Appendix M

Action and Alternative Operational Scenario Modelling in the WMOP

ACTION AND ALTERNATIVE OPERATIONAL SCENARIO MODELLING IN THE WMOP

Truckee Basin Water Management Options Pilot, Memorandum of Agreement, Task 6: Technical Analyses

2021 Hydrologic Engineering Analysis Tasks, Task F: "TROA Model Development"

Abstract

Stakeholders in the Truckee Basin Water Management Options Pilot developed several alternative operational scenarios to flood control operational criteria to the 1985 Water Control Manual for the Truckee Basin during the project's Plan Formulation. This paper documents the technical methods utilized to (1) model the alternative operational scenarios and (2) quantify/optimize their performances. Ultimately, project stakeholders would utilize results provided by the technical design described in this paper to select a Preferred Operational Scenario to propose to the United States Army Corps of Engineers as a revision to the Water Control Manual.

To: Truckee Basin Water Management Operations Pilot

DATE: August 10, 2023

RE: []

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ACRONYMS AND ABBREVIATIONS

Acronym/Abbreviation	Full Phrase
CA DWR	California Department of Water Resources
cfs	Cubic feet per second
CNRFC	California Nevada River Forecast Center
HEAT	Hydrologic Engineering Analysis Tasks
MOA	Memorandum of Agreement
Other key stakeholders	National Oceanic and Atmospheric Administration, California Nevada River Forecast Center, Truckee River Flood Management Authority, and United States Army Corps of Engineers
Planning Model	Truckee River Operating Agreement Planning Model
PLPT	Pyramid Lake Paiute Tribe
Technical Team	US Department of the Interior, Bureau of Reclamation, Truckee Meadows Water Authority, US District Court Water Master, California Department of Water Resources, and Pyramid Lake Paiute Tribe
TMWA	Truckee Meadows Water Authority
TRFMA	Truckee River Flood Management Authority
TROA	Truckee River Operating Agreement
USACE	United States Army Corp of Engineers
USBR	United States Bureau of Reclamation
TBWMOP	Truckee Basin Water Management Options Pilot

1 Introduction

The Truckee Basin Water Management Options Pilot (TBWMOP) 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 Plan Formulation of the TBWMOP, 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 adopted in 1985. The problems and opportunities are best summarized as follows (Bureau of Reclamation, 2021):

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 "The [WCM] suffers from outdated rule curves, inflexible storage requirements, constrained reservoir release thresholds, and a constrained downstream regulation goal at Reno.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

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

As a response to problems and opportunities identified in the Plan Formulation, the Technical Team and other key stakeholders developed alternative operational scenarios to the regulation criteria in the WCM that utilize more flexible rule curves, implement changes to downstream regulation targets, and incorporate ensemble driven Forecast Informed Reservoir Operations (FIRO). The goal of the technical effort in the TBWMOP was to model the study's alternative operational scenarios and allow the Technical Team to determine the alternative flood control operation criteria that best meets the study objectives.

The purpose of this report is to document the methods employed by the Technical Team to model alternative operational scenarios to the WCM. The report begins by including a summary of the key findings of the Plan Formulation phase of the study. Next, the report provides an overview of an integral piece of the technical infrastructure used to model alternative operational scenarios in the TBWMOP: the Multi-Objective Evolutionary Algorithm (MOEA). Following this, the report documents how each component of the Plan Formulation was adjusted and implemented into the technical infrastructure of the TBWMOP Analysis. Lastly, the report provides a limited set of results from and discussion on the MOEA.

2 PLAN FORMULATION

The Plan Formulation for the TBWMOP occurred over a series of workshops where members of the Technical Team and other key stakeholders determined key components of the study (Bureau of Reclamation, 2021). These components included:

1. Identifying Problems and Opportunities
2. Identifying Study Constraints and Objectives
3. Defining Actions
4. Defining Alternative Operational Scenarios
5. Refining Alternative Operational Scenarios

These components of the Plan Formulation informed the technical design of the action and alternative operational scenario modelling discussed in this report, and the following subsections summarize the key findings for each component in detail. Note, more comprehensive documentation of the Plan Formulation workshops is found in the referenced *Alternative Operational Scenarios Development Report* (Bureau of Reclamation, 2021)

2.1 IDENTIFYING PROBLEMS AND OPPORTUNITIES

During the Plan Formulation, the Technical Team and other key stakeholders determined four problems with the regulation criteria of the WCM that represent "opportunities" for improvement to stakeholder objectives in the Truckee Basin. Table 1 provides a summary of these problems and opportunities.

Table 1: Summary of the Problems and Opportunities identified in the Plan Formulation. [1]

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.

[1] The improvements to Stampede Dam included raising the dam by 11.5 feet to address dam safety concerns related to large flood events, "constructing a Mechanically Stabilized Earth wall over the dam and dike, constructing two small dikes near the south end of the reservoir to fill low-lying areas of the reservoir rim and reconstructing the spillway crest structure to limit outflows during large floods" (Bureau of Reclamation, 2020).

2.2 STUDY CONSTRAINTS AND OBJECTIVES

During the Plan Formulation, the Technical Team and other key stakeholders in the Truckee Basin determined objectives and constraints for the study (see Table 2). The objectives represent "goals" for the TBWMOP, and they allow for a relative comparison between the alternative operational scenarios in the study. Table 3 provides a summary of the ten study constraints developed during the Plan Formulation. These constraints represent limits that the results of the study must remain within to be considered viable.

Table 2: Objectives defined for the TBWMOP during the Plan Formulation.

Objective Number	Objective Description
1	Maximize the number of Floriston Rate days or the amount of Floriston Rate water in storage.
2	Maximize the flexibility for timing of drawdown under flood control measures.
3	Maximize flexibility for refill in reservoirs up to the maximum conservation elevations.
4	Improve environmental instream flows downstream of reservoirs.
5	Minimize use of surcharge space above the spillway.
6	Reduce risk of damage from flooding downstream.
7	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.
8	Allow flexibility for varying future operating conditions of Martis Creek Dam.
9	Allow flexibility for future increases in flood thresholds because of flood improvements downstream.
10	Optimize storage to satisfy water demands through the year.
11	Develop methodologies that are implementable in an operational mode.

Table 3: Constraints defined for the TBWMOP during the Plan Formulation.

Constraint Number	Constraint Description
1	Do not increase damage from flooding as a result of changed reservoir operations.
2	Comply with requirements of TROA and other governing agreements.
3	Can be addressed through updates to the WCM
4	Do not change the total amount of authorized flood control space (e.g., 30,000 AF between Boca and Stampede)
5	Do not increase probability of dam failure from overtopping or internal failure.
6	Must be technically feasible to implement.
7	Must not decrease the number of projected Floriston Rate days compared with continuing management under the No Action.
8	Don't negatively impact the T&E species in the river.
9	Don't change water rights.
10	Must be within the scope of this pilot study as defined in the WMOP Memorandum of Agreement (MOA).

2.3 Defining Actions

During the Plan Formulation, the Technical Team and other key stakeholders in the Truckee Basin determined actions to address the problems and opportunities determined by the group (see **Section 2.1: Identifying Problems and Opportunities**). Following the Plan Formulation workshop the Technical Team met over a period of several months to establish the technical approach to each action so that its effects could be quantified and compared. Table 4 provides a summary of the actions developed for each problem, and the remainder of this section provides a high-level discussion of each of these actions. More in depth documentation will be provided in **Section 4: Action Modelling**.

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	-

The Technical Team and other key stakeholders determined two similar actions for the problems of Reservoir Refill and Fall Drawdown. The first action, the Revised Guide Curve, determined a new rule curve for the Truckee Basin flood reservoirs based on updated historical data and methodology (see **Section 4.2.1: Revised Guide Curve**). The second action, the "By a Model" Method, utilized FIRO with ensemble forecasts to determine flood space requirements (see **Section 4.2.2: "By a Model" Method for Required Flood Space**).

In Normal Flood Operations, the WCM prescribes that Boca, Stampede, and Prosser Creek Reservoirs be operated to a downstream target of 6,000 cfs at the Reno Gage. Two actions were identified to address opportunities the Technical Team found with these operations. 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 (see **Section 4.1.1: Updated Target Location**). 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 (see **Section 4.1.2: Updated Flood Target Flow**).

Lastly, one action was identified for the Little Truckee Flood Space problem. The current operation of the WCM regulation criterion reserves 26.7% of the total Little Truckee Flood Space in Boca Reservoir and the remaining 73.3% in Stampede Reservoir. The Reproportion action explored benefits to stakeholder objectives associated with adjusting the flood space allocation percentages between Boca and Stampede Reservoirs (see **Section 4.3: Actions for Little Truckee Flood Space**).

2.4 Defining Alternative Operational Scenarios

During the Plan Formulation of the study, the Technical Team and other key stakeholders took steps toward defining alternative operational scenarios for the TBWMOP. These scenarios are defined in the *Alternative Operational Scenarios Development Report* (Bureau of Reclamation, 2021) and are summarized in this section. Each alternative operational scenario consisted of a set of actions to address each problem or opportunity in the study and was given a quantitative description. The actions associated with each scenario are summarized in Table 5, and the qualitative description of each scenario is listed below:

- **Alternative Operational Scenario 1:** the No Action Alternative, 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, represented a scenario that best meets objectives related to satisfying water demands throughout the year. The objective also sought to improve environmental in-stream flows, to allow for more reservoir operations flexibility considering changing runoff conditions.
- **Alternative Operational Scenario 3:** the Dynamic Flood Risk Reduction Criteria Alternative, provided the most potential for dynamic management based on real-time conditions. This alternative operational scenario emphasizes a real-time model based on forecasts while operating flood events to downstream flood targets at both the Reno and Vista gages.
- **Alternative Operational Scenario:** the Updating Flood Risk Management Alternative, prioritized downstream flood risk reduction and ease of implementation. Similarly, to Alternative 3, this action relied on modeling to determine appropriate operations.
- **Alternative Operational Scenario 5:** the Hybrid Rule Curve Alternative, combined actions that addressed the greatest number of objectives, regardless of the ability of the action to address each objective.

Table 5: Alternative Operational Scenario configurations defined in the Plan Formulation. Each scenario is a combination of different Actions in response to the four Problems/Opportunities. [2]

Alternatives		Problems/Opportunities				
#	**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	

Alternative Operational Scenario 4, if selected, would update the WCM without implementing any new FIRO components, whereas Alternative Operational Scenario 3, if selected, would be implementing the most comprehensive FIRO approach that could be identified by the Technical Team. Alternative Operational Scenarios 2 and 5 were different blends of Alternative Operational Scenarios 3 and 4 that utilize FIRO to varying degrees.

2.5 Follow-up Actions

During the Plan Formulation, the Technical Team and other key stakeholders identified Follow-up Actions to the TBWMOP. One of these follow up actions pertained to the limited operation of Martis Creek Reservoir's due to dam safety concerns.[3] The team

[2] Anywhere in the action and alternative operational scenario modelling that referenced the Reno Gage Flood Target Flow was designed to flexibly adapt to changes in the Reno Gage Flood Target Flow. Thus, a 6,500 cfs target at the Reno Gage could be used to perform the analysis and select the best performing alternative operational scenario. Once the final decision of the flood target flow was made, this would be updated in the modelling to model the final Preferred Operational Scenario.

[3] A risk-screening conducted in 2008 on Martis Creek Reservoir ultimately led to its current limited operation (Moen, 2023). The risk-screening was the culmination of several other issues that had been

determined that improvements to dam safety on Martis Creek Dam represent an opportunity for increased flood protection in the Truckee Basin. While the alternative operational scenarios described in the previous section assume that Martis Creek Reservoir would operate under its current dam safety limitations, the Plan Formulation specified that the effects of Martis Creek Reservoir being fully operational should be explored to document potential benefits of rehabilitating the dam.

3 MOEA Overview

The Multi-Objective Evolutionary Algorithm (MOEA) used within the study provided an efficient way to model some of the actions defined in the Plan Formulation. While more in-depth documentation of how MOEA was used in the study is provided later in this report, a brief introduction is warranted prior to documentation in **Section 4: Action Modelling**.

MOEA's 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 defined objectives and decision variables. MOEA provides an intelligent, 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 (Reed, Herman, Kasprzyk, & Kollat, 2013).

discovered with Martis Creek Dam and Reservoir in previous years. Seepage issues were discovered on Martis Creek Dam in 1995 during a fill test. Furthermore, a spillway capacity study in 2002 determined the spillway capacity of Martis Creek Dam was inadequate. As a result, in 2005 USACE categorized Martis Creek Dam as "high-risk"(US Army Corps of Engineers, 2022).

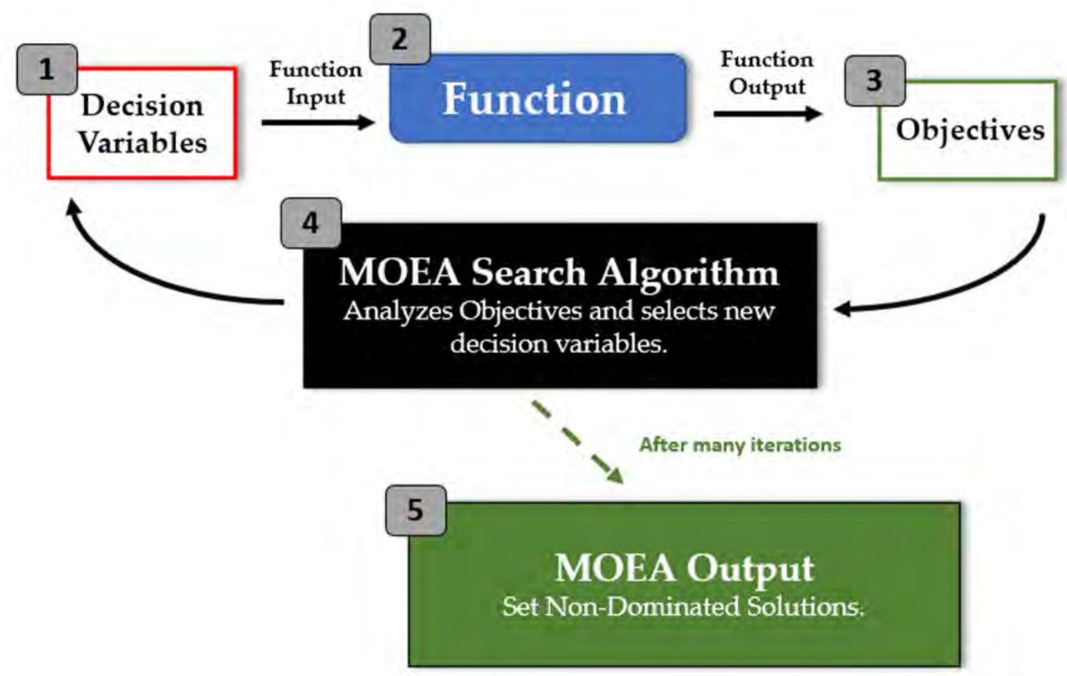

Figure 1: Interactions between the 5 main components of the MOEA.

Figure 1 provides a schematic summarizing the 5 main components of the MOEA and the interactions between them. Central to MOEA is the ***function***, or an equation (simpler)/model (more complex) that is undergoing optimization. ***Decision variables***, which represent the parameters that the MOEA will optimize, are input to the function by the MOEA. ***Objectives*** are output from the function and represent the performance of the function given an input set of decision variables. As the MOEA runs, the ***MOEA Search Algorithm*** intelligently selects new sets of decision variables to evaluate in the function by learning the relationship between decision variables and objective performances. The process of evaluating the function's objective performances with new sets of decision variables is repeated many times until the MOEA converges on a solution.

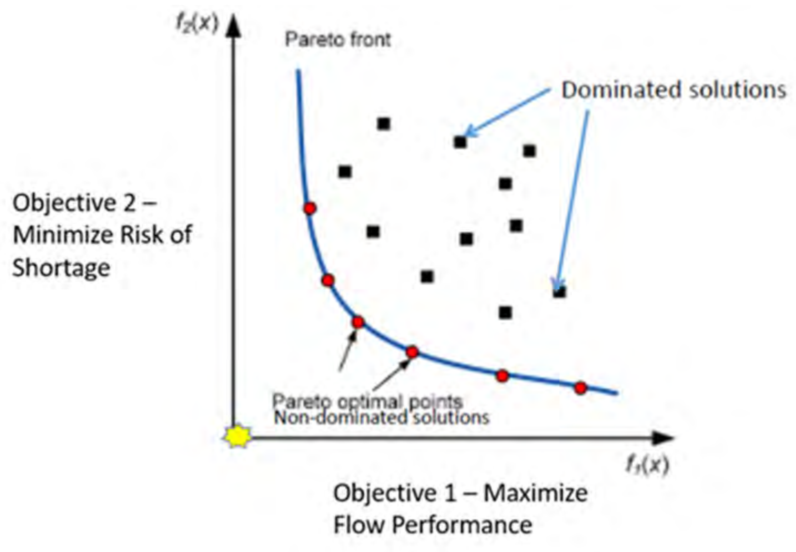

Figure 2: Illustration of 2D Pareto-Front and Non-dominated vs. Dominated Solutions (adapted from CADSWES, 2019).

Due to the multi-objective nature of the optimization analysis, there is often a competing nature between different objectives (i.e., what's good for one objective is not always good for other objectives). Thus, the output from the MOEA, or optimal results, are generally not single solutions, but are instead represented by sets of "nondominated solutions" (also called "Pareto optimal points"). A ***nondominated solution*** is a solution that provides an optimal trade-off between objectives, in that no objective can be further improved without harming another objective. In contrast, a ***dominated solution*** is a solution where one of the objectives can be improved without harming any of the other objectives (i.e., there is no trade-off to improving that objective because it does not affect the performance of other objectives), and thus, is not an optimal trade-off point. The collection of nondominated solutions is often referred to as the ***Pareto Front***. These concepts are illustrated in Figure 2 for a conceptual two objective (i.e., two-dimensional) problem where the objectives are to minimize both the x and y values. From this set of nondominated solutions, the "optimal solution" is determined through a more subjective analysis of the tradeoffs between objectives.

For a more detailed introductory discussion on MOEA, refer to the referenced report titled *Multi-Objective Evolutionary Algorithm (MOEA) Tool Utilization and Development* (Precision Water Resources Engineering, 2022). Included in this report is documentation of the MOEA framework, why it was selected for the TBWMOP, and the tools developed to run the MOEA within the TBWMOP.

3.1 Introducing MOEA in the Context of the TBWMOP

The configuration of the components of the MOEA (see Figure 1) within the context of the TBWMOP is discussed in detail in **Section 7.1.2: Utilization of the MOEA in Alternative Operational Scenario 3 Modelling**. A brief description of the configuration to a subset of the MOEA components for the TBWMOP is included here to provide helpful context to some of the intervening discussion.

In the TBWMOP, the ***function*** of the MOEA was configured to be a combination of two RiverWare© models designed to simulate the Truckee River Basin long term water supply and flood operations under both baseline and alternative regulation criteria: the *TROA Planning Model* and the *TR Hourly River Model*. These models are introduced further in **Section 6.1: Planning Model Overview** and **Section 6.2: Hourly Model Overview**.

The ***decision variables*** of the MOEA were configured to represent variations of flood control regulation criteria. More specifically, these decision variables are comprised of parameters associated with the "By a Model" Method and Reproportion of Little Truckee Flood Space actions. These parameters are discussed in more detail in the proceeding section of this report.

The ***objectives*** of the MOEA were configured to represent the objectives defined in the Plan Formulation. **Section 5.1: Objectives Modelling** provides more detail on these objectives.

4 Action Modelling

This section of the report details the actions corresponding to each problem identified in the Plan Formulation. **Section 2.3: Defining Actions** introduced these actions, and this section provides a detailed overview of each action, including:

- How the action was modeled/implemented technically.
- A description of the potential benefits of incorporating the action as regulation criteria.
- The required input parameters of the action and how the input parameter was determined.

Input parameters to each action were determined via one of three main methods. The first method was through analysis of the inundation maps that were developed as a part of the TBWMOP by HDR, Inc. and River Focus, Inc. (Blum, Weaver, Gusman, Viducich, & Bertrand, 2022). The second method was utilizing the MOEA. As mentioned in the preceding section, the ***decision variables*** of the MOEA were configured to be input parameters to some of the actions within the study, and the MOEA aided the Technical Team in selecting the optimal set of parameters. The third method of selecting input parameters was inherent to the configuration of an alternative operational scenario and, therefore, defined during the Plan Formulation.

4.1 Actions for Normal Flood Operations

The WCM requires that Flood Control Reservoirs (Boca Reservoir, Stampede Reservoir, Prosser Creek Reservoir, and Martis Creek Reservoir) store into their flood space when flows at the Reno Gage would otherwise exceed an operational target (or flood target flow) during a flood. When flows drop to the operational target or below, the reservoirs release the storage in the flood space. The WCM specifies the following flood target flows at the Reno Gage:

- 6,000 cfs at the Reno Gage for Prosser Creek Reservoir, Stampede Reservoir, and Boca Reservoir.
- 14,000 cfs at the Reno Gage for Martis Creek Reservoir.

Since the WCM was written in 1985, several issues have been discovered with Martis Creek Dam regarding dam safety, and the reservoir is currently not operated as it is intended in the WCM (United States Army Corps of Engineers, 2022). Rather, Martis Creek Reservoir is currently operated to maintain a storage of 800 acre-feet, and this operation is what is reflected in the alternative operational scenarios defined in the Plan Formulation. Furthermore, the term Active Flood Control Reservoirs is used for the remainder of this paper to denote the three reservoirs in the Truckee Basin that are currently operated as intended in the WCM: Prosser Creek Reservoir, Boca Reservoir, and Stampede Reservoir.

The following two subsections document the two actions developed in the Plan Formulation to address the problem of Normal Flood Operations.

4.1.1 Updated Target Location

The Updated Target Location action seeks to explore the potential benefits of operating Active Flood Control Reservoirs to flood target flows at both the Reno and Vista Gages. The benefits of this action could include reduced flood damage in the Truckee River downstream of the Reno Gage.

In practice, operating to both the Reno and Vista Gages would require assessing whether flows at the Reno and Vista gages were violating their respective flood target flows. If either gage was violating its flood target flow, Active Flood Control Reservoirs would be required to store into their designated flood space as possible to reduce the flows in the river so that both gages measure flows beneath their respective flood target flows.

Table 6 summarizes the modelling parameter required by this action: the Target Location. This parameter was selected by the Technical Team for each alternative operational scenario during the Plan Formulation. The parameter can take a value of either (1) the Reno Gage or (2) the Reno and Vista Gages.

Table 6: The parameter associated with the Updated Target Location action and the method utilized by the Technical Team to select the parameter.

Action	Parameter	Selection Method
Updated Target Location	Target Location	Defined by Alternative

4.1.2 Updated Flood Target Flow

The Updated Flood Target Flow action seeks to explore the benefits of raising the 6,000 cfs flood target flow at the Reno Gage specified by the WCM. The current 6,000 cfs target is below the level where flood damages occur. Increasing the flood target flow closer to the flows where damages begin to occur would allow Active Flood Control Reservoirs to evacuate encroachment more efficiently and reduce the risk of having insufficient flood space should a second flood event occur prior to the flood encroachment being evacuated from the first event. During the runoff in large years the flows in Reno can exceed 6,000 cfs for extended periods of time causing encroachment into flood space when no flooding occurs, reducing the available flood space should a larger event occur. This action also required the selection of a flood target flow for the Vista Gage which is not specified in the WCM and is near the areas along the river impacted by flooding.

Table 7 summarizes the two modelling parameters required by this action: the Reno and Vista Gage Flood Target Flows. These parameters were selected by the Technical Team and other key stakeholders through analysis of flood inundation maps provided by HDR, Inc. and River Focus, Inc. (Blum, Weaver, Gusman, Viducich, & Bertrand, 2022). The parameter values represent the maximum flow that could be sustained in the Truckee River at the Reno and Vista Gages without causing damage due to flooding along the river. Note, the Reno Gage Flood Target Flow was preliminarily selected to be 6,500 cfs by the Technical Team and other key stakeholders through initial analysis of the flood inundation maps at a workshop during June of 2022 (June of 2022 Workshop). The target would be updated in the modelling once additional inundation analysis was completed (see referenced *WMOP Preferred Operational Scenario Selection Process* report) (Gwynn & Noe, WMOP Preferred Operational Scenario Selection Process, 2023).

Table 7: The parameter associated with the Updated Target Flow action, the method utilized by the Technical Team to select the parameters, and the selected parameter values.

Action	Parameter	Selection Method	Parameter Value
Updated Target Flow	Reno Gage Flood Target Flow	Analysis of Inundation Maps	6,500 cfs
	Vista Gage Flood Target Flow	Analysis of Inundation Maps	8,500 cfs

4.1.2.1 Flexibility of the Updated Flood Target Flow in the Action Modelling

The flood target flow parameters discussed in the previous section were integral pieces to several aspects of the action and alternative operational scenario modelling. Namely, both the "By a Model" Method and Revised Guide Curve (see **Section 4.2: Actions for Reservoir Refill and Fall Drawdown Problems**) actions require the Reno Gage Flood Target Flow to make calculations of required flood space. Furthermore, the alternative operational scenario modelling necessitated that the *TR River Hourly Model* operate Active Flood Control Reservoirs to the flood target flows.

As described in **Section 2.2: Study Constraints and Objectives**, Objective 9 of the TBWMOP states, "Allow flexibility for future increases in flood thresholds because of flood improvements downstream." To meet this objective of the study, the Flood Target Flow inputs for the Reno Gage necessary to the "By a Model" Method action and the Revised Guide Curve action were designed to maintain "flexibility": if the flood target flows were to change in the future, the modelling could adapt to the new flood target flows with a simple change in input to each of these modelling components. Similar flexibility was built into the *TR Hourly River Model*. Alternative Operational Scenarios operate to either the Reno Gage or the Reno and Vista Gages; as a result, the hourly model was developed to have flexible inputs for both the Reno and Vista Gages to accommodate future changes in flow target flows.

4.2 Actions for Reservoir Refill and Fall Drawdown Problems

4.2.1 Revised Guide Curve

Guide curve diagrams, also referred to as rule curve diagrams, prescribe daily reservoir flood space volume requirements as evidenced by the location-specific relationship between (1) unregulated runoff larger than a specified flood target and (2) forecasted remaining runoff flow. As a part of the TBWMOP, guide curves for Prosser Creek Reservoir, Boca Reservoir, Stampede Reservoir, and Martis Creek Reservoir were updated using the latest data and methodology according to USACE and NRCS guidelines. Effects of updating the guide curves include potential water supply benefits and increased operational flexibility compared to the previous set of curves. For more detailed information regarding the methodology and findings of the analysis that produced the Revised Guide Curves, refer to the referenced report *Revised Guide Curve Modelling* (Gwynn, Revised Guide Curve Modeling, 2022).

Table 7 summarizes the modelling parameter required by the Revised Guide Curve action: the Reno Gage Flood Target Flows. The parameter value represents the maximum flow that could be sustained in the Truckee River at the Reno Gage without causing flood damage in the river. It was preliminarily selected to be 6,500 cfs by the Technical Team and other key stakeholders through initial analysis of the HDR flood inundation maps. Refer to **Section 4.1.2: Updated Flood Target Flow** for more documentation on the Reno Gage Flood Target Flow selection.

Table 8: The parameter associated with the Revised Guide Curve action, the method utilized by the Technical Team to select the parameters, and the selected parameter values.

Action	Parameter	Selection Method	Parameter Value
Revised Guide Curve	Reno Gage Flood Target Flow	Analysis of Inundation Maps	6,500 cfs

4.2.2 "By a Model" Method for Required Flood Space

One of the major goals of the TBWMOP was to develop flood control regulation criteria that would be flexible and adaptable to future advances in technology. To accomplish this, a methodology named the "By a Model" Method was developed to utilize probabilistic forecasts provided by the CNRFC to make determinations of flood space requirements. This method was designed so that any future advances in forecasting technology would seamlessly integrate into the determination of flood space requirements.

The following subsections document the "By a Model" Method action. This includes a summary of the method's input data requirements and structure. Next, the method's algorithm is described in detail using an example of how it derives flood space requirements from an ensemble forecast while maintaining the appropriate balance with forecast skill and flood risk.

