Work Plan for the Russian River Forecast-Informed Reservoir Operations (FIRO) Viability Expansion Assessment: Lake Sonoma

Prepared by HDR

Sonoma County, California

April 14, 2022

Contents

Tables

Figures

ACRONYMS AND ABBREVIATIONS

AR	atmospheric river
CDEC	California Data Exchange Center
DSS	Decision Support System
EFO	Ensemble Forecast Operations
ERDC	Engineering Research and Development Center
FIRO	Forecast-Informed Reservoir Operations
FCD	flood control diagram
HEC	Hydrologic Engineering Center
HEMP	Hydrologic Engineering Management Plan
HQ	headquarters
IVT	integrated water vapor transport
PVP	Potter Valley Project
SME	subject matter expert
SPN	USACE, San Francisco District
USACE	U.S. Army Corps of Engineers
WCM	water control manual
WCP	water control plan

CHAPTER 1 INTRODUCTION

The 1,485-square mile Russian River watershed, shown in Figure 1, is a narrow valley between two adjacent northern coastal mountain ranges and is characterized by a Mediterranean climate with 93% of annual precipitation in October through May. A large percentage of the rainfall typically occurs during three or four major winter storms that often come in the form of an atmospheric river (AR). Climatic conditions vary across different portions of the watershed. Average annual precipitation is as high as 80 inches in the mountainous coastal region of the watershed and 20 to 30 inches in the valleys. Precipitation can also vary significantly from season to season, which can result in a large amount of variability in flows in the Russian River. Much of this rain occurs in just a few atmospheric river storms (AR) each year. ARs, such as that shown in Figure 2, provide 40-50% of watershed’s rainfall annually.

The watershed has two major reservoirs, Lake Mendocino and Lake Sonoma, both of which are multi-purpose and are primarily used for water supply and flood management in the region. The available storage in each reservoir and the operations there of are important to regional water supply reliability. In dry years Lake Mendocino is water supply is used to maintain minimum streamflows in in the Upper Russian River and Lake Sonoma augmenting these flows downstream of Dry Creek. In flood events, both are used to regulate and reduce peak flows in the system.

Operations at each are governed by their respective water control manuals (WCMs). These manuals were originally developed without the benefit of modern weather and streamflow forecasting information. Each WCM specifies reservoir operation according to a guide curve, which dictates water storage during a flood event and safe water releases soon thereafter to create storage space for the next potential flood.

The guide curve at Lake Mendocino is predicated on historical weather patterns—wet during the winter, dry otherwise—so the required flood control space is larger in the winter while smaller in the remainder of the year. Whereas the guide curve at Lake Sonoma, shown in Figure 3, is a constant value that does not reflect seasonality.

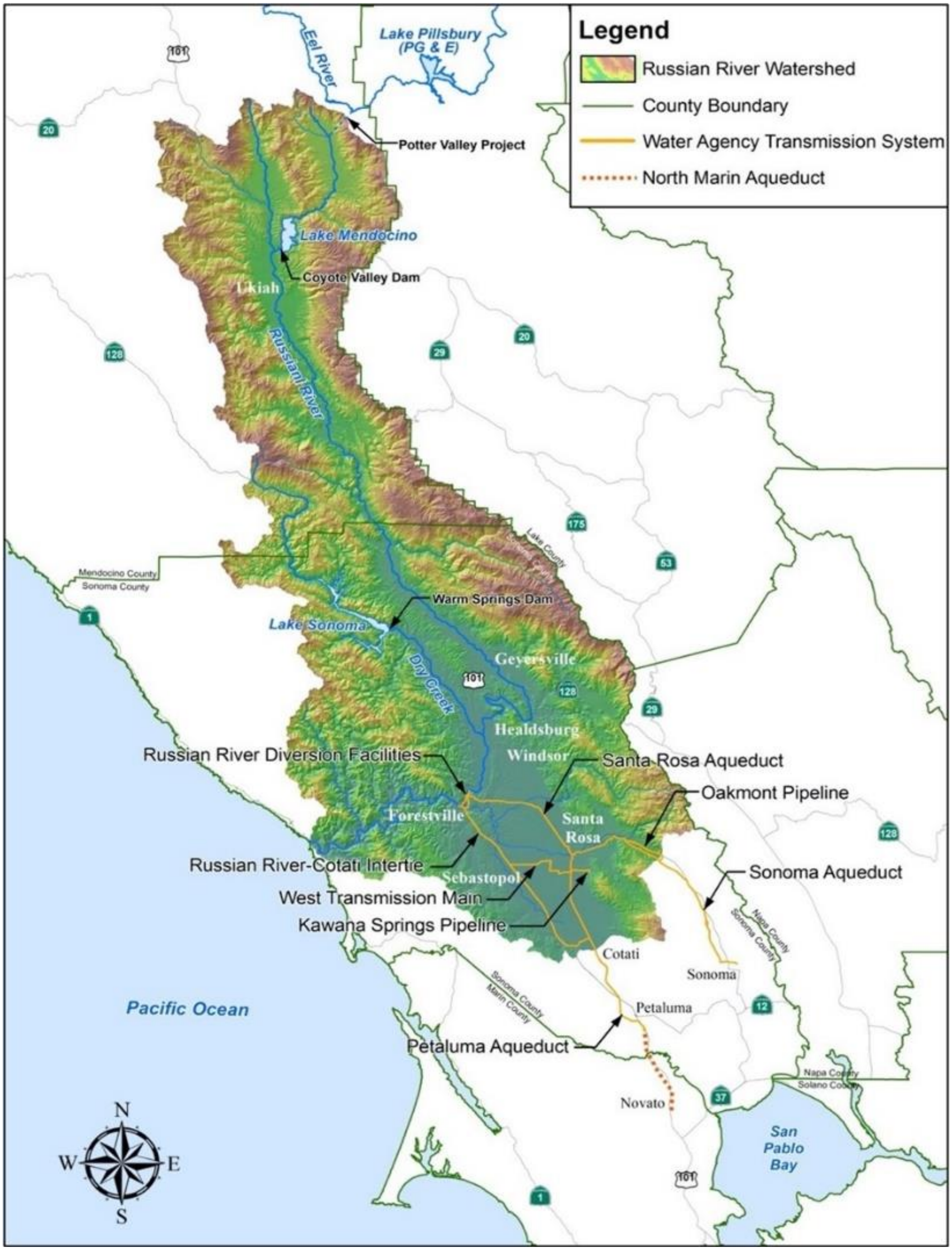

Figure 1. Schematic of the Russian River watershed (FIRO Steering Committee 2015)

