Phase III of Forecast-Informed Reservoir Operations in the USACE: National Expansion Pathfinder

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Abstract

Since 2014, the US Army Corps of Engineers (USACE) has been engaged in a multi-agency research and development effort called Forecast-Informed Reservoir Operations (FIRO) which is exploring how advances in weather prediction and observations can inform operations and policy decisions at federal, state and local water management agencies with the collaborative engagement and support of researchers, engineers, operators and stakeholders. FIRO represents a new phase of water management for USACE wherein forecast information can now be used for planning future operations, a significant change from the decades-long policy of operating solely to "water on the ground." Phase I of FIRO developed a process for assessing the viability of FIRO at the initial pilot reservoir, Lake Mendocino in northern California. Phase II, which completes in FY23, explored transferability of viability assessments to additional pilot sites. The lessons learned from the application of FIRO to all the pilots was also used to develop a FIRO screening process that results in an index of FIRO suitability for a portfolio of dams to identify promising candidates for full FIRO viability assessments. The FIRO R&D effort has now entered Phase III, the National Expansion Pathfinder, and over the next five years, will consist of the following major efforts: 1) National forecast skill assessment and improvement campaign which will include a continued major investment in Atmospheric River (AR) and other storm type improvements that have yielded significant benefits to date; 2) Completion of viability assessments begun in Phase II to support planned Water Control Manual (WCM) updates at those reservoirs; 3) Explore application of FIRO to systems of dams by conducting a full FIRO viability assessment on the Willamette Valley (OR) system of dams (14 dams in total); 4) Conduct a full viability assessment for a system of 8+ dams in another region nationally where different storm types (in addition to ARs) are key to heavy rain and flooding (e.g. tropical storms/hurricanes, long-lived thunderstorm cluster, Nor'Easters, etc.); 5) Conduct full viability assessments on two single dams in other regions nationally; and 6) Apply the FIRO screening process to the USACE portfolio of dams (~700 dams) to obtain a FIRO suitability index to prioritize future FIRO viability assessment efforts. Lessons learned from FIRO Phases I and II will be presented along with plans for how Phase III will be carried out over the next five years.

Introduction

Background

The U.S. Army Corps of Engineers (USACE) has been engaged in the Forecast-Informed Reservoir Operations (FIRO) effort since 2014. In Fiscal Year (FY) 2015, Congressionally-directed additional funding was provided in the Water Operations Technical Support (WOTS) program to conduct research into atmospheric rivers to improve weather forecast skill and to develop a better understanding of the balance between water supply, flood risk management and ecosystem benefits at multi-purpose reservoirs. Since December of 2014, the USACE has actively participated in a multi-agency, multi-discipline research and development effort to investigate how FIRO approaches might be safely and appropriately applied at the pilot reservoir, Lake Mendocino, in the Russian River watershed in northern California. This initial FIRO investigation (Phase I), carried out over 5 years, concluded successfully in early 2021, after demonstrating substantial benefits in a severe drought year by increasing water availability for the dry summer by almost 20 percent. The investigation results motivated a 5-year deviation from the existing water control plan to continue FIRO operations there while an update to its water control manual (WCM) has been initiated to permanently incorporate the FIRO principles and methods.

Prior to the conclusion of Phase I in 2019, the FIRO effort began a 5-year transferability study (Phase II) focused on exploring transferability of Lake Mendocino's results across a broader range of reservoirs and watershed conditions, all within the western coastal region where atmospheric rivers are the dominant storm type. Through Phases I and II, FIRO has shown that significant improvements in achieving a better balance between water supply, flood risk management and ecological benefits can be achieved. The improvements come at negligible negative impact to the multi-purpose objectives, but rather provide increased benefits to all objectives simultaneously through improved efficiency in operations, as opposed to costly and lengthy infrastructure changes. The USACE believes similar benefits will be realized at other reservoirs through execution of the atmospheric and hydrologic research and initial exploration of applicability nationally that the FIRO Phase III plan will develop and deliver. Phase III represents a National Expansion Pathfinder, as described below.

Previous FIRO Phases

FIRO Phase I: "Pilot"

FIRO Phase I was begun in FY15 and led to the development of an effective process to determine if weather forecast skill for a reservoir is adequate to safely incorporate forecast information in reservoir operations and concluded that it is. This was demonstrated initially for a single pilot dam, Lake Mendocino, on the East Branch of the Russian River in northern California that supports a climate-change-vulnerable region, where atmospheric river-type storms are the cause of both flooding and provider of water supply. Talbot et al. (2019) describes this effort in detail along with the Final Viability Assessment (FVA) of FIRO at Lake Mendocino published by the Lake Mendocino FIRO steering committee in 2020 (Jasperse et al., 2020).

