TECHNICAL REPORT

ASSESSMENT OF POTENTIAL OF SHASTA DAM REOPERATION FOR FLOOD CONTROL AND WATER SUPPLY IMPROVEMENT

February 2004

Prepared By

MBK ENGINEERS
2450 Alhambra Boulevard, Second Floor
Sacramento, California 95817

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 BACKGROUND

The U.S. Bureau of Reclamation, Mid-Pacific Region (USBR) is conducting a feasibility investigation considering increasing the reliability of water supply to the CVP primarily focusing on enlarging Shasta Dam and Reservoir. As lead agency for implementing the study, USBR selected MWH Americas (MWH) to assist in preparing an initial element of the feasibility report.

The feasibility study is being conducted in four basic phases:

- **Mission Statement Phase** – Identify without-project future conditions, define resulting resources problems and opportunities, define a specific set of planning objectives, identify the constraints and criteria in addressing the planning objectives, and develop a mission statement based on the study objectives.
- **Initial Plans Phase –** Identify potential resources management measures to address the study objectives and formulate, coordinate, and compare an initial set of potential alternative plans.
- **Alternative Plans Phase –** From the initial plans, formulate specific alternative plans to address the planning objectives; evaluate, coordinate, and compare the plans; and identify a plan for tentative recommendation.
- **Recommended Plan Phase –** Complete development of a tentatively recommended plan and prepare, coordinate, and process supporting decision documentation.

On 30 September 2002, USBR awarded MWHN a firm-fixed-price task order for the "Enlarge Shasta Dam and Reservoir Investigation" (a.k.a. Shasta Lake Water Resources Investigation – SLWRI)" to prepare a Mission Statement Milestone Report (MSMR) satisfying the first phase above. The MSMR was provided to USBR in March 2003. On 18 July 2003, USBR awarded MWH a modification to the task order primarily to prepare an Initial Alternatives Information Report satisfying the second phase above. To date a series of potential water resources management measures have been identified with several selected for potential inclusion into alternative plans. Three of the measures included the reoperating Shasta Dam and Reservoir for increased water supply reliability and/or increased flood control. MBK Engineers (MBK) is tasked to assist in the current work effort by assessing the potential for these three measures.

1.2 PURPOSE AND SCOPE

The goal of this report is to detail the assessment of the potential to reoperate Shasta Dam primarily for increased flood control and/or water supply reliability. This includes assessing if modifying the water supply and/or flood control operation of Shasta, including use of updated or evolving technology such as advances in weather forecasting, enhanced basin runoff predictions, pre-releases, or other innovative reservoir operation possibilities have the potential to result in increasing the water supply yield and/or improve the discharge-frequency relationships from the project and are worthy of more detailed evaluation.

1.3 BASIN DESCRIPTION

The drainage area upstream of Shasta Dam is approximately 6,400 square miles. The McCloud and Pit Rivers are the principal conveyors of this drainage into Shasta Lake. There is an additional 2,500 square miles of drainage area contributing to the Sacramento River between the Dam and Bend Bridge downstream that affects the operation of Shasta Dam. This drainage area consists of the Clear Creek and Cottonwood Creek draining the eastern slopes of the Trinity and Coastal mountain ranges, respectively, and Cow, Battle, and Paynes Creeks draining the western slope of the Cascades. More detailed description of the basin geography can be found in the Shasta Dam and Lake Report on Reservoir Regulation for Flood Control (flood manual; USACE, 1977).

2. HYDROLOGY

2.1 PERTINENT FLOOD STUDIES

2.1.1 USACE Cottonwood Creek Study

As part of its Cottonwood Creek Feasibility Study (USACE, 1977b), USACE examined the hydrology of the Sacramento River above Bend Bridge. This examination included development of regulated frequency curves for both Shasta Dam and the Sacramento River at Bend Bridge. The hydrologic approach used in this report was to use three synthetic storm types covering three geographic areas where a storm could potentially be centered and affect the basin. The areas chosen were the above Shasta Dam, on the Cottonwood Creek watershed, and on the Cow Creek watershed. A historical review of the relative frequency of these storm centerings was performed, and a composite regulated frequency curve was developed based on the regulated flow resulting from each of the centerings weighted by the relative frequency of occurrence of each centering.

2.1.2 FEMA Studies

The Federal Emergency Management Agency (FEMA) has conducted flood insurance studies locally for Shasta County (FEMA, 1999), Tahama County (FEMA, 2003), the City of Red Bluff (FEMA, 1996), and the city of Redding (FEMA, 1998). The reports all used the hydrology developed by USACE for the Cottonwood Creek Hydrology report as a basis for Sacramento River flows. There are minor differences between the flow-frequency relationships portrayed in some of these reports and the Cottonwood Creek Hydrology report, but these reports essentially restate the findings of the Cottonwood Creek Hydrology report.

2.1.3 Sacramento and San Joaquin River Basins Comprehensive Study

The Sacramento and San Joaquin Basins Comprehensive Study (Comp Study USACE, 2002) has a substantial section on flood hydrology consisting of a review of historical flood events and the development of synthetic flood centerings. The review of the historical events consisted of assigning exceedence probabilities for 1-day, 3-day, 7-day, 15-day, and 30-day durations to the largest 19 historical flood events that have occurred throughout the Sacramento River basin. The historical storm information (referred to as the historical storm matrix) was quite useful in selecting representative storm events to use in this study. In the Comp Study, synthetic storms for the Shasta basin were developed based on interpretation of the historical storm matrices. A main stem centering for the Sacramento River at Latitude of Ord Ferry and a tributary-specific Shasta to Ord Ferry centering were developed as part of the Comp Study.

2.2 FLOOD-FREQUENCY RELATIONSHIPS

Both the Shasta Dam and Lake Report on Reservoir Regulation for Flood Control (USACE, 1977a) and the Cottonwood Creek Hydrology Report (USACE, 1977b) contain flood-frequency information for the Shasta basin. These include unregulated and regulated flow frequency curves for the Sacramento River at Shasta Dam (Keswick) and Bend Bridge. The Comp Study updated the unregulated flow-frequency curves at several durations with data through water year 1997. Figures 1 and 2 are the Shasta Dam and Bend Bridge flow-frequency curves from this work.

2.3 HISTORICAL FLOODING

Major floods in the Shasta Dam watershed have occurred in 1940, 1956, 1965, 1970, 1974, 1986, and 1997. Shasta has never had to release more than the immediate downstream objective of 79,000 cfs for any of these historical events. The Comp Study historical storm matrices (USACE, 2002) provide a useful summary of these and other historical events. The flood manual (USACE, 1977a) shows detailed plots of the 1956, 1965, 1970, and 1974 flood events.

2.4 DESIGN FLOOD DEVELOPMENT

Two storm centerings were selected for this study. The first centering (Shasta Dam centering) has the greatest impact on inflows to Shasta Dam and the potential for the reservoir to fill and spill. The second centering (Bend Bridge) has the greatest impact on flows from the unregulated drainage downstream from Shasta Dam.

2.4.1 Shasta Dam Centering

The Shasta Dam centering was based on the flood event of January 1970 (see Figure 3). This event featured a double peak, meaning that there was a significant but smaller flow event prior to the main flood wave. The first wave with a peak inflow to Shasta Dam of just over 100,000 cfs and was followed by a second wave coming about one week later with approximately 210,000 cfs as its peak flow rate. The annual exceedence probabilities for this event at various durations (USACE, 2002) can be seen in Table 1. This event was classified as the (above) Shasta Dam centering because the event was less frequent (larger magnitude) for the Sacramento River at Shasta Dam than for the Sacramento River at Bend Bridge, i.e., the storm had greater concentration in the watershed above the Dam than below. As can been seen in the table, this event was less frequent for the longer durations than the shorter ones. This is due to the double peak which contributed a significant amount to the durations longer than 3 days.

Table 1. Annual Exceedence Probabilities for 1970 Flood Event (above Shasta Dam centering) at Specified Location with Specified Duration.

Values are AEP: Chance of 1 in ___

Location	1-Day	3-Day	7-Day	15-Day	30-Day
Shasta Dam	38	41	45	82	44
Bend Bridge	23	32	38	63	33

2.4.2 Bend Bridge Centering

The Bend Bridge centering was based on the January 1974 flood event (see Figure 4). In contrast to the multiple peak inflow to Shasta Dam event used for the Shasta Dam centering, this event consisted of a single peak of approximately 215,000 cfs. The annual exceedence probabilities for this event at various durations (USACE, 2002) can be seen in Table 2. Since this event was a single peak that rose and fell within approximately 1 day, it shows flow-frequency behavior with duration that is different than the 1970 flood event. The frequency of the event for the Sacramento River at Shasta Dam and at Bend Bridge increase (decreasing relative magnitude) with increasing duration. As can also be seen in Table 2, the annual exceedence probabilities for this event were approximately the same at Shasta and Bend Bridge for all durations. The relative equal proportioning of the storm event above and below the Dam is why this event was characterized as the Bend Bridge centering., i.e., the event was equally distributed in the watershed above the Sacramento River at Bend Bridge.

Table 2. Annual Exceedence Probabilities for 1974 (Bend Bridge Centering) Flood Event at Specified Location with Specified Duration.

Values are AEP: Chance of 1 in ___

Location	1-Day	3-Day	7-Day	15-Day	30-Day
Shasta Dam	103	40	30	16	9
Bend Bridge	69	36	30	15	9

2.4.3 Flow Hydrograph Development

In order to obtain an event of specific AEP at Shasta Dam and Bend Bridge, the ordinates of the historical flood event were multiplied by a factor so that the volumes equaled that of the particular AEP for the critical duration. The critical durations were determined to be 7 days for the 1970 flood event and 3 days for the 1974 flood event.

Unregulated Bend Bridge hydrographs do not exist for the historical events, so they were calculated from the historical data by assuming a 12-hour travel time to Bend Bridge (USACE, 1977a), by subtracting the lagged Shasta outflow from the observed total flow at Bend Bridge, and adding the lagged unregulated flow at Shasta (inflow) to the local Bend Bridge flow.

This procedure allowed a range of events exhibiting the same characteristics as the 1970 and 1974 flood events but with varying magnitude to be constructed. The Shasta inflow and total local flow at Bend Bridge were then each multiplied by the proper ratio so that they represented the particular AEP values for the critical duration (3 days or 7 days) at a particular location (Shasta or Bend Bridge).

