Final Report

Economic Benefits of Alternative Reservoir Operations

WaterSMART Basin Study Program - Reservoir Operations Pilot Study

BUREAU OF RECLAMATION

ERG

Sonoma Water

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Cover photo courtesy of Sonoma Water.

List of Acronyms and Abbreviations

AEP	annual exceedance probability
ac-ft	acre-feet
BLS	Bureau of Labor Statistics
cfs	cubic feet per second
CNRFC	California Nevada River Forecast Center
CPI-U	Consumer Price Index for All Urban Consumers
CVD	Coyote Valley Dam
DST	decision support tool
EAD	expected annual damage
EAP	expected annual population at risk
EFO	Ensemble Forecast Operations
EIA	Energy Information Administration
FDA	Flood Damage Assessment
FIA	Flood Impact Analysis
FIRO	Forecast Informed Reservoir Operations
ft	feet
FY	fiscal year
FVA	Final Viability Assessment
HEC	Hydrologic Engineering Center
HEC-DSS	HEC Data Storage System
HEC-ResSim	HEC Reservoir System Simulation
HEC-RAS	HEC River Analysis System
HEMP	Hydrologic Engineering Management Plan
Ln	natural logarithm
MWh	mega-watt hour
M&I	municipal and industrial
NED	National Economic Development
NOAA	National Oceanic and Atmospheric Administration
NPV	net present value
NQH2O	Nasdaq Veles California Water Index
OHV	off-highway vehicle
PAR	population at risk
P&G	Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies
PR&G	Principles, Requirements, and Guidelines for Water and Land Related Resources Implementation Studies
PV	Present Value
PVA	Preliminary Viability Assessment
Reclamation	Bureau of Reclamation
SWP	State Water Project
TMWA	Truckee Meadows Water Authority
TNC	The Nature Conservancy

TOC	top of conservation
TUCP	Temporary Urgency Change Petitions
UDV	unit day values
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USFS	United States Forest Service
USGS	United States Geological Survey
VERS	Visitation Estimation and Reporting System
WCM	Water Control Manual
WCP	Water Control Plan
WMOP	Water Management Options Pilot
WTP	willingness to pay
WY	water year

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1 Executive Summary

The purpose of this project was to assess the economic benefits of alternative reservoir operations at Lake Mendocino and test transferability of the methods to other reservoirs. Following research of economic benefit methodologies, and consultation with other economists at a facilitated roundtable session, final methods were chosen and subsequently tailored. ERG developed an economic decision support tool (DST) to support and facilitate the transferability of the methods. The potential costs of FIRO were not considered as part of this work and therefore the net benefits of FIRO remain uncertain. Future work should consider assessing the costs of FIRO.

This work was funded through Reclamation's WaterSMART Basin Study Program. Sonoma Water was awarded $150,000 through the WaterSMART: Reservoir Operations Alternatives—Calculating Economic Effects (BOR-DO-18-F004) grant. ERG was hired as a subcontractor to Sonoma Water.

ERG estimated the benefits of Forecast Informed Reservoir Operations (FIRO) at Lake Mendocino for six benefit types. Five of these benefits were then incorporated into the DST.

In accordance with Reclamation standards, ERG assessed "with project" alternatives as compared to the "without project" condition. We refer to the "without project" condition as "baseline" because it represents a continuation of the existing reservoir operations. The "with project" alternatives are referred to generally as FIRO "alternatives" or specifically by the type of alternative reservoir operating conditions.

Benefits were quantified for two FIRO alternatives: Modified Hybrid and Ensemble Forecast Operations (EFO). These alternatives were chosen as part of the Lake Mendocino Final Viability Assessment (FVA) Hydrologic Engineering Management Plan (HEMP), which assessed the performance of these two alternatives in addition to three others (including existing operations, or baseline) in terms of 16 metrics. The EFO alternative operates without a traditional guide curve and uses 15-day ensemble streamflow forecasts to identify required flood releases. The Modified Hybrid alternative is a combination of the baseline operations and the EFO alternative, but with a "corner-cutting" strategy that allows for greater storage to begin in late winter to help with spring refill.

FIRO's impacts on Lake Mendocino water levels were estimated using data from a 33-year hindcast from January 1, 1985, through September 30, 2017. For each benefit type, we calculated the average annual benefit over this hindcast period and adjusted the benefits to 2019 dollars. As shown in Table 1, FIRO's total estimated annual benefits are either $9.4 million or $9.9 million, depending on the alternative.

Table 1. Summary of incremental average annual FIRO benefits (thousands of 2019 dollars)

Benefit Type	Modified Hybrid	EFO
Agriculture water supply [a]	$114.1	$118.4
Municipal and industrial water supply [b]	$2,674.6	$2,778.9
Hydropower [c]	-$1.9	-$43.8
Fisheries [d]	$5,726.4	$5,726.4
Recreation	$802.7	$1,239.2
Reduced operating, maintenance, and replacement costs	$45.5	$53.0
Total	**$9,361.4**	**$9,872.2**

[a] The method used is expected to underestimate total benefits, because it only reflects the average marginal value and not the value of increased reliability.
[b] A sensitivity analysis that assumes no change in price estimated benefits of $1.04 and $1.08 million under the Modified Hybrid and the EFO alternatives, respectively.
[c] The negative annual benefit is due to a current rule in the Water Control Manual that requires hydropower production to stop when reservoir elevations exceed 755 ft. If this rule were to change, we would expect FIRO alternatives to provide a positive benefit.
[d] Estimated using the cost to raise the height of Coyote Valley Dam as a proxy for benefits. The alternative method using water transaction prices results in larger values.

Irrigation Water Supply

Using water for crop irrigation and frost protection can result in improved quality and quantity of agricultural goods. FIRO can help attain that economic benefit with better forecasting that results in more reliable water availability. ERG used the residual imputation method (also known as the residual value method) to impute the “shadow price of water” (i.e., the estimated price when a good or service does not have a market price). This method subtracts all known input costs from total revenue for a crop. Our analysis focused on wine grapes (Chardonnay and Pinot Noir), the dominant crop in the region. The remainder—the value attributed to water—is then divided by the amount of water used to generate a value per unit of water.

We used these values to extrapolate to other crops. Depending on the crop, the value of an acre-foot[1] (ac-ft) of water is up to $634. We estimate average annual benefits of $114,079 under the Modified Hybrid and $118,394 under the EFO. However, in a dry year, benefits may exceed $775,000 under the EFO alternative.

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[1] An ac-ft is defined as an acre of water one foot deep, equivalent to 325,851 gallons.

Municipal and Industrial Water Supply

FIRO operations at Lake Mendocino may increase reliability of water supply to municipal, commercial, and industrial users. We estimated the demand curve for municipal and industrial (M&I) water and used the price elasticity of demand to quantify changes in consumer surplus (i.e., the amount consumers are willing to pay above the purchase price) due to an increase in water reliability. The price elasticity of demand is a measure of the change in quantity of a good or service demanded based on a change in the price of that good or service—in this case, water. Next, we used the elasticity to generate a demand curve and calculate how price might change due to a change in water reliability. We then used the old and new prices and quantities to calculate change in consumer surplus.

The increase in consumer surplus was estimated at $2.7 million under the Modified Hybrid and $2.8 million under the EFO. We also conducted a sensitivity analysis assuming no change in price because of the increase in water reliability. This results in an annual benefit of $1.04 million under the Modified Hybrid and $1.08 million under the EFO.

Hydropower

We calculated the benefit from hydropower by multiplying the average wholesale electricity price ($/MWh) by the power generation (MWh) for each of the alternatives. The daily hydroelectric power production values were determined as part of the HEMP, and historical wholesale price data were retrieved from the U.S. Energy Information Administration's Wholesale Electricity and Natural Gas Market Data.

In aggregate, the Modified Hybrid alternative generates $1,868 less in benefits annually from the baseline, while the EFO alternative generates $43,750 less annually. Note that both alternatives generate less economic benefit than baseline operations due to the current Water Control Manual (WCM) rule, which does not allow power generation when the pool elevation is higher than 755 ft. If this rule were changed to increase the pool elevation threshold, we would expect that the Modified Hybrid and EFO alternatives would provide greater economic benefits than baseline.

Fisheries

By increasing the water level of the reservoir, FIRO may improve streamflow and reduce water temperature. To estimate these benefits, we conducted an abbreviated least-cost alternative analysis that considered alternative projects that would result in the same impact as FIRO. The cost of the least-cost alternative that would achieve the same goal was then used as an estimate of the benefit to fish. In consultation with fisheries experts, and given time and scope limitations, we selected an alternative that was previously considered for which cost information was available.

Temperature and flow are the key salmonid metrics that can be correlated with FIRO operations, and we selected raising the elevation of the dam as the option that could achieve similar temperature and flow benefits to salmonid populations below Lake Mendocino. Raising the dam has been studied in the past, but was never built, primarily due to cost.

Based on guidance from Sonoma Water, we assumed that raising the dam 6 ft would result in roughly equivalent flow and temperature benefits for fisheries as the FIRO alternatives. To estimate that cost, we used an existing estimated cost to raise the dam by 36 ft and applied certain assumptions to approximate the cost for a 6-ft increase. We estimate a cost of $154.6 million. If the dam is expected to last 50 years, the annualized value, discounted at 2.75 percent to reflect the present value, would be $5.73 million.

Recreation

FIRO can lead to increases in quantity and quality of recreation (e.g., camping, boating, fishing) at Lake Mendocino. We estimated the increased level of recreational activity due to increased water levels at Lake Mendocino using a multivariable regression analysis, then applied unit day values (UDVs) to those increased recreation levels. Data on historical recreational usage were provided by the U.S. Army Corps of Engineers (USACE). Using these data, we developed a use estimating model to evaluate how usage would change under FIRO.

Next, a dollar value needed to be placed on the increased recreational usage. We used UDVs from Bowker et al. (2009). The UDVs range from $23 to $92 depending on the activity (adjusted to 2019 dollars). We then calculated the value of increased recreation as the product of the increased levels of recreation and UDVs. Using this method, benefits under the Modified Hybrid alternative total $802,700 per year and benefits under the EFO alternative total $1.2 million per year.

Reduced Operation, Maintenance, and Replacement Costs

FIRO may result in a reduction in the cost of environmental reviews because there may be fewer Temporary Urgency Change Petitions (TUCPs). Each petition costs about $250,000 (D. Seymour, Sonoma Water, personal communication, June 6, 2020). Using data from 1985 to 2017, we identified instances where FIRO may have avoided these TUCPs. We estimate that the Modified Hybrid approach would reduce the prevalence of TUCPs by 18.2 percent and the EFO alternative would reduce the prevalence by 21.2 percent. Therefore, we estimate an annual average savings of $45,455 for the Modified Hybrid alternative and $53,030 for the EFO alternative. We have not incorporated this benefit into the DST because it is unique to Lake Mendocino.

DST and Prosser Reservoir Transferability

A DST was developed to facilitate FIRO transferability. Users can enter project-specific data into the DST to develop economic benefit estimates, then compare benefits between baseline and different alternative reservoir operation scenarios. The tool utilizes user inputs and calculations to assess five economic benefits: irrigation water supply, M&I water supply, hydropower, fisheries, and recreation. We tested the DST for Prosser Reservoir in the Truckee River Basin, applying data to three benefits: irrigation water supply, M&I water supply, and recreation. Estimates for M&I water supply and recreation were vetted at a stakeholder workshop, where methods for valuing fisheries benefits were also discussed. Participants provided feedback on the usability of the tool, and refinements were made based on their input. For fisheries benefits, water rights transfers were identified as the most appropriate alternative cost for the region.

2 Introduction

California experiences frequent droughts and floods. Other stressors, such as wildfires, population growth, and competition for limited water resources have necessitated new approaches to carefully manage reservoirs.

A variety of approaches have been considered to increase the reliability of California's water supplies. For example, increasing the height of dams (e.g., Los Vaqueros Reservoir Expansion Project) and constructing new dams (e.g., Sites Reservoir Project) are under consideration following the passage of Proposition 1, approved by California voters in November 2014. This proposition provided $7.5 billion for water management projects, including $2.7 billion for water storage projects (PPIC, 2017).

Scientific and technological advancements in weather and streamflow forecasting provide water managers with an innovative approach to increasing reservoir resilience. Forecast Informed Reservoir Operations (FIRO) is a flexible water management strategy that uses observation data and modern weather and hydrologic forecasting to help water managers selectively retain or release water from reservoirs based on current and forecasted conditions. FIRO uses emerging science and technology to optimize limited resources and adapt to changing climate conditions without costly infrastructure improvements.

The Lake Mendocino FIRO project has shown that existing weather forecasting skill can be leveraged to improve water supply reliability while not compromising, and potentially benefiting, flood risk management and other uses such as recreation and fisheries. The Lake Mendocino FIRO Steering Committee (see text box below) identified the need for an economic assessment to evaluate benefits as part of the FIRO Final Viability Assessment (FVA). Sonoma Water applied for and was awarded a Bureau of Reclamation (hereafter Reclamation) grant (BOR-DO-18-F004) through Reclamation's WaterSMART Basin Study Program to meet this need and to establish a framework and methodology for application to other potential FIRO sites in the future. To provide implementation support, the project team developed a decision support tool (DST) to facilitate the use of the developed methodology and demonstrate its application at a Reclamation site.

The WaterSMART program works cooperatively with states, tribes, and local entities to help develop and implement plans to increase water supply in the American West as the region addresses a multitude of serious problems, including widespread droughts, increasing populations, aging infrastructure, and growing environmental concerns (Reclamation, 2020a). Reclamation conducts site-specific pilot projects under the WaterSMART Basin Study Program, and in 2015, Reclamation began the Reservoir Operations Pilot Initiative with the aim to support optimal water management by identifying ways to increase flexibility in reservoir operations (Reclamation, 2020b). The initiative aligns with the October 19, 2018, Presidential Memorandum on Promoting the Reliable Supply and Delivery of Water in the West, which recognizes the need to utilize scientific and technological advancements to increase water reliability.

Lake Mendocino Steering Committee

In 2014, the Lake Mendocino FIRO Steering Committee was formed. Self-started without any mandate, the inter-agency group came together out of mutual interest in exploring alternatives that could improve reservoir operations compared to strictly following the "guide curve" in the Lake Mendocino Water Control Manual. Starting out as a research and development activity, it morphed into a Research and Operations Partnership, where an atmosphere of trust allowed researchers and practitioners to experiment with new ideas through approved major deviations to the guide curve. Members of the Steering Committee are listed below:

- Jay Jasperse, Sonoma Water
- F. Marty Ralph, UC San Diego, Scripps Institution of Oceanography, Center for Western Weather and Water Extremes
- Alan Haynes, National Weather Service, California Nevada River Forecast Center
- Robin Webb, NOAA Office for Atmospheric Research
- Nick Malasavage, USACE San Francisco District
- Cary Talbot, USACE Engineer Research and Development Center
- Joseph Forbis, USACE Sacramento District
- Levi Brekke, Bureau of Reclamation
- Mike Anderson, California Department of Water Resources
- Mike Dettinger, UC San Diego, Scripps Institution of Oceanography, Center for Western Weather and Water Extremes (formerly U.S. Geological Survey)

The Lake Mendocino Steering Committee's representative from Reclamation identified this economic analysis of FIRO as an important opportunity for technical transfer between Lake Mendocino—a reservoir managed by the U.S. Army Corps of Engineers (USACE) in concert with Sonoma Water—and Reclamation reservoir operators exploring alternative reservoir operations, building on Reclamation's WaterSMART pilots.

This report represents the culmination of the work performed with the grant's funding.

2.1 Project Tasks

This project consisted of nine tasks, which included stakeholder engagement, discussions on the economic benefits methodologies, and testing the transferability of these methods. These nine tasks are described briefly below.

- **Task 1: Plan and gather initial stakeholder input.** We developed a detailed and comprehensive plan of study to address each team member's responsibilities, the timeline of tasks, deliverables, and other details of the work to be performed. The plan also described the proposed technical study approach, including the research to be conducted and the economic analysis methods to be considered in estimating economic effects. In addition, it included a stakeholder outreach and management plan. Due to the COVID-19 pandemic, there were less opportunities for stakeholder engagement than was originally envisioned.

- **Task 2: Develop a transferable economic benefits methodology.** We developed a comprehensive assessment of potential benefit types, including categories and methodologies, to ensure the project outcomes are transferable to other reservoir locations.
- **Task 3: Choose a Reclamation test site.** Prosser Reservoir, which is managed by Reclamation, was chosen to apply the economic methodology developed for Lake Mendocino.
- **Task 4: Develop alternative scenarios.** Two alternative water management scenarios that reflect hydrologic models and seasonal variability were evaluated to compare the impacts of different operational regimes. These scenarios were developed as part of the Lake Mendocino FIRO FVA. The scenarios were designed to be general enough that they are applicable to Lake Mendocino and other Reclamation reservoirs.
- **Task 5: Calculate water availability.** Based on the scenarios developed in Task 4, we calculated the difference in storage volume between baseline ("business as usual") operations and the alternative operations used in the study. Daily storage volumes were estimated from modeling based on 33 years of hindcast data (1985–2017). The modeled storage volumes for each reservoir operation scenario took into consideration water allocation agreements and water rights.
- **Task 6: Estimate economic benefits.** The economic benefits of Lake Mendocino FIRO were identified and quantified where possible. We estimated economic benefits associated with six benefit types: agricultural water supply; municipal and industrial water supply; hydropower; fisheries; recreation; and reduced operation, maintenance, and replacement costs. These estimates are based on reputable studies that identify relevant economic values and models.
- **Task 7: Develop a decision support tool.** The DST was developed as a stand-alone tool for general use to help water managers conduct their own economic benefits assessments. In conjunction with the DST summary and user guidance document, the DST includes the appropriate methodologies for monetizing specific benefits and describes data needed and key factors to consider in the analysis, accounting for issues such as uncertainty.
- **Task 8: Ground-truth with stakeholders at the Reclamation site.** A workshop was held to discuss the methodology and the DST at Prosser Reservoir. ERG used the DST to develop initial economic estimates for this site, based on available data, to serve as a starting point for discussion. Participants provided feedback on the DST and its transferability to the test site through oral discussions and survey/polling responses.
- **Task 9: Develop a report and present findings.** This report represents the final task of the project. It documents the process, describes the methodologies used, presents the case

study, and discusses findings from the Reclamation workshop. It also describes the transferability of the methodology along with appropriate caveats and qualifiers.

2.2 Organization of This Report

This report incorporates deliverables from the tasks outlined above and is organized as follows:

- **Section 1** is an executive summary of the project and summarizes the results.
- **Section 2** describes the background and purpose of this work, the funding that made it possible, and the tasks associated with the project.
- **Section 3** provides an overview of FIRO at Lake Mendocino, including the FIRO alternatives chosen for economic analysis and the way in which the water availability estimates associated with those alternatives were calculated.
- **Section 4** presents the economic benefits of FIRO at Lake Mendocino and the methodologies used.
- **Section 5** provides user guidance to the DST.
- **Section 6** discusses the transferability of the methods based on the feedback received during the Prosser Reservoir workshop.
- **Section 7** presents the conference poster developed for this project and discusses feedback received from conference attendees.
- **Section 8** discusses the findings and conclusions of the project.

3 Overview of FIRO at Lake Mendocino

3.1 FIRO Alternatives

3.1.1 Background

In 2014, the Lake Mendocino Forecast Informed Reservoir Operations (FIRO) Steering Committee undertook a study to evaluate whether Lake Mendocino could be managed to adapt to weather extremes under authorized project purposes by explicitly integrating weather and inflow forecasts in release schedule decision making. That study, referred to as the Preliminary Viability Assessment (PVA), confirmed that FIRO was a viable approach for increasing Lake Mendocino's storage without adversely affecting flood risk management (FIRO Steering Committee, 2017). The U.S Army Corps of Engineers (USACE), which is responsible for flood control releases from Lake Mendocino and is represented on the Steering Committee, agreed with the finding and subsequently approved a major deviation from the Lake Mendocino Water Control Plan (WCP). This temporary deviation permitted greater flexibility in managing Lake Mendocino flood control storage to test FIRO viability and, pending additional studies, incorporate FIRO procedures in a formal, USACE-approved Water Control Manual (WCM) revision.

The PVA evaluated candidate FIRO strategies in a reconnaissance-level technical study, confirming the viability of FIRO in concept. However, the PVA did not recommend a single specific strategy for integrating FIRO into a future WCP. That task was completed as part of the Final Viability Assessment (FVA).

The objective of the FVA is to identify, through appropriate detailed technical analyses and other considerations, the best FIRO strategy for Lake Mendocino. In addition, the FVA seeks to outline a strategy that Sonoma Water and USACE can use to implement FIRO in real-time operations and revise the WCP as necessary to permanently make that change. The FVA also evaluates potential adaptive strategies that allow operators to utilize new technologies and improved forecast skills as they become available in the future.

The Steering Committee identified technical studies consistent with USACE guidance to analyze FIRO strategies in the FVA, and prepared a Hydrologic Engineering Management Plan (HEMP) that provides a technical outline of the hydrologic engineering studies needed. The HEMP aimed to identify and evaluate Lake Mendocino FIRO alternatives in a systematic, defendable, repeatable manner, and help the Steering Committee identify a preferred FIRO strategy. The full text of the HEMP is included in Appendix B of the FVA (Lake Mendocino FIRO FVA, 2020).

This section of the report (Overview of FIRO at Lake Mendocino) is a synthesis of information taken directly from the FVA (Lake Mendocino FIRO FVA, 2020).

3.1.2 WCP Alternatives

During development of the HEMP, the Steering Committee defined and refined five WCP alternatives for evaluation in the FVA. Table 2, below, provides a basic description of each alternative, along with one important metric—increase in storage. Complete information on each is provided in Appendix B of the FVA.

Table 2. WCP alternatives and increases in median May 10th Lake Mendocino reservoir storage over baseline WCM operations

Alternative	Description	Percent Increase in Median May 10th Storage
Existing Operation (Baseline)	Includes the seasonal guide curve and release selection rules from the 1986 USACE WCM and 2003 update to the flood control diagram.	0%
EFO	Operates without a traditional guide curve and uses the 15-day ensemble streamflow forecasts to identify required flood releases.	27%
Hybrid EFO	A combination of the baseline approach and the EFO. This option was used for major deviation operations in water years 2019 and 2020.	15%
Modified Hybrid EFO	Identical to Hybrid EFO but with a "corner-cutting" strategy that allows for greater storage to begin February 15 to aid with spring refill.	20%
Five-Day Deterministic Forecast	Defines alternative guide curves with 11,000 ac-ft encroachment space and 10,000 ac-ft draft space above and below the baseline guide curve. Uses five-day deterministic streamflow forecasts to choose the guide curve and make release decisions.	18%

In addition to the baseline operation, this study evaluated four FIRO WCPs. Three of the alternatives were ensemble forecast operations (EFO)-type plans, while the USACE Hydrologic Engineering Center (HEC) and San Francisco District developed the fourth alternative to leverage the California Nevada River Forecast Center's (CNRFC's) five-day deterministic forecasts and employ a simpler operation approach. To ensure direct comparison, each WCP had to meet hard (inviolable) operational constraints (Table 3) and a set of operational considerations (Table 4) that could be measured. The details associated with the hard constraints and operational considerations are available in the PVA.

Table 3. Hard (inviolable) operational constraints that all WCP alternatives must satisfy

ID	Limiting Condition
1	Must satisfy limits on release rate of change
2	Must minimize exceeding target maximum flow at Hopland relative to the baseline of current operations
3	Must accommodate maximum release schedule
4	Must not require forecast updates beyond currently available frequency
5	Must meet instream minimum flow requirements
6	Must properly represent current Potter Valley Project diversion
7	Must account for contributions to flood mitigation downstream of Hopland

Table 4. Operational considerations that should be evaluated

ID	Operational Consideration
1	Should simulate operation of Ukiah Power and limits on that operation
2	Should avoid spillway flow to maximum extent possible
3	Should consider Lake Mendocino bank protection desires
4	Should consider and address Lake Mendocino Campgrounds operation objective
5	Should consider adverse impact to Lake Sonoma flood operations relative to baseline/current operations
6	Should not require excessive frequency of gate changes

3.1.2.1 *Baseline WCP*

The baseline WCP is drawn directly from the 1986 WCM and 2003 update to the flood control diagram. The maximum release schedule (as a function of reservoir elevation) is applied to all other WCP options. The baseline WCP has a winter top of conservation (TOC) of 68,400 acre-feet (ac-ft) and a summer TOC of 111,000 ac-ft. Drawdown to the winter TOC begins October 1 and is to be completed by November 1. Spring refill can begin March 1 and be completed by May 10. Figure 1 (black line) shows the guide curve (also referred to as a rule curve) for the baseline WCP. The baseline WCP does not utilize forecasts. Storage above the guide curve is always evacuated as quickly as feasible. The performance of the baseline WCP provides the conditions against which all WCP alternatives are measured.

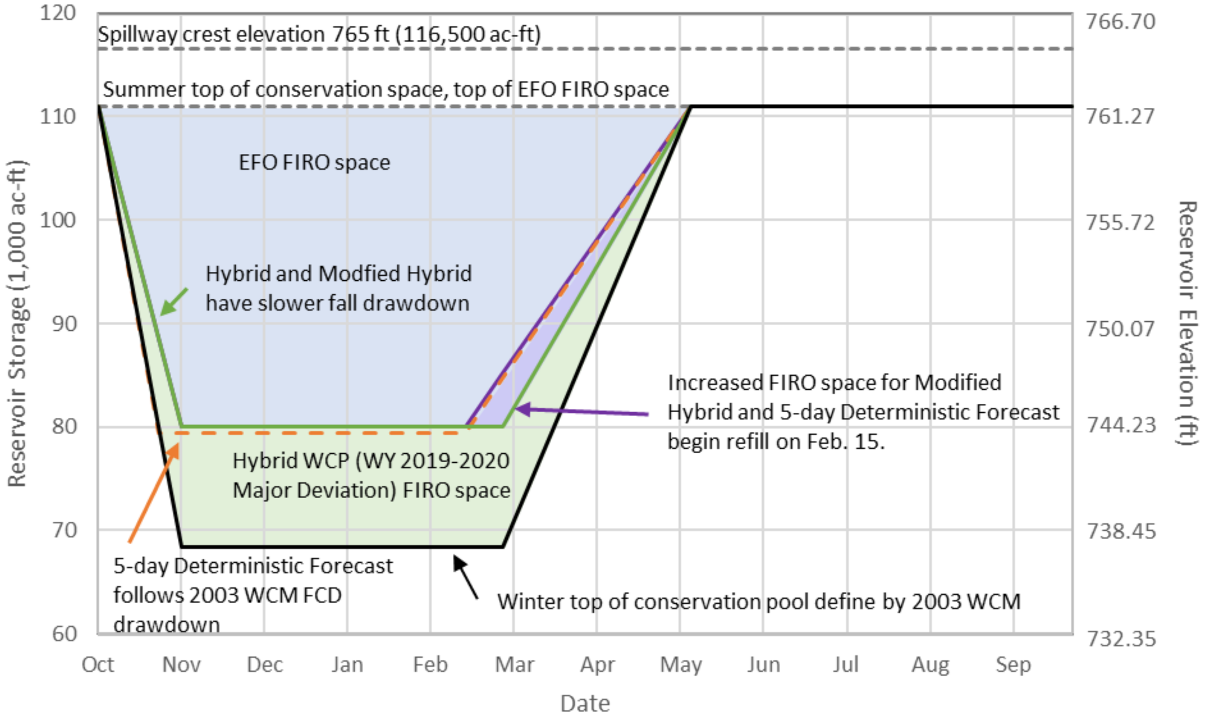


Figure 1. Lake Mendocino guide curves: Baseline WCP (black line), conditional storage spaces for the EFO (all shaded areas), Hybrid WCP (light green shaded area), and Modified Hybrid WCP (light green plus light purple shaded areas). (Source: Lake Mendocino FIRO FVA, 2020)

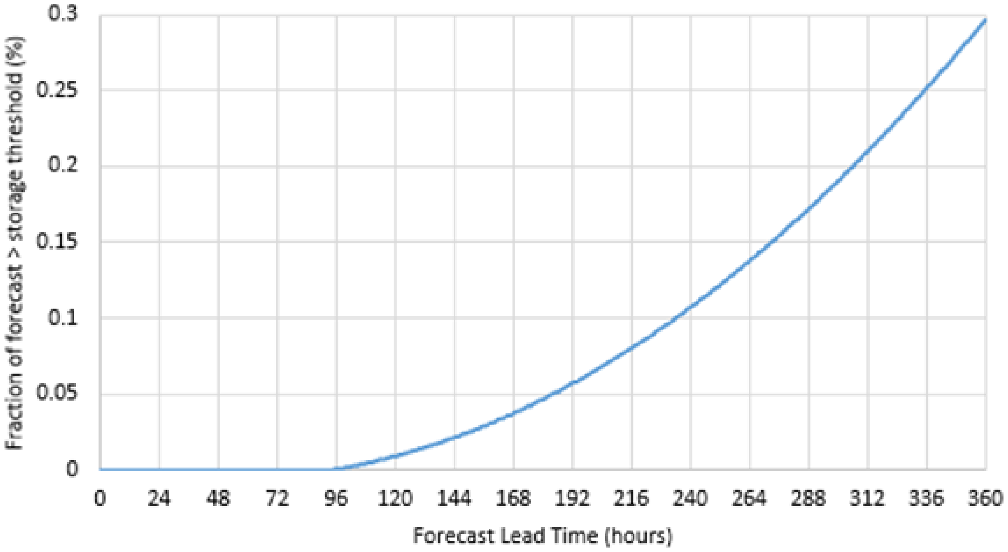
3.1.2.2 *Ensemble Forecast Operations*

As a part of the Lake Mendocino PVA, Sonoma Water developed the EFO WCP. This option leverages the skill in the 15-day ensemble streamflow forecasts that the CNRFC operationally provides to manage the probability of the reservoir rising above the summer TOC (111,000 ac-ft). To accomplish this, the EFO model processes each inflow forecast ensemble member into the reservoir assuming zero release. The resulting ensemble members of reservoir storage for the next 15 days are then measured against a "risk curve" that defines the allowable risk of exceeding the summer TOC over the forecast's 15-day time domain. Risk is defined by the fraction of ensemble members exceeding the summer TOC.

Figure 2 provides a sample risk curve. Whenever an issued forecast results in risk above the allowable level, the model identifies the release needed to mitigate the risk to the acceptable level (i.e., reduce the number of ensemble members exceeding the TOC). The release is also subject to the physical and system constraints common to all alternatives.

Figure 3 shows the forecast ensemble storage and risk of exceeding the storage threshold before modifying the release, while Figure 4 shows the same information after identifying the recommended release and processing it into the forecast storage ensembles. The forecasted risk (solid red line) shown in the risk forecast of Figure 3 is brought below the risk threshold (dotted blue line) once the recommended release has been identified (Figure 4). The recommended release is identified by the model as the release that brings the forecasted risk below the risk threshold. Therefore, the releases are constantly updated based on new information to ensure that the forecasted risk is below the risk threshold.

Figure 1 also shows the domain where the EFO model permits conditional retention of storage in the reservoir given the current streamflow forecast (all shaded areas above the baseline guide curve). The EFO model permits unbounded drafting of the storage below the winter TOC as needed when an extreme flood event is forecast.



Note: The blue line describes the maximum percentage of ensemble storage members that can exceed the 111,000 AF threshold with time in hours.

Figure 2. Sample risk curve for EFO-type WCPs (Source: Lake Mendocino FIRO FVA, 2020)

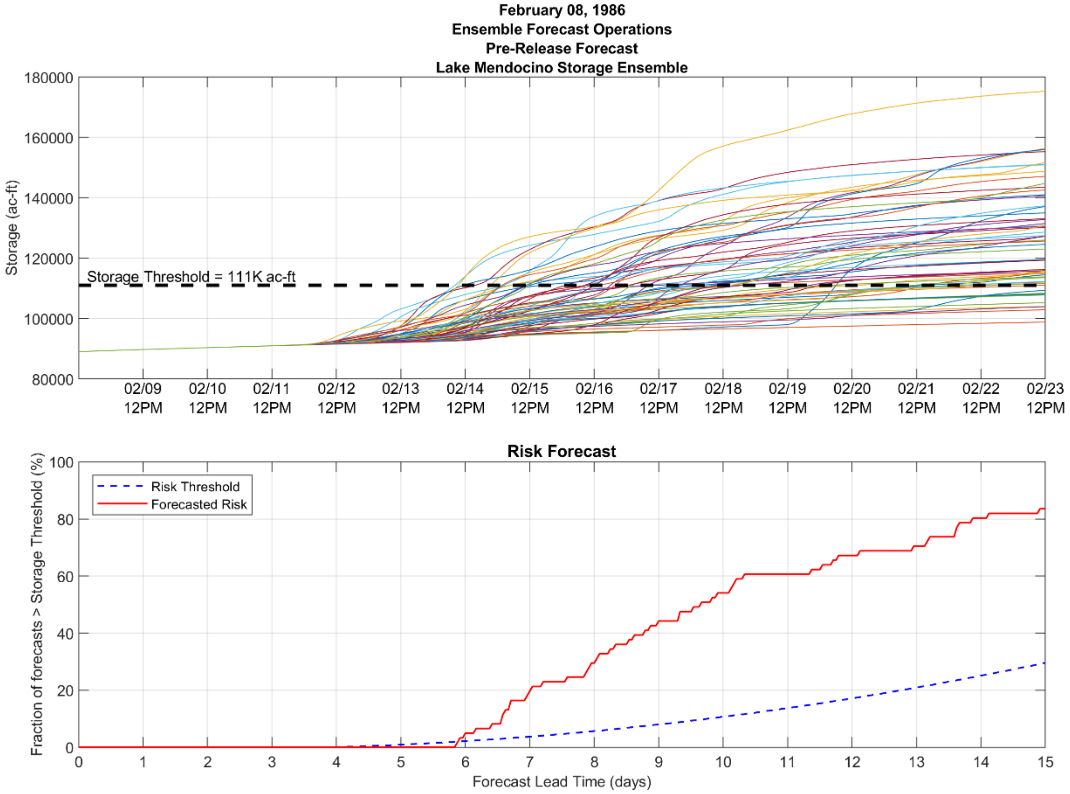


Figure 3. Forecast ensemble storage (top plot), risk curve (blue dashed line, bottom plot), and frequency of storage threshold exceedance (red line, bottom plot) with time before identifying recommended release and processing it into storage ensemble members. (Source: Lake Mendocino FIRO FVA, 2020)

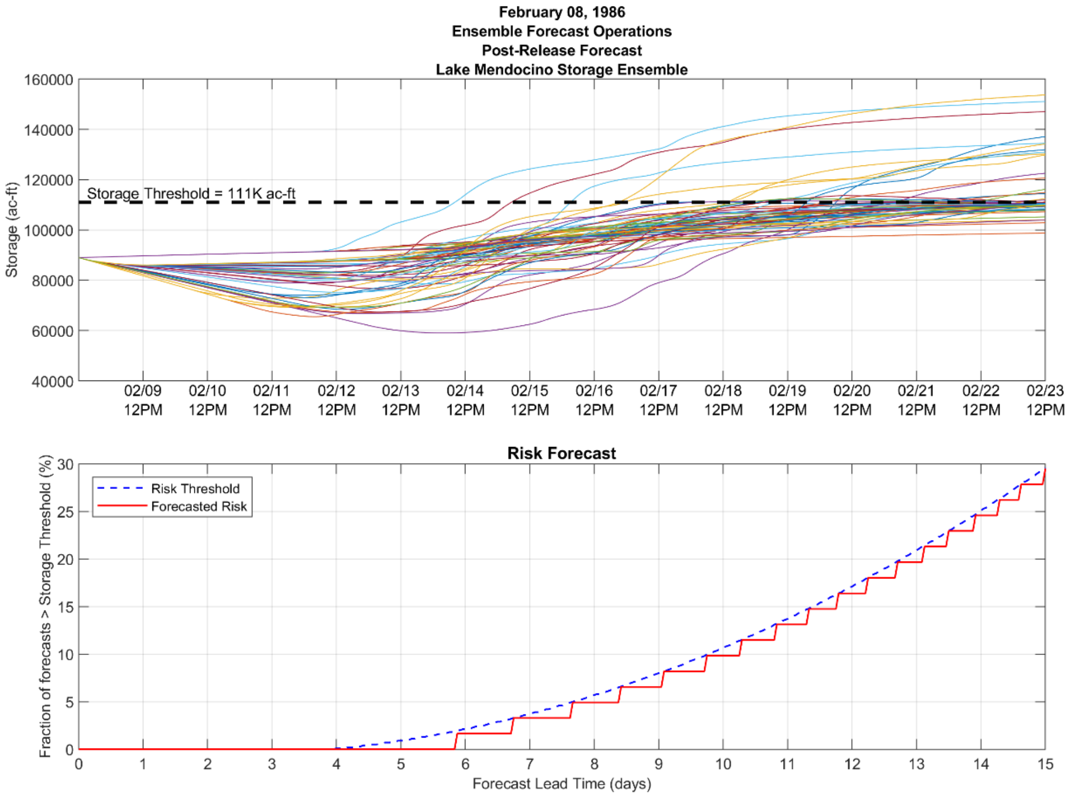


Figure 4. Forecast ensemble storage (top plot), risk curve (blue dashed line, bottom plot), and frequency of storage threshold exceedance (red line, bottom plot) with time after identifying recommended release and processing it into storage ensemble members. (Source: Lake Mendocino FIRO FVA, 2020)

3.1.2.3 *Hybrid EFO*

The Hybrid EFO model is identical to the EFO model except that it only allows the conditional retention of storage up to 80,050 ac-ft at mid-winter. This creates a “FIRO Space” that conditionally retains storage. Above this storage level, excess water is released as quickly as feasible. The Hybrid model also permits unbounded drafting of the storage below the winter TOC as needed when an extreme flood event is forecast. This WCP was the basis of the major deviation operations during water years (WYs) 2019 and 2020. Figure 1 shows the FIRO Space associated with the Hybrid WCP (light green shaded area).

3.1.2.4 *Modified Hybrid EFO*

The Modified Hybrid EFO WCP is identical to the Hybrid EFO except that the FIRO Space allows the spring refill to begin on February 15. As with the EFO and Hybrid EFO, this WCP also permits unbounded drafting of the storage below the winter TOC as needed when an extreme flood event is forecast. Figure 1 shows the FIRO Space associated with the Modified Hybrid EFO (light green plus light purple shaded areas).

3.1.2.5 *Five-Day Deterministic Forecast*

The USACE HEC and San Francisco District developed the Five-Day Deterministic Forecast WCP. This WCP option employs a simpler forecast informed operation that chooses among three alternative guide curves based on the CNRFC's five-day deterministic streamflow forecasts. Because five-day deterministic forecasts were not archived for the full 1985–2017 evaluation period, HEC developed a process to approximate the deterministic forecast volumes from the ensemble reforecasts available for that full period. HEC took the Lake Mendocino deterministic five-day inflow volume forecast as the ensemble mean volume, or the ensemble 75th percentile volume, and the Hopland deterministic forecast as the ensemble 75th percentile flow for each day. The FVA documents this procedure in detail.

This alternative primarily achieves the operation decisions by making simple changes in the guide curve based on the deterministic inflow forecast. In the absence of a large inflow forecast, the flood control pool is "encroached" by 11,000 ac-ft (state 1). When the five-day volume forecast exceeds trigger 1 (15,000 ac-ft), the guide curve returns to the standard (state 0). When the five-day volume forecast exceeds trigger 2 (20,000 AF), the guide curve drops to the "draft" guide curve 10,000 ac-ft below the standard (state -1). As forecasts decrease, the guide curve returns to higher levels only as forecasted volume falls below the trigger minus a buffer volume of 3,000 ac-ft (an "untrigger"). This prevents oscillation when the forecast is close to the trigger. Spring refill for the encroachment space begins on February 16. This WCP's allowance for a 10,000 ac-ft draft into the conservation pool to accommodate a major flood event is limited to the November 1–March 1 period. Figure 1 shows the encroached guide curve for the Five-Day Deterministic Forecast WCP along with the other alternatives. Figure 5 shows the encroached 11,000 ac-ft and draft 10,000 ac-ft curves.

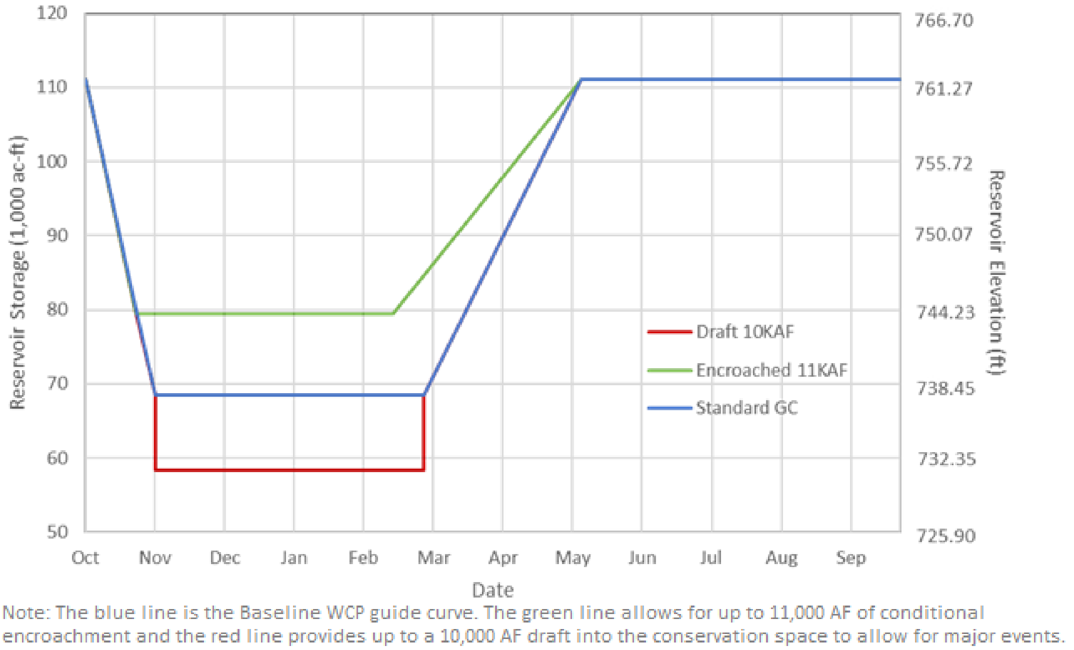


Figure 5. Lake Mendocino guide curves for the Five-Day Deterministic Forecast WCP (Source: Lake Mendocino FIRO FVA, 2020)

3.2 Water Availability Estimates

3.2.1 WCP Performance Metrics

In the HEMP, the Steering Committee defined a set of 16 metrics, shown in Table 5, to consistently evaluate the WCP alternatives. The HEMP (Appendix B of the FVA) describes details associated with each metric, as well as the process for simulation and evaluation.

Table 5. Summary of performance metrics identified in the HEMP

Metric	Metric Description
M1	Annual maximum flow frequency function at Hopland, Healdsburg, and Guerneville
M2	Annual maximum pool elevation frequency function of Lake Mendocino
M3	Annual maximum pool elevation frequency function of Lake Sonoma
M4	Annual maximum Lake Mendocino total release frequency function
M5	Annual maximum Lake Sonoma total release frequency function
M6	Annual maximum uncontrolled spill frequency function for Lake Mendocino
M7	Annual maximum uncontrolled spill frequency function for Lake Sonoma
M8	Expected annual inundation damage at critical Russian River locations
M9	Expected annual potential (statistical) loss of life due to floodplain inundation at critical Russian River locations (assessed as "population exposed")
M10	Reliability of water supply delivery, as measured by annual exceedance frequency of Lake Mendocino's May 10 reservoir storage levels
M11	The ability to meet instream flows to support threatened and endangered fish during the summer rearing season, as measured by the annual exceedance of the number of days that June–September flows exceed 125 cfs
M12	The ability to meet instream flows to support fall spawning migration, as measured by the annual exceedance of the number of days that October 15 –January 1 flows exceed 105 cfs

Metric	Metric Description
M13	Impacts to the Bushay Campground during the recreational season (Memorial Day–Labor Day), as measured by the annual exceedance of the number of days that Lake Mendocino water-surface elevation exceeds 750 ft (elevation of access road)
M14	Impacts to power production of the Coyote Valley Dam powerhouse
M15	Lake Mendocino bank protection, as measured by annual frequency of elevation exceeding 758.8 ft (later refined to capture the number of days above 758.8 ft)
M16	Impacts to hours of operation (as measured by the number of required gate changes)

3.2.2 Procedure

The project team simulated the operation of each Lake Mendocino WCP alternative using an HEC Reservoir System Simulation (HEC-ResSim) model of the Russian River, then hydraulically routed the reservoir releases using an HEC River Analysis System (HEC-RAS) model. The HEC-ResSim and HEC-RAS model results were then processed to evaluate the metrics defined in the HEMP (Table 5).

3.2.3 Study Boundary Conditions

The primary factor driving this analysis is the availability of historical ensemble forecast information (hindcasts) in the hydrologic dataset. The CNRFC has created a limited series of hindcasts and scaled ensembles. The FVA project team used the same hydrologic dataset to evaluate all alternatives, which includes:

- Historical reservoir inflow and downstream local flows; the CNRFC and Sonoma Water compute the local flows.
- Hindcasts for the period of record of 1/1/1985–9/30/2017; this period includes the largest annual events for WYs 1985–2017.
- Design events that represent events rarer than those seen in the hindcast period. Specifically, the CNRFC created eight design events based on two scalings each for four historic event patterns. This dataset includes reservoir inflows, coincident downstream local flows, and associated ensembles representing forecast information for the design event. Table 6 lists the eight design events, and a detailed discussion of the scaling process is provided in the FVA.

Further descriptions of the hindcast and ensemble development can be found in the *Development of Forecast Information Requirements and Assessment of Current Forecast Skill Supporting the Preliminary Viability Assessment of FIRO on Lake Mendocino* report from the CNRFC (CNRFC, 2017).

