Appendix P

Preferred Operational Scenario Probable Maximum Flood Routings Analysis

TRUCKEE BASIN WATER MANAGEMENT OPTIONS PIOLT (TBWMOP) PROBABLE MAXIMUM FLOOD ROUTINGS

Routing existing Probable Maximum Floods (PMFs) with the proposed changes to the Water Control Manual (WCM)

Abstract

The Truckee Basin Management Options Pilot proposes changes to the Truckee Basin Water Control Manual. This report routes the existing PMF events for Prosser Creek and the Little Truckee River through the respective reservoirs to identify if the proposed changes to the WCM impact the reservoir's ability to manage the PMFs.

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1 Introduction

The Truckee Basin Water Management Options Pilot Study (TBWMOP) is an effort to study potential improvements to flood control operations on the Truckee River for the benefit of water management in the basin. The goal of the TBWMOP project is to develop a proposed revision to 1985 United States Army Corps of Engineers (USACE) Truckee Basin Water Control Manual (WCM) (US Army Corps of Engineers, 1985) that governs management of flood reservoirs in the Truckee Basin for downstream flood control. The issues the TBWMOP aims to address are best summarized as follows (Department of Interior 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 “The [WCM] suffers from outdated rule curves, inflexible storage requirements, constrained reservoir release thresholds, and a constrained downstream regulation goal at Reno.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.”

Stakeholders that contributed to addressing this set of issues and to the larger TBWMOP effort fall into two categories: the Technical Team and other key stakeholders. The Technical Team is comprised of cost share partners who signed the Truckee Basin Memorandum of Agreement (Department of Interior Bureau of Reclamation, 2021) including the United States Bureau of Reclamation (USBR), Pyramid Lake Paiute Tribe (PLPT), the United States District Court Water Master (USWM), the California Department of Water Resources (CA DWR), and the Truckee Meadows Water Authority (TMWA). Other key stakeholders contributing to the effort include the Truckee River Flood Management Authority (TRFMA), California Nevada River Forecast Center (CNRFC), the National Weather Service (NWS) and USACE.

The TBWMOP technical modeling approach is centralized on using a Multi-Objective Evolutionary Algorithm (MOEA) to adjust the study parameters to meet the study operational objectives while being within the study constraints[1]. The details of this process are summarized in the “Action and Alternative Modelling in the WMOP” report (Noe, 2023).

The MOEA analysis was completed using a dataset that consisted of historical data from 1986 through 2020 [(Precision Water Resources Engineering, 2022), (Lawler, 2022a), (Lawler, 2022b)] as well as scaled versions of historical events to represent the 1/100-yr, 0.5/100-yr and 0.2/100-yr[2] recurrence intervals determined by the 2022 Flood Frequency Analysis (Imgarten, 2022; Lahde, et al., 2022). CNRFC created scaled versions of select historical events by scaling up event precipitation so that the Reno Unregulated Flow equaled the average flow for the respective recurrence interval and period flows. CNRFC also produced hindcasts of their Hydrologic Ensemble Forecasting System (HEFs) for all the historical period and for the scaled historical events. These HEFs hindcasts are comparable to the forecasts that would have been available during the events had the current forecasting technologies been in place at the time and are necessary inputs for the alternatives examined in the TBWMOP.

[1] The study objectives and constraints were defined by a stakeholder group (Bureau of Reclamation, 2021).

[2] The 2022 Flood Frequency Analysis used the 1/100-yr 0.5/100-yr and 0.2/100-yr terminology to refer to events instead of the more commonly used 100-yr, 200-yr and 500-yr terminology. The source report terminology was used here for consistency.

The events in the TBWMOP dataset are not sufficiently large to pose a risk to dam failure by overtopping or internal failure making it impossible for the MOEA to effectively evaluate the study constraint to “not increase the probability of dam failure from overtopping or internal failure”. Larger Probable Maximum Flood (PMF) hydrographs that would potentially pose a risk to the dam overtopping and/or internal failure are available. However, the operational scenarios that are being examined in the TBWMOP rely on the CNRFC HEFS forecasts which have not been developed for these PMFs and development of analogous hindcasts was not part of the scope of the TBWMOP. Given the data gap, and that preliminary screening of risks to dam failure based on the proposed changes to the WCM found that the changes were not expected to impact the risk of dam failure, the Technical Team decided to limit the analysis of the larger events to the Preferred Operational Scenario rather than attempting to incorporate it into the MOEA evaluation.

The goal of this study is to route the latest PMF hydrographs for Prosser Creek and the Little Truckee River through their respective flood reservoirs for the Baseline (current operations under the 1985 WCM), the “Preferred Operational Scenario” and the “Revised Guide Curves” scenarios from the TBWMOP. The selection process for the Preferred Operational Scenario is summarized in “Preferred Operational Scenario Selection Process” (Gwynn & Noe, 2023). For comparison purposes, the Revised Guide Curve scenario is included in this report to illustrate the impact to the PMF routings if no flood space encroachment under Forecast Informed Reservoir Operations (FIRO) occurred. This is also the backstop operational scenario if the CNRFC forecast is unavailable. The revised guide curves were developed based the latest available Reno unregulated flow data (Lahde, et al., 2022) and ensure that sufficient flood space is reserved to protect against the historical flooding that occurred by season and remaining water year runoff (Gwynn, 2022). These routings should be used to evaluate if the Preferred Operational Scenario and Revised Guide Curve scenarios meet the TBWMOP study constraint to “not increase the probability of dam failure from overtopping or internal failure”.

2 Reservoir Initial State Routing Methodologies

2.A PMF Data Sources

The available PMF data for both Prosser Creek and the Little Truckee River were developed in 2002 by the United States Bureau of Reclamation Technical Services Center (TSC) in Denver, CO. These updated PMFs were developed based on the criteria from HMR 58 and 59 (HMR 58, 1998; HMR 59, 1999). The HMR 58-59 criterion includes two types of events: General and Local. The General events are based on heavy antecedent snowpack based on the conditions present in December 1996 and January 1997 and is more typical of the rainy season months of December through March. The Local storms are based on a short duration thunderstorm type event occurring on saturated soils and snow free ground which is more typical of a summertime event (Bullard, 2002a; Bullard, 2002b).

2.A.1 Prosser

In 2006, TSC completed routings of the 2002 Prosser General PMF and Local PMF events after a 2-foot 8-inch concrete parapet wall barrier was added to the upstream edge of the dam crest to address overtopping during the PMF. This barrier raises the top of the dam to 5763.6’ NGVD29 or 50,019 acre-feet capacity (Cohen, 2006). The 2006 routings also introduced 10,000-year versions of the general (called Prosser 10kyr General) and local storms (called Prosser 10kyr Local) based on a 2001 flood frequency analysis. The 10kyr General is nearly identical to the General PMF while the 10kyr Local peak flow is 60% of the Local PMF peak flow (Kamstra, 2001). The 2006 routings are summarized and compared to the Spillway Design Flood that was referenced in the 1985 Water Control Manual in Table 1 and Figure 1. Note that the snowmelt driven PMFs have more than double the peak flow and 1.4 times the volume of the 1985 Spillway Design Flood for the General and 10kyr events. The larger flows in the more recent PMFs relative to the Spillway Design Flood explains why the dam is not able to pass the more recent PMFs without overtopping.

Table 1: Summary of Prosser PMF Events compared to event used in the 1985 WCM

Event	Peak Flow (cfs)	Volume (acre-feet)	Duration (hours)	Assumed Initial State
1985 WCM Spillway Design Flood[3]	*13,900*	*41,200*	*96*	*20,000 acre-feet of flood space (9,840 acre-feet storage)*
Prosser General PMF	30,200	59,000	96	Storage after antecedent event
Prosser 10kyr General	30,100	59,000	96	Storage after antecedent event
Prosser Local PMF	48,200	16,800	24	Max Capacity
Prosser 10kyr Local	28,700	9,400	24	Max Capacity

[3] The 1985 Spillway Design Flood was not routed as part of this analysis and is included in Table 1 and Table 2 for reference only.

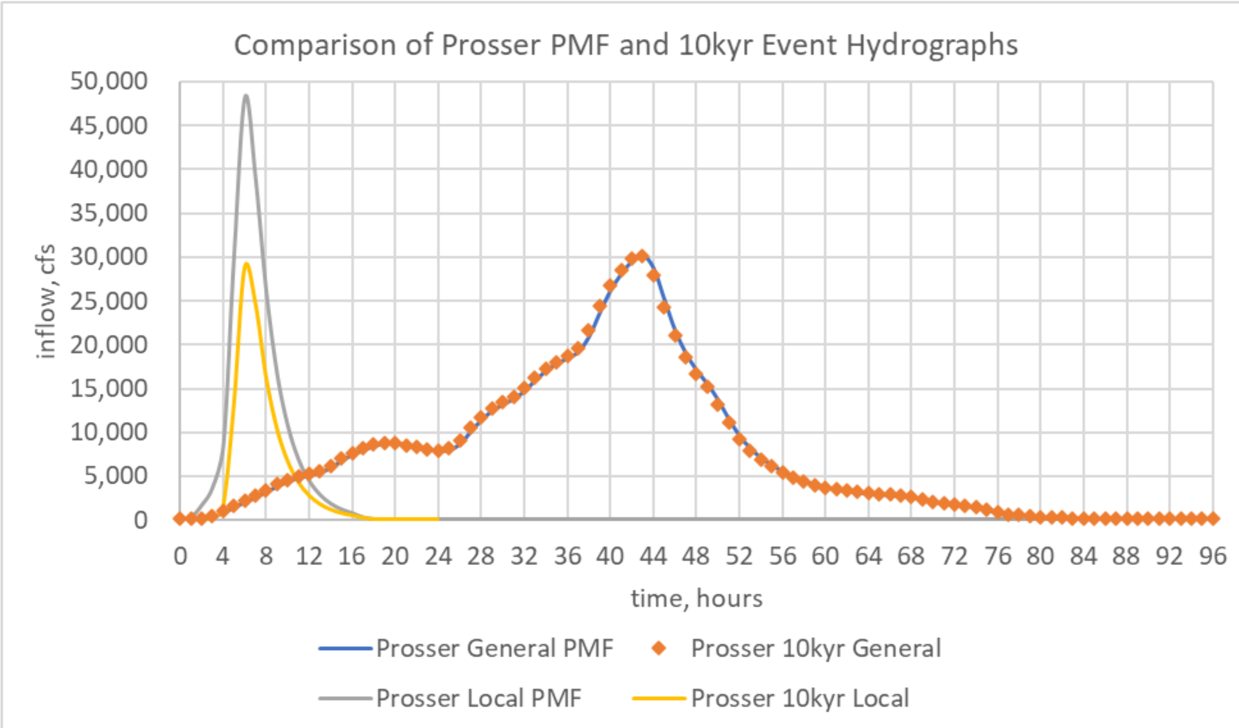

Figure 1: Comparison of Prosser PMF and 10kyr Event Hydrographs

2.A.2 Little Truckee River PMFs

Boca and Stampede are reservoirs on the Little Truckee River, which is the largest tributary to the Truckee River. The dams are in series, seven miles apart, and operated as a unit. The latest PMF event for the Little Truckee River was developed in 2002 by the same authors and using similar methods as the Prosser PMF events. The Little Truckee PMFs contain a version of the General and Local PMF where the storm centered over each Little Truckee reservoir creating a total of four events (Bullard, 2002b). Thus, the General scenarios are called LT General PMF Abv Stampede and LT General PMF Abv Boca and the Local scenarios are called LT Local Above Stampede and LT Local Above Boca herein. A 2009 Flood Frequency analysis established a 250,000-year recurrence interval for the 80,395 cfs peak inflow to Stampede in the LT General PMF Abv Stampede scenario (Kinkel, 2009). The Stampede unregulated inflows for these events are summarized and compared to the 1985 WCM Spillway Design Flood in Table 2 and Figure 2, and the intervening inflow between Boca and Stampede is summarized in Table 3. Note that the Boca inflow includes the routing of the Stampede PMF through the reservoir in addition to the runoff summarized in Table 3 and Figure 3.

Table 2: Summary of Stampede PMF Events compared to event used in the 1985 WCM

Event	Peak Flow (cfs)	Volume (acre-feet)	Duration (hours)	Assumed Initial State
1985 WCM Spillway Design Flood[4]	*29,900*	*95,900*	*156*	*22,000 acre-feet flood space*
LT General PMF Abv Stampede	80,400	158,900	96	Storage after antecedent event
LT General PMF Abv Boca	79,100	156,000	96	Storage after antecedent event
LT Local PMF Abv Stampede	97,700	34,000	20	Max Capacity
LT Local PMF Abv Boca	90,300	33,800	20	Max Capacity

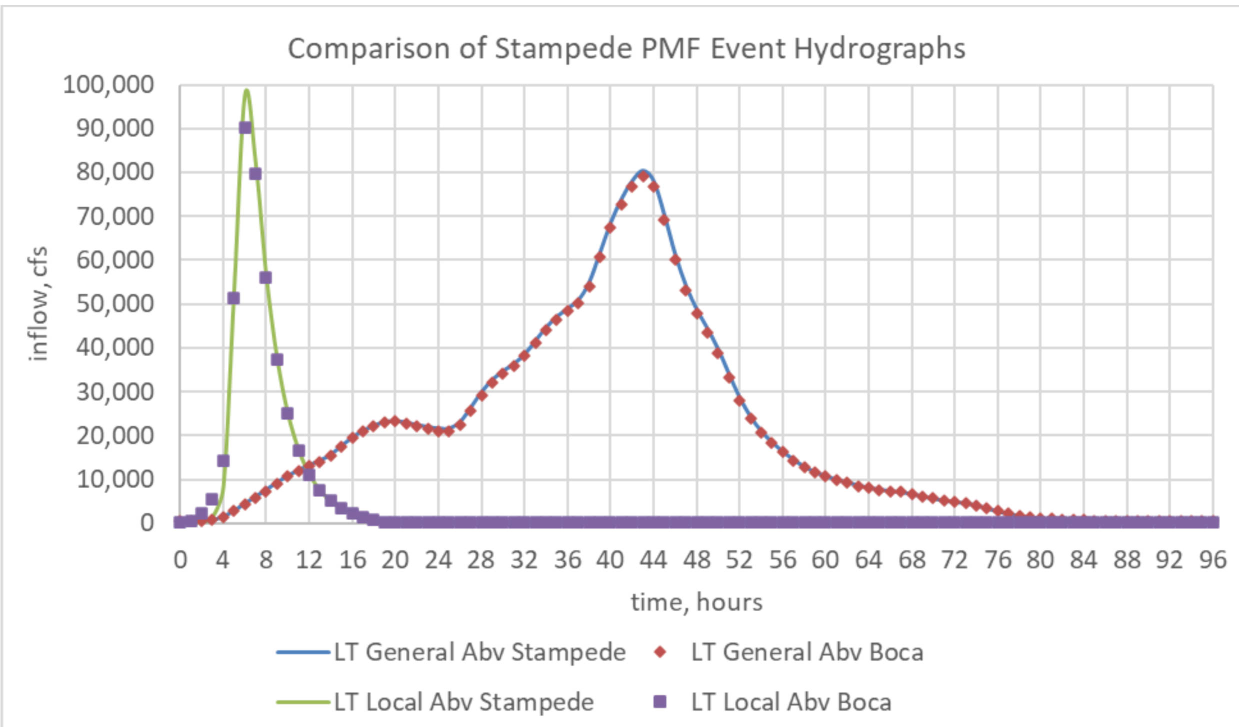

Figure 2: Comparison of Stampede PMF Event Hydrographs

[4] The 1985 Spillway Design Flood was not routed as part of this analysis and is included in Table 1 and Table 2 for reference only.

Table 3: Summary of PMF intervening inflow between Stampede and Boca Events compared to event used in the 1985 WCM

Event	Peak Flow (cfs)	Volume (acre-feet)	Duration (hours)	Assumed Boca Initial State
1985 WCM Spillway Design Flood[5]	*5,170*	*10,400*	*144*	*Max Capacity*
LT General PMF Abv Stampede	14,900	25,300	96	Storage after antecedent event
LT General PMF Abv Boca	16,300	28,100	96	Storage after antecedent event
LT Local PMF Abv Stampede	72,500	13,600	20	Max Capacity
LT Local PMF Abv Boca	72,500	13,600	20	Max Capacity

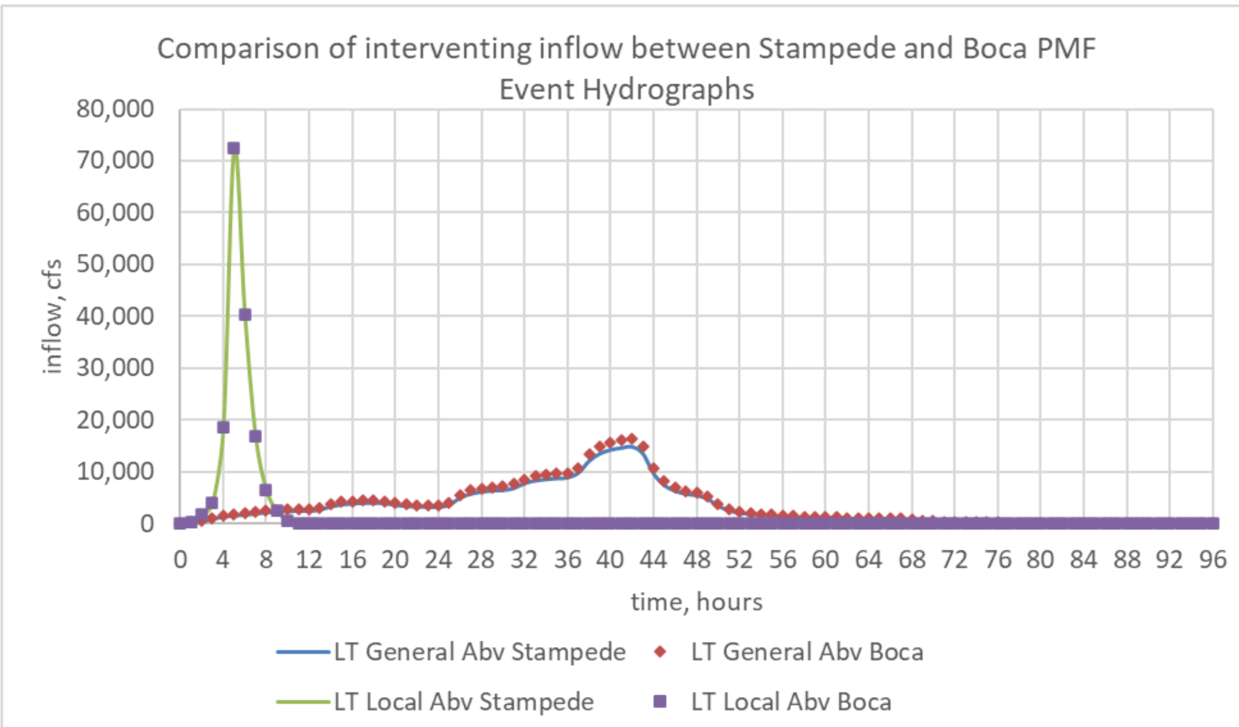

Figure 3: Comparison of intervening inflow between Stampede and Boca PMF Event Hydrographs

[5] The 1985 Spillway Design Flood was not routed as part of this analysis and is included in Table 1 and Table 2 for reference only.

2.B Reservoir Initialization Methods

The reservoir initial states for these PMFs were determined following ER 1110-8-2 (U.S. Army Corps of Engineers, 1991), which states:

> *"the minimum starting elevation for routing the IDF will be assumed as the full flood control pool level or the elevation prevailing five days after the last significant rainfall of a storm that produces one-half the IDF, whichever is most appropriate."*

ER 1110-8-2 uses the term IDF or Inflow Design Flood, whereas this effort was completed using the previously mentioned PMF's developed by USBR which are assumed to be interchangeable for the sake of this study. The Local PMFs were developed to represent summer thunderstorms on saturated soils. For these events, the full flood control pool is most appropriate to use as the initial condition since reservoirs are permitted to be full in the summertime in 1985 WCM and all TBWMOP scenarios. The required flood space in the winter months is variable and altered by the TBWMOP scenarios which could alter the required flood space during the winter months when these General events could occur. Because of this, the most appropriate initial reservoir elevations for the General PMF's were determined to be the elevation prevailing five days after the end of significant rainfall in the flood event in the TBWMOP dataset that was the nearest match to fifty percent of the PMF volume. Since the storage at the end of these winter events is used as the initial state for the General PMFs, the altered storage could impact the TBWMOP study constraint to "not increase the probability of dam failure."

The reservoir routings were completed using the Truckee Hourly RiverWare model which was developed as part of the TBWMOP project. The flow routing calibration is summarized in a report by Olson (Olsen, Erkman, & Vandegrift, 2021) and reservoir operations are summarized in a report by Noe (Noe, 2022). This model operates the Truckee Basin reservoirs collectively to the following guidelines. Whenever the reservoir storage was below the full flood control pool, releases would be operated per the Water Control Manual or applicable TBWMOP scenario for the benefit of the downstream flood target. Once the reservoir pool elevation reached or exceeded the full flood control pool, outlet works' releases are increased in addition to flow over the reservoir's respective spillway to the maximum extent necessary to return the reservoir to the full flood control pool. In the event that the reservoir elevation reached the top of the dam, flow over the dam was estimated.

2.C Antecedent Event Selection

The changes that are being proposed to the WCM as part of the TBWMOP would impact how the Little Truckee flood space is distributed between Boca and Stampede and how the reservoirs are operated during a flood when the reservoir storage is below the top of the flood control pool. The proposed operations may lead to different end storages after an event, meaning the TBWMOP scenario may impact the initial state in the snowmelt driven General PMFs. As part of the TBWMOP, Stetson Engineers derived historical hourly inflow data for all the subbasins in the Truckee River Basin which includes a total of 15 flood events that occurred between 1986 and 2020 (Lawler, 2022b). In addition to these historical events, CNRFC's computed scaled events provide 12 additional flood events (Imgarten, 2022). These events give a total of 27 events to run the proposed modeling structure as potential antecedent events for the four-snowmelt driven General PMFs. All the Local summer thunderstorm PMFs were assumed to occur in mid-July following the record setting 2017 runoff when the reservoir would be at the full flood control pool in the in the 1985 WCM and all the TBWMOP scenarios.

Table 4 summarizes the selection criteria for antecedent events for each of the four General PMFs. The events were selected based on the event in the TBWMOP dataset that was nearest to 50% of the PMF volume for the respective tributary. For all the General events, the selected antecedent event was around 44% of the PMF, near the 50% guidance. The Truckee River Basin reservoirs were operated to the flood operation criteria for each scenario during the antecedent event and for the five days following the cessation of significant precipitation in the antecedent event. Reservoir elevations that existed after this period were the beginning elevation(s) for the PMF routing (this was done as one seamless simulation run in the TR Hourly Model). The end of significant precipitation was determined based on the last day that the measured daily precipitation at the Cooperative Observer Network (COOP) weather station at Tahoe City exceeded 0.5 inches/day (USWM, 2023). Note that the precipitation measurements are taken each morning recording the previous 24-hours precipitation so the time that precipitation ended was assumed to be 8 AM of the last day with over 0.5 inches of daily precipitation.

Table 4: Summary of Antecedent Event Selection for Snowmelt Driven PMFs

Snowmelt Antecedent Event Summary				
	Prosser General PMF	**Prosser General 10kyr**	**LT General Abv Stampede**	**LT General Abv Boca**
Tributary	Prosser Creek	Prosser Creek	Little Truckee River[6]	Little Truckee River[6]
Antecedent Event	DecJan1997	DecJan1997	DecJan1997_100yr	DecJan1997_100yr
Precipitation Scale Factor	1	1	1.05	1.05
Antecedent Event Volume	26,100	26,100	80,500	80,500
PMF Volume	59,000	59,000	184,200	184,100
Ratio	44.2%	44.2%	43.7%	43.7%
Last Significant Precip	1/3/1997 8:00	1/3/1997 8:00	1/3/1997 8:00	1/3/1997 8:00
Start of PMF	1/8/1997 9:00	1/8/1997 9:00	1/8/1997 8:00	1/8/1997 8:00

2.D Hydrographs

The resulting hydrographs for each PMF including the antecedent event for the General PMFs are shown in the following figures.

[6] Table 4 displays the total Little Truckee River runoff volumes while Table 2 and Table 3 summarize the volume that would be captured in Stampede and Boca, respectively. The Little Truckee river volumes in Table 3 are the sum of the volumes from Table 2 and Table 3.

