Appendix G

Truckee River Hourly Model Verification for WMOP

TRUCKEE RIVER HOURLY MODEL VERIFICATION FOR WMOP

Truckee Basin Water Management Options Pilot, Memorandum of Agreement, Task 4: Model and Dataset Development

2021 Hydrologic Engineering Analysis Tasks, Task F.2: "TR Hourly River Model Development"

Abstract

This report documents the verification of the Truckee River Hourly Flood Routing Model developed as a part of the WMOP project for the purpose of simulating flood operations according to the Water Control Manual.

To: Truckee Basin Water Management Options Pilot Technical Team

By: Patrick Noe

DATE: February 7, 2023

RE: Hourly Model Verification on behalf of TMWA

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1 INTRODUCTION

The 2021 Hydrologic Engineering Analysis Tasks (HEAT) describes the work to be completed as part of the larger Truckee Basin Water Management Options Pilot (WMOP) Study (United States Bureau of Reclamation, 2021). The WMOP Study seeks to analyze and address issues with the current regulation criteria defined in the Water Control Manual (WCM) (US Army Corps of Engineers, 1985). These issues were determined by stakeholders during the Plan Formulation phase of the study (United States Bureau of Reclamation, 2021):

> "The [WCM] suffers from outdated rule curves, inflexible storage requirements, constrained reservoir release thresholds, and a constrained downstream regulation goal at Reno. It also does not reflect the Truckee River Operating Agreement (TROA), flood mitigation projects completed in Reno and Sparks since 1985, or the 2017 crest raise at Reclamation's Stampede Dam."

Task F.2 of the HEAT prescribes development, calibration, and validation of an hourly RiverWare© model for the Truckee River Basin known as the *TR Hourly River Model*. The purpose of this model in the WMOP Study is to provide a tool to route historical flood events at an hourly timestep and to facilitate analysis of how potential changes to flood space requirements prescribed by the Water Control Manual (WCM) impact flood damages downstream. This model will be used with the *TROA Planning Model*, which operates at a daily timestep, and results from the *TR Hourly River Model* will aid in the selection of the best alternative to the WCM.

The development of the *TR Hourly River Model* was completed in three phases:

1. Development of the routing parameters of the *TR Hourly River Model.*
2. Local Inflow dataset development using the calibrated/validated routing parameters of the *TR Hourly River Model.*
3. Development of the *TR Hourly River Model* solution logic to determine Flood Control Reservoir operations during flood events consistent with the operational criteria prescribed in the Water Control Manual (WCM) (US Army Corps of Engineers, 1985).

Calibration and validation of the model's routing times and the peak timing of flood events was completed and documented by Precision Water Resources Engineering

(PWRE) as a part of Phase 1 (Olsen, Erkman, & Vandegrift, 2021). Calibration and Validation of the hydrograph volumes is documented by Stetson Engineers as a part of Phase 2 of development (Lawler, 2022). The purpose of this report is to document the process of codifying the regulation criteria of the WCM into the *TR Hourly River Model* and to provide verification that the *TR Hourly River Model* adequately models operations specified by the WCM.[1]

2 METHODOLOGY

2.1 WCM REGULATION CRITERIA IMPLEMENTED IN THE TR HOURLY RIVER MODEL

The WCM calls for several regulation criteria of Flood Control Reservoirs (Prosser Creek Reservoir, Boca Reservoir, Stampede Reservoir, and Martis Creek Reservoir) during flood operations. These criteria include the following:

- Flood space requirements:
  - During non-flood events, Flood Control Reservoirs are required to maintain a volume of flood space within the reservoir derived through methods specified by the WCM.
- Storage into flood space:
  - The flood control operations of Prosser Creek Reservoir, Stampede Reservoir and Boca Reservoir "will be coordinated to limit the flows in the Truckee River, at Reno, insofar as possible, to a maximum of 6,000 cubic feet per second (cfs)." During an event, these reservoirs will store in their designated flood space.
  - For Martis Creek Reservoir, "When flood forecasts indicate that flows through Reno probably will equal 14,000 cfs, outlet gates will be closed and as much of Martis Creek flows stored as possible until flows recede below 14,000 cfs."
  - While Flood Control Reservoirs are storing into flood space during an event, the WCM requires, when possible, proportional storage

[1] The HEAT specified only calibration/validation of the *TR Hourly River Model.* It was determined that a verification paper was better suited to assess the model's ability to operate to the WCM. This decision was made with approval from Jonathan Moen and Marchia Bond of the United States Army Corps of Engineers that a verification paper was sufficient.

into flood space between Prosser Creek Reservoir and Little Truckee reservoirs (Boca and Stampede Reservoir).

- Evacuation of flood space:
    - For Prosser Creek Reservoir, Boca Reservoir, and Stampede Reservoir, after the event has passed, flood storage "will be released as rapidly as possible without exceeding non-damaging capacities of downstream channels." The non-damaging capacity of downstream channels was assumed to be the 6,000 cfs referenced elsewhere.
    - For Martis Creek Reservoir, "When flows through Reno are below 14,000 cfs and Martis Creek inflows are receding, water stored in Martis Creek Lake will be released as rapidly as practicable until the flood control space is restored, except that, releases from Martis Creek Lake shall not exceed inflow during periods when flows in the Truckee River below Reno are in excess of 6,000 cfs."
- Limitations on release changes
    - Release changes on Flood Control Reservoirs must be limited to 1,000 cfs or less per hour.

These regulation criteria prescribed by the WCM were codified into the *TR Hourly Model* to operate the system.

2.1.1 Martis Creek Reservoir in the WCM and TR Hourly River Model

Since 1985 when the WCM was written, several issues have been discovered with Martis Creek Dam regarding dam safety. In 2008, a risk-screening was conducted on Martis Creek Reservoir that ultimately led to changes in the reservoirs regulation criteria that same year, and Martis Creek Reservoir is not currently operated to the regulation criteria specified in the WCM (Moen, 2023). [2] Rather, Martis Creek Dam's gates are left open, and the reservoir only provides incidental flood protection when inflows to the reservoir exceed its release capacity (US Army Corps of Engineers, 2022).

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[2] The risk-screening was the culmination of several other issues that had been discovered with Martis Creed Dam and Reservoir in previous years. Seepage issues were discovered on Martis Creek Dam in 1995 during a fill test. Furthermore, a spillway capacity study in 2002 determined the spillway capacity of Martis Creek Dam was inadequate. As a result, USACE determined in 2005 that Martis Creek Dam is one of the top 6 most high-risk USACE dams in the nation (US Army Corps of Engineers, 2022).

The primary purpose of the WMOP Study is to determine how changes to the regulation criteria of the WCM could address issues identified in the Plan Formulation (see Section **1 Introduction**). More specifically, a result of the Plan Formulation was the set of five Final Alternative Operational Scenarios, and in each of these alternatives, Martis Creek Reservoir would continue to operate under its current limitations (United States Bureau of Reclamation, 2021). In addition to these alternatives, the Plan Formulation identified several Follow-up Actions for the project which included assessing the benefits of making Martis Creek Reservoir operational again.

To accomplish this technically, the *TR Hourly River Model* was flexibly designed to allow two different modes of operation for Martis Creek Reservoir:

1. Martis Creek Reservoir Non-Operational – Martis Creek Reservoir is operated to current dam safety limitations.
2. Martis Creek Reservoir Operational – Martis Creek Reservoir is operated to the current regulation criteria of the WCM.

This report will provide a verification of both operation modes of Martis Creek Reservoir in the *TR Hourly River Model*.

2.2 Overview of the Hourly Model

The *TR Hourly River Model* encompasses the geographic region between the seven upstream Truckee Basin Reservoirs in California and the Truckee at Wadsworth USGS gage in Nevada (see Figure 1). The inflow datasets computed by Stetson Engineers provide the input hydrology needed for the model to solve. These datasets, corresponding to historical flood events, are comprised of hourly timeseries of inflows to seven upstream reservoirs (Boca Reservoir, Stampede Reservoir, Prosser Creek Reservoir, Martis Creek Reservoir, Independence Lake, Donner Lake, and Lake Tahoe) and contain hourly timeseries for lateral inflows to the Truckee River not captured by reservoirs. Inflows to reservoirs are hereby referred to as Hydrologic Inflow, and lateral inflows hereby referred to as Local Inflow. For more information on the computation of these data, refer to the referenced *Technical Memorandum – Truckee River Basin Historical Hourly Data Development Methodologies: Water Years 1986 – 2021* (Lawler, 2022). The inflow datasets are routed in the model utilizing the Muskingum Routing Method from their source through the Truckee Meadows and the City of Reno to the Truckee at Wadsworth Gage (Figure 1). For additional information on both the selection criteria for this routing method and documentation on the calibration and validation of the associated routing parameters used associated with this routed method, refer to the referenced *WMOP Truckee River Hourly River Model Time Lag Routing* report (Olsen, Erkman, & Vandegrift, 2021).

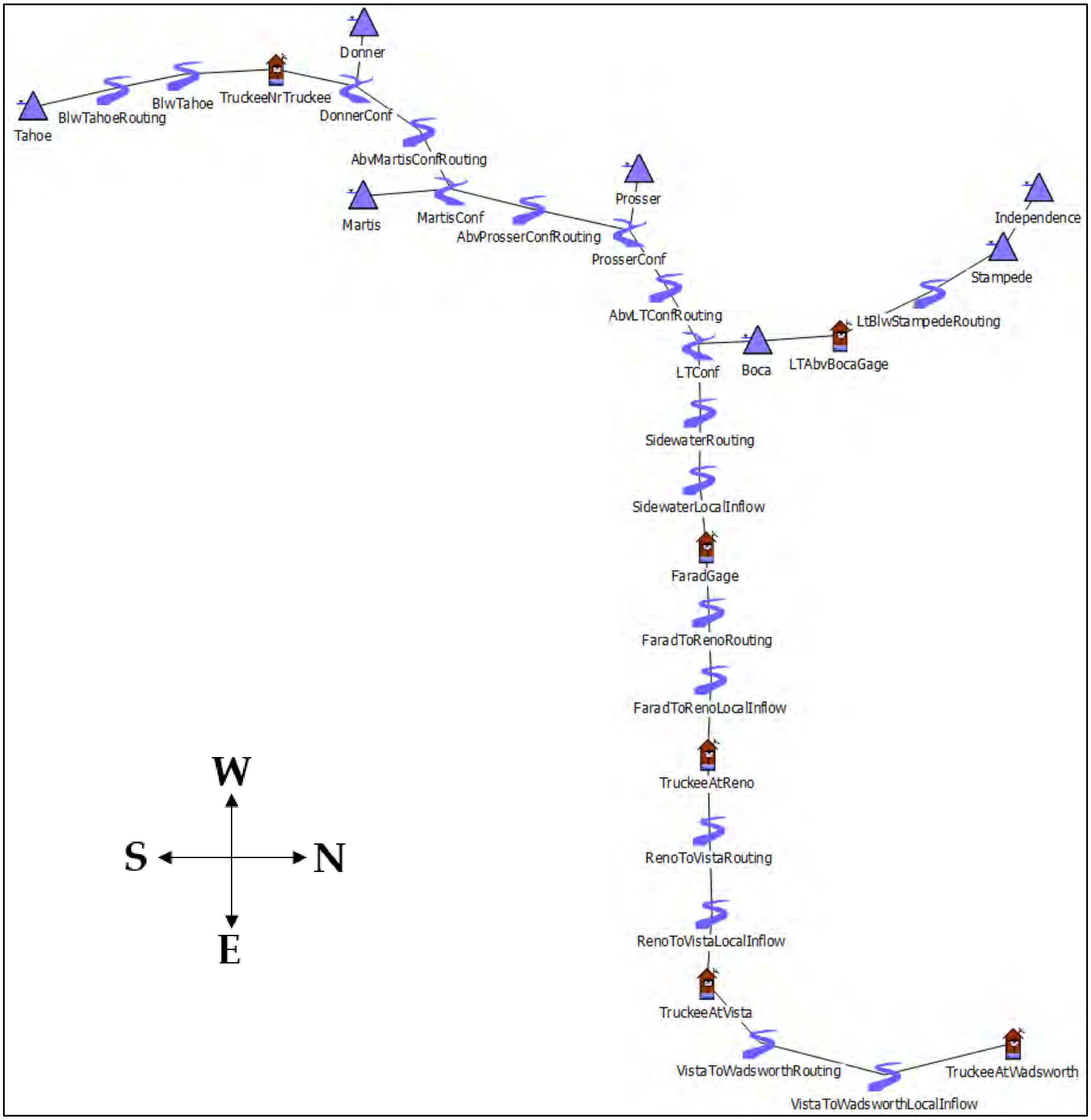

Figure 1. Schematic of the TR Hourly River Model RiverWare workspace.

The seven upstream reservoirs/dams in the *TR Hourly River Model* are configured with physical characteristic tables that specify:

1. The relationship between elevation and storage for the reservoir.
2. The rating of the dam's outlet works and spillways.

These physical characteristics tables are further detailed in **Appendix 1: Reservoir Characteristics Tables in the TR Hourly River Model**.

As the model solves, reservoir water balances are computed utilizing the following equation:

Equation 1. Water Balance equation utilized for reservoirs in the TR Hourly River Model.

$$Storage_t = Storage_{t-1} + Upstream\ Inflow_t + Hydrologic\ Inflow_t - Outflow_t$$

In Equation 1, $Outflow_t$ represents the outflow volume of a reservoir, $Upstream\ Inflow_t$ represents the inflow volume to a reservoir due to an upstream reservoir's outflow, and $Hydrologic\ Inflow_t$ represents the net inflow volume to a reservoir due to lateral inflows from the reservoirs subbasin, surface precipitation, lake evaporation, etc.

For the purposes of this verification effort, the reservoirs of the system were initialized with their historical pool elevations prior to each event. For reservoirs in series, $Upstream\ Inflow$ is propagated from an upstream reservoir to a downstream reservoir utilizing the routing method in the model. $Hydrologic\ Inflow$ for each reservoir is an input time series to the model. Lastly, the model solves the $Outflow$ for reservoirs utilizing RiverWare Policy Language Logic.

The model is configured to solve for the outflows of Active Flood Control Reservoirs (Prosser Creek Reservoir, Stampede Reservoir, Boca Reservoir, and, if operational, Martis Creek Reservoir) differently from the other reservoirs (Lake Tahoe, Donner Lake, Independence Lake, and, if non-operational, Martis Creek Reservoir):

- Active Flood Control Reservoirs – Solution logic within the model is configured to solve for the releases of these reservoirs in accordance with the operational criteria prescribed by the WCM. Martis Creek Reservoir is included in this category if it is configured within the model to be operational (see Section **2.1 WCM Regulation Criteria Implemented in the TR Hourly River Model**).
- Other reservoirs and Martis Creek Reservoir (if non-operational) – Solution logic within the model is configured to set releases of these reservoirs to their historical outflows. Martis Creek Reservoir is configured to be in this category if it is configured within the model to be non-operational.

The purpose of setting the releases of other reservoirs and, if non-operational, Martis Creek Reservoir to historical values for this verification effort is to allows for the isolation of Active Flood Control Reservoirs in evaluating the model's ability to accurately reflect the regulation criteria of the WCM. The final hourly model utilized in the WMOP Study will have an alternative configuration to support the study; a detailed description of the alternative configuration in the final hourly model can be found in **Appendix 2: TR Hourly River Model Configuration for the WMOP Analysis**.

2.2.1 Active Flood Control Reservoir Outflows

Utilizing the Muskingum Routing Method in *TR Hourly River Model* presented complexities in setting Active Flood Control Reservoir outflows to meet a downstream target per the WCM; to address this, the model employs a unique approach to setting these reservoir's outflows.

Applying the Muskingum Routing Method to an upstream hydrograph results in a downstream hydrograph that is both lagged in time and dispersed (see Figure 2). In the *TR Hourly River Model*, each reservoir has a unique lag time from the outlet of the reservoir to the flood target location at the Reno Gage. Furthermore, each reservoir's outflow is dispersed as it is routed down the river. As an example, a reduction in the outflow of 100 cfs on Prosser Creek Reservoir doesn't result in a 100 cfs reduction at the Reno Gage some lag time later. Rather, this flow reduction in the river is manifested at the Reno Gage over several timesteps.

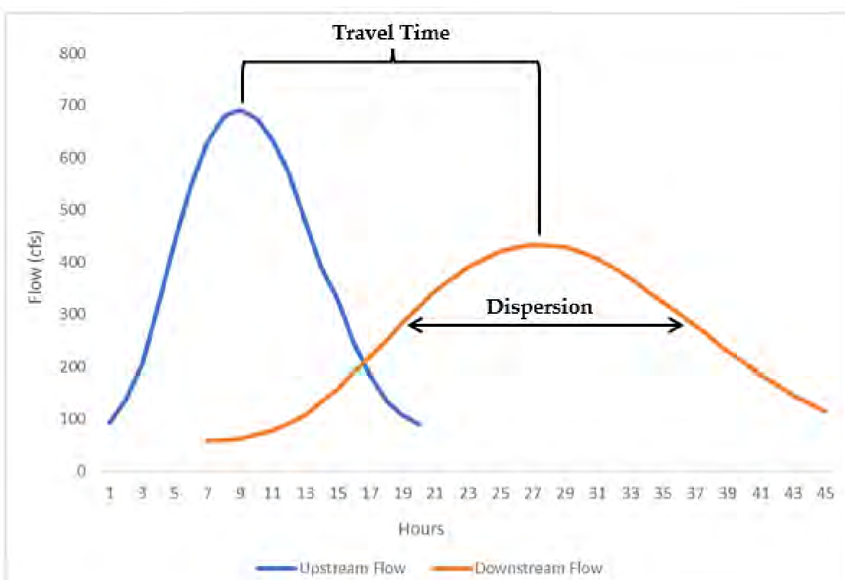

Figure 2. Schematic for Muskingum Routing Method translation of upstream flows to downstream flows.

To account for this, the *TR Hourly River Model* approaches setting Active Flood Control Reservoir outflows iteratively through time (see Figure 3). The rectangle of this schematic represents the time series of outflows from an Active Flood Control Reservoir. For the model's Current Timestep, the model assesses if and by how much the flows at the Reno Gage exceed the flow target of 6,000 cfs. If flows at the Reno Gage exceed the flood target, the model attempts to lower Active Flood Control Reservoir outflows in the past by an amount that lowers the flow at the Reno Gage at the Current Timestep to be at or below the flow target. To reduce reservoir outflows appropriately with the Muskingum Routing Method, the model looks back in time to the timesteps when reservoir outflows most greatly influence flows at the Reno Gage on the Current Timestep (the green rectangle on Figure 3), and it makes reductions in outflows from the reservoir at these timesteps in order to achieve or be as close as is possible to the 6,000 cfs target at the Reno Gage on the Current Timestep. Once outflow cuts for Active Flood Control Reservoirs on the Current Timestep have been completed, the model moves forward to the next timestep.

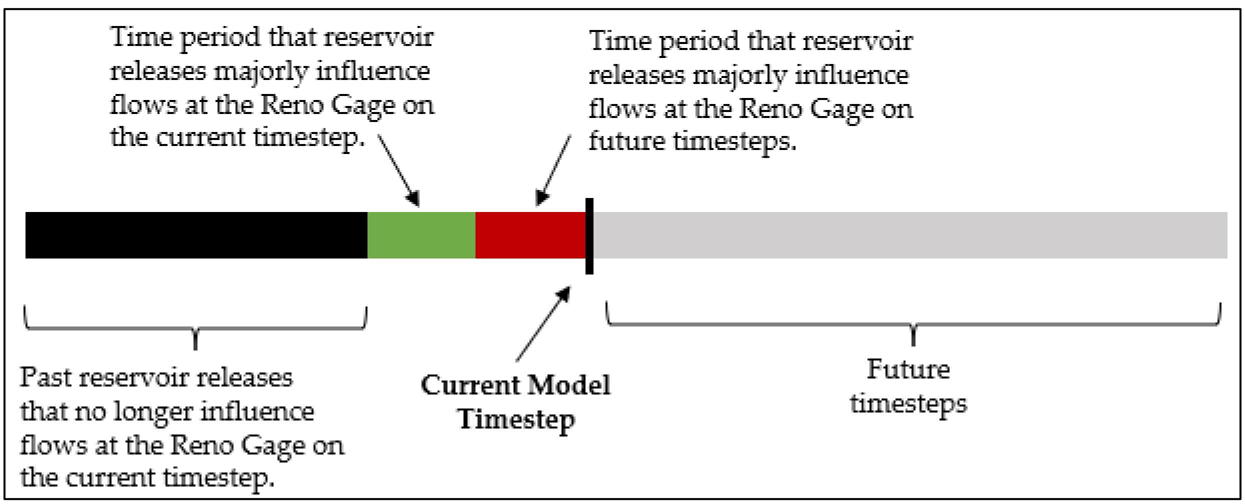

Figure 3. Schematic to illustrate how the model sets Active Flood Control Reservoir outflows.

2.2.2 Limitations of the TR Hourly River Model

This type of solution logic in conjunction with the Muskingum Routing Method introduces complexities in the model solution when adhering to WCM criterion of maintaining proportional storage into flood space between Prosser Creek Reservoir and the Little Truckee reservoirs. Because of this, Active Flood Control Reservoir outflows solved by the model can at times (particularly when both Prosser and Little Truckee Reservoirs are encroached) show fluctuations in magnitude hour to hour. While these fluctuations are limited to the ramping rate prescribed by the WCM of 1,000 cfs, they can manifest in unrealistic ways. Because of this, a 5-hour centered smoothing average is applied to all Active Flood Control Reservoir outflows at the end of the model run. This 5-hour window was chosen based on conversations with the dam operations, and it represents the estimated frequency of release changes operators would make during floods. A sensitivity analysis may be needed on this smoothing average in future studies.

2.2.3 Data Requirements for the TR Hourly River Model

For the verification effort, the required *TR Hourly River Model* data inputs and their sources were as follows:

1. Inflow Datasets – Hourly historical Hydrologic Inflows to reservoirs and Local Inflows to the Truckee River.
2. Reservoir Release Datasets – Hourly historical releases from all reservoirs. [3]
3. Pool Elevations Datasets – Hourly historical pool elevations of reservoirs in the system.
4. Flood Control Capacity Datasets – Flood Control Capacity for Active Flood Control Reservoirs.

Table 1 provides a list of all historical flood events and their respective start and end dates that hourly inflow datasets were computed by Stetson Engineers (Lawler, 2022). [4] Table 2 provides a summary of the data source used to compile the Reservoir Release datasets. Hourly reservoir release data for each of these reservoirs was compiled for the duration of the flood events described in Table 1. Furthermore, Table 2 also provides a summary of the data source used to compile Pool Elevation Datasets for all reservoirs in the *TR Hourly River Model*. Hourly pool elevation data was compiled for each reservoir for duration between the hour prior to each flood event's start date (the initialization timestep) to the flood event's end date.[5] Lastly, the Flood Control Capacity Datasets for

[3] The *TR Hourly River Model* only **solves** for the releases of Active Flood Control Reservoirs, but historical release data is used to make comparisons of model solution to historical values.

[4] For the verification effort, the *TR Hourly River Model* utilizes the "Calibration Dataset" Hydrologic Inflows to reservoirs and Local Inflows to the Truckee River provided by Stetson Engineers.