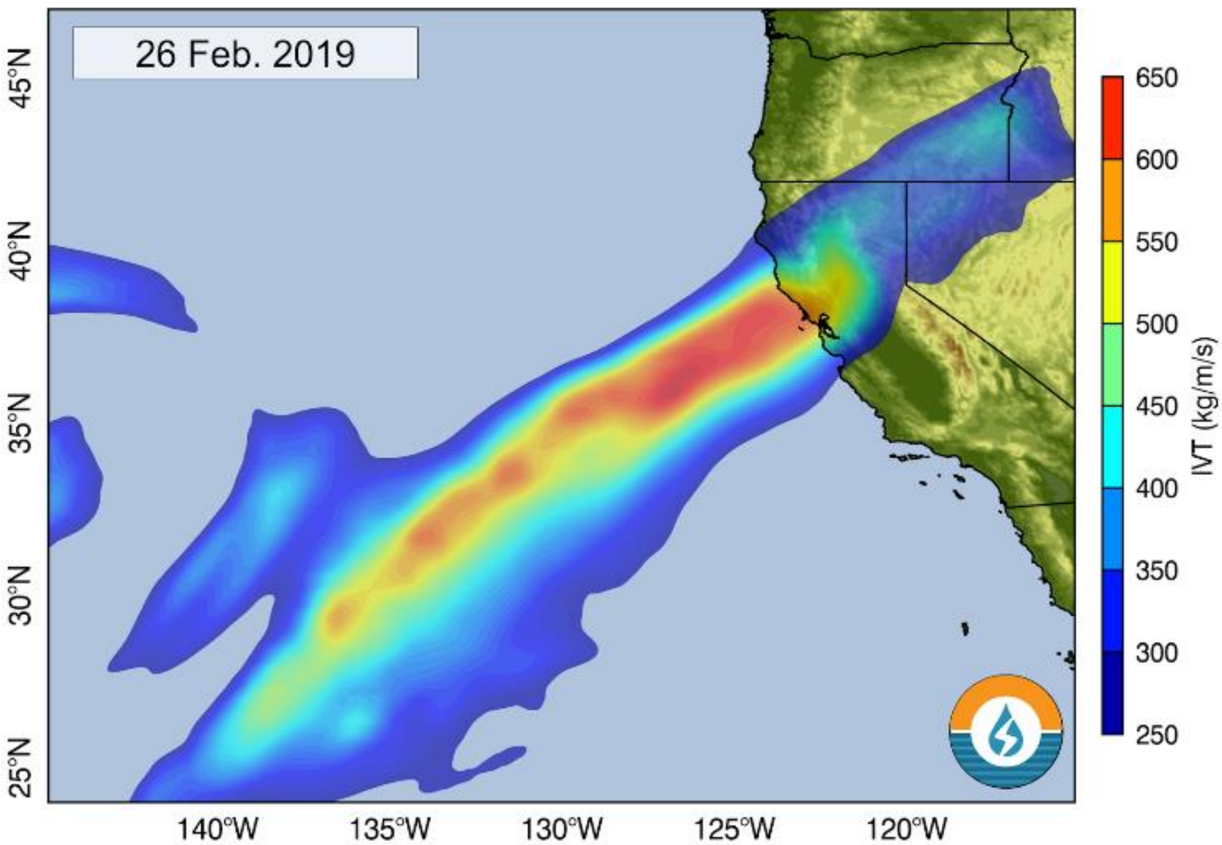

Figure 2. An AR making landfall in the Russian River area on February 26, 2019. Shading represents integrated water vapor transport (IVT), which indicates the strength of the AR.

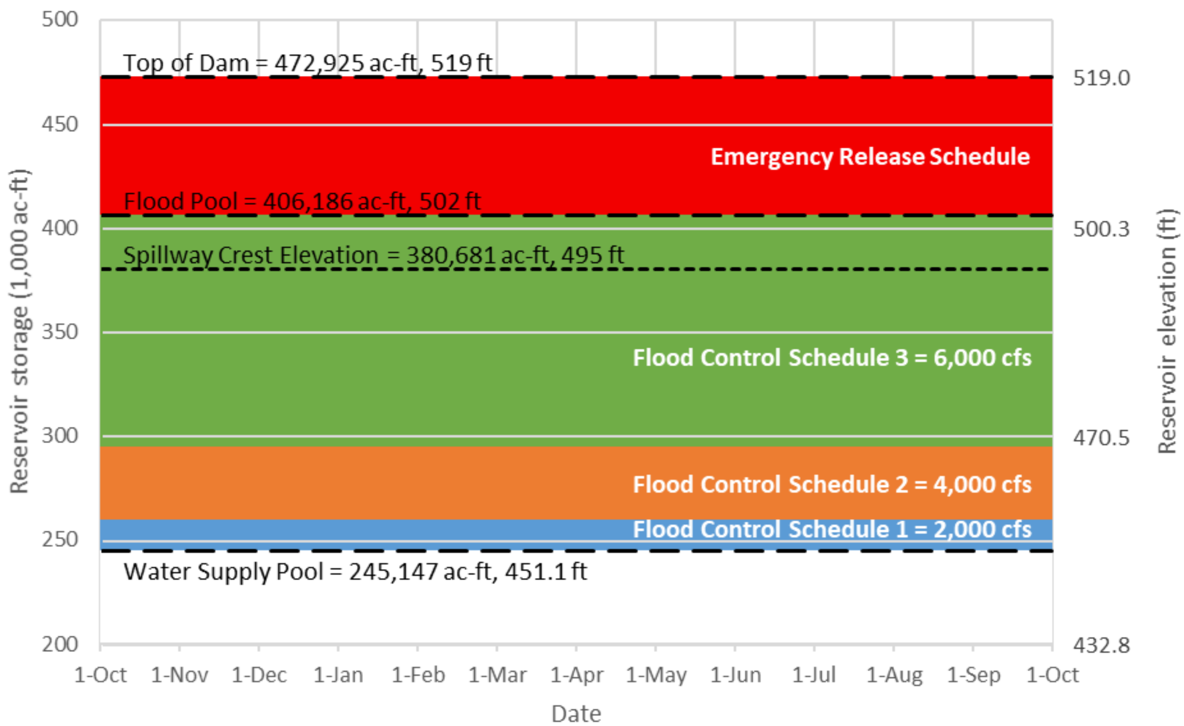

Figure 3. Lake Sonoma operations guide curve

As noted above, this region experiences some of the most variable climate in California, with frequent droughts and floods. The guide curve does not account for climate variability that has taken place in the past 20-30 years nor a 56 percent reduction of diversions into Lake Mendocino from the Eel River due to changes in hydroelectric operations of the Potter Valley Project (PVP) that began in 2006. As a result, the collective water supply reliability of Lake Mendocino and Lake Sonoma is impaired, with significant consequences to downstream municipal and agricultural water users as well as threatened and endangered salmonids.

The impacts of climate variability on water supply reliability were best illustrated at Lake Mendocino in water years 2012 and 2013. Figure 4 shows that both years experienced similar total rainfall, but timing of the rainfall relative to the reservoir guide curve resulted in dramatically different storage outcomes. This experience prompted the question of whether some of the inflow and storage that occurred in December 2012 could have been saved to mitigate the subsequent precipitous decline in reservoir storage that followed over the next two years due to a lack of rainfall that resulted in drought conditions for the watershed.