4.2.2.1 CNRFC Hindcasts and Scaled Hindcasts

CNRFC regularly produces ensemble forecasts of river flows for locations within the California/Nevada region utilizing their Hydrologic Ensemble Forecasting System (HEFS). These forecasts are composed of 41 traces or "potential futures" of river flows at a particular location. To produce the traces, HEFS utilizes a coupled rainfall-runoff and snow model that is initialized with current soil and snow conditions. This model is run with an ensemble of climate data where each trace is based in-part on climate from a historical year. The short-term outlooks are driven by short-term weather forecasts, then the traces blend into historical weather climatology for the respective year as the weather forecast skill decreases. The ensemble of traces contained within a forecast allow computation of the risk/probability that the forecasted runoff will be within specified ranges.

As input to the "By a Model" Method in the TBWMOP, CNRFC developed a dataset of daily hindcasts, or "re-forecasts", for several locations within the Truckee River Basin. Hindcasts represent what the forecasts *would have been* if the current meteorological and hydrological models and analysis methods were available in the past. While forecasts apply current modeling technology to predict future flows that have not yet occurred, hindcasts are forecasts produced with current models for periods of time that have already occurred. In specific, CNRFC provided daily hindcasts for the period spanning water years 1990 to 2020. Additional hindcasts were provided for the timeframe around the large flood event that occurred in the basin in February and March of 1986. This set of hindcasts provided the ability to assess the relationship between forecasting skill and risk in determining flood space requirements in the Truckee Basin.

The hindcast dataset period of record includes fifteen high flow events, but the 6000 cfs Reno flood target was only exceeded in seven of these events (Lawler, Technical Memorandum - Truckee River Basin Historical Hourly Data Development Methodologies: Water Years 1986 - 2021, 2022). The events contained in the hindcast dataset gives a few test cases on how the alternative operational scenarios would have handled past floods. As shown in Figure 3 and Figure 4, the average Reno unregulated flow in the historical events (denoted by solid lines) only exceed the 2/100 year flow for their respective season in two instances: the January 1997 event (see Figure 3) and May 1996 event (see Figure 4). Thus, the historical dataset gives limited sampling of the range of high flows that could occur in the rain and snowmelt season as summarized by the flood frequency analysis (Lahde, et al., 2022).

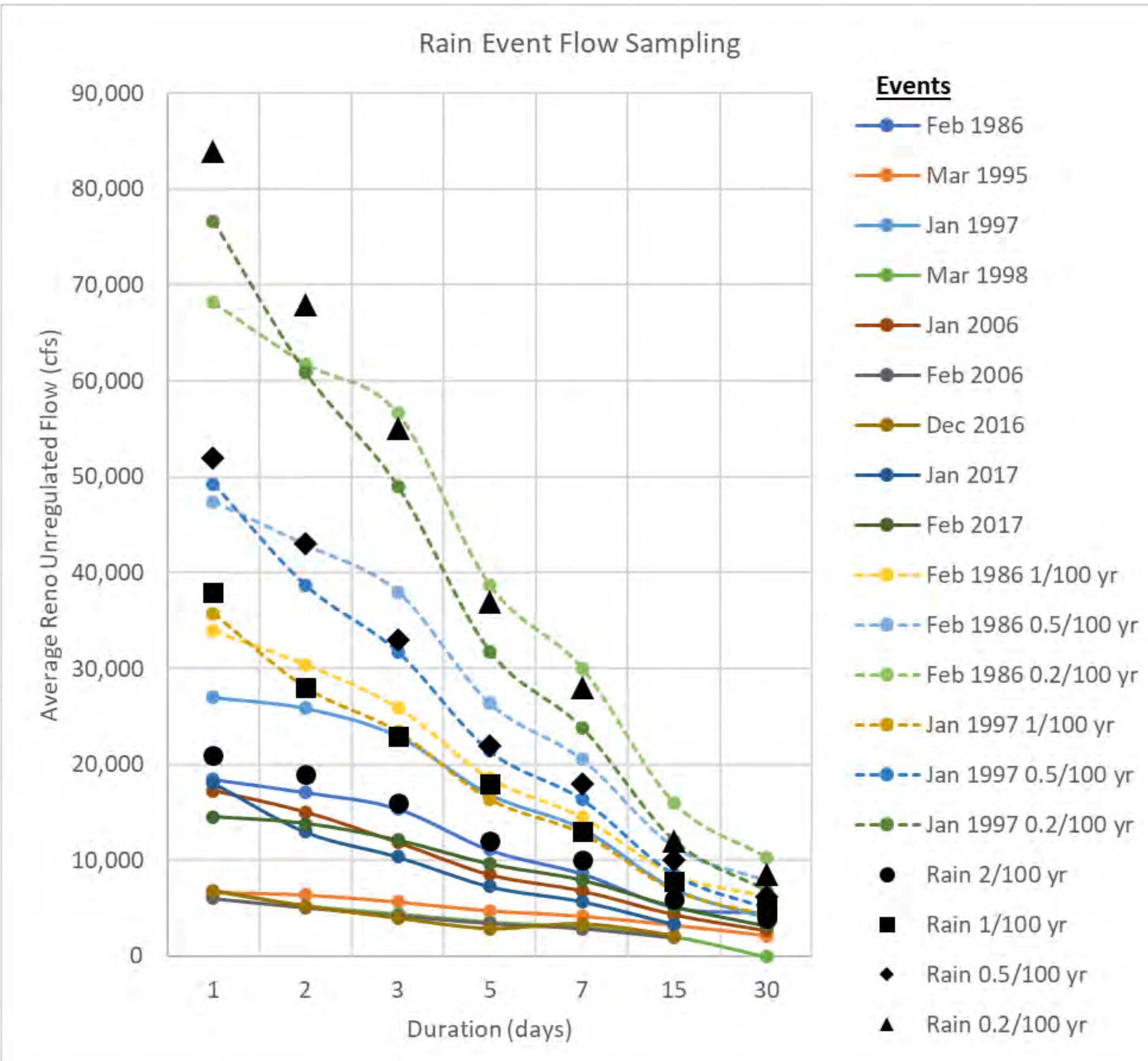

Figure 3: Summary of Truckee River at Reno Unregulated Conditions average flow for rainy season (October through March) flood events data that was used. Solid lines denote historical flows (Lawler, 2022), dashed lines denote scaled hindcasts (Imgarten, 2022) and the black shapes denote the respective recurrence intervals (Lahde, et al., 2022).

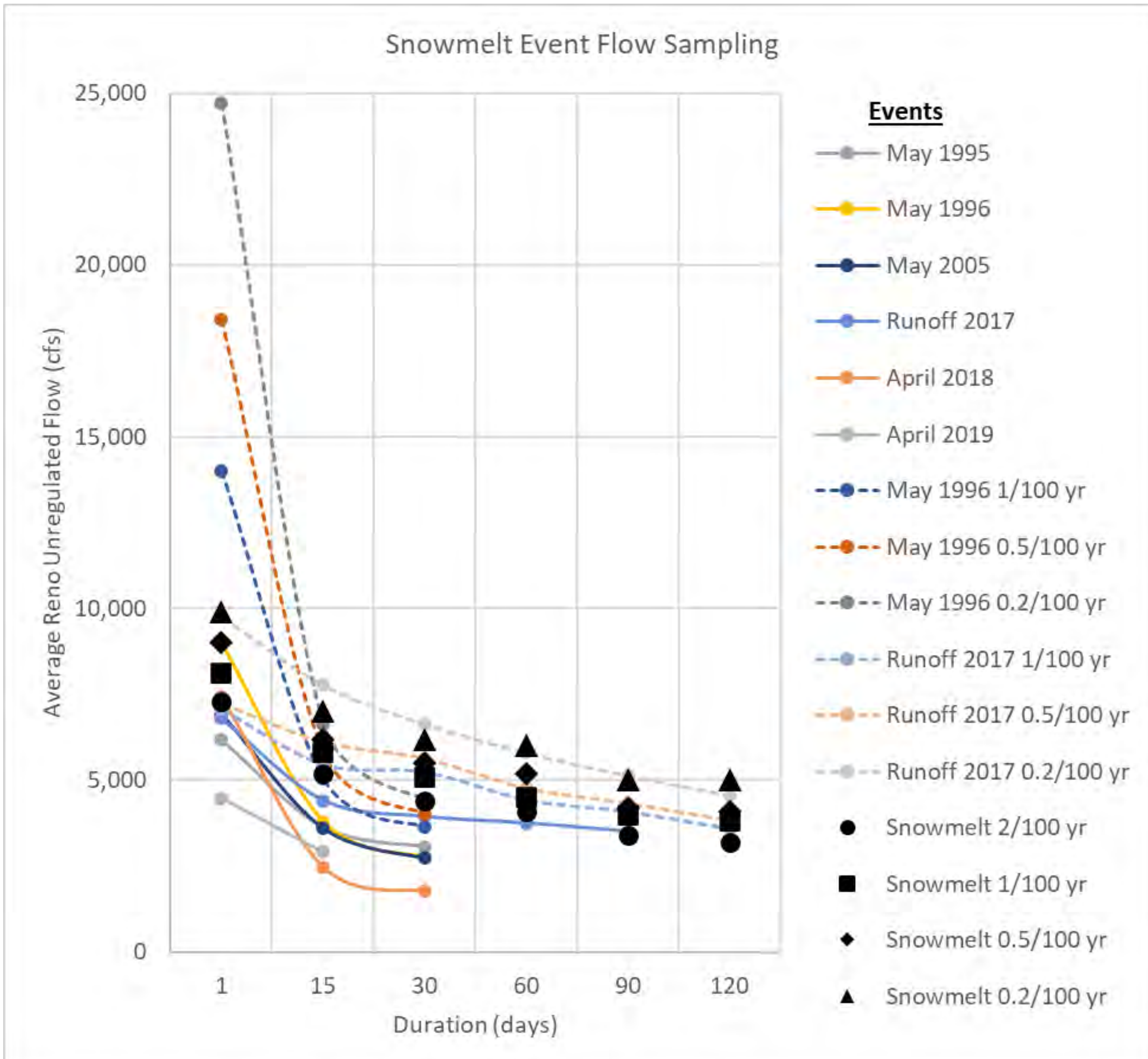

Figure 4: Summary of Truckee River at Reno Unregulated Conditions average flow for snowmelt season (April through July) flood events data that was used. Solid lines denote historical flows, dashed lines denote scaled hindcasts and the black shapes denote the respective recurrence intervals (Lahde, et al., 2022).

To facilitate testing the alternative operational scenarios with events that matched the 1/100-year, 0.5/100-year and 0.2/100-year volumes identified by the flood frequency analysis for the rain and snowmelt season, CNRFC scaled up the precipitation forcing for select historical events in the hindcast to produce the desired volumes. CNRFC has utilized a similar process when developing hindcast datasets for the previous FIRO projects (Yuba-Feather FIRO Steering Committee, 2022). These scale factors were then applied to the precipitation forecast to produce "scaled hindcasts" that are larger versions of the historical events. The January 1997 and February 1986 events were scaled to achieve the 1/100-year, 0.5/100-year and 0.2/100-year volumes for the rain season, and the 2017 and May 1996 events were scaled to produce the 1/100-year, 0.5/100-year and 0.2/100-year volumes for the snowmelt season. The scale factors, period of precipitation that was scaled, target and simulated flows are summarized in Table 9. The simulated flow (e.g. modeled runoff with observed climate inputs) for the rain flood events for January 1997 and February 1986 were within 110% of the target recurrence intervals. For the May 1996 runoff event, the unscaled simulated flow was higher than all the ensemble members, so the scale factors were set so that the largest ensemble member met the target resulting in the simulated flow exceeding the target (Imgarten, 2022). For the January 2017 event, since snowmelt runoff driven flooding had not been evaluated in previous FIRO efforts, the team decided to scale up the precipitation to increase the modeled snow accumulation during that event which would provide a larger snowpack going into the runoff season. These event scaling's were determined in a similar iterative way to achieve the desired 30-day average flows during the runoff season. The simulated flow exceeded the target flow for all events so the scaled hindcasts represent a conservative estimate of the 1/100-year, 0.5/100-year and 0.2/100-year flows.

Table 9: Scaled Hindcast Event Scale Factors (Imgarten, 2022)

		Jan-97	Feb-86	May-96	Runoff 2017
	First Forecast	12/30/1996	2/12/1986	5/1/1996	12/25/2016
	Last Forecast	2/15/1997	3/31/1986	5/31/1996	9/30/2017
	Selected Duration	3	5	1	30
	Dates Scaled	1/1 @06Z - 1/3 @12Z	2/14 @06Z - 02/21@00Z	5/15 @00Z - 5/19 @00Z	1/7 @18Z - 1/12 @18Z
1/100 Year Recurrence Interval (p=0.01)	Target flow (cfs)	25,000	17,000	8,200	5,150
	Scale Factor	1.05	1.15	1.2	1.1
	Simulated Flow (cfs)	26,500	18,500	14,000	5,250
	Simulated/Target flow	106%	109%	171%	102%
0.5/100 Year Recurrence Interval (p=0.005)	Target flow (cfs)	35,000	24,000	9,000	5,650
	Scale Factor	1.2	1.3	1.3	1.25
	Simulated Flow (cfs)	36,100	26,000	18,400	5,650
	Simulated/Target flow	103%	108%	204%	100%
0.2/100 Year Recurrence Interval (p=0.002)	Target flow (cfs)	55,000	37,000	10,000	6,300
	Scale Factor	1.45	1.5	1.4	1.6
	Simulated Flow (cfs)	55,700	38,600	24,700	7,000
	Simulated/Target flow	101%	104%	247%	111%

The following subsection details how hindcast skill was analyzed and addressed in the TBWMOP, and the remaining sections document the methodology of the "By a Model" Method and explain how it balanced forecast skill with risk.

4.2.2.2 Hindcast Uncertainty Analysis

Because hindcasts represent the primary input data to the "By a Model" Method, an analysis was conducted to assess their skill, or accuracy and precision. Results of this analysis identified that hindcast skill is dependent on both seasonality and outlook. Specifically, with respect to seasonality, median hindcasts were more precise in predicting historical cumulative volumes during the runoff season (see Figure 5), though these precise volumes tended to over-forecast historical volumes at shorter outlooks (see Figure 6).

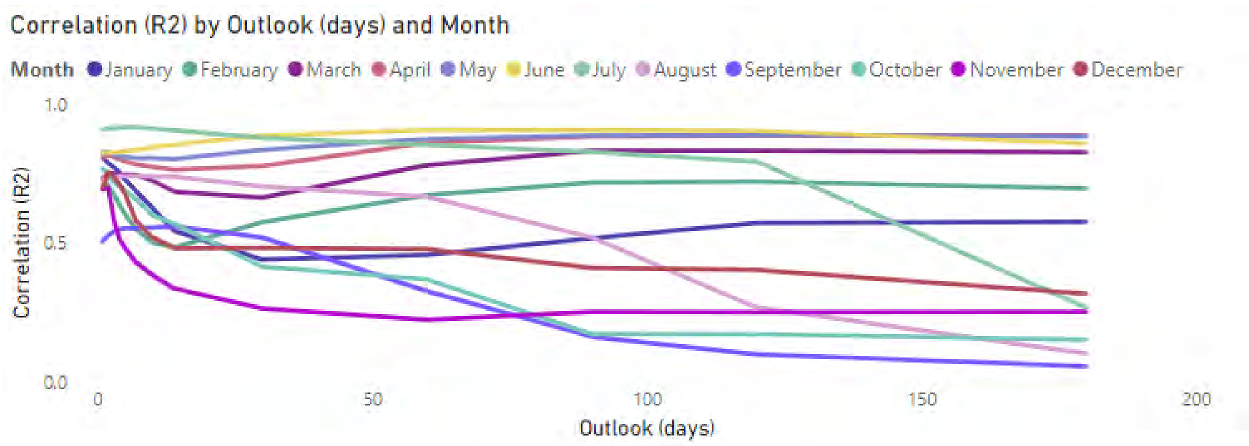

Figure 5: Measure of Precision of Hindcasts, R-Squared Coefficient of Determination N-Day Volumes compared to Historical Cumulative N-Day Volume Across Outlooks

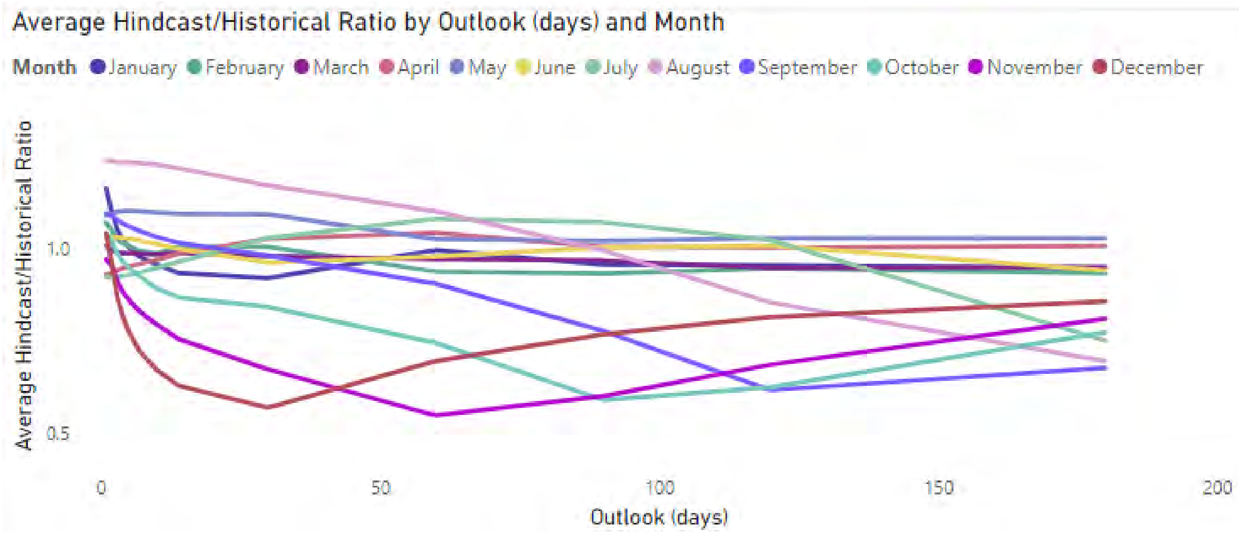

Figure 6: Measure of Accuracy of Median Hindcasted N-Day Volumes compared to Historical Cumulative N-Day Volume Across Outlooks

Results suggested that the range of forecasted volumes was outside the 10%-90% exceedance range more frequently than expected and therefore inside the 10-90% exceedance range less frequently than expected. Thus, the range of hindcasted volumes was too small. Figure 7 illustrates this by looking at the 5-day cumulative Farad Natural Flow Volume that was hindcasted vs. what was observed. The plot shows that, for this outlook, the percentage of time the historical volume was less than the ninety percent exceedance volume of a hindcast was 45%, which is much greater than the expected 10%. Furthermore, the percentage of time the historical volume was greater than the 10% exceedance was 37%, which again is much greater than the expected value of 10%. For detailed information on this analysis, reference the report titled *Inflow Uncertainty Analysis* (Gwynn, Inflow Uncertainty Analysis, 2022).

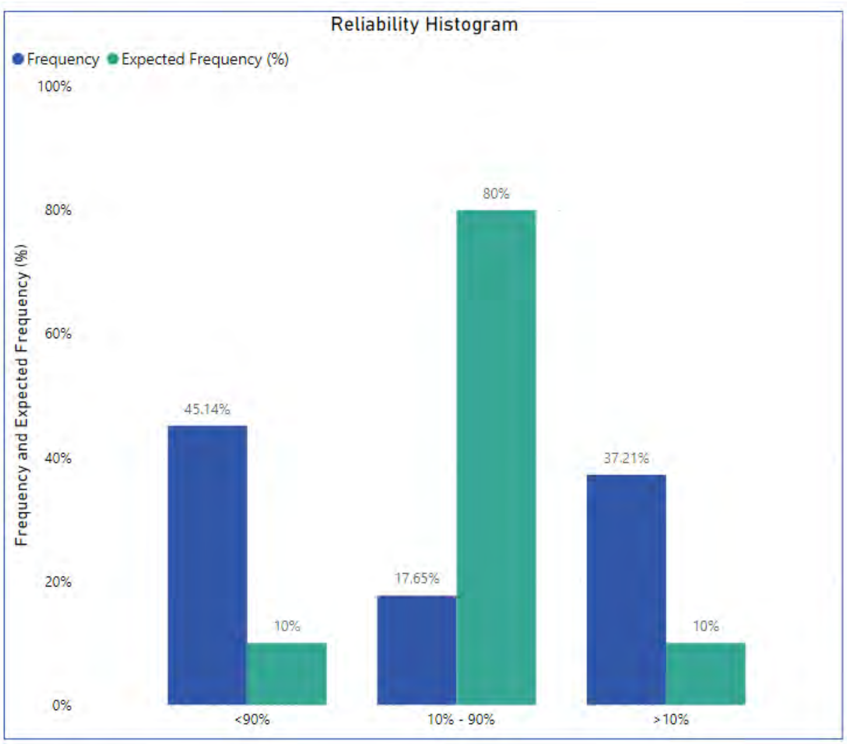

Figure 7: Reliability Histogram of 10-90% Exceedance Interval, 5-Day Cumulative Volumes

As a response to this analysis, the Technical Team decided to incorporate a bias correction method that adjusts the CNRFC hindcasts to match the variability of observed flows. This method shifts and expands the CNRFC forecast ensembles based on that the tendency for observed flows being outside of the hindcast range more than expected and/or for the median forecast being generally too high or low for each outlook. A similar method is used regularly by the USWM in Reno, Nevada to adjust CNRFC forecasts to match the Natural Resource Conservation Service (NRCS) runoff volume forecasts.

The major benefit of employing the Bias Correction method is that it would introduce flexibility to the "By a Model" Method to adapt with future improvements in forecasting technology to either better represent the range in possibilities or improve the accuracy. More specifically, improvements made to forecasting technology could be incorporated into the "By a Model" Method after completing an updated hindcasting effort and revising the relatively simple Inflow Uncertainty Analysis on the updated hindcasts. The methodology of the bias correction method is discussed in detail in **Section 4.2.2.5: Bias Correction Method**.

4.2.2.3 Relationship between Risk and Skill

Fundamentally, ensemble forecasts (or hindcasts) are more accurate at shorter outlooks than longer outlooks (Gwynn, Inflow Uncertainty Analysis, 2022). Also, with a longer outlook there is more lead time to prepare by evacuating flood space, so the acceptable level of risk that additional flood space is required can be inversely related with the outlook, which coincides with the relationship between forecast skill and outlook. For example, if a large rain event is forecasted to occur at a 1-day outlook, there is a strong meteorologic signal that this event is very likely to occur. Also, at 1-day out there is very little time to evacuate flood space; as a result, operations should be very conservative to protect against the forecast being low. The "By a Model" Method should respond to these issues at a 1-day outlook by operating more conservatively and requiring sufficient flood space to mitigate impacts of the coming storm. If a similar rain event is forecasted at a 14-day outlook, this event could occur, but it is less certain to occur than in the case of the 1-day outlook. Also, at a 14-day outlook, there is additional time to evacuate flood space in the intervening days while the forecast becomes more certain than in comparison with the 1-day outlook. The flood space requirements determined by the "By a Model" Method are designed to respond to the reduction in skill of hindcasts with outlook. The method is engineered to allow this relationship to be optimized using an MOEA. That is, using the large dataset of hindcasts provided by CNRFC as a proxy for the forecasts that would have been available in history, the relationship between hindcast skill and acceptable level of risk can be optimized while (1) considering operational nuances like how much flood space can be evacuated, and (2) promoting study objectives like environmental flows and water supply.

4.2.2.4 Volume over Target Calculations

The goal of flood control operations in the Truckee Basin is to maintain appropriate space in reservoirs to be able to store inflow to the basin and protect against downstream flooding. The amount of flood space that is necessary can be computed by the volume of inflows that would need to be stored to prevent the downstream Reno Gage from exceeding the flood target flow. This concept is reflected in the fundamental equation in "By a Model" Method to determine flood space:

Equation 1: Cumulative Volume Over the Flood Target:

$$RFS = \sum_{t=0}^{t_f} \max\left(I_t - T_{Flood\ Target\ Flow}, 0\right)$$

In this equation, RFS is the required flood space, $\boldsymbol{I_t}$ is the hindcasted Reno unregulated flows at time $\boldsymbol{t}$ for a particular CNRFC trace, $\boldsymbol{T_{Flood\,Target\,Flow}}$ is the flood target flow at the Reno Gage, and $\boldsymbol{t_f}$ is a given outlook (i.e., 10 days). This is like the method applied to determine the seasonal flood space requirement, where the primary difference is that the equation is applied to seasonal historical flows to determine the seasonal flood space, whereas in the "By a Model" Method it is applied to HEFS forecasts (Gwynn, Revised Guide Curve Modeling, 2022).

As discussed above, there is a tradeoff between the collective accuracy of hindcasts versus the acceptable level of risk. To account for this, the "By a Model" Method assesses flood risk at varying outlooks by computing the volume of flood space that would be exceeded by a specified percentage of traces. This "exceedance percentage" is the percent of traces where the flood space would be insufficient to store flood waters should that trace occur and is thus an estimate of the risk of filling all the flood space associated with a having a specified volume of flood space. Note that this is an estimate of the risk associated with having sufficient flood space as the hindcasts (and all models and meteorological forecasts that they are based on) may have biases and inaccuracies based on the current state of the science. The percentage used can vary by outlook and be adjusted to meet the study objectives. To facilitate this computation, Equation 1 is applied to all traces of a hindcast at multiple outlooks.

To provide a simple example, assume a hindcast for a given day is composed of ten traces. Equation 1 is applied to each trace of this hindcast at outlooks of 1, 2, 5, 7 and 14 days resulting in the Cumulative Storage over the flood target flow summarized by Table 10. Note, implementation of the "By a Model" Method in the TBWMOP included outlooks up to 365 days to incorporate runoff information contained in forecasting into the methodology.

Table 10: Example of applying the Cumulative Storage over Flood Target Flow calculation to a hindcast.

Unregulated Inflow Volume over Flood Target Flow (acre-feet)		Outlook (days)				
		1-Day	2-Day	5-Day	7-Day	14-Day
	Trace 1	0	0	5,000	15,000	15,000
	Trace 2	0	1,000	4,000	10,000	11,000
	Trace 3	100	1,500	3,000	12,000	12,000
	Trace 4	0	0	2,000	12,500	12,700
	Trace 5	0	0	2,000	12,500	12,500
	Trace 6	0	200	3,000	11,500	11,500
	Trace 7	50	100	1,000	10,000	10,000
	Trace 8	500	2,000	5,000	6,000	7,000
	Trace 9	0	500	1,500	11,500	11,500
	Trace 10	0	0	0	10,000	11,000

4.2.2.5 Bias Correction Method

The Inflow Uncertainty Analysis identified that observed flows are outside of the 10%-90% exceedance interval from the CNRFC hindcast more frequently than expected at various outlooks. This indicates that the CNRFC hindcasts underestimate the risks that high flows will occur. Hopefully this issue will be resolved or improved in the future, but in the interim period the TBWMOP team decided to expand the range of the CNRFC hindcasts to compensate for the underestimate of the range. The bias correction method essentially compares observed values to the ranges of CNRFC hindcast traces and identifies the frequencies that the observed is with the 10%-90% exceedance interval (Table 11). The range of traces is then expanded and/or shifted so that the observed values land between 10%-90% exceedance range the expected frequency of the time (i.e., 80% of the time). A visual demonstration of the impact of implementing the bias correction is shown in Figure 8. In this figure, the Unscaled Volume line represents the unscaled exceedance distribution for the fourteen-day Farad Natural Flow Volume seen in the ensemble traces for the hindcast produced for March 24, 1986, and the Scaled Volumes line represents the bias corrected distribution for the same day.

