Appendix O

Preferred Operational Scenario Selection Process

PREFERRED OPERATIONAL SCENARIO SELECTION PROCESS

Truckee Basin Water Management Options Pilot, Memorandum of Agreement Task 7: Select Preferred Operational Scenario

Abstract

Truckee Basin Water Management Options Pilot Cost Share Partners collaborated on June 28th and 29th, 2023, to analyze simulations of alternative flood control operational criteria to the 1985 Water Control Manual. Over the course of these two days, stakeholders arrived at a Preferred Operational Scenario to recommend to the United States Army Corps of Engineers as a revision to the Water Control Manual. This report documents the methodology of this analysis and provides an overview the Preferred Operational Scenario.

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DATE: August 23, 2023

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1 INTRODUCTION

The Truckee Basin Water Management Options Pilot (WMOP) Study is a preliminary effort to update and improve flood control operations on the Truckee River for the benefit of water management in the basin. As a part of the study's Plan Formulation, stakeholders in the project identified problems with the United States Army Corps of Engineers' (USACE) Water Control Manual (WCM), the governing flood control regulation criteria for the Truckee River Basin that was adopted in 1985. The problems are best summarized as follows (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 "The [WCM] suffers from outdated rule curves, inflexible storage requirements, constrained reservoir release thresholds, and a constrained downstream regulation goal at Reno.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."

Outdated rule curves (also known as guide curves) refer to diagrams used to determine daily top of conservation pool storages last developed in the 1980s. Since these diagrams are based on data collected from the 1980s or earlier, the resulting flood space reservation requirements may not be reflective of more recent basin conditions. Constrained reservoir release thresholds generally refer to the timing of fall drawdown and spring refill reservoir operations, which can require water to be released faster than is demanded downstream. Further, the inflexibility of release timing can make meeting instream flow rate requirements more difficult and result in negative biological impacts. The "constrained downstream regulation goal at Reno" refers to the set flood operations target flow through Reno of 6,000 cfs. Given relatively recent insight into on-the-ground impacts of flood damage, and advancements in flood inundation modeling, 6,000 cfs may no longer be an ideal governing threshold for operations. TROA refers to the governing river policy of the Truckee River Basin, which is not reflected by the 1985 WCM (Truckee River Operating Agreement, 2008). Finally, the 2017 crest raise at Reclamation's Stampede Dam encompasses an 11.5 ft raise to address dam safety concerns related to large flood events (Bureau of Reclamation, 2020).

As a response these problems, the WMOP Cost Share Partners developed Alternative Operational Scenarios to the regulation criteria in the WCM (Noe, Erkman, & Gwynn, Action and Alternative Operational Scenario Modeling in the WMOP Study, 2023). Cost

Share Partners, also referred to as the Technical Team, that contributed to developing these Alternative Operational Scenarios and to the larger WMOP effort included 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).

This group developed six Alternative Operational Scenarios, each focusing on one of the following major goals:

- **Alternative Operational Scenario 1:** the No Action Alternative Operational Scenario, represented continued management as described in the current Water Control Manual (US Army Corps of Engineers, 1985).
- **Alternative Operational Scenario 2:** the Optimizing Storage for Fisheries and Water Supply Alternative Operational Scenario, represented a scenario that best meets objectives related to satisfying water demands. It sought to improve environmental in-stream flows, allow for more reservoir operations flexibility considering changing runoff conditions.
- **Alternative Operational Scenario 3:** the Dynamic Flood Risk Reduction Criteria Alternative Operational Scenario, provided the most potential for dynamic management based on real-time conditions. This Alternative Operational Scenario emphasizes a real-time model based on forecasts.
- **Alternative Operational Scenario 4:** the Updating Flood Risk Management Alternative Operational Scenario, prioritized downstream flood risk reduction and ease of implementation.
- **Alternative Operational Scenario 5:** the Hybrid Rule Curve Alternative Operational Scenario, combined actions that addressed the greatest number of objectives, regardless of the ability of the action to address each objective.
- **Alternative Operational Scenario 6:** the Variable Percent of Revised Guide Curve to Maintain Alternative Operational Scenario, very similar to Alternative Operational Scenario 2, with added Variable Percent of Revised Guide Curve to Maintain dependent on water year Farad Natural Flow forecasted volume.[1]

These Alternative Operational Scenarios were modelled as a part of the project's technical effort to provide the Technical Team with analysis necessary to selecting a

[1] This Alternative Operational Scenario was not developed during the Plan Formulation; rather, it was developed by the Technical Team once preliminary results were available. A more detailed overview of Alternative Operational Scenario 6 is provided in **Section 2.3 Alternative Operational Scenarios**

Preferred Operational Scenario for the study (Noe, Erkman, & Gwynn, Action and Alternative Operational Scenario Modeling in the WMOP Study, 2023). The purpose of this report is to document the process by which the Technical Team evaluated and compared alternative regulation criteria to determine a Preferred Operational Scenario to be proposed to USACE for an update to the WCM. The paper begins by providing key background and a summary of the technical methods used to model the Alternative Operational Scenarios. Next, it documents two key decisions made in the Select Preferred Operational Scenario Process. Lastly, the paper provides an overview of the Preferred Operational Scenario for the study.

2 BACKGROUND

Prior to the Select Preferred Operational Scenario Process, there were two key phases of the WMOP: the Plan Formulation and the Technical Analysis. During the Plan Formulation of the WMOP, members of the Technical Team and other key stakeholders developed several key components of the study including:[2]

- Study constraints and objectives.
- Actions to address the identified problems with current regulation criteria.
- Alternative Operational Scenarios, or combinations of actions, for the study.

In the Technical Analysis phase of the project, the Technical Team implemented decisions from the Plan Formulation into a modeling infrastructure that would provide the necessary information to (1) evaluate and compare Alternative Operational Scenarios in the study, and (2) select the Preferred Operational Scenario. The following subsections provide contextual details about the technical modelling in the WMOP that are important to understanding the Select Preferred Operational Scenario Process. This includes overviewing the Objectives, Actions, Alternative Operational Scenarios, Decision Variables, and Multi Objective Evolutionary Algorithm (MOEA) employed in the WMOP. For more comprehensive documentation on the Plan Formulation and Technical Analysis, refer to:

- *Multi Objective Evolutionary Algorithm Tool Utilization and Development* (Precision Water Resources Engineering, 2022).

[2] Other key stakeholders contributing to the effort include the Truckee River Flood Management Authority (TRFMA), California Nevada River Forecast Center (CNRFC), National Oceanic and Atmospheric Administration, the National Weather Service (NWS) and USACE.

- *Alternative Operational Scenarios Development Report* (Reclamation, 2021).
- *Action and Alternative Operational Scenario Modeling in the WMOP Study* (Noe, Erkman, & Gwynn, Action and Alternative Operational Scenario Modeling in the WMOP Study, 2023).

2.1 Objectives

During the Technical Analysis, study objectives defined in the Plan Formulation were categorized as either Quantifiable or Non-Quantifiable Objectives (Noe, Erkman, & Gwynn, Action and Alternative Operational Scenario Modeling in the WMOP Study, 2023). Quantifiable Objectives represent those that are more objective in nature and could be calculated from model results for a given Alternative Operational Scenario. An additional quantifiable objective not pictured in Table 1 is the Cumulative Storage Over Dam Failure Elevations Objective. This objective ensures that any considered MOEA Solution cannot increase the risk of dam failure. All MOEA Solutions discussed in this report demonstrated a Cumulative Storage Over Dam Failure Elevations of 0 acre-feet.

Non-Quantifiable Objectives represent those that are more subjective in nature and that could not be calculated from the model results of a given Alternative Operational Scenario. As discussed later in this document, both sets of objectives played a significant role in the Select Preferred Operational Scenario Process.

Table 1: Quantifiable WMOP Objectives.

Objective Name	Calculation	Goal
Average Annual Volume for FR	Calculates the volume of Floriston Rate water within each of the 37 years of the planning model run and takes the average of these 37 years.	Maximize
Average Prosser Boca Stampede Storage	Calculates the average combined storage in Prosser, Boca, and Stampede over the model run.	Maximize
Average Annual Volume for Flow Regime	Calculates for each of the 37 years of the model run the average annual flow at Nixon limited the Flow Regime Target and then takes the average of these values. The flow regime target is computed within the planning model.	Maximize
RMS Flow over Flood Target	Using the historical dataset and the 100-year Scaled Hindcasts, the Square root of the sum of the squared hourly flows over 6500 cfs.	Minimize
Average Daily Increase in Flood Space Requirement	The average daily increase in the basin Flood Space requirement, limited to the days when the Flood Space requirement increases	Minimize

Table 2: Non-Quantifiable WMOP Objectives

Non-Quantifiable Objective Descriptions
Maximize the flexibility for timing of drawdown under flood control measures.
Maximize flexibility for refill in reservoirs up to the maximum conservation elevations.
Bring the WCM up to date with current technologies and capabilities and allow for flexibility for future improvements in data availability/forecasting of future climate conditions.
Allow flexibility for varying future operating conditions of Martis Creek Dam.
Allow flexibility for future increases in flood thresholds because of flood improvements downstream.
Develop methodologies that are implementable in an operational mode.

The modeling effort also calculated a set of 33 Supplemental Metrics that provide more details on the performance of the Alternative Operational Scenarios. Some of these metrics calculate a different or more detailed measurement of an objective. For example, the Floriston Rate (FR) objective calculates the Average Annual Floriston Rate flow in cfs over the 37-year model run; this objective is complemented with a Supplemental Metric that calculates the Average Annual Days Missing Floriston Rate. Further, this metric is broken down by how many days the Floriston Rate is missed each season. Other metrics provide information of importance to specific stakeholders. For example, the metrics provide information on individual TROA parties' water storage and establishment. The Key Stakeholders rarely discussed the Supplemental Metrics during the workshops or Technical Team meetings; however, some stakeholders and individuals did use the metrics to help inform their selection of the Best-Performing MOEA and Preferred Operational Scenario and the results are presented in subsequent sections.

2.2 Actions

During the Plan Formulation, the Technical Team identified four problems (Table 3) with current regulation criteria and then developed actions to address each of them (Table 4). Two actions were developed to address the Problems of Reservoir Refill and Fall Drawdown. The first action, the Revised Guide Curve, determined a new (revised) rule curve (also known as guide curve) for the Truckee Basin Flood Control Reservoirs

(Prosser Creek Reservoir, Boca Reservoir, Stampede Reservoir, and Martis Creek Reservoir) based on updated historical data and methodology (Gwynn, 2022). The second action, the "By a Model" method, leveraged probabilistic ensemble forecast information from the California Nevada River Forecasting Center (CNRFC) to determine flood space requirements (Noe, Erkman, & Gwynn, Action and Alternative Operational Scenario Modeling in the WMOP Study, 2023). This "By a Model" method was further constrained by the Percent of Revised Guide Curve to Maintain. This decision variable (see **Section 2.5 Decision Variables**) serves as a safety factor on the minimum permissible magnitude of daily flood space requirements determined by the "By a Model" approach. Both actions were designed to increase operational flexibility during fall drawdown and spring refill.

Table 3: Problems and Opportunities identified during the Plan Formulation

Reservoir Refill	**Problem Description**	The current rule curves miss opportunities for storing inflow.
	Opportunity	Under updated rule curves, inflow that would have been passed under current rule curves to maintain flood space in the winter could be stored for later use.
Fall Drawdown	**Problem Description**	The current timing of drawdown, which has reservoirs fully drawn down by November 1st, can require water to be released from reservoirs that is not demanded downstream. This problem can also make it difficult to meet instream flow requirements resulting in biological impacts on factors such as water temperature in the Truckee River or exposing fish species in the river.
	Opportunity	Under updated rule curves, water that would have been released to maintain flood space requirements could instead be conserved for later use when it is demanded.
Normal Flood Operations	**Problem Description**	The set flood operations target flow at the Reno Gage of 6,000 cfs may no longer be the reasonable threshold that should govern operations.
	Opportunity	If the flow target could be increased, flood space could be evacuated more efficiently, helping minimize risk of downstream flooding.
Little Truckee Flood Space	**Problem Description**	The WCM has not been updated to account for 2017 improvements to Stampede Dam.[1]
	Opportunity	Leveraging these improvements, reproportioning the flood space between Boca Reservoir and Stampede Reservoir could benefit water supply or help minimize risk of downstream flooding.

Table 4: Actions defined for each Problem identified in the Plan Formation

Problem	Action 1	Action 2
Reservoir Refill	Revised Guide Curve	"By a Model" Method
Fall Drawdown	Revised Guide Curve	"By a Model" Method
Normal Flood Operations	Updated Target Flow	Updated Target Location
Little Truckee Flood Space	Reproportion	-

During Normal Flood Operations, the WCM prescribes that Prosser Creek Reservoir, Boca Reservoir, and Stampede Reservoir be operated to a downstream target of 6,000 cfs at the Reno Gage. Two actions were identified to address problems the Technical Team found with this regulation criteria. The first, the Updated Target Location action, explored if operating reservoirs during floods to both the Reno Gage *and* the Vista Gage provided benefits to reducing downstream flood damages. The second, the Updated Target Flow action, sought to identify benefits associated with increasing the downstream flood target to a flow target greater than 6,000 cfs at the Reno Gage (Noe, Erkman, & Gwynn, Action and Alternative Operational Scenario Modeling in the WMOP Study, 2023).

Lastly, one action was identified for the problem with Little Truckee Flood Space. The current WCM regulation criterion reserves roughly 26.7% of the total Little Truckee Flood Space in Boca Reservoir (referred to in this report as the Boca Portion of Flood Space) and the remaining 73.3% in Stampede Reservoir. The Reproportion action explored the benefits to stakeholder objectives associated with adjusting the flood space allocation percentages between Boca and Stampede Reservoirs (Noe, Erkman, & Gwynn, Action and Alternative Operational Scenario Modeling in the WMOP Study, 2023).

2.3 Alternative Operational Scenarios

The Technical Team combined the actions defined in the previous section to form the Alternative Operational Scenarios of the WMOP. Alternative Operational Scenarios 1 through 5 were determined during the Plan Formulation of the WMOP. These Alternative Operational Scenarios are discussed in detail in *Action and Alternative Operational Scenario Modeling in the WMOP Study* (Noe, Erkman, & Gwynn, Action and Alternative Operational Scenario Modeling in the WMOP Study, 2023). Alternative Operational Scenario 6 was added to the study after preliminary results were presented to stakeholders and concerns of large fluctuations of reservoir releases exhibited by some Alternative Operational Scenarios were discovered. More discussion on fluctuating reservoir releases is discussed later in this report. The following paragraphs introduce Alternative Operational Scenario 6 in more detail.

This Operational Scenario, in principle, combines Alternative Operational Scenarios 2 and 4 by allowing the Percent of Revised Guide Curve to Maintain to fluctuate between 40% (as defined by Alternative Operational Scenario 2) and 100% depending on the forecasted Farad Natural Flow (FNF) water year (WY) forecast (California Nevada River Forecast Center, National Oceanic and Atmospheric Administration, 2023). When the forecasted FNF increases above roughly median volumes, the Percentage of Revised Guide Curve to Maintain will increase from 40% up to a maximum of 100%. When the FNF forecast decreases in magnitude to or below roughly median values, the Percentage of Revised Guide Curve to Maintain decreases to a minimum of 40%. It is important to note that at no point, regardless of the magnitude of the FNF water year forecast, will the Percentage of the Revised Guide Curve to Maintain fall below the percentage determined by the Best Performing MOEA Scenario (Table 7). Essentially, this combination of Alternative Operational Scenarios 2 and 4 employs a more conservative safety factor to FIRO "By a Model" method for determining flood space requirements, and transitions more toward 100% of the Revised Guide Curve method for determining flood space requirements as the magnitude of the FNF water year forecast increases.

This transition from 40% to 100% of the Revised Guide Curve flood space had to be based on a forecast to be viable in real-world operations. In search of an appropriate forecasted parameter to base this transition on, additional analysis of the WMOP Study's planning data and *TROA Operations and Accounting Model* ensemble results indicated that there is a relationship between FNF WY Volume and filling Prosser Creek, Boca, and Stampede Reservoirs. Specifics of this relationship include:

1. A WY FNF Volume forecast of approximately 300,000 acre-feet was the minimum volume associated with filling Prosser, Boca, and Stampede reservoirs (Figure 1).
2. A WY FNF Volume forecast of 600,000 acre-feet or larger was correlated with ensemble traces with a volume filling Prosser, Boca, and Stampede reservoirs (Figure 2).

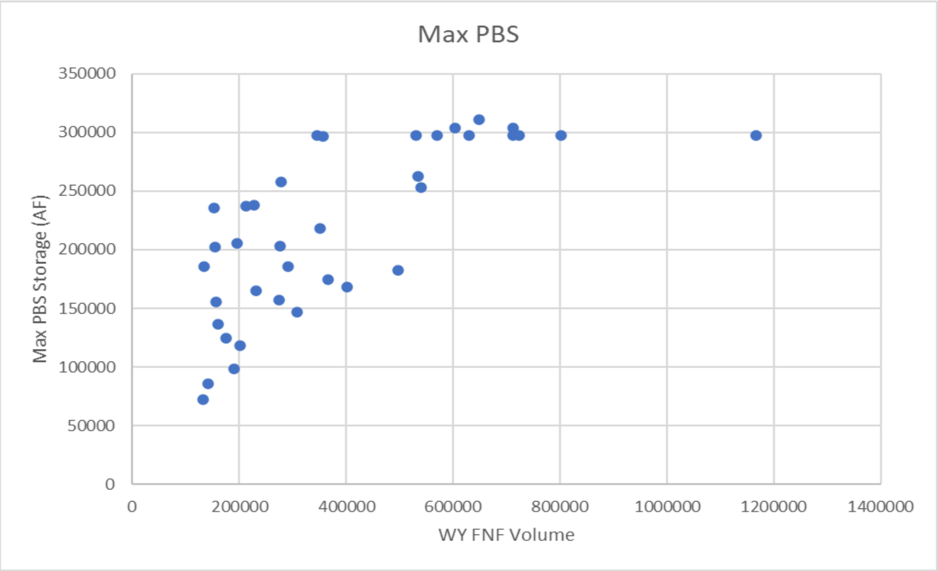

Figure 1: Planning Model Data Relationship Between WY FNF Volume and Max Prosser Boca and Stampede Storage

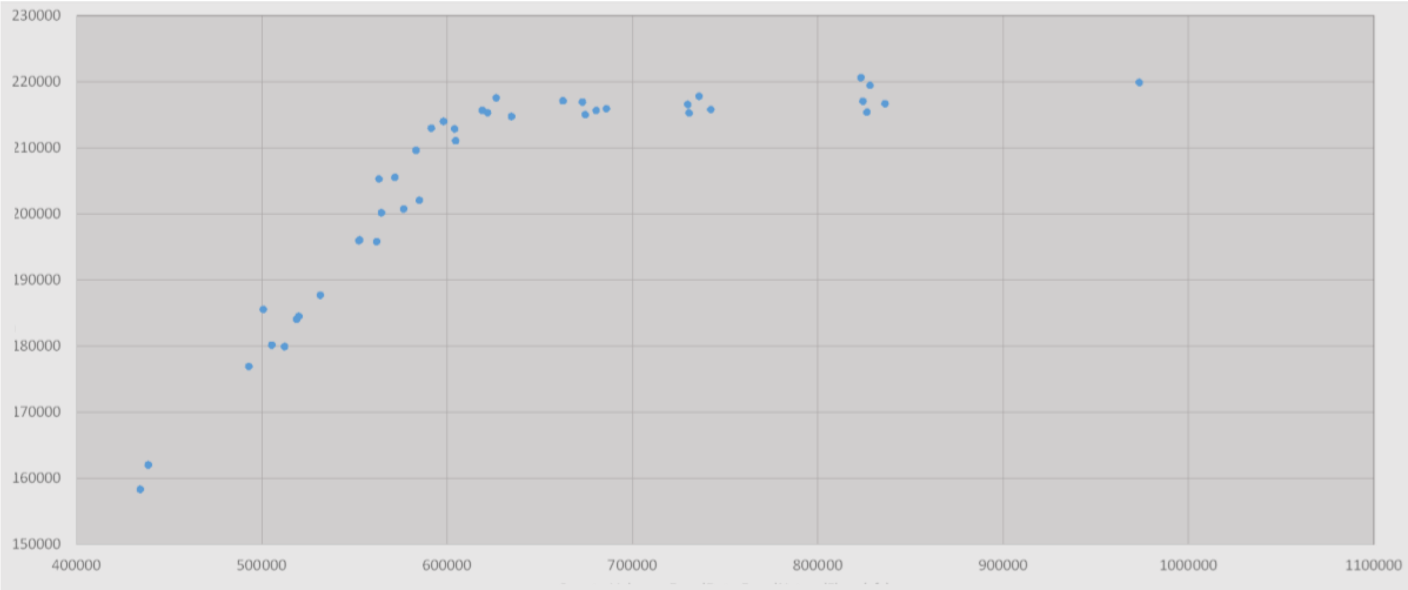

Figure 2: TROA Operations Model Relationship Between Farad Natural Flow Volume (x-axis) and Prosser, Boca, and Stampede Storage (y-axis)

Thus, the median WY Farad Natural Flow Volume forecast, regularly provided by the CNRFC, was determined to be a useful indicator for the appropriate Percent of Revised Guide Curve to Maintain. After comparing four methods to calculate this transition, the Technical Team agreed that 40% of the Revised Guide Curve flood space would be maintained for Farad WY Natural Flow forecasts of 300,000 acre-feet or less, and 100% of the Revised Guide Curve flood space would be required for WY Farad Natural Flow forecasts of 600,000 acre-feet or more. Between 300,000 and 600,000 acre-feet, the Percent of Revised Guide Curve to Maintain would relate linearly with the WY Farad Natural Flow forecast. Additionally, to mitigate the effects of day-to-day fluctuations observe in WY Farad Natural Flow Volume forecasts, the Technical Team opted to limit the Percent of Revised Guide Curve to Maintain flood space to:

- Change by at most 2% per day.
- Be based upon the WY FNF Volume Forecasted rounded to the nearest 50,000 acre-feet.

Table 5 provides a summary of all six Alternative Operational Scenarios. During the Select Preferred Operational Scenario Process, the Technical Team evaluated the modeling results of this set of Alternative Operational Scenarios to ultimately determine the Preferred Operational Scenario in the study.

Table 5: WMOP Study Alternative Operational Scenarios. Each Alternative Operational Scenario is a combination of different Actions in response to the four Problems/Opportunities.

