences with the lower Tuolumne River just upstream of the Modesto gage, inflows from Dry Creek are accounted for the this management objective.
DRY CREEK					
--	Dry Creek at Tuolumne River Confluence	DWR: B04130/CDEC: DCM	October 1 1970 – September 30 2010	Qualifiers are provided: Good data, Estimated Data or Missing Data. About 1.2% of the daily values are estimated or missing.	Dry Creek is a tributary to the Tuolumne River at RM 16.2. Dry Creek operations changed substantially in 1987. Prior to 1987, substantially greater flows were diverted at LaGrange into the Modesto Canal in fall (October-December) months, with a portion being returned back to the Tuolumne River through Dry Creek.

USGS = US Geological Survey
DWR = Department of Water Resources
[2] USGS defines fair as having accuracy to approximately 8%, and poor as greater than 8% (Turnipseed, 2010). Typically natural bottomed streamflow measurements are considered "good" if accurate to about 5% (Turnipseed, 2010).

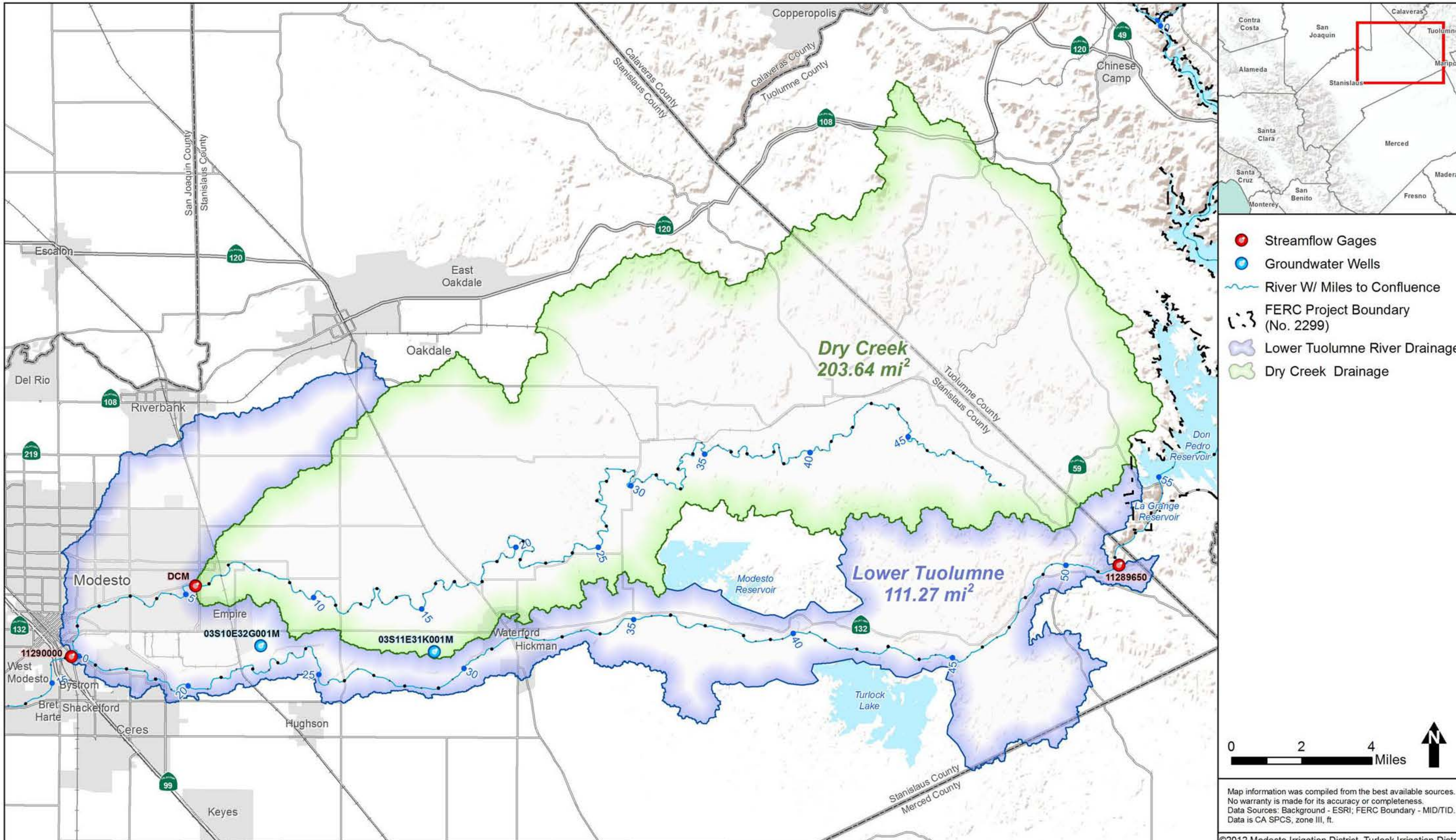

Figure 1. Map of lower Tuolumne drainage, Dry Creek drainage, and gages.

Using data collected at the three gages, accretion was calculated for the lower Tuolumne through the following equation:

Accretion flow (cfs) = Flow at the Modesto gage (cfs) − Flow at La Grange gage (cfs) − Flow at Dry Creek gage (cfs)

Average daily accretions in the Lower Tuolumne range from 40 cfs to 200 cfs, with an annual average accretion of 218 cfs from water year 1970-1987 and 103 cfs from water year 1988-2010, resulting in a water year 1970-2010 average of 152 cfs (calculated daily accretion data are provided in Attachment B). Deviations from the average are highest in the winter months; as the flows increase, so does the uncertainty in the gage rating. The largest difference in flow observed was during the January 1997 storm; it has been determined that the computations are not reliable during large storm events due to the cumulative gage rating uncertainty associated with the calculation.

A review of the historical gage data from these three locations indicates a higher degree of variability of accretions than would be expected to naturally occur. For example, as shown in Figure 2, when calculated accretions[1] are graphed without any data smoothing or other adjustment, values are erratic and frequent negative flows are observed.