[5] The *TR Hourly River Model* only requires an initial pool elevation; however, the Verification Effort makes comparisons to historical pool elevations and therefore the pool elevations for the entire events were queried.

Flood Control Reservoirs was compiled from the USACE Sacramento District website (US Army Corps of Engineers, 2022).

Table 1. Flood Events and their associated start and end dates that hourly inflow data was developed for by Stetson Engineers.

Flood Event	Event Start Date	Event End Date
February to March 1986	2/1/1986	3/27/1986
March 1995	2/23/1995	3/23/1995
May 1995	4/17/1995	6/6/1995
May 1996	5/2/1996	6/2/1996
1997 Flood	12/9/1996	2/12/1997
March 1998	3/10/1998	4/6/1998
May 2005	5/5/2005	6/2/2005
January 2006	12/16/2005	1/15/2006
February 2006	2/14/2006	3/13/2006
December 2006	11/27/2016	12/23/2016
January 2017	12/24/2016	1/19/2017
February 2017	1/20/2017	2/25/2017
March to May 2017	3/7/2017	6/13/2017
April 2018	3/24/2018	4/24/2018
April 2019	3/26/2019	4/22/2019

Table 2. Table of data sources for Reservoir Release and Pool Elevation Datasets. The Gage Number is provided for data sourced from the United States Geological Survey (USGS), and the Site ID is provided for data sourced from the TROA Information System (TIS).[6]

	Data Source	Releases Gage Number/Site ID	Pool Elevation Gage Number/Site ID
Boca Reservoir	USGS	10344500	10344490
Stampede Reservoir	USGS	10344400	10344300
Independence Lake	USGS	10343000	10342900
Prosser Creek Reservoir	USGS	10340500	10340300
Donner Lake	USGS	10338400	10338400
Lake Tahoe	USGS	10337500	10337000
Martis Creek Reservoir	TIS	150021	150021

[6] USGS data sourced from National Water Information System (U.S. Geological Survey (USGS), 2021). TIS data source reference TIS Website (Federal Water Master, 2022). Note, any data utilized from USGS and TIS was also utilized for the Inflow Dataset development by Stetson Engineers. Any adjustments to this data in the quality control process is documented by Stetson Engineers (Lawler, 2022).

2.3 Evaluating Model Performance

Several key plots are utilized within this report to evaluate model performance. These plots allow for:

1. Evaluation of how well the model adhered to the regulation criteria of the WM.
2. Comparisons to historical operations.

For more quantitative metrics, this verification effort utilized two metrics: the Nash-Sutcliffe Efficiency Factor (NSE) and the Percent Bias (PBIAS).

More detailed descriptions of the key plots and the two quantitative metrics are provided in the following two subsections.

2.3.1 Key Plots for Evaluating Model Performance

There are six key plots utilized by this report that evaluate the model's performance. The first two of these plots, the Flood Flows Plot and Flood Storage Plot, provide a system view allowing for comparisons of simulated (characterized by solid lines) and observed (characterized by dashed lines) data. These two plots are color coded by reservoir:

- Prosser Creek Reservoir data is signified by red colors.
- Stampede Reservoir data is signified by green colors.
- Boca Reservoir data is signified by blue colors.
- Reno Gage data is signified by black colors.

Figure 4 provides an example of the Flood Flows Plot utilizing data from the January 2006 Flood Event. This plot displays the observed and simulated data for Reno Gage flows and outflows from the three Active Flood Control Reservoirs. Furthermore, it provides a dotted black line signifying the Reno Gage flow target of 6,000 cfs prescribed by the WCM to allow for assessment of how well the flood target was met when Active Flood Control Reservoirs were evacuating flood space.

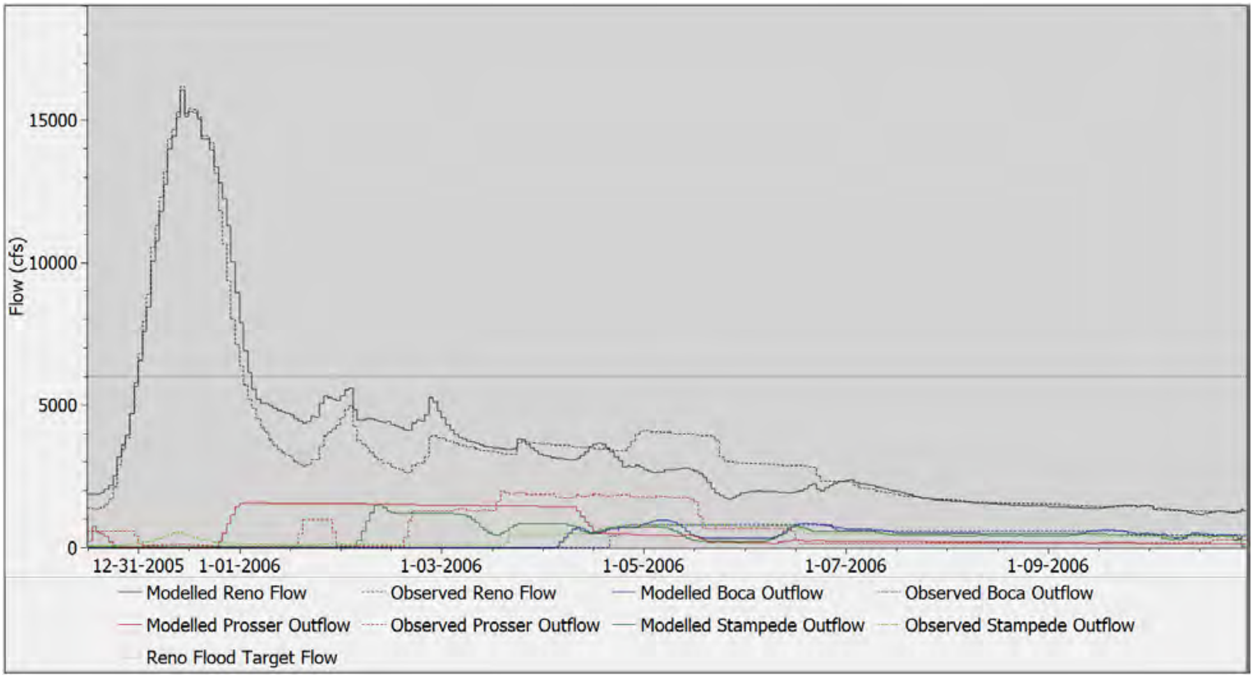

Figure 4. Example of the Flood Flows Plot for the January 2006 Flood Event.

Figure 5 provides an example of the Flood Storage Plot utilizing data from the January 2006 Flood Event. In general, this plot allows for the evaluation of where and how encroachment and surcharge was accumulated for the event and how long it took to evacuate the flood space. The dotted lines on this plot (color coded by reservoir) represent the total flood space prescribed by the WCM for each of the Active Flood Control Reservoirs. A reservoir is encroached when its flood storage is greater than zero, and a reservoir is surcharging once it has fully encroached and its flood storage is above its respective line for total flood space.

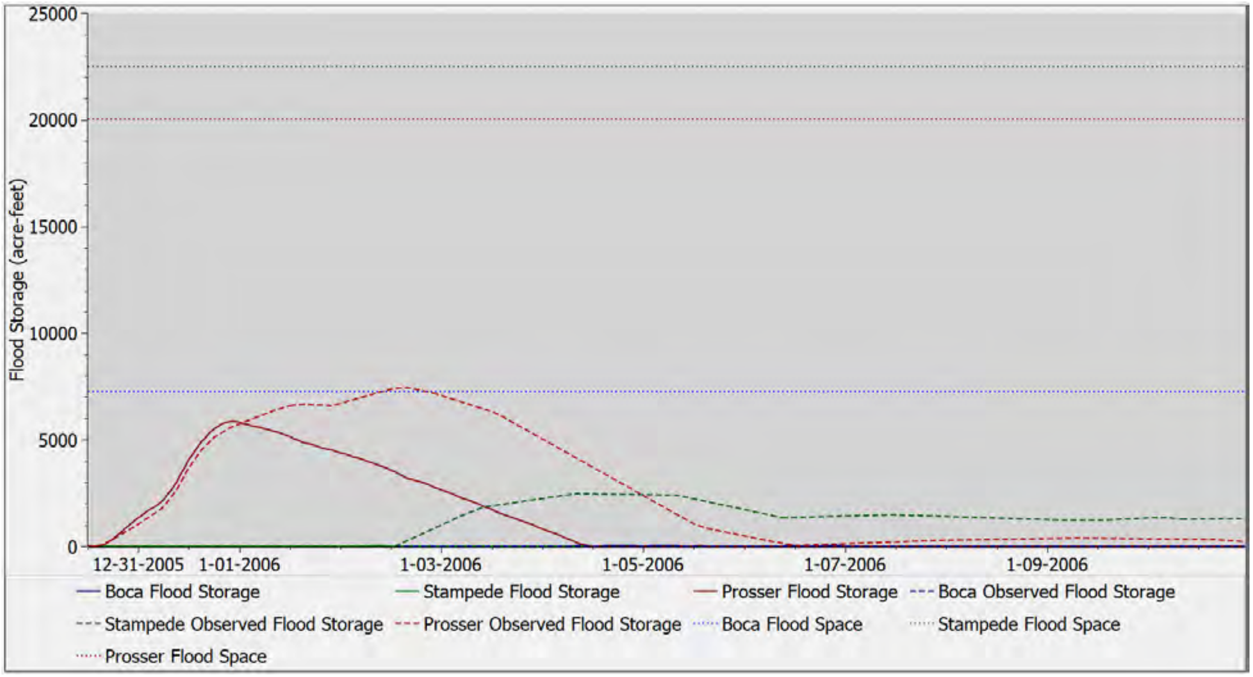

Figure 5. Example of the Flood Storage Plot for the January 2006 Flood Event.

Three additional Reservoir Plots are used to assess model performance and focus specifically on each Active Flood Control Reservoir. Reservoir Plots show the following data:

- Simulated and observed reservoir outflows and storages.
- Hydrologic inflow to the reservoir.
- Flood control capacity for the reservoir as prescribed by the WCM.
- The max physical capacity of the reservoir.

Figure 6 provides an example of the Prosser Creek Reservoir Plot utilizing data from the January 2006 Flood Event. These plots allow for more in-depth analysis on comparisons between how the model simulated reservoir operations to how the reservoir was operated in history.

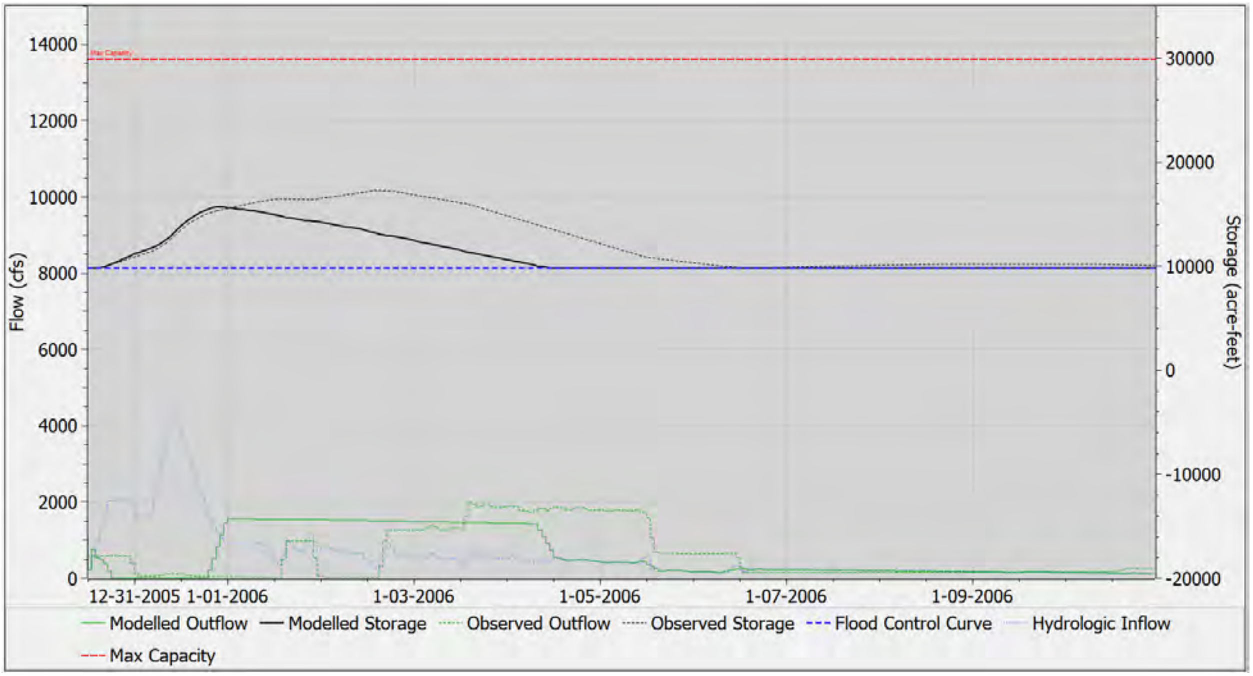

Figure 6. Example of the Prosser Reservoir Plot for the January 2006 Flood Event.

The last plot utilized by this report to assess model performance is the Flood Storage Proportions Plot. The purpose of this plot is to evaluate how well the model achieves proportional flood storage between Little Truckee Flood Control Reservoirs and Prosser Creek Reservoir (see Section **2.1 WCM Regulation Criteria Implemented in the TR Hourly River Model**). Figure 7 provides an example of this plot utilizing simulated results from the 1997 Flood Event. On this plot, results for the Little Truckee Reservoirs are colored black, and results for Prosser Creek Reservoir are colored red. The dotted lines represent the proportions of flood storage to maintain prescribed by the WCM. Solid lines on the plot represent a time series of the hourly proportion of the total flood storage that the reservoirs maintained. When this time series is zero, it means there was no flood storage in the system. An important note on this plot is that its utilization is limited because achieving proportional flood space is highly dependent on reservoir initialization: there are cases when some of the Active Flood Control Reservoirs started the event with storages well below the flood control capacity and only one of the reservoirs during the event encroached. In these cases, this plot is omitted from evaluation of model performance.

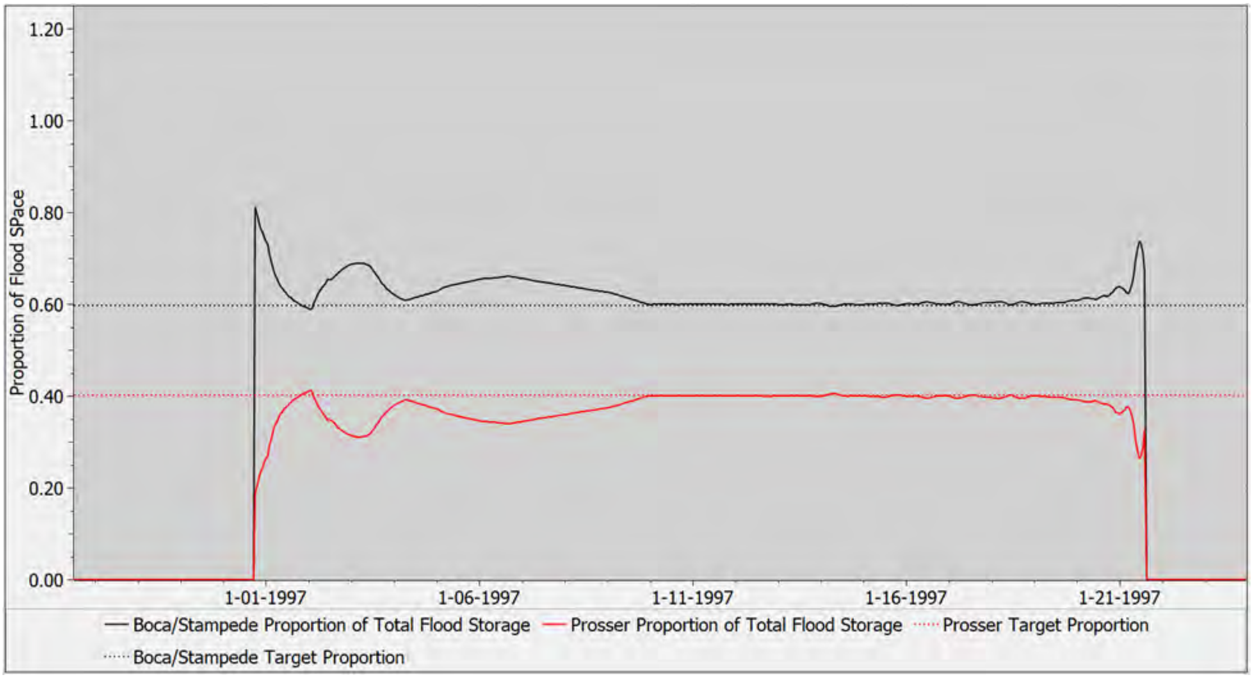

Figure 7. Example of the Flood Storage Proportions Plot for the 1997 Flood Event.

2.3.2 NSE

The NSE is recommended by the American Society of Civil Engineers and has been found to be a reliable objective function for reflecting the overall fit of a hydrograph (McCuen et al, 2006). The NSE evaluates how well the observed versus simulated data points match the 1:1 line. Equation 2 displays the NSE Formula with the variable Y representing the dataset being evaluated. The NSE ranges from -∞ to 1. Typically, an NSE score between 0 and 1 is viewed as an acceptable level of performance; however, a stricter criterion, displayed in Table 3, categorizes scores of less than 0.5 as unsatisfactory (Moriasi et al, 2007).

Equation 2. Nash Sutcliffe Efficiency Formula.

$$NSE = 1 - \left[\frac{\sum_{I=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{I=1}^{n}\left(Y_i^{obs} - Y^{mean}\right)^2}\right]$$

Table 3. Nash Sutcliffe Efficiency Grading Criteria (Moriasi et al, 2007).

NSE Score Range	Performance Description
0.75 - 1.00	Very Good
0.65 - 0.75	Good
0.50 - 0.65	Satisfactory
< 0.50	Unsatisfactory

The NSE factor is utilized within this report to assess the model's performance specifically at the Reno Gage. The NSE calculation is limited to the timeframe around when the model was in flood operations. Specifically, the calculation is performed on the period from twelve hours prior to the time the modeled flows at the Reno Gage reach 6,000 cfs to twelve hours past when the modeled flood storage was evacuated. NSE Scores are assessed in this report based on the performance descriptions provided in Table 3.

2.3.3 PBIAS

The PBIAS allows for quantification of modelled flows tendency to be biased high or low relative to observed flows. Equation 3 provides the calculation for PBIAS, where *Y* represents the dataset being evaluated.

Equation 3. PBIAS Formula (RDocumentation, 2023).

$$PBIAS = 100\frac{\sum_{i=1}^{n} Y_i^{sim} - Y_i^{obs}}{\sum_{i=1}^{n} Y_i^{obs}}$$

The PBIAS calculation is utilized within this report to assess the model's performance for each verification event at the Reno Gage. Like the NSE calculation, the PBIAS calculation is limited to the timeframe around when the model was in flood operations.

2.3.4 Additional Notes on Evaluating Model Performance

The *TR Hourly River Model* was developed to operate flood reservoirs strictly to operational criteria of the WCM and not necessarily to what occurred historically. The important distinction is that, in certain instances, how the reservoirs were operated historically deviated from operational criteria outlined in the WCM. These deviations, often a result of human decision, include but are not limited to:

- Reservoir releases changes were made manually through these events and access to the facilities was at times infeasible, which can limit the number of release changes that can be made.

- Historical evacuation was adjusted to forecasted weather.
- Actual release may be more conservative historically when maintaining flow targets.
- Assumed reservoir operations during surcharge.

Some of these differences are discussed in more detail in the proceeding section of this report, and, in certain cases, they do have a negative bearing on the NSE and PBIAS used to quantitatively evaluate model performance. Secondly, when these flood events were being operated by the Federal Water Master at the time of the event in history, unapproved USGS data at the Reno Gage was used to make operational decisions on reservoir releases. The inflow data utilized by the model was computed using approved USGS data, and this could cause discrepancies in comparing model results to historical events.

2.4 Verification Events

Table 4 provides a list of all historical flood events and their respective Peak Regulated Flows (PRF) at the Reno Gage, as computed by Stetson Engineers (Lawler, 2022). Flood events utilized for verification are signified by green outlines in the table.

Table 4. All flood events with available hourly data and their respective peak regulated flow at the Reno Gage. Events outlined in green signify events selected for verification.

Flood Event	Peak Regulated Flow at Reno Gage(cfs)
February to March 1986	10,000
March 1995	6,248
May 1995	5,335
May 1996	7,433
1997 Flood	18,100
March 1998	5,480
May 2005	4,100
January 2006	16,100
February 2006	5,678
December 2016	5,063
January 2017	12,200
February 2017	10,208
March to May 2017	6,550
April 2018	6,453
April 2019	5,098

For the purposes of this verification effort, six major flood events that required flood operations per the WCM (i.e., any observed event where the Peak Regulated Flow (PRF) at the Reno Gage was observed to be above the flood target at the Reno Gage of 6,000 cfs) were selected as verification events. This verification effort further categorized major flood events in the following manner:

- Small Event – Observed PRF at the Reno Gage between 6,000 to 7,000 cfs.
- Medium Event – Observed PRF at the Reno Gage between 7,000 cfs to 12,000 cfs.
- Large Event – Observed PRF at the Reno Gage greater than 12,000 cfs.

The six selected verification events were comprised of two Small Events, two Medium Events, and two Large Events. Table 5 provides a summary of the six selected events.

Table 5. Summary of the small, medium, and large events selected for verification.

Flood Event	Peak Regulated Flow at Reno Gage (cfs)	Event Categorization
April 2018	6,453	Small Event
March 1995	6,248	Small Event
February to March 1986	10,000	Medium Event
February 2017	10,208	Medium Event
1997 Flood	18,100	Large Event
January 2006	16,100	Large Event

2.4.1 Event Selection Criteria

The two Small Event selected for verification were the April 2018 event (PRF of 6,453 cfs) and the March 1995 event (PRF 6,248 cfs). The only other event that met the Small Event criteria was the March to May of 2017 event. This event was excluded as a verification event due to unique operations that occurred historically during this period in response to a construction project on Stampede Reservoir (Precision Water Resources Engineering, 2018).

The Medium Events selected for verification were the February 2017 event (PRF of 10,208 cfs) and the February to March 1986 event (PRF of 10,000 cfs). This February to March of 1986 event was selected for verification because it was a unique event that had two peaks within the dataset which produced conditions that stress the system. The January of 2017 event (PRF of 12,200) was excluded as a verification event because reservoir storages were low going into the event and the event did not stress the system.

The remaining potential Medium Event, the May 1996 Event (PRF of 7,433 cfs) was excluded because it was a relatively small event in comparison to the other Medium Events.

Lastly, the two Large Event selected for verification were the 1997 Flood event (PRF of 18,100 fs) and the January 2006 event (PRF 16,100 cfs). These events were selected because they constituted the only two large events in the dataset.

2.4.2 Martis Creek Reservoir Operational Verification Events

As discussed in Section **2.1 WCM Regulation Criteria Implemented in the TR Hourly River Model**, the WCM specifies that flood operations occur on Martis Creek Reservoir when a flow of 14,000 cfs is expected at the Reno Gage. Only two flood events within the historical dataset met the criteria of 14,000 cfs flows at the Reno Gage: the January 2006 event and the 1997 Flood event. As a result, these are the only two events utilized for verification of the Martis Creek Reservoir Operational mode in the *TR Hourly River Model*.