Alternatives		Problems/Opportunities				
Alternative Number	Description	Reservoir Refill	Fall Drawdown	Normal Flood Operations	Little Truckee Flood Space	
1	No Action	Current Guide Curve	Current Guide Curve	Target Location: Reno Gage Reno Target Flow: 6,000 cfs	Current Proportion	Actions
2	Optimizing Storage for Fisheries and Water Supply	"By a Model" Method	"By a Model" Method	Target Location: Reno Gage Reno Target Flow: 6,500 cfs	Reproportion	
3	Dynamic Flood Risk Reduction Criteria	"By a Model" Method	"By a Model" Method	Target Location: Reno and Vista Gages Reno Target Flow: 6,500 cfs	Reproportion	
4	Updating Flood Risk Management	Revised Guide Curve	Revised Guide Curve	Target Location: Reno Gage Reno Target Flow: 6,500 cfs	Reproportion	
5	Hybrid Rule Curve	"By a Model" Method	Revised Guide Curve	Target Location: Reno Gage Reno Target Flow: 6,500 cfs	Reproportion	
6	Variable 'By a Model' Method	Variable "By a Model" Method	Variable "By a Model" Method	Target Location: Reno Gage Reno Target Flow: 6,500 cfs	Reproportion	

2.4 MOEA

As described above, the Truckee Basin has seen significant changes in the decades since the 1985 WCM was developed. Because of this, the Technical Team strived to develop regulation criteria that incorporated improvements to technology (i.e., forecasting). This led to the implementation of an MOEA to facilitate the technical analysis of the study. MOEAs are best defined as follows:

> "MOEAs are non-linear, stochastic optimization methods that can be used to identify the best compromise solutions along a path of potential policy alternatives given a set of objectives. MOEAs provide a systematic process for developing a solution that balances the achievement of multiple (often competing) objectives. It provides users with a quantitative way to evaluate tradeoffs" (Precision Water Resources Engineering, 2022).

Within context of the WMOP Study, such competing objectives include (at a high level) water supply, environmental concerns, and flood risk mitigation. Intuitively, having a more conservative flood risk mitigation policy could negatively impact water supply by requiring more conservative flood control pools. Similarly, instituting regulation criteria with more water supply benefits might sacrifice flood risk benefits.

A few pieces of terminology are key to understanding how the MOEA works (Precision Water Resources Engineering, 2022):

- **Function**: the model that is undergoing optimization.
- **Decision variables**: the parameters that the MOEA will optimize, input to the function by the MOEA.
- **Objectives:** the output from the function that represents the performance of the function given an input set of decision variables.
- **MOEA Search Algorithm**: Algorithm that selects new sets of decision variables to evaluate in the function by learning the relationship between decision variables and objective performances.
- **Nondominated solutions**: the results of the MOEA. In a nondominated solution, no objective can be further improved without a cost, or tradeoff, to another objective.

These concepts are illustrated in Figure 3.

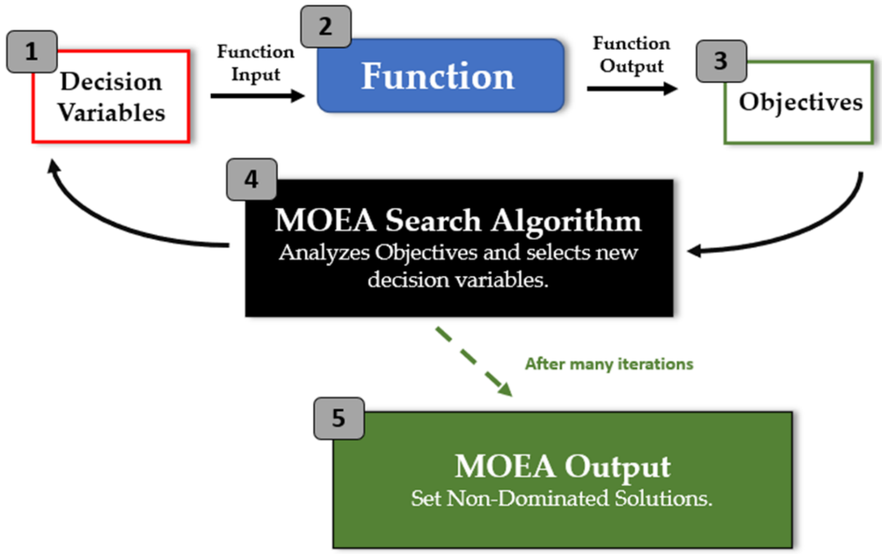

Figure 3: Five main components of the MOEA.

2.5 Decision Variables

As introduced above, decision variables represent the parameters to be optimized in the study. Such decision variables are input to the optimization process. In total, the MOEA used for the WMOP had five decision variables. Three of these five decision variables in the WMOP Study define the FIRO Operations developed by the Technical Team known as the "By a Model" method for determining flood space requirements. Specifically, these three decision variables define how conservative or not a regulation criterion is in determining flood control reservoirs' daily flood space requirements from CNRFC ensemble hindcasts. The variables, known as Exceedance Coefficients A, B, and C, define the shape of the Exceedance and Outlook Relationship in the "By a Model" method.[3] Figure 4 provides a *prototype* Exceedance vs. Outlook Relationship for conceptual purposes. This curve defines that at a 1-day outlook, the 0% exceedance, or largest ensemble trace, should be analyzed to determine flood space requirements in the basin. In other words, at a 1-day outlook (one day in advance of a forecasted event), the most conservative (i.e., largest) ensemble trace should be protected against when determining the flood space requirement. In contrast, for the 14-day outlook, the prototype Exceedance vs. Outlook Relationship shows that the 60% exceedance trace of

[3] For more extensive documentation on the "By a Model" Method and its underlying Exceedance vs. Outlook Relationship, refer to the report *Action and Alternative Operational Scenario Modeling in the WMOP Study* (Noe, Erkman, & Gwynn, Action and Alternative Operational Scenario Modeling in the WMOP Study, 2023).

the ensemble should be analyzed to determine flood space requirements in the basin. Intuitively, because there is less skill in and more time to react to a 14-day outlook than a 1-day outlook, a less conservative volume of flood space is permissible by this Exceedance vs. Outlook Relationship (Noe, Erkman, & Gwynn, Action and Alternative Operational Scenario Modeling in the WMOP Study, 2023). Note, the required flood space is calculated for each outlook and exceedance point on the Exceedance vs. Outlook Relationship. The largest, or most conservative, flood space requirement across all outlooks calculated when applying the curve to an ensemble forecast is selected as the daily flood space requirement.

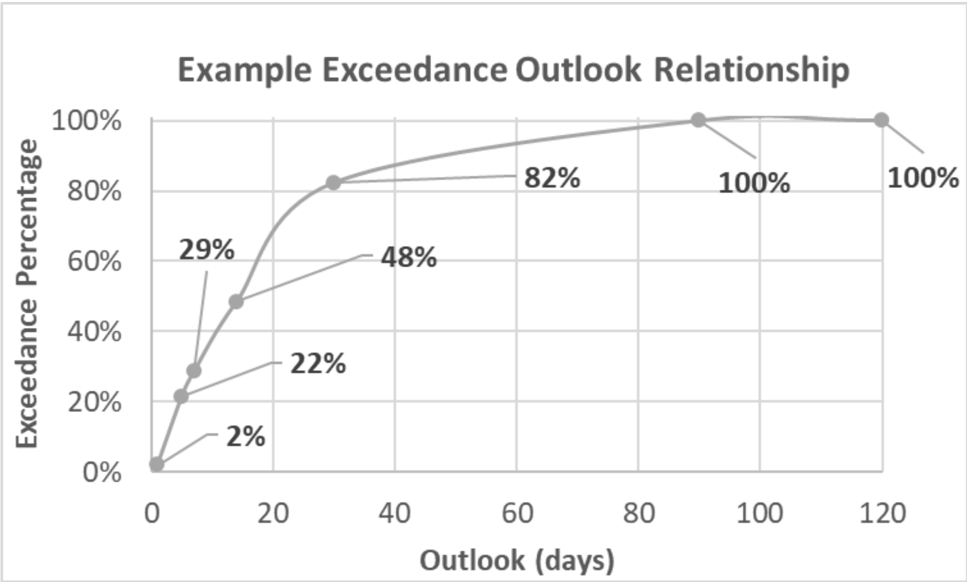

Figure 4: Example Exceedance vs. Outlook Curve

The fourth decision variable quantifies the Reproportion of Little Truckee Flood Space actions. More specifically, this decision variable seeks to explore the benefits of adjusting Boca Reservoir's portion of Little Truckee flood space prescribed by the WCM (Noe, Erkman, & Gwynn, Action and Alternative Operational Scenario Modeling in the WMOP Study, 2023).

The fifth and final decision variable, the Percent of Revised Guide Curve to Maintain, serves as a safety factor on the "By a Model" method in that it, regardless of the flood space requirements determined by the "By a Model" approach, requires a minimum percentage of the Revised Guide Curve's flood space requirement to be kept empty in the flood control reservoirs (Noe, Erkman, & Gwynn, Action and Alternative Operational Scenario Modeling in the WMOP Study, 2023).

3 Methods

The process to evaluate the Alternative Operational Scenarios and select a Preferred Operational Scenario tied together all the pieces of the WMOP up to that point. The Alternative Selection Process entailed multiple remote sessions with the Technical Team, some of which also included the larger group of Key Stakeholders, as well as two in-person multi-day workshops. The second workshop is hereby referred to as the WMOP Select Preferred Operational Scenario Workshop, which took place from June 28^{th} to June 29^{th}, 2023. During this workshop, stakeholders discussed time series results associated with each of the four remaining MOEA Scenarios and determined the best performing scenario.

Modeling the Actions and Alternative Operational Scenarios was integral to the Select Preferred Operational Scenario Process because it allowed the Technical Team and other key stakeholders the ability to evaluate and compare different flood control regulation criteria against one another. While the technical design for the Alternative Operational Scenario modeling is documented in full in *Action and Alternative Modeling in the WMOP Study*, this section of the report provides a summary to contextualize the decision-making process documented in this report.

Two RiverWare© models were central to the technical infrastructure of the WMOP:

1. The *Truckee River Operating Agreement Planning Model* (Planning Model)
2. The *Truckee River Hourly River Model* (Hourly Model).

The Planning Model is the preeminent planning tool for the Truckee Basin designed to operate the Truckee and Carson basin reservoirs in accordance with the *Truckee River Operations Agreement* (TROA), the governing river policy of the Truckee River Basin (Truckee River Operating Agreement, 2008). Additionally, the model simulates:

- Current water user demands.
- Operations of the Truckee Canal (a major diversion on the Truckee River).
- Water Rights.
- Environmental flow strategies and operations.
- Operations of all major stakeholders in the Truckee River Basin.

The Hourly Model, developed as a part of the WMOP, is an hourly timestep RiverWare model utilized for short term flood event routing within the Truckee Basin. The model utilizes the Muskingum Routing Method to route water from the seven upstream

Truckee Basin Reservoirs in California to the Truckee at Wadsworth USGS gage in Nevada. Logic codified into the model operates reservoirs to various flood control regulation criteria including those specified in the WCM.[4]

The Planning Model and Hourly Model worked in tandem to model water years 1986 through 2022 for each of the Alternative Operational Scenarios in the WMOP. The two models accomplished a specific purpose: the Planning Model evaluated water supply and environmental objectives and the Hourly Model evaluated flood damages. Each model developed to simulate the Alternative Operational Scenarios of the study is summarized in *Action and Alternative Operational Scenario Modeling in the WMOP Study* (Noe, Erkman, & Gwynn, Action and Alternative Operational Scenario Modeling in the WMOP Study, 2023).

Figure 5 provides the high-level structure of the Alternative Operational Scenario modeling highlighting the two decisions required by the Technical Team to select the Preferred Operational Scenario. As illustrated in the figure, the Technical Team utilized an MOEA to model Alternative Operational Scenario 3.[5] The MOEA simulated the Alternative Operational Scenario 3 model thousands of times, resulting in 150 non-dominated solutions. This set of solutions, referred to as MOEA Scenarios, represented the best performing versions of Alternative Operational Scenario 3 (Noe, Erkman, & Gwynn, Action and Alternative Operational Scenario Modeling in the WMOP Study, 2023), and as part of the Select Preferred Operational Scenario process, the Technical Team would select one of the 150 MOEA Scenarios to represent Alternative Operational Scenario 3 by evaluating which one best met stakeholder objectives. In doing so, the Technical Team also "optimized" the parameters associated with the "By a Model" Method and Reproportion actions.

Figure 5 also demonstrates how some of the parameters of Alternative Operational Scenario 3, once optimized, were utilized to model Alternative Operational Scenarios 2,

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[4] Documentation for the calibration and validation of the routing method used in the Hourly Model, refer to *WMOP Truckee River Hourly River Model Time Lag Routing* (Olsen, Erkman, & Vandegrift, 2021). For verification of reservoir operations in the Hourly Model, refer to (Noe, Truckee River Hourly Model Verification for WMOP, 2022).

[5] For an overview of MOEA and its related terminology see *Multi-Objective Evolutionary Algorithm (MOEA) Tool Utilization and Development Technical Memorandum* (Precision Water Resources Engineering, 2022). For a detailed documentation of how the MOEA was used in the WMOP, see *Action and Alternative Operational Scenario Modeling in the WMOP Study* (Noe, Erkman, & Gwynn, 2023).

4, 5 and 6. Once all the Alternative Operational Scenario were modeled, the Technical Team would select a Preferred Operational Scenario by evaluation the study objectives.[6]

Given the large volume of data output by the technical analysis, development of a decision-making framework to decide (1) the Best Performing MOEA Scenario and (2) the Preferred Operational Scenario was essential. This framework and the two decisions made by the Technical Team are documented in the following two sections.

Of note, the Key Stakeholders undertook the Alternative Operational Scenario Selection Process twice, due to an error in the MOEA code detected during a technical review conducted after the first workshop to select a Preferred Operational Scenario (March 2023). After remedying the error and conducting additional quality assurance, PWRE re-ran the MOEA, and the Alternative Operational Scenario Selection Process was undertaken again with the updated results (June 2023). With only slight modification to avoid repetition, the same procedural Alternative Operational Scenario Selection Process Framework (Figure 27) was undertaken on both occasions. Further, due to the similarity in results and objectives scores before and after the coding error was remedied, the Key Stakeholders reached the same decision on the Preferred Operational Scenario. Due to these similarities, this section focuses on the second Alternative Operational Scenario Selection Process with the corrected MOEA code.

[6] For detailed descriptions of each Alternative Operational Scenario and how they were modelled, see Action and Alternative Operational Scenario Modeling in the WMOP Study (Noe, Erkman, & Gwynn, 2023).

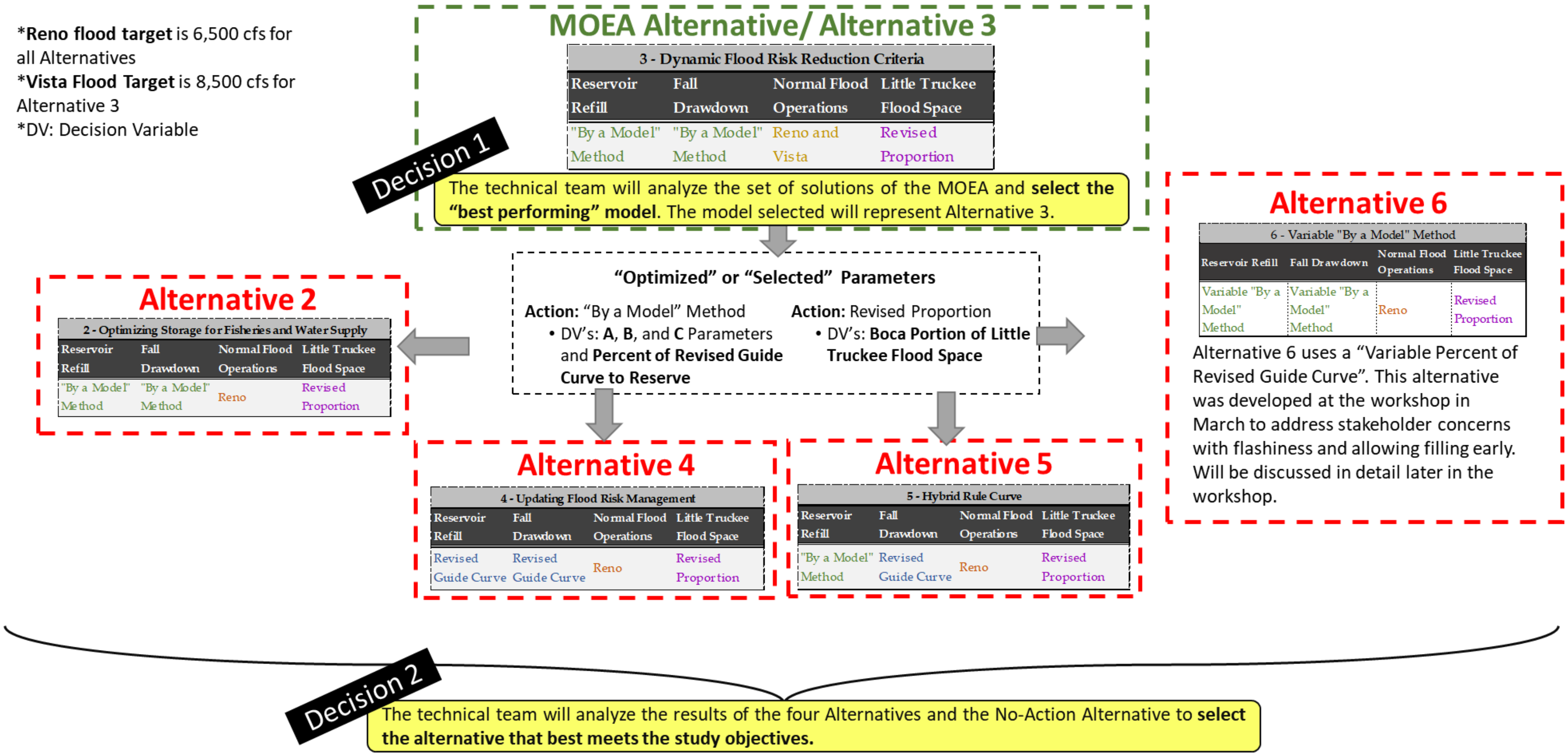

Figure 5: Summary of the Alternative Operational Scenarios Modeling. Parameters of Alternative Operational Scenario 3 were optimized using an MOEA and then utilized to model Alternative Operational Scenarios 2, 4, 5, and 6.

4 SELECT BEST PERFORMING MOEA SCENARIO

Three distinct steps were undertaken to arrive at a Best Performing MOEA Scenario. These steps allowed for efficient elimination of several less desirable MOEA Scenarios so that stakeholders could focus detailed analysis and discussion on a curated, short list of "best" MOEA scenarios. These three steps are summarized in Figure 6, and each one is explained further in the proceeding sections.

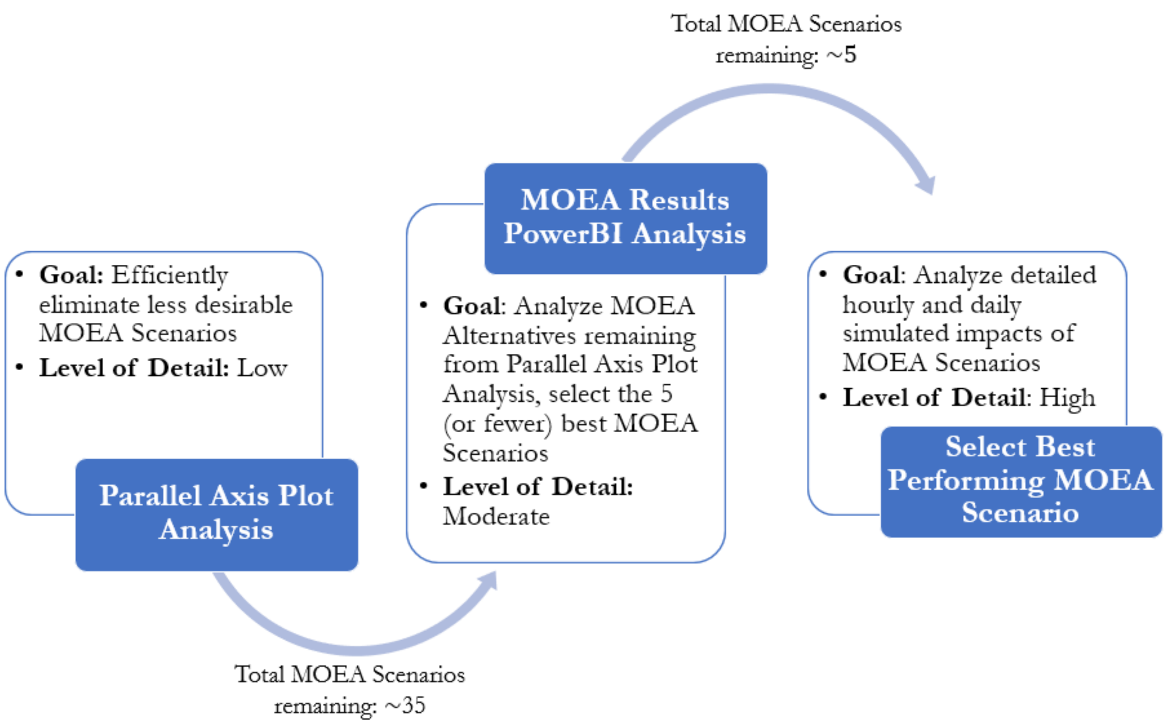

Figure 6: The three steps used by the Technical Team to select the Best Performing MOEA Scenario.

4.1 PARALLEL AXIS PLOT ANALYSIS

Parallel Axis Plots are visualizations used to compare many output together and illustrate the relationships between them (Parallel Coordinates Plot, n.d.). These plots feature several vertical axes, one per objective, oriented from smallest to largest values, bottom to top, respectively. In this context, one axis exists for each quantifiable objective (see **Section 2.1 Objectives)**, and each MOEA Scenario is represented by a line joining each objective score from left to right. These plots allow for high level evaluation of:

1. How well MOEA Scenarios performed in terms of objective scores relative to each other (smaller scores are better).

2. What tradeoffs exist between the objectives (i.e., flood mitigation benefits in contrast to water supply benefits).

In context of the WMOP, the purpose of this analysis was to efficiently eliminate less desirable MOEA Scenarios by broadly comparing all scenarios in terms of their relative objective scores. Figure 7 demonstrates a Parallel Axis Plot of the 150 MOEA Scenarios output from the MOEA Analysis. Each MOEA Scenario is illustrated as a continuous line connecting its objective scores across each vertical axis. The objective scores of the Baseline Operational Scenario (Alternative Operational Scenario 1 in Table 5 or Baseline) are indicated by the green line in this figure. An ideal MOEA Scenario would populate the minimum objective score for every objective; however, as demonstrated in Figure 7, this scenario does not exist due to tradeoffs between some of the objectives. For example, Figure 7 demonstrates that many MOEA Scenarios with the best (smallest) scores for the RMS Flow Over Flood Target objective also have some of the largest scores (worst) for the Average Annual Volume for Flow Regime objective. This indicates that in several MOEA Scenarios, there is a tradeoff between RMS Flow Over Flood Target (benefits to flood risk mitigation) and Average Annual Volume for Flow Regime (benefits to environmental flows).