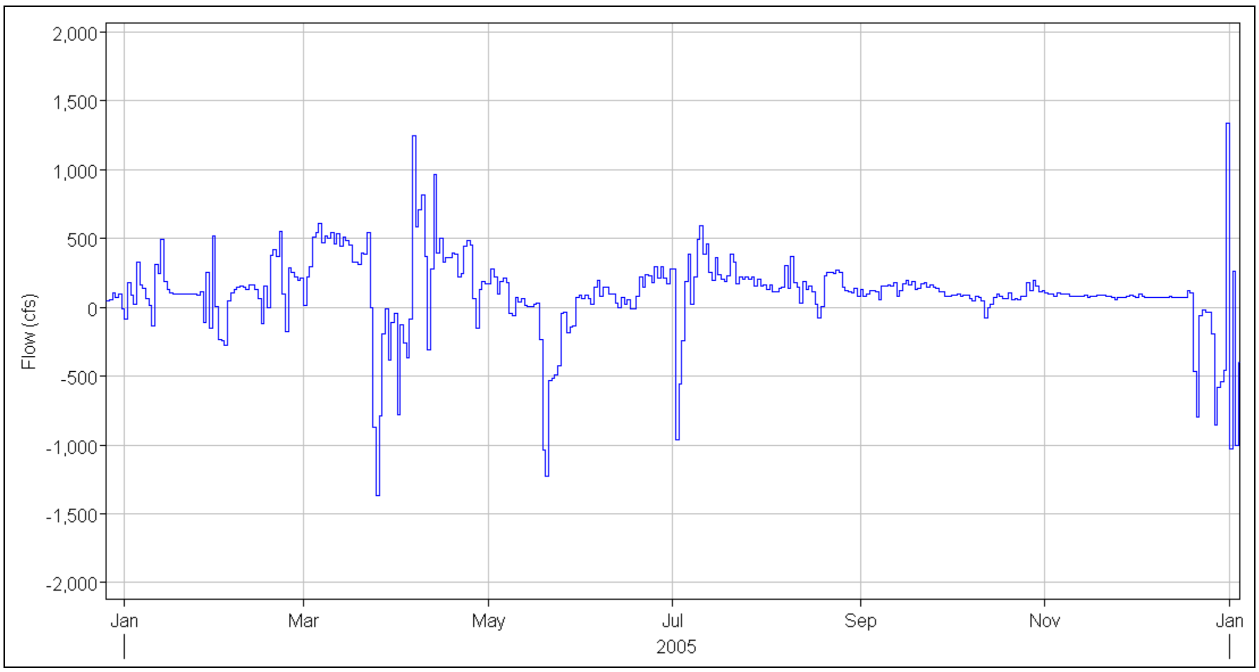

Figure 2. Sample computation of daily Lower Tuolumne accretion (flows at Modesto gage less La Grange gage and Dry Creek gage).

This variability is likely due to the relatively small magnitude of accretions compared to the actual gaged flow; relatively small errors and hydrograph timing differences and would explain much of the variability in accretions determined through a strict mathematical interpretation of

[1] It should be noted that this calculation does not allow for any travel time between locations; at the typical flow rates in the lower Tuolumne River, travel time would be expected to be on the order of hours rather than days.

USGS and DWR gage data. Additionally there may be agricultural withdrawals and return flows that are not being accounted for, as well as some interaction with the groundwater.

Inclusion of these data “as is” into the operations model will introduce variability that is distracting to the planning process, and at times invalid. A synthetic daily time series that represents the total accretion flow between La Grange Dam and the Modesto gage (including the contributions of Dry Creek) is therefore necessary to provide a reasonable estimate for modeling and planning purposes.

3.0 Methods

Due to the nature and quality of data, slightly different approaches were followed for synthesizing Dry Creek accretion and the lower Tuolumne accretion data sets. In addition, the total accretion calculations were split into two separate approaches for estimation of groundwater baseflow and surface runoff contributions. The two approaches are then aggregated to provide an estimate of total accretion.

3.1 Dry Creek

There are several locations within Dry Creek where accretion and depletion may occur. The gage on Dry Creek located about 5.6 miles upstream of the confluence with the Tuolumne River, is the best available approximation of the total flow at the mouth of Dry Creek.

Monthly synthetic baseflow values were then estimated using the average monthly flow rate in months that had less than ¾ inches of rain, representing periods with minimal expected surface runoff.

Surface runoff was estimated for Dry Creek manually using baseflow separation techniques. The entire period of record of the gage was examined graphically to determine if the flows recorded were likely to be surface runoff, baseflow, or return flow from irrigation canals. The synthetic baseflow values were then used to fill in all hydrograph values judged to be baseflow, or return flow.

Attachment A contains the synthetic flow record for Dry Creek for the period of 1970-2010, using the methods described above. Attachment B provides all the data files used to derive the synthetic flow record.

3.2 Lower Tuolumne

An estimate of total accretion for the 35.3 mile reach between the La Grange and Modesto gages was developed from the available gage data. Methods were separated into independent baseflow and surface runoff estimates, similar to the approach used to estimate Dry Creek accretion.

For the lower Tuolumne, the long-term daily median demonstrates the annual trend more clearly than the daily calculation using observed data, due to erratic swings in the daily calculation between large values and negative values. Long-term daily median in this case is the 50% exceedance of each individual date across all years in the record (e.g. the 50% exceedance of all October 1st daily values from 1988 to 2010 is used to represent a single October 1st estimate). During periods of agricultural return flows, rainfall, or high flow, the values can be especially erratic, so the yearly median was examined for comparison to the yearly average.

The long-term daily median datasets were restricted to synthesized values from water year 1988-2010 because the pre-1987 Dry Creek flows from irrigation sources significantly impacted the gage calculation. A piece-wise linear synthetic time series was developed using visual inflection points from the yearly median, while honoring the annual volume estimate derived from the long-term daily median. This piece-wise linear estimation of the median annual accretion curve was then applied to the whole period (1970 to 2010). Figure 3 shows the annual median and resulting synthetic accretion. Attachment B contains the results of this computation.

The gage calculation was too erratic to be useful for surface runoff estimation. Therefore, a simple drainage area proration was applied to estimate surface runoff for the lower Tuolumne natural runoff accretion. This was done using the Dry Creek gage hydrographs, separated from baseflows as described in Section 3.1 above.

4.0 Results

4.1 Baseflow Calculations

Calculated daily time step accretions are provided in the accompanying Attachment B, along with supporting measured gage data.

Synthetic baseflow values[2] for Dry Creek are developed in Attachment B and summarized, by month, in Table 2. These values were inserted into the daily accretion series, provided in Attachment B.

Table 2. Synthetic baseflow rates for Dry Creek by month in cubic feet per second (cfs).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10	30	30	40	45	50	55	70	65	30	3	1

Synthetic baseflow accretion values for the lower Tuolumne reach between La Grange and Modesto gages are developed in Attachment B and summarized by month in Figure 3.

[2] The observed base flow in Dry Creek likely includes agricultural return flows during the typical growing season of April through October. Flows typically recede sharply in November, suggesting the elimination of seasonal return flows.