3 Verification Results and Discussion

This section of the report provides a discussion of verification results for the *TR Hourly River Model*, and it is organized into two major sections corresponding to the operational modes of Martis Creek Reservoir within the *TR Hourly River Model*. The first section provides verification of the Martis Creek Reservoir Non-Operational mode of the model. The second section provides verification of the Martis Creek Reservoir Operational mode of the model. A summary of the *TR Hourly River Model* performance for its respective mode is provided at the end of each section.

3.1 Martis Creek Reservoir Non-Operational Verification Results

For the results within this section, the *TR Hourly River Model* was configured in its Martis Creek Non-Operational mode. Active Flood Control Reservoirs for this mode (Stampede Reservoir, Prosser Creek Reservoir, and Boca Reservoir) are operated to the current regulation criteria of the WCM, and Martis Creek Reservoir is operated to its current dam safety limitations.

3.1.1 Small Event Results Discussion

3.1.1.1 April 2018 Flood

The April 2018 verification flood event occurred between April 7, 2018, and April 8, 2018, and the event had a PRF at the Reno Gage of roughly 6,452 cfs. This flood event occurred once spring runoff had started, and though it is a smaller event in terms of the PRF, the flows at the Reno Gage remained relatively higher for longer. Furthermore, this flood event occurs as the flood space requirement for reservoirs began to decrease.

Figure 8 and Figure 9 show the Flood Flows Plot and Flood Storage Plot for this event. Both Stampede and Prosser Creek Reservoir started the event with encroachment. Both the modeled and observed flows at the Reno Gage peak above the 6,000 cfs target; however, the model muted the peak flow for this event slightly because it was able to cut releases from reservoirs contributing to flows at Reno during the peak of the event to hit more closely the 6,000 cfs target at Reno.

On the recession limb of the hydrograph, flows at the Reno Gage began to differ greatly between what was modeled and observed. Once the peak of the event passed, the model begins to move water down to Boca from Stampede. As this occurred, the modeled hydrograph shows flows at the Reno Gage recessing down to roughly 5,000 cfs. As Boca Reservoir begins to accrue more storage from inflows from Stampede Reservoir, the model starts releasing Boca Reservoir to evacuate the Little Truckee flood space efficiently. Throughout the time the model evacuates flood storage, the model maintains flows at the Reno Gage below the flood target. Modeled flows at the Reno Gage during this time were between 5,500 cfs and 6,000 cfs.

Historically, this operation did not occur. Observed flow at the Reno Gage during the period that the model evacuated flood storage was between 4,000 – 5,000 cfs. This discrepancy occurs because the model is operated strictly to the criteria outlined in the WCM; that is to evacuate flood space as efficiently as possible. However, as shown in Figure 9, the observed encroachment for both Stampede Reservoir and Prosser Creek Reservoir remained higher in the observed event than what was modeled, and the observed encroachment wasn’t evacuated immediately. The likely explanation for this is that the required flood space, as defined by the WCM, for both Prosser Creek Reservoir and Stampede Reservoir was going to increase within the next few days. Operators at the time decided to hold the storage in anticipation that the encroachment would soon be within flood control capacity. Regardless, this historical operation represents a deviation from the regulation criteria in the WCM and is therefore not modeled. Once modeled encroachment was fully evacuated at the end of the day on April 10th, modeled flows at the Reno Gage quickly recess to between 500 - 1,000 cfs less than observed flows.

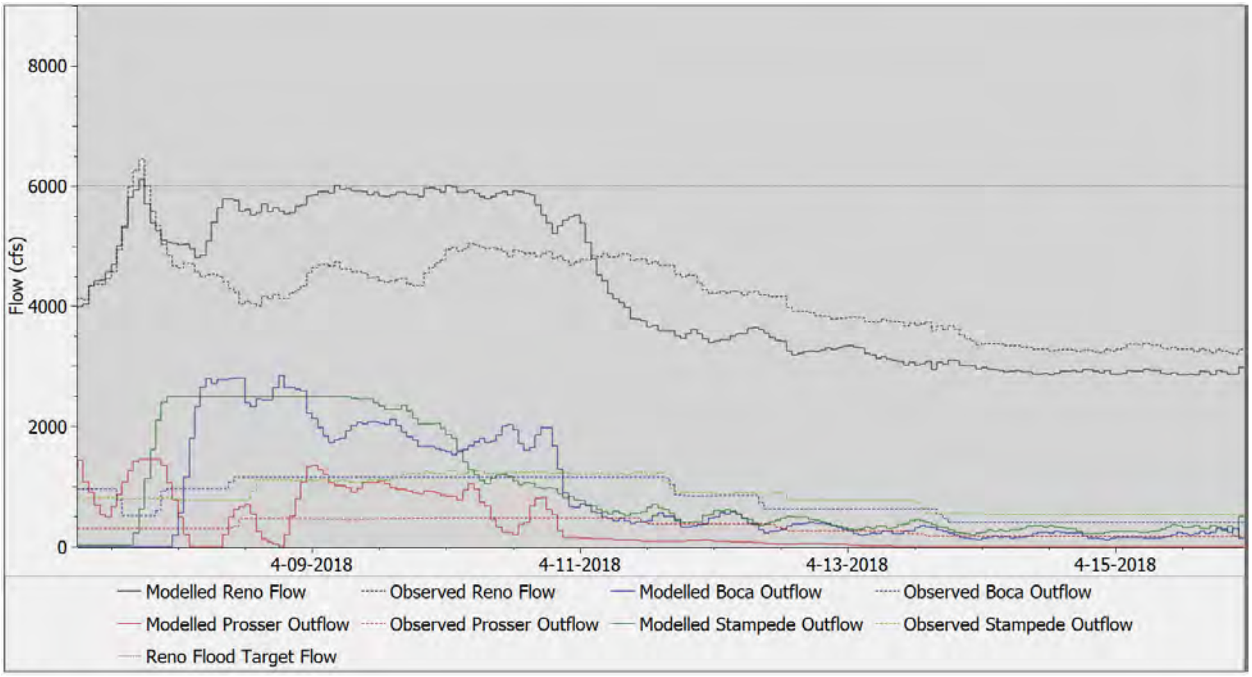

Figure 8. Flood Flows Plot for the April 2018 verification flood event.

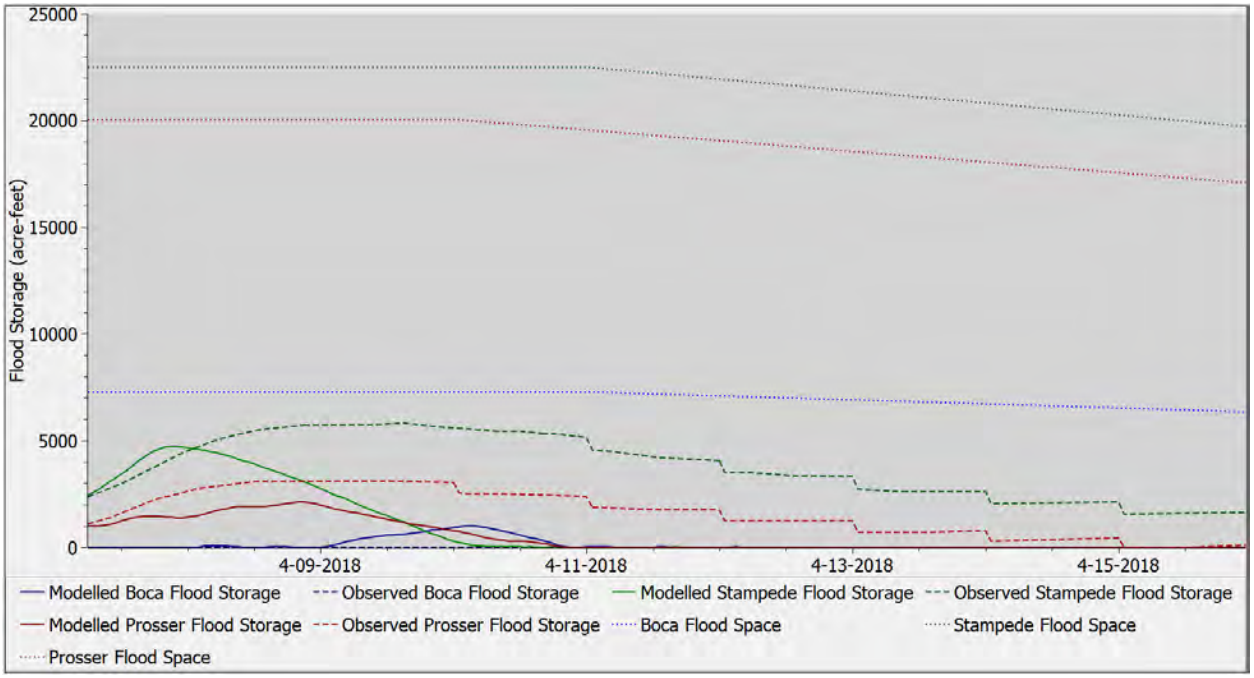

Figure 9. Flood Storage Plot for the February 2017 verification flood event.

Figure 10, Figure 11, Figure 12 show the Reservoir Plots for the three Active Flood Control Reservoirs. As noted above, the main deviation on Prosser Creek Reservoir from what was modeled to what was observed is that the flood space in the model is evacuated. The observed data shows that Prosser Creek Reservoir encroached, but that this encroachment was maintained until the required flood space reduced in the days following the event. In the model, Boca Reservoir was maintained at or slightly above its flood control capacity while the observed data shows the reservoir being maintained slightly lower than its flood control capacity. The modeled results show Stampede Reservoir encroaching slightly until the reservoir releases its flood storage down to Boca. The observed data shows that Stampede did not release as much water to Boca and maintained its encroachment until the required flood space reduced.

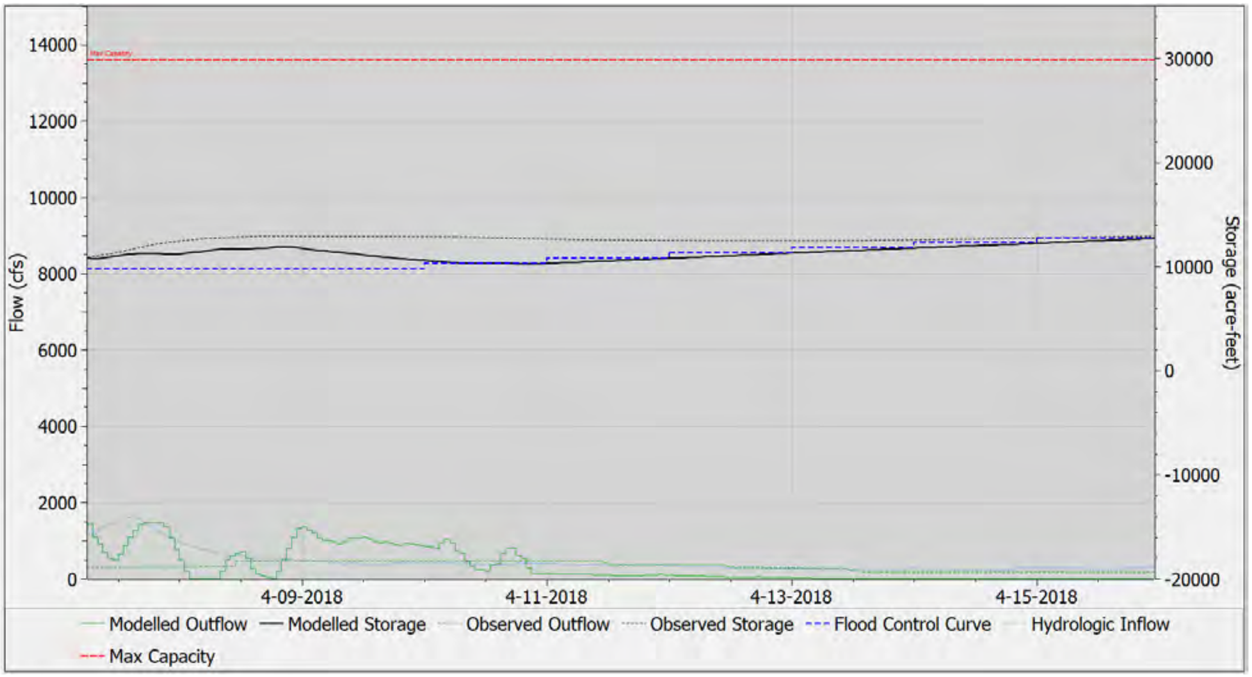

Figure 10. Reservoir Plot for Prosser Creek Reservoir during the April 2018 verification flood event.

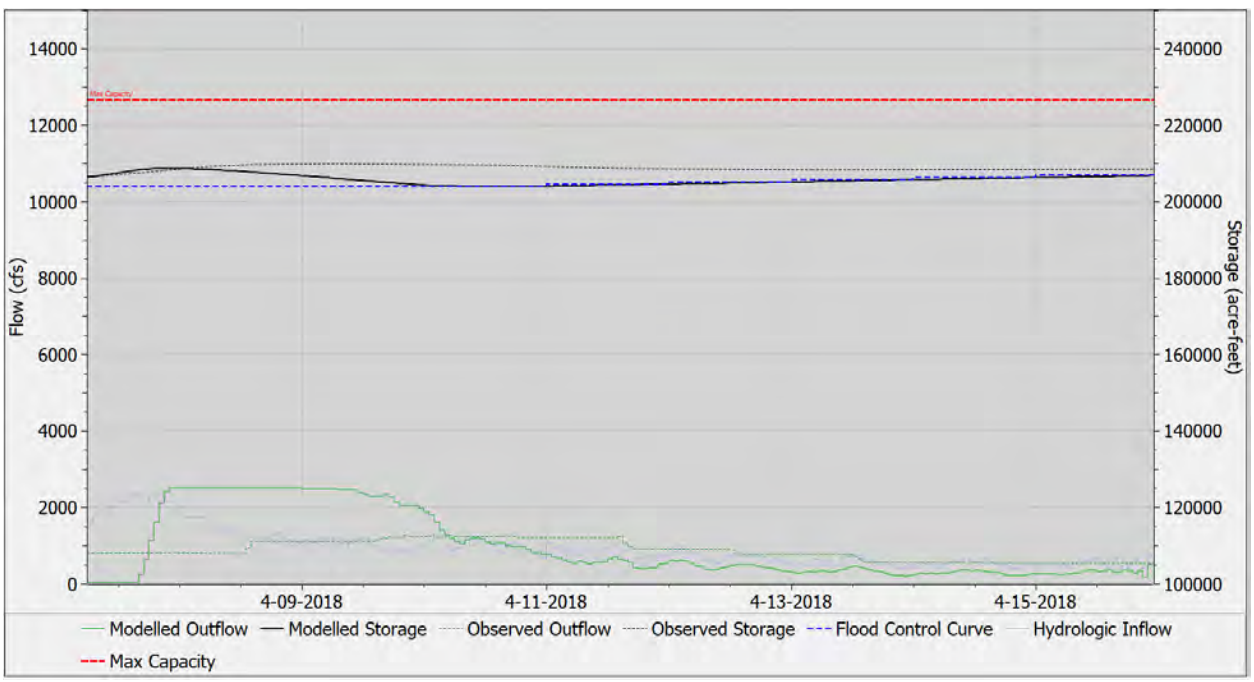

Figure 11. Reservoir Plot for Stampede Reservoir during the April 2018 verification flood event.

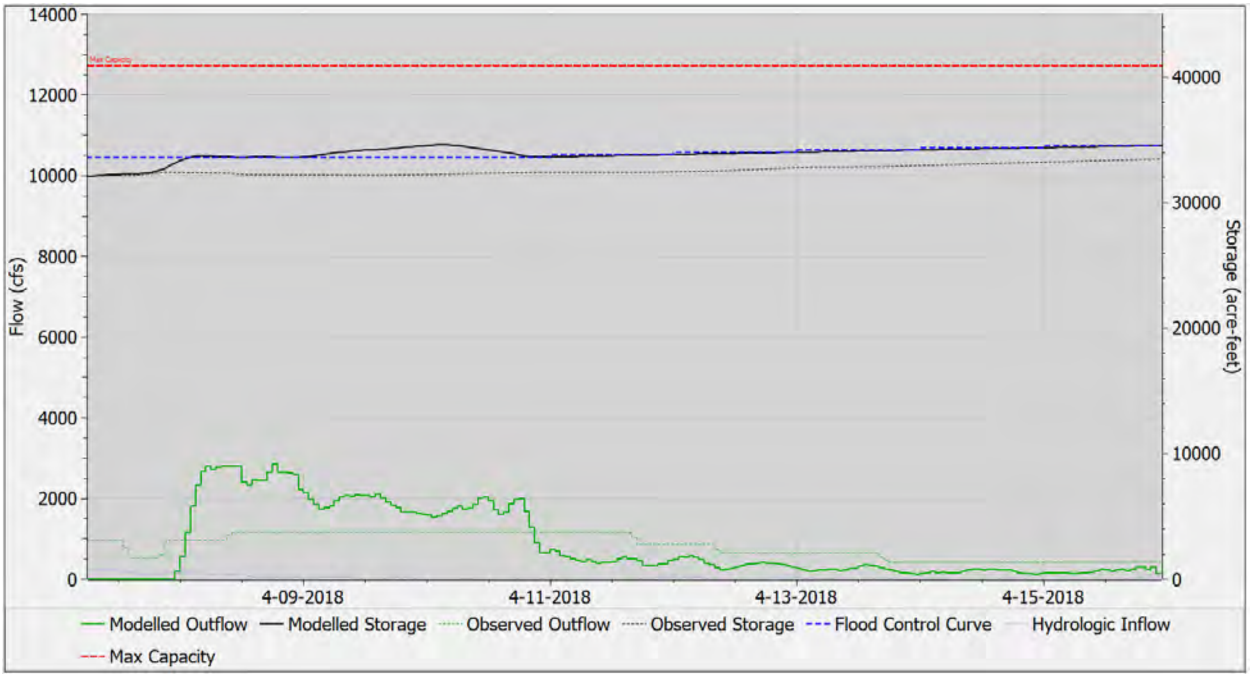

Figure 12. Reservoir Plot for Boca Reservoir during the April 2018 verification flood event.

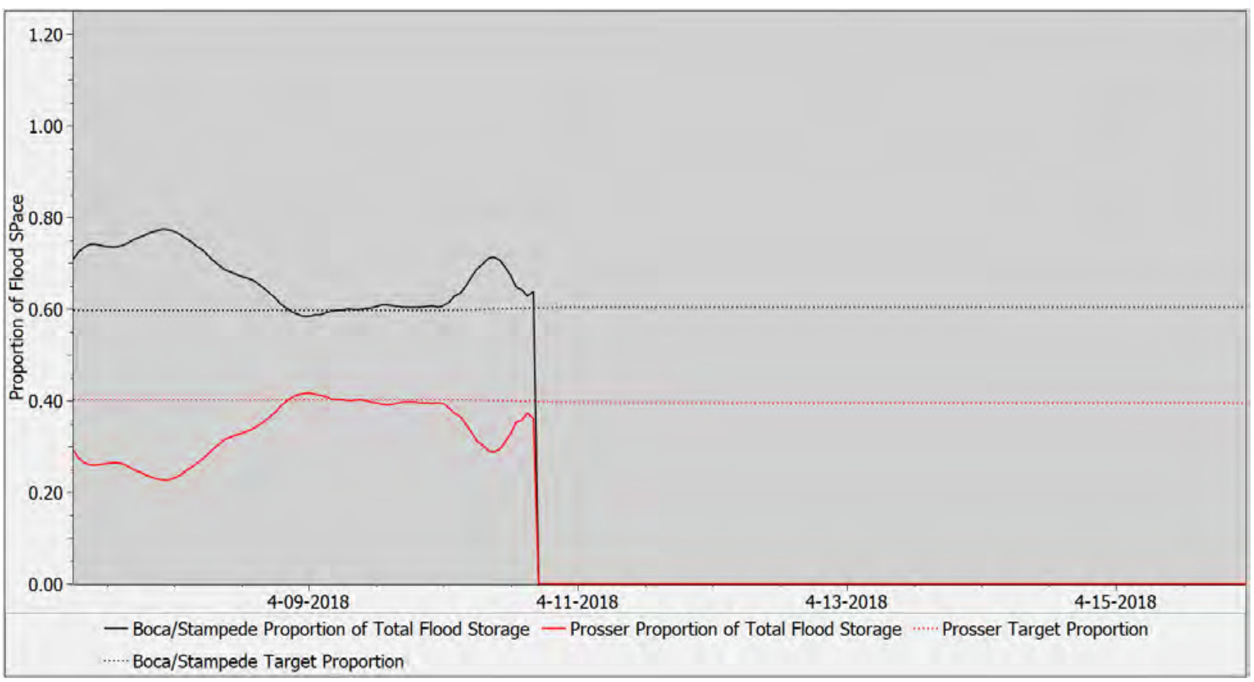

Figure 13. Flood Storage Proportions Plot April 2018 verification flood event.

Figure 13 shows the Flood Storage Proportions Plot for the April 2018 flood event. At the initialization of the event, the reservoirs started off with encroachment proportions between the Little Truckee Reservoirs and in Prosser Creek Reservoir not in accordance with those specified by the WCM. After the inflow event, the model performs well at maintaining the proportions throughout the time the reservoirs were encroached.

Both the NSE and PBIAS for this modeled event was calculated over the period surrounding flood operations in the model, from April 7, 2018, at 6am to April 11, 2018, at 8am. The NSE over this time frame was calculated to be -4.41, which is considered an "unsatisfactory" NSE score (Moriasi et al, 2007). Furthermore, the PBIAS for this event shows a 16.45% bias of simulated flows over historical flows. The major reason for both the poor NSE performance and large positive bias of this verification event is because the model evacuates flood space more efficiently than what occurred historically while adhereing to the WCM.

3.1.1.2 March 1995 Flood

The March 1995 verification flood event occurred between March 10, 1995, and March 13, 1995, and the event had a PRF at the Reno Gage of roughly 6,248 cfs.

Figure 14 and Figure 15 show the Flood Flows Plot and Flood Storage Plot for this event, respectively. The modeled flows at the Reno Gage closely match the observed flows at the Reno Gage during the rising limb, peak, and initial portion of the falling limb of the hydrograph. Once the Reno Gage recesses to around 4,000 cfs, the modeled results show Reno Gage flows being roughly 500 – 1,000 cfs higher than observed flows for roughly three days. Operations on Prosser Creek Reservoir are the reason for this difference. The outflow hydrograph for Prosser Creek Reservoir shows that both modeled and observed releases began in the afternoon of March 10. Modelled flows continued to grow in magnitude until Prosser Creek Reservoir reached its maximum outflow of roughly 1,500 cfs around midday on March 11. Maximum outflow on Prosser was sustained until the flood space in the reservoir was evacuated early on March 14. Observed releases show that Prosser Creek Releases were reduced to minimum flows in the evening of March 10 until midday on March 11. At this point, observed data shows Prosser Creek Reservoirs outflow sustaining at around 1,000 cfs until midday on March 14. The result of these discrepancies on Prosser Creek Reservoirs outflow hydrograph is that the reservoir was observed to have more encroachment for longer than what was modeled, i.e., the model was able to operate more efficiently at protecting flood space and evacuating flood space while maintaining the Reno Gage hydrograph below the flood flow target.