2.4.4 Historical Relative Frequency of Centerings

A review of the significant historical floods for which daily or more frequent Shasta inflow data was available was preformed to gain an understanding of the relative historical frequency of the two design flood events used in this study. Of particular concern was the key duration for the historical floods. Ten flood events (1951, 1956, 1958, 1965, 1970, 1974, 1983, 1986, 1995, and 1997) were examined. Three of these events (1958, 1970, and 1983) exhibited a significant pre-flood wave to the main flood wave, as is characterized by the 1970 flood based Shasta Dam Centering. The remaining seven events showed only the primary peak flood wave, as with the 1974 flood based Bend Bridge centering. The historical storm matrix in the Comp Study was also consulted to help determine the historical frequency of the two storm centerings. It showed that the above Shasta Dam centering has occurred more frequently. In considering all of the above, it was determined the equal weighting of each centering provided the best estimate of hydrologic conditions (centering and duration).

3. SHASTA DAM OPERATIONS

3.1 OPERATIONAL RULES

The operation of Shasta Dam's storage allocated for flood control is governed by the flood control manual (USACE, 1977a). This document describes the rules by which Shasta's flood space can be determined and managed during floods. The prescribed rules come in the form of a flood control diagram (FCD, Figures 5a-b) and emergency spillway release diagram (ESRD, Figure 6) which describe the Dam operation during typical and emergency flood situations, respectively.

The FCD specifies the amount of flood space required in Shasta Lake. The volume required is dependent on the time of the year and a rainflood parameter which is based on the accumulation of seasonal inflow. The FCD also provides guidance on how to evacuate the flood space once it begins to fill. The release schedule on the FCD shows the required release based on the percentage the flood space being used and the actual or forecast inflow. The FCD also states that releases will be made so that flows do not exceed the values of 79,000 cfs and 100,000 cfs in the Sacramento River below Keswick Dam and at Bend Bridge, respectively. The FCD contains the provision that releases are not allowed to be increased by more than 15,000 cfs or decreased by more than 4,000 cfs in any 2-hour period.

3.1.1 Rainflood Parameter

A rainflood parameter based on reservoir inflow allows the amount of regulated flood space to vary throughout the year. This parameter measures the antecedent wetness of the basin. The parameter is initialized on October 1 to be 100,000 cfs. On each subsequent day, the parameter is updated by adding the current day's inflow to 95% of the parameter value from the previous day. The parameter works with the FCD such that more flood space is required when the parameter value is higher. This is appropriate, since the risk of basin runoff is greater when the ground wetness is higher.

3.1.2 Downstream Targets

As described on the FCD, Shasta is required to operate so that flows in the Sacramento River below Keswick Dam do not exceed 79,000 cfs and flows in the Sacramento River at Bend Bridge gage do not exceed 100,000 cfs. Operationally, this means that Shasta operators must have knowledge of the downstream tributary flows in order to determine a release that is consistent with these flow targets. The obvious exception is when the Dam is at risk due to high storage/inflow combinations and greater releases are required. This situation is explicitly covered by the ESRD (Figure 6) which supercedes the FCD.

In comparison with the flow targets for other Central Valley reservoirs of similar size, the Bend Bridge flow target of 100,000 cfs is frequently exceeded. On average this flow is exceeded once every 4.5 years (USACE, 1977). The local tributary flow below Shasta alone has significantly exceeded 100,000 cfs several times since the Dam has been constructed. This flow target forces Shasta to release only minimal outflow for extended periods (several days) during flood operations, which is particularly restrictive and results in higher lake levels.

3.1.3 Rate of Release Change

The FCD mandates that releases not be increased by more the 15,000 cfs or decreased by more than 4,000 cfs in any 2-hour period. This means that it takes Shasta approximately 9 hours to get from its maximum power release of 15,000 cfs to its maximum flood control objective release of 79,000 cfs. On the other hand, it takes approximately 32 hours to reduce outflow to the maximum power release from the maximum flood control objective release. The latter is of particular concern when the tributary flow is increasing below the Dam and release reductions are made to maintain downstream flow criteria.

The limiting of the Shasta release decreases to a maximum of 4,000 cfs in 2 hours is quite restrictive and implies substantial knowledge of downstream tributary flows well in advance of their occurrence in order to operate Shasta optimally.

3.2 EXISTING CONDITIONS

The operation of Shasta under existing conditions refers to existing facilities (without Shasta Dam raise) and existing operational flood control rules. Several assumptions were made with respect to the representation of existing conditions. This section of the report contains an account of these assumptions and a generalized description and verification of the model used for the analysis performed for this study.

3.2.1 Assumptions

Several operational assumptions were necessary to compute the results contained in this report. These assumptions pertain to travel times of water flowing in the Sacramento River, Shasta inflow and downstream tributary flow forecast lead-time and uncertainty, and the initial starting storage available in Shasta prior to the start of the flood event.

Travel Time

According to the Corps, the travel time for water in the Sacramento River between Shasta Dam and Bend Bridge is 12 hours (USACE, 1977a). This lag time was used to combine the released water from Shasta and the unregulated tributary flow coming into the Sacramento River between Shasta Dam and Bend Bridge.

Flow Forecasting

Although the uncertainty in Bend Bridge local inflow forecasts has not been explicitly quantified by the California-Nevada River Forecast Center (CNRFC), the USBR operators indicated that a Bend Bridge flow target below the regulatory mark of 100,000 cfs is used operationally to account for uncertainty in the forecasts. The range given by the operators is consistent with 30% uncertainty in these forecasts, i.e., they use a surrogate Bend Bridge flow target approximately 30% less than the official 100,000 cfs target. As such, this was used as the forecast uncertainty in the existing reservoir operation which was needed to make release decisions at Shasta Dam with respect to the downstream flow targets. The forecast was constructed by adding the Shasta outflow to 130% (actual future flow + 30% for forecast uncertainty) of the local tributary flow at Bend Bridge 12 hours (lag time) from the time of analysis. Therefore, the implicit assumption was made that the Bend Bridge local flow forecasts would be available at least 12 hours ahead of time. This uncertainty assumption causes a reduction in outflows from the dam to account for the uncertainty in the forecast.

The forecast uncertainty in the Shasta inflow forecast was incorporated by assuming a forecast accurate enough to be used operationally would be available with a 24-hour lead time. Although flow forecasts are made by the CNRFC as far ahead of time as 5 days, it was determined that the operators base their decisions on forecasts occurring on the shorter 24 hour time horizon. This 24-hour lead time was applied to determine the inflow forecast that was used in the interpretation of the release schedule on the FCD which calls for releases depending on the actual or forecast inflow.

Incidental Flood Storage

Since major floods can occur as early in the season as December and the typical Shasta carryover at the end of the irrigation season is well below the bottom of the flood pool, there is a chance that incidental flood storage space might be available during a flood event. As such, the potential for incidental flood storage was characterized as part of this study.

In order to include incidental flood storage, the amount of flood storage historically available prior to large floods needed to be determined. Ordinarily, this could have been done by simply reviewing the historical floods in the basin and tabulating the starting storage in Shasta prior to each flood event. However, because studying an enlarged Shasta, for which no historical data exists, was within the scope of this study and consistency between the existing and enlarged reservoir studies was crucial, it was necessary to rely upon model results of the starting storage for the existing condition.

For this purpose, this study relied upon a CALSIM analysis of the existing Sacramento/San Joaquin River system and analyses of both of the Shasta raises, both provided by MWH. The CALSIM model operates on a monthly basis, so only end-of-month storages were available. In order to estimate the storage prior to each of the historical flood events that was consistent with the modeled storages, the change in observed storage between the end of the month prior to and the day before each historical flood event was added to the modeled storage for the end of the month prior to the flood event. This created an estimate of the modeled storage for the day prior to each flood event. The model also produced top-of-conservation storages at the end of each month. These values were assumed to be the same on the day prior to each flood event as they were at the end of the previous month.

The subtraction of the estimated starting storage from the top-of-conservation storage yielded a volume of incidental flood storage available for each of the historic events. Since the CALSIM model only ran through water year 1994, the incidental flood storage for the 1995, 1997, and 1998 flood events was computed solely from historical data. In all, the incidental flood storage available was calculated for 16 historical events. Table 3 details these calculations.

As can be seen in Table 3, no incidental flood space was available for the majority of the historical flood events. This fact, coupled with the assumptions that runoff values as significant as those studied for this report would likely come during times when the basin was particularly wet (maximum FCD rainflood parameter) and would likely occur during the peak storm season between December and March (maximum flood space requirements) meant that the starting Shasta storage assumed for this study was 3.252 million acre-feet (bottom of flood pool under previously mentioned assumed conditions).

3.2.2 Operations Model and Calibration

The model used to perform the reservoir operation portion of the analyses in this report was a custom application designed using the C programming language. The model operates Shasta on an hourly time step and explicitly incorporates all the flood control rules specified in the FCD and the ESRD. The model relied upon the operational assumptions provided in the previous section of this report.

In order to ensure the program functioned properly, the actual operation of the 1996/1997 New Year’s flood event was compared with a modeled operation of the same event. Figure 7 compares the two operations. The model closely reflects the flood operation of Shasta for this event. The minor discrepancies between the modeled and actual operations can mainly be attributed to the differences in the forecast information used. The model uses a forecast simulated from the actual data, while the operators of Shasta in 1997 had actual real-time forecasts from the CNRFC. This different forecast information available to the real-time operators and the computer model leads to slightly different release decisions.

3.2.3 Methodology and Results

The operations model was run for the two storm centerings for each of the following AEP: 1-in-10, 1-in -50, 1-in -100, 1-in -150, 1-in -200, and 1-in-500. For each AEP the results of the two centerings were weighted as previously described (50% for the Shasta Dam centering and 50% for the Bend Bridge centering). Tables 4 and 5 (see rows labeled "Existing") show the resulting regulated peak flows in the Sacramento River below Keswick and at Bend Bridge for the existing conditions. The shaded entries in Table 4 represent conditions when the objective release of 79,000 cfs in the Sacramento River below Keswick Dam was exceeded. In Table 5, the parenthetical values indicate the unregulated peak hourly tributary flow at Bend Bridge. The shaded values in this table indicate conditions for which a Shasta Dam release in excess of the minimum 15,000 cfs power release contributed to the peak Sacramento River at Bend Bridge flow. The results generally indicate that the peak flows in the Sacramento River at Bend Bridge are a combination of a relatively low Shasta release and a high combined unregulated tributary (Cottonwood Creek, Battle Creek , Cow Creek, etc…) flow contribution. The potential combination of peak Shasta releases and peak tributary flows to produce large flows in the Sacramento River below Bend Bridge is not generally an issue, because the arrival of peak tributary flow can be adequately predicted, and Shasta has enough flood storage to maintain the minimum flood release for relatively long periods of time (many days to weeks).