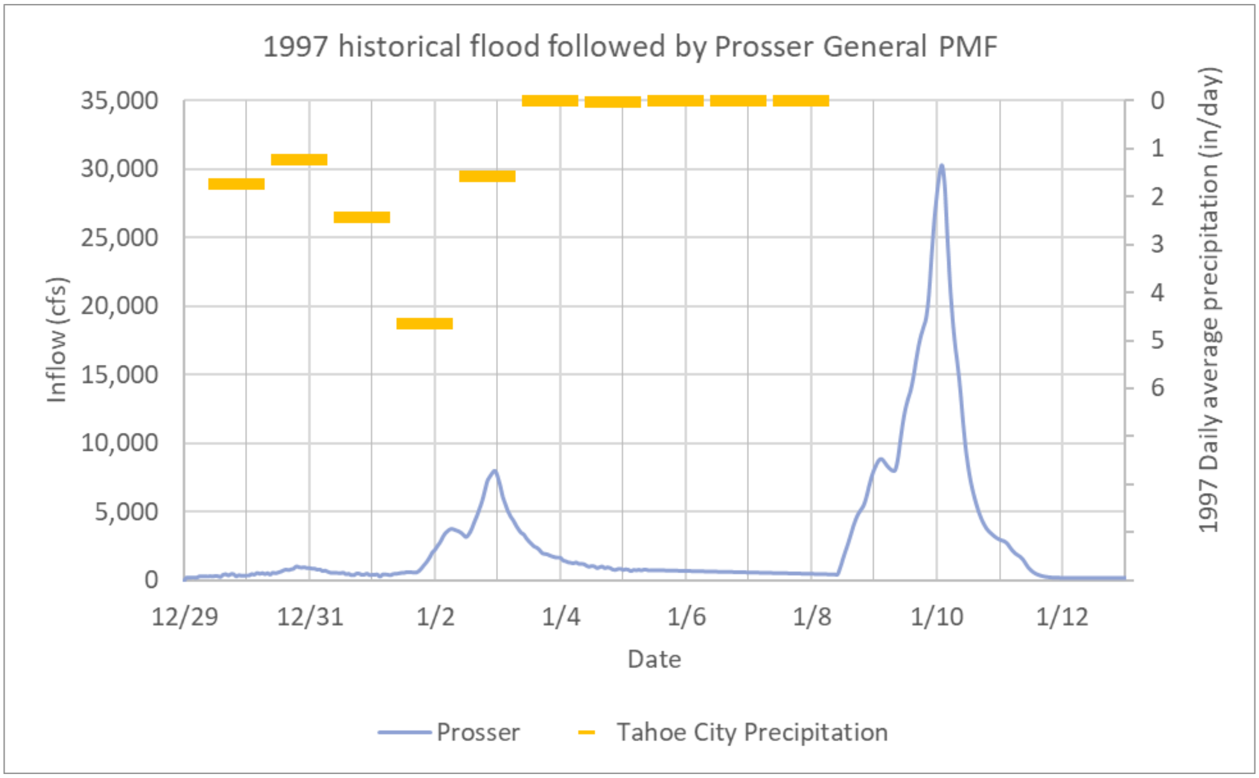

Figure 4: Prosser General PMF with historical 1997 flood as the antecedent event

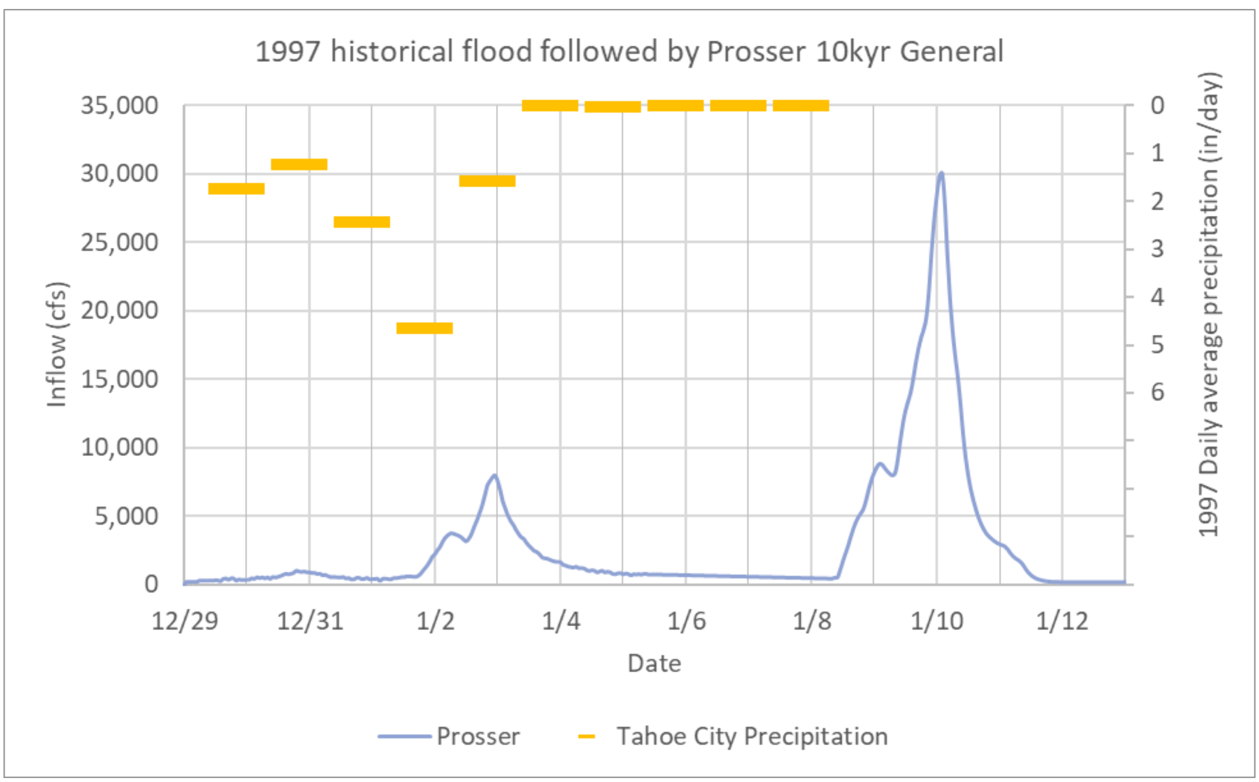

Figure 5: Prosser 10kyr General with 1997 historical flood as the antecedent event

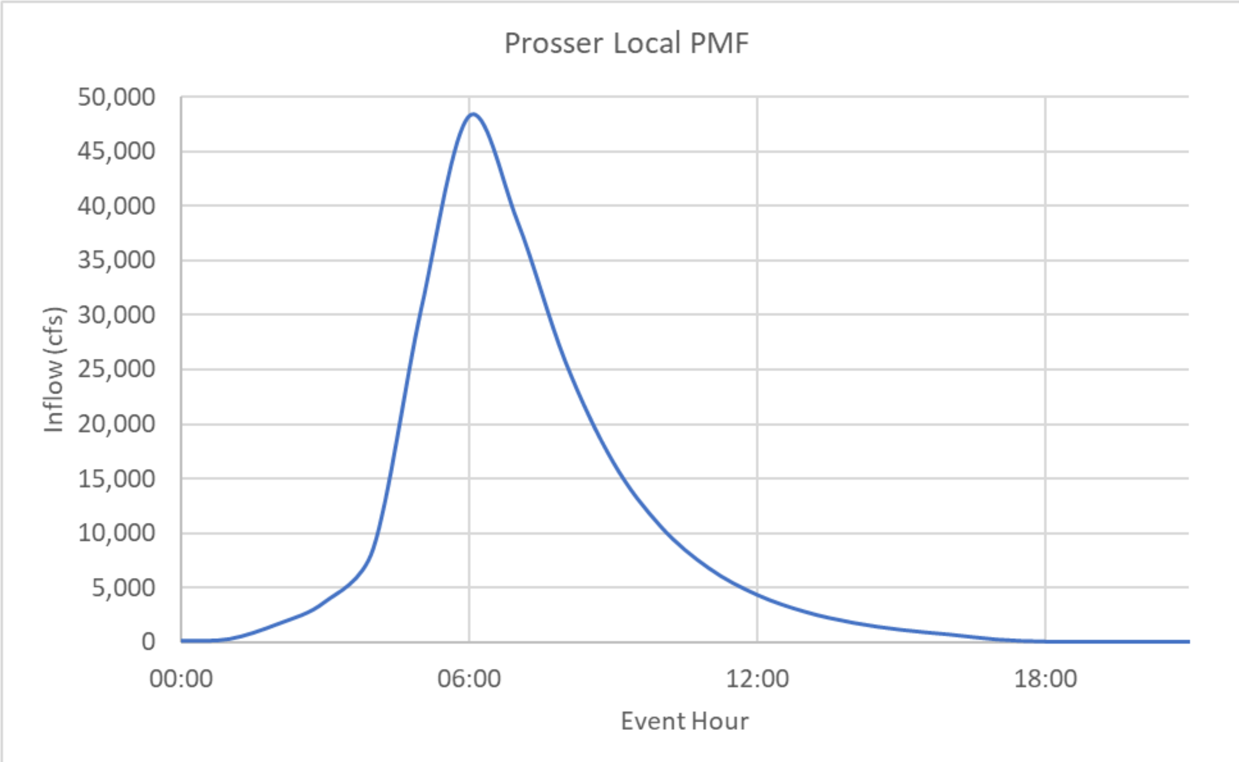

Figure 6: Prosser Local PMF. This event was assumed to begin after the runoff in 2017

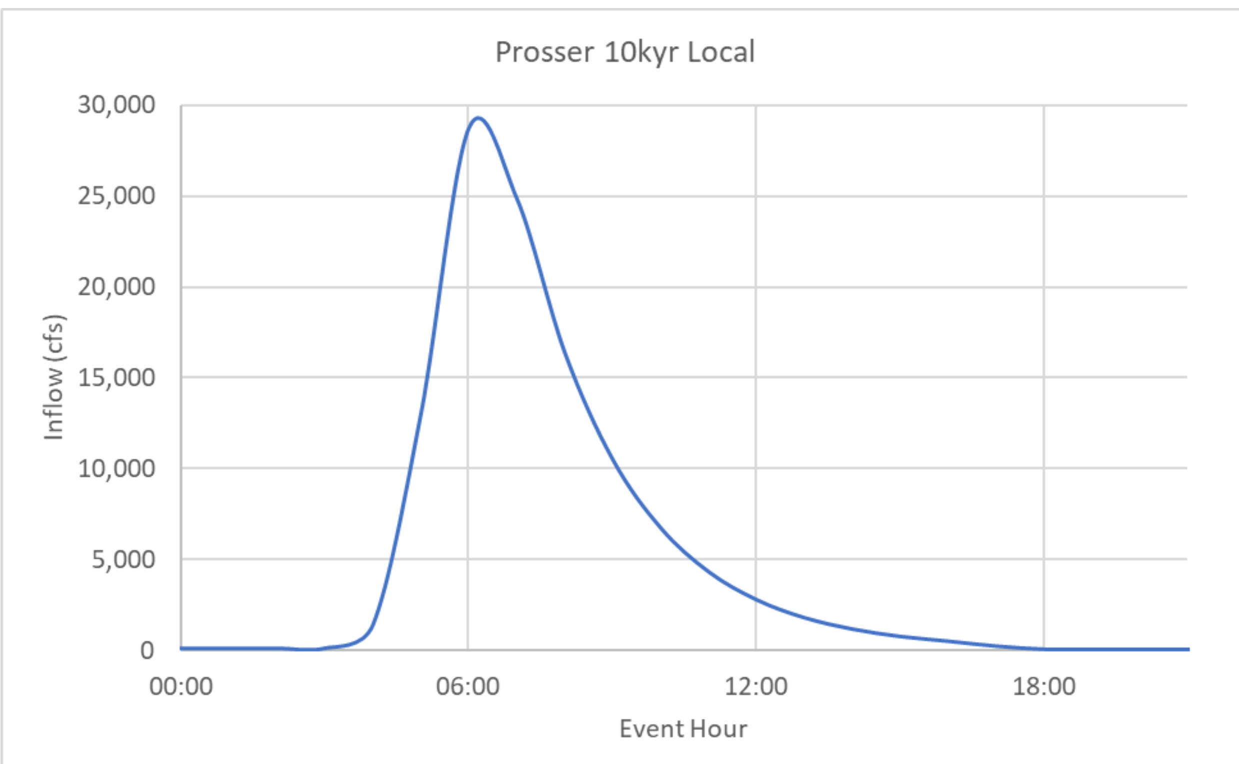

Figure 7: Prosser 10kyr Local. This event was assumed to begin after the runoff in 2017

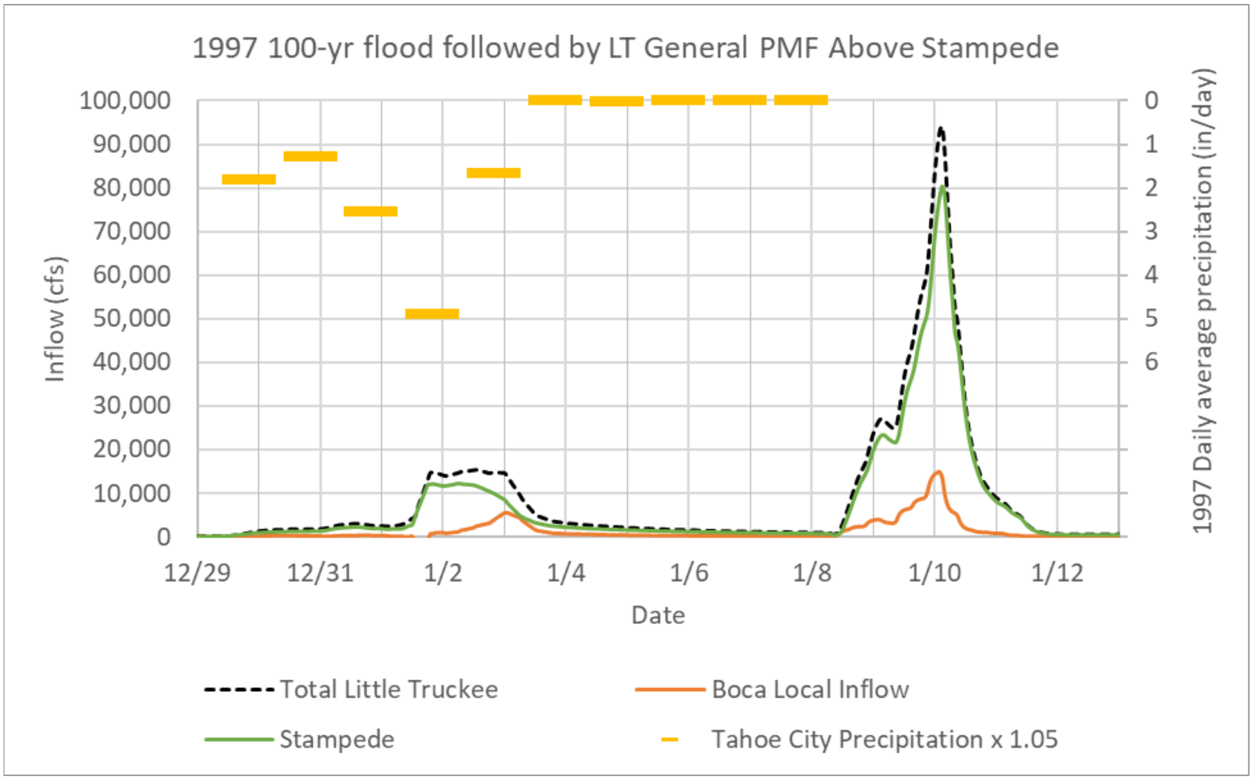

Figure 8: LT General Above Stampede PMF with 1997 100-yr flood as the antecedent event

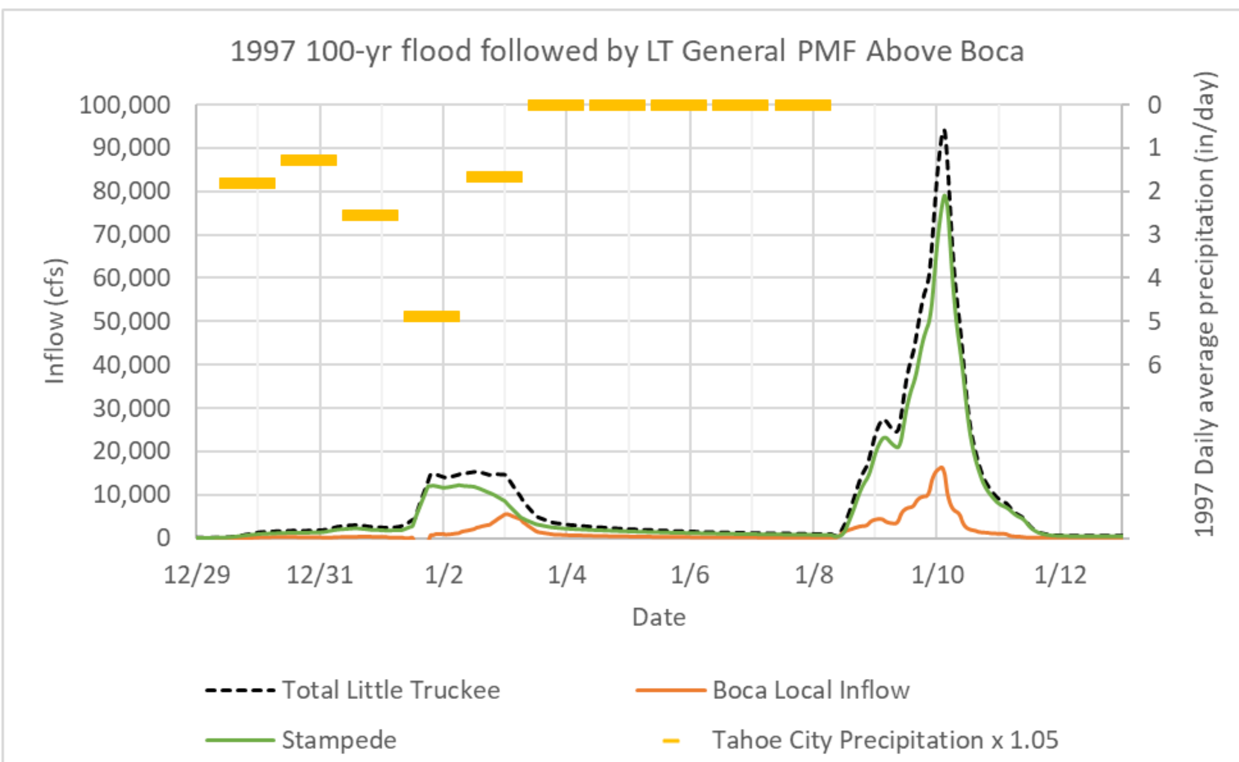

Figure 9: LT General Above Boca PMF event with 1997 100-yr flood as the antecedent event

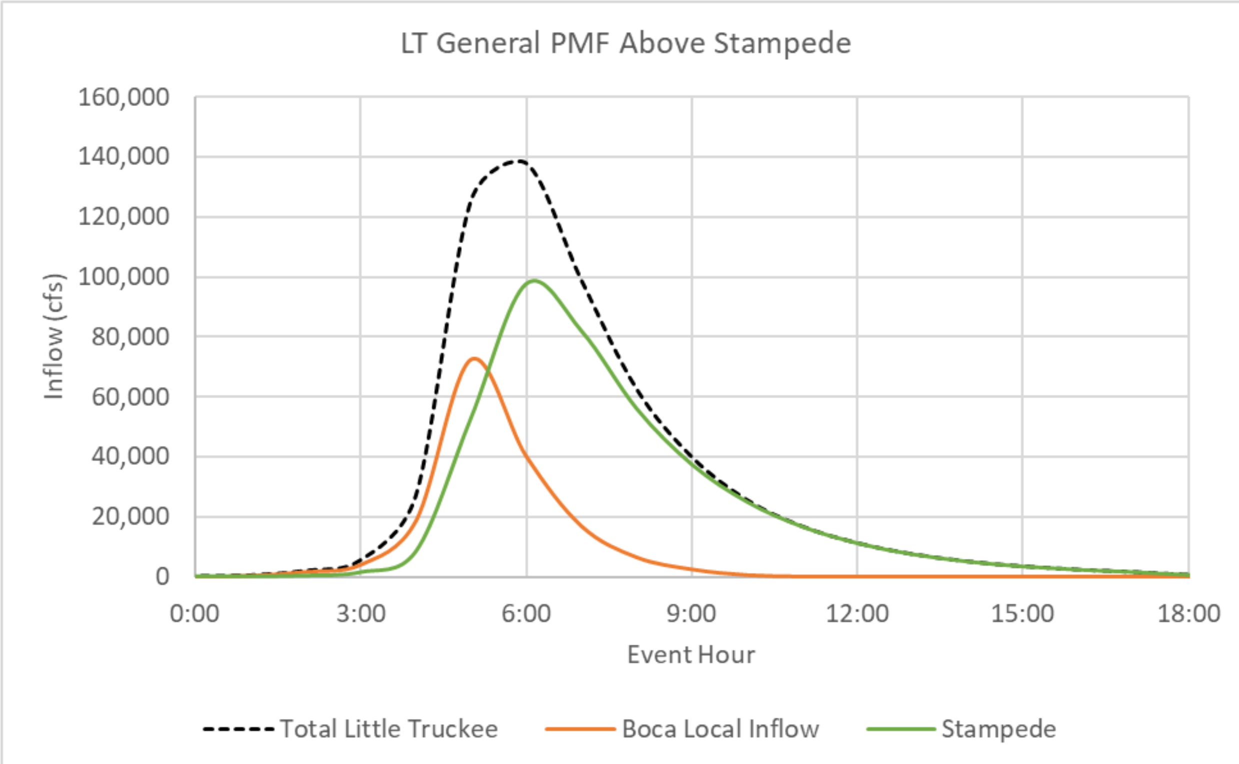

Figure 10: LT Local Above Stampede PMF. This event was assumed to begin after the runoff in 2017

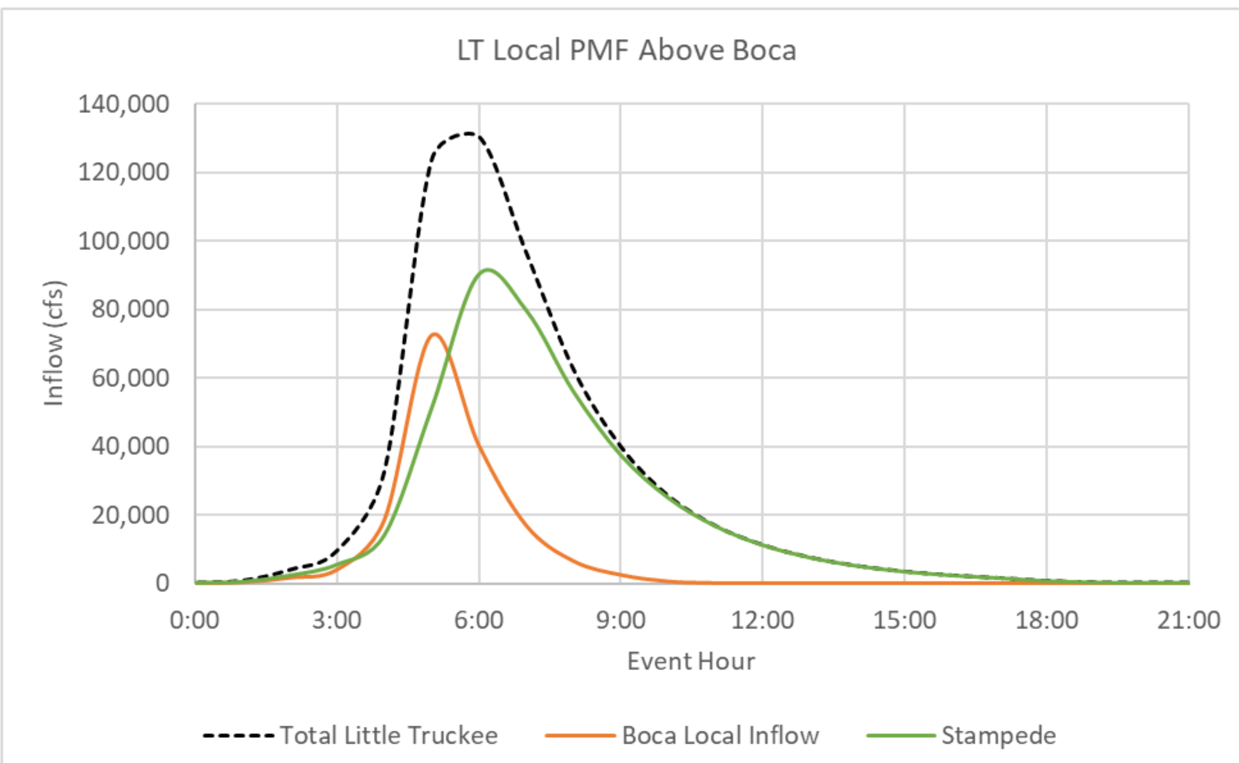

Figure 11: LT Local Above Boca PMF. This event was assumed to begin after the runoff in 2017

3 PMF Routings

3.A Prosser

The minimum Prosser freeboard for each the four Prosser Creek PMFs and scenarios are summarized in Table 5. The two-snowmelt driven PMF events have a negative freeboard for all scenarios indicating that the dam was overtopped (the estimation of overtopping flow is discussed in Section 3.A.1). In both events the antecedent event fills all of the flood space and the five days spacing between the end of precipitation in the antecedent event and the PMF is sufficient to evacuate the surcharge, but it is insufficient to evacuate a significant amount of flood space (as shown in Sections 3.A.2 and 3.A.3). The amount that the dam crest was exceeded is the same in all scenarios, 2.51 feet and 2.61 feet in the General and 10kyr PMFs, respectively. The Local events have the same initialization assumption (top of spillway) and peak elevation in all scenarios. All Local events have more than 7 feet of freeboard.

Table 5: Prosser freeboard summary by PMF Event

Event	Baseline	Preferred Operational Scenario	Revised Guide Curve
Prosser General PMF	-2.54	-2.53	-2.53
Prosser 10kyr General	-2.53	-2.53	-2.53
Prosser Local PMF	7.28	7.27	7.27
Prosser 10kyr Local	13.72	13.69	13.69

Comparison of the pool elevation in the different scenarios for each event as well as plots of Prosser storage, outflow, and unregulated spill (sum of the flow over the spillway and top of the dam) for each scenario and event are summarized in the following sections which are organized by event.

3.A.1 Prosser Dam Overtopping Flow Estimate

Given that the General PMF and 10kyr General storms show that the dam is overtopped in all scenarios, it is necessary to estimate the flow that would occur over the dam to accurately capture the maximum pool elevations during the events.

In 2005, Prosser's dam was raised with the installation of a 2 foot 8-inch-tall concrete parapet wall barrier on the upstream edge of the dam. This raises the top of the dam to 5767.6' NAVD88 or 5763.6' NGVD29 (note that NGVD29 is used for all figures in this analysis while NAVD88 is used for some design drawings). Based on the SOP, the flow over the parapet wall was estimated based on a broad crested weir equation ($Q = CLH^{\frac{3}{2}}$) with a length of 1,830 feet and a coefficient of 2.62. The resultant flow over the parapet wall and total unregulated flow (including the flow over the spillway) is shown in Figure 12.

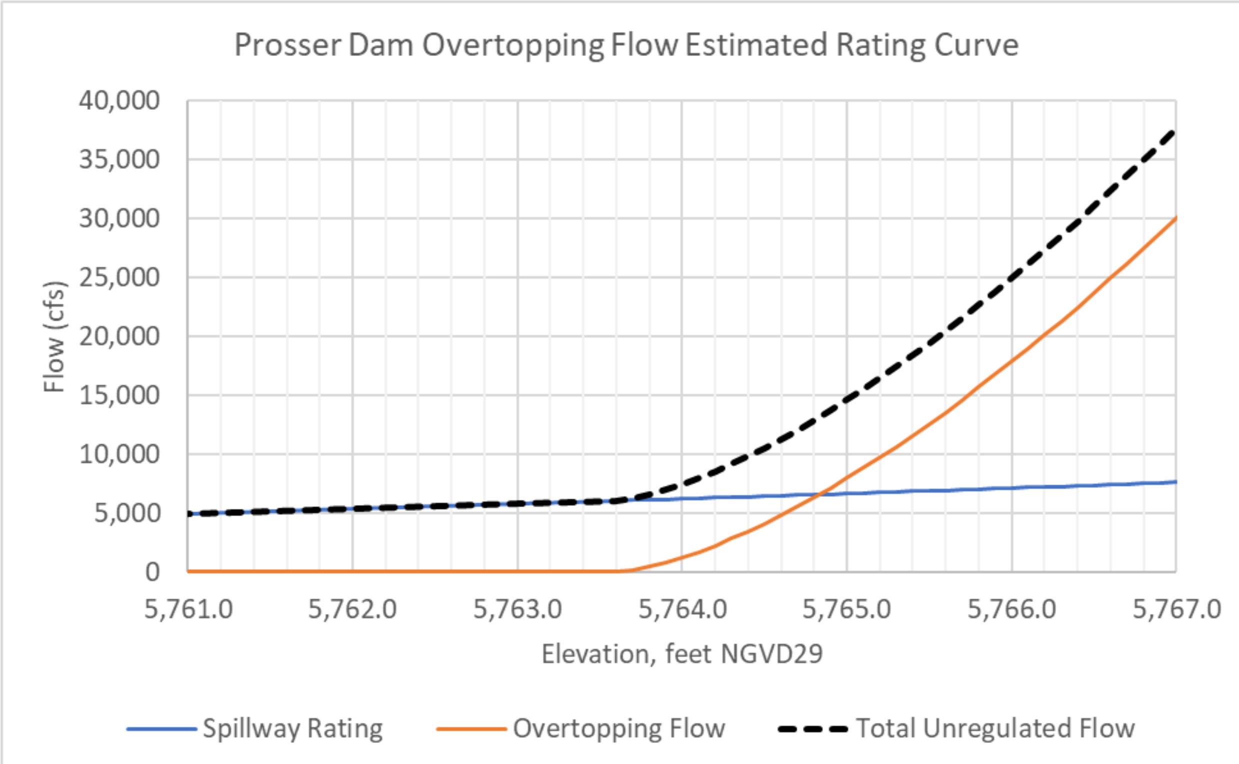

Figure 12: Prosser Dam overtopping flow estimated rating curve

The flow over the dam that occurred in the General PMF and 10kyr General events is summarized in Table 6. In both events the average velocity[7] of the water over the dam peaked at 4.17 feet per second. The total volume of flow over the dam was around 12,000 acre-feet in all scenarios. Note that the 2005 addition to Prosser increased the reservoir capacity by 2,700 acre-feet, so these volumes would be 2,700 acre-feet or 30% more had the addition not taken place.