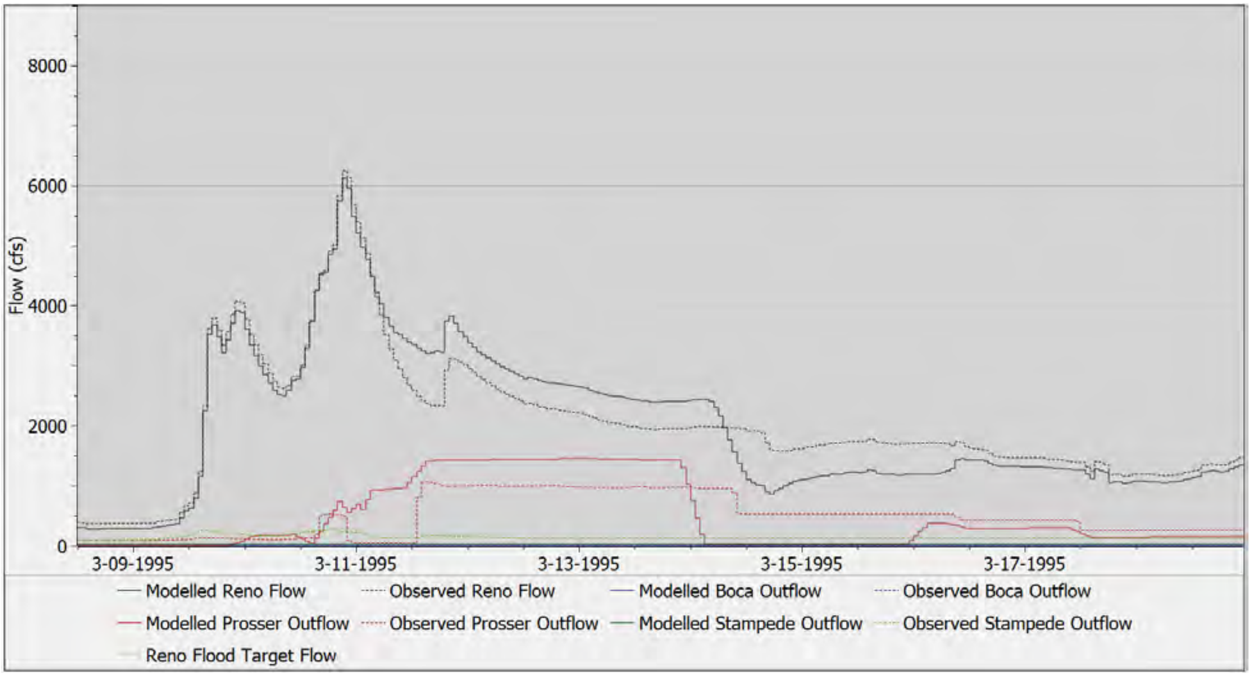

Figure 14. Flood Flows Plot for the March 1995 verification flood event.

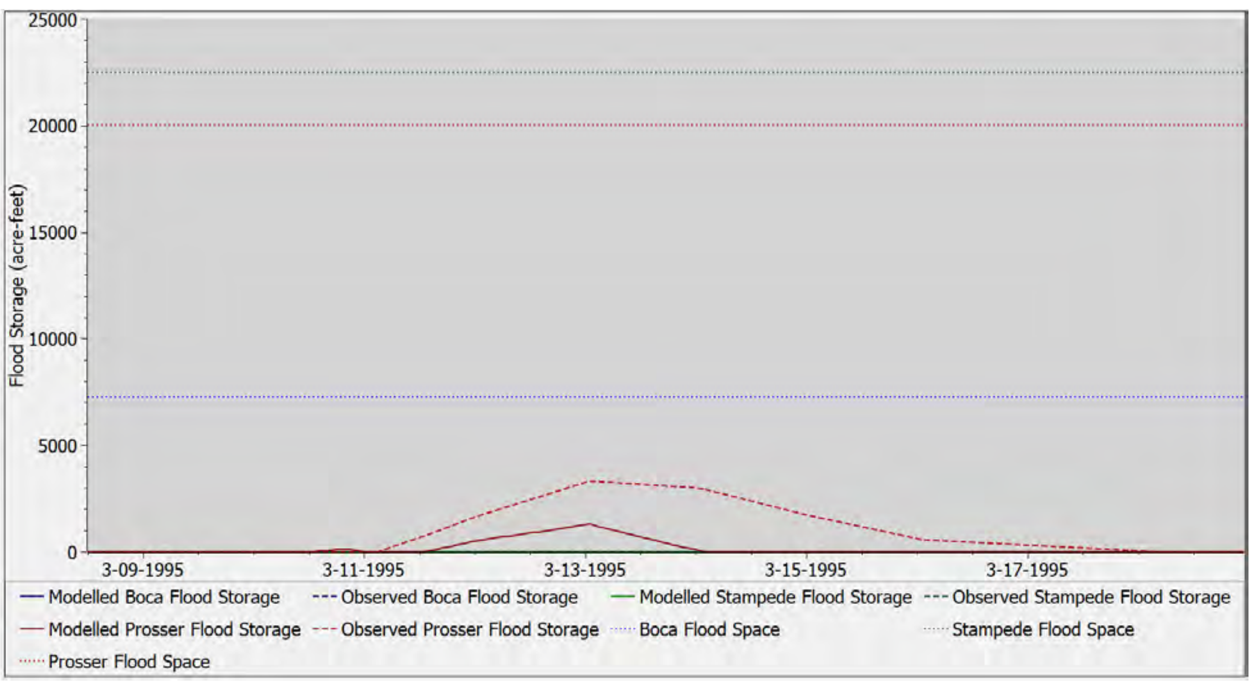

Figure 15. Flood Storage Plot for the March 1995 verification flood event.

Figure 16, Figure 17, and Figure 18 show the Reservoir Plots for the three Active Flood Control Reservoirs. Differences on Prosser Creek Reservoir are detailed above. Because Boca Reservoir and Stampede Reservoir started the event well below their flood control capacities, neither reservoir encroached during the event. Furthermore, Boca Reservoir and Stampede Reservoir show only a minor difference between observed data and what was modeled: the observed data shows that slightly more water was released from Stampede Reservoir down to Boca Reservoir.

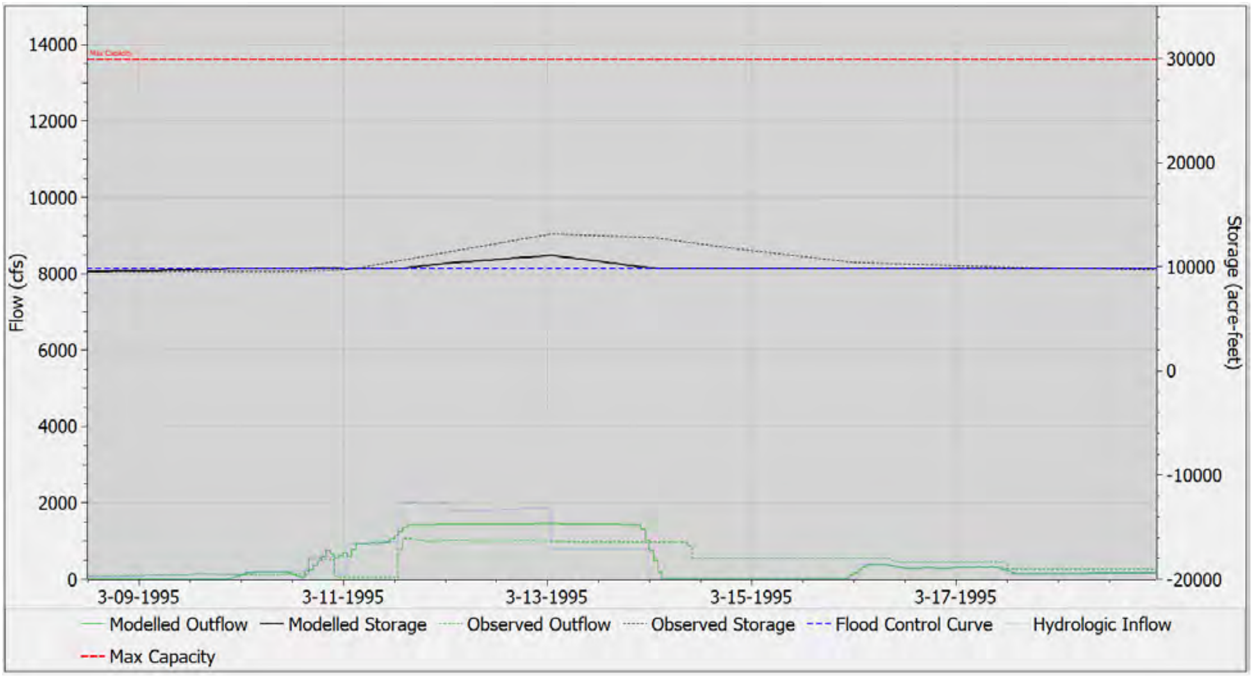

Figure 16. Reservoir Plot for Prosser Creek Reservoir during the March 1995 verification flood event.

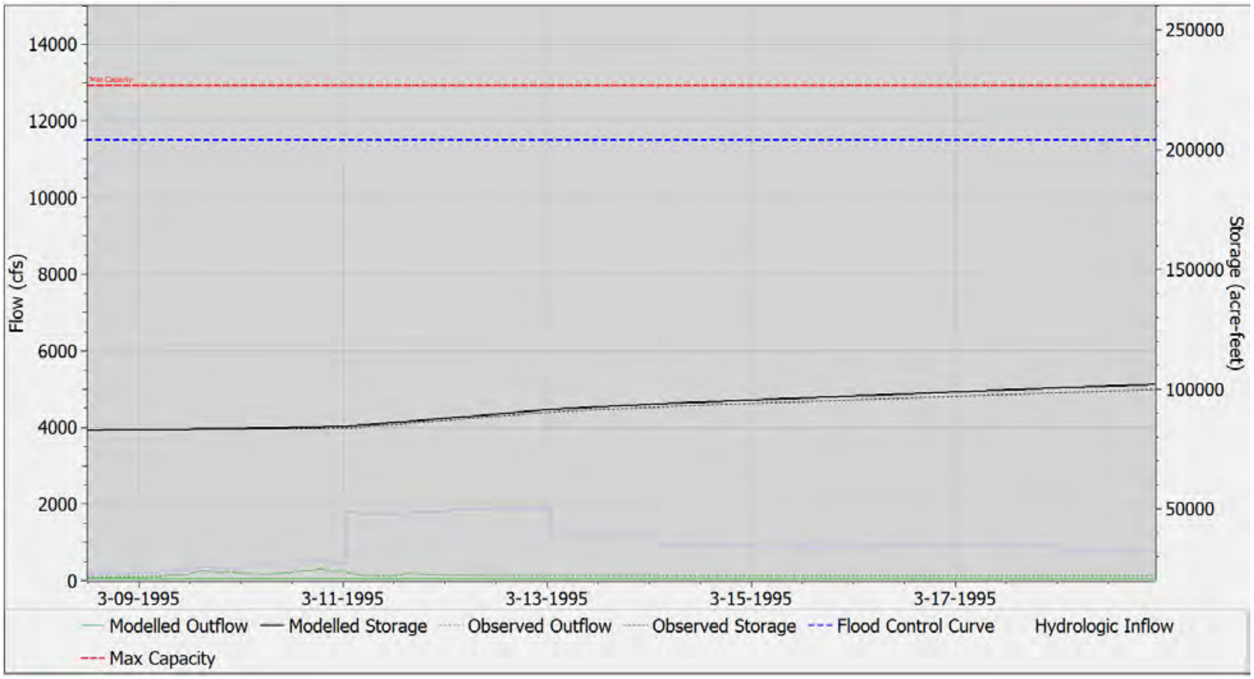

Figure 17. Reservoir Plot for Stampede Reservoir during the March 1995 verification flood event.

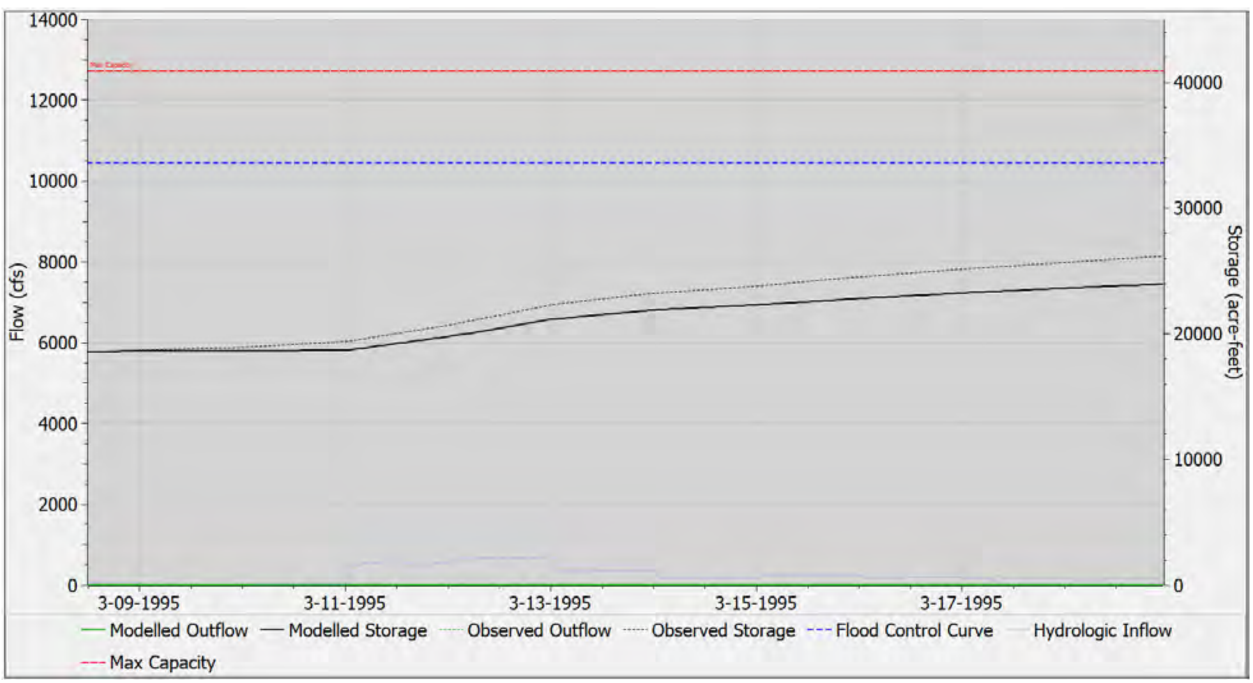

Figure 18. Reservoir Plot for Boca Reservoir during the March 1995 verification flood event.

The Flood Storage Proportions Plot is not included for this event because Prosser Creek Reservoir was the only reservoir to encroach. The NSE for this model was calculated over the period of flood operations in the model, from March 10, 1995, at 10 am to

March 14, 1995, at 1 pm. The NSE over this time frame was calculated to be 0.81, which is considered a “very good” NSE score (Moriasi et al, 2007). Furthermore, the PBIAS for this event shows a 11.15% bias of simulated flows over historical flows. Like the April 2018 event, this larger positive bias is due to the model’s ability to evacuate flood space more efficiently. Despite these differences from history, the model operated the March 1995 flood event in accordance with the WCM.

3.1.2 Medium Event Results and Discussion

3.1.2.1 February 2017 Flood

The February 2017 verification flood event occurred between February 7, 2017, and February 10, 2017, and the event had a PRF at the Reno Gage of roughly 10,300 cfs.

Figure 19 and Figure 20 show the Flood Flows Plot and Flood Storage Plot for this event. The modeled flows at the Reno Gage closely match the observed flows at the Reno Gage during the entire event until flows at the Reno Gage recess below 6,000 cfs. At this point (noon on February 10th) the model ramps up Prosser Creek Reservoir releases to the reservoir’s maximum outflow to evacuate the reservoirs flood space while not exceeding the 6,000 cfs target at the Reno Gage. Observed Prosser Creek Reservoir releases show that the flood space from the reservoir was evacuated more slowly over time. Observed releases show that Prosser Creek Reservoir began evacuating flood storage at a rate of 500 cfs 8 hours after modeled evacuations began. It wasn’t until a day after modeled Prosser releases were at max release capacity that observed releases were made at the maximum outflow. As a result, the modeled flows at the Reno Gage are much higher and closer to 6,000 cfs when Prosser Creek Reservoir is evacuating flood storage; the observed data shows that Reno Gage flows were allowed to recess down to as low as 4,000 cfs before Prosser Creek Reservoir releases to evacuate flood space started. This is further validated in Figure 20 which shows that flood space encroachment in Prosser was evacuated more efficiently in the model than what was observed.

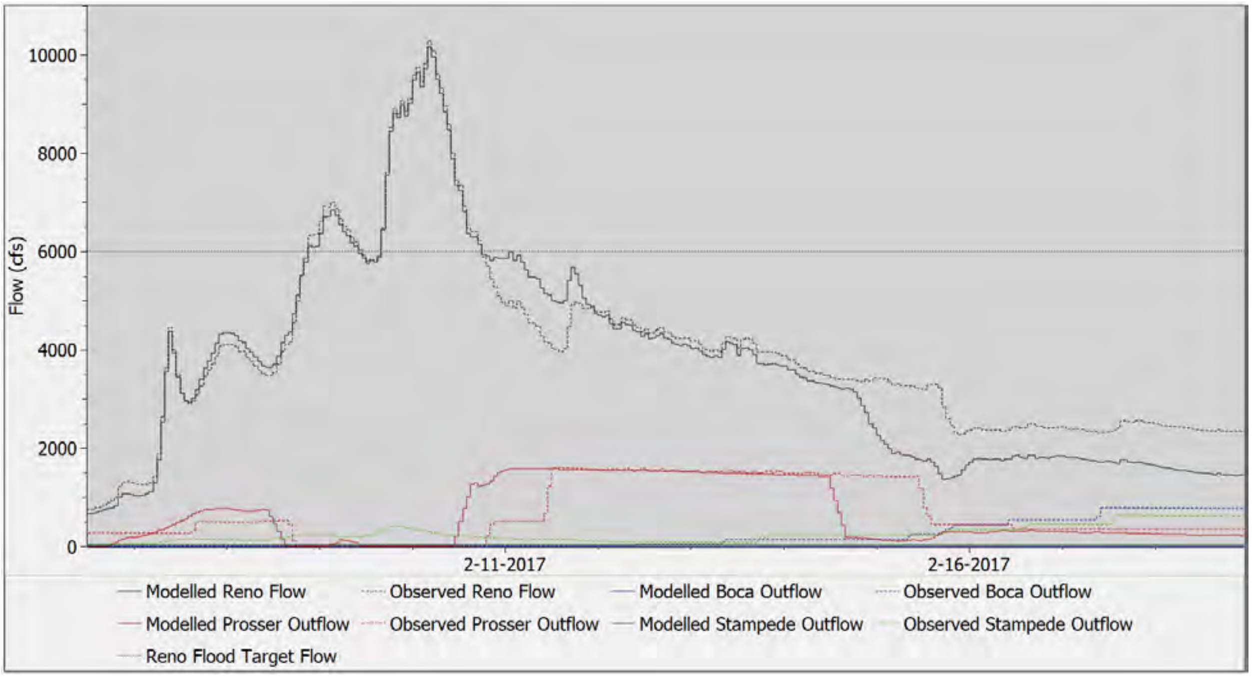

Figure 19. Flood Flows Plot for the February 2017 verification flood event.

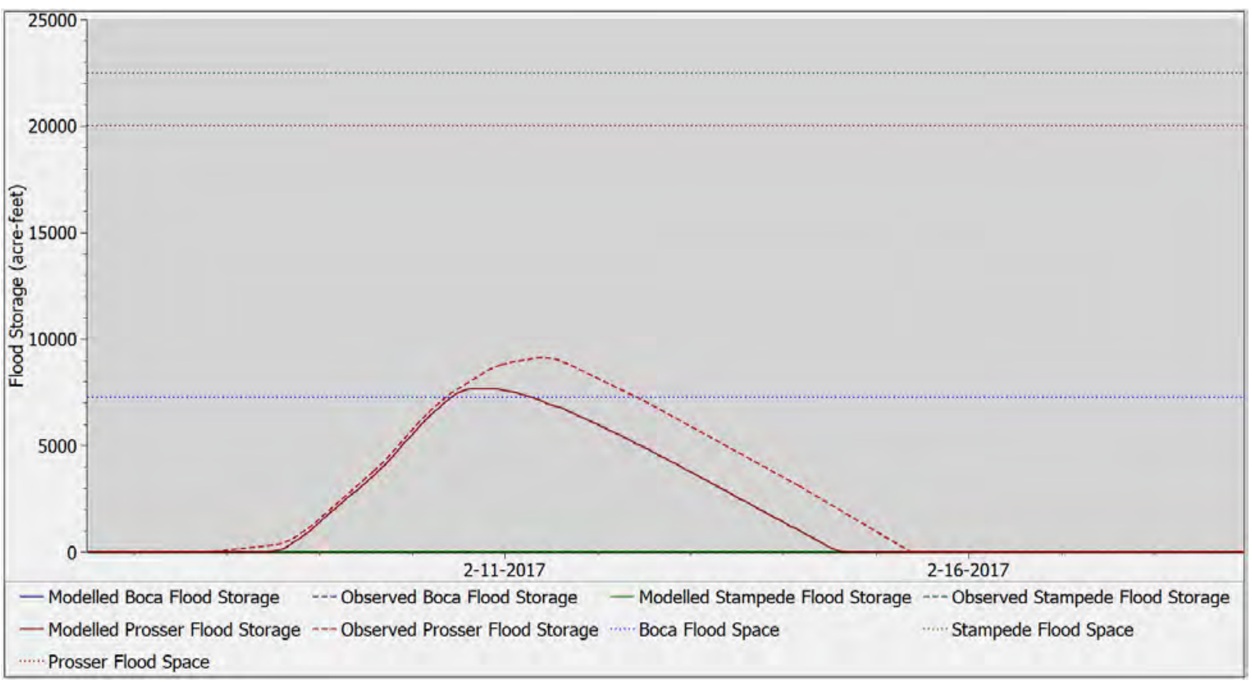

Figure 20. Flood Storage Plot for the February 2017 verification flood event.

Figure 21, Figure 22, Figure 23 show the Reservoir Plots for the three Active Flood Control Reservoirs. The differences in the plot for Prosser Creek Reservoir are explained by the differences in timing flood space evacuation in the model than what was done in practice discussed above. Boca Reservoir and Stampede Reservoir show only minor differences in outflows and storages outside of the flood event. The main difference on Boca between modeled and observed data is that after the event, Boca is observed to make releases while the model maintained the minimum release requirements out of the reservoir. On Stampede, the observed data shows that, throughout the event, Stampede was releasing water down to Boca to maintain space in Stampede for a construction project on the spillway (Precision Water Resources Engineering, 2018). The model holds this water in Stampede because the reservoir has not yet reached its flood control capacity.