3.3 ENLARGED SHASTA

The potential flood control benefit of enlarging Shasta Dam is due to the potential for increased incidental flood storage. The incidental flood storage for the 6.5 foot and 18 foot raised Shasta configurations for historical flood events can be seen in Table 3. The analysis to compute these tabular values relied upon CALSIM modeling of the raised Shasta provided by MWH. As the table shows, the raised Shasta provides significant additional incidental flood space in years with low carryover storage in Shasta (i.e., years after a drought period). The results show that raising Shasta would have added significant incidental flood storage (greater than 200,000 acre-feet) in 3 of the 13 years for which the model data was available and significant floods occurred.

4. POTENTIAL IMPROVEMENTS TO FLOOD CONTROL

As part of this study, potential operational changes and their ability to improve the flood control provided by Shasta Dam and Lake were examined. Other potential system modifications such as changing the flood control rules and total flood space were also appraised. This section details the methodology and results of these approaches.

4.1 POTENTIAL OPERATION CHANGES

As part of this work, the potential operational changes from improving Shasta Lake inflow and downstream tributary flow forecasts and operating with forecast-based drawdown were examined.

4.1.1 Improved Forecasting

Having improved forecasts would allow the Shasta operators to become more efficient in the operation of the water in Shasta Lake. Less forecast uncertainty means they could make larger releases (downstream tributary forecast improvement) and make them sooner (Shasta inflow forecast improvement). These forecast improvement elements have been analyzed individually for this study.

Reservoir Inflow Forecasts

It was assumed in the existing operation of Shasta Dam the operators rely upon inflow forecast data available 24 hours ahead of time in making release decisions. It was also assumed that this information was used in interpreting the release schedule of the FCD. If Shasta inflow forecasts were to become more accurate, the operators could presumably make operational decisions further ahead of time than they currently do without sacrificing operational performance. The operational effect of having improved Shasta inflow forecasts was examined by assuming forecasts with 48-hour and 72-hour lead times were able to be used in the interpretation of the FCD's release schedule.

Tables 4 and 5 (see rows labeled "48 hour inflow forecast lead time (Shasta)" and "72 hour inflow forecast lead time (Shasta)") display the results of the improved inflow forecasting at Shasta. As these results show, there is little flood operation benefit to gain in improving Shasta inflow forecasts. This is mainly due to the fact that the local tributary flow dominates the peak flow in the Sacramento River at Bend Bridge. Improved forecastibility, while it may allow for additional early releases, does not reduce the peak release nor peak downstream flow.

Downstream Tributary Forecasts

Recall that 30% forecast uncertainty was used in the existing conditions operation of Shasta. In order to evaluate the effect that improved tributary forecasting would have on the operation of Shasta and points downstream, the operational model was run using 20%, 10%, and 0% (perfect forecast) uncertainty in the tributary forecasts. The reduced uncertainty, as related to the existing condition, allows Shasta to operate more closely to the Bend Bridge 100,000 cfs flow target and release more water than it would otherwise be able to.

Tables 4 and 5 (see rows labeled "20% forecast uncertainty (Bend Bridge)", "10% forecast uncertainty (Bend Bridge)", and "0% forecast uncertainty (Bend Bridge)") display the results of the improved tributary flow forecasting. These results show that improving downstream tributary flow forecasts is more valuable than improving Shasta inflow forecasts for these large flood events. The most appreciable benefits of improved downstream forecasting are obtained for events more severe than the 1-in-100 AEP event. For example, perfect downstream forecasting is estimated to lower the peak Sacramento River at Bend Bridge flow for the 1-in-150 AEP event from approximately 238,000 cfs (under existing 30% forecast uncertainty) to 195,000 cfs, an 18% reduction in peak flow.

4.1.2 Forecast-Based Drawdown

As the name implies, forecast-based drawdown involves releasing water from Shasta based on a forecast. This operation would be performed to increase the flood protection provided by the reservoir. For this study, it was assumed that this action would be triggered when an inflow exceeding 200,000 cfs was forecast within a 72-hour forecast window. The amount of conservation space used for this operation was limited to 100,000 acre-feet. This limit was imposed to reduce the risk associated with releasing conservation space water based on an inflow forecast that may not be fully realized. If forecast-based drawdown was implemented at Shasta, it is suggested that this limit be reexamined and based on a comprehensive risk analysis weighing the benefit to flood control and the risk to water supply of releasing this water in advance of a forecast event.

Tables 4 and 5 (see rows labeled “FBO”) display the results of using this forecast-based drawdown approach. The relatively large amount of existing flood space in Shasta and the restrictiveness of the Bend Bridge flow target limit the effectiveness of this operation. No peak flow reduction is realized for events of smaller magnitude than 1-in-200 AEP event at Keswick or Bend Bridge. The 1-in-200 AEP event results in a 5,000 cfs peak flow reduction at Keswick and no reduction in the peak at Bend Bridge, and the 1-in-500 AEP event results in a 17,000 cfs peak flow reduction at Keswick and a 10,000 cfs reduction in the peak flow at Bend Bridge.

Despite its apparent limitations in enhancing flood protection, this operational strategy should not necessarily be overlooked. It has no construction cost and may be used in parallel with regulated encroachment of the flood space to create a dual water supply/flood control benefit. This strategy may be most effective during the spring refill period.

4.2 OTHER POTENTIAL SYSTEM MODIFICATIONS

4.2.1 Changes in Operation Rules

During the course of this study, a few of the Shasta operational flood control rules presented themselves as particularly restraining to the flood control operation of Shasta Dam. These are rules which upon revision could enhance Shasta’s flexibility to operate during a flood.

<u>Shasta Dam Outflow Rate of Change</u>

The first of these is the rate of change criterion for decreasing the release from Shasta Dam. This criterion, specified in the FCD, allows Shasta to decrease its release by only 4,000 cfs over any 2-hour period during a flood operation. This is particularly constraining since the combined downstream tributary flow often increases at a rate that exceeds 4,000 cfs per 2 hours. When this happens, Shasta is not able to reduce its outflow fast enough, and the 100,000 cfs flow target at Bend Bridge can be exceeded. The reason for the necessity of this restrictive rate of change is unknown. It is suggested the restrictive rate of decrease in release criterion be examined. Tables 4 and 5 (see rows labeled “10 kcfs/hr rate of change”) display the results of increasing the rate of decreasing outflows to 10,000 cfs per hour. The increased rate of change of outflow results in slightly lower peak flow at Bend Bridge for the 1-in-10 AEP event due to the increased ability to cut Shasta releases as downstream tributary flow is on the rise. However, this same ability to cut the reservoir outflow becomes a liability for larger flood events. Shasta storage space fills faster due to the faster release cuts, and peak flows of up to 10,000 cfs over the existing condition operation are realized for the 1-in-150 and 1-in-200 AEP events at Keswick and Bend Bridge. An operational strategy that cuts releases at the increased 10,000 cfs/hr rate when operating for events predicted to be in the 1-in-10 AEP range and limits reducing the Shasta release for larger predicted events would likely prove to be beneficial (or no worse than the existing operation).

Bend Bridge Flow Targets

The second rule which warrants review is the flow target at Bend Bridge of 100,000 cfs. This target restricts Shasta’s operation during any flood of even moderate magnitude. Review of the regulated flow-frequency curve at Bend Bridge reveals that 100,000 has an AEP of approximately 1 in 4.5. This exceedence frequency is quite high when compared with the downstream flow targets for other Central Valley flood control reservoirs. The appropriateness of this flow target should be examined by estimating the amount of property damage expected to occur when the 100,000 cfs target is exceeded. Since, the flow target is frequently exceeded, a review of past events where the target was exceeded could also reveal the relative amount of damage done. Operationally, Shasta could provide additional flood protection if a higher flow target was acceptable, since it could make increased releases throughout a flood operation. This is evident in Tables 4 and 5 (see rows labeled “125 kcfs Bend Bridge Target” and “150 kcfs Bend Bridge Target”) which display the effect of an increase in target flow.

As these tables show, the peak flow at Bend Bridge is increased over existing conditions for the 1-in-100 AEP event. This is due to operating for the increased downstream flow target. However, for events greater than the 1-in-100 AEP event, there is a significant reduction in the peak flow at Bend Bridge. As an example, operating for a Bend Bridge flow target of 125,000 cfs allowed for a reduction in peak Bend Bridge flow of 42,000 cfs and 81,000 cfs for the 1-in-150 and 1-in-200 AEP events, respectively. Figure 8 shows the effect of the operation using the increased 125,000 cfs Bend Bridge Flow Target for the 1-in-200 AEP event centered at Shasta Dam. This example shows the effect of the increased flow target on the resulting peak downstream flows can be quite dramatic. On the contrary, there was no reduction in peak Sacramento River flow at Bend Bridge for the 1-in-200 AEP event with the Bend Bridge centering.

Operating for a 150,000 cfs Bend Bridge target actually faired slightly worse than with the 125,000 cfs target due to the restrictive rate of release change on Shasta which doesn’t allow Shasta sufficient time to reduce its higher releases while downstream unregulated flows are on the rise. For the 1-in-150 and 1-in-200 AEP events, peak Bend Bridge flow reductions of 39,000 cfs and 71,000 cfs were estimated with this target. This seems to suggest that only the 125,000 cfs flow target at Bend Bridge need be adopted, unless the rate of release change at Shasta Dam was also increased to accommodate the additional time need to reduce the reservoir release with the higher flow target.

4.2.2 Changes in Total Flood Space

This study has not demonstrated the need for additional flood space at Shasta Dam.

5. POTENTIAL IMPROVEMENTS ON WATER SUPPLY YIELD

Opportunities to enhance the water supply for Shasta by changing the flood control diagram parameters were examined. Two aspects were considered. The first aspect studied was aimed at increasing the reservoir's water supply yield by changing the way the rainflood parameter on the FCD is computed. The other aspect involved altering part of the release schedule of the FCD to prolong minimal encroachment of the flood space.

5.1 RAINFLOOD PARAMETER MODIFICATION

The maximum potential of a rainflood parameter modification was assessed by looking at the relative frequency that water supply spilled in the winter and was not later replaced with spring refill. The CALSIM model was used to evaluate this effect. An evaluation of the data shows that Shasta spilled in January through March without spilling after March in 18 out of 73 (25%) years studied. Adjusting the rainflood parameter could potentially help in these years.

