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

ATTACHMENT C

MODEL VALIDATION REPORT

TABLEOF CONTENTS

Section No. — Description — Page No.

List of Figures

Figure No. — Description — Page No.

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-2 Study Plan, page 7). This Model Validation Report is an attachment to the Model Development Report and provides information concerning the wellness of the Model to assist in evaluating alternative Project operations as part of the relicensing process. Wellness in this instance is being defined by the performance of the Model to reasonably capture the behavior of the physical system being modeled when making "what if" assumptions for different inputs. These inputs include such parameters as inflows to reservoirs and required releases to streams. The validation process establishes the credibility of the Model by demonstrating its ability to reasonably mimic the historical and projected decision process of reservoir operations.

2.0 VALIDATION

Validation in this modeling process has been undertaken to identify the ability of the Model in providing a systematic reaction to changing hydrologic conditions and system demands. As is the case with any model, the Tuolumne River Daily Operations Model is only a depiction of project operations, and is limited to representing CCSF and District operations to the extent that their operations can be described numerically and consistently by various equations and algorithms. Actual operations of the two independently operated systems may vary from those depicted by the Model due to circumstantial conditions of hydrology and weather, facility operation, and complex and sometimes inconsistent human decisions. Although the historical operation of the two systems serve as the Model's validation comparison, caution is advised to not overly rely on the absolute comparison of the Model's results and the historical record for determining the validity of the Model. Validation of the Model is also a matter of reviewing the results of the algorithms that represent the actions of the respective water system operators.

The simulation period of the Model is WY 1971 through WY 2009. While the record of the two project's operations extends back to WY 1971, the period of record used for developing and refining the Model's algorithms was limited to recent historical periods, the period subsequent to the 1987-1992 extended drought period and primarily post 1996. Additional, significant deference was given to discussions with District and CCSF operations staff related to recent operations decision-making. The focus on more recent operations is appropriate for several reasons. For instance, the 1987-1992 drought caused a re-thinking of water operations planning in the two systems, just as the drought of 1976-1977 caused re-thinking at that time. During the 1987-1992 drought, and immediately following, many water management and long-term conservation practices were honed and implemented to react to the extreme shortage of water. As the result of the drought, the two systems are generally not operated today as they were prior to the extensive drought. Limited value occurs from comparing a contemporary operation of the systems with history (prior to the 1987), and it can be problematic. Even the regulatory environment has changed since project development. Instream flow requirements for the Tuolumne River have changed since early Project operation, most significantly with the amendment of the fish flow requirements of the Don Pedro license by FERC in 1996.

The Model is intended to provide a depiction of current operations by CCSF and the Districts on the Tuolumne River. In addition to the overarching moving target dilemma that the historical record creates for a comparison to Model results, there are additional factors that need to be considered when establishing the performance marker for the Model. Factors affecting direct comparison to the historical record include:

- The two systems are constantly adjusting to real-time events. Facilities, policies and requirements may change with time.
- Modeling will not always capture issues that arise in actual operation. Decisions based on real-time circumstances may change year to year, and not always consistently.
- Modeled demands assume a constant land use (i.e. crops planted), not recognizing year to year variation.

- Models do not fully capture daily decisions, or the real-time operational discretion to modify operational goals and constraints, including dealing with potential flood management situational objectives.
- The model will not capture forced outages, unforeseen maintenance or emergency activities that have occurred during historical operations.

However, there is utility in comparing the Model simulation of basin operations with the recent historical record of operations. Most salient to the comparison is how reservoirs are managed during periods when water supplies exceed minimum requirements. It is a simple matter to illustrate against historical operations a model that simply balances inflows and outflows when all supplies can be managed without excess releases. The validation of the Model comes with providing a depiction of how water in excess of minimum requirements is managed, particularly during periods of flood control or reservoir drawdown operation.

3.0 DON PEDRO RESERVOIR AND RELEASES

The Model's simulation of Don Pedro Reservoir management and releases is validated by comparing the Model's depiction of storage and releases to historical operations. Although a record of historical operations since 1970 exists, a comparison using the early records is inappropriate due to the Project's initial filling sequence over several years. In some respects even a comparison of the Model's results with recent operational records is subject to some uncertainty due to inherent differences between the historical values of inputs and simulated values (e.g., inflows).

Several years have been selected to illustrate the performance of the Model in depicting Don Pedro Reservoir operations. Each of these years represents a period of hydrology and circumstances that allow an illustration of certain Model decision processes. As a method to illustrate specific elements of Model decision making, such as reservoir storage objectives vis-a-vi stream releases, certain other elements of hydrology such as inflow and diversions have been set to historically recorded values.

3.1 Don Pedro Reservoir Storage and Stream Release

Several sample years were selected for validating the Model's algorithms related to Don Pedro storage targets. The years 1998, 1999, 2000, 2001, 2004, 2005, and 2006 have been selected as illustrative of circumstances when Don Pedro Reservoir released in excess of minimum demands (canal demand and minimum instream flow requirements). To eliminate the confounding influence of differences in inflow and canal diversions between the historical record and modeling assumptions, both of these parameters have been set to historical values for the sample years.

Figure 3.1-1 illustrates the actual and modeled operation of Don Pedro Reservoir for the year 1998. Of particular importance to this component of validation is the tracking of actual reservoir