Table 6. Design events that the CNRFC developed to evaluate Lake Mendocino FIRO WCPs

ID	Event Year	Annual Exceedance Probability (AEP) /Scaling
1	1986	p=0.005 (200-year)
2	1986	p=0.002 (500-year)
3	March 1995	p=0.005 (200-year)
4	March 1995	p=0.002 (500-year)

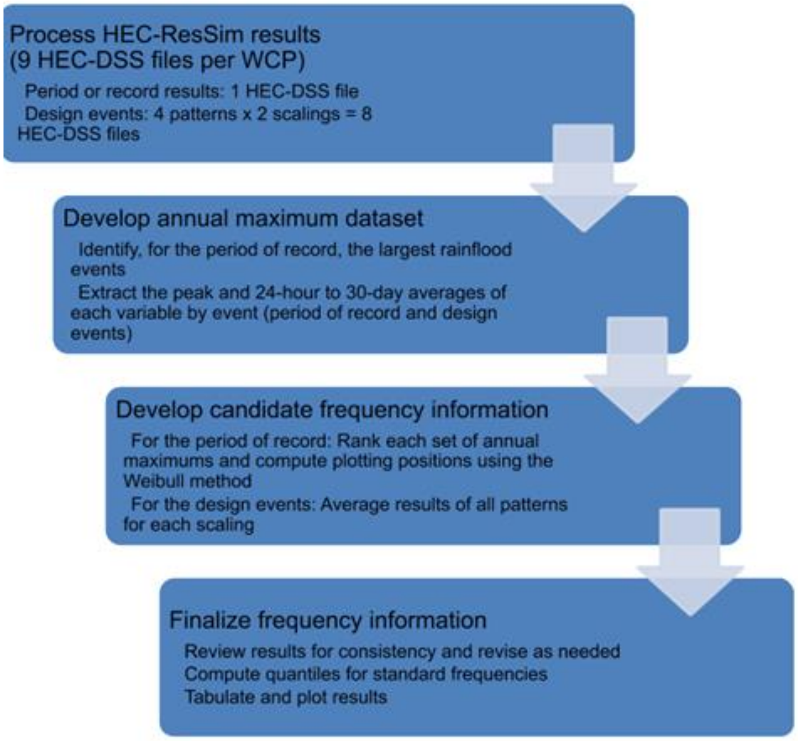
ID	Event Year	Annual Exceedance Probability (AEP) /Scaling
5	1997	p=0.005 (200-year)
6	1997	p=0.002 (500-year)
7	2006	p=0.005 (200-year)
8	2006	p=0.002 (500-year)

3.2.4 Analysis Methods

Procedures for computing each metric were coordinated with Sonoma Water and USACE HEC staff. These procedures are detailed in two technical memoranda titled *Proposed Procedure for Consequence Analysis* and *Procedures for Computation of Non-Consequence* Metrics (HDR, July 2, 2020), provided in Appendix B of the FVA.

3.2.5 Non-Consequence Analysis Methods

Figure 6 captures the general procedure to assess the non-consequence metrics. Here "non-consequence" means those metrics that do not require HEC Flood Impact Analysis (FIA) or HEC Flood Damage Assessment (FDA) procedures.



Process HEC-ResSim results (9 HEC-DSS files per WCP)

Period or record results: 1 HEC-DSS file

Design events: 4 patterns x 2 scalings = 8 HEC-DSS files

Develop annual maximum dataset

Identify, for the period of record, the largest rainflood events

Extract the peak and 24-hour to 30-day averages of each variable by event (period of record and design events)

Develop candidate frequency information

For the period of record: Rank each set of annual maximums and compute plotting positions using the Weibull method

For the design events: Average results of all patterns for each scaling

Finalize frequency information

Review results for consistency and revise as needed

Compute quantiles for standard frequencies

Tabulate and plot results

Note: The procedure for calculating M10–M16 is the same with the exclusion of the design events.

Figure 6. Procedure to calculate M1–M7 (Source: Lake Mendocino FIRO FVA, 2020)

3.2.6 Consequence Analysis Methods

The methodology used historical streamflow information and hydrologic datasets from CNRFC hindcasts in addition to scaled event datasets, including associated ensembles, as input to the HEC-ResSim, HEC-RAS, HEC-FIA, and HEC-FDA computer programs. These programs were used to compute consequences for the baseline condition and proposed alternatives in the FVA. Figure 7 shows the general overall workflow for each alternative (more details are provided in the FVA):

1. **Develop floods of record dataset**. The project team used reservoir outflows and local inflows from historical streamflow data to identify annual peak flow events for the period of record from WYs 1985–2017. They then hydraulically routed these floods of record and computed consequences (flood damage and loss of life) for each annual peak flow. For WCP alternatives that require forecast information, the hindcast dataset was used as forecast information. The project team approximated deterministic forecasts from the ensembles per a procedure developed by the HEC (see the HEMP in Appendix B of the FVA).
2. **Develop design events dataset.** The project team used design events—based on two historical event patterns scaled to match outflows for the p=0.005 (200-year) and p=0.002 (500-year) events—to determine reservoir outflow for the baseline condition and proposed alternatives. They then hydraulically routed reservoir outflows and local inflows and computed consequences (flood damage and population exposed) for each design event. For WCP alternatives that require forecast information, the project team used ensembles associated with each event. The deterministic forecasts were approximated from the ensembles per a procedure developed by the HEC (see the HEMP in Appendix B of the FVA).
3. **Compute annualized consequences.** The project team combined outputs from steps 1 and 2 to create the necessary HEC-FDA input frequency functions for each of the four event patterns. These were used to calculate expected annual damage (EAD) and expected annual population at risk (EAP) for each of the four event patterns. The project team averaged the EAD/EAP for the four event patterns to determine the final EAD/EAP of the chosen alternative.

This methodology was repeated for each alternative.

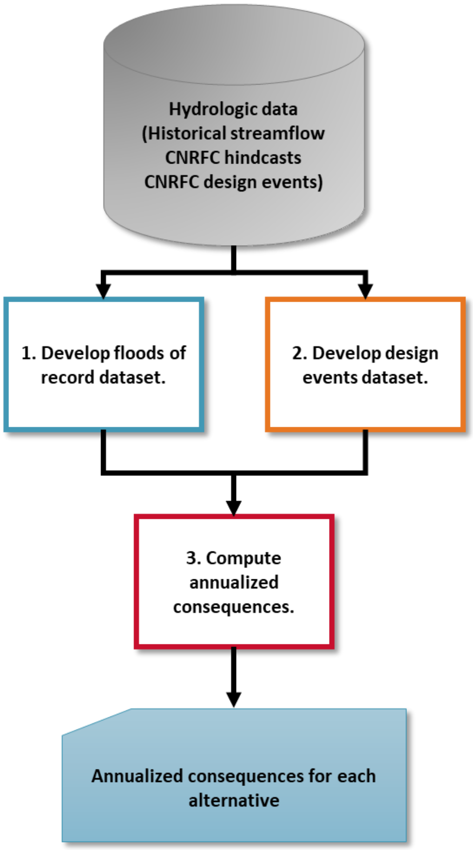


Figure 7. Overview of proposed consequence analysis methodology for Lake Mendocino FVA. (Source: Lake Mendocino FIRO FVA, 2020)

3.2.7 Results

The HEMP requires that the efficacy of each WCP alternative be evaluated using a set of measurable, objective statistics. The Steering Committee defined a set of 16 evaluation metrics in the HEMP (see Table 5 above). The technical memorandum *WCP Alternative Analysis Results and Metrics: Alternative Comparison* provides a complete summary of all evaluated metrics (see the HEMP in Appendix B of the FVA).

3.2.8 Key Findings

After reviewing the analysis results for these 16 metrics, the project team identified eight key findings:

1. All FIRO WCPs result in reductions in the annual frequency and magnitude of uncontrolled spills at Lake Mendocino compared to baseline, as shown in Figure 8 and Table 7.
2. For all FIRO WCPs, as shown in Figure 9 and Table 8, the annual flow frequency quantiles at Hopland for events less frequent than the p=0.5 (1/2-year) event are generally the same (within 1 percent of baseline) and decrease by up to 5 percent from baseline for the p=0.002 (1/500-year) event.

3. The total EAD and EAP values for the Russian River are generally the same (within 1 percent of baseline) and may decrease slightly for all FIRO WCPs, as shown in Figure 10, Table 9, and Table 10. However, EAD values for all WCPs along the reach from Hopland to Cloverdale showed slight (within 2 percent) increases from baseline. This increase in total EAD is because of increased damages to structures for specific events simulated. EAP values for this reach are generally the same (within 1 percent). Similarly, the reach, including Dry Creek, shows slightly (within 4 percent) increased EAD values for this reason. In addition, the Five-Day Deterministic Forecast alternative shows slight (less than 1 percent) increases in total EAD for the reaches of Santa Rosa and Monte Rio for the same reason.
4. The water supply reliability—as measured by the median (50th percentile exceedance) of May 10 storage—increases for all FIRO WCPs, as shown in Figure 11.
5. The ability to meet instream flows for rearing or spawning habitat generally increases for all FIRO WCPs, as shown in Figure 12 and Figure 13.
6. All FIRO WCPs would negatively impact the ability to access Bushay Campground during the recreation season (Memorial Day to Labor Day), as shown in Figure 14.
7. City of Ukiah hydropower generation increases slightly (approximately 4 percent) for the Hybrid, Modified Hybrid, and Five-Day Deterministic Forecast WCPs, and it decreases by 13 percent for the EFO WCP, as shown in Figure 15.
8. There are no impacts on Lake Sonoma operations, as shown in Figure 16.

The box and whisker plots that follow are configured to show the maximum and minimum (whiskers), 25 percent to 75 percent range (box), median (heavy horizonal bar), and mean (heavy dot). The color labeling for WCPs is consistent across all figures and tables.

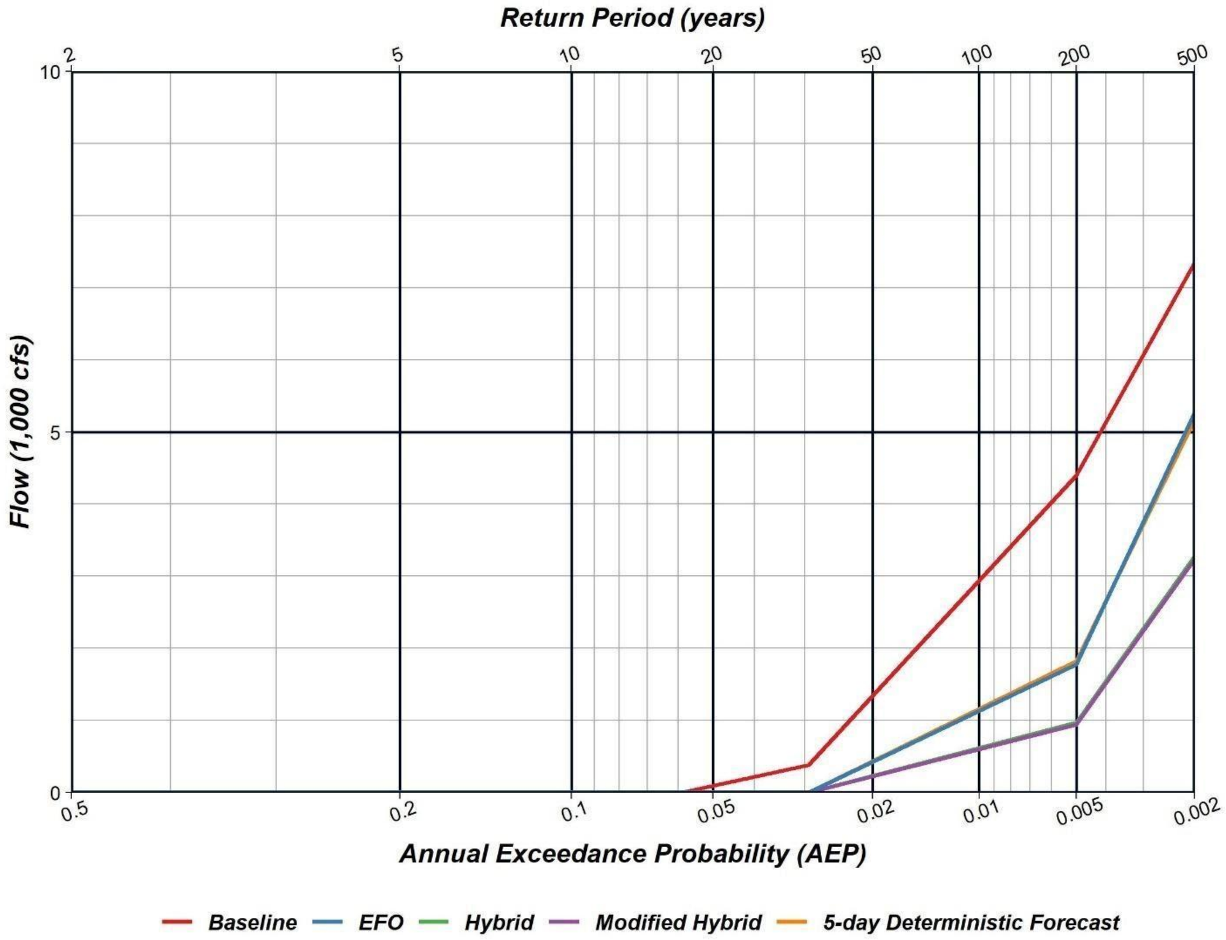


Figure 8. Annual maximum uncontrolled spill frequency in Lake Mendocino. The Hybrid and Modified Hybrid results are nearly identical (lower lines), and the Five-Day Deterministic Forecast and EFO results are also nearly identical (middle lines). (Source: Lake Mendocino FIRO FVA, 2020)

Table 7. Difference from baseline in annual uncontrolled spill frequency quantile (ft) and [%] at Lake Mendocino

AEP	1/AEP	EFO	Hybrid	Modified Hybrid	5-day Deterministic Forecast
0.5	2	0 [0%]	0 [0%]	0 [0%]	0 [0%]
0.2	5	0 [0%]	0 [0%]	0 [0%]	0 [0%]
0.1	10	0 [0%]	0 [0%]	0 [0%]	0 [0%]
0.05	20	-94 [-100%]	-94 [-100%]	-94 [-100%]	-94 [-100%]
0.02	50	-916 [-68%]	-1,110 [-83%]	-1,116 [-83%]	-906 [-68%]
0.01	100	-1,807 [-61%]	-2,322 [-79%]	-2,338 [-80%]	-1,780 [-61%]
0.005	200	-2,621 [-60%]	-3,431 [-78%]	-3,456 [-79%]	-2,580 [-59%]
0.002	500	-2,082 [-28%]	-4,064 [-55%]	-4,111 [-56%]	-2,174 [-30%]

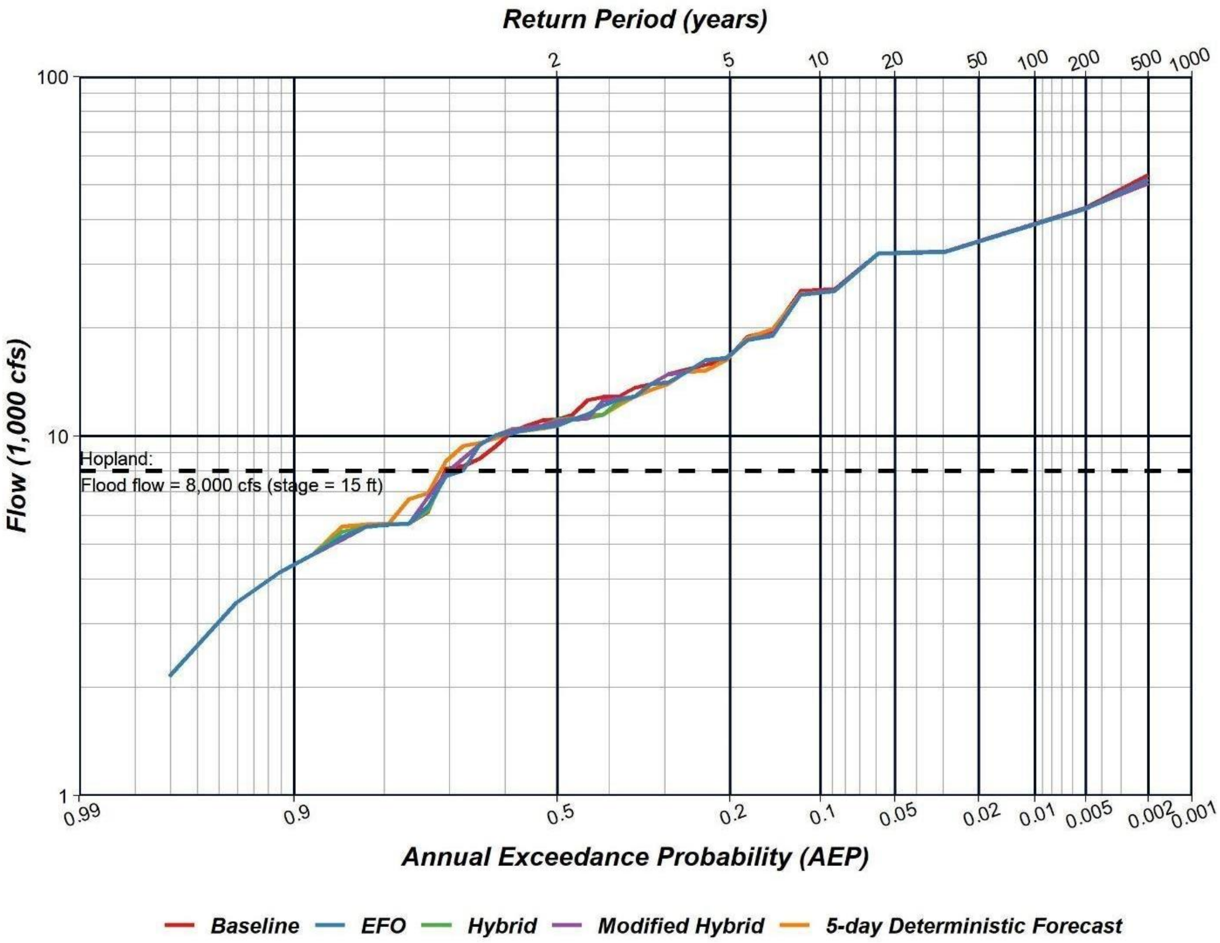


Figure 9. Annual maximum flow exceedance probability at Hopland. (Source: Lake Mendocino FIRO FVA, 2020)

Table 8. Difference in annual maximum regulated flow frequency quantile (cfs) and [%] at Hopland

AEP	1/AEP	EFO	Hybrid	Modified Hybrid	5-day Deterministic Forecast
0.5	2	-466 [-4%]	0 [0%]	-171 [-2%]	-466 [-4%]
0.2	5	105 [1%]	73 [0%]	72 [0%]	-17 [0%]
0.1	10	-402 [-2%]	-403 [-2%]	-404 [-2%]	-374 [-1%]
0.05	20	-15 [0%]	-14 [0%]	4 [0%]	20 [0%]
0.02	50	-127 [0%]	-75 [0%]	5 [0%]	35 [0%]
0.01	100	-187 [0%]	-56 [0%]	-17 [0%]	-43 [0%]
0.005	200	-243 [-1%]	-38 [0%]	-38 [0%]	-115 [0%]
0.002	500	-1,335 [-3%]	-2,804 [-5%]	-2,804 [-5%]	-2,829 [-5%]

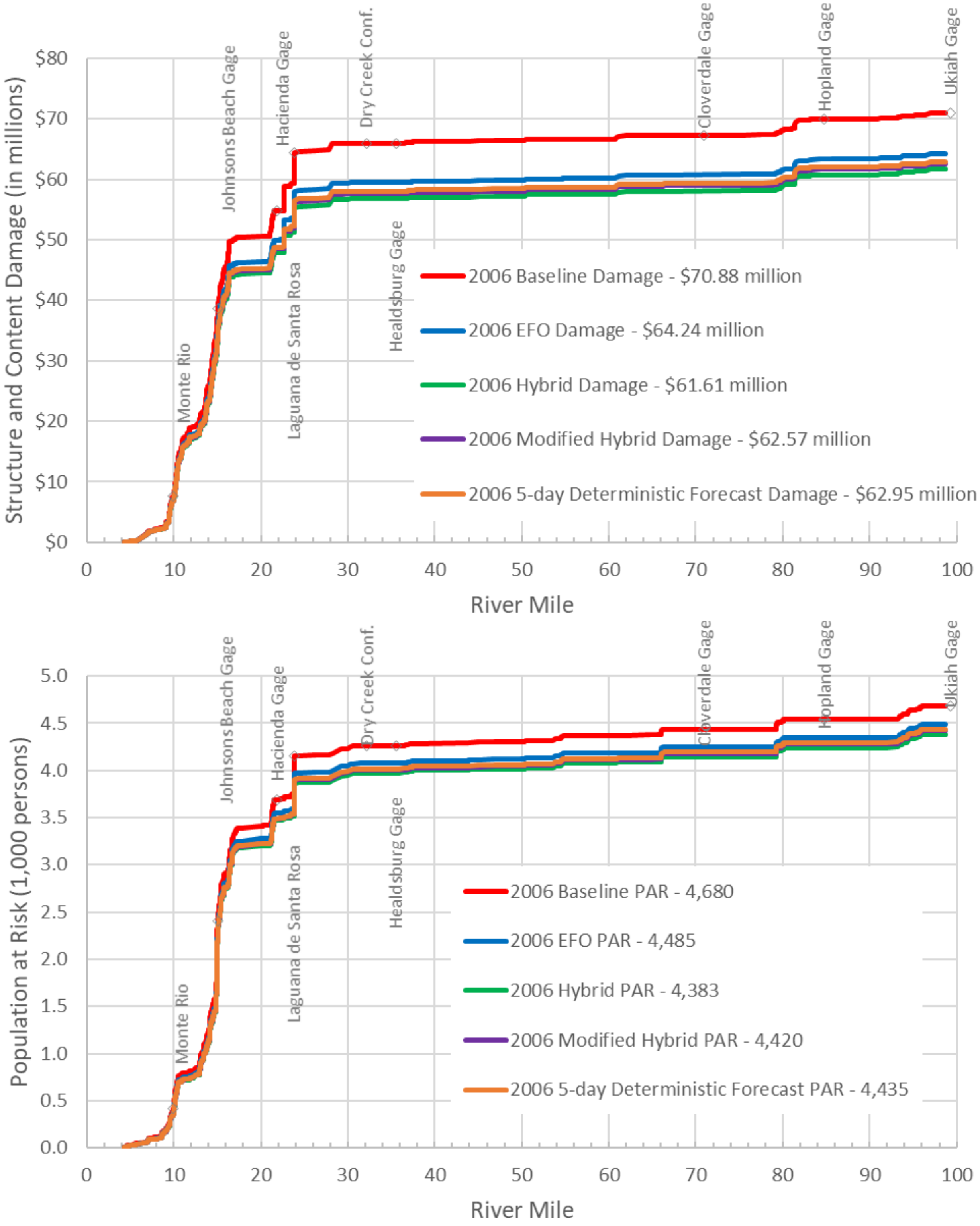


Figure 10. Damage and population at risk (PAR) values along the Russian River for each WCP alternative for the historical 2006 event. (Source: Lake Mendocino FIRO FVA, 2020)

Table 9. EAD values for each WCP alternative (thousands)

Location	Baseline	EFO	Hybrid	Modified Hybrid	5-day Deterministic Forecast
Hopland	104.09	101.10	98.50	100.60	103.68
Cloverdale	703.02	719.32	705.61	705.59	706.39
Geyserville	191.71	185.16	189.74	189.74	189.40
Healdsburg	542.20	532.17	533.05	535.03	540.82
Dry Creek	2.63	2.66	2.69	2.68	2.68
Windsor	265.56	259.56	258.48	258.48	260.23
Santa Rosa	1,121.14	1,119.92	1,104.01	1,100.50	1,122.80
Green Valley Creek	648.73	631.87	615.95	617.86	628.51
Guerneville	11,282.16	11,207.26	11,065.81	11,049.95	11,274.18
Monte Rio	369.84	366.74	364.47	363.75	370.06
Total EAD	15,231.08	15,125.73	14,938.30	14,924.16	15,198.73

Table 10. EAP values for each WCP alternative (persons)

Location	Baseline	EFO	Hybrid	Modified Hybrid	5-day Deterministic Forecast
Hopland	15.3	14.7	14.6	14.7	14.9
Cloverdale	42.8	42.7	42.4	42.4	42.6
Geyserville	10.9	10.5	10.8	10.8	10.8
Healdsburg	48.4	48.2	48.3	48.3	48.5
Dry Creek	0.4	0.4	0.4	0.4	0.4
Windsor	39.9	39.9	39.9	40.0	40.2
Santa Rosa	101.5	100.8	99.2	99.1	101.5
Green Valley Creek	2.6	2.5	2.5	2.5	2.5
Guerneville	697.0	688.1	683.2	683.2	690.3
Monte Rio	21.4	21.3	20.9	20.8	21.2
Total EAD	980.2	969.1	962.2	962.2	972.9

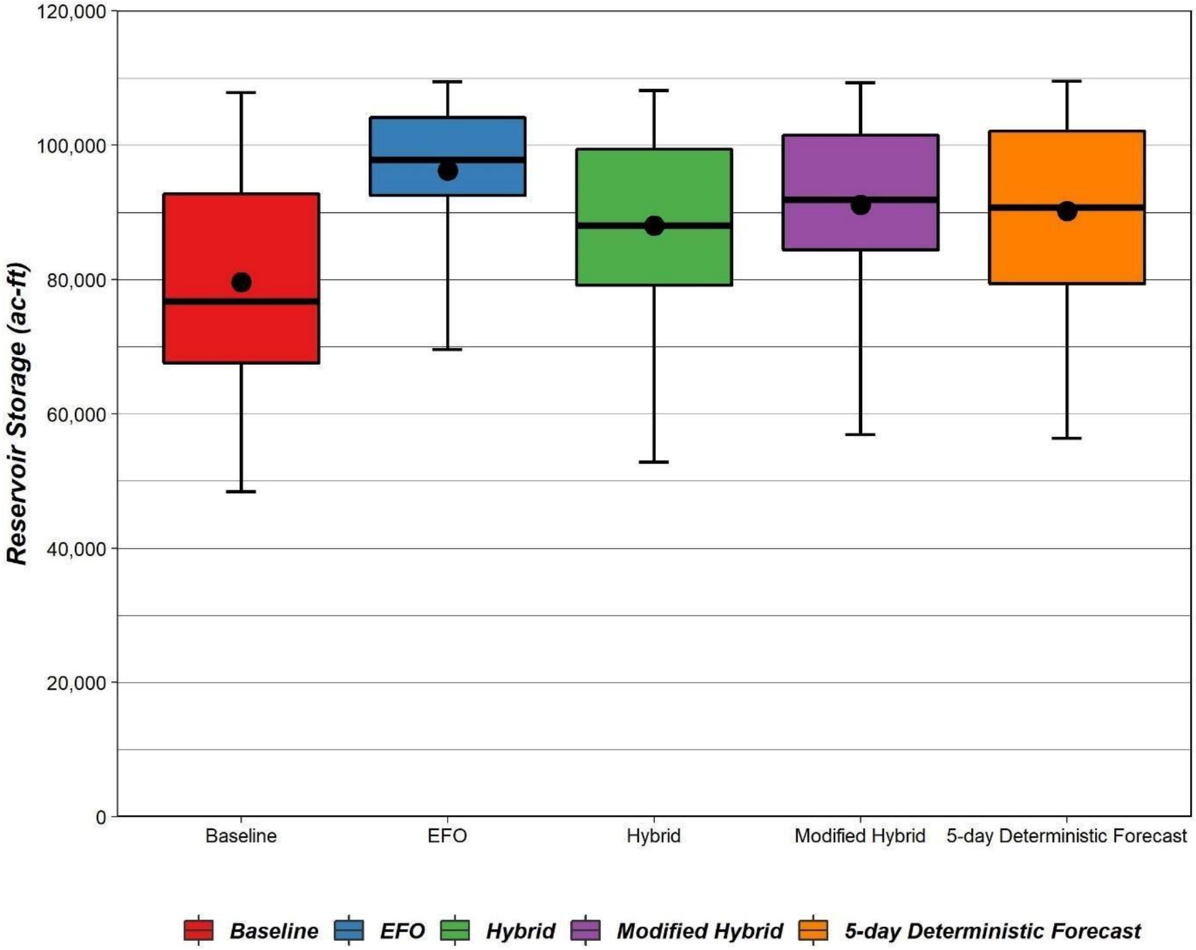


Figure 11. Lake Mendocino storage on May 10 (Source: Lake Mendocino FIRO FVA, 2020)

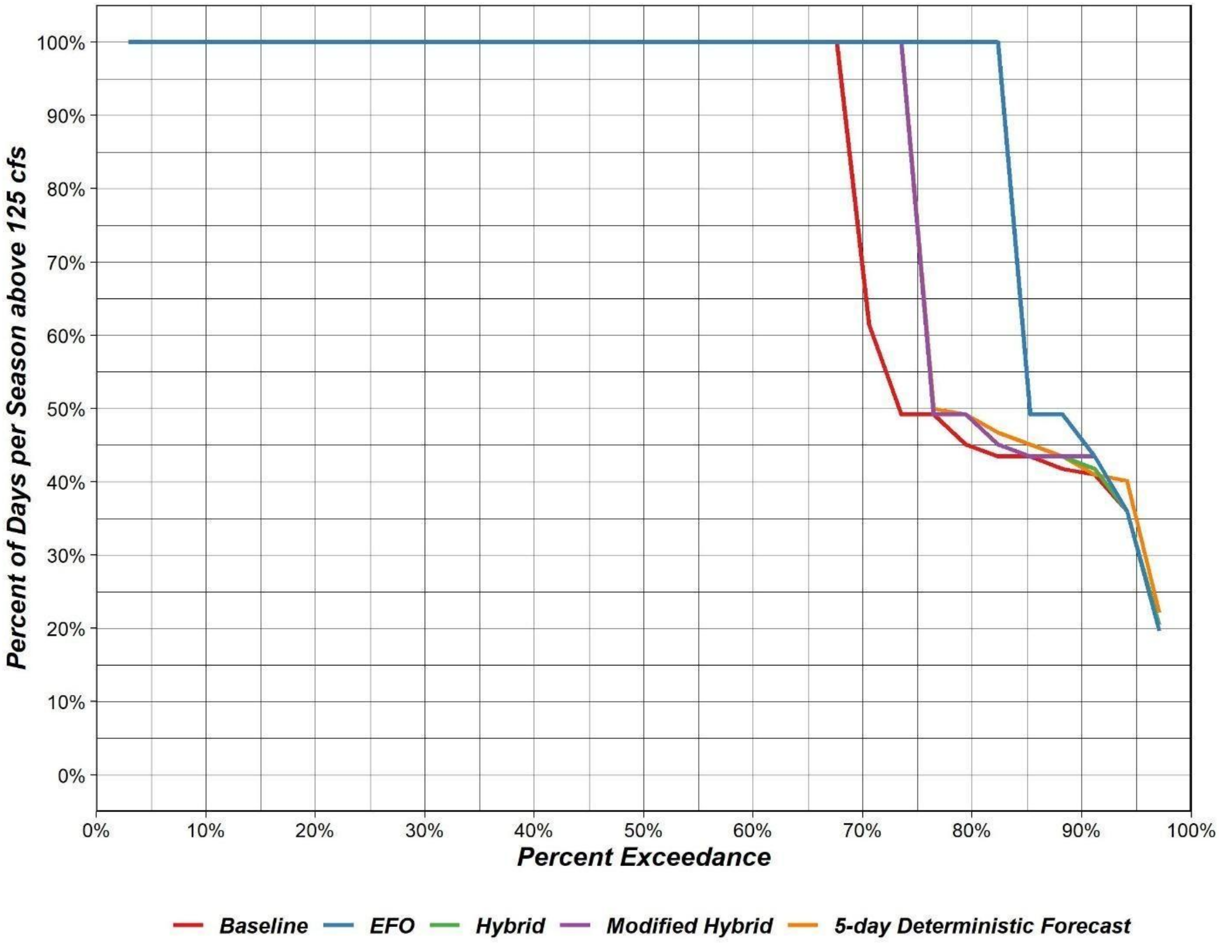


Figure 12. Percent of days per season (June–September) in which flows satisfy 125 cfs at Cloverdale (higher is better). Hybrid, Modified Hybrid, and Five-Day Deterministic Forecast WCPs are nearly identical through 76 percent exceedance. (Source: Lake Mendocino FIRO FVA, 2020)

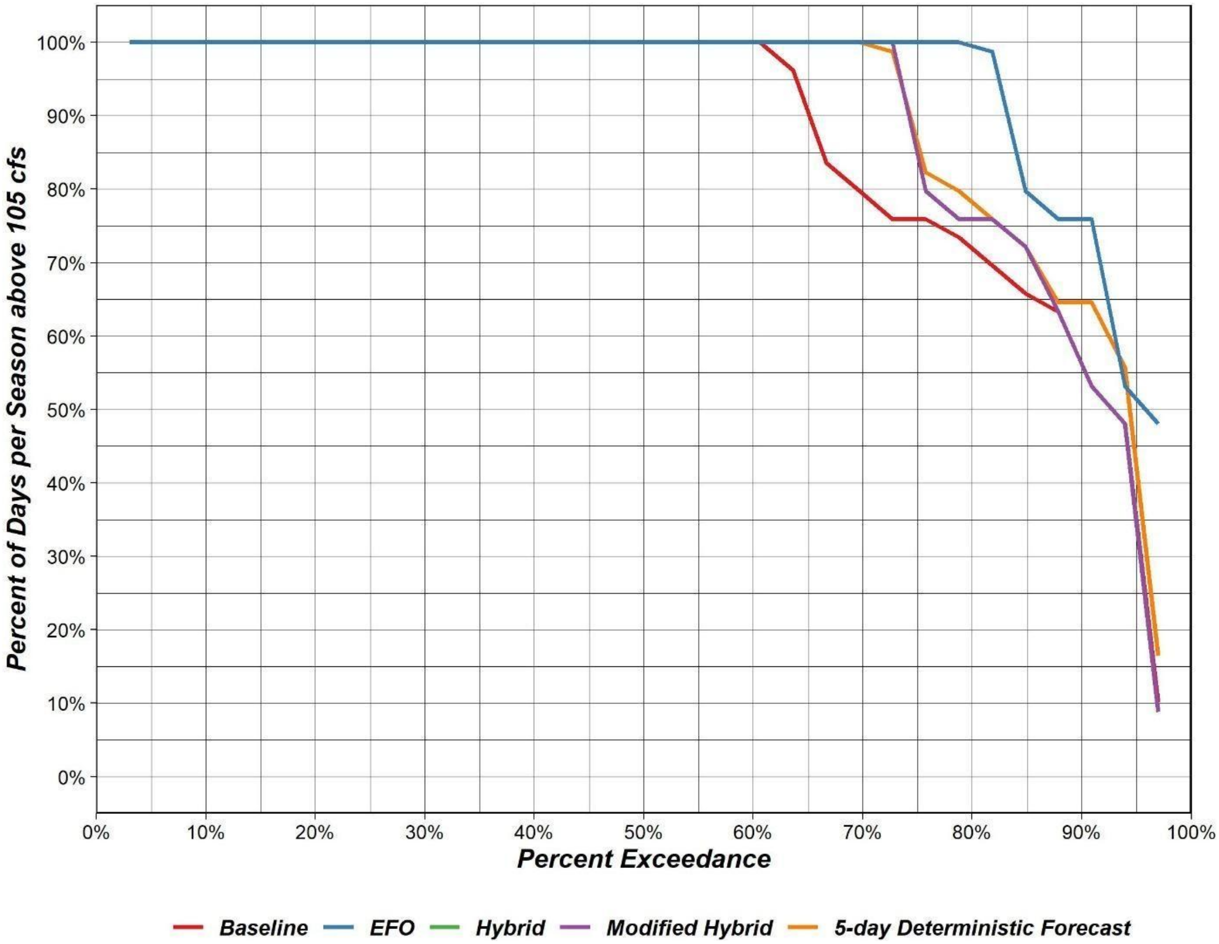


Figure 13. Percent of days per season (October 12–January 1) in which flows satisfy 105 cfs at Healdsburg (higher is better). (Source: Lake Mendocino FIRO FVA, 2020)

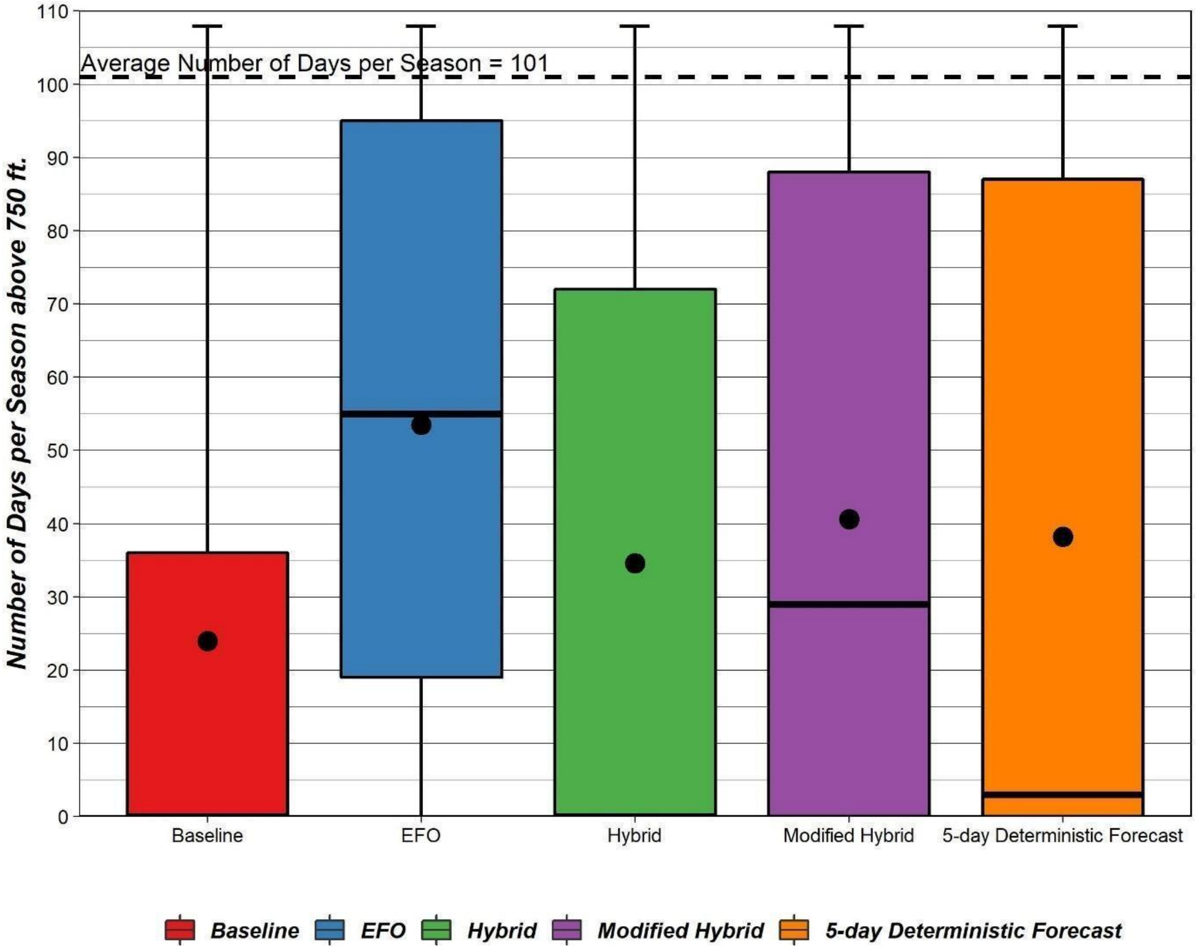


Figure 14. Number of days per recreation season during which access to Bushay Campground is limited (pool elevation exceeds 750.0 ft; lower is better). (Source: Lake Mendocino FIRO FVA, 2020)

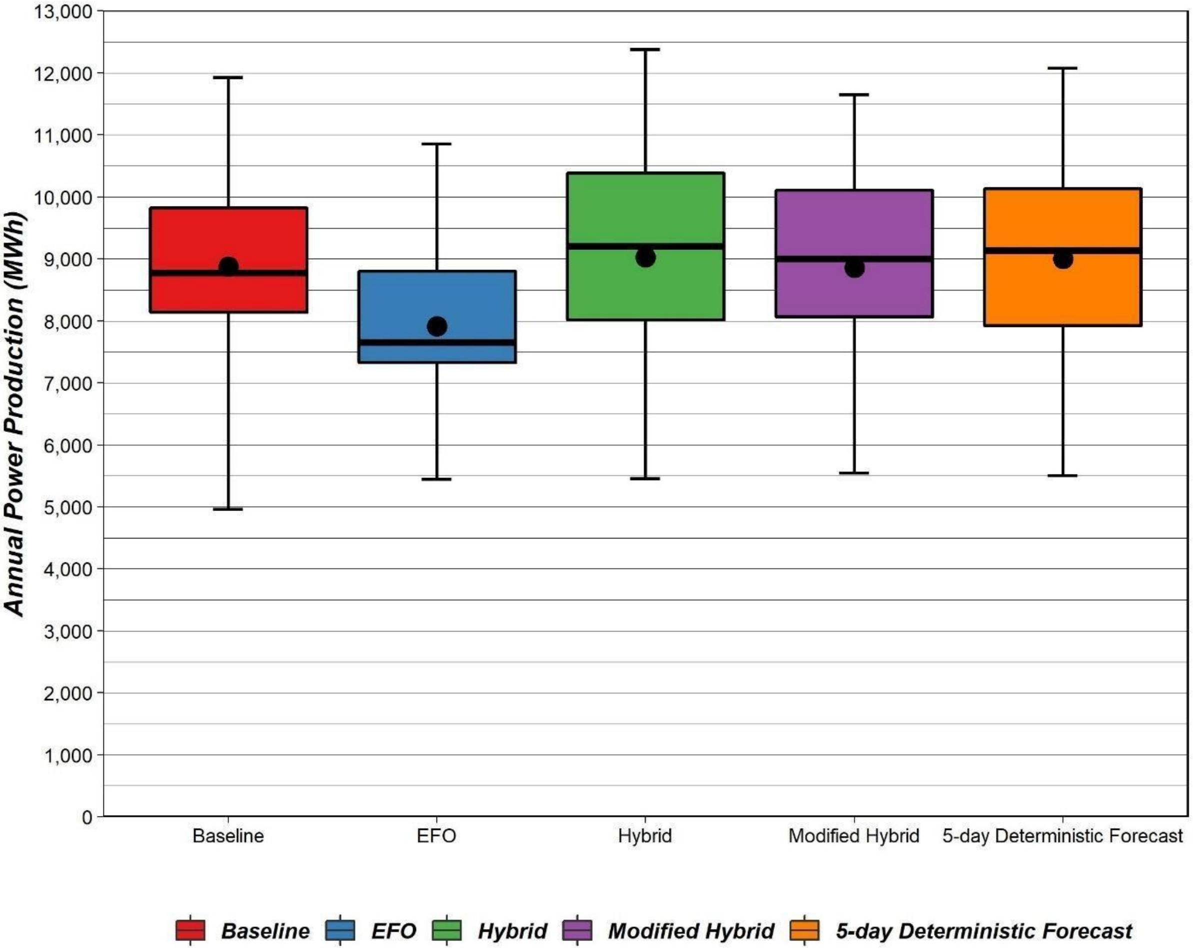


Figure 15. Annual (calendar year) power production for Lake Mendocino (higher is better). (Source: Lake Mendocino FIRO FVA, 2020)

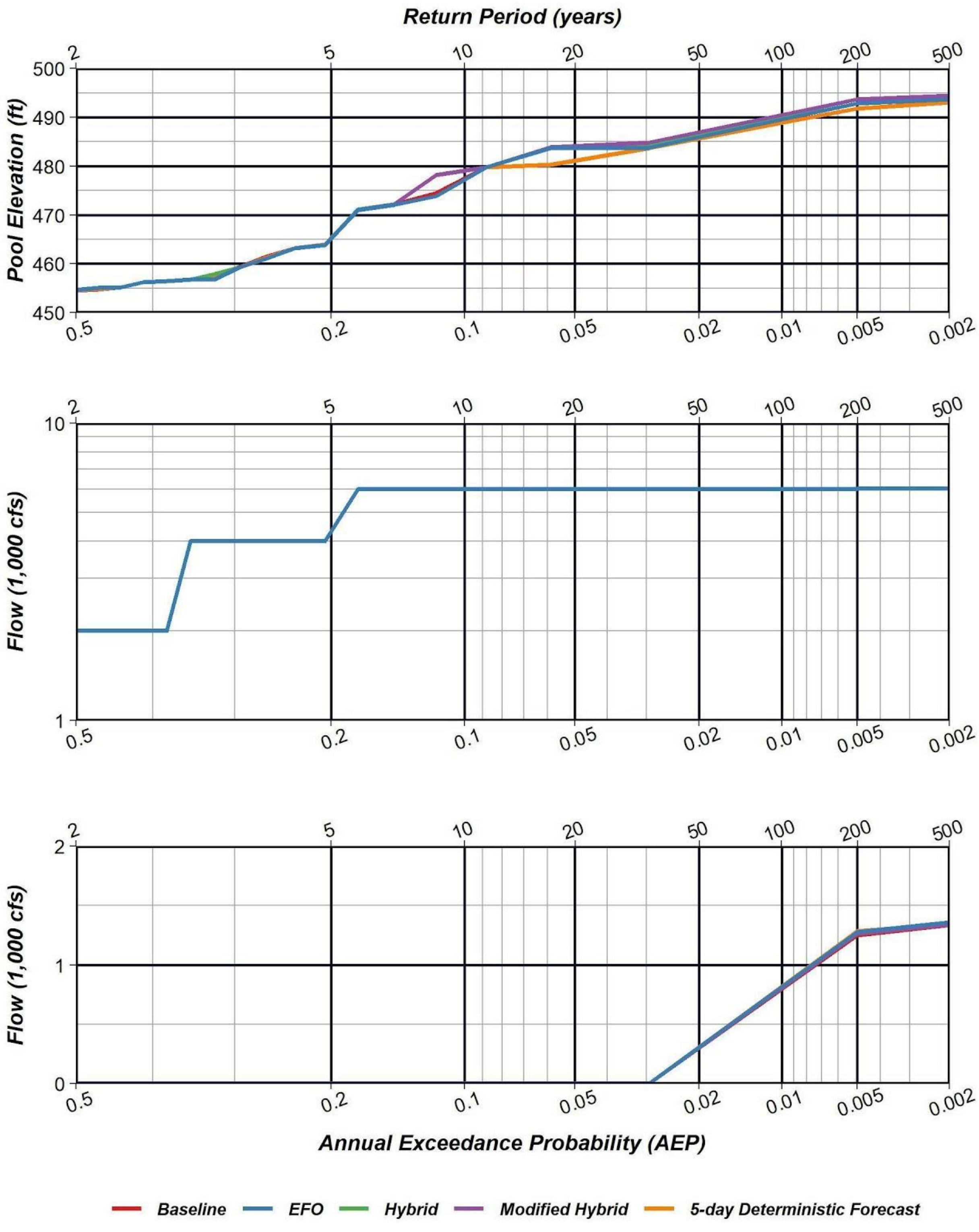


Figure 16. Annual maximum (a) pool elevation, (b) total release, and (c) uncontrolled spill frequency functions at Lake Sonoma. Results for all alternatives are nearly identical in the bottom two plots. (Source: Lake Mendocino FIRO FVA, 2020)

3.3 FIRO Alternatives Considered for Economic Analyses

Five alternatives were assessed in relation to their performance on the 16 metrics. These alternatives are summarized in Table 11 and described in more detail in Section 3.1.2 (WCP Alternatives) above. The 16 metrics defined by the Steering Committee are provided in Table 5 of that same section. The metrics were developed to assess each alternative's performance on flooding (M1–9); water supply and environmental concerns (M10–12); and recreation, power, dam safety, and operations (M13–16).