The relative frequency of this effect is not changed with either of the enlarged Shasta alternatives studied in this report. Model results incorporating the 6.5-ft and 18-ft raise showed this effect is 17 and 18, respectively, of the 73 years studied. So, the benefit of possible changes to the rainflood parameter would also apply, if Shasta Dam was raised.

5.2 RELEASE SCHEDULE MODIFICATION

This option involves changing the required release for the low flood space encroachment and low flood forecast condition (region from 0% to 25% encroachment and from 0 cfs to 40,000 cfs actual or forecast inflow) of the release schedule on the FCD from "maximum power release" to "minimum flood release". This means that the maximum power release of 15,000 cfs would not have to be maintained under these conditions, but a lesser release requirement would be established. The quantification of this change is beyond the scope of the current long-term water supply modeling tools, such as CALSIM. A daily time step model with a water supply representation akin to CALSIM which incorporated all the details of the Shasta FCD would be required for this analysis. An analysis of recent historical data could be performed to get a basic understanding of the effects of making this release schedule change. The new "minimum flood release" would be incorporated with forecast-based operation triggers that would enhance both reservoir operations.

6. RECOMMENDATIONS / FUTURE STUDIES

In considering recommendations and future studies, it should be noted that none of the flood control scenarios studied in this report produced benefits for the more frequent flood events below Keswick (1-in-10 or 1-in-50 AEP). Similarly, the results at Bend Bridge show little or no improvement for the 1-in-10, 1-in-50, or 1-in-100 AEP events. This is mainly due to the relatively large flood storage reservation at Shasta which allows most floods up to the 1-in-100 AEP magnitude to be controlled under existing conditions and the large unregulated flow at Bend Bridge which controls (contribution of Shasta outflow to the peak at Bend Bridge is minimal) the peak Sacramento River flow at Bend Bridge flow. In total, this indicates that flood control benefits are not likely to occur frequently, regardless of the action taken; perhaps only once or twice over the planning horizon. However, this does not mean there are not beneficial flood control and water supply measures that have been identified through this study.

In order to provide guidance as to which of the flood control and water supply measures studied in this report was potentially most beneficial, Table 6 categorizing the potential flood control and water supply benefits of each of the studied elements as “low”, “medium”, or “high” was developed. “Low” was used to describe an element that provided little to no benefit. It is not recommended that the elements marked with “low” potential be pursued. “Medium” was used to describe an element of moderate potential that should be pursued at a minimal cost. “High” was used to represent the most promising options. Pursuing these options is highly recommended. If a combination of elements significantly enhanced the potential benefit, this was identified with a footnote in the table.

Table 6. Potential Flood Control and Water Supply Benefits of Studied Elements

Option	Potential Flood Control Benefit	Potential Water Supply Benefit
Improved Shasta Inflow Forecasts	Low (1)	Low
Improved Tributary Inflow Forecasts	Medium (1)	Low
FBO	Low (1)	Medium
Shasta Outflow Rate of Change	Low (1)	Low
Bend Bridge Target Flow	High	Low
Rainflood Parameter Modification	Low	High
Release Schedule Modification	Low	Medium
Enlarged Shasta Incidental Flood Space	Medium	---

(1) Option’s benefit becomes “high” when coupled with Bend Bridge flow target increase

Based on the results of this study, there are three items that merit further evaluation. The first item that requires investigation is the Sacramento River at Bend Bridge 100,000 cfs flow target. This target is very small compared to those of other similar basins and is frequently exceeded by unregulated tributary flow alone. The amount of damage attributable to Sacramento River at Bend Bridge flow of 100,000 cfs should be investigated. The second item requiring attention is forecast-based drawdown. Although for this report it was just studied as a flood control enhancement, the increased release ability could also be used to allow encroachment of the flood space when forecasts suggested little imminent flood risk. This comprehensive package is quite attractive because dual water supply and flood control benefits can be derived from it. The third item warranting further study is the rainflood parameter on the FCD. It is recommended that a new methodology be conceived to reduce the frequent spill and subsequent lack of refill witnessed under the current parameter.

6.1 BEND BRIDGE FLOW TARGET

It is recommended that the appropriateness of the Sacramento River at Bend Bridge flow target of 100,000 cfs be assessed. In comparison to other flow targets on similar systems, the Bend Bridge target seems excessively low. On average, it has been exceeded every 4.5 years. As the study results show, the ability to raise the flow target significantly contributes to reducing the peak release for events in the 1-in-100 to 1-in-200 AEP range. If the investigation of this target shows that there is little reason (e.g., damageable property) at 100,000 cfs, it is suggested that a higher flow target be considered.

6.2 FORECAST-BASED DRAWDOWN

The Shasta flood control diagram accounts for antecedent wetness conditions through varying the amount of flood space based on the rainflood parameter. The amount of flood space required throughout the year also changes. This is due to knowledge that large flood-producing storms are more likely in the winter than at other times of the year. These are both instances where knowledge and understanding of the physical flood-producing mechanisms allows optimization of the management of the reservoir for flood control and water supply. Forecast-based drawdown is the next logical application of the same principle.

It is recommended that forecast-based operation be studied more comprehensively. The aim of this additional effort would be to study comprehensive approaches to forecast-based reservoir operation that would allow regulated encroachment of the flood space when the risk of having large inflows in the immediate future was low and would call for forecast-based flood releases when inflow forecasts were high enough to indicate flood releases would be needed. The goal of the study would be to find a set of combined encroachment/drawdown operational parameters that would maximize the mutual water supply/flood control benefit while not imposing significant additional risk to either entity. Since regulated encroachment would require adjustment of the FCD parameters, it is recommended that the USACE be consulted with the approach prior to beginning any study

6.3 RAINFLOOD PARAMETER

Based on the relative frequency that the rainflood parameter on the FCD seems to hamper the spring refill of and thus water supply provided by Shasta Lake, it is recommended that a new parameter be investigated to determine if this condition can be improved.

It will also be important to consider the additional flood risk that will be invoked if the parameter is changed to require less flood space. Perhaps, changing the rainflood parameter could be incorporated with forecast-based drawdown, so a methodology will be put in place to minimize any additional assumed flood risk.

REFERENCES

FEMA (Federal Emergency Management Association), 1996. Flood Insurance Study, City of Red Bluff, CA.

FEMA (Federal Emergency Management Association), 1998. Flood Insurance Study, City of Redding, CA.

FEMA (Federal Emergency Management Association), 1999. Flood Insurance Study, Shasta County, CA.

FEMA (Federal Emergency Management Association), 2003. Flood Insurance Study, Tehama County, CA.

USACE (United States Army Corps of Engineers), 1977. Report on Reservoir Regulation for Flood Control, Shasta Dam and Lake, Department of the Army, Sacramento District, Sacramento, CA.

USACE (United States Army Corps of Engineers), 1977. Cottonwood Creek Hydrology, Department of the Army, Sacramento District, Sacramento, CA.

USACE (United States Army Corps of Engineers), 2002. Sacramento and San Joaquin River Basins Comprehensive Study Technical Studies Documentation, Department of the Army, Sacramento District, Sacramento, CA.