The Technical Team used a two-step process to filter the MOEA Scenarios from 150 to approximately 35. The first step was to remove all MOEA Scenarios that performed worse than the Baseline for any objective other than the Average Daily Increase in Flood Space Requirement. MOEA Scenarios performing worse than the Baseline for this objective were not removed because they were not required by the Plan Formulation to perform better than the Baseline (Noe, Erkman, & Gwynn, Action and Alternative Operational Scenario Modeling in the WMOP Study, 2023). Next, the Technical Team further filtered down the number of MOEA Scenarios by removing as many of the worst performing scores for each objective as possible while keeping some of the best performing scenarios for each objective. This yielded approximately 35 MOEA Scenarios as shown in Figure 8. Note that the majority of these MOEA Scenarios represent similar tradeoffs at this level of detail. For instance, there is a tendency for the RMS Flow Over the Flood Target scores to increase with decreasing scores for Avereage Annual Volume for Flow Regime amongst most of if not all the MOEA Scenarios. Given the similar tradeoffs between MOEA Scenarios' objective scores, the process of selecting the Best Performing MOEA Scenario was mostly based on objective scores with a few instances where timeseries data was the deciding factor.

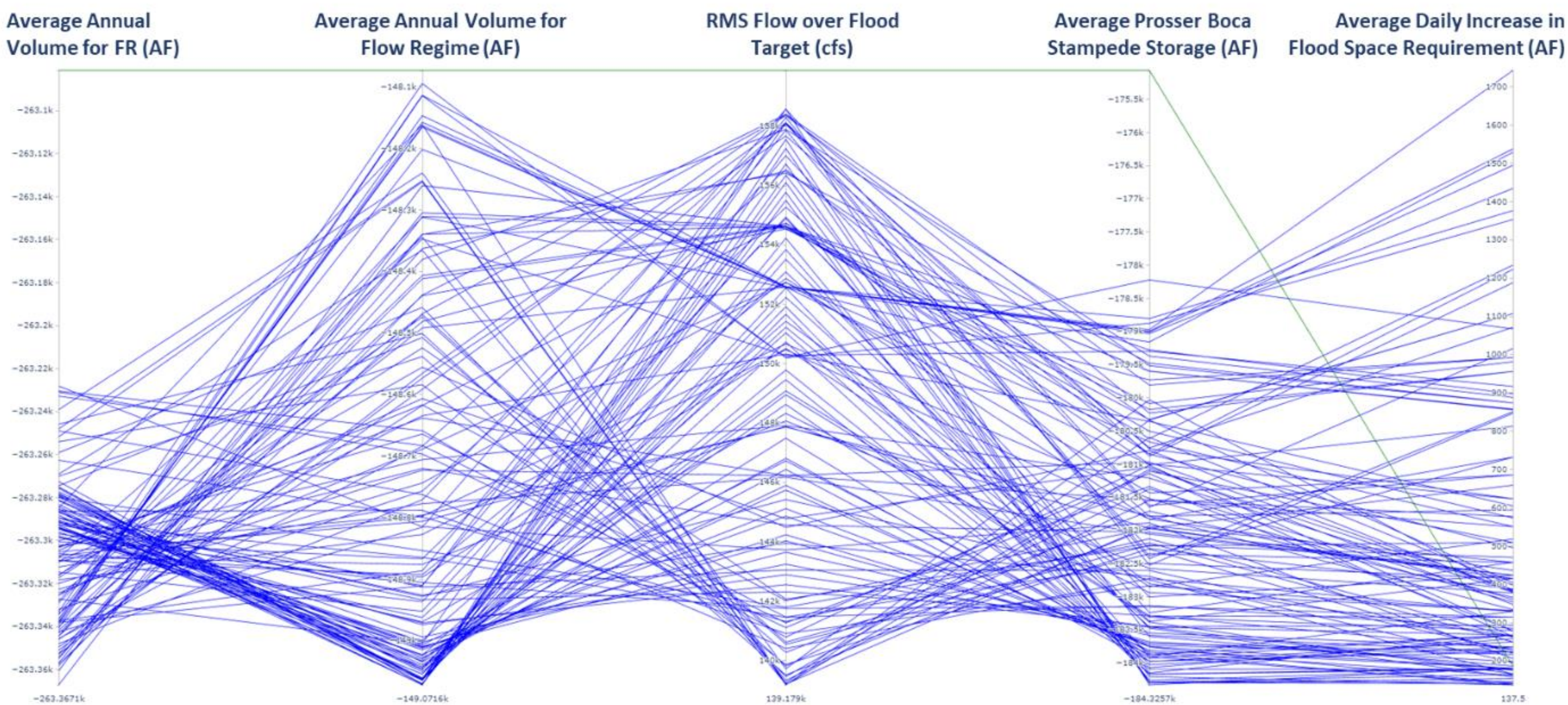

Figure 7: Parallel Axis Plot of the 150 MOEA Scenarios (blue) and the Baseline (green).

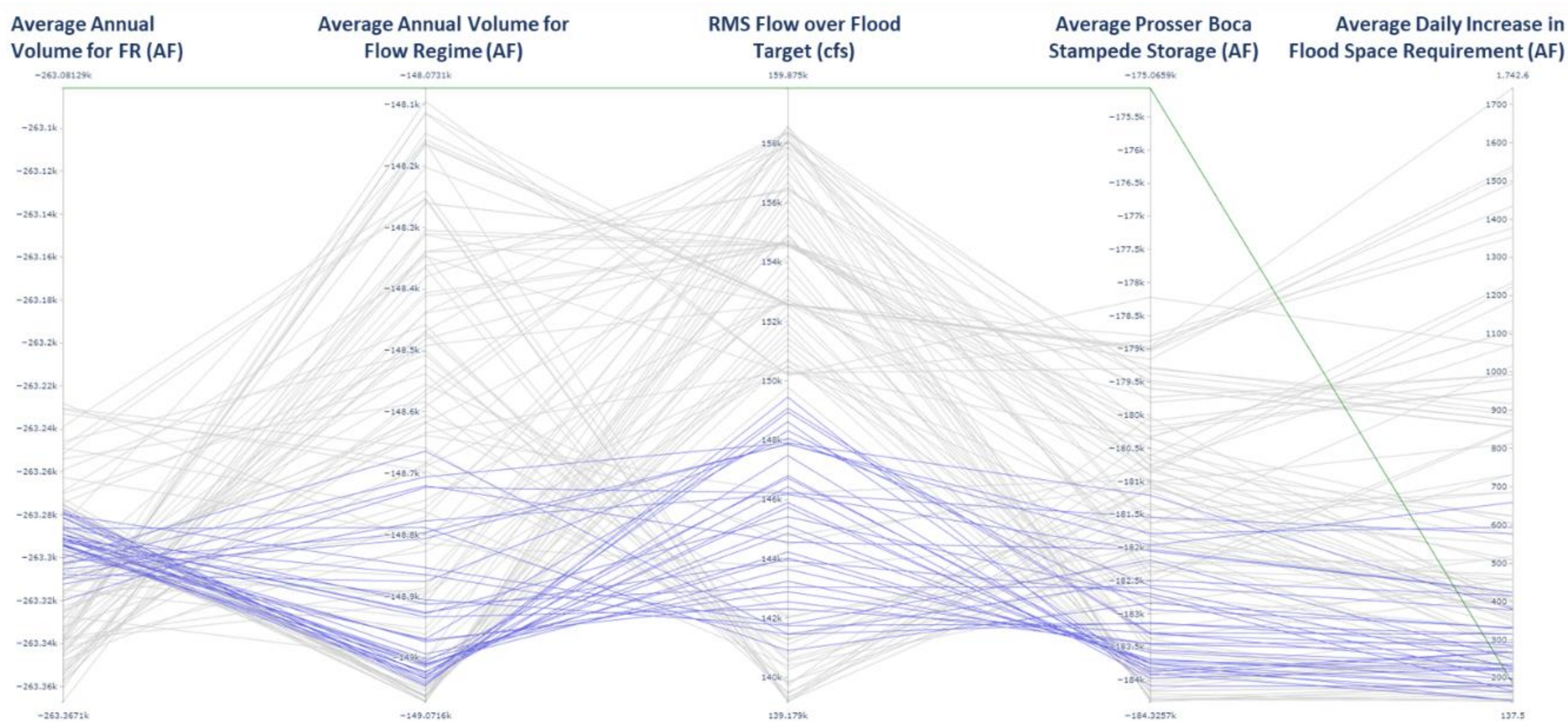

Figure 8: Parallel Axis Plot of the 35 remaining MOEA Scenarios (blue) after the two-step initial filtering process. MOEA Scenarios removed in this two-step process are signified by the light gray lines.

4.2 MOEA Scenarios PowerBI Analysis

This phase of the analysis involved a more detailed review of the remaining 35 MOEA Scenarios to ultimately determine the top four best MOEA Scenarios.

A PowerBI viewer was configured to visualize objective scores and the parameters associated with each of the remaining MOEA Scenarios. This MOEA results viewer facilitated comparison of each MOEA Scenario performance in terms of two objectives. In other words, this tool zooms in on two of the axes of the Parallel Axis Plot at a time to compare the performance of the MOEA Scenario. Any two of the Quantifiable Objectives could be compared using this tool.

The following example from the PowerBI viewer compares the Average Annual Volume for Flow Regime and RMS Flow Over Flood Target objectives on the x and y axis, respectively. As previously discussed, smaller objective scores were better within context of MOEA Analysis, therefore solutions closest to the bottom left of the graph shown in Figure 9 were generally best in terms of their Quantifiable Objectives. This example shows the tradeoffs associated with these two objectives; there existed several points where the score for the Average Annual Volume for Flow Regime objective could not be decreased without increasing the score of the RMS Flow Over Flood Target objective, and vice versa. These points are visible on the perimeter of the points closest to the origin shown in Figure 9. Thus, some subjective evaluation between appropriate objective tradeoffs is inherently involved in determining what MOEA Scenarios are best in this context.

Each agency of the Technical Team was required to determine their top 20 MOEA Scenarios using this PowerBI and their own more subjective criteria of what represented the best MOEA Scenarios to them. The subjective decision criterion for each agency is summarized in Table 6.

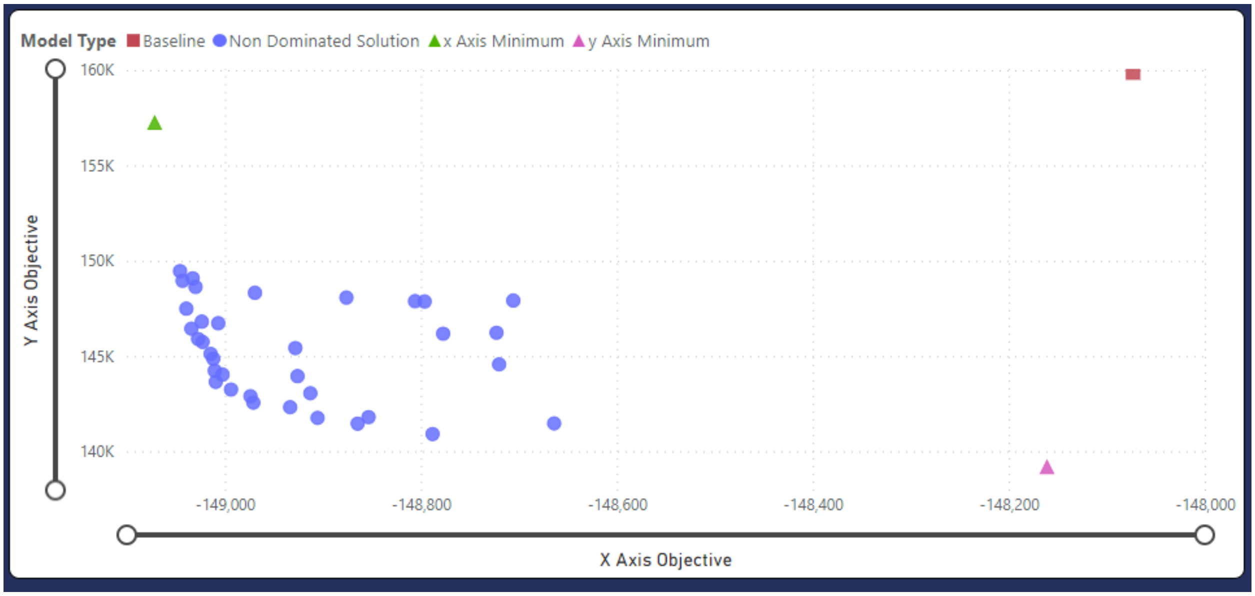

Figure 9: Two-Objective Comparison of Nondominated MOEA Scenarios

Table 6: Main Goals of Each Cost Share Partner's Selected Top 20 MOEA Scenarios

Cost Share Partner	Main Goals of Top 20 MOEA Scenarios
PLPT	Maximize Average Annual Volume for Flow Regime, Maximize Average Boca Prosser Stampede Storage, Minimize Average Daily Increase in Flood Space Requirement, Maximize Annual Average Volume for FR
CA DWR	Maximize Average Boca Prosser Stampede Storage Objective, Minimize RMS Flow Over Flood Target, Maximize Average Annual Volume for Flow Regime
TMWA	Maximize Annual Average Volume for FR Objective w/ no adverse affects to RMS Flow Over Flood Target Objective
Reclamation	Prioritized Scenarios where Percent of Revised Guide Curve to Reserve of 40% and higher, Maximize Average Annual Volume For Flow Regime, Maximize Prosser Boca Stampede Storage, and Minimize Average Daily Increase in Flood Space Requirement
USWM	Eliminate worst scenarios for Average Annual Volume for Flow Regime Objective and Boca Portion of Flood Space Decision Variable greater than 50%. Ultimately ranked solutions based on Average Daily Increase in Flood Space Requirement Objective

Once completed, a small committee, consisting of at least one representative from each agency on the Technical Team, met to determine the top five best MOEA Scenarios. To do this, any MOEA Scenario not within any of the agencies' top 20 was eliminated. Then, a ranking system was applied to each of the MOEA Scenarios as demonstrated in Equation 1.

Equation 1: MOEA Nondominated Scenario Score

$$MOEA\ Nondominated\ Scenario\ Score = \sum \frac{1}{party\ rank}$$

Given that there were only three MOEA Scenarios ranking within the top 20 scenarios for all parties, these models were accepted by the small committee for additional consideration by the larger Technical Team. Another scenario was added to this short list given that it was within all top 20 rankings of all agencies but one. All members of the committee agreed to consider this MOEA Scenario as well, making four MOEA Scenarios in total to be considered for selection by the larger Technical Team. Table 7 summaries the objective scores of these MOEA Scenarios (identified by model number), in addition to their decision variables. From this point on, these top four MOEA Scenarios will be referred to by their MOEA Scenario Model Name (Table 7).

Table 7: Top Four MOEA Scenarios Objectives scores.

	Baseline	A	B	C	D
Annual Average Volume For FR	-263,081	-263,281	-263,279	-263,278	-263,303
Average Annual Volume For Flow Regime	-148,073	-149,046	-149,039	-149,027	-148,706
Average Daily Increase In Flood Space Requirement	187	179	268	268	379
Average Prosser Boca Stampede Storage	-175,066	-184,088	-183,926	-183,867	-181,210
RMS Flow Over Flood Target	159,875	149,457	147,487	145,897	147,915

4.3 Selecting the Best Performing MOEA Scenario

After agreeing upon the top four MOEA Scenarios, stakeholders met at the WMOP Select Preferred Operational Scenario Workshop, which took place between June 28th through June 29th, 2023, to discuss time series results associated with each the four remaining MOEA Scenarios and determine the best performing scenario.

Timeseries results related to WMOP Study objectives and other related modeled parameters are summarized in the proceeding sections. Materials employed for this timeseries analysis involved the Alternative Operational Scenario Output Viewer and Hourly Alternative Operational Scenario Output Viewer. The Alternative Operational Scenario Output Viewer allowed for several types of comparisons between all Alternative Operational Scenarios (Erkman, Alternative Output Viewer-Alternatives, 2023). Comparison types encapsulated within the Alternative Operational Scenario Output Viewer are summarized in Table 8. The Hourly Output Viewer serves the purpose of viewing hourly results of specific hourly flood events modeled in the WMOP Study (Erkman, Hourly Data Alternative Viewer, 2023).

Table 8: Time Series Comparison Types and their Definitions

Timeseries Comparison Type	Definition
Annual Aggregation	The annual max, min, average, sum, or end of year, or end of water year value of a selected parameter
Annual Aggregation Change from Baseline	The difference between a selected parameter's annual max, min, average, sum, or end of year, or end of water year value and the Baseline No-Action Alternative's annual max, min, average, sum, or end of year, or end of water year value for the same parameter
Daily Timeseries	Daily values of a selected parameter
Daily Timeseries Change from Baseline	The difference between a selected parameter's daily values and the Baseline No-Action Alternative's daily values for the same parameter

Initial discussions and comparisons of differences between the MOEA Scenarios focused on the Decision Variables related to the Boca Portion of Flood Space and highest Percent of Revised Guide Curve to Maintain.

Scenarios with a higher Boca Portion of Flood Space had the expected outcomes of:

- Increased flood protection provided by Boca Reservoir.
- Possible reduced operational flexibility of Boca Dam.
- Increased Stampede Dam surcharge risk during extreme flood events.
- Higher carry-over storage further upstream.

Scenarios with a higher Percent of Revised Guide Curve have expected outcomes of:

- Less benefit to water supply.
- More preparedness for an under-forecasted or short lead time storm.
- Less reliance on reacting to a forecast with sufficient lead time (less risk).

Firstly, the Cost Share Partners eliminated MOEA Scenario D since it generally showed poorer objective score performance than the other Scenarios decision variables. Scenario D had the worst objective score for the following objectives:

- Average Annual Volume for Flow Regime
- Average Daily Increase in Flood Space Requirement
- Average Prosser, Boca, Stampede Storage

The poorer performance of Scenario D is related to the high Percent of Revised Guide Curve and high Boca Portion of Flood Space when the Percent of Revised Guide Curve is also taken into consideration. The reduced operational flexibility in Boca, perceived increased risk of Stampede Surcharge during extreme flood events, and decreased water supply benefits associated with Scenario D also made it less desirable to some of the Cost Share Partners. While Scenario D had the best objective score for Average Annual Volume For FR, the extremely small range of this objective makes differences between the MOEA Scenarios ranking less significant than other objectives. Because it was the worst performing Scenario for three of the five objectives, Scenario D was eliminated from further consideration for the Preferred Operational Scenario.

Next, Scenario B was eliminated, since it offered the least conservative Exceedance vs. Outlook Relationship at outlooks between 7 and 30 days (more CNRFC ensemble traces would need to predict a flood than other Scenarios to reserve flood space), and it was outperformed by other Scenarios in terms of objective scores. Specifically, Scenario B performed the second worst of the three remaining scenarios for Average Annual Volume For FR, and it had the second worst Average Daily Increase In Flood Space Requirement objective score of the three remaining scenarios. Exceedance vs. Outlook Relationship for each MOEA Scenario are pictured in Figure 10.

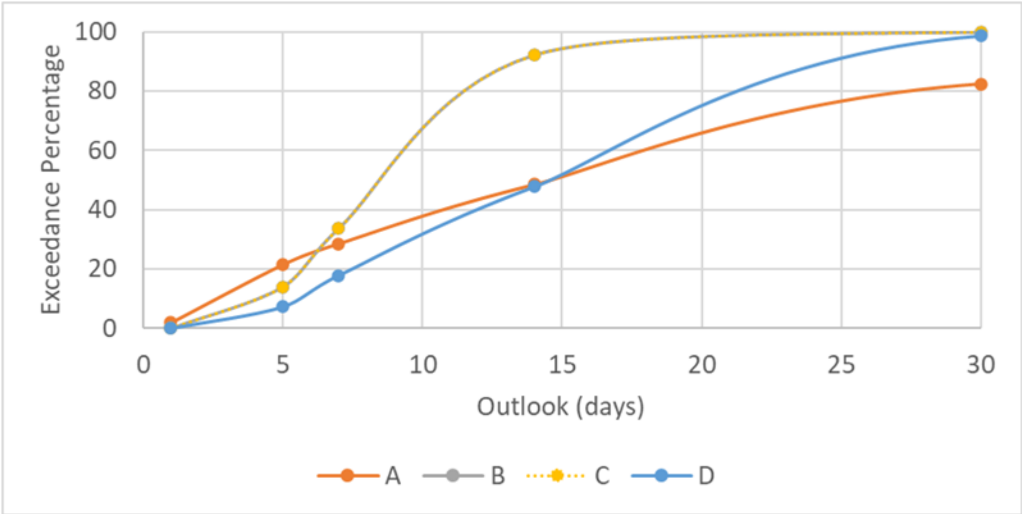

Figure 10: Exceedance vs. Outlook Relationship Top Four MOEA Scenarios, where Scenarios B and C Overlap

Finally, Scenario A and C were compared, and Scenario A was selected over C because A offered the most conservative Exceedance vs. Outlook Relationship in the short term (i.e., flood space requirements determined in Scenario C are more responsive to storm event signals in the forecast). Further, Scenario A was the only MOEA Scenario offering a better score than the Baseline for this "flashiness" objective, meaning that it was the only scenario to dampen the fluctuations in flood space requirements and resulting flashy flows downstream of flood control reservoirs (Table 9). Reducing "flashiness" of reservoir releases is important for promoting hospitable conditions for fish and wildlife.

Table 9: Average Daily Increase in Flood Space Requirement MOEA Scenario Objective Scores

Objective: Average Daily Increase In Flood Space Requirement (acre-feet)		
Scenarios:	**Value**	**Change**
Baseline	186.64	0.00
A	178.54	-8.10
B	267.76	81.12
C	267.76	81.12
D	379.50	192.86

An example of "less flashy" flood space requirements and resulting releases occurs in 2011, a big snow year. In the period between December of 2010 and July of 2011, there was one flood space evacuation in Scenario C and no evacuations in Scenario A. Figure 11, along with all other plots of flood control capacity provided in this report, represents, in USACE terms, the top of conservation storage in the reservoir. This type of plot allows for analysis of how the required flood space changes over time. Fewer fluctuations in the flood space requirement result in more consistent reservoir releases and flows in the river, which can be hospitable to native fish populations.