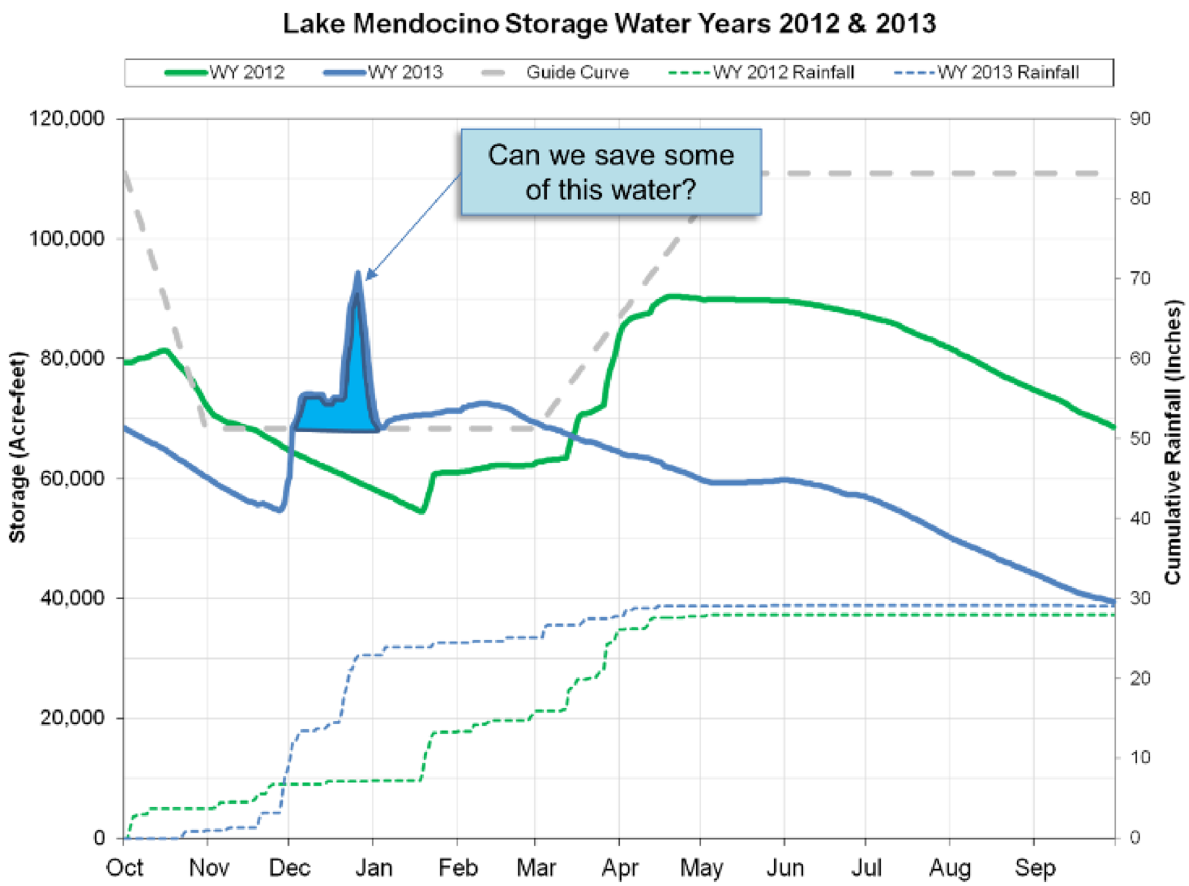

Figure 4. Lake Mendocino Storage (solid lines) and cumulative precipitation (dashed lines) for water years 2012 (green) and 2013 (blue).

This question was answered by the Lake Mendocino FIRO Final Viability Assessment (FVA), the culmination of a six-year effort led by the Lake Mendocino FIRO multi-agency Steering Committee (SC). The FVA demonstrated the viability of FIRO and established the basis and pathway for updating the WCM to explicitly incorporate forecasts in order to improve water supply reliability and environmental conditions in the upper Russian River watershed. An outcome of this demonstrated viability is a major deviation at Lake Mendocino that applies the Modified Hybrid Ensemble Forecast Operations (EFO) water control plan, which has proven water supply benefits at Lake Mendocino. Figure 5 shows a comparison of Lake Mendocino storage with- and without-FIRO for WY 2020 operations, a period in which FIRO resulted in a 19% increase in storage.

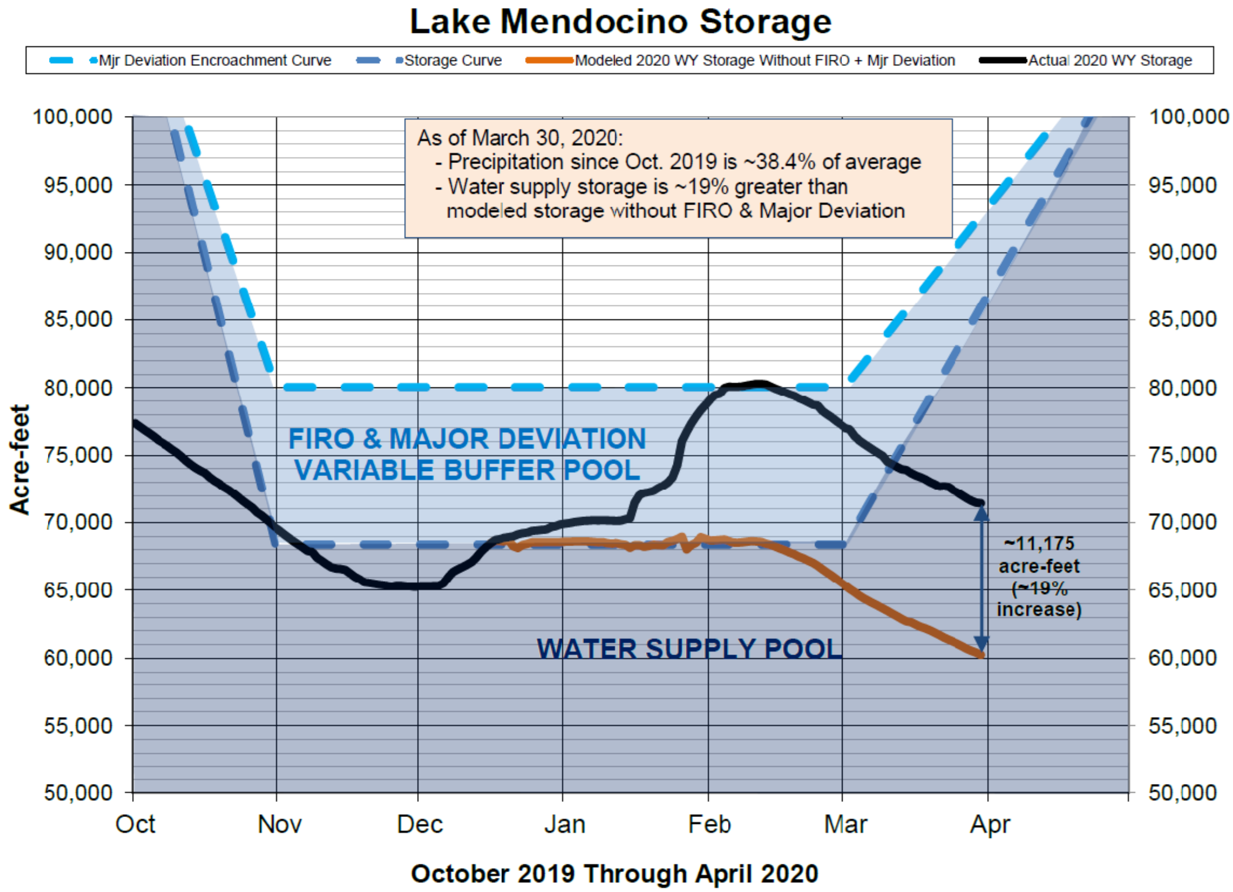

Figure 5. Lake Mendocino storage increased by 19 percent (more than 11,000 acre-feet) during major deviation operations in WY 2020

Now that the Lake Mendocino FIRO FVA is complete, a major deviation in place, and the update of the Lake Mendocino WCM is underway, the Lake Mendocino FIRO SC has reformed as the Russian River FIRO SC (hereafter referred to as the SC) with the focus of expanding FIRO throughout the Russian River watershed, specifically to Lake Sonoma on Dry Creek. The SC is a multi-agency team, comprised of water managers (flood, water supply, and environmental) and scientists (hydrology, weather/climate, modeling) that will undertake the evaluation described in this work plan. Table 1 lists the current SC members. This work plan establishes a common understanding of the needs and goals for Russian River FIRO expansion and outlines the analysis method, timeline, and process for assessing viability of FIRO as applied to Lake Sonoma and the lower Russian River.