Table 3

Computation of Incidental Storage for Existing and Enlarged Shasta Dam and Lake

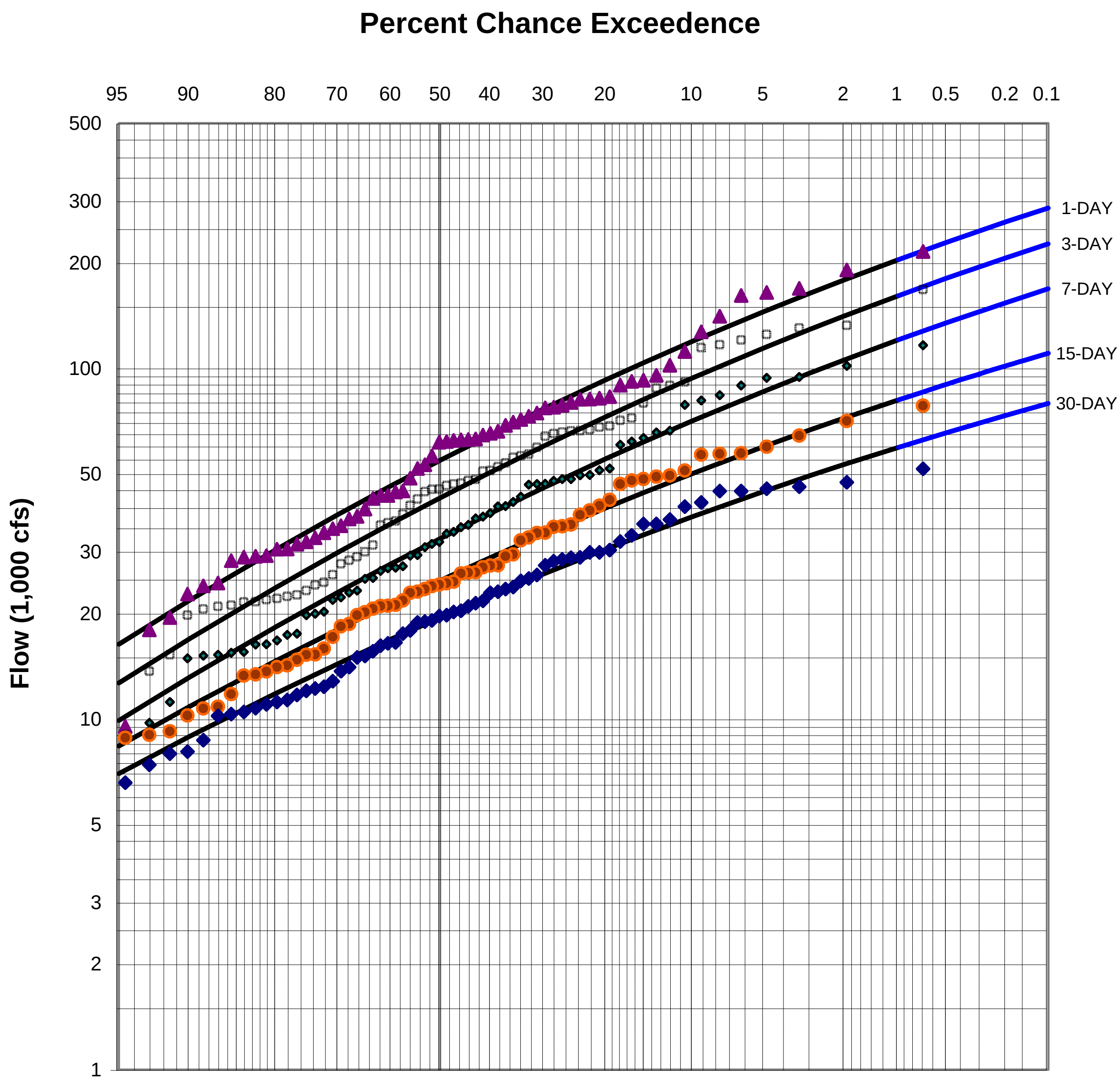
Beginning Date of Historical Flood Event	Historical Conditions: Storage at End of Day Before Event (TAF)	Historical Conditions: Storage at End of Month Before Event (TAF)	Historical Conditions: Storage Defining Bottom of Flood Pool (TAF)	Historical Conditions: Incidental Flood Space Available (TAF)	Base Model Conditions: Storage at End of Month Before Event (TAF)	Base Model Conditions: Estimated Storage at End of Day Before Event (TAF)	Base Model Conditions: Storage Defining Bottom of Flood Pool (TAF)	Base Model Conditions: Estimated Incidental Flood Space Available (TAF)	6.5 ft Model Conditions: Storage at End of Month Before Event (TAF)	6.5 ft Model Conditions: Estimated Storage at End of Day Before Event (TAF)	6.5 ft Model Conditions: Storage Defining Bottom of Flood Pool (TAF)	6.5 ft Model Conditions: Estimated Incidental Flood Space Available (TAF)	18 ft Model Conditions: Storage at End of Month Before Event (TAF)	18 ft Model Conditions: Estimated Storage at End of Day Before Event (TAF)	18 ft Model Conditions: Storage Defining Bottom of Flood Pool (TAF)	18 ft Model Conditions: Estimated Incidental Flood Space Available (TAF)
28-Oct-52	2,492	2,329			2,404	2,567	3,400	833	2,620	2,783	3,690	907	2,888	3,051	4,023	972
21-Dec-55	2,845	2,357			2,546	3,034	3,252	218	2,579	3,067	3,542	475	2,766	3,254	3,875	621
24-Feb-58	3,577	3,558			3,531	3,550	3,531	0	3,821	3,840	3,821	0	4,154	4,173	4,154	0
21-Dec-64	2,576	2,351			2,626	2,851	3,252	401	2,441	2,667	3,542	875	2,563	2,789	3,875	1,086
29-Jan-67	3,387	3,163			3,335	3,558	3,335	0	3,625	3,849	3,625	0	3,958	4,181	3,958	0
11-Feb-69	3,289	3,206			3,358	3,441	3,358	0	3,911	3,994	4,082	88	3,981	4,064	3,981	0
22-Jan-70	3,795	3,200			3,317	3,912	3,317	0	3,607	4,202	3,607	0	3,940	4,535	3,940	0
15-Jan-74	3,280	3,100			3,267	3,447	3,267	0	3,557	3,737	3,557	0	3,890	4,070	3,890	0
14-Jan-78	1,857	1,172			1,130	1,815	3,350	1,535	1,191	1,875	3,640	1,765	1,234	1,918	3,973	2,055
17-Mar-80	3,729	3,793			3,292	3,229	3,292	63	3,582	3,519	3,582	63	3,915	3,852	3,915	63
19-Dec-81	3,423	3,337			3,252	3,339	3,252	0	3,542	3,629	3,542	0	3,875	3,962	3,875	0
1-Mar-83	3,579	3,579			3,252	3,252	3,252	0	3,542	3,542	3,542	0	3,875	3,875	3,875	0
17-Feb-86	3,795	2,974			3,118	3,939	3,658	0	3,238	4,059	3,948	0	3,379	4,200	4,281	81
9-Mar-95	3,648		3,792	144												
30-Dec-96	3,441		3,287	0												
6-Mar-98	3,388		3,252	0												
Average	3,256	2,932	3,539	72	2,956	3,226	3,347	235	3,174	3,443	3,671	321	3,417	3,686	3,970	375

Median Sacramento River below Keswick Peak Hourly Regulated Flow (1,000 cfs)

Scenario	Annual Exceedence Probability					
	1-in-10	1-in-50	1-in-100	1-in-150	1-in-200	1-in-500
Existing	**60**	**79**	**95**	**116**	**148**	**232**
48 hour Inflow Forecast Lead Time (Shasta)	60	79	95	116	143	232
72 hour Inflow Forecast Lead Time (Shasta)	60	79	95	116	143	232
FBO	60	79	95	116	138	215
0% Forecast Uncertainty (Bend Bridge)	60	79	90	99	110	212
10% Forecast Uncertainty (Bend Bridge)	60	79	95	99	116	222
20% Forecast Uncertainty (Bend Bridge)	60	79	95	104	130	229
10 kcfs/hr rate of change	60	79	95	124	157	232
125 kcfs Bend Bridge Target	60	79	79	99	104	182
150 kcfs Bend Bridge Target	60	79	79	79	104	126

Median Sacramento River at Bend Bridge Peak Hourly Regulated Flow (1,000 cfs)

Scenario	Annual Exceedence Probability					
	1-in-10	1-in-50	1-in-100	1-in-150	1-in-200	1-in-500
Existing	**117** ***(100)***	**162** ***(147)***	**183** ***(167)***	**238** ***(179)***	**285** ***(187)***	**377** ***(215)***
48 hour Inflow Forecast Lead Time (Shasta)	117 *(100)*	162 *(147)*	183 *(167)*	238 *(179)*	285 *(187)*	377 *(215)*
72 hour Inflow Forecast Lead Time (Shasta)	117 *(100)*	162 *(147)*	183 *(167)*	238 *(179)*	285 *(187)*	377 *(215)*
FBO	117 *(100)*	162 *(147)*	183 *(167)*	238 *(179)*	285 *(187)*	367 *(215)*
0% Forecast Uncertainty (Bend Bridge)	123 *(100)*	162 *(147)*	183 *(167)*	195 *(179)*	230 *(187)*	367 *(215)*
10% Forecast Uncertainty (Bend Bridge)	119 *(100)*	162 *(147)*	183 *(167)*	203 *(179)*	249 *(187)*	377 *(215)*
20% Forecast Uncertainty (Bend Bridge)	118 *(100)*	162 *(147)*	183 *(167)*	223 *(179)*	266 *(187)*	377 *(215)*
10 kcfs/hr rate of change	115 *(100)*	162 *(147)*	186 *(167)*	251 *(179)*	295 *(187)*	377 *(215)*
125 kcfs Bend Bridge Target	131 *(100)*	165 *(147)*	184 *(167)*	196 *(179)*	204 *(187)*	343 *(215)*
150 kcfs Bend Bridge Target	140 *(100)*	173 *(147)*	189 *(167)*	199 *(179)*	214 *(187)*	272 *(215)*



ADOPTED STATISTICS:

	Mean	Std.Dev.	Skew
1-day	4.721	0.290	-0.4
3-day	4.614	0.292	-0.4
7-day	4.498	0.287	-0.4
15-day	4.380	0.261	-0.4
30-day	4.275	0.246	-0.4

NOTES:

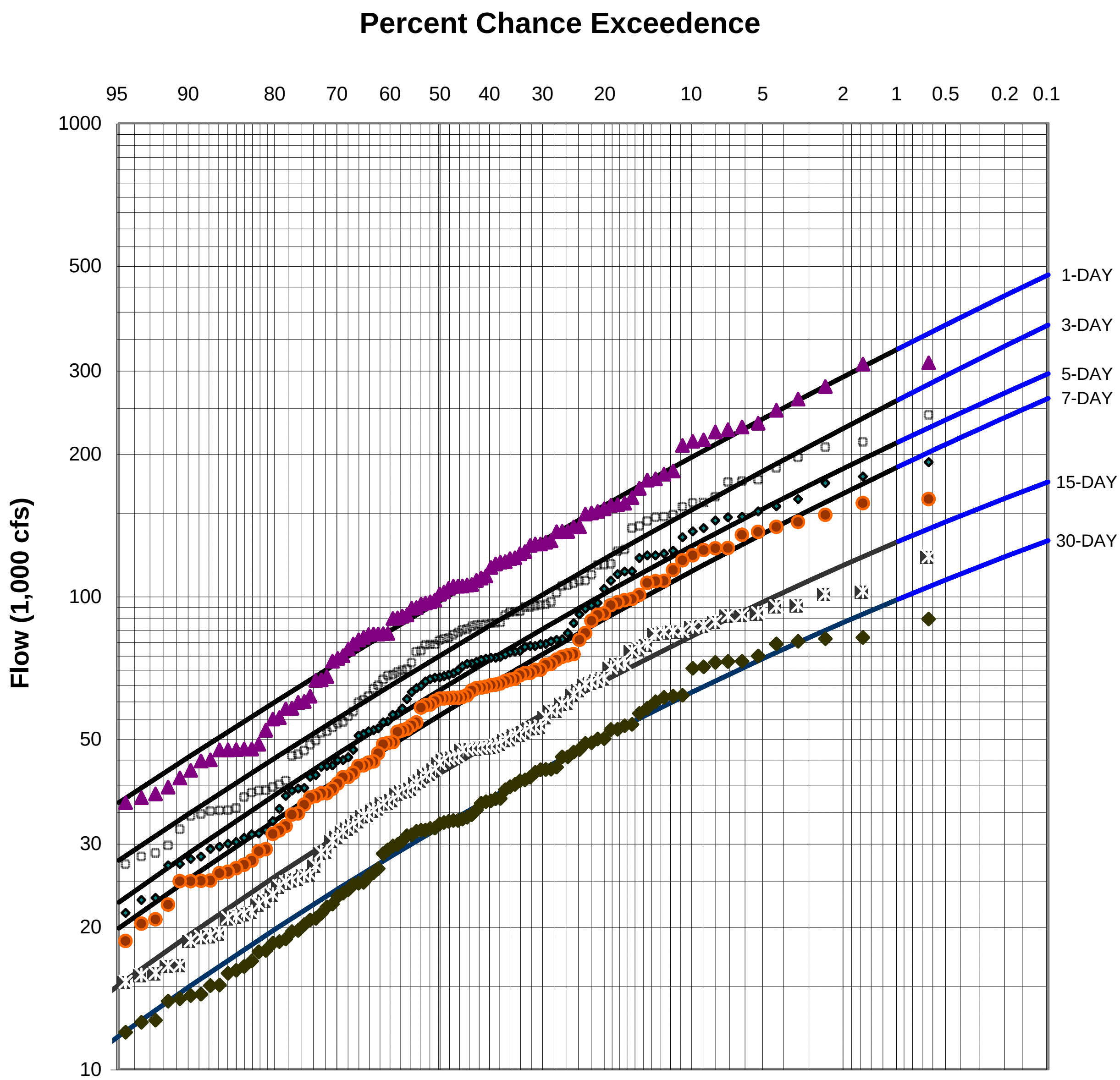
1. Equivalent years of record after correlation with Bend Bridge (1892-1998) is 98 years.
2. Adjusted USGS gage 11370000 to account for daily change in storage at upstream reservoirs (potential channel, out-of-channel, or storage losses neglected).
3. Median plotting positions.
4. Drainage area: 6,421 sq. mi.
5. Period of record: 1932-1998.