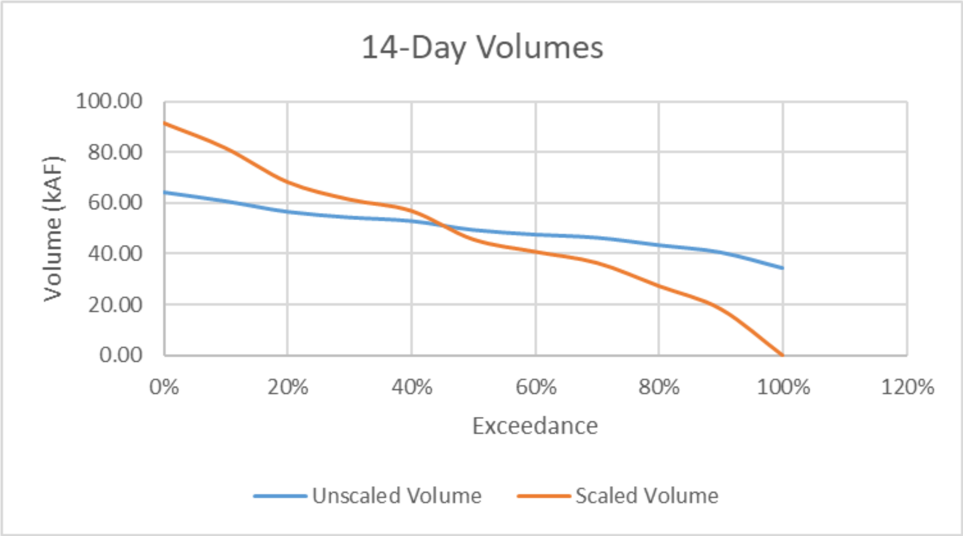

Figure 8: 14-Day Volume Farad Natural Flow Bias Correction Example

The bias correction applied to the Unscaled Volume distribution in Figure 8 and to each CNRFC hindcast in the dataset ultimately relies on Equation 2, which characterizes the range of a given outlook's hindcasted n-day volumes relative to the median volume as a function of exceedance.

Equation 2: Bias Correction Equation

$$V_{(e\%)} = \mu + \alpha_{(e\%)}\sigma$$

In this equation, V is the approximated hindcasted cumulative n-day volume at a given exceedance and outlook, μ is the median, $\alpha_{(e\%)}$ represents the number of standard deviations V is from the median n-day volume, and σ is the standard deviation. Finally, a subscript of $e\%$ indicates the parameter is dependent on exceedance.

The hindcasted n-day volume in Equation 2, V, is known from the hindcast dataset by applying an empirical exceedance distribution of V. This empirical exceedance distribution describes the percent of hindcasted traces whose n-day volumes exceed a volume corresponding with α standard deviations from the median. The independent variable of this empirical exceedance distribution, α, represents the range of hindcasted n-day volumes in terms of the number of standard deviations from the median.

Equation 3: Range of values for independent variable α in the Empirical Exceedance Distribution.

$$A \leq \alpha \leq B$$

$$A = \frac{Min(V) - Median(V)}{\sigma}$$

$$B = \frac{Max(V\ ) - Median(V\ )}{\sigma}$$

The dependent variable of the empirical exceedance distribution, $e(\%)$, represents the percent of hindcasted n-day volumes exceeding the volume associated with α standard deviations from the median. This dependent variable of the empirical exceedance distribution is calculated by the following equation, where n is the number of standard deviations from the median.

Equation 4: *Empirical Exceedance Distribution Dependent Variable e(%)*

$$e(\%) = \frac{Count(V > \alpha_{(e\%)} * \sigma + \ \mu)}{Count(V)}$$

The exceedance distribution is now known, therefore $\alpha_{(e\%)}$ at any exceedance percentage can be gleaned by referencing this exceedance distribution.

To describe how the range of hindcasted traces should be scaled according to Equation 2, the scaled and unscaled ranges of hindcast traces must be derived mathematically using a theoretical example. For instance, if the hindcast data were to suggest that the 10% expected exceedance is exceeded 20% of the time by the hindcasted traces, it would be known that that the 10% exceedance unscaled n-day volume, $V_{u(10\%)}$, is equivalent to $V_{s(20\%)}$, the scaled 20% exceedance n-day volume. Thus, the equations describing $V_{u(10\%)}$ is:

Equation 5: *Theoretical Unscaled 10% Exceedance Volume*

$$V_{u(10\%)} = \mu_s + \alpha_{(20\%)}\sigma_s$$

$$V_{u(10\%)} = V_{s(20\%)}$$

Similarly, if it were known that the 90% exceedance was really exceeded 75% of the time, another way of describing $V_{u(90\%)}$ would read as follows:

Equation 6: Theoretical Unscaled 90% Exceedance Volume

$$V_{u(90\%)} = \mu_s + \alpha_{(75\%)}\sigma_s$$

$$V_{u(90\%)} = V_{s(75\%)}$$

These equations can be utilized to derive μ_s, which represents the median of the scaled hindcasted n-day volumes:

Equation 7: Scaled Median Volume

$$\mu_s = V_{u(10\%)} - \alpha_{(20\%)}\sigma_s = V_{u(90\%)} - \alpha_{(75\%)}\sigma_s$$

The scaled hindcasted n-day volumes' standard deviation, σ_s, can then be solved by substituting Equation 7 into Equation 6 and rearranging the resulting equation:

Equation 8: Scaled Standard Deviation

$$\sigma_s = \frac{V_{u(90\%)} - V_{u(10\%)}}{\alpha_{(75\%)} - \alpha_{(20\%)}}$$

Finally, given that all variables in Equation 2 are known, the unscaled and scaled volumes for each hindcasted n-day volume trace can be calculated and compared using the system of equations described in Equation 9.

Equation 9: Unscaled and Scaled Hindcasted n-Day volumes.

$$V_{u(e\%)} = \mu_u + \alpha_{(e\%)}\sigma_u$$

$$V_{s(e\%)} = \mu_s + \alpha_{(e\%)}\sigma_s$$

Given that the confidence interval employed for the bias correction was 90%-10%, terms $\alpha_{(90\%)}$ and $\alpha_{(10\%)}$ employed in Equation 9 were obtained from the Inflow Uncertainty Analysis' observed frequencies as shown in Table 11 (Gwynn, Inflow Uncertainty Analysis, 2022). Values describing $\alpha_{(75\%)}$ and $\alpha_{(20\%)}$ were calculated from the hindcast data.

Table 11: Inflow Uncertainty Analysis Observed and Expected Frequencies for which CNRFC Hindcasted Cumulative Volumes Fell Within A Given Exceedance Interval

Outlook	Exceedance	Expected Frequency	Observed Frequency
1	90%	10%	51%
	10%	10%	49%
5	90%	10%	45%
	10%	10%	37%
7	90%	10%	44%
	10%	10%	35%
14	90%	10%	41%
	10%	10%	31%
30	90%	10%	36%
	10%	10%	25%
90	90%	10%	28%
	10%	10%	17%
120	90%	10%	26%
	10%	10%	15%
180	90%	10%	21%
	10%	10%	12%
200	90%	10%	20%
	10%	10%	11%
365	90%	10%	11%
	10%	10%	7%

Finally, the scaling factor applied to each hindcast's N-Day outlook calculations is defined as the ratio between the scaled volume (V_s) to the unscaled volume (V_u) at a given outlook.

Equation 10: Bias Correction Scaling Factor

$$Bias\ Correction\ Scaling\ Factor = \frac{V_s}{V_u}$$

This bias correction was applied to each hindcast, for every outlook, so long as the range of traces was larger than a specific threshold. This threshold for trace scaling to occur was dependent upon the magnitude of difference between $\alpha_{(90\%)}$ and $\alpha_{(10\%)}$. If the difference was less than 0.1 standard deviations, traces were not scaled. This threshold prevents trace scaling when almost all the N-day volume traces are approximately the same magnitude. After this, the Risk Assessment portion of this method was applied.

4.2.2.6 Evaluating Performance of the Bias Correction

After the bias correction was applied to each hindcast, a statistical test was conducted to demonstrate how well traces were representative of the exceedance distribution. Bias-corrected hindcasted N-Day volumes were input to a Reliability Histogram identical in structure to that shown in Figure 7. As shown in Table 12, the 10% exceedance bias-corrected volume was actually exceeded between 5-20% of the time across outlooks greater than one day. On the other hand, the 90% exceedance was actually exceeded between 19-27% of the time at outlooks larger than one day.

Table 12: Inflow Uncertainty Analysis Observed, Expected, and Bias Corrected Frequencies for which CNRFC Hindcasted Cumulative Volumes Fell Within A Given Exceedance Interval

Outlook	Exceedance	Expected Frequency	Observed Frequency	Bias Corrected Frequency
1	90%	10%	51%	52%
	10%	10%	49%	39%
5	90%	10%	45%	19%
	10%	10%	37%	15%
7	90%	10%	44%	22%
	10%	10%	35%	16%
14	90%	10%	41%	23%
	10%	10%	31%	12%
30	90%	10%	36%	20%
	10%	10%	25%	14%
90	90%	10%	28%	27%
	10%	10%	17%	9%
120	90%	10%	26%	26%
	10%	10%	15%	8%
180	90%	10%	21%	25%
	10%	10%	12%	6%
200	90%	10%	20%	25%
	10%	10%	11%	7%
365	90%	10%	11%	20%
	10%	10%	7%	5%

The 90% exceedance interval was not as effectively bias corrected as the 10% exceedance interval due to the inherent shape of the hindcasts' exceedance distribution, which is often skewed. As shown in the example below of a hindcast's 30-day outlook exceedance distribution, an α of zero reflects the median hindcasted 30-day volume. In this example distribution, the range of traces smaller than the median is too small to be effectively bias corrected.

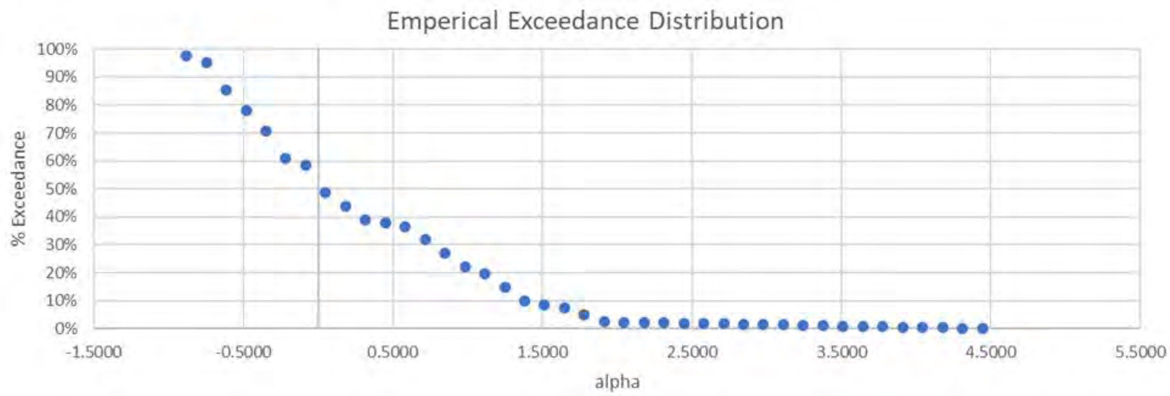

Figure 9: Example Empirical Exceedance Distribution for 30-day Outlook Hindcasted Farad Natural Flow Volumes

It is expected that the 1-day outlook also shows relatively poor bias correction performance due to the small range of 1-day outlook volumes predicted by RFC hindcasts, in which the range between the 10% exceedance α and 90% exceedance α was too small to allow for effective bias correction of 1-day outlook traces. If the difference was less than 0.1 standard deviations, traces were not scaled.

4.2.2.7 Exceedance vs. Outlook: Balancing Hindcast Skill with Risk

The risk assessment portion of the "By a Model" Method boils down the bias corrected results of the "Cumulative Volume over the Target Calculation" to a single flood space requirement by defining an Exceedance vs. Outlook Curve. For a particular forecast, the volume of flood space is evaluated for each outlook based on the respective exceedance (value exceeded by a desired percentage of the CNRFC hindcast traces) from the Exceedance Outlook curve. The largest volume for flood space required by one of the outlooks determines the flood space requirement.

Figure 10 provides an example of a prototype Exceedance vs. Outlook Curve. This curve defines that at a 1-day outlook, the 0% exceedance of the hindcasted 1-day Cumulative Storage over flood target flow should be used in the determination of the flood space requirement. In other words, at a 1-day outlook, the most conservative (i.e., largest) forecasted volume for flood space requirements should be considered. In contrast, at the 14-day outlook, the 60% exceedance of the hindcasted 14-day Cumulative Storage over flood target flow should be considered in the determination of the flood space requirement. 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 requirements is permissible by this Exceedance vs. Outlook Curve.

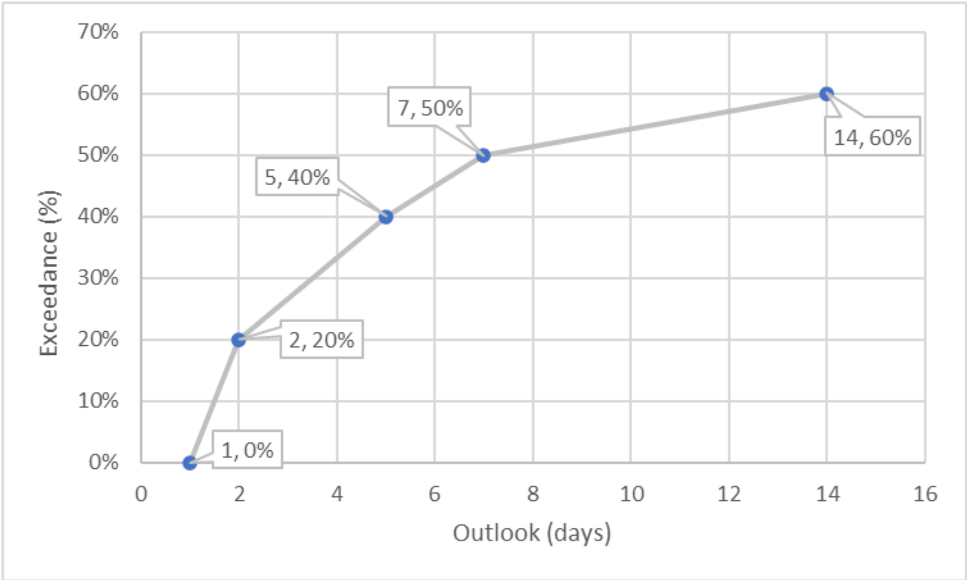

Figure 10: Example Exceedance vs. Outlook Curve

Applying the Exceedance vs. Outlook Curve from Figure 10 to the Cumulative Storage over flood target flow values for the example hindcast (see Table 10) results in values for required flood space by outlook shown in Table 13.[4] The "By a Model" Method selects the required flood space for this hindcast based on the most conservative value defined by the Exceedance vs. Outlook Curve. For this example, the required flood space is controlled by the 11,500 acre-feet of flood space computed for the 7-day outlook.

Table 13: Required Flood Space calculations by outlook and risk, and the required flood space as calculated by the "By a Model" Method for the example hindcast.

Outlook	1-Day	2-Day	5-Day	7-Day	14-Day	"By a Model" Method Required Flood Space
Exceedance	0%	20%	40%	50%	60%	
Required Flood Space by Outlook (acre-feet)	500	1,100	3,000	11,500	11,300	**11,500**

The last step of the "By a Model" Method acts as a factor of safety in the "By a Model" Method and is like the "Modified Hybrid EFO model" recommended in a similar project on the Russian River (Jasperse, et al., 2020). The "By a Model" Method applies a

[4] Note, the bias correction adjusts the cumulative volume over target calculation by correcting the hindcasts prior to performing the calculation using the Exceedance vs. Outlook Curve. For the sake of simplicity, the bias correction step is left out of the example.

minimum value to the required flood space calculation determined by the Exceedance vs. Outlook Curve as a percentage of the Revised Guide Curve to maintain. That is, the required flood space, as calculated by the "By a Model" Method, will always be at least as large as a specified percentage of the flood space required by the Revised Guide Curve. How this percentage is determined is discussed in the proceeding section. The following equation represents this interaction between the percentage of the Revised Guide Curve to maintain and the calculations for required flood space as determined by the hindcast data and the Exceedance vs. Outlook Curve:

Equation 11: Final equation used to calculate the required flood space.

$$RFS_{Final} = Max[\%\ Revised\ Guide\ Curve * Revised\ Guide\ Curve\ Flood\ Space\ , RFS_1, RFS_2, RFS_5, RFS_7, RFS_{14}, \dots]$$

In this equation, RFS_{Final} represents the final required flood space as determined by the "By a Model" Method and RFS_n represents the required flood space calculated utilizing the Exceedance vs. Outlook Curve at an n day outlook.

4.2.2.8 Parameterization of the "By a Model" Method

As described above, the Exceedance vs. Outlook Curve is designed to determine a flood space requirement from an CNRFC Ensemble, but the question remained of how to select the Exceedance vs. Outlook Curve for the Truckee Basin. Ultimately, the MOEA allowed the Technical Team to determine the Exceedance vs. Outlook Curve through an assessment of what relationship between Exceedance and Outlook balanced the tradeoffs of forecast skill and risk to best met the study objectives.

To facilitate this, the Exceedance vs. Outlook Curve was parameterized by the following equation:

Equation 12: Parameterization of the Exceedance vs. Outlook Curve

$$Exceedance = C + A(Outlook)^B$$

A, B, and C in Equation 12 are coefficients characterizing the shape of the Exceedance vs. Outlook Curve. By constraining the B coefficient to values greater than 0, the resulting exceedance percentage will be increasing as a function of outlook. Thus, for smaller outlooks, more conservative flood space requirements should be implemented, in contrast to longer outlooks, whose forecasted flood space requirements are relatively more uncertain and, therefore, should not require highly conservative flood space requirements long in advance of their possible materialization. Further documentation on how A, B, and C were constrained for the TBWMOP analysis are provided later in the report in **Section 7.1.2.1.1: Decision Variables.**

4.2.2.9 "By a Model" Method Input Parameters

In total, the "By a Model" Method required five parameters (see Table 14). Four of these parameters were optimized by the MOEA through analysis of what configuration of these parameters best met the water supply, flood risk mitigation, and environmental flow objectives in the study. The last parameter, the Reno Gage Flood Target Flow, was preliminarily selected for the technical analysis to be 6,500 cfs (see **Section 4.1.2: Updated Flood Target Flow**).

Table 14: Parameters required by the "By a Model" Method

Action	Parameter	Selection Method	Parameter Value
"By a Model" Method	Exceedance Coefficient A	MOEA Analysis	
	Exceedance Coefficient B	MOEA Analysis	
	Exceedance Coefficient C	MOEA Analysis	
	Percentage of Revised Guide Curve to Maintain	MOEA Analysis	
	Reno Gage Flood Target Flow	Analysis of Inundation Maps	6,500 cfs

4.3 Actions for Little Truckee Flood Space

4.3.1 Reproportion

During the Plan Formulation of the TBWMOP, the Technical Team and other key stakeholders identified potential benefits associated with reevaluating the proportion of total Little Truckee flood space required between Boca and Stampede Reservoirs per the WCM. Table 15 provides a summary of the Little Truckee flood space requirements per the WCM. The WCM specifies "a minimum of 25 percent and a maximum of 8,000 acre feet of the combined flood control space for Stampede and Boca Reservoirs will be in Boca Reservoir" (US Army Corps of Engineers, 1985, pp. A-4). This has historically been implemented by reserving 8,000 acre-feet (26.7%) in Boca with the remaining 22,000 acre-feet (or 73.3%) in Stampede Reservoir.

Table 15: Summary of Little Truckee Flood Space prescribed by the WCM.

	Boca Reservoir	Stampede Reservoir
Maximum Reservoir Capacity (acre-feet)	40,868	226,500
Reservoir Drawdown Storage (acre-feet)	32,868	204,500
Maximum Flood Space Requirement (acre-feet)	8,000	22,000
Proportion of Total Little Truckee Flood Space	26.7%	73.3%

Total Little Truckee Flood Space (acre-feet)
30,000

The Reproportion of Little Truckee Flood Space action is designed to explore the benefits of adjusting Boca Reservoir's portion of Little Truckee flood space from what is prescribed by the WCM. The Technical Team identified potential benefits of reducing Boca Reservoirs proportion of Little Truckee flood space below 26.6% as:

- Improved ability to store project water in Boca Reservoir during the winter.
- Improved ability to store stakeholder credit water in Boca Reservoir during the winter.

The Technical Team also identified potential benefits of increasing the Boca proportion of Little Truckee flood space above 26.7%. These benefits included increased flood protection by allowing additional space in Boca Reservoir to capture local inflows to Boca Reservoir and releases from Stampede Reservoir during a flood event. However, it was also identified that reducing the storage in Boca Reservoir could possibly impact water supply by reducing the space available for storage of credit water and project water in Boca in the winter. Since not adversely impacting the Floriston Rate is one of the constraints of the study, the concern of violating this constraint would be explored in the modeling results.

The Reproportion of Little Truckee Flood Space action required one modelling parameter: the Boca Portion of Little Truckee Flood Space. This parameter was selected by the Technical Team using a Multi Objective Evolutionary Algorithm (MOEA) (see Table 16). **Section 7: Alternative Operational Scenario Modelling** will detail how the Technical Team utilized the MOEA to select this parameters value.

Table 16: The parameter associated with the Reproportion of Little Truckee Flood Space action and the method utilized by the Technical Team to select the parameter.

Action	Parameter	Selection Method
Reallocation of Little Truckee Flood Space	Boca Portion of Little Truckee Flood Space Percentage	MOEA Analysis

5 Objectives and Constraints Modelling

Table 2 and Table 3 provide a list of all the study objectives and constraints that were determined during the Plan Formulation**.** The objectives listed in Table 2 represent the stakeholders' goals in implementing changes to the regulation criteria in the WCM. The constraints listed in Table 3 represent bounds that distinguish an acceptable alternative operational scenario from an unacceptable one.

Further development of the objectives and constraints identified in the Plan Formulation was completed by the Technical Team and other key stakeholders primarily at the June of 2022 Workshop, but refinement continued until the analysis was started in January of 2023. During this period, the Technical Team and other key stakeholders:

1. Agreed upon categorizations of objectives/constraints as either non-quantifiable or quantifiable.[5]
2. Refined the Quantifiable Objectives to a smaller list of objectives that accurately captured the original quantifiable objectives defined in the Plan Formulation.[6]
3. Agreed upon calculations for the Quantifiable Objectives and Constraints.

This section of the report seeks to document the results development and discuss how the more qualitative descriptions of objectives and constraints identified during the Plan Formulation were captured in the modelling design of the TBWMOP.

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[5] Non-Quantifiable Objectives/Constraints represent those that are subjective in nature and that could not be calculated from the model results of a given alternative operational scenario (i.e., "Develop methodologies that are implementable in operational model"). Quantifiable objectives/constraints represent those that or more objective in nature and could be calculated from models results for a given alternative operational scenario (i.e., "Maximize the number of Floriston Rate days").

[6] Objectives were refined to a smaller list to enhance the performance of the Multi-Objective Evolutionary Algorithm (MOEA). Optimizing to a smaller set of objectives allows for the MOEA to arrive at a solution space more efficiently.

5.1 OBJECTIVES MODELLING

Table 17 provides a description of the objectives identified in the Plan Formulation. Of the eleven total objectives, four were characterized as being non-quantifiable; these objectives are highlighted green in Table 17. Additionally, seven objectives were identified as quantifiable; these objectives are highlighted blue in Table 17. The proceeding two subsections detail how Non-Quantifiable and Quantifiable objectives were incorporated into the modelling of the TBWMOP.

Table 17: Study objectives defined in the Plan Formulation of the TBWMOP. Non-Quantifiable Objectives are highlighted in green, and Quantifiable Objectives are highlighted in blue.

Objective Number	Objective Description
1	Maximize the number of Floriston Rate days or the amount of Floriston Rate water in storage.
2	Maximize the flexibility for timing of drawdown under flood control measures.
3	Maximize flexibility for refill in reservoirs up to the maximum conservation elevations.
4	Improve environmental instream flows downstream of reservoirs.
5	Minimize use of surcharge space above the spillway.
6	Reduce risk of damage from flooding downstream.
7	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.
8	Allow flexibility for varying future operating conditions of Martis Creek Dam.
9	Allow flexibility for future increases in flood thresholds because of flood improvements downstream.
10	Optimize storage to satisfy water demands through the year.
11	Develop methodologies that are implementable in an operational mode.

5.1.1 Non-Quantifiable Objectives

This section of the report describes how the four Non-Quantifiable Objectives were designed for in the TBWMOP.

The first Non-Quantifiable Objective (Objective 7 of Table 17) states:

> *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.*

This objective is designed for in the action modelling through the "By a Model" Method (see **Section 4.2.2: "By a Model" Method for Required Flood Space**).

This method utilizes CNRFC Ensemble Forecasts which are regularly improved with advances in technology, and improvements to this forecasting technology would automatically permeate through this methodology. In concept the "By a Model" method could also be utilized with any ensemble-based runoff forecast which could be produced by other forecasting frameworks furthering the flexibility to adapt to future improvements in data and forecasting.

The second and third Non-Quantifiable Objectives (Objective 8 and 9 of Table 17) are designed for through the methodologies of the Revised Guide Curves and the "By a Model" actions. Objective 8 pertains to maintaining flexibility to allow for varying future operating conditions on Martis Creek Reservoir. While the analysis in the study operated Martis Creek Reservoir to its current limitations, the Revised Guide Curves were developed to allow for analysis of varying operations on the reservoir. For Objective 9, the goal is to maintain flexibility of flood target flows downstream if improvements are made to the Truckee River channel that reduce flood damages. The Revised Guide Curves were developed based on flow rates from 6,000 cfs to 8,000 cfs at 500 cfs increments (Gwynn, Revised Guide Curve Modeling, 2022), and the "By a Model" method can determine the forecasted flood space based on an input downstream target at Reno. In this way, the TBWMOP was designed to take as input a flood target flow. If these improvements are made, the flood target flow could be updated and incorporated into operations with ease.

The fourth Non-Quantifiable Objective (Objective 11 of Table 17) aims to ensure that the results of this study produce regulation criteria that is feasible to implement operationally. This objective sought to allow for concerns such as ensuring that the daily analysis that is required of the CNRFC forecasts could be completed efficiently each day, necessary information could be easily disseminated to the various entities of interest (i.e., USWM, USBR, USACE, etc.), and that operations to the forecast could be made subject to real-world concerns not evaluated in the modeling. To address these concerns, the methodologies were developed and reviewed with operators in the Truckee River Basin to ensure that the proposed revisions to the WCM were in fact operationally feasible. Furthermore, the Technical Team deliberated on and discussed this objective throughout the select Preferred Operational Scenario process (Gwynn & Noe, WMOP Preferred Operational Scenario Selection Process, 2023).

5.1.2 Quantifiable Objectives

Developing calculations for the Quantifiable Objectives in the study was integral to the modelling in the study because it allowed:

- The performance of alternative operational scenarios to be evaluated.
- The ability to make comparisons between alternative operational scenarios.
- The MOEA to optimize the decision variables to meet these objectives.

Calculations were designed for each Quantifiable Objective to both accurately quantify the performance of an objective in an alternative operational scenario *and* to evaluate to a single number. Both concerns are critical when using an optimization methodology such as an MOEA, so that the changes to the objectives' values represent the changes in the broader objective.

Prior to the June 2022 Workshop, PWRE developed calculations for each of the seven Quantifiable Objectives identified in the Plan Formulation, and the calculations were presented to the Technical Team at the workshop. The Technical Team and other key stakeholders agreed that reducing the total number of Quantifiable Objectives would benefit the alternative operational scenario selection process by reducing the complexity of making comparisons between alternative operational scenarios. This decision was largely made to reduce the dimensionality of the objective space of the MOEA, allowing the algorithm to learn the relationship between decision variables and objectives more efficiently (Precision Water Resources Engineering, 2022). To facilitate this, the Technical Team refined the list of seven Quantifiable Objectives from the Plan Formulation into five Alternative Modelling Objectives. These five Alternative Modelling Objectives were designed to capture the goals of the original seven Quantifiable Objectives. The following subsections describe each of the five Alternative Modelling Objectives, their respective calculations, and their relationship to the objectives from the Plan Formulation.