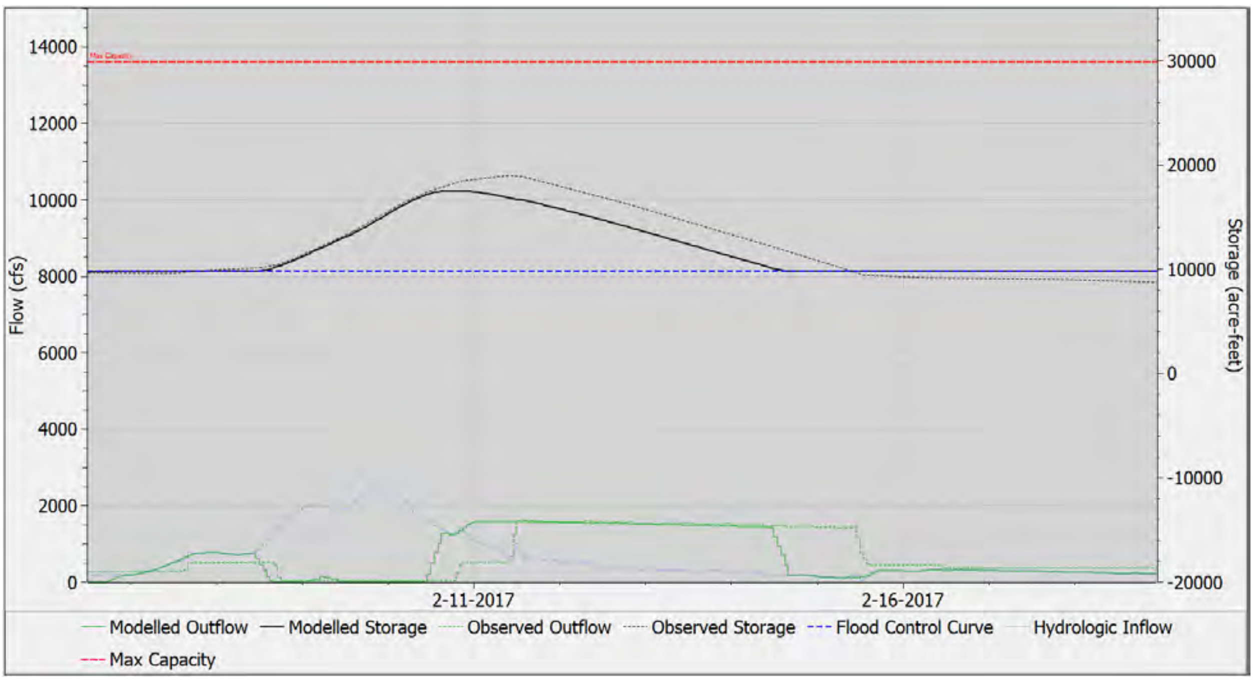

Figure 21. Reservoir Plot for Prosser Creek Reservoir during the February 2017 verification flood event.

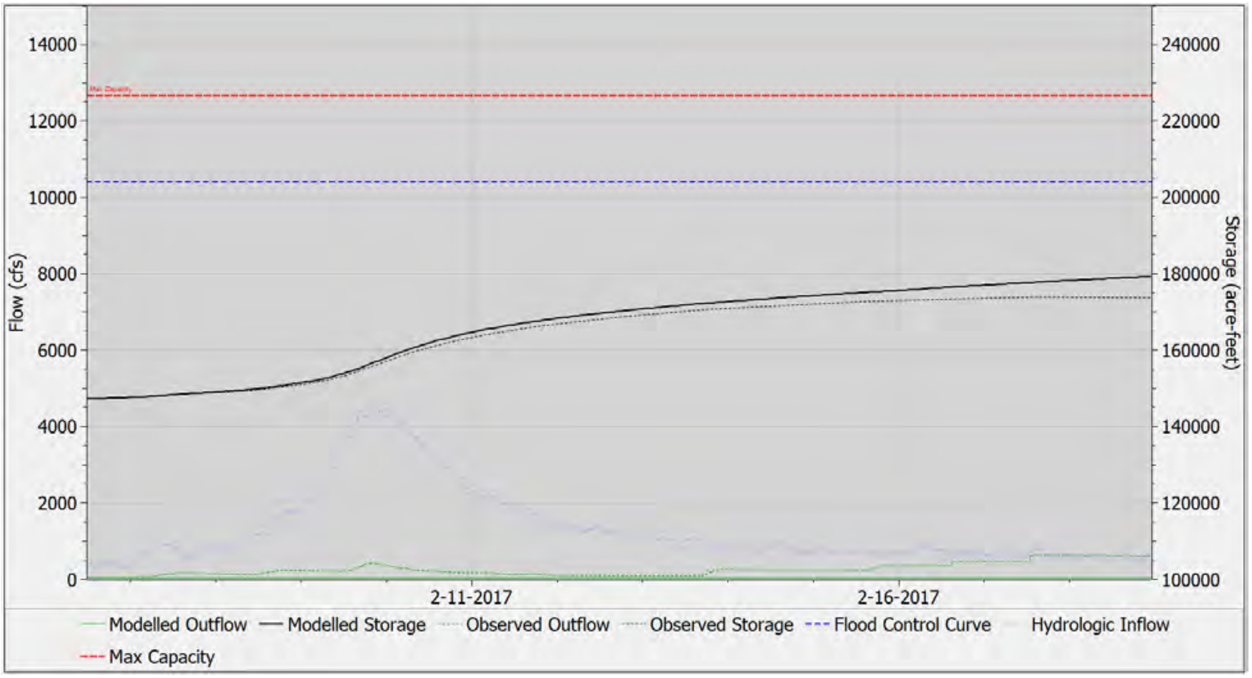

Figure 22. Reservoir Plot for Stampede Reservoir during the February 2017 verification flood event.

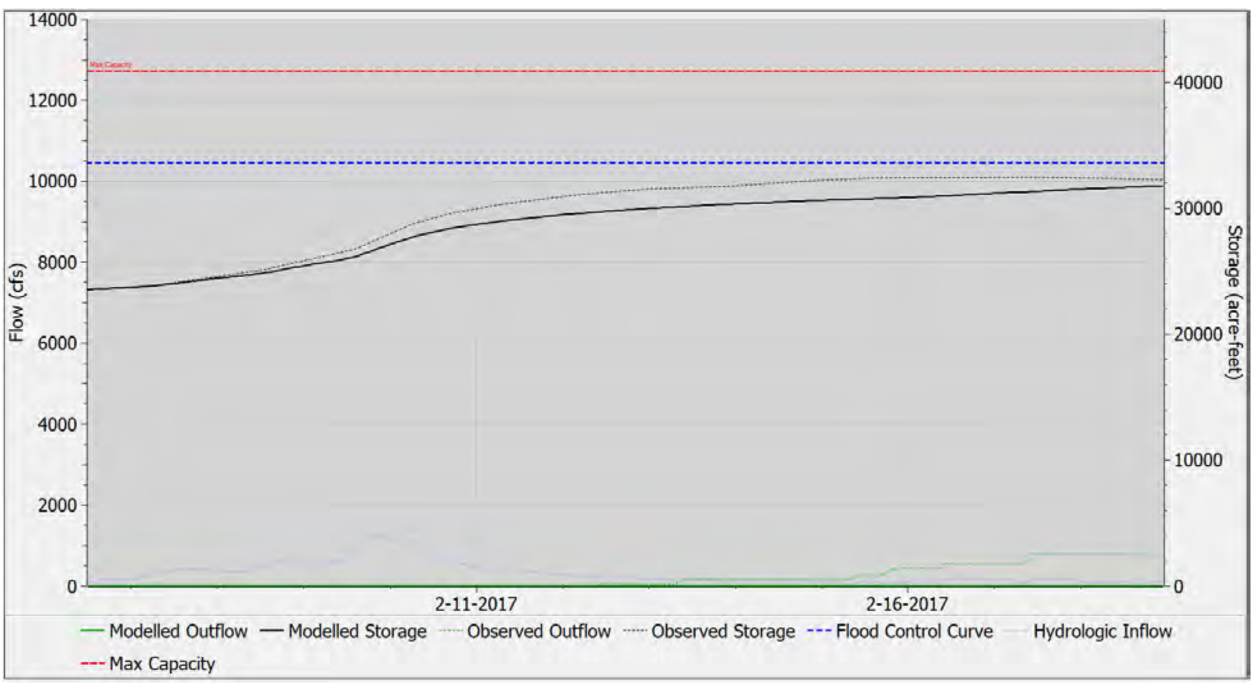

Figure 23. Reservoir Plot for Boca Reservoir during the February 2017 verification flood event.

The Flood Storage Proportions Plot is not included for this event because Prosser Creek Reservoir was the only reservoir to encroach. The NSE for this model was calculated over the period of flood operations in the model, from February 8, 2017, at 10 am to

February 15, 2017, at 3pm. The NSE over this time frame was calculated to be 0.94, which is considered a "very good" NSE score (Moriasi et al, 2007). Furthermore, the PBIAS was 0.01%, suggesting that modelled flows were biased only slightly higher at the Reno Gage.

3.1.2.2 February to March 1986 Flood

The February to March 1986 verification flood event was unique in that it had a double peak. The first inflow event occurred between February 16, 1986, and February 21, 1986, and had a PRF of around 10,000 cfs at the Reno Gage. The second inflow event occurred between March 7, 1986, and March 10, 1986, and it had a PRF of roughly 9,000 cfs at the Reno Gage.

Figure 24 and Figure 25 show the Flood Flows Plot and Flood Storage Plot for this event, respectively. During the initial event, observed and modeled peak flows differ by less than 200 cfs. Prosser Creek Reservoir was the only reservoir to encroach into flood space during the first event. After flows at the Reno Gage recessed below 6,000 cfs, Prosser Creek Reservoir begins evacuating surcharge at its maximum outflow of around 1,700 cfs in both the modeled and observed results. During the second event, modeled and observed peak flows differ by roughly 250 cfs. Model results show that both Boca and Prosser Creek Reservoirs encroached, while observed results show that only Prosser Creek Reservoir encroached. As a result, after the event, modeled results show increases in Boca Reservoirs outflows that are not reflected in observed data (see Figure 28). Furthermore, observed data shows that Prosser Creek Reservoir was delayed by a few days in evacuating flood storage, while the model started flood storage evacuations as soon as Reno Gage flows recessed to around the 6,000 cfs flood target. As a result, modeled Reno Gage flows remain higher in the model than what was observed for several days after the event, and flood space was evacuated more efficiently in the model.

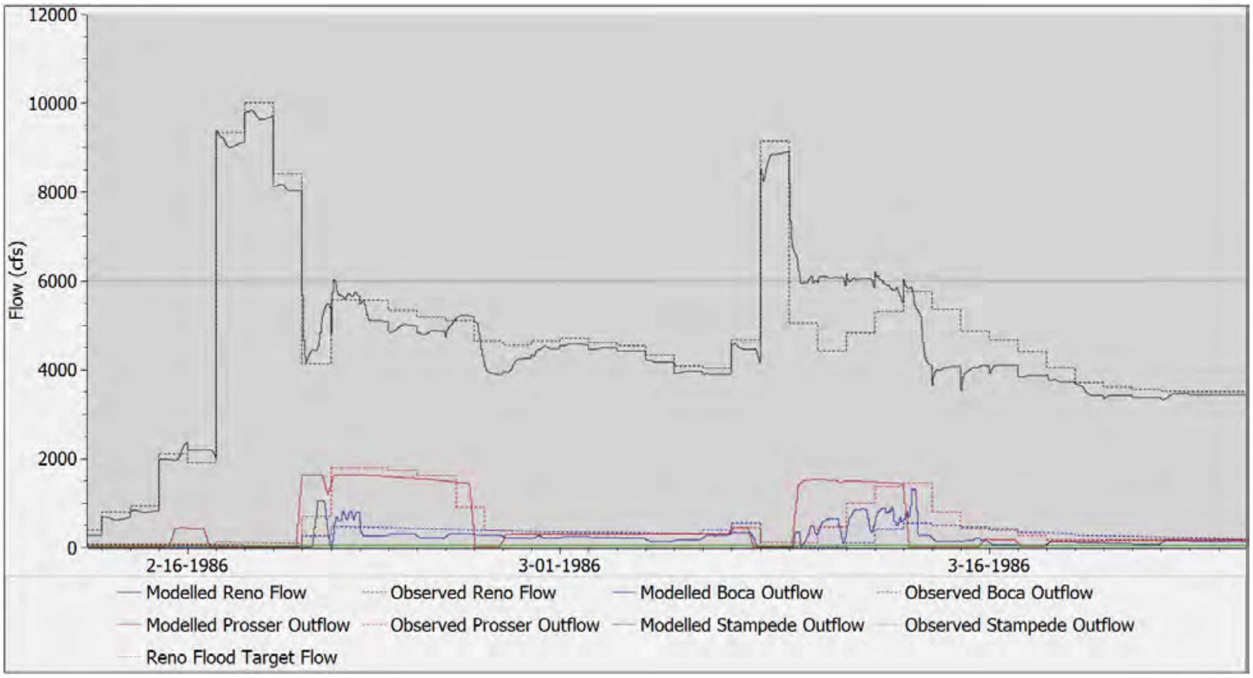

Figure 24. Flood Flows Plot for the February to March 1986 verification flood event.

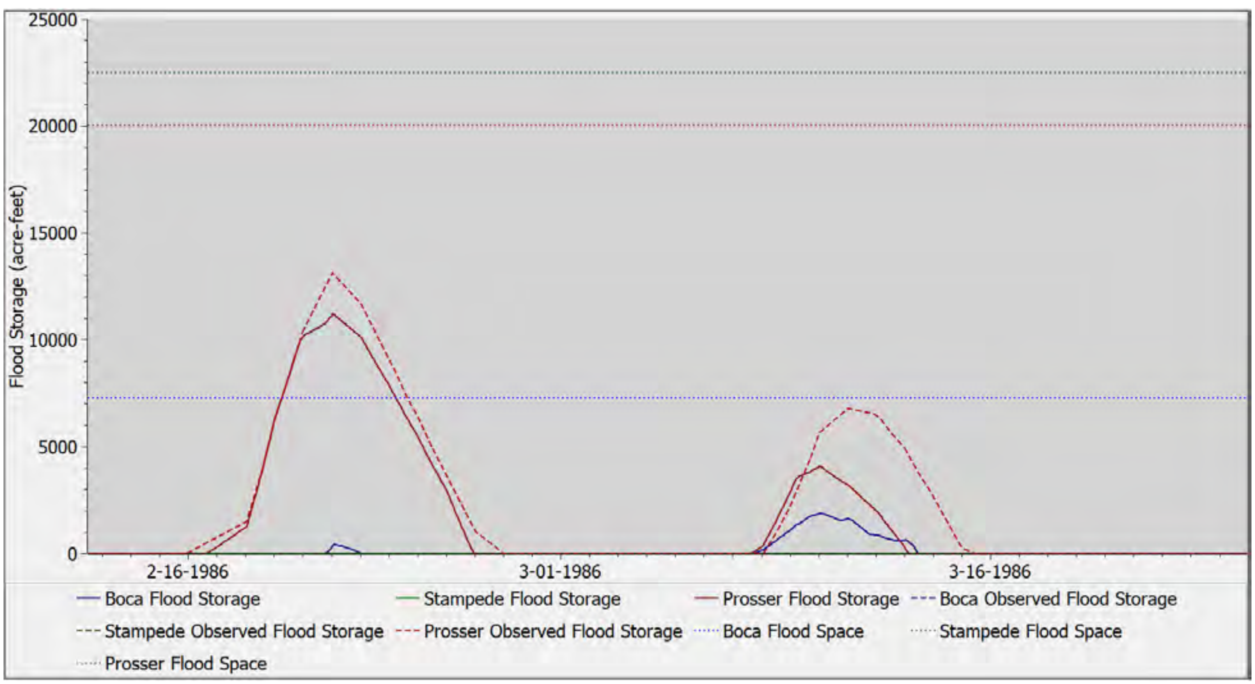

Figure 25. Flood Storage Plot for the February to March 1986 verification flood event.

Figure 26, Figure 27, Figure 28 show the Reservoir Plots for the three Active Flood Control Reservoirs. Prosser Creek Reservoir's modeled storage and outflow agree well with observed data for the first peak of the February to March 1986 flood event. During the second peak, model results show the flood space from Prosser Creek Reservoir's was evacuated more efficiently. Observed results show that releases of encroachment in Prosser Creek Reservoir were delayed, and as a result, the reservoir encroached roughly twice as much. Because Stampede Reservoir started the event well below its flood control capacity, the reservoir was able to store through both peaks of the event without encroaching. Stampede Reservoir was held at minimum outflow for the entirety of the event in both the observed and modeled outflows. On Boca Reservoir, both the modeled and observed show the reservoir reaching its flood control capacity during the first peak of the event. After the initial peak, observed data shows that Boca Reservoir was drawn down slightly while model results show Boca Reservoir being held at its flood control capacity. As a result, Boca Reservoir begins the second event at a higher storage in the model than what was observed, and the model shows the reservoir encroaching. This did not occur historically.

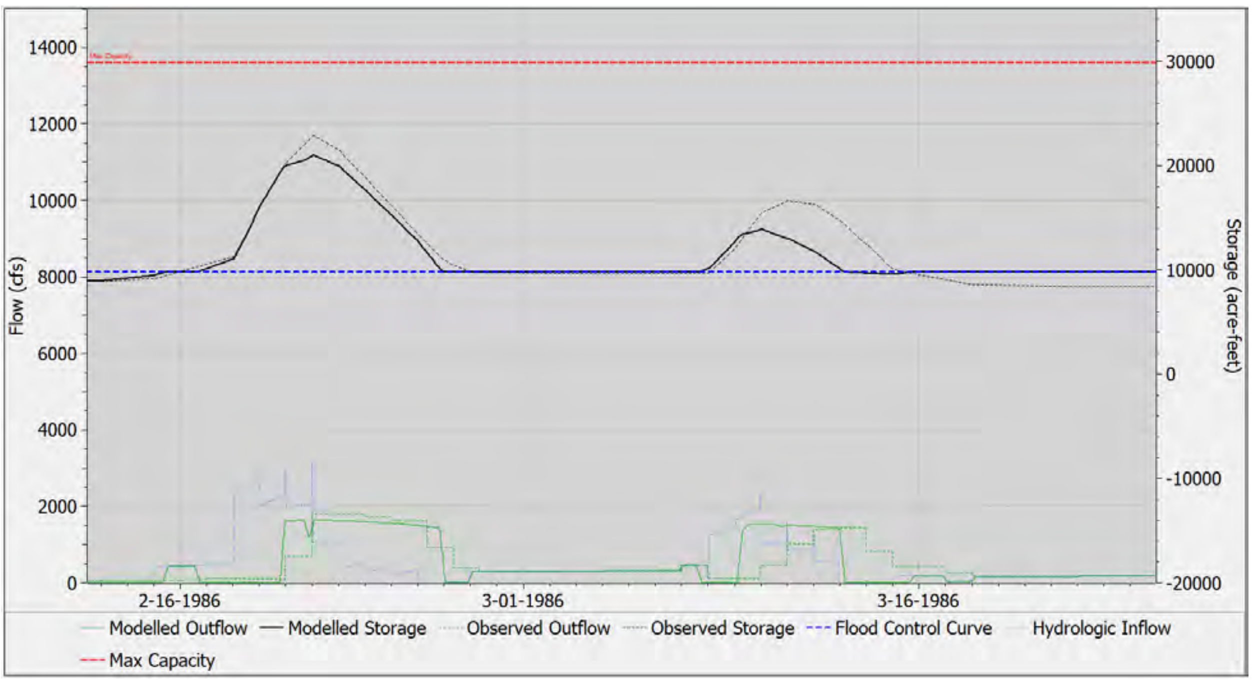

Figure 26. Reservoir Plot for Prosser Creek Reservoir during the February to March 1986 verification flood event.

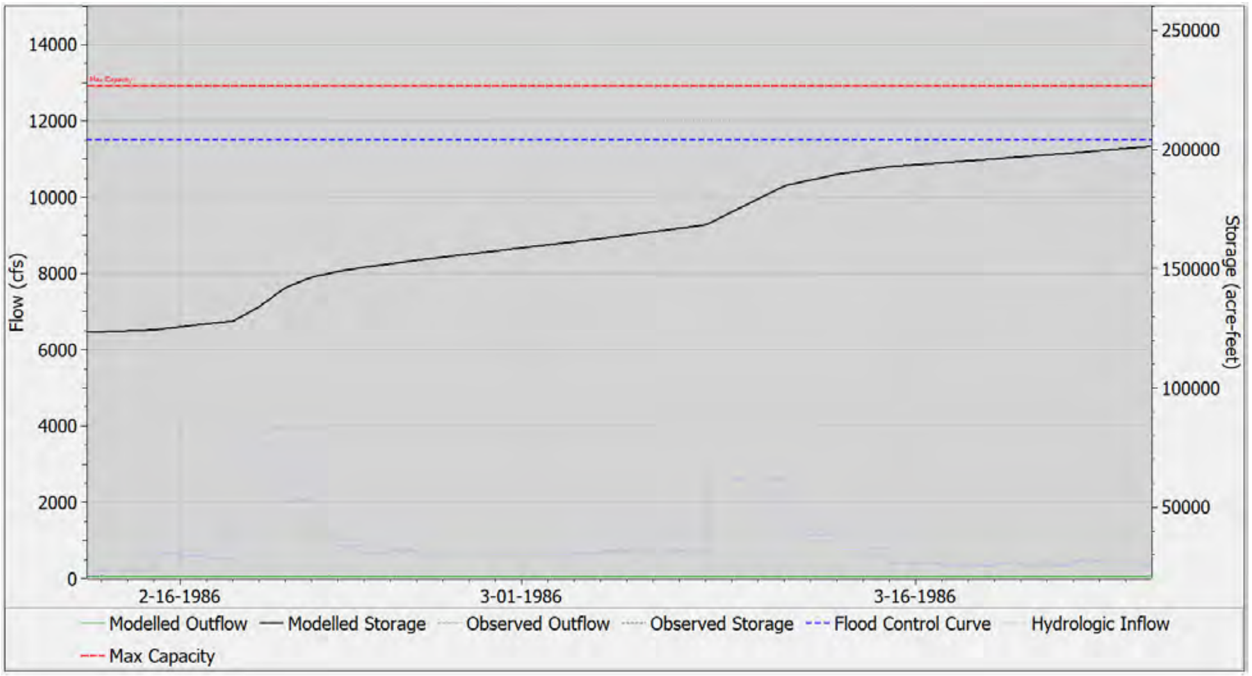

Figure 27. Reservoir Plot for Stampede Reservoir during the February to March 1986 verification flood event.