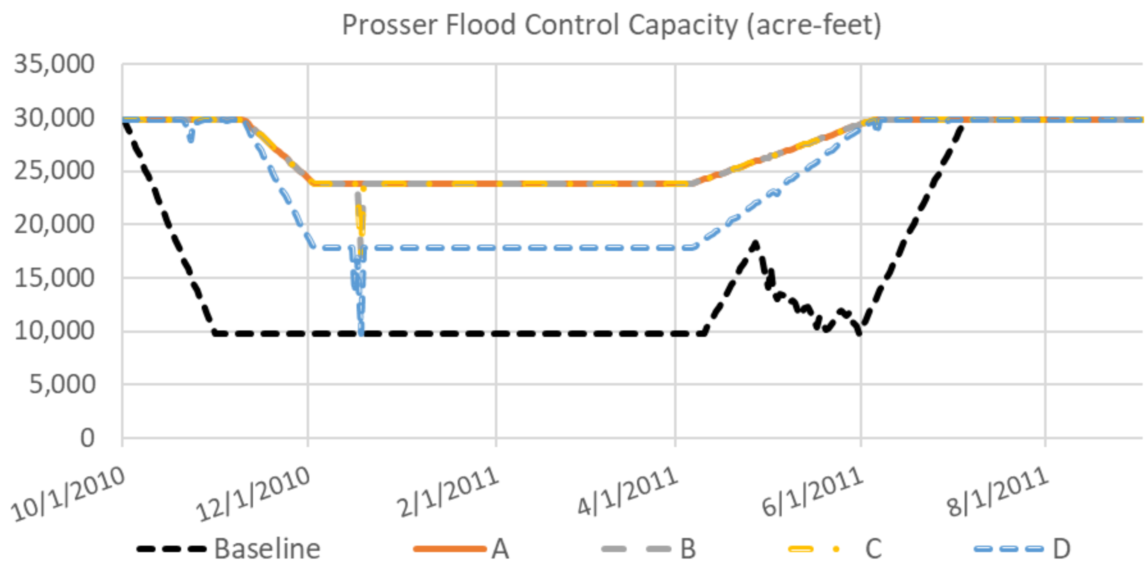

Figure 11: Prosser Flood Control Capacity Representing Flashiness in Flood Space Requirements for WY 2011. MOEA Scenario A overlaps with all other operational scenarios except during mid-December. When the other three MOEA Scenarios demonstrate a large decrease in flood space capacity during this period, Scenario A maintains more consistent flood space capacity.

Additionally, Scenario A was the best performing Scenario for the Average Prosser Boca Stampede Storage objective in terms of objective scoring (Table 10).

Table 10: Average Prosser, Boca, and Stampede Storage Objective Scores

Objective: Average Prosser Boca Stampede Storage (acre-feet)		
Scenarios:	**Value**	**Change**
Baseline	-175,025.54	0.00
A	-184,087.97	-9,062.42
B	-183,926.37	-8,900.83
C	-183,867.31	-8,841.76
D	-181,209.87	-6,184.33

A specific instance of preferable storage in Scenario A over other scenarios occurred between the years 1996-2000. After filling in 1995, Scenario A consistently has the highest (or is tied for the highest) winter storage in 1996-2000 of all the MEOA Scenarios during this period (Figure 12).

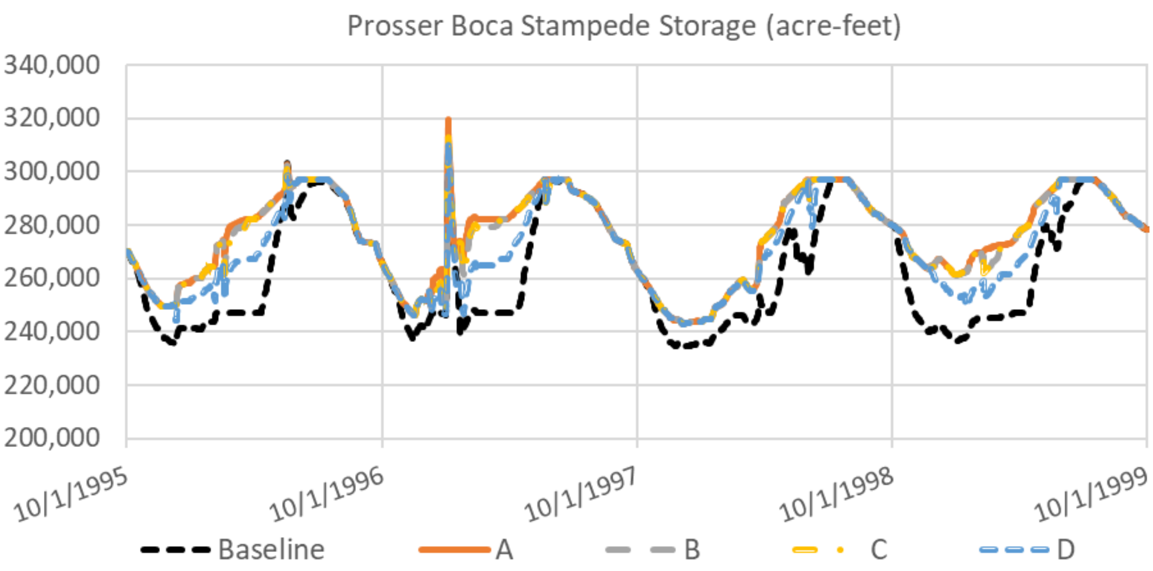

Figure 12: Prosser, Boca, and Stampede Storage October 1995 through October 1999

Figure 13 demonstrates a parallel axis plot with objective scores of the Best Performing MOEA Scenario compared to those of all other MOEA Scenarios and the Baseline. As shown in Figure 13, the Best Performing MOEA Operational Scenario scored within the top 2% of the Average Daily Increase in Flood Space Requirement and Average Annual Volume for Flow Regime objectives, and it scored within the top 3% of the Average Prosser, Boca, and Stampede Storage objective scores (Table *11*). In other words, this MOEA Solution was one of the best for minimizing flashy flood space requirements and consequential downstream flows, maximizing benefit to environmental flows, and maximizing storage in Prosser, Boca, and Stampede reservoirs, all the while minimizing flood risk and benefitting water supply.

Table 11: Best Performing MOEA Scenario Ranking, where all 150 nondominated solutions were better than the Baseline for all objectives except for Average Daily Increase in Flood Space Requirements

Preferred MOEA Scenario Ranking Within All 150 Nondominated Solutions	
Objective	**Top N% of MOEA Solutions**
Annual Average Volume for Floriston Rate	33%
Average Prosser, Boca, and Stampede Storage	3%
Average Annual Volume for Flow Regime	2%
RMS Flow Over Flood Target	51%
Average Daily Increase in Flood Space Requirement	2%

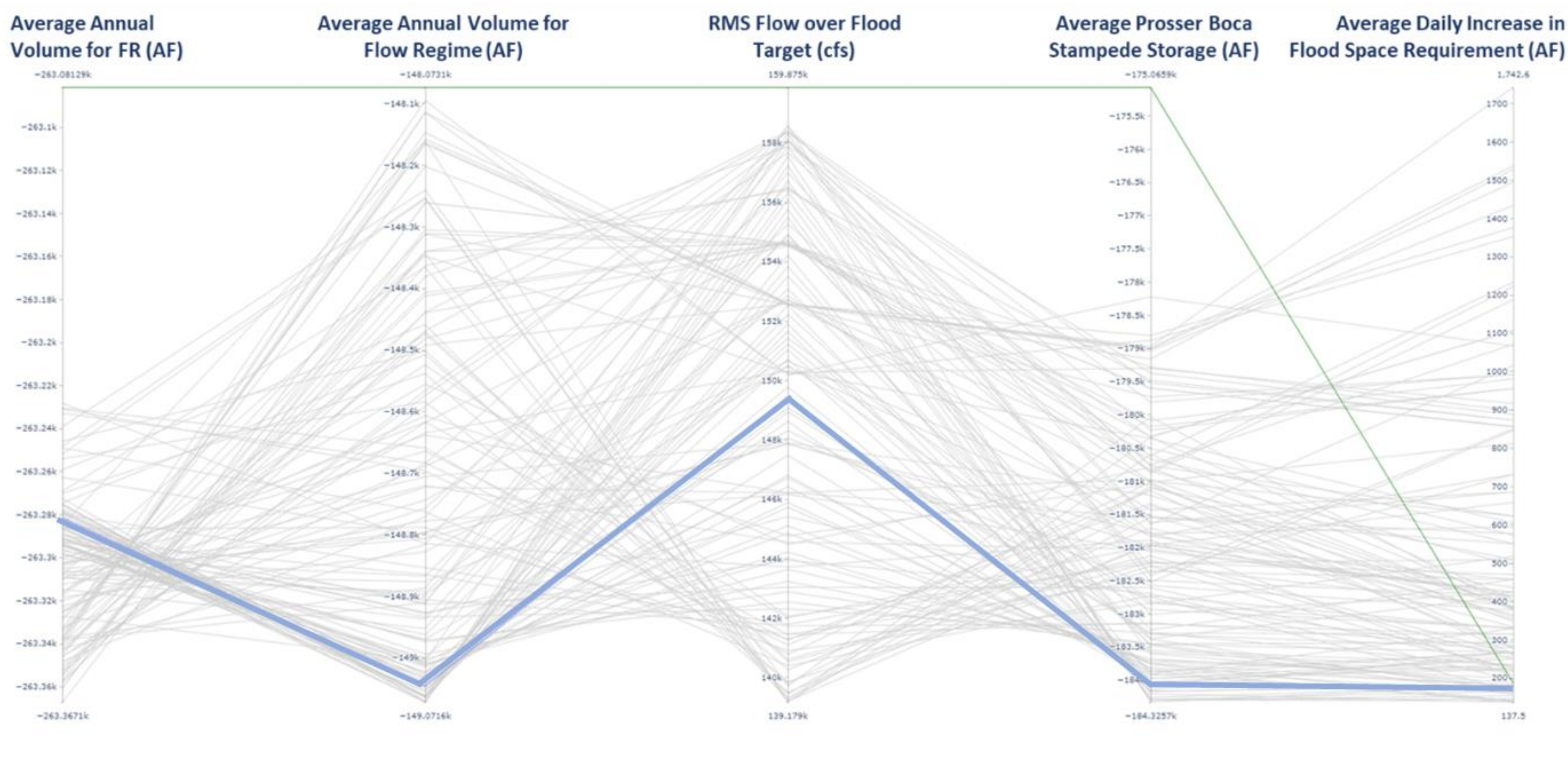

Figure 13: MOEA Parallel Axis Plot Highlighted with Baseline (Green), Nondominated Scenarios (grey and blue), and Best Performing MOEA Scenario (Purple)

5 Analyzing Operational Scenario Results

By selecting the Best Performing MOEA Scenario, stakeholders had essentially "optimized" Alternative Operational Scenario 3 and selected the best performing set of parameters associated with the "By a Model" Method and Reproportion of Little Truckee Flood Space actions. As illustrated in Figure 5, these parameters were utilized to model Alternative Operational Scenarios 2, 4, 5, and 6. In this section, all Alternative Operational Scenario titles are denoted with a number followed by "A", which signifies that these scenarios were configured using decision variables resulting from the Best Performing MOEA Scenario A (see Figure 5).

5.1 Average Annual Volume for FR Objective

As mentioned previously, the Alternative Operational Scenarios exhibited a relatively small range of Average Annual Volume for the FR, where the best and worst Alternative Operational Scenario only differ by 72 acre-feet per year. Alternative Operational Scenarios 2, 3, and 6 provided the most overall benefit for the Average Annual Volume for FR water supply objective. These three best performing Alternative Operational Scenarios offer roughly 202 acre-feet per year of additional benefit to meeting the FR Target over the Baseline. Meeting the FR Target is the primary indicator of water supply in the basin, and 202 acre-feet per year is equivalent to about 7,500 acre-feet of additional water over the Baseline available to meet the FR Target across the entire 37-year model run (Table 12).

Table 12: Average Annual Volume for FR (acre-feet) Objective Scores

Objective: Average Annual Volume For FR (acre-feet)		
Scenarios:	**Value**	**Change**
Baseline	-263,079.29	0.00
2A	-263,281.44	-202.16
3A	-263,281.44	-202.15
4A	-263,209.62	-130.33
5A	-263,221.78	-142.50
6A	-263,280.57	-201.28

The benefits to FR of the Alternative Operational Scenarios were concentrated in a few select years in the 37-year model run. Figure 14 demonstrates this by showing the annual end of water year Total FR Storage measured in terms of difference in magnitude from the Baseline. As shown in the plot, 2011 recorded a 9,000 acre-foot increase in FR Storage over the Baseline in Alternative Operational Scenarios 2, 3 and 6.

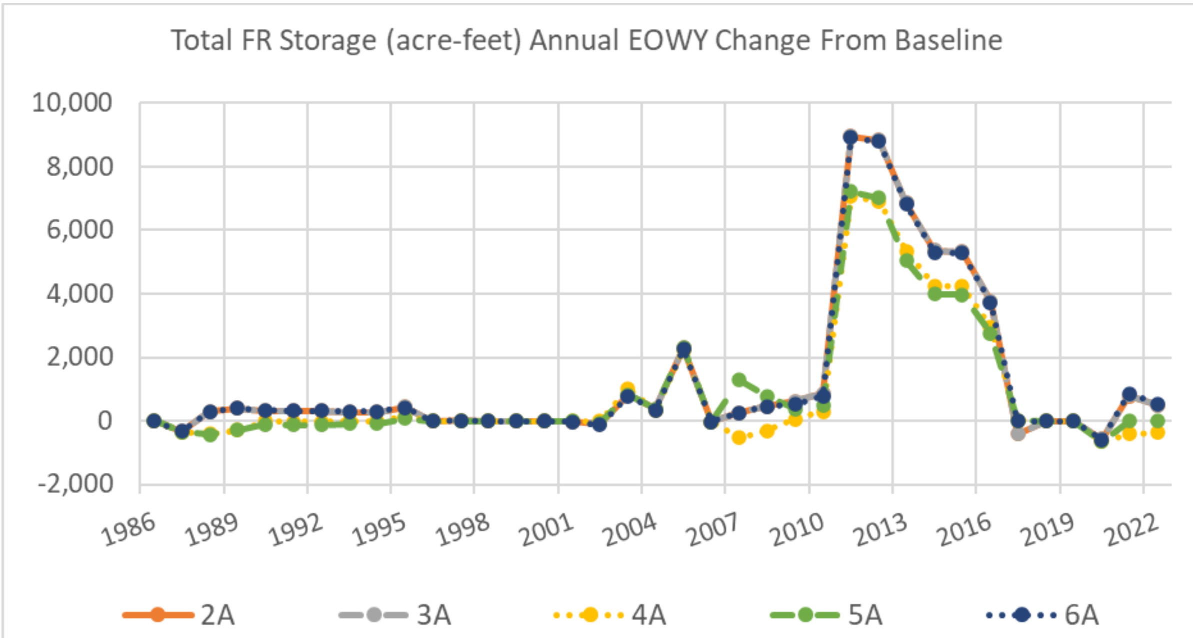

Figure 14: End of Water Year (EOWY) Total FR Storage (acre-feet) Change from Baseline 1986 through 2022

The increase in Total FR Storage in WY 2011 seen over the Baseline is attributed to the Tahoe Prosser Exchange (TPX), an operation that virtually moves Tahoe FR water from Tahoe to Prosser to maintain the minimum flow from Tahoe. In this operation, water that is moved from Tahoe to Prosser is labeled TPX Storage, and this water maintains its type as FR Storage when moved to Prosser. Figure 15 provides simulated results in the Baseline for Prosser Flood Control Capacity, Prosser Storage, and TPX Storage. As shown in the plot, Prosser Storage reaches the winter Prosser Flood Control Capacity, and the allowable storage capacity decreases in Prosser from 18,300 AF on April 27th to 9,840 AF on June 1. Given that the TPX Storage had already been exchanged into Prosser, and TPX Storage comprises most of the storage in Prosser during this period, some of the TPX Storage was spilled in May of 2011 to maintain the allowable Prosser Flood Control Capacity. Figure 16 provides a similar plot but for Alternative Operational Scenario 2, which is representative of all the Alternative Operational Scenarios. As shown in this plot, the scenario does not have this decrease in allowable storage capacity, so the spill does not occur, resulting in a net benefit of 4,500 acre-feet more TPX Storage at the end of WY 2011 relative to Baseline. This additional storage could be utilized in the ensuing years in various ways like meeting higher FR Target in 2013 (see Figure 17).

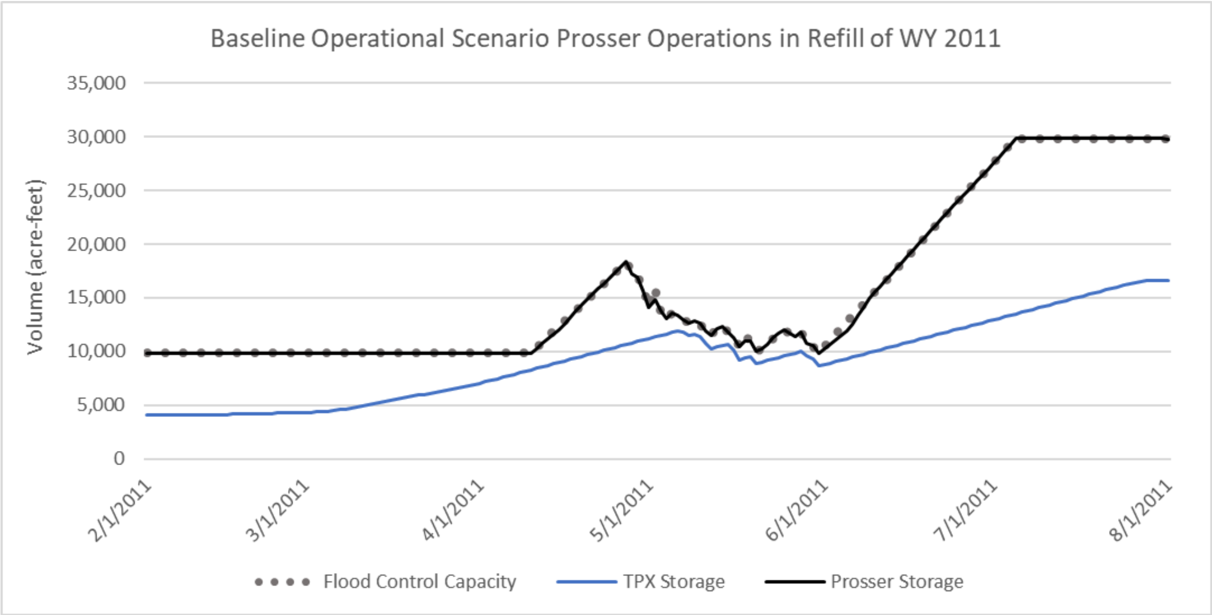

Figure 15: Prosser Creek Reservoir Flood Control Capacity, Storage, and TPX Storage in the Baseline during refill season of WY 2011.

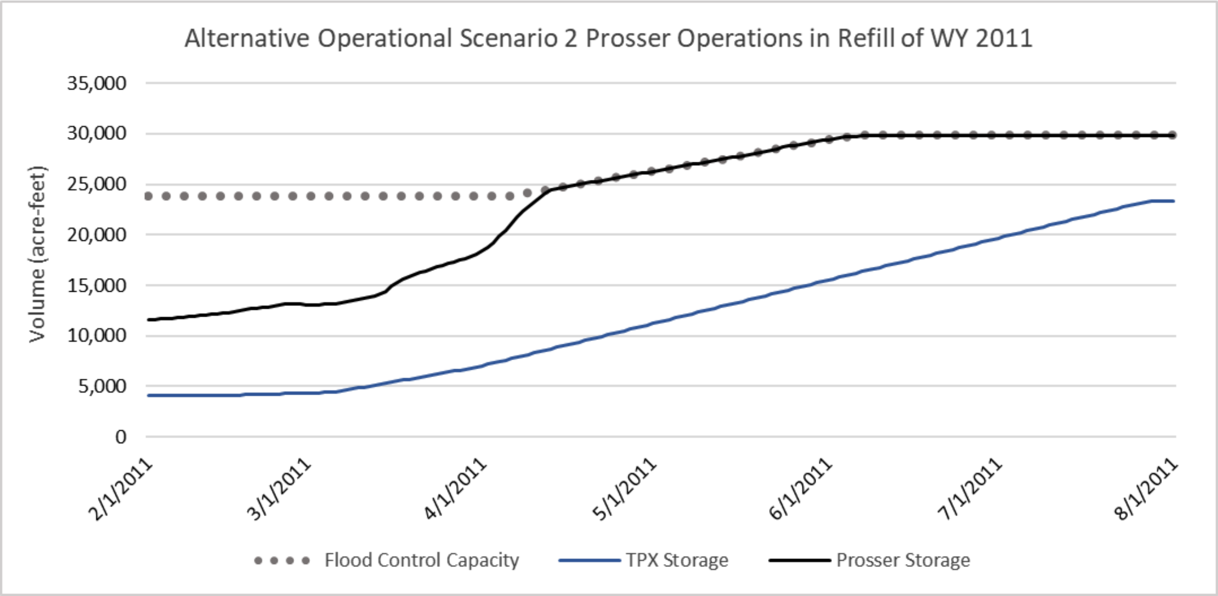

Figure 16: Prosser Creek Reservoir Flood Control Capacity, Storage, and TPX Storage in Alternative Operational Scenario 2 during refill season of WY 2011.

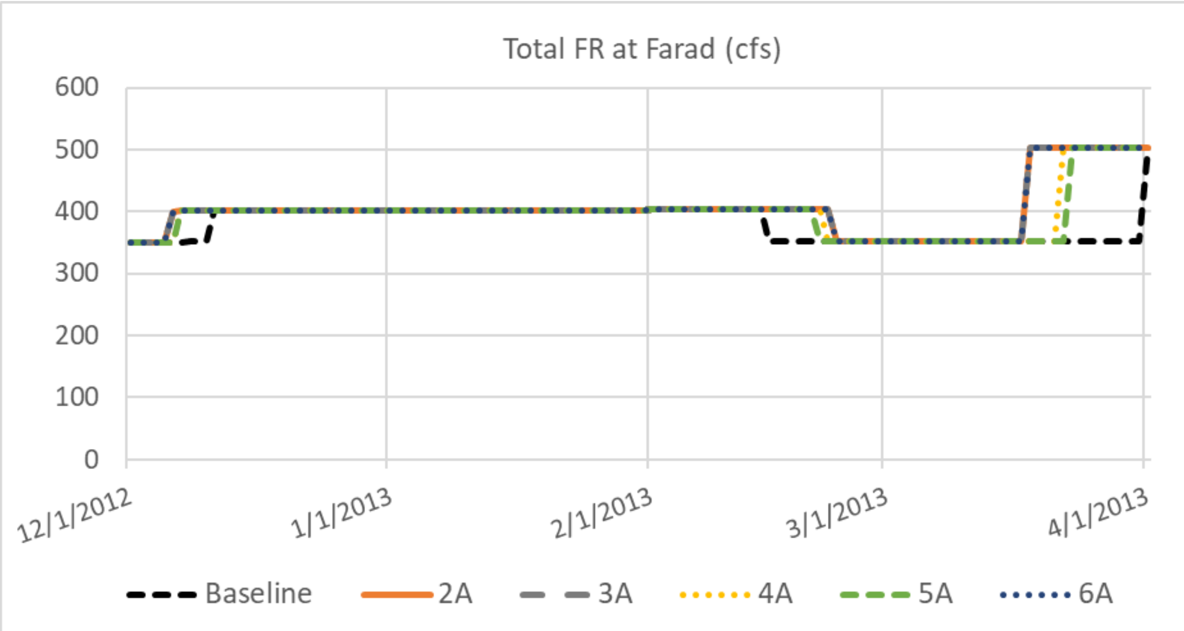

Figure 17: Total Floriston Rate at Farad Gage December 2012 through March 2013. Alternative Operational Scenarios 2, 3, and 6 (overlapping blue line) meet a higher Floriston Rate target for 6 more days in the spring of 2013 than the Baseline due to their ability to carryover water from WY 2011 to use during drier periods.