As part of the FIRO viability assessment process, major deviations, defined as plans that deviate greater than 5% from the existing water control plan contained in the WCM, were requested and

FIRO scenarios were tested in water years (WY – defined as October 1 to September 30 in California) 2019 and 2020. In WY 2019, a relatively wet year, FIRO demonstrated increased flood risk management benefits while in WY 2020, the third-driest year on record at the time, nearly 20 percent more water was made available leading in to the dry summer period through flexibility in operations made available to water managers through use of FIRO (Figure 1). This amount of water is roughly equivalent to the annual water use of 22,000 households. FIRO Phase I efforts concluded in FY 2019 and thereafter the USACE San Francisco District began a FIRO-based update to the Lake Mendocino WCM which is expected to be complete in 2023. The FVA-recommended plan defines a buffer zone, which is 10% of the Lake Mendocino storage volume, as flexible space available to the water manager to use to meet multipurpose objectives, based on forecasted weather, watershed and downstream conditions.

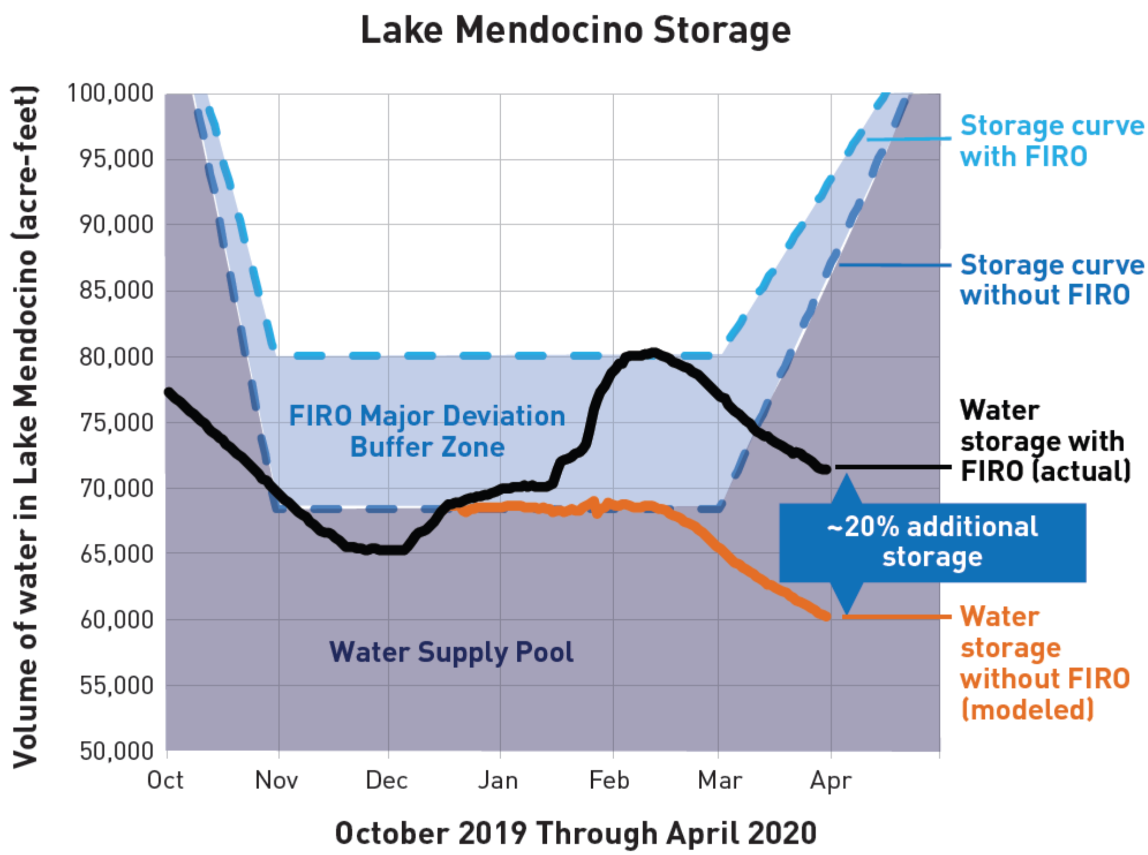

Figure 1. Lake Mendocino storage increased by ~20 percent during major deviation operations in WY 2020, compared with modeled storage without FIRO, during a year when precipitation was 38 percent of average. (figure credit: Sonoma Water)

FIRO Phase II: "Transferability"

Phase II, begun in FY19, is exploring the transferability of the findings from Phase I to other dams where ARs are also the primary storm type, but with differing context (urban vs rural vs snow-dominated) and reservoir purposes (flood control only vs combination of supply and flood), as well as reservoir sizes and connectivity to much bigger water supply/flood control systems. These assessments are being conducted on 4 reservoirs as described below.