5.1.2.1 Annual Average Volume for Floriston Rate

The first Alternative Modelling Objective, Annual Average Volume for Floriston Rate, computes the average annual volume of water used to meet the Floriston Rate Target plus the change in storage that occurred over the model run. This objective is designed to quantify how well an alternative operational scenario maximizes the number of days for Floriston Rate in the system (Objective 1 from Plan Formulation, Table 17).

5.1.2.2 Average Prosser, Boca, and Stampede Storage

The second Alternative Modelling Objective, Average Prosser, Boca, and Stampede Storage, calculates the average combined daily storage in the three Active Flood Reservoirs over the duration of an alternative operational scenario model run. This objective indirectly characterizes an alternative operational scenarios performance at maximizing the flexibility of timing of reservoir drawdown and ability to refill reservoirs (Objectives 2 and 3 from Plan Formulation, Table 17). The concept is that if it were possible to have more storage in the reservoirs, then the basin stakeholders could use the flexibility allowed by TROA to better meet their objectives. Secondarily, this objective helps to quantify how well an alternative operational scenario optimizes storage to satisfy water demands through the year (Objective 10 from Plan Formulation, Table 17): better scores for this objective in an alternative operational scenario model means that the reservoirs generally had higher storages which could provide benefits to water supply (note that the TROA Planning model make releases to meet demands so additional storage is an indication of additional drought supply).

5.1.2.3 Average Annual Volume for Flow Regime

The third Alternative Modelling Objective, Average Annual Volume for Flow Regime, computes the average annual volume at the Nixon Gage limited to the Flow Regime Target plus the change in PLPT storage over the model run. Scores for this objective can be improved in alternative operational scenarios where (1) the Flow Regime Targets were higher, (2) the Flow Regime Targets were met more often, or (3) PLPT ended the alternative operational scenario model run with more water in storage. Each of these cases benefit lower river environmental flows. Note, the Flow Regime Target used by this objective is calculated within the Planning Model of an alternative operational scenario based on the current operational criteria to support the endangered Cui-ui (FishPro A Division of HDR, 2004). This objective is designed to quantify how well an alternative operational scenario improves environmental flows downstream of reservoirs (Objective 4 from Plan Formulation, Table 17).

5.1.2.4 Root Mean Squared Flow Over Flood Target

The fourth Alternative Modelling Objective was the Root Mean Squared (RMS) Flow Over Flood Target. This objective is the main flood objective in the alternative operational scenario modelling, and it quantifies how well an alternative operational scenario reduces the risk of flooding downstream of reservoirs (Objective 5 of Plan Formulation, Table 17).[7] This objective is calculated using the following equation:

Equation 13: Alternative Modelling Objective calculation for Root Mean Squared Flow Over Flood Target

$$RMS\ Flow\ Over\ Target = \sqrt{\sum_{Hourly\ Timesteps} Max(\ (Reno\ Flow_t - Flood\ Target\ Flow)^2, 0)}$$

The objective calculation, which occurs at an hourly timestep over the course of an entire alternative operational scenario model run, assesses the magnitude of flows at the Reno Gage above the flood target flow of 6,500 cfs (see **Section 4.1.2: Updated Flood Target Flow** for more information on the determination of this flood target). This objective is meant to capture the effects of flood damages associated with the following:

- Peak Flows – Peak flow is the primary indicator of flood damage, and in the calculation, higher flows penalize this objective more due to the squared term in Equation 13.
- Duration of Inundation – Sustained flood flows over the target can also contribute to damage as the flood plain storage may not have been filled with the initial brief peak and sustained inundation could increase damage and/or flood fighting expenses. These concerns are also represented in the calculation.

It is important to note that for the flood events in the dataset of the TBWMOP, there is limited ability to improve the peak flows because in most historical flood events, reservoirs are storing into their flood space at the time the peak flow occurs; as a result, the reservoirs are not making releases downstream at the time peak flows occurs. This was not true for some of the synthetic scaled hindcast events ran as a part of the alternative operational scenarios, justifying the use of the scaled events in the objective scoring (see **Section 6.2.1.1: Hourly Model Hydrology**). Also noteworthy is that this objective also indirectly quantifies an alternative operational scenario's ability to reduce surcharge (storage exceeding the reservoirs designed full storage) in the reservoirs (Objective 5 from Plan Formulation, Table 17). The reason for this is the modelling assumes that when a reservoir is in surcharge, the outlet works would be operated to evacuate the surcharge from reservoirs as quickly as possible even if this causes downstream flows to exceed or further exceed the flow target. This operation occurs

[7] This objective was discussed at the June 2022 Workshop, but the development of the calculation was completed over the following weeks and reviewed/approved initially by George Robison of the Truckee River Flood Management Authority (TRFMA). The calculation was then approved by the Technical Team.

because if the reservoir exceeds the full storage and the storage continues to rise to the point that the dam is overtopped the dam may fail. Therefore, alternative operational scenarios that result in more surcharge will decrease the performance of the RMS Flow Over Flood Target because reservoirs in these scenarios will spend a longer duration of time making releases not limited to the downstream flow target.

5.1.2.5 Average Daily Increase in Flood Space Requirement

The fifth Alternative Modelling Objective, Average Daily Increase in Flood Space Requirement, calculates the daily average increase in the flood space requirement in Active Flood Control Reservoirs over the duration of an alternative operational scenario for any day a storm was forecasted. This objective was added at the June 2022 Workshop to address undesirable outcomes of utilizing FIRO to calculate flood space requirements. For example, if ensemble forecasts leading up to an event required immediate evacuation of flood space and the event did not occur, storage would needlessly have been evacuated downstream and negatively impact water supply. Furthermore, preliminary analysis using the "By a Model" Method showed the potential for large day to day fluctuations in the required flood space. These fluctuations in flood space could result in large day to day fluctuations in flows in the Truckee River due to flood space evacuation. These flow fluctuations would have negative environmental impacts and would potentially be operationally infeasible.

The Average Daily Increase in Flood Space Requirement objective helps to quantify how well an alternative operational scenario avoids the above situations (Objectives 10 and 4 from Plan Formulation, respectively, Table 17). Furthermore, this objective also supports the Non-Quantifiable Objective in the study to develop methodologies that are feasible to implement (Objective 11 from Plan Formulation, Table 17).

5.2 CONSTRAINTS MODELLING

Table 7 provides a description of the constraints identified in the Plan Formulation. Of the ten study constraints, five were characterized as Non-Quantifiable Constraints (highlighted yellow in Table 7), and five were characterized as Quantifiable Constraints (highlighted red in Table 7). The proceeding two subsections detail how Non-Quantifiable and Quantifiable Constraints were incorporated into the modelling of the TBWMOP.

Table 18: Study constraints defined in the Plan Formulation of the TBWMOP. Non-Quantifiable Constraints are highlighted in yellow, and Quantifiable Constraints are highlighted in red.

Constraint Number	Constraint Description
1	Do not increase damage from flooding as a result of changed reservoir operations.
2	Comply with requirements of TROA and other governing agreements.
3	Can be addressed through updates to the WCM
4	Do not change the total amount of authorized flood control space (e.g., 30,000 AF between Boca and Stampede)
5	Do not increase probability of dam failure from overtopping or internal failure.
6	Must be technically feasible to implement.
7	Must not decrease the number of projected Floriston Rate days compared with continuing management under the No Action.
8	Don't negatively impact the T&E species in the river.
9	Don't change water rights.
10	Must be within the scope of this pilot study as defined in the WMOP Memorandum of Agreement (MOA).

5.2.1 Non-Quantifiable Constraints

The first Non-Quantifiable Constraint, that the study must comply with requirements of TROA and other governing agreements (Constraint 2, Table 7), was accomplished through the model utilized for the alternative operational scenarios: the *TROA Planning Model*. This model is a daily timestep RiverWare model designed to follow the requirements of TROA, water rights, the WCM and other governing agreements allowing for planning type studies in the Truckee River Basin. The *TR Hourly River Model* is an hourly timestep RiverWare model developed as part of the TBWMOP and designed to operate the Truckee Basin during floods in accordance with the regulation criteria set forth in the WCM and alternative operational scenarios evaluated in the TBWMOP. These two models are discussed in more detail in **Section 6: No-Action Alternative Operational Scenario Model Setup and Configuration**.

Constraint 4, to not change the total amount of authorized flood space, limited the sort of changes that were considered in the Plan Formulation and was addressed through the technical infrastructure of the alternative operational scenarios modelling. The alternative operational scenarios within this study were limited to not alter the following regulation criteria from the WCM:

- Total maximum flood space in Prosser Creek Reservoir of 20,000 AF
- The maximum total Little Truckee (Boca Reservoir, Stampede Reservoir) flood space of 30,000 AF

The remaining three Non-Quantifiable Constraints (Constraints 3 and 10, Table 7) were addressed as part of the Plan Formulation of the study. Constraint 6 was preliminarily addressed in the Plan Formulation of the study but was ultimately met through discussions and revisions made during alternative operational scenario selection process (Gwynn & Noe, WMOP Preferred Operational Scenario Selection Process, 2023).

5.2.2 Quantifiable Constraints

The Quantifiable Constraints listed in Table 7 allowed for alternative operational scenarios to be compared and constrained out when compared against the No-Action Alternative. Constraints 1, 7, 8 and 9 in Table 7 are directly related to Quantifiable Objectives described in **Section 5.1.2: Quantifiable Objectives**, and each of these constraints were quantified utilizing the same calculations used to compute the related objective. Constraint 5 in Table 7 required an additional calculation described in the proceeding section.

5.2.2.1 Cumulative Storage over Dam Failure Elevations

The Quantifiable Constraint Cumulative Storage over Dam Failure Elevations calculates the cumulative storage that occurs above a reservoirs dam failure storage over the course of an alternative operational scenario.[8] Any scenario that failed this constraint was excluded from consideration in the WMOP. Note, this constraint was modeled in the MOEA as an objective to ensure that dam failure risk was an influencing component of the MOEA optimization. Ultimately, in the process of selecting the Preferred Operational Scenario, the Cumulative Storage over Dam Failure Elevations calculation served as a constraint.

[8] Note, dam failure elevations were provided by Scott Schoenfeld of the U.S. Bureau of Reclamation. These elevations were converted to storages using physical characteristic tables within the *TROA Planning Model*.

6 No-Action Alternative Operational Scenario Model Setup and Configuration

Alternative 1, the No Action Alternative Operational Scenario (or Baseline Scenario) developed in the Plan Formulation represents the baseline scenario for the TBWMOP (Bureau of Reclamation, 2021). This scenario utilizes two RiverWare models, the *TROA Planning Model* (Planning Model) and the *TR Hourly River Model* (Hourly Model), that are configured to model the Truckee River Basin under contemporary policy. This section of the report discusses each of these models in detail and the interactions that occur between them to model the Baseline Scenario.

6.1 Planning Model Overview

The Planning Model is a daily timestep RiverWare model utilized for long term planning studies within the Truckee Basin. Within the TBWMOP, the results of the Planning Model for the Baseline Scenario (Baseline Planning Model) allow for the quantification of baseline scores for water supply and environmental objectives (see **Section 5.1.2: Quantifiable Objectives**).

The Planning Model is designed to model the Truckee and Carson River system in accordance with the major agreements, contemporary water rights and demand structures, and stakeholder operational strategies in the basin. Namely, the Planning Model operates reservoirs in the system in accordance with the *Truckee River Operations Agreement* (TROA), which is the governing river policy of the Truckee River Basin (Truckee River Operating Agreement, 2008). Furthermore, the Planning Model adheres to flood control regulation criteria prescribed by the WCM. Namely, flood control capacity curves for Active Flood Control Reservoirs are calculated within the Planning model in accordance with the WCM. The Little Truckee Flood Space allocation between Boca and Stampede also adheres to proportions prescribed by the WCM. Namely, roughly 26.7% and 73.3% of Little Truckee Flood Space is reserved in Boca Reservoir and Stampede Reservoir respectively (US Army Corps of Engineers, 1985). In addition, the Planning Model also models the following agreements, strategies, and characteristics in the basin:

- Operating Criteria and Procedures for the Newlands Reclamation Project, Nevada (Operating Criteria and Proedures for the Newlands Reclamation Project, 1997).

- Flow Regimes Targets – environmental flow targets in the Truckee River at the Nixon Gage based on current operational criteria to support the endangered Cui-ui (FishPro A Division of HDR, 2004)
- Demands – all major diversions in the Truckee and Carson Rivers including but not limited to the Truckee Canal, Truckee Division, Carson Division, Chalk Bluff Water Treatment Plant, Glendale Water Treatment Plant, Orr Ditch, and Steamboat Ditch.
- Water Rights – Prior Appropriation water rights for all listed and unlisted demand locations and the Orr Ditch Decree (United States of America v. Orr Water Ditch Company, 1944).
- California Preferred Flows – CADWR preferred environmental flow targets downstream of reservoirs and preferred storage targets within reservoirs (California Department of Water Resources, California Department of Fish and Wildlife, Truckee River Basin Water Group, 2018).

The Baseline Planning Model was configured to span water years 1986 through 2022, and it modeled the system during this time frame in accordance with the agreements. As a part of the TBWMOP, members of the Technical Team reviewed the Planning Model to ensure that logic was modelling the basin appropriately. Furthermore, before the TBWMOP project a verification study was completed for the Planning Model in the referenced report *TROA Planning Model Verification* (Noe & Powell, TROA Planning Model Verificaiton, 2022).

6.1.1 Planning Model Input

To facilitate the Baseline Planning Model run, four sets of input were required (see Figure 11). The first was inflow hydrology for water years 1986 through 2022. The second was the initialization state of reservoirs in the system. Third, the model required an input demand scenario representing downstream demands of water users in the system. Lastly, the model required input of daily CNRFC hindcasts.

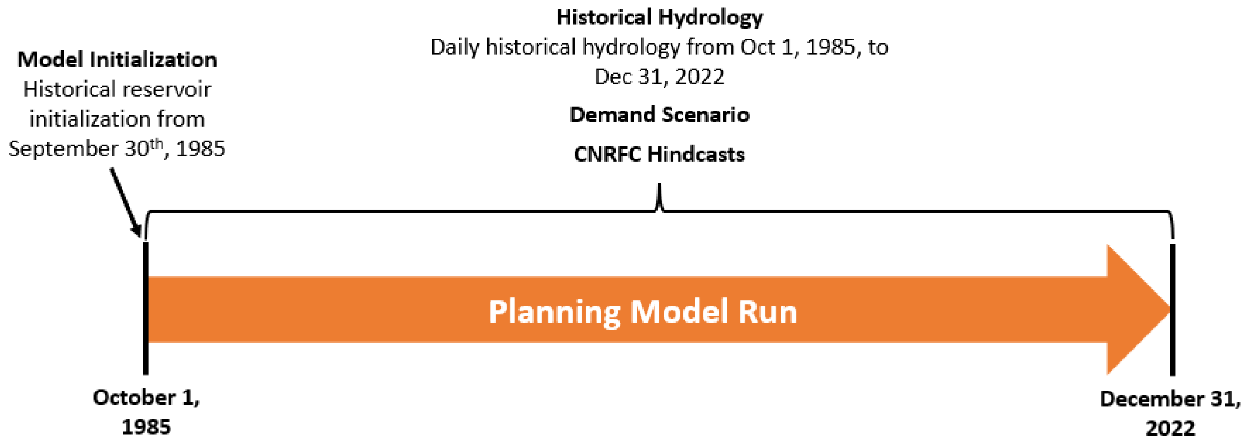

Figure 11: Schematic of Planning Model Run Inputs.

6.1.1.1 Planning Model CNRFC Hindcasts

The CNRFC hindcasts used in the Baseline Planning Model were the same set of hindcasts provided by CNRFC for the "By a Model" Method Action (see **Section 4.2.2.1: CNRFC Hindcasts and Scaled Hindcasts**). While these hindcasts were not used to calculate flood space requirements in the Baseline Scenario, they provided necessary input for Seasonal Forecasts, a piece of development added to the Planning Model for this study described in more detail in **Section 6.1.2: Baseline Planning Model Development**.

6.1.1.2 Planning Model Hydrology

The required hydrology inputs to the Planning Model include daily unregulated inflow datasets to the seven primary upstream reservoirs (Boca Reservoir, Stampede Reservoir, Prosser Creek Reservoir, Martis Creek Reservoir, Independence Lake, Donner Lake, and Lake Tahoe) and eleven additional timeseries for lateral inflows to the Truckee River not captured by reservoirs. This data was developed in two efforts. The first, undertaken by Precision Water Resources Engineering, developed and documented the methodology for computing daily historical hydrology in the Truckee Basin. As a part of this effort, historical data was developed for water years 2001 through 2021 (Precision Water Resources Engineering, 2022). The second effort, completed by Stetson Engineers, utilized the same methodology to develop Truckee Basin hydrology for water years 1986 to 2000. The development of this set of hydrology is documented in *Technical Memorandum - Truckee River Basin Historical Data Development Methodologies: Water Years 1986-2000* (Lawler, Technical Memorandom - Truckee River Basin Historical Data Development Methodologies: Water Years 1986-2000, 2022)

In the Baseline Planning Model, CNRFC hindcasts were a required input, and the CNRFC hindcast dataset was limited to water years 1990-2020 and February through March of 1986. This limited dataset was less effective for evaluation of water supply objectives because it begins in a drought (1990) and ends at the beginning of a drought reducing the ability to see additional storage maintained in wet periods and later delivered. To address this concern, the years 1986-1989 and 2021-2022 used historical analog years within the 1990-2020 period where CNRFC hindcast data was available. Table 10 provides a summary of the historical analog years used for each year of the model run. The historical analog years were selected by finding the most similar historical years to the model year within the CNRFC hindcast dataset. Similar years were identified by looking at the R^2 of monthly flows, April through July volumes, and water year volumes. Note, model year 1986 was unique because, while it used the historical analog year 1996 for hydrology, the historical February 1986 flood event was spliced into its hydrology. This was done to promote conditions within the dataset that would allow for robust evaluation of tradeoffs between the study objectives.

Table 19: Summary of Baseline Planning Model Hydrology used in the Baseline Planning Model and summary statistics used to calculate analog years. WY Volume refers to water year Volume and AJ Volume refers to April through July Volume.

		Comparison Metrics		
Baseline Model Year/s	**Analog Year**	**R^2 of Monthly Volumes**	**Historical Year WY Volume / Analog Year WY Volume %**	**Historical Year AJ Volume / Analog Year AJ Volume %**
1986	1996*	0.56	86%	121%
1987	2001	0.85	88%	94%
1988	1994	0.90	109%	119%
1989	2018	0.77	106%	102%
1990-2020	1990-2020	N/A	N/A	N/A
2021	2001	0.91	117%	100%
2022	2004	0.93	90%	107%

6.1.1.3 Planning Model Initialization

The Baseline Planning Model requires input for initial pool elevation for each of the modeled reservoirs and Pyramid Lake.[9] Initial pool elevations for these reservoirs and Pyramid Lake were determined by historical pool elevations from the United States

[9]Modeled reservoirs here refers to Boca Reservoir, Stampede Reservoir, Prosser Creek Reservoir, Martis Creek Reservoir, Independence Lake, Lake Tahoe, Donner Lake, and Lahontan Reservoir.

Geological Survey website for initialization timestep of the model (September 30th, 1985) (U.S. Geological Survey (USGS), 2021).

6.1.1.4 Planning Model Demand Scenario

The demand scenario utilized in the Baseline Planning Model is the most up-to-date demand configuration for planning studies within the Truckee Basin. The scenario represents current demands in the basin, and it was utilized by TMWA as a part of the organization's *2020-2040 Water Resource Plan* (Truckee Meadows Water Authority, 2020).

6.1.2 Baseline Planning Model Development

Several items of development were incorporated into the Baseline Planning Model for the TBWMOP. First, each of the Alternative Modelling Objective calculations (see **Section 5.1.2: Quantifiable Objectives**) were codified into the Planning Model to summarize the Baseline Scenario's performance. Furthermore, the Planning Model required development of the ability to run the Hourly Model from within a Planning Model. This interaction between the Planning Model and Hourly Model is detailed below in **Section 6.3: Baseline Scenario Modelling Framework**. Lastly, Seasonal Forecast capabilities, or the ability to operate the Planning Model using forecast information, was also developed to use the seasonal CNRFC forecast volumes in lieu of the perfect forecasts. This is documented in the proceeding section.

6.1.2.1 Seasonal Forecast Development

Within the *TROA Planning Model*, there are many instances where logic is engineered to perform an operation based off a forecast. Prior to the TBWMOP, the Planning Model utilized the same hydrology that was used as input to run the model as it did for the "forecasts" within the model that operations were based on; in other words, the Planning Model had "perfect" knowledge of the future when performing some of its operations. To leverage the additional seasonal forecast data available from the CNRFC hindcasts, development was incorporated into the Planning Model to introduce uncertainty to some of the model's operations. This development allows for the Planning Model to operate to seasonal forecasts, or aggregations of CNRFC hindcast data, as opposed to input hydrology (see **Section 4.2.2.1: CNRFC Hindcasts and Scaled Hindcasts** for more documentation on hindcasts). Aggregations of hindcast data were performed in Python, resulting in a daily timeseries of hindcasted volumes for seven locations within the basin that were ingested by the Planning Model and utilized within its operations logic. A summary of these calculations and what they are used for in the model is provided in Table 20. Note, the seasonal forecast used to calculate the Revised Guide Curve was used only in the study alternative operational scenarios modelling and not in the Baseline Planning Model.

Table 20: Summary of calculations made on CNRFC hindcast data to compute seasonal forecast data for the Baseline Planning Model.

Forecast Location	Calculation Description	Use of Forecast in Planning Model
Tahoe	Median hindcasted Max Tahoe Gates Closed Rise for each day of the Water Yater	Releases from Lake Tahoe
Donner	Median hindcasted remaining April through July Donner inflow volume for each daily hindcast in the dataset.	Fill season of Donner Lake
Stampede	Median hindcasted remaining March through July Stampede inflow volume for each daily hindcast in the dataset.	Determination of Environmental Flow Regimes at Nixon Gage
Independence	Median hindcasted remaining April through July Independence inflow volume for each daily hindcast in the dataset.	Determination of Environmental Flow Regimes at Nixon Gage
Farad	Median hindcasted remaining April through July Farad natural inflow volume for each daily hindcast in the dataset.	Snow Melt Parameter Calculation
Farad	Median hindcasted remaining Water Year Farad natural inflow volume for each daily hindcast in the dataset.	Revised Guide Curve Calculation
Carson at Fort Churchill	Median hindcasted remaining Carson at Fort Churchill inflow volume for each daily hindcast in the dataset.	Determination of OCAP Quantities

6.2 Hourly Model Overview

The Hourly Model is an hourly timestep RiverWare model utilized for short term flood event routing within the Truckee Basin. The results of the Hourly Model in the Baseline Scenario allow for the quantification of baseline scores for the flood damage objective in the study (see **Section 5.1.2: Quantifiable Objectives**).

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. The Hourly Model operates flood events in accordance with the regulation criteria set forth in the WCM (US Army Corps of Engineers, 1985), including:

- During non-flood events, Prosser Creek Reservoir, Boca Reservoir, and Stampede Reservoir are required to maintain a volume of flood space within the reservoir derived through methods specified in the WCM.
- During flood events, indicated by the WCM as flows at the Reno Gage being greater than 6,000 cfs, Prosser Creek Reservoir, Boca Reservoir, and Stampede Reservoir releases must be limited to reduce flows in the river to 6,000 cfs or as much as possible, and these reservoirs will store into their designated flood space.
- While Flood Control Reservoirs are storing into flood space during an event, the WCM requires, when possible, proportional storage into flood space between Prosser Creek Reservoir and Little Truckee reservoirs (Boca and Stampede Reservoir).
- After the event has passed, flood space must be evacuated in a manner that keeps the flows at the Reno Gage at or below 6,000 cfs.
- Release changes on Flood Control Reservoirs must be limited to 1,000 cfs or less per hour.
- Should all the flood space in a reservoir be filled and the reservoir goes into surcharge, the requirements of the WCM no longer control and releases are made to evacuate the surcharge as quickly as possible.

6.2.1 Hourly Model Inputs

To facilitate an Hourly Model run, three sets of input are required (see Figure 12). The first is the hourly inflow hydrology for the flood event. The second is the initial pool elevation of reservoirs in the system. Lastly, the model requires three additional flood operation inputs.

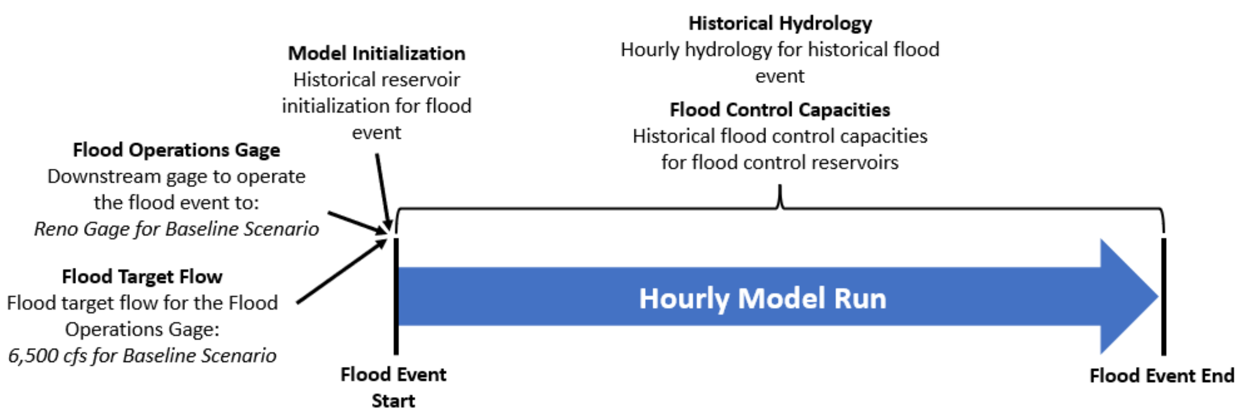

Figure 12: Schematic of Hourly Model Run Inputs.

6.2.1.1 Hourly Model Hydrology

The required hydrology inputs to the Hourly Model include hourly unregulated inflow datasets to the seven upstream reservoirs (Boca Reservoir, Stampede Reservoir, Prosser Creek Reservoir, Martis Creek Reservoir, Independence Lake, Donner Lake, Lake Tahoe) and five additional timeseries for lateral inflows to the Truckee River not captured by reservoirs. As a part of TBWMOP, two sets of hourly flood event hydrology were developed for the Hourly Model. The first set of hydrology includes each major historical flood event that occurred in the Truckee River Basin between water years 1986 and 2020. The second set of hydrology includes synthetic 1/100-year, .5/100-year, and .2/100-year scaled historical events (see **Section 4.2.2.1: CNRFC Hindcasts and Scaled Hindcasts**).

6.2.1.1.1 Historical Hydrology Set

The set of hourly data for historical flood events includes fifteen floods that occurred between water years 1986 and 2020. The historical flood events and their respective historical peak regulated flow at the Reno Gage are displayed in Table 21. The hourly datasets associated with each of these historical flood events were developed by Stetson Engineers, and the development process is documented in the *Technical Memorandum – Truckee River Basin Historical Hourly Data Development Methodologies: Water Years 1986 - 2021* (Lawler, Technical Memorandum - Truckee River Basin Historical Hourly Data Development Methodologies: Water Years 1986 - 2021, 2022).

Table 21: List of all hourly historical flood event datasets and their respective peak regulated flow at the Reno Gage.