5.2 Average Daily Increase In Flood Space Requirement Objective

Alternative Operational Scenarios 2 and 3 were the only Alternative Operational Scenarios that scored better than the Baseline for the "Average Daily Increase in Flood Space Requirement" objective. Alternative Operational Scenario 5 scored the worst of all objectives with an average daily increase in the flood space requirement of about 350 acre-feet (Table 13). Alternative Operational Scenarios that utilized the "By a Model" Method to determine flood space generally scored better for this objective. However, problems with the "By a Model" Method are apparent in specific flood years. This ultimately necessitated the modeling of Alternative Operational Scenario 6 which imposes a more conservative Percent of Revised Guide Curve to Maintain during wet years (see **Section 2.3 Alternative Operational Scenarios**).

Table 13: Average Daily Increase in Flood Space Requirement Objective Scores (acre-feet)

Objective: Average Daily Increase In Flood Space Requirement (acre-feet)		
Scenarios:	**Value**	**Change**
Baseline	186.64	0.00
2A	178.54	-8.10
3A	178.54	-8.10
4A	275.69	89.05
5A	349.14	162.50
6A	219.93	33.29

Figure 18 provides additional resolution into performance of Alternative Operational Scenarios for the Average Daily Increase in Flood Space Requirement Objective by looking at the values of this objective on an annual basis. As shown in the plot, Alternative Operational Scenarios 2 and 3, which utilize the "By a Model" Method, perform better than the Baseline in all years of the model except for five (all of which contained major flood events).

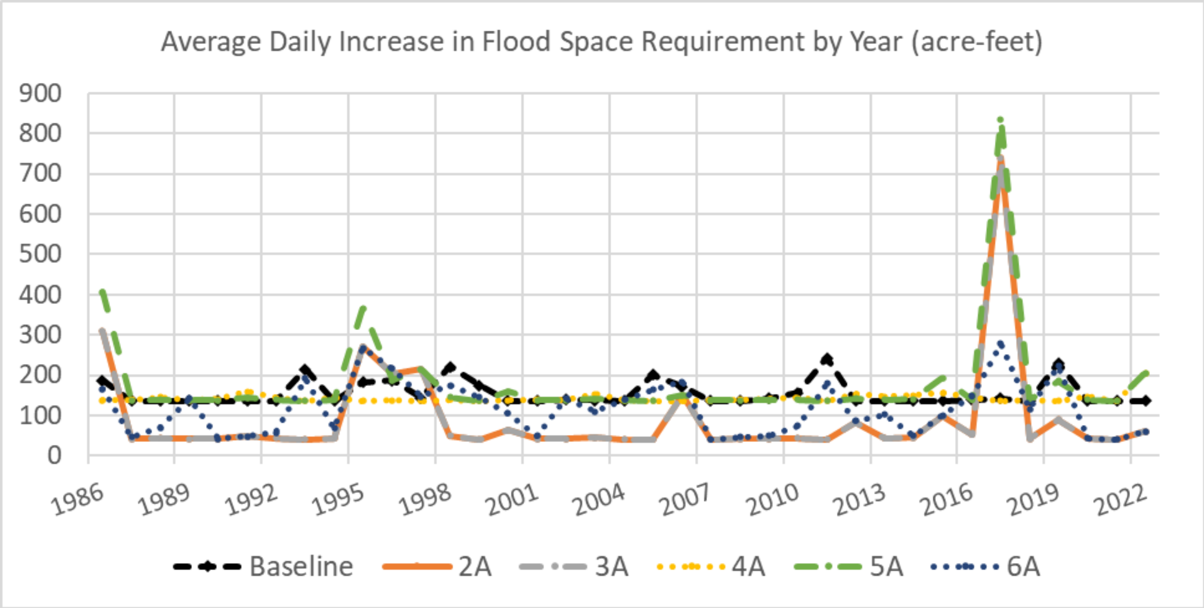

Figure 18: Average Daily Increase in Flood Space Requirements by year for each Alternative Operational Scenario.

This section of the report analyzes how the Average Daily Increase in Flood Space Requirement objective is influenced by hydrology by looking at three distinct hydrologic years:

- 2015 – a dry year with no flood events.

- 2011 – a wet year that was cold and recorded no floods.
- 2017 – a wet year that recorded floods.

Each year is analyzed in subsequent sections by looking at Prosser Creek Reservoir's flood control capacity. Flood control capacity is an insightful quantity to analyze when interpreting the Daily Increase in Flood Space Requirement Objective because it allows for illustrations of the following aspects of an Alternative Operational Scenario:

- How far reservoirs must be drawn down.
- How often Alternative Operational Scenarios (particularly those that utilize the "By a Model" Method) require immediate evacuations of flood space that *could* result in large fluctuations in flow downstream.

It is important to note the emphasis on *"could"* above. The "By a Model" Method can, in certain circumstances, require large increases in flood space at times when reservoir storages are low. In these cases, fluctuations in flood space requirements may not translate into fluctuations of river flows (a major concern for the Technical Team) because reservoir storages were sufficiently low enough as to not require an evacuation. At other times, these large increases in flood space do require evacuations of flood space which cause large fluctuations in river flows. When analyzing results, the Technical Team was generally more concerned with the existence of large fluctuations in flood space requirements regardless of if this translated into fluctuations in river flows or not.

Lastly, the results in the following subsections are limited to plots of flood control capacity for Prosser Creek Reservoir; plots for other Flood Control Reservoirs are omitted because the qualities of their flood control capacities are like that of Prosser Creek Reservoir.

5.2.1 WY 2015

In 2015, an extremely dry year, Alternative Operational Scenarios 2, 3, and 6 offer the most flexibility in terms of flood space requirements because they allow more encroachment into flood space than other scenarios. Figure 19 illustrates this behavior on Prosser Creek Reservoir where Alternative Operational Scenarios 2, 3, and 6 are required to be drawn down much less than the Baseline and Alternative Operational Scenarios 4 and 5. This occurs because the "By a Model" Method (which is used in these scenarios) identifies little threat of floods and, therefore, requires reservoirs to be drawn down less. This contributes to a better performance of the Average Daily Increase in

Flood Space Requirement objective because in drawing down less, less increases in flood space requirements (or decreases in flood control capacity) are observed. The additional space is of benefit because if any storms were to occur during this extremely dry year, there would be sufficient space available in the reservoirs to capture the storms' runoff, resulting in relatively small fluctuations in downstream flows. It is important to note the "spike" in flood space requirements that occurs in early February of 2015 in Alternative Operational Scenarios 2, 3 and 6. This occurs because the "By a Model" Method saw a flood event in the forecast and responded by requiring additional flood space. This "spike" impacts the score for Average Daily Increase in Flood Space Requirements negatively, but not to the degree where these scenarios perform worse that scenarios that require full drawdown. These "spikes" are observed in greater frequency in flood event years and will be discussed more in **Section 5.2.3 WY 2017**.

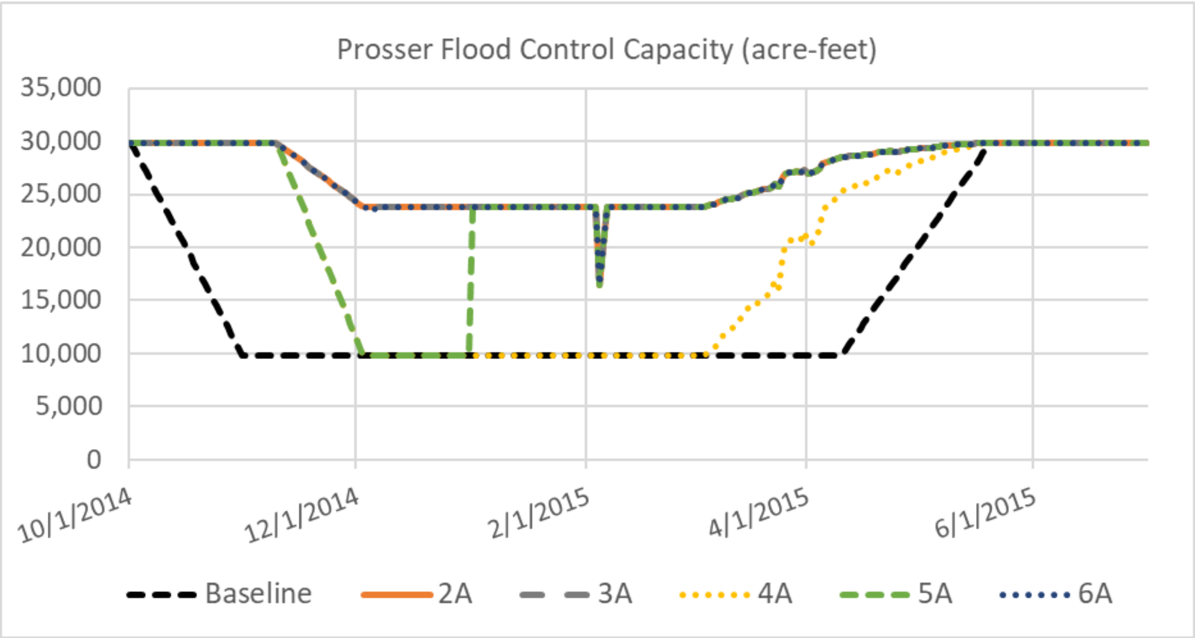

Figure 19: Prosser Flood Control Capacity October 2014 through July 2015. Alternative Operational Scenarios 2, 3, and 6 overlap throughout the period shown above.

The behavior of Prosser Flood Control Capacity for Alternative Operational Scenario 5 is unique. This scenario matches Prosser Flood Control Capacity of:

- Alternative Operational Scenario 4 (which utilizes the Revised Guide Curve) through December 31st.
- Alternative Operational Scenarios 2 and 3 after January 1st.

The occurs because of the way Alternative Operational Scenario 5 is defined: it uses the Revised Guide Curve in the fall and the "By a Model" Method in the spring (see **Section 2.3 Alternative Operational Scenarios**). The behavior illustrated in this plot is exhibited in all years of the model run for this scenario. Ultimately, this scenario's poor performance in the Average Daily Increase in Flood Space Requirement objective is explained by its use of both the Revised Guide Curve and "By a Model" Method: the scenario requires full drawdown in the fall while also containing the "spikes" in flood space requirements associated with the "By a Model" Method in the spring.

5.2.2 WY 2011

WY 2011 (a wet, cold year that recorded no floods) is an interesting year because it highlights a major issue that the Technical Team identified with the WCM. This issue is exhibited by the Baseline in Figure 20 where Prosser Creek is allowed to partially fill in April prior to being forced to drawdown again fully. Stakeholders have found these types of requirements in flood space operationally challenging. As a result of this regulation criteria, the Baseline performed the worst in this year of all the Alternative Operational Scenarios for the Average Daily Increase in Flood Space Requirement objective (see Figure 18).

Figure 20 also illustrates how, again, Alternative Operational Scenarios 2 and 3 require less fluctuations in flood space requirements than other scenarios. This is true because no floods were forecasted. As a result, these scenarios allow the greatest operational flexibility for reservoir drawdown and refill (i.e., more allowed encroachment into flood space). Furthermore, because no floods were forecasted in WY 2011, the scenarios that use the "By a Model" Method show no "spikes" in the flood space requirements as were observed in WY 2015.

Alternative Operational Scenario 6 necessitates more variable flood space requirements during this type of wet year than Alternative Operational Scenarios 2 and 3 due to its Variable Percent of Revised Guide Curve. This can be seen in Figure 20 as, throughout the winter of 2011, flood space requirements for Prosser Creek Reservoir continue to grow as more snow is accumulated until, ultimately, Alternative Operational Scenario 6 maintains the same flood control capacity as Alternative Operational Scenario 4 (which uses only the Revised Guide Curves). While Alternative Operational Scenario 6 still performs better this year for the Average Daily Increase in Flood Space Requirements objective than the Baseline, it performs worse than other Alternative Operational Scenarios.

Similar to results of WY 2015, Alternative Operational Scenario 5 scores worse that Alternative Operational Scenarios 2, 3 and 4 because of its dual use of the Revised Guide Curve and "By a Model" Method.

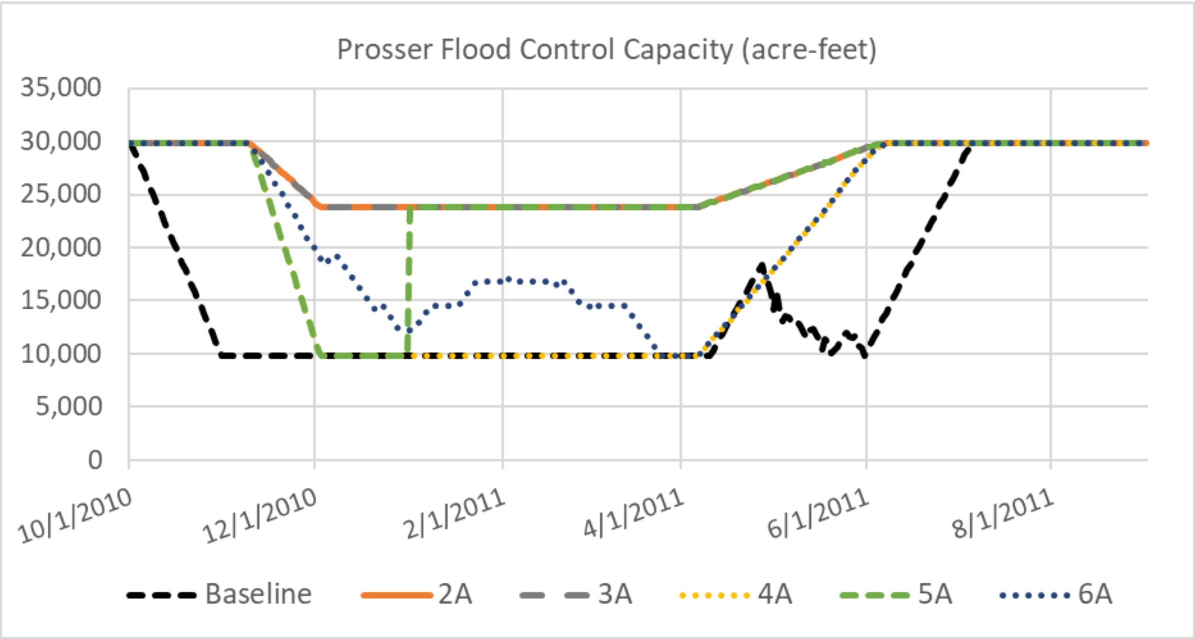

Figure 20: Prosser Flood Control Capacity October 2010 through September 2011. Alternative Operational Scenarios 2 and 3 overlap throughout the demonstrated period above, whereas Alternative Operational Scenario 5 increases flood space capacity significantly on January 1st due to switch in method of flood space determination from Revised Guide Curve to the "By a Model" Method.

5.2.3 WY 2017

In WY 2017, a large precipitation year where flooding did occur, the Baseline and Alternative Operational Scenario 4 showed the least fluctuations in flood space requirements (see Figure 18, Figure 21). Alternative Operational Scenarios 2, 3 and 5, on the other hand, exhibit the largest single year scores for Average Daily Increase in Flood Space Requirements seen in the modeling. These scenarios, which utilize the "By a Model" Method, exhibit a high frequency of "spikes" in flood space requirements during the winter months and fill season. Some of these "spikes" were as large as 14,000 acre-feet in a single day. These fluctuations in flood space requirements during a year like WY 2017 when reservoir storages are high result in large fluctuations in reservoir outflows to maintain the flood control capacity, and this type of operation was undesirable by the Technical Team. In contrast, Alternative Operational Scenario 6 offers a relatively steady drawdown and refill of Prosser Creek Reservoir, and many of the "spikes" observed in some of the other scenarios were smoothed out.

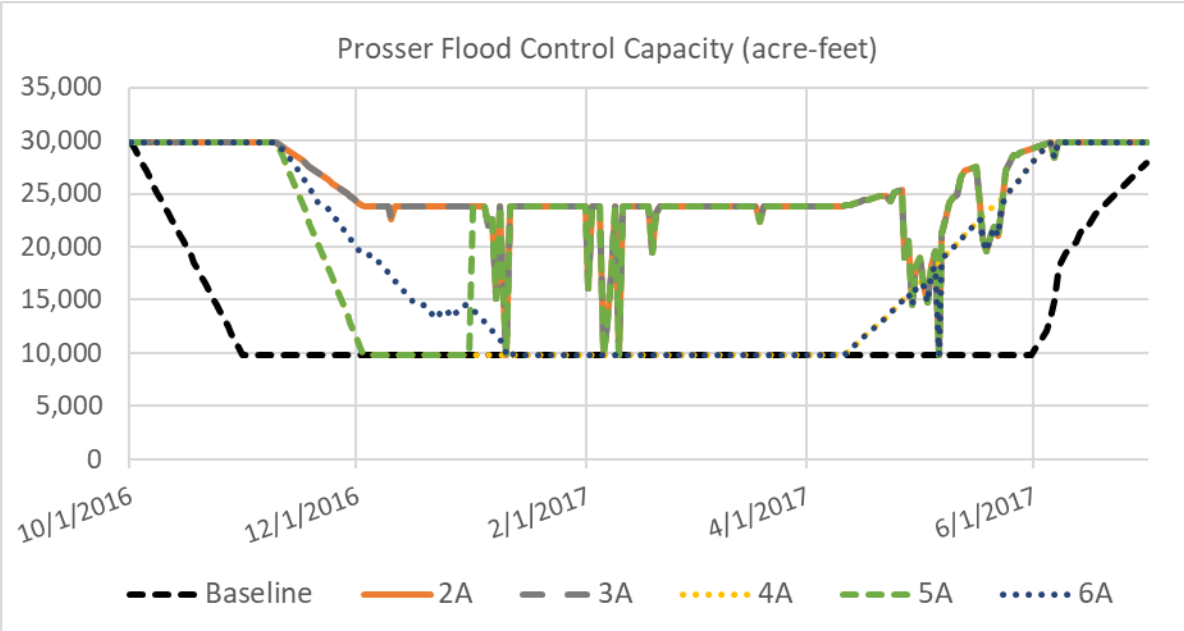

Figure 21: Prosser Flood Control Capacity October 2016 through July 2017. Alternative Operational Scenarios 2, 3, and 5 overlap from January 2017 through July 2017. Fluctuations in flood control capacity in Alternative Operational Scenarios 2, 3, and 5 are explained by the "By a Model" Method of flood space determination's fluctuating flood space requirements.

5.3 Average Annual Volume for Flow Regime Objective

Alternative Operational Scenarios 2 and 3 provided the largest overall benefit to the "Average Annual Volume For Flow Regime" objective. These Alternative Operational Scenarios resulted in an additional 980 acre-feet per year of storage available to meet Flow Regime Targets over the Baseline. This is equivalent to about 36,300 acre-feet of total benefit across the 37-year model run (Table 14). On an annual basis, the greatest average annual benefits to this objective were observed in the years 1990 and 2015.

Table 14: Average Annual Volume for Flow Regime (acre-feet) Objective Scores

Objective: Average Annual Volume For Flow Regime (acre-feet)		
Scenarios:	**Value**	**Change**
Baseline	-148,066.91	0.00
2A	-149,046.40	-979.49
3A	-149,045.71	-978.80
4A	-148,552.70	-485.79
5A	-148,404.14	-337.23
6A	-149,015.22	-948.31

The benefits seen in fall 1990 originated from additional storage accumulated during the drawdown in 1986: as much as 9,000 acre-feet of additional storage was retained during this timeframe. This additional storage was maintained until the drought year of 1990 when it was used to meet flow regime targets as much as eight weeks longer in the fall than the Baseline (Figure 22). Alternative Operational Scenarios 2, 3, and 6 demonstrate the best performance in Table 14 due to their flexible "By a Model" Model approach to fall drawdown operations.

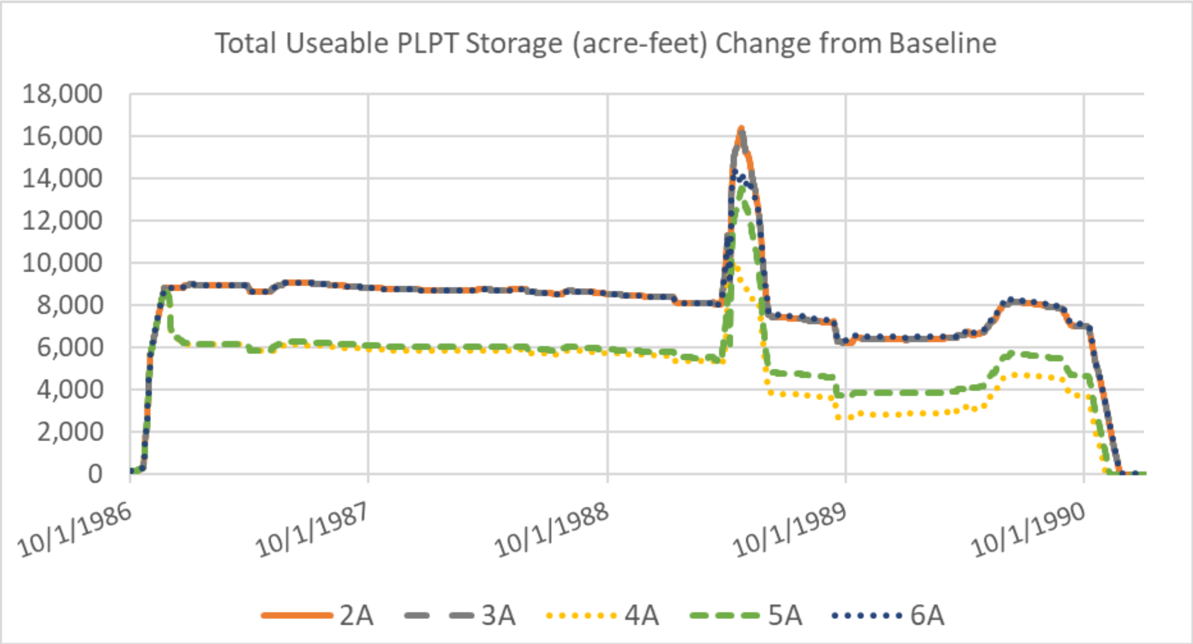

Figure 22: Simulated PLPT Storage October 1986 through October 1990. Alternative Operational Scenarios 2, 3, and 6 overlap throughout the demonstrated period.