Table 11. Candidate FIRO alternatives to be evaluated

WCP Alternative	Description	Percent Increase in Median May 10th Storage
Existing WCP operation (baseline)	This is the baseline condition against which performance of all alternatives will be measured. It includes the seasonal guide curves and release selection rules from the 1986 USACE WCM and 2003 update to the flood control diagram. This plan calls for winter season storage of 68,400 ac-ft and a summer storage of 111,000 ac-ft with fall and spring drawdown and refill (see standard guide curve). No forecasts are utilized. Storage above the guide curve is always evacuated as quickly as feasible.	0%
Ensemble Forecast Operations (EFO)	Uses the 15-day ensemble streamflow forecasts from the CNRFC. Assesses the probability of storage above 111,000 ac-ft (model parameter) given the inflow ensembles and a release schedule and compares this with a probability threshold defined through calibration. If probability exceeds the tolerable likelihood anywhere in the 15-day period, a flood release is computed to reduce the probability to an acceptable level. Recommended release can be updated with each forecast cycle.	27%
WY19 Hybrid (WY19 major deviation)	A combination of the existing WCP and the EFO where the variable space is managed by the EFO process. In mid-winter, the variable space resides between 68,400 and 80,050 ac-ft and maintains the same drawdowns and refill start dates as the WCP. Storage above the variable space is always evacuated as quickly as feasible. Recommended release can be updated with each forecast cycle.	15%
Modified Hybrid	Similar to WY19 Hybrid, with higher mid-winter storage and/or a corner-cutting adjustment to the guide curve in March to aid with spring refill. More than one variant of this strategy may be evaluated.	20%
Five-Day Deterministic Forecast	Allowable storage above 68,400 ac-ft and reservoir release informed by current storage and the five-day deterministic forecast for Lake Mendocino inflow. Recommended release can be updated with each forecast cycle.	18%

To solicit input among participants concerning their views on the performance of each WCP alternative and to facilitate the decision making process, participants at a special work session ranked the alternatives' performances against the 16 metrics. Table 12 through Table 15 present these results, which are grouped by flood risk management metrics; water supply and environmental metrics; recreation, power, dam safety, and operations metrics; and finally flood risk management metrics for Lake Sonoma. Voters were asked to assign a number from one to five for each alternative, with “1” indicating the most successful alternative and “5” indicating the least successful alternative. The results were color-coded, where green indicates the most successful alternative and red indicates the least successful alternative.

Following the voting process, results from an objective ranking system were presented to meeting participants.[2] The results, shown in Table 16 through Table 19, reveal that these objective rankings had close agreement with the rankings determined from participant voting.

Table 12. Vote rankings of WCP alternatives by flood risk management metrics

Metric ID	Baseline	EFO	Hybrid	Modified Hybrid	Five-Day Deterministic Forecast
M1	4.0	2.0	1.5	1.4	2.1
M2	4.3	3.4	1.5	1.5	3.0
M4	4.5	2.8	1.3	1.0	2.8
M6	4.5	3.4	2.3	1.0	3.1
M8	3.9	2.6	1.4	1.3	2.6
M9	4.1	2.0	1.3	1.3	2.2
Average	**4.2**	**2.7**	**1.4**	**1.3**	**2.6**

Table 13. Vote rankings of WCP alternatives by water supply and environmental metrics

Metric ID	Baseline	EFO	Hybrid	Modified Hybrid	Five-Day Deterministic Forecast
M10	5.0	1.0	2.7	2.1	2.4
M11	4.9	1.1	2.4	2.4	2.3
M12	4.9	1.2	2.8	2.4	2.3
Average	**4.9**	**1.1**	**2.6**	**2.3**	**2.4**

Table 14. Vote rankings of WCP alternatives by recreation, power, dam safety, and operations metrics

Metric ID	Baseline	EFO	Hybrid	Modified Hybrid	Five-Day Deterministic Forecast
M13	1.6	4.4	2.9	3.1	2.9
M14	2.0	4.4	1.7	1.9	1.7
M15	1.3	4.8	2.2	2.0	2.6
M16	2.2	1.2	2.9	3.0	4.3
Average	**1.8**	**3.7**	**2.4**	**2.5**	**2.9**

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[2] A process was devised to rank each alternative for each metric. For several metrics, the process was complicated by multiple locations and WCP performance within the most important range of the frequency distributions. Additionally, practical “significant differences” needed to be established to allow for ranking WCP options the same when the outcomes were practically the same.

Table 15. Vote rankings of WCP alternatives by Lake Sonoma flood risk management metrics

Metric ID	Baseline	EFO	Hybrid	Modified Hybrid	Five-Day Deterministic Forecast
M3	2.2	1.7	2.0	1.9	1.8
M5	1.1	1.1	1.1	1.1	1.1
M7	1.4	1.3	1.1	1.1	1.1
Average	**1.6**	**1.3**	**1.4**	**1.4**	**1.3**

Table 16. Objective ranking of WCP alternatives by flood risk management metrics

Metric ID	Baseline	EFO	Hybrid	Modified Hybrid	Five-Day Deterministic Forecast
M1	5	3	1	1	4
M2	5	3	1	1	3
M4	5	3	1	1	4
M6	5	4	2	1	3
M8	1	1	1	1	1
M9	1	1	1	1	1
Average	**3.7**	**2.5**	**1.2**	**1.0**	**2.7**

Table 17. Objective ranking of WCP alternatives by water supply and environmental metrics

Metric ID	Baseline	EFO	Hybrid	Modified Hybrid	Five-Day Deterministic Forecast
M10	5	1	4	2	3
M11	5	1	2	2	2
M12	5	1	4	2	3
Average	**5.0**	**1.0**	**3.3**	**2.0**	**2.7**

Table 18. Objective ranking of WCP alternatives by recreation, power, dam safety, and operations metrics

Metric ID	Baseline	EFO	Hybrid	Modified Hybrid	Five-Day Deterministic Forecast
M13	1	5	1	4	3
M14	4	5	1	1	1
M15	1	5	2	2	4
M16	2	1	3	4	5
Average	**2.0**	**4.0**	**1.8**	**2.8**	**3.3**

Table 19. Objective ranking of WCP alternatives by Lake Sonoma flood risk management metrics

Metric ID	Baseline	EFO	Hybrid	Modified Hybrid	Five-Day Deterministic Forecast
M3	1	1	1	1	1
M5	1	1	1	1	1
M7	1	1	1	1	1
Average	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**

M3, M5, and M7 are metrics associated with assessing the impacts the alternatives have on flood risk management at Lake Sonoma. Both the results from the vote ranking and objective ranking assessed that there is minimal to no impact on Lake Sonoma regardless of the alternatives considered.

Additional metrics relating to flood risk management assess the impacts of each of the alternatives on flooding at downstream locations (M1); pool elevation, reservoir releases, and uncontrolled spill from Lake Mendocino (M2, M4, and M6); and expected costs and loss of life due to inundation damage (M8 and M9).

The EFO, Hybrid, Modified Hybrid, and Five-Day Deterministic Forecast alternatives scored better than the baseline alternative for M1, M2, M4, and M6 based on both the voting results and the objective analysis. This provides strong evidence that flood risk can be greatly improved upon from current baseline operations regardless of which other alternatives are recommended in the FVA. Based on the voting results and the objective analysis, the Hybrid and Modified Hybrid alternatives perform the best on M1, M2, M4, and M6. The EFO and the Five-Day Deterministic Forecast received similar rankings to each other, both ranking better than baseline but worse than the Hybrid and Modified Hybrid alternatives.

M8 and M9 focus on the economic costs and loss of life, respectively, due to inundation damage at ten critical Russian River locations. These metrics are particularly important as they are direct measures of costs associated with implementing each of the alternatives. Although the EAD and EAP did not change significantly from one alternative to the next, the Modified Hybrid and Hybrid alternatives were voted to perform the best for M8 and M9, while the baseline was voted as performing the worst. The objective ranking did not assess any statistically significant difference between the performance of the five alternatives.

The alternatives were also evaluated based on their ability to increase the reliability of water supply in Lake Mendocino (M10) and to meet environmental standards to support fish populations (M11 and M12). The results from both the ranking by votes and by objective analysis suggest that EFO provides the greatest improvement in relation to M10–M12. The Hybrid, Modified Hybrid, and Five-Day Deterministic Forecast all scored similarly, falling behind EFO but scoring well ahead of the baseline. The finding that baseline operations performed the worst on M10–M12 indicates that significant improvement in water reliability and the frequency that environmental standards are met can be achieved by any of the alternatives over baseline operations.

The final criteria in assessing the alternatives relate to their impacts on recreation (M13), power generation (M14), dam safety (M15), and operational hours (M16). Baseline operations were determined to perform the best based on voting and objective analysis for M13 and M15. The Hybrid, Modified Hybrid, and Five-Day Deterministic Forecast alternatives performed similarly to each other, but not as well as the baseline, and EFO performed the worst. These results align with the findings that EFO, Hybrid, Modified Hybrid, and Five-Day Deterministic Forecast improve water reliability by storing more water at certain times of the year than the baseline. This increase in water storage leads to increases in the number of days the Bushay Campground access road is inundated (M13), as well as increasing the frequency that the reservoir elevation reaches a point that may exacerbate erosion (M15). The ranking of alternatives for M16 found that EFO performed the best, followed the baseline, Hybrid, Modified Hybrid, and finally the Five-Day Deterministic Forecast.

The alternatives' performances on M14 assesses the impact on the annual power production of the Coyote Valley Dam hydropower facility. The rankings for M14 indicate that the Hybrid, Modified Hybrid, and Five-Day Deterministic Forecast perform the best, followed by the baseline and then EFO. These rankings result from the HEMP analysis show that implementation of the Hybrid, Modified Hybrid, and Five-Day Deterministic Forecast alternatives provide a significant increase in the annual power production of the Coyote Valley Dam hydropower facility over baseline operations, particularly in December through March.

The Steering Committee concluded that the baseline, EFO, and Modified Hybrid alternatives provide a low, medium, and high range of benefits, respectively. Based on the metrics, as well as operator confidence and communication considerations, the Modified Hybrid alternative was selected as the preferred alternative. Recognizing that scientific and technological advancements will be made before the next WCM update, EFO will be considered as a reach goal to provide a growth path for the WCP.

ERG performed the economic analysis for FIRO at Lake Mendocino based on the Steering Committee's decision to continue forward with the Modified Hybrid and EFO alternatives.

4 Economic Benefits of FIRO at Lake Mendocino

4.1 Introduction

ERG estimated the benefits of Forecast Informed Reservoir Operations (FIRO) at Lake Mendocino for six benefit types:

- Agricultural water supply
- Municipal and industrial (M&I) water supply
- Hydropower
- Fisheries
- Recreation
- Reduced operation, maintenance, and replacement costs

For each benefit category, we provide background information, an overview of the methods, and details on the calculations performed.

Flood risk reduction benefits are not included here because they were considered as part of the Hydrologic Engineering Management Plan (HEMP) in accordance with accepted the U.S. Army Corps of Engineers' (USACE's) Hydrologic Engineering Center (HEC) methods for estimating expected annual flood damages. The HEMP is included as Appendix B of the Lake Mendocino Final Viability Assessment (Lake Mendocino FIRO FVA, 2020).

The potential costs of FIRO were not considered as part of this work and therefore the net benefits of FIRO remain uncertain. Future work should consider assessing the costs of FIRO.

This assessment did not directly evaluate impacts to tribes nor estimate cultural values. Cultural significance is important but is outside this scope of work. Some benefits to local tribes, such as fisheries, may be captured indirectly in the benefits quantified, but our methods do not distinguish the beneficiary.

To develop the methods, ERG studied the U.S. Bureau of Reclamation's (Reclamation's) prior work on these benefit categories; reviewed the 2013 Principles, Requirements and Guidelines for Water and Land Related Resources Implementation Studies (PR&G) and the 1983 Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (P&G); assessed the scope of the project and data availability; and held an all-day meeting with expert economists on March 11, 2020, to vet the methods. The National Economic Development (NED) procedures from the P&G provided useful guidance for developing our methodologies. These procedures outline the steps to estimate various benefits using a variety of techniques, such as benefit transfer, estimating demand curves, and least-cost alternatives. The NED procedures played a major role in developing the strategies for estimating each benefit. The 1983 P&G and the 2013 PR&G are discussed in more detail in the following section.

In accordance with Reclamation standards, ERG assessed "with project" alternatives as compared to the "without project" condition. We refer to the "without project" condition as "baseline" because it represents a continuation of the existing reservoir operations. The "with project" alternatives are referred to generally as FIRO "alternatives" or specifically by the type of alternative reservoir operating conditions.

Benefits were quantified for two FIRO alternatives: The Modified Hybrid and the Ensemble Forecast Operation (EFO). These two alternatives were chosen following the HEMP analysis, which assessed the performance of all five alternatives (including existing operations, or baseline) in relation to 16 metrics that evaluated flood risk management; environmental concerns; water supply reliability; and dam safety, recreation, hydropower production, and operational considerations. Based on the results from the HEMP analysis, the Modified Hybrid was selected for Lake Mendocino FIRO. The EFO alternative was recommended as a reach goal to provide a growth path for the Water Control Plan (WCP) as scientific and technological advancements are made. Section 3.3 of this report provides context for why these FIRO alternatives were chosen.

FIRO's impacts on Lake Mendocino water levels were estimated using data from a 33-year hindcast from January 1, 1985, through September 30, 2017 (see Section 3.2 of this report for detail about how these water levels were estimated). A variety of water year (WY) types are included in the hindcast data and the data also captures the largest annual events for WYs 1985–2017. Therefore, the benefits reflect the natural variability between dry and wet years. This is critical because the benefits of FIRO are very different in dry years than wet years. For each benefit, average annual benefits were calculated over these 33 years. However, because average benefits obscure the variability across different types of WYs, for some benefits we present estimates for one wet and one dry year to demonstrate this variability.

We chose not to project impacts forward due to uncertainty in future weather and climate conditions. To do so would require significant additional hydrological analysis that is beyond the scope of this project. Instead, we have assumed future impacts of FIRO are represented based on the hindcast period. Climate change could alter the impacts of FIRO in multiple ways. For example, drier conditions could lead to larger benefits of preserving additional water in the flood pool. Conversely, a higher prevalence of multi-year droughts could result in smaller benefits of FIRO because the water level may never exceed the guide curve and allow for water conservation in the later years of the drought. Future conditions involve several other uncertainties that could be evaluated if needed in a follow-up assessment.

All benefits are in 2019 dollars. When necessary, the Bureau of Labor Statistics' Consumer Price Index for All Urban Consumers (CPI-U) was used to convert figures to 2019 dollars.

Table 20 provides an overview of the estimated benefits. The Modified Hybrid alternative results in total estimated annual benefits of $9.4 million. The "reach" alternative, EFO, has estimated total annual benefits of $9.9 million. Assuming benefits accrue for 50 years, the present value (PV) of these benefits would be $259.7 million and $273.9 million.[3]

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[3] Reclamation recommended discount rate at the time of writing was 2.75 percent (Reclamation, 2019).

Table 20. Summary of incremental average annual FIRO benefits (thousands of 2019 dollars)

Benefit Type	Modified Hybrid	EFO
Agriculture water supply [a]	$114.1	$118.4
M&I water supply [b]	$2,674.6	$2,778.9
Hydropower [c]	-$1.9	-$43.8
Fisheries [d]	$5,726.4	$5,726.4
Recreation	$802.7	$1,239.2
Reduced operating, maintenance, and replacement costs	$45.5	$53.0
Total	**$9,361.4**	**$9,872.2**

[a] The method used is expected to underestimate total benefits because it only reflects the average marginal value and not the value of increased reliability.
[b] A sensitivity analysis that assumes no change in price estimated benefits of $1.04 and $1.08 million under the Modified Hybrid and the EFO approaches, respectively.
[c] The negative annual benefit is due to a current rule in the Water Control Manual that requires hydropower production to stop when reservoir elevations exceed 755 ft. If this rule were to change, we would expect FIRO alternatives to provide a positive benefit.
[d] Estimate using the cost to raise the height of Coyote Valley Dam as a proxy for benefits. The alternative method using water transaction prices results in larger values.

4.2 Federal Guidelines for Estimating Economic Benefits

Federal water resource projects are governed by the 2013 PR&G, which supersedes and expands upon the 1983 P&G. Major water projects use this framework to promote consistency and informed decision making. This section provides an overview of the guidance relevant to our economic analysis. Specific guidance for each benefit type is included below in the relevant section of the report. Our methods deviate from the P&G and PR&G methods due to data availability or the scope of this project. The P&G methods are designed for an in-depth analysis to justify the costs of large-scale water projects. Evaluating the benefits of FIRO does not require such a detailed analysis.

The following outlines procedural steps to estimate various benefits using a variety of techniques, such as benefit transfer, estimated demand curves, and least cost alternatives. The P&G and PR&G documents played a major role in helping develop the specific strategies for estimating each benefit; however, the methods used for this study were also shaped by Reclamation’s prior work, members of the project team, and the economists who attended the March 11, 2020 meeting.

Identifying the baseline: Any analysis of programmatic benefits must identify the relevant baseline against which the benefits will be assessed. At a minimum, this requires identifying the current levels of ecosystem services, but also current trends and variability if resources permit. The baseline assessment should include both the targeted water resource and other resources that may be affected by the program. The FIRO HEMP conducted a detailed analysis of the current hydrological conditions at Lake Mendocino. These water levels are used to identify our baseline conditions. Secondary data sources are also used such as recreational levels on and around Lake Mendocino provided by USACE.

Projecting forward: The guidelines suggest projecting the future conditions of the study area. We agree this is preferable; however, it is beyond the scope of this project. We have used the 33-year hindcast period to assess benefits rather than projecting forward. Implications of this are discussed in Section 4.1.

Time periods: The guidance suggests using the same period of analysis for all alternative plans. All the benefits are based on the 33-year hindcast period mentioned above.

Discount rate: The guidance recommends using the discount rate determined and published annually.[4]

NED accounting: The guidance outlines four accounts, (1) NED procedures, (2) environmental quality, (3) regional economic development, and (4) other social effects. The NED account reflects effects on the national economy and is the basis for our benefits estimation. Benefits estimates should therefore reflect the benefit to the nation as a whole. Transfers between regions are not considered in a NED analysis.

4.3 Agricultural Water Supply

Summary of Findings

The value of water was estimated using the residual imputation method. Using the estimated average value of an acre-foot of water, and assuming a hypothetical average increase in water for agriculture of 740 or 768 acre-feet under the Modified Hybrid and EFO alternatives, respectively, we estimate average annual benefits of $114,079 and $118,394. In a dry year, benefits may exceed $775,000.

4.3.1 Background

Water used for frost protection for wine grapes and for crop irrigation can generally result in improved quality and quantity of agricultural goods, which leads to an economic benefit from avoided crop losses.[5] FIRO can help attain that economic benefit by utilizing better forecasting and allowing reservoir operations to change based on the predicted incoming flow.

Agriculture output is significant in Mendocino and Sonoma counties. In 2018, agricultural output was valued at $320.8 million in Mendocino and $1.1 billion in Sonoma, according to the 2018 Mendocino and Sonoma County crop reports, respectively. The impact of FIRO on agriculture is expected to be small because agriculture generally can access enough water.

Surface water diversions are "regulated" under water rights, but rarely enforced. Groundwater withdrawals are currently unregulated. Further complications in the Russian River basin limit the

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[4] Reclamation recommended discount rate for fiscal year 2021 is 2.5 percent (Reclamation, 2020c). At the time of writing, the discount rate was 2.75 percent (Reclamation, 2019).

[5] The benefits of FIRO to agriculture include additional water for irrigation, heat suppression, and frost suppression. We collectively call these "agricultural benefits" in this report. Elsewhere, researchers sometimes refer specifically to irrigation benefits. However, we are using broader terminology to ensure that heat and frost suppression are also included.

effectiveness of the existing regulatory framework, including a complicated system of water rights in the Russian River watershed, complex interaction of surface water and groundwater, the absence of groundwater regulation in the region, and a need for greater collection and reporting of surface water and groundwater use in the region. Unlike many river systems in the Western United States, the Russian River has not been adjudicated, nor does it have a watermaster with the authority to strictly control and regulate surface water and groundwater use. The Sustainable Groundwater Management Act, signed into law in 2014, provides a framework for sustainable groundwater management through regional groundwater sustainability plans. Steps are being taken to implement this act in the Russian River basin in the coming years.

We developed a framework to quantify the agricultural benefits because future changes in water availability and the regulatory framework may significantly impact the agricultural benefits provided by FIRO. Additionally, agricultural benefits may be more prominent for other reservoirs that may use the decision support tool (DST), and it is important that the DST is transferable.

4.3.2 Methods and Results

We calculated annual avoided losses from agricultural production due to the revised water management practices of the FIRO alternatives using a net income approach. Specifically, we use the residual imputation method (also known as the residual value method) which imputes the "shadow price of water" (i.e., the estimated price for when a good or service does not have a market price). This method subtracts all known input costs from total revenue for a crop. The remainder is the value attributed to water. This remainder is then divided by the quantity of water used to generate a value per unit of water. We use the residual imputation method because of its applicability to Lake Mendocino but also because it is transferable and therefore lends itself well to being incorporated into the DST. The Farm Budget tool, often used by Reclamation, was not used because it was decided by consulted economists that it would not be readily transferable.

This methodology, which is explained in more detail in the following sections, includes:

- Calculating net returns per acre for prevalent crops (i.e., revenue minus costs).
- Calculating the value of a unit of water by dividing net returns by water usage.
- Estimating the potential increase in water supply.
- Calculating the annual avoided losses by multiplying the estimated value of a unit of water by the increase in water supply.

The residual imputation method is a common technique used to value irrigation water. Young and Loomis (2008) provide a detailed overview of this method.

The average marginal value of water, however, is only one of the benefits of the improved reliability of FIRO, which will be especially beneficial in years with extreme water shortages. In these dry years, FIRO can provide additional water that may allow vineyards to continue operations without damaging crops, whereas without FIRO, they may have had significant long-term damage that would impact their production for many years. This additional water would provide a large agricultural benefit; however, due to difficulties in estimation, these long-term impacts are not estimated. Instead, we present the benefit of FIRO in a dry year when this situation may occur for demonstration purposes.

Our approach assumes the number of acres of each crop planted is not impacted by FIRO. For example, FIRO would not lead to farmers switching crops or expanding acreage. There are some models, such as the Statewide Agricultural Production model, that include these decisions as part of the modeling process. We have chosen not to use these models because the additional water supply for agriculture from FIRO is relatively small and thus will likely not have a large impact on planting choices.

The 1983 P&G and the 2013 PR&G recommend using a farm budget analysis to estimate changes in net income. It recommends estimating revenues with and without the project and taking the difference to approximate the value. The residual imputation method uses a farm budget analysis to estimate net returns. However, we have not directly estimated revenues with the FIRO alternatives because of data availability.

4.3.2.1 *Step 1: Calculate Net Returns for Chardonnay and Pinot Noir*

This analysis focuses on wine grapes because they are the dominant crop in this region. According to the Sonoma County and Mendocino County annual crop reports, wine grapes are 71 percent of the agricultural value in Sonoma County and 73 percent in Mendocino County (excluding timber from the total which is included in the reports). UC Davis has detailed sample cost data for Chardonnay and Pinot Noir grapes in the Russian River Valley of Sonoma County (UC Davis, 2016a). These costs are for a hypothetical vineyard using typical production practices for the region. There are many assumptions used to develop these estimates, which are detailed in their report. UC Davis reports that total costs per acre are $14,416 for Chardonnay and $15,673 for Pinot Noir (January 2017 dollars). Adjusting to 2019 dollars using the CPI-U results in costs of $15,036 and $16,347, respectively.

UC Davis calculates revenues using average annual yields and average prices from 2012–2016. However, we chose to use more recent price data for 2014–2018 as reported in the Sonoma Crop Reports (for years 2014, 2016, and 2018) (Table 21). Five-year average prices, adjusted to 2019 dollars, are $2,310 per ton for Chardonnay and $3,837 per ton for Pinot Noir. The P&G guidelines recommend using normalized crop prices issued by the U.S. Department of Agriculture (USDA ERS, 2020). However, wine grapes are not included in this data series. When this is the case, the guidance suggests using statewide average prices over the three previous years. We used local prices, rather than statewide averages, because the price of wine grapes is highly variable depending on region, even within a state.

We used the reported average yields from UC Davis (6.75 and 4 tons per acre for Chardonnay and Pinot Noir, respectively). These yields reflect the average annual yield over the life of the vines in a mature vineyard.

Net returns are estimated to be $554 for an acre of Chardonnay and -$998 for an acre of Pinot Noir. In our baseline estimates, we assume zero value for water for Pinot Noir grapes due to the negative net return. However, we provide an alternative estimate for Pinot Noir using price and yield data from only 2018, which was a very good year for Pinot Noir grapes in this region. In 2018, the net return for an acre of Pinot Noir grapes was $430.

According to economic theory, negative net revenues should not persist because a rational producer would exit the business. There are several reasons we may observe negative net revenue for Pinot Noir grapes. First, there may be errors in our values. Second, due to price and yield fluctuations, growers may experience negative returns in some years, but remain profitable over a longer time horizon. Other studies have found negative values, such as Speelman et al. (2008), Lange (2006), and OECD (n.d.).

4.3.2.2 *Step 2: Estimate the Value of a Unit of Water*

We used an estimated 0.87 acre-feet (ac-ft) per acre of water usage for wine grapes, a value determined from McGourty et al. (2008).[6] In their study, the authors estimated the total acreage of wine grapes in the upper Russian River and the total water usage for irrigation, heat protection, frost protection, and postharvest. Dividing the total water usage of 13,569 ac-ft by 15,539 acres results in an estimate of 0.87 AF per acre per year. Dividing the net returns for Chardonnay by 0.87 ac-ft results in a value of $634 per ac-ft (Table 21). Dividing the net returns for Pinot Noir in 2018 by 0.87 act-ft results in a value of $493 per ac-ft.

Note that we have calculated the gross benefit of water including costs for water irrigation. Net and gross benefits are very similar in this instance because the cost of irrigation water is estimated to be only $33 per acre. Gross benefits are useful when estimating the societal benefit (i.e., the total value of the water to all sources), whereas net benefits are relevant specifically to farmers.

Table 21. Calculation of the value of an acre-foot of water ($2019)

Value	Source	Chardonnay	Pinot Noir
Total costs/acre	UC Davis	$15,036	$16,347
Yield (average)	UC Davis	6.75	4
Yield (2018 only)	Sonoma Crop Report 2018	5.56	4.33
Price per ton (2014–2018 average)	Sonoma Crop Reports 2014–18	$2,310	$3,837
Price per ton (2018 only)	Sonoma Crop Report 2018	$2,410	$3,871
Net returns	Calculation	$554.00	-$998.00
Net returns (2018 only)	Calculation	-$1,638.00	$430.00
Water use per acre	McGourty et al. (2008)	$0.87	$0.87
Value per ac-ft of water	Calculation	$634.00	-$1,143.00
Value per ac-ft of water (2018 only)	Calculation	-$1,875.00	$493.00

4.3.2.3 *Step 3: Estimate Additional Water Reliability*

As noted above, the impact of FIRO on agriculture is expected to be small because agricultural users generally can access sufficient quantities of water. However, for illustrative purposes, we

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[6] We did not use data from UC Davis's sample costs because it only provides water usage during mid-June through September.

present benefit estimates with hypothetical increases in water availability. We used the same methodology to estimate increases in water reliability as we did for M&I consumers above. This method uses the volume below the target storage level as a proxy for water scarcity. The amount FIRO can reduce this deficit would then represent benefits of increased water reliability due to FIRO. See the previous section for more details and Appendix Table A-1 for the data used in these calculations. We calculate average annual increases in total water reliability of 1,480 and 1,536 ac-ft for the Modified Hybrid and EFO alternatives, respectively. Of this amount, *we attribute half to agriculture (740 ac-ft and 768 ac-ft)*. If M&I water supply reached a threshold where health and safety would be threatened (we assumed 30 percent of total M&I water consumptive demand), agriculture's share would go to zero. However, this does not occur in our historical data.

These 740 and 768 ac-ft are then allocated across different commodities based on acreage.[7] For example, Chardonnay grapes in Sonoma and Mendocino counties are 21 percent of the total agricultural value in these counties, so 155 and 161 ac-ft would be allocated to Chardonnay grapes for the Modified Hybrid and EFO alternatives, respectively.

The crop reports for Sonoma and Mendocino county include livestock and timber, but these industries were excluded from this analysis. The timber industry generally does not receive water from lake Mendocino. Young and Loomis (2008) suggest not including livestock because this is a secondary product and the value of water has already been incorporated into the value of the intermediary product, the feed.

4.3.2.4 *Step 4: Extrapolate to Other Commodities*

Next, we extrapolate to other wine varietals and commodities. To extrapolate to other wine grapes, we:

- Estimated cost per varietal as the average cost per acre for Chardonnay and Pinot Noir.
- Estimated revenue per varietal by multiplying average yields for 2017–2018 by average value per ton (both from the Sonoma County Crop Report, 2018).
- Took the difference between costs and revenues to estimate net returns, imposing a lower-bound of zero for each varietal.
- Took a weighted average of net returns across all varietals (excluding Chardonnay and Pinot Noir, weighting by value).
- Divided the average net returns of $29.05 by 0.87 ac-ft to generate a value of water of $33.27.

To extrapolate to other commodities, we:

- Estimated total agricultural expenditures in Sonoma County of $870.6 million (USDA, 2018).
- Estimated total revenues in Sonoma county of $919.1 million (USDA, 2018).

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[7] We used acres bearing rather than total acres to distribute water supply because we believe it is a better measure of water usage.

- Estimated total farm acres in Sonoma county of 567,284 (USDA, 2018).[8]
- Used these values to estimate average net returns of $85.44 per acre.

Calculating an average water use of 2.38 per acre (Lewis et al. 2008) involved dividing net returns by average water usage per acre, as shown in Table 22.

Table 22. Calculation of water usage

Commodity	Water Usage (ac-ft/year)	Acreage	Use per Acre (ac-ft/year/acre)
Total	25,669	20,614	1.25
Wine grapes	13,569	15,539	0.87
Remainder	12,100	5,075	2.38

4.3.2.5 *Step 5: Estimate Benefits of FIRO*

Table 23 shows the benefit associated with an average annual increase of 740 or 768 AF of water for agriculture in Sonoma and Mendocino counties. We estimated an average annual benefit of $114,079 for the Modified Hybrid approach and $118,394 for EFO. Assuming benefits accrue for 50 years, the PV of these benefits would be $3.2 million and $3.3 million.[9]

However, as noted above, the estimated value of water can differ significantly across years for wine grapes due to price and yield fluctuations. Using 2018 values for Pinot Noir increases the estimated benefits by $60,505 and $62,793 for the Modified Hybrid and EFO alternatives, respectively.

Table 23. Average annual agricultural benefits

Commodity	Value per ac-ft ($2019)	Acres (Bearing)	Share of Acreage	Additional ac-ft: Modified Hybrid	Additional ac-ft: EFO	Benefit ($2019): Modified Hybrid	Benefit ($2019): EFO
Chardonnay	$634.32	20,272.5	21%	155.0	160.9	$98,314	$102,033
Pinot Noir	$0.00	16,066.6	17%	122.8	127.5	$0	$0
Total	**-**	**-**	**-**	**-**	**-**	**$98,314**	**$102,033**
Other wine grapes	$33.27	40,328.1	42%	308.3	320.0	$10,258	$10,646
Total imputing for other wine varietals	**-**	**-**	**-**	**-**	**-**	**$108,572**	**$112,679**
Other crops	$35.83	20,099.8	21%	153.7	159.5	$5,507	$5,715
Total imputing for all crops	**-**	**-**	**-**	**-**	**-**	**$114,079**	**$118,394**

In addition to presenting the average annual benefit of FIRO to agriculture, we also present the benefit in an extremely dry year to demonstrate the range of potential benefits. These extremely

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[8] Note that all the data from the USDA Census of Agriculture includes livestock production, so the acreage will not match the numbers provided elsewhere in this analysis.

[9] Reclamation recommended discount rate at the time of writing was 2.75 percent (Reclamation, 2019).

dry years are when FIRO may be most beneficial.[10] To demonstrate the potential of FIRO, we use 2009 as an example. In 2009, the Modified Hybrid and EFO alternatives would have resulted in an estimated increase of 4,121 and 5,045 ac-ft of water for agriculture, resulting in a benefit of $635,452 and $777,854, respectively. This considers that the additional ac-ft of water is higher in certain dry years. However, the marginal value of water may also be higher because the value of a unit of water is higher when there is scarcity. Additionally, this estimate does not consider long-term damage to vines due to insufficient water supply. Thus, it is likely still an underestimate of the value of FIRO in critically dry years.

4.3.3 Caveats and Limitations

The residual imputation method has inherent assumptions and limitations. One limitation of this method is that the values are sensitive to measurement errors in costs or revenues, or the omission of any costs. For example, any costs omitted will skew the value of water upwards. Additionally, if output prices or yields vary significantly from one year to the next, as may occur for wine, then the value of water can vary significantly. For example, Table 4-B in the UC Davis sample costs report shows how the net returns for Pinot Noir can vary from -$8,661/acre to $5,973/acre depending on yield and price (UC Davis, 2016a). Also, this method assumes that all net revenues can be attributed to the value of water, which hinges on the product exhaustion theorem.[11] Lastly, the costs incurred at the farm level may be underestimated because we did not take into consideration the costs to water suppliers (e.g., transportation costs).

Additional assumptions are:

- Increased water reliability from FIRO will be distributed across crops based on agricultural acreage.
- Crops without cost and revenue data can be represented well with the average calculated value of water.
- The value of water to Pinot Noir grapes is zero.
- The average marginal value of water reflects the value of FIRO. FIRO benefits may exceed this value due to increased reliability or the avoidance of long-term damages from droughts.

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[10] The exception would be a multi-year drought when FIRO often has limited impacts after the first year.

[11] The product exhaustion theorem assumes that the value of each factor of production is equal to its marginal product, and hence the summation of the values for each factor of production will equal the total value.

4.4 Municipal and Industrial Water Supply

Summary of Findings

Consumer surplus is the benefit consumers receive when they value a good or service more than the market price. The shift in the supply curve from FIRO, and the resulting decrease in price and increase in quantity, creates an increase in consumer surplus. The increase in consumer surplus is estimated to be $2,674,599 under the Modified Hybrid and $2,778,931 under the EFO alternative. Using an alternative method that does not assume the price of water will change as a result of the change in supply results in estimated benefits of $1.04 and $1.08 million under the Modified Hybrid and EFO alternatives, respectively.

4.4.1 Background

FIRO operations at Lake Mendocino may increase reliability of water supply to municipal, commercial, and industrial users. We present these benefits for all users together because the methodology is very similar and available data does not allow the impacts to be disaggregated.

Additional water storage at Lake Mendocino may result in a more reliable water supply for local businesses, resulting in avoided production losses. Providing a reliable water supply for M&I users could have a significant impact on avoiding lost economic output and jobs. An example of the potential impact can be seen from a study that estimated the economic impact of the water supply from the Colorado River, finding that the river contributed $657.45 billion towards gross state product in 2014, and contributed to over 7 million jobs in seven counties in Southern California alone (James et. al, 2014).

Improved forecasts and FIRO will also improve water reliability for households that rely on Lake Mendocino for water, especially in times of drought. In particular, FIRO will reduce the likelihood of water curtailments to residential users during droughts. Improved consumer water supply reliability would benefit all residents that rely on Lake Mendocino water for many purposes, including drinking water. The Sonoma County Water Agency (now Sonoma Water) estimated in 2009 that “Lake Mendocino and Lake Sonoma water plays a significant role in providing drinking water to about 750,000 residents in portions of Mendocino, Sonoma and Marin counties” (Sonoma County Water Agency, 2009).

4.4.2 Methods and Results

The P&G provides general guidance for estimating M&I water supply benefits, but does not discuss specific methodologies. For example, the NED procedures suggest that when the price of water reflects its marginal cost, that price should be used to reflect the willingness to pay of consumers. However, it does not provide details on how to define the relevant price (i.e., marginal or average) or how to evaluate changes in price. We used Reclamation’s Technical Memorandum Number EC-2009-02 as the basis for our analysis. This memorandum “presents methods and provides specific guidance for estimating M&I water supply benefits under a wide range of conditions that is not included in the P&G’s.”

We estimated the demand curve for M&I water supply and used the price elasticity of demand to quantify changes in consumer surplus due to an increase in water reliability. The price elasticity of demand is a measure of the change in the quantity of a good or service demanded based on a change in the price of that good or service, in this case water. The elasticity is then used to generate a demand curve and calculate how price may change due to a change in water reliability. The old and new prices and quantities are then used to calculate change in consumer surplus.

The NED procedures from the 1983 P&G and the 2013 PR&G suggest estimating the future water supply and the future M&I water needs for the given study area for scenarios in which no project is implemented and for the project being implemented—in this case, FIRO. Then, an economic benefit can be calculated by using water cost estimates in conjunction with the change in water usage from the project. Estimating future supply and demand is beyond the scope of this project. Therefore, we assume future supply and demand (in a typical year) are represented by current conditions.

If the impact on price is insignificant, the 1983 P&G acknowledge that the current market price can be used to estimate benefits. However, in this case, the additional supply is large enough that it may have a sizable impact on price. To account for this possibility, we have chosen to model the demand curve and the change in price attributable to FIRO. The alternative of using the current market price may overstate the benefit. However, because prices are not set in a competitive market, it is unclear how much prices may change because of FIRO. M&I water suppliers tend to set prices every few years at a level that is expected to cover their costs. By providing more water, FIRO may reduce the average cost of a unit of water by spreading the fixed costs over a greater number of ac-ft. Therefore, there is a theoretical basis for FIRO reducing the price of water. However, we also present the benefit as a function of only the market price and the change in quantity as a lower-bound.

4.4.2.1 *Step 1: Estimate the Price Elasticity of Demand*

The first step in this analysis is to identify the appropriate price elasticity of demand. After reviewing the literature, an elasticity of -0.4 was chosen. This means that a 10 percent increase in the price of water will result in a reduction in demand of 4 percent. Young and Loomis (2014) believe a range from -0.3 to -0.6 is appropriate for municipalities in the U.S. Dalhuisen et al. (2003) also reviewed the literature and found a mean price elasticity of demand of -0.41 and a median elasticity of -0.35 for residential users. Worthington and Hoffman (2008) found that for residential demand, “Price elasticity estimates are generally found in the range of zero to 0.5 in the short-run and 0.5 to unity in the long-run.”[12]

There are fewer studies in the literature measuring the elasticity of demand for commercial and industrial usage because data tend to be unavailable, expensive, or time-consuming to acquire, and because water tends to have a small role in the industrial cost structure (Young and Loomis, 2014). The literature indicates somewhat more elastic estimates for commercial and industrial users than municipalities, likely because water generally tends to be a small input for commercial

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[12] See also Espey et al. (1997) and Sebri (2014).

and industrial users and thus a change in price has a small impact on production. We have assumed a perfectly inelastic supply curve.

As a sensitivity analysis, we also present benefit estimates using a range of elasticities from -0.1 to -1.

4.4.2.2 *Step 2: Estimate the Increase in Water Supply Reliability*

Lake Mendocino area users generally have access to adequate water supply, but during some years, the reservoir is below the target storage level. We chose to use the volume below the target storage level as a proxy for water scarcity. The amount FIRO can reduce this deficit would then represent benefits of increased water reliability due to FIRO. Data are available from 1985 to 2017.

On average, water storage levels on October 1 are below the target storage level of 40,000 ac-ft by 1,536 ac-ft during baseline operations (see Appendix Table A-1). The target is, however, met 79 percent of the time. In years when the storage level is not met, there is an average deficit of 7,239 ac-ft. In contrast to the storage deficit resulting from baseline operations, FIRO almost always results in the target being met. The Modified Hybrid alternative results in the target being met in all but one year (2009) and the EFO alternative meets the target every year. We calculated average annual increases in water reliability of 1,480 ac-ft and 1,536 ac-ft for the Modified Hybrid and EFO alternatives, respectively.

We assume equal curtailment for agriculture and M&I users unless M&I water supply reaches a threshold where health and safety are impacted (we assumed 30 percent of total M&I is consumptive demand). This threshold is not reached in the data considered. On average, 740 ac-ft is attributable to M&I users under the Modified Hybrid and 768 ac-ft under EFO.

4.4.2.3 *Step 3: Estimate the Demand Curve and Estimate the Average Change in Price*

Next, the elasticity of demand, current price, and current quantity were used to develop demand curves for M&I users. Table 24 summarized the relevant values.

Sonoma Water provided the average quantity of water usage between 2009 and 2013 for the upper reaches of the Russian River, which was 12,041 ac-ft per year. This figure is the summation of water usage for Calpella, Redwood Valley, Hopland, Cloverdale, and Healdsburg. We assumed consumers in these areas would receive project water.

The current price of water is from the City of Ukiah's Final Draft Water Rate Study (City of Ukiah, 2020).[13] Prices vary across the cities using project water, but Ukiah's prices tend to be in line with surrounding cities (see Exhibit I-2 in source). As of January 1, 2020, the price per 100 cubic feet in Ukiah was $3.22 for municipal, commercial, and industrial users. Converting to price per ac-ft by multiplying by 435.599 yields a price of $1,403 per ac-ft.

Ukiah also charges a flat monthly rate per meter type. We chose to only use the marginal price because the average price, which incorporates the monthly charge, would vary by consumer.

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[13] We used retail prices to reflect the total value to end-users. However, retail prices include any value-added due to purification or distribution. Elsewhere, wholesale prices are sometimes used.

Based on the elasticity literature, this elasticity is applicable to both a marginal price and an average price.

Table 24. Values for water demand equations

Input Value or Derived Value	Parameter	Modified Hybrid	EFO
Input Value	Price elasticity of demand	-0.4	-0.4
Input Value	Current water rate ($/ac-ft)	$1,403	$1,403
Input Value	Current water demand (ac-ft)	12,041	12,041
Input Value	Proposed change in supply (ac-ft)	740	768
Derived Value	New supply (ac-ft)	12,781	12,809
Derived Value	β	-3.43	-3.43
Derived Value	α	16,857	16,857
Derived Value	p	$1,187	$1,179
Derived Value	Change in price	$216	$224

The demand for water can be written as $Q_D = \alpha + \beta P$ and the elasticity[14] can be defined as $\varepsilon = \beta * \frac{P}{Q_D}$, where:

- Q_D is the quantity of water demanded
- α is a parameter reflecting the quantity of water demanded if the price was zero
- β is a parameter reflecting the change in quantity given a change in price
- P is the market price
- ε is the elasticity

Rearranging to solve for the unknown parameter of β gives the equation $\beta = \varepsilon * \frac{Q_D}{P}$. We calculate:

$$\beta = -0.4 * \frac{12{,}041\ acft}{\$1{,}403} = -3.43$$

Rearranging the demand equation to solve for α yields: $\alpha = Q_D - \beta P$, so:

$$\alpha = 12{,}041\ acft - (-3.43\ * \$1{,}403) = 16{,}857$$

The estimated demand equations are:

$$Q_D = 16{,}857\ acft - 3.43P$$

We can then estimate the new prices using the new demand and the demand curve rearranged to solve for P:

- Modified Hybrid: $P = \frac{12{,}781\ acft - 16{,}587\ acft}{-3.43} = \$1{,}187\ per\ acft$
- EFO: $P = \frac{12{,}809\ acft - 16{,}857\ acft}{-3.43} = \$1{,}179\ per\ acft$

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[14] We have assumed a linear demand curve here. Data are not available to test alternative functional forms.

4.4.2.4 *Step 4: Estimate the Change in Consumer Surplus*

Consumer surplus is the benefit consumers receive when they value a good or service more than the market price. In a supply and demand model, it is represented as the area under the demand curve and above market price, as shown in Figure 17.

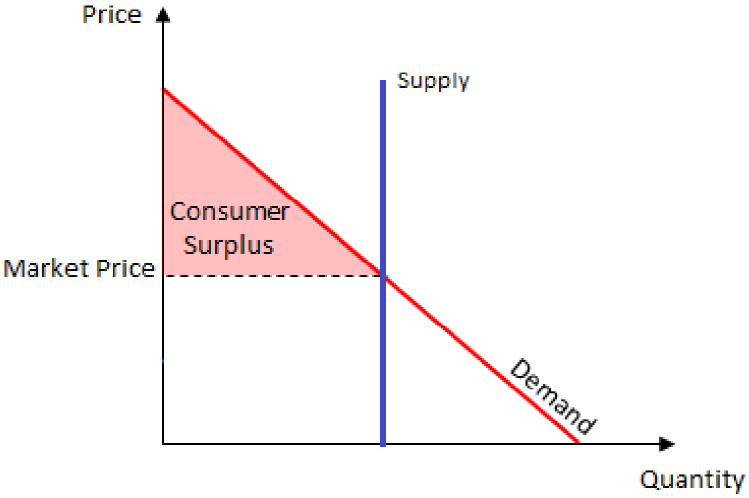

Figure 17. Change in consumer surplus

The shift in the supply curve from FIRO creates an increase in consumer surplus. The increase in consumer surplus is calculated as:

- Modified Hybrid: $\frac{740\ acft * \$216\ per\ acft}{2} + (12{,}041\ acft * \$216\ per\ acft) = \$2{,}674{,}599$
- EFO: $\frac{768\ acft * \$224\ per\ acft}{2} + (12{,}041\ acft * \$224\ per\ acft) = \$2{,}778{,}931$

Assuming benefits accrue for 50 years, the PV of these benefits would be $74.2 million and $77.1 million.[15]

Similarly, producer surplus is the benefit producers receive from selling a good or service above the cost of production. The increase in producer surplus can be represented by the area above the supply curve and below market price. We have not quantified the change in producer surplus because the elasticity of water supply is unknown and many water suppliers set price so that revenues equal total costs, and consequently producer surplus is zero.