Table 6: Summary of Prosser Dam overtopping flow

Event	Quantity	Baseline	Preferred Operational Scenario	Revised Guide Curve
Prosser General PMF	Maximum Velocity (ft/s)	4.17	4.17	4.17
	Total Volume (acre-feet)	12,115	12,067	12,068
Prosser 10kyr General	Maximum Velocity (ft/s)	4.17	4.17	4.16
	Total Volume (acre-feet)	12,167	12,112	12,112

[7] The average velocity was computed by dividing the flowrate (cfs) by the length of dam (feet) and the depth of flow over dam (feet). This is the average flow velocity at the upstream edge of the dam and does not account for the nappe or estimate the velocity of flow down the dam.

3.A.2 Prosser General PMF

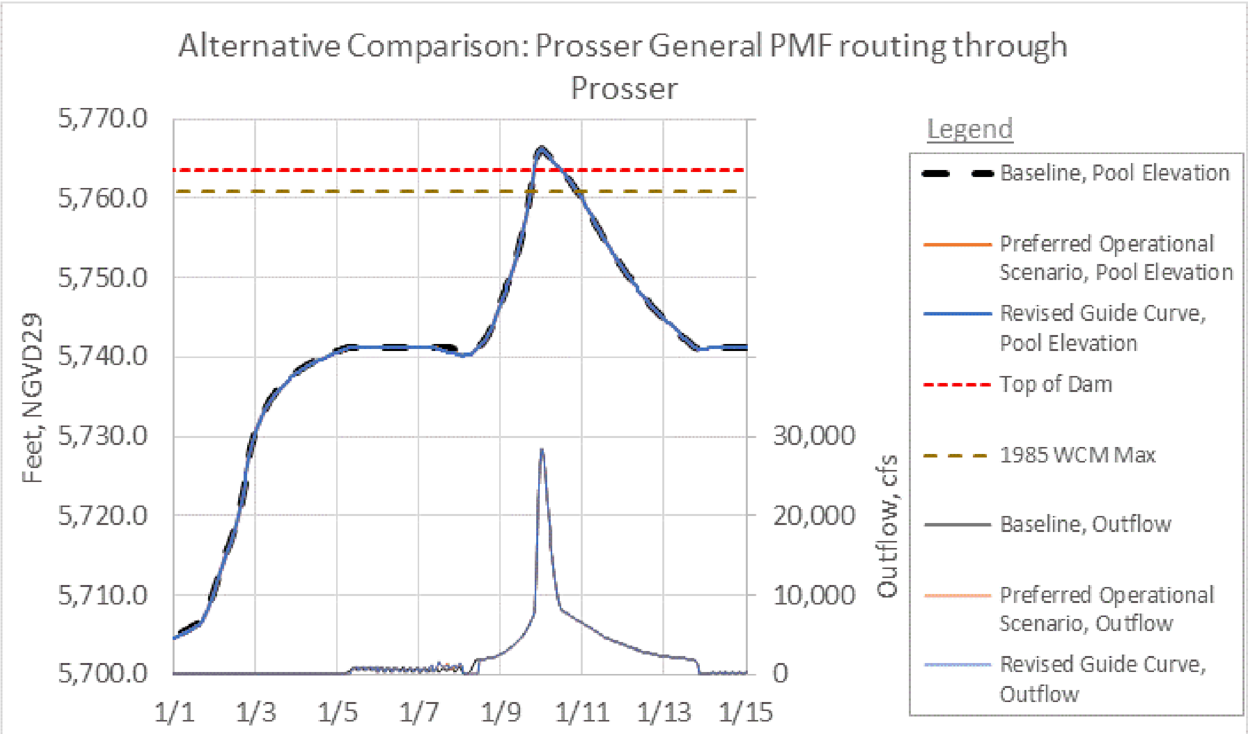

Figure 13: Comparison of Prosser Pool Elevation and outflow in Prosser General PMF

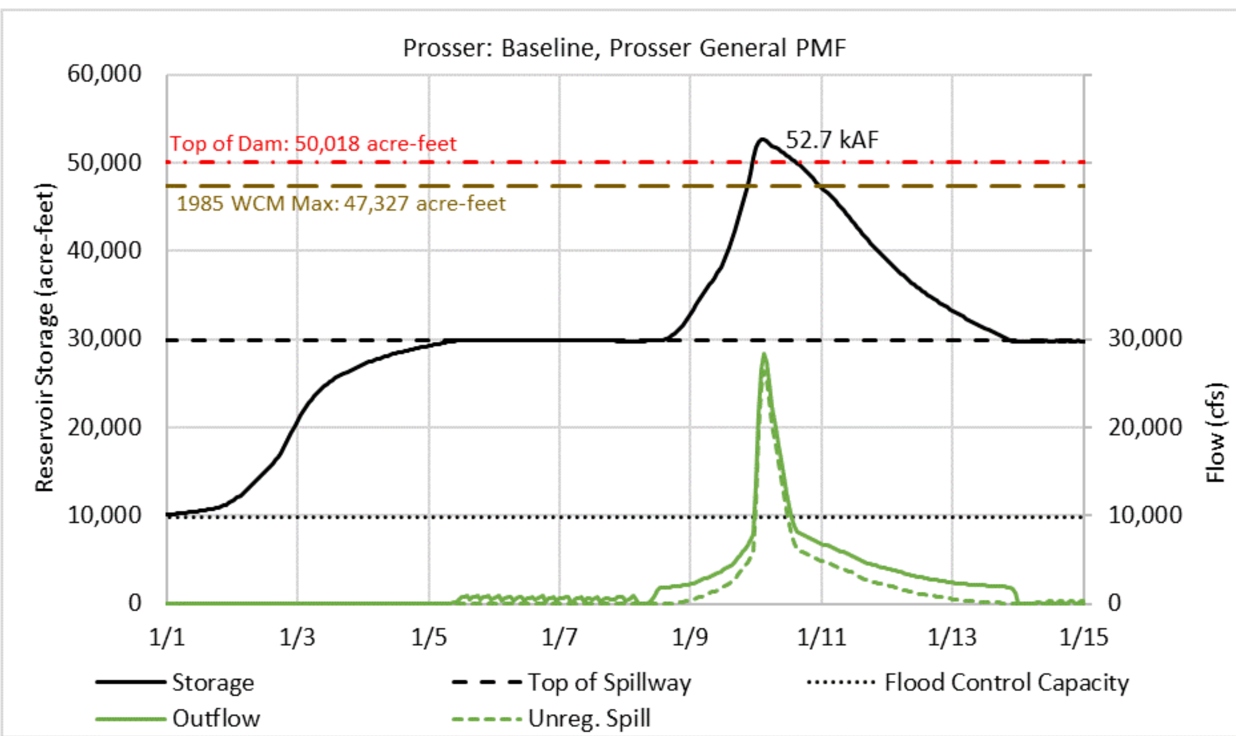

Figure 14: Baseline routing of Prosser General PMF through Prosser

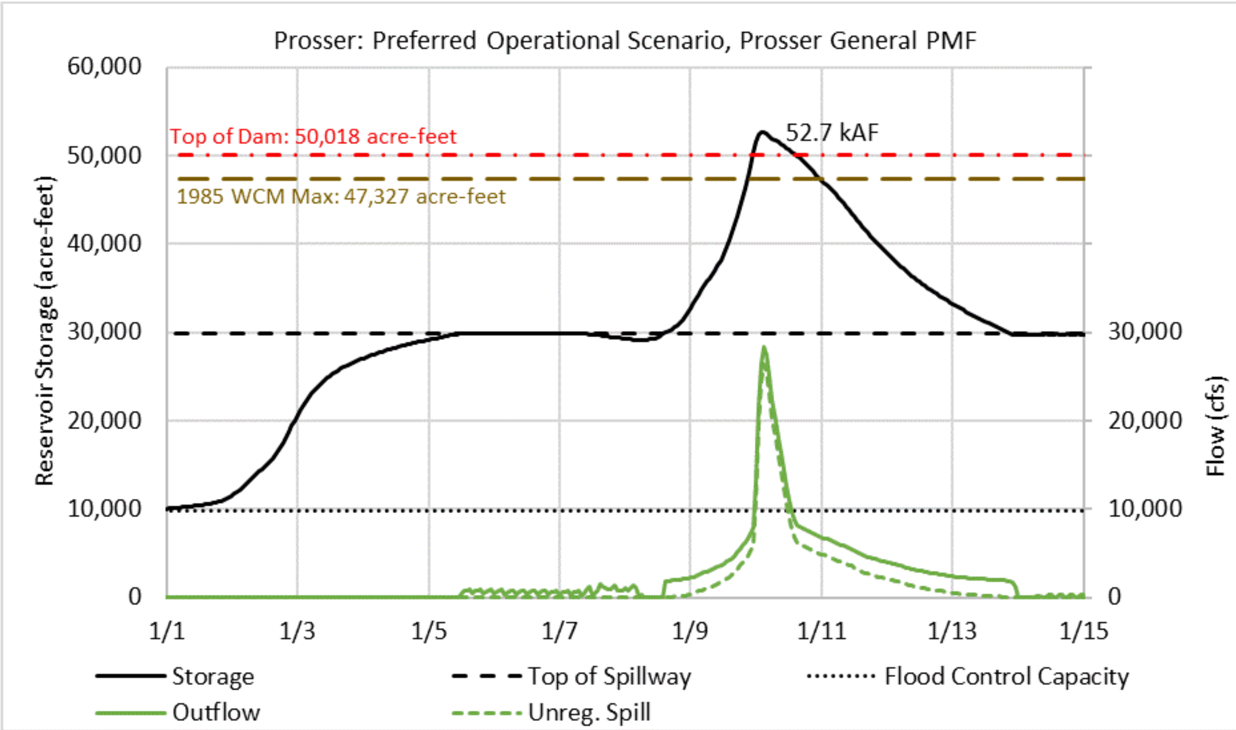

Figure 15: Preferred Operational Scenario routing of Prosser General PMF through Prosser

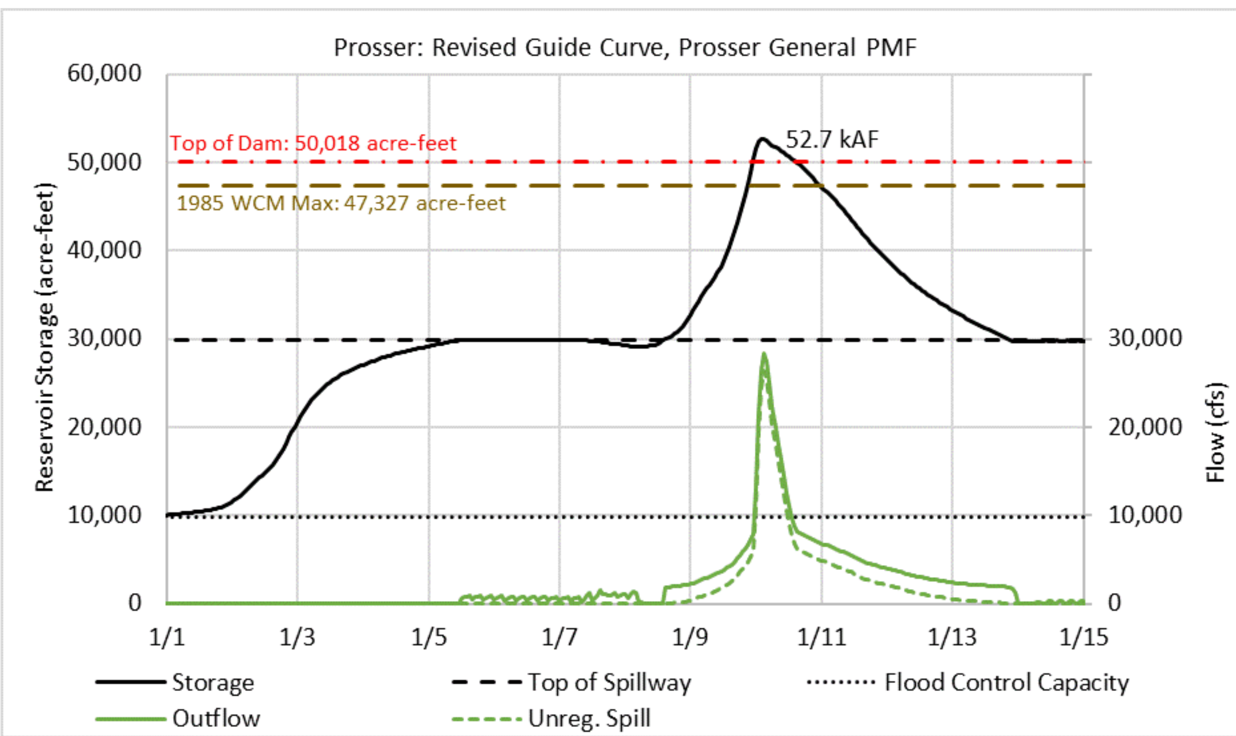

Figure 16: Revised Guide Curve routing of Prosser General PMF through Prosser

3.A.3 Prosser 10kyr General

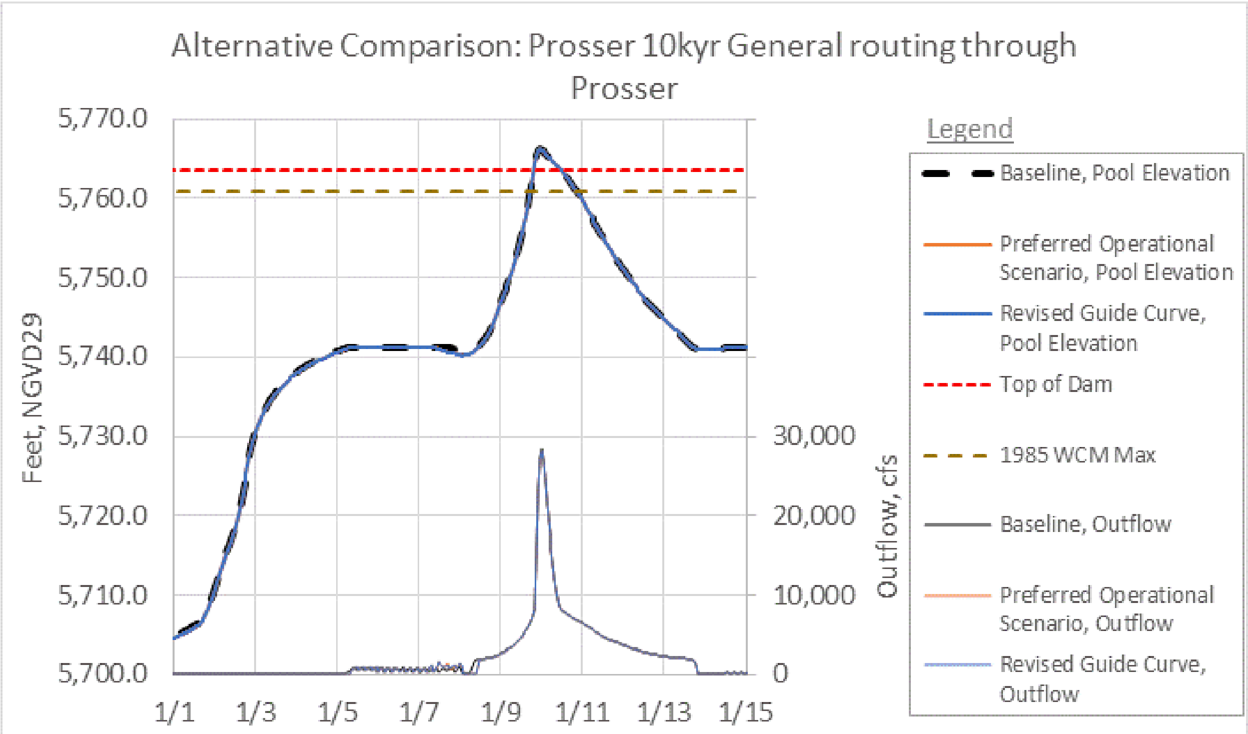

Figure 17: Comparison of Prosser Pool Elevation and outflow in Prosser 10kyr General

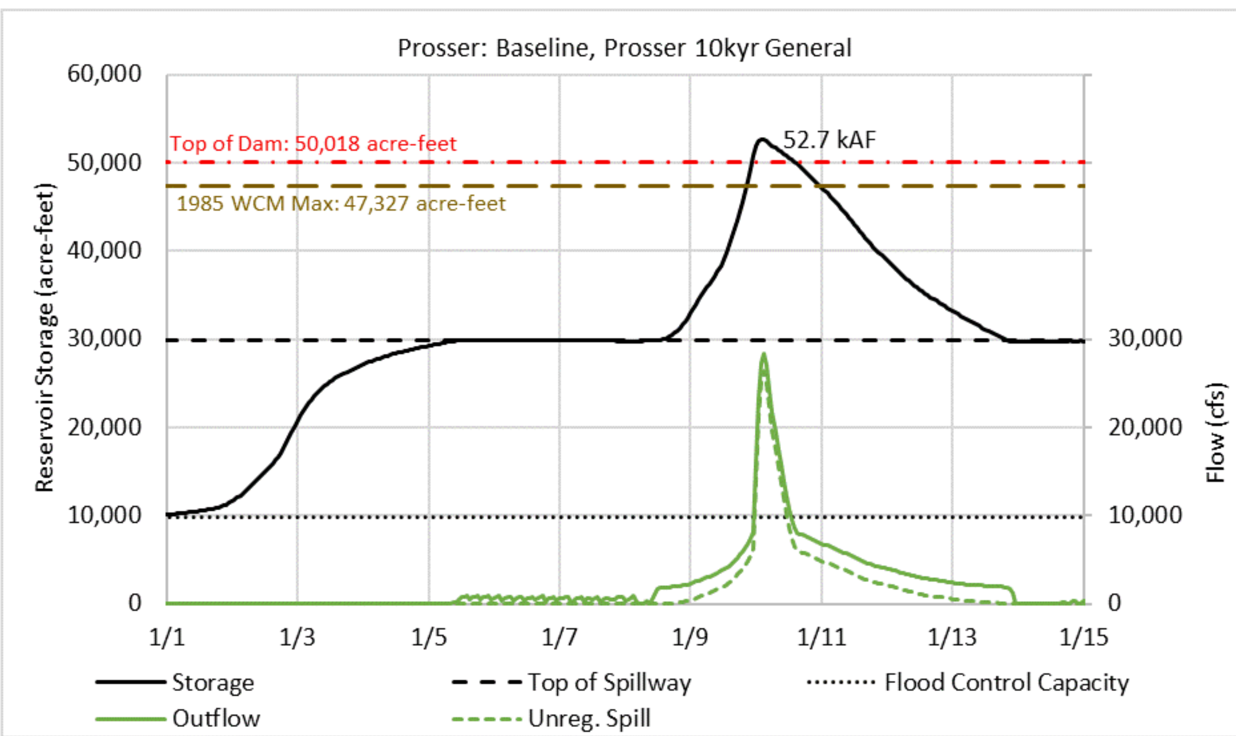

Figure 18: Baseline routing of Prosser 10kyr General through Prosser

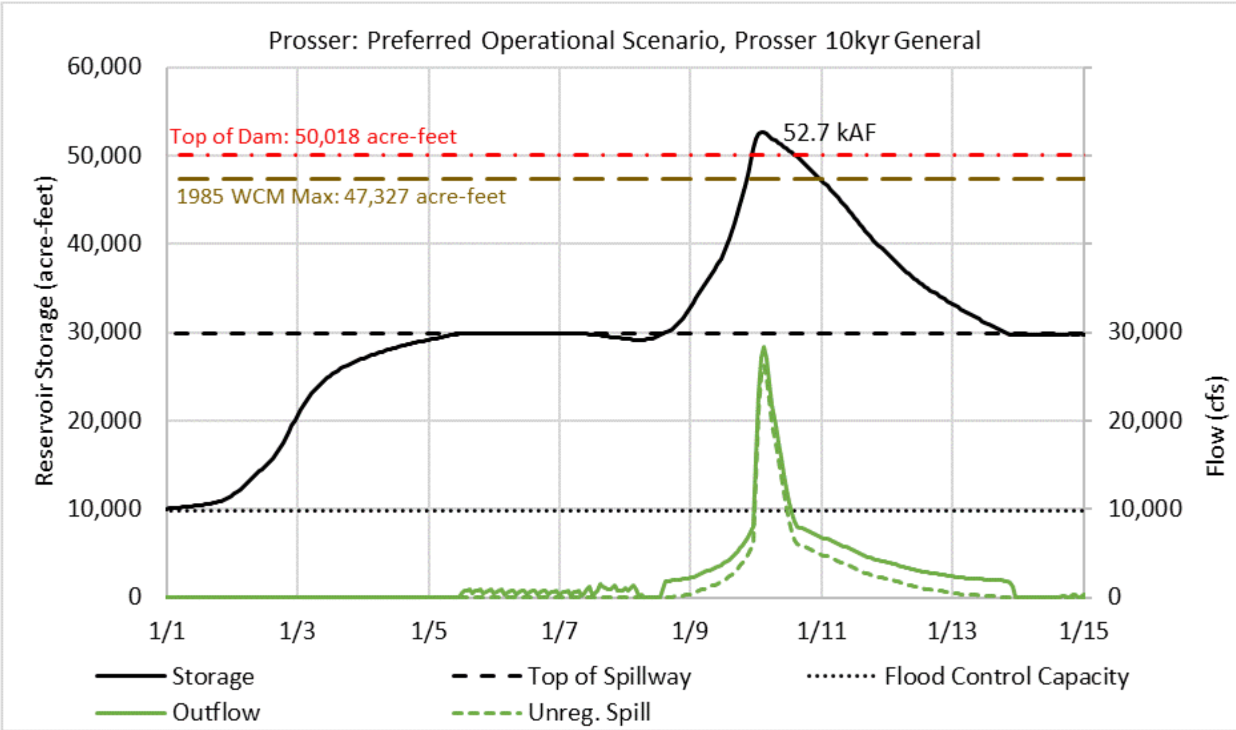

Figure 19: Preferred Operational Scenario routing of Prosser 10kyr General through Prosser