SACRAMENTO-SAN JOAQUIN COMPREHENSIVE STUDY
SACRAMENTO RIVER BASIN, CALIFORNIA

RAIN FLOOD FREQUENCY CURVES
SACRAMENTO RIVER AT SHASTA DAM
UNREGULATED CONDITIONS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

01-Sep-00



ADOPTED STATISTICS:

	Mean	Std.Dev.	Skew
1-day	4.984	0.247	-0.2
3-day	4.868	0.251	-0.2
5-day	4.791	0.254	-0.3
7-day	4.738	0.255	-0.3
15-day	4.612	0.248	-0.4
30-day	4.498	0.244	-0.4

NOTES:

1. Adjusted USGS gage 11377100 to account for daily change in storage at Shasta Lake and Whiskeytown Reservoir (potential channel, out-of-channel, or storage losses neglected).
2. WY 1977 censored as low outlier.
3. Median plotting positions.
4. Drainage area: 8,900 sq. mi.
5. Period of record: 1893-1998.

SACRAMENTO-SAN JOAQUIN COMPREHENSIVE STUDY
SACRAMENTO RIVER BASIN, CALIFORNIA

RAIN FLOOD FREQUENCY CURVES
SACRAMENTO RIVER AT BEND BRIDGE
UNREGULATED CONDITIONS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

01-Sep-00

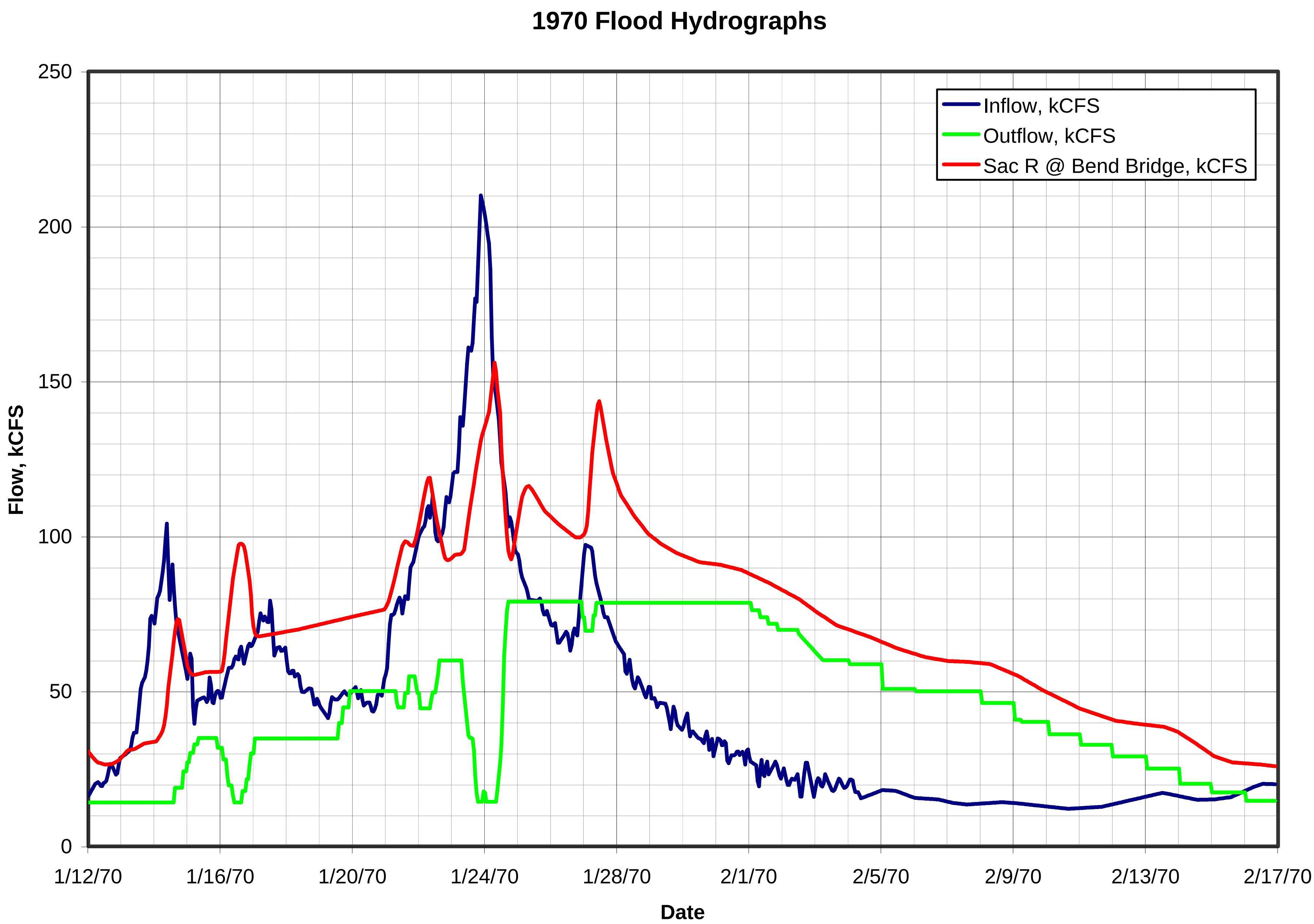
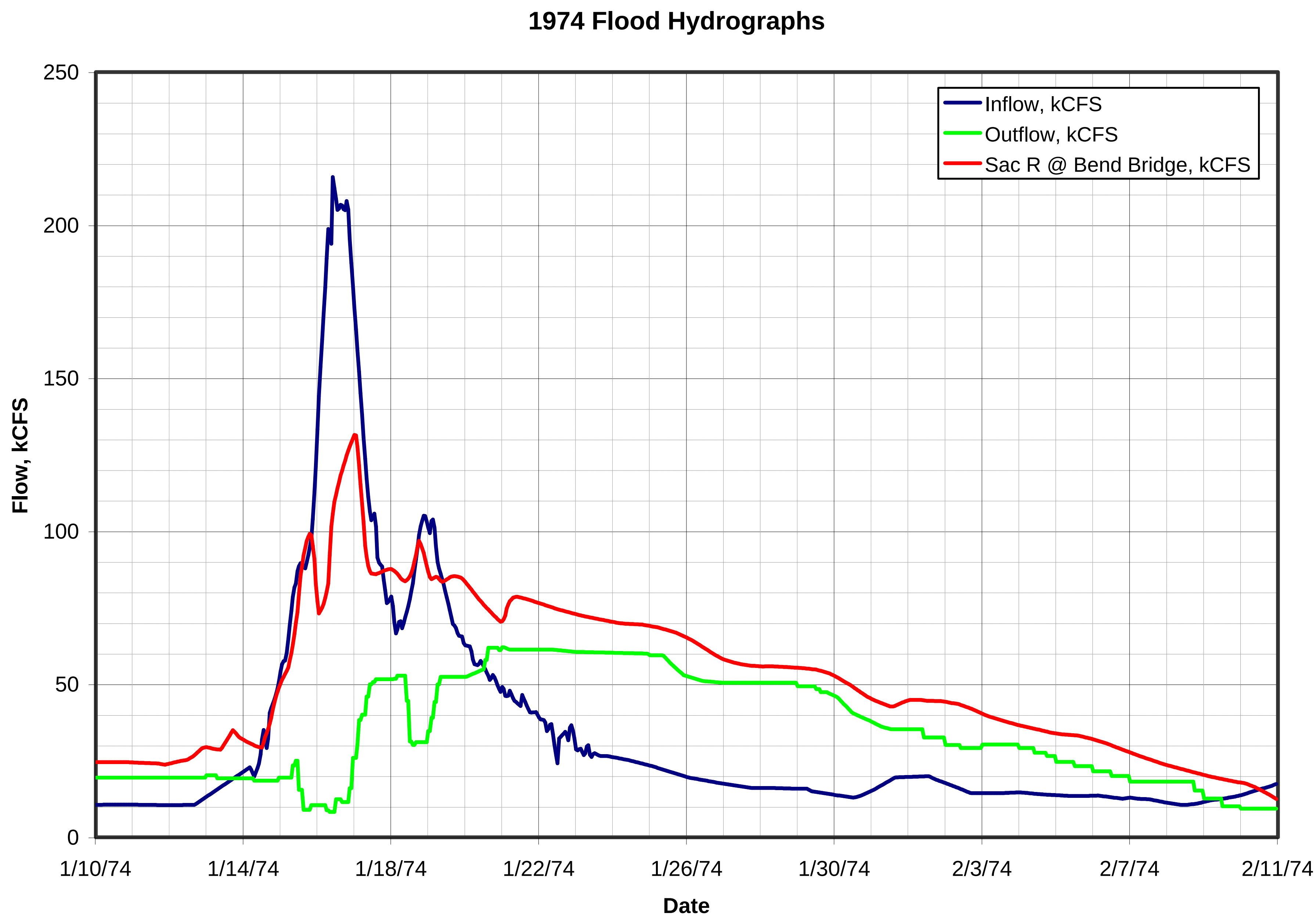

1970 Flood Hydrographs
Flow, kCFS
0
50
100
150
200
250
Inflow, kCFS
Outflow, kCFS
Sac R @ Bend Bridge, kCFS
1/12/70
1/16/70
1/20/70
1/24/70
1/28/70
2/1/70
2/5/70
2/9/70
2/13/70
2/17/70
Date