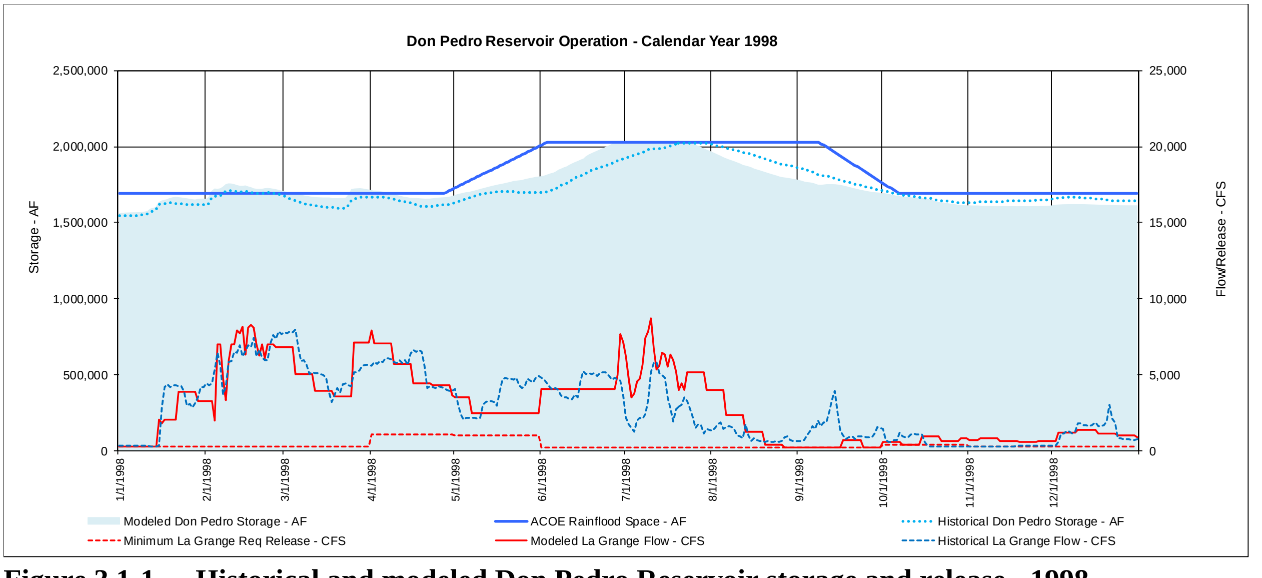

Figure 3.1-1. Historical and modeled Don Pedro Reservoir storage and release - 1998.

storage and stream flow (releases) to the Tuolumne River below La Grange Dam. The results show the modeled storage (light blue fill chart) tracking well with the historical record of storage (light blue dotted line). These storage traces are the result of historical and modeled decisions that were guided by decisions concerning storage targets. Shown coincidentally with the resultant storage are the stream releases, which when combined with releases for the Districts' canal diversions (not shown), resulted in the storage levels. The historical release to the Tuolumne River below La Grange Dam is shown as the dark blue dashed line and the modeled release is shown as the solid red line. Other information shown in the graph are the minimum flows required by the current FERC license depicted by a dashed red line, and the ACOE rain flood storage reservation shown as a solid blue line.

For year 1998, the Model makes total release decisions to provide an additional buffer of storage in addition to the ACOE rain flood space during the fall, winter and early spring.[1] To provide this storage objective the Model's 7-day encroachment logic advised total releases in excess of minimum demands. Although encroachment into storage space above the target occurs, the Model reacts to the encroachment in an effort to remedy the circumstance. Throughout this period the modeled stream release is following the *trend* of historical stream releases and the actual amount of encroachment that occurred.

Beginning in April of the subjet year, both the Model's 7-day encroachment and snow-melt release algorithms guide reservoir total releases. Evident in Figure 3.1-1 is the Modeled reservoir operation during May and June that results in reservoir storage being below the storage target which is an indication that releases are advised in excess of minimum demands so as to distribute occurring and impending snow-melt runoff prior to reservoir filling at the end of June. Some difference occurs between modeled operation and actual historical operation, but in general the modeled and historical storage and coincidental stream releases during this period trend well with each other.

After June 30, the Model uses the 7-day encroachment release algorithm to draw the reservoir down during the summer according to storage targets. Although the historical operation illustrates maintaining the reservoir near full capacity for a longer period that summer, both operations (modeled and historical) drew the reservoir back to the ACOE rain flood reservation space by fall. Both operations illustrated releases to the Tuolumne River below La Grange Dam in excess of minimum requirements during the summer.

Figure 3.1-2 illustrates the historical and modeled operation of Don Pedro Reservoir for the year 1999. The year 1999 illustrates a year that is less abundant in runoff than the previous year. During the winter and early spring of year 1999 the Model again makes release decisions to provide an additional buffer of storage in addition to the ACOE rain flood space. To provide this storage objective the Model's 7-day encroachment logic advised releases in excess of minimum demands. Throughout this period the modeled stream release is following the trend of historical releases and the amount of encroachment that occurred.

[1] An additional buffer of storage is circumstantial and may not occur consistently from year to year, or within a year. For these Model validation examples a buffer was assumed when the historical record of operations appeared to show such a consideration. The current FERC license allows real time operations decision making related to this item.

During April of the year, the Model's 7-day encroachment algorithm continues to guide total reservoir releases, but by May stream releases are reduced to the minimum required. Modeled reservoir operation during April and May differs from historical operations which included consideration of managing stream releases for the Vernalis Adaptive Management Plan (VAMP). Thereafter, both the modeled operation and historical operation released to meet minimum demands (minimum flow requirements and canal diversions).

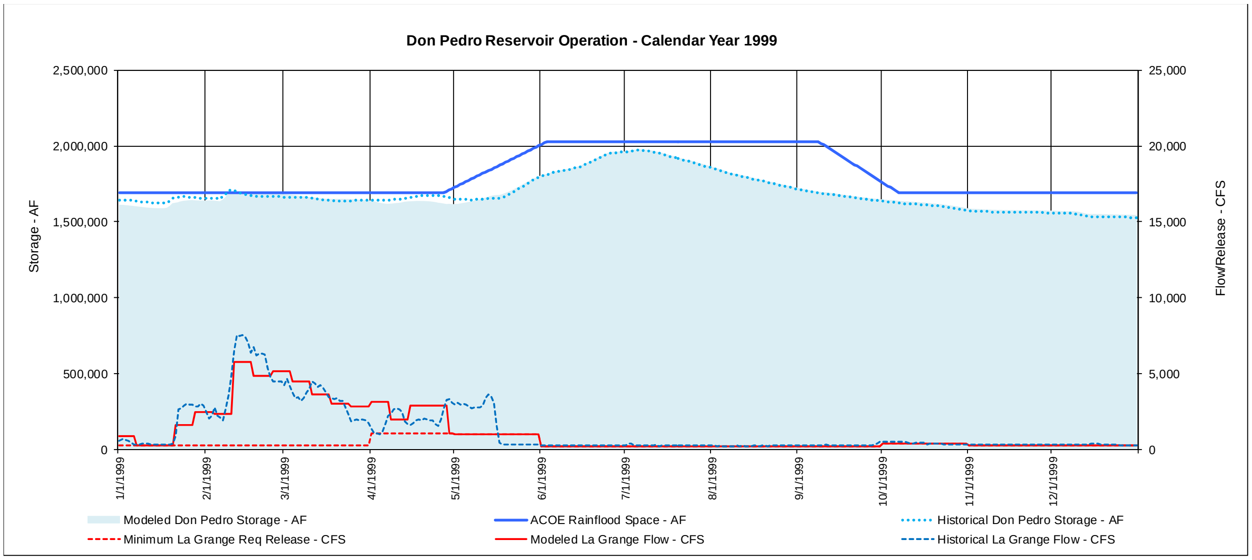

Figure 3.1-2. Historical and modeled Don Pedro Reservoir storage and release - 1999.