Table 1. Russian River FIRO Working Group members, including Steering Committee Members

Name (1)	Agency (2)
Nicholas Malasavage (Co-chair)	USACE, San Francisco District
Jay Jasperse (Co-chair)	Sonoma Water
F. Martin Ralph (Co-chair)	U.C. San Diego, Scripps Institution of Oceanography, Center for Western Weather and Water Extremes (CW3E)
Michael Anderson	California Department of Water Resources
Levi Brekke	US Bureau of Reclamation
Michael Dettinger	U.C. San Diego, Scripps Institution of Oceanography, CW3E
Joseph Forbis	USACE, Sacramento District
Alan Haynes	NOAA, National Weather Service, California-Nevada River Forecast Center
Joshua Fuller	NOAA, National Marine Fisheries Service
Patrick Sing	USACE, San Francisco District
Cary Talbot	USACE, Engineer Research and Development Center
Robert Webb	NOAA, Office of Oceanic and Atmospheric Research, Earth System Research Laboratory

1.1 Need for FIRO Expansion to Lake Sonoma

Since the preparation of the Warm Springs Dam and Lake Sonoma WCM, significant changes have occurred throughout the Russian River system, including the listing of Chinook salmon, coho salmon, and steelhead as threatened or endangered and National Marine Fisheries Service issuance of the 2008 Russian River Biological Opinion. To ensure the survival of endangered coho salmon, the Biological Opinion directed Sonoma Water and the U.S. Army Corps of Engineers (USACE) to enhance six miles of habitat in Dry Creek and operate a conservation hatchery at Warms Springs Dam.

The $75 million dollar program has expanded rearing and spawning habitat into flood plain areas adjacent to mainstem Dry Creek. These areas provide critical habitat for juvenile fish but are vulnerable to geomorphic changes induced by sustained high flow releases from Warm Springs Dam. Changing the frequency and magnitude of flood releases effects sediment transport in Dry Creek and reducing the frequency of high flow releases may improve the long-term function of habitat features in the channel.

The survival of hundreds of thousands of fish reared at the hatchery depends on clean and cold water released from Lake Sonoma. Low storage levels in Lake Sonoma during the past two droughts significantly degraded water quality in the hatchery and necessitated the implementation of emergency measures including the relocation of some fish to facilities outside the Russian River basin. If improved forecasting and reservoir management results in deeper, cooler pool volumes and great reliability of cold-water releases, Don Clausen Fish Hatchery can sustain its role as a regional recovery facility. Without the habitat enhancement and hatchery programs, coho salmon would be extirpated from the Russian River watershed (NOAA, National Marine Fisheries Service. *Issuance of an Endangered Species Act Section 10(a)(1)(A) Permit to the United States Army Corps of Engineers for Operation of the Russian River Coho Salmon Captive Broodstock Program at the Don Clausen Fish Hatchery*. July 2020.)

Furthermore, in the last decade storage at Lake Sonoma declined to critically low levels on two occasions. During the drought of 2013-2015, storage at Lake Sonoma dropped to approximately 137,000 acre-feet in December 2014 (56% of the water supply pool). More concerning, Lake Sonoma declined to approximately 105,000 acre-feet on October 23, 2021 (43% of the water supply pool), despite significant actions taken by Sonoma Water over the previous year that resulted in temporary reductions in releases from the reservoir. The 2021 storage levels were the lowest since the reservoir began operation in 1958.

A recent water supply analysis completed by Jacobs on behalf of Sonoma Water indicated that if water year (WY) 2021 was followed by a hydrologic period similar to WY1976 through WY 1980, Lake Sonoma would drain resulting in an approximately 20,000 acre-feet water supply deficit for the cities and districts that rely on purchasing wholesale water from Sonoma Water. This clearly illustrates the need to optimize water supply and flood control operations at Lake Sonoma.

Additional challenges to the system stem from changes to the PVP. Owned and operated by Pacific Gas & Electric Company (PG&E), the PVP is located on the East Fork Russian River and Eel River in Mendocino and Lake counties. PG&E's Lake Pillsbury is impounded by Scott Dam. Natural flows of Eel River water and water released from Lake Pillsbury storage are diverted 12 miles downstream from Scott Dam at Cape Horn Dam and then are conveyed through a diversion tunnel and penstocks to the Potter Valley Powerhouse, which is located in the Russian River watershed. Some of the water discharged from the powerhouse is diverted into canals from which the Potter Valley Irrigation District (PVID) receives water under a water supply agreement with PG&E and its own appropriative water rights license. The remaining water discharged from the powerhouse not consumptively used by PVID flows down the East Fork Russian River into Lake Mendocino.

The average annual transfer through the PVP between 1922 and 2006 was approximately 150,000 acre-feet. Since 2007, the average annual transfer through the PVP has been approximately 60,000 acre-feet. This significant reduction in transferred Eel River water from PVP is the result of an Order issued by the Federal Energy Regulatory Commission (FERC) in January 2004 that amended PG&E's operating license.

In October 2021, PG&E informed Sonoma Water that the transformer bank at the PVP powerhouse had failed and would need to be replaced in order to convey water through the powerhouse for power generation. PG&E estimates it will take up to two years to replace the transformer bank at a cost of up to $10 million. It is highly uncertain whether PG&E will make the necessary repairs to continue power generation, as its FERC operating license expires in April 2022. PG&E has indicated that without the ability to generate hydropower, it is unlikely PG&E will make discretionary transfers of Eel River water through the PVP above its FERC license and PVID contract obligations. Depending on hydrologic conditions, that obligation is between approximately 27,000 acre-feet and 33,000 acre-feet annually. This will result in an additional 50 percent reduction in the annual transfer of Eel River water into the Russian River watershed.

Because late spring storm events do not reliably occur, there have been a number of years since 2006 that Lake Mendocino storage is insufficient to meet water supply needs without risking draining the reservoir. As a result, Sonoma Water has needed to file Temporary Urgency Change Petitions with the State Water Resources Control Board in 2007, 2009, 2013, 2014, 2015, 2020, and 2021 to reduce minimum instream flow requirements in order to prevent draining Lake Mendocino.

As mentioned above, PVP's FERC license expires in April 2022 and PG&E has decided not to seek a new license for the project. On March 1, 2019, FERC issued a solicitation for any parties interested in filing a license application to file a Notice of Intent by July 1, 2019. On June 28, 2019, a partnership made up of Mendocino Inland Water and Power Commission, Sonoma Water, California Trout, the Round Valley Indian Tribes, and the County of Humboldt (Parties) filed a joint Notice of Intent with FERC to investigate the feasibility of relicensing the project. However, the Parties were unable to secure funding for the necessary studies or make progress forming a regional entity to ultimately own and operate the project. Consequently, on January 31, 2022, the Parties filed a report with FERC stating they would not be filing an application to relicense PVP.

It is anticipated shortly after the current license expires in April 2022, FERC will issue an order requiring PG&E to submit a plan and schedule for filing an application for license surrender. During the interim of PG&E completing license surrender and decommissioning the project (which will likely take decades), FERC will issue annual licenses to PG&E for continued operation of the project. This will significantly increase the uncertainty of continued transfers of Eel River water to the Russian River watershed. Offsetting this uncertainty was a key driver for the Lake Mendocino FIRO implementation. It may be possible to offset this uncertainty further through the expansion of FIRO to Lake Sonoma.

1.2 Lake Sonoma FIRO Goals

A successful FIRO implementation at Lake Sonoma will satisfy the goals identified by the SC. Specifically:

- Enhance, or maintain, flood risk reduction.
- Protect fisheries habitat on Dry Creek (including engineered restoration and bank protection projects).
- Improve Lake Sonoma cold water pool reliability for the Don Clausen Fish Hatchery.
- Improve regional water supply resilience, specifically:
    - Mitigate for the reduction in water transfers from the Eel River through the Potter Valley Project (PVP).
    - Reduce Sonoma Water's reliance on Lake Mendocino storage for water supply.
    - Augment flows for fisheries habitat on the lower Russian River (particularly during summer months and during drought years).

  - Support and enhance groundwater recharge at Sonoma Water's Mirabel and Wohler Collectors
- Improve drought resiliency to support water supply reliability, environmental, and recreational benefits.

1.3 Potential FIRO Alternative Strategies

The SC will develop potential FIRO alternative strategies for assessment, each describing a modified Lake Sonoma reservoir operation plan for water management. Such strategies may be prescriptive, similar to the 5-day deterministic forecast alternative assessed in the Lake Mendocino FVA, or iterative, similar to the ensemble forecast operations (EFO) model. Table 2 lists candidate strategies. Refinement and finalization of this list and development of the specific alternatives to be assessed through the validation process. This validation will be a simulation of FIRO strategies with results that demonstrate that one or more of the FIRO goals can likely be achieved without adversely impacting the other goals.