Prado Dam: Prado Dam, on the Santa Ana River in southern California, was built by the USACE in 1941. The Orange County Water District (OCWD) and USACE have worked together since then to maximize the capture and groundwater recharging of stormwater held behind the dam after storm events. Figure 2 shows the elevations and volumes of the current conservation pool as well as tested FIRO elevations. USACE releases water temporarily captured at Prado Dam and OCWD recharges the water into the ground 10 miles downstream. The water conservation pool has been operated at elevations up to 505 feet based on a five-year major deviation approved by USACE in March 2018. The Prado Basin Ecosystem Restoration and Water Conservation Feasibility Study was approved in 2021 to make the 505-foot conservation pool a permanent feature within the Interim WCM (Ralph et al., 2021).

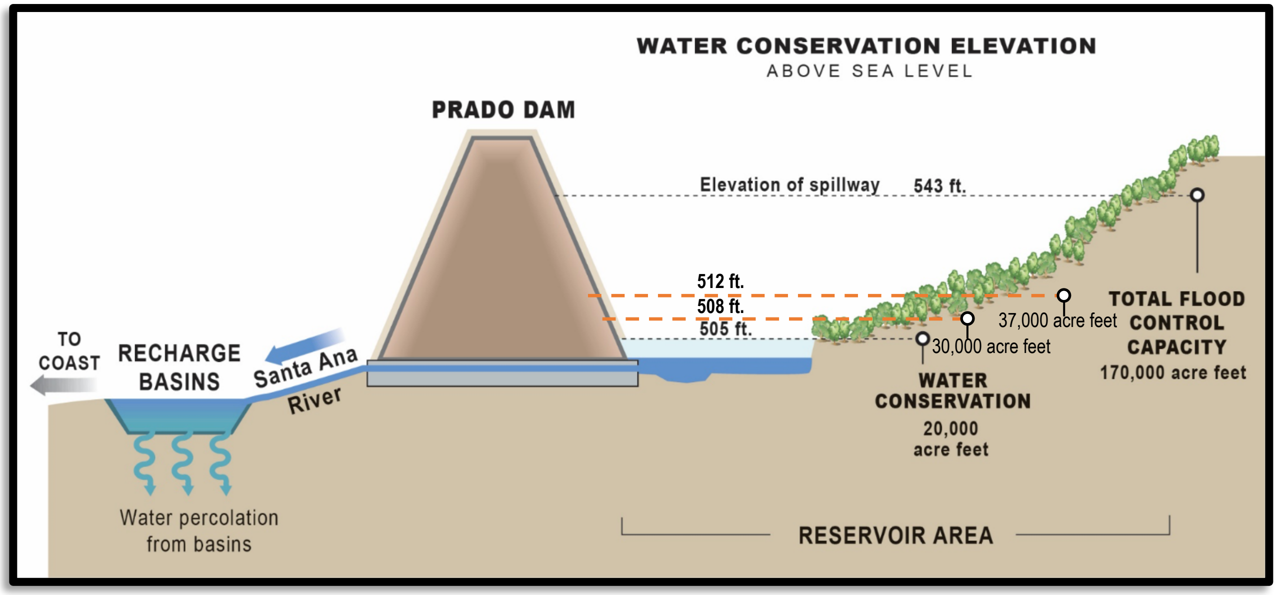

Figure 2. Schematic of Prado Dam water conservation elevation for stormwater storage and capture with tested FIRO buffer pool levels of 508 and 512 feet. (figure credit: OCWD).

Over the past 25 years, OCWD has recharged an average of 55,000 acre-feet (ac-ft) per year of stormwater with an annual maximum of 117,000 ac-ft in 1995. For planning purposes, OCWD assumes that 40,000 ac-ft of stormwater will be captured and recharged in an average year, which is enough water for 320,000 people annually. Local stormwater capture is important because it lessens demands on imported water supplies, which are more costly and increasingly unreliable due to oversubscription, ongoing drought, and changes in climate.

Like most current WCMs within the