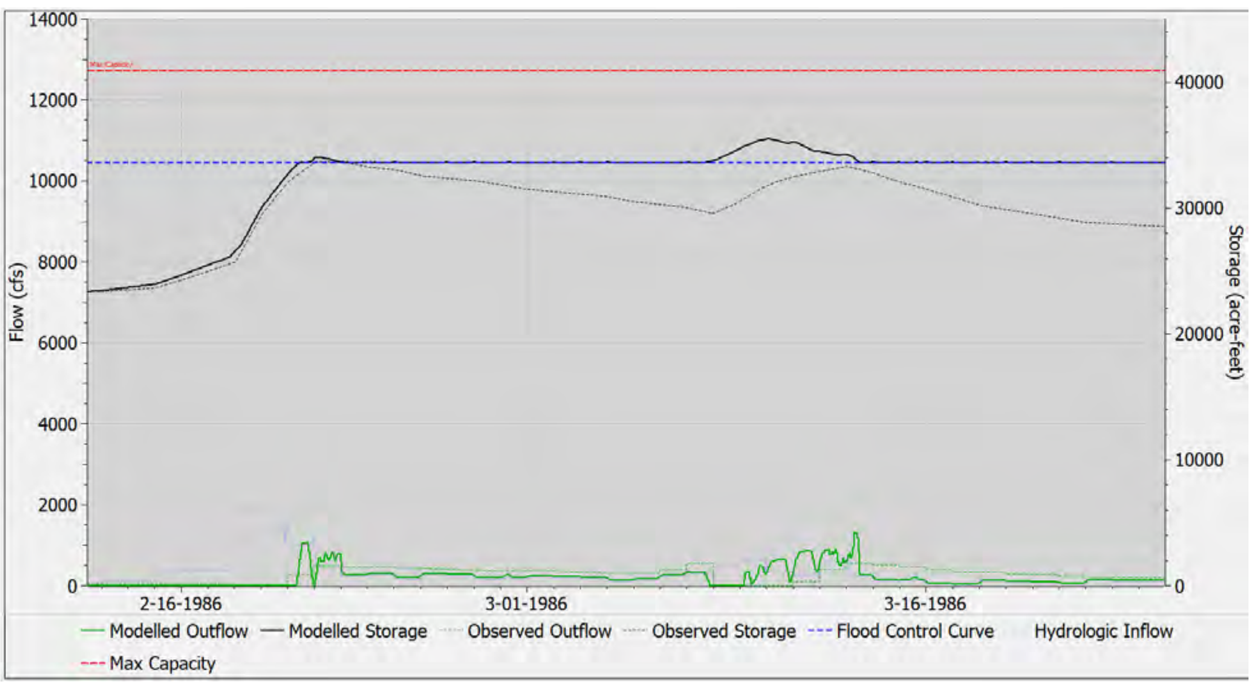

Figure 28. Reservoir Plot for Boca Reservoir during the February to March 1986 verification flood event.

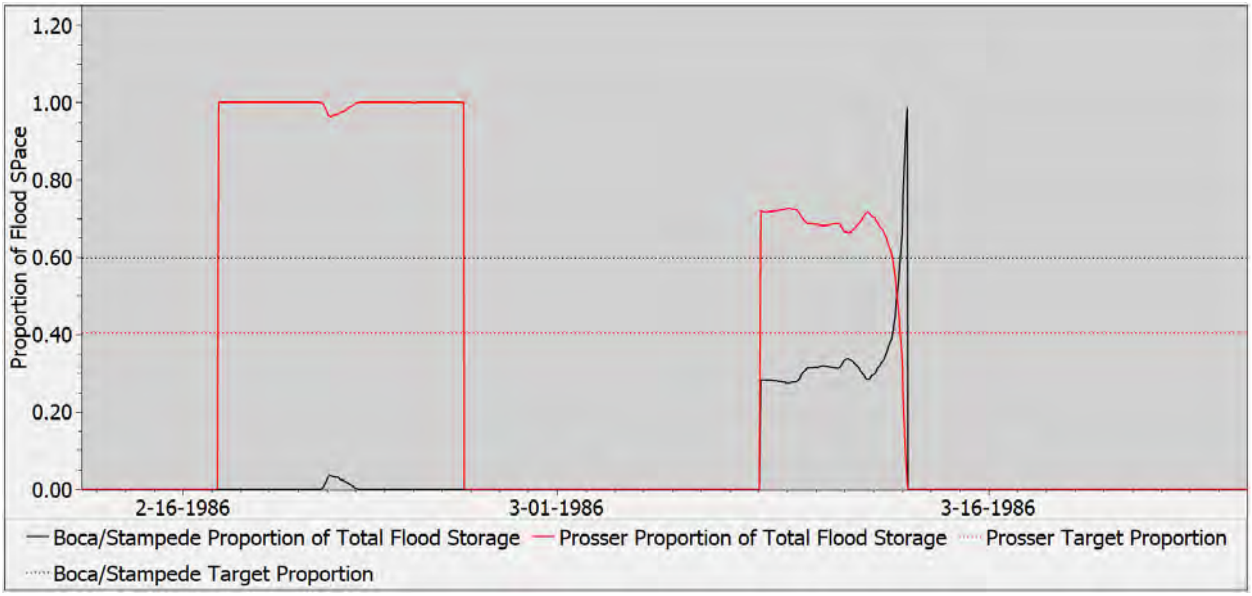

Figure 29. Flood Storage Proportions Plot for the February to March 1986 verification flood event.

Figure 29 shows Flood Storage Proportions Plot for the February to March 1986 Flood Event. During the first peak of the event, because Little Truckee Reservoirs started the event well below flood control capacity, almost all the encroachment was in Prosser Creek Reservoir, and there was no opportunity for the model to achieve proportional flood storage. During the second peak, Boca Reservoir and Prosser Creek Reservoir were encroached and the model was unable to achieve proportional storage between the two. The main reason for this is that Stampede Reservoir, after the second event, was still below its flood control capacity. Thus, less flood storage was accumulated in Little Truckee Reservoirs.

The NSE for this model was calculated over the period of flood operations in the model, from twelve hours prior to the time flows at the Reno Gage reached 6,000 cfs (February 16, 1986, at 1 pm) to twelve hours past when the modeled flood storage in the system was evacuated (March 14, 1986, at 12 am). The NSE over this time frame was calculated to be 0.88, which is considered a "very good" NSE score (Moriasi et al, 2007). Further substantiating the NSE score, the PBIAS for this event was 0.45%, suggesting that modelled flows at the Reno Gage were biased only slightly higher than historical flows.

3.1.3 Large Event Results and Discussion

3.1.3.1 1997 Flood

The 1997 Flood verification event was a major event that occurred between December 30, 1996, and January 4, 1997, and the event had a PRF at the Reno Gage of roughly 18,100 cfs. This event represented the largest event in the period of record.

Figure 30 and Figure 31 show the Flood Flows Plot and Flood Storage Plot for this event, respectively. The modeled flows at the Reno Gage closely match the observed flows at the Reno Gage during the entire event until flows at the Reno Gage recess below 8,000 cfs. Once this occurs, model results deviate significantly from what was observed. This occurred for two compounding reasons.

The first is that, during this event, operators in the system were allowed an emergency variance to the normal flood target at the Reno Gage of 6,000 cfs.[7] As shown in the hydrograph in Figure 30, flood space evacuations were made historically in an amount that resulted in Reno Gage flows between 7,000 and 8,000 cfs from January 3, 1997, to January 16, 1997. Alternatively, the model strictly attempts to maintain flows at 6,000 cfs. As a result, the observed flood storage in the system was evacuated at a much faster rate than what was modeled.

The second reason for differences between model results and what was observed is in how surcharge, particularly on Stampede Reservoir, was operated during the event. Figure 31 shows that, historically, Stampede was allowed to surcharge more volume than what the model allowed, and this surcharge was released at a more controlled rate. The Reservoir Plot for Stampede Reservoir (Figure 33) further validates this. Alternatively, the model is configured to prioritize dam safety when reservoirs are in surcharge, and, as a result, the model releases surcharge as quickly as possible regardless of downstream flood flow targets. Because of this, the modeled Reno Gage hydrograph in Figure 30 shows, after the event, flows at the Reno Gage recessing briefly to 6,000 cfs before rising again to between 10,000 and 11,000 cfs for several days. This large increase in Reno Gage flows in the model is due to the evacuation of surcharge from Stampede Reservoir and Prosser Creek Reservoir. Stampede Reservoir surcharge is evacuated at Stampede's maximum outflow down to Boca Reservoir until Boca Reservoir reaches its max capacity. At this point, the model shows Boca Reservoir's releases increase dramatically to keep the reservoir from surcharging. Once the

[7] DRAFT, waiting on reference to this variance from Water Master's Office.

surcharge in the flood reservoirs is fully evacuated in the model, flows at Reno are maintained at 6,000 cfs until the encroachment is evacuated. This differs significantly from observed results which maintained Reno Gage flows between 7,000 to 8,000 cfs for this period until observed encroachment was evacuated.

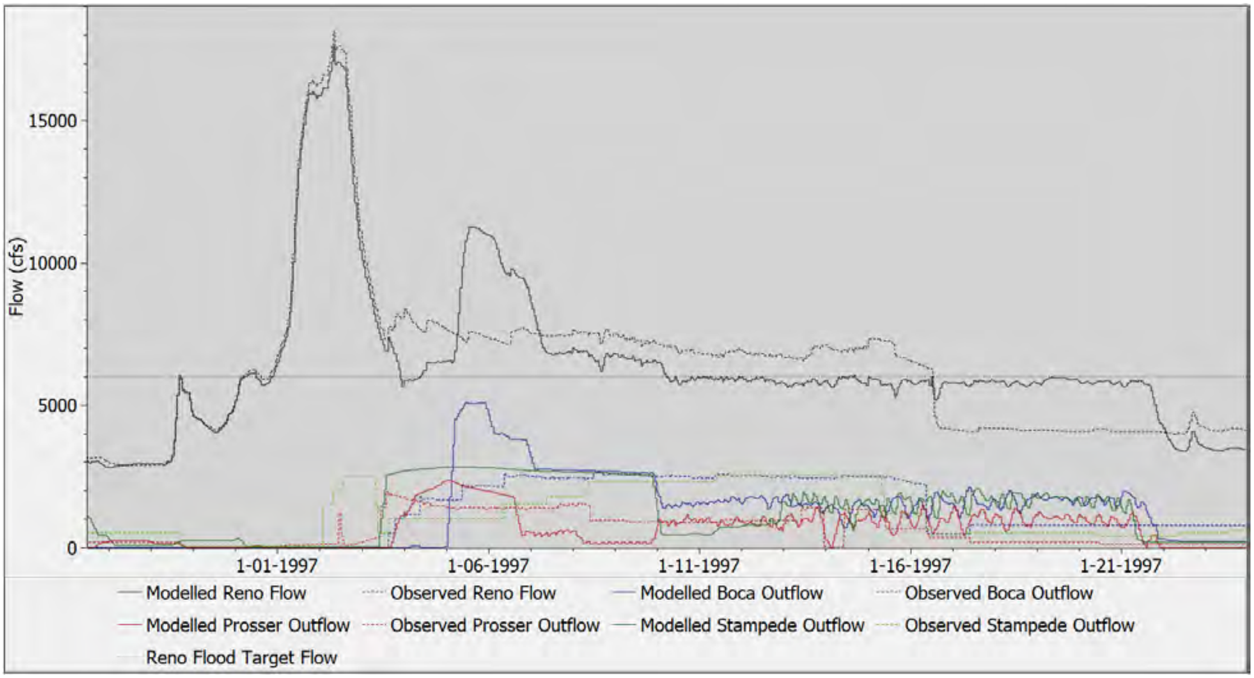

Figure 30. Flood Flows Plot for the 1997 Flood verification flood event.

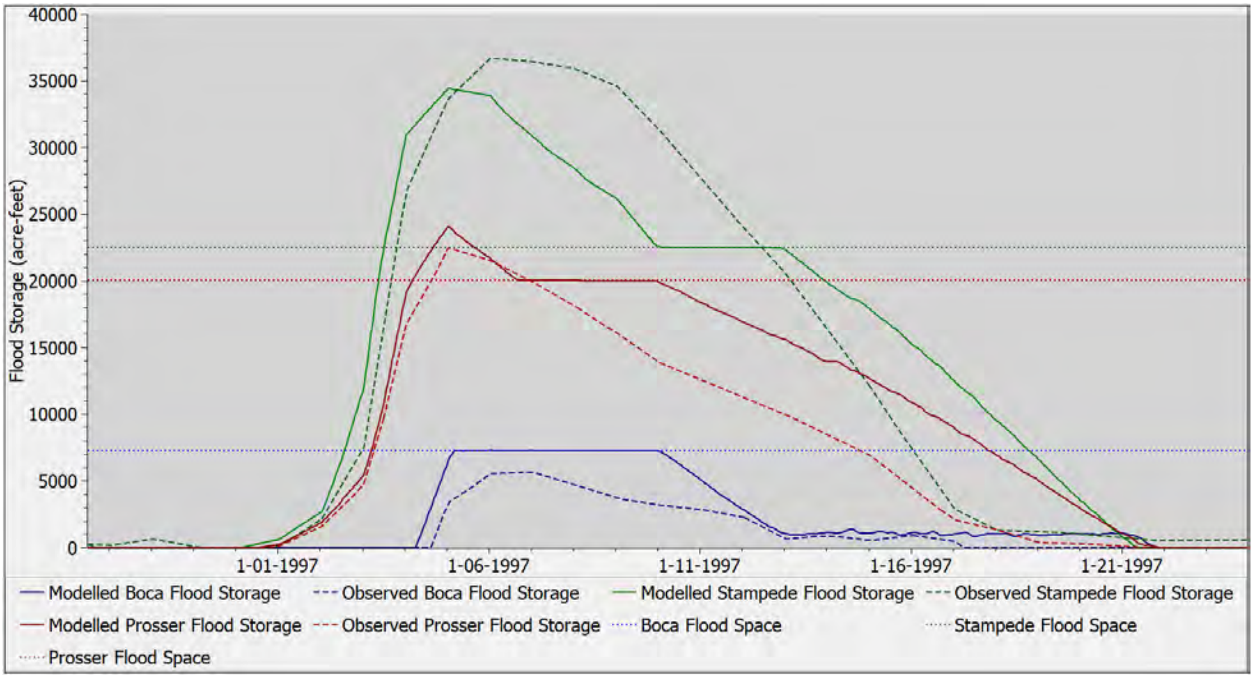

Figure 31. Flood Storage Plot for the 1997 Flood event.

It is worth noting how the model operates the system when reservoirs are in surcharge. When a reservoir is in surcharge, the model will prioritize the evacuation of surcharge. Figure 31 shows that when surcharge occurred in the model on Stampede Reservoir and Prosser Creek Reservoir, Boca Reservoir was maintained at its maximum capacity. Boca Reservoir remained at maximum capacity until all surcharge in the system was evacuated. At this point, the model prioritizes evacuating Boca Reservoir's encroachment prior to evacuating Stampede Reservoir's encroachment while maintaining proportional flood storage between the Little Truckee Reservoirs and Prosser Creek Reservoir (see Figure 35). Boca Reservoir encroachment is coded within the model to be evacuated over Stampede Reservoir encroachment until Boca Reservoir storages get to levels closer to its flood control capacity. This logic was included per the direction of the Federal Water Master. Once Boca Reservoir's encroachment is mostly evacuated, releases from Stampede Reservoir begin to evacuate its flood storage.

Figure 32, Figure 33, and Figure 34 show the Reservoir Plots for the three Active Flood Control Reservoirs. Most of the differences in the reservoir figures are due to the model's limited ability to evacuate flood space because of its strict adherence to the WCM and dam safety protocol during surcharge. Another notable difference for Boca Reservoir is that historically, the reservoir was operated to remain roughly 2,000 Acre-Feet (AF) below its max capacity. The model shows Boca Reservoir filling and remaining full for roughly 6 days. The operators during this event left a buffer on Boca Reservoir to minimize the risk of water flowing over the radial gates. Furthermore, it is worth noting that the model results for outflow of each of the Active Flood Control Reservoirs show large fluctuations during the period when encroachment is being evacuated. Historical outflows are much steadier and there are clear release changes on the reservoirs. These fluctuations in the modeled releases are due to the model's attempt to maintain proportional flood storage while evacuating and historical operations required manual gate changes resulting in more discrete flows. See Section **2.2.2 Limitations of the TR Hourly River Model** for more explanation on this issue.

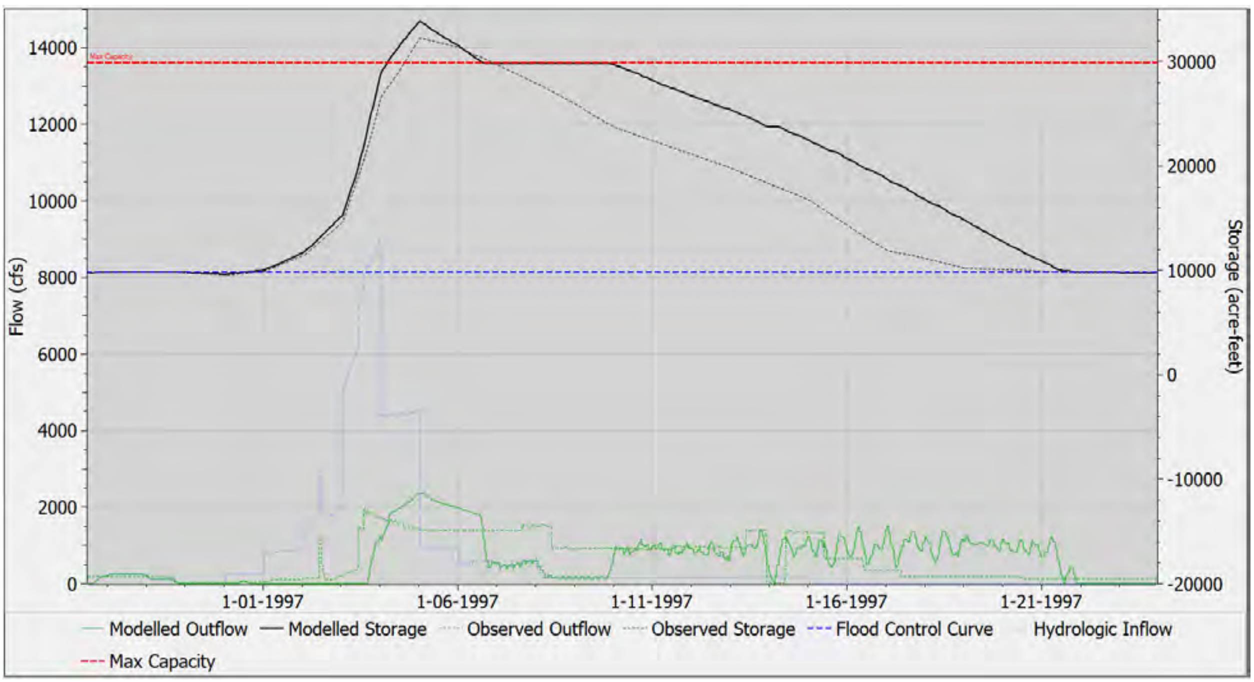

Figure 32. Reservoir Plot for Prosser Creek Reservoir during the 1997 Flood verification flood event.

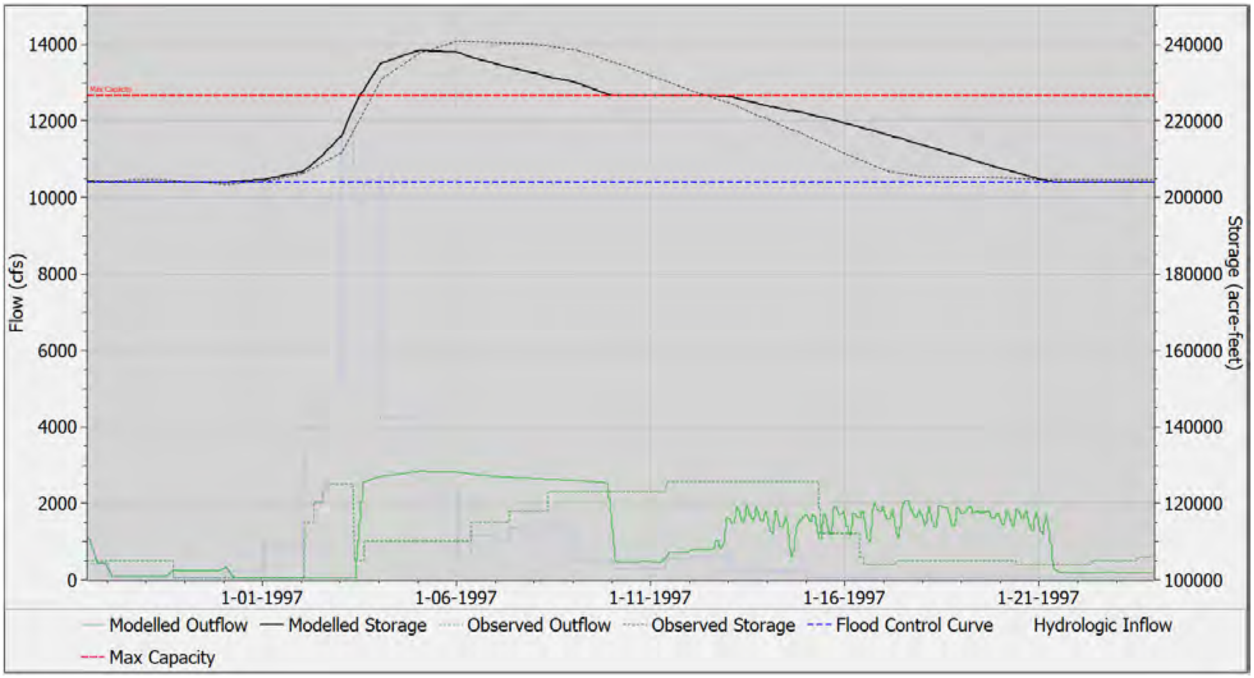

Figure 33. Reservoir Plot Stampede Reservoir during the 1997 Flood verification flood event.

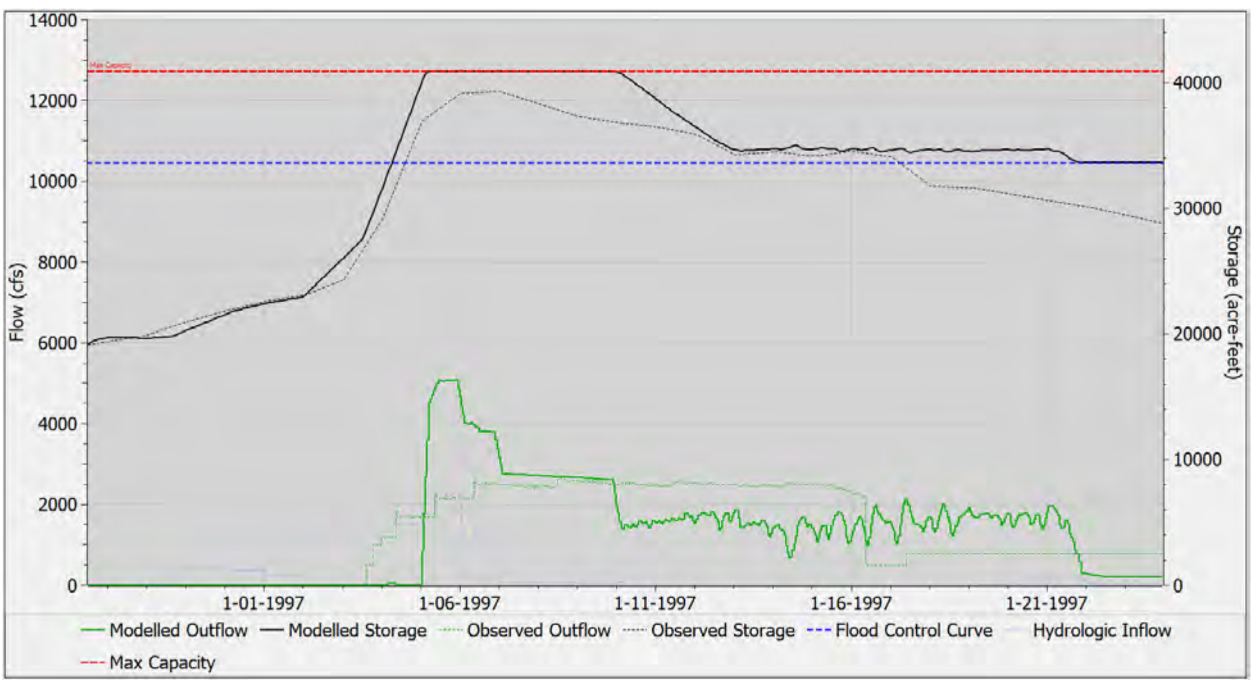

Figure 34. Reservoir Plot for Boca Reservoir during the 1997 Flood verification flood event.