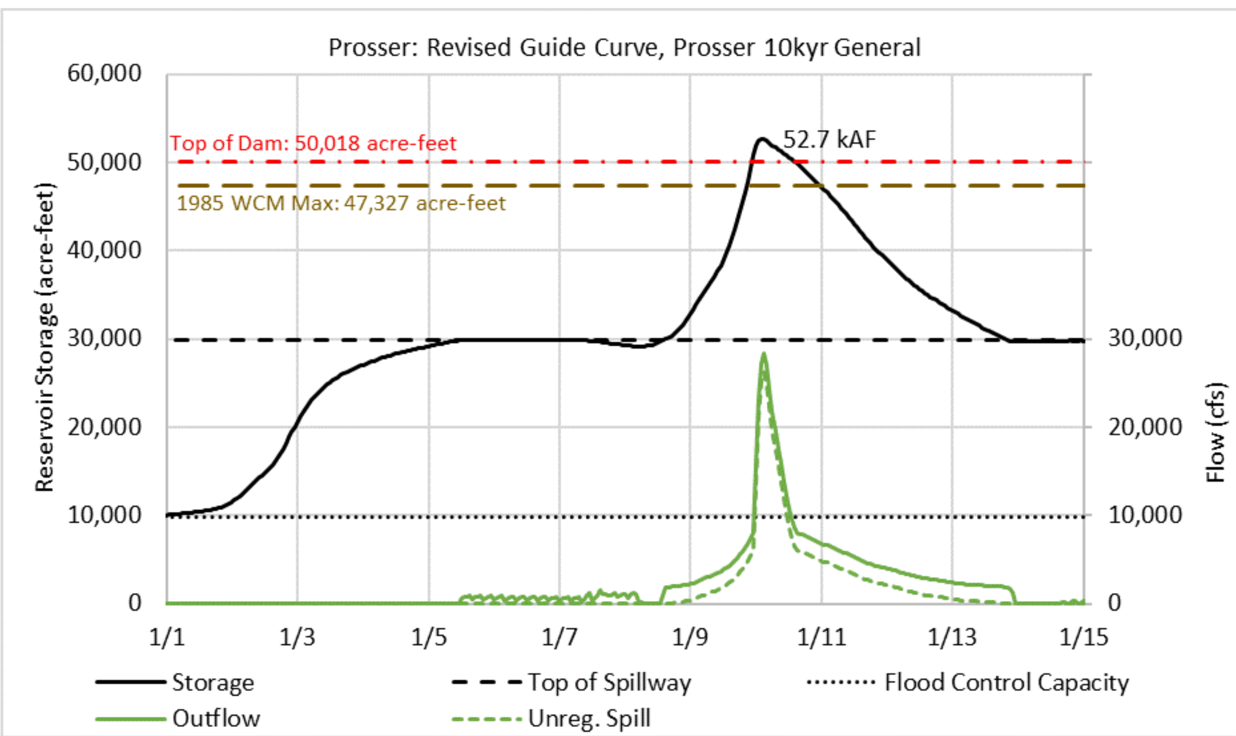

Figure 20: Revised Guide Curve routing of Prosser 10kyr General through Prosser

3.A.4 Prosser Local PMF

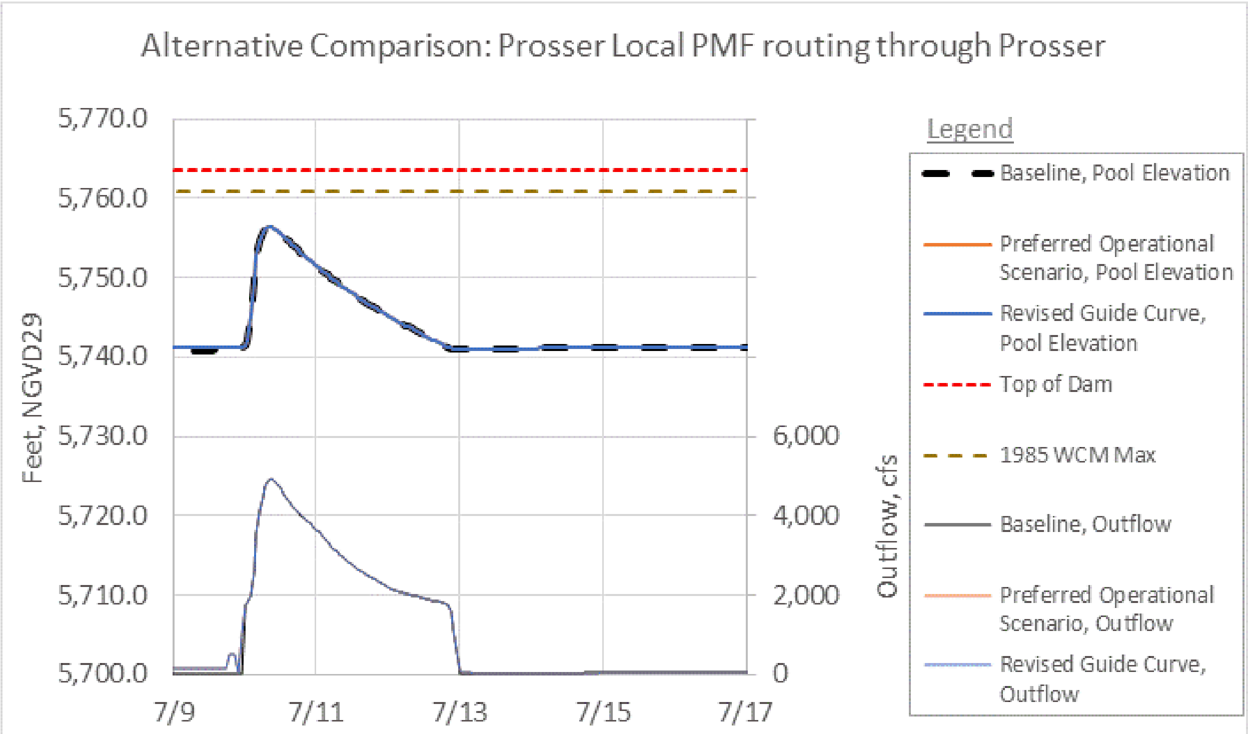

Figure 21: Comparison of Prosser Pool Elevation and outflow in Prosser Local PMF

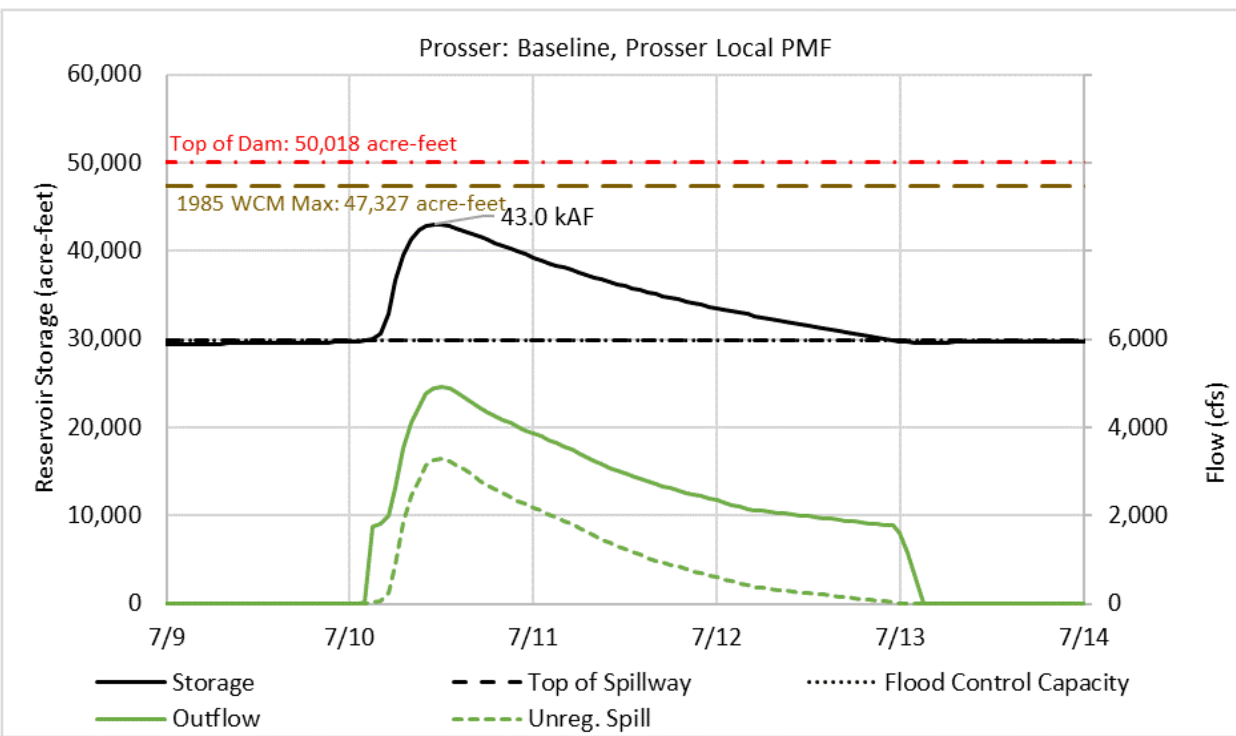

Figure 22: Baseline routing of Prosser Local PMF through Prosser

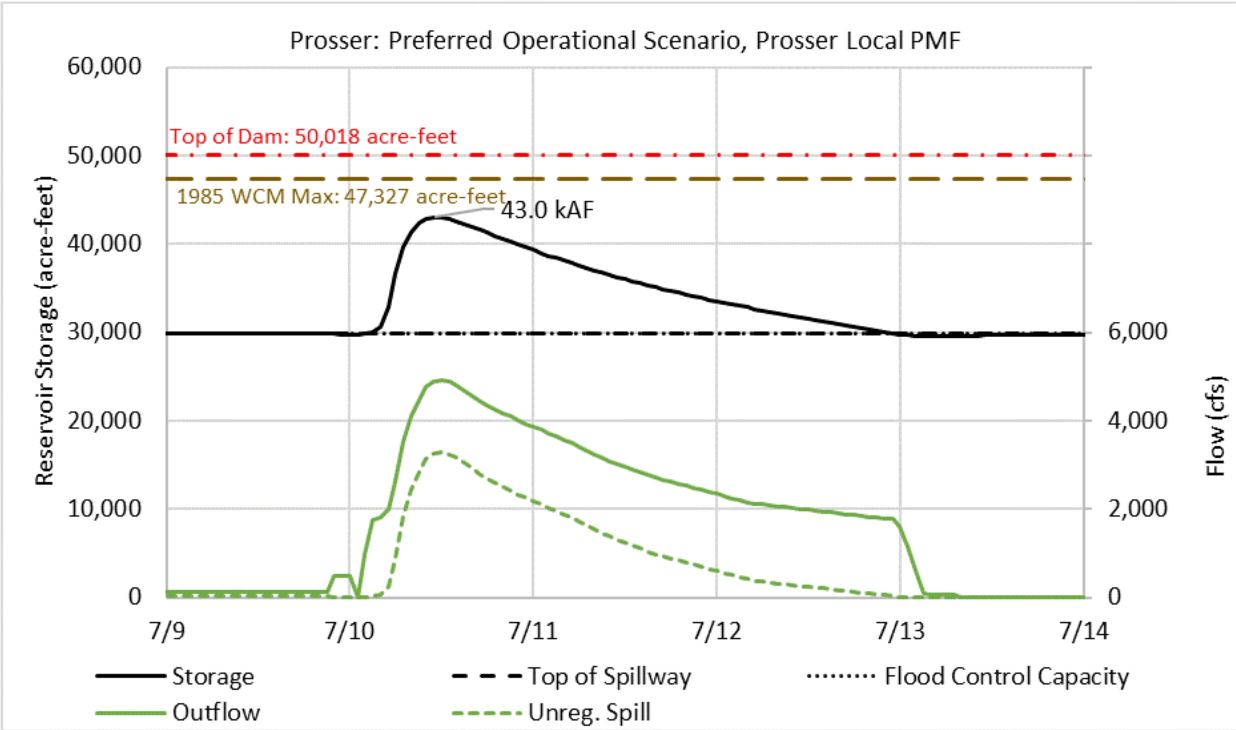

Figure 23: Preferred Operational Scenario routing of Prosser Local PMF through Prosser

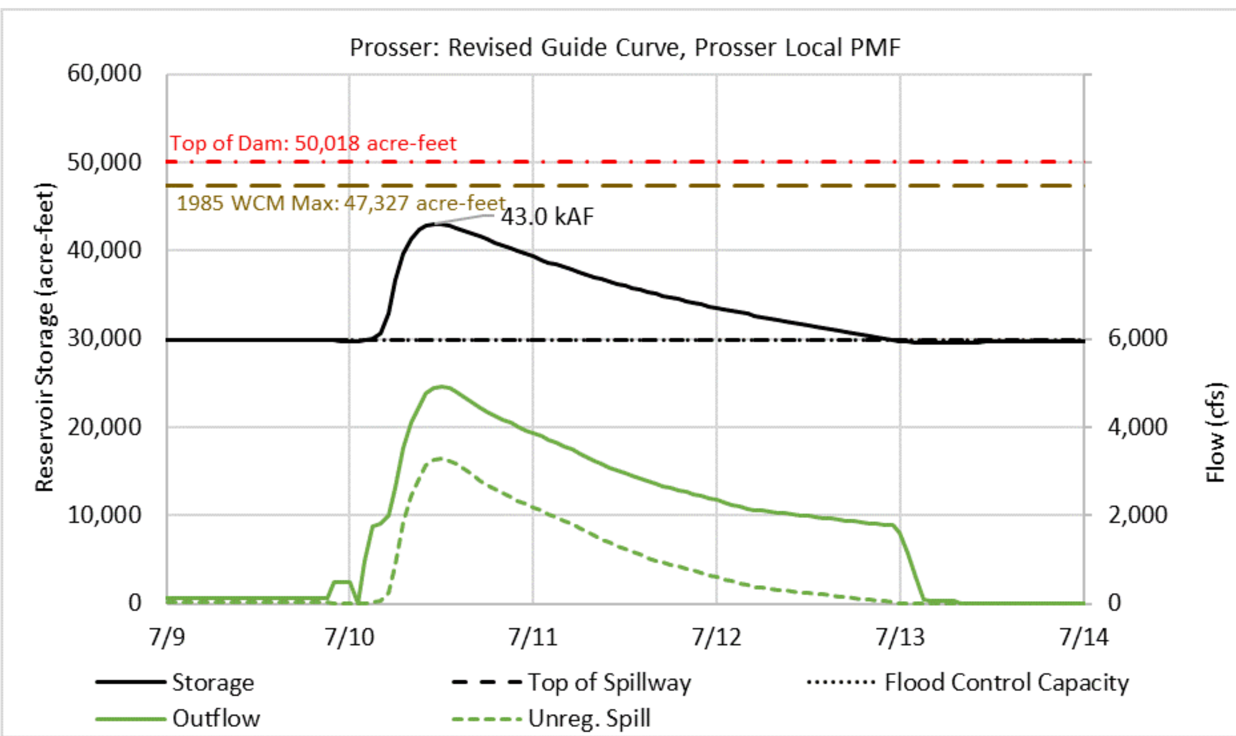

Figure 24: Revised Guide Curve routing of Prosser Local PMF through Prosser

3.A.5 Prosser 10kyr Local

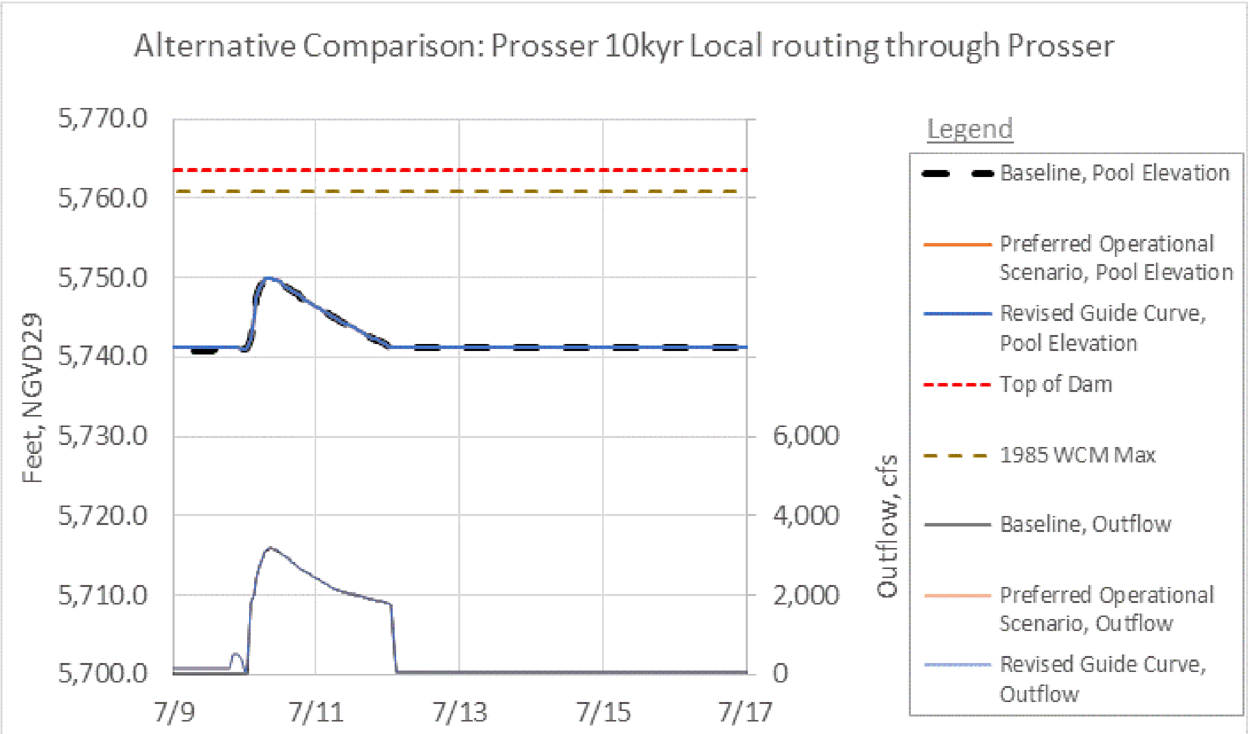

Figure 25: Comparison of Prosser Pool Elevation and outflow in Prosser 10kyr Local

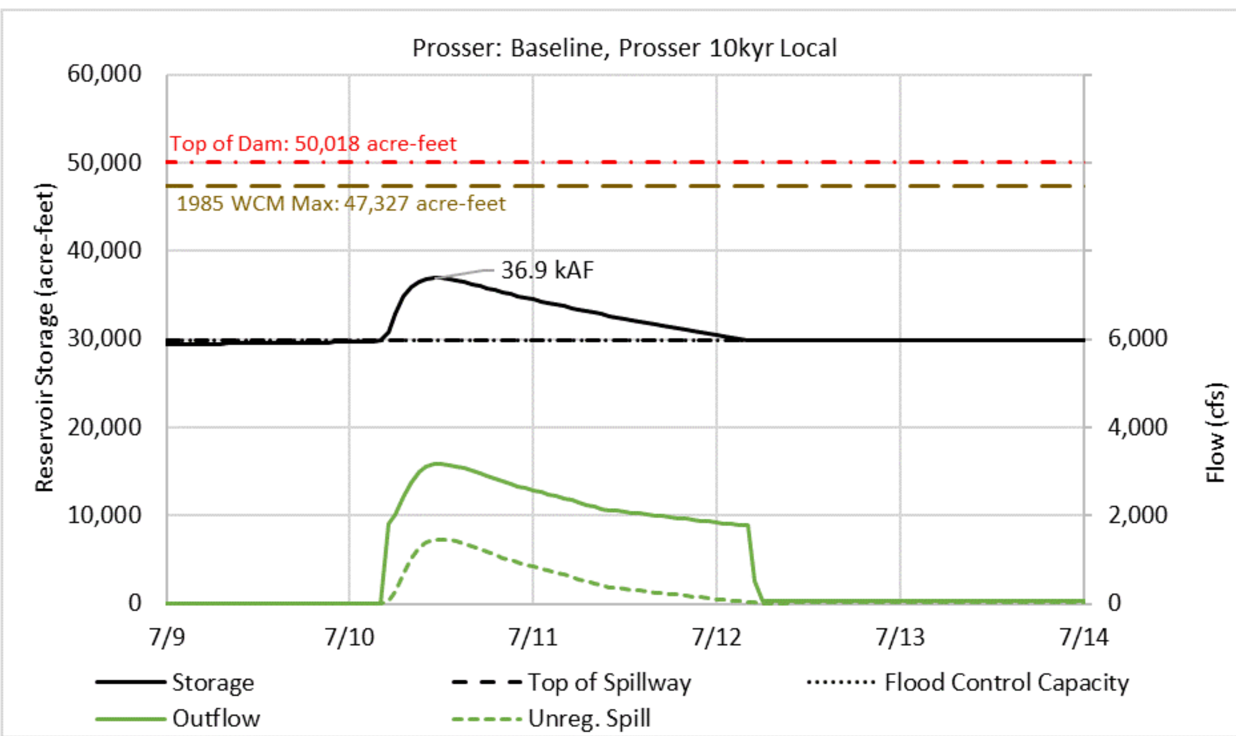

Figure 26: Baseline routing of Prosser 10kyr Local through Prosser

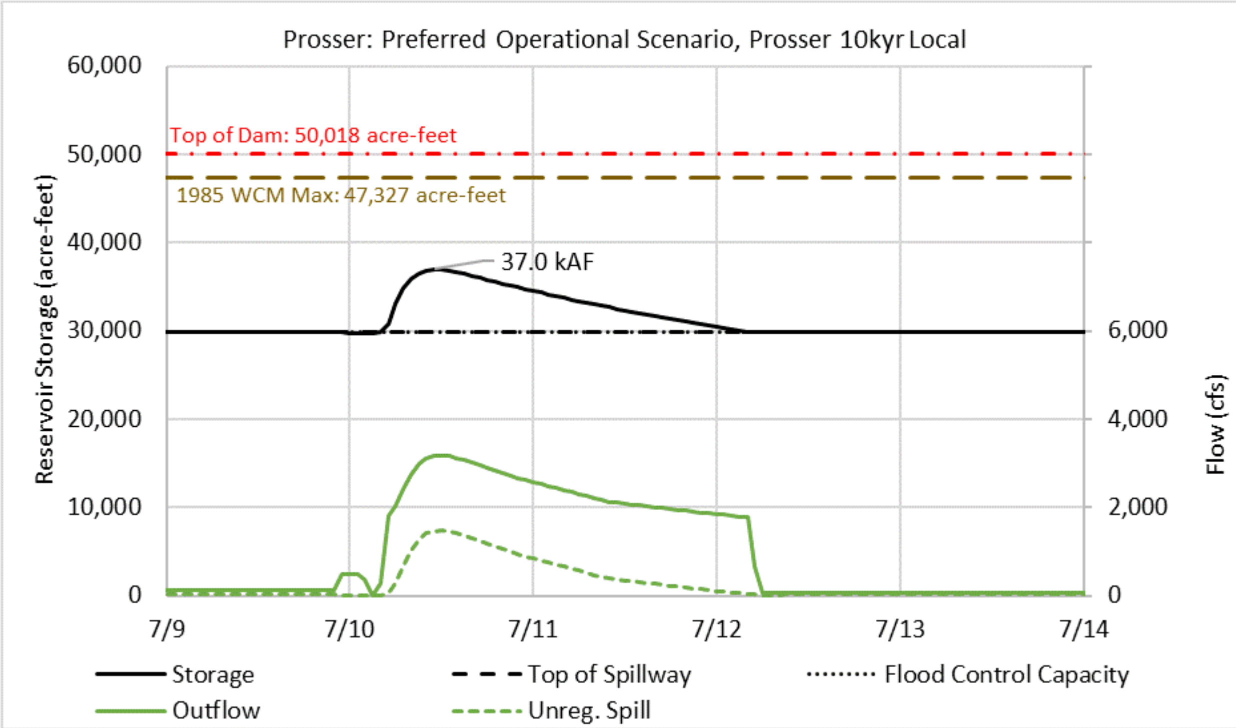

Figure 27: Preferred Operational Scenario routing of Prosser 10kyr Local through Prosser

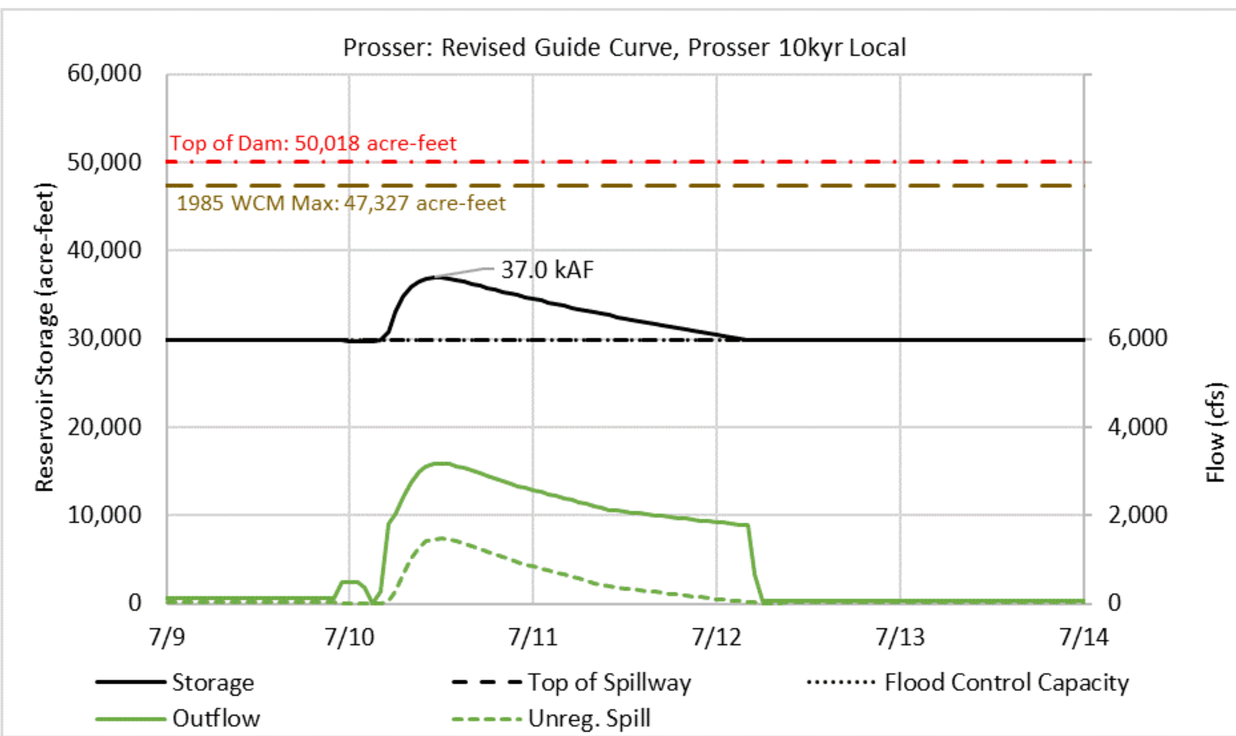

Figure 28: Revised Guide Curve routing of Prosser 10kyr Local through Prosser

3.B Stampede

The minimum Stampede freeboard for each the four Little Truckee PMFs and scenarios are summarized in Table 7. The two snowmelt driven events have a negative freeboard indicating that the dam was overtopped (the estimation methods for overtopping flow are summarized in Section 3.B.1). In both events the antecedent event surcharges Stampede. The five day spacing between the end of precipitation in the antecedent event and the PMF is insufficient to draw the reservoir back down below the spillway so that there is 3,500 acre-feet more storage (1 foot of elevation) in the reservoir in the Preferred Operational Scenario than in the Baseline leading into the PMF (as shown in Sections 3.B.2 and 3.B.3). However, the amount that the dam crest was exceeded is only 0.21 feet higher in the Preferred and Revised Guide Curve Scenarios than in the Baseline scenario despite the 1-foot higher initial elevation due to the increased head through the event. The Local PMF events have the same initialization assumption (top of spillway) and routing assumptions in all scenarios. These Local events have more than 24 feet of freeboard in all scenarios.

Table 7: Stampede freeboard summary by PMF Event

Event	Baseline	Preferred Operational Scenario	Revised Guide Curve
LT General PMF Above Stampede	-0.45	-0.66	-0.66
LT General PMF Above Boca	-0.26	-0.49	-0.49
LT Local PMF Above Stampede	24.47	24.47	24.47
LT Local PMF Above Boca	24.54	24.54	24.54

Comparison of the pool elevation in the different scenarios for each event as well as plots of Stampede storage, outflow, and unregulated spill (flow over the spillway and top of dam) for each scenario and event are summarized in the following sections which are organized by event.

3.B.1 Stampede Dam Overtopping Flow Estimate

The recent construction project on Stampede raised the height of the dam and the nearby dike from elevation 5,970.0 to an elevation of 5,981.6’ NGVD29 or 5,985.5’ NAVD88 (note that the NGVD29 datum was used in all analysis for this project while NAVD88 was used for the Safety of Dam’s design drawings). The original dam had a length of 1,511 feet while the original dike had a length of 1,449 feet for a total length of 2,960 feet In between the dam and the dike was a section of natural ground that was higher in elevation than the dam and dike crest elevation. The crest width of both the dam and dike is 40-foot wide, and a 30-foot-wide roadway runs over both the dam and dike. The dam is the main impoundment of water while the dike only impounds water when the elevation is higher than 5,885.0’. During the 2017 construction, both the dam and the dike were raised to an elevation of 5,981.6’. Due to the raise in elevation of the dam and dike, the section of natural ground between the dam and dike also needed to be raised to elevation 5,981.6’, adding to the length of the dike. After completion of the Dam Safety Project, the dam length increased from 1,551 feet to 1,960 feet and the length of the dike increased from 1,444 feet to 2,400 feet. Because of this consistent elevation, the length of both the dam and the dike contribute to the length of the road that is overtopped giving a total length of 4,360 feet. The Hydraulic Design of Highway Culvert guidance for roadway overtopping was used to extend the spillway rating as shown in Figure 29 (Federal Highway Administration, 2012).

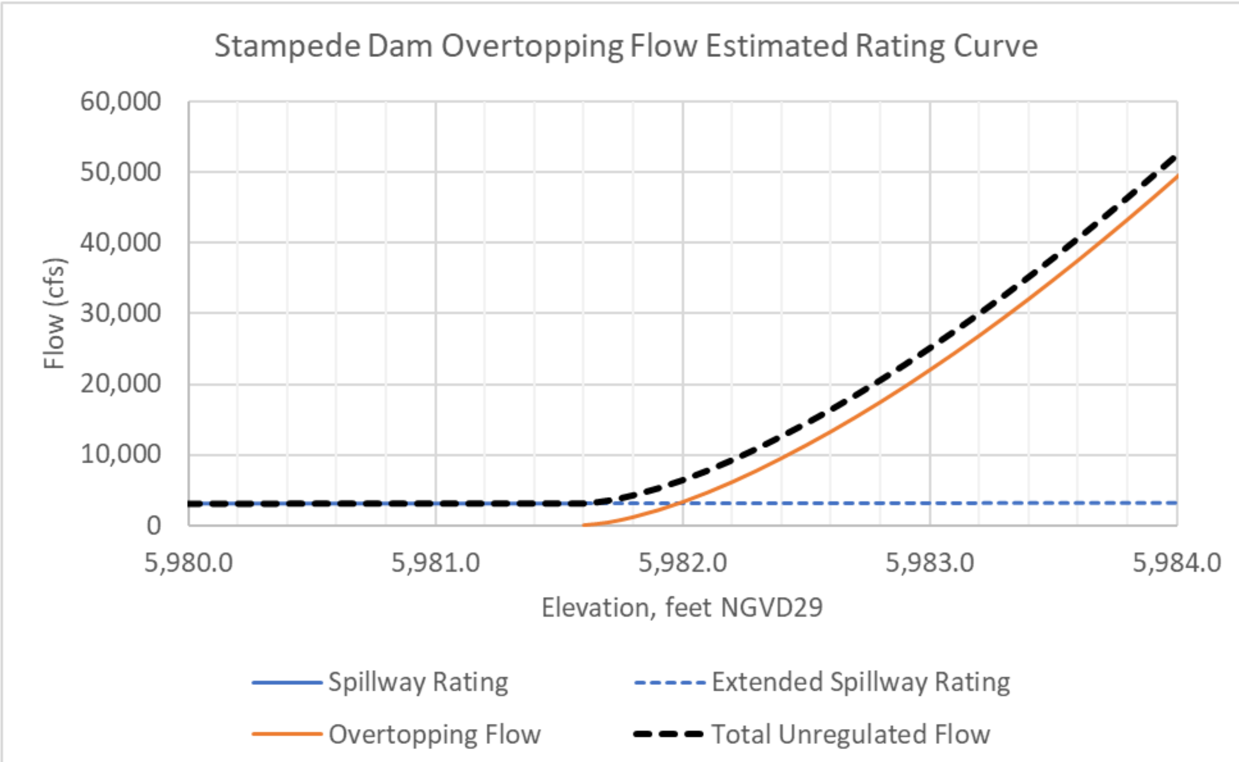

Figure 29: Stampede Dam overtopping flow estimated rating curve

The flow over the dam that occurred in the LT General PMF Above Stampede and LT General PMF Above Boca events is summarized in Table 8. Flow velocities[8] and volumes of flow are higher in the Above Stampede Event where the precipitation was centered over the Stampede drainage area. In the Preferred Operational Scenario and the Revised Guide Curve Scenarios the velocity of flow over the dam was 0.56 feet per second, 0.23 feet per second faster than in the Baseline. The total volume of flow over the dam is 859 acre-feet in those scenarios which is 497 acre-feet more than the Baseline. Similar differences exist in the LT General PMF Above Boca scenarios, but the magnitude of the overtopping is less because that event's precipitation was centered on the Boca drainage basin downstream of Stampede. The 2017 dam raise project increased Stampede capacity by 62,800 acre-feet. Without this additional capacity the volume of overtopping flow would be significantly higher and may have caused Boca to overtop as well.