4.4.3 Sensitivity Analyses

We conducted two sensitivity analyses. The first assumes no change in price as a result of the increase in water reliability. Because pricing decisions are not decided in a competitive market, but instead are determined by the supplier based on a variety of factors, and because the availability of FIRO water is uncertain when pricing decisions must be made, the modeled change in price may not be accurate. Therefore, benefit was estimated as the product of the

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[15] Reclamation recommended discount rate at the time of writing was 2.75 percent (Reclamation, 2019).

current price and the change in ac-ft of water, reflecting the change in revenue. This results in an annual benefit of $1.04 million under the Modified Hybrid and $1.08 under EFO. For comparison, the benefits using the consumer surplus approach are $2.7 million and $2.8 million, respectively.

The second sensitivity analysis uses a range of elasticities to model the demand curve. Our preferred estimated elasticity is -0.4. Here we use a range from -0.1 to -1. Benefits associated with the Modified Hybrid range from $1.1 million to $10.7 million, while benefits associated with EFO range from $1.1 million to $11.1 million.

4.4.4 Caveats and Limitations

This model has several assumptions. First, it assumes that the prices observed in the data reflect market equilibrium prices. In other words, the prices are set based on supply and demand. Because water prices are often set based on suppliers' costs, a supply and demand framework may not always be appropriate. Second, it assumes that the elasticity of labor demand stated in the literature is appropriate for this region. We do not have any reason to believe this elasticity would not be appropriate.

4.5 Hydropower

Summary of Findings

We calculated the benefit from hydropower by multiplying the average wholesale electricity price ($/MWh) by the power generation (MWh) for each FIRO alternative. The Modified Hybrid alternative generates $1,868 less in benefits annually compared to the baseline and the EFO alternative generates $43,750 less annually. These results are highly dependent on the current Water Control Manual, which—if updated—would result in FIRO alternatives providing greater economic benefit than baseline operations.

4.5.1 Background

Lake Mendocino was created in 1958 following completion of the Coyote Valley Dam. In addition to providing flood control, water supply, recreation, and streamflow regulation, Lake Mendocino also generates hydroelectric power (hydropower) from the dam's associated electrical power plant. The City of Ukiah is responsible for maintaining and operating the Lake Mendocino Hydroelectric Plant, while USACE is responsible for maintaining and operating the dam in accordance with the Lake Mendocino Water Control Manual (WCM) (1959, revised in 1986).

Hydropower is an important renewable, efficient, and local energy source for communities in the Lake Mendocino area. In 2017, the City of Ukiah received 11 percent of its energy from small hydroelectric power plants, one of which was the power plant at Lake Mendocino (City of Ukiah, 2017). FIRO has the possibility to increase water storage at Lake Mendocino, and therefore has the potential to allow for more hydropower generation. Increasing the ability to produce hydropower at Lake Mendocino would provide a direct economic benefit to the supplier by increasing sales, with an indirect benefit to the businesses and individuals who would utilize the electricity production.

Coyote Valley Dam's hydroelectric plant operations are dependent on the water elevation in Lake Mendocino. Based on a rule in the WCP, the plant must shut down when the flood pool elevation exceeds a 755-ft threshold. The rationale for this rule is to ensure that the reservoir can be evacuated as quickly as possible when the pool elevation is very high. The flood control gates can release much more water than the power plant, and the power plant cannot operate when the flood control gates are open. With FIRO, however, rapid release of the reservoir when the pool elevation exceeds 755 ft may not always be necessary. As a result, although this rule is reasonable under the current WCM paradigm, this rule will likely be re-evaluated in the WCM update.[16]

The HEMP analysis determined hydropower generation in accordance with the current operating rules of the WCM. Based on the historical data for which the alternatives were assessed, the Modified Hybrid and EFO alternatives reached the 755 ft flood pool elevation more often than the baseline scenario. As a result, there were more days when power generation had to be shut off for the FIRO alternatives, and in turn more days for which the FIRO alternatives do not provide hydropower generation. If the WCM were updated with an increased flood pool elevation threshold to trigger power generation shutoff, the economic benefit of the FIRO alternatives would increase significantly. The current analysis presents findings based on the total economic benefit over the historical period of analysis, as well as specific years to showcase how the FIRO alternatives provide benefits in years when hydropower generation was not shut off due to a high flood pool elevation.

4.5.2 Methods and Results

We calculated the hydropower benefit by estimating the increased electricity generated under FIRO alternatives at Lake Mendocino and the value of a unit of electricity. The following steps were taken to calculate the economic benefit:

- Determine the wholesale cost of electricity in the Lake Mendocino region.
- Determine the hydropower generated based on baseline operations and the FIRO alternatives.
- Calculate the economic benefit by multiplying the average monthly price by the daily hydropower generation.

The NED guidelines present two methods to value hydropower. The first is the resource cost of the most likely alternative. This method is more appropriate when evaluating a hydropower construction project. Instead, our analysis assesses the value of additional hydropower from an existing plant with no construction modifications, where increased generation is a byproduct of FIRO. Therefore, the resource cost of the most likely alternative is not appropriate. The alternative approach recommended by the NED guidelines, using market prices to reflect the

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[16] This assessment is based on the discussion during the HEMP analysis results presentation on June 2, 2020.

benefit of additional supply, is thus more applicable here (referred to as the user-value method by some sources).

Unlike the water supply benefit assessed below (Section 5.3), we do not calculate a change in price because of the change in quantity. This is because the additional power generation provided by FIRO is relatively small compared to the total electricity provided by the City of Ukiah, and thus it is unlikely to impact the price (i.e., the plant is a price taker). This finding is confirmed by the P&G, which notes that little change in price would generally be expected.

4.5.2.1 *Step 1: Obtain the Cost of Electricity*

As recommended in the NED guidance, wholesale market price data were used to value the additional electricity generated. Historical wholesale price data were compiled for the Northern California hub, or NP-15, using the weighted average daily price for NP-15 EZ Gen DA LMP Peak. We downloaded data from the U.S. Energy Information Administration’s Wholesale Electricity and Natural Gas Market Data. We averaged daily values, across ten years of historical data (2010–2019), to estimate average monthly prices. All prices were converted to 2019 dollars using the CPI-U. Table 25 presents the monthly averages. Monthly prices were used to consider seasonal price fluctuations. Future prices were not projected, so this analysis also assumes that future wholesale prices are reflected well by historical prices.

Table 25. Monthly average wholesale electricity rates for NP-15 (2010–2019)

Month	Average Price ($/MWh)	Month	Average Price ($/MWh)
Jan	$43.87	**Jul**	$53.33
Feb	$51.91	**Aug**	$51.83
Mar	$40.79	**Sep**	$45.56
Apr	$40.84	**Oct**	$44.98
May	$41.54	**Nov**	$44.92
Jun	$43.81	**Dec**	$46.05

4.5.2.2 *Step 2: Obtain Hydropower Generation Data*

The daily hydroelectric power production, in MWh, for the baseline, Modified Hybrid alternative, and EFO alternative was determined as part of the HEMP analysis. As previously mentioned, the HEMP analysis evaluated hydropower generation according to the existing WCM rule that requires the power plant to shut off when the flood pool elevation exceeds 755 ft. Based on this rule, there were 656, 1,348, and 2,285 days when the baseline, Modified Hybrid, and EFO, respectively, had zero power generation during the 33-year evaluation period (see Table 26). Therefore, the Modified Hybrid and EFO alternatives were required to shut off power generation for 708 and 1,639 more days, respectively, than during baseline operations. This corresponds to a 6 percent and 14 percent increase. The daily data was aggregated to provide the monthly hydroelectric power production over the 33 years of record (1985–2017).

4.5.2.3 *Step 3: Calculate Hydropower Economic Benefit*

Using the data gathered in the previous two steps, we calculated the economic benefit from hydropower for baseline operations and the Modified Hybrid and EFO alternatives. The average annual value of hydropower production was calculated by multiplying the monthly averaged wholesale price of electricity ($/MWh) by the power generation (MWh) for each of the alternatives.[17] In aggregate, the Modified Hybrid alternative generates $1,868 less in benefits annually from the baseline and the EFO alternative generates $43,750 less annually. Assuming benefits accrue for 50 years, the PV of these benefits would be -$51,800 and -$1.2 million.[18]

It is important to note that the Modified Hybrid and EFO alternatives generate less economic benefit than baseline operations due to the current WCM rule that does not allow power generation when the pool elevation is higher than 755 ft. If this rule were changed to increase the pool elevation threshold, we would expect that the Modified Hybrid and EFO alternatives would provide greater economic benefits than baseline operations.

To demonstrate how the economic benefits of the alternatives differ depending on whether hydropower generation was shut off, we calculated benefits based on WY type classifications provided by Sonoma Water. These data provide the daily water supply condition, classified as a 1 (normal), 2 (dry), or 3 (critical), from 1985–2017. These daily classifications were averaged for each year and then rounded to the nearest whole number to provide a single classification (1, 2, or 3) for the entire year. For the 33-year period of record, 29 years were classified as a 1, and 4 years were classified as a 2. No years were classified as a 3, although some days did receive a value of 3. The Modified Hybrid and EFO alternatives generate $4,653 and $53,380 less in annual benefits than baseline operations for years classified as a 1. In drier years (years classified as a 2), however, the Modified Hybrid and EFO alternatives generate $18,318 and $26,064 more annually than baseline operations.

Figure 18 and Figure 19 show the total economic benefit of hydropower for the baseline, Modified Hybrid alternative, and EFO alternative during a dry year (2014) and a wet year (2017). These years were classified as a 2 and a 1, respectively, based on the WY type classifications. Table 26 shows the number of days with zero power generation, which provides context as to why the FIRO alternatives result in less economic benefit than baseline in 2017. The Modified Hybrid and EFO alternatives generally provide greater economic benefits than baseline during dry years because they generally store more water in the reservoir during dry periods. This additional stored water can then be used for hydropower production. In wet years, however, the FIRO alternatives seem to provide less economic benefit than baseline operations. This is due to the WCM rule that requires the power plant to shut off when the pool elevation exceeds 755 ft, which often happens during wet years. If this WCM rule were not in place, we would expect that the Modified Hybrid and EFO alternatives would provide more economic benefit than baseline operations.

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[17] To demonstrate, in January 1985, the overall value of hydropower at Coyote Valley Dam, under the baseline scenario, was calculated as $43.87/MWh x 1061.99 MWh for a total value of $46,579.

[18] Reclamation recommended discount rate at the time of writing was 2.75 percent (Reclamation, 2019).

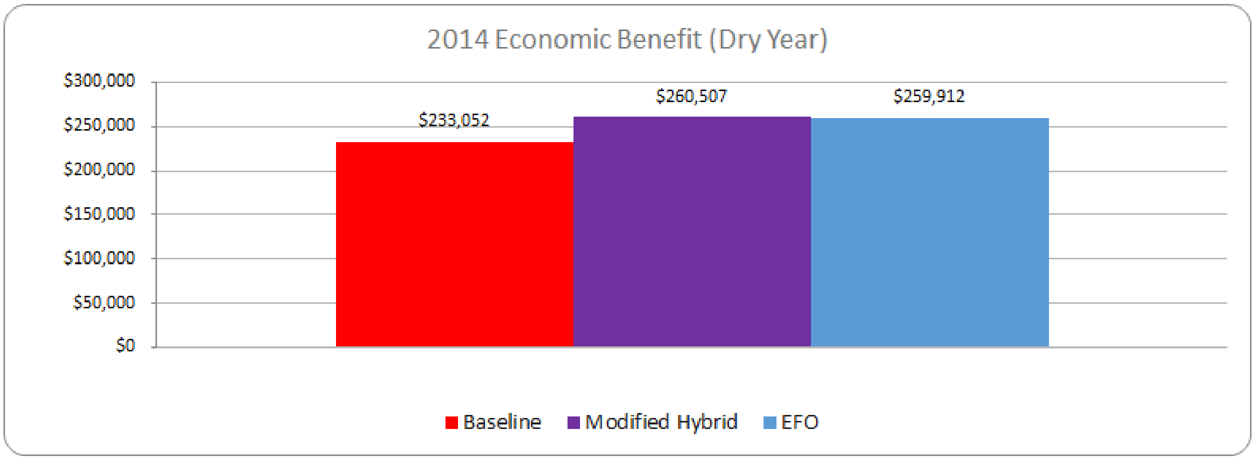

Figure 18. Hydropower economic benefit during a dry year

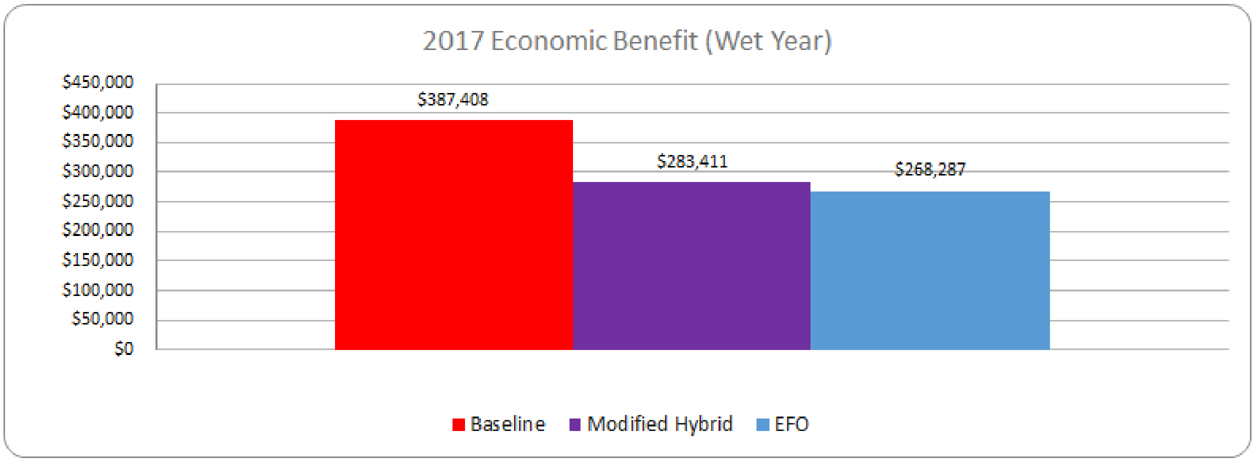

Figure 19. Hydropower economic benefit during a wet year

Table 26. Number of days with zero power generation

Year	Baseline	Modified Hybrid	EFO
All years	656	1,348	2,285
2014	0	0	0
2017	2	109	112

4.5.3 Caveats and Limitations

The hydropower economic benefit analysis conducted for Lake Mendocino assumes that the safety mechanism that prevents production when water elevation levels reach 755 ft would remain during FIRO. Without this rule, the benefits of FIRO may be markedly different. The analysis also assumes that historical wholesale prices reflect future prices and marginal values.

4.6 Fisheries

Summary of Findings

Two methods were used to estimate the fisheries benefit. One assumes that an alternative to achieving FIRO benefits could be accomplished by raising the height of Coyote Valley Dam by 6 ft. Annualizing this cost over 50 years results in an estimated annual benefit of $5.73 million. Alternatively, using water transaction prices, we estimate that the benefit of FIRO to fisheries may total $7.7 million or $11.4 million annually using the Modified Hybrid and EFO alternatives, respectively.

4.6.1 Background

FIRO may benefit fish populations and habitat in the Russian River watershed. By increasing the water level stored in the reservoir, FIRO may improve streamflow and reduce water temperature. Additionally, it may allow for better controlled releases from Lake Mendocino, which will reduce turbidity. There are three endangered or threatened salmonid species in the Russian River that would benefit: Coho salmon, Chinook salmon, and steelhead trout. In general, healthy habitat provide a benefit to society: “studies have shown that regardless of direct interaction with salmon populations, many Californians hold a positive willingness to pay to ensure the long-term survival of salmon” (ECONorthwest, 2012). Additionally, improved habitat and salmonid populations will directly benefit the local community, local businesses, and the tourism industry.

Although estimating the fisheries benefit in addition to considering increased fishing as a recreation benefit (see section 4.7) may pose a risk of double-counting the benefit, we believe our analysis does not double-count fish benefits because the recreation benefit is at Lake Mendocino and the fisheries benefit is downstream of the dam and therefore does not overlap with the recreation benefit.

4.6.2 Methods Overview

Estimating benefits to salmonid populations can be difficult because there is not a market price to reflect the value of healthy salmonid habitat to society. Economists therefore must use other methods to approximate this value. For example, surveys have been conducted to estimate the value placed on healthy fish populations, such as willingness to pay (WTP) surveys. Another method is the least-cost alternative, which considers alternative projects that would result in the same impact as the proposed project (e.g., a predetermined increase in fish populations or a specific change in temperature of the river beneficial to salmonids). The least-cost alternative that would achieve the same goal is then used as an estimate of the benefit. We use an abbreviated least-cost alternative approach, described in more detail below.

We also conduct a secondary analysis because of the uncertain costs to raise Coyote Valley Dam and the feasibility of this alternative. For this secondary analysis, we use water transaction prices as a proxy for value. This method is more easily applied to a DST than the least-cost method, and therefore more transferable to other reservoirs. Lastly, we include a short section on using benefit transfer of WTP studies, because this method is included in the DST.

The NED guidelines discuss quantifying benefits for commercial fishing, but not other benefits associated with improved fish populations or habitat. They suggest measuring the change in harvest and harvest cost as the basis for monetizing benefits. We have chosen not to use this methodology because it does not capture the full range of benefits associated with increased fish populations and improved habitat. Additionally, it would require inputs that are not available. The general guidance provided in the 1983 P&G (i.e., not specific to any one benefit type) mentions the least-cost alternative as a viable method, saying: "The cost of the most likely alternative may be used to estimate NED benefits for a particular output if non-Federal entities are likely to provide a similar output in the absence of any of the alternative plans under consideration and if NED benefits cannot be estimated from market price or change in net income."

4.6.3 Abbreviated Least-Cost Alternative Method and Scoping of Alternatives

There are two direct ways in which FIRO can benefit threatened salmonid populations (e.g., Chinook salmon, steelhead trout) in the upper Russian River watershed. By storing more water in the reservoir through FIRO, there is:

- More water available to be released in the fall to help migrating Chinook salmon, and more desirable flows for summer rearing juvenile steelhead trout.
- More cold water at greater depths that, when released, reduces downstream temperatures and benefits juvenile steelhead trout in the summer months. It also benefits returning adult Chinook salmon in the fall, when water temperatures are critical for survival and production, early migration (before ambient temperature cool), and successful reproduction/spawning.

A full least-cost alternative analysis would consider all feasible options that would achieve the same impact on fish populations, river flow, or river temperatures. Conducting a full least-cost alternative analysis to estimate the value to fisheries requires significant resources to consider the feasibility and costs of a wide range of possible alternatives, each of which has variables that are difficult to quantify. That analysis is beyond the scope of this project. Therefore, after consulting with local fisheries experts, we have selected an alternative project that has been previously considered, and for which at least some basic cost information is readily available. We use that cost as an estimate of the avoided costs from FIRO.

In consultation with fisheries experts, we identified temperature and flow as the key salmonid fisheries metrics that can be correlated with FIRO operations. Raising Coyote Valley Dam would also achieve similar impacts to temperature and flow, and consequently similar benefits to salmonid populations below Lake Mendocino. Raising the dam has been considered in the past, although this option has stagnated due to funding and safety concerns. However, this is an appropriate alternative to consider for the purposes of this report, and there is evidence from USACE that it is the least-cost alternative to FIRO: "Based on draft preliminary economic analysis, costs for the full dam raise could increase to $560 million before non-CVD alternatives for water supply would challenge the dam raise as the least costly alternative per acre feet per year" (USACE, 2018).

The project team also researched and discussed other alternatives. A review of the literature to identify alternative possibilities in the region did not identify any alternatives besides raising the height of the dam that have been seriously considered or that have had costs estimated.

Three other alternatives we considered were planting trees to reduce water temperature, buying water rights to reduce water withdrawals, and expanding hatchery operations to increase salmonoid populations. However, these alternatives are likely to be infeasible. A full-scale evaluation of these alternatives was not possible within the timeframe of this study, but these options are discussed briefly here as they may be pertinent to other localities.

Planting trees. Increased canopy over parts of the river could potentially decrease temperatures and benefit juvenile steelhead trout in the summer. However, tree plantings may not be sufficient to achieve the same benefits as FIRO because there is only so much land available for trees, therefore capping their potential impact. Additionally, it would be expensive to plant trees because the land along the river is very valuable and easements would need to be secured, involving lengthy and costly litigation. To complicate things further, the benefits would be uncertain and unintended negative impacts (e.g., increased water uptake, leaf litter, evapotranspiration by the trees) would need to be considered.

Buying water rights or purchasing water transfers. Purchasing water has the potential to increase water flow in the Russian River and benefit salmonid populations. However, water rights in the Russian River Valley are very complicated and it may be extremely difficult and take a long time to obtain the necessary amount of water to accomplish the needed benefits. Although purchasing water was deemed difficult under the current administrative landscape, and hence not a feasible alternative that would qualify for the least-cost alternative methodology, transaction costs are a good proxy for value and are used for the secondary analysis conducted below.

Expanding hatchery operations. The Coyote Valley Fish Facility is located just below the Coyote Valley Dam and Lake Mendocino. Eggs are retrieved and fertilized at the facility and then transported to Warm Springs Hatchery to be incubated, hatched and raised to a yearling stage. The yearling steelhead are then transported back to the fish facility and eventually released into the East Branch of the Russian River (California Department of Fish and Wildlife, 2020). Although theoretically these operations could be expanded to increase steelhead populations, increasing hatchery production will not enhance the population in the same way that improved habitat conditions would.[19]

Avoided Cost of Raising the Dam Height. Both flow and temperature benefits could be achieved by raising the height of Coyote Valley Dam at Lake Mendocino. Therefore, we estimated the cost of raising the dam to a height that would achieve the equivalent flow and temperature benefits as FIRO. This estimate is based on very simplified assumptions.

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[19] There are several ways hatcheries tend to have deleterious effects on the viability of wild salmonid populations, including: (1) increasing the risk of negative interactions (e.g., predation, competition) among hatchery and wild fish; (2) decreasing genetic diversity through selective breeding, leading to the loss of traits important to survival in the wild; and (3) increasing risk of disease transmission.

4.6.3.1 *Step 1: Estimate the Necessary Height Increase of the Dam*

Based on guidance from Sonoma Water (J. Mendoza, personal communication, August 31, 2020), we assumed that raising the dam 6 ft would result in roughly equivalent flow and temperature benefits for fisheries as would FIRO alternatives. We assumed the maximum water supply benefit produced by the Modified Hybrid alternative is approximately 12,000 ac-ft, which is due to the maximum allowable winter water supply pool storage being 80,050 ac-ft with the FIRO alternative and 68,400 ac-ft under the current WCM. We assumed that raising the dam would be done without FIRO, so the flood pool space would need to remain the same as the current WCM and we would simply be increasing the water supply volume. The height of the spillway is currently at 765 ft, which corresponds to a total reservoir volume of approximately 117,000 ac-ft. We used the current storage-elevation curve and found that to add an additional 12,000 ac-ft of storage, the spillway and the dam height would need to be raised by 6 ft. This would result in the spillway being at an elevation of about 771 ft and the dam height changing from 784 ft to 790 ft.

4.6.3.2 *Step 2: Estimate the Cost to Raise the Dam Six Feet*

The cost to raise Coyote Valley Dam by 6 ft has not been calculated in an engineering study. To estimate that cost, we used the estimated cost to raise the dam by 36 ft and applied certain assumptions to approximate the cost for a 6-foot increase. In 2015, the estimated cost to raise the dam by 36 ft was at least $320 million (USACE, 2018). According to USACE, "This rough estimate is based on [a] 2015 update to [a] 1974 cost estimate and does not account for potential dam safety issues." We increased this estimate to $350 million to include some of these costs, and then adjusted for inflation using the CPI-U. This increase results in a cost estimate of $377.5 million in 2019 dollars, which includes both fixed costs and incremental costs related to the dam height increase.

Estimated cost is highly dependent on the share of the cost that is fixed. Additionally, there is little information in the literature from which to derive the fixed component, and the two relevant sources identified, and discussed below, have very different implications. We therefore averaged the two estimates.

The first approach assumes that $10 million is a fixed cost that occurs regardless of whether the dam is raised by 6 ft or 36 ft. This figure is based roughly on a Reclamation report that identified the lowest total cost associated with increasing the height of a dam similar to Coyote Valley Dam was $6 million (Reclamation, 2014).[20] This cost includes raising the dam and adding a new auxiliary spillway to be 3 ft higher than the existing spillway.[21] We rounded up to $10 million to take into account inflation and to provide a conservative cost estimate. If the fixed cost is larger, then the cost to raise the dam by 6 ft would also be larger. We then imputed a $10.2 million cost per foot ([$375 million - $10 million]/36 ft). This results in an estimated construction cost of

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[20] See "Example No. 1 – Dam T Modification," Figure "Comparative Costs - New Auxiliary Spillway + Dam Raise."

[21] This cost is based on an embankment dam that is 250 ft high and has a crest length of 2,200 ft. The Coyote Valley Dam is structurally similar in that it is an earth-filled embankment dam that is roughly 160 ft high and 3,500 ft long.

$71.3 million for a 6-ft increase in the height of the dam ($10 million + [$10.2 million per ft x 6 ft]).

The second approach uses cost estimates of raising the Shasta Dam to determine the fixed, incremental, and ultimately the total cost of raising the Coyote Valley Dam by 6 ft. First, the average per-foot incremental cost from the Shasta Dam study was calculated to be $24 million per foot (see Table A-2 in Appendix A). Using this incremental cost, we determined the average fixed cost of raising Shasta Dam to be $925.4 million (see Table A-2 in Appendix A). The incremental and fixed costs calculated for Shasta Dam are based on total capital cost estimates of raising the dam by 6.5 ft, 12.5 ft, and 18.5 ft. We then used the incremental and fixed cost estimates to estimate the total cost of raising Shasta Dam by 36 ft (the equivalent height as the Coyote Valley Dam cost appraisal), which we found to be $1,775 million ($925.4 million + [36 ft * $24 million per ft]). The share of the total cost that is fixed is therefore 52.1 percent ($925.4 million / $1,775 million). We then apply this ratio to the total cost estimate of $377.5 million for a 36-ft increase at Coyote Valley Dam to get a fixed cost of $196.8 million for any height raise construction at Coyote Valley Dam. The incremental cost of construction at Coyote Valley Dam was then imputed to be $5 million per foot ([$377.5 million - $196.8 million]/36 ft). Finally, the total cost of raising Coyote Valley Dam by 6 ft was calculated to be $226.9 million ($196.8 million + [6 ft * $5 million per ft]).

We then averaged $71.3 million and $226.9 million to estimate a cost of $149.1 million. In addition to the direct costs of raising the dam, there are other costs such as pre-building planning and assessment costs and ongoing operating and maintenance costs. The upfront research costs to determine the feasibility and costs of raising the dam are approximately $5.5 million (USACE, 2018). We added this cost to the estimated cost of $149.1 million to raise the dam by 6 ft for a total cost of $154.6 million. We assume that the incremental operation and maintenance costs from the 6-foot increase are negligible (i.e., equivalent with current dam operation and maintenance costs).

4.6.3.3 *Step 3: Estimate the Average Annual Value*

The benefit of FIRO could then be estimated as the $155 million avoided cost from not raising the height of the dam. This represents benefits over the life of the dam. For example, if the dam is expected to last 50 years, the annualized value, discounted at 2.75 percent to reflect the PV, would be $5.73 million (excluding incremental operation and maintenance costs associated with the additional six feet and assuming all construction costs occur in Year 1) (Reclamation, 2019).[22]

Ideally, the avoided cost estimate should reflect the costs of a project that would have occurred in the absence of FIRO. Although raising the height of the dam has been considered in the past, this alternative has stagnated in recent years due to funding and safety concerns. Therefore, this methodology may overestimate benefits.

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[22] The relevant time horizon is unknown. The fisheries literature tends to use 50-years, but dam projects often use 100-years. As a sensitivity check, we estimated avoided costs of $4.55 using a 100-year horizon.

4.6.4 Valuation Using Water Transaction and Conveyance Prices

As noted above, we cannot assert that raising the height of the dam is the least-cost alternative without assessing all alternatives. Therefore, to provide an alternative estimate, we have chosen to use water transaction and conveyance prices as a proxy for the value of water. The transaction price is the market price at which users have purchased and sold water. The conveyance price is the cost to transport that water to the user. Together, these prices reflect the value placed on this resource by the user. They also reflect the avoided damages associated with a reduction in water usage (e.g., the price at which a farmer is willing to sell water reflects the marginal revenue product associated with using that water to irrigate crops).

Neither water transaction prices nor conveyance prices were available specific to the Russian River. Therefore, we used data from the Nasdaq Veles California Water Index (NQH2O), which tracks the price of water rights in the state of California, as determined by water entitlement transactions in the five largest markets in California.[23] These prices reflect the purchase price of water and do not include additional transportation or transaction costs. The NQH2O has tracked weekly water rights prices since October 31, 2018.[24] The average weekly price for the most recent 12 months (August 2019 through July 2020) is $346.63 per ac-ft. Adjusting to 2019 dollars for the seven months in 2020 (using monthly CPI-U data), the average weekly price is $344.34 per ac-ft.[25]

We applied the approximate average ratio of conveyance costs to market prices from Reclamation's Shasta Lake Water Resources Investigation. Reclamation estimated both State Water Project (SWP) and non-SWP conveyance costs, but chose to use non-SWP costs because they are more "reflective of the opportunity cost for use of the resource." (Reclamation, 2015) They also estimated conveyance costs for ten regions (North Bay Aqueduct, South Bay Aqueduct, etc.).[26] We took the average conveyance cost from Table 3-9 in the Economic Valuation Appendix of the Reclamation investigation and inflated the values to 2019 dollars using the CPI-U, resulting in an average conveyance cost of $291 per ac-ft.[27] Lastly, the report applied either a 10 percent or a 25 percent conveyance loss depending on the region. We have incorporated the average of 17.5 percent loss. Combining the price of water, the conveyance cost, and the conveyance loss cost together results in a price of $695.23 per ac-ft.

On average over the 33-year evaluation period, FIRO is expected to increase lake levels by 11,018 ac-ft under the Modified Hybrid approach and by 16,459 ac-ft under the EFO approach.

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[23] This includes the Central Basin, the Chino Basin, the Main San Gabriel Basin, the Mojave Basin (Alto Subarea), and surface water.

[24] See the 2019 NQH2O methodology for additional details.

[25] If we use only prices during the summer rearing and fall migration months (July–October), the average price is slightly lower at $318.68.

[26] WTP for water is reflected by the total price, comprising both the market price and the conveyance costs. Therefore, market prices are dependent on conveyance costs, and hence conveyance costs should be for the same vicinity as the water market prices used. There is some, but imperfect overlap between the area used to derive market prices and conveyance prices in the Reclamation study.

[27] Ideally, this analysis would identify the party/parties that would sell their water diversions to maintain in-stream flows and where they would purchase water from to offset the reduction from Lake Mendocino. From this information, we would identify the conveyance costs specific to that route. However, lacking this information, we believe using an average from existing estimates is appropriate.

Multiplying these values results in an estimated annual benefit to fisheries of $7.7 million under the Modified Hybrid Approach and $11.4 million under EFO. For comparison, we estimated benefits as $5.73 million using the dam height raise method.

4.6.5 Valuation Using WTP Benefit Transfer

It is possible to use benefit transfer of WTP studies to estimate the fisheries benefit. We did not use this method for Lake Mendocino, but have included this short methodology section because this method is in the DST.

Benefit transfer is the process of finding values from previous studies in areas with similar local conditions (e.g., geography, type of fish, socio-economic conditions) and applying those values to your area. Benefit transfer can be a reasonable and cost-effective approach, as it does not require primary data collection. WTP values can be derived from a variety of survey techniques, such as contingent valuation or choice modeling. To use this method, the user would conduct a review of the literature and find a study with similar conditions. The WTP value would then be applied to the current project. For example, a hypothetical study on the value of salmon in Oregon may be appropriate to apply to a project in Washington that would improve salmon habitat because these states are both in the Pacific Northwest and have similar perspectives on the importance of salmon.

Next, the values reported from the study must be applied to the current project, which requires measuring a similar metric between both the study and the current project. For example, if the WTP is per fish and the current project has an estimate of the change in fish populations, then the WTP can be directly applied by multiplying it by the change in fish. In other instances, calculations may be necessary to convert the WTP value to an applicable metric.

4.6.6 Caveats and Limitations

The estimate using the cost of raising the dam as the alternative, avoided cost assumes that:

- In the absence of FIRO, raising the height of the dam is a realistic alternative that could be considered.
- The cost to raise the dam is appropriate. This estimate is based on a very rough approximation. The true cost could be somewhat higher or lower.
- The dam would be raised solely for the purpose of improving fish habitat. If the dam raise would be enacted for multiple purposes, then this may be an overestimate of the value to fish. However, the least-cost alternative often provides a lower bound on benefits because benefits would have to exceed costs for the project to be enacted.

The estimate using water transaction prices as a measure of value assumes that:

- The transaction price is relevant to the Russian River Valley. This price is based on five large markets in California where demand for water may differ from this locality.
- The demand for water, as reflected by prices in 2019 and 2020, is representative of future prices. If the real price of water increases (e.g., due to increases in population or climate change), then the benefit of FIRO would be higher.

- The value of water can adequately be captured in a market analysis, which assumes perfect competition.

4.7 Recreation

Summary of Findings

We estimate the value to recreation as the product of increased recreation and daily use values. Benefits under the Modified Hybrid alternative total $802,700 per year and benefits under the EFO alternative total $1.2 million per year.

4.7.1 Background

FIRO can lead to increases in quantity and quality of recreation at Lake Mendocino and on the Russian River. FIRO operations would affect recreational participation by increasing reservoir water surface elevations, decreasing reservoir drawdown during the peak recreation season (May to September), and increasing average annual reservoir surface area over existing reservoir operation conditions. The additional surface area will provide more space for water-based activities, and the higher elevations will sometimes improve lake access because the boat launches are only accessible above certain elevations. Land-based activities such as hiking, biking, and camping may also benefit from improved aesthetics, as low water levels often result in unsightly mud flats or reservoir rings.

There is a large market for recreational activities at Lake Mendocino and along the Russian River. In fiscal year (FY) 2016, there were 809,764 visitors to Lake Mendocino (USACE, 2019). In Sonoma county alone, outdoor recreation is valued at $731 million per year (Sonoma EDB, 2018). Ward et al. (1996) estimated that at Lake Mendocino in the 1980s, an additional acre-foot was worth between $12.28 and $244.91 in recreational value, depending on lake levels and adjusted to 2019 dollars using the CPI-U. Analyses for other regions show the potential for economic benefits from recreation stemming from increased water supply. A study on the Colorado River showed that a 100,000 ac-ft increase in water over one year would result in over 18,000 additional visits to nearby lakes, and over $350,000 in additional spending from tourism related activities (Neher, 2013).

There are several beneficiaries from additional recreational opportunities. First, those who enjoy recreation will benefit directly. Second, the additional recreation will also benefit businesses directly involved with recreation, as well as those indirectly involved (e.g., gas stations and local restaurants). For this analysis, we focus on the direct benefits to recreationalists. Additionally, we only estimate benefits associated with increased recreation at and around Lake Mendocino, not along the Russian River.

4.7.2 Methods and Results

The NED guidelines suggest using WTP estimates from either a travel cost method or a contingent valuation method, if applicable. If these methods are either not feasible or not justified for the project, then the unit day value (UDV) method should be used. We chose to apply UDVs in a benefit transfer analysis because the time and resources were not available to conduct a survey.

ERG estimated the increased level of recreational activity due to increased water levels at Lake Mendocino using multivariable regression analysis, and then applied UDVs to those increased recreation levels. Our estimates do not consider recreation along the river or that quality would increase for current visitors. This analysis includes several steps:

1. Obtain recreational use data for Lake Mendocino.
2. Estimate the relationship between recreational usage and water levels at Lake Mendocino.
3. Apply this relationship to the change in water levels attributable to FIRO.
4. Identify a UDV estimate for each recreation type.
5. Estimate the value of increased recreation as the product of the increased levels of recreation and daily use values.

4.7.2.1 *Step 1: Obtain Recreational Use Data for Lake Mendocino*

The Lake Mendocino Master Plan from the USACE San Francisco District and the Fish Habitat Flows and Water Rights Project Draft Environmental Impact Report from Sonoma Water both include information on the different types of recreation that occur on and around the lake. The map in Figure 20, replicated from the draft report, shows the locations of the campgrounds, day use areas, boat ramps, and other recreational facilities.

Figure 20. Map of Lake Mendocino recreational sites

To estimate usage, we used USACE's Visitation Estimation and Reporting System (VERS).[28] The VERS primarily uses vehicle meters to track entrances to recreation areas managed by USACE. The number of vehicles is then adjusted using load factors to estimate the number of visitors. The VERS data measures visits, where a visit can be as short as 15 minutes or as long as 14 days.[29] We have assumed each visit lasts for one day. Data was provided from 1984 to 2019, but ultimately only data for FY2014 through FY2017 were used due to data consistency over time.[30]

4.7.2.2 *Step 2: Estimate the Relationship Between Recreational Usage and Water Levels*

We developed a use estimating model to evaluate how usage would change under FIRO operations. We used ordinary least squares regressions to determine the relationship between water levels and monthly recreation. Our use estimating model was developed after reviewing the relevant literature, including Ward et al. (1996), Platt (1999), Platt (2001), Bowker et al. (2009), and Neher et al. (2013).

We considered several variables as indicators of water levels:

- Monthly average ac-ft, elevation, and surface area.
- The above three variables transformed to a percent of full measure (e.g., ac-ft divided by total storage) (Ward et al., 1996).
- Start of the season water levels or seasonal drawdown of water levels (e.g., from May to September) (Bowker et al., 1994). These measures were rejected as inappropriate for use with monthly data.

Surface area was ultimately chosen because, conceptually, surface area is more appropriate than elevation or ac-ft. The surface area is directly related to the amount of water available for recreation, whereas elevation and storage are only indirectly related. Methodological Appendix A shows the results for percent of full ac-ft and percent of full elevation.

We chose a log-log model to ensure predicted visitation is positive. An additional aspect of a log-log model is the coefficients can be interpreted as a 1 percent change in visitation as a result of a 1 percent change in the explanatory variable.

Several control variables were considered in the regressions, including:

- Median real household income in Mendocino county (annual values from the Census Bureau's Small Area Income and Poverty Estimates).
- Population in Mendocino county (annual values from the Census Bureau's population estimates).

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[28] These data were generously provided by Taylor Baughn and Poppy Lozoff at USACE.

[29] USACE also has data on camping reservations in recent years from the National Recreation Reservation System (NRRS), which can measure the number of recreation days; however, these data are not in a format that can be easily applied to our analysis.

[30] Data for 1984–1999 are limited to total annual recreational days or visits (i.e., no monthly or site-specific data are available). Data for FY2018 and FY2019 are excluded because water level data are not available. Data reporting methods changed significantly in FY2014 and began including more locations. Prior to FY2014, data was only available for camping and Pomo area day use.

- Monthly precipitation and average monthly temperature for Ukiah Airport (from National Oceanic and Atmospheric Administration's Global Summary of the Month data).
- Season dummies, where "summer" equals one during the summer months of May through August and otherwise equals zero, and "shoulder" equals one during the spring and fall months of March, April, September, and October and otherwise equals zero.

We ultimately decided against including median household income or population in the regressions because our short time period did not show much variation in these variables. We also excluded seasonal dummies, as is explained in further detail below.

All months were included in the model to estimate both peak and non-peak recreation. We included temperature and precipitation variables to capture seasonal variation. A log-log model considers that a change in surface area may have a larger impact on recreation visits during the peak season because it measures the percent change in recreation. In other words, it assumes that the percent change is similar across seasons, and since recreational use is larger in the peak season, the change in visitation is also larger. An alternative way to account for seasonal variation in recreation is to directly include monthly or seasonal dummy variables, to capture level differences, and to include interaction terms between the surface area and the month or season to capture differences in how recreation responds to surface area by season. This alternative is included in the methodological appendix (Appendix A).

The relationship between recreation and water levels will likely differ by recreation type. We aggregated visitation data for several locations with similar activities:

- Camping (includes Kyen, and Chekaka campgrounds; FY2014–FY2017).
- Boating and fishing (North Boat Ramp only; FY2014–FY2017)
- General recreation (includes Inlet Road and Pomo Visitor Center; FY2014–FY2017)

The years used vary based on data availability. Some months with incomplete data are excluded. Recreation at some locations is excluded entirely due to frequent missing data (e.g., Bushay campground, South Boat Ramp). Removing these sites will underestimate total benefits because we are excluding any change in recreation at these sites from the benefit calculation.

Some locations are inaccessible above or below certain reservoir levels. When the monthly average elevation levels are outside these ranges, we exclude the data from the model (i.e., greater than 750 ft for the general model and less than 728 ft for the boating and fishing model). We also replace predicted recreation with zero.

The third model is a catch-all for other recreation not covered by camping, boating, or fishing. Identifying the relevant locations for inclusion was not straightforward. The first consideration was that data are missing for many locations in certain months or years. There are very few months with data for all localities. The second consideration was double counting. For example, visitation to Inlet Road and Mesa day use areas may overlap. However, since most people visiting Mesa must travel along Inlet Road, including both numbers would overestimate visitation. We ultimately chose to limit the analysis to Inlet Road and Pomo Visitor Center. We believe most people visiting Lake Mendocino for purposes other than camping, boating, or fishing would visit at least one of these sites. This choice minimizes months with incomplete data and the risk of double counting.

Table 27 shows regression results for these three models. The coefficients on “Ln Surface Area” (i.e., the natural log of surface area) are the primary parameters of interest. The coefficients for the camping and boating models are positive and significant; however, the coefficient for the general model is not significant. A non-significant coefficient indicates that we cannot say that it differs from zero (i.e., no impact on recreation). The camping coefficient of 1.5 means that for a 1 percent increase in surface area, recreation would increase by 1.5 percent per month. Assessed at the means of 11,712 monthly visits and 1,544 acres, this implies that for an increase of roughly 15.4 acres, there will be 117 more campers per month. Because the coefficient for general recreation is not statistically significant, we assume no change in general recreation as a result of FIRO.

The sample sizes are small due to our short time period. This is unfortunate because it limits our statistical precision; however, as noted above, it is not advisable to combine earlier data collected using different techniques due to inconsistencies over time (e.g., there is a large drop in the number of camping visits once the methodology changes). Fortunately, the relationship is strong enough that we could obtain significant coefficients for surface area in two of the three models.

The amount of variation in visitation, as measured by the R^2, ranges from 0.14 to 0.68. The variation explained in the camping model is especially small. The R^2 values for the other two models are generally considered acceptable. In addition, the appropriateness of the signs on the coefficients for control variables, and their statistical significance, vary. We expected a negative sign for precipitation because rainy weather reduces recreation and because recreation is higher during the dry summer period. The coefficients on precipitation are not statistically significant. We expected a positive sign for temperature, which is observed, and it is significant in two of the three models.

Table 27. Recreational regression results

Variables	(1) Camp Ln Camping	(2) Boat Ln Boating	(3) General Ln General
Ln Surface Area	1.532* (0.810)	8.338*** (2.425)	1.000 (0.586)
Ln Precipitation	-0.00155 (0.0865)	0.102 (0.0751)	0.0159 (0.0575)
Ln Temperature	0.801 (1.392)	3.122* (1.450)	2.369** (0.933)
Constant	6.080 (5.662)	-4.276 (5.978)	-0.427 (3.817)
Observations	43	15	25
R-squared	0.142	0.682	0.555

Standard errors in parentheses
* $p<0.1$, ** $p<0.05$, *** $p<0.01$

4.7.2.3 Step 3: Apply this Relationship to the Change in Water Levels Attributable to FIRO

We applied the coefficients from Table 27 to the estimated daily storage levels at Lake Mendocino from 10/2001 to 9/2017 under the baseline and FIRO alternatives. For each day, we estimated the monthly visitation levels under the three scenarios for each activity type. To demonstrate with September 29, 2017 and the camping model, under baseline operations, plugging in the relevant values results in the following:

$$e\hat{}\{constant + [\beta_1 * \ln(S.A.)] + [\beta_2 * \ln(Prec.)] + [\beta_3 * \ln(Temp.)]\}$$

$$e\hat{}\{-5.390 + [1.532 * \ln{(1{,}700)}\,] + [-0.00155 * \ln{(0.03)}\,] + [0.801 * \ln{(69.6)}\,]\} = 12{,}205\ camping\ trips$$

These daily predictions of monthly levels are then averaged over the 16-year period to calculate a monthly average. This is then multiplied by 12 months to reflect the annual average. FIRO's impact on recreation is the difference between the predicted recreational levels under the baseline and the two FIRO alternatives. Average annual visitation increases by 18,154 visits under the Modified Hybrid alternative and 27,229 visits under the EFO alternative. Average annual findings are shown in Table 28, under Step 4, below. Monthly averages are shown in Appendix A.

Some locations are inaccessible above or below certain reservoir levels. When the daily elevation levels exceed these thresholds, predictions are adjusted to be zero visitation. These thresholds include greater than 750 ft for the general model (because many sites become inundated at this threshold) and less than 728 ft for the boating and fishing model (because the boat launch becomes unusable). The Kyen Lower campground is inundated at 756 ft, but other portions of the campground remain open, so we did not impose a restriction in the camping model. Additionally, recall that Bushay, which does become inaccessible beginning around 750 ft, is not included in the camping model due to lack of data.