Table 2. Candidate FIRO strategies to be evaluated

ID (1)	Alternative strategy name (2)	Description (3)
1	Existing WCP operation (Baseline)	This is the baseline condition against which performance of all alternatives will be measured. It includes the guide curves and release selection rules from the 1984 USACE WCM and 2004 update to the flood control diagram (FCD). This plan calls for constant storage of 245,147 ac-ft. No forecasts are utilized. Storage above the rule curve is always evacuated as quickly as feasible given system constraints.
2	Ensemble Forecast Operations (EFO)	Iterative approach. Uses the 15-day ensemble streamflow forecasts from the CNRFC. Assesses the probability of storage above a specified storage level (a model parameter to be determined) 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.
3	Hybrid	Iterative approach. A combination of the existing (baseline) WCP and the EFO where the variable space is managed by the EFO process. In mid-winter the variable space resides between 245,147 and 269,662 ac-ft (10% storage increase). Storage above the variable space is always evacuated as quickly as feasible given system constraints. Recommended release can be updated with each forecast cycle.
4	5-day deterministic forecast	Prescriptive approach. Allowable storage above 245,147 ac-ft and reservoir release informed by current storage and the 5-day deterministic forecast for Lake Sonoma inflow and the local flow on Dry Creek as issued by the CNRFC. Recommended release can be updated with each forecast cycle.

1.4 Alternative System Physical Configurations

As the climate variability continues, the long-term impacts on threatened and endangered fish species will likely continue to increase, as will the need to address such impacts. A reliable increase in water supply availability at Lake Sonoma from FIRO could potentially be used to address regional water supply issues provided there was an interconnection between Lake Sonoma and the Upper Russian River.

Expansion of FIRO to Lake Sonoma may provide unique opportunities to modify the physical configuration of the system to improve regional water supply resiliency goals. Here, “physical configuration” refers to specific system modifications to be analyzed. Examples would include a new outlet at Lake Sonoma or a diversion from Lake Sonoma to the Russian River above Dry Creek. The SC will identify the alternative physical configurations of the system that could be analyzed.

Alternative physical configurations will be evaluated using a water balance perspective. By using a water balance, the SC will be able to assess whether the concept of an alternative configuration may improve water supply reliability. If such reliability is demonstrated from a water balance perspective, then a feasibility-level study would be required to provide more detailed analysis and information needed for implementing a physical change to the system.

CHAPTER 2 ASSESSMENT STRATEGY

A four-phase approach for the Lake Sonoma FIRO watershed expansion assessment will be completed as follows:

- **Phase 1**: Develop Workplan and Validate FIRO Expansion (FIRO Workplan and preliminary viability assessment equivalent)
- **Phase 2**: Refine Analysis Strategy (hydrologic engineering management plan development and alternative refinement)
- **Phase 3**: Alternative Simulation and Evaluation (alternative assessment and viability assessment)
- **Phase 4**: Interim operation(s) and Water Control Manual (WCM) Update (post-viability assessment activities)

Figure 6 shows the general schedule for the FIRO expansion assessment, the tasks associated with each phase, and the questions to be answered by the task. The following subsections describe the activities associated with each task. Phase 1, Task 2 in Figure 7 represents this Workplan.

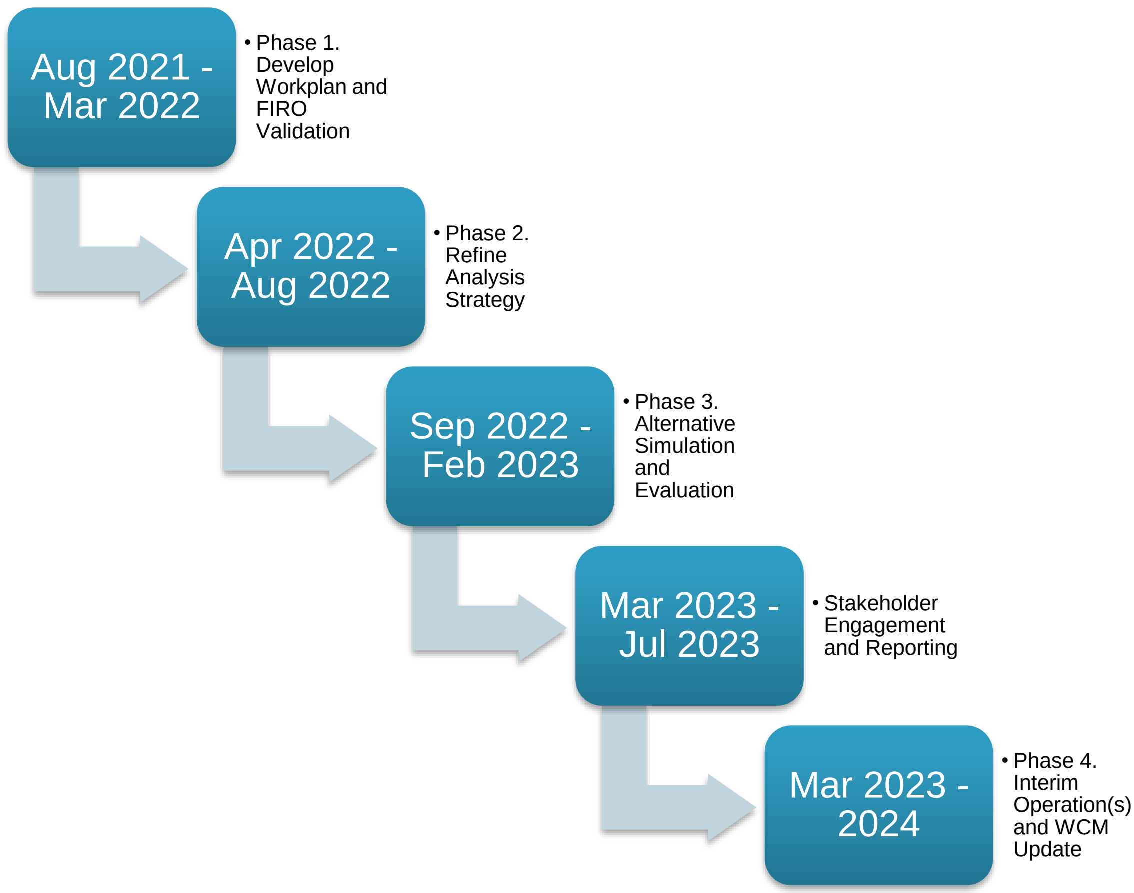

Figure 6. Generalized Lake Sonoma FIRO watershed expansion assessment and WCM update schedule