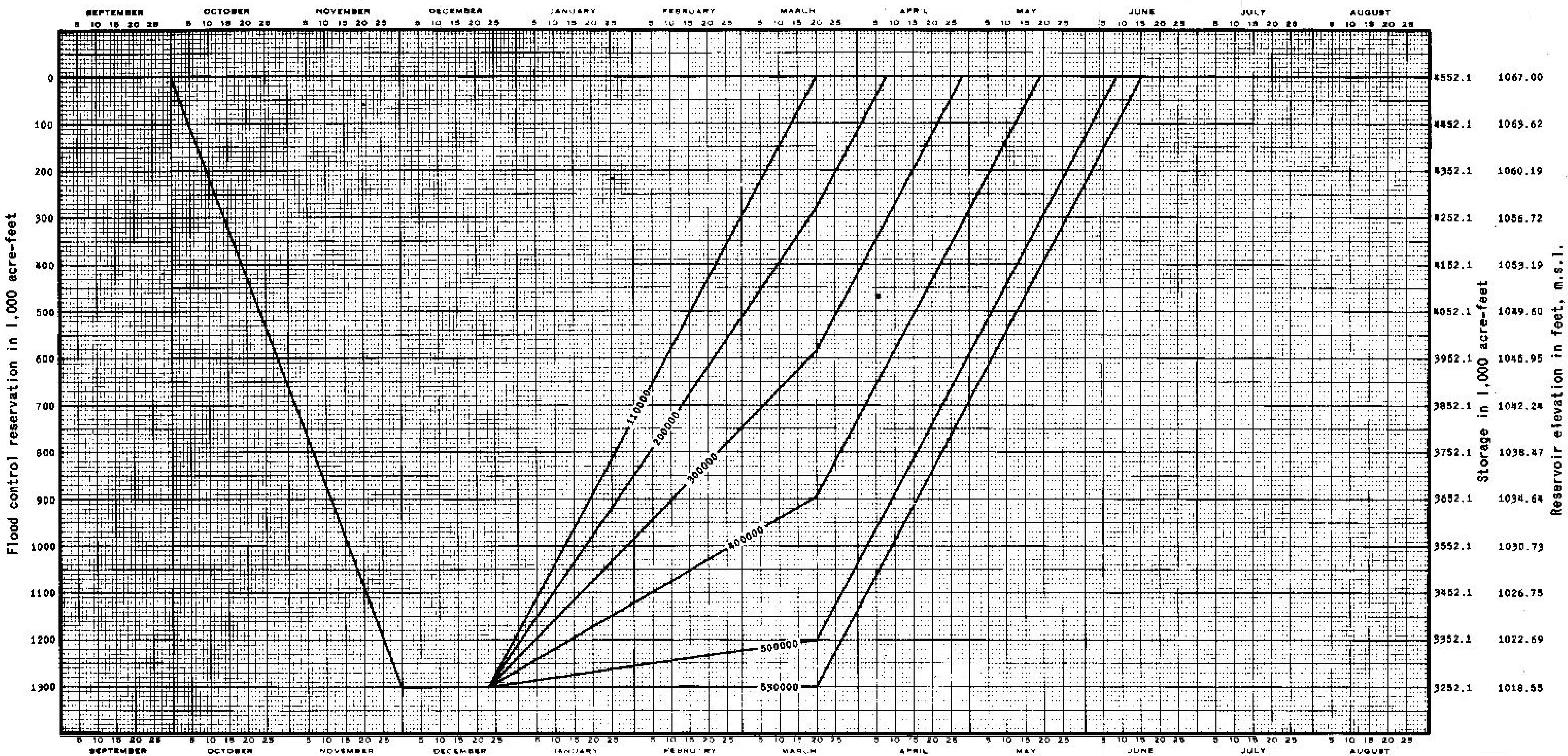
Figure 3



1974 Flood Hydrographs
Flow, kCFS
0
50
100
150
200
250
1/10/74
1/14/74
1/18/74
1/22/74
1/26/74
1/30/74
2/3/74
2/7/74
2/11/74
Date
Inflow, kCFS
Outflow, kCFS
Sac R @ Bend Bridge, kCFS

Figure 4

Figure 5a



SOURCE: USACE (United States Army Corps of Engineers), 1977. Report on Reservoir Regulation for Flood Control, Shasta Dam and Lake, Department of the Army, Sacramento District, Sacramento, CA.

Figure 5b

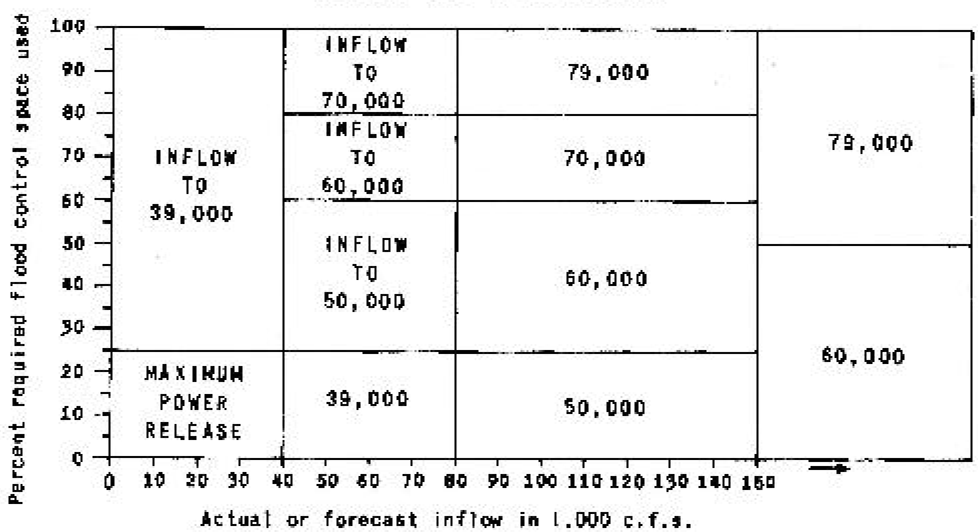
USE OF DIAGRAM

1. Rainflood parameters relate the accumulation of seasonal inflow to the required flood control space reservation on any given day. Parameter values are computed daily, from the accumulation of seasonal inflow by adding the current day's inflow in cubic feet per second (cfs) to 95% of the parameter value computed through the preceding day.*

2. Except when releases are governed by the emergency spillway release diagram currently in force (File No. SA-26-92), water stored in the flood control reservation, defined hereon, shall be released as rapidly as possible, subject to the following conditions:
   a. That releases are made according to the Release Schedule hereon.
   b. That flows in Sacramento River below Keswick Dam do not exceed 79,000 cfs.
   c. That flows in Sacramento River at Bend Bridge gage do not exceed 100,000 cfs.
   d. That releases are not increased more than 15,000 cfs or decreased more than 4,000 cfs in any 2-hour period.

*Flood Control Diagram is initialized each flood season by assuming a parameter value of 100,000 c.f.s. day on 1 October.

RELEASE SCHEDULE



SOURCE: USACE (United States Army Corps of Engineers), 1977. Report on Reservoir Regulation for Flood Control, Shasta Dam and Lake, Department of the Army, Sacramento District, Sacramento, CA.

SHASTA DAM AND LAKE
SACRAMENTO RIVER, CALIFORNIA

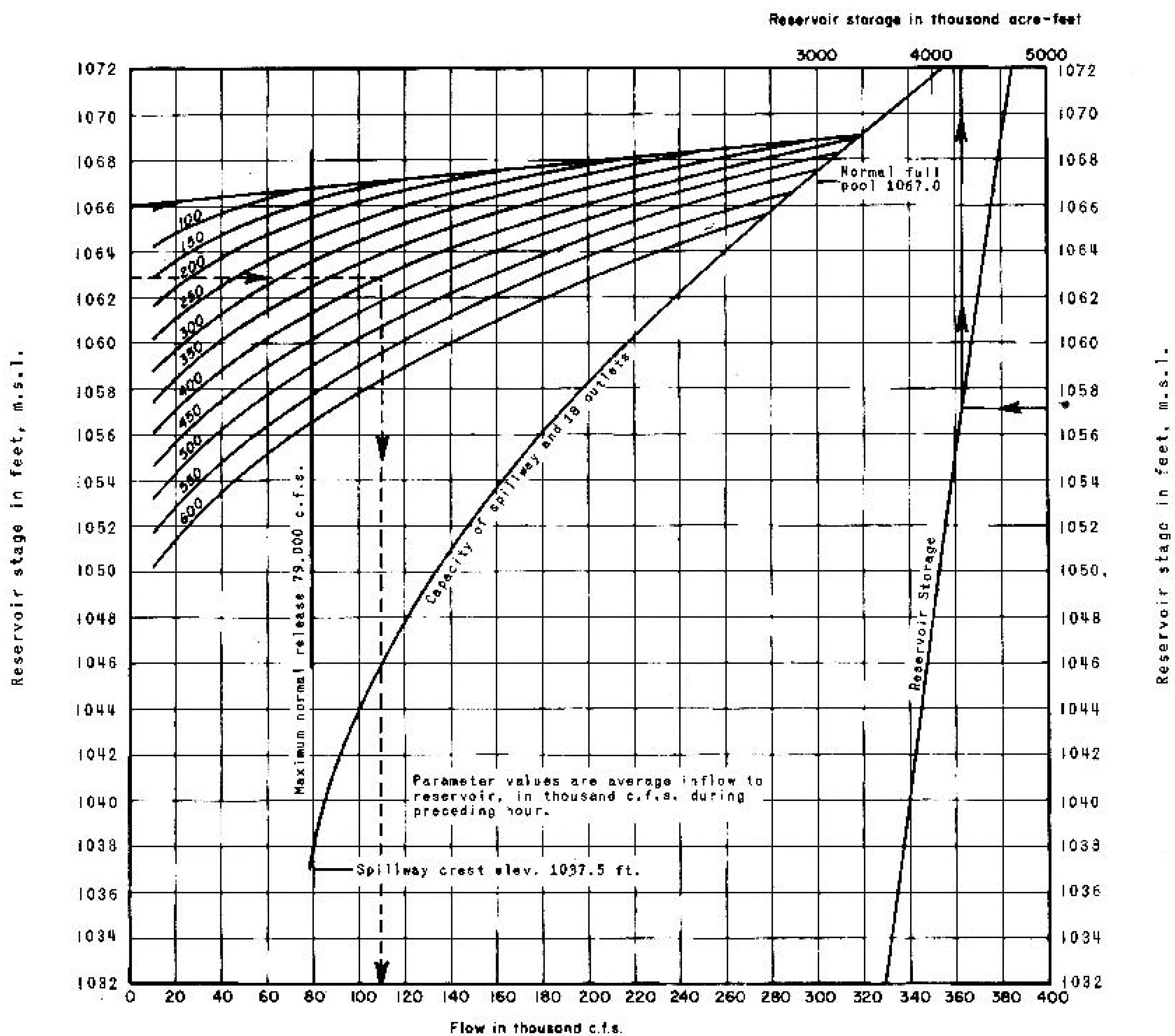
FLOOD CONTROL DIAGRAM

Prepared Pursuant to Flood Control Regulations for Shasta Dam and Lake

APPROVED: ______________________
Brigadier General, USA, Division Engineer
South Pacific Division

APPROVED: ______________________
Regional Director Mid Pacific Region
U.S.B.R.