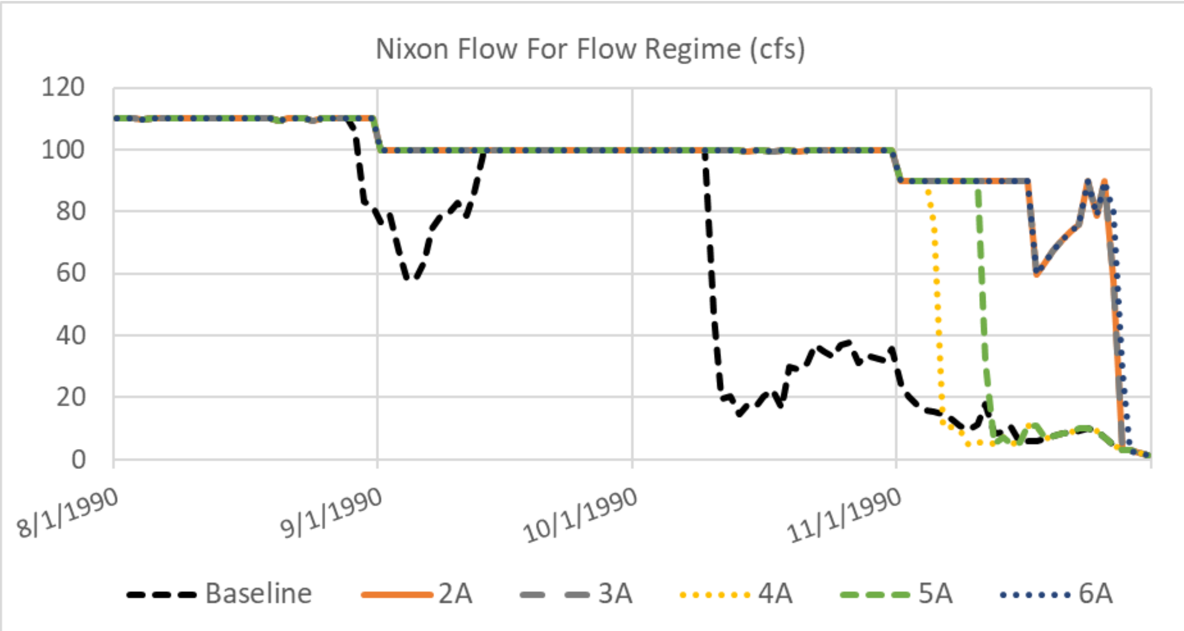

Figure 23: Nixon Flow for Flow Regime August 1990 through December 1990. All Alternative Operational Scenarios overlap (except for the Baseline) until early November 1990, after which Operational Scenarios 2, 3, and 6 overlap.

A similar benefit is seen in spring 2015 due to additional storage accumulated over the Baseline during drawdown in 2011. Approximately 15,000 acre-feet of additional storage accumulated in scenarios 2, 3, and 6 in 2011 is carried over until spring 2015 when it is used to meet flow regime targets as much as two months longer during spawning season (see Figure 25). Meeting environmental flow targets at Nixon is particularly important to provide hospitable conditions to Endangered Species Act-listed Lahontan Cutthroat Trout and Cui-ui during the spring spawning season. Extending the period of those hospitable conditions for fish by two months is a significant improvement, especially during spawning season. Note, Alternative Operational Scenarios 4 and 5 show less pronounced improvement over the Baseline as well.

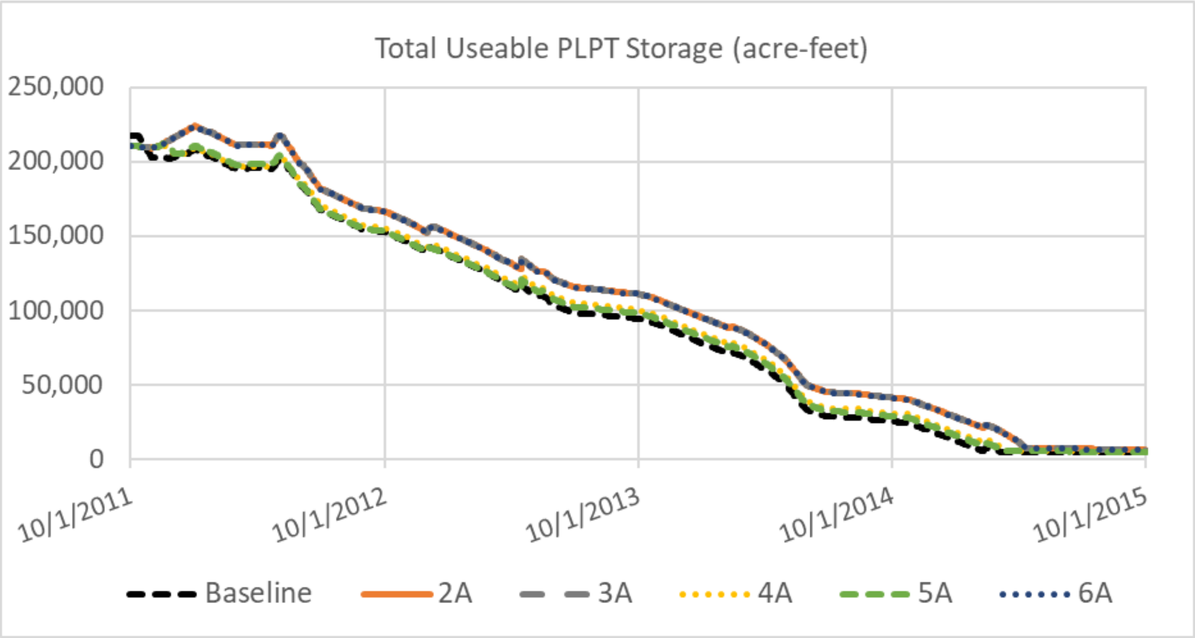

Figure 24: Total Useable PLPT Storage October 2011 through October 2015 (acre-feet). Alternative Operational Scenarios 2, 3, and 6 overlap throughout the demonstrated period, as do Operational Scenarios 4 and 5.

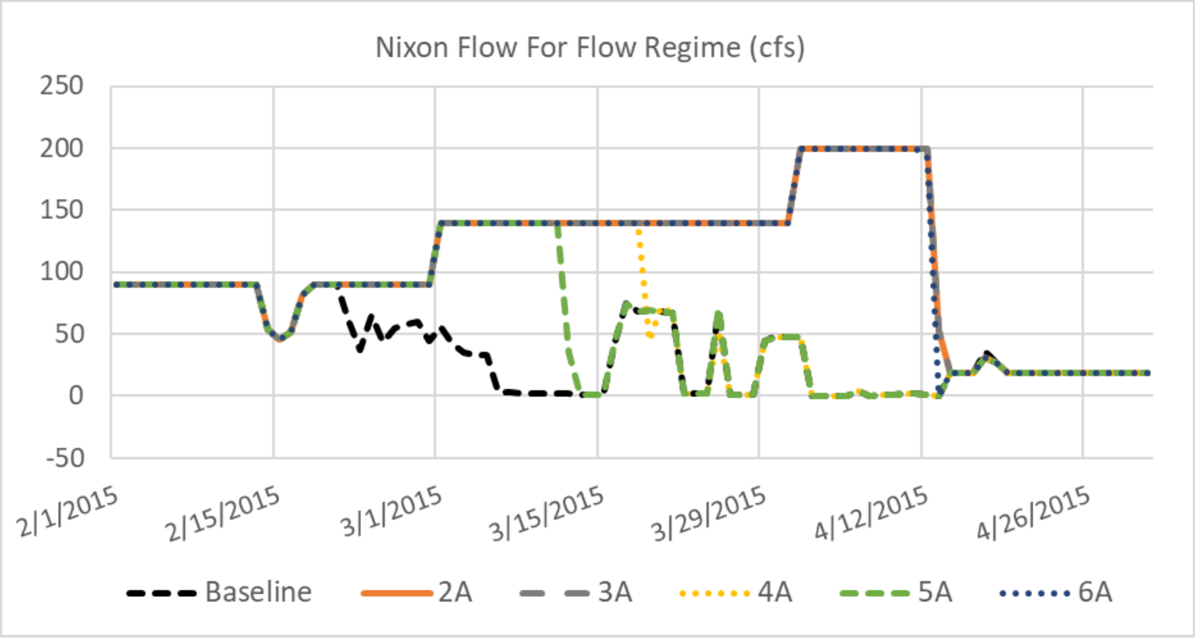

Figure 25: Nixon Flow for Flow Regime February 2015 through April 2015 (cfs). Alternative Operational Scenarios 2, 3, and 6 overlap throughout the demonstrated period, whereas Alternative Operational Scenarios 4 and 5 overlap after mid-March 2015.

5.4 AVERAGE PROSSER BOCA STAMPEDE STORAGE

Table 15: Average Prosser Boca Stampede Storage (acre-feet) Objective Scores

Objective: Average Prosser Boca Stampede Storage (acre-feet)		
Scenarios:	**Value**	**Change**
Baseline	-175,025.54	0.00
2A	-184,089.35	-9,063.81
3A	-184,087.97	-9,062.42
4A	-178,001.56	-2,976.02
5A	-180,046.59	-5,021.04
6A	-181,804.09	-6,778.55

Alternative Operational Scenarios 2 and 3 offered the largest benefit of about 9,000 acre-feet of additional Average Prosser Boca Stampede Storage over the Baseline. Alternative Operational Scenario 4 scored the worst for this objective, offering an additional 3,000 acre-feet of storage on average over the Baseline. Note, while Alternative Operational Scenario 6 performed less well than 2 and 3 for this objective, the same water supply benefits were observed amongst these three scenarios. This is because, in big years, Alternative Operational Scenario 6 maintains lower reservoirs lower until later in the runoff season, but the reservoirs still fill regardless.

During the fall 1986 drawdown, additional storage was preserved that was available until storage was depleted in the drought of 1990. In Figure 26, Alternative Operational Scenarios 2, 3, and 6 are nearly identical due to their flexible "By a Model" Method fall drawdown policies.

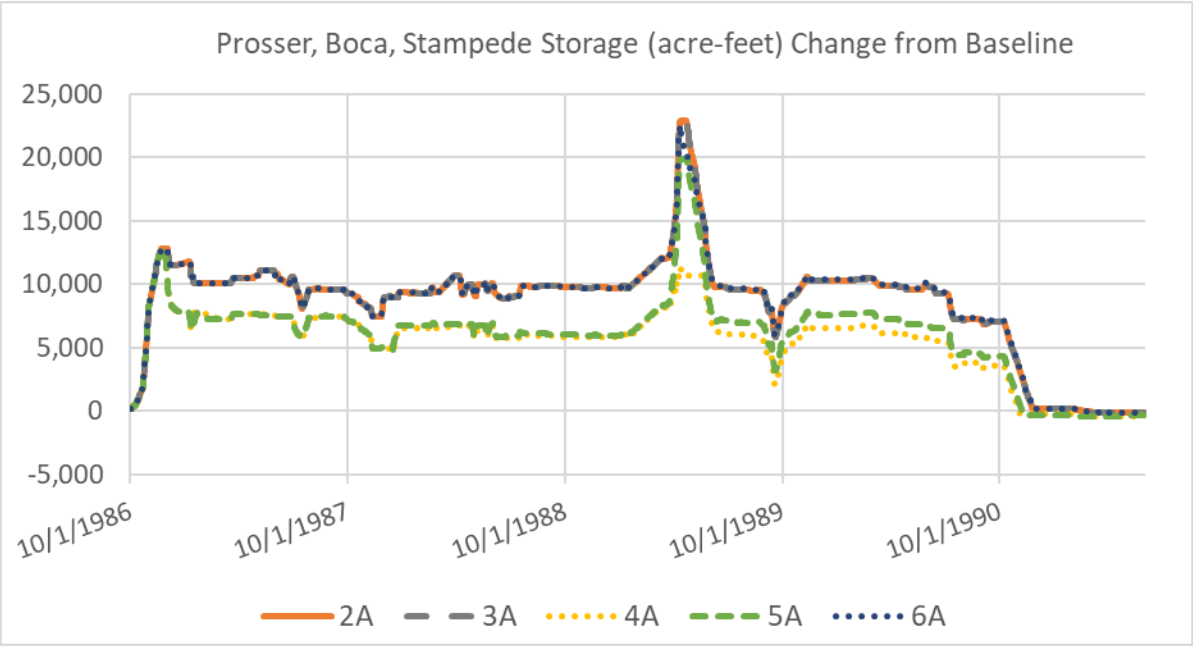

Figure 26: Prosser Boca Stampede Storage October 1986 through October 1990. Alternative Operational Scearios 2, 3, and 6 overlap throughout the demonstrated time period, whereas Alternative Operational Scenarios 4 and 5 overlap prior to mid-1989.

Secondly, due to additional storage carried over in 2006, higher storage is maintained in Alternative Operational Scenarios 2, 3, and 6, until reservoirs fill again in 2011 (Figure 27). Scenarios 2, 3, and 6 demonstrate the largest carryover storage in 2006 due to their more flexible "By a Model" Meth fall drawdown and spring refill regulation criteria. While this additional storage eventually spilled in 2011 and was not put to beneficial use, it does represent a benefit if a dry year had occurred during this timeframe. Regardless, after the fill in 2011, reservoirs again carry additional storage in Alternative Operational Scenarios over the Baseline.

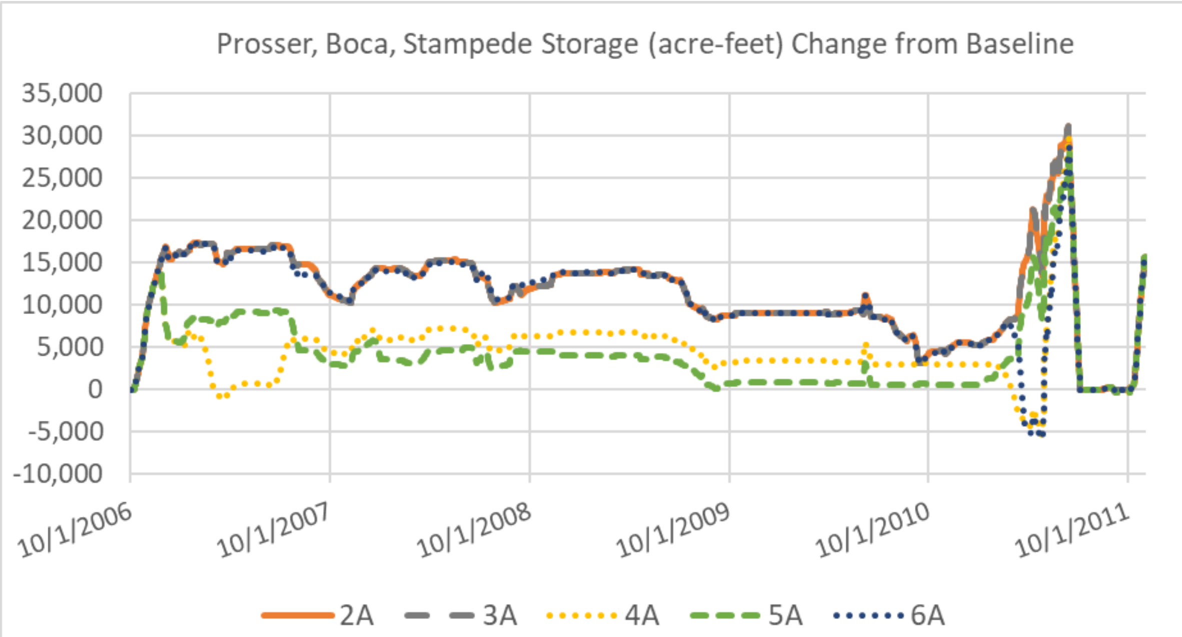

Figure 27: Prosser Boca Stampede Storage October 2006 through October 2011. Alternative Operational Scenarios 2, 3, and 6 overlap throughout the demonstrated time frame.

5.5 RMS Flow Over Flood Target Objective

Alternative Operational Scenario 6 offered the greatest benefit to the RMS Flow Over Flood Target objective of approximately 14,000 cfs less than the Baseline. Alternative Operational Scenario 3 offered the least benefit of approximately 10,500 cfs less than the Baseline (Table 16).

Table 16: RMS Flow Over Flood Target Objective Scores

Objective: RMS Flow Over Flood Target (cfs)		
Scenarios:	**Value**	**Change**
Baseline	159,960.15	0.00
2A	149,386.61	-10,573.54
3A	149,457.32	-10,502.83
4A	146,188.92	-13,771.24
5A	146,586.62	-13,373.53
6A	146,029.17	-13,930.98

To examine the time series impacts of these Alternative Operational Scenarios for this objective, it is most useful to analyze hourly results. Table 17 demonstrates the potential for the Alternative Operational Scenarios to significantly reduce the Baseline's peak flow during several simulated hourly events, demonstrated particularly the larger winter storms and May 1996 events. Alternative Operational Scenarios have virtually identical peak flows for most events shown in Table 17. The February 1986 500-year scaled event demonstrates the largest reduction of peak flow of about 6,900 cfs for all Alternative Operational Scenarios relative to the Baseline's peak flow.

Table 17: Truckee at Reno Event Maximum Hourly Gage Flow (cfs) Change from Baseline. The events with the recurrence interval listed represent simulations of scaled historical events.

	Reno Gage Flow Peak Flows (cfs)	Change in Peak from Baseline in Action Alternatives (cfs)				
Event	Baseline	2A	3A	4A	5A	6A
Runoff 2017, 500 yr	63,604	0	0	0	0	0
Feb 1986, 500 yr	57,247	-6,862	-6,844	-6,862	-6,862	-6,862
Jan 1997, 500 yr	41,609	-1,525	-1,525	-1,525	-1,525	-1,525
Feb 1986, 100 yr	26,409	-1,298	-1,297	-1,298	-1,298	-1,298
Jan 1997, 100 yr	18,010	0	0	-12	-12	0
May 1996, 500 yr	15,657	41	40	49	41	32
Jan 2017	12,275	9	9	6	6	10
May 1996, 100yr	11,479	5	5	0	5	-98
Feb 2017	10,305	-11	-11	13	-15	13
May 1996	7,793	284	284	-1,251	340	-1,272

These Alternative Operational Scenarios demonstrate almost identical reductions in peak flow relative to the Baseline for most events due to their shared values for Boca Portion of Flood Space of 0.5. The Baseline has a Boca Portion of Flood Space of roughly 0.27. Essentially, higher values of Boca Portion of Flood Space mean that more flood space will be reserved in Boca Reservoir and less in Stampede Reservoir. Because of (1) Boca Reservoir's additional flood space and (2) Stampede's limited release capacity, Boca Reservoir will fill and be forced to make releases later in Alternative Operational Scenarios than in the Baseline. Ultimately, this results in a reduction of peak flows. The relationship between the Boca Portion of Flood Space variable and the RMS Flow Over Flood Target objective can be further assessed through a sensitivity analysis derived from the MOEA solutions (Figure 28). As shown in the figure, higher values of Boca Portion of Flood Space result in larger reductions in RMS Flow Over Flood Target which supports why Alternative Operational Scenarios, in general, perform better than the Baseline.

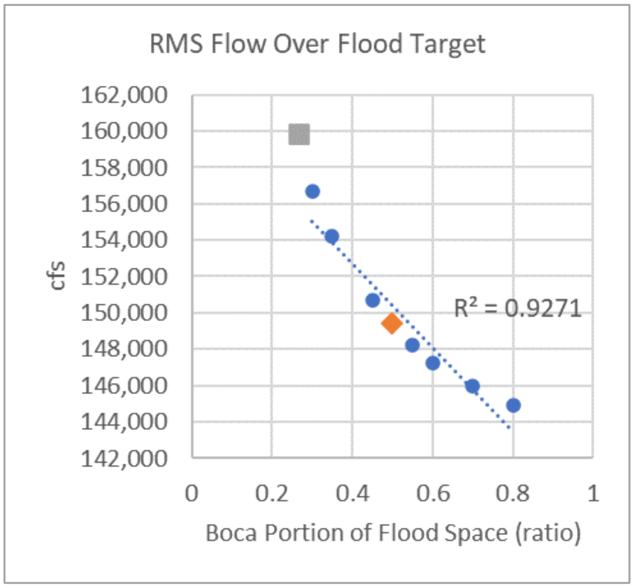

Figure 28: Sensitivity Analysis of RMS Flow Over Flood Target to the Boca Portion of Flood Space decision variable.

Figure 29 provides a plot of the simulated Truckee at Reno Gage flows during the 1986 Flood Event scaled to the 100-year recurrence. In this event, all Alternative Operational Scenarios lessen the time that flows are over the Reno flood flow target of 6,500 cfs. Furthermore, all Alternative Operational Scenarios reduce the second peak flow on February 19th from about 26,000 cfs to about 22,500 cfs. The 6,500 cfs Reno flood flow target allows for swifter evacuation of reservoir flood space over the course of the event, resulting in a lower peak flow at the time of the second event that occurred on March 8th for all Alternative Operational Scenarios (Figure 29). Also pictured in Figure 29, and other similar timeseries, is a series titled “NWS Flood Stage” which depicts the National Weather Service (NSW) flow rate associated with the flood stage at Reno.

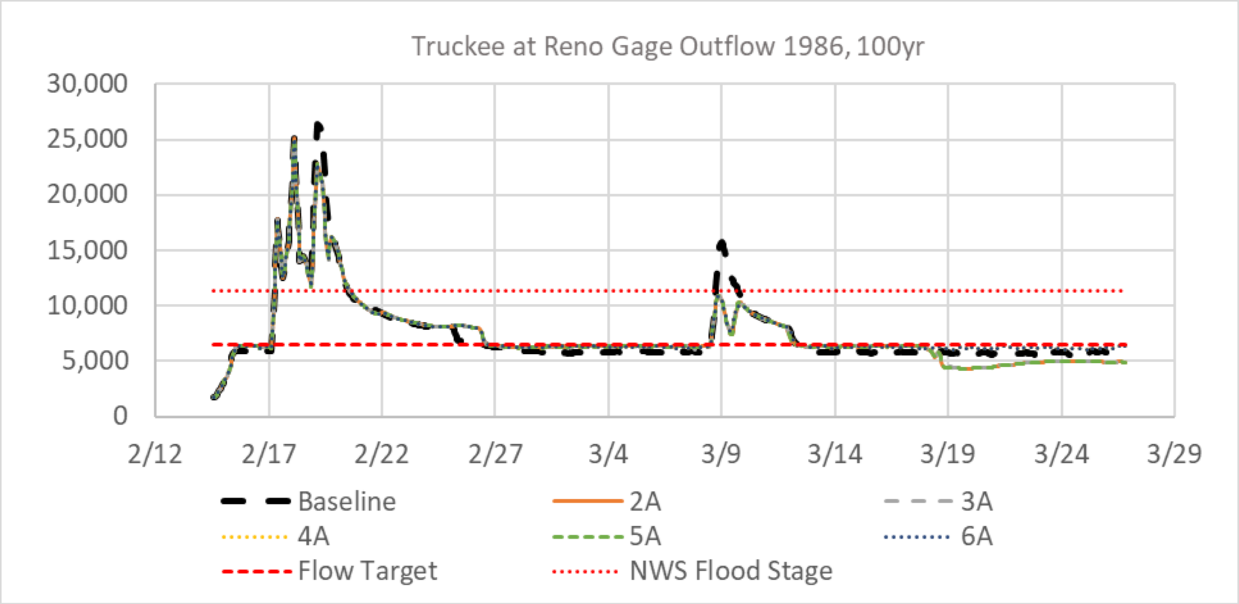

Figure 29: Feb 1986 100-Year Flows over the Flood Flow Target. Flow Target series refers to the Reno food flow target of 6,500 cfs. All Alternative Operational Scenarios overlap throughout most of the demonstrated period.