Modeled and historical operations for the years 2000, 2001, 2004, 2005, and 2006 are shown in Figure 3.1-3, Figure 3.1-4, Figure 3.1-5, Figure 3.1-6, and Figure 3.1-7, respectively. The results for each of these years demonstrate the Model's consistency of managing releases in excess of minimum demands, and the Model's reasonable depiction of historical operation.

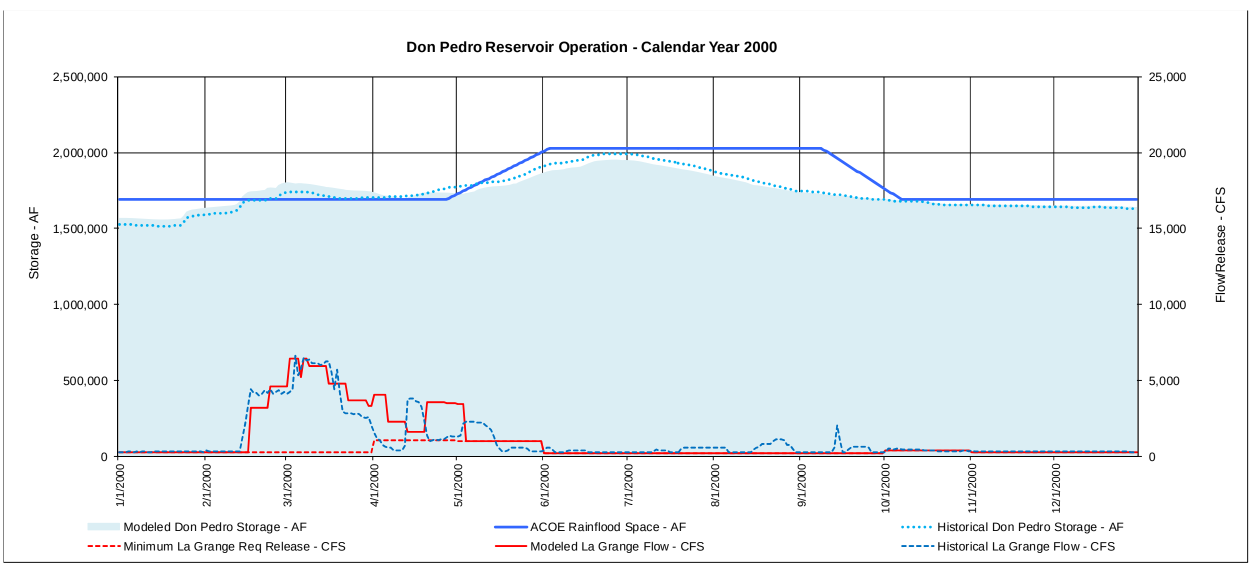

Figure 3.1-3. Historical and modeled Don Pedro Reservoir storage and release - 2000.

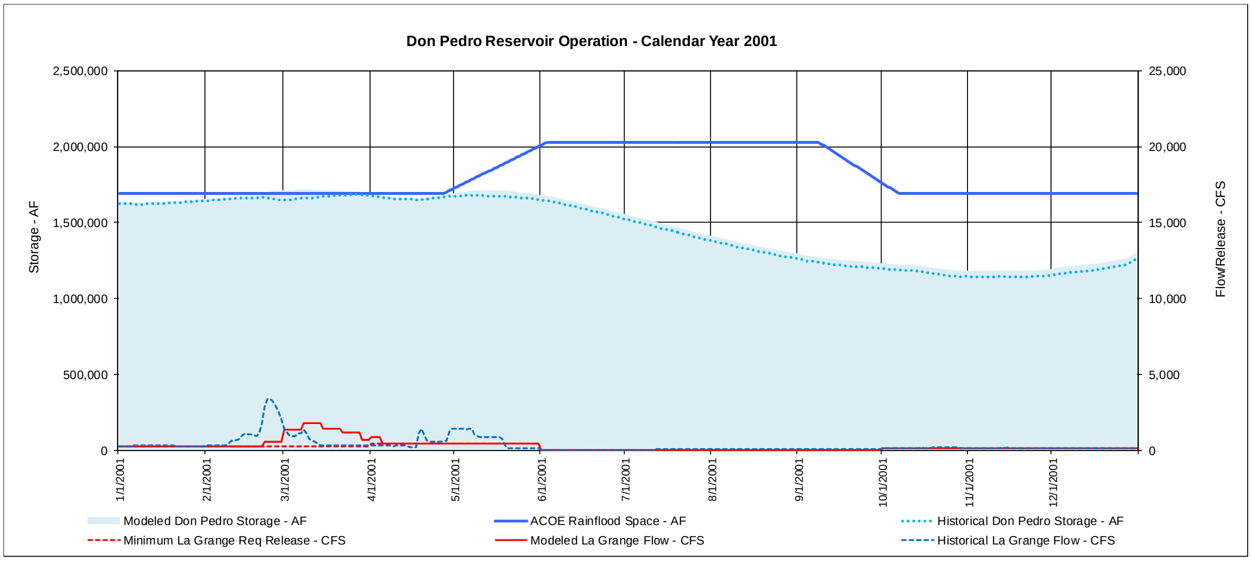

Figure 3.1-4. Historical and modeled Don Pedro Reservoir storage and release - 2001.