[8] The average velocity was computed by dividing the flowrate (cfs) by the length of dam (feet) and the depth of flow over dam (feet). This is the flow velocity at the upstream edge of the dam and does not account for the nappe or estimate the velocity of flow down the dam.

Table 8: Summary of Stampede Dam overtopping flow

Event	Quantity	Baseline	Preferred Operational Scenario	Revised Guide Curve
LT General PMF Above Stampede	Maximum Velocity (ft/s)	0.33	0.56	0.56
	Total Volume (acre-feet)	362	859	859
LT General PMF Above Boca	Maximum Velocity (ft/s)	0.15	0.37	0.37
	Total Volume (acre-feet)	84	424	424

3.B.2 LT General PMF Abv Stampede

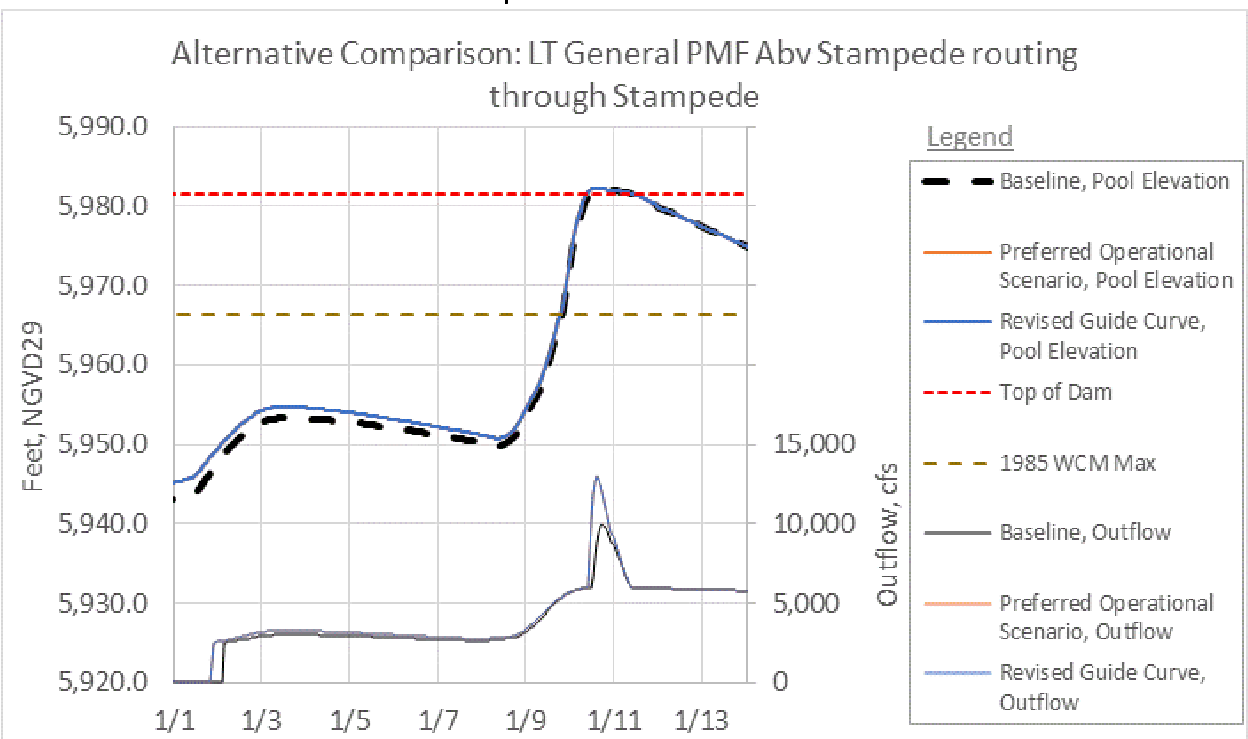

Figure 30: Comparison of Stampede Pool Elevation and outflow in LT General PMF Above Stampede

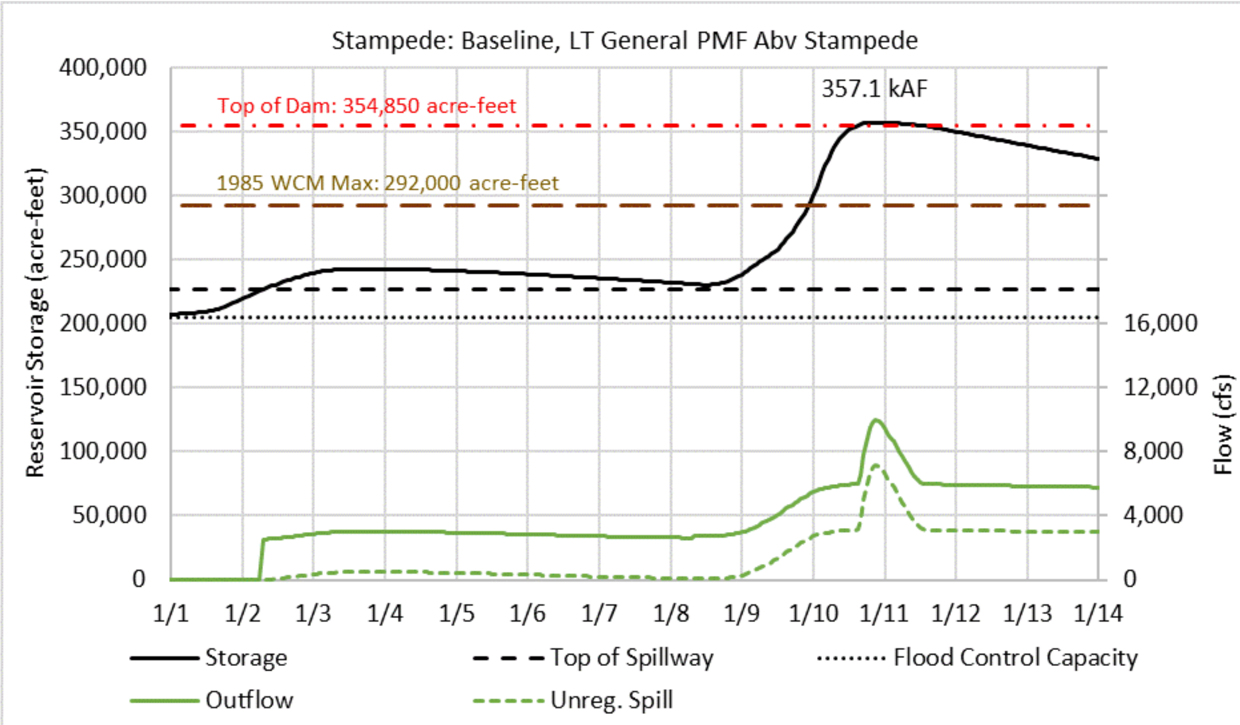

Figure 31: Baseline routing of LT General PMF Above Stampede through Stampede

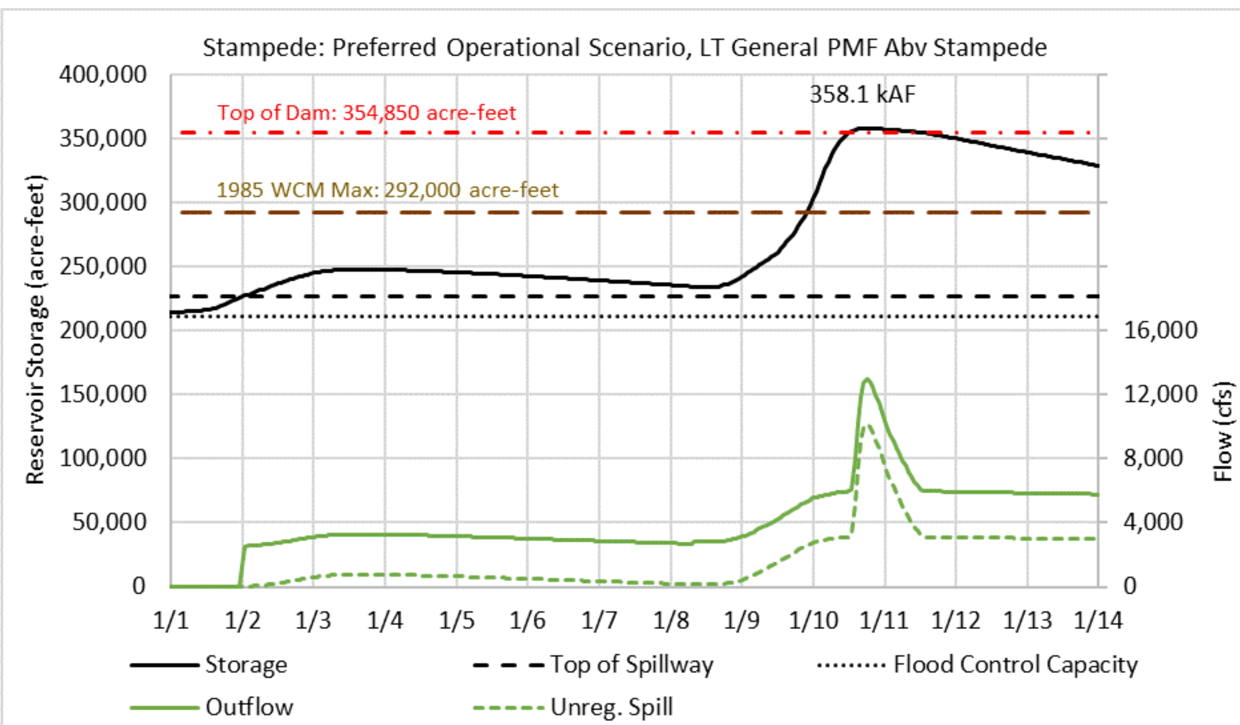

Figure 32: Preferred Operational Scenario routing of LT General PMF Above Stampede through Stampede

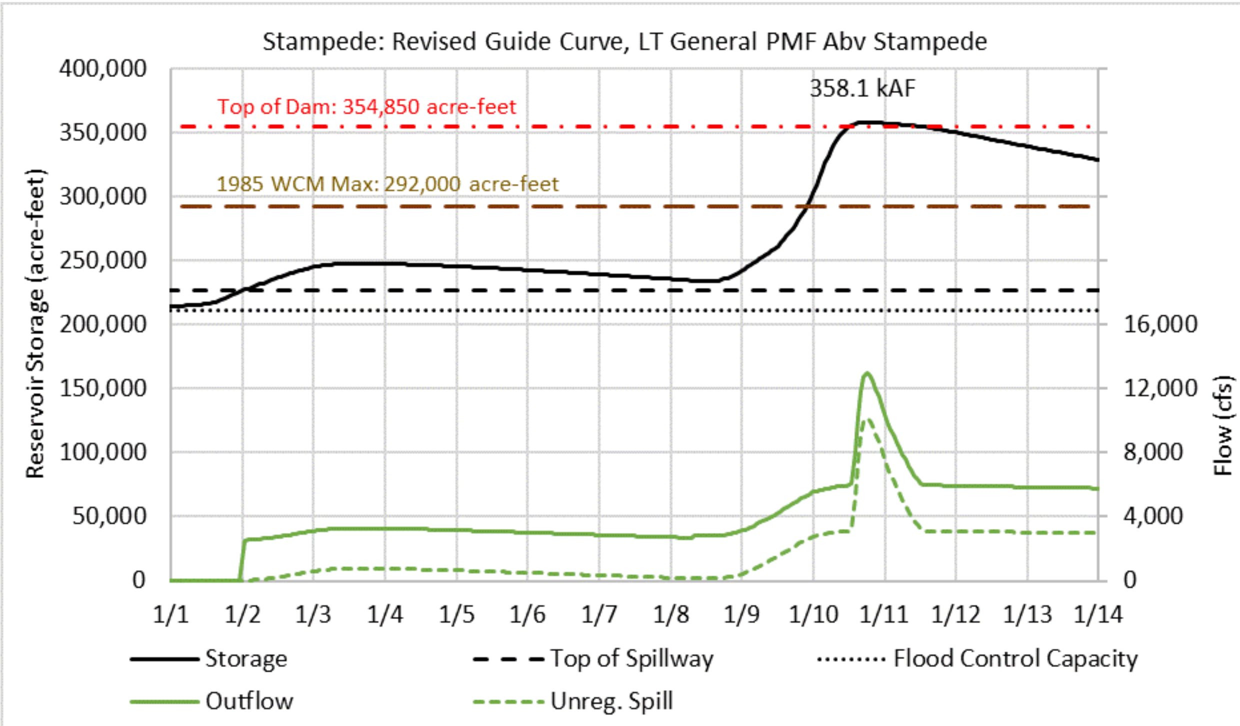

Figure 33: Revised Guide Curve routing of LT General PMF Above Stampede through Stampede

3.B.3 LT General PMF Abv Boca

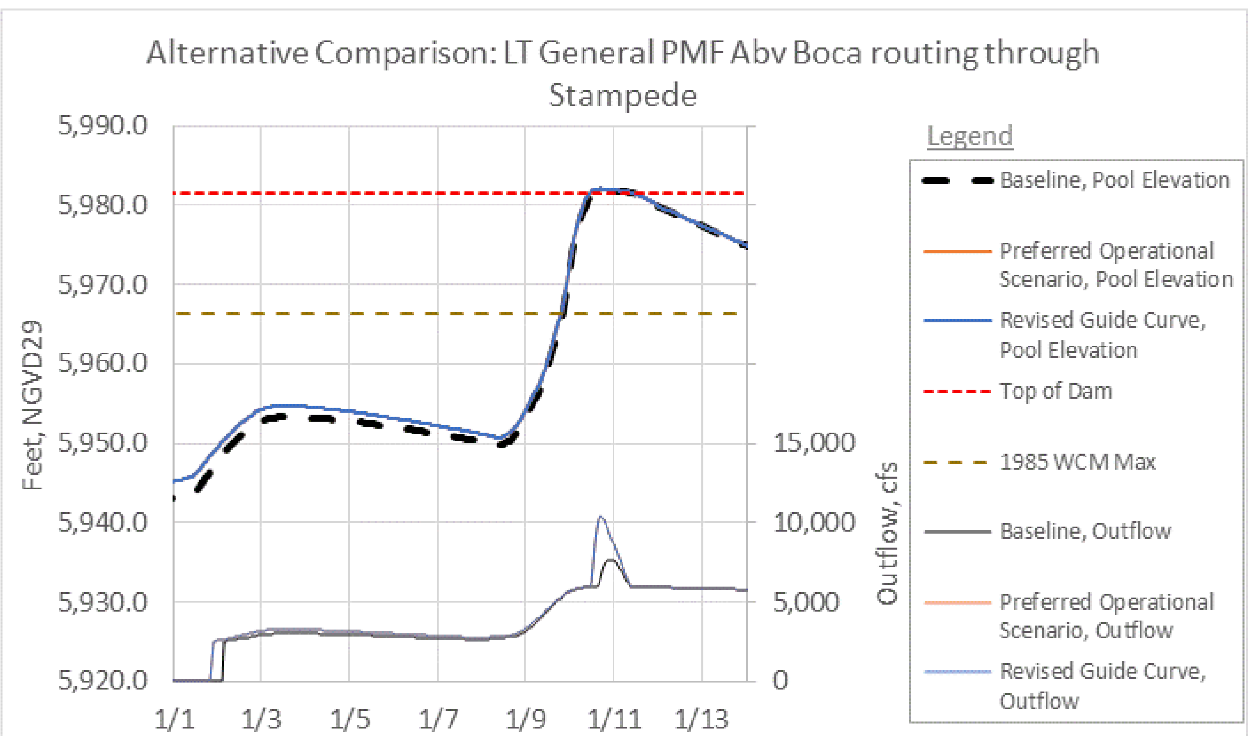

Figure 34: Comparison of Stampede Pool Elevation and outflow in LT General PMF Above Boca

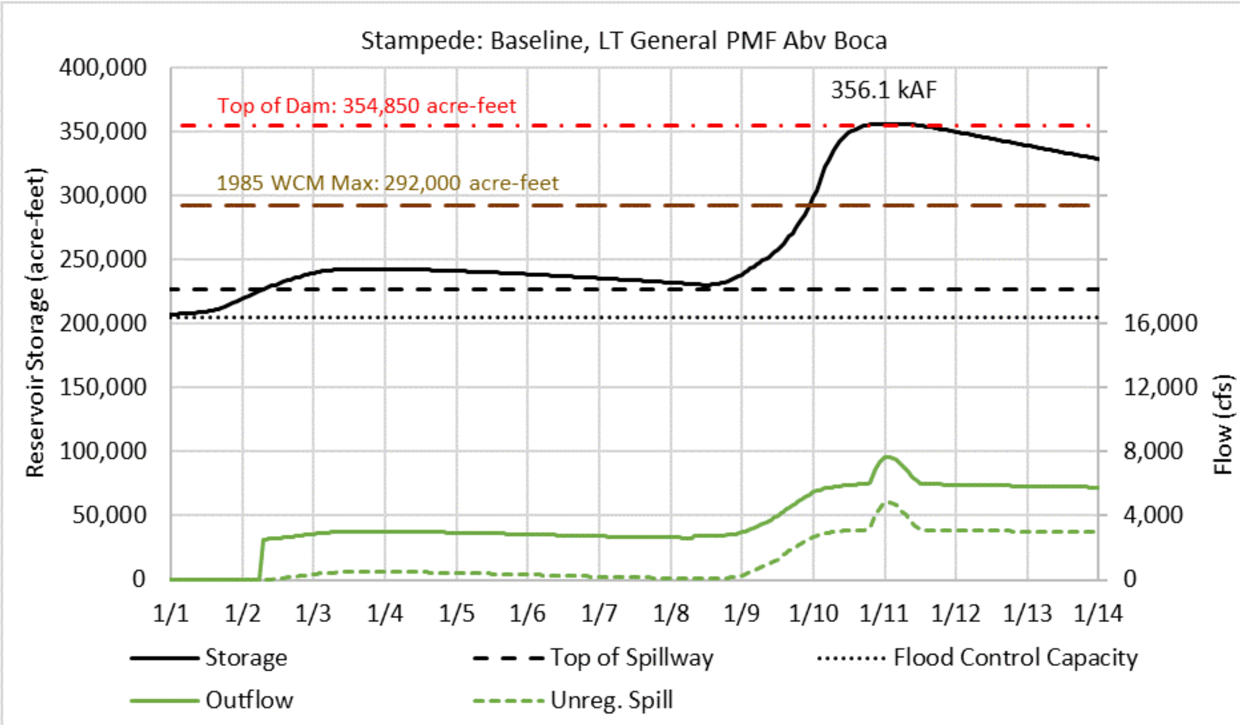

Figure 35: Baseline routing of LT General PMF Above Boca through Stampede

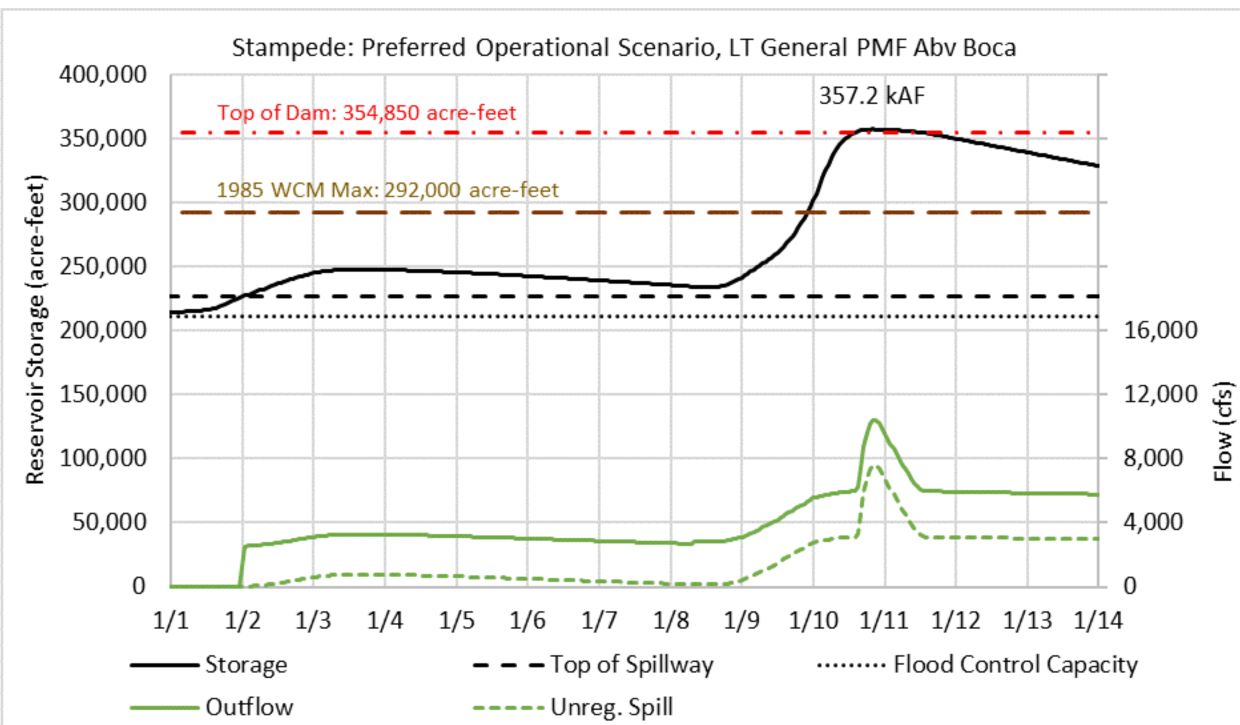

Figure 36: Preferred Operational Scenario routing of LT General PMF Above Boca through Stampede

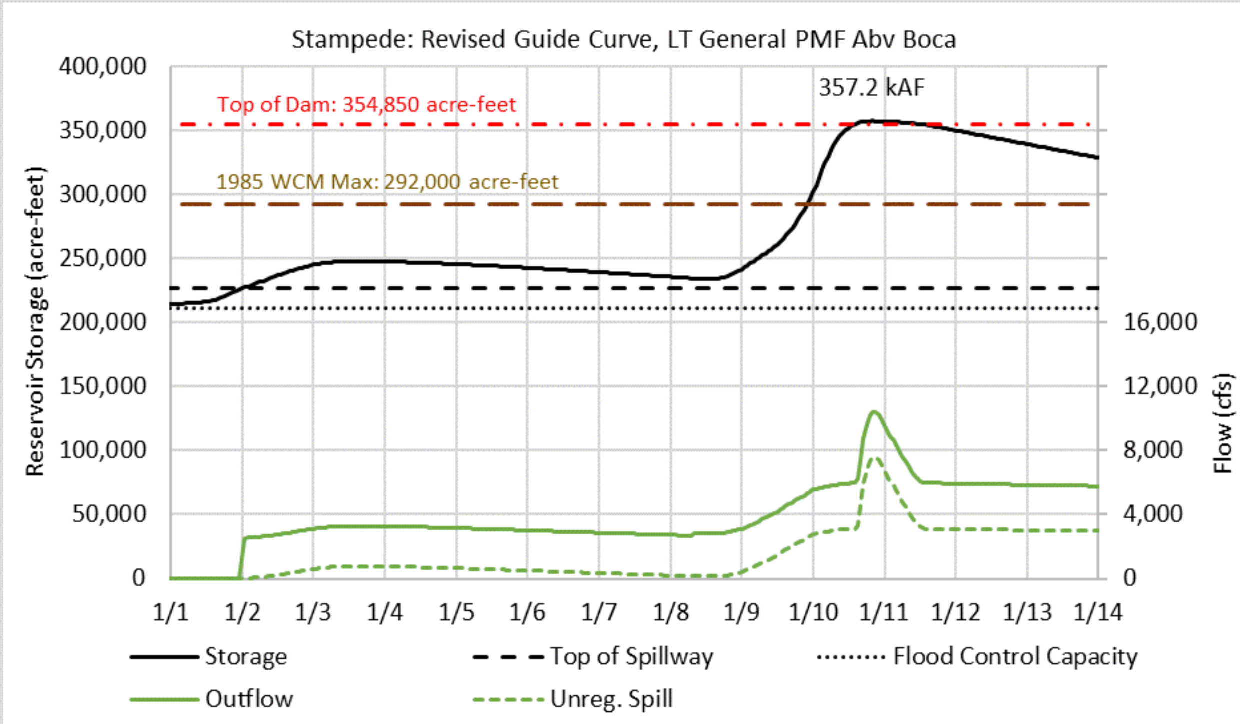

Figure 37: Revised Guide Curve routing of LT General PMF Above Boca through Stampede