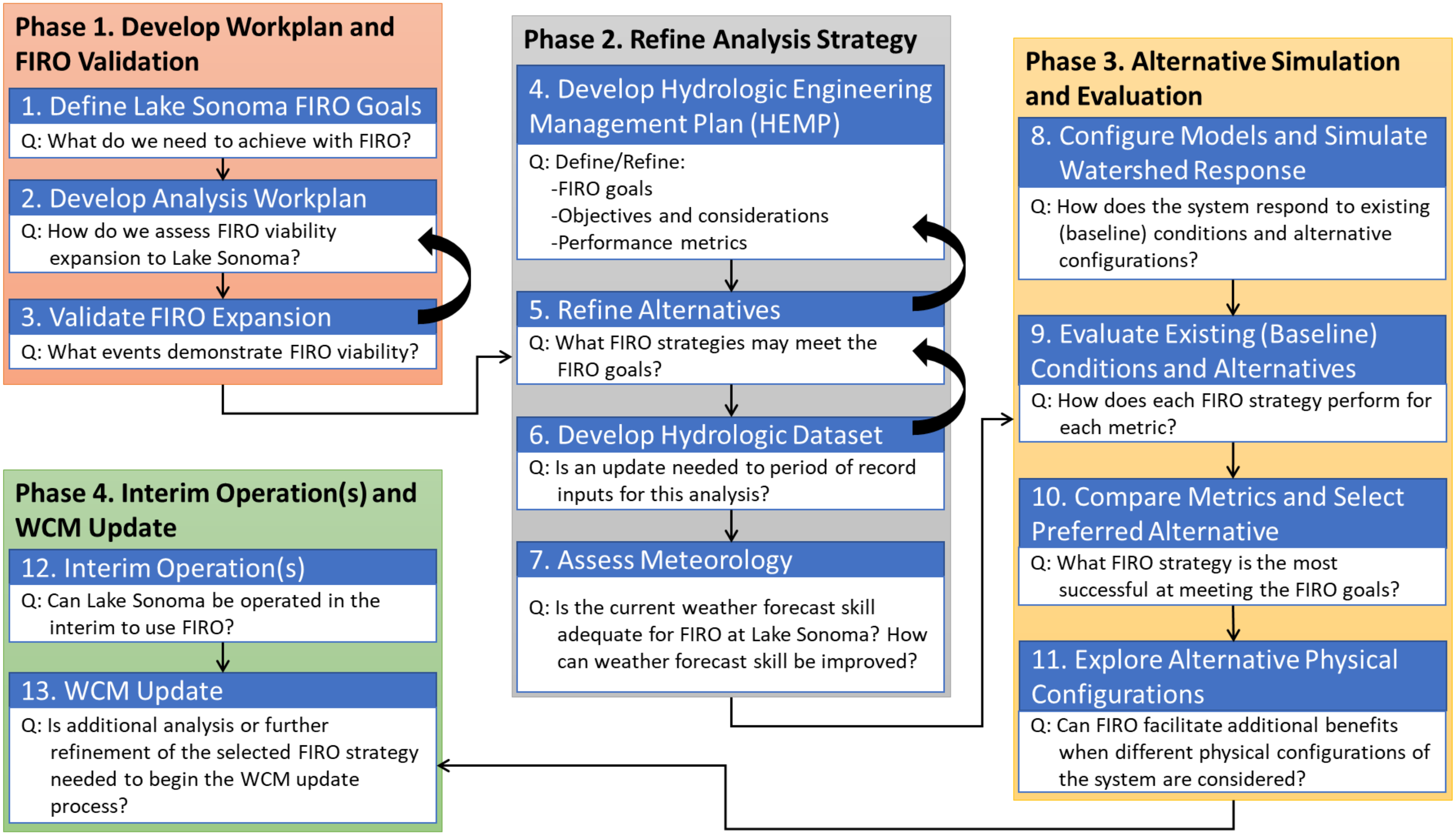

Figure 7. Lake Sonoma FIRO watershed expansion assessment

2.1 Phase 1: Develop Workplan and FIRO Validation

The purpose of Phase 1 is to develop a common understanding of the goals and objectives of a FIRO implementation at Lake Sonoma, as defined by the SC. This Workplan is designed to foster such understanding and to layout a roadmap for assessing expansion of FIRO to Lake Sonoma given the work of the Lake Mendocino FVA.

In addition to the Workplan, the SC will undertake and complete analysis to validate that FIRO expansion to Lake Sonoma may be beneficial. The process steps will be similar to analyses completed in the Lake Mendocino PVA, and are as follows:

1. Examine the historical record to identify examples where changes in operation at Lake Sonoma may have resulted in more beneficial storage outcomes while satisfying flood management, environmental, and other operational objectives.
2. Develop a reservoir operation simulation plan that evaluates benefits and/or impacts at a conceptual level. This plan will be informed by the FIRO strategies proposed and the historical examples identified. It may be event-based or a period-of-record analysis as appropriate
3. Execute the simulation plan and evaluate results to identify potential benefits and/or impacts. Here, results are evaluated against historical operations. For example, comparisons of maximum pool elevation and reservoir release for an event, or annual storage levels at a specific date will be used to evaluate the results.

The process followed and the insights and outcomes from Phase 1 will inform Phase 2.

2.2 Phase 2: Refine Analysis Strategy

The purpose of Phase 2 is to further define the analysis methods and refine the FIRO alternative strategies and/or develop new strategies based on the outcomes of the analysis performed in Phase 1. The outcome of this phase will be a detailed Hydrologic Engineering Management Plan (HEMP) that lists the required inputs, performance metrics, analysis methods, and schedule. The SC found that the HEMP used in the Lake Mendocino FIRO FVA proved to be an important tool for all project team members and was key to completing analysis tasks and management activities successfully and on time. The SC anticipates that a HEMP will be similarly important for the Lake Sonoma FIRO effort.

2.2.1 Develop HEMP

The SC will prepare the HEMP as a technical outline of the hydrologic engineering studies necessary to formulate a solution to a water resources problem (Engineering Pamphlet 1110-2-9).

The HEMP will include the following:

- Statement of objective and overview of technical study process to provide information needed for assessment of FIRO expansion to the Lake Sonoma watershed.

- Specification of requirements for the specific FIRO alternatives that will be considered, including: (1) hard (inviolable) operational constraints that must be satisfied by all FIRO strategies, and (2) operational considerations that should be evaluated.
- Identification of tasks to be completed for the technical analysis. These tasks will include selection of performance metrics and nomination/formulation of FIRO strategies that will be considered. At this time, it is anticipated that the metrics and strategies will be similar to those in the Lake Mendocino FVA.
- Identification of physical configurations of the system to be explored, including the appropriate rating curves and physical operation limitations. For any alternative physical configurations, the SC will use subject matter experts to aid in the development of these constraints.
- Identification of analysis tools and methods to be used for the study.
- Identification of the project team members and their roles and responsibilities for conduct, review, and approval of the hydrologic engineering study.
- Analysis schedule.

2.2.2 Refine Alternatives

In parallel with HEMP development, the SC will refine specific FIRO alternatives given the FIRO strategies already defined and the results of the Phase 1 validation analysis. Development and refinement of these alternatives may require additional reservoir simulation analysis. Here, such analysis would be of the same level as that completed for the validation. The outcome of this task would be a set of alternatives that define reservoir operations using one or more FIRO strategies.

The HEMP will list and define the candidate FIRO alternatives. The definition of each alternative should include the following:

- **Forecast inputs**. Specifically, what forecast information is required to make operational decisions. For example, EFO alternatives require the CNRFC ensemble forecast.
- **Processing methods required**. Specifically, what procedure should be followed to develop a required input from available data or information. For example, details how the ensemble forecast should be processed to create a 5-day 75% non-exceedance volume for use in a given FIRO alternative would be specified here.
- **Operational targets and limitations specific to the alternative**. For example, the specific storage levels that a given FIRO alternative would use as FIRO space. This may vary seasonally.

2.2.3 Develop Hydrologic Dataset

The hydrologic dataset required to assess FIRO expansion to Lake Sonoma will consider: (1) the reservoir simulation analysis plan, and (2) the needs of the specific FIRO alternatives to be evaluated. It will include observed streamflow, river stage, reservoir elevation, reservoir release, and forecast information (deterministic and ensembles) as appropriate to define boundary conditions and initial states of the system to be considered in simulation for comparison and for completion of the reservoir simulation analysis defined in the HEMP. Here, the existing hydrologic dataset developed for the Lake Mendocino FIRO FVA will be leveraged as appropriate.