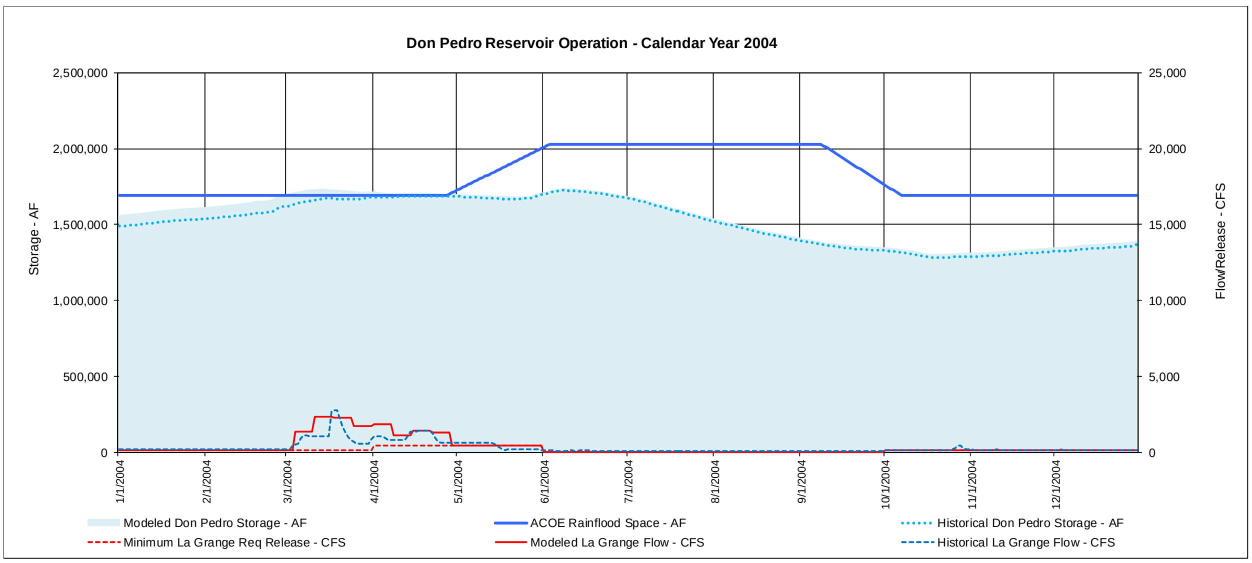

Figure 3.1-5. Historical and modeled Don Pedro Reservoir storage and release - 2004.

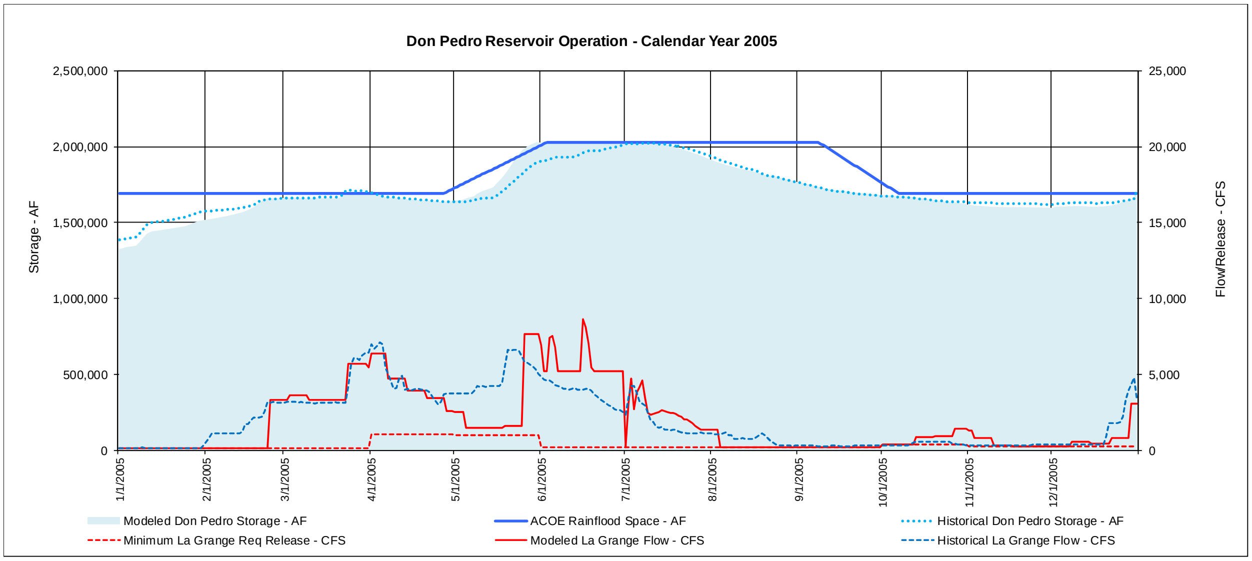

Figure 3.1-6. Historical and modeled Don Pedro Reservoir storage and release - 2005.

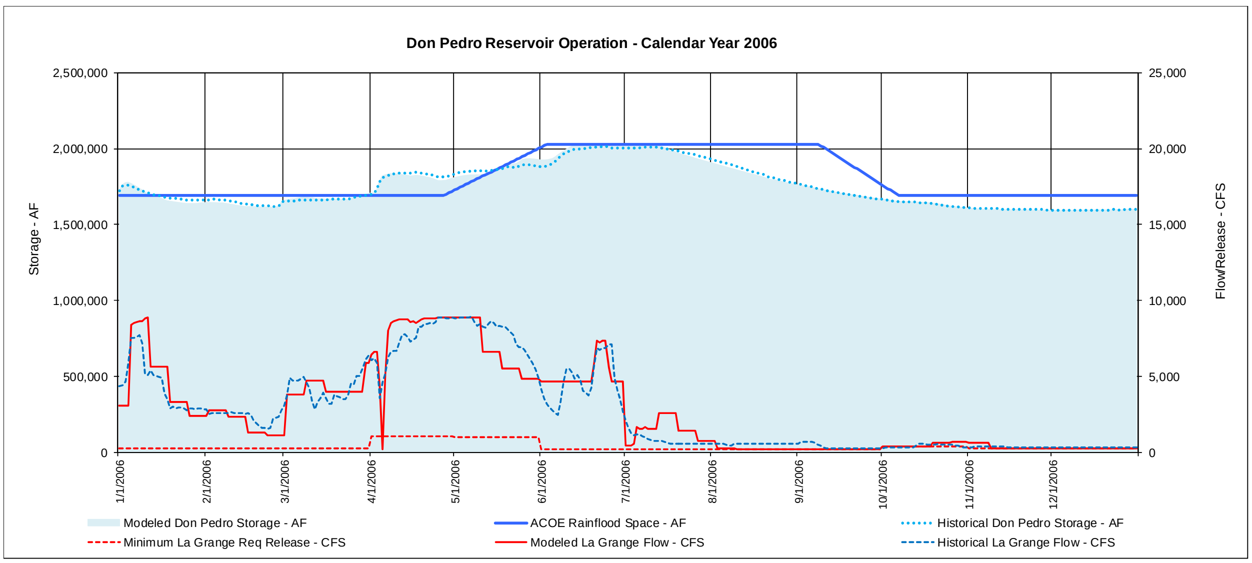

Figure 3.1-7. Historical and modeled Don Pedro Reservoir storage and release - 2006.