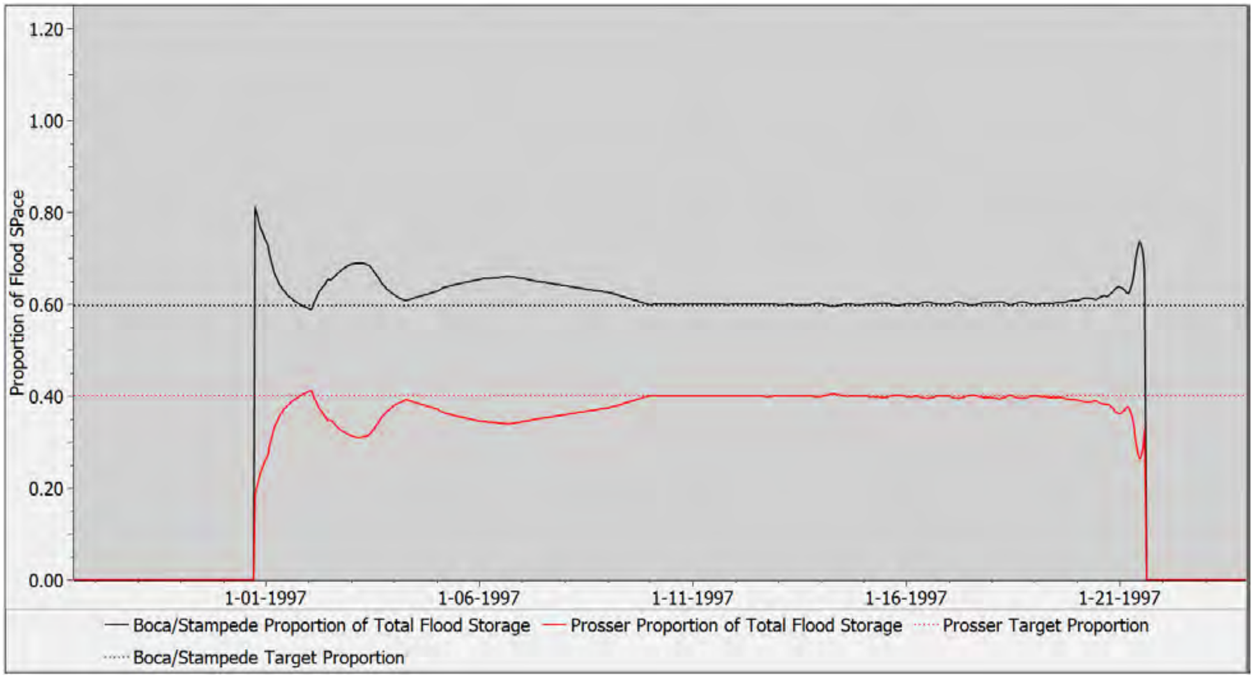

Figure 35. Flood Storage Proportions Plot for the 1997 Flood verification flood event.

Figure 35 shows the Flood Storage Proportions Plot for the 1997 Flood Event. Overall, the model performed well at maintaining flood storage proportions in accordance with the WCM and particularly well once the surcharge from the flood reservoirs was evacuated. The NSE for the modeled 1997 Flood event was calculated over the period of flood operations in the model, from December 30, 1996, at 8 pm to January 22, 1997, at 9 am. The NSE over this time frame was calculated to be 0.76, which is considered a "very good" NSE score (Moriasi et al, 2007). The PBIAS for the 1997 Flood was 0.86%, suggesting that modelled flows at the Reno Gage were only slightly higher than the historical flows.

3.1.3.2 January 2006 Flood

The sixth and final verification event, the January 2006 flood, occurred between December 30, 2005, and January 8, 2006, and the event had a Peak Regulated Flow (PRF) at the Reno Gage of roughly 16,175 cfs.

Figure 36 and Figure 37 show the Flood Flows Plot and Flood Storage Plot for this event, respectively. The modeled flows at the Reno Gage closely match the observed flows during the rising limb of the hydrograph, at the peak flows, and during the initial part of the falling limb of the hydrograph. Deviations begin to occur from what was observed once flows recess below 6,000 cfs at Reno. At this point, the model ramps up Prosser Creek Reservoir releases (limited to 1,000 cfs ramping limit per hour) to the reservoirs maximum outflow of around 1,800 cfs to evacuate its flood space. These releases do not violate the 6,000 cfs target at the Reno Gage. Observed Prosser Creek Reservoir releases show that the flood space from the reservoir was not evacuated immediately; rather, flood space from Prosser was not observed to be evacuated until roughly 3 days after the model began its evacuations. This is confirmed both in the Flood Storage Plot (Figure 37) and Reservoir Plot for Prosser Creek Reservoir (Figure 38). As depicted in these plots, encroachment in Prosser was evacuated much more quickly in the model than what was observed. Furthermore, Figure 37 shows that Stampede Reservoir was observed to have encroached into its flood space slightly, but this is not reflected in the model results showing that the model was more efficient at keeping the reservoir at its flood control capacity while not violating the 6,000 cfs target at the Reno Gage. The reason for the deviation on Stampede Reservoir storages is that Stampede Reservoir began releasing water down to Boca so as not to encroach in Stampede Reservoir while the observed data shows that Stampede was allowed to encroach slightly to keep Boca Reservoir's storage lower (see Figure 39 and Figure 40).

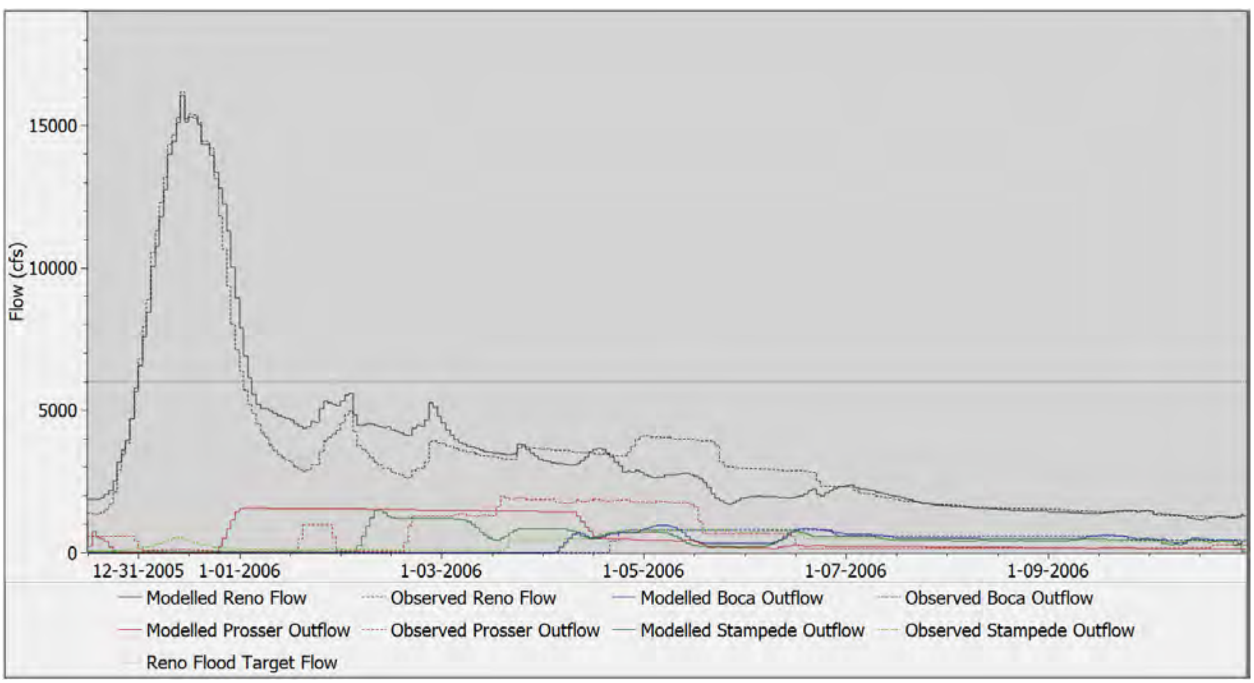

Figure 36. Flood Flows Plot for the January 2006 verification flood event.

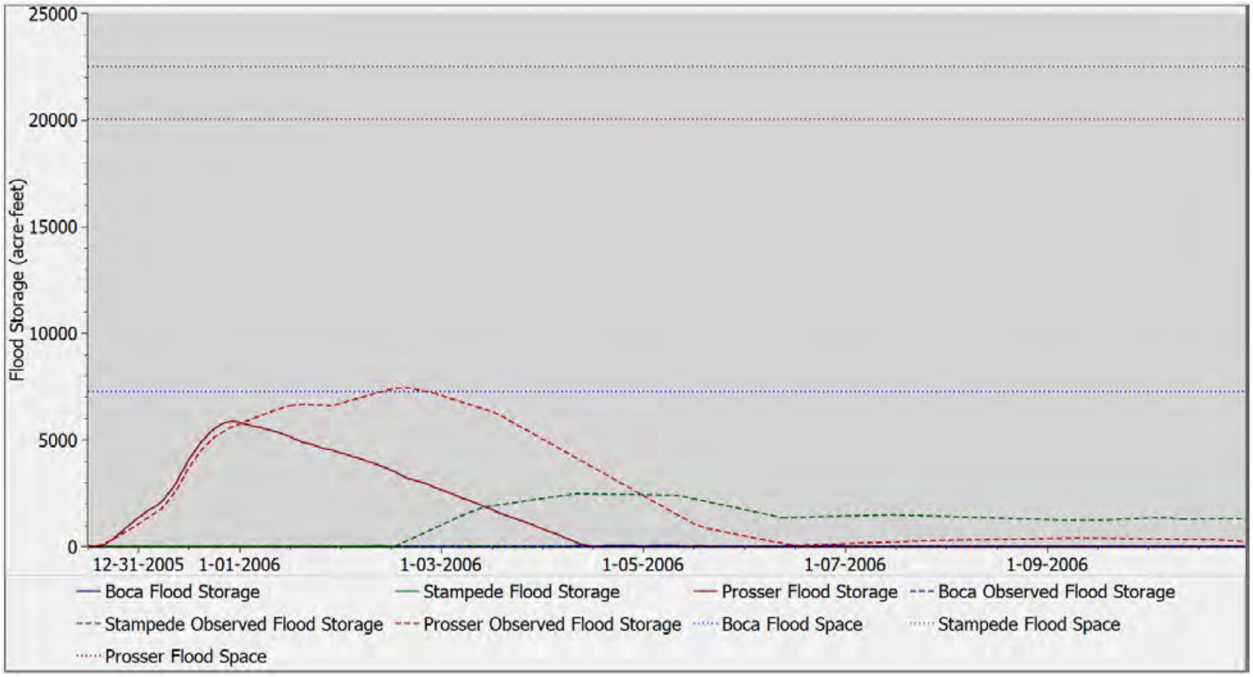

Figure 37. Flood Storage Plot for the January 2006 verification flood event.

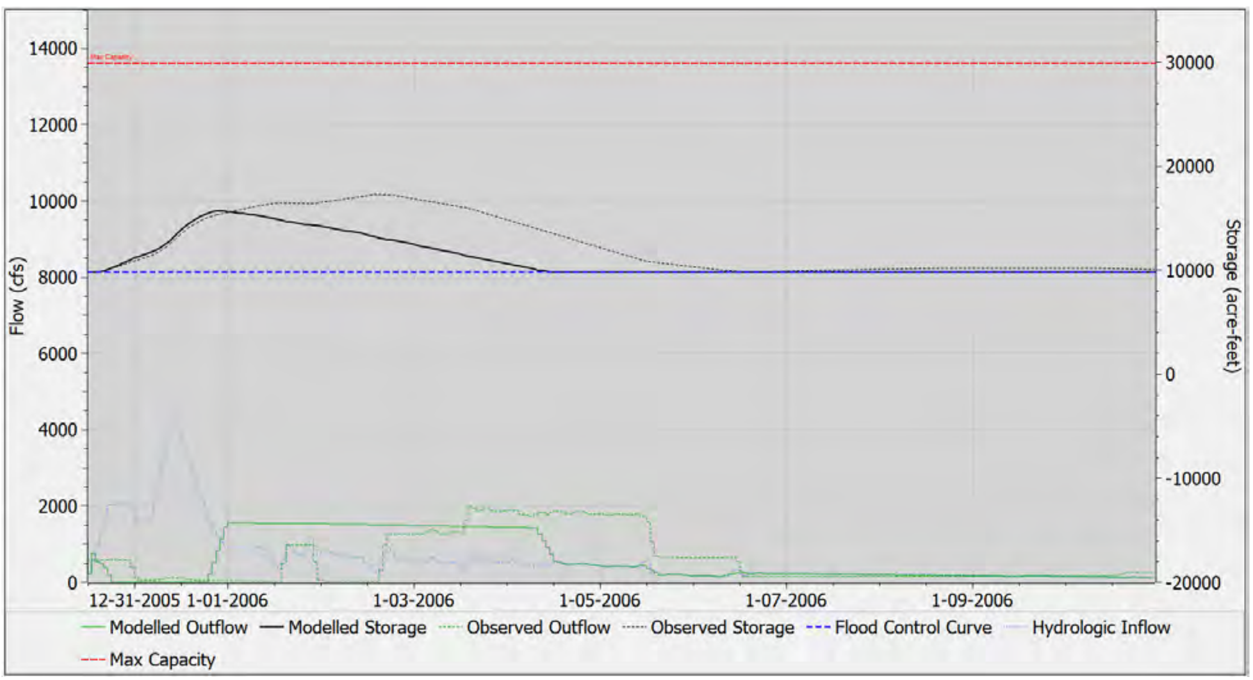

Figure 38. Reservoir Plot for Prosser Creek Reservoir during the January 2006 verification flood event.

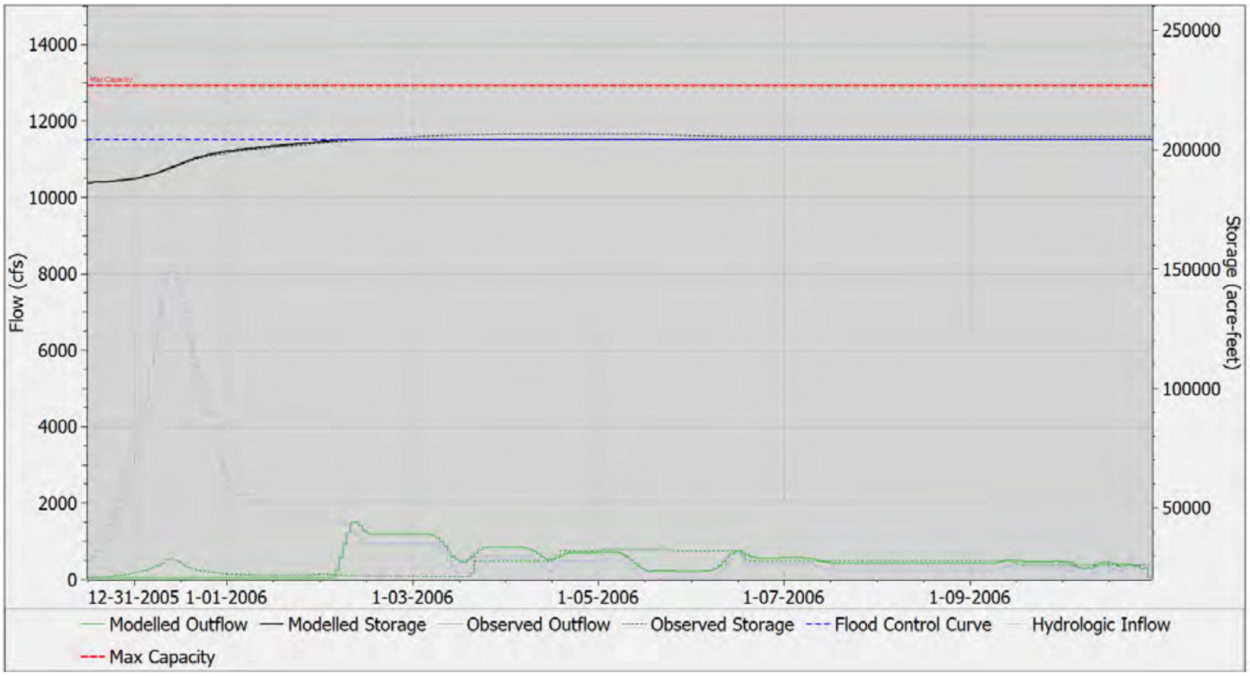

Figure 39. Reservoir Plot for Stampede Reservoir during the January 2006 verification flood event.

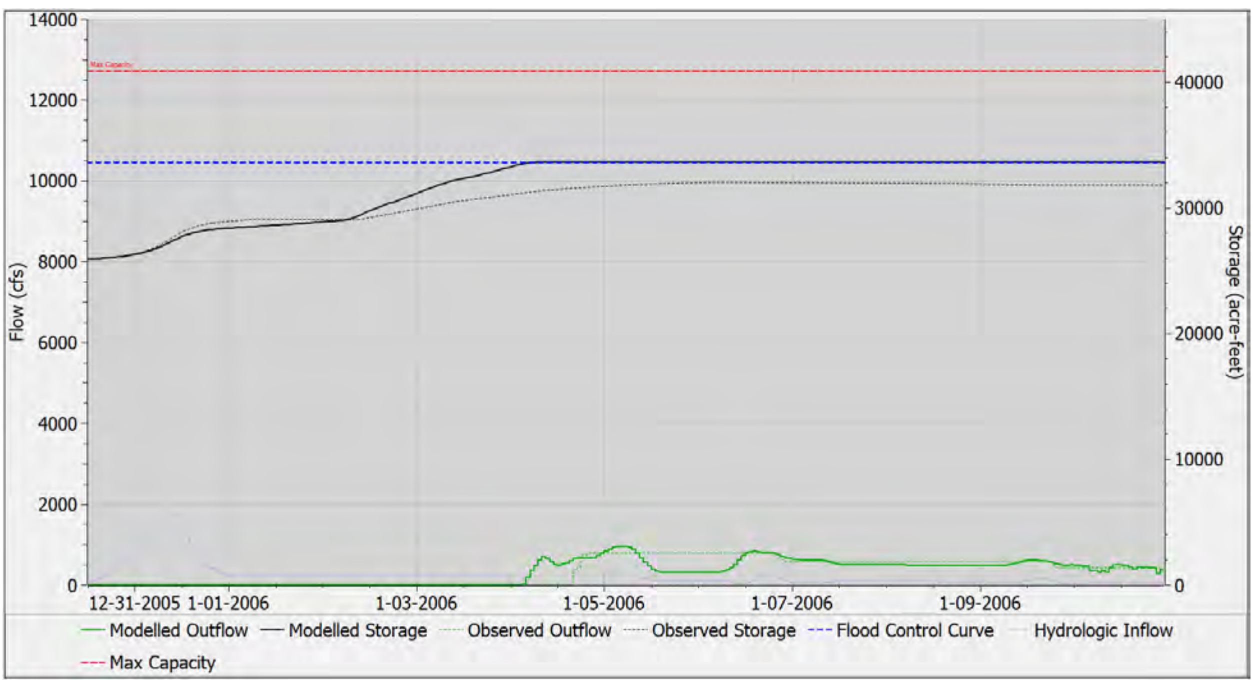

Figure 40. Reservoir Plot for Boca Reservoir during the January 2006 verification flood event.

The Flood Storage Proportions Plot is not included for this event because Prosser Creek Reservoir was the only reservoir to encroach. The NSE for this model was calculated over the period of flood operations in the model, from December 30th, 2005, at 1pm to

January 5, 2006, at 12am. The NSE over this time frame was calculated to be 0.94, which is considered a "very good" NSE score (Moriasi et al, 2007). The PBIAS was 9.11% suggesting a positive bias of modelled flow at the Reno Gage over the historical flows. Like other events, this bias is caused by the model's ability to evacuate flood storage more efficiently.

3.1.4 Summary of Model Performance

The *TR Hourly River Model* performed well at operating Active Flood Control Reservoirs to the regulation criteria set forth in the WCM when running the model in the Martis Creek Reservoir Non-Operational. Namely, the model showed adequate abilities to:

- Maintain Active Flood Control Reservoir storages at their required flood control capacities prior to events and after flood space was evacuated.
- Solve Active Flood Control Reservoir releases to reduce flows in the river at the Reno Gage to 6,000 cfs or reduce flows at the Reno Gage as much as possible.
- Store into designated flood space of Active Flood Control Reservoirs when the 6,000 cfs target at the Reno Gage was unable to be met.
- Maintain, when possible, proportional encroachment into flood space between Prosser Creek Reservoir and Little Truckee Reservoirs.
- Limit hourly release changes on Active Flood Control Reservoirs to 1,000 cfs or less.

While implementing this regulation criteria, the *TR Hourly River Model* was also able to replicate historical operations well. Table 6 provides a summary of each verification events NSE score for the Reno Gage, the events performance categorization (Moriasi et al, 2007), and the event's PBIAS. The NSE Score of all events met the criteria of "very good" other than the April 2018 flood event. The poor performance of this event was largely due to deviations historically from strict adherence to the WCM. The model results for the April 2018 event were in line with the regulation criteria set forth in the WCM.

Table 6. Table of NSE Scores and performance descriptions for each of the verification events.

Event	NSE Score	Performance Description	Percent Bias
April 2018	-4.41	Unsatisfactory	16.65%
March 1995	0.81	Very Good	11.15%
February to March 1986	0.88	Very Good	0.45%
February 2017	0.94	Very Good	0.01%
1997 Flood	0.76	Very Good	0.86%
January 2006	0.94	Very Good	9.11%

Three events had large positive biases of modelled Reno Gage flows over historical values: April 2018, March 1995, and January 2006. These deviations were not suggestive of the model not operating in accordance with the WCM. Rather, they were due to the model's ability to evacuate flood storage more efficiently than what was observed in history while maintaining flows at the Reno Gage at or below the 6,000 cfs target per the WCM. Table 7 shows, for each flood event, the number of hours earlier that flood space in the model was evacuated over what was observed. In all events except the 1997 Flood event, the model was more efficient at evacuating flood space. The 1997 Flood event was unique historically because operators at the time were able to obtain a variance to maintain flows at the Reno Gage higher than 6,000 cfs, and this is not reflected in the modelling.

Table 7. Table displaying, for each flood event, the number of hours earlier the model was able to evacuate flood space more efficiently than what was observed.