3.B.4 LT Local PMF Abv Stampede

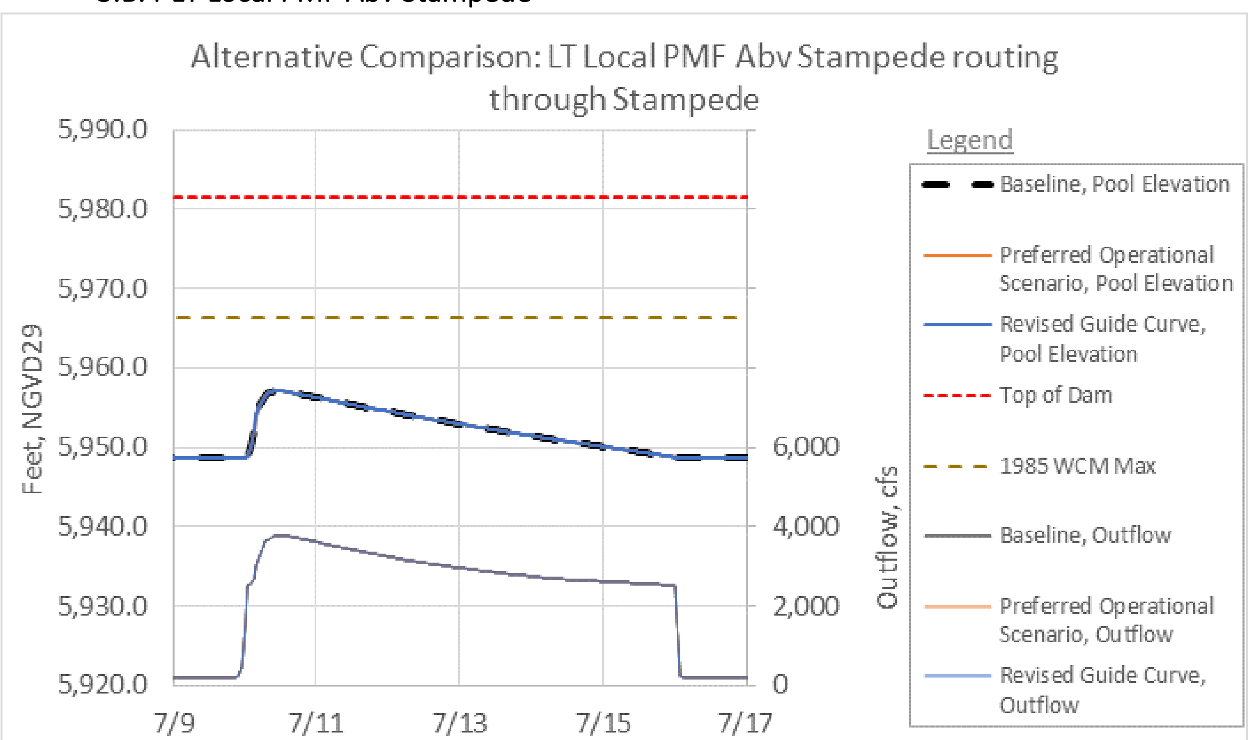

Figure 38: Comparison of Stampede Pool Elevation and outflow in LT Local PMF Above Stampede

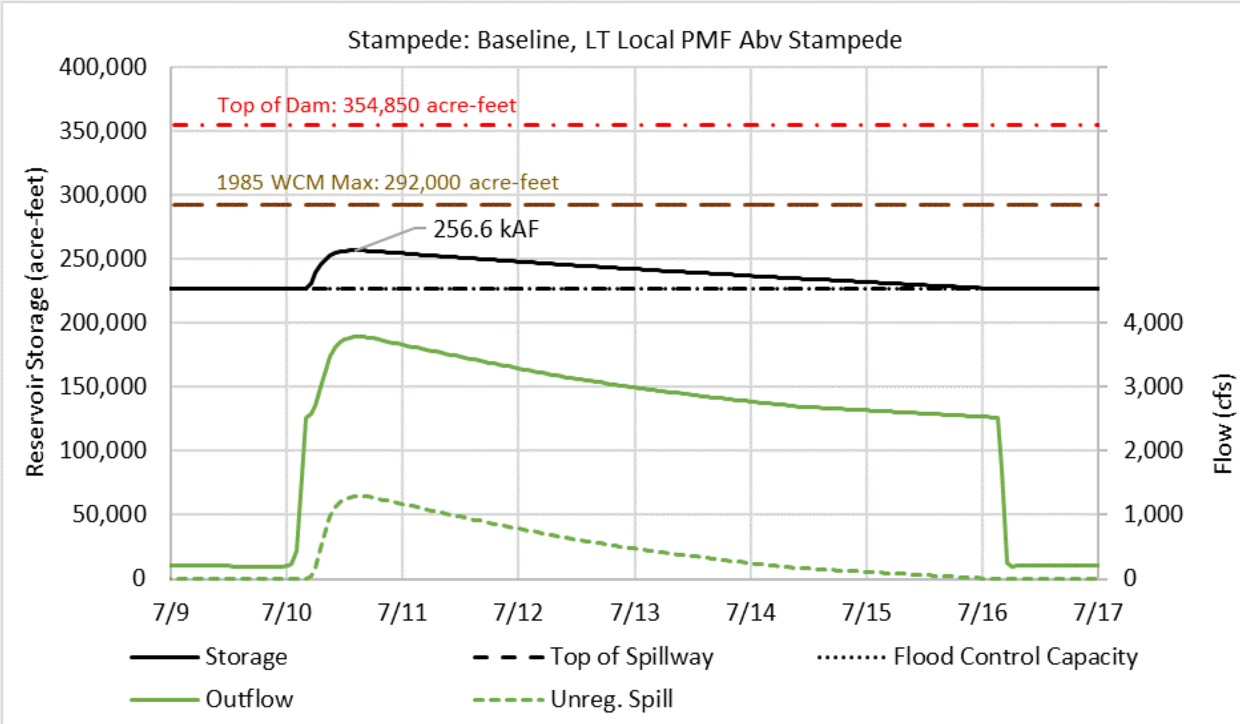

Figure 39: Baseline routing of LT Local PMF Above Stampede through Stampede

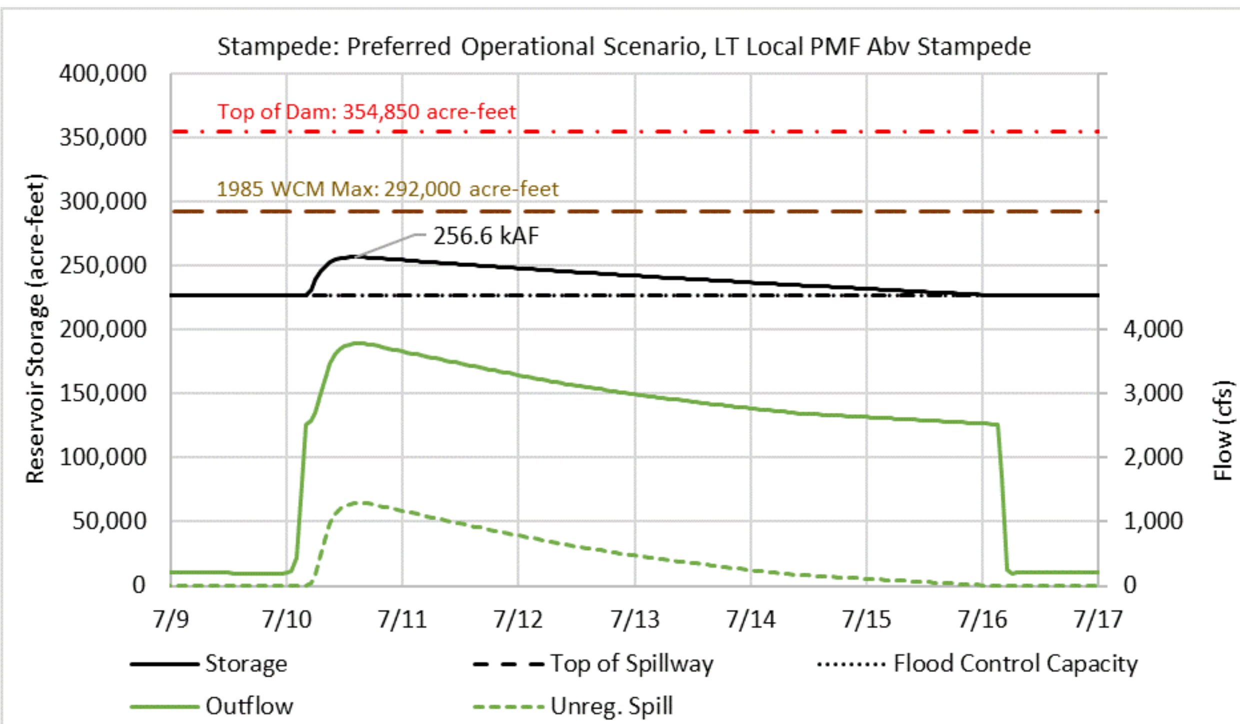

Figure 40: Preferred Operational Scenario routing of LT Local PMF Above Stampede through Stampede

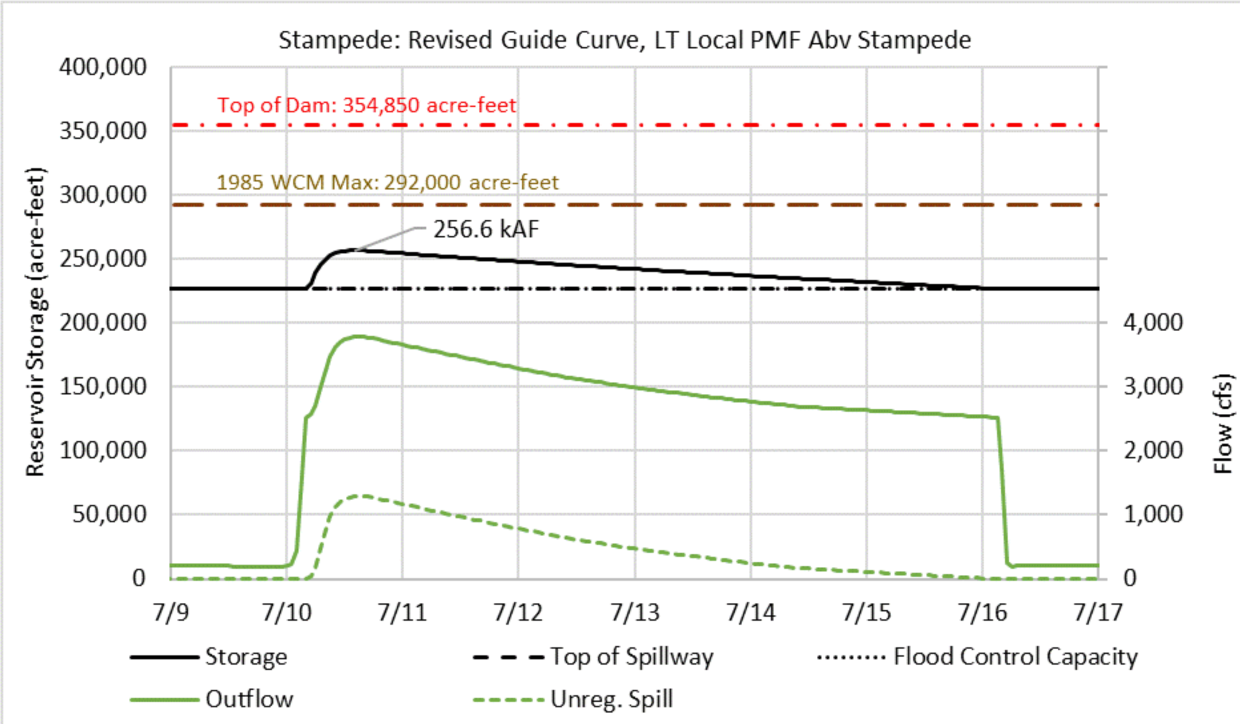

Figure 41: Revised Guide Curve routing of LT Local PMF Above Stampede through Stampede

3.B.5 LT Local PMF Abv Boca

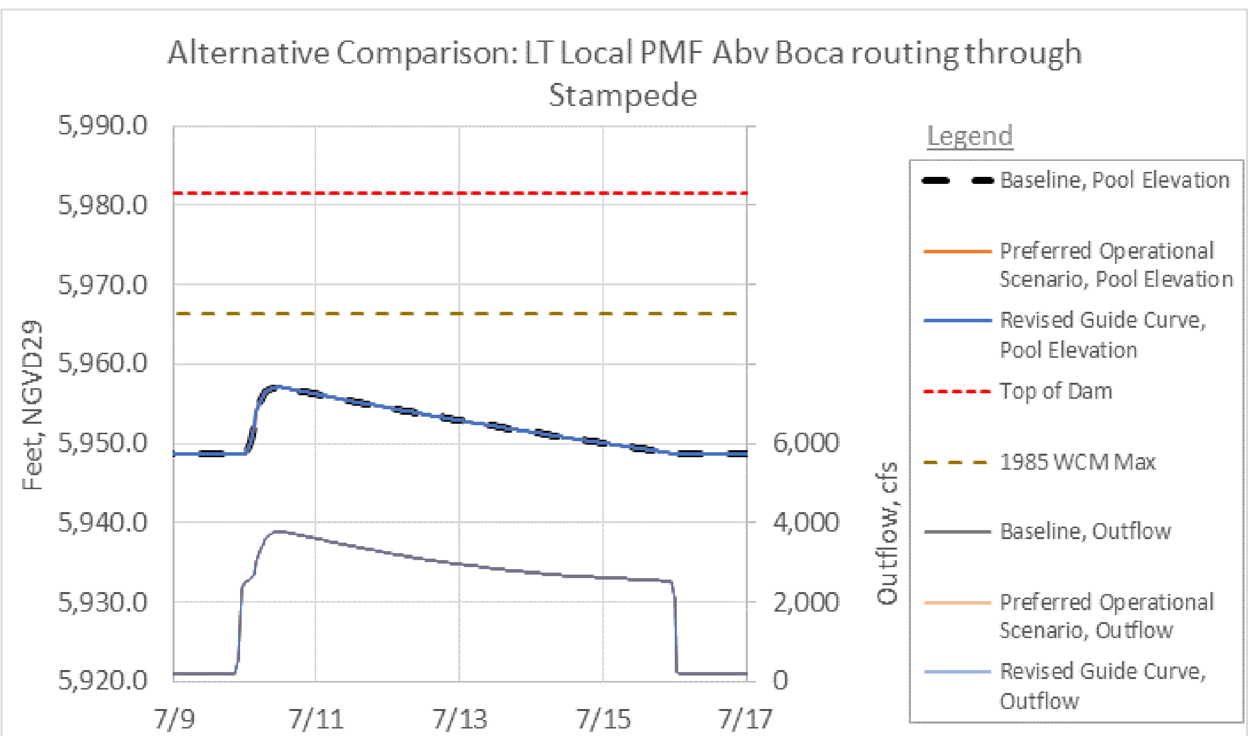

Figure 42: Comparison of Stampede Pool Elevation and outflow in LT Local PMF Above Boca

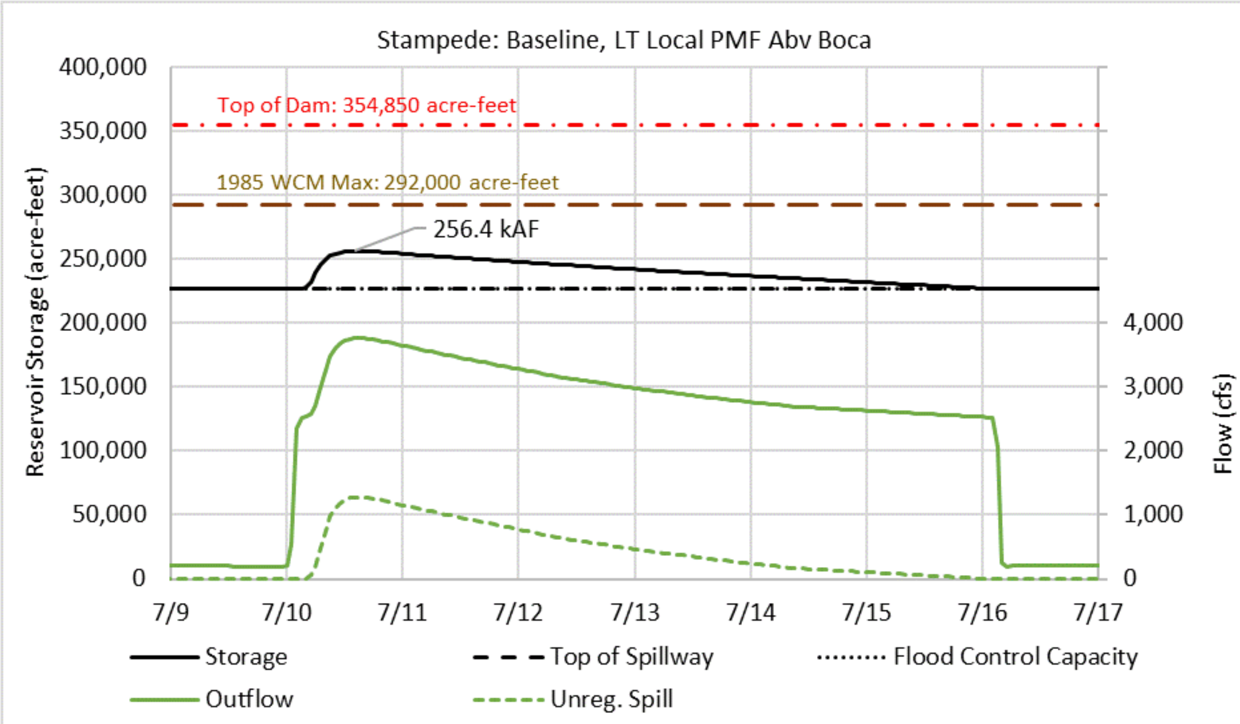

Figure 43: Baseline routing of LT Local PMF Above Boca through Stampede

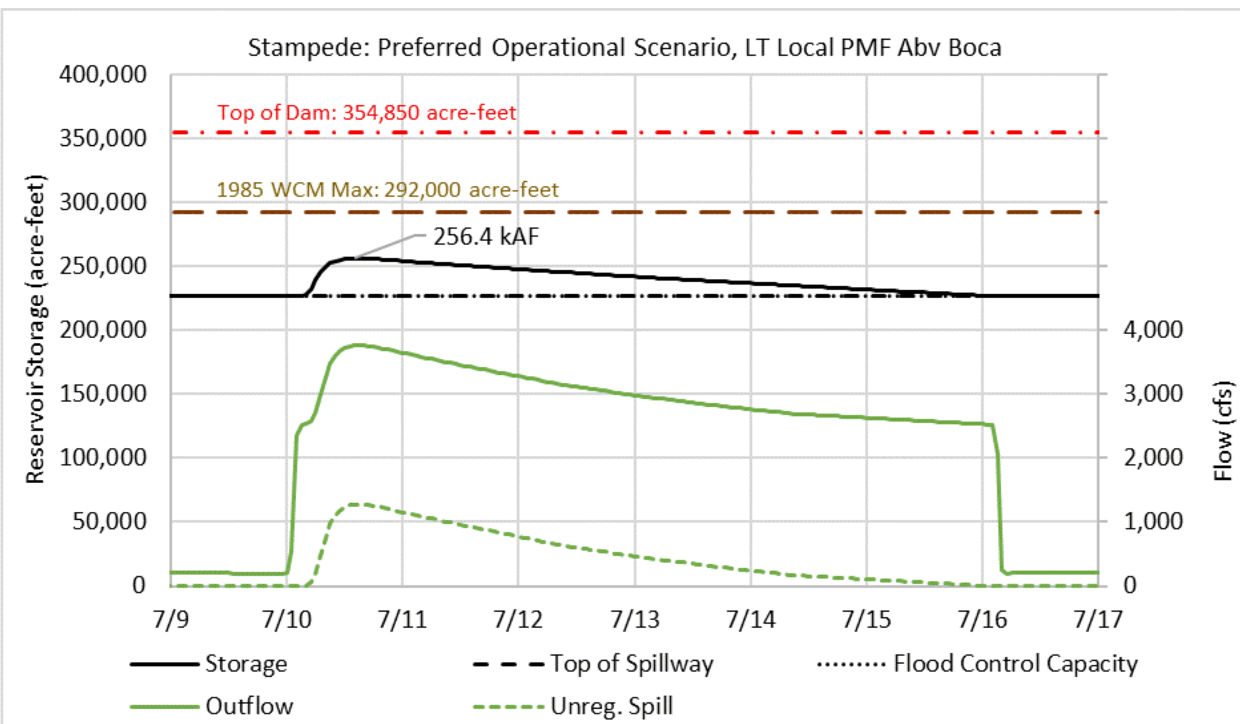

Figure 44: Preferred Operational Scenario routing of LT Local PMF Above Boca through Stampede

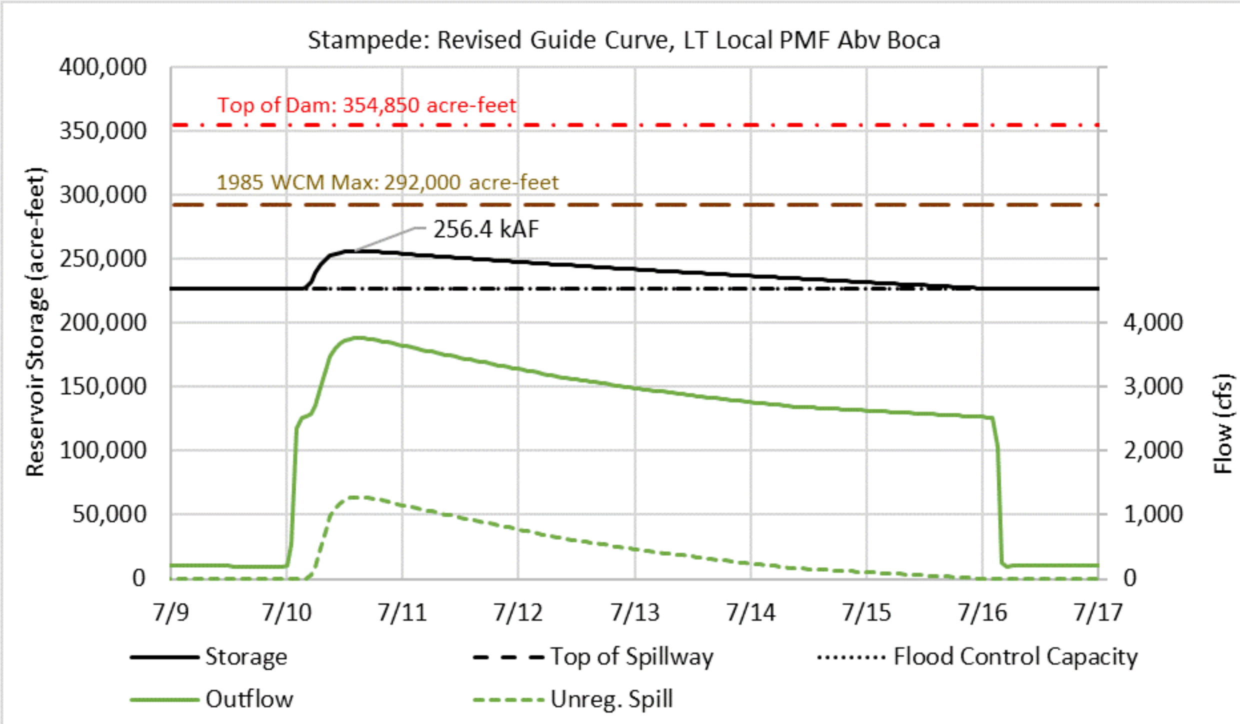

Figure 45: Revised Guide Curve routing of LT Local PMF Above Boca through Stampede

3.C Boca

The minimum freeboard in Boca for each of the four Little Truckee PMFs and scenarios are summarized in Table 9. While the General events have more freeboard than the Local events, all events maintain over one foot of freeboard. In the General events the freeboard is 0.08' less than Baseline in the Preferred and Revised Guide Curve scenarios for the Above Stampede and Above Boca events, respectively. For the General events, Boca has already reached its peak storage and began to recede when Stampede overtops such that the additional flow from Stampede does not cause the peak elevation in Boca (see Figure 46 and Figure 50).

Table 9: Boca freeboard summary by PMF Event

Event	Baseline	Preferred Operational Scenario	Revised Guide Curve
LT General PMF Above Stampede	4.05	3.97	3.97
LT General PMF Above Boca	3.20	3.12	3.12
LT Local PMF Above Stampede	1.16	1.16	1.16
LT Local PMF Above Boca	1.13	1.13	1.13

Comparison of the pool elevation in the different scenarios for each event as well as plots of Boca storage, outflow, and Stampede outflow (combination of Stampede outlet work, spillway flow and flow over dam) for each scenario and event are summarized in the following sections which are organized by PMF event. Because positive freeboard is maintained for all scenarios it was not necessary to estimate the overtopping flow on Boca.