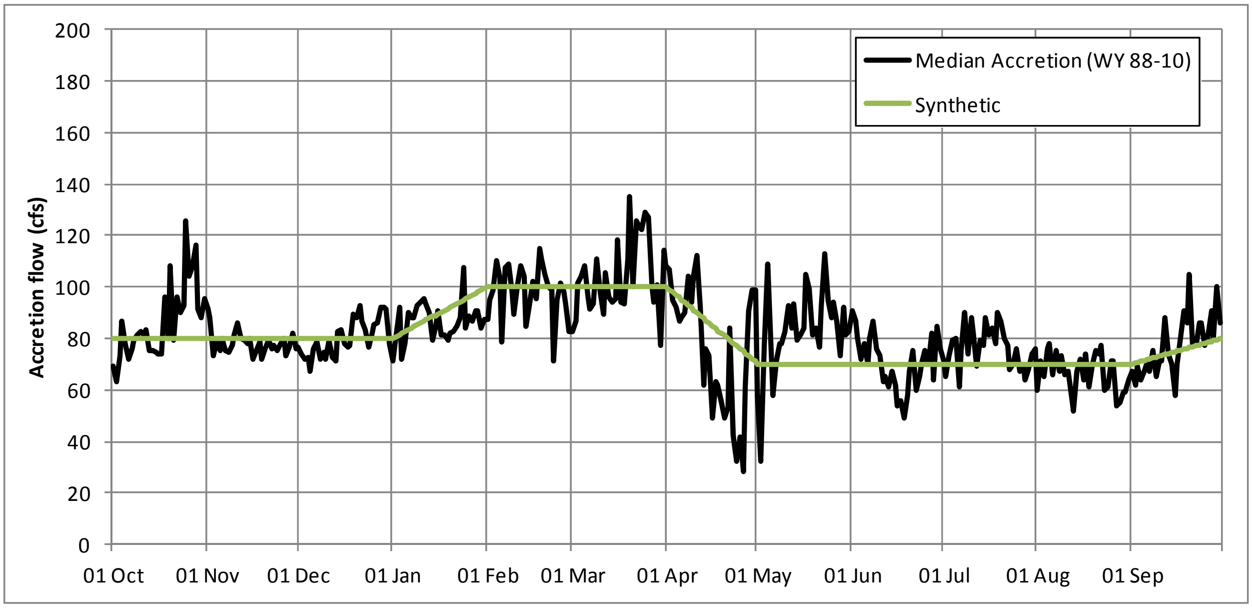

Figure 3. Synthetic accretion flow rates for lower Tuolumne in cubic feet per second (cfs).

4.2 Surface Runoff Calculations

The drainage area to the Dry Creek gage was measured to be 203.6 mi², and the accretion drainage area of the lower Tuolumne was measured to be 111.3 mi². This yields a proration factor of 0.5464, therefore all of the hydrographs separated for use in the Dry Creek synthetic time series were multiplied by 0.5464. A visual examination of the gage computation and synthetic time series for the lower Tuolumne demonstrated that erratic swings in the gage computation are coincident with runoff events in Dry Creek. An example of this phenomenon is shown in Figure 4.

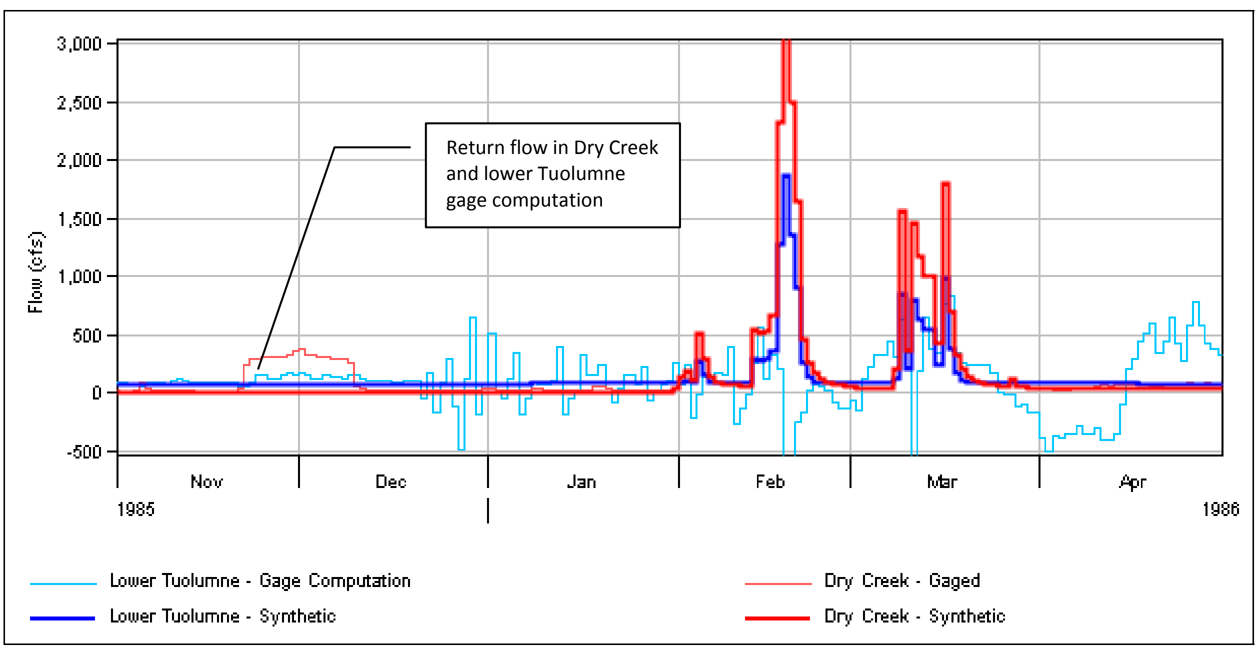

Figure 4. Sample synthetic and gaged data for lower Tuolumne accretion and Dry Creek.

5.0 Discussion

5.1 Dry Creek Accretion

From 1987 to 2011, the period for which Dry Creek operations have been relatively consistent, the volume of synthetic baseflow with observed surface runoff hydrographs is compared to the volume of the unaltered gage data in Figure 5, which indicates the synthetic baseflow values are an appropriate substitute for the gaged data.