3.2 Consideration of Modesto Flood Management Objective

Another element of validation is the Model's performance related to flood management operations that are constrained due to flood flow guidelines at the Modesto 9th Street Bridge location. The ACOE flood flow guideline at the Modesto location is to not exceed 9,000 cfs. The Model includes an algorithm that considers both the accretions that occur between La Grange Dam and Modesto and the flow into the Tuolumne River from Dry Creek when making decisions for releases to the Tuolumne River from Don Pedro Reservoir.

Figure 3.2-1 illustrates year 1983 when releases from the Project were affected by the Modesto flood flow objective. Figure 3.2-1 illustrates results of the modeled operation for 1983. Shown are the modeled and historical depiction of reservoir storage, and a modeled depiction of flows in the Tuolumne River below La Grange Dam and the flow at Modesto. Also shown is the Model's assumption of flow from Dry Creek and the combined flow of Dry Creek and the lower Tuolumne River (LTR) accretions above Modesto. The results show how the Model reacts to accretion flow and the objective. During periods when the combined release and accretion flow would exceed the flow objective, the Model will decrease the release from Don Pedro Reservoir in order to maintain the flow objective. Not shown in this example is an exceedence of the flood flow objective, if needed, to maintain the reservoir below elevation 830 ft. Figure 3.2-2 illustrates the historical record of operations and flows at Modesto during 1983.[2] Reductions to releases to the river can be seen during March in response to the flow objective at Modesto.

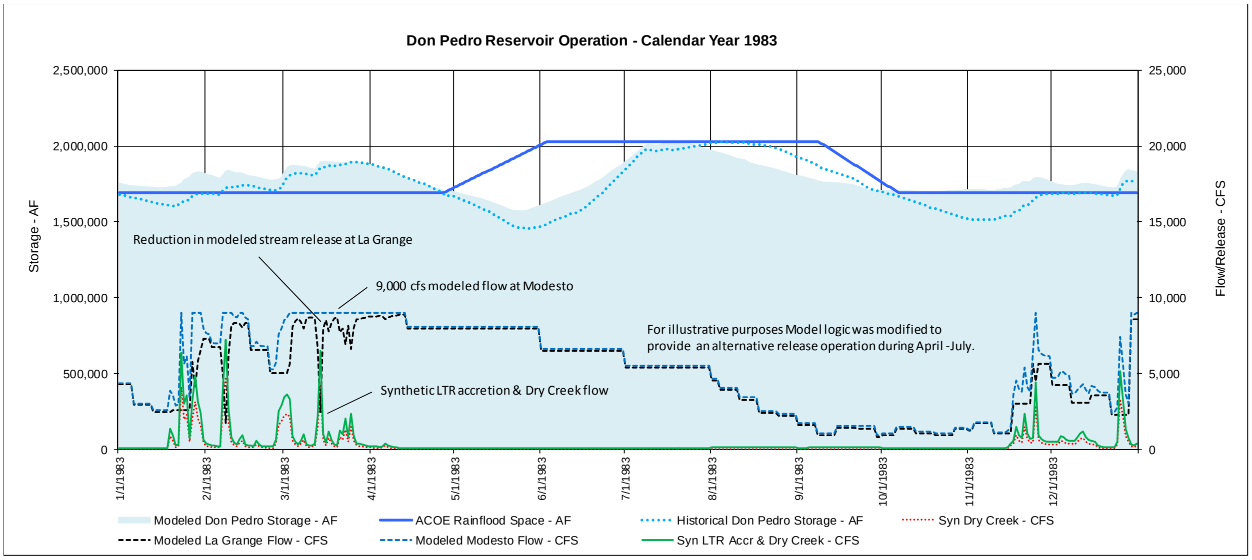

Figure 3.2-1. Historical and modeled operations affected by flow at Modesto – 1983.

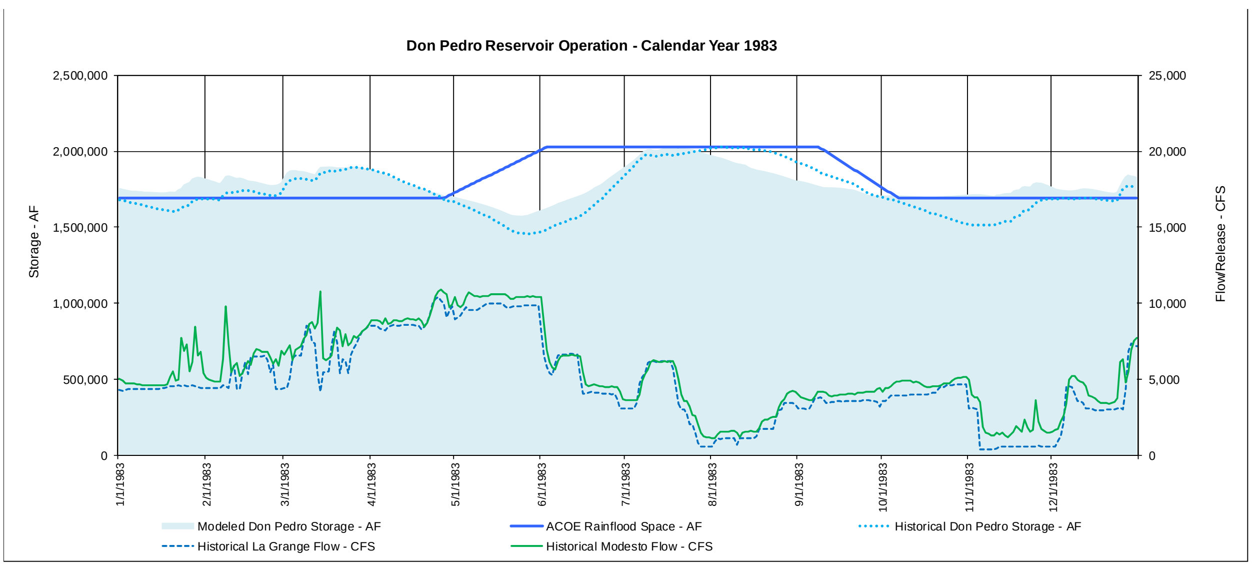

Figure 3.2-2. Historical and modeled operations affected by flows at Modesto – 1983.