In the May of 1996 Flood Event, Alternative Operational Scenarios 2, 3, and 5 have 300 cfs higher peak flow, whereas Alternative Operational Scenarios 4 and 6 maintain the flood flow target of 6,500 cfs, lowering the peak flow by about 1,200 cfs (Figure 30). Due to the lower initial storage in Alternative Operational Scenario 4 and 6 heading into this event, these Alternative Operational Scenarios reserve enough flood space to capture the event (Figure *31*).

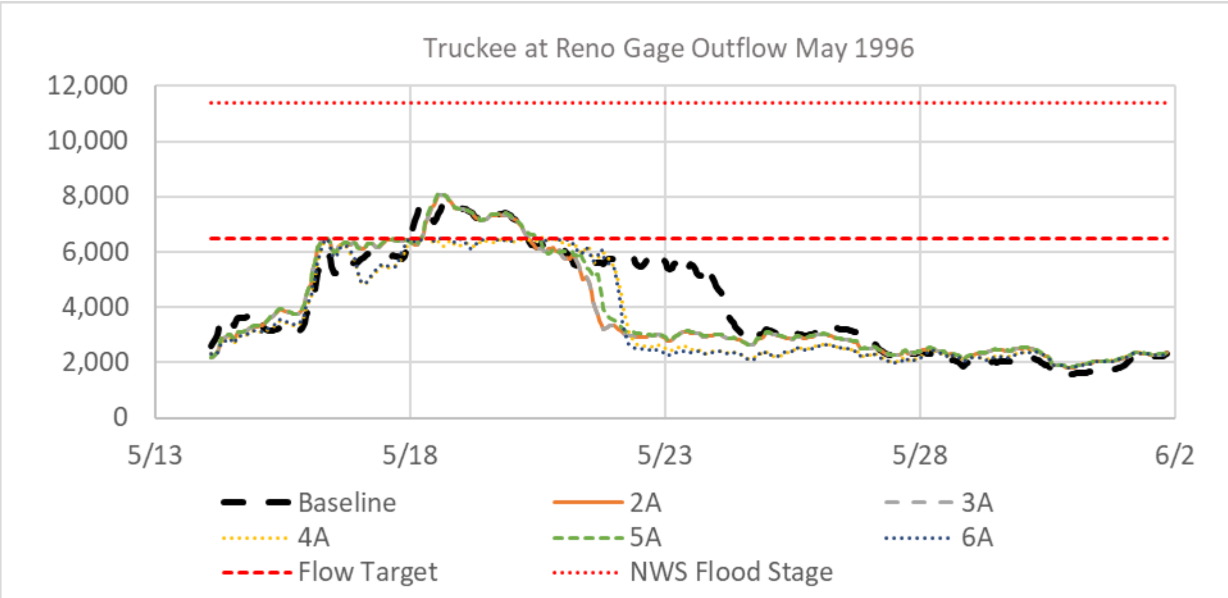

Figure 30: Truckee at Reno Gage Outflow May 1996 with a 6,500 cfs flood flow target

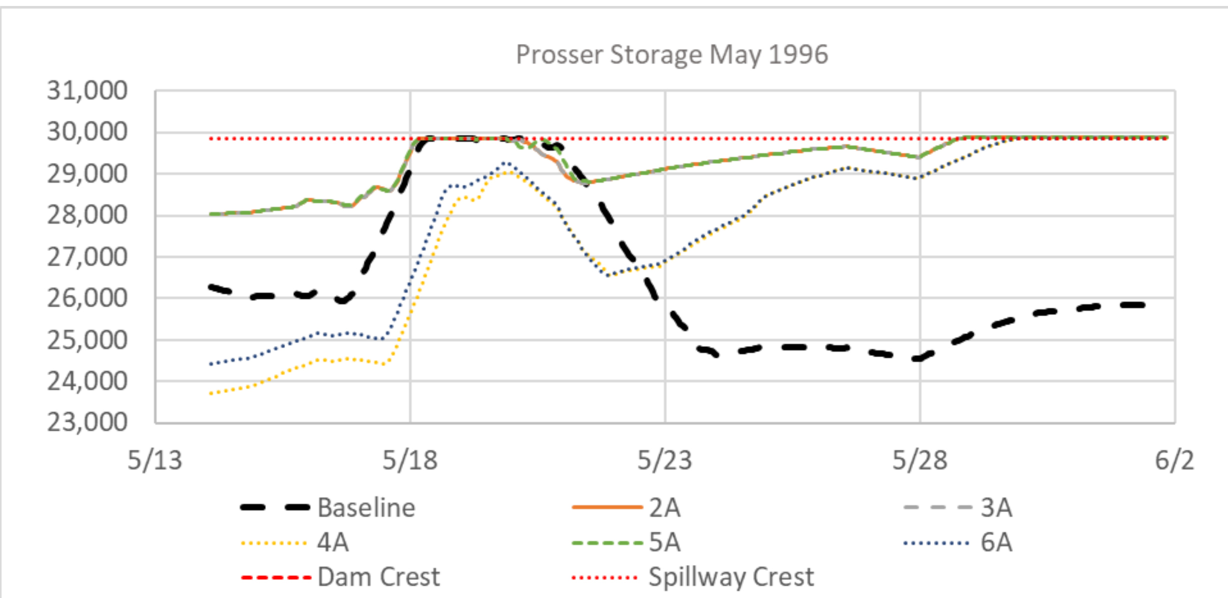

Figure 31: Prosser Storage May 1996

6 PREFERRED OPERATIONAL SCENARIO

Although the formal evaluation criteria was useful to frame the desirability of each Alternative Operational Scenario, a few select Quantifiable and Non-Quantifiable objectives (see **Section 2.1 Objectives**) were the main decision factors of the Preferred Operational Scenario. These main decision factors included:

- Develop methodologies that are implementable in an operational mode.
- Bring the WCM up to date with current technologies and capabilities and allow flexibility for future improvements in data availability and forecasting of future climate conditions.
- Maximize Average Annual Volume for FR.
- Minimize Average Daily Increase in Flood Space Requirement.
- Minimize RMS Flow Over Flood Target.

Cost Share Partners first eliminated less attractive Alternative Operational Scenarios and then discussed pros and cons of remaining Alternative Operational Scenarios in terms of the above objectives to arrive at a Preferred Operational Scenario.

6.1.1 Elimination of Less Competitive Alternative Operational Scenario

Firstly, Cost Share Partners worked to eliminate scenarios that were not competitive for the Preferred Operational Scenario. The Technical Team utilized objective score performance as the means to eliminate underwhelming Alternative Operational Scenarios. The team first eliminated Alternative Operational Scenario 3 because it offers the same water supply benefits as Alternative Operational Scenario 2 with added complexity of implementation. Both Alternative Operational Scenarios offered some of the best objective scores for Average Annual Volume for FR and Average Annual Volume for Flow Regime due to added flexibility, specifically during the fall drawdown after wet years, of the "By a Model" Method approach to flood space determination (Table 12). However, Alternative Operational Scenario 3 is more difficult to implement in an operational mode with its additional requirement of operating to Vista. Operating to Vista in addition to Reno adds complication for operators involving accounting for travel time and additional forecasting requirements in the lower river.

Next, Alternative Operational Scenario 5 was eliminated since it had the worst objective score performance of all Alternatives for the Average Daily Increase in Flood Space Requirement (Table 9).

6.1.2 Flood Risk, Water Supply, and Environmental Instream Flows

This left three Alternative Operational Scenario for consideration as the Preferred Operational Scenario: 2, 4, and 6. These Alternative Operational Scenarios each offered different benefits to the Technical Team. When comparing Alternative Operational Scenarios 2 and 4 to one another, Alternative Operational Scenario 2 emphasized water supply benefits in lieu of flood risk benefits, whereas Alternative Operational Scenario 4 emphasized flood risk benefits in lieu of water supply benefits (see Table 12 and Table

16). Additionally, Alternative Operational Scenario 4 allowed for more consistent flood space requirements that resulted in less fluctuations in river flows. The Technical Team was concerned with the flashy behavior observed in the flood space requirements of Alternative Operational Scenario 2 in comparison with Alternative Operational Scenario 4. This is discussed in detail in the proceeding section.

To exemplify these concerns Figure 32 provides simulated results for Prosser Flood Control Capacity, Storage, and Outflow for Alternative Operational Scenario 2. This Alternative utilized the "By a Model" Method, which permitted 22,000 acre-feet of storage until April 1, 2017, except for a few days when storms were forecasted. Contrarily, Alternative Operational Scenario 4 utilized the Revised Guide Curve and only allowed 10,000 acre-feet of storage through April 10th (Figure 33). While a key benefit of using the "By a Model" Method is the ability to maintain higher winter reservoir levels and more carryover water from one year to another, workshop participants pointed out that 2017 was a wet year with a historic runoff. As such, there wasn't any need to fill early in the season since all the reservoirs would fill during spring runoff because snow was already on the ground. The Baseline, on the other hand, started refilling Prosser from 9,840 acre-feet in late May. The reservoir was still able to fill. Further, in addition to the flashy winter flows in "By a Model" Method, the higher reservoir levels during spring refill also result in flashier flood storage requirements and outflows in the spring (Figure 32). The main concern expressed by the Technical Team in relation to the operation in Alternative Operational Scenario 2 was, "in a wet year, why would operators need the flexibility to maintain higher storages earlier in the year?" In other words, in a snowmelt driven basin like the Truckee River Basin, if it is a wet year and much snow is already on the ground, what benefit is there to allowing encroachment into flood space and filling earlier in the year? The Technical Team saw this as an unnecessary risk to take and rather wanted to see regulation criteria that, in a wet year, would give operators justification for delaying the fill and keeping reservoirs lower.

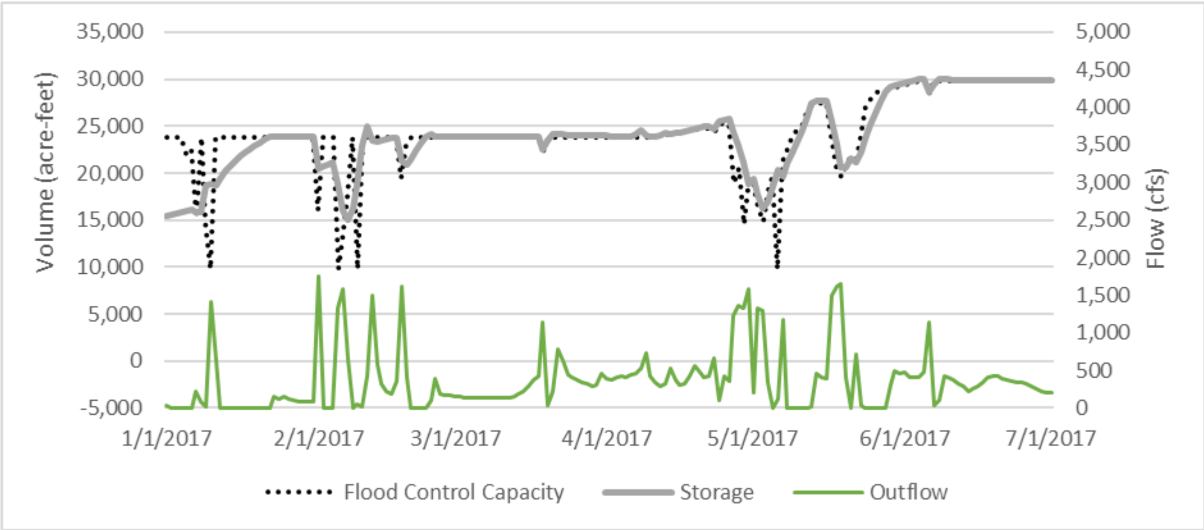

Figure 32: Prosser Flood Control Capacity in Alternative Operational Scenario 2 January 2017 through July 2017.

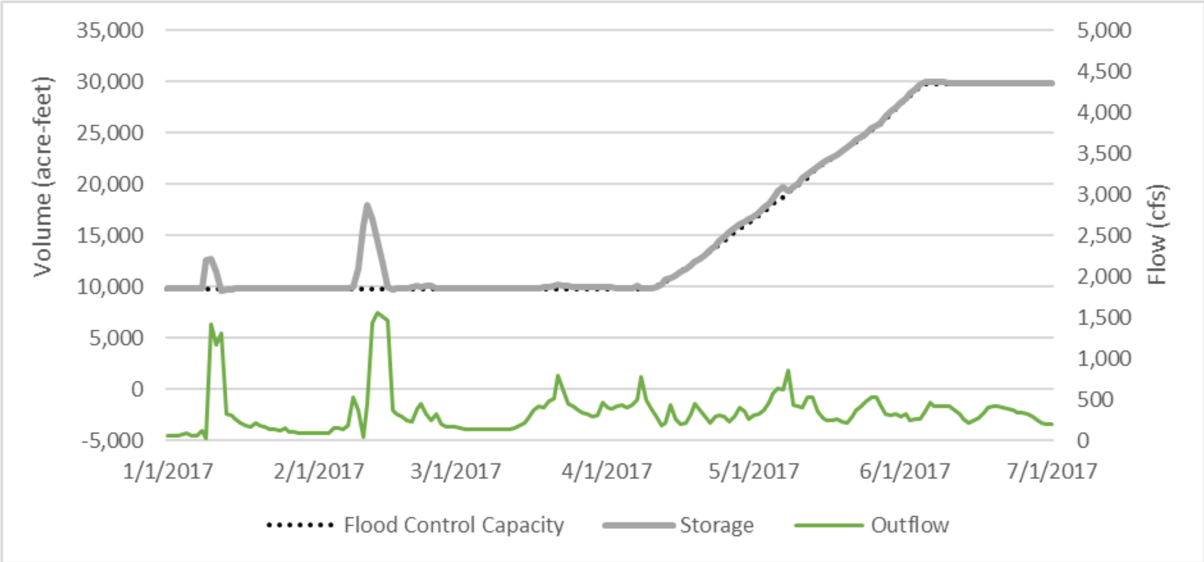

Figure 33: Prosser Flood Control Capacity in Alternative Operational Scenario 4 January 2017 through July 2017.

Alternative Operational Scenario 6 offered a solution that leveraged both the water supply benefits of Alternative Operational Scenario 2 and benefits to flood risk mitigation and river flashiness of Alternative Operational Scenario 4. It accomplished this by incorporating the Variable Percent of Revised Guide Curve to Maintain (see **Section 2.3 Alternative Operational Scenarios)**. Ultimately, this Alternative Operational Scenario is very similar to Alternative Operational Scenario 2 except that its regulation criteria prevents reservoirs from filling early in wet years. As a result, during wet years, Alternative Operational Scenario 6 mitigates unnecessarily risky encroachment into flood space while still providing water supply benefits associated with Alternative Operational Scenario 2 in low water years with lower probability of floods (see Figure 34). Alternative Operational Scenario 6 fills less smoothly than Alternative Operational Scenario 4, but more smoothly than Alternative Operational Scenario 2. Additionally, Alternative Operational Scenario 6 releases are more flashy than Alternative Operational Scenario 4, but less so than Alternative Operational Scenario 2.

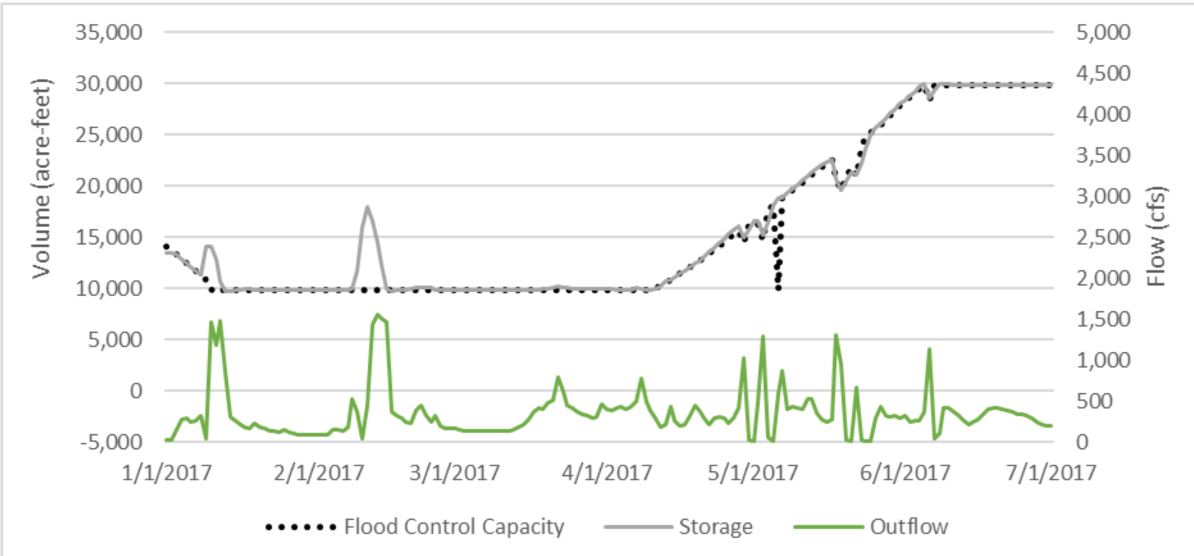

Figure 34: Prosser Flood Control Capacity in Alternative Operational Scenario 6 January 2017 through July 2017.

Further, in 2011, a wet year, Alternative Operational Scenario 6 best balances encroachment into flood space while simultaneously mitigating flood risk. In Figure 35, Alternative Operational Scenario 2 encroaches into flood space the most during this wet year, whereas Alternative Operational Scenario 4 draws down fully at a potential sacrifice to water supply. On the other hand, Alternative Operational Scenario 6 encroaches variably into flood space, towing the line between benefiting water supply while mitigating flood risk.

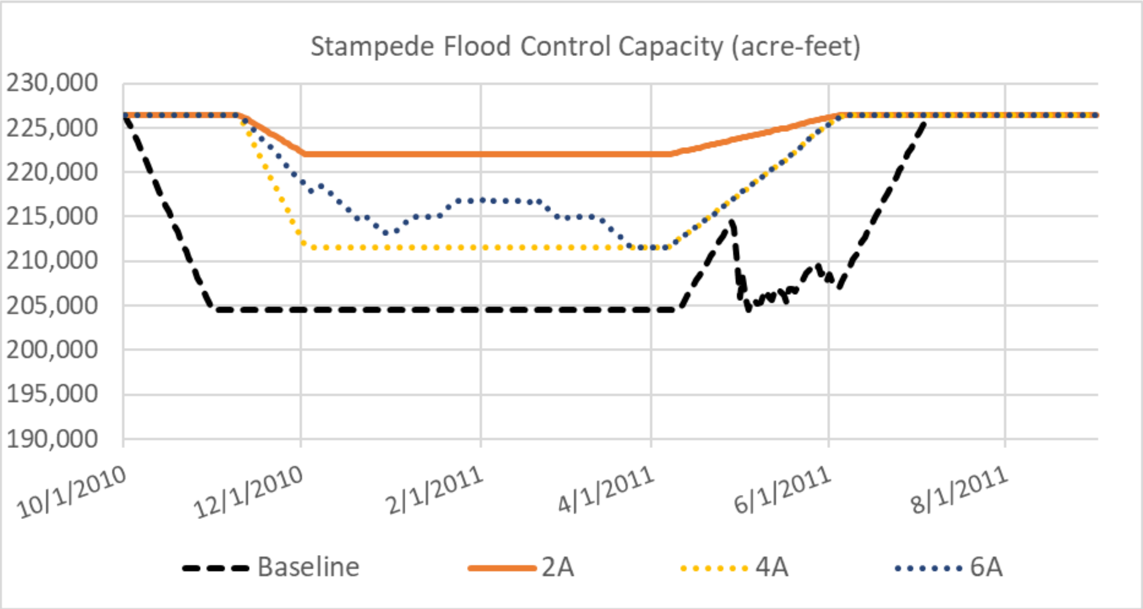

Figure 35: Prosser Flood Control Capacity 2011

6.1.3 Ease of Implementation in an Operational Mode

Alternative Operational Scenario 4 was determined to be easier to implement in an operational mode (a non-quantifiable objective, see **Section 2.1 Objectives**) since its flood space requirements were governed by Revised Guide Curves. These Revised Guide Curves are the most similar flood space determination method to the current WCM, which requires a simple table look-up to obtain daily flood space requirements in contrast with the more complicated “By a Model” Method approach. Alternative Operational Scenario 6 was determined to be implementable in an operational mode, although it was considered by the Technical Team to be more challenging to implement than Alternative Operational Scenario 4 due to its “By a Model” Method approach and Variable Percent of Revised Guide Curve to Maintain. Given Alternative Operational Scenario 6’s superior performance over Alternative Operational Scenario 4 for other quantifiable and non-quantifiable objectives, its selection in terms of ease of implementation was justified.

6.1.4 Multiplicative Nature of Boca Portion of Flood Space and the Percent of Revised Guide Curve to Maintain

One benefit identified by the Technical Team in Alternative Operational Scenarios 2 and 6 was in how they allowed reservoir operations to be adaptable to forecast conditions, promoting both water supply and flood control benefits.[7] The adaptability manifested in these Alternative Operational Scenarios because of a nuanced interplay between the Percentage of Revised Guide Curve to Maintain and Boca Portion of Flood Space decision variables.[8]

The Percentage of Revised Guide Curve to Maintain decision variable was developed as a safety factor on the FIRO driven "By a Model" Method used to determine flood space requirements. It prescribes a minimum value of the Revised Guide Curve that must be maintained regardless of what the "By a Model" Method determined by analyzing ensemble forecasts. Thus, when no flood events are in the forecast, this variable multiplied with the required flood space as determined by the Revised Guide Curve for a given day represents the total required flood space. Table 18 provides examples of how this decision variable is used alongside the Revised Guide Curve and the "By a Model" Method to calculate flood space. Note, examples from this table assume a Percentage of Revised Guide Curve to Maintain from Alternative Operational Scenarios 2 and 6 of 30%.[9]

In Example 1 of Table 18, the "By a Model" Method calculates a Little Truckee Required Flood Space of 0 acre-feet, insinuating that there *no flood events the forecast*. In this example, the Revised Guide Curve is at its maximum allocation for Little Truckee Flood Space of 30,000 acre-feet, and when this value is multiplied by 30%, you get a minimum value required for Little Truckee Flood Space of 9,000 acre-feet. Because this is greater than the value of Little Truckee Flood Space calculated by the "By a Model" Method, this becomes the required Little Truckee Flood Space. Example 2 in Table 18, provides a similar example except *there is a flood in the forecast*, and the "By a Model" Method calculates a value of 15,000 acre-feet. Because this is greater than the value of minimum required flood space in the Little Truckee, 15,000 acre-feet is the required Little Truckee flood space.

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[7] Note, since Alternative Operational Scenarios 3 and 5 have already been eliminated, they are not included here. The benefit described in this section does, however, apply to them as well.
[8] Alternative Operational Scenario 4 does not exhibit this benefit because it does not incorporate the Percentage of Revised Guide Curve decision variable (see Figure 5).
[9] This value was determined when selecting the Preferred MOEA Scenario Selection (see Figure 5).