2.2.4 Assess Meteorology

Expansion of FIRO to the Lake Sonoma watershed requires forecast information have sufficient skill with enough lead time for operators to make informed release decisions. The Lake Mendocino FVA demonstrated that forecast information available in the Russian River watershed generally meets these criteria. The forecast information will be reassessed here given the context of the Lake Sonoma FIRO goals. The SC will review the forecast assessment methods used in the Lake Mendocino FVA and confirm or revise as appropriate. Specifically, the SC will develop and outline methods for the following:

- Determining forecast lead time required for the desired FIRO operations.
- Determining current AR, precipitation and streamflow forecast skill, including false alarms, misses and critical success index.
- Assessing AR orientation impacts on Lake Sonoma inflows.
- Support improved forecast skill specific to Lake Sonoma, including collection of specialized observations (e.g., soil moisture) in the Lake Sonoma watershed.

The long-term goal is to translate and extend existing knowledge from previous studies in the Russian River to advance the estimation and prediction of precipitation and runoff/reservoir inflow, especially during high impact events, that result in heavy precipitation, saturated soils, and high streamflow rates at Lake Sonoma in the Russian River. Orographic modulation of precipitation in this portion of the Russian River basin is a key process that can lead to substantial differences between behaviors at the Lake Sonoma Catchment relative to Lake Mendocino. These differences can lead to differences in forecast skill and sensitivities to details of AR conditions at the coast. Although much has been learned about the forecast considerations for Lake Mendocino, it is important to extend and quantify these considerations. This effort will be completed in parallel with the other activities outlined in this Workplan and into the future as science and tools improve.

The need exists for improved hydrometeorological measurements of appropriate variables, with appropriate siting (spatial distribution) and temporal resolution, to support answering research questions about AR dynamics and evolution, orographic modulating of AR precipitation as well as the atmospheric river conditions that enhance the precipitation. Example activities to address these improvements are:

- Measuring hydrometeorological properties associated with ARs that bring large atmospheric moisture fluxes to the watershed and result in heavy precipitation. Conduct stream-gauge siting to record flows relevant to FIRO goals and conduct analysis of streamflow hydrology (e.g., hydrologic modification of travel time in streamflow).
- Extending the Russian River soil moisture network to cover more fully the conditions in Lake Sonoma's catchment area.
- Observing vertical profiles of hydrometeors and hydrometeors at the surface, in particular the microphysics of warm and mixed-phase cloud in relation to precipitation amount and timing at Lake Sonoma.

Improvements needed in understanding the meteorological context for QPF distribution in the Russian River to support verification efforts. Understanding can be improved by:

- Cataloging AR characteristics and precipitation mechanisms that impact streamflow rates at Lake Sonoma. Study how orientation, atmospheric stability, vertical distribution of water vapor flux, and the presence of different cloud types, explain variability in the amount of precipitation produced by an event at Lake Sonoma's catchment area, relative to Lake Mendocino's. This analysis can be conducted using existing radiosonde data collected during the Lake Mendocino FIRO Final Viability Assessment.
- Diagnosing meteorological differences across case studies and interpret their influence on precipitation forecasts and impacts. Calculate the threshold in precipitation that categorizes an extreme event in Lake Sonoma watershed.

Numerical weather prediction models suffer from systematic low quantitative precipitation forecast (QPF) in coastal mountains and redistribute the heaviest precipitation from the Russian River to the Napa River watershed, especially in ARs. An appropriate bias correction is required based on precipitation type. Development of such a bias correction requires:

- Developing CW3E's Weather Research and Forecasting model tailored for the West (West-WRF) for decision support and research hydrologic model forcing in the Russian River.
- Evaluating West-WRF performance in terms of its ability to reproduce the climatology of mixed-phase rain vs. warm rain in the coast range where the radar and disdrometer observations are available (e.g., Cazadero).
- Completing idealized WRF sensitivity studies using ensemble of boundary conditions that represent the range of cloud macro and environmental properties observed.
- Evaluating systematic impacts that aerosol might have on warm and mixed-phase precipitation timing and location.

2.3 Phase 3: Alternative Simulation and Evaluation

The purpose of Phase 3 is the execution of the analysis plan specified in the HEMP and determination of the viability of FIRO expansion to the Lake Sonoma watershed. In this phase, the FIRO alternatives identified in Phase 2 will be modeled, simulated, evaluated, and compared relative to the existing (baseline) conditions. The evaluations of each alternative will consider the set of metrics (defined in the HEMP) to identify potential benefits relative to current operations. The outcome of this phase will be the identification of one or more FIRO alternatives that can be recommended by the SC as candidates for updating the Lake Sonoma WCM (a USACE process).

2.3.1 Configure Models and Simulate Watershed Response

Each FIRO alternative and the existing (baseline) conditions will be configured in the existing HEC-ResSim model and operations simulated given a consistent set of hydrologic boundary conditions and system constraints. The results of these simulations will be release schedules, simulated storages, and computed downstream flows. Results will be stored in a database for future use.

2.3.2 Evaluate Existing (Baseline) Conditions and Alternatives

Each alternative FIRO strategy and the existing (baseline) conditions will be analyzed, and the appropriate performance metric statistics computed using the simulation results. This involves implementation of software applications (e.g., scripts, spreadsheets) developed to compute the performance metrics. In addition, HEC-FIA and HEC-FDA models will be used to compute flood consequences consistent with the procedures used in the Lake Mendocino FVA.

2.3.3 Compare Metrics and Select Alternatives

Each alternative FIRO strategy evaluation will be compared against the baseline and each other. These evaluations and comparisons will be reported in the form of charts and tables of the computed statistics for each performance metric. Each FIRO alternative will be ranked objectively using a multiple criterion ranking system consistent with that used in the Lake Mendocino FVA. Each alternative FIRO strategy comparison will be reviewed, a preferred alternative identified, and all findings will be documented.

2.3.4 Explore Alternative Physical Configurations

The results of the selected preferred alternative will be used to inform which alternative physical configurations of the system will be explored. These could be the same alternative configurations previously identified by the SC, refinements of the same, or new configurations born from review of the alternative assessment.

Here, the alternative physical configurations of the system will be configured in the HEC-ResSim models and the selected preferred FIRO alternative will be simulated given the defined set of hydrologic boundary conditions and system constraints. These results will be evaluated consistent with the methods used in evaluation of the other FIRO alternatives, and the performance compared to that of the FIRO alternative with the existing (baseline) physical conditions. Results will be compared, evaluated, and ranked to identify potential physical configurations of the system that would better satisfy the defined FIRO goals.

Exploration of alternative physical configurations may require significant refinements to the FIRO WCP to work a as designed and different analysis methods than those outlined in this work plan. For example, a water supply operations and reliability analysis could be undertaken to understand how FIRO might augment supply in the basin. The SC will outline the analysis plan in the HEMP and refine that plan based on the FIRO alternative assessment results.

Although the goal is to detail the evaluation of FIRO for both the existing and potential alternative configuration, the analysis and exploration of the alternative physical configurations may require a greater timeline than anticipated depending on the specific questions being asked and the detail of the analysis. It is possible that the selected preferred alternative could be implement using the existing system configuration while a longer-term FIRO solution using an alternative system configuration is studied and potentially implemented. If FIRO is found to be viable for an alternative configuration, additional studies and activities such as an engineering feasibility study, design and potentially funding agreements will be necessary prior to a WCM update for this scenario. Exploration of physical configurations may occur in parallel with Phase 4 so as to not impact interim operations of the WCM update process.

2.4 Phase 4: Interim Operations(s) and Water Control Manual Update

The purpose of Phase 4 is to implement the findings of the Lake Sonoma watershed FIRO viability assessment. This includes phased, temporary implementations such as those specified in Minor and Major Deviation requests, and permanent implementation in a formal WCM update. Similar to the Lake Mendocino FVA effort, the anticipated path is to first secure a Major Deviation that will implement the selected preferred alternative while the WCM update process is undertaken. .Any potential structural changes explored or considered would likely not be included in this update of the WCM.