Event	Hours Flood Space Evacuated sooner in Model vs. Observed
April 2018	> 240
March 1995	96
February to March 1986 Peak 1	24
February to March 1986 Peak 2	40
February 2017	24
1997 Flood	-56
January 2006	> 100

3.2 MARTIS CREEK RESERVOIR OPERATIONAL VERIFICATION EVENTS

For the results within this section, the *TR Hourly River Model* was configured in its Martis Creek Reservoir Operational mode. In this mode, all Flood Control Reservoirs, inclusive of Martis Creek Reservoir, are modelled to adhere to the regulation criteria specified by the WCM (see Section **2.1 WCM Regulation Criteria Implemented in the TR Hourly River Model**). Because Martis Creek Reservoir flood operations in the WCM are both unique and largely independent from the other Flood Control Reservoirs, simulations for the other reservoirs are minimally impacted by Martis Creek Reservoir being operational or not. As a result, the verification in this section is limited to reservoir plots describing historical and modelled operations on Martis Creek Reservoir. Verification discussions of the two events will be limited to the periods of time when Martis Creek Reservoir is in flood operations per the WCM.

3.2.1 January 2006 Flood

Figure 41 and Figure 42 provide plots of observed and modelled results, respectively, for Martis Creek Reservoir during the January 2006 verification flood event. Observed flows at the Reno Gage were recorded above 14,00 cfs during the between 8am and 6pm on December 31st, 2005 (see Figure 41). Throughout this timeframe and until midday on January 1st, 2006, Martis Creek Reservoir was observed to maintain an outflow of approximately 75 cfs. Around midday on the 1st, Martis Creek Reservoir's outflow increased to its max release to begin evacuating flood space. Martis Creek Reservoir's outflows were reduced again around midnight on January 2nd and increased back to max release twelve hours later.

Modelled Martis Creek Reservoir results show slightly different operations (see Figure 42). In contrast to observed releases, modelled releases were 0 cfs throughout the duration of the time that Reno Gage flows were greater than 14,00 cfs. Furthermore, once Reno Gage flows recessed below 14,000 cfs, releases from Martis Creek Reservoir were limited in accordance with the WCM: outflows did not exceed inflows until Reno Gage flows recessed below 6,000 cfs. Overall, the model was able to evacuate flood space more efficiently in the January 2006 event than what was observed historically, and the model was able to operate more strictly to the regulation criteria prescribed by the WCM for Martis Creek Reservoir.

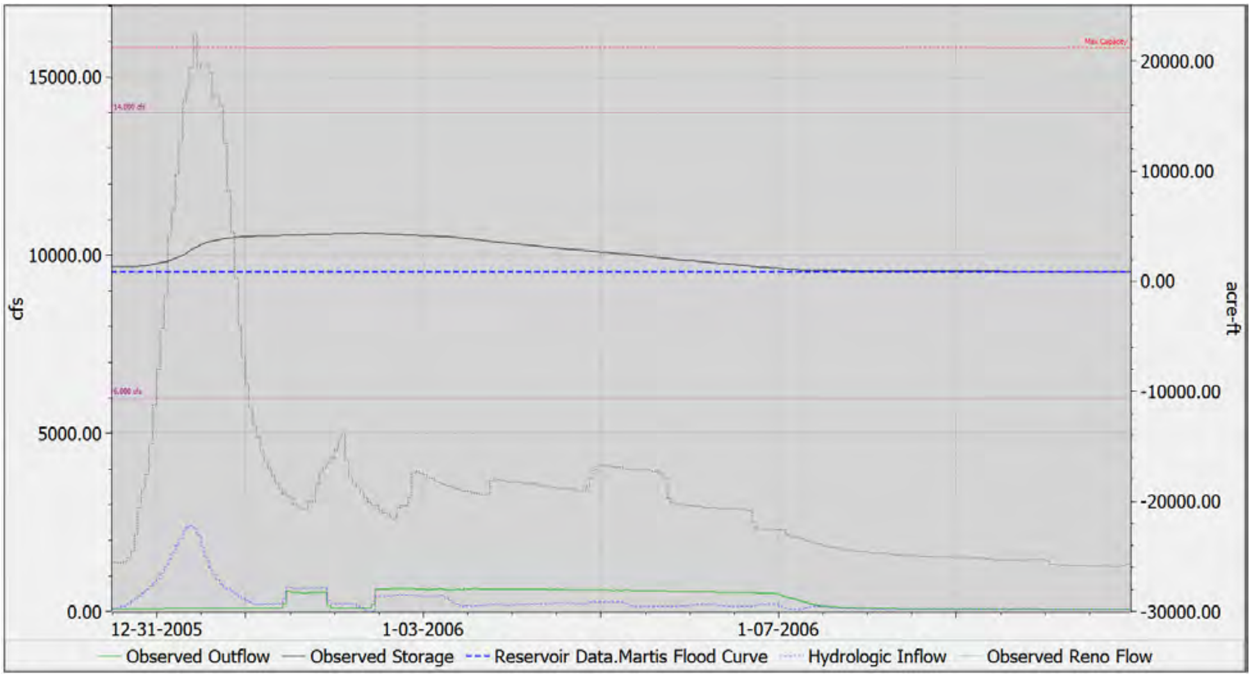

Figure 41: Observed Reno Gage flows and Observed Martis Creek Reservoir Storage, Outflow, Hydrologic Inflow and Flood Control Capacity January 2006 Flood Event.

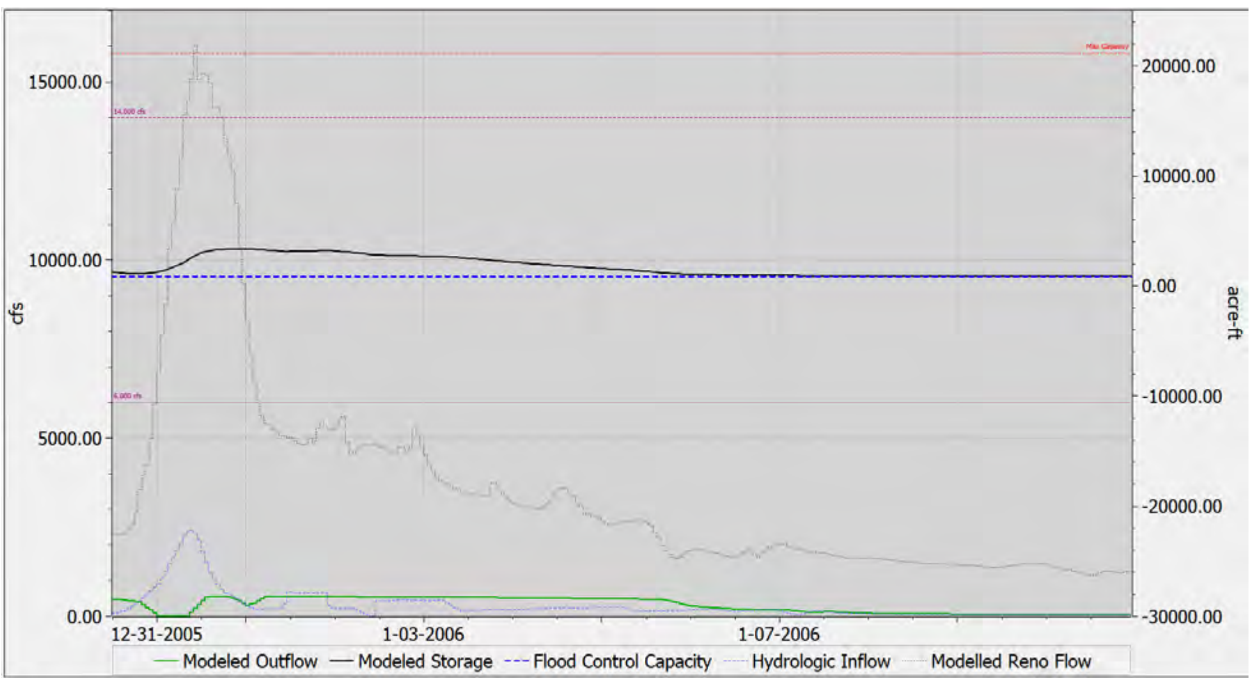

Figure 42: Modelled Reno Gage flows and Modelled Martis Creek Reservoir Storage, Outflow, Hydrologic Inflow and Flood Control Capacity for the January 2006 Flood Event.

3.2.2 1997 Flood

Figure 43 and Figure 44 provide plots of observed and modelled results, respectively, for Martis Creek Reservoir during the 1997 Flood event. Observed data shows that Martis Creek Reservoir outflows were not fully shutoff during the period that Reno Gage flows were above 14,000 cfs (from 3pm on January 1st, 1997, to 7pm January 2nd, 1997); rather, outflows during this timeframe were maintained between 100 and 350 cfs. In contrast, the model recorded outflows from Martis Creek Reservoir of 0 cfs during the timeframe that modelled Reno Gage flows were above 14,000 cfs, and this operation is more consistent with regulation criteria of the WCM than the observed operation.

After flows at the Reno Gage recessed below 14,000 cfs and during the period in which Martis Creek Reservoir has observed encroachment, observed outflows are maintained consistently between 100 and 350 cfs. Specifically, between January 10th and January 16th, Reno Gage flows were measured between 7,000 to 8,000 cfs, and outflows from Martis Creek Reservoir were measured to be greater than the reservoir inflows. In contrast, modelled results show Martis Creek Reservoir outflows rising to max release once Reno Gage flows recess below 14,000 cfs. Throughout the period that Reno Gage flows are greater than 6,000 cfs, Martis Creek Reservoir's modelled outflows are limited to its inflow or max release, whichever was smaller. During the timeframe when reservoirs are evacuating flood storage and Reno Gage flows are maintained around 6,000 cfs, Martis Creek Reservoir's outflow begins to fluctuate. These fluctuations are due to the model attempting to evacuate Martis' flood storage without causing flows to increase above the 6,000 cfs target at the Reno Gage, else Martis Creek Reservoir's outflows would be limited to the inflow per the WCM.

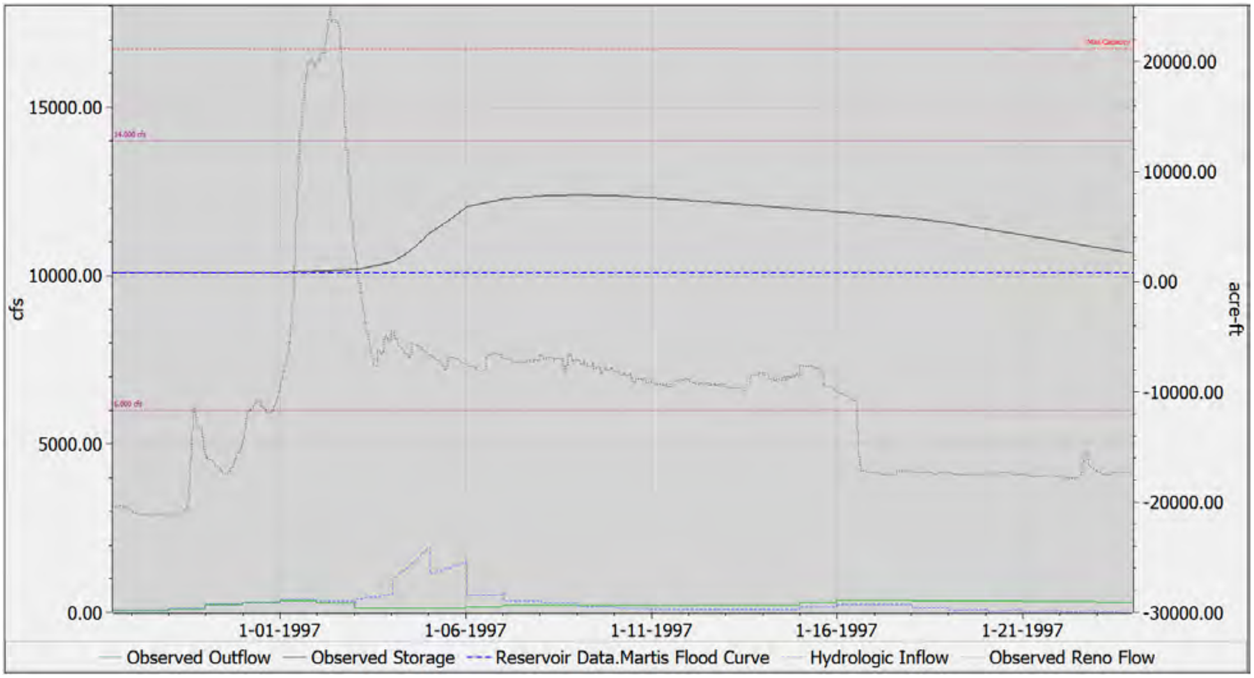

Figure 43: Observed Reno Gage flows and Observed Martis Creek Reservoir Storage, Outflow, Hydrologic Inflow and Flood Control Capacity 1997 Flood Event.

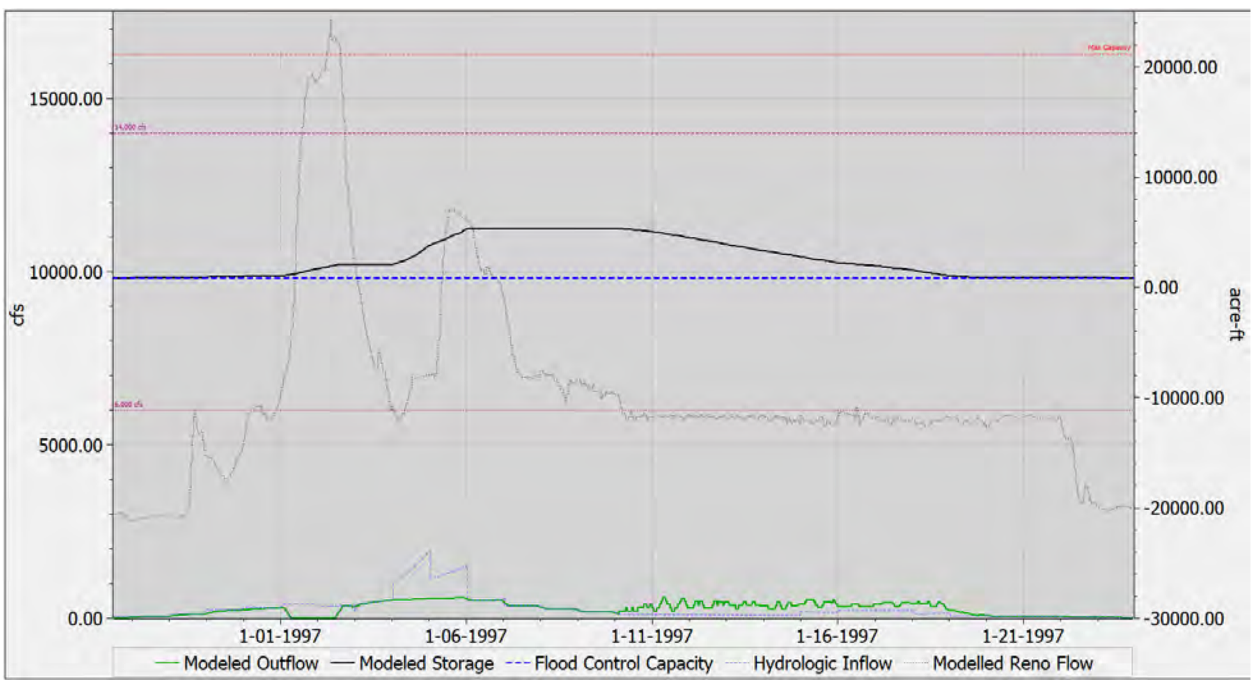

Figure 44: Modelled Reno Gage flows and Modelled Martis Creek Reservoir Storage, Outflow, Hydrologic Inflow and Flood Control Capacity for the 1997 Flood Event.

3.2.3 Summary of Model Performance

The *TR Hourly River Model* verified well at performing flood operations of Martis Creek Reservoir consistent with the regulation criteria of the WCM. Instances occurred where the model did not reproduce historical operations accurately because historical operations deviated from the WCM. In these cases, modelled operations followed more strictly the regulation criteria of the WCM. For more explanation of reasons why historical operations deviated from the WCM, refer to Section **2.3.4 Additional Notes on Evaluating Model Performance**.

4 CONCLUSION

This report shows that the *TR Hourly River Model* verified well at operating the system to the regulation criteria of the WCM. Furthermore, the model performed well at replicating historical operations when these operations were in line with the regulation criteria prescribed by the WCM adequately operate the system.

As a result, this modeling tool meets the requirements set forth in the HEAT, and it provides a crucial component for the analysis to determine updated flood space requirements in Truckee River Basin's WMOP Study.

APPENDIX 1: RESERVOIR CHARACTERISTICS TABLES IN THE TR HOURLY RIVER MODEL

The reservoirs within the *TR Hourly River Model* contain characteristic tables that define the physical properties of a given reservoir and its dam. Each of the reservoirs in the model contains an Elevation Volume Table that represents how much storage a reservoir contains at a given pool elevation. Dam characteristics for a reservoir's outlet works and spillway are represented in the following RiverWare tables:

- Max Release Table
- Regulated Spill Table
- Unregulated Spill Table

The *TR Hourly River Model* utilizes these three tables in different ways to model a reservoir's dam dependent on modelling needs for each reservoir. The following subsections provide a more detailed description of how the physical characteristics of each reservoir's dam was modeled and where the physical characteristic tables in the *TR Hourly Model* were sourced from.

Table 8 provides a summary of the tables utilized to model each reservoir's physical characteristics and the respective sources of these tables. The four sources listed in the table correspond to:

- *TROA Operations and Accounting RiverWare Model* – Operations model utilized and maintained by the Federal Water Master in Reno, Nevada.
- *Corps Water Management System (CWMS) for the Truckee River* – River model built and maintained by the U.S. Army Corps of Engineers (United States Army Corps of Engineers, 2020).
- *TSC* – The Bureau of Reclamation Technical Service Center.
- *Donner Rim Rating Report* – A Study that updated the rating for Donner Lake

Table 8. Summary table of characteristic tables for each reservoir in the TR Hourly River Model and their respective source.

	Elevation Volume Table	Max Release Table	Regulated Spill Table	Unregulated Spill Table
Stampede Reservoir	TROA Operations and Accounting Model	N/A	TSC	TSC
Boca Reservoir	TROA Operations and Accounting Model	USACE	USACE	N/A
Prosser Creek Reservoir	TROA Operations and Accounting Model	USACE*	N/A	USACE*
Martis Creek Reservoir	TROA Operations and Accounting Model	USACE	N/A	USACE*
Lake Tahoe	TROA Operations and Accounting Model	TROA Operations and Accounting Model	N/A	N/A
Donner Lake	TROA Operations and Accounting Model	Donner Rim Rating Report	N/A	N/A
Independence Lake	TROA Operations and Accounting Model	TROA Operations and Accounting Model	N/A	N/A

Table was extended from source to higher pool elevations using second degree polynomial fit *

4.1 Stampede Reservoir

Stampede Reservoir was modeled in the *TR Hourly River Model* utilizing an Elevation Volume Table, a Regulated Spill Table, and an Unregulated Spill Table. Stampede Reservoir's Elevation Volume Table is sourced in the *TROA Operations and Accounting RiverWare Model.* The Regulated Spill Table for Stampede Reservoir represents the total amount of controlled release that could be made from the reservoir given pool elevation. This table is sourced from the "Stampede Dam Outlet Works Rating Curve" developed by the Bureau of Reclamation's Technical Service Center (TSC) in 2019. The Unregulated Spill Table for Stampede Reservoir represents the amount of uncontrolled spill that would occur from the reservoir given pool elevation. This table is sourced from the "Stampede Dam Spillway Rating Curve" developed by TSC in 2019 (Bureau of Reclamation Technical Service Center, 2019) updating the capacity of the spillway after the construction that occurred in 2017 (Precision Water Resources Engineering, 2018).

4.2 Martis Creek Reservoir and Prosser Creek Reservoir

The physical characteristics for both Martis Creek Reservoir and Prosser Creek Reservoir and their respective dams are modeled in the *TR Hourly River Model* utilizing an Elevation Volume Table, a Max Release Table, and an Unregulated Spill Table. The Elevation Volume Tables for the reservoirs are sourced from the *TROA Operations and Accounting RiverWare Model.*

The Max Release Table for both Martis Creek Reservoir and Prosser Creek Reservoir in the *TR Hourly River Model* represent the maximum amount of release through the outlet works that can be made from the reservoir at a given pool elevation. These tables are sourced from Table 7.2b in the report *Corps Water Management System (CWMS): Final Report for the Truckee River Watershed*. The Unregulated Spill Table for each of these reservoirs represents the amount of unregulated spill that would occur from each reservoir given pool elevation. The source for these tables is Table 7.3 of the *Corps Water Management System (CWMS): Final Report for the Truckee River Watershed* (United States Army Corps of Engineers, 2020). Note, both the Max Release Table and the Unregulated Spill Tables for these reservoirs were extended to higher elevations than what is provided in the CWMS report to allow for modelling of larger scale non-historical flood events. These tables were extended using a second order polynomial fit.

4.3 Boca Reservoir

Boca Reservoir was modeled in the *TR Hourly River Model* utilizing an Elevation Volume Table and a Max Release Table. Boca Reservoir's Elevation Volume Table is sourced in the *TROA Operations and Accounting RiverWare Model.* Boca Reservoir's Max Release Table in the *TR Hourly River Model* indicates the maximum outflow the reservoir can maintain from both its outlet pipes and regulated radial gate spillway given the pool elevation. This table was derived by combining the Outlet Rating and Spillway Rating (Tables 7.2b and 7.3, respectively) in the report *Corps Water Management System (CWMS): Final Report for the Truckee River Watershed*.

4.4 Lake Tahoe, Independence Lake, and Donner Lake

The physical characteristics of Lake Tahoe, Independence Lake and Donner Lake and their respective dam are modeled similarly in the *TR Hourly River Model*. Each reservoir utilizes an Elevation/Volume Table and a Max Release Table. The Elevation/Volume Table for these reservoirs are sourced from the *TROA Operations and Accounting RiverWare Model*. The Max Release Table for these reservoirs indicates the maximum outflow a reservoir can maintain (inclusive of both spills, if applicable, and release from outlet works) given pool elevation. The Max Release Tables for Lake Tahoe and Independence Lake are sourced from the *TROA Operations and Accounting RiverWare Model*. The Max Release Table for Donner Lake was derived in the *Donner Rim Rating Report* (Gwynn, 2021).

Appendix 2: TR Hourly River Model Configuration for the WMOP Analysis

There are two main differences in the configuration of the *TR Hourly River Model* utilized in this verification effort to how the model is configured for the WMOP Study. This first difference is the initialization conditions for reservoirs. The *TR Hourly River Model* in the WMOP Study will be ran alongside the daily *TROA Planning Model*, and it will receive its initialization conditions from the *TROA Planning Model* which will propagate the water supply impacts of the proposed WCM scenario to the initial reservoir states prior to the flood events. The second difference is how Non-Flood Control Reservoirs and Martis Creek Reservoir are operated. For the WMOP Study, logic was introduced to the *TR Hourly River Model* to operate Non-Flood Control Reservoirs and Martis Creek Reservoir in accordance with how these reservoirs are operated in the *TROA Planning Model* ensuring consistency between the model assumptions for these reservoirs. For the WMOP Study, both the *TR Hourly River Model* and the *TROA Planning Model* operate Martis Creek Reservoir to evacuate flood storage as quickly as practicable and thus only provides incidental flood mitigation

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