[2] The historical operation of year 1983 is not within the range of years previously described appropriate for Model validation purposes; however, for the limited purpose of validating the Modesto flow flood control operation algorithm comparison of modeling results to historical operations during the early spring of 1983 is valid.

4.0 DON PEDRO RESERVOIR INFLOW AND CCSF UPSTREAM OPERATION

The elements of Model validation discussed in Chapter 3 above primarily concern the algorithms that systematically advise the Model on Don Pedro reservoir storage and flows to the Tuolumne River below La Grange Dam. Components of hydrology, reservoir inflow and canal demands, were set at the historical record thus allowing a comparison to historical decision processes without the confounding effect of differences between historical and modeled inflow and canal demands. The validation of the upstream CCSF operations, and thus the resultant modeled inflow to Don Pedro Reservoir, requires a different and more general approach.

The operation of CCSF's facilities upstream of Don Pedro Reservoir has changed throughout the modeling period, and continues to evolve. Several factors that have affected the operation include water demand that increased after 1971 but has since decreased twice due to drought and/or regional economic conditions. Current water deliveries are less than were experienced at the beginning of the modeling period, but are projected to increase in the future. Also affecting the evolving operation has been physical changes in CCSF facilities such as the addition of upstream generation capacity and a temporary reduction in local Bay-Area storage as the result of Division of Safety of Dams requirements. Significant changes in the year to year operation of CCSF reservoirs were implemented after the 1987-1992 drought when the potential for extended drought and limited water supply was starkly recognized. These experiences have led to changes in the diversion from the basin and a moving target of regulated releases.

As mentioned previously, the Model does not attempt to mimic the precise historical operations of Don Pedro Reservoir or CCSF facilities, which have experienced changed operating objectives and water demands throughout history. The Model does incorporate a contemporary operation of the Districts' and CCSF's systems layered on top of the underlying hydrology of the basin.

The CCSF water system is modeled by CCSF with a planning model (Hetch Hetchy/Local Simulation Model – HHLSM) which is described in documents supporting CCSF's Water System Improvement Program (WSIP). The relevant operation objectives and constraints of HHLSM for CCSF's Tuolumne River facilities have been incorporated into the Model including current regulatory requirements such as minimum instream flows. The Model does not include an explicit operation of the CCSF Bay-Area system, but instead incorporates the diversion demand of the San Joaquin Pipeline (SJPL). This demand, in addition to CCSF facility operation objectives and requirements, lead to defining the regulated inflow to Don Pedro Reservoir. Other than this single element of diversion demand (SJPL) the Model simulates the operation of the CCSF Tuolumne River system.

Figure 4.0-1 illustrates a Test Case and historical total inflow to Don Pedro Reservoir. The inflow to Don Pedro Reservoir is constructed of two components. One component is the inflow that occurs to the reservoir from sources that are not regulated by CCSF facility operations. This component contributes to an average 40 percent of the total inflow to the reservoir, and is unaffected by the Model's simulated operation of CCSF facilities. The second component of reservoir inflow is affected by CCSF operations. The Test Case incorporates an annual average customer demand from the CCSF system of 238 million gallons per day (MGD) and reflects CCSF's facilities and resultant operations described in the WSIP as currently approved and permitted. The illustration shows a comparison between modeled and historical total inflow for the entire modeling period; however, most germane to the Model validation is a comparison for the period beginning in 1999. While even since 1999 CCSF operations and demands have continued to change, it reflects a relatively consistent, stable period of system operation objectives.

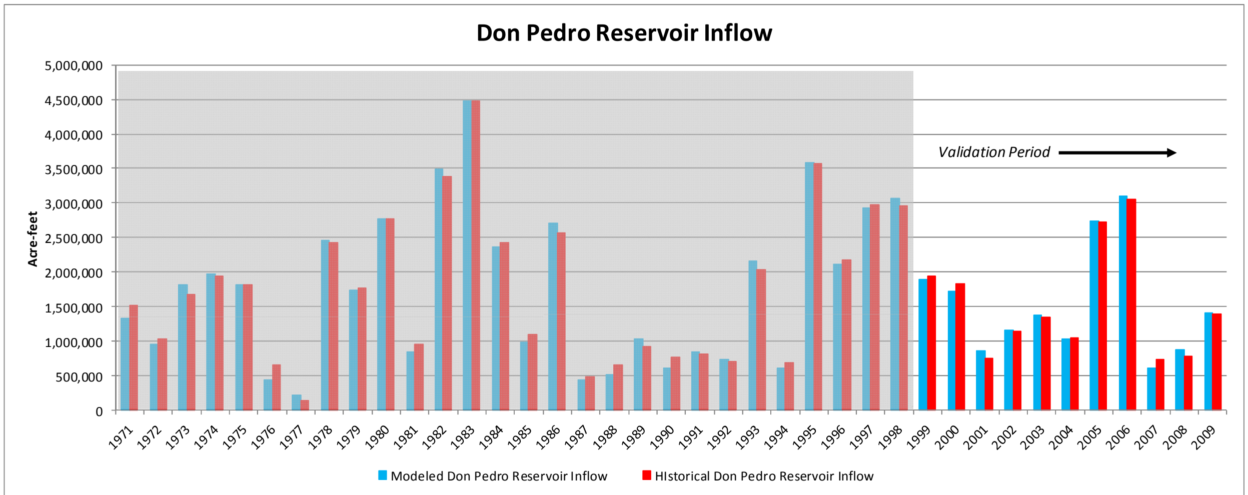

Figure 4.0-1. Modeled and historical Don Pedro Reservoir inflow (water year).