Table 18: Two examples of flood space calculations in the Truckee using the preferred Boca Portion of Flood Space of .5, the preferred Percentage of Revised Guide Curve to Maintain of 30%, the Revised Guide Curve, and the "By a Model" Method. All table values are in acre-feet.

Example Number	Revised Guide Curve Little Truckee Flood Space	Minimum Revised Guide Curve Space Required	"By a Model" Method Little Truckee Flood Space Requirement	Little Truckee Required Flood Space	Boca Flood Space Requirement
1	30,000	9,000	0	9,000	4,500
2	30,000	9,000	15,000	15,000	7,500

The second decision variable, the Boca Portion of Flood Space, denotes the portion of required Little Truckee flood space to be maintained in Boca Reservoir. The Boca Portion of Flood Space in Alternative Operational Scenarios 2 and 6 is 0.5. Thus, continuing with Example 1 of Table 18, since the required Little Truckee flood space when no flood events were in the forecast was 9,000 acre-feet, the required Boca flood space is 4,500 acre-feet. Similarly, in Example 2, since the required Little Truckee flood space when there was a flood event in the forecast was 15,000 acre-feet, the required Boca flood space is 7,500 acre-feet.

As mentioned above, the multiplicative nature of these variables to determine Boca's flood space provides a unique benefit of adaptability. This is true for two reasons. The first is in the case when there is a big flood in the forecast. In this case the "By a Model" Method would calculate that the maximum allowed flood space in the Little Truckee of 30,000 acre-feet would be required, and, per the Boca Portion of Flood Space, 15,000 acre-feet of this would be in Boca (see Table 19). As discussed in **Section 5.5 RMS Flow Over Flood Target Objective**, the space available in Boca Reservoir approaching a flood has a direct impact on reducing (1) how long it would be before Boca would be forced to make releases to maintain its max capacity, and (2) peaks flows at the Reno Gage. As shown in Table 19, Alternative Operational Scenarios provide an additional 7,000 acre-feet of flood space in Boca when a big flood event is in the forecast.

Table 19: Required Boca flood space for Alternative Operational Scenarios 2, 3, 5 and 6 and the Baseline in the case that there is a large flood event in the forecast and no flood event in the forecast. All table values are in acre-feet.

	Required Flood Space in Boca		
	Alternative Operational Scenarios	Baseline	Difference
Large Flood Event in Forecast	15,000	8,000	7,000
No Flood Event in Forecast	4,500	8,000	-3,500

The second reason for the increased adaptability in the remaining Alternative Operational Scenarios occurs when there is no flood in the forecast, which is most of the time. In this case, only 4,500 acre-feet of flood space is required in Boca, compared to 8,000 acre-feet of flood space required in the Baseline. This additional storage space can be used for conservation and represents a benefit to water supply.

In summation, because of the multiplicative nature of the Boca Portion of Flood Space and Percentage of Revised Guide Curve to Maintain decision variables, Alternative Operational Scenarios 2 and 6 offer an adaptable flood control regulation criteria that in times of floods offers more flood protection and in times of no floods offers more space for water supply.

6.1.5 Bring WCM Up to Date with Current Technologies

Alternative Operational Scenario 2 and 6 better allow for incorporation of future improvements in forecasting technology due to its FIRO "By a Model" Method approach to determining flood space requirements (Noe, Erkman, & Gwynn, Action and Alternative Operational Scenario Modeling in the WMOP Study, 2023). As ensembles get more accurate, their improved predicative performance will automatically be integrated into calculations of flood space requirements.

6.2 Selecting the Preferred Operational Scenario

After reviewing the Quantifiable Objective scores and timeseries data, the main selection criterion of the Preferred Operational Scenario regarding Quantifiable Objectives was the ability to balance water supply and environmental objectives while mitigating large fluctuations in river flows and flood risk. In addition to this, meeting the Non-Quantifiable objectives was imperative to the decision making process.

Workshop participants were split into three groups and asked to fill out the scoring criteria defined in Table 20 and Table 21 for the six Alternative Operational Scenarios.

Table 20: Alternative Operational Scenario Evaluation Criteria

Evaluation Criterion	Possible Values
Maximize Benefit to Floriston Rate (e.g., amount of Floriston Rate water in storage, timing storage available)	Score of -3 to 3 <0 is Excluded from Further Consideration
Maximize Benefit to Threatened and Endangered Fish Species (e.g., VIFR, storage available)	Score of 0-5 <0 is Excluded from Further Consideration
Improve Environmental Instream Flows Downstream of Reservoirs	Score of -3 to 3
Optimize Storage to Satisfy Water Demands Through the Year (e.g., improve refill probability, flexibility of drawdown timing)	Score of -3 to 3
Reduce Risk of Damage from Flooding Downstream	Score of -3 to 3 <0 is Excluded from Further Consideration
Minimize Use of Surcharge Space Above the Spillway	Score of -3 to 3
Do not Increase Probability of Dam Failure	Score of -3 to 3 <0 is Excluded from Further Consideration
Bring WCM up to date with current technologies and capabilities and allow flexibility for future improvements in data availability and forecasting of future climate conditions	Score of -3 to 3
Implementable in an Operational Mode (i.e., Feasible to Implement).	Score of -3 to 3

Table 21: Evaluation Criteria Scoring System

Possible Rating	Meaning
-3	Significantly worse than baseline
-2	Moderately worse than baseline
-1	Slightly worse than baseline
0	No change from baseline
1	Minor improvement over baseline
2	Moderate improvement over baseline
3	Significant improvement over baseline

Each evaluation criterion was given a score according to the rating system defined in Table 21. To select this Preferred Operational Scenario, the Technical Team and other key stakeholders analyzed timeseries data and compared the Alternative Operational Scenarios utilizing the "Alternative Output Viewer-Alternatives" spreadsheet (Erkman, Alternative Output Viewer-Alternatives, 2023).

Each group provided similar scores for the six Alternative Operational Scenarios and unanimously determined Alternative Operational Scenario 6 to be the Preferred Operational Scenario.

Table 22: Ranking the six Alternative Operational Scenarios

	Alternative Operational Scenario 1	Alternative Operational Scenario 2	Alternative Operational Scenario 3	Alternative Operational Scenario 4	Alternative Operational Scenario 5	Alternative Operational Scenario 6
	No Action	Optimizing Storage for Fisheries and Water Supply	Dynamic Flood Risk Reduction Criteria	Updating Flood Risk Management	Hybrid Rule Curve	Variable Guide Curve
Group 1	0	9	8	6	3.5	9
Group 2	0	11	10	8	7	12
Group 3	0	12	11.75	7.5	5.5	16.25
AVERAGE	0	10.7	9.9	7.2	5.3	12.4

Alternative Operational Scenario 6 elegantly maintains the benefits to:

- Water supply and environmental flows observed in Alternative Operational Scenario 2.
- Flood control operations during wet years observed in Alternative Operational Scenario 4 by constraining the flexibility for reservoir refill operations in wet years.
- Limited fluctuations in downstream flow due to changes in flood space requirements.

Thus, Alternative Operational Scenario 6 was the best Operational Scenario for leveraging water supply benefits associated with the "By a Model" Method approach to flood space determination while mitigating the unnecessary risk associated with high storage during wet hydrologic years.

6.3 Updating the Flood Target Flow at the Reno Gage

Another decision made by the WMOP stakeholders was the recommended updated Reno flood flow target. Based upon results of the *Channel Capacity Analysis Report* (Blum, Weaver, Gusman, Viducich, & Bertrand, 2022) and personal communication with Dr. Robison, the team recommended a 7,000 cfs flood flow target at Reno. The three major reasons for this recommendation included:

1. Survey evidence provided via personal communication with Dr. Robison suggested 21-day simulations of 7,000 cfs flows, which include tributary inputs, did not jeopardize any structures in the WMOP Study's geographical areas of interest (Robison, 2023).

2. Although the *Chanel Capacity Analysis Report* suggests that significant flooding near the Truckee River occurs at a 7,000 cfs flow, some key assumptions (i.e., 1D modeling, model detail, etc.) of this effort indicate potential for more flood damages in the modeling than expected by Dr. Robison at that flow rate (Blum, Weaver, Gusman, Viducich, & Bertrand, 2022).
3. The National Weather Service Flood Stages, updated in 2018, support a raised flood flow target to 7,000 cfs.

Further evidence supporting the recommendation is being compiled at the time of this report.

6.4 Results of the Preferred Operational Scenario

After the Technical Team selected a Preferred Operational Scenario and recommended a Reno Flood Flow Target at the Select Preferred Operational Scenario Workshop, results were compiled to compare objective performance of the Preferred Operational Scenario with a Reno Flood Flow Target of 6,500 cfs and 7,000 cfs. As shown earlier in Table 5, each Alternative Operational Scenario was simulated with a Reno Flood Target Flow of 6,500 cfs within the MOEA Scenario and Alternative Operational Scenario analyses so they could be compared directly, whereas the Baseline has a Reno Flood Flow Target of 6,000 cfs to reflect the current operational criteria. (Noe, Erkman, & Gwynn, Action and Alternative Operational Scenario Modeling in the WMOP Study, 2023). As not to be repetitive, this section highlights high-level objective performance differences of the Preferred Operational Scenario operated to a Reno flood target flow of 6,500 cfs and 7,000 cfs.

When the Baseline is compared to the 7,000 cfs Preferred Operational Scenario, as shown in Table 23, the 7,000 cfs Preferred Operational Scenario had the same if not better objective performance than the Baseline for all objectives except for the Average Daily Increase in Flood Space Requirement objective. For this objective, the Baseline outperformed the 7,000 cfs Preferred Operational Scenario by an average of just 18 acre-feet per year.

When the 6,500 cfs Preferred Operational Scenario is compared to the 7,000 cfs Preferred Operational Scenario, the 7,000 cfs Preferred Operational Scenario performs about as well as the 6,500 cfs Preferred Operational Scenario for all of the objectives. Note that the magnitude of most of these objective score differences is relatively small; for example, the 7,000 cfs Preferred Operational Scenario's Average Annual Volume for

FR objective is within 3 acre-feet per year on average of the 6,500 cfs Preferred Operational Scenario (Table 23).

Table 23: Preferred Operational Scenario (7,000 cfs) MOEA Modeled Preferred Operational Scenario (6,500 cfs) compared to Baseline.

	Average Annual Volume For FR (acre-feet)	Average Annual Volume For Flow Regime (acre-feet)	Average Prosser Boca Stampede Storage (acre-feet)	Average Daily Increase In Flood Space Requirement (acre-feet)	RMS Flow Over Flood Target (cfs)
Baseline	-263,079	-148,067	-175,024	187	159,960
6500 cfs	-263,281	-149,015	-181,804	220	146,029
7000 cfs	-263,277	-149,023	-181,559	204	144,811
7,000 cfs - Baseline	-197	-956	-6,534	18	-15,150
7,000 cfs - 6,500 cfs	4	-8	245	-16	-1,218

Time series data of two flood events demonstrates the key improvements of the 7,000 cfs Preferred Operational Scenario in RMS Flow Over the Flood Target objective performance: the historical flood of 1997 and the February through March of 1986 100 year flood event. In the 1997 flood simulation, the 6,500 cfs and 7,000 cfs Preferred Operational Scenarios reduce the period over which the gage flow at Reno was close to or above the flood flow target. On January 4th, 1997, the 6,500 cfs and 7,000 cfs Preferred Operational Scenarios reduced the flow of the Baseline by about 4,000 cfs. When compared to the 6,500 cfs Preferred Operational Scenario, the 7,000 cfs Preferred Operational Scenario reduced the period in which the reservoirs were under flood operations (i.e., operating to the 7,000 cfs flood target flow at the Reno Gage) by two days, since the higher flood target flow allows for higher releases.

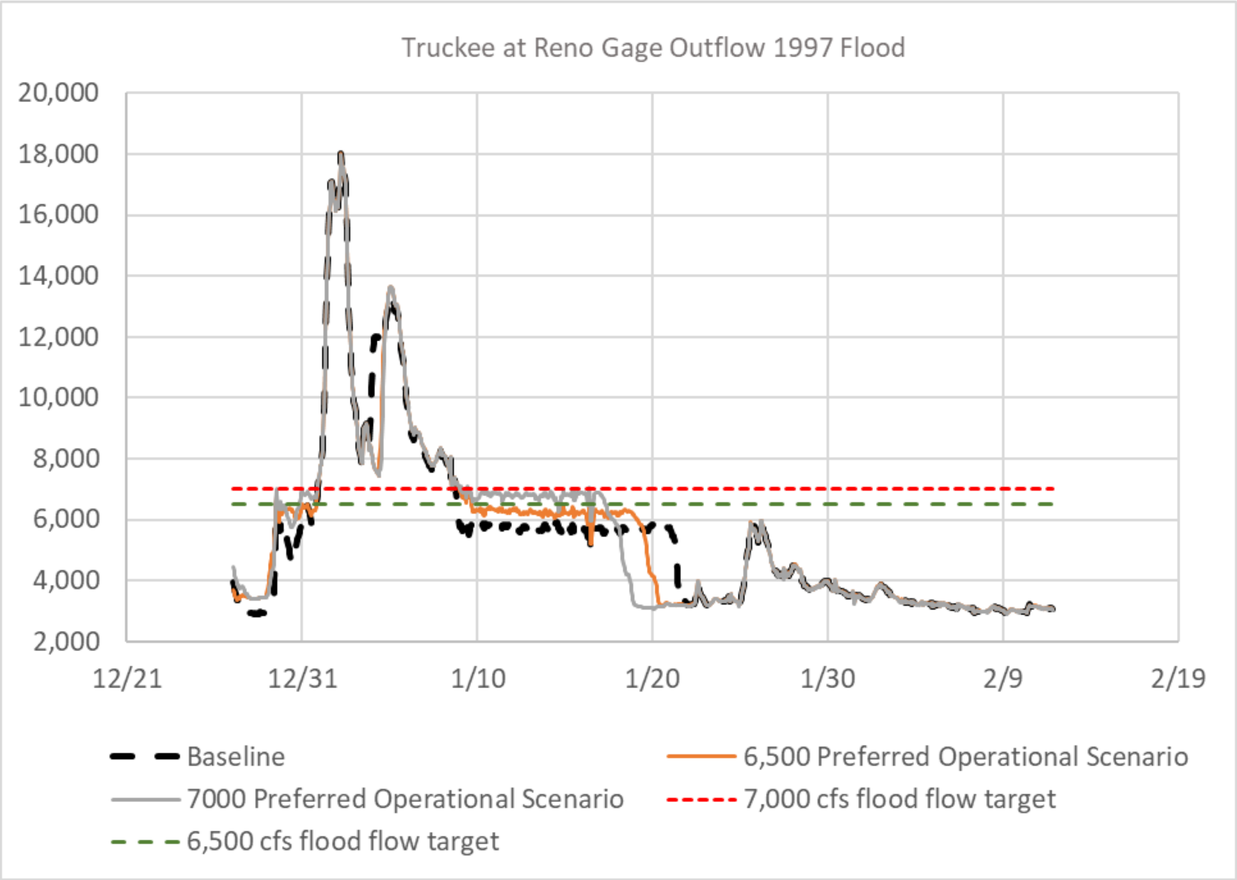

Figure 36: Truckee at Reno Gage Outflow 1997 Flood

In the scaled 100-year flood of 1986, occurring between February and March, lies another period of significant differences between the Baseline, 6,500 cfs and 7,000 cfs Preferred Operational Scenarios' Reno gage flows. When compared to the Baseline, the 7,000 cfs Preferred Operational Scenario reduces the March 9th peak flow from about 15,500 cfs to 10,000 cfs. Compared to the 6,500 cfs Preferred Operational Scenario, the 7,000 cfs Preferred Operational Scenario reduces the period during which the Marth 9th flows were over the flood flow target by a few days (Figure 37).

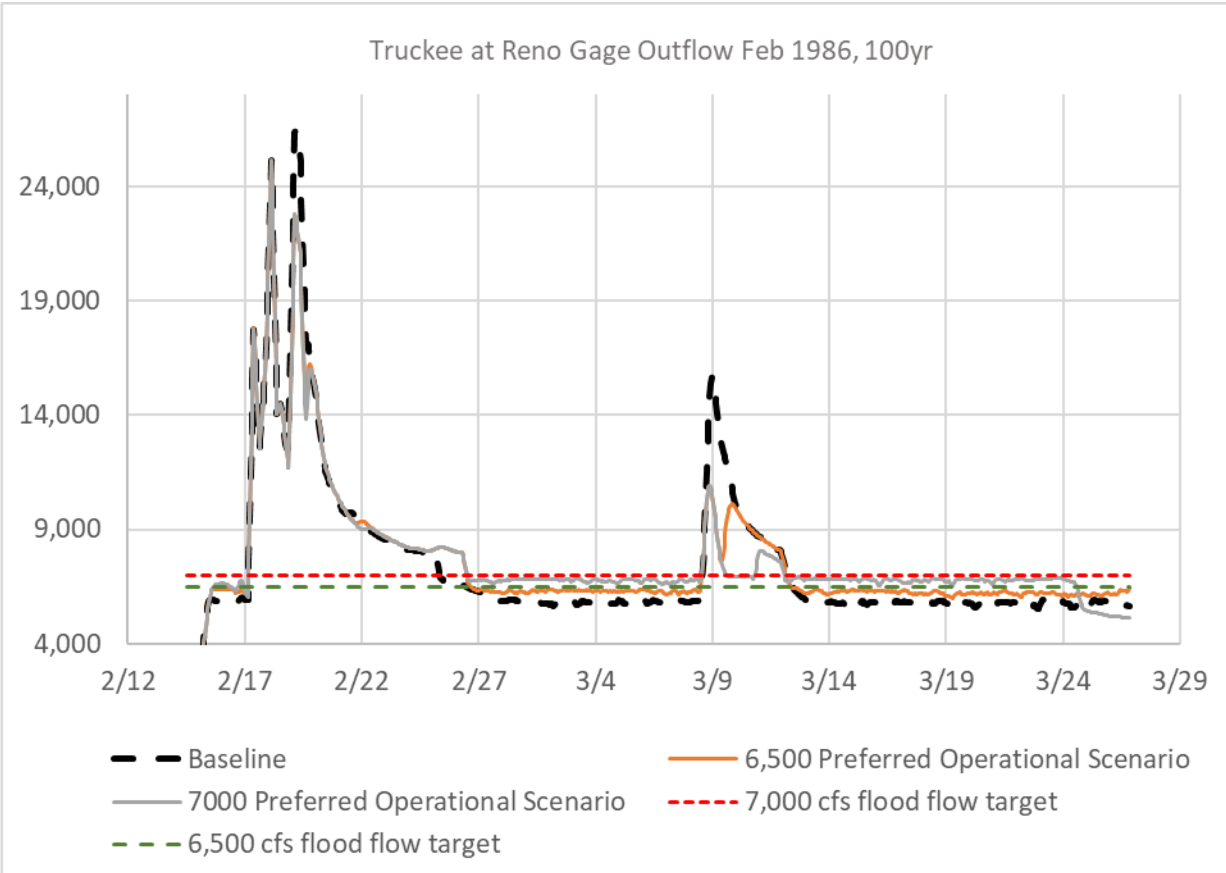

Figure 37: Feb-Mar 1986 100-Year Scaled Flood

Raising the flood flow target to 7,000 cfs has been shown in these two simulated events to reduce the duration of Reno gage flows at or above the Reno flood flow target. Reducing periods near or above the Reno flood flow target may bode well for flood damage mitigation, particularly in years when multiple events occur: the increased flood target flow allows for more efficient evacuation of reservoir encroachment.

7 Conclusion

Developing and implementing a holistic structure for selecting the Best Performing MOEA Scenario and the Preferred Operational Scenario allowed for the WMOP Technical Team to arrive at a recommended modification to the WCM. This process permitted objective comparison of model results while allowing room for subjective stakeholder opinion.

The Technical Team recommend Alternative Operational Scenario 6 operating to 7,000 cfs at the Reno Gage as the Preferred Operational Scenario. In developing the Preferred

Operational Scenario, the Technical Team was successful in reducing the frequency of large fluctuations in instream flows due to issues with lead time in forecasts. The set of regulation criteria represented by the Preferred Operational Scenario offers a novel approach to flood control regulation criteria that optimizes water supply and environmental flow objectives while reducing flood damages in the basin. Ultimately, this set of regulation criteria promotes innovation in the Truckee Basin, allowing administrators to seamlessly incorporate the latest advances in forecasting technology into flood control regulation criteria.

8 REFERENCES

Blum, M., Weaver, K., Gusman, J., Viducich, J., & Bertrand, D. (2022). *Truckee Basin Water Management Options Pilot Study--Channel Capacity Analysis.* US Bureau of Reclamation, US Department of the Interior.

Bureau of Reclamation. (2020, 11 9). *Stampede Dam (LBAO)*. Retrieved from Bureau of Reclamation : https://www.usbr.gov/mp/sod/projects/stampede/index.html

California Nevada River Forecast Center, National Oceanic and Atmospheric Administration. (2023, March). *Truckee River Farad 2023 Water Year Trend Plot*. Retrieved from NOAA: https://www.cnrfc.noaa.gov/ensembleProduct.php?id=FARC1&prodID=9

Erkman, C. (2023, 3 1). Alternative Output Viewer-Alternatives. Loveland, CO, USA.

Erkman, C. (2023, Mar). Hourly Data Alternative Viewer. Loveland, CO, 80537.

Erkman, C. (2023, June 28). Seelect Preferred Alternatives Workshop #2 MOEA Results Overview. Reno, Nevada, United States of America.

Erkman, C. (2023, June 29). Select Preferred Alternatives Workshop #2 Alternative Results Overview - MOEA Scenario A. Reno, Nevada, United States of America.

Gwynn, K. (2022). *Revised Guide Curve Modeling.* Loveland.

Noe, P. (2022). *Truckee River Hourly Model Verification for WMOP.* Loveland.

Noe, P., Erkman, C., & Gwynn, K. (2023). *Action and Alternative Operational Scenario Modeling in the WMOP Study.* Loveland.

Olsen, K., Erkman, C., & Vandegrift, T. (2021). *WMOP Truckee River Hourly River Model Time Lag Routing.* Loveland.

Parallel Coordinates Plot. (n.d.). Retrieved from The Data Visualisation Catalogue: https://datavizcatalogue.com/methods/parallel_coordinates.html

Precision Water Resources Engineering. (2022). *Multi-Objective Evolutionary Algorithm (MOEA) Tool Utilization and Development Technical Memorandum.* Loveland.

Reclamation. (2021). *Truckee Basin Water Management Options Pilot Study Alternative Operational Scenarios Development Report.* Bureau of Reclamation, U.S. Department of the Interior.

Reed, P. M., Herman, J. D., Kasprzyk, J. R., & Kollat, J. B. (2013). Evolutionary multiobjective optimization in water resources: The past, present, and future. *Advances in Water Resources, 438-456*(51). Retrieved from https://doi.org/10.1016/j.adwatres.2012.01.005

Robison, G. (2023, March 3). Truckee River Breakouts and Drainage. Reno, Nevada, USA.

(2008). *Truckee River Operating Agreement.* Reno.

US Army Corps of Engineers. (1985). *Water Control Manual.* Sacramento.