2.4.1 Interim Operations

Interim operations at Lake Sonoma can be accomplished with the request and approval of a deviation from USACE. At this time, it is anticipated that FIRO would encroach into the existing flood management volume by approximately 5% to 10%, which requires a Major Deviation to the existing Water Control Plan. The anticipated efforts required to support a Major Deviation request are as follows:

- **Develop virtual operations**. Here, simulations of the existing (baseline) operations will be compared to those of the selected preferred alternative. Continuous tracking and comparison of these operations will inform operators and decision makers, giving additional confidence in the viability of the preferred FIRO alternative(s).
- **Update the Russian River FIRO Decision Support System (DSS)**. Here, the Lake Sonoma FIRO alternative planned for inclusion in the Major Deviation will be configured in the HEC-ResSim model integrated in the Russian River FIRO DSS. The enhanced DSS will be tested and deployed in coordination with California Data Exchange Center (CDEC) staff. The DSS will be used by USACE operators and water managers in combination with their spreadsheet tools to make operational decisions and gain insight and confidence in the FIRO expansion to Lake Sonoma.
- **Submit a request for a Major Deviation**. Here, either the SC or Sonoma Water will serve as the partner agency to USACE and will be the requester of the Major Deviation. The SC will complete the relevant studies and analysis required to support such a request as determined through coordination with USACE.

2.4.2 WCM Update

The Lake Sonoma WCM update process will be completed by the USACE San Francisco District. The SC will coordinate with USACE and support the District's effort as appropriate. Example activities include, but are not limited to, the following:

- Reservoir simulation analysis.
- Hydraulic analysis.
- Frequency analysis.
- Forecast skill assessment.

- Integration of FIRO 2.0 (an adaptive WCM process).

The WCM update process could be in multiple phases. In the near term, the update process could begin with an administrative update followed by an update to the WCP given the existing physical configurations of the system. In the longer term, an update of the WCP that uses a potential alternative configuration of the system could be undertaken.

CHAPTER 3 PROJECT SCHEDULE

The SC desires to complete the FIRO viability expansion assessment by early 2023. To that end, the SC has already begun work on Phase 1. Figure 8 shows the proposed schedule for completing the four-phased approach defined in this Work Plan. The proposed schedule draws heavily on the process, relationships, and work completed for the Lake Mendocino FIRO PVA and FVA. For example, forecast skill research and hydrologic datasets from the prior analyses can be used here where applicable.

The Lake Sonoma FIRO expansion effort will take advantage of the previous FIRO-related analyses in the Russian River and leverage the data, information, and other work products to complete FIRO assessment at Lake Sonoma in an accelerated manner. This includes the potential for interim operations (Phase 4) beginning in water year 2022 with a minor deviation, and potentially a major deviation in water year 2023 as this FIRO viability expansion assessment is completed.

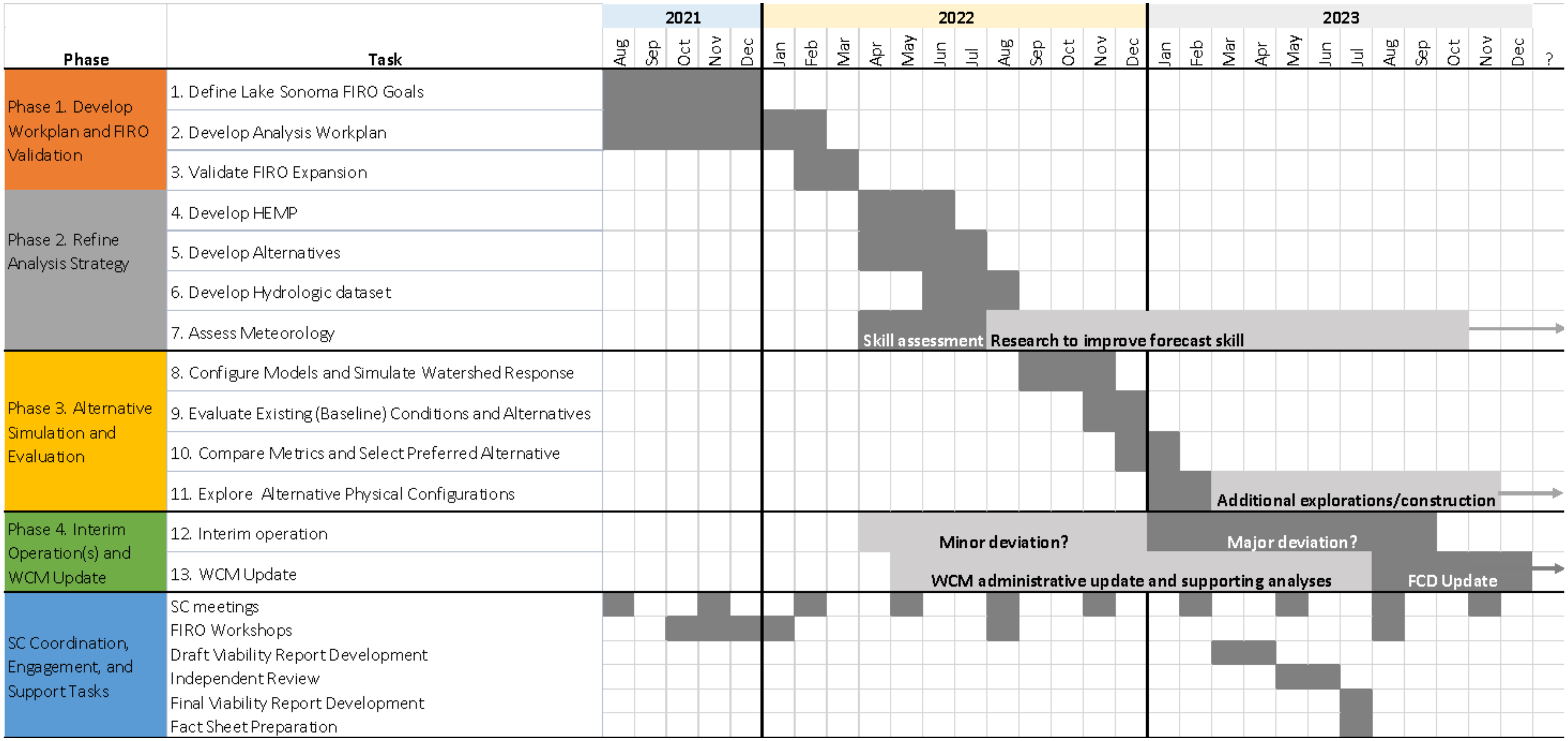

Figure 8. Proposed Lake Sonoma watershed FIRO expansion schedule

CHAPTER 4 ROLES AND RESPONSIBILITIES

The Russian River FIRO SC will lead the Lake Sonoma FIRO watershed expansion viability assessment and direct members of the Project Delivery Team (PDT). The PDT includes subject matter experts (SMEs) who will complete the analyses described herein, report on the findings and understandings, and recommend a single approach to be taken by the SC, and managers who will oversee the work effort. PDT members are identified below:

- Russian River FIRO SC
- SW technical staff
- USACE Headquarters staff (HQ)
- USACE Hydrologic Engineering Center (HEC) staff
- USACE Engineering Research and Development Center (ERDC) staff
- Center for Western Weather and Water Extremes, Scripps Institution of Oceanography at University of California, San Diego (CW3E)
- USACE, San Francisco District (SPN) staff

The PDT members have roles consistent with established project management planning, as shown in Table 3. These roles vary by hydrologic engineering task.

Table 3. Project roles

ID (1)	Role (2)	Description of duties (3)
R	Responsible	Responsible for completing the analyses described herein. .
A	Accountable	Answerable for correct and thorough completion of task; ensures requirements are met; delegates work to those responsible.
C	Consulted	As SMEs, offer opinions through two-way communication with those responsible and accountable, about conduct of analyses.
I	Informed	Kept up to date on progress through two-way communication.