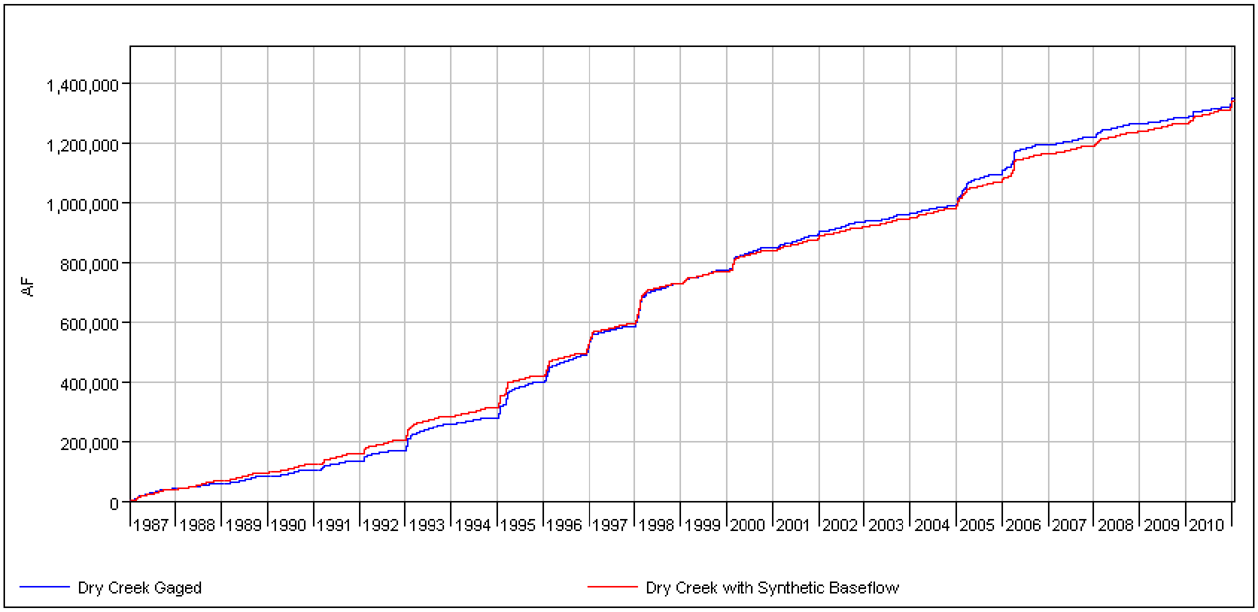

Figure 5. Dry Creek synthetic baseflow and gaged flow, cumulative volumes 1987-2010.

This comparison provides excellent validation in both the annual and long-term volumetric approach to accretion estimates in Dry Creek.

5.2 Lower Tuolumne Accretion

Below, the influence of groundwater synthetic baseflow volume is examined, followed by a comparison of the synthetic accretion dataset to the unaltered gage computation.

5.2.1 Groundwater Influence

The influence of groundwater interactions with the river on computed lower Tuolumne accretions (Modesto flows, less La Grange and Dry Creek) is further examined in Figure 6. The purpose of this examination is to explore the extreme variability in the accretion computation – whether it's due to gage errors, gage re-rating (Modesto gage has been at four different locations during this time[3]), or interactions with the groundwater. The location of two representative groundwater wells relative to the basin can be seen in Figure 1.

[3] United States Geologic Survey (USGS), 2010. *Water-Data Report 2010. 11290000 Tuolumne River at Modesto, CA.* <http://wdr.water.usgs.gov/wy2010/pdfs/11290000.2010.pdf>

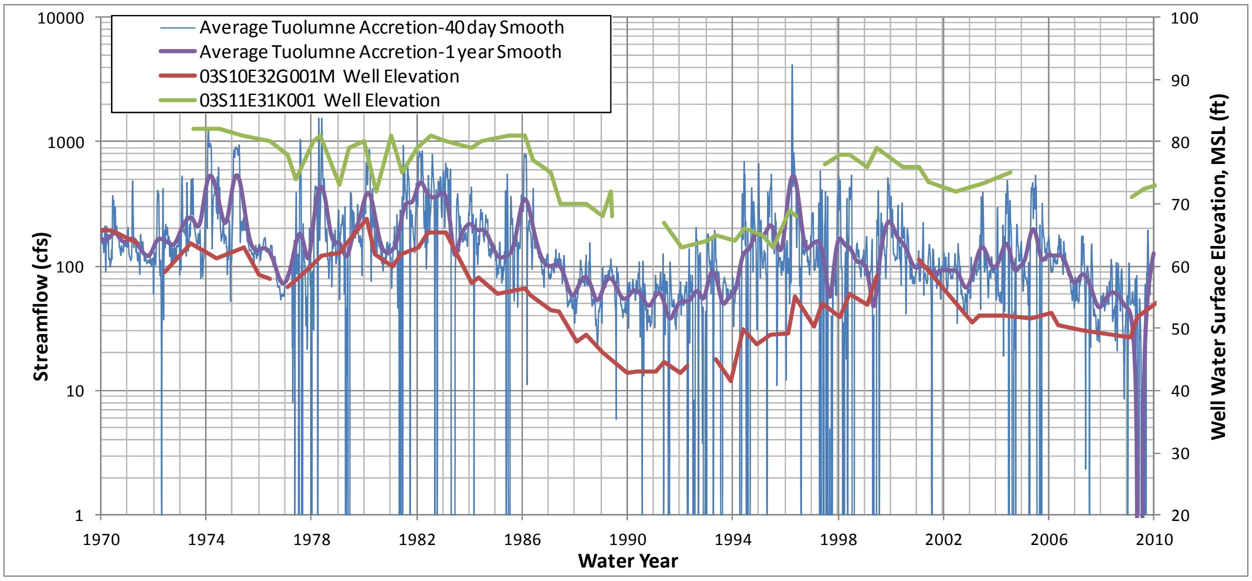

Figure 6. Relationship between lower Tuolumne accretion and groundwater wells 1970-2010.

It can be seen that baseflow and groundwater level roughly correspond to one another. Even though 1977 is the driest year in this period of record, it is a relatively short drought period, and groundwater levels do not have a chance to respond, but in the six-year drought period of 1987-1992, groundwater levels drop dramatically, and accretions respond accordingly.

Given that there is a demonstrated relationship between groundwater level and accretion, this leaves several factors that can cause the extreme variation in the daily time series.

- Gage lag-time and inaccuracy
- Local rainfall runoff
- Agricultural return flows and withdrawals
- Agricultural irrigation and M&I withdrawals from groundwater

Quantifying these factors would require many assumptions, as available information is highly uncertain and/or unavailable. It is possible that the periods of depletion in the time series are actually during groundwater pumping or they could be due to something else. Accounting for all of these factors in development of the synthetic accretion values would require many additional assumptions. Given the accuracy and precision of the input data, it could not be reported with any additional confidence.

5.2.2 Comparison to synthetic accretion

The synthetic accretion data set for the lower Tuolumne (Section 4.0) is checked against period of consistent hydrology (1987-2008) in Figure 7. In other words, Figure 7 shows the computed accretion volumes for the reach between the La Grange and Modesto gages compared to synthetic values.