3.C.1 LT General PMF Abv Stampede

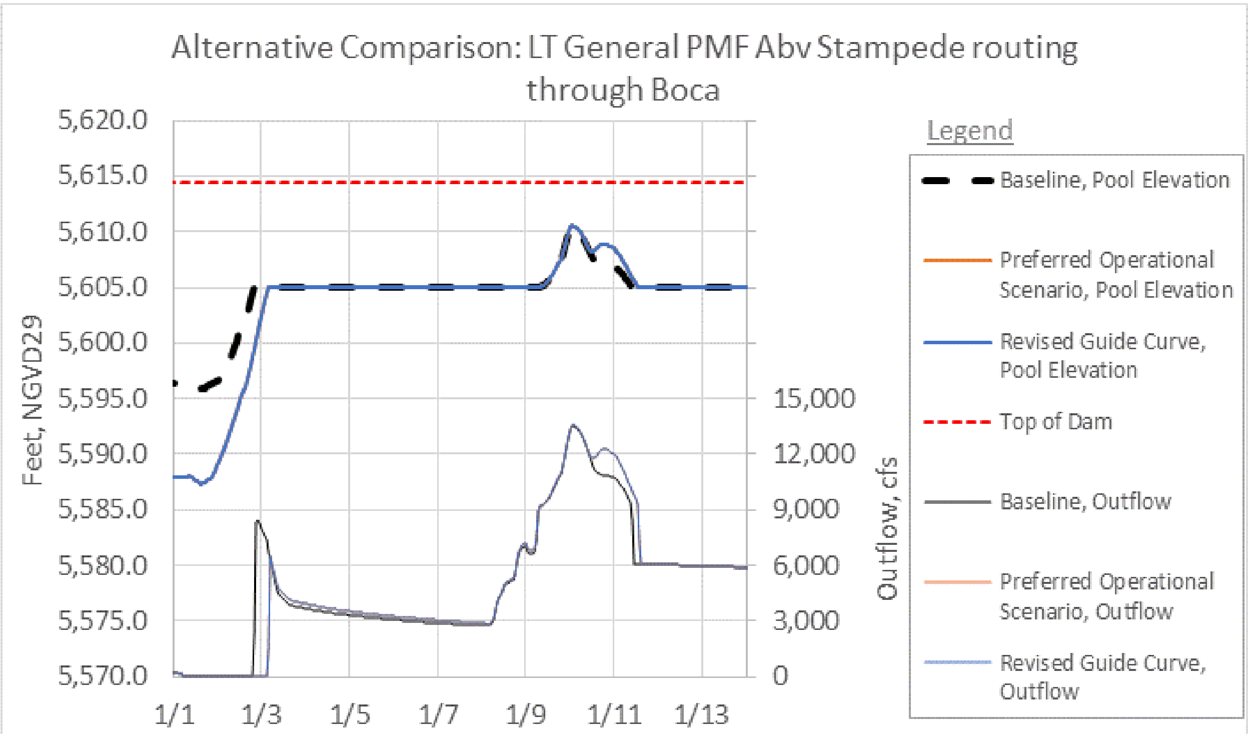

Figure 46: Comparison of Boca Pool Elevation and outflow in LT General PMF Above Stampede

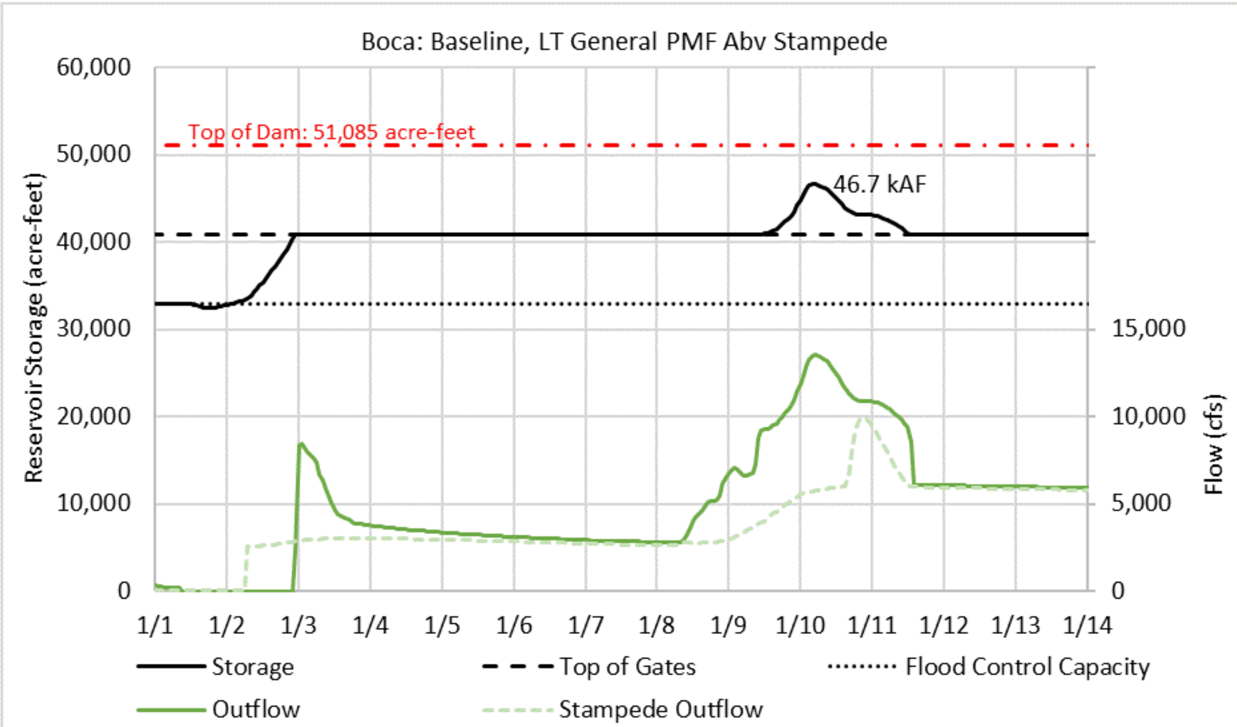

Figure 47: Baseline routing of LT General PMF Above Stampede through Boca

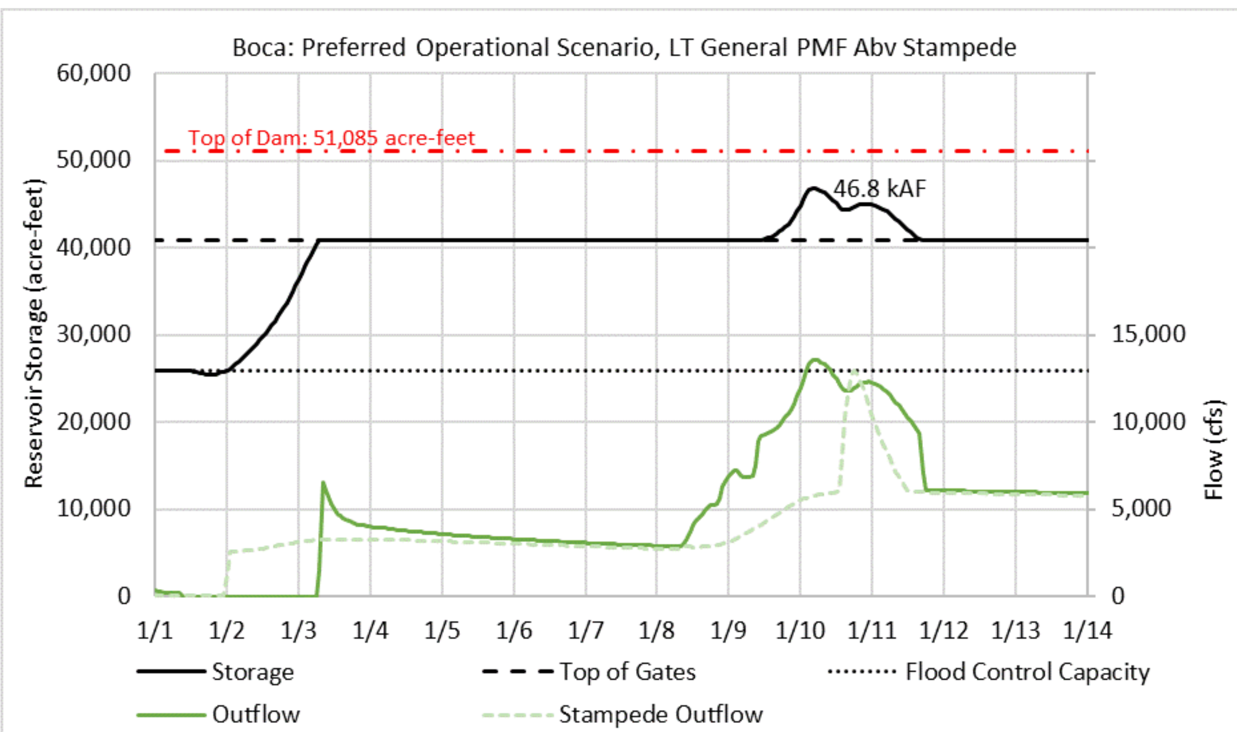

Figure 48: Preferred Operational Scenario routing of LT General PMF Above Stampede through Boca

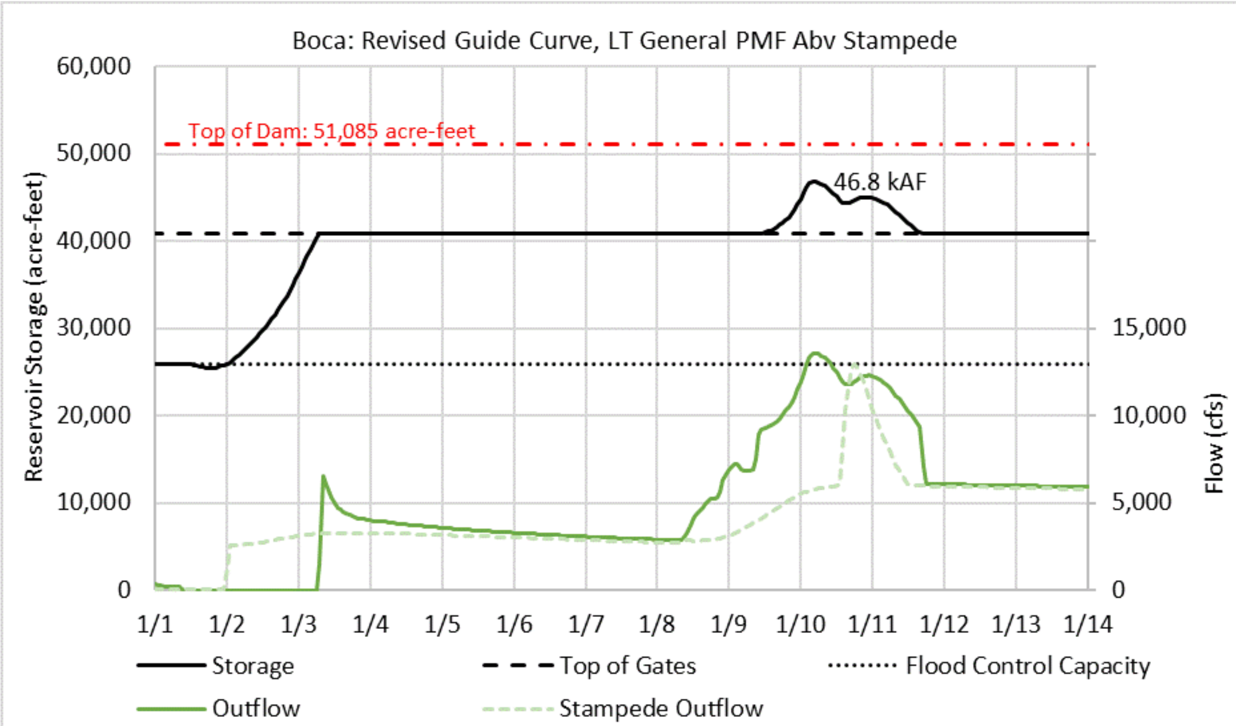

Figure 49: Revised Guide Curve routing of LT General PMF Above Stampede through Boca

3.C.2 LT General PMF Abv Boca

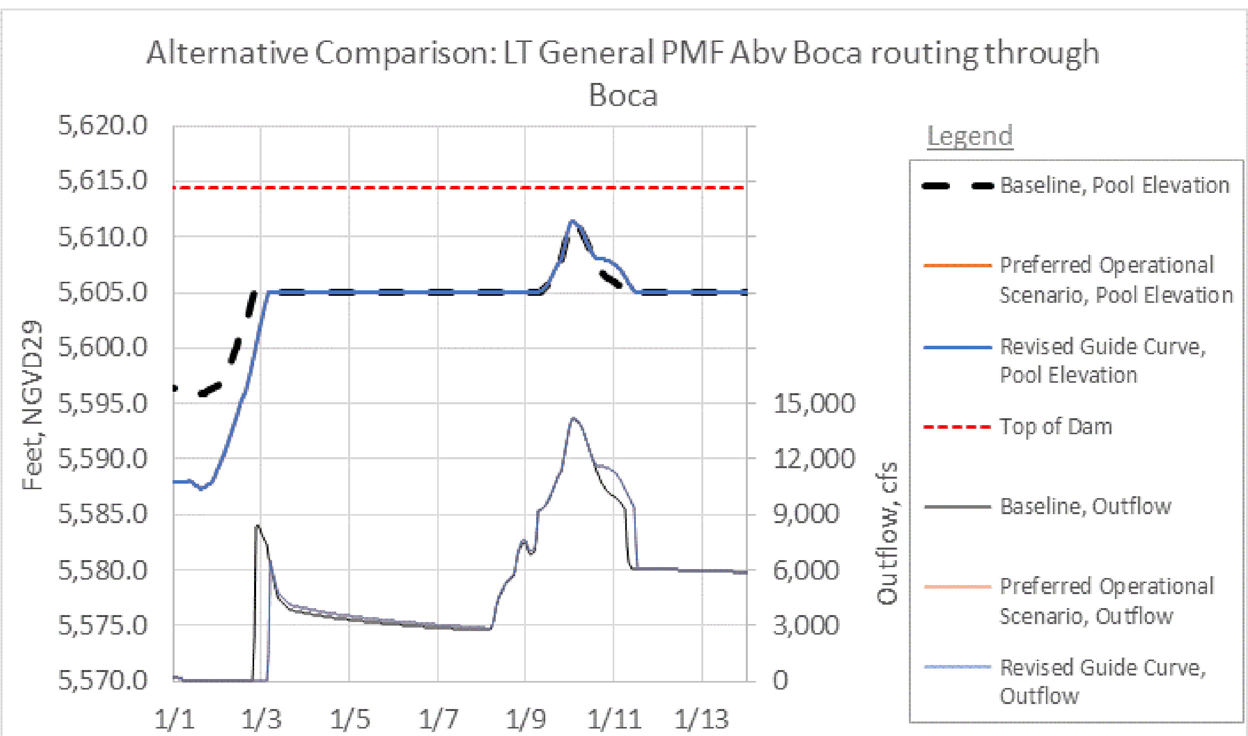

Figure 50: Comparison of Boca Pool Elevation and outflow in LT General PMF Above Boca

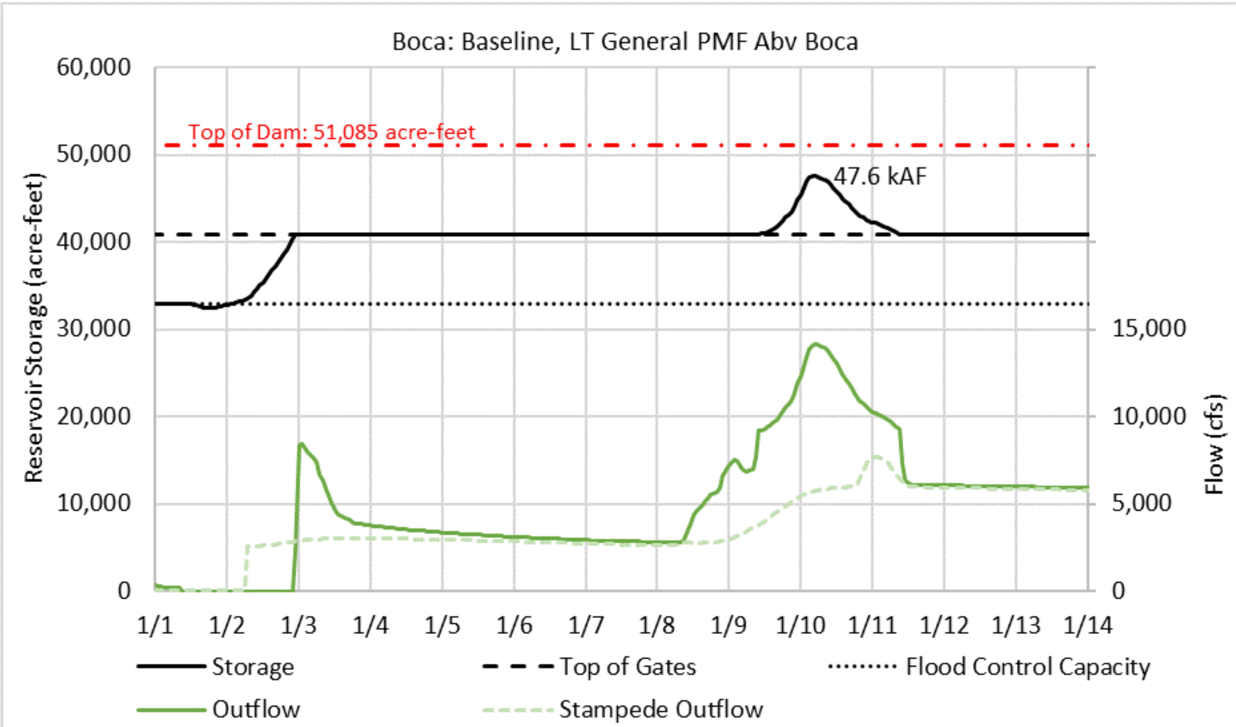

Figure 51: Baseline routing of LT General PMF Above Boca through Boca

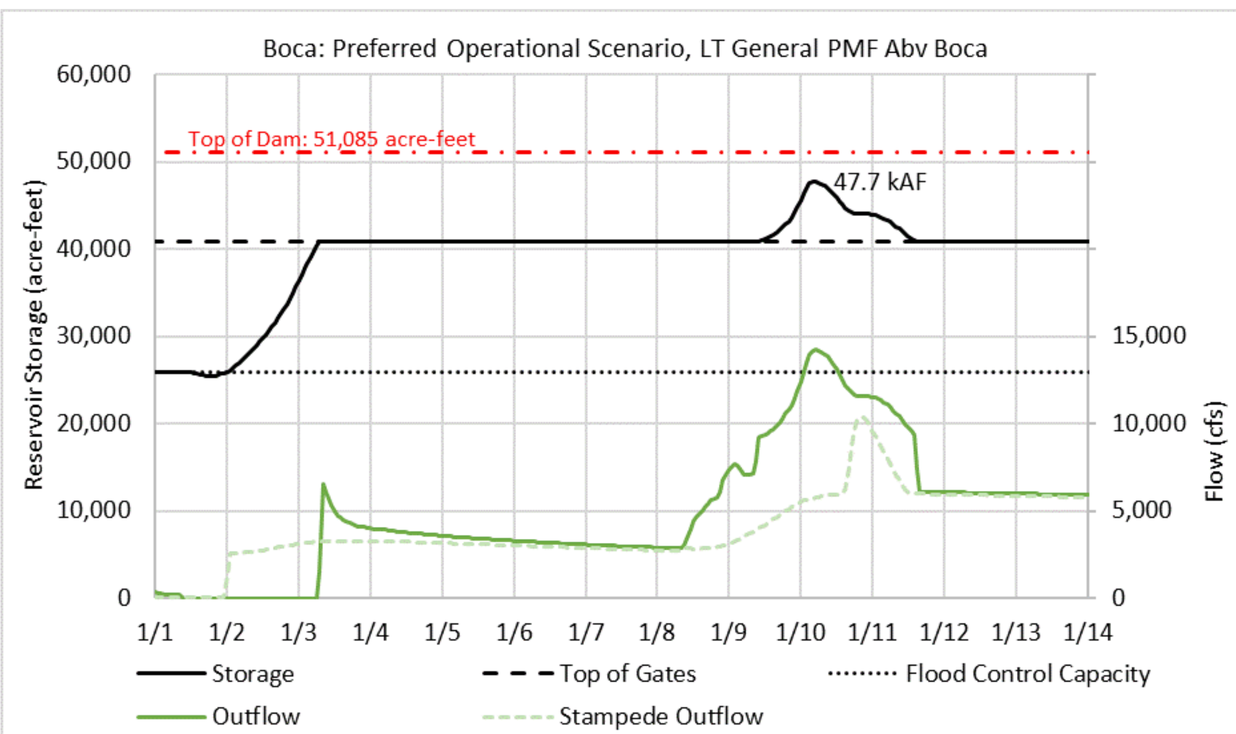

Figure 52: Preferred Operational Scenario routing of LT General PMF Above Boca through Boca

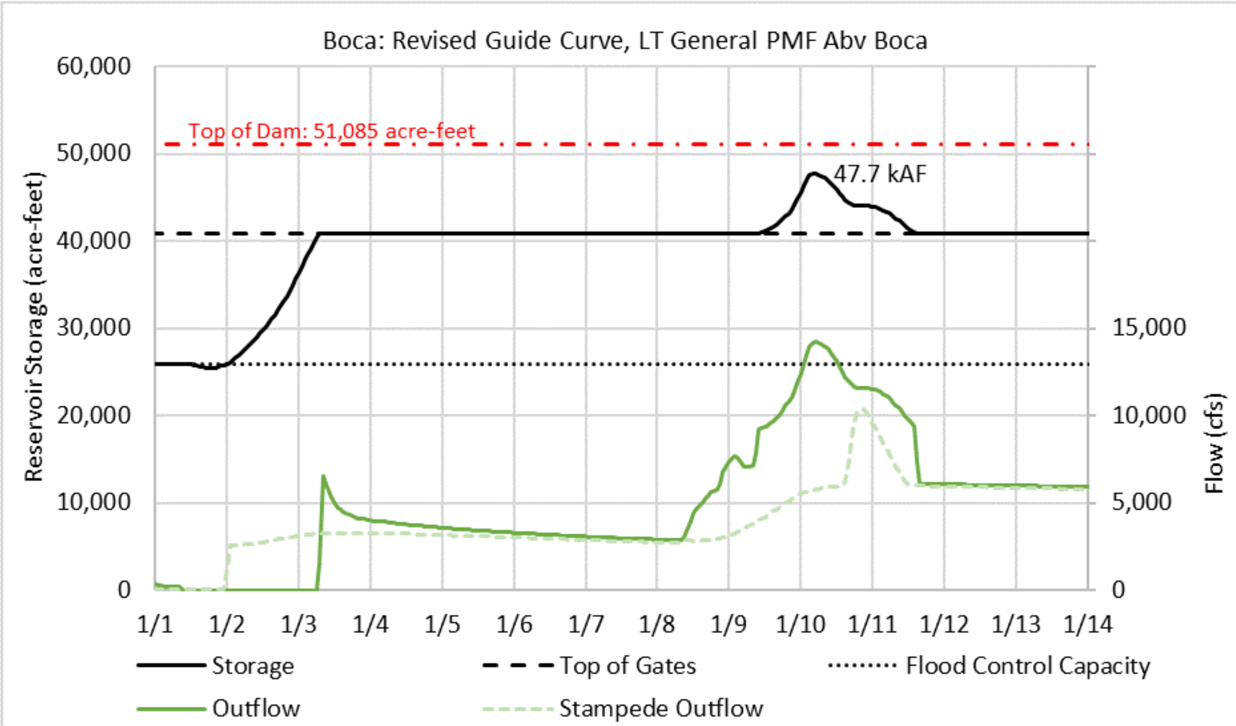

Figure 53: Revised Guide Curve routing of LT General PMF Above Boca through Boca

3.C.3 LT Local PMF Abv Stampede

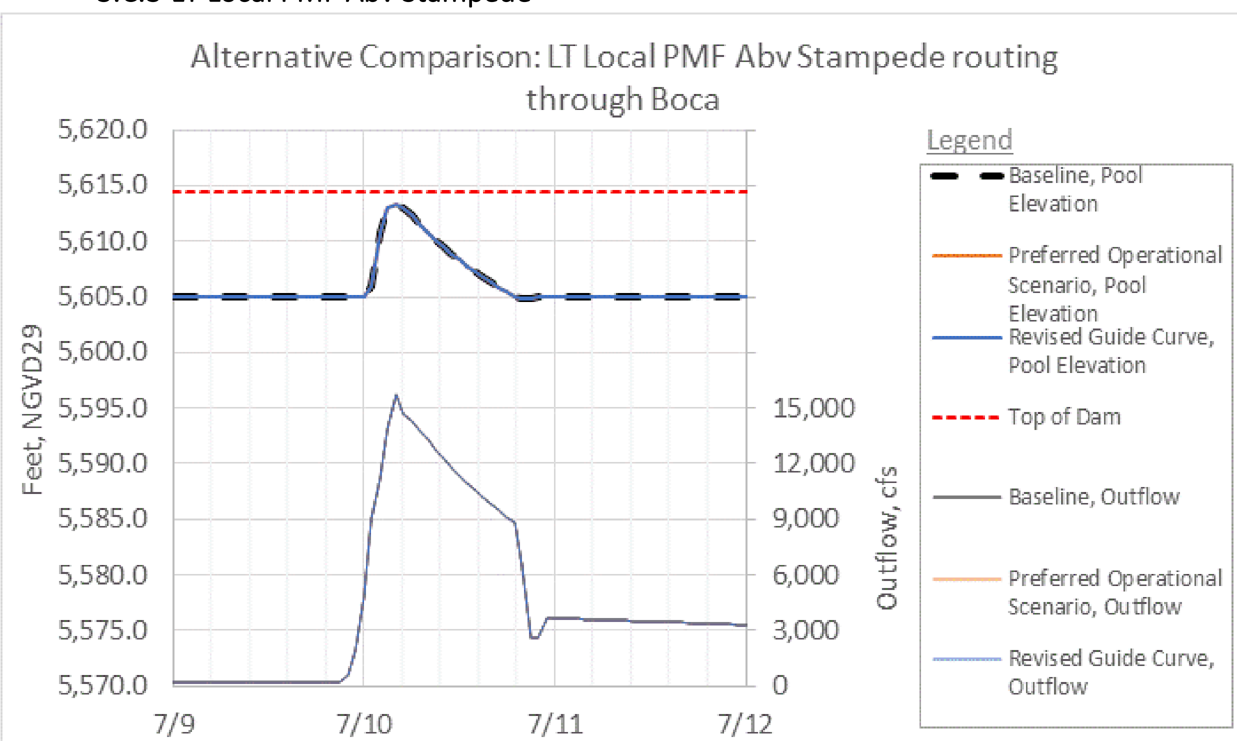

Figure 54: Comparison of Boca Pool Elevation and outflow in LT Local PMF Above Stampede

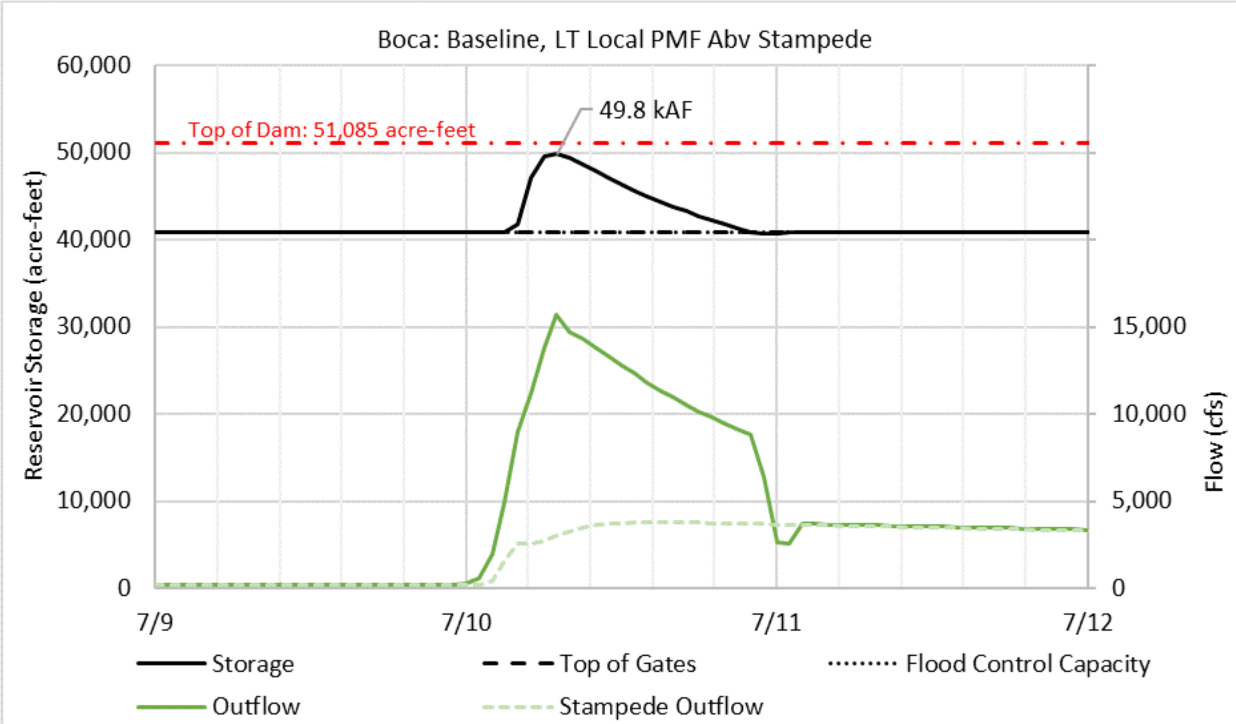

Figure 55: Baseline routing of LT Local PMF Above Stampede through Boca

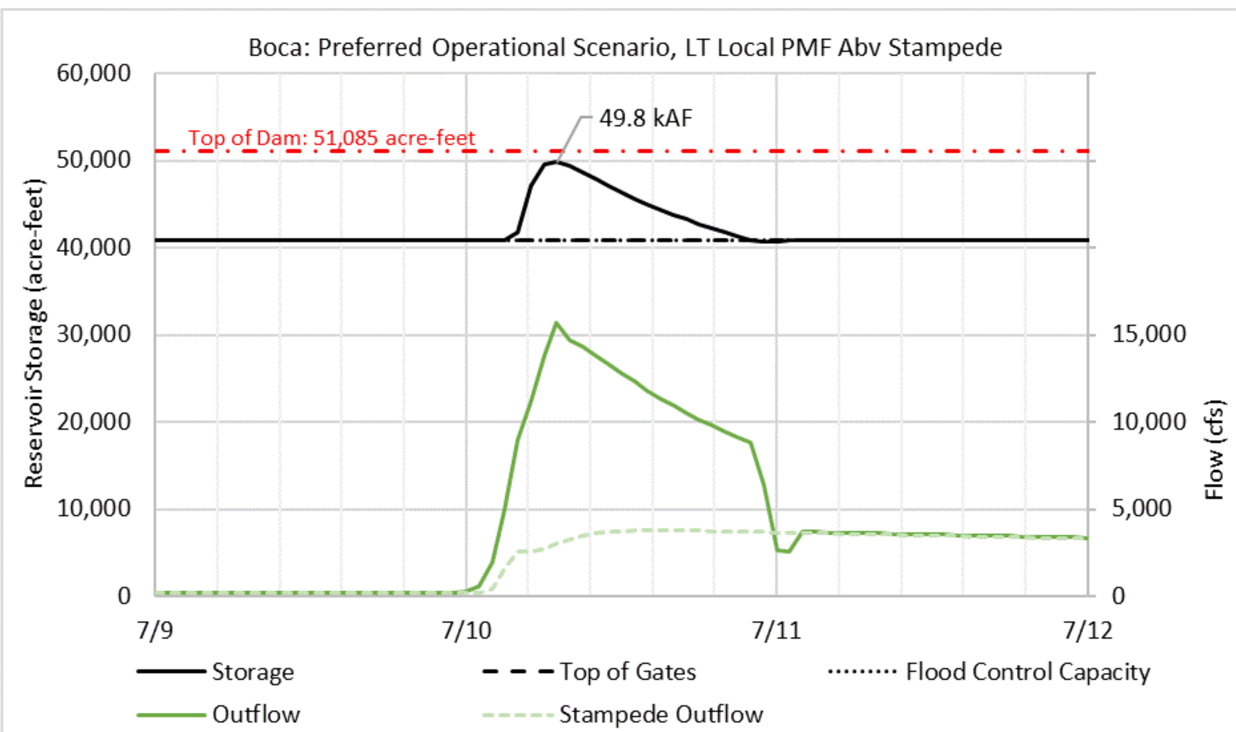

Figure 56: Preferred Operational Scenario routing of LT Local PMF Above Stampede through Boca