4.7.2.4 Step 4: Obtain UDVs

Next, a dollar value needs to be placed on the increased recreational usage. Some types of recreation have market values that can be observed. For example, the rental price for a campsite is observed and is a lower bound on the value of a day of camping for that party. However, the true value derived will generally exceed the price paid. For other forms of recreation, there are often no market values observed, for example hiking on many public lands. To value recreational usage when market values are either unknown or expected to underestimate the true value, economists tend to use surveys and stated preference methodologies to derive values. Common examples include contingent valuation and travel cost methodology. Conducting such a study tends to be expensive and time intensive, so we chose a benefit transfer analysis to estimate values for this project.

We considered using values from USACE's Economic Guidance Memorandum, 20-03, Unit Day Values for Recreation for Fiscal Year 2020 (as recommended by the NED guidance). However, these values are generally believed to underestimate the true value of recreation (USDA, 2019b). We also considered using averages from the U.S. Geological Survey (USGS) Benefit Transfer and Use Estimating Model Toolkit, which has compiled many studies estimating daily use values into a searchable database. However, using specific values from the literature that are appropriate to this location results in more defensible estimates.

To identify appropriate values, we reviewed USGS's Toolkit and Oregon State University's Recreation Use Values Database. Ultimately, daily use values from Bowker et al. (2009) were chosen. In Bowker's study, a recreation demand model was developed for visitors to National Forests using on-site survey data and travel cost estimates. The model was used to estimate WTP for fourteen recreation activities regionally.

We preferred use values from Bowker's study because the analysis is rigorous and the study was relatively recent. Additionally, this paper provided values for many different types of recreation, which allowed us to compile all recreational values from one paper, rather than compiling values across sources. However, there are a few drawbacks to this study. First, it is not limited to the Lake Mendocino area; it covers the entire Pacific region. Second, it is not limited to recreation on or around a lake. Some of the data are from non-water areas and some are from riverine areas. Notwithstanding these limitations, these values are the most appropriate for the purposes of this project.

Table 28 includes the relevant unit values taken from Bowker et al. (2009) and their values updated to 2019 dollars.[31] UDVs are the total value derived from an activity. Using these values assumes the value derived from the activity one would otherwise have partaken in is zero. Researchers sometimes adjust UDVs to reflect the marginal benefit from this activity over a second preference.

Table 28. Unit day values

Activity	Reported Values (2004$)	Adjusted Values (2019$)
Camping or resort stay at the forest	$17.57	$23.78
Driving, motorboating, site seeing, and other motorized activities	$27.88	$37.73
Fishing	$67.92	$91.92
Swimming and non-specific forest recreation	$43.46	$58.82
Hiking	$62.80	$84.99
Nature-based activities (e.g., special forest product gathering, historical site visit, nature center visit, nature study)	$23.45	$31.74
Off-highway vehicle activities	$52.61	$71.20
Picnicking	$23.45	$31.74
Trail use (e.g., bicycling, horseback riding, non-motorized water activities)	$56.23	$76.10
Viewing activities (e.g., nature viewing, off-site viewing, wildlife viewing)	$30.26	$40.95

Source: Bowker et al. (2009). Table 15 Consumer Surplus Results TOP5 Data.

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[31] The report includes several estimates using different assumptions. We chose to use their estimates from the trimmed sample that excludes the top five percent of distances traveled to report conservative estimates. We also chose to use the values that incorporate opportunity cost, estimated as one-third of the imputed wage rate.

4.7.2.5 *Step 5: Calculate the Economic Benefit*

The last step is to estimate the value of increased recreation as the product of the increased levels of recreation and UDVs. In some instances, several day use values would be applicable to a model. For example, the North Boat Ramp is associated with both boating and fishing recreation. In these instances, a simple average of the relevant activities' values was used.

As shown in Table 29, benefits under the Modified Hybrid alternative total $802,743 per year and benefits under the EFO alternative total $1.2 million per year. Assuming benefits accrue for 50 years, the PV of these benefits would be $22.3 million and $34.4 million.[32]

Table 29. Recreational benefit of FIRO at Lake Mendocino

Model	Average Unit Day Value	Average Annual Visitation	Average Annual Change in Visitation: Modified Hybrid	Average Annual Change in Visitation: EFO	Benefit: Modified Hybrid (thousands)	Benefit: EFO (thousands)
Camping	$23.78	140,542	9,115	12,814	$216.7	$304.7
Boating and fishing	$64.83	29,945	9,039	14,415	$586.0	$934.5
General recreation [a]	$38.22	137,394	0	0	$0	$0
Total	**-**	**307,881**	**18,154**	**27,229**	**$802.7**	**$1,239.2**

[a] The primary types of recreation used in the model are hiking, picnicking, beach use, swimming, and nature viewing.

4.7.3 Alternative Estimates and Validity Assessment

For comparison, Ward et al. (1996) estimated that at Lake Mendocino in the 1980s, the value of an additional ac-ft of water to recreation was between $12.28 and $244.91, depending on current lake levels (adjusted to 2019 dollars using the CPI-U).[33] On average, FIRO is expected to increase lake levels by 11,018 ac-ft under the Modified Hybrid approach and 16,459 ac-ft under the EFO approach. Dividing our total benefits of $802,743 and $1.2 million by these levels results in per acre-foot values of $73 and $75, respectively. These values show that our estimates are in line with the previous findings from Ward et al. ($12.28 to $244.91).

Alternatively, the values from Ward et al. (1996) could be directly used to estimate recreational benefits. This analysis is conducted as a sensitivity analysis and to demonstrate the type of calculation that could be performed if a demand curve for recreation cannot be calculated for a location in the DST.

This analysis assumes visitation levels and the value of a visit are similar today as compared to the 1980s (when measured in real dollars). Ward et al. reports 230,000 campers per year and

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[32] Reclamation recommended discount rate at the time of writing was 2.75 percent (Reclamation, 2019).

[33] The authors used data on visitors before and during the early part of the 1985–1991 California drought to estimate the relationship between water levels and visitation. They also conducted a travel cost model with water level as a visit predictor to compute marginal values of water in recreation.

121,000 day visitors per year, adding up to 351,000 visitors total. We estimate 307,900 annual visitors, a comparable number.

Hindcast data from 1985–2017 for the FIRO alternatives was applied to Ward et al.'s findings. For each day in our sample, we estimated the additional ac-ft of water under the two alternatives and the fullness of the pool. Fullness was calculated by dividing the surface area under the baseline by the full pool surface area of 1,785 acres. This generates a distribution of "fullness" days. These values were mapped to the deciles used by Ward et al. For example, 47 percent of days in our sample have a "percent full" between 85 percent and 95 percent full, and hence are classified in the 90 percent full category.

The daily additional ac-ft values in a decile category were then averaged to generate an average annual increase in ac-ft. When averaging, values were weighted by the average share of annual visitors in that month because the additional value of an acre-foot is higher during the peak recreation season than the non-peak season.

The additional ac-ft were then multiplied by the marginal recreational value of an acre-foot to calculate total benefits. Estimated annual recreational benefits are approximately $900,000 under the Modified Hybrid and $1.3 million under the EFO alternative, as shown in Table 30. These values are very similar to our baseline estimates of $802,743 under the Modified Hybrid and $1.2 million under the EFO alternative. This validates our findings.

Table 30. Benefits calculated using Ward et al. (1996) parameters

Percent Full	Marginal Value of 1 ac-ft (1994$)	Marginal Value of 1 ac-ft (2019$)	Average Additional ac-ft*: Modified Hybrid	Average Additional ac-ft*: EFO	Average Additional Value: Modified Hybrid	Average Additional Value: EFO
100	$44.99	$76.23	3,047	3,687	$232,292	$281,075
90	$46.73	$79.18	5,899	9,672	$467,111	$765,809
80	$50.41	$85.41	1,184	1,891	$101,142	$161,507
70	$57.58	$97.56	676	893	$65,911	$87,171
60	$71.62	$121.35	266	351	$32,318	$42,648
50	$100.00	$169.44	26	34	$4,479	$5,821
40	$144.54	$244.91	0	0	$0	$0
30	$112.55	$190.70	0	0	$0	$0
20	$34.42	$58.32	0	0	$0	$0
10	$7.25	$12.28	0	0	$0	$0
Total	**-**	**-**	**11,099**	**16,529**	**$903,252**	**$1,344,030**

*Weighted by visitation

4.7.4 Caveats and Limitations

The VERS system measures visits, where a visit can be as short as 15 minutes or as long as 14 days. Because this system is combined with values based on daily use, it introduces some error into our estimates. On the one hand, if a visitor stays several days without leaving, their use value will be underestimated. Or, if a visitor visits several locations around Lake Mendocino in a day, their value may be overestimated because each activity will have a day value applied.

Because the magnitude of these two biases is unknown, the estimates have not been adjusted to reflect them.

The benefit estimate may also be underestimated if visitors do not visit one of these areas, for example if only the Overlook day use area is visited. We considered an adjustment to add estimated use of the South Boat Ramp to the analysis, taking a ratio of use at the South Boat Ramp to the North Boat Ramp in months when both are available and using this ratio to adjust upward the estimate of boating and fishing recreational benefits. However, there are only five months with data for both localities, which would require an extrapolation that introduces unacceptable error.

4.8 Reduced Operation, Maintenance, and Replacement Costs

FIRO may result in a reduction in the cost of environmental reviews because there may be fewer Temporary Urgency Change Petitions (TUCPs). According to Sonoma Water, each of these petitions cost approximately $250,000 (D. Seymour, personal communication, June 6, 2020). These costs are incurred by Sonoma Water. The reduced costs are viewed as a benefit from the perspective of Sonoma Water and therefore the reduction in these costs is presented as a benefit to Sonoma Water, rather than as a reduction in reservoir operating costs. Using data from 1985 to 2017, we identified instances where FIRO may have avoided these TUCPs. We estimate that the Modified Hybrid approach would reduce the prevalence of TUCPs by 18.2 percent and the EFO alternative would reduce the prevalence by 21.2 percent. Therefore, we estimate an annual average savings of $45,455 for the Modified Hybrid and $53,030 for EFO. Assuming benefits accrue for 50 years, the PV of these benefits would be $1.3 million and $1.5 million.[34] We have not incorporated this benefit into the DST because it is unique to this situation.

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[34] Reclamation recommended discount rate at the time of writing was 2.75 percent (Reclamation, 2019).

5 Economic Decision Support Tool Summary and User Guidance

5.1 Introduction

The purpose of the economic decision support tool (DST) is to facilitate the transferability of economic benefit methods developed for Lake Mendocino. The DST allows users to enter their own project-specific data into the tool to develop economic benefit estimates and compare benefits between baseline and alternative reservoir operations, and between different alternative reservoir operation scenarios.

The DST was developed based on the Forecast Informed Reservoir Operations (FIRO) flagship project at Lake Mendocino. The transferability of the DST to other sites was tested at Prosser Reservoir in the Truckee River Basin. Adjustments to the DST were made based on input from stakeholders in the Truckee River Basin.

This section outlines how to use the Alternative Reservoir Operations Economic DST and documents the methods and data sources. It also provides guidance to the user on sources for data inputs.

The DST provides decision makers with a screening-level assessment of the potential benefits of alternative reservoir operations. It should be used by economists, or in consultation with economists. Although estimates from the DST may not be site-specific enough for regulatory purposes, it can serve as a useful starting point to understand the methods that can be used, the data needed, and an estimate of benefits.

The DST has been developed in Microsoft Excel for Office 365 and does not include any Macros. All calculations are performed within the workbook itself, although some calculations are hidden to streamline the presentation.

The DST will help decision makers assess the benefits of implementing alternative reservoir operations. The DST does not incorporate costs or allow for a cost-benefit comparison. The tool allows for up to six alternative reservoir operation scenarios to be assessed. The scenarios are referred to as “Alternative 1,” “Alternative 2,” etc., throughout the DST and are collectively referred to in this report as “alternatives”. Each benefit requires an estimate of the additional water made available by each alternative. This is not calculated within the DST, but can be determined through hydrologic modeling of the alternative reservoir operation scenarios. If this modeling has not been done, the user can provide estimates or goals of the additional water that will be available as a result of the alternative operations. The DST was designed for alternatives that increase water quantities, although some of the benefits can be calculated for decreased quantities.

The DST is designed to quantify average annual benefits. Therefore, when entering estimates of additional water supply or changes in water levels, it is important to identify averages over a sufficiently long period of time to capture dry and wet years. For example, the Lake Mendocino calculations use a 33-year period. The DST also calculates the PV of benefits. The user can enter the years over which the benefit will accrue (the time horizon) and a discount rate.

The tool assesses five economic benefits based on user inputs and calculations:

- Irrigation water supply[35]
- Municipal and industrial (M&I) water supply
- Hydropower
- Fisheries
- Recreation

The DST includes an *Instructions* tab that provides an overview of what the tool is intended to accomplish, a brief description of how to use the tool, and an outline of what user input data are required to calculate each of the benefits.

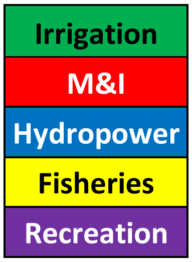
Throughout the DST, the user is prompted to enter data or select from dropdown menus. Figure 21 shows the key that is visible on each tab of the DST that requires user input to reiterate to the user which cells provide instructions and which cells require values to be input.

Key	Instructions	User Input

Figure 21. Key indicating cell purpose in the DST

The *Benefits Summary* tab reports the average annual benefit for each benefit category and the present value for each benefit. The tables in this tab populate once the individual benefit categories have been completed. The present value of the benefits is calculated based on the user input discount rate and years of benefit accrual (time horizon) in rows 25 and 26.

Each benefit category has one or more tabs associated with it and is color-coded to indicate to the user which tabs correspond to which benefit. Figure 22 shows the color-coding scheme used throughout the DST.



Irrigation
M&I
Hydropower
Fisheries
Recreation

Figure 22. Color-coding scheme in DST

Each part of Section 5 of this report corresponds to a benefit category and the subsections correspond to any additional tabs associated with that benefit. Limitations and considerations associated with each benefit are also discussed.

The DST does not consider flood risk reduction. Reservoirs managed by the U.S. Army Corp of Engineers (USACE) require a Hydrologic Engineering Management Plan (HEMP) analysis prior

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[35] The irrigation water supply benefit includes water that is used for irrigation, frost protection, and heat suppression. The term "irrigation" is used in this section of the report as a catch-all term for all agricultural-related water use.

to updating the Water Control Manual (WCM), and the HEMP would assess the flood risks associated with each alternative. Other flood risk assessments, such as flood damages determined from stage-damage relationships, can provide an understanding of the alternatives' impacts on flood risks.

Section 5.7 details what changes would need to be made to keep the DST up to date.

5.2 Irrigation Water Supply

The irrigation water supply benefit calculations are contained within the single *Irrigation* tab in the DST. These calculations use the residual imputation method to calculate the shadow price of water. This method involves calculating the value per acre-foot (ac-ft) of water by dividing net revenue for the commodity by the volume of irrigation water applied per acre for that commodity. A brief overview of the steps and the associated calculations of the residual imputation method is provided below. For a more thorough description, the user is referred to Young and Loomis (2014).

To calculate this benefit, the user must provide the following data:

- Annual average additional water, in ac-ft, supplied for irrigation use per alternative
- Commodities that receive irrigation water from the reservoir
- Cost per acre for each commodity
- Revenues per acre for each commodity
- Average water usage per acre for each commodity
- Share of agricultural acreage for each commodity

5.2.1 Step 1: Additional Water

First, the user must enter the annual average additional water, in ac-ft, supplied for irrigation use in row 8 for each alternative. The user should only enter the additional water that will be supplied for irrigation use, not the total additional volume of water made available by the alternative. The user may not know how the additional water will be distributed. One option is to apply the current distribution to the additional water. For example, if 30 percent of water from the source is consumed for irrigation and 70 percent for M&I users, then allocate 30 percent of the new project water to irrigation.

5.2.2 Step 2: Identify Commodities

Next, the user should enter the commodities in the region that receive irrigation water from the reservoir, and for which data are available, in rows 25–39, column B. For each commodity, additional values will be required to calculate the shadow price of water. If these values are not available, and cannot be estimated, remove the commodity from the list.

5.2.3 Step 3: Calculate Net Revenue

Net revenues are the difference between revenues and costs. To estimate revenues, the user can either:

- Enter crop yield and price information for each commodity in rows 25–39, columns C and D. The product of these values is then populated in column E.
- Enter revenue directly in column F.[36] If the user provides yield and price information, the yields should reflect normal operations and average at least three years of data.

In accordance with the 1983 Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (P&G) and the 2013 Principles, Requirements, and Guidelines for Water and Land Related Resources Implementation Studies, the total revenue per acre should be calculated using normalized crop prices issued by the U.S. Department of Agriculture (USDA ERS, 2020). When the commodity in question is not included in the data series provided by the USDA, the P&G guidance suggests using statewide average prices over the three previous years. If the price of the commodity varies greatly within the state, the user may be justified in using more local price data. However, several years of data should still be used to diminish the influence of year-to-year variation.

Total costs must then be entered by the user in rows 25–39, column G. Net revenue will then populate column H.

Estimates of the total input cost per acre can be determined from a review of the relevant literature.[37] For example, UC Davis provides sample cost data for select commodities and counties in California (UC Davis, 2020). These data should include all costs incurred in the production and marketing of crops, including, but not limited to, seeds, fertilizer, fuel, equipment, repairs, depreciation, property taxes, and interest. These data should also include both fixed and variable costs. Fixed capital costs are incorporated as the annual depreciation and interest costs for a capital investment. If input prices fluctuate annually, use an average of the three most recent years, if possible.

If data by commodity are not available, some very rough estimates can be calculated using aggregated data from the Census of Agriculture (see text box below).

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[36] If the user enters yield and price data, the DST will use the calculated revenue from column E regardless of whether the user has also entered their own estimate of revenue in column F.

[37] Note that due to large variations in estimates by geographic region, the literature review should focus on geographically and climatically similar regions.

County-Wide Alternative

If data by commodity is unavailable, aggregate data from the USDA's Census of Agriculture for the county can be used to estimate net revenues for all crops. We advise against this method if commodity-level data are available because aggregation may make it difficult to properly calculate average irrigation per acre. Additionally, these numbers include both crops and animals. To calculate net revenue, you will need:

1. Commodity totals – sales, measured in $ (Table 2: Market Value of Agricultural Products Sold)
2. Expense totals, operating – expense, measured in $ (Table 3: Farm Production Expenses)
3. Farm Operations – Acres Operated (Table 1: County Summary Highlights)

Then subtract (2) from (1) and divide by (3) to generate average net revenues per acre.

For example, for Autauga, AL, in 2017, revenue was $21,460,000, expenses were $18,918,000, and there are 113,236 acres. This generates total net revenues of $2,542,000 and net returns per acre of $22.45.

Alternatively, you could directly use net cash farm income from Table 4, but we believe this is less appropriate because it includes government subsidies, which should not be included in the shadow price of water.

Source: https://www.nass.usda.gov/Quick_Stats/CDQT/chapter/1/table/1

5.2.4 Step 4: Identify Water Usage

The residual imputation method calculates the value of an acre-foot of water. Therefore, net revenues per acre must be divided by the average water applied per acre, by commodity. The user must enter irrigation water needs in rows 25–39, column I.

A thorough literature review should be conducted to determine an appropriate estimate for each commodity. Due to large variations in estimates by geographic region, the literature review should focus on geographically and climatically similar regions to the site in question. In addition to a literature review, the user could estimate the volume of water required for prevalent commodities in the county using CROPWAT, a decision support tool developed by the Land and Water Development Division of the Food and Agriculture Organization of the United Nations. Lastly, the USDA's Irrigation and Water Management Survey provides data on total irrigation across a state that can be used to estimate the average ac-ft of water applied per acre of land across the state (USDA, 2019a). However, since cropping patterns and weather can vary significantly across a state, this method should only be used when other options are not available.

5.2.5 Step 5: Calculate the Shadow Price of Water

With estimates of net revenues and the volume of water required per acre, the value per acre-foot of water (i.e., the shadow price) can be calculated for each commodity by dividing the net revenues by the required volume of water.
$V = NR/I$, where:

- V is the value per acre-foot calculated in column J
- NR is net revenue calculated in column H
- I is average irrigation needs, entered by the user in column I

5.2.6 Step 6: Distribute Additional Water Across Commodities

The DST assumes that project water will be distributed across commodity types based on current land use. The user must enter the percent of the total agricultural acreage in the region that is used for each commodity in column K. Estimates of total agricultural acreage in the region and acreage by commodity can be obtained from county crop reports or the USDA's National Agricultural Statistics Service. The user will receive an error alert if the sum of the share of agricultural acreage is greater than 100 percent. Values may total less than 100 percent if value estimates are not available for some commodities.

5.2.7 Step 7: Calculate Benefits

For each alternative, the benefit from each commodity will populate in columns L through Q once the necessary data have been provided by the user. The benefit for each commodity is calculated as $B = V * W * A$, where:

- B is the calculated benefit, in dollars
- V is the value per acre-foot calculated in column J (i.e., the shadow price)
- W is the additional ac-ft of water associated with the alternative entered by the user in row 8
- A is the percent of the total agricultural acreage that is used for the commodity, entered by the user in column K

The total benefit value from the commodities entered by the user is calculated in row 41, columns L through Q.

If the commodities for which the user has provided data do not represent 100 percent of the agricultural acreage, the DST will estimate the benefit for each alternative from the missing commodities in row 43, columns L through Q. The benefit from the missing commodities is calculated by the following equation:

$$B = \left(1 - \sum A\right) * \frac{\sum(V * A)}{\sum A} * W$$

The total annual benefit for each alternative reported in row 45 is the sum of the benefit from known commodities (row 41) and the estimated benefit from missing commodities (row 43). The average annual benefit reported in row 45 for each alternative is used to populate the irrigation row of the *Benefits Summary* tab.

5.2.8 Limitations and Considerations

The residual imputation method employed to calculate the irrigation water supply benefit has inherent assumptions and limitations. One limitation of this method is that the values are sensitive to measurement errors in costs or revenues, or the omission of any costs. For example, any costs omitted will bias the value of water upwards. Additionally, the estimate of the value of water may vary significantly if output prices or yields vary significantly from one year to the next. Lastly, this approach is most appropriate for staple agricultural commodities, where the production process is simple, standardized, and stable over time, and where water represents a significant contributor to the value of production.

This benefit calculation also assumes that the additional water made available by the alternatives will be distributed across crops based on agricultural acreage and that commodities without cost and revenue data can be represented well with the average calculated value of water.

5.3 M&I Water Supply

The M&I water supply benefit calculations are contained within the single *M&I* tab in the DST.

The DST provides two ways for calculating the M&I water supply benefit. Option 1 assumes that the price of M&I water is not affected by the additional supply provided by the alternatives. This option uses the current wholesale price of water to calculate the benefit. This option reflects the change in revenue. Option 2 estimates a new price of water based on the increase in water quantity supplied to customers and the price elasticity of demand. The new price of water is then used to determine the benefit by calculating the change in consumer surplus. Both options require the same data.

To calculate this benefit, the user must provide the following data:

- Annual water quantity supplied to customers
- Expected average annual change in water quantity supplied to customers for each alternative
- Current wholesale price of water

The *M&I* tab begins by asking the user to select in cell F12 which of the two options they will use to calculate the benefit.

The user can either provide the above data based on all M&I customers, or disaggregated data broken down by residential customers and commercial and industrial (C&I) customers. The user must select from the dropdown menu which data will be provided in cell F17: “Residential and C&I” or “All.” Although data can be entered for all three options—residential customers, C&I customers, and all customers—the average annual benefit that is reported out in the *Benefits Summary* tab is based on the user’s input in cell F17.

The user must provide the necessary data on a consistent volume-unit basis. The user can select either ac-ft, cubic feet, or gallons as the volume-unit in cell F19. Once this selection is made by the user, the “Unit” column in the tables on this tab will populate with the appropriate unit.

Row 30 requires the user to input the average annual water quantity supplied to customers. These data can often be provided by the local water supply authority. If possible, historical data from the past five years should be used to determine the average annual water quantity supplied. Using five years should limit the influence of outlying years (e.g., especially dry years when more water may be used for watering lawns and gardens). Local climatic knowledge and a review of the data can also help identify whether there are outlying values that should be removed, or if more data are necessary.

Rows 32–37 require the user to input the expected average annual change in water quantity supplied to customers for each alternative. The user should only enter the additional water that will be supplied for M&I water supply use, not the total additional volume of water made available by the alternative. If the distribution of additional water is unknown, the user can apply the distribution of water to the additional water.

Once the user has provided the expected average annual change in water quantity supplied to customers for each alternative, the DST calculates the estimated new water quantity supplied to customers. The new water quantity supplied is calculated by summing the current water supplied and the expected change in water supplied for each alternative.

Row 52 requires the user to input the current wholesale price of water. These data can often be found on the local water supply authority's website, or by contacting them directly. The price provided by the user should reflect the marginal price per unit of water and should not include fixed fee costs. If water prices are applied on a tiered basis, the user should enter the weighted average of the tiered prices (if known), or the lower value of the tiered prices to be conservative.[38]

5.3.1 Option 1

Option 1 does not require the user to enter any additional data. The benefit is calculated as the product of the change in water quantity and the wholesale price of water and is reported in rows 62–67.

5.3.2 Option 2

The next section of the M&I tab estimates the new price of water for each alternative and the change in consumer surplus. The current price of water, current quantity of water, and an assumed price elasticity of demand are used to map the demand curve for M&I water. This method involves using an assumed price elasticity of demand to estimate a relationship between price and the demand of water. A similar method was implemented by Piper (2009).

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[38] An example of tiered prices would be if the utility charges $1.80 per 1,000 gallons for customers that use 0 to 6,000 gallons per billing period (Tier 1), $2.90 per 1,000 gallons for customers that use 6,001 to 25,000 gallons per billing period (Tier 2), and $3.40 per 1,000 gallons for customers that use more than 25,000 gallons per billing period (Tier 3)

The user must enter the assumed price elasticity of demand in cell F78. The suggested default value is -0.6.[39] An elasticity of -0.6 means a 10 percent increase in the price of water would result in a 6 percent reduction in demand.

After the user inputs the current price of water, the DST calculates the estimated new price of water for each alternative through the steps outlined below.

The demand for water can be written as $Q_D = \alpha + \beta P$ and the elasticity can be defined as $\varepsilon = \beta * \frac{P}{Q_D}$, where:

- Q_D is the quantity of water demanded, entered by the user in row 30
- α is a parameter reflecting the quantity of water demanded if the price were $0 per unit
- β is a parameter reflecting the change in quantity given a change in price
- P is the market price, in dollars, entered by the user in row 52
- ε is the elasticity entered by the user in row 78

The DST first solves for the unknown β parameter by rearranging the elasticity equation to be $\beta = \varepsilon * \frac{Q_D}{P}$. The DST then solves for the unknown α parameter by rearranging the water demand equation to be $\alpha = Q_D - \beta P$. This assumes that the demand for labor is constant.

With α and β now known, the price of water (P) can be determined for any quantity of water demanded (Q_D). In rows 83–88, the DST solves for the new price of water based on the new quantity of water supplied to M&I customers, as previously calculated by the DST in rows 39–44.

The change in consumer surplus is then calculated in rows 90–95 of the DST. Consumer surplus is the benefit consumers receive when they value a good or service more than the market price. In a supply and demand model, it is represented as the area under the demand curve and above market price, as shown in Figure 23. We have assumed a perfectly inelastic supply curve.

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[39] The default value is based on a thorough literature review, including Dalhuisen et al. (2003), Espey et al. (1997), Sebri (2014), Young and Loomis (2014), and Worthington and Hoffman (2008).

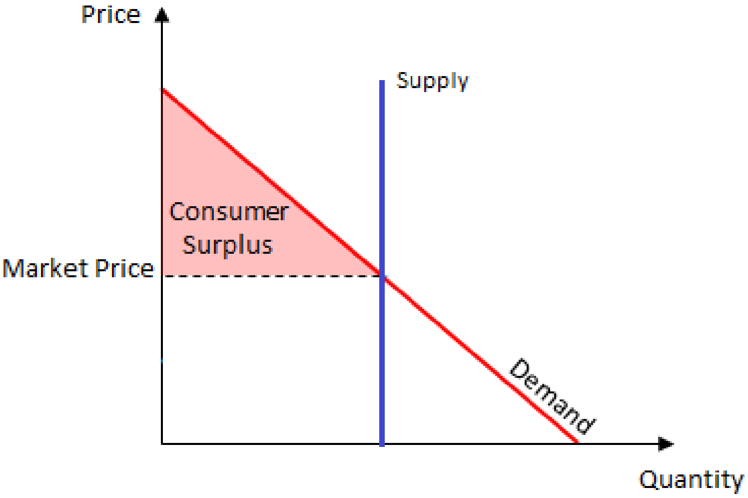

Figure 23. Consumer surplus

The additional water made available for M&I water supply by the alternatives shifts the supply curve, and thus creates an increase in consumer surplus. The change in consumer surplus is calculated as $\Delta CS = (Q_D * \Delta P) + \frac{(\Delta Q_D * \Delta P)}{2}$, where:

- ΔCS is the change in consumer surplus, in dollars
- Q_D is the current water quantity demanded
- ΔQ_D is the change in water quantity demanded for each alternative
- ΔP is the change in the price of water for each alternative

The annual benefit reported for Option 2 is based on the change in consumer surplus calculated in rows 90–95.

Once the user has entered all necessary information, the average annual benefit is reported in rows 100–105. If the user has selected, in cell F17, that disaggregated data are provided based on residential and C&I customers separately, then the average annual benefit is calculated as the sum of the benefit for residential and C&I customers. If the user has selected, in cell F17, that data are provided based on all customers, then the average annual benefit is simply what is reported for all customers.

The average annual benefits used to populate the M&I row of the *Benefits Summary* tab reflect the benefits reported in rows 100–105 for the option that the user selected in cell F12.

5.3.3 Limitations and Considerations

The methodology employed to calculate the M&I benefit assumes that the prices observed in the data reflect market equilibrium prices. For the wholesale market, this tends to be a reasonable assumption. However, some rigidities may exist that prevent the wholesale market from functioning as a competitive market.

Additionally, the price elasticity of demand provided by the user may significantly affect the M&I benefit calculations. The user should conduct a thorough literature review to provide justification for the elasticity chosen.

Lastly, this methodology assumes demand is linear, at least along the relevant portion of the demand curve. If demand was non-linear, then the change in consumer surplus would differ. This is unlikely to cause a large difference if the change in water quantity is relatively small, but it may become a concern with large changes in quantity.

5.4 Hydropower

The hydropower benefit calculations require user input in the *Hydropower* tab, as well as in the *Hydropower Generation* tab. Electricity price data used to calculate this benefit are included in the *Wholesale Electricity Prices* tab.

To calculate this benefit, the user must provide the following information:

- The region where the site is located, or the region that is most similar to the site, in order to determine which wholesale electricity rates to apply
- Daily hydropower production, in megawatt hours (MWh), for baseline reservoir operations and each alternative

The *Hydropower* tab in the DST first instructs the user to select the region where the site is located, or the region most similar to the site, in row 8 of the *Hydropower* tab. The regions correspond to eight major electricity hubs at which electricity is traded. Wholesale electricity rate data are selectively pulled based on the region chosen by the user. Figure 24 marks the locations of the price hubs from which the user can select. For additional information regarding the electricity rate data, see the Wholesale Electricity Prices section of this report below.

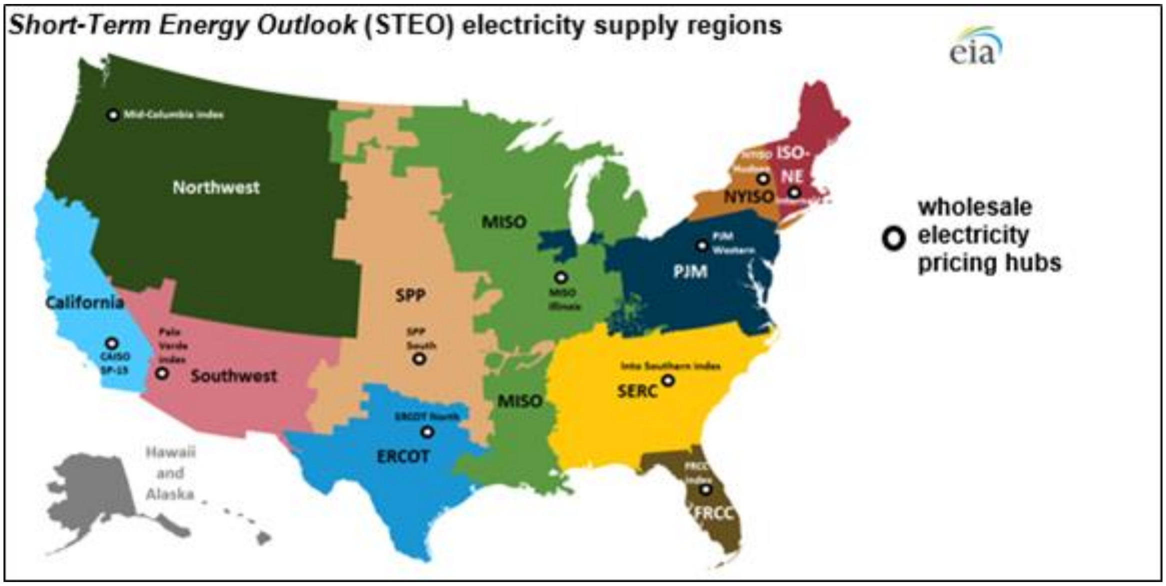

Figure 24. Regions corresponding to wholesale electricity prices (Source: U.S. Energy Information Administration, 2019)

The user must then select whether the hydropower benefit should be reported on either an annual or monthly basis in row 11. Note that this selection only changes the frequency that the benefit is reported beginning in row 15. Even if the user selects "Monthly," the benefit reported in the

Benefit Summary tab is still the average annual benefit. The monthly option is included because hydropower benefits may be seasonal.

Next, the user must input the daily hydropower production in the *Hydropower Generation* tab. See the Hydropower Generation section of this report below for additional details regarding what user input is required.

Once all the necessary information has been provided in the *Hydropower* and *Hydropower Generation* tabs, the economic benefit from hydropower will then populate in the table beginning in row 15. The power production is calculated by summing the daily power production in columns K through Q of the *Hydropower Generation* tab based on either a monthly or annual basis, depending on the user's selection. The average annual production reported in row 17 is calculated by summing the daily power production from the *Hydropower Generation* tab over each year, and then taking the average of these annual production values. The average annual benefit reported in row 18 is simply the baseline average annual production subtracted from the average annual production of each of the alternatives.[40]

The average annual benefit reported in row 18 is used to populate the hydropower row of the *Benefits Summary* tab.

5.4.1 Hydropower Generation

The user must provide the daily hydropower production, in MWh, for baseline operations and each of the alternatives in columns A through H of the *Hydropower Generation* tab. The DST allows up to 50 years of daily data to be entered. Historical daily hydropower production for baseline operations may be obtained from the utility that operates the hydropower plant at the site where FIRO is being evaluated. The daily hydropower production for the alternatives can be obtained through hydrologic hindcast modelling.

This tab requires daily values. If only aggregated data are available, please list the value multiple times to reflect the number of days it reflects (e.g., if monthly averages, enter the January average value 31 times).

Once the hydropower production data has been entered into the DST, the user must return to the *Hydropower* tab and select the region that the site is located in. After this selection has been made, monthly average wholesale electricity rates corresponding to the selected region are used to calculate the daily power production reported in columns K through Q of the *Hydropower Generation* tab. The daily power production is calculated as $P_P = P_d * P_m$, where:

- P_P is the calculated daily hydropower production, in dollars
- P_d is the daily hydropower production, in MWh, provided by the user in columns B through H
- P_m is the monthly average wholesale electricity price, in \$/MWh, reported in the *Wholesale Electricity Prices* tab

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[40] Note that the average annual production and benefit reported in rows 17 and 18 will always be listed on an annual basis, and thus will not change based on the user's selection of either a monthly or annual reporting basis in row 11.

Please see the Wholesale Electricity Prices section of this report below for more information regarding these rates. The daily power production reported in columns K through Q is then used to calculate the benefit reported in the *Hydropower* tab.

5.4.2 Wholesale Electricity Prices

Daily wholesale electricity prices beginning in row 6, columns E through P, are based on data from the U.S. Energy Information Administration (EIA) for eight major electricity hubs (EIA, 2020). Data are provided in the DST for 2015–2019. Column E indicates the region that corresponds to the price hub. Column S converts the weighted average price provided by the EIA to current-year dollars using the Consumer Price Index for All Urban Consumers (CPI-U).

Once the user has selected a region in row 8 of the *Hydropower* tab, the table in cells B5–C19 of the *Wholesale Electricity Prices* tab will populate. The region selected by the user will show in cell C5, and the average price for each month from the selected region will populate in the rows below. The monthly average prices are calculated based on the weighted average price in 2019 dollars reported in column S.

The monthly average prices reported in cells C8–C19 for the region selected by the user are used to calculate the daily power production in columns K through Q of the *Hydropower Generation* tab. Each monthly average price is multiplied by the hydropower production, in MWh, for days within that month. For example, the monthly average price for February will be multiplied by all hydropower produced in the selected region in February.

5.4.3 Limitations and Considerations

The hydropower benefit is calculated based on historical wholesale prices. Therefore, an inherent assumption about this benefit calculation is that historical wholesale prices reflect future prices.

Additionally, the wholesale prices made available by the EIA represent eight major electricity hubs in the U.S. out of more than two dozen hubs and delivery points in North America. The EIA republishes and makes public the market data collected by the Intercontinental Exchange. The EIA does not have access to data for the other electricity hubs as a result of their limited agreement with the Intercontinental Exchange. Due to this data limitation, the user should select the region from the nearest similar location. However, it must be noted that these prices may not perfectly reflect the wholesale price of electricity at the user's site.

5.5 Fisheries

Estimating the economic benefit to fisheries is challenging for numerous reasons, most notably because of the difficulty and lack of consensus around how to determine an appropriate economic value for fish, and due to the many indicators or metrics that can be used to assess the fish habitat. First, we provide context around how and why an indicator metric must be chosen prior to using the DST. Then, we discuss the three different methods incorporated in the DST.

Regardless of the method used, it is important to note that this benefit is meant to capture the indirect value to fisheries. It should not include direct use values, such as benefits from recreational fishing as this may lead to double-counting the benefit (if recreational benefits are also included).

5.5.1 Indicator Metrics

The health of a fishery can be assessed and measured using a variety of indicator metrics. These metrics include, but are not limited to, the change in fish populations, habitat area (e.g., rearing habitat or floodplain habitat), degree days, and instream flows. Each of these metrics measure a physical change and can be used by fisheries experts to help assess the health of the fishery.

To estimate the economic benefit to fisheries, the DST user must understand how the alternative reservoir operation scenarios they are considering will impact fisheries. To ensure an appropriate economic estimate, the user must indicate what indicator metric they are using to evaluate the health of the fishery. The user should choose an indicator metric for which the relationship between the alternative and the metric has been modelled or estimated (e.g., how the additional water stored in the reservoir as a result of the alternative scenarios impacts the indicator metric).

The indicator metric the user chooses to evaluate the fisheries benefit is the first user input needed to calculate the fisheries benefit. The user must enter the metric used to assess the health of the fishery and the units associated with that metric in rows 16 and 17, respectively.

Next, the user must provide an estimate of how much the chosen metric will change as a result of each alternative reservoir management scenario. The user enters these data in row 22. The economic benefit to fisheries is determined based on the estimated change in the metric.

5.5.2 Fisheries Economic Benefit Estimation Methods

There are a variety of methods commonly used to estimate the economic benefit to fisheries that require site-specific data to calculate reasonably appropriate benefit estimates. The DST incorporates three methods, each requiring different amounts of outside research from the user and each with different limitations and caveats. The user is strongly encouraged to thoroughly consider which method is appropriate for their site based on the available data and the accuracy and reliability of these data.

Table 31 provides the three methods used to assess fisheries and a brief overview of the data needs and limitations of each method. The sections following the table provide a more detailed and thorough explanation of each method.

The user must select in row 26 which of the three options they will use to calculate the fisheries benefit. The values reported in the *Benefits Summary* tab will be based on whichever option the user selects in row 26.

Table 31. Overview of methods to calculate the fisheries benefit

Description	Option 1: Least-Cost Alternative	Option 2: Market Price of Water	Option 3: Benefit Transfer Using Willingness to Pay (WTP) Values
Overview	Use the cost of another project that would achieve the same physical benefit to fisheries as the alternative reservoir operation scenarios as a proxy for benefits.	Apply the market price of water to the additional volume of water stored in the reservoir as a result of the alternative reservoir operation scenarios.	Identify the WTP for fish population improvements from a literature review. Then apply the WTP from a comparable site to the current site.

Description	Option 1: Least-Cost Alternative	Option 2: Market Price of Water	Option 3: Benefit Transfer Using Willingness to Pay (WTP) Values
Data Requirements	Costs associated with projects that are feasible and would achieve the same physical benefit to fisheries.	Average annual additional ac-ft of water stored in the reservoir. Local price and conveyance cost data are encouraged.	Outside research needed to identify and apply appropriate WTP values.
Advantages	Often results in a conservative benefit estimate.	Does not require significant additional research or analysis.	Can provide a more holistic benefit estimate.
Limitations	Requires significant outside research that can be costly to conduct and may involve many assumptions.	Assumes that the economic benefit to fisheries can be estimated using the market price of water. This may not be appropriate in all cases.	Reliability of estimate is significantly impacted by the WTP values that are used and their applicability to the project site.

5.5.2.1 *Option 1: Least-Cost Alternative*

This method requires the user to perform outside research to determine any feasible alternative projects that could be implemented to achieve the same change in the indicator metric chosen by the user. The user must determine the cost for each feasible alternative project and choose the alternative with the lowest cost.

First, the user must identify alternative projects that will achieve the same change in the indicator metric as specified by the user in row 22. For example, if the user has indicated that alternative reservoir management scenario 1 will decrease flow temperatures by 1 degree Celsius, the user must identify alternative projects that will similarly decrease instream temperatures by 1 degree Celsius. Hypothetical alternative projects might include raising the height of the dam and planting trees to increase shading over the river. The cost associated with each of these alternative projects must be estimated. Of all feasible alternative projects, the least-cost alternative should be entered in row 46. Note that the least-cost alternative project may be different for each alternative reservoir management scenario. The user must provide the net present value (NPV) associated with the least-cost alternative, including capital costs and operating and maintenance costs, in row 47. In row 48, enter the expected lifespan, in years, associated with the project. The DST will then calculate the annual cost associated with the least-cost alternative project in row 49. The annual cost, also referred to the average annual benefit associated with this method, is calculated as $C = B = NPV/Y$, where:

- C is the annual cost in $/year
- B is the average annual benefit in $/year
- NPV is the net present value, in dollars, associated with the alternative project
- Y is the expected lifespan of the alternative project, in years

5.5.2.1.1 Limitations and Considerations

The least-cost alternative method requires significant outside research to determine projects that can achieve the same physical benefit to fisheries as the alternative reservoir management scenarios. The user should consult with local fisheries experts to identify possible projects that have been considered, understand by how much these projects will impact the chosen indicator metric, and identify costs associated with these projects.

The least-cost alternative method often results in a conservative estimate of the economic benefit to fisheries because it uses a market valuation approach. Therefore, this method does not consider additional benefits that are not captured in market prices. The least-cost alternative method is a well-regarded approach; however, the reliability and accuracy of the estimates associated with it greatly depend on the user to determine the appropriate least-cost alternative project.

5.5.2.2 *Option 2: Market Price of Water*

This method uses a proxy for the value of water to determine the fisheries benefit. This results in a very rough estimate of the fisheries benefit. Users are strongly encouraged to implement additional methods to gain a better understanding of the possible economic benefit to fisheries from alternative reservoir operations.

Users should note that water purchases may be the least-cost alternative. In that case, option 1 and option 2 would be the same.

To calculate this fisheries benefit using option 2, the user must provide data on the amount of additional water, in ac-ft, generated from the project for each alternative.

This method calculates the fisheries benefit by using water transaction prices and conveyance costs as a proxy for the value of water.[41] The transaction price is the market price at which users have purchased and sold water. The conveyance price is the cost to transport water to the user. Together, these reflect the value placed on this resource by the user. It also reflects the avoided damages associated with a reduction in water usage (e.g., the price at which a farmer is willing to sell water reflects the marginal revenue product associated with using that water to irrigate crops). The total of the transaction price and conveyance cost provide a total cost estimate, which is then multiplied by the additional volume of water made available by the alternatives to determine the fisheries benefit. Note that this method assumes the additional water solely benefits fish. It is likely the water would also benefit other wildlife, and thus the benefit may be better described as a fish and wildlife benefit.

The user must enter the total annual average additional water, in ac-ft, made available by each alternative in row 64. This can be calculated as the average difference in storage.

Row 68 provides the default transaction price, in $/ac-ft, that will be used to calculate the fisheries benefit if a local price estimate is not provided by the user. This default transaction price is the average of weekly market price data from August 2019 to July 2020, as provided by the Nasdaq Veles California Water Index (NQH2O), converted to 2019 dollars. Although these data are specific to the California market, no other similar market price data for water was

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[41] Willingness to pay for water is reflected by the total price, comprising both the market price and the conveyance costs. Market prices are dependent on conveyance costs, and hence ideally the market prices and conveyance costs should be for the same region.

readily available. Therefore, these prices are used as a default transaction price for all users of the DST, regardless of the site's location. The *NQH2O Price Data* tab provides this weekly price data, as well as the CPI-U for each month, which was used to convert the 2020 prices to 2019 dollars. For further information regarding the NQH2O data, please see the NQH2O Price Data section of this report.

If local transaction price data are available, the user can input the annual average $/ac-ft price in 2019 dollars in row 69. These data may be available from state water resources agencies or local utilities. If an estimate of the local transaction price is not available, the default transaction price in row 68 will be used. This price should reflect the wholesale price for untreated water to prevent inappropriately including any value-added from treatment costs or distribution costs.

Row 73 provides the default conveyance cost, in $/ac-ft, used to calculate the fisheries benefit if a local conveyance cost estimate is not provided by the user. This default conveyance cost is an estimate based on the average of conveyance costs reported in the Economic Valuation Appendix of Reclamation's Shasta Lake Water Resources Investigation (Reclamation, 2015). The *Conveyance Cost* tab provides the conveyance cost estimates as reported in the Economic Valuation Appendix, as well the costs once converted to 2019 dollars using the CPI-U.