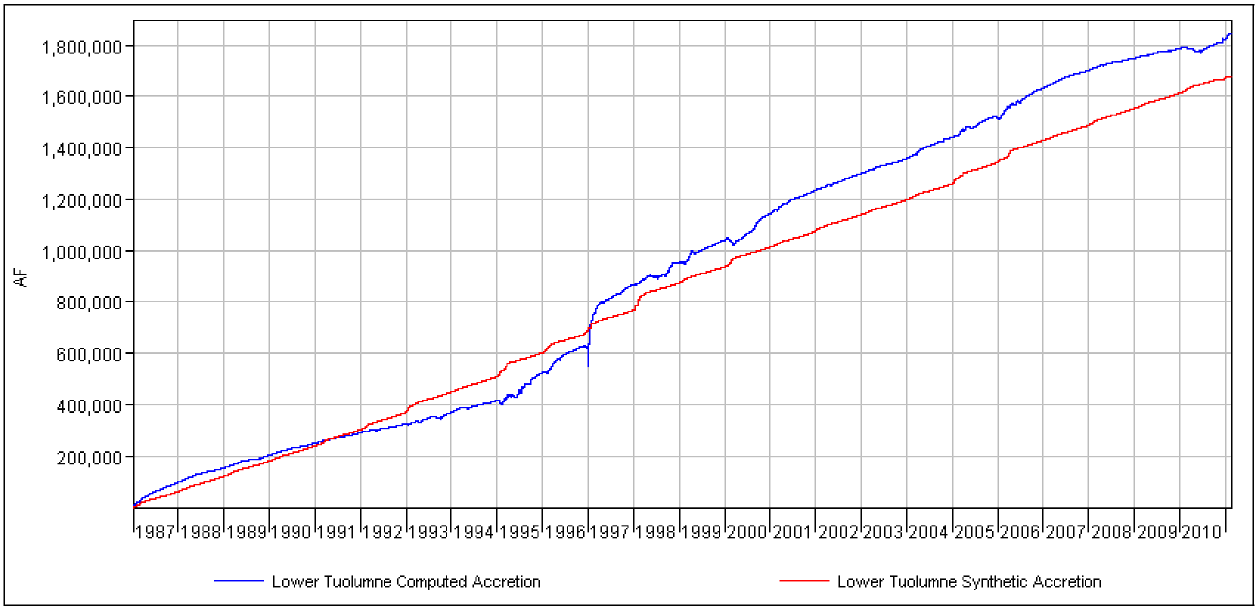

Figure 7. Lower Tuolumne River accretion, synthetic and computed, cumulative volumes (1987-2010).

A significant discontinuity can be seen following the New Years Day 1997 storm. Upon closer examination, it was found that following the 1997 flood, the gage at La Grange had to be re-rated, making its measurements during the storm unreliable. Further, the average accretion between Jan 2nd to Jan 10th 1997 from the gage calculation is about 4,000 cfs, which is just 7% of the peak flow observed at Modesto of 55,800 cfs, well within the margin or error for a three-gage calculation at high flow. If the discontinuity following the New Years Day storm is ignored, the cumulative volume of the synthetic accretion appears to match the cumulative volume of the computed accretion.

5.2.3 Comparison to Accretion Flows Measured in June 2012

On June 25, 2012, Modesto Irrigation District and Turlock Irrigation District collected flow information for the lower Tuolumne River between the La Grange Gage and the San Joaquin River confluence, as well as within Dry Creek. Table 3 presents the results of the measurement.

Table 3. Measured and gaged discharge on the Tuolumne River and Dry Creek.

Location	Measured Discharge (cfs)	Gaged Discharge (cfs)	Percent Difference (%)
Tuolumne at La Grange	114.9	130	12
Tuolumne at Modesto	208.2	219	5
Dry Creek [a]	55.5	38 [b]	46
Lower Tuolumne Accretion	55.3 [c]	-	-

[a] Measured at confluence with Tuolumne River, 5.3 miles downstream of the gage.
[b] Value from CDEC (DCM), not yet available on Water Data Library (B04130).
[c] Using Dry Creek gaged discharge, rather than measured.

It is important to note that the Dry Creek measurement was not taken at the gage. The lower Tuolumne accretion calculation discussed herein uses values from the gage on Dry Creek, and does not attempt to subtract any accretions below the Dry Creek gage. The accretions in Dry Creek, below the gage, are therefore included in the lower Tuolumne accretion numbers. Another distinction to make is that the Dry Creek gage values are published twice, first in real time on CDEC (DCM), and later on the Water Data Library (B04130) after some quality control procedures by the California Department of Water Resources. The computations in this report used the Water Data Library values when available, and CDEC values only to fill in gaps in the record, and the values are often considerably different.

The synthetic baseflow value for Dry Creek in June is 50 cfs, which is in the range of values estimated by the measurement. The synthetic accretion for the lower Tuolumne in June (including accretion below the Dry Creek gage) is 70 cfs. In this case the synthetic accretion is more than the measured accretion (55 cfs), which could be due to lower groundwater levels in 2012. The lower amount could also be due to efforts to minimize all operational spills into the Tuolumne River during the measurement. Using the gaged measurements alone, the accretion would be estimated to be 51 cfs.

The Dry Creek gage has been deemed to provide the most reliable data for estimation for surface runoff-based accretion in the entire lower Tuolumne River drainage. Other elements of accretion estimation, such as groundwater contributions, have been estimated by honoring as much of the source data as possible in the lower Tuolumne. The resulting synthetic, aggregate hydrograph provides a reasonable estimate for both long-term and rainfall event-driven contributions to the lower Tuolumne River from the La Grange gage to the Modesto gage.

6.0 Attachments

The following attachments to this memo are available on http://www.donpedro-relicensing.com.

- AttachmentA.pdf
- AttachmentB.dss

Attachment A contains the final time series data for Dry Creek, lower Tuolumne (excluding Dry Creek), and total accretion from La Grange to Modesto gage.

A brief description of each of the DSS tables that comprise Attachment B is provided as Table 3.

Table 3. Attachment B Contents, final datasets indicated with bold font.