Event Name	Reno Gage Peak Regulated Flow (cfs)
Feb 1986	10,000
Mar 1995	6,248
May 1995	5,335
May 1996	7,433
Jan 1997	18,100
Mar 1998	5,480
May 2005	4,100
January 2006	16,100
Feb 2006	5,678
Dec 2016	5,063
Jan 2017	12,200
Feb 2017	10,208
Runoff 2017	6,550
Apr 2018	6,453
Apr 2019	5,098

6.2.1.1.2 Scaled Event Hydrology Set

The scaled event hydrology employed in the TBWMOP was comprised of daily and hourly CNRFC scaled hindcasts. This dataset results from the same technology utilized to produce the standard CNRFC hindcast products used for the TBWMOP as described in **Section 4.2.2.1: CNRFC Hindcasts and Scaled Hindcasts,** though these hindcasts are manipulated to represent three flow recurrence probabilities: the 1/100, 0.5/100, and 0.2/100-year events. The unscaled hindcasts include an ensemble of runoff traces that can be compared back to the observed flows to evaluate how making select decisions based on the hindcasts would result with the historical flows. For the scaled hindcasts this is not possible. To create the analogous "observed" flow for the scaled hindcasts CNRFC also provided their runoff model output with the events observed precipitation scaled to the factors identified in Table 9.

Table 22: Table of hourly Scaled Hydrology events. The event name indicates the historical event that was scaled, and the Recurrence Interval indicates the recurrence that this historical event was scaled to.

Event Name	Recurrence Interval
Feb 1986	1/100 year
Feb 1986	.5/100 year
Feb 1986	.2/100 year
May 1996	1/100 year
May 1996	.5/100 year
May 1996	.2/100 year
Jan 1997	1/100 year
Jan 1997	.5/100 year
Jan 1997	.2/100 year
Runoff 2017	1/100 year
Runoff 2017	.5/100 year
Runoff 2017	.2/100 year

6.2.1.2 Hourly Model Initialization

The Hourly Model requires input initial pool elevations of each of the modeled reservoirs. For historical events, initial pool elevations for reservoirs are determined by the state of the Baseline Planning Model at the time the historical hourly event occurred. This interaction between the Planning Model and Hourly Model will be discussed more in depth in **Section 6.3: Baseline Scenario Modelling Framework**. For scaled events, initial pool elevations of Active Flood Control Reservoirs were set to each reservoir's top of conservation elevation as defined by the alternative operational scenario's regulation criteria. For the Baseline Scenario, these elevations are prescribed by the WCM, and for other alternative operational scenario's, the elevations are determined by the Revised Guide Curve and/or "By a Model" Method actions. The initial pool elevation for non-Active Flood Control Reservoirs, exclusive of Lake Tahoe, when running scaled events was set to their historical pool elevations from the United States Geological Survey website for initialization timestep of the scaled flood event (U.S. Geological Survey (USGS), 2021). Lake Tahoe initial pool elevation was set to the relatively high elevation of 6,228.0 ft for scaled events as a conservative measure.

6.2.1.3 Flood Operations Inputs

The Hourly Model requires three inputs for flood operations. The first input is the Flood Operations Gage(s). This input represents the downstream gage or gages that Active Flood Control Reservoirs are operated to in the modelling to during floods. This input can be either the Reno Gage, the Vista Gage or both the Reno and Vista gages. For the Baseline Hourly Model, this input was set to the Reno Gage, which is prescribed in the WCM.

The second input is the flood target flow. This input represents the downstream target flow at the input Flood Operations Gage. Active Flood Control reservoirs in the model are operated to meet this target flow. For the baseline scenario Hourly Model, this value was set to the flood target flow at the Reno Gage prescribed by the WCM of 6,000 cfs.

The third flood operations input required by the Hourly Model is the daily timeseries of flood control capacities for each of the flood reservoirs. For the baseline scenario Hourly Model, this data is input from the Baseline Planning Model. The Planning Model calculates flood reservoirs flood control capacity curves in accordance with the WCM, and this information is passed to the Hourly Model from the Planning Model. This interaction between the Planning Model and Hourly Model is described in more detail in the proceeding section.

6.2.2 Baseline Hourly Model Development

The Hourly Model was developed for the TBWMOP in two phases. In the first phase, the routing method in the model was developed, calibrated, and validated. The process is documented in the report *WMOP Truckee River Hourly River Model Time Lag Routing* (Olsen, Erkman, & Vandegrift, 2021). The second phase of development for the Hourly Model was to develop the reservoir operations logic in accordance with the WCM in the model. The Hourly Model's ability to perform these operations is verified in the report *Truckee River Hourly Model Verification for WMOP* (Noe, Truckee River Hourly Model Verification for WMOP, 2022).

6.3 Baseline Scenario Modelling Framework

The Baseline Scenario utilizes both the Planning Model and Hourly Model in tandem to model the basin between water years 1986 to 2022 under contemporary policy. Figure 13 provides a schematic of how the Planning Model and Hourly Model work together to model the Baseline Scenario, and the following three subsections discuss this figure in more detail.

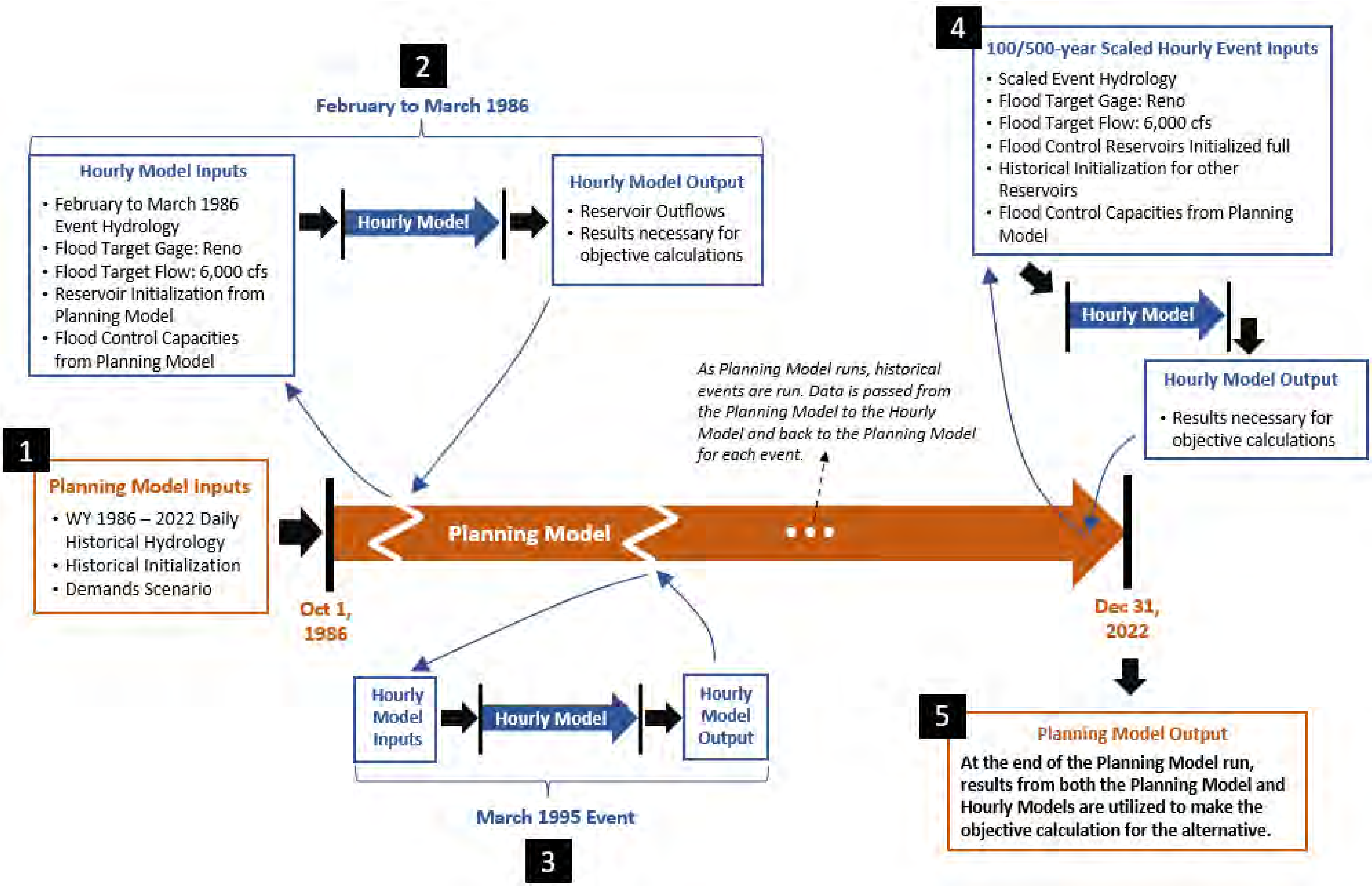

Figure 13: Schematic of the Baseline Scenario model structure. As the Planning Model runs, it initiates historical hourly model events.

6.3.1 Running Historical Flood Events within the Planning Model

As depicted in Step 1 of Figure 13, Planning Model inputs (see **Section 6.1.1: Planning Model Input**) are passed into the Planning Model, and the model run starts on October 1, 1986. The Planning Model continues to run until it arrives at the first historical hourly flood event in the run period, the February 1986 flood event. Once this occurs, the Planning Model pauses and sends the necessary input information, including flood control capacity calculations made in the Planning Model, to the Hourly Model (see **Section 6.2.1: Hourly Model Inputs**). This input information allows the Hourly Model to begin its run from the current state that exists within the Planning Model. The Hourly Model then runs the February to March of 1986 flood event (see Step 2 of Figure 13). Upon completion, results from the Hourly Model, including reservoir outflows and data needed for objective calculations, are sent back to the Planning Model. The Planning Model continues to run utilizing the reservoir outflow solutions from the Hourly Model until the time frame that the Hourly Model ran is passed; once this occurs, the Planning Model begins solving reservoir outflows again. The Planning Model continues until the next hourly flood event, March of 1995, and the Hourly Model run process is repeated (see Step 3 of Figure 13). The process of running historical flood events from the initialization state of the Planning Model at the time of the event and sending Hourly Model results back to the Planning Model continues for each of the flood events throughout the duration of Planning Model run.[10]

6.3.2 Scaled Hourly Events within the Planning Model

Step 4 of Figure 13 shows how the scaled hourly events are also run as a part of the Baseline Scenario. During the Planning Model run, the Hourly Model runs an additional eight times for each of the 1/100-year and .5/100-year events listed in Table 22.

The 1/100-year events were included in the alternative operational scenario due to limitations of the historical dataset in assessing flood damages. Because the flood damage objective RMS Flow Over Flood Target weights higher flows more, only the largest historical flood events contributed to this score (see **Section 5.1.2.4: Root Mean**

[10] An important distinction here is that the Hourly Model is only run by the Planning Model when flood operations on reservoirs are required. In other words, the Hourly Model is only run for events when the regulated flows at the Reno Gage in the Planning Model are projected to be above the Reno Flow Target of 6,000 cfs.

Squared Flow Over Flood Target). This resulted in only three of the fifteen historical flood events shown in Table 21 contributing to the flood damage objective (February 1986, the January 1997, and January 2006). To expand the space of events that contribute to the RMS Squared Flow Over Flood Target objective score, the 1/100-year scaled events, which exhibit a similar magnitude of RMS Flow Over Flood Target to the large historical events, were incorporated into the objective score and therefore ran as a part of the baseline scenario.[11]

The .2/100-year events were included in the Baseline Scenario because these events stressed the system and resulted in reservoir elevations that were near the dam failure elevation, allowing the dam failure constraint to be evaluated in alternative operational scenarios (see **Section 5.2.2.1: Cumulative Storage over Dam Failure Elevations)**.

As shown in Step 4 of Figure 13, the Hourly Model runs are initialized slightly differently than that of historical hourly events. To be conservative from a flood control perspective, Active Flood Control Reservoirs are initialized at their respective top of conservation storages (i.e., the reservoirs are initialized as full with no encroachment). Note, top of conservation storages are defined by the WCM for the Baseline Scenario. Non-Active Flood Control Reservoirs are initialized with their historical pool elevations. Once the hourly scaled events are run, results from the hourly model needed for objective calculations are passed back to the Planning Model.

6.3.3 Baseline Scenario Output

Step 5 of Figure 13 depicts how the objective calculations described in **Section 5.1: Objectives Modelling** are made within the Baseline Scenario. Once the Planning Model and all the associated Hourly Model runs are complete, information contained in the Planning Model relevant to the five Quantifiable Objectives is summarized and the objective calculations are made. These objective calculations represent the Baseline Scenario objective scores, and they provide the basis from which to make high level comparisons between the other modeled alternative operational scenarios.

[11] The decision to include 1/100-year events in the alternative operational scenario modelling was made by the Technical Team at a meeting in September of 2022.

7 Alternative Operational Scenario Modelling

Table 5 of **Section 2.4: Defining Alternative** outlines how actions were combined to make the alternative operational scenarios of the TBWMOP. Alternative Operational Scenario 1 represents the Baseline Scenario and was described in detail in the preceding section of this report. Alternative Operational Scenarios 2 through 5 each represent variations of flood control regulation criteria that were evaluated against one another and the Baseline Scenario to select the Preferred Operational Scenario for the study.

Alternative Operational Scenarios 2 through 5 each utilize the same modelling framework as the Baseline Scenario (see **Section 6: No-Action Alternative Operational Scenario Model Setup** and Configuration). The changes made to the Baseline Scenario to model Alternative Operational Scenarios 2 through 5 were limited to what was necessary to model the differences in regulation criteria represented by each alternative operational scenario's actions. These changes will be highlighted in each alternative operational scenario's respective subsection to follow.

Table 23: Table of required parameters for each action and the selection method used to select the parameter value.

Action	Parameter	Selection Method
"By a Model" Method	Exceedance Coefficient A	MOEA Analysis
	Exceedance Coefficient B	MOEA Analysis
	Exceedance Coefficient C	MOEA Analysis
	Percentage of Revised Guide Curve to Maintain	MOEA Analysis
	Reno Gage Flood Target Flow	Analysis of Inundation Maps
Revised Guide Curve	Reno Gage Flood Target Flow	Analysis of Inundation Maps
Reproportion of Little Truckee Flood Space	Boca Proportion of Little Truckee Flood Space Percentage	MOEA Analysis
Updated Target Location	Target Location	Defined by Alternative
Updated Target Flow	Reno Gage Flood Target Flow	Analysis of Inundation Maps
	Vista Gage Flood Target Flow	Analysis of Inundation Maps

The different combination of actions employed in Alternative Operational Scenarios 2 through 5 required selections of each action's parameters. Table 23 provides a summary of the parameters required by each action and the method used to select the parameters value. These actions were documented in detail in **Section 4: Action Modelling**.

The MOEA provided a robust technical approach and decision-making framework that allowed the Technical Team to select the best performing set of parameters for the "By a Model" Method and Reproportion of Little Truckee Flood Space actions. To accomplish this, the MOEA was configured to model Alternative Operational Scenario 3. [12] Once Alternative Operational Scenario 3 was modeled using the MOEA, the optimized parameters for these two actions were utilized in the remaining three alternative operational scenarios where applicable.

The following sections provide additional detail for how Alternative Operational Scenarios 2 through 5 were modeled. Alternative Operational Scenario 3 is discussed first as it constituted the most complicated modelling approach and was a prerequisite for modelling the remaining alternative operational scenarios. Next, Alternative Operational Scenario 2, 4 and 5 modelling is discussed along with descriptions of how each of these alternative operational scenarios incorporated the optimized parameters of Alternative Operational Scenario 3.

7.1 Alternative Operational Scenario 3: Dynamic Flood Risk Reduction Criteria

Alternative Operational Scenario 3 Modelling was completed in two efforts. First, the Baseline Scenario model was adapted to model the flood control regulation criteria represented by the actions of Alternative Operational Scenario 3 (see Table 24). Second, a MOEA was utilized to determine the necessary parameters associated with the "By a Model" Method and Reproportion of Little Truckee Flood Space actions. The development associated with these two efforts is described in detail in the following two subsections.

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[12] Note, the MOEA was utilized for Alternative Operational Scenario 3 because it constituted the alternative operational scenario in the study with the most dynamic set of actions.

Table 24: Alternative Operational Scenario 3 configuration of actions to address problems identified in the Plan Formulation.

Alternative		Problems/Opportunities				
Alternative Number	Description	Reservoir Refill	Fall Drawdown	Normal Flood Operations	Little Truckee Flood Space	
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	Actions

7.1.1 Alternative Operational Scenario 3 Model Setup and Configuration

The changes applied to the Baseline Scenario to model Alternative Operational Scenario 3 were limited to those provided in Table 25. Namely, the Alternative Operational Scenario 3 Model was configured to use the "By a Model" Method to determine flood space requirements as opposed to determining flood space requirements for Active Flood Control Reservoirs per the WCM (see **Section 4.2.2: "By a Model" Method for Required Flood Space**). Furthermore, the Alternative Operational Scenario 3 Model was configured to operate floods to both the Reno Gage and the Vista Gage. For the Alternative Operational Scenario 3 Model, the flood target flow for the Reno Gage and Vista Gages was input to be 6,500 cfs and 8,500 cfs, respectively (see **Section 4.1: Actions for Normal Flood Operations**). Lastly, the Alternative Operational Scenario 3 model was configured to utilize a revised proportion of flood space between Boca and Stampede Reservoirs (see **Section 4.3: Reproportion**).

Table 25: Changes applied to the Baseline Scenario modelling made to model Alternative Operational Scenario 3.

	Baseline Scenario	Alternative 3
Flood Space Requirements	Calculated per the WCM	Calculated per the "By a Model" Method
Flood Operations Target Gage	Reno Gage per the WCM	Reno Gage and Vista Gage
Flood Operations Max Flow Guide	6,000 cfs at Reno Gage per the WCM	6,500 cfs at Reno Gage 8,500 cfs at Vista Gage
Little Truckee Flood Space	26.7% in Boca Reservoir 73.3% in Stampede Reservoir	Reproportioned

7.1.2 Utilization of the MOEA in Alternative Operational Scenario 3 Modelling

Modelling the TBWMOP alternative operational scenarios necessitated the selection of parameters associated with the "By a Model" Method and Reproportion of Little Truckee Flood Space actions.[13] To accomplish this, a MOEA was used to model Alternative Operational Scenario 3. The proceeding subsections describe the configuration of the MOEA components within the context of the TBWMOP and how it was designed to determine the optimal set of parameters associated with the "By a Model" Method and Reproportion of Little Truckee Flood Space actions. These parameters were then used, where applicable, to model Alternative Operational Scenarios 2, 4 and 5. Refer to **Section 3: MOEA Overview** for an introduction to MOEA and its relevant definitions.

7.1.2.1 MOEA Configuration

Table 26 provides a summary of the configuration of the MOEA utilized in the TBWMOP. The following subsections document the MOEA configuration of each of the listed components of the MOEA.

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[13] The Flood Operations Flood Target Flows for the Reno and Vista Gages were excluded from the MOEA as they were determined by the Technical Team at the June of 2022 Workshop.

Table 26: Summary of MOEA configuration for the TBWMOP.

MOEA Component	WMOP Configuration
Decision Variables	Exceedance Coefficient A Exceedance Coefficient B Exceedance Coefficient C Percentage of Revised Guide Curve to Maintain Boca Proportion of Flood Space
MOEA Objectives	Annual Average Volume for Floriston Rate Average Prosser, Boca, and Stampede Storage Average Annual Volume for Flow Regime RMS Flow Over Flood Target Cumulative Storage Over Dam Failure Elevations
MOEA Constraints	Not worse than Baseline Scenario for: Annual Average Volume for Floriston Rate RMS Flow Over Flood Target
Function	Alternative 3 Model Number of Evaluations: 3,000
Output	Number of Non-Dominated Solutions: 150

7.1.2.1.1 Decision Variables

The MOEA was configured to utilize the five parameters associated with the "By a Model" Method and Reproportion of Little Truckee Flood Space action as decision variables. Each of these decision variables required two additional inputs to define the size and granularity of the decision variable space. The first additional input was the acceptable range of values of a given decision variable. The second input was the step size for a decision variable to limit the number of values within the acceptable range a decision variable may take in the MOEA run. Determining the range and step size of the decision variables provided efficiency of the MOEA analysis because it limited the decision variable space and, therefore, reduced the number of function evaluations the MOEA would need to make to converge on a solution.

The ranges and step sizes for the "By a Model" Method's Exceedance Coefficients A, B and C were determined by exploring the space of the Exceedance vs. Outlook Curve defined by these parameters (see **Section 4.2.2: "By a Model" Method for Required**

Flood Space). The goal in determining the ranges and step sizes of these decision variables was to limit the number of combinations of Exceedance Coefficients A, B, and C without excluding potential combinations of these parameters that may have represented viable Exceedance vs. Outlook Curves for the "By a Model" Method. Figure 14 provides a plot of the Exceedance vs. Outlook Curves associated with the 784 potential combinations of Exceedance Coefficients A, B, and C defined by their respective ranges and step sizes. This configuration was determined to be acceptable because in shorter outlooks, when forecasts are generally driven by meteorology, there was a high density of curves for the MOEA to explore. This would allow the MOEA to tune the Exceedance Coefficients A, B, and C to capture meteorological information contained in the forecasts. The larger outlooks of this configuration exhibited a much lower density of curves. This was determined to be sufficient because these outlooks would have more time to evacuate flood space should a storm materialize. Furthermore, the full range of exceedance percentages was still well represented in larger outlooks.

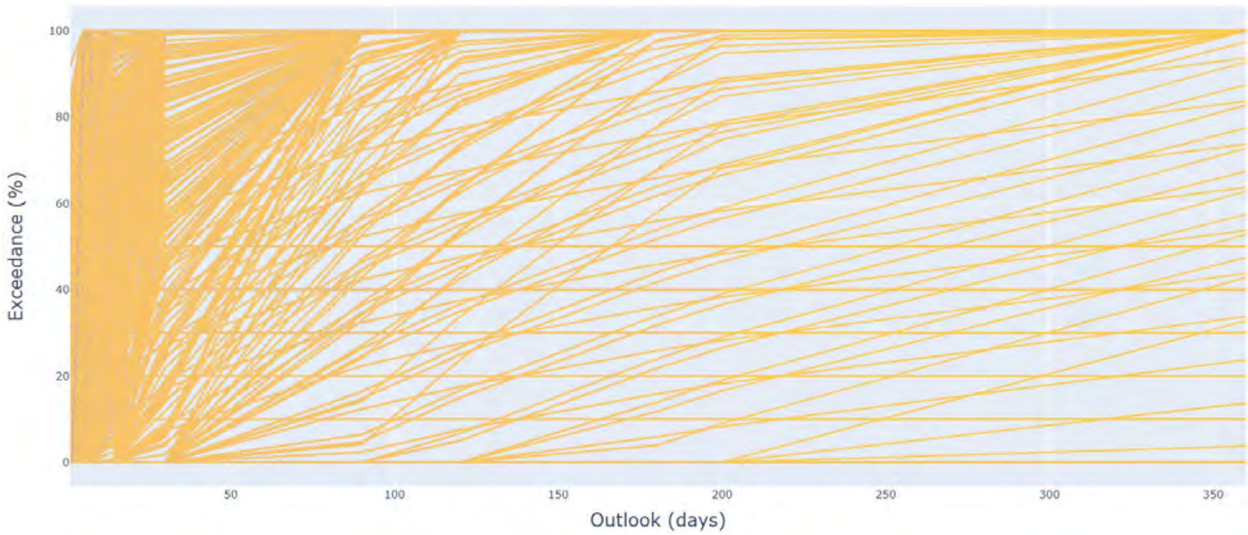

Figure 14: Possible Exceedance vs. Outlook Curves in the MOEA Analysis represented by the ranges and step sizes of Exceedance Coefficients A, B, and C.

The fourth decision variable associated with the "By a Model" Method, the Percentage of Revised Guide Curve to Maintain, was allowed to vary between 30% and 80% by 10% increments. This range was selected through preliminary testing of the MOEA and reasoning that percentages of 80% would provide marginal benefit to the basin while requiring a more complex operation.

Lastly, the Boca Portion of Flood Space Percentage decision variable was allowed to vary between 10% and 80% by 5% increments. The range and step size of this decision variable was limited only slightly to allow the MOEA to search most of the space for this decision variable, and the range was selected through discussions with basin operators of what they would consider feasible values.

Table 27 provides a list of each decision variable and its respective input range and step size. In total, the decision variable space utilized for the MOEA had a total of 70,560 unique combinations of decision variables. The machine available to the Technical Team to perform the MOEA analysis was able to run twenty-five models simultaneously, and each batch of twenty-five models took approximately 3.25 hours to complete. If every combination of the decision space was run, the analysis would have taken 382.2 days to complete. This was well outside the schedule for the project, and the MOEA offered an efficient method by which to thoroughly search the decision space while only looking at a fraction of the potential decision variable combinations (see **Section 7.1.2.1.5: Number of Evaluations**).

Table 27: Decision variables of the MOEA utilized in the TBWMOP and their respective allowable ranges and step sizes.

Action	Decision Variable	Range	Step Size	Possible Values
"By a Model" Method	Exceedance Coefficient A	0 to 42	6	7
	Exceedance Coefficient B	.4 to 1	0.1	7
	Exceedance Coefficient C	-100 to 50	10	16
	Percentage of Revised Guide Curve to Maintain	30% to 80%	10%	6
Reproportion of Little Truckee Flood Space	Boca Proportion of Flood Space Percentage	10% to 80%	5%	15
			Total Combinations:	**70,560**

7.1.2.1.2 MOEA Objectives

The objectives utilized by the MOEA were the same quantifiable objectives utilized to assess the performance of the TBWMOP alternative operational scenarios. These set of objectives include:

1. Annual Average Volume for Floriston Rate

2. Average Prosser, Boca, and Stampede Storage
3. Average Annual Volume for Flow Regime
4. RMS Flow Over Flood Target
5. Average Daily Increase in Flood Space Requirement
6. Cumulative Storage Over Dam Failure Elevations

The calculations for each objective, defined in **Section 5.1.2: Quantifiable Objectives**, were made for each evaluation of the Alternative Operational Scenario 3 Model within the alternative operational scenario's Planning Model.

7.1.2.1.3 Constraints

Two constraints identified during the Plan Formulation were applied in the MOEA to define the bounds/limits of acceptable performance of an evaluation of the Alternative Operational Scenario 3 Model made by the MOEA. The constraints limited solutions of the MOEA to those that scored equal to or better than the baseline scenario for the following two study objectives:

- Average Annual Volume for Floriston Rate
- RMS Flow Over Flood Target

A constraint in the MOEA was intentionally not applied for two constraints defined in the Plan Formulation of the study: the Cumulative Storage over Dam Failure Elevations constraint and the Average Annual Nixon Flow for Flow Regime constraint. Each of these constraints were configured as an MOEA objective to allow the algorithm to learn how to optimize this objective so that results of the MOEA resulted in (1) no increased risk of dam failure and (2) optimal environmental flows. MOEA results that showed *any* risk of dam failure or performances worse than the Baseline Scenario for environmental flows were filtered out prior to the selection process of Alternative Operational Scenario 3. Lastly, the number of constraints applied to the MOEA was also limited because of the rationale that scenarios only slightly worse than the Baseline Scenario may be worth further consideration and these could always be filtered out if desired in the selection process.

7.1.2.1.4 Function

The Alternative Operational Scenario 3 Model was configured as the function of the MOEA in the TBWMOP (see **Section 7.1.1: Alternative Operational Scenario 3 Model Setup and Configuration**).

7.1.2.1.5 Number of Evaluations

The MOEA was configured to evaluate the Alternative Operational Scenario 3 Model 3,000 times. This number of evaluations was determined to be adequate by conducting three MOEA test runs with a preliminary version of the Alternative Operational Scenario 3 Model. Table 28 provided a summary of the three test runs including the following information:

- Number of Evaluations – total number of times the Alternative Operational Scenario 3 Model was run by the MOEA.
- Successful Evaluations – of the total evaluations, the number of Alternative Operational Scenario 3 Model runs that ran successfully and passed the MOEA constraints.
- Failed Constraints – of the total number of evaluations, the number of Alternative Operational Scenario 3 Model runs that did not pass constraints.
- Run Time – the total run time, in days, of the three MOEA test runs.

Table 28: Summary of the three MOEA test runs.