Conveyance costs are inherently site-specific because they are based on the energy required to transport water from one location to another, which depends on the elevation profile of the transport path and the distance the water is traveling. Therefore, the DST allows the user to enter a more appropriate conveyance cost estimate, in $/ac-ft, in row 74. These data may be available from region specific reports, similar to the Reclamation report found for Shasta Lake. If an estimate of the local conveyance cost is not available, the default conveyance cost in row 73 will be used.

The user should enter the percent of water lost during conveyance in row 79. Regional reports should be reviewed to determine an appropriate estimate for water losses. If no relevant local information can be found, a value of 17.5 percent is suggested as the default.[42]

Row 82 provides the total cost that will be used to calculate the fisheries benefit. The total cost is calculated as $C = C_T + C_C + C_L$, where:

- C is the calculated total cost value that is then used to calculate the fisheries benefit
- C_T is the local transaction price if provided by the user in row 69, or the default transaction price in row 68
- C_C is the local conveyance cost if provided by the user in row 74, or the default conveyance cost in row 73
- C_L is the cost associated with water lost during conveyance, calculated in row 80

The fisheries benefit is reported in row 85 and is calculated as $B = \Delta W * C$, where:

- B is the calculated fisheries benefit, in dollars, associated with the alternative

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[42] The suggested default value of 17.5 percent is the average of the percentages used in the Shasta Lake Water Resources Economic Valuation Appendix (10 percent and 25 percent).

- ΔW is the annual average additional water, in ac-ft, made available by the alternative and reported by the user in row 64
- C is the cost, in $/ac-ft, reported in row 82

If the user has selected option 2 in row 26, the average annual benefit reported in row 85 for each alternative is used to populate the fisheries row of the *Benefits Summary* tab.

5.5.2.2.1 NQH2O Price Data

Transaction price data used to determine the default transaction price in the *Fisheries* tab are provided in the NQH2O *Price Data* tab of the DST. Weekly transaction prices are provided by the NQH2O (Nasdaq, 2020). This index tracks the spot rate price of water rights in the state of California. The prices provided by the NQH2O represent the commodity value of water at the source and do not include costs associated with conveyance or losses. For this reason, the costs associated with conveyance and losses are added to the transaction cost in order to calculate the fisheries benefit. Please see the NQH2O methodology report for additional information regarding this price index (Nasdaq, 2019).

5.5.2.2.2 Conveyance Cost

The default conveyance cost in the *Fisheries* tab is based on conveyance cost estimates from the Economic Valuation Appendix of Reclamation's Shasta Lake Water Resources Investigation (Reclamation, 2015). Shasta Lake is a reservoir created by Shasta Dam and is operated in conjunction with other Central Valley Project facilities in California. The report estimates the cost to convey water to M&I users by estimating the cost to move water through State Water Project (SWP) facilities. The conveyance cost estimates in the Shasta Lake Economic Valuation Appendix include the SWP wheeling rate, power costs, and the cumulative power demand.[43] Table 3-9 in the Economic Appendix provides total conveyance cost estimates for each of the ten regions considered in the analysis. Please see the Shasta Lake Economic Valuation Appendix for further details regarding these conveyance cost estimates.

5.5.2.2.3 Limitations and Considerations

As previously noted, the default transaction and conveyance cost estimates are based on estimates specific to California. If using this option, the fisheries benefit will be more accurate if the user is able to provide more regionally relevant estimates for these costs. Additionally, the methodology used to calculate the fisheries benefit assumes that the value of water can be adequately captured in the market, therefore assuming perfect competition. The methodology also assumes that the demand for water as reflected by historical transaction prices is representative of future prices.

The fisheries benefit calculated by the DST should be considered as a very rough estimate of the economic benefit provided to fisheries by the FIRO alternatives. A more accurate assessment of the fisheries benefit may be estimated using the least-cost alternative method (option 1).

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[43] The cumulative power demand is based on estimations of power use per unit of water for SWP power facilities.

5.5.2.3 *Option 3: Benefit Transfer Using WTP Values*

The third method to calculate the fisheries benefit is applying willingness to pay (WTP) values in a benefit transfer approach. These WTP values are often derived from contingent valuation surveys of a subset of the population to determine how that population values non-market resources. A WTP value is a measure of the survey respondents' willingness to pay for a specified resource.

Option 3 requires the user to specify the dominant fish species in the project's region (column B) before providing a WTP value, in current dollars, associated with that species in column D. The user should indicate the study region that the WTP value is based on in Column C. This field is not used in the calculations, but is helpful to remind the user of the importance of choosing a WTP value appropriate to the region.

The user is encouraged to perform their own literature review and consult with local fisheries experts to identify any studies that have been done in a similar region and with the same fish species. The user can also refer to the *WTP Database* tab of the DST to identify potentially relevant WTP values that could be used for the fisheries benefit calculation.

The WTP Database provides the WTP value and the associated unit for various fish species, as reported in the cited reference. All WTP values are then converted to annual estimates, in current dollars, in column H. WTP values that are based on one-time payments are converted to annual estimates assuming a 2.75 percent discount rate and a 50-year time horizon.[44]

The WTP value entered in the *Fisheries* tab must be in the same unit as the chosen indicator metric. Although some WTP values are already on a per fish basis (i.e., the unit reported in column E is "per fish"), the majority are on a per household basis. WTP values that are on a per fish basis can be used directly in the 'Fisheries' tab if the indicator metric being used is the change in the number of fish. WTP values that are on a per household basis must be converted to the same unit as the chosen indicator metric, which requires the user to carefully review the study they are using as the basis for the WTP value. Often, WTP studies ask respondents about a specific change that will result in a projected change in the fish population. The user must review the specific language in the WTP survey to convert it to a value that can be applied to the chosen indicator metric (e.g., convert WTP value to a per fish basis if the chosen metric is the change in the number of fish).

The fisheries benefit associated with this method is reported in row 118 and is calculated as $B = WTP * \Delta M$, where:

- B is the calculated fisheries benefit, in dollars, associated with the alternative
- WTP is the WTP value, in \$/unit (where the unit is that specified in row 17), reported by the user in column D
- ΔM is the change in the metric associated with each alternative and reported in row 22

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[44] The discount rate is based on Reclamation recommended rates (Reclamation, 2019). The appropriate time horizon is unknown, but 50 years is generally considered an appropriate length in the fisheries literature.

5.5.2.3.1 Limitations and Considerations

Appropriate WTP values that are applicable to the study area must be identified, and sometimes appropriate values are not available. The reliability of the economic benefit estimates using this method are significantly impacted by the WTP values that are used and how appropriate they are to the project site. If the WTP values are from a study that is very different with regards to region or species of fish, it is important to include caveats when reporting the economic benefit estimates.

5.6 Recreation

The recreation benefit calculations are contained within the *Recreation* tab; however, data are selectively drawn from the *USGS Data* tab as needed.

The DST provides two ways for calculating the recreation benefit. The user should select the option for which they have the required data, noting that option 1 is the preferred method. The following data are needed for the two options:

- **Option 1:**
    - Change in annual recreation, in days, by recreation type for each alternative
- **Option 2:**
    - Average storage of the reservoir, in ac-ft
    - Estimated change in storage, in ac-ft, for each alternative
    - Annual recreation, in days, by recreation type

The *Recreation* tab begins by asking the user to select in cell C8 which of the two options they will use to calculate the recreation benefit. Although data can be entered for both options, the average annual benefit that is reported in the *Benefits Summary* tab is based on the user’s input in cell C8.

The user must then select in cell C11 the region where their site is located. This question is asked because the average unit day values (UDVs) associated with each recreation type differ across regions. If the user would like to use average UDVs that are based on all relevant studies, not restricted to a specific region, the user can select the “Total Sample” option for this question.

5.6.1 Option 1

Option 1 requires the user to select in column B, rows 21–47, the recreation types that are available at the site from the drop-down list. Once a recreation type is selected, the corresponding average day use value associated with the selected region will populate in column C. These average UDVs are compiled from the U.S. Geological Survey (USGS) Benefit Transfer Toolkit and are provided in the *USGS Data* tab of the DST. Please see the USGS Data section for more details about this data. Note that there are some recreation types that do not have associated day use values for certain regions. In these instances, the average day use value will show “---” and the annual benefit will not be calculated for this recreation type.

Once the recreation type is selected, the user must enter in columns D through I the estimated change in annual recreation for each alternative, in days, by recreation type.

The change in annual recreation for each alternative can be obtained by estimating the relationship between monthly water levels and recreation use through regression analysis. Prior to conducting this analysis, relevant literature should be reviewed, including but not limited to Bowker et al. (2009), Neher et al. (2013), Platt (1999), Platt (2001), and Ward et al. (1996). For additional information on how to perform such an analysis, see Section 4.3.2.

Average monthly recreation day use estimates by recreation type can often be obtained through the agency that manages the land around the reservoir, which in some instances may be USACE, Reclamation, or the U.S. Forest Service (USFS). At recreational areas managed by USACE, the user may be able to use data from their Visitation Estimation and Reporting System (VERS).[45]

After the user has entered the change in annual recreation for each alternative, the annual value by recreation type will populate in columns J through O. The annual value is calculated as the product of the average UDV and the change in annual recreation.

The total annual benefit for each alternative is calculated in row 50, columns J through O, as the sum of the annual values associated with the recreation types for that alternative. These values are used to populate the Recreation row of the *Benefits Summary* tab if the user has selected "Option 1" in cell C8 of the *Recreation* tab.

5.6.2 Option 2

Option 2 requires the user to first enter the average annual storage of the reservoir in cell C56. This should be computed from at least five years of data. Ideally, users should input the surface area, but if this is not available, ac-ft can be used.

The user must then enter the estimated annual change in storage, in ac-ft, for each alternative in row 60. These estimates can be obtained through hydrologic modeling of the alternatives. If this modeling has not been done, the user can provide estimates or goals of the additional water that will be stored as a result of the alternatives.

Next, the user must select in column B, rows 68–94, the recreation types that are available at the site from the dropdown list. Once a recreation type is selected, the corresponding average UDV associated with the selected region will populate in column C. Please see the Option 1 and USGS Data sections of this report for further details about the average UDVs.

For each recreation type selected, the user must enter the assumed elasticity for that recreation type. The appropriate elasticity can either be calculated with a regression analysis or obtained from the literature. Elasticities within the range of 0.5 to 10.0 are accepted, and an elasticity of 1.0 is suggested if the user is unsure what an appropriate value would be. Generally, activities directly associated with the lake will have higher elasticities (e.g., boating, swimming) than peripheral activities (e.g., camping, hiking). An elasticity of 1.0 indicates that a 1 percent increase in the water storage level will result in a 1 percent increase in recreation days. Depending on the shape of the reservoir, the appropriate elasticity may vary depending on whether users measure the change in water levels by surface area or ac-ft.

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[45] The user will need to contact USACE directly to obtain VERS data because they are not publicly available.

Some prior estimates that may be helpful include:

- Ward et al. (1996), which found that a 1 percent increase in lake levels, measured as percent of the full surface area, results in a 2.08 percent increase in camping and a 4.38 percent increase in day use at reservoirs in the Sacramento District managed by USACE.
- The FIRO analysis for Lake Mendocino, which found that a 1 percent increase in surface area results in a 1.5 percent increase in camping and an 8.4 percent increase in boating activities.

Next, the user must enter the current annual recreation, in days, by recreation type in column E. These data can often be obtained through the agency that manages the land around the reservoir, which may be USACE, Reclamation, USFS, or the National Parks Service.[46] If possible, the user should obtain data by recreation type or recreation location, from which activity types can be inferred. If not, total recreation can be distributed across recreational types based on some assumptions. Additionally, recreation data over the past five to ten years should be used to obtain the average annual recreation. Using data that span five to ten years will diminish the impact of outliers (e.g., an especially wet year that limited outdoor recreation or the impact of COVID-19). At recreational areas managed by USACE, the user may be able to use VERS data.

The estimated change in recreation, by recreation type, will populate in columns F through K once the user has entered all necessary information into the DST. This is calculated as $\Delta R = \frac{\Delta S}{S} * \varepsilon * R$, where:

- ΔR is the estimated annual change in recreation use, in days
- ΔS is the change in storage, in ac-ft, provided by the user in row 60
- S is the average storage, in ac-ft, provided by the user in row 56
- ε is the assumed elasticity provided by the user in column D
- R is the current annual recreation, in days, provided by the user in column E

The annual value by recreation type for each alternative is calculated in columns L through Q as the product of the average UDV and the estimated change in recreation.

The total annual benefit for each alternative is calculated in row 97, columns L through Q as the sum of the annual values associated with the recreation types for that alternative. These values are used to populate the Recreation row of the *Benefits Summary* tab if the user has selected "Option 2" in cell C8 of the *Recreation* tab.

5.6.3 USGS Data

The *USGS Data* tab of the DST includes recreation types and their associated UDV estimates. These data were compiled from the USGS Benefit Transfer Toolkit (USGS, 2016). The toolkit reports the minimum, maximum, and average per person, per day value by region, based on relevant published studies. The regions are delineated in Figure 25. Further details about the methodology used to obtain these value estimates can be found through the Toolkit.

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[46] National Park Service visitor use statistics can be retrieved from https://irma.nps.gov/STATS/.

Figure 25. USGS recreation regions (Source: USGS Benefit Transfer Toolkit)

The UDVs reported in the USGS Benefit Transfer Toolkit are reported in 2016 dollars. These values have been adjusted to 2019 dollars using the CPI-U. The *CPI-U* tab of the DST provides annual CPI-U values. The USGS values are adjusted to 2019 dollars by the following equation:

$$UDV_{2019} = UDV_{2016} * \frac{CPI - U_{2019}}{CPI - U_{2016}}$$

Note that there are some recreation types that do not have associated UDVs for certain regions.

5.6.4 Limitations and Considerations

The recreation benefit uses average UDVs by region and recreation type as provided by the USGS Benefit Transfer Toolkit. Although this dataset is quite comprehensive, there are some regions for which UDVs for certain recreation types are not available. In these situations, the user may choose to select the "Total Sample" option for the region to ensure that a UDV is available to calculate the value for that recreation type.

Additionally, UDVs differ across locations, so using regional estimates may not always be appropriate. For example, the value of a day of boating in Florida may be very different from the value for a day in Maryland in the middle of the winter. Therefore, users should review the literature to see if more appropriate values are available, such as site specific estimates.

There are a few additional factors the user should consider when applying UDVs to recreation counts. First, UDVs are the total value derived from an activity. Using these values assumes the value derived from the activity one would otherwise have partaken in is zero. Researchers sometimes adjust UDVs to reflect the marginal benefit from the activity over the second preference (e.g., 25 percent of the UDV to reflect the marginal value). Second, these UDVs should only be applied to the primary activity. For example, a hiker may also engage in picnicking and nature viewing, but their primary activity is hiking, and thus only that UDV should be applied.

The DST requires at a minimum that users know their site's current recreational levels. If recreational levels are unknown, the methods implemented in the DST cannot be used. As an alternative, previous estimates of recreational values per additional ac-ft can be used as a rough approximation. For example, Ward et al. (1996) estimated the value of an ac-ft of water to recreation for 10 reservoirs in USACE's Sacramento District. The value varies depending on location and how full the reservoir is, but the average value is $112.90 per ac-ft, converted to 2019 dollars using the CPI-U. If no recreation data are available, this value could be used as a *very rough* approximation of the recreational value. The user may want to review the values in Ward et al. (1996) to identify which value is most appropriate, or review other literature to identify the relevant value.

5.7 Keeping the DST Up to Date

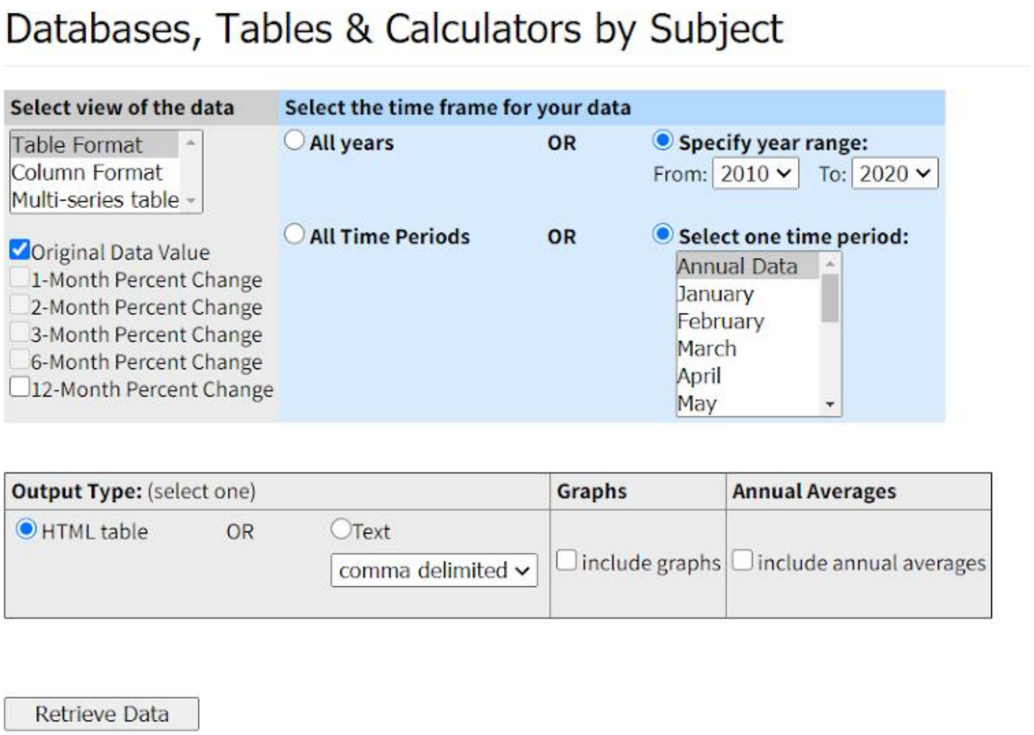
There are three data sources that need to be updated regularly in the DST: the CPI-U, wholesale electricity prices, and NQH2O data. We recommend updating these data in the DST every January, after the middle of the month when data become available. Additionally, USGS recreation values may need to be updated periodically.

To make these data changes, you will need to unprotect some sheets by right clicking on the tab and then selecting "Unprotect Sheet." Please remember to select "Protect Sheet" again after making the changes.

In addition to updating the data in the three tabs outlined below, the user should find and replace all instances of "$2019" with the current dollar year in each sheet in the DST.

5.7.1 The CPI-U

The DST presents all values in 2019 dollars, which should periodically be updated to reflect more recent dollars. We have used the CPI-U to adjust values to real dollars. The annual CPI-U data are released in mid-January. Data can be downloaded from the U.S. Bureau of Labor Statistics (BLS) by typing "CUUR0000SA0,CUUS0000SA0" into the Series Report page at https://data.bls.gov/cgi-bin/srgate. After clicking "Next," be sure to select "Annual Data" as the time period. Figure 26 shows what selections should be made on the BLS website.



Databases, Tables & Calculators by Subject

Select view of the data

Table Format

Column Format

Multi-series table

☑ Original Data Value

☐ 1-Month Percent Change

☐ 2-Month Percent Change

☐ 3-Month Percent Change

☐ 6-Month Percent Change

☐ 12-Month Percent Change

Select the time frame for your data

○ All years OR ● Specify year range:

From: 2010 To: 2020

○ All Time Periods OR ● Select one time period:

Annual Data

January

February

March

April

May

Output Type: (select one)

● HTML table OR ○ Text

comma delimited

Graphs

☐ include graphs

Annual Averages

☐ include annual averages

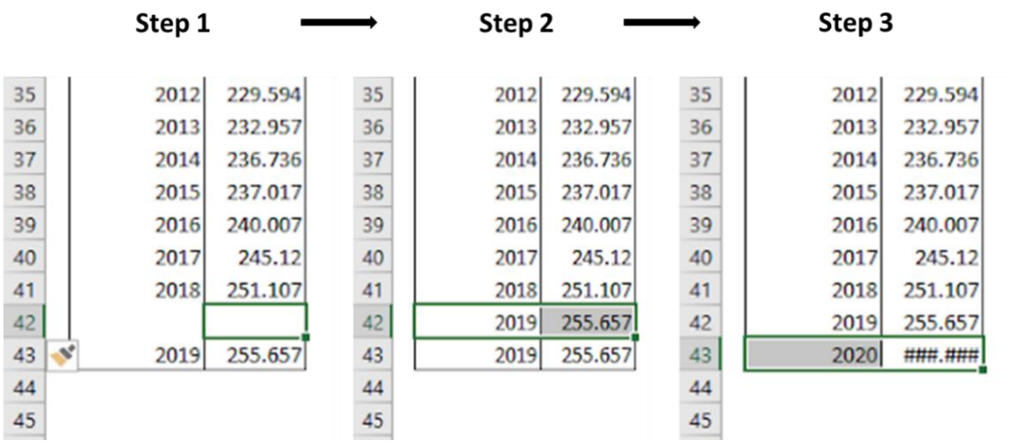
Figure 26. How to pull data from BLS

If the new value is added in a specific way, then all formulas referencing that cell will automatically update. To update the CPI-U data, follow these three steps:

1. Insert a row before the last row of data
2. Enter the values from the last row into the second to last row
3. Enter the data for the new year in the last row.

Figure 27 outlines these three steps. Alternatively, you could add the new data at the bottom and update all formulas, but this is more time consuming and may result in errors being made.

Lastly, go through each sheet and find and replace all references to “$2019” and “2019 dollars” with the updated dollar year.



Step 1

35	2012	229.594
36	2013	232.957
37	2014	236.736
38	2015	237.017
39	2016	240.007
40	2017	245.12
41	2018	251.107
42		
43	2019	255.657
44		
45		

Step 2

35	2012	229.594
36	2013	232.957
37	2014	236.736
38	2015	237.017
39	2016	240.007
40	2017	245.12
41	2018	251.107
42	2019	255.657
43	2019	255.657
44		
45		

Step 3

35	2012	229.594
36	2013	232.957
37	2014	236.736
38	2015	237.017
39	2016	240.007
40	2017	245.12
41	2018	251.107
42	2019	255.657
43	2020	###.###
44		
45		

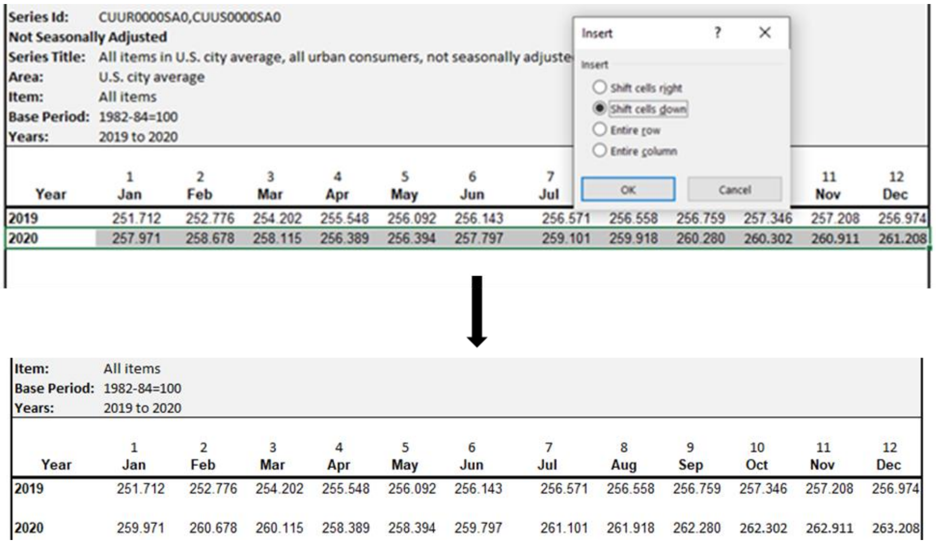
Figure 27. Three step process to update CPI-U data

5.7.2 NQH2O Data

The NQH2O data are updated weekly. We recommend adding data from the previous year every January. In order to convert the data to the current dollar year, monthly CPI-U data must be downloaded. We recommend updating this tab through updating monthly CPI-U data and then updating NQH2O price index data. Both steps are explained in detail below. It should be noted that values in the pictures for Aug 2020 through Dec 2021 are made up and shown purely for demonstration purposes.

Step 1: Update the monthly CPI-U data

- **Step 1A:** In the NQH2O tab of the DST, insert cells <u>before</u> the last row of the CPI-U data. (Note: First unprotect the sheet). See Figure 28 for reference.



Series Id: CUUR0000SA0,CUUS0000SA0
Not Seasonally Adjusted
Series Title: All items in U.S. city average, all urban consumers, not seasonally adjuste
Area: U.S. city average
Item: All items
Base Period: 1982-84=100
Years: 2019 to 2020

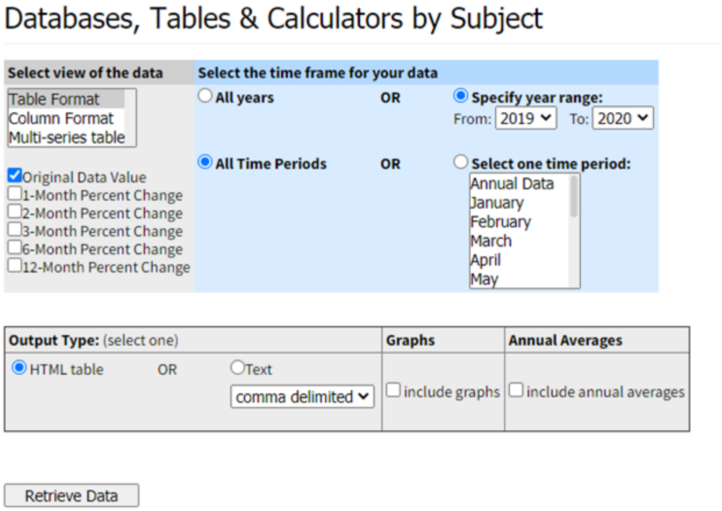
Year	1 Jan	2 Feb	3 Mar	4 Apr	5 May	6 Jun	7 Jul				11 Nov	12 Dec
2019	251.712	252.776	254.202	255.548	256.092	256.143	256.571	256.558	256.759	257.346	257.208	256.974
2020	257.971	258.678	258.115	256.389	256.394	257.797	259.101	259.918	260.280	260.302	260.911	261.208

Item: All items
Base Period: 1982-84=100
Years: 2019 to 2020

Year	1 Jan	2 Feb	3 Mar	4 Apr	5 May	6 Jun	7 Jul	8 Aug	9 Sep	10 Oct	11 Nov	12 Dec
2019	251.712	252.776	254.202	255.548	256.092	256.143	256.571	256.558	256.759	257.346	257.208	256.974
2020	259.971	260.678	260.115	258.389	258.394	259.797	261.101	261.918	262.280	262.302	262.911	263.208

Figure 28. Update the monthly CPI-U data: Step 1A

- **Step 1B**: Download monthly CPI-U data from BLS by typing "CUUR0000SA0,CUUS0000SA0" into the Series Report page at https://data.bls.gov/cgi-bin/srgate. After clicking “Next”, be sure to specify the specific year range as 2019 to the current year and select “All Time Periods” as the time period. Then select “Retrieve Data.” See Figure 29 for reference.



Databases, Tables & Calculators by Subject

Select view of the data: Table Format / Column Format / Multi-series table

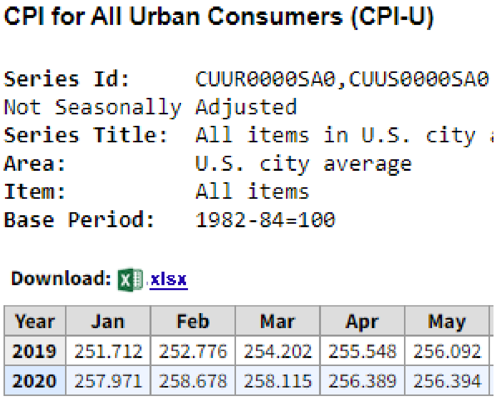
☑ Original Data Value
☐ 1-Month Percent Change
☐ 2-Month Percent Change
☐ 3-Month Percent Change
☐ 6-Month Percent Change
☐ 12-Month Percent Change

Select the time frame for your data
○ All years OR ● Specify year range: From: 2019 To: 2020
● All Time Periods OR ○ Select one time period: Annual Data / January / February / March / April / May

Output Type: (select one) ● HTML table OR ○ Text (comma delimited)
Graphs: ☐ include graphs
Annual Averages: ☐ include annual averages

Figure 29. Update the monthly CPI-U data: Step 1B

- **Step 1C:** Download the data by selecting the Excel icon. See Figure 30 for reference.



CPI for All Urban Consumers (CPI-U)

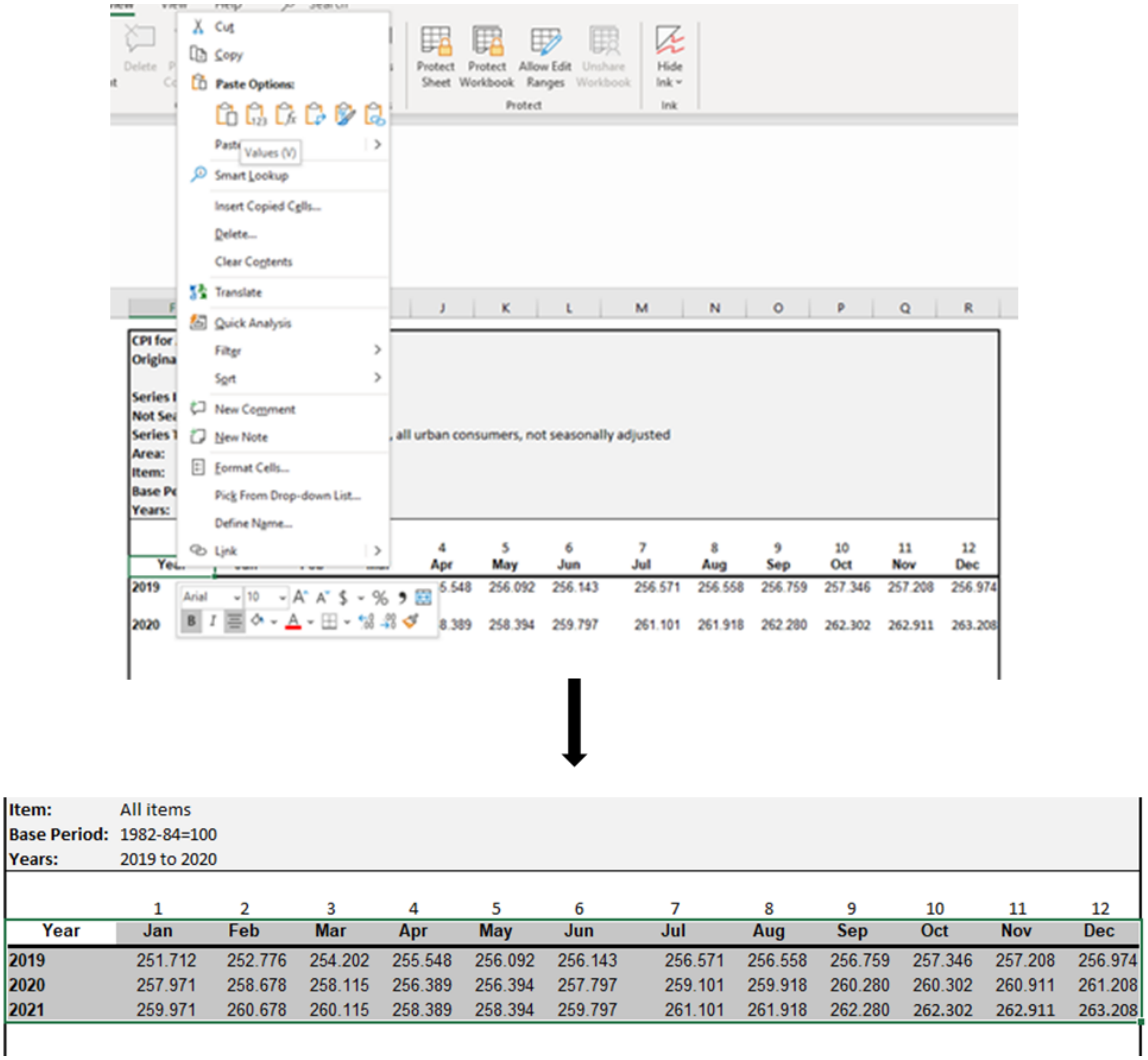
```
Series Id:     CUUR0000SA0,CUUS0000SA0
Not Seasonally Adjusted
Series Title:  All items in U.S. city
Area:          U.S. city average
Item:          All items
Base Period:   1982-84=100
```

Download: xlsx

Year	Jan	Feb	Mar	Apr	May
2019	251.712	252.776	254.202	255.548	256.092
2020	257.971	258.678	258.115	256.389	256.394

Figure 30. Update the monthly CPI-U data: Step 1C

- **Step 1D:** Paste the CPI-U data into cell F14 of the NQH2O tab by right clicking and selecting the “Paste as Values” option. See Figure 31 for reference.



Item: All items
Base Period: 1982-84=100
Years: 2019 to 2020

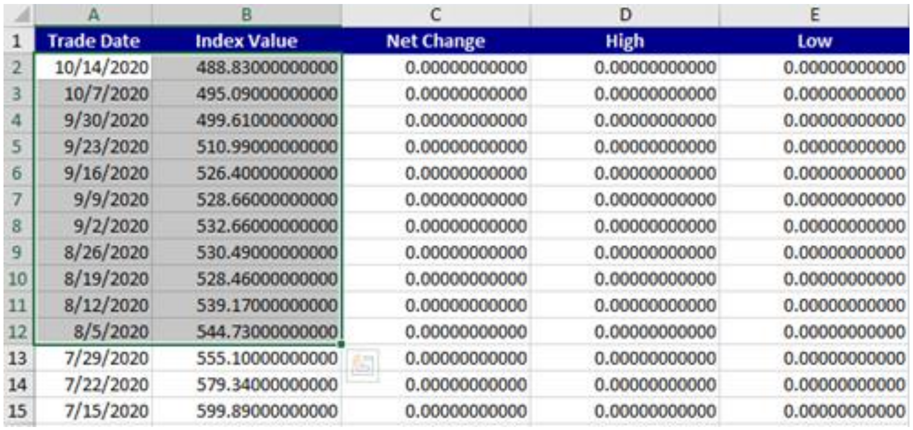
	1	2	3	4	5	6	7	8	9	10	11	12
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2019	251.712	252.776	254.202	255.548	256.092	256.143	256.571	256.558	256.759	257.346	257.208	256.974
2020	257.971	258.678	258.115	256.389	256.394	257.797	259.101	259.918	260.280	260.302	260.911	261.208
2021	259.971	260.678	260.115	258.389	258.394	259.797	261.101	261.918	262.280	262.302	262.911	263.208

Figure 31. Update the monthly CPI-U data: Step 1D

Step 2: Update the NQH2O price index data

- **Step 2A:** Download the latest NQH2O price index data by selecting “Export” at the top right of the chart on the NQH2O page: https://indexes.nasdaqomx.com/Index/History/NQH2O. The default is one year of data; however, the user can adjust the start date to retrieve less than one year of data. It is important to update these data *at least* annually because currently the website does not allow the user to view data dated more than one year from the current date. To ensure that the DST includes weekly price index data and to avoid any potential issues with data access, it is strongly encouraged that the NQH2O data is updated every six months.

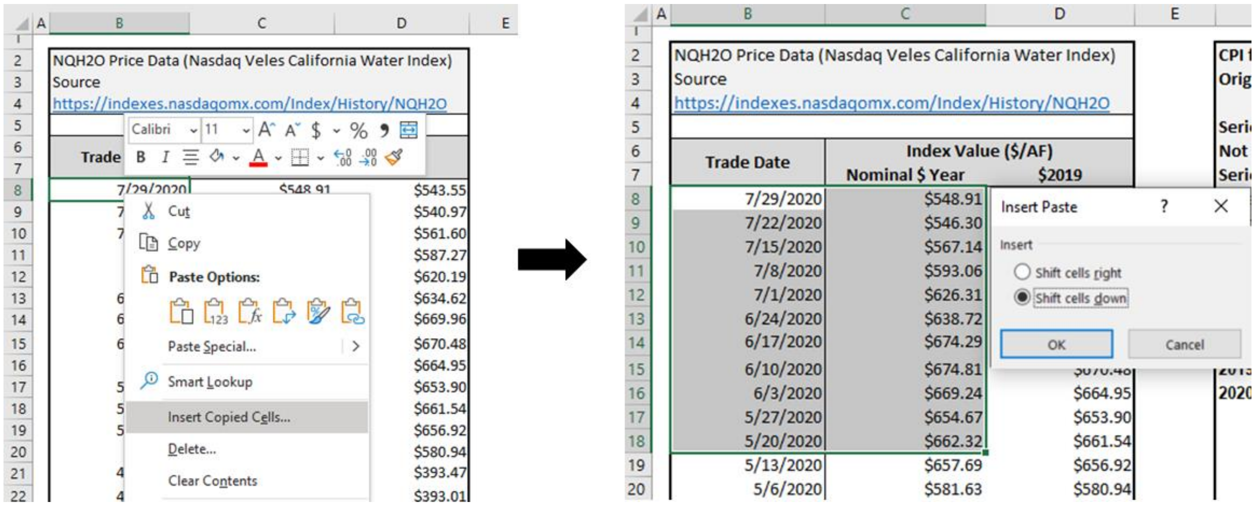
- **Step 2B:** From the downloaded data, only copy the values beginning in row 2 up until the date for which the data is already in the NQH2O tab. Only values in the "Trade Date" and "Index Value" columns need to be copied. See Figure 32 for reference.



	A	B	C	D	E
1	Trade Date	Index Value	Net Change	High	Low
2	10/14/2020	488.83000000000	0.00000000000	0.00000000000	0.00000000000
3	10/7/2020	495.09000000000	0.00000000000	0.00000000000	0.00000000000
4	9/30/2020	499.61000000000	0.00000000000	0.00000000000	0.00000000000
5	9/23/2020	510.99000000000	0.00000000000	0.00000000000	0.00000000000
6	9/16/2020	526.40000000000	0.00000000000	0.00000000000	0.00000000000
7	9/9/2020	528.66000000000	0.00000000000	0.00000000000	0.00000000000
8	9/2/2020	532.66000000000	0.00000000000	0.00000000000	0.00000000000
9	8/26/2020	530.49000000000	0.00000000000	0.00000000000	0.00000000000
10	8/19/2020	528.46000000000	0.00000000000	0.00000000000	0.00000000000
11	8/12/2020	539.17000000000	0.00000000000	0.00000000000	0.00000000000
12	8/5/2020	544.73000000000	0.00000000000	0.00000000000	0.00000000000
13	7/29/2020	555.10000000000	0.00000000000	0.00000000000	0.00000000000
14	7/22/2020	579.34000000000	0.00000000000	0.00000000000	0.00000000000
15	7/15/2020	599.89000000000	0.00000000000	0.00000000000	0.00000000000

Figure 32. Update the NQH2O price index data: Step 2B

- **Step 2C:** In the *NQH2O* tab of the DST, paste the copied data by right clicking in cell B8 and select "Insert copied cells." Be sure to select "Shift cells down" when prompted. See Figure 33 for reference.

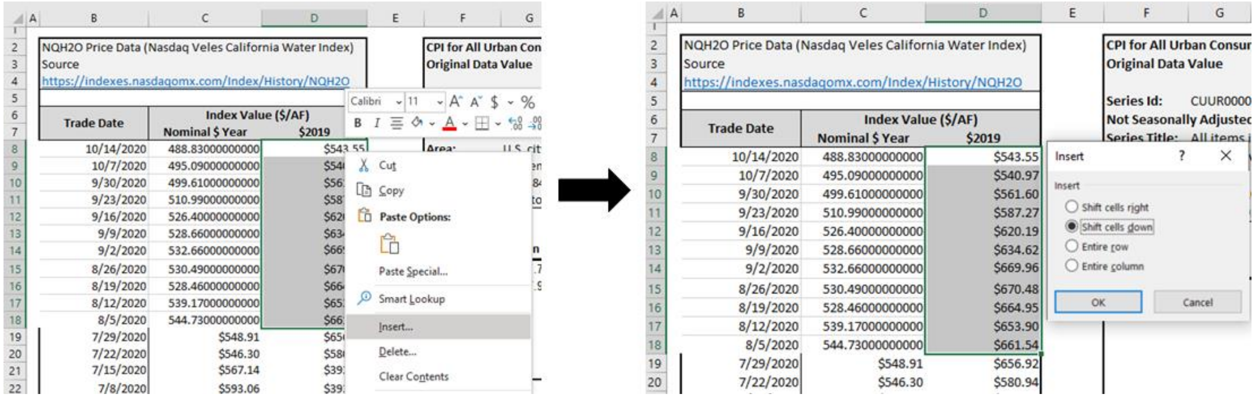


NQH2O Price Data (Nasdaq Veles California Water Index)
Source
https://indexes.nasdaqomx.com/Index/History/NQH2O

	Trade Date	Index Value ($/AF) Nominal $ Year	$2019
8	7/29/2020	$548.91	
9	7/22/2020	$546.30	
10	7/15/2020	$567.14	
11	7/8/2020	$593.06	
12	7/1/2020	$626.31	
13	6/24/2020	$638.72	
14	6/17/2020	$674.29	
15	6/10/2020	$674.81	
16	6/3/2020	$669.24	$664.95
17	5/27/2020	$654.67	$653.90
18	5/20/2020	$662.32	$661.54
19	5/13/2020	$657.69	$656.92
20	5/6/2020	$581.63	$580.94

Figure 33. Update the NQH2O price index data: Step 2C

- **Step 2D:** To ensure the formulas that convert the index values from nominal to current year dollars in column D are not affected, shift the values beginning in cell D8 down by the same number of rows that you have just inserted. Do this by highlighting the cells, right clicking, selecting "Insert," and then selecting "Shift cells down." See Figure 34 for reference.



NQH2O Price Data (Nasdaq Veles California Water Index)
Source
https://indexes.nasdaqomx.com/Index/History/NQH2O

Trade Date	Index Value ($/AF) Nominal $ Year	$2019
10/14/2020	488.83000000000	$543.55
10/7/2020	495.09000000000	$540.97
9/30/2020	499.61000000000	$561.60
9/23/2020	510.99000000000	$587.27
9/16/2020	526.40000000000	$620.19
9/9/2020	528.66000000000	$634.62
9/2/2020	532.66000000000	$669.96
8/26/2020	530.49000000000	$670.48
8/19/2020	528.46000000000	$664.95
8/12/2020	539.17000000000	$653.90
8/5/2020	544.73000000000	$661.54
7/29/2020	$548.91	$656.92
7/22/2020	$546.30	$580.94
7/15/2020	$567.14	
7/8/2020	$593.06	

CPI for All Urban Consur
Original Data Value
Series Id: CUUR0000
Not Seasonally Adjustec
Series Title: All items i

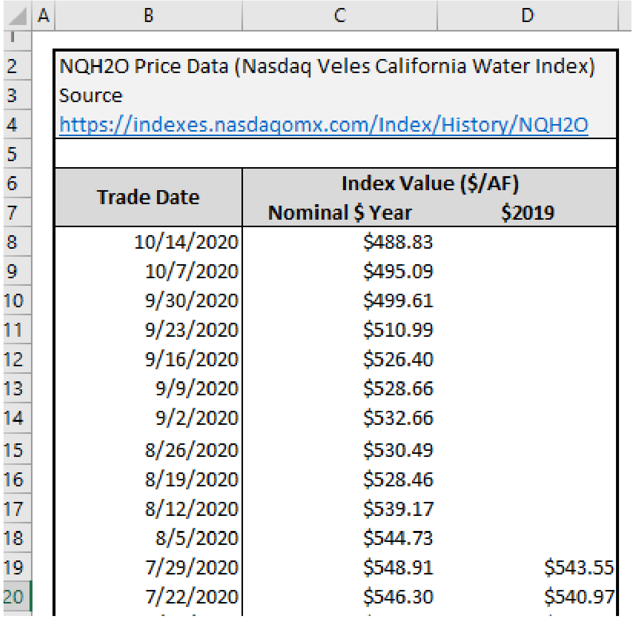
Insert

○ Shift cells right
● Shift cells down
○ Entire row
○ Entire column

OK Cancel

Figure 34. Update the NQH2O price index data: Step 2D

- **Step 2E:** Change "Nominal $ Year" in column C to be in the currency format. Reformat cell fill colors to be white and adjust cell borders to maintain stylistic formatting. See Figure 35 for reference.

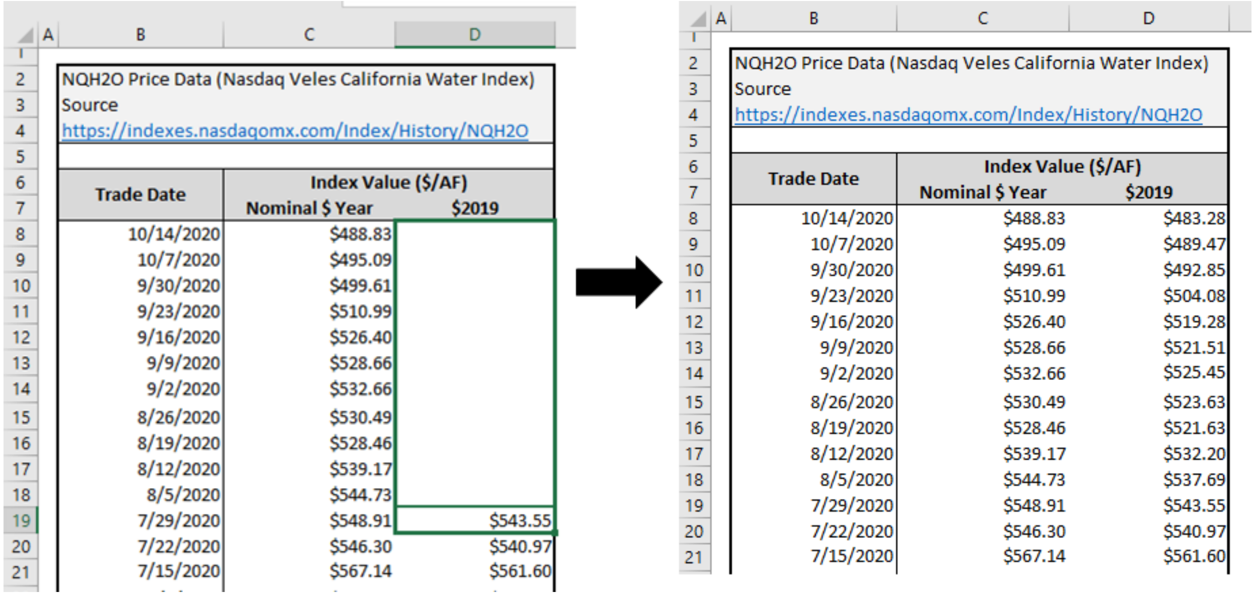


NQH2O Price Data (Nasdaq Veles California Water Index)
Source
https://indexes.nasdaqomx.com/Index/History/NQH2O

Trade Date	Index Value ($/AF) Nominal $ Year	$2019
10/14/2020	$488.83	
10/7/2020	$495.09	
9/30/2020	$499.61	
9/23/2020	$510.99	
9/16/2020	$526.40	
9/9/2020	$528.66	
9/2/2020	$532.66	
8/26/2020	$530.49	
8/19/2020	$528.46	
8/12/2020	$539.17	
8/5/2020	$544.73	
7/29/2020	$548.91	$543.55
7/22/2020	$546.30	$540.97

Figure 35. Update the NQH2O price index data: Step 2E

- **Step 2F:** Select the first cell that has the converted dollar value populated in column D (cell D19 in this example). Fill the formula in the rows above by selecting the bottom right of D19 and dragging upward until D8. (Note: remember to protect the sheet after this step). See Figure 36 for reference.