Name - /LOWER TUOLUMNE/B/C//E/F/	**Contents**
//DRY CREEK/FLOW//1MON/BASEFLOW/	A time series containing averaged monthly baseflow values in months with less than 0.75" of precipitation (cfs)
//DRY CREEK/FLOW//1DAY/DCM_ADJUSTED/	Gaged flow at Dry Creek DWR record B04130 , combined with CDEC DCM, for missing days (cfs)
//DRY CREEK/FLOW//1DAY/HYD_ONLY/	Dry creek gaged flow, with baseflow deleted (cfs)
//DRY CREEK/FLOW//1DAY/SYNTHETIC/	**Synthetic time series using BASEFLOW_EST in all places that HYD_ONLY is missing data (cfs)**
//DRY CREEK 87/ACCUM//1DAY/DCM_ADJUSTED/	1987-2010 cumulative volume for gaged dry creek flow (acre-ft)
//DRY CREEK 87/ACCUM//1DAY/SYNTHETIC/	1987-2010 cumulative volume for SYNTHETIC dry creek

Name - /LOWER TUOLUMNE/B/C//E/F/	**Contents**
	dataset (acre-ft)
//TUOLUMNE ACCRETION/FLOW//1DAY/COMPUTED/	Time series of computation: Modesto [11290000] minus La Grange [11289650] and Dry Creek [DCM_ADJUSTED] (cfs)
//TUOLUMNE ACCRETION/FLOW//1DAY/BASEFLOW/	Generalized median of COMPUTED values from 1988 to 2010 (cfs)
//TUOLUMNE ACCRETION/FLOW//1DAY/HYD_ONLY/	//DRY CREEK///HYD_ONLY/ times the drainage area proration of 0.5464 (cfs)
//TUOLUMNE ACCRETION/FLOW//1DAY/SYNTHETIC/	**Synthetic time series using greater of HYD_ONLY and BASEFLOW (cfs)**
//TUOLUMNE ACCRETION 87/ACCUM//1DAY/COMPUTED/	1987-2010 cumulative volume of COMPUTED daily accretion (acre-ft)
//TUOLUMNE ACCRETION 87/ACCUM//1DAY/SYNTHETIC/	1987-2010 cumulative volume of SYNTHETIC daily accretion (acre-ft)

7.0 References

Durbin, T.J., 2003, *Turlock Groundwater Basin Water Budget 1952-2002.* Turlock Groundwater Basin Association. ftp://ftp.water.ca.gov/uwmp/completed-plans/Ceres/2.pdf

TID/MID 2012. Study W&AR 2 Operations Model Action Item from April 9, 2012, Hydrology Workshop Proposed Lower Tuolumne Flow Accretion and Depletion Measurement Locations. Memo to Relicensing Participants. June 6.

Turnipseed, D.P., and Sauer, V.B., 2010, *Discharge measurements at gaging stations:* U.S. Geological Survey Techniques and Methods book 3, chap. A8, 87 p. <http://pubs.usgs.gov/tm/tm3-a8/>

TUOLUMNE RIVER DAILY OPERATIONS MODEL

APPENDIX C

FIELD ACCRETION MEASUREMENT INFORMATION

REVIEW

ONE COMPANY *Many Solutions*℠

Memo

To:	Don Pedro Relicensing Participants		
From:	Turlock Irrigation District / Modesto Irrigation District	Project:	Don Pedro Hydroelectric Project
Date:	June 6, 2012		

RE: Study W&AR 2 Operations Model
Action Item from April 9, 2012, Hydrology Workshop
Proposed Lower Tuolumne Flow Accretion and Depletion Measurement Locations

In accordance with our Study Plan W&AR-2 (November 22, 2011), the FERC Study Plan Determination (December 22, 2011), and the most recent FERC Study Dispute Determination (May 24, 2012), we are planning to undertake between June 25 and 29, 2012, flow measurements along the lower Tuolumne River between La Grange Gage and the San Joaquin River confluence, as well as within Dry Creek, to develop estimates of flow accretions and/or depletions (Table 1 and Figure 1). Using accepted flow measurement methodologies, flows will be measured at permanent gage locations, established Instream Flow Incremental Methodology (IFIM) transect locations, and other sites where flow changes may be discernible. Fieldwork will consist of direct measurement of in-channel discharge at ten locations when flows of 100 cubic feet per second are scheduled, as well as opportunistic flow data acquisition at six additional irrigation canal outflow locations, if outflows are occurring. Discharge at each site will be measured using standard methods for collecting data in wadeable streams (Rantz 1982). Depths and mean column water velocities will be measured across each transect using the same methods as used in the co-occurring IFIM stream habitat assessment (Stillwater Sciences 2009). Where transects have a series of water depths greater than approximately 3.5 feet, depth and velocity may be measured using Acoustic Doppler Current Profiler methods (e.g., Simpson 2002). ***Please provide suggestions or comments on this plan to John Devine (john.devine@hdrinc.com) by Wednesday, June 20th.*** This data is targeted to be compiled, checked, and then shared with Relicensing Participants by the first week in August.

Table 1. Flow measurement and data acquisition June 2012.

River Mile	Location
51.5	Near La Grange Gage
49.1	Basso Pool
43.4	Bobcat Flat
39.5	Roberts Ferry Bridge
37.1	Santa Fe Aggregates
33	Waterford Main (MID)[1]
33	Hickman Spill (TID)[2]
31.5	Waterford
20	Faith Home Spill (TID)[2]
18	Lateral No. 1 (MID)[1]
17.2	Legion Park
16.4	Dry Creek Gage
16.2	Modesto Gage
11	Lateral 1 (TID)[2]
3.4	Shiloh Road
2	Lateral No. 5 (MID)[1]

[1]Opportunistic site. Flow data provided by MID if outflow is occurring during study period
[2]Opportunistic site. Flow data provided by TID if outflow is occurring during study period