Effective Date: 6 JUL 1977 File No. SA-17-26-18



SOURCE: USACE (United States Army Corps of Engineers), 1977. Report on Reservoir Regulation for Flood Control, Shasta Dam and Lake, Department of the Army, Sacramento District, Sacramento, CA.

USE OF DIAGRAM

When reservoir stage is rising, determine the average inflow to the reservoir during the preceding hour.

From the parameter line corresponding to this inflow, read the flow corresponding to the current reservoir stage.

When this value of flow exceeds the current release, increase the release to this value.

. Repeat steps 1 through 3 each hour until maximum gate opening has been reached.

. Maintain this maximum gate opening until reservoir stage begins to fall and is below elevation 1069 feet.

. When the reservoir stage is falling and is below elevation 1069 feet determine the average inflow to the reservoir during the preceding hour.

. Decrease the release by .3 of the value obtained in step 6.

. Repeat steps 6 through 7 each hour, as long as the reservoir level is receding, until the release have been reduced to the value required by the Flood Control Diagram.

. Once operation in accordance with the Emergency Spillway Release Diagram is initiated, gate changes shall be made only at such times as criteria under steps 1 through 4 require increased gate openings or criteria under steps 6 through 8 require decreased gate openings, until the release has been reduced to the value required by the Flood Control Diagram.

NOTES:

Top of spillway gates in raised position is at elevation 1065.0 feet.

Spillway discharge is controlled by three 110 feet by 28 feet drum gates.

SHASTA DAM AND LAKE
SACRAMENTO RIVER, CALIFORNIA

EMERGENCY SPILLWAY RELEASE DIAGRAM

Prepared Pursuant to Flood Control Regulations for Shasta Dam and Lake

APPROVED: Richard M. Connell
Brigadier General, USA, Division Engineer
South Pacific Division

APPROVED: B. E. Martin
Regional Director Mid Pacific Region
U.S.B.R.

Effective Date: 8 JUL 19— File No. SA-26-92

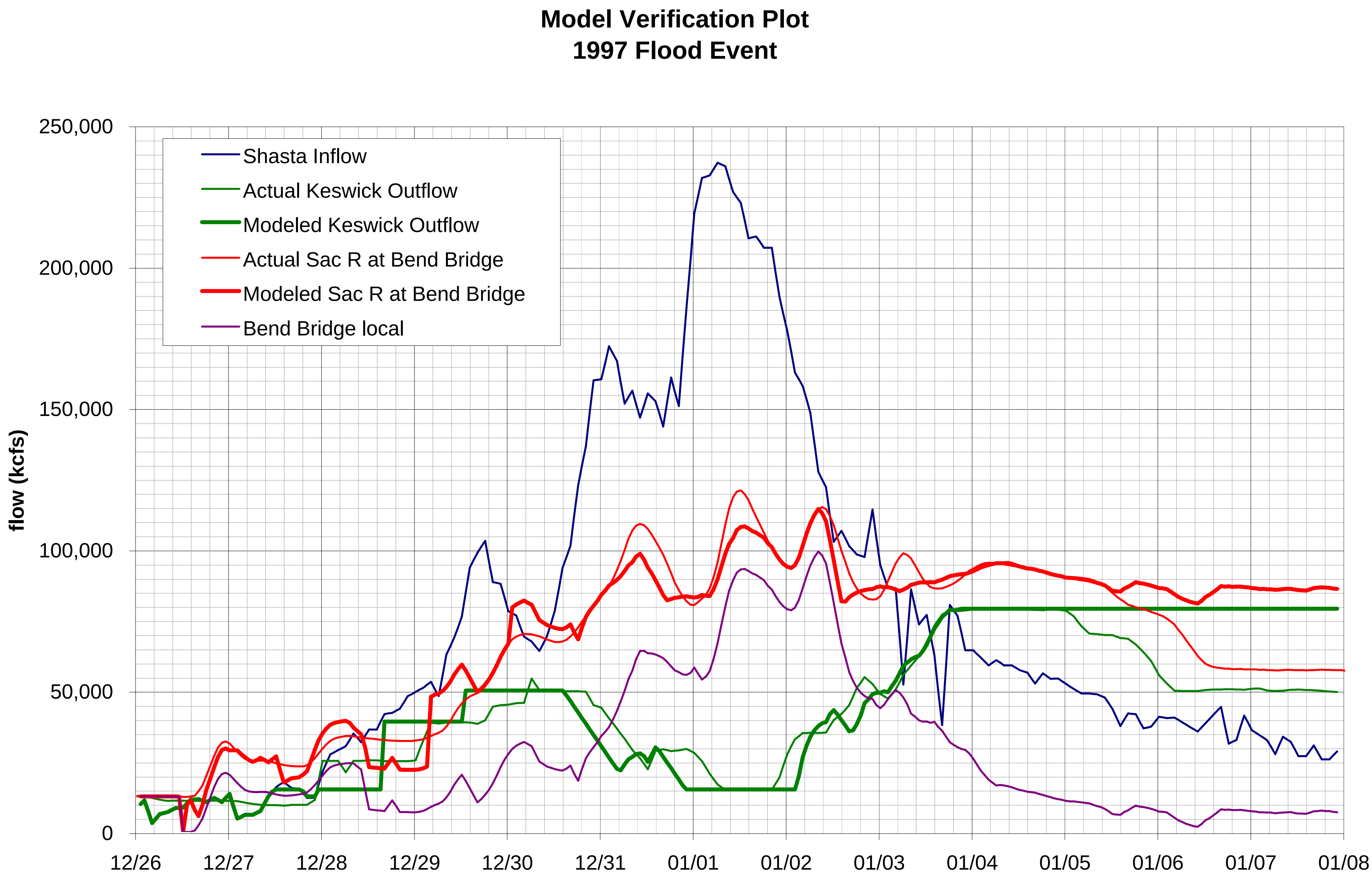


Figure 7

MBK Engineers
1/12/2004

R:\3499 MWH Shasta Enlargement\Excel\Model Verification - 1997 event.xls

3499
MWH Shasta

Comparison of Existing Operations at Shasta Dam and Operation with 125,000 cfs Bend Bridge Flow Target for the 1-in-200 AEP Shasta Dam Centering Flood Event

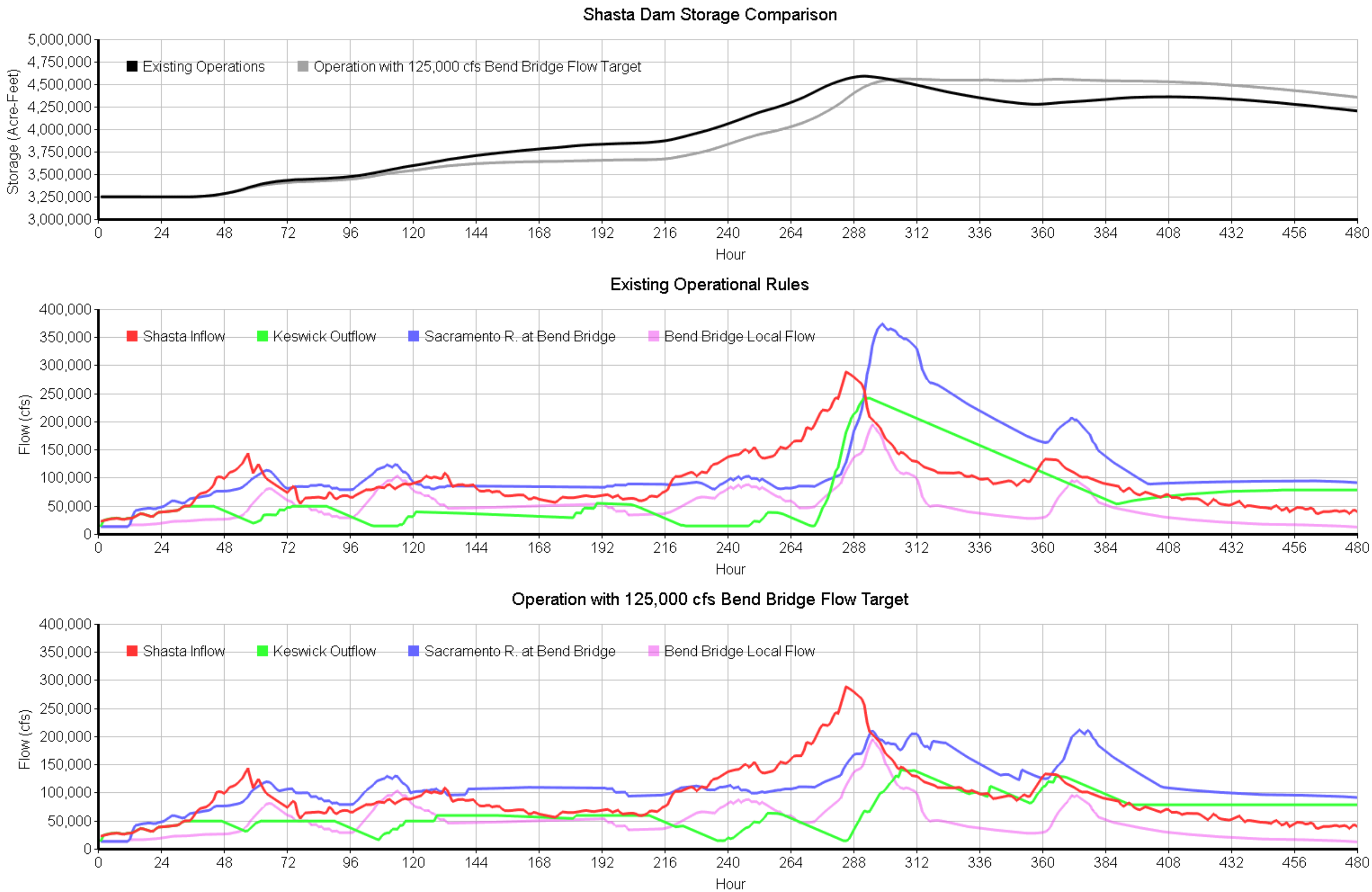


Figure 8