NQH2O Price Data (Nasdaq Veles California Water Index)
Source
https://indexes.nasdaqomx.com/Index/History/NQH2O

Trade Date	Index Value ($/AF) Nominal $ Year	$2019
10/14/2020	$488.83	
10/7/2020	$495.09	
9/30/2020	$499.61	
9/23/2020	$510.99	
9/16/2020	$526.40	
9/9/2020	$528.66	
9/2/2020	$532.66	
8/26/2020	$530.49	
8/19/2020	$528.46	
8/12/2020	$539.17	
8/5/2020	$544.73	
7/29/2020	$548.91	$543.55
7/22/2020	$546.30	$540.97
7/15/2020	$567.14	$561.60

NQH2O Price Data (Nasdaq Veles California Water Index)
Source
https://indexes.nasdaqomx.com/Index/History/NQH2O

Trade Date	Index Value ($/AF) Nominal $ Year	$2019
10/14/2020	$488.83	$483.28
10/7/2020	$495.09	$489.47
9/30/2020	$499.61	$492.85
9/23/2020	$510.99	$504.08
9/16/2020	$526.40	$519.28
9/9/2020	$528.66	$521.51
9/2/2020	$532.66	$525.45
8/26/2020	$530.49	$523.63
8/19/2020	$528.46	$521.63
8/12/2020	$539.17	$532.20
8/5/2020	$544.73	$537.69
7/29/2020	$548.91	$543.55
7/22/2020	$546.30	$540.97
7/15/2020	$567.14	$561.60

Figure 36. Update the NQH2O price index data: Step 2F

Cell D12 of the *Fisheries* tab will automatically incorporate the newly added data into the calculation of the default transaction price. The default transaction price is calculated by averaging the price index data in the *NQH2O* tab.

Once the NQH2O data set covers five years, you may want to adjust the formula in the *Fisheries* tab, cell D12, to only pull data for the most recent five years.

5.7.3 Wholesale Electricity Price Data

Wholesale electricity data are available at: https://www.eia.gov/electricity/wholesale/. These data are updated biweekly. Download the most recent year by clicking on either Electricity → Current Year or Electricity and Natural Gas → Historical. Delete all columns except "price hub," "trade date," and "wtd avg price." See Figure 37 for reference.

Electricity

- Current year (2020)

Electricity and Natural gas

- Historical (2014-2019)

Figure 37. Update the wholesale electricity price data

Add additional rows at the bottom of the "Wholesale Electricity Prices" tab. Then, paste in the new data below the last row of data, beginning in column F. Add year and month to columns I and J. Copy the formulas in column K to the new rows. Add the Region to column E.

5.7.4 USGS Recreation Values

The USGS recreation UDVs are currently several years old. USGS may update this database in the future. If so, the values in the DST should also be updated. Data can be downloaded from https://sciencebase.usgs.gov/benefit-transfer/. “Average Values by Region” for each recreation type will need to be downloaded and updated in the DST’s *USGS* data tab. See Figure 38 for reference.

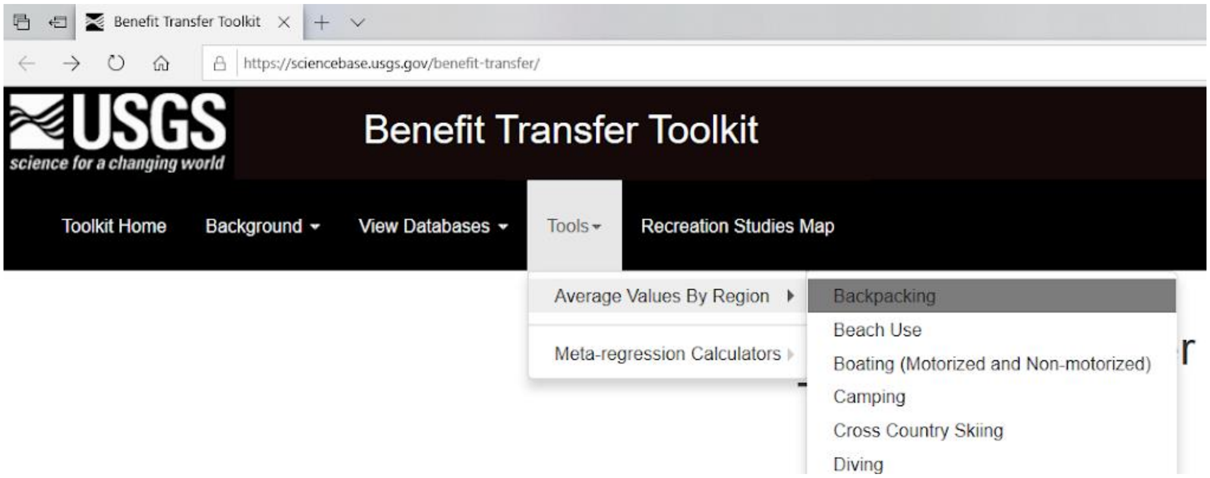


Figure 38. Update the USGS recreation value

6 Prosser Reservoir: Transferability and Workshop

6.1 Introduction

The methodologies implemented in the decision support tool (DST) were chosen because of their transferability to other sites. To ensure that the chosen methods were in fact transferable and to determine any potential issues related to data availability, the DST was tested at Prosser Reservoir in the Truckee River Basin.

Prosser Reservoir was selected as the test site for the DST following an application screening process. Applications were solicited from Bureau of Reclamation (Reclamation) reservoir managers that might be interested in assessing whether Forecast Informed Reservoir Operations (FIRO) can help address water resource management challenges. An ideal test site was described as including multiple potential benefits from FIRO, competing demands, an engaged group of stakeholders, information on water resources benefits, operational streamflow forecasts and reservoir operations models, and a lack of highly politicized litigious issues that could distract from the task. Prosser Reservoir was selected based on these criteria.

An introductory call was held on September 23, 2020, to prepare the Truckee Basin Water Management Options Pilot (WMOP) team for the upcoming DST workshop. This preparatory call included a brief demonstration of the DST, how it is used, and the data requirements for each benefit.

Reclamation members of the Truckee Basin WMOP team identified the key benefits associated with Prosser Reservoir: municipal and industrial (M&I) water supply, recreation, and fisheries. ERG performed benefit estimate calculations for each of the three benefit categories based on readily available data.

A workshop was then convened with the Truckee Basin WMOP team which includes representatives from Reclamation, the U.S. Water Master's Office, the Pyramid Lake Paiute Tribe, the Truckee Meadows Water Authority, and the California Department of Water Resources. The purpose of the workshop was to explore with the Truckee Basin WMOP team how the DST could be used to calculate benefit estimates and receive feedback on applicability to Prosser Reservoir and the usefulness of the DST. Please see the Calculations section below for data sources and calculations performed to determine the benefit estimates. A summary of the workshop and participants' perceptions and feedback on the DST follows (see Section 6.3).

6.2 Calculations

We applied data from Prosser Reservoir to three different benefits categories in the DST: irrigation water supply, M&I water supply, and recreation. We also considered how best to estimate fisheries benefits at Prosser and identified some relevant values. For all benefits, placeholder values are included for the hypothetical change in water supply at Prosser.

6.2.1 Irrigation Water Supply

The irrigation benefit at Prosser is likely to be small because of the limited amount of agriculture that relies on the reservoir for its water needs. However, we performed some benefit calculations because it allowed us to verify the usability of the DST and we wanted to consider even small benefits to ensure a complete benefit analysis.

We began by trying to apply raw data to the DST. However, we ultimately chose to use relevant values already calculated in the literature. Below, we describe both the process taken to obtain raw data and the method ultimately used.

The DST is set-up to calculate the value per acre-foot (ac-ft) of water via the residual imputation method (see Section 5 of this report). This value is then multiplied by the change in ac-ft to generate the total benefit. The residual imputation method requires net revenue data and irrigation data by major commodity. To obtain these data, we began by identifying the counties that use Prosser water for irrigation and the prevalent crops in those counties. Lyon and Churchill counties in Nevada were identified as the relevant localities. For each, we conducted internet searches to obtain data on crop patterns and revenues. The best source of information we identified was the Census of Agriculture, which provides county-level data on the number of operations, acreage, and tonnage by major commodity. In both Lyon and Churchill counties, between 86 and 87 percent of acres harvested is for hay and haylage. The second most prevalent crop is corn silage, which comprises 5 percent of acres harvested in Lyon and 11 percent in Churchill.

We then searched for sample farm cost data for hay and haylage in these counties and surrounding counties. The University of Nevada Cooperative Extension has production cost and return data for several crops in these regions, including alfalfa hay in Churchill county. However, these data are from 2004 and thus may be outdated. UC Davis also has sample costs on orchard grass hay in Shasta, Lassen, and Siskiyou counties in California (UC Davis, 2016b). While Lassen County is close to the project area, prices may differ across states due to taxes and regulations.

These data could be used to calculate net returns, which would generate the shadow price of water when combined with irrigation data. However, the Boca Dam Safety of Dams Modification Project, Economic Benefit Analysis and Damage Assessment (2018) has already calculated applicable numbers. We believe using these numbers is the best approach because:

- Their methodology is rigorous, and the analysis is thoroughly conducted.
- They provide estimates specific to the Truckee Basin, which is appropriate for this analysis.
- They provide estimates for both alfalfa/corn silage and irrigated pasture, which are two of the major land uses in the counties likely impacted by Prosser.
- It creates consistency among economic benefit assessments in the region.
- Data on sample costs are limited and the applicability questionable.

The Boca report provides the necessary data in Tables 2.1 and 2.2. From these, we determined the necessary value of an ac-ft of water to irrigated crops, which averaged to $80.36. Note that the data cannot be disaggregated by crop.

Next, some assumptions must be made on the additional water availability from the project. We assumed a total hypothetical increase of 1,000 ac-ft, and that 11 percent of this increase could be used for agriculture. This is the share of water that goes toward agriculture in the region. We are thus assuming that additional water will be distributed across uses in a similar manner to current water supplies. Lastly, we used Census of Agriculture crop data for Lyon and Churchill counties to allocate water increases across both counties. The annual benefit is calculated as:

$$1{,}000\ acft * 11\% * \$80.36 = \$8{,}839$$

There are several takeaways from this exercise. First, specific to Prosser, some relevant data exist for an irrigation benefit to be calculated. We hope that identifying the sources will be of use to the project team. Second, the DST seemed to function well. However, as we were aware prior to this exercise, making these calculations requires a lot of outside work to identify the relevant values, even when using the DST. Third, the DST may not be well-equipped to handle the complexities of a multi-reservoir system like Truckee-Carson, where additional water supplies are determined among several reservoirs based on a variety of factors.

6.2.2 M&I Water Supply

The DST provides two ways for calculating the M&I benefit. Option 1 assumes that the price of M&I water is not affected by the additional supply provided by the alternatives. This option uses the current price of water to calculate the benefit. Option 2 estimates a new price of water based on the increase in water quantity supplied to customers and the price elasticity of demand. The new price of water is then used to determine the benefit by calculating the change in consumer surplus. Both options require the same data:

- Annual water quantity supplied to customers
- Expected average annual change in water quantity supplied to customers
- Current price of water

For Prosser, water quantity data for 2010–2019 were obtained from the Truckee Meadows Water Authority. We used the five-year average from 2015–2019 to smooth any yearly variations. The average annual quantity of water supplied is 66,155 ac-ft.

The expected average annual change in water quantity as a result of implementing FIRO at Prosser Reservoir is unknown. We therefore used the same hypothetical value as for irrigation water supply benefits: an average increase of 1,000 ac-ft per year. The historical distribution of water usage was applied to determine how much of the current 66,155 ac-ft, and how much of the additional 1,000 ac-ft, would go towards M&I users (Table 32). The new water quantity supplied is then calculated by summing the current water supplied and the expected change in water supplied.

Table 32. Current supply and change in supply by M&I customer type

Water Supplied	Residential Customers	Commercial Customers	Total
Historical distribution	71.5%	17.5%	89.0%
Current water quantity	47,301	11,577	58,878
Change in water quantity	715	175	890
New water quantity	48,016	11,752	59,768

The last necessary piece of data is the current price of water. We obtained data from TMWA on their customer rate schedules and used the tier 1 Commodity Charge per 1,000 gallons. This rate is the same across all meter sizes and user types. We only included the incremental charge per unit of water because the flat fee does not change based on the quantity of water supplied. The tier 1 price is $1.82 per 1,000 gallons. Converting to price per ac-ft by multiplying by 435.599 yields a price of $593 per ac-ft. We chose to use tier 1 prices over tier 2 or 3 prices to ensure a conservative estimate.

6.2.2.1 *Option 1*

To calculate benefits under option 1, we need to multiply the change in water quantity by the unit price: $890\ acft * \$593 = \$527{,}813$. Note that the product differs slightly due to rounding.

6.2.2.2 *Option 2*

Option 2 assumes the price of water is a function of the quantity of water supplied. The price elasticity of demand is used to calculate how price would change as a result of the change in supply. The benefit is then calculated as the change in consumer surplus. A similar method was implemented by Piper (2009).

This method involves using an assumed price elasticity of demand to estimate a relationship between price and the demand of water. The assumed price elasticity of demand is -0.6, which means a 10 percent increase in the price of water would result in a reduction in demand of 6 percent.

Next, the elasticity of demand, current price, and current quantity were used to develop demand curves for M&I users. Table 33 summarizes the relevant values.

Table 33. Prosser values for water demand equations

Input Value or Derived Value	Parameter	Value
Input Value	Price elasticity of demand	-0.6
Input Value	Current water rate ($/ac-ft)	$593
Input Value	Current water demand (ac-ft)	58,878
Input Value	Proposed change in supply (ac-ft)	890
Derived Value	New supply (ac-ft)	59,768
Derived Value	β	-60
Derived Value	α	94,205
Derived Value	p	$578
Derived Value	Change in price	$15

The demand for water can be written as $Q_D = \alpha + \beta P$ and the elasticity can be defined as $\varepsilon = \beta * \frac{P}{Q_D}$, where:

- Q_D is the quantity of water demanded, in ac-ft
- α is a parameter reflecting the quantity of water demanded if the price was zero
- β is a parameter reflecting the change in quantity given a change in price
- P is the market price
- ε is the elasticity

Rearranging to solve for the unknown parameter of β gives the equation $\beta = \varepsilon * \frac{Q_D}{P}$. We calculate:

$$\beta = -0.6 * (58{,}878\, acft \div \$593) = -60$$

Rearranging the demand equation to solve for α yields: $\alpha = Q_D - \beta P$, so:

$$\alpha = 58{,}878\, acft - (-60 * \$593) = 94{,}205$$

The estimated demand equation is:

$$Q_D = 94{,}205 - 60P$$

We can then estimate the new price using the new demand and the demand curve rearranged to solve for P:

$$P = (94{,}205 - 59{,}768\, acft) \div 60 = \$578\, per\ acft$$

Consumer surplus is the benefit consumers receive when they value a good or service more than the market price. In a supply and demand model, it is represented as the area under the demand curve and above market price. The shift in the supply curve from FIRO creates an increase in consumer surplus, which is calculated as:

$$[(890\, acft * \$15\, per\ acft) \div 2] + (58{,}878\, acft * \$15\, per\ acft) = \$886{,}337$$

At the workshop, there was some discussion on which of these options is more realistic for Prosser. In general, attendees reported that in the short to medium run, price is unlikely to change in response to quantity, although it may change in the long run. For example, TMWA currently does not adjust prices due to fluctuations in precipitation. Therefore, it is unclear still which method is more appropriate, although we know the timeframe will influence this decision. It may also be difficult to apply this method to just Prosser because Prosser is part of an operating system with other reservoirs.

6.2.3 Recreation

The literature has shown a positive correlation between water levels at a lake and the amount and quality of recreational activity. Therefore, FIRO generates a benefit in the form of greater recreational value. To estimate this benefit, we need to know:

- Current recreation levels
- Unit day values (UDVs)
- The relationship between water levels and recreational levels
- Current water levels and the hypothetical change due to FIRO

6.2.3.1 *Current Recreation Levels*

Recreation at Prosser Reservoir is monitored by the U.S. Forest Service (USFS). We contacted the USFS to obtain data on recreational use on and around the reservoir. They did not have data sets on recreation, but they were able to provide some estimates, as shown in Table 34 below (E. Jerin and R. Westaby, personal communication, September 16, 2020). ERG generated annual counts based on the daily counts provided. We have assumed a person only partakes in one activity per day, or that the data only reflects the primary activity.

Table 34. Prosser recreation estimates, 2019

Season	Activity	Day of Week	Daily Count	Annual Count
May–October	Camping	Weekend	470	24,507
May–October	Camping	Weekday	60	7,821
May–October	OHV, hiking, fishing, boating, and biking	Weekend	100	5,214
May–October	OHV, hiking, fishing, boating, and biking	Weekday	70	9,125
November–April	Camping	Weekend	0	0
November–April	Camping	Weekday	0	0
November–April	OHV, hiking, fishing, boating, and biking	Weekend	50	2,607
November–April	OHV, hiking, fishing, boating, and biking	Weekday	30	3,911

We have only obtained data on recreation at, and around, Prosser Reservoir. It is possible FIRO will also impact recreational levels at other lakes in the system or along the river. For example, at the DST workshop, one participant noted that there is a significant amount of fishing downstream from Prosser that may be impacted. Future work should consider whether these additional recreational locations can be incorporated.

6.2.3.2 *UDVs*

UDVs were obtained from the U.S. Geological Service (USGS) Benefit Transfer Toolkit (USGS, 2016). The toolkit reports the minimum, maximum, and average per person, per day value by region, based on relevant published studies. We use the average UDV in the Pacific Coast region by activity, adjusted to 2019 dollars.

The recreational data on camping can be directly mapped to the USGS category for camping. Camping has an average UDV of $34.79. The other category of recreation provided by USFS is “Off-highway vehicle (OHV), hiking, fishing, boating, and biking,” which does not map directly to a USGS activity type. Therefore, we must make some assumptions on how to distribute the recreation days across these activities. Based on consultation with people familiar with Prosser, and participants of the workshop, the primary types of recreation are fishing and boating. We applied 40 percent of the visitor days to fishing, 30 percent to boating, and 10 percent to each of the other three activities of hiking, OHVs, and biking. Table 35 shows the UDVs, visitor days, and elasticities used to calculate the hypothetical annual benefit of FIRO at Prosser Reservoir.

Table 35. Prosser UDVs, visitor days, elasticities, and hypothetical benefit

Recreation Type	Average UDV	Visitor Days	Assumed Elasticity	Change in Visitor Days	Annual Benefit
Camping	$34.79	32,329	1	2,541	$88,396
Fishing—Freshwater	$76.00	8,343	2	1,311	$99,667
Non-Motorized Boating [a]	$68.10	6,257	2	984	$66,980
Hiking	$54.53	2,086	1	164	$8,939
Off-Highway Vehicle	$73.11	2,086	1	164	$11,985
Leisure Bicycling [b]	$51.74	2,086	1	164	$8,482

[a] There is a 10-mph speed limit on the lake (USFS, 2020). Therefore, we have used the UDVs for non-motorized boating to better reflect the recreational value.

[b] The USGS database does not have a UDV for leisure bicycling in the Pacific Coast region. Therefore, we used the average value across the total sample.

We made a few additional assumptions when applying these UDVs. First, these UDVs are the total value derived from an activity. Using these values assumes the value derived from the activity one would otherwise have partaken in is zero. Researchers sometimes adjust UDVs to reflect the marginal benefit from this activity over the second preference (e.g., 25 percent of the UDV to reflect the marginal value). We have chosen to include the entire value here because we are uncertain of the correct adjustment factor. Future researchers should consider adjusting this figure. Second, UDVs should only be applied to the primary activity. For example, a hiker may also engage in picnicking and nature viewing, but their primary activity is hiking, and thus only that UDV should be applied. We do not have details on how these activity counts were derived and have thus assumed they reflect only the primary activity.

6.2.3.3 *The Relationship Between Water Levels and Recreational Levels*

Because data are not available over time, we cannot map the relationship between water levels and recreational activity at Prosser. Therefore, we will apply assumed elasticities to current recreational data to estimate the benefits of FIRO. In this context, the elasticity represents the percent change in recreation in response to a 1 percent increase in the water levels. The water level can be measured in a variety of ways, including surface area, ac-ft, of elevation. An elasticity of 1 indicates that a 1 percent increase in the water storage level will result in a 1 percent increase in recreation days.

We have assumed for this work that fishing and boating at Prosser have an elasticity of 2 and other activities have an elasticity of 1. We used a higher elasticity for recreation types that directly involve the lake, and lower elasticities for activities occurring around the lake.

Elasticities can vary significantly based on the reservoir, type of recreation, and modeling techniques. Additionally, the size of the elasticity can have a large impact on the estimated benefit levels. Therefore, we caution that the elasticities used here are preliminary and additional research is necessary to determine whether they are appropriate for Prosser.

Based on discussion at the workshop, participants agreed there would be a positive relationship between the water levels and recreation. One participant pointed out that fishing exists at Prosser at all water levels, but there is clearly a positive relationship with the water level. Another participant pointed out that the unpaved boat ramp is unusable below 19,000 ac-ft, although boaters can still use the beach to launch boats. Therefore, there may be a non-linear relationship between boating levels and water levels with a change in slope occurring at 19,000 ac-ft. Lastly, one participant noted that prior to April, the water levels are constrained, and so there is the potential for a large benefit in those early months of the year if the water level increases.

6.2.3.4 *Current Water Levels and the Hypothetical Change due to FIRO*

We obtained data on the historical storage level at Prosser (California Data Exchange Center, 2020). Between September 2002 and September 2018, the average monthly level was 12,724 ac-ft. As noted previously, we do not know how water levels will change due to FIRO. Therefore, we have assumed a hypothetical average increase of 1,000 ac-ft. Applying these numbers generates the hypothetical benefit numbers in Table 35 above. To demonstrate, the camping benefit of $88,396 is calculated as the change in recreation (2,541 more visitor days) multiplied by the UDV ($34.79). The change in recreation is calculated as $\Delta R = \frac{\Delta S}{S} * \varepsilon * R$, where:

- ΔR is the estimated annual change in recreation use (2,541 days)
- ΔS is the change in storage (1,000 ac-ft)
- S is the average storage, in AF (12,724 ac-ft)
- ε is the assumed elasticity (1)
- R is the current annual recreation (32,329 days)

6.2.4 Fisheries

We did not generate hypothetical numbers for fisheries at Prosser. Instead, we used time during the workshop to discuss different potential methods and reach a consensus on which method is most appropriate for Prosser. The consensus is that purchases of water rights is likely to be the least-cost alternative and is an appropriate way to approximate the benefit. There is an active water rights market in this area from which data can be obtained.

For example, Nevada Assembly Bill 380 (AB 380) in 1999 established a water rights “buy-out” program. The goal of the program was to purchase and retire 6,500 acres of Newlands Project water rights. Carson Water Subconservancy District implemented the program to buy and retire water rights from willing sellers. It became known as the “AB 380 Program.” At the conclusion of the AB 380 Program, 4,623.54 acres of water rights had been acquired and retired in 1,328 transactions for a total expenditure of $14,020,655 (Reclamation, n.d.). To demonstrate how these numbers could be used, we assume that there are 3 ac-ft of water rights per acre of land. Dividing the total expenditure by the number of ac-ft of water results in a price of $1,011/ac-ft.

Converting to 2019 dollars, this would be $1,368/ac-ft.[47] This value could then be multiplied by the average change in storage from FIRO to approximate the economic benefit and the benefit to fisheries. Clearly this is a very rough estimate, but it demonstrates how historical water right purchase data can be used to calculate benefits.

Another potential source of data for water rights is The Nature Conservancy (TNC). This potential source was identified by a workshop participant who is familiar with TNC's water rights program, which seeks to use investment capital to purchase water through the open market. The Water Share report (Richter, 2016) and any related data should be reviewed to assess if this is an appropriate source. TNC is currently working with Ventura County, California, to create a cap-and-trade water market that allows water rights to be bought and sold in a conservation-oriented way (TNC, 2020). The work in Ventura County could serve as a data source to estimate the cost of this alternative.

6.3 Workshop

The Prosser DST workshop was a three-hour virtual meeting held on November 5, 2020. See Appendix D for meeting notes taken during the workshop.

During the workshop, attendees were introduced to FIRO and the success to date at Lake Mendocino. ERG then led the attendees through the benefit estimates calculated for Prosser for recreation, M&I water supply, and fisheries. After going through each of the benefit estimates, ERG asked polling questions to prompt discussion.

At the conclusion of the workshop, a follow-up survey was sent to attendees to elicit further feedback. Six attendees completed the follow-up survey. Responses and comments related to the usability of the DST are summarized below:

- Respondents have a good understanding of how the DST works.[48]
- The DST would be more easily understood if an application using actual data was performed and presented.
- The fisheries benefit is the most challenging benefit to estimate.
- The DST is useful for high level analyses, but may not be sufficient to satisfy strict economic estimate requirements.

Limitations and recommendations were also highlighted in the respondents' comments. These comments are summarized below:

- The DST's intended use and audience should be made clear.
- The DST is not currently suited to estimate benefits in a multiple-reservoir system. For reservoirs that are part of a larger system (like Prosser Reservoir), it would be helpful to have a way to account for benefits from all the reservoirs.

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[47] We assumed the expenditures were in 2004 dollars; this is the median of the timeframe between 1999 and 2009 during which the program ran.

[48] Question: "How well do you understand how the DST works? (1: Not at all; 5: Very well)". Four of the six respondents selected option 4, and two respondents selected option 5.

- The DST will be helpful for high level planning, but likely will not provide specific enough estimates to use for a feasibility report.
- The DST would benefit from having a “Cost” tab so that the user can perform a cost-benefit analysis. This would truly make the tool a “decision support tool” and not just a “benefit estimation tool.”

In response to the comments received, we added additional language to the DST User Guidance to clearly indicate the purpose of the DST and who should use it. The DST is meant to provide decision makers with an initial understanding of the potential benefits of alternative reservoir operations.

The feedback highlights future improvements to the DST. For example, capturing costs would provide decision makers with a better understanding of the tradeoffs of alternative reservoir operations relative to current operations. Although the site-specific nature of cost analyses makes it difficult to estimate them in a DST, it is worth exploring if the funding is available in the future.

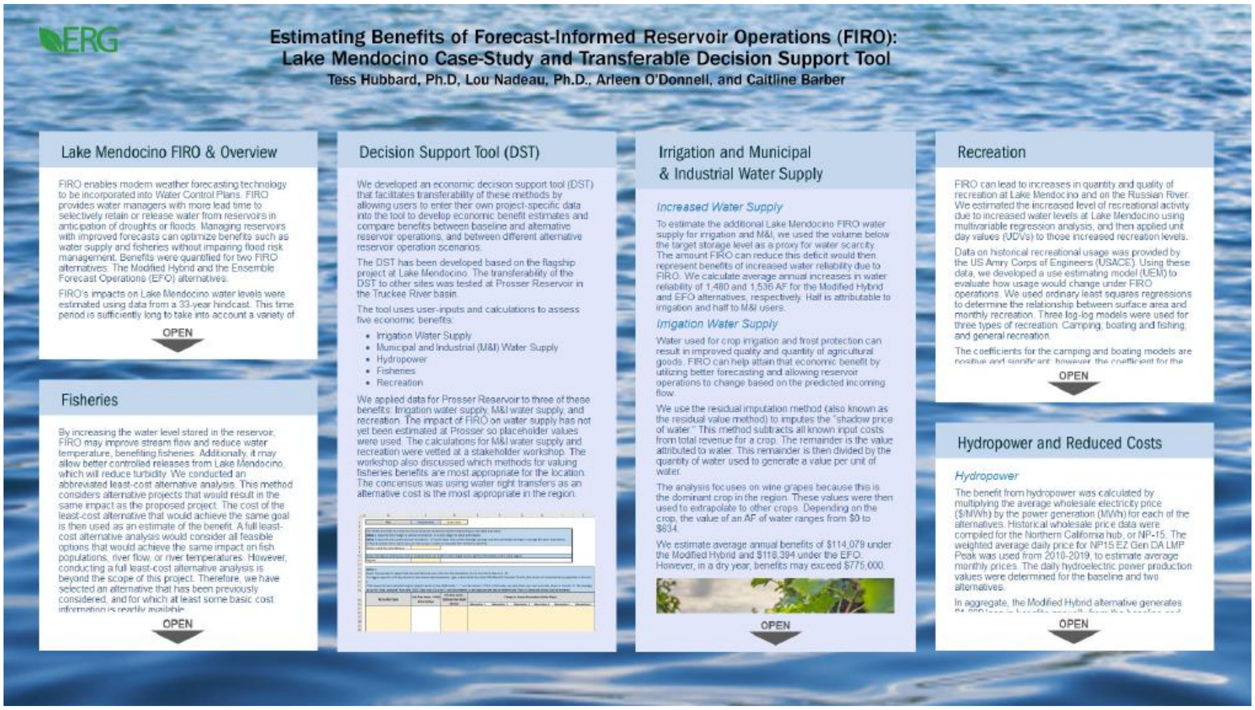
In addition, the DST is not currently designed to capture the benefits of alternative reservoir operations in multi-reservoir systems. An analysis of multi-reservoir systems would require detailed hydrologic modeling to understand how changes in reservoir storage and releases at each reservoir in the system would impact the others. Once the impacts were understood, it would be possible to estimate the economic impacts, though care would need to be taken to ensure that no benefits were being double counted.

7 Broader Stakeholder Input and Communicating Results: American Geophysical Union Conference Poster

We presented our work on benefit estimations for Forecast Informed Reservoir Operations (FIRO) at the American Geophysical Union Fall Meeting 2020. During the conference, we participated in a session where we, among others, introduced our poster and highlighted key findings, as well as a session where we were available for questions from attendees as they reviewed the posters.

The work was well received, and participants were interested in obtaining the decision support tool. Most questions were for clarification. One participant asked how the findings may change with implementation of "FIRO 2.0," or future improvements to FIRO that are being considered.

The poster is available online at http://developer.erg.com/~kkang/iposter/.



Estimating Benefits of Forecast-Informed Reservoir Operations (FIRO): Lake Mendocino Case-Study and Transferable Decision Support Tool

Tess Hubbard, Ph.D, Lou Nadeau, Ph.D., Arleen O'Donnell, and Caitline Barber

Lake Mendocino FIRO & Overview

FIRO enables modern weather forecasting technology to be incorporated into Water Control Plans. FIRO provides water managers with more lead time to selectively retain or release water from reservoirs in anticipation of droughts or floods. Managing reservoirs with improved forecasts can optimize benefits such as water supply and fisheries without impairing flood risk management. Benefits were quantified for two FIRO alternatives: The Modified Hybrid and the Ensemble Forecast Operations (EFO) alternatives.

FIRO's impacts on Lake Mendocino water levels were estimated using data from a 33-year hindcast. This time period is sufficiently long to take into account a variety of

Fisheries

By increasing the water level stored in the reservoir, FIRO may improve stream flow and reduce water temperature, benefiting fisheries. Additionally, it may allow better controlled releases from Lake Mendocino, which will reduce turbidity. We conducted an abbreviated least-cost alternative analysis. This method considers alternative projects that would result in the same impact as the proposed project. The cost of the least-cost alternative that would achieve the same goal is then used as an estimate of the benefit. A full least-cost alternative analysis would consider all feasible options that would achieve the same impact on fish populations, river flow, or river temperatures. However, conducting a full least-cost alternative analysis is beyond the scope of this project. Therefore, we have selected an alternative that has been previously considered, and for which at least some basic cost information is readily available.

Decision Support Tool (DST)

We developed an economic decision support tool (DST) that facilitates transferability of these methods by allowing users to enter their own project-specific data into the tool to develop economic benefit estimates and compare benefits between baseline and alternative reservoir operations, and between different alternative reservoir operation scenarios.

The DST has been developed based on the flagship project at Lake Mendocino. The transferability of the DST to other sites was tested at Prosser Reservoir in the Truckee River basin.

The tool uses user-inputs and calculations to assess five economic benefits:

- Irrigation Water Supply
- Municipal and Industrial (M&I) Water Supply
- Hydropower
- Fisheries
- Recreation

We applied data for Prosser Reservoir to three of these benefits: Irrigation water supply, M&I water supply, and recreation. The impact of FIRO on water supply has not yet been estimated at Prosser so placeholder values were used. The calculations for M&I water supply and recreation were vetted at a stakeholder workshop. The workshop also discussed which methods for valuing fisheries benefits are most appropriate for the location. The concensus was using water right transfers as an alternative cost is the most appropriate in the region.

Irrigation and Municipal & Industrial Water Supply

Increased Water Supply

To estimate the additional Lake Mendocino FIRO water supply for irrigation and M&I, we used the volume below the target storage level as a proxy for water scarcity. The amount FIRO can reduce this deficit would then represent benefits of increased water reliability due to FIRO. We calculate average annual increases in water reliability of 1,480 and 1,536 AF for the Modified Hybrid and EFO alternatives, respectively. Half is attributable to irrigation and half to M&I users.

Irrigation Water Supply

Water used for crop irrigation and frost protection can result in improved quality and quantity of agricultural goods. FIRO can help attain that economic benefit by utilizing better forecasting and allowing reservoir operations to change based on the predicted incoming flow.

We use the residual imputation method (also known as the residual value method) to imputes the "shadow price of water." This method subtracts all known input costs from total revenue for a crop. The remainder is the value attributed to water. This remainder is then divided by the quantity of water used to generate a value per unit of water.

The analysis focuses on wine grapes because this is the dominant crop in the region. These values were then used to extrapolate to other crops. Depending on the crop, the value of an AF of water ranges from $0 to $834.

We estimate average annual benefits of $114,079 under the Modified Hybrid and $118,394 under the EFO. However, in a dry year, benefits may exceed $775,000.

Recreation

FIRO can lead to increases in quantity and quality of recreation at Lake Mendocino and on the Russian River. We estimated the increased level of recreational activity due to increased water levels at Lake Mendocino using multivariable regression analysis, and then applied unit day values (UDVs) to those increased recreation levels.

Data on historical recreational usage was provided by the US Army Corps of Engineers (USACE). Using these data, we developed a use estimating model (UEM) to evaluate how usage would change under FIRO operations. We used ordinary least squares regressions to determine the relationship between surface area and monthly recreation. Three log-log models were used for three types of recreation: Camping; boating and fishing; and general recreation.

The coefficients for the camping and boating models are positive and significant; however, the coefficient for the

Hydropower and Reduced Costs

Hydropower

The benefit from hydropower was calculated by multiplying the average wholesale electricity price ($/MWh) by the power generation (MWh) for each of the alternatives. Historical wholesale price data were compiled for the Northern California hub, or NP-15. The weighted average daily price for NP15 EZ Gen DA LMP Peak was used from 2010-2019, to estimate average monthly prices. The daily hydroelectric power production values were determined for the baseline and two alternatives.

In aggregate, the Modified Hybrid alternative generates

Figure 39. Screenshot of virtual poster

8 Findings and Conclusions

Western water resources are being subjected to weather extremes. Forecast Informed Reservoir Operations (FIRO) allow reservoir managers to use modern forecasting science and technology to better adapt to these extremes. The Bureau of Reclamation may consider FIRO as an approach to resilient reservoir management in the future. FIRO does not require major infrastructure investments and has been proven in Lake Mendocino. It can be readily applied to Reclamation sites, and methods to estimate its economic benefits are also transferable across reservoirs.

ERG estimated the benefits of FIRO at Lake Mendocino for six benefit types: irrigation water supply; municipal and industrial (M&I) water supply; hydropower; fisheries; recreation; and reduced operation, maintenance, and replacement costs. We quantified benefits for two FIRO alternatives using estimated water levels from a 33-year hindcast. Total estimated annual benefits of FIRO are either $9.4 million or $9.9 million, depending on the alternative. These estimates help demonstrate the value of FIRO.

This study identified methods and data needs for estimating the benefits of FIRO at Lake Mendocino, and these will be helpful to future researchers. There are a variety of methods to estimate benefits. In choosing the right method, it is important to consider obvious factors such as data needs versus available data, the validity of the intended use, and the resources needed to complete the assessment. Less obvious criteria involve social, cultural, historical, and environmental contexts. Future applications of these methods will also need to identify limitations and points of contention, especially on topics where stakeholders are deeply invested.

For example, there was a wide range of opinions on how best to estimate the benefits to fisheries. However, after much discussion, and after considering several approaches, both Lake Mendocino and Prosser Reservoir stakeholders settled on least-cost alternative methods as the preferred approach. Ability to be implemented was key in arriving at the least-cost alternative method in both cases—even more important than verifying that, in fact, the alternative would be the least costly. Stakeholders felt that alternatives that lacked clear pathways to implementation would not be least-cost given delays, cost of litigation, and uncertainty in achieving an outcome comparable to FIRO benefits.

ERG also developed an economic decision support tool (DST) to give decision makers a screening-level assessment of the potential benefits of alternative reservoir operations. The DST is easy to use with the accompanying guidance, and is transferable to other reservoirs. It has limits: for example, the DST does not provide site-specific numbers, and outside research (sometimes substantial) is often needed to generate estimates. Nonetheless, the DST serves as a useful starting point to learn what data will be needed, understand what methods can be used, and generate initial benefit estimates.

We tested the DST when developing preliminary methods and identifying data for Prosser Reservoir for three benefits: irrigation water supply, M&I water supply, and recreation. Although we could not estimate true benefit numbers because the change in water supply under FIRO has not been calculated, the DST provided a useful framework for envisioning how the analysis would be conducted and what data would be needed. We recommend that the Truckee Bain Water Management Options Pilot team revisit the DST as they develop their FIRO alternatives for Prosser Reservoir to more precisely identify associated benefits and any additional data sources to quantify those benefits. Once FIRO water availability estimates are computed, the team should use these methods to calculate benefits and inform FIRO alternative decisions.

Some future work identified from this project:

- This work estimated the benefits of FIRO. Future work could assess the costs of FIRO to understand the net benefits that alternative reservoir operations may provide.
- Initial willingness to pay estimates were developed for fisheries benefits. Other papers and fields could be added to the DST to provide more information and enable more estimates. Some of the calculations could also be converted from a per household basis to a per fish basis, which would help users apply the values in a different way.
- We compiled some papers estimating the relationship between water levels at a lake and the level of recreation. A more extensive review and compilation of the literature would be beneficial.
- Adapting the DST to calculate the costs associated with FIRO would help decision-makers understand both the benefits and the costs of implementing FIRO.
- It would be helpful to modify the DST and guidance for assessing the benefits of FIRO in multi-reservoir systems.
- Applying the DST to reservoirs where alternative reservoir operations have been studied, or are being studied, would provide more testing for a range of reservoirs and benefits.

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Appendix A: Lake Mendocino Data and Methodological Appendix

Table A-1. Target storage level deficits (acre-feet)

Year	10/1 Storage (Baseline)	10/1 Storage (MH)	10/1 Storage (EFO)	Volume Below Target Storage (Baseline)	Volume Below Target Storage (MH)	Volume below Target Storage (EFO)	Difference (MH)	Difference (EFO)
1985	46,535	61,766	62,947	0	0	0	0	0
1986	53,569	67,214	69,047	0	0	0	0	0
1987	31,411	44,660	46,489	8,589	0	0	8,589	8,589
1988	31,151	45,450	49,778	8,849	0	0	8,849	8,849
1989	62,431	72,447	78,024	0	0	0	0	0
1990	49,839	59,618	65,139	0	0	0	0	0
1991	47,040	56,662	62,165	0	0	0	0	0
1992	46,301	55,355	58,057	0	0	0	0	0
1993	65,958	81,228	81,583	0	0	0	0	0
1994	40,463	56,921	66,181	0	0	0	0	0
1995	87,526	89,215	87,976	0	0	0	0	0
1996	63,997	77,729	79,432	0	0	0	0	0
1997	53,863	60,833	72,354	0	0	0	0	0
1998	98,853	101,303	99,127	0	0	0	0	0
1999	69,816	81,116	84,182	0	0	0	0	0
2000	48,532	62,863	64,413	0	0	0	0	0
2001	32,103	45,311	46,814	7,897	0	0	7,897	7,897
2002	44,254	60,311	69,119	0	0	0	0	0
2003	85,145	85,157	84,782	0	0	0	0	0
2004	42,755	58,758	74,693	0	0	0	0	0
2005	90,367	90,290	90,280	0	0	0	0	0
2006	83,693	87,404	87,558	0	0	0	0	0
2007	48,782	55,870	73,611	0	0	0	0	0
2008	38,599	54,234	67,024	1,401	0	0	1,401	1,401
2009	29,911	38,153	41,200	10,089	1,847	0	8,242	10,089
2010	84,413	86,780	85,966	0	0	0	0	0
2011	70,220	81,418	84,925	0	0	0	0	0
2012	65,611	74,143	69,828	0	0	0	0	0
2013	42,699	56,458	68,501	0	0	0	0	0
2014	31,860	45,144	45,030	8,140	0	0	8,140	8,140
2015	34,290	47,169	49,719	5,710	0	0	5,710	5,710
2016	58,381	68,799	76,526	0	0	0	0	0
2017	73,415	83,316	81,552	0	0	0	0	0
Average	-	-	-	1,536	-	-	1,480	1,536
Share zero	-	-	-	79%	-	-	79%	79%
Average if >0	-	-	-	7,239	-	-	6,975	7,239

MH: Modified Hybrid; EFO: Ensemble Forecast Operations

Table A-2. Imputed incremental dam raise construction cost

Option	Total Capital Cost ($ millions)	Crest Raise (feet)	Imputed Incremental Cost per Foot ($ millions) [a]	Fixed Cost ($ millions) [b]
CP1	$1,073	6.5	N/A	$920
CP2	$1,180	12.5	$18	$885
CP3	$1,362	18.5	$24	$925
CP4	$1,370	18.5	$25	$933
CP4A	$1,371	18.5	$25	$934
CP5	$1,391	18.5	$27	$954
Average	**N/A**	**N/A**	**$24**	**$925**

Source: Bureau of Reclamation Shasta Lake Water Resources Investigation, Table ES-3: Summary of Potential Benefits and Costs of Comprehensive Plans (2015).

[a] Calculated as the difference in capital costs between the relevant option and CP1 divided by the difference in height.

[b] Calculated as: Capital Cost - (Crest Raise * Incremental Cost).