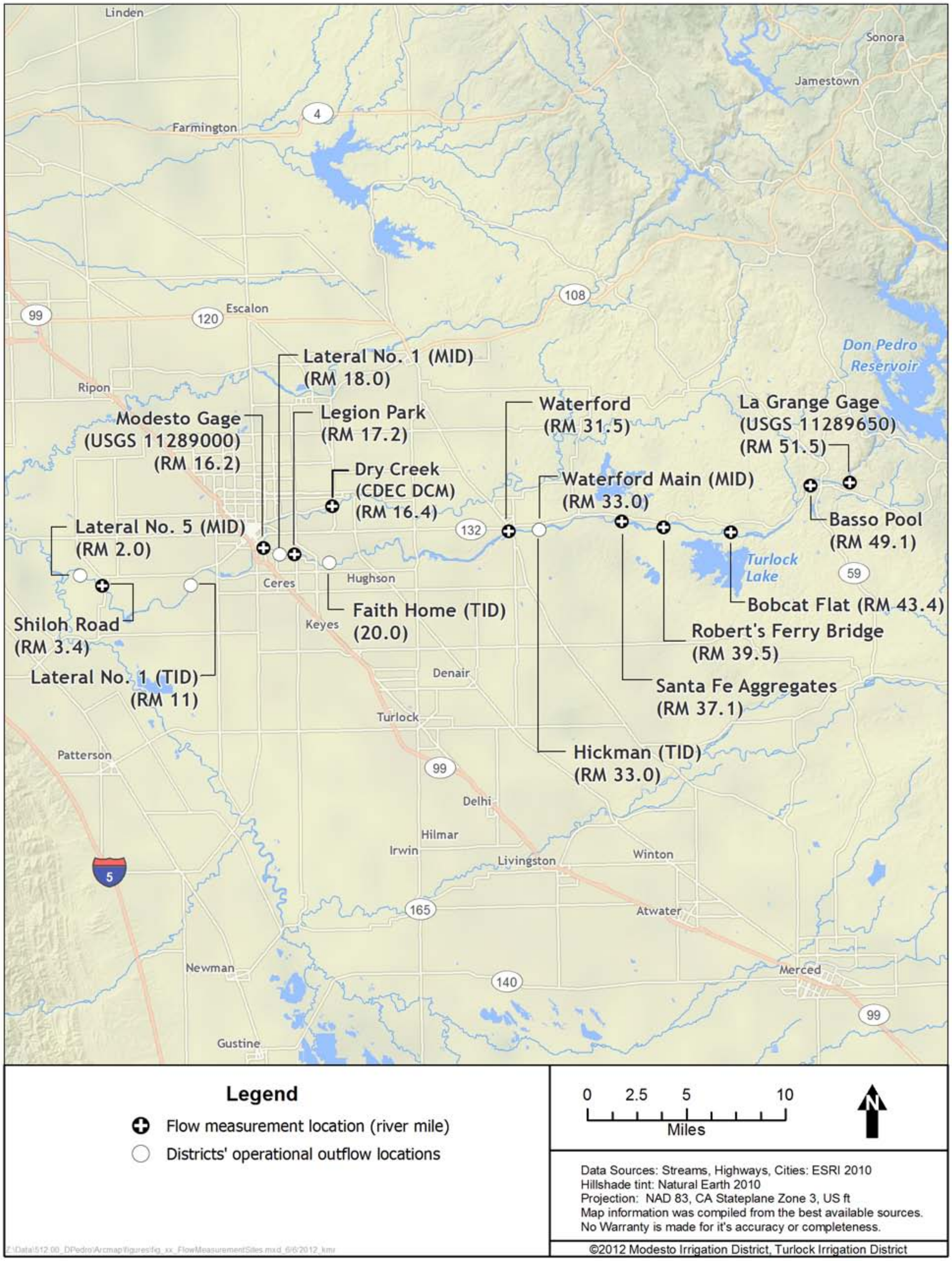

Figure 1. Flow measurement site locations along the lower Tuolumne River, June 2012.

References

Rantz, S.E. 1982. Measurement and computation of streamflow: volume 1. Measurements of stage and discharge. USGS Water Supply Paper 2175. U.S. Geological Survey.

Stillwater Sciences. 2009. Tuolumne River Instream Flow Studies. Final Study Plan. Prepared by Stillwater Sciences, Davis, California for Turlock Irrigation District and Modesto Irrigation Districts, California.

Simpson, M.R., 2002, Discharge measurements using a Broad-Band Acoustic Doppler Current Profiler: U.S. Geological Survey Open-File Report 01-01, 123 p.

Tuolumne River and Dry Creek Flow Measurements
June 25, 2012

Site	Date	Dry Creek River Mile	Tuolumne River Mile	Time (military)		Field Measurements[a] Measured Discharge (ft^3/sec)				Discharge (ft^3/sec)	Difference between Gage & Measured[b] (%)
				Start	End	Q1[c]	Q2	Q3	AVG		
Tuolumne River at La Grange gage house	6/25/12	--	51.5	0950	1120	119.2	110.6	--	114.9	114.9	--
Tuolumne River at La Grange (USGS 11289650)[d]	6/25/12	--	51.5	0945	1130	--	--	--	--	130	12
Tuolumne River at La Grange (CDEC LGN)[e]	6/25/12	--	51.5	0000	2345	--	--	--	--	94	22
Tuolumne River at Basso Pool	6/25/12	--	49.1	1325	1440	101.3	103.7	--	102.5	102.5	--
Tuolumne River at Bobcat Flat	6/25/12	--	43.4	1300	1625	93.3	105.5	99.0	99.2	99.2	--
Tuolumne River at Roberts Ferry Bridge	6/25/12	--	39.5	1535	1635	128.6	122.4	--	125.5	125.5	--
Tuolumne River at Santa Fe Aggregates	6/25/12	--	37.1	1720	1830	119.1	126.0	--	122.5	122.5	--
Waterford Main (MID)[f]	6/25/12	--	33	1800	2000	--	--	--	--	8	--
Hickman Spill (TID)[g]	6/25/12	--	33	0000	2345	--	--	--	--	0	--
Tuolumne River at Waterford	6/25/12	--	31.5	1834	1932	122.0	118.5	--	120.2	120.2	--
Tuolumne River at Delaware Road[h]	6/29/12	--	30.5	1045	1230	138.7	138.1	--	138.4	138.4	--
Faith Home Spill (TID)[g]	6/25/12	--	20	0000	2345	--	--	--	--	0	--
Lateral No. 1 (MID)[f]	6/25/12	--	18	1115	1230	--	--	--	--	1	--
Tuolumne River at Legion Park	6/25/12	--	17.2	1115	1230	169.1	181.6	--	175.4	175.4	--
Dry Creek (CDEC DCM)[e,i]	6/25/12	5.3	16.4	0000	2345	--	--	--	--	38	--
Dry Creek[j]	6/25/12	0.0	16.4	0915	1015	56.4	54.7	--	55.5	55.5	46[k]
Tuolumne River at Modesto 9th St. Bridge	6/25/12	--	16.2	1300	1400	204.2	212.1	--	208.2	208.2	--
Tuolumne River at Modesto (USGS 11290000)[d]	6/25/12	--	16.2	1300	1400	--	--	--	--	219	5
Tuolumne River at Modesto (CDEC MOD)[e]	6/25/12	--	16.2	0000	2345	--	--	--	--	216	4
Lateral 1 (TID)[g]	6/25/12	--	11	0000	2345	--	--	--	--	0	--
Tuolumne River at Shiloh Bridge	6/25/12	--	3.7	1530	1700	241.3	251.3	--	246.3	246.3	--
Lateral No. 5 (MID)[f]	6/25/12	--	2	0900	2000	--	--	--	--	26.5	--

-- not measured or not applicable

Grey is used to highlight inflow locations and flows.

Notes:

[a] Measurements collected by Stillwater Sciences using standard methods for collecting data in wadeable streams (Rantz 1982).