MOEA Run Name	Number of Evaluations	Successful Evaluations	Failed Constraints	Run Time (days)
2,300 Evals	2,332	1,356	976	10.8
4,300 Evals	4,257	2,583	1,674	20.5
5,500 Evals	5,446	3,352	2,094	28.3

The test runs were seeded identically; that is, the 2,300 Evals test run was identical to the first 2,300 evaluations of the 4,300 Evals test run. Furthermore, the 4,300 Evals test run was identical to the first 4,300 evaluations of the 5,500 Evals test run. The Pareto Fronts of several of the objectives were compared between the three test runs to determine the benefit of larger numbers of evaluations. Figure 15 provides a comparison of the Pareto Front between the RMS Flow Over Flood Target and the Average Annual Days of Missing the Floriston Rate objectives for the 2,300 Evals and 4,300 Evals test run. [14] The plot shows an improvement in the Pareto Front, particularly in the region of RMS Flow Over Flood Target of 200,000 cfs or less. Figure 16 provides a similar Pareto Front comparison between 4,300 Evals and 5,500 Evals test runs. As shown in this plot, while the Pareto Front for the 5,500 Evals test is slightly more

[14] These tests were conducted with a preliminary version of the Alternative Operational Scenario 3 Model in parallel to the development of the final Alternative Operational Scenario 3 Model. At this time, slightly different objectives were being used to evaluate model performance of the MOEA.

defined than the 4,300 Evals test run, the overall Pareto Front did not improve between the two runs.

For the final MOEA Analysis, the decision space was reduced by nearly 60%. Leveraging the preliminary Pareto Front analysis and this reduction in the decision variable space, it was decided that 3,000 iterations was enough iterations for the MOEA.

Figure 15: Comparison of the Pareto Front of the 2,300 Evals MOEA test run to the 4,300 Evals MOEA test run for the RMS Flow Over Flood Target and Average Annual Days of Missing FR objectives. Minimizing each of these objectives represents a "better" model performance.

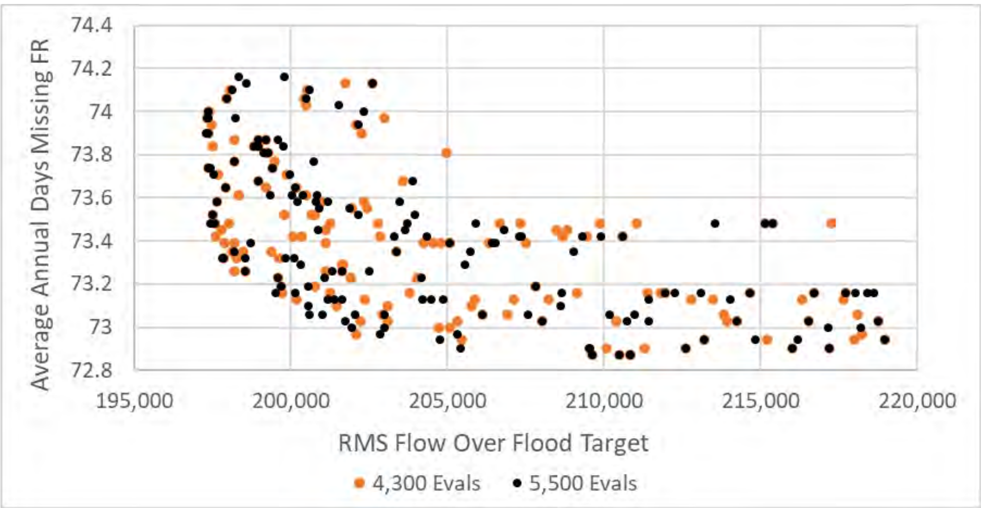

Figure 16: Comparison of the Pareto Front of the 4,300 Evals MOEA test run to the 5,500 Evals MOEA test run for the RMS Flow Over Flood Target and Average Annual Days of Missing FR objectives.

7.1.2.1.6 MOEA Output

The MOEA was configured to output a total of 150 non-dominated solutions. After tests were done, 150 was chosen because it was determined to be a large enough number to adequately characterize the Pareto Front.

7.1.2.2 MOEA Component Interactions

Figure 17 provides a schematic of the interaction between the MOEA components in the TBWMOP analysis as the MOEA solves. The MOEA solved by evaluating the six objectives' performances of the Alternative Operational Scenario 3 model for a given set of the five decision variables. The objective performances were analyzed by the NSGA II Algorithm, and a new set of five decision variables was selected to be input into the Alternative Operational Scenario 3 model. This process was repeated roughly 3,000 iterations of unique sets of decision variables. As the MOEA progressed, it learned the relationship between decision variables and objectives, and it intelligently selected new combinations of decision variables to attempt to improve objective performances. Once the 3,000 evaluations were completed, the MOEA output a set of 150 non-dominated solutions. The Technical Team and other key stakeholders analyzed this set of non-dominated solutions and selected the best performing solution to represent Alternative Operational Scenario 3 of the TBWMOP – the decision process is outlined in the report *WMOP Preferred Operational Scenario Selection Process* (Gwynn & Noe, WMOP Preferred Operational Scenario Selection Process, 2023). A brief overview of some of the MOEA results is presented in the paper in **Section 8: Results**.

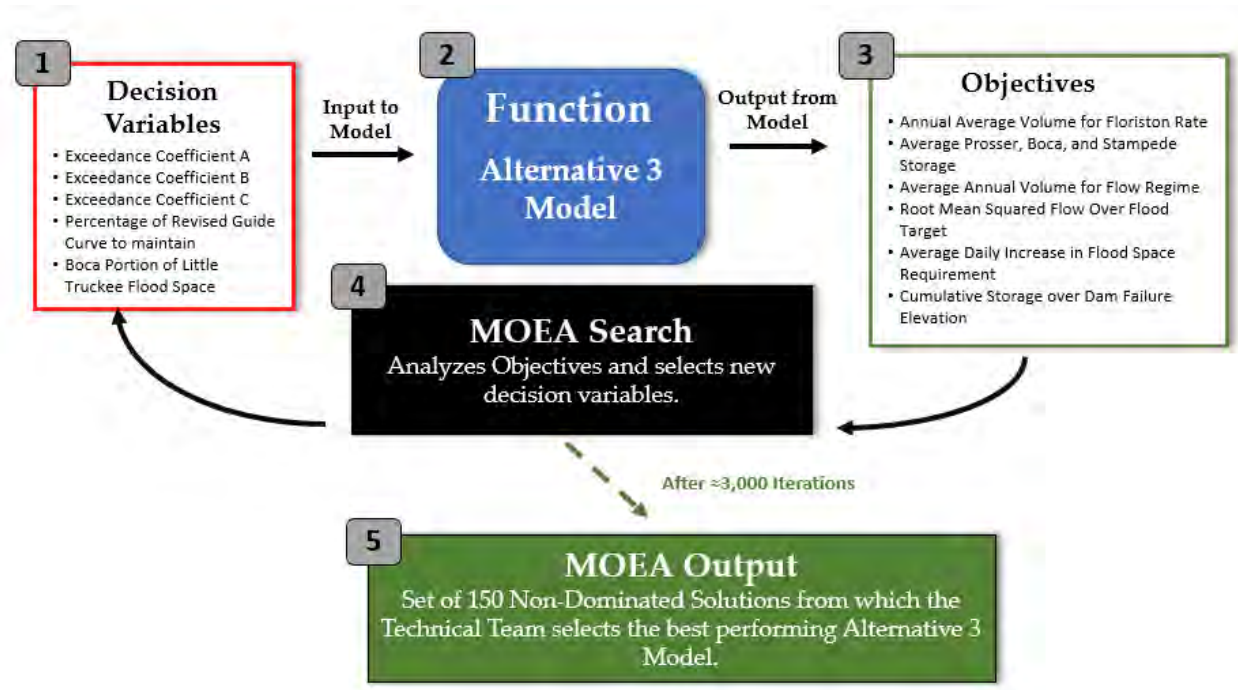

Figure 17: Schematic of the Relationship of MOEA Components

7.2 Alternative Operational Scenario 2: Optimizing Storage for Fisheries and Water Supply

Table 29 provides a summary of the actions that were combined to create Alternative Operational Scenario 2. The changes applied to the Baseline Scenario to model Alternative Operational Scenario 2 were limited to those provided in Table 30. The Alternative Operational Scenario 2 model was configured to use the "By a Model" Method to determine flood space requirements as opposed to determining flood space requirements for Active Flood Control Reservoirs per the WCM (see **Section 4.2.2: "By a Model" Method for Required Flood Space**). Furthermore, the Alternative Operational Scenario 2 Model was configured to utilize a revised proportion of flood space between Boca and Stampede Reservoirs (see **Section 4.3: Reproportion**). The parameters for these two actions were determined by the MOEA utilized in Alternative Operational Scenario 3. Lastly, the Alternative Operational Scenario 2 model was configured to have a flood target flow at the Reno Gage of 6,500 cfs as opposed to the 6,000 cfs target specified by the WCM (see **Section 4.1: Actions for Normal Flood Operations**). Note, the only difference between Alternative Operational Scenario 2 and Alternative Operational Scenario 3 is that the former operates floods to only the Reno Gage, while the latter operates floods to both the Reno and Vista gages.

Table 29: Alternative Operational Scenario 2 configuration of actions to address problems identified in the Plan Formulation.

Alternative		Problems/Opportunities				
#	Description	Reservoir Refill	Fall Drawdown	Normal Flood Operations	Little Truckee Flood Space	
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	Actions

Table 30: Changes applied to the Baseline Scenario modelling made to model Alternative Operational Scenario 2.

	Baseline Scenario	Alternative 2
Flood Space Requirements	Calculated per the WCM	Calculated per the "By a Model" Method
Flood Operations Max Flow Guide	6,000 cfs at Reno Gage per the WCM	6,500 cfs at Reno Gage
Little Truckee Flood Space	26.7% in Boca Reservoir 73.3% in Stampede Reservoir	Reproportioned

7.3 Alternative Operational Scenario 4: Updating Flood Risk Management

Table 31 provides a summary of the actions that were combined to create Alternative Operational Scenario 4. The changes applied to the Baseline Scenario to model Alternative Operational Scenario 4 were limited to those provided in Table 32. The Alternative Operational Scenario 4 model was configured to use the Revised Guide Curve action to determine flood space requirements as opposed to determining flood space requirements for Active Flood Control Reservoirs per the WCM (see **Section 4.2.1: Revised Guide Curve**). Furthermore, the Alternative Operational Scenario 4 Model was configured to utilize a revised proportion of flood space between Boca and Stampede Reservoirs (see **Section 4.3: Reproportion**). The parameters for these two actions were determined by the MOEA utilized in Alternative Operational Scenario 3. Lastly, the Alternative Operational Scenario 4 Model was configured to have a flood target flow for the Reno Gage during flood operations of 6,500 cfs as opposed to the 6,000 cfs target specified by the WCM (see **Section 4.1: Actions for Normal Flood Operations**).

Table 31: Alternative Operational Scenario 4 configuration of actions to address problems identified in the Plan Formulation.

Alternative		Problems/Opportunities				
#	Description	Reservoir Refill	Fall Drawdown	Normal Flood Operations	Little Truckee Flood Space	
4	Updating Flood Risk Management	Revised Guide Curve	Revised Guide Curve	Target Location: Reno Gage Reno Target Flow: 6,500 cfs	Reproportion	Actions

Table 32: Changes applied to the Baseline Scenario modelling made to model Alternative Operational Scenario 4.

	Baseline Scenario	Alternative 4
Flood Space Requirements	Calculated per the WCM	Calculated per the Revised Guide Curve
Flood Operations Max Flow Guide	6,000 cfs at Reno Gage per the WCM	6,500 cfs at Reno Gage
Little Truckee Flood Space	26.7% in Boca Reservoir 73.3% in Stampede Reservoir	Reproportioned

7.4 Alternative Operational Scenario 5: Hybrid Rule Curve

Table 33 provides a summary of the actions that were combined to create Alternative Operational Scenario 5. The changes applied to the Baseline Scenario to model Alternative Operational Scenario 5 were limited to those provided in Table 34. Alternative Operational Scenario 5 represented a unique approach amongst the Alternative Operational Scenarios in determining flood space requirements: flood space requirements were determined seasonally using two different actions. For the Reservoir Refill season (January 1st through July 5th), Alternative Operational Scenario 5 utilized the "By a Model" Method (see **Section 4.2.2: "By a Model" Method for Required Flood Space**). For the Spring Runoff season (October 1st to December 31st), Alternative Operational Scenario 5 utilized the Revised Guide Curve action (see **Section 4.2.1: Revised Guide Curve**).[15] Furthermore, the Alternative Operational Scenario 5 Model was configured to utilize a revised proportion of flood space between Boca and Stampede Reservoirs (see **Section 4.3 Reproportion**). Lastly, the Alternative Operational Scenario 5 Model was configured to have a flood target flow at the Reno

[15] Note, the time frame of July 6th through September 30th is excluded historically because there has been no flood space required by the WCM during this time frame.

Gage of 6,500 cfs as opposed to the 6,000 cfs target specified by the WCM (see **Section 4.1: Actions for Normal Flood Operations**). Note, the parameters required by Alternative Operational Scenario 5 for the "By a Model" Method and Reproportion of Little Truckee Flood Space actions were determined by the MOEA utilized in Alternative Operational Scenario 3.

Table 33: Alternative Operational Scenario 5 configuration of actions to address problems identified in the Plan Formulation.

Alternative		Problems/Opportunities				
Alternative Number	Description	Reservoir Refill	Fall Drawdown	Normal Flood Operations	Little Truckee Flood Space	
5	Hybrid Rule Curve	"By a Model" Method	Revised Guide Curve	Target Location: Reno Gage Reno Target Flow: 6,500 cfs	Reallocation	Actions

Table 34: Changes applied to the Baseline Scenario modelling made to model Alternative Operational Scenario 5.

	Baseline Scenario	Alternative 5
Flood Space Requirements during Reservoir Refill Season	Calculated per the WCM	Calculated per the "By a Model" Method
Flood Space Requirements during Fall Drawdown Season	Calculated per the WCM	Calculated per the Revised Guide Curve
Flood Operations Max Flow Guide	6,000 cfs at Reno Gage per the WCM	6,500 cfs at Reno Gage
Little Truckee Flood Space	26.7% in Boca Reservoir 73.3% in Stampede Reservoir	Reproportioned

8 RESULTS

The results in this paper are limited to high level and generalized results of the MOEA analysis. More in depth results and documentation on how the Technical Team selected both the best performing MOEA Scenario from the set of non-dominated solutions and the Preferred Operational Scenario in the study can be found in the referenced report *WMOP Preferred Operational Scenario Selection Process* (Gwynn & Noe, WMOP Preferred Operational Scenario Selection Process, 2023).

8.1.1 MOEA Run Summary and High-Level Results Parallel Axis Plot

Table 35 provides a summary of the MOEA Run. In total, the MOEA evaluated the Alternative Operational Scenario 3 model 2,965 times. Of the total evaluations, 1,705 (58%) were successful, 1,254 (42%) failed constraints (see **Section 7.1.2.1.3: Constraints**), and less than 1% failed due to a model error.

Table 35: MOEA Run summary.

	Number of Runs	Percent of Total
Successful Run	1,705	58%
Failed Constraints	1,254	42%
Model Fail	6	< 1%
Total	2,965	

The Parallel Axis Plot in Figure 18 provides a high-level summary of the non-dominated solutions, or MOEA Scenarios, output from the MOEA compared to the Baseline Scenario. Each line that connects and crosses the vertical axes on the Parallel Axes Plot, referred to as scenario lines, represents either a MOEA Scenario (colored grey or blue on the plot) or the Baseline Scenario (colored green on the plot). The vertical axes each represent an objective of the MOEA, and performance is indicated by where the scenario lines cross an objective's axis. Down on a vertical axis is always a better score for that objective. The blue line on this plot represents the MOEA Scenario that was ultimately selected by the Technical Team through the select Preferred Operational Scenario process (Gwynn & Noe, WMOP Preferred Operational Scenario Selection Process, 2023). Figure 18 provides a way to efficiently understand how much improvement over the Baseline Scenario the MOEA was able to identify for each objective and what tradeoffs, if any, exist between the objectives. Table 36 provides additional information on the percentile for each objective of the MOEA Scenario ultimately selected by the Technical Team amongst the 150 MOEA Scenarios and the percent benefit of the selected scenario relative to the total range of potential benefit. The total range of potential benefit is defined as the difference in score between the best performing MOEA Scenario and the Baseline Scenario for all objectives other than Average Prosser Boca and Stampede Storage and the Average Daily Increase in Flood Space Requirement objectives, which were not constrained by the study to be better than baseline. For these objectives, the total range of benefit is defined as the range between the best and worst performing MOEA scores for that objective.

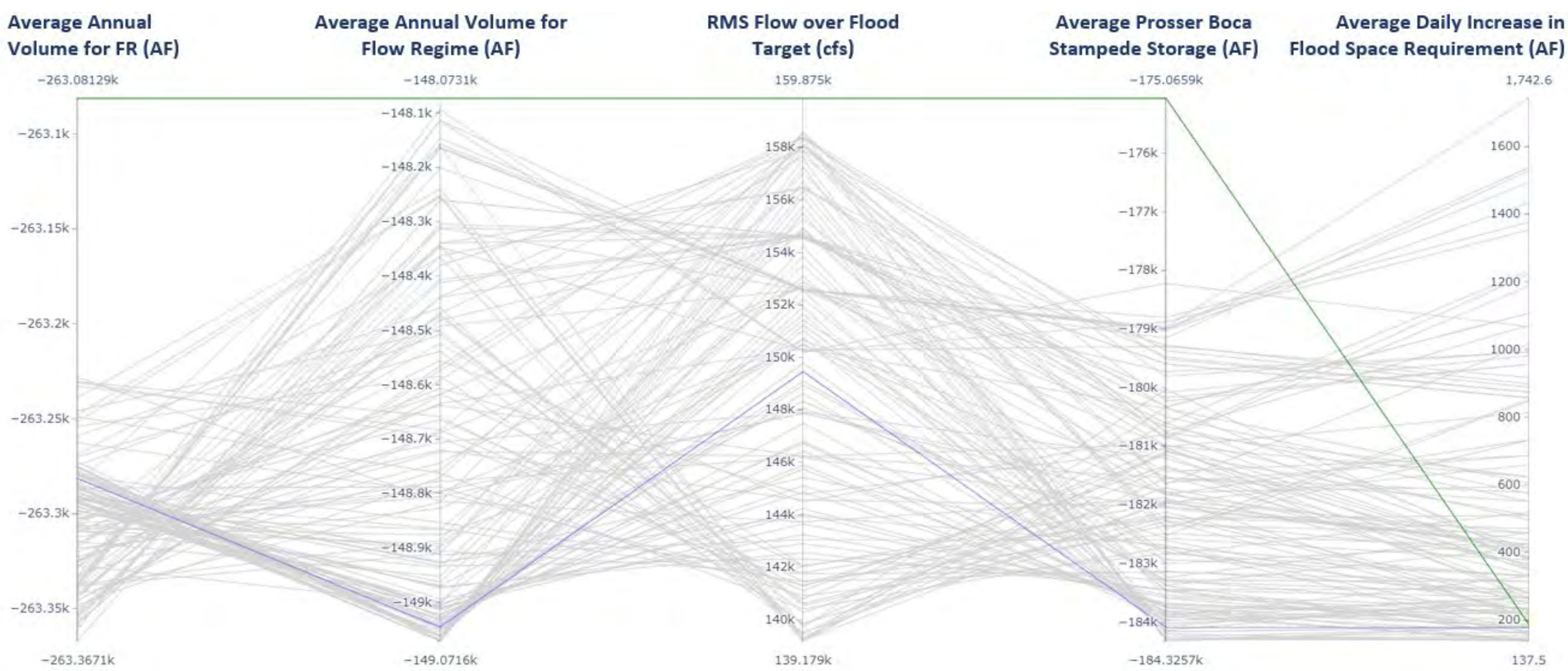

Figure 18: Parallel Axis Plot of the non-dominated solutions from the MOEA (grey and blue) and the Baseline Scenario (green). The MOEA Scenarios ultimately selected by the Technical Team through the select Preferred Operational Scenario process is colored blue.

Table 36: Percentiles for each objective of the MOEA Scenario ultimately selected by the Technical Team amongst the 150 MOEA Scenarios and the percent benefit relative to the total range of benefit for each objective.

	Objectives				
	Average Annual Volume for FR	Average Annual Volume for Flow Regime	RMS Flow over Flood Target	Average Prosser, Boca and Stampede Storage	Average Daily Increase in Flood Space Requirement
Percentile of Selected Scenario among the 150 MOEA Scenarios	20.3%	87.4%	53.8%	92.3%	88.8%
Benefit relative to range of Potential Benefit	69.1%	98.8%	50.3%	97.9%	98.8%

8.1.2 Improvements over Baseline Scenario

Table 37 provides a summary of the Baseline Scenario model scores for each objective in comparison to the best performing MOEA Scenario. In this table, smaller values signify better objective scores. The following subsections provide more context for these improvements in the objectives as well as timeseries results from MOEA Scenarios that support the observed improvements in objectives over the Baseline Scenario. Note, the Cumulative Storage over Dam Failure Elevations objective is not included in the analysis in this section because it evaluated to 0 AF for all MOEA Scenarios, signifying that no scenario failed the dam failure constraint.

Table 37: Overview of how the best MOEA Scenario for each of objective compared to the Baseline Scenario and a description of that improvement. Note, smaller values signify better scores for the objective values.

	Baseline Value	Best MOEA Scenario Value	Difference from Baseline
Annual Average Volume For FR	-263,081 AF	-263,371 AF	-290 AF
Average Annual Volume For Flow Regime	-148,073 AF	-149,072 AF	-998 AF
RMS Flow Over Flood Target	159,875 cfs	139,179 cfs	-20,697 cfs
Average Prosser Boca Stampede Storage	-175,066 AF	-184,326 AF	-9,260 AF
Average Daily Increase In Flood Space Requirement	187 AF	137 AF	-49 AF

8.1.2.1 Improvements to the Annual Average Volume for FR Objective

For the Annual Average Volume for FR objective, the best MOEA Scenario scored 290 AF better than the Baseline Scenario. This means that, on average, an additional 290 AF per year of FR water was available to meet the Floriston Rate target in the best MOEA Scenario for this objective per year over the Baseline Scenario. This is equivalent to 10,730 AF across the 37-year model run, and most of this benefit was observed in a select few years.

Figure 19 depicts the differences in the Floriston Rate Storage between an MOEA Scenario and the Baseline Scenario. In 2011, an additional 8,800 AF of Floriston Rate Storage is accumulated in the MOEA Scenario over the Baseline Scenario. The storage is, in part, utilized to better meet the Floriston Rate Target and, in part, carried over year to year. Figure 20 provides an example of how this storage was used to meet better meet Floriston Rate flows. In December of 2012, March of 2013, and April of 2013, the additional storage accumulated in the MOEA Scenario in 2011 could be utilized to meet a higher Floriston Rate Targets.

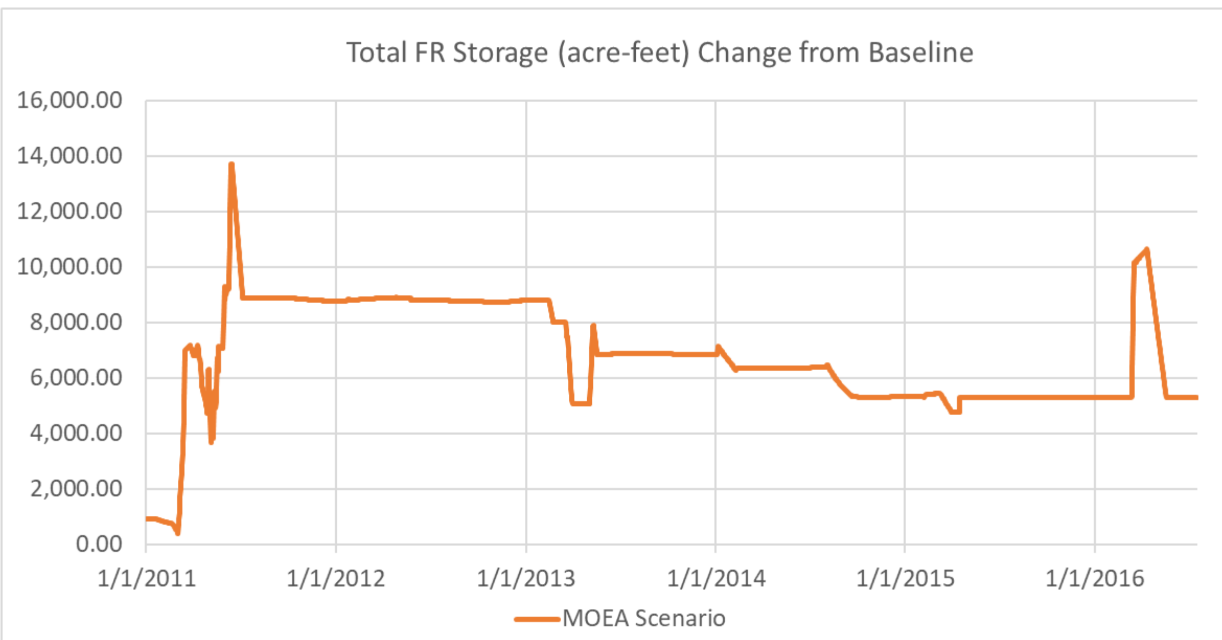

Figure 19: Daily difference in Total Floriston Rate Storage between the MOEA Scenario and Baseline Scenario for calendar years 2011 through 2016.

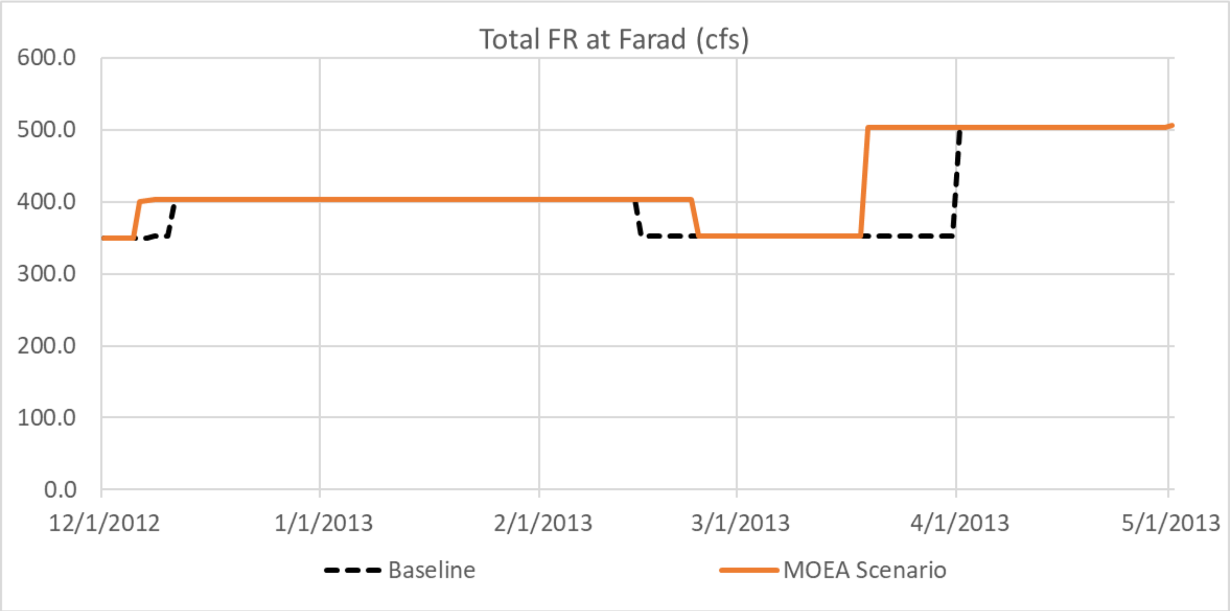

Figure 20: The daily total Floriston Rate Water at the Farad Gage in the MOEA Scenario and Baseline Scenario from December 2012 through April 2013.

8.1.2.2 Improvements to the Average Annual Volume for Flow Regime Objective

Similarly, the best performing MOEA Scenario for the Average Annual Volume for Flow Regime objective scored 998 AF better for this objective than that of the Baseline Scenario. This means that an additional 998 AF of water was available to meet flow regime targets per year in the best MOEA Scenario which is equivalent to roughly 36,926 AF across the 37-year model run. The benefits to the lower river environmental flows were seen in two drought years within the 37-year model run. In general, MOEA Scenarios were able to accumulate and/or retain additional environmental water supply storage in comparison to the Baseline Scenario during drawdown after wet years. This additional storage would carry over until a dry year when it would result in flow targets being met more adequately.