While during the validation period there are annual differences between modeled and historical inflow, ranging approximately ± 100,000 acre-feet (+13% to -16% of historical inflow), the average difference for the 11-year period is less than 4,000 acre-feet, with the differences merely a shifting between water years.

The Model performs operations with a daily time step, capturing the intricacies of sub-monthly and sometimes sub-weekly variations in hydrology and operational decision making. Figure 4.0-2 illustrates a summary of monthly volumes of inflow to Don Pedro Reservoir for the 10-year period Water Year 2000 through 2009. The modeled operation tracks well with seasonal historical inflow. The consistently greater modeled inflow occurring during May is primarily due to a recent change in CCSF operations at Hetch Hetchy Reservoir which was not occurring in the reported historical operation. This recent change in operation provides for scheduling/shifting of forecasted springtime spills from Hetch Hetchy Reservoir into May. The annual differences, if any, due to this change in operations are included in the results presented in Figure 4.0-1.

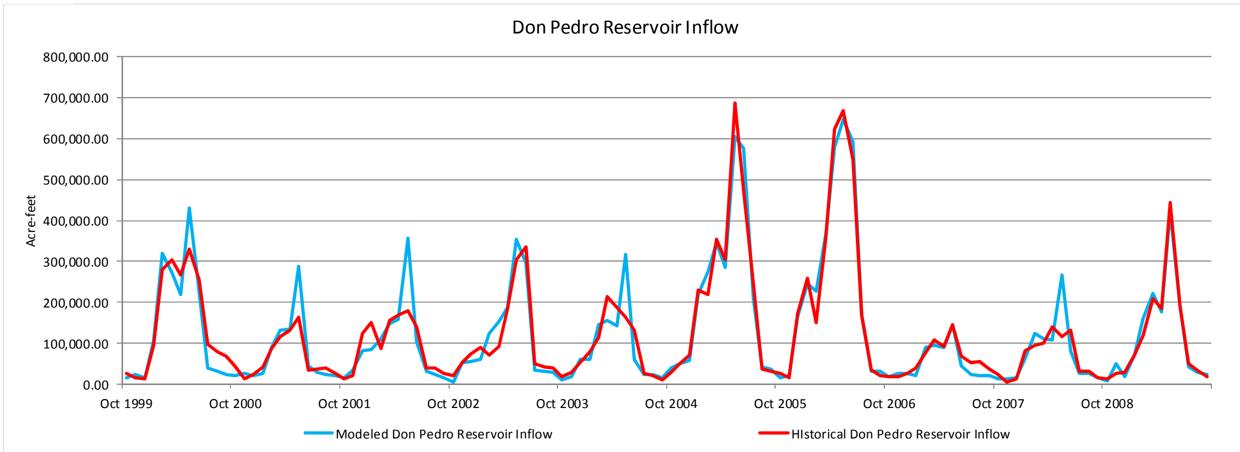

Figure 4.0-2. Modeled and historical Don Pedro Reservoir inflow (monthly volumes).

5.0 DISTRICT CANAL DIVERSIONS

The Model's depiction of the two Districts' canal diversions is another element of hydrology in the Model which reflects contemporary conditions. Due to annual changes in land use (crops planted), groundwater use, rainfall, and changing District and land owner practices the historical record of diversions varies from year-to-year. Therefore, similar to depicting reservoir inflow, the Model uses a projected canal diversion demand based on a planning model approach.

The projected canal diversions are assumed to be driven by three components: (1) a fluctuating customer component, called the projected demand of applied water (PDAW), that varies year to year and month to month, (2) a relatively constant depiction of District and land owner system operation efficiencies, and (3) an overriding water supply availability factor based on Don Pedro Reservoir storage and inflow. The development of projected canal diversions is described in the Tuolumne River Operations Model Report, Appendix B, Model Description and User's Guide, Section 3.

Figure 5.0-1 illustrates a Test Case and the historical diversions of the two Districts for the entire modeling period. The recent period beginning in year 1999 again serves as the period to validate the Model. The annual values represent a February through following January diversion period. Year 2009 contains a partial year of results.

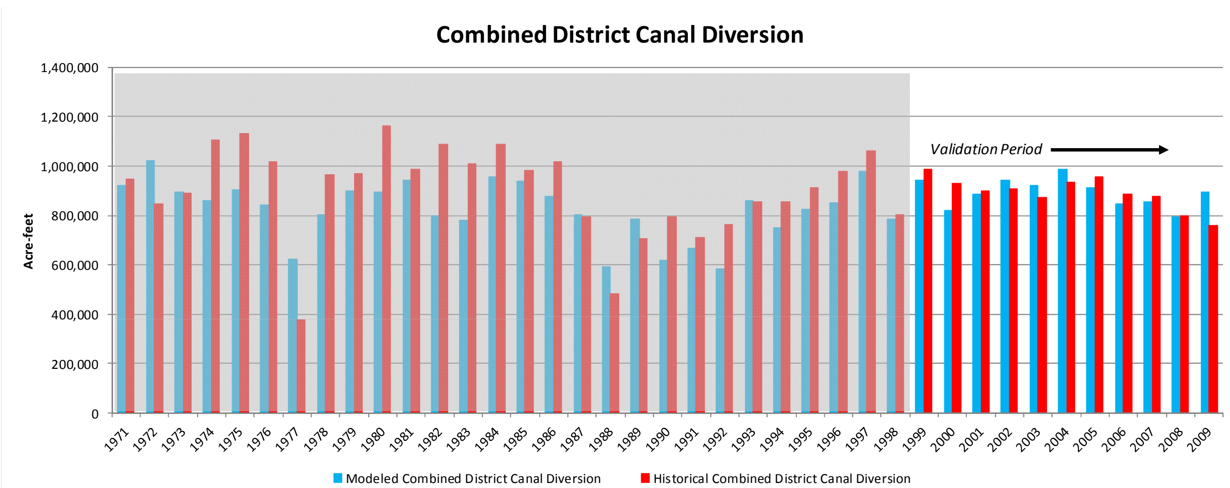

Figure 5.0-1. Historical and modeled combined Districts canal diversion.