[b] Percent Difference = $|1 - Q_{measured}/Q_{gage}| * 100$, where $Q_{measured}$ is the measured flow and Q_{gage} is the gage flow.

[c] Q = flow. Q1, Q2, and Q3 are replicate measurements.

[d] Average data for measurement time interval, downloaded from USGS NWIS website: **http://waterdata.usgs.gov/usa/nwis/sw**. Flows reflect a rating curve "shift" retroactively applied by USGS on or about June 28, 2012. The difference between flows reported under the old and new rating curves for that date and time is aproximately 30 cfs.

[e] Mean daily flow downloaded from CDEC website: **http://cdec.water.ca.gov/selectQuery.html**. Does not reflect La Grange gage's updated rating curve.

[f] Average flow for the time interval, provided by MID (Ward, pers. comm. 2012)

[g] Daily flow provided by TID (Boyd, pers. comm. 2012)

[h] In Waterford downstream of Waterford Water Treatment Plant discharge. Data collected later than other sites; however, the temporary stage installed for the co-occuring IFIM study upstream at the Waterford site (RM 31.5) was within 1/100 ft between the two sample dates, indicating little change in flow between 6/29/12 versus 6/25/12.

[i] Dry Creek gage located upstream at Dry Creek RM 5.3 at Claus Rd., Modesto.

[j] Measurements taken in Dry Creek at confluence with Tuolumne River.

[k] Unlike the other locations, Dry Creek flow measurements were not taken at the gage. This number expresses how much flows increase below the gage. On June 25, flows increased almost 50% below the gage, accounting for 1/3 of the total flow.

Tuolumne River and Dry Creek Flow Measurements
October 3-4, 2012

Site	Date	Dry Creek River Mile	Tuolumne River Mile	Time (military)		Field Measurements[a] Measured Discharge (ft^3/sec)			Discharge (ft^3/sec)	Difference between Gage & Measured[b] (%)	Stream Temp. (°C)
				Start	End	Q1[c]	Q2	AVG			
Tuolumne River at La Grange gage house	10/3/12	--	51.5	1330	1430	203.1	201.3	202.2	202.2	--	12.7
Tuolumne River at La Grange (USGS 11289650)[d]	10/3/12	--	51.5	1330	1430	--	--	--	179	13	--
Tuolumne River at La Grange (CDEC LGN)[e]	10/3/12	--	51.5	1300	1400	--	--	--	170	--	--
Tuolumne River at Basso Pool	10/3/12	--	49.1	1530	1700	185.1	196.8	191.0	191.0	--	15.5
Tuolumne River at Zanker property	10/4/12	--	45.5	1020	1130	184.2	181.5	182.9	182.9	--	14.9
Tuolumne River at Bobcat Flat	10/4/12	--	43.4	1245	1350	163.3	169.1	166.2	166.2	--	16.2
Tuolumne River at Roberts Ferry Bridge	10/4/12	--	39.5	0900	1005	200.7	192.2	196.4	196.4	--	16.4
Tuolumne River at Santa Fe Aggregates	10/4/12	--	37.1	1032	1144	182.1	185.2	183.6	183.6	--	17.8
Waterford Main (MID)[f]	10/3/12	--	33.0	0000	2300	--	--	--	1.0	--	--
Hickman Spill (TID)[g]	10/3/12	--	33.0	0000	2300	--	--	--	0	--	--
Tuolumne River at Waterford	10/3/12	--	31.5	1440	1620	194.0	189.4	191.7	191.7	--	21.6
Tuolumne River at Delaware Road[h]	10/3/12	--	30.5	1250	1400	183.0	185.7	184.4	184.4	--	21.5
Tuolumne River at Fox Grove Park	10/4/12	--	26.0	1430	1520	207.8	206.6	207.2	207.2	--	23.0
Faith Home Spill (TID)[g]	10/3/12	--	20.0	0000	2300	--	--	--	24	--	--
Lateral No. 1 (MID)[f]	10/3/12	--	18.0	0000	2300	--	--	--	1.6	--	--
Tuolumne River at Legion Park	10/3/12	--	17.2	1330	1420	192.3	188.0	190.1	190.1	--	24.8
Dry Creek (CDEC DCM)[e,i]		5.3	16.4	--	--	--	--	--	24	35	--
Dry Creek at gage	10/4/12	5.3	16.4	0830	0910	36.5	37.8	37.1	37.1	--	19.5
Dry Creek 2.0	10/4/12	2.0	16.4	0940	1030	30.8	31.6	31.2	31.2	--	19.5
Mouth of Dry Creek[j]	10/3/12	0.0	16.4	1440	1515	38.2	36.7	37.4	37.4	--	22.3
Tuolumne River at Modesto 9th St. Bridge	10/3/12	--	16.2	1110	1205	205.9	212.6	209.3	209.3	--	23.7
Tuolumne River at Modesto (USGS 11290000)[d]	10/3/12	--	16.2	1115	1200	--	--	--	227	8	--
Tuolumne River at Modesto (CDEC MOD)[e]	10/3/12	--	16.2	1115	1200	--	--	--	238	12	--
Lateral 1 (TID)[g]	10/3/212	--	11.0	--	--	--	--	--	0	--	--
Tuolumne River near Riverdale Park	10/3/12	--	10.0	0930	1100	250.0	249.2	249.6	249.6	--	21.2
Tuolumne River at Shiloh Bridge	10/3/12	--	3.7	0930	1020	219.3	220.5	219.9	219.9	--	22.2
Lateral No. 5 (MID)[f]	10/3/12	--	2.0	0000	2300	--	--	--	14.3	--	--

-- not measured or not applicable

Grey is used to highlight inflow locations and flows.

Notes:

[a] Measurements collected by Stillwater Sciences using standard methods for collecting data in wadeable streams (Rantz 1982).

[b] Percent Difference = $|1 - Q_{measured}/Q_{gage}| * 100$, where $Q_{measured}$ is the measured flow and Q_{gage} is the gage flow.

[c] Q = flow. Q1 and Q2 are replicate measurements.

[d] Average data for measurement time interval, downloaded from USGS NWIS website: **http://waterdata.usgs.gov/usa/nwis/sw**.

[e] Mean daily flow downloaded from CDEC website: **http://cdec.water.ca.gov/selectQuery.html**. Does not reflect La Grange gage's updated rating curve.

[f] Daily average flow for date reported, provided by MID (Ward, pers. comm. 2012)

[g] Daily flow provided by TID (Boyd, pers. comm. 2012)

[h] In Waterford downstream of Waterford Water Treatment Plant discharge.

[i] Dry Creek gage located upstream at Dry Creek RM 5.3 at Claus Rd., Modesto.

[j] Measurements taken in Dry Creek at confluence with Tuolumne River.