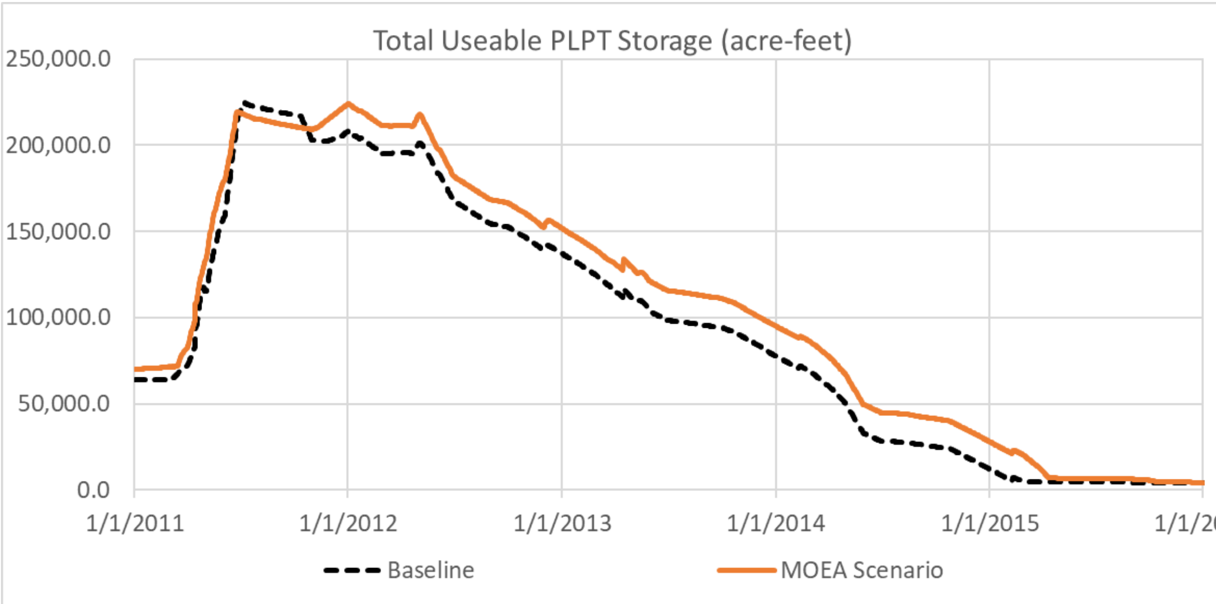

Figure 21: Comparison of an MOEA Scenario to Baseline Scenario values for Total Useable PLPT Storage, which represents storage in upper basin reservoirs that is used to meet lower river environmental flows.

To exemplify this, an MOEA Scenario is compared against the Baseline Scenario in Figure 21 and Figure 22. Figure 21 shows the Total Useable PLPT Storage, which represents storage in upper basin reservoirs that is used to meet lower river environmental flows, between 2011 and 2015. During the drawdown of calendar year 2011, an additional 15,000 AF of storage is retained in the MOEA Scenario over the Baseline Scenario. This storage difference is maintained until the drought year of 2015 when the additional storage in the MOEA Scenario is used to better meet environmental flow targets. Figure 22 shows results for environmental flows at the Nixon Gage during the spawning season of 2015. As shown in the plot, the additional storage in the MOEA Scenario is beneficially used during this time frame to meet environmental flow targets for an additional two months.

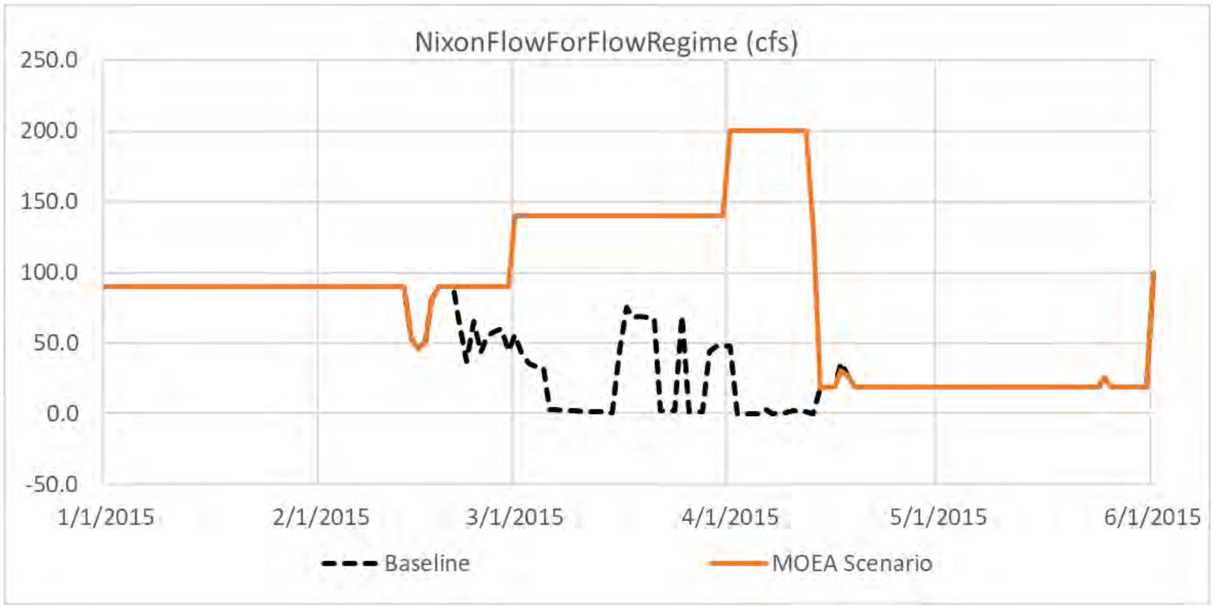

Figure 22: Comparison of lower river flows between the Baseline Scenario and an MOEA Scenario during the spawning season of 2015, a dry year.

8.1.2.3 Improvements to the RMS Flow over Flood Target Objective

The maximum improvement of the RMS Flow Over Flood Target objective was 20,697 cfs. While this value is less intuitive, analysis of the hourly modelling results shows a reduction in the peak flows at the Reno Gage in some of the hourly events and reductions in the non-peak flows in many events during time frames that the flood target flow was exceeded. Event peak flows at the Reno Gage were reduced by over 6,000 cfs in two of the .2/100-year scaled events and by over 3,000 cfs in 2 of the 1/100-year scaled events (see Table 38). Note, there was limited opportunity for improvement in peak flows for any of the historical hourly events because Active Flood Control Reservoirs were never forced to release due to surcharge during the peaks of the events (see **Section 5.1.2.4: Root Mean Squared Flow Over Flood Target**).

Table 38: Table of peak flows at the Reno Gage for each of the hourly events in the Baseline Scenario and an MOEA Scenario and their respective difference. Note, events with peak flows below 6,500 cfs are within the Reno Gage Max Flow Guide. Further note, the May 2005 event for the MOEA Scenario did not run because flows were never projected to get close enough to the Max Flow Guide at Reno to trigger an hourly event simulation.

Event	Baseline	MOEA Scenario	Difference
DecMay2017_500yr	63,604	63,604	0
Feb1986_500yr	57,247	50,055	-7,192
DecJan1997_500yr	41,609	35,523	-6,086
Feb1986_100yr	26,409	25,111	-1,298
DecJan1997_100yr	19,215	15,245	-3,970
DecMay2017_100yr	7,252	6,493	-759
1997Flood	18,010	18,011	1
Jan2006	16,285	16,287	2
May1996_500yr	15,657	15,207	-450
Jan2017	12,275	12,284	9
May1996_100yr	11,479	8,116	-3,363
Feb2017	10,305	10,295	-11
May1996	7,793	6,523	-1,271
Mar1998	6,528	6,699	170
March1995	6,481	6,651	170
April2018	6,295	5,449	-846
MarMay2017	6,045	6,481	437
Feb2006	5,784	5,268	-516
May2005	5,366	N/A	N/A
May1995	4,539	6,375	1,836

Figure 23 provides an example of the observed reduction in peak flows for the scaled 1/100-year January 1997 event by plotting the simulated Reno Gage flows in an MOEA Scenario and the Baseline Scenario. For this event, the MOEA Scenario reduces the peak Reno Gage by nearly 4,000 cfs from roughly 19,000 cfs to 15,000 cfs, which is a significant improvement. In general, peak flows of all events described in **Section 6.2.1.1: Hourly Model Hydrology** were either reduced or unaffected in comparison to the Baseline Scenario. Figure 23 also depicts the MOEA Scenario operating to the 6,500 cfs target once flood space evacuations begin around January 10th until early on January 15th. The Baseline Scenario is operated to 6,000 cfs per the WCM for over a week longer until January 22nd. The reason for this is two-fold. The first is the rate of evacuation. The MOEA Scenario can evacuate nearly 1,000 acre-feet a day more than the Baseline Scenario, and maintaining the ability to evacuate flood space more efficiently does represent a benefit over Baseline Scenario even though this benefit is not captured in the

RMS Flow Over Flood Target objective score.[16] The second is that the MOEA Scenario has less water to evacuate because, after the storm, the 50,000 acre-feet of total flood space in the basin does not have to be fully evacuated like it is in the Baseline Scenario because the "By a Model" Method does not "see" another storm in the forecast.

These potential benefits and hourly results will be discussed more in *WMOP Preferred Operational Scenario Selection Process* (Gwynn & Noe, WMOP Preferred Operational Scenario Selection Process, 2023).

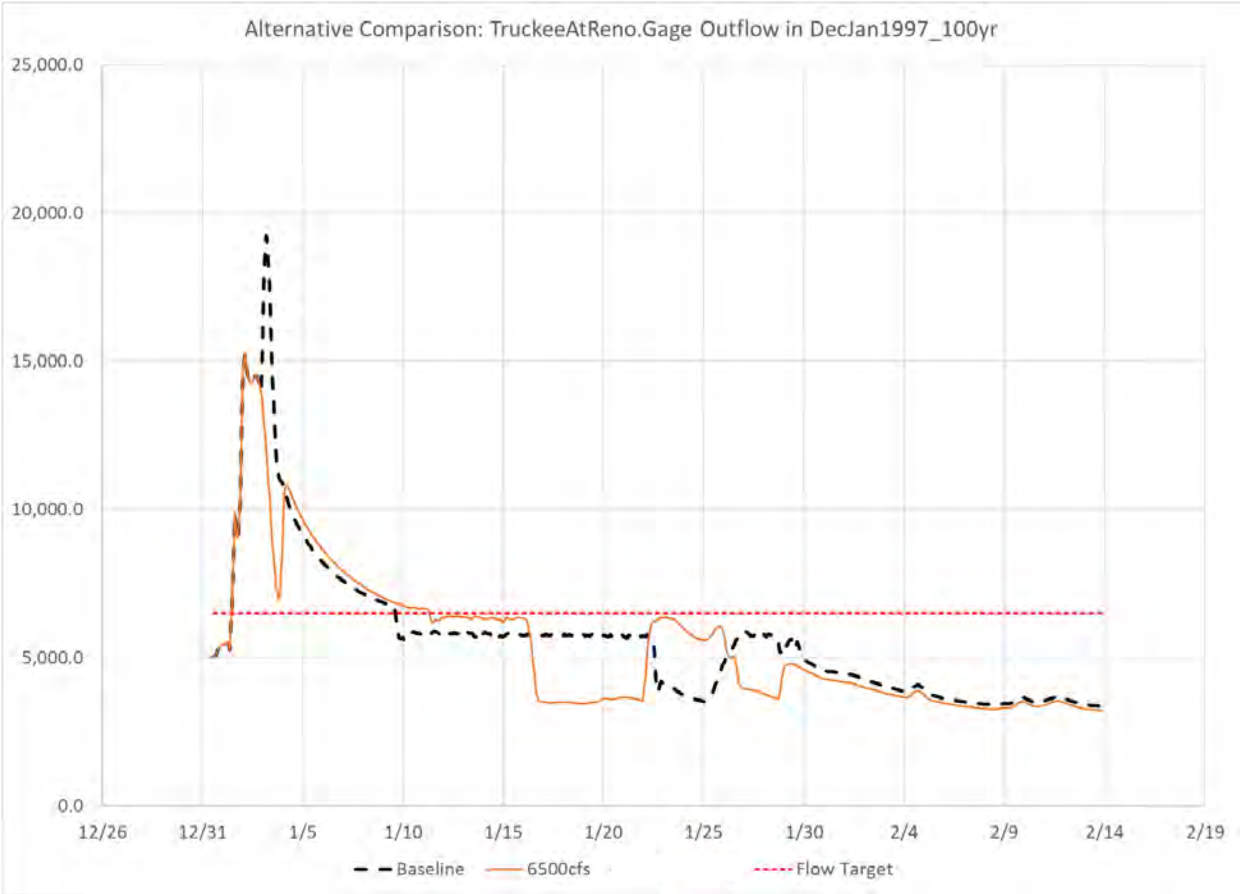

Figure 23: Simulated results at the Reno Gage for the MOEA Scenario and Baseline Scenario during the January 1997 Event. Note, the MOEA Scenario is operated to the Flow Target of 6,500 cfs shown in the plot. The Baseline Scenario is operated to 6,000 cfs per WCM.

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[16] This benefit is not captured in the RMS Flow Over Target Calculation because, when evacuating flood space, flows maintained below the flood target flow do not represent damages and are therefore not included in the RMS Flow Over Flood Target calculation (see **Section 5.1.2.4 Root Mean Squared Flow Over Flood Target**).

8.1.2.4 Improvements to the Average Prosser Boca Stampede Storage Objective

The best MOEA Scenario scored 9,260 AF better for the Average Prosser Boca Stampede Storage objective than the Baseline Scenario; that is, the best MOEA Scenario shows the ability of having, on average, an additional 9,260 AF of combined storage in the three reservoirs.

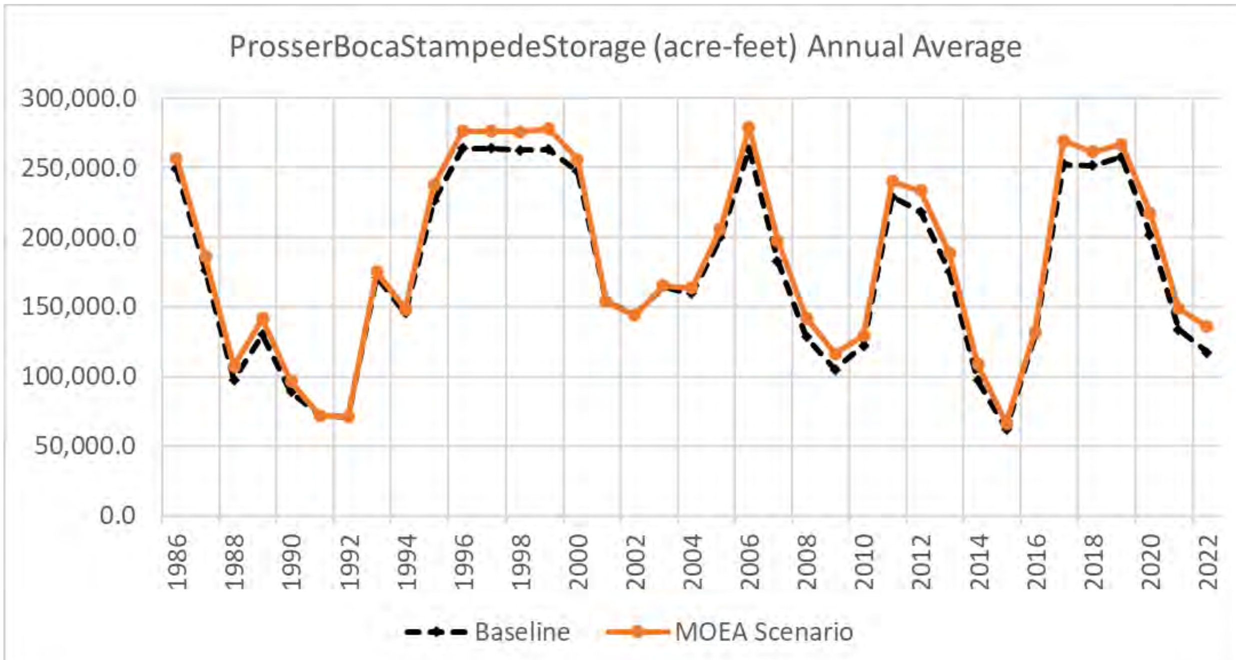

Figure 24: Annual average combined storage of Prosser, Boca, and Stampede Reservoirs for an MOEA Scenario and the Baseline Scenario.

Figure 24 shows how an MOEA Scenario compared to the Baseline Scenario for annual average values of total combined storage for Prosser, Boca, and Stampede Reservoirs. In some years, the MOEA Scenario shows more than 15,000 AF additional storage on average in the three reservoirs. Figure 25 shows Prosser Creek Reservoir's storage for both the Baseline and MOEA Scenario during 2011. As shown in the plot, Prosser's fill curve is much smoother than the Baseline Scenario. In fact, the behavior exemplified in the Baseline Scenario where Prosser Creek Reservoir fills some, then spills, then fills again is undesirable by basin stakeholders and represented some of the motivation for the TBWMOP study. Regardless of this undesirable fill pattern on Prosser Creek Reservoir in the Baseline Scenario, it still fills; however, the operations in the MOEA Scenario exhibit more flexibility on flood space requirements by allowing fill to occur earlier. Similar flexibility of being able to fill sooner is exhibited on Boca and Stampede Reservoir during this time frame as well (plots not provided). This earlier fill on Prosser is particularly useful because its project water is primarily used to support the

Threatened and Endangered species in the Lower Truckee River which requires releases to supplement the runoff in May and June—before the reservoir is permitted to be full in the Baseline Scenario.

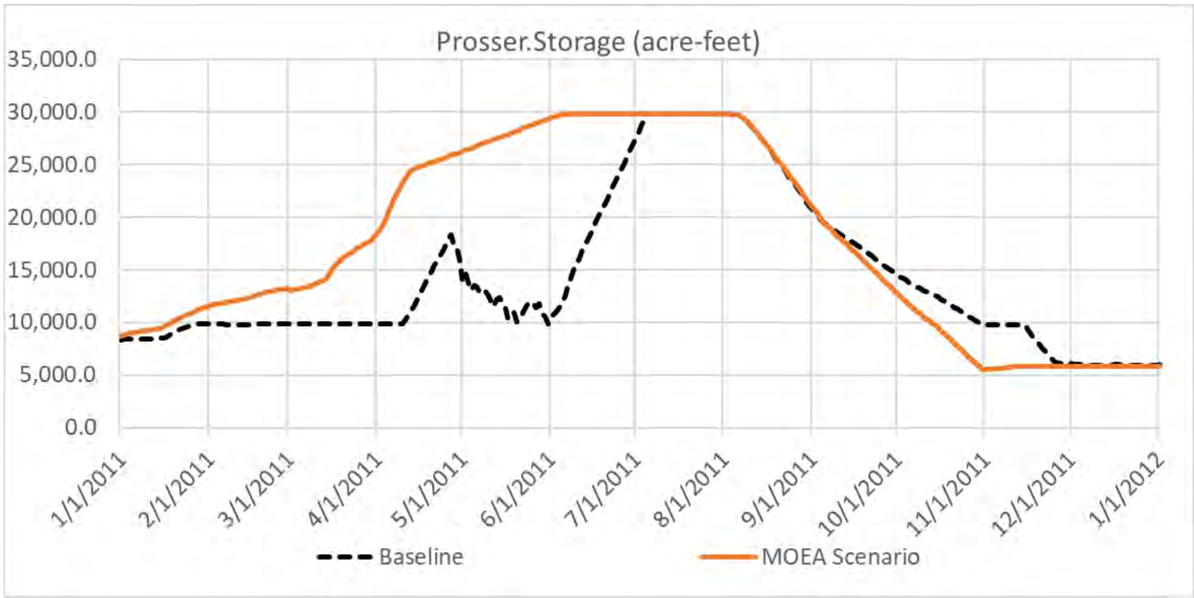

Figure 25: Storage curves for the Baseline Scenario and an MOEA Scenario during the fill and drawdown season in 2011.

Lastly, Figure 26 shows the difference between Prosser, Boca, and Stampede Reservoir storage between the Baseline and the MOEA Scenario. This plot shows that during the refill season, the three reservoirs accumulated a large volume of water over the Baseline Scenario by filling earlier. The scenarios equalize in the summer as all the reservoirs fill in the Baseline Scenario as well. However, in the fall, drawdown flexibility in the MOEA Scenario allows reservoirs to retain additional storage, and this storage is carried into the future to be used to meet water demands during a drier year.

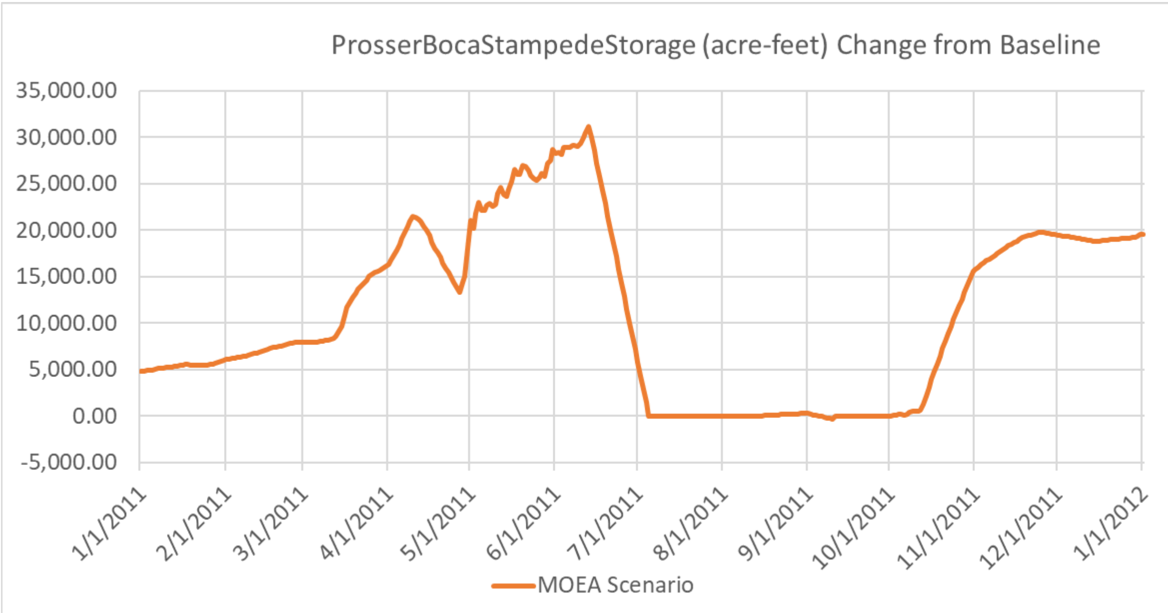

Figure 26: Change from the Baseline Scenario of an MOEA Scenario for the total combined storage of Prosser, Boca, and Stampede Reservoirs in 2011.

8.1.2.5 Improvements to the Average Daily Increase in Flood Space Requirement Objective

The water supply benefits of the MOEA scenario are achieved by allowing encroachment into flood space when there is no flood in the forecast then evacuate the flood space should a flood come into the forecast. The Average Daily Increase in Flood Space objective shows on average how quickly the flood space is required to be evacuated in the MOEA Scenario. Scenarios that require less dramatic evacuation of flood space are desired for operational and environmental reasons. In the Baseline Scenario, the flood space requirement is not adaptive to forecasted rain events and the required flood space only increases when required by the snowmelt parameter in the spring and with the fall drawdown. Because of this the Average Daily Increase in Flood Space Requirement objective is primarily for evaluating MOEA Scenarios against each other, and it is rather remarkable that the best MOEA Scenario showed a 49 AF improvement in the Average Daily Increase in Flood Space Requirement over the Baseline Scenario. As expected, most MOEA Scenarios performed worse than the Baseline Scenario as the necessity to evacuate flood space is one of the operational costs that would be required to achieve the potential water supply benefits obtained from encroaching into flood space. As shown in Figure 18, the selected MOEA Scenario was one of best performers for this objective among the MOEA Scenarios. Additional discussion of the results of the Average Daily Increase in Flood Space Requirement is can be found in **Section 8.1.4: Exploring the “By a Model” .**

8.1.3 Objective Tradeoffs

Figure 27 provides a scatter plot of the Average Annual Volume for Flow Regime objective and the RMS Flow Over Flood Target objective scores for both the Baseline and MOEA Scenarios.[17] As exhibited in the plot by the approximated Pareto Front (red dashed line), there exist relatively well-defined tradeoffs between these two objectives. This behavior was anticipated because the MOEA Scenarios that performed better for reducing flood damage have less encroachment into the flood space and evacuated flood space more aggressively. The tradeoff of these precautionary measures is that they limit the ability to accumulate additional storage to help meet environmental flow targets during dry periods.

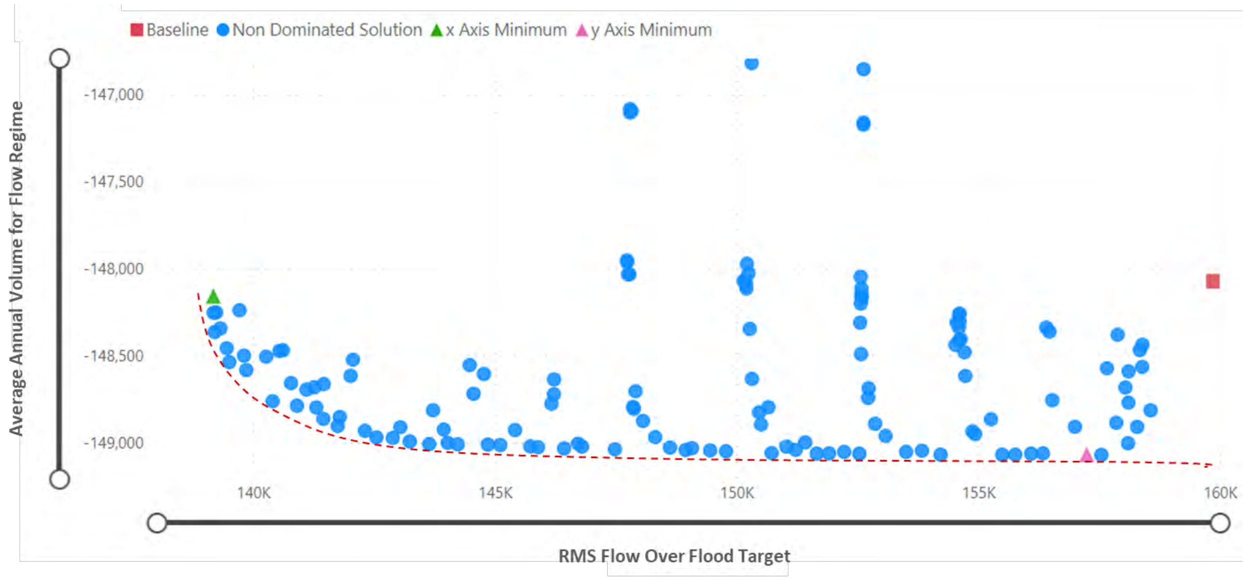

Figure 27: Plot of Average Annual Volume for Flow Regime and RMS Flow Over Flood Target objective scores for the Baseline and MOEA Scenarios. The Pareto Front between the two objectives is estimated by the red dashed line.

To extend this idea, Figure 28 provides the Exceedance vs. Outlook Curves used to determine flood space requirements in the best performing MOEA Scenario for reducing flooding (green triangle in Figure 27) and the best performing MOEA Scenario for improving environmental flows in the lower river (purple triangle in Figure 27). As described in **Section 4.2.2.7: Exceedance vs. Outlook: Balancing Hindcast Skill with**

[17] Because the MOEA Analysis used 6 objectives, the space of the MOEA results was six dimensional. To reduce the complexity of viewing results, plots comparing the results of the MOEA were limited to two objectives at once. While each non dominated solution lies on the Pareto Front of all six objectives, the two-dimensional plots were helpful to identifying what the characteristics of the Pareto Front *between two objectives*. This provided insight to the tradeoffs between objectives represented in the non-dominated solutions to the MOEA.