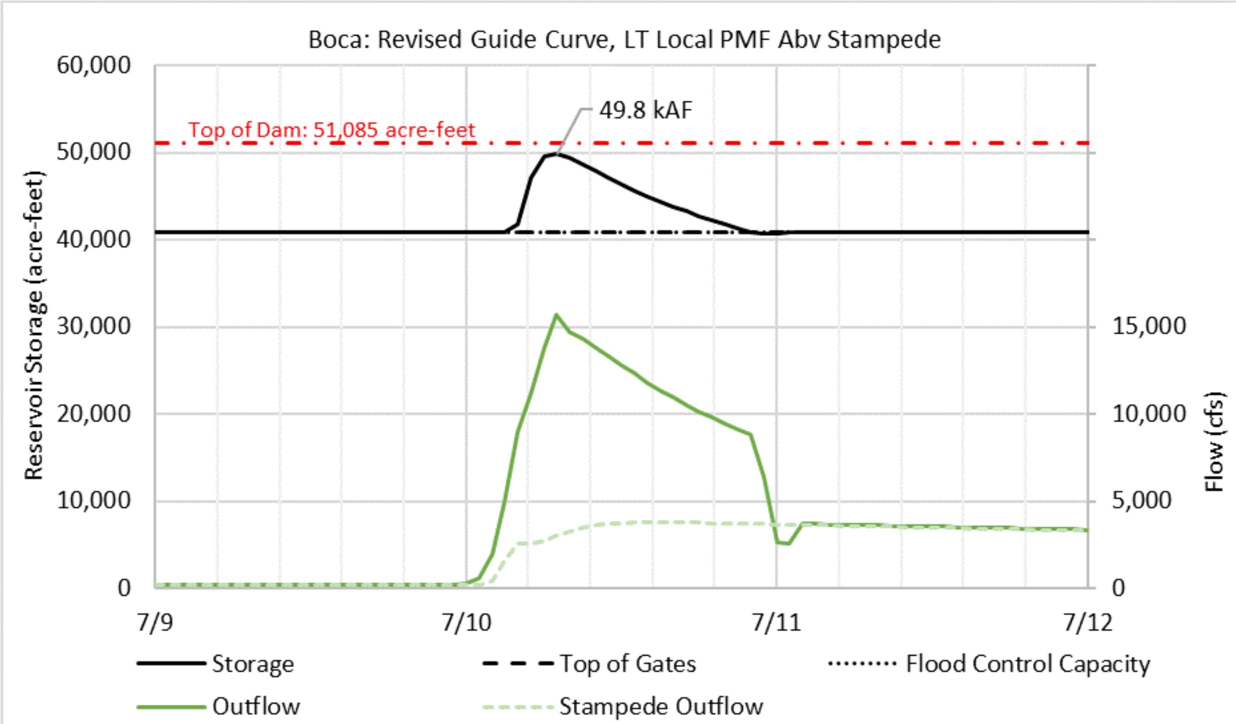

Figure 57: Revised Guide Curve routing of LT Local PMF Above Stampede through Boca

3.C.4 LT Local PMF Abv Boca

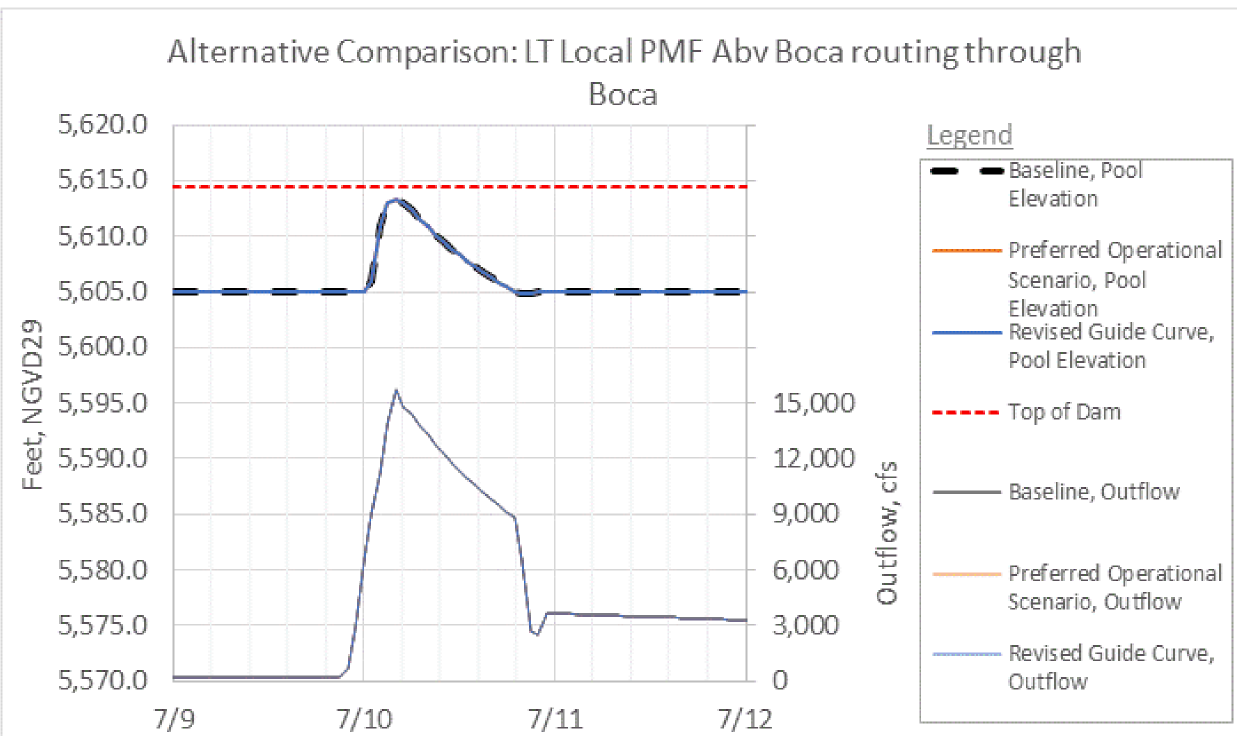

Figure 58: Comparison of Boca Pool Elevation and outflow in LT Local PMF Above Boca

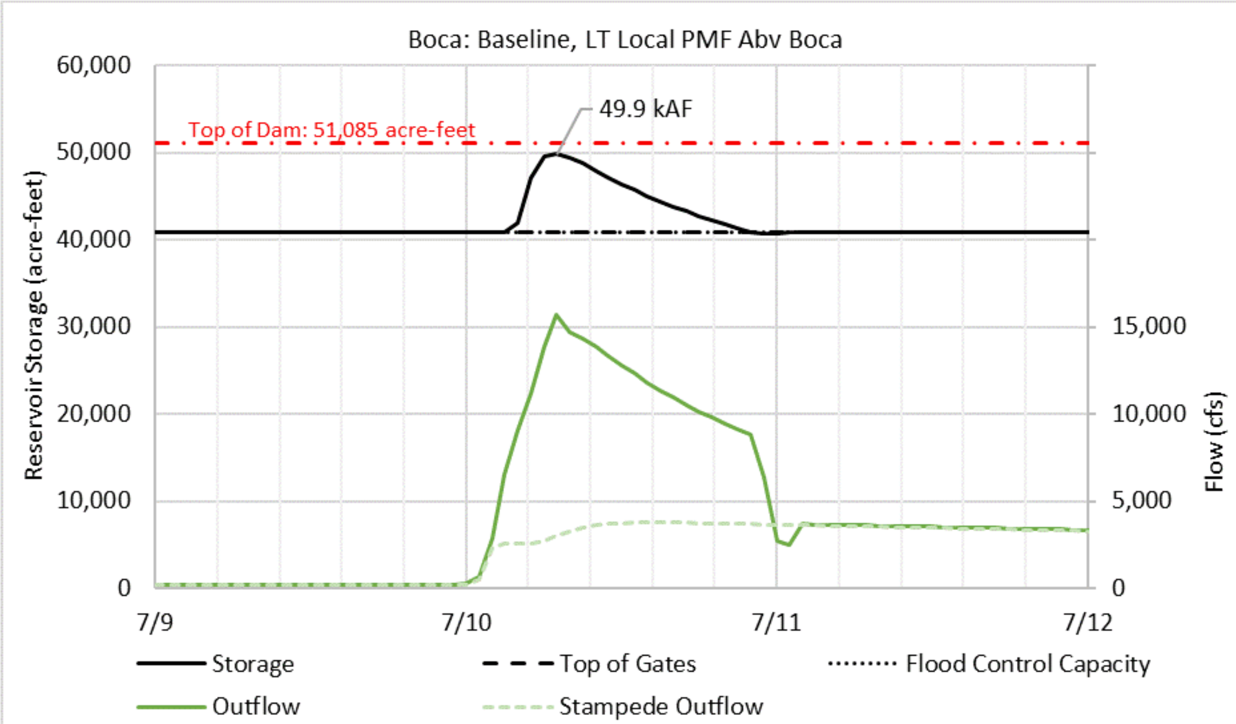

Figure 59: Baseline routing of LT Local PMF Above Boca through Boca

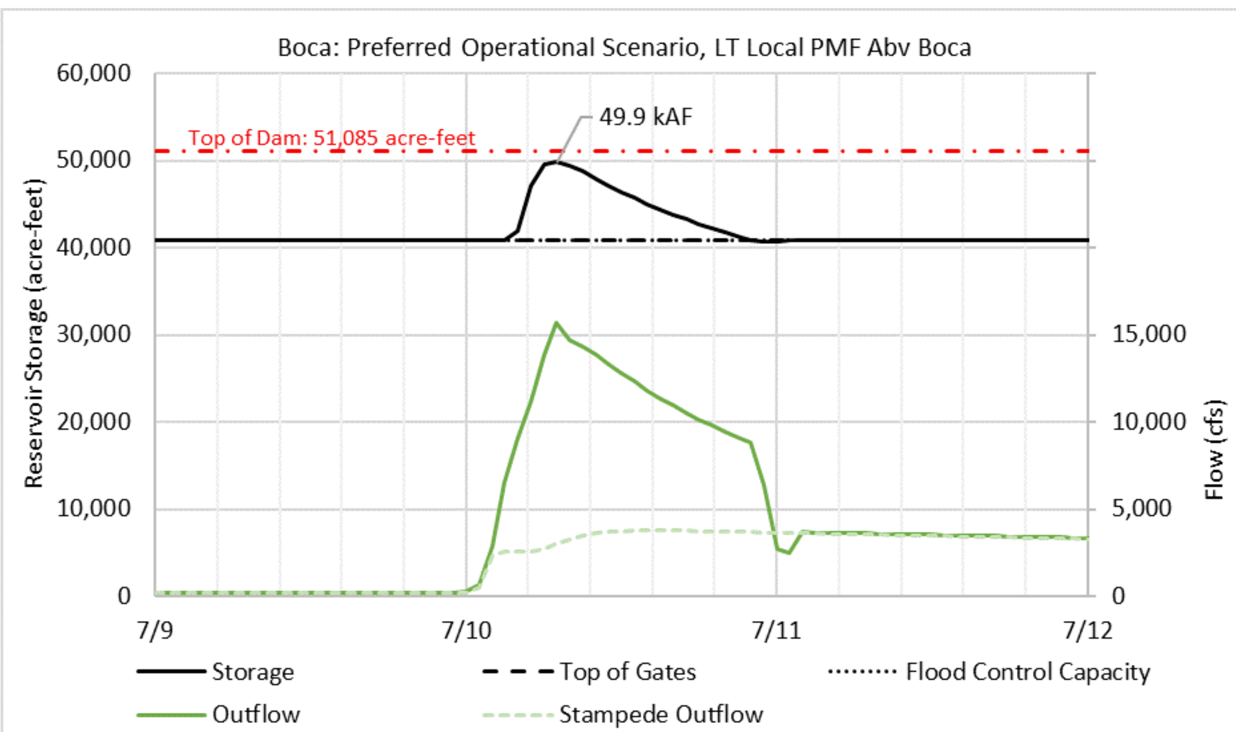

Figure 60: Preferred Operational Scenario routing of LT Local PMF Above Boca through Boca

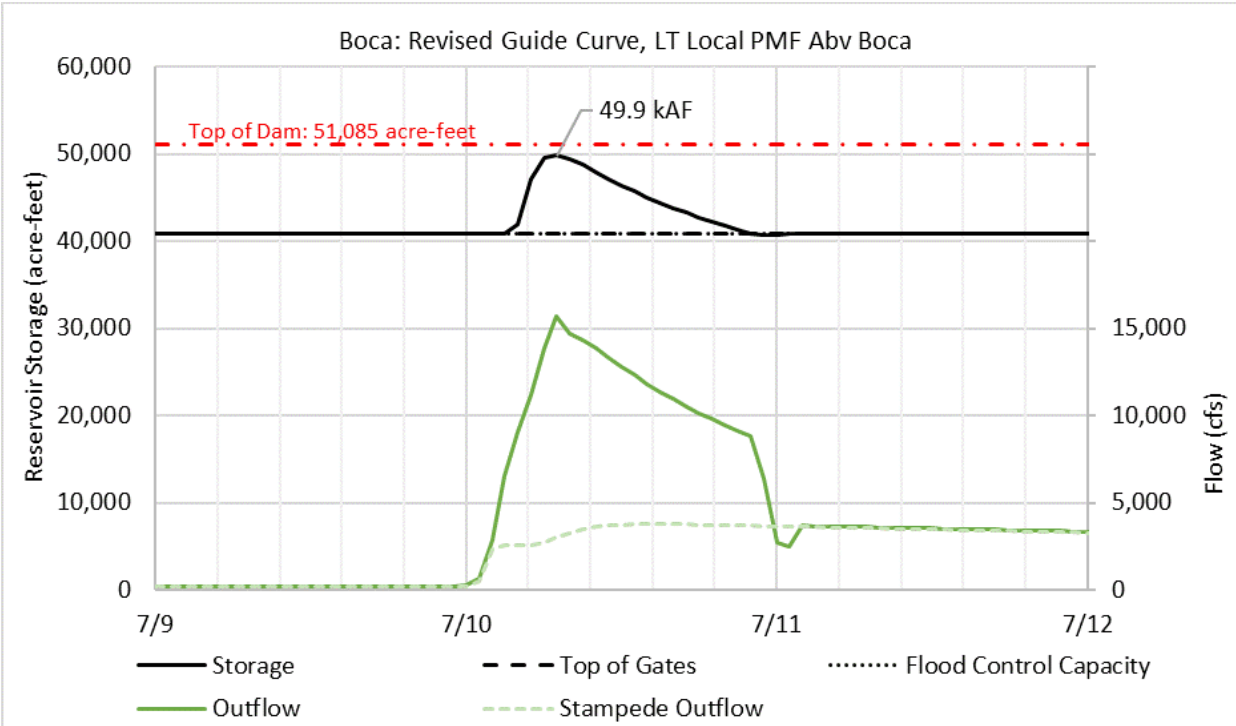

Figure 61: Revised Guide Curve routing of LT Local PMF Above Boca through Boca

4 Summary of impacts of the TBWMOP Scenarios

Routings of the PMFs through the TBWMOP scenarios shows that the routings of most events are unaffected by the changes being proposed by the TBWMOP. For the Local events, the initial state is unaffected by the TBWMOP scenarios because these events are characteristic of summer events that would occur while reservoirs are permitted to be full in the Baseline and all TBWMOP scenarios. The TBWMOP scenarios do not change the prescribed operations when the reservoirs are in surcharge, so the TBWMOP scenarios are the same as the Baseline scenario. Analysis also shows that the TBWMOP Preferred Operational Scenario and the Revised Guide Curve scenarios have identical routings of all PMF Events. These are identical because the Preferred Operational Scenario includes a provision to only encroach into the Flood Space required by the Revised Guide Curve if the forecasted water year Farad natural flow is less than 600,000 acre-feet which is 155% of the 1985-2021 average (Gwynn & Noe, 2023; Lawler, 2022a). For all the antecedent events used for the General PMF routings a large snowpack existed prior to these events which were near the 1/100-year recurrence interval. This large snowpack was sufficient to increase the forecasted runoff to more than 600,000 acre-feet disabling encroachment under FIRO and making the Preferred Operational Scenario identical to the Revised Guide Curve Scenario.

Thus, the General events which occur in the rainy season when the WCM is in effect have the most potential to impact the PMF routings. For Prosser the initial state prior to the antecedent event is the same in the Baseline and TBWMOP scenarios. In these events Prosser is operated identically through the antecedent event and into the PMF as it is in the Baseline. This is because the flood mitigation changes being proposed in the TBWMOP primarily alter operations in flood events smaller than the 1997 historical flood that was used as the antecedent event for the Prosser PMF routings.

On the Little Truckee River, the TBWMOP scenarios do impact the PMF routings which show a peak elevation on Stampede that is higher than Baseline. This is caused by the proposed changes to the Boca Portion of Little Truckee Flood space. In the Baseline scenario, 26.7% of the 30,000 acre-feet of flood space allotted to the Little Truckee River reservoirs is reserved in Boca, while the Preferred Operational Scenario and Revised Guide Curve scenarios propose to change this to 50%. This change in flood space distribution in the Little Truckee River increases Stampede’s winter Top of Conservation storage by 7,000 acre-feet with a compensating decrease in Boca’s storage. The additional space in Boca allows more of the Little Truckee River inflows to be captured in Boca before it reaches its max capacity as illustrated in Figure 46: Comparison of Boca Pool Elevation and outflow in LT General PMF Above Stampede and Figure 50: Comparison of Boca Pool Elevation and outflow in LT General PMF Above Boca. In some flood events, this additional space in Boca reduced the peak flow at Reno compared to the Baseline scenario. However, the reduced space in Stampede increases the maximum elevation in the General PMF routings. So, there is a tradeoff between flood protection and Stampede’s peak elevation in the PMF routings.

To help evaluate this trade off, the results of the MOEA model runs with all the same decision variables as the Preferred Operational Scenario except the Boca Portion of flood space were compiled as a preliminary sensitivity analysis. Note that the Preferred Operational Scenario differs from the MOEA scenarios in two ways (1) in a flood reservoirs are operated to maintain just the Reno gage below the flood target instead of both the Reno and Vista gages, and (2) encroachment into flood space under FIRO could occur for any Farad Natural Flow Water Year Forecast instead of just periods when the forecast is under 600,000 acre-feet. The sensitivity analysis (shown in Figure 62 and summarized in Table 10) shows how the studies' objectives are correlated to the Boca Portion of Flood Space. Each subplot in Figure 62 has one of the TBWMOP objectives as the y-axis where scenarios lower on the plot are better for the objective. The Average Daily Increase in Flood Space Requirement Objective was not included in Figure 62 because this objective is independent of the Boca Portion of Flood space decision variable. The methodologies, decision variables and objectives used in the MOEA are discussed in more detail in the *Action and Alternative Modeling in the WMOP* report by Noe (Noe, 2023). This sensitivity analysis shows that the increase in the Boca Portion of Flood space proposed by the TBWMOP has only small impacts in four of the five study objectives, but it is attributable to 69% of the improvement over the Baseline flood protection.

Table 10: Summary of MOEA Objective sensitivity to Boca Portion of Flood Space

Objective	Description	R^2 to Boca Portion	Impact of decreasing Boca Portion of Flood Space to 30%
Average Annual Volume For FR	Metric for basin water supply	0.47	2% Increase in improvement over Baseline
Average Annual Volume for Flow Regime	Metric for water supply for Threatened and Endangered Species	0.98	2% increase in improvement over Baseline
RMS Flow Over Flood Target	Metric for duration and magnitude that the Reno Flood Target is exceeded	0.93	69% decrease in improvement from Baseline
Average Prosser Boca Stampede Storage	Average daily storage in the Flood Control reservoirs	0.97	2% increase in improvement over Baseline
Average Daily Increase in Flood Space Requirement	Metric for frequency and magnitude of release changes for FIRO	1.00	No change

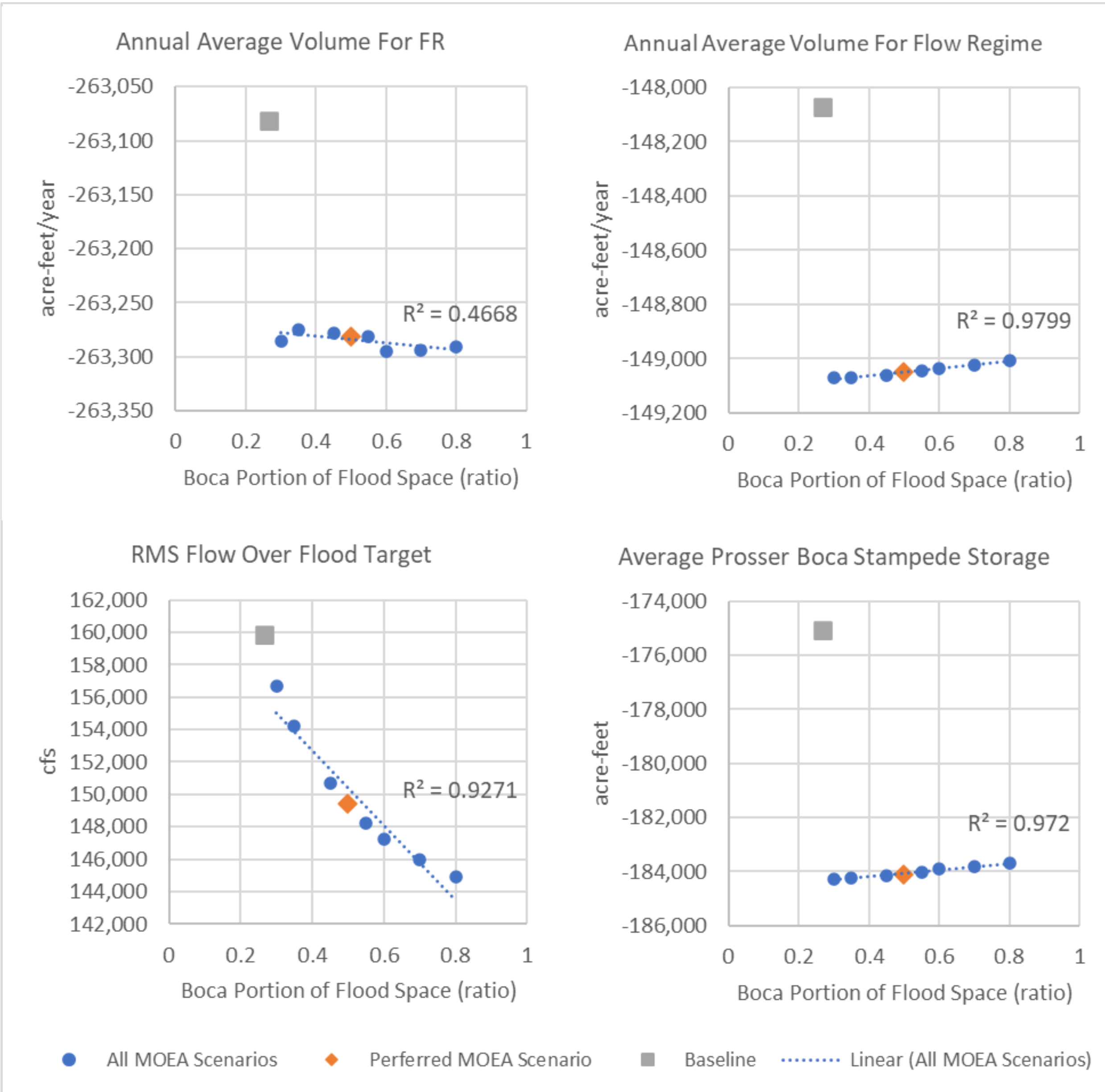

Figure 62: Boca Portion of Flood Space Sensitivity to TBWMOP Objectives

5 Conclusion

The most recent PMFs for both Prosser Creek and the Little Truckee River were routed through their respective reservoir(s) to evaluate the impacts of the proposed TBWMOP scenarios to dam safety. The PMF routings for the Preferred Operational Scenario are identical to the routings for the Revised Guide Curve scenario because a Farad Natural Flow water year forecast exceeding 600 KAF was present in all the antecedent events which disabled encroaching into flood space in the Preferred Operational Scenario. For Prosser Creek Reservoir, the maximum elevation is identical in the Preferred Operational Scenario and Revised Guide Curve scenarios as it is in the Baseline scenario for all PMF Events. On the Little Truckee Reservoirs, the TBWMOP scenarios increase Boca Portion of Flood space which reduces the Stampede flood space and increases the initial storage of Stampede. For the snowmelt driven PMF events, the higher initial storage on Stampede due to the change in the Boca Portion of Flood Space results in higher peak storage on both Boca and Stampede during these events. For Stampede the peak elevation is increased by 0.21 feet in the most severe LT General PMF Abv Stampede PMF Event and by 0.23 feet in the less stressing LT General PMF Abv Boca PMF Event. However, the volume of water that flows over the dam in the LT General PMF Abv Stampede PMF Event is increased by only 496 acre-feet in the TBWMOP scenarios compared to Baseline. The Boca peak elevation is also increased in these events but by a lesser amount, 0.08 feet in both LT General PMF events. Sensitivity analysis of the Boca Portion of Flood space to TBWMOP objectives shows that increasing the Boca Portion of Flood space increases the improvement over the Baseline RMS Flow Over Flood Target objective by 69% with minimal impact of other study Objectives. Future studies should analyze how the increased elevations of Boca and Stampede during the General PMFs impact the dam safety and evaluate whether or not the Preferred Operational Scenario and Revised Guide Curve Scenarios meet the TBWMOP study constraint to “not increase the probability of dam failure from overtopping or internal failure”.

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