While during the validation period there are annual differences between modeled and historical combined diversions, ranging approximately ± 100,000 acre-feet (+18% to -12% of historical annual diversions), the average difference for the 11-year period is less than 1,000 acre-feet, with the differences shifting between water years.

Figure 5.0-2 illustrates a summary of monthly volumes of modeled and historical combined diversions for the 10-year period Water Year 2000 through 2009. The modeled operation tracks well with seasonal historical diversions. The occasional difference in modeled diversion occurring during late spring reflects the challenges of modeling the early portion of the annual irrigation season.

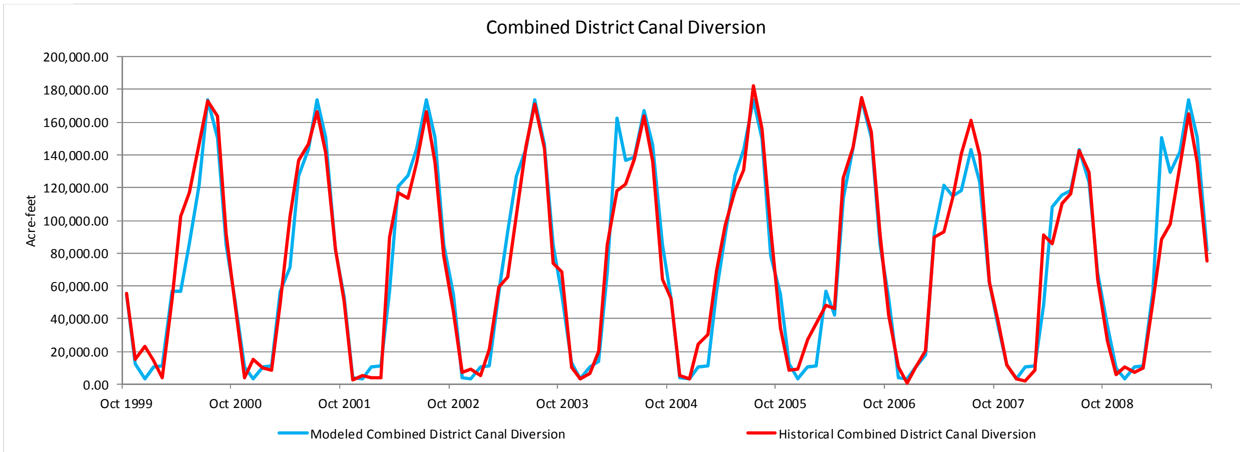

Figure 5.0-2. Historical and modeled combined District canal diversion (seasonal).

6.0 DON PEDRO PROJECT HYDOELECTRIC GENERATION

The hydroelectric generation capability of the Don Pedro powerhouse is currently depicted in the Model by a mathematical equation relating station electrical output to Don Pedro Reservoir storage. The relationship was derived from results relying upon the following equation:

$$Power = (Q \times H \times \eta) \div 11.815$$

Where:

Q = flow through the turbines
H = the effective head in feet (related to reservoir storage)
Ŋ = turbine efficiency as percent

The units of power are kilowatts

The current equation, which results in defining generation efficiency (kwh/acre-foot of turbine flow) based on DonPedro Reservoir storage, was compared to the historical performance of the powerhouse. The historical performance of the powerhouse was evaluated by computing generation efficiency from the historical record of generation, reservoir storage and estimated powerhouse releases. Juxtaposing the illustration of the Model's mathematical relationship between reservoir storage and generation efficiency and the analysis of historical generation yields the results shown in Figure 6.0-1.

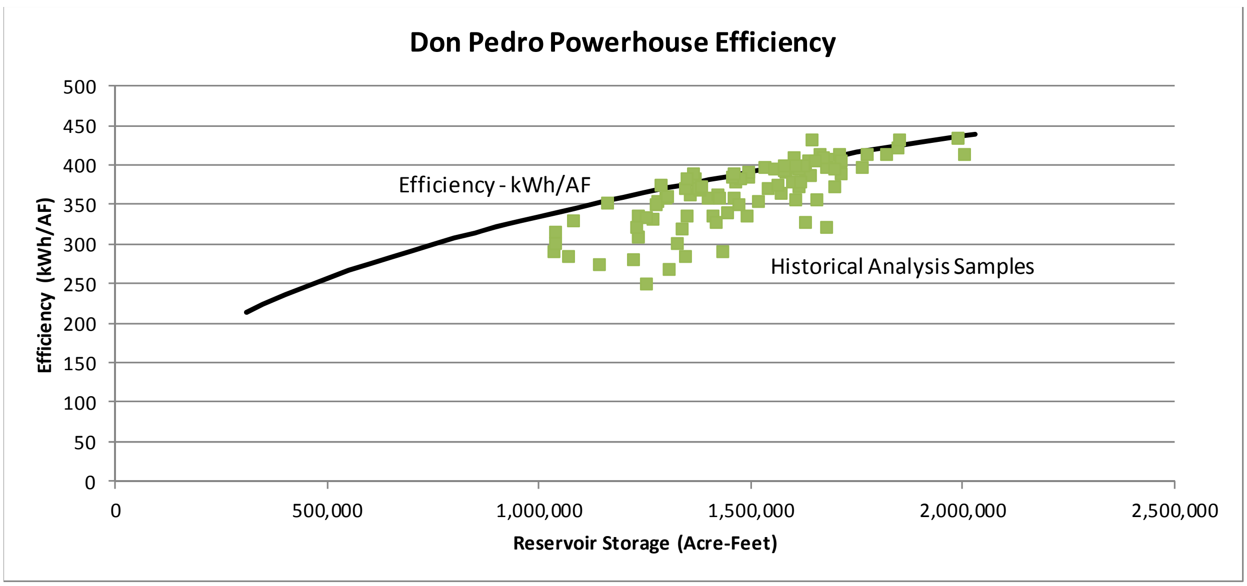

Figure 6.0-1. Comparison between historical generation efficiency and model generation efficiency.

Additional research and development of a refined power output characteristic curve for the Don Pedro powerhouse is being conducted. The refinement will be implemented in the Model coincident with the development of the "base case" scenario to be submitted by the Districts in March, 2013.