Risk, the Exceedance vs. Outlook Curve defines how conservative (or not) the "By a Model" Method is in determining flood space requirements. Comparing the two curves in Figure 28, generally small exceedances of the ensemble forecasts were used to determine the flood space requirements of the MOEA Scenario that performed better at flooding: this MOEA Scenario utilized ensemble traces with larger volumes to calculate the required flood space. As a result, the scenario operated more conservatively by leaving more space in reservoirs to capture floods, and this came at a cost to accumulating storage in reservoirs that could be used to meet flow regime targets in the lower river (see Figure 28).

The MOEA Scenario that performed best at meeting the environmental flow regimes used relatively higher exceedances of the ensemble forecasts, or ensemble traces with smaller volumes, to determine flood space requirements: this scenario operated less conservatively by allowing more space in reservoirs to store inflows used to meet environmental flow regimes during dry periods. This less conservative operation came at a cost to the flood damage objective.

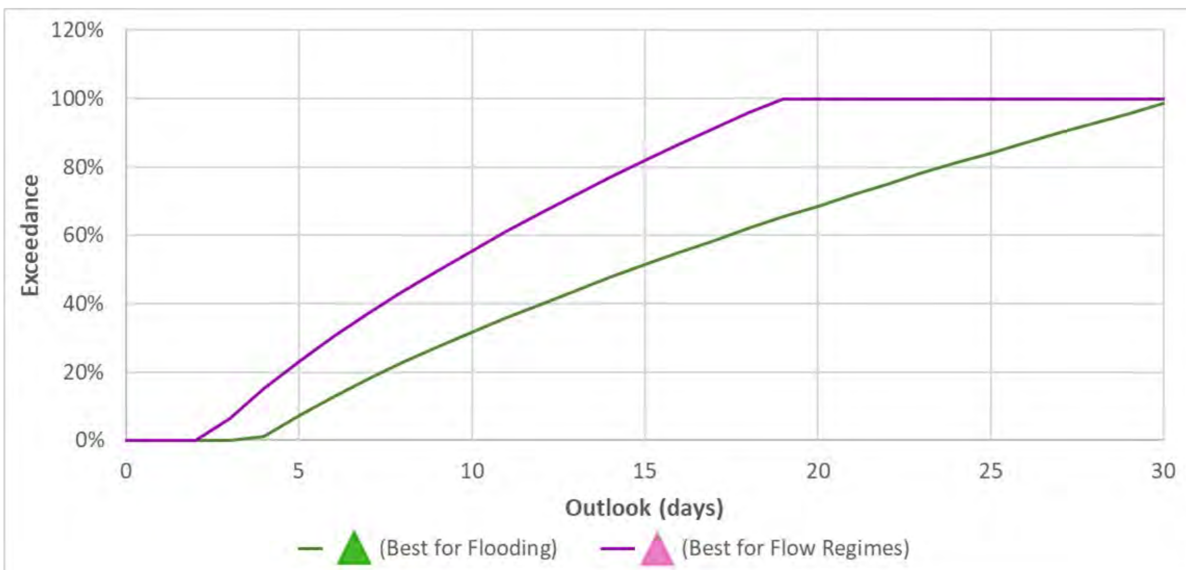

Figure 28: Plot of the Exceedance vs. Outlook Curves for the best performing MOEA Scenarios for flooding (green) and meeting environmental flows (purple).

Similar plots evaluating the tradeoffs between objectives are configured in the following figures for different objectives. Figure 29 illustrates the tradeoffs in the MOEA Scenarios between the Annual Average Volume for FR and RMS Flow Over Flood Target objectives. The Annual Average Volume for FR objective is like the Average Annual Volume for Flow Regime except that it evaluates a scenario's ability to accumulate and utilize water supply to meet the Floriston Rate Target. As a result, similar yet slightly less pronounced tradeoffs exist between the objectives in Figure 29 as did with the objectives in Figure 28.

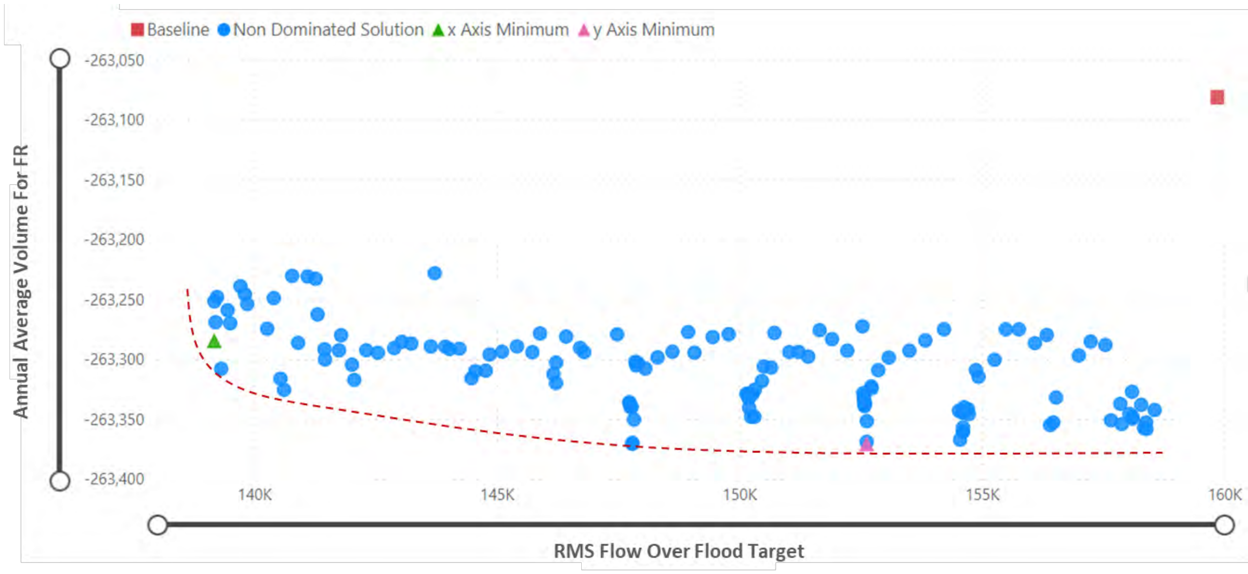

Figure 29: Plot of Annual Average Volume for FR and RMS Flow Over Flood Target objective scores for the Baseline and MOEA Scenarios. The Pareto Front between the two objectives is estimated by the red dashed line.

Figure 30 provides a plot of the Annual Average Volume for FR and the Average Annual Volume for Flow Regime objectives. A Pareto Front exists between these two objectives though it is less well defined than those of the previous two examples. The tradeoffs between these objectives are largely due to the Reproportion of the Little Truckee Flood Space action. As an example, in scenarios where the Reproportion of the Little Truckee Flood Space action specifies more flood space to be required in Boca Reservoir (i.e., less space available for water supply) and less flood space in Stampede Reservoir (i.e., more space available for water supply), Boca Reservoir's project water (Floriston Rate Project Water) could be adversely affected and Stampede Reservoirs Project water (environmental flows project water) could see benefits. The converse is also true when less flood space is required in Boca Reservoir and more in Stampede Reservoir. As shown in Figure 30, the Average Annual Volume for Flow Regime objective is more sensitive than the Annual Average Volume For FR objective to this interaction.

Figure 31 provides a plot of the Average Annual Volume for Flow Regime and Average Prosser Boca Stampede Storage objectives. This plot is unique in that it shows a positive correlation between the two objectives. This behavior was anticipated because project water that is used to meet environmental flow regime targets is stored in Prosser and Stampede and is generally the largest category of water in storage among the three reservoirs.

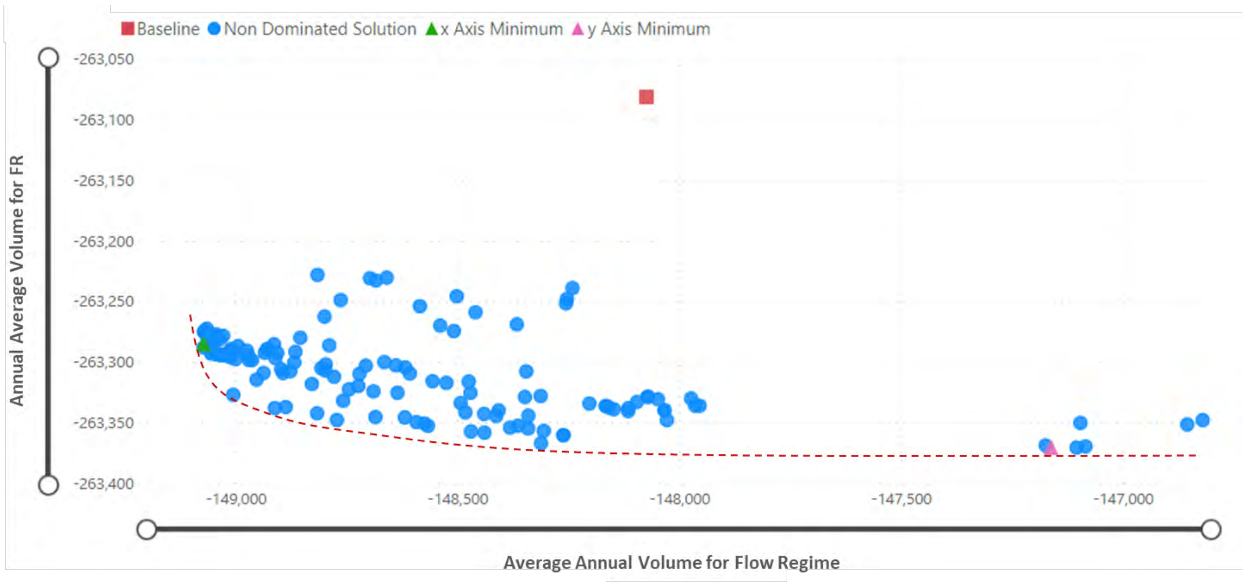

Figure 30: Plot of Annual Average Volume for FR and Average Annual Volume for Flow Regime objective scores for the Baseline and MOEA Scenarios. The Pareto Front between the two objectives is estimated by the red dashed line.

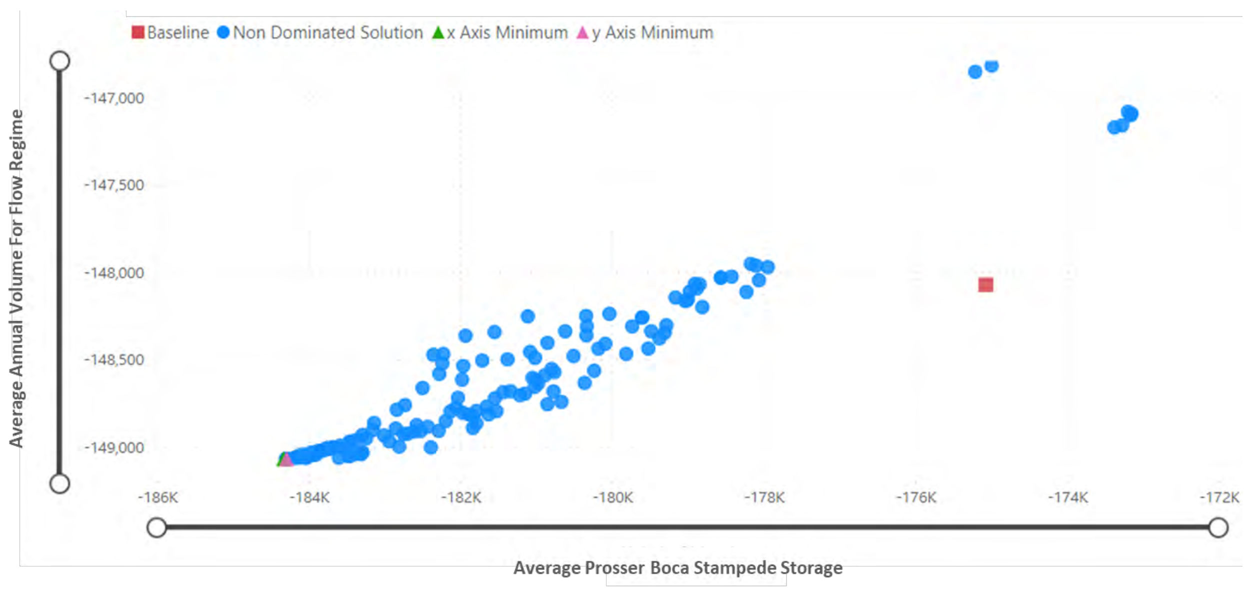

Figure 31: Plot of Average Annual Volume for Flow Regime and Average Prosser Boca Stampede Storage objective scores for the Baseline and MOEA Scenarios.

8.1.4 Exploring the "By a Model" Method

As described in **Section 4.2: Actions for Reservoir Refill and Fall Drawdown Problems**, the "By a Model" Method action was designed to address problems that the Technical Team identified with reservoir refill and drawdown by making calculations of flood space requirements using CNRFC ensemble hindcasts. This section is designed to explore the results of utilizing this action in the modelling.

An MOEA Scenario was selected with the decision variable configuration outlined in Table 39. The Exceedance Coefficients in this table utilize Equation 12 to define the Exceedance vs. Outlook Curve for this MOEA Scenario. As shown in Figure 32, the Exceedances used to calculate flood space requirements grow with outlook. Utilizing this relationship with CNRFC hindcasts, flood space requirements were calculated for the duration of this MOEA Scenario for each of the Active Flood Control Reservoirs.

Table 39 : Decision variable configuration that represents the MOEA Scenario discussed in this section.

	MOEA Scenario Decision Variables
Exceedance Coefficient A	12
Exceedance Coefficient B	0.7
Exceedance Coefficient C	-10
Percentage of Revised Guide Curve to Maintain	30%
Boca Portion of Flood Space	45%

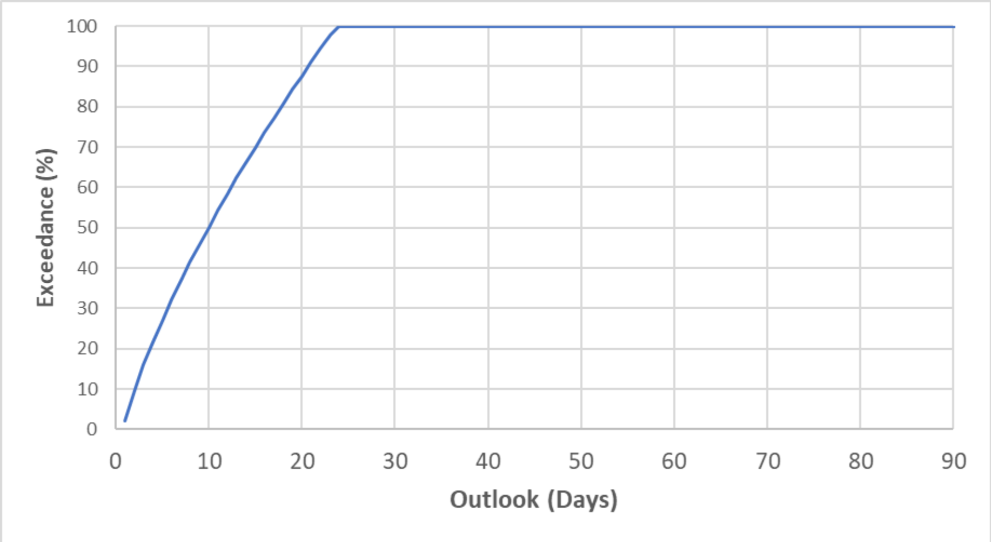

Figure 32: Exceedances vs. Outlook Curve associated with the Exceedance Coefficients from Table 39.

Figure 33 illustrates the differences in flood space requirements between the Baseline and MOEA Scenario in WY 2015, which was a dry year. In the Baseline Scenario, Prosser Creek Reservoir is required to draw down starting in October, and it is required to be fully drawn down to 9,800 AF by November 1st. Furthermore, the reservoir is not allowed to start filling until April 10th. In the MOEA Scenario, Prosser Creek Reservoir is required to draw down in November only to 23,840AF, the flood control capacity associated with reserving 30% of the Revised Guide Curve (defined by the Percentage of Revised Guide Curve to Maintain variable). The flood control capacity for Prosser Creek Reservoir remains constant at this level in the MOEA Scenario until early March when reductions in flood space requirements begin to allow for reservoir refill. At no point in 2015 was more flood space required than the minimum required 30% of Revised Guide Curve per the “By a Model” Method. This is because little to no storms were hindcasted in 2015, and the “By a Model” Method allowed for reservoir encroachment into flood space up to 30% of the Revised Guide Curve because there was no forecasted risk of flooding. This operation exhibits the flexibility of the “By a Model” Method that could allow for potential benefits to water supply in dry years like 2015.

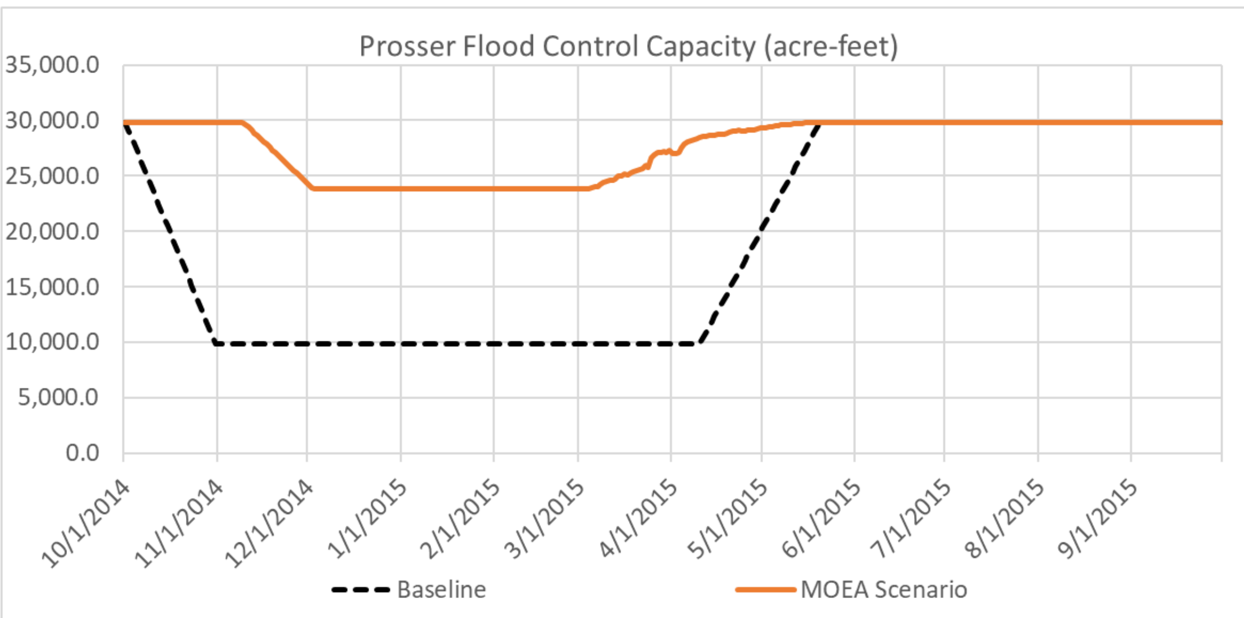

Figure 33: Prosser Flood control capacity during WY 2015, a dry year.

Figure 34 depicts differences in the Baseline Scenario and MOEA Scenario flood space requirements in water year 2017, an extremely wet year where several floods occurred. In the Baseline Scenario, Prosser Creek Reservoir drawdown requirements are identical to those of the Baseline Scenario in water year 2015. However, because water year 2017 was wet, refill is not allowed to begin until early June. In the MOEA Scenario, Prosser Creek Reservoir drawdown requirements are like those of the water year 2015 MOEA Scenario. However, during the timeframe in which Prosser Creek Reservoir is required to be drawdown to 23,840 AF, there are several instances in January and February where Prosser Creek Reservoir's flood control capacity increases sharply in response to a flood resulting in no encroachment into flood space for a brief period. Instances of this behavior also occur during reservoir refill when runoff exceeded the Reno flood target, but they are of longer duration. These sharp increases in flood space requirements are due to floods that the "By a Model" Method sees and responds to by requiring evacuations of flood space if the reservoir has encroached. Once the storm has passed, the flood control capacity returns to the level defined by the Percentage of Revised Guide Curve to Maintain, and the reservoir is allowed to encroach into its flood space again (or maintain the encroachment that occurred during the flood). Basin operators and administrators found this "flashiness" in flood control capacity undesirable because it could result in (1) operations that were infeasible to implement or (2) fluctuations in river flows that were harmful to the environment. This issue represented one of the major concerns with the "By a Model" Method, and it was resolved through discussions and additional modelling during the select Preferred Operational Scenario process. Ultimately, this resolution involved creating a new alternative operational scenario that combined Alternative Operational Scenario's 2 and 4. This new alternative operation scenario introduced an additional conservative measure to flood space requirement calculations that delayed the fill in big years and smoothed flows in the river (Gwynn & Noe, WMOP Preferred Operational Scenario Selection Process, 2023). For more documentation on this additional alternative, reference the paper *WMOP Preferred Operational Scenario Selection Process*.

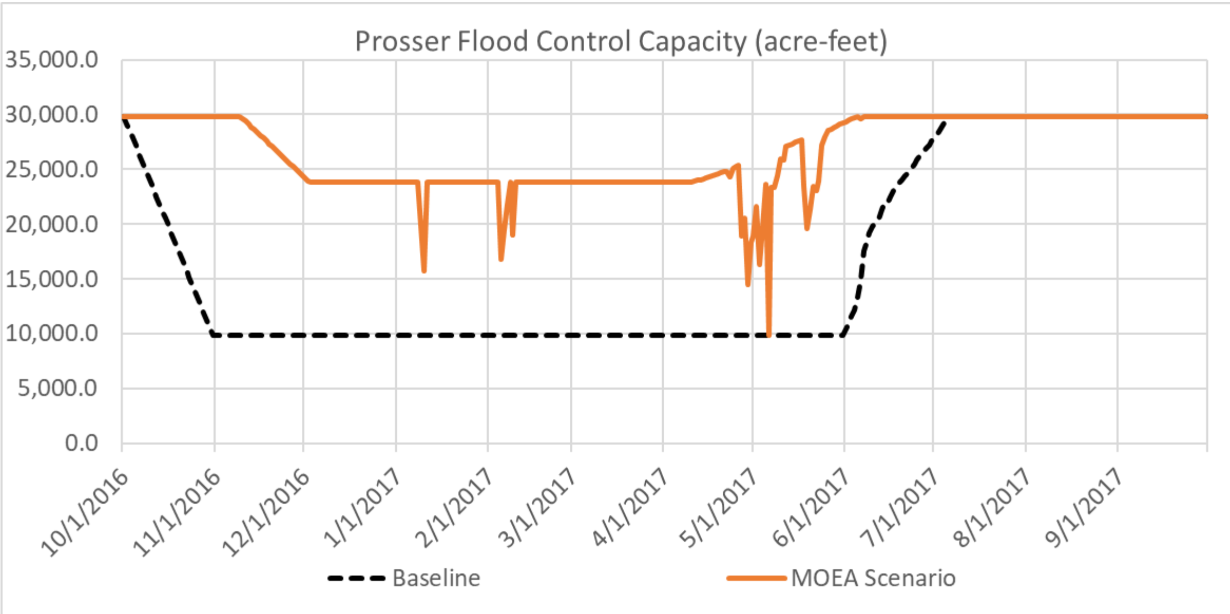

Figure 34: Prosser Creek Reservoir flood control capacity during WY 2017, a wet year with several rain and runoff driven flood events.

Lastly, Figure 35 provides an example of Prosser Creek Reservoir flood control capacity during water year 2011, a wet year where no flood events occurred. The Baseline Scenario shows fill starting in April, but then the flood space requirement increases late April and into May because of the large runoff volume (i.e., "high snowmelt parameter"). This requires any storage that had accumulated to be evacuated. This type of fill pattern was undesirable by basin stakeholders and represented a primary motivation for the TBWMOP. The MOEA Scenario, on the other hand, exhibits a much smoother fill pattern in contrast to water year 2017. This difference is because the "By a Model" Method accurately assessed that, unlike 2017 additional flood space (beyond the 30% of the Revised Guide Curve) was not required to protect against flooding in 2011 despite the large snowpack and its resulting runoff.

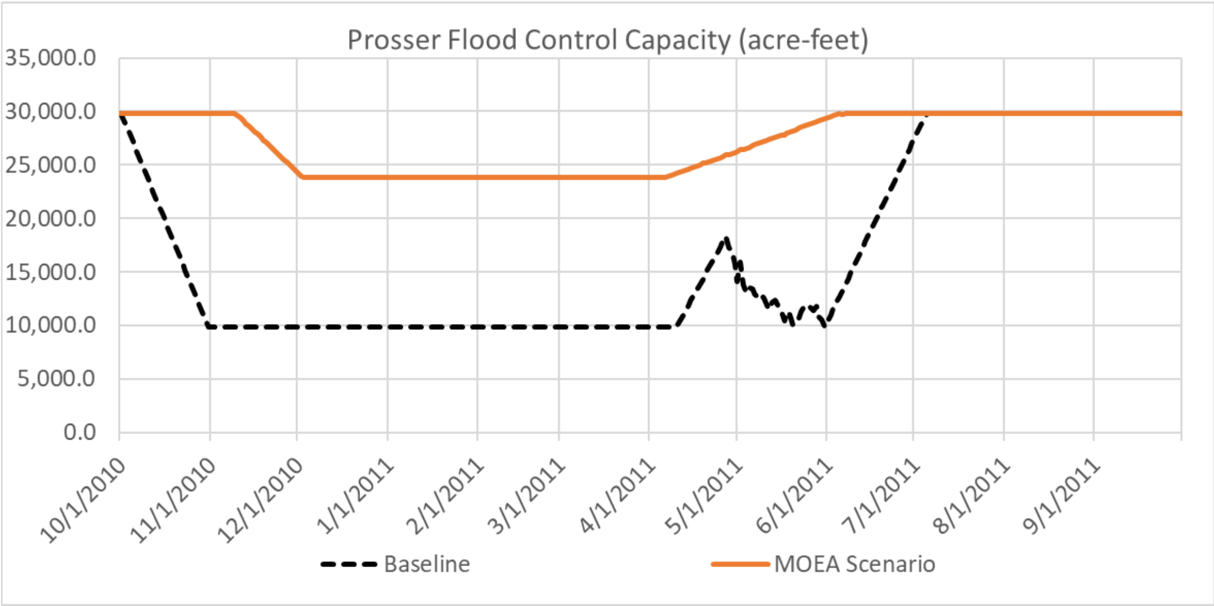

Figure 35: Prosser Creek Reservoir flood control capacity during WY 2011, a wet year with no floods.

9 Conclusion

The TBWMOP is a preliminary effort to update and improve flood control operations on the Truckee River for the benefit of water management in the basin. The technical effort in the TBWMOP focused on thoroughly implementing both the breadth and depth of analysis required by the Plan Formulation of the project. Throughout development, the Technical Team and other key stakeholders were consulted regularly to ensure that the design was both appropriate to the study and correct. This design integrated the most advanced modelling technology within the Truckee Basin with wider analysis tools such as MOEA. These tools, while complex, allowed the Technical Team to robustly collect an immense amount of information on variations of the flood control regulation criteria in the Truckee River Basin that leverages the skill within the CNRFC Forecasts to predict both high and low flow periods and prepare adequately for both. Despite the overly narrow range of the CNRFC Forecasts, the MOEA was able use these bias corrected HEFS to improve the performance of all study objectives including the flood damage objective. The MOEA also provided an efficient framework by which to analyze results and identify tradeoffs between study objectives. Ultimately, this analysis was the supporting evidence for the Preferred Operational Scenario selected by stakeholders in the project. Refer to the *WMOP Preferred Operational Scenario Selection Process* report for detailed documentation on how the results of this technical effort were used to select the Preferred Operational Scenario (Gwynn & Noe, WMOP Preferred Operational Scenario Selection Process, 2023).

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