Table A-3. Recreation analysis summary statistics (FY2014–FY2017)

Variable	Number of Observations	Mean	Std. Dev.	Min	Max
Elevation (ft)	45	732	13	707	754
Acre-feet	45	60,170	20,014	25,709	97,645
Surface area (acres)	45	1,544	212	1,019	1,781
Camping visits	43	11,712	6,574	1,040	24,382
Boating visits	27	2,495	1,287	1,361	5,652
General recreation visits	24	11,449	7,812	4,643	35,063
Median real household income	45	$48,151	$2,384	$46,264	$52,622
Population	45	87,280	164	87,107	87,576
Precipitation (in.)	45	2.9	4.1	0.0	14.9
Temperature (avg. degrees F)	45	61.7	10.1	44.2	77.3

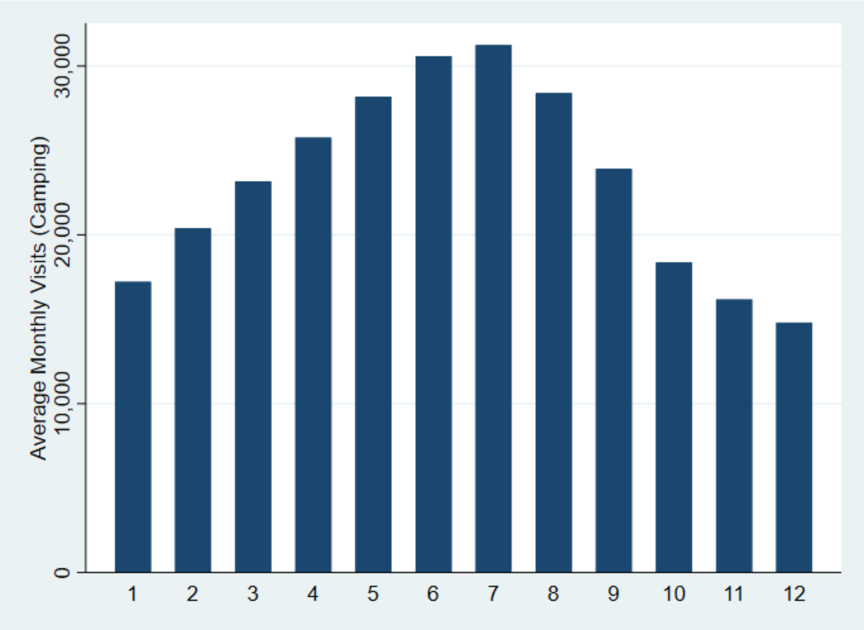

Figure A-1. Visitation counts by month—camping

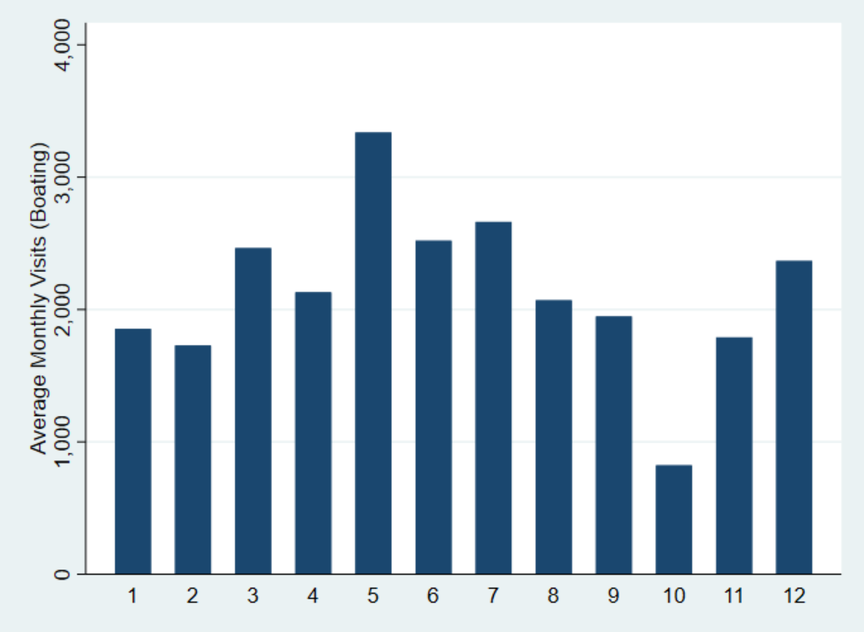

Figure A-2. Visitation counts by month—boating

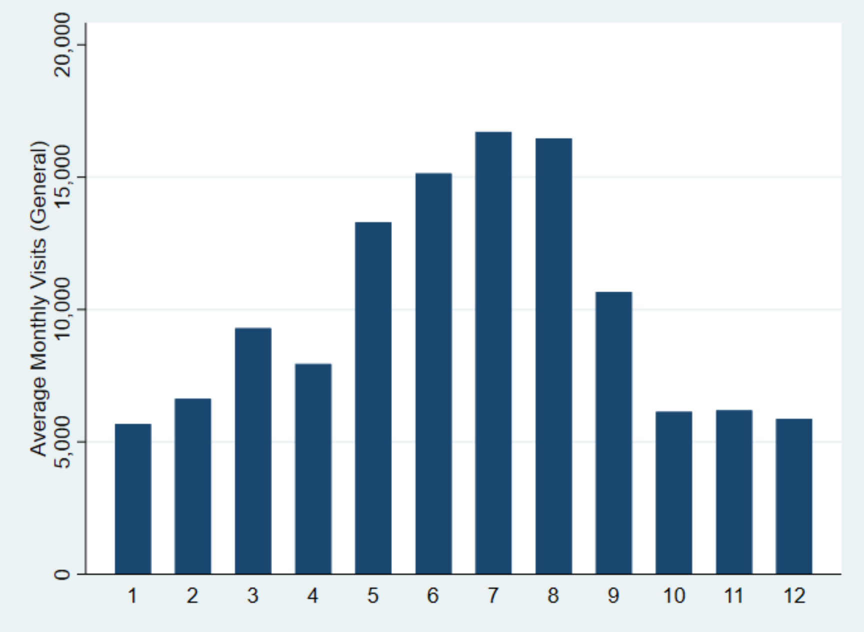

Figure A-3. Visitation counts by month—general recreation

Table A-4. Monthly average change in camping recreation

Month	Modified Hybrid	EFO
1	617	930
2	627	961
3	533	775
4	474	708
5	526	768
6	600	850
7	723	1,008
8	830	1,161
9	924	1,299
10	1,145	1,534
11	1,260	1,638
12	853	1,178

Table A-5. Monthly average change in fishing and boating recreation

Month	Modified Hybrid	EFO
1	343	639
2	512	904
3	784	1,187
4	757	1,155
5	900	1,357
6	987	1,432
7	1,326	1,934
8	1,180	1,678
9	992	1,544
10	578	1,095
11	334	856
12	326	615

Table A-6. Alternative regression specifications for camping model

Variables	(1) Preferred Ln Camping	(2) All Years Ln Camping	(3) Pre 2013 Ln Camping	(4) Seasons Ln Camping	(5) AF Ln Camping	(6) Elevation Ln Camping
Ln Surface Area	1.532* (0.810)	1.213*** (0.389)	-0.216 (0.219)	0.768 (1.096)	-	-
Ln Acre-Feet	-	-	-	-	0.615 (0.332)	-
Ln Elevation	-	-	-	-	-	12.73* (6.955)
Ln Precipitation	-0.00155 (0.0865)	-0.0207 (0.0388)	0.00873 (0.0220)	-	0.00308 (0.0869)	0.00488 (0.0871)
Ln Temperature	0.801 (1.392)	0.399 (0.596)	1.289*** (0.337)	-	0.900 (1.391)	0.919 (1.393)
Summer	-	-	-	1.105 (21.06)	-	-
Ln Summer*SA	-	-	-	-0.0908 (2.855)	-	-
Shoulder	-	-	-	-16.06 (14.18)	-	-
Ln Shoulder*SA	-	-	-	2.217 (1.940)	-	-
Constant	-5.390 (7.884)	-0.689 (3.411)	6.546*** (1.879)	3.284 (7.956)	-1.285 (6.597)	-78.62* (46.04)
Observations	43	172	126	43	43	43
R-squared	0.142	0.100	0.298	0.174	0.139	0.138

Standard errors in parentheses
* $p<0.1$, ** $p<0.05$, *** $p<0.01$

Table A-7. Alternative regression specifications for boating model

Variables	(1) Preferred Ln Boating	(2) Seasons Ln Boating	(3) AF Ln Boating	(4) Elevation Ln Boating
Ln Surface Area	8.338*** (2.425)	-1.054 (12.80)	-	-
Ln Acre-Feet	-	-	2.232*** (0.631)	-
Ln Elevation	-	-	-	39.79*** (11.26)
Ln Precipitation	0.102 (0.0751)	-	0.0868 (0.0755)	0.0824 (0.0761)
Ln Temperature	3.122* (1.450)	-	2.840* (1.454)	2.740* (1.465)
Summer	-	-71.73 (96.51)	-	-
Ln Summer*SA	-	9.741 (13.03)	-	-
Shoulder	-	-97.11 (98.40)	-	-
Ln Shoulder*SA	-	13.09 (13.29)	-	-
Constant	-66.70*** (17.08)	15.47 (94.76)	-28.58*** (7.395)	-266.1*** (72.33)
Observations	15	15	15	15
R-squared	0.682	0.792	0.691	0.691

Standard errors in parentheses
* p<0.1, ** p<0.05, *** p<0.01

Table A-8. Alternative regression specifications for general model

Variables	(1) Preferred Ln General	(2) Seasons Ln General	(3) AF Ln General	(4) Elevation Ln General
Ln Surface Area	1.000 (0.586)	0.134 (0.730)	-	-
Ln Acre-Feet	-	-	0.438* (0.236)	-
Ln Elevation	-	-	-	9.283* (5.017)
Ln Precipitation	0.0159 (0.0575)	-	0.0100 (0.0573)	0.00829 (0.0575)
Ln Temperature	2.369** (0.933)	-	2.307** (0.927)	2.288** (0.931)
Summer	-	-11.69 (13.39)	-	-
Ln Summer*SA	-	1.717 (1.815)	-	-
Shoulder	-	-8.522 (7.746)	-	-
Ln Shoulder*SA	-	1.199 (1.061)	-	-
Constant	-7.913 (4.815)	7.730 (5.308)	-5.129 (3.847)	-61.48* (32.08)
Observations	25	25	25	25
R-squared	0.555	0.705	0.565	0.564

Standard errors in parentheses
* p<0.1, ** p<0.05, *** p<0.01

Appendix B: Economic Benefit Methodologies

This document provides a brief outline of the methods that ERG will implement to measure the benefits of FIRO for Lake Mendocino. To develop these methods, ERG reviewed Reclamation's prior work on these benefit categories, performed research into potential methods and data sources, and held a meeting with project stakeholders on March 11, 2020.

The document provides methods for six benefit categories:

- Recreation
- Hydropower
- Commercial and Industrial Water Supply
- Municipal (Consumer) Water Supply
- Fisheries and Habitat
- Agricultural Water Supply

For each benefit category, we provide background information on each, an outline of the methods that we expect to use, and consideration for incorporating the estimates into a decision support tool (DST) for the project.

Each benefit estimation will be an average annual estimate based on information about FIRO's impact on water supply, availability, and dependability obtained from the viability assessment. The analysis will also account for the benefits that occur in "wet" years compared to "dry" years. The DST will incorporate functions to allow for users to vary whether a given year for estimation is average, wet, or dry. The annualized value will be computed over a timeframe of 20 years using a discount rate of 2.75 percent (Reclamation, 2019).

The National Economic Development (NED) procedures from the 1983 guidelines provide useful parameters for our methodology. These procedures outline steps to estimate various benefits, using a variety of techniques such as benefit transfer, estimating demand curves, and least cost alternatives. The NED procedures played a major role in helping develop the specific strategies for estimating each benefit, however the methods laid out in this document were also shaped by the members of the ERG team, as well as stakeholders who attended the aforementioned meeting on March 11, 2020.

B.1 Recreation

1. Background

FIRO can lead to increases in quantity and quality of recreation at Lake Mendocino. Improved reservoir elevation conditions from FIRO will allow for people to have easier access to the reservoir and make the reservoir more aesthetic itself. In addition, improved reservoir levels will lead to additional AF for boating and improved habitat for reservoir fish species that will improve fishing related activities. This methodology outlines an approach to measure the benefit of increased recreational activity at Lake Mendocino due to FIRO, which will then be incorporated into a DST that will allow users to measure the benefit of increased recreation for other FIRO projects. We may also consider increased recreation along the river if data and time permit.

There is a large market for recreational activities along the Russian River. Just in Sonoma county in 2012, tourists spent $1.6 billion, 18.4 percent of which came from recreational activities (Sonoma County, 2014). Similar analyses for other areas also show the potential for economic benefits from recreation stemming from increased water supply. A study on the Colorado River showed that a 100,000 acre feet increase in water over a year would result in over 18,000 visits to nearby lakes, and over $350,000 in spending from tourism related activities (Neher, 2013).

Additional recreational opportunities will have several beneficiaries. First, those who enjoy recreation will benefit directly. Second, the additional recreation will also benefit businesses directly involved with recreation, as well as those indirectly involved (e.g., gas stations and local restaurants). In our methods below, however, we only focus on the benefits to those who recreate at the Lake or along the river.

2. Methods and Data

The NED guidelines suggest using willingness to pay estimates from either a travel cost method, contingent valuation method, or unit day value method. In addition, general steps involved with the valuation process include defining the study area, estimating the current recreation use, determining the future recreation with and without the proposed changes (in our case, FIRO implementation), and computing the benefit based on the difference in recreation and a determined valuation of that recreation. To the extent feasible with available studies, ERG will estimate the increase in recreation in the area rather than simply estimating the transfer of activities from other activities to Lake Mendocino.

For this work, ERG plans to develop an estimate of the increased level of (daily) recreational activity due to increased water levels at Lake Mendocino, or increased river flows downstream of the lake, and then apply a daily use value to those increased levels. One major consideration for this analysis is the seasonality of recreation, and how reservoir elevation, river elevation, and river flow changes caused by FIRO will correlate to seasonal variation in recreation. Our analysis will include:

- Determining the annual frequency for each type of recreational activity that occurs at Lake Mendocino and downstream.
- Determining the additional recreation, in days, that will occur due to FIRO.
- Identifying an estimate of the daily use value for each recreation type. The USGS Benefit Transfer and Use Estimating Model Toolkit provides a starting point for the daily use values. In addition, the unit day values for recreation from the USACE are useful for our purposes (USACE, 2020).
- Estimating the value of increased recreation as the product of the increased levels of (daily) recreation and daily use values.

3. DST Considerations

The general methodology presented here can be applied to both Lake Mendocino and other sites, depending on data availability. Both the USGS Benefit Transfer and Use Estimating Model

Toolkit and the USACE unit day values both would facilitate implementation in the DST since the values can be applied to other areas as well.

B.2 Hydropower

1. Background

Hydropower can be an important energy source for communities and provide efficient power that other sources cannot provide. FIRO has the possibility to increase the water supply at Lake Mendocino, which could potentially allow for more hydropower generation to the region. This methodology outlines an approach to measure the benefit of increased hydropower generation. Increasing the ability to produce hydropower from the water supply at Lake Mendocino would provide a direct economic benefit to the entities who produce hydropower by maximizing production, which would increase sales, with an indirect benefit to the businesses and individuals who would be able to potentially utilize the electricity production at lower costs.

2. Methods and Data

The NED guidelines suggest estimating the future demand for electric power, while defining the current system for generating resources, then evaluating the different between the future demand and the current system's capabilities. The NED procedures, however, are more extensive than what is needed for this project since FIRO results in additional flow at times during the year that can be used for hydropower. Thus, ERG's approach for this benefit category simplifies the NED approach by focusing solely on the value of the increased reservoir releases through hydropower turbines. This will involve:

- Identifying weekly market prices. California compiles these data which can be used for Sonoma county in this analysis and other California counties in the DST (Electricity Local, 2020). Other sources will be necessary for other states in the DST.
- Identifying the appropriate price to use, either the market price of the price that producers receive. ERG will determine that as we implement the method.
- Determining the additional generation that could occur due to FIRO, which could be done based on the findings of the viability assessment.
- Calculating the benefit by multiplying the price by the additional generation.

3. DST Considerations

The electricity market in California is significantly different than many other areas, in terms of sources, supply of renewables, carbon markets, and other factors. Thus, it will be important to explain in the tool these differences and any implications.

B.3 Commercial and Industrial (C&I) Water Supply

1. Background

Commercial and industrial (C&I) operations depend on the water supplied from Lake Mendocino. Additional water supply will result in a more reliable water supply for local businesses avoiding reduced production. This methodology outlines an approach to measure the benefit of a reliable water supply at Lake Mendocino for C&I purposes due to FIRO, which will then be incorporated into a decision support tool that will allow users to measure the benefit of increased municipal and industrial water supply for other FIRO projects.

Providing a reliable water supply for C&I projects could have a significant impact on avoiding lost economic output, gross state product, and jobs. An example of the potential impact can be seen from a study that estimated the economic impact of the water supply from the Colorado river, finding that the river led to a gross state product of $657.45 billion in 2014, and contributed to over 7 million jobs just for 7 counties in Southern California (James et al., 2014).

The main beneficiaries of this benefit are the entities in both the public and private sectors who utilize the water supply from Lake Mendocino.

2. Methods and Data

The NED guidelines suggest estimating the future water supply and the future water needs for C&I purposes for the given study area, for scenarios in which no project is implemented and for the project being implemented, in our case this is FIRO. Then an economic benefit can be calculated by using water cost estimates in conjunction with determining the difference in water usage between implementing the project, and not implementing the project.

For this work, ERG plans to calculate a demand equation and subsequently annual economic benefit from increases in industrial and municipal water supply due to FIRO. This will include:

- Determining the price and demand for water at a variety of locations around the country to develop the basis for a demand curve.
- Conducting a log-log regression of water price on water usage.
    - The model will be based on the work by Steven Piper from the Bureau of Reclamation (Piper, 2009). Other sources will also be reviewed to determine the appropriate functional form and control variables.
    - The model will control for median annual household income, various climate variables such as average annual precipitation and average annual temperature, and household size.
    - The monthly price for various meter sizes for industrial and commercial uses can be obtained from the 2019 Water and Wastewater Rate Survey-Book (AWWA, 2019); those data also contain the number of accounts and daily gallons of water sold figures. The other data will be obtained from the US Census Bureau and NOAA.
- Estimating the increase in water supply provided by FIRO based on the viability assessment for this project.
- Creating a statistical model to estimate the demand for water.
- Calculating the economic benefit by calculating the consumer and producer surplus associated with the increase in water and change in price.

ERG will assess future conditions as part of this by reviewing relevant literature. In the absence of definitive projections, ERG will assume current conditions approximate future conditions.

ERG will also need to determine the share of the additional water that will be available for C&I users, residential users, and agriculture. Attributing the total volume change to each of these benefit categories would result in double-counting.

3. DST Considerations

For the DST, ERG may need to have recommendations for alternative sources in the event that a study area is not covered in the Water and Wastewater Rate Survey-Book.

In conducting this analysis, we must consider the impact FIRO would have on a prolonged drought, which would result in benefits from storing additional water, but not enough to offset a sustained drought period. For the DST, it will be important to consider the period of analysis for these benefits, and whether a year to year projection of demand will be sufficient, or if a long-term horizon is needed.

B.4 Consumer Water Supply

1. Background

Households' ability to store and use water has immense use-value benefits. By storing more water during wet periods and having the ability to release more water dry periods, FIRO's improved forecasts will improve water availability for households that rely on Lake Mendocino for water, especially in times of drought. In particular, FIRO will reduce the likelihood of curtailments to household water supply. This methodology outlines an approach to measure the benefit of more reliable water supply for consumer usage due to FIRO, which will then be incorporated into a DST will allow users to measure the benefit of either more reliable water supply, or increased consumer water supply, for other water projects.

Improved consumer water supply reliability would benefit all residents that rely on Lake Mendocino for water for many purposes, including, but not limited to, drinking water. Sonoma County Water Agency (now Sonoma Water) estimated in 2009 that "Lake Mendocino and Lake Sonoma water plays a significant role in providing drinking water to about 750,000 residents in portions of Mendocino, Sonoma and Marin counties." (SCWA, 2009). This analysis will include Sonoma and Mendocino counties.

2. Methods and Data

The NED procedures from the 1983 guidelines do not specifically mention consumer water supply. However, the recommendations for Municipal and Industrial water supply have similar themes that can be applied. The guidelines for Municipal and Industrial water supply suggest estimating the future water supply and the future water needs for municipal and industrial purposes for the given study area, for scenarios in which no project is implemented and for the project being implemented, in our case this is FIRO. Then an economic benefit can be calculated by using water cost estimates in conjunction with the change in water usage from the project. For consumer water supply, a similar approach could be taken to look at the water supply and future water needs for consumers at Lake Mendocino.

For this work, ERG plans to calculate a demand equation, and subsequently annual economic benefit, from increased consumer water supply reliability due to FIRO. This methodology will be the same as the methodology outlined above for C&I water supply.

3. DST Considerations

In the event that a study area is not covered in the Water and Wastewater Rate Survey-Book, there may need to be recommendations for alternative sources or guidance on whether the parameters and values from the model are applicable and transferable.

We must consider how a prolonged drought would impact FIRO benefits. In a prolonged drought the water levels may never reach the thresholds that result in additional water releases. For the DST, it will be important to consider the period of analysis for these benefits, and whether a year to year projection of demand will be sufficient, or if a long-term horizon is needed. Even in a multi-year analysis, the impacts would differ depending on the duration of a drought and the timing of droughts (e.g., back to back droughts or droughts occurring at more traditional intervals).

An alternative metric to use could be the consumer's willingness to pay for the supply of water, but in either scenario the model should accurately represent the fact that the value of water being provided should be greater than the cost of the water to the provider.

B.5 Fisheries and Habitats

1. Background

A major benefit of FIRO is it may allow the Army Corps of Engineers to release more water from the reservoir during dry periods, improving streamflow conditions. Additionally, it may allow better controlled releases when precipitation is forecast, which will improve habitat by reducing turbidity. There are three endangered or threatened fish species in the Russian River that would benefit: the Coho salmon, the Chinook salmon, and the Steelhead trout (however, the largest impact would probably be for Chinook since they spawn in the mainstem of the Russian River). In general, healthy habitat provide a benefit to society: "studies have shown that regardless of direct interaction with salmon populations, many Californians hold a positive willingness to pay to ensure the long-term survival of salmon" (ECONorthwest, 2012). This document outlines an approach to measure the benefit of maintaining fish populations and habitat along the Russian River due to FIRO, which will then be incorporated into a DST.

There will be multiple beneficiaries for this benefit. The use value of having healthier fish populations will benefit the local population, local businesses, and the tourism industry. The non-use, passive, existence value of improved habitat is a benefit to society.

2. Methods and Data

For this work, ERG will estimate the benefit from improved fish habitat due to FIRO using a least cost method.[49] This will include:

- Determine the value of having healthier habitat at the study site. This can be done by determining the current fish population for the species of concern For Lake Mendocino, we can use the Salmon Snapshot for 2012/13 (The Nature Conservancy, 2013).
- Determine the alternatives to FIRO for achieving the desired habitat, and what it would cost to obtain the same value as FIRO using these other alternatives. A few alternatives include:
    - Planting trees
    - Developing reservoir dams
    - Buying water rights
- Choose the alternative that has the least cost.
- Find the benefit by comparing the costs of FIRO and the cost of the least costly alternative.

Willingness to pay estimates for threatened and endangered species, specifically for species of concern for the project area, may be useful for our analysis, but are not included as part of the proposed least cost method. Some of the relevant literature is listed below as a reference, in case it is determined useful:

- A comparison of regional and national values for recovering threatened and endangered marine species in the United States (Wallmo and Lew, 2016).
- Valuing improvements to threatened and endangered marine species: An application of stated preference choice experiments (Wallmo and Lew, 2011).
- Public Willingness to Pay for Recovering and Downlisting Threatened and Endangered Marine Species (Wallmo and Lew, 2012).
- Passive use values of wild salmon and free-flowing rivers (Loomis, 1999).
- Multiple Programs to Improve Fish Populations (Layton et al., 1999).

3. DST Considerations

The DST will need to identify potential restoration methods that can be considered by projects in other areas and include, to the extent feasible, representative costs (e.g., cost per river mile) that other projects could draw from. Overall, the implementation of least cost methods for fisheries and habitat in the DST will leave a number of decisions for projects using the DST in the future.

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[49] The 1983 NED guidelines discuss quantifying benefits for commercial fishing, but not other benefits associated with improved fish populations or habitat. They suggest measuring the change in harvest and harvest cost as the basis for monetizing benefits. We have chosen not to use this methodology because it does not capture the full range of benefits associated with increased fish populations and improved habitats. Additionally, it would require inputs that are not available.

B.6 Agriculture

1. Background

Having better crop irrigation can result in improved quality and quantity of agricultural goods, which leads to an economic benefit from avoided losses. FIRO can help attain that economic benefit by providing better forecasting, which in turn will allow more water to be stored in Lake Mendocino during wet periods and more water to be released during dry periods. This methodology outlines an approach to measure the benefit of avoided losses for the agricultural industry due to FIRO, which will then be incorporated into a DST that will allow users to measure the benefit of avoided losses in the agricultural industry for other projects.

Agriculture output is significant in Mendocino County; in 2018, agricultural output was valued at $320.8 million (Department of Agriculture, County of Mendocino, 2019). Of that, the leading commodity was wine grapes, which accounted for $137.9 million of the total agricultural output. Additionally, the effect water shortages have on that output cannot be ignored; in 2014 the grape industry estimated that it lost 19 percent of expected output due to drought (Department of Agriculture, County of Mendocino, 2015).

The main beneficiaries of this benefit will be the local businesses in the agricultural industry that produce grapes and other agricultural products utilizing water from Lake Mendocino.

2. Methods and Data

For this work, ERG will calculate annual avoided losses from agricultural production due to revised water management due to FIRO. Specifically, we will use the residual imputation method (also known as the residual value method). This method imputes the value of water by subtracting all known input costs from the total value of the crop. This remainder is attributed to water. This methodology will include:

- Determine the acreage of land and market value of prevalent crops. For Lake Mendocino this can be determined from the Sonoma County Crop Report and the Mendocino County Crop Report.
- Determine the input costs per crop. Data still need to be identified for this step.
- Use the residual imputation method to calculate the value of a unit of water.
- Calculate the annual avoided losses due to FIRO by multiplying the estimated value of a unit of water by the increase in water supply available for agriculture generated by FIRO.

An underlying assumption we are making for this benefit is that producers are price takers on the market.

3. DST Considerations

For Lake Mendocino specifically, there is not a great possibility for intensification benefits, because of this and data availability, calculating agricultural benefits from avoided losses is more transferrable to other sites. The DST may need to be broader in our analysis of this benefit given the different possible impacts of projects and the variability of different sites. Other sites may have more possibility for intensification benefits.

For future analyses and for the DST, ERG could consider using a multi-year analysis, with assumptions made for dry and wet year percentages, and a sensitivity analysis for intensification by various percentages. We would use a discount rate of 2.75 percent (Reclamation, 2019).

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Appendix C: Economic DST

The DST is an Excel file and has been delivered separately from this report.

Appendix D: Transferability Workshop Notes

Economic Benefits of Alternative Reservoir Operations
Prosser Reservoir: Decision Support Tool Workshop
Thursday November 5, 2020
12:00-3:00PM Pacific Time

ATTENDEES:

Arleen O'Donnell, Lou Nadeau, Tess Hubbard, Caitline Barber, Eliza Berry, ERG
Mike Dietl, Vince Barbara, Ken Richard, Matt Elmer, Austin Olah, Dan Deeds, Reclamation
Rob Hartman, RK Hartman Consulting Services

Truckee Basin Water Management Options Pilot (WMOP) Team:
Laurie Nicholas, John Hunter, Dan Lahde, Scott Schoenfeld, Reclamation
Chad Blanchard, Dave Wathen, Patrick Fritchel, US Water Master's Office
Ali Shahroody, Donna Noel, Pyramid Lake Paiute Tribe
Jim Eto, Dan Yamanaka, CA Department of Water Resources
Caleb Erkman, Precision Water Resources Engineering

NOTES:

Opening Session

Following introductions, Mike Dietl opened by providing background on WaterSMART. He explained that the Bureau of Reclamation (Reclamation) wants to see how the economic benefits decision support tool (DST) can be applied to other reservoirs. The tool can't be applied yet for Prosser Reservoir because there are no FIRO scenarios that have been developed to estimate change in storage, but it is ready to inform decision making. Prosser was suggested as a test site because it has competing demands, good data, engaged stakeholders.

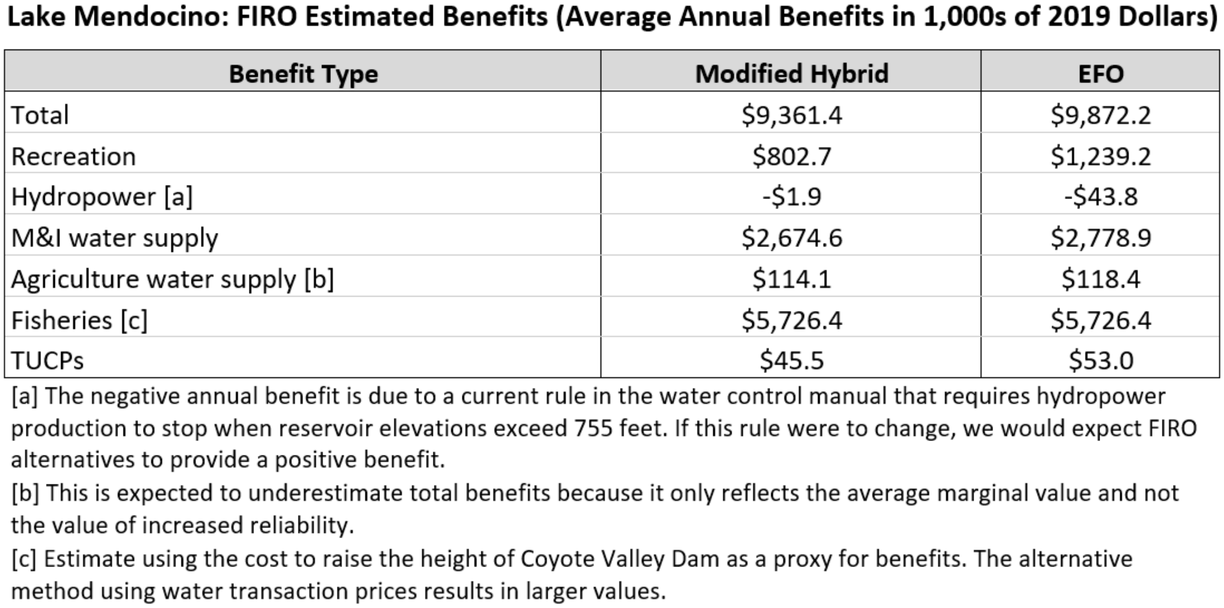
Laurie Nicholas explained that the site was also selected because there is a FIRO project in the basin. The goal of today's workshop is to get your input on outstanding questions regarding transferability of the DST.

Introduction to FIRO and Lake Mendocino success to date, Rob Hartman
Rob explained that Water Control Manuals (WCMs) have generally excluded the use of forecasts in managing the reservoirs. This is changing. Through viability assessments, FIRO is demonstrating that it is possible, productive, and safe to do. Rob noted that increased storage space is now managed at Lake Mendocino based on weather (precipitation and runoff) forecasts. For Lake Mendocino, this was motivated by the fact that the current guide curve does not account for a 56 percent reduction in diversion into Lake Mendocino. This jeopardizes water supply reliability. We're also experiencing more climate extremes, so we need to adapt. The key concept of FIRO is: If you don't need to get rid of the water, then don't! Hold onto it until absolutely necessary! Among other uses, water is important for fish populations, including salmonids. In this project, the Lake Mendocino FIRO Steering Committee applied major

deviations (a change in storage in excess of 5 percent of gross pool) to test FIRO viability and found that 19 percent more storage could be safely achieved under FIRO operations compared to existing WCM.

Transferability Discussion

Lou Nadeau and Tess Hubbard provided an overview of their economic analysis of FIRO benefits, considering 2 FIRO alternatives: the Modified Hybrid, and the “reach” alternative, Ensemble Forecast Operations (EFO). Results as shown below indicate a total economic benefit of between $9.4 and $9.9 million annually.



Lake Mendocino: FIRO Estimated Benefits (Average Annual Benefits in 1,000s of 2019 Dollars)

Benefit Type	Modified Hybrid	EFO
Total	$9,361.4	$9,872.2
Recreation	$802.7	$1,239.2
Hydropower [a]	-$1.9	-$43.8
M&I water supply	$2,674.6	$2,778.9
Agriculture water supply [b]	$114.1	$118.4
Fisheries [c]	$5,726.4	$5,726.4
TUCPs	$45.5	$53.0

[a] The negative annual benefit is due to a current rule in the water control manual that requires hydropower production to stop when reservoir elevations exceed 755 feet. If this rule were to change, we would expect FIRO alternatives to provide a positive benefit.

[b] This is expected to underestimate total benefits because it only reflects the average marginal value and not the value of increased reliability.

[c] Estimate using the cost to raise the height of Coyote Valley Dam as a proxy for benefits. The alternative method using water transaction prices results in larger values.

<u>Question:</u> What is the difference between EFO and Modified hybrid?

<u>Answer (Rob Hartman):</u> EFO utilizes a new guide curve that allows you to store water within 3ft of spillway crest, which is a little scary for the Corps of Engineers, who operates the dam. The Modified Hybrid is less aggressive but allows for some early refill.

Economic Decision Support Tool Demonstration, Caitline Barber

Caitline explained that the tool is intended to help decision makers assess potential economic benefits of FIRO and support estimates for 5 sectors (irrigation water supply, municipal and industrial water supply, hydropower, fisheries, and recreation). In order to use the tool, you need to understand estimated change in storage between existing operations and the FIRO alternative(s). The Lake Mendocino team has worked through the tool at Lake Mendocino and now want to see if it is applicable to Prosser, and other reservoirs.

Caitline demonstrated the tool, focusing on three sections that are most relevant to Prosser:

1. Recreation Benefit
    a. The user needs to do outside research to come up with some of the data to input. There is a “user guidance report” that includes methods and tips for how users can find the data they need.

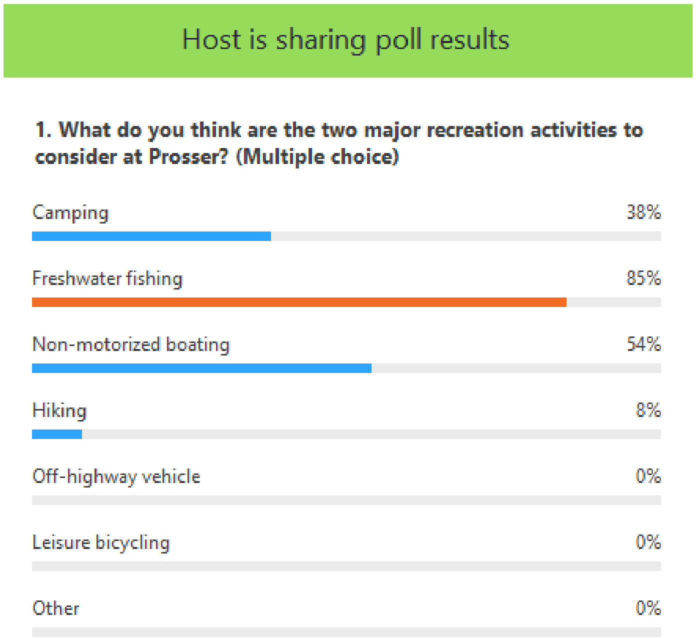
    b. Two different methods for estimating the recreation benefit are included in the DST. Method 1 requires that the user puts in “change in annual recreation” (you must understand the relationship between the FIRO alternative and recreation).

2. Annual Water Supplied Benefit
    a. Option 1 requires you to know: current water quantity, how much it will change, and current price of water.
    b. Option 2 also requires the price elasticity of demand.
3. Fisheries Benefits
    a. A framework of 3 options the user can use to calculate benefits. It requires a fair amount of outside research.
    b. It’s hard to relate water storage to fisheries benefits. A lot of this is based on your comfort with the method options and data availability.

Discuss Recreation Benefit, Tess Hubbard

Tess walked through how this tool might be applied at Prosser, starting with the recreation benefit. At Lake Mendocino, they were able to look at time series data connecting recreation counts with water levels. US Forest Service (USFS) could not provide this kind of time series data for Prosser, but they did get current data on camping, fishing, boating, etc.

Tess used Recreation Option 2 and included US Geological Service (USGS) unit day values (UDVs) for different types of recreation. To distribute aggregated recreation across several types of recreation, she used a uniform distribution. She also assigned assumed elasticities (e.g., higher water levels might lead to more recreation benefits). For fishing and boating they assumed higher elasticities than camping because these types of recreation that directly use the lake may be more responsive to changes in water levels.



Host is sharing poll results

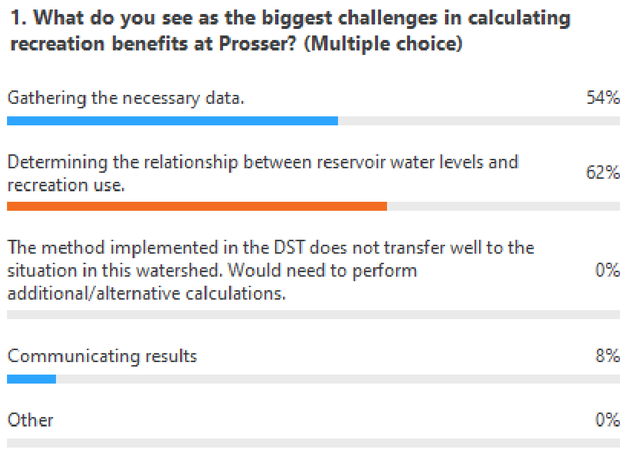
1. What do you think are the two major recreation activities to consider at Prosser? (Multiple choice)

Camping	38%
Freshwater fishing	85%
Non-motorized boating	54%
Hiking	8%
Off-highway vehicle	0%
Leisure bicycling	0%
Other	0%

Tess will tweak distribution of recreation days based on this feedback from the group.

Dave Wathen noted that the whole reservoir is a non-motorized fishing reservoir. There is a Forest Service Campground, run by a third party.

Chad Blanchard said they get a lot of calls around water levels and their camping and fishing activities.



1. What do you see as the biggest challenges in calculating recreation benefits at Prosser? (Multiple choice)

Gathering the necessary data.	54%
Determining the relationship between reservoir water levels and recreation use.	62%
The method implemented in the DST does not transfer well to the situation in this watershed. Would need to perform additional/alternative calculations.	0%
Communicating results	8%
Other	0%

Dave said there is a boat ramp that has a preferred minimum level (19,000 AF). If it is lower, the boats can still launch from the beach.

Dave: Maybe you just survey the campers to help get this benefit data? There are also additional benefits such as major benefits to recreation in fishing streams downstream of the reservoir. Additional fisheries benefit as well (this is really important).

Tess: At Lake Mendocino, we decided to focus only on the reservoir for recreation, but at Prosser you may want to include downstream recreation too if that is prevalent.

Ali Shahroody: The fish in Prosser is incidental. The goal of the reservoir is to provide water to the listed species downstream.

Laurie: How does use vary with reservoir levels? You’d need to see how the Forest Service tracks their visitor numbers.

Caleb Erkman said that right now Prosser is kept low until April 10th. If you’re doing this for the first time, how do you estimate the benefits of something that has never happened before?

Discuss M&I Benefit Estimate

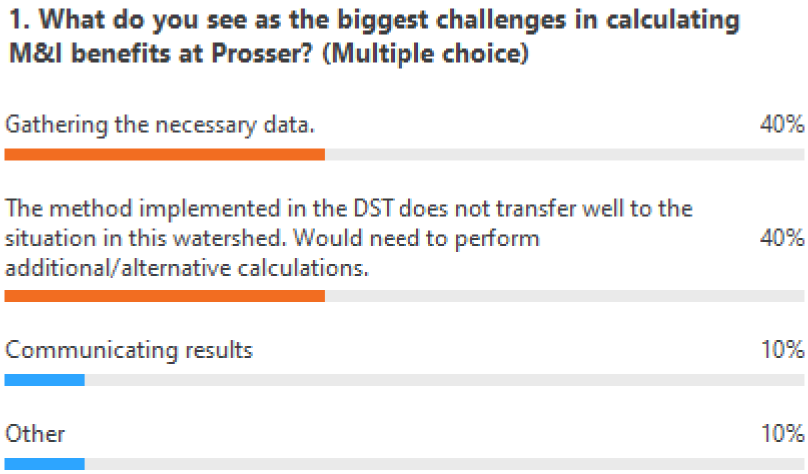
Tess explained that she and the team estimated current water quantity supplied to residential and commercial and industrial customers based on 10 years of Truckee Meadows Water Authority (TMWA) data. Tess walked us through the calculations and explained that one method assumes that more water reduces the price of water. The other option does not make this assumption.

Question: Are these retail or wholesale prices? Matthew Elmer says you need to convert to wholesale price so that you’re not overstating the benefit. This conversion would make the prices comparable to irrigation. He could provide guidance on how to do the calculation to convert from retail to wholesale. Tess does not think these are wholesale prices and needs to confirm why the literature indicated she should use retail prices. She needs to give some thought to whether or not option 1 can work with wholesale price.

Caleb Erkman noted that Prosser doesn't store water for TMWA. I wouldn't expect changes at Prosser to impact TMWA so this isn't relevant. Some disagreed with this: Depending on how much storage changes, Prosser could provide more water for TMWA.

Laurie thinks this calculation may need to be in the tool (in terms of many other reservoirs), it just isn't as relevant for Prosser.

The price of water is stable. Caleb Erkman said he's not exactly sure how the pricing structure works, but he doesn't expect that FIRO would lead to cheaper rates.



1. What do you see as the biggest challenges in calculating M&I benefits at Prosser? (Multiple choice)

Gathering the necessary data.	40%
The method implemented in the DST does not transfer well to the situation in this watershed. Would need to perform additional/alternative calculations.	40%
Communicating results	10%
Other	10%

Discuss Fisheries Benefit Approach

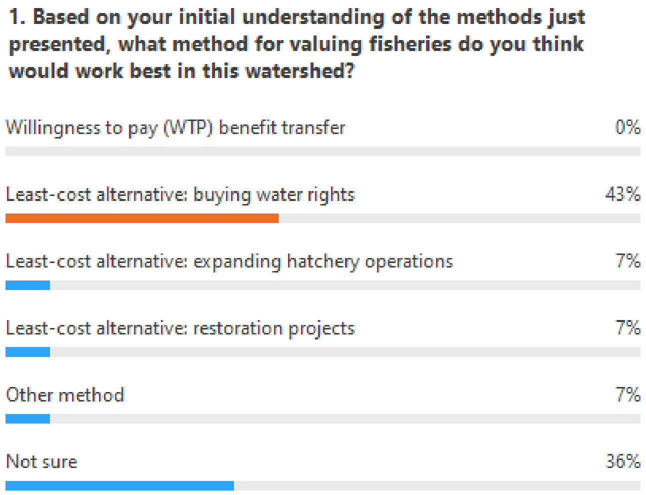
Lou described what was done in Russian River (Lake Mendocino), where the main goal was to reduce water temperature for fisheries. The team looked at benefits through two approaches:

1. Abbreviated least cost alternative approach
    a. Cost of raising the dam
2. Water transaction prices as a proxy for the value of water

For Prosser, the team developed two different approaches:

1. Willingness to pay (WTP) benefit transfer
    a. You find an estimate from a different study area and then apply it to Prosser
        i. Draw on studies in similar regions, focus on the same fish species.
        ii. Found a few relevant WTP studies for cutthroat trout, but not cui-ui.
2. Least cost alternative
    a. Find feasible alternatives to achieve the same physical benefit
    b. Chose the alternative with the least cost
    c. Use this as a proxy of the benefit you would get from implementing FIRO
    d. You need to be clear on what metric you're trying to achieve: reduce downstream temperature? Increase spawning habitat?
    e. Alternatives to consider at Prosser:
        i. Nevada Assembly bill AD380 established a water right buyout program

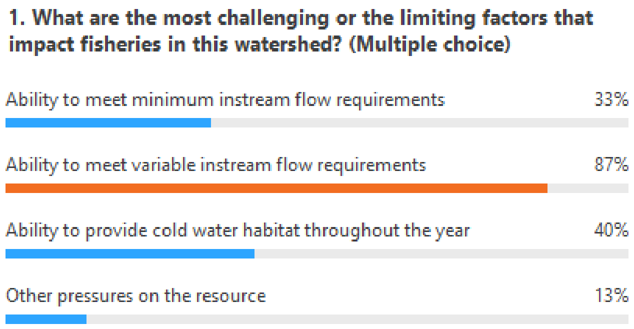
    ii. Expand hatchery operation
    iii. Restoration project



1. Based on your initial understanding of the methods just presented, what method for valuing fisheries do you think would work best in this watershed?

Willingness to pay (WTP) benefit transfer	0%
Least-cost alternative: buying water rights	43%
Least-cost alternative: expanding hatchery operations	7%
Least-cost alternative: restoration projects	7%
Other method	7%
Not sure	36%

Ali Shahroody explained that there is lots of data over the last 15 years on purchasing water rights. You can see how the price changed pre and post 2008/2009 economic crash. Ali says we should use the 6,700 acres-feet purchases too. There are many different purchases to review to help identify metrics.



1. What are the most challenging or the limiting factors that impact fisheries in this watershed? (Multiple choice)

Ability to meet minimum instream flow requirements	33%
Ability to meet variable instream flow requirements	87%
Ability to provide cold water habitat throughout the year	40%
Other pressures on the resource	13%

Arleen asked: Is there a formula to identify where rights are most valuable for fisheries? Ali's response: First thing is volume. Then, you need to work with water managers on scheduling. Purchases are public information. Laurie did not think it was proper to share detailed information on some of the open grants; however, there are closed grants where data can be gathered. Land purchases are public information so we could gather the information that way.

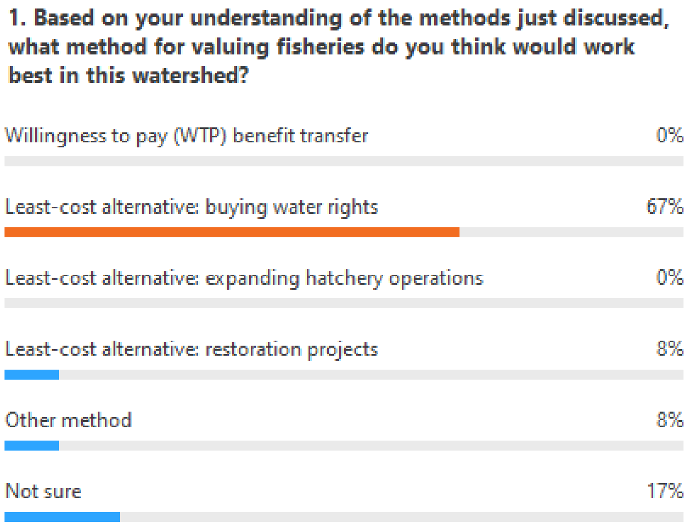
Lou asked: How many water rights transactions per year?

Ali's response: 50–80

Laurie noted work by local tribes and efforts in the Walker basin provide a lot of available data.

Lou noted that these are good starting points for us to include: price data, least cost alternative data. He then asked the group: What kind of restoration project price data should we consider? What kind of alternatives could we use?

Ali’s response: Contact The Nature Conservancy (TNC) in Reno. They work with water rights and shading. TNC might have some temperature modeling. They have certainly done this in other rivers.



1. Based on your understanding of the methods just discussed, what method for valuing fisheries do you think would work best in this watershed?

Willingness to pay (WTP) benefit transfer	0%
Least-cost alternative: buying water rights	67%
Least-cost alternative: expanding hatchery operations	0%
Least-cost alternative: restoration projects	8%
Other method	8%
Not sure	17%

In terms of the current status of the fisheries, they could not operate the hatchery this year due to COVID (so no spawning). There is a lack of current data on endangered species status.

Workshop Wrap-Up and Next Steps

Arleen explained that we’ll revise the tool based on this input. We think this is a good functional model that will help you calculate benefits. We’ll deliver this tool and report to the Bureau of Reclamation at the end of the calendar year.

Mike will follow up with Arleen on scheduling.

Ali was wondering if this group can review the final report and product before we submit to Reclamation. Mike will look into this and follow up.

Mike Dietel was wondering about creating a scenario to run through the tool. Laurie will ask her team about the scenario question. She thinks it's probably premature since they are not looking at alternatives until next year.

Laurie’s next steps, include:

- Hydrologic Engineering Management Plan (HEMP). They are drafting their HEMP to inform their next steps. Will include:
  - RiverWare modeling
  - HEC-RAS modeling
- Hindcast development by the River Forecast Center
- Discussing alternatives next calendar year. They want to bring on a facilitator to assist.
- They have a 3-year timeline for the study that started in June 2020.

All attendees were thanked for their participation and notes from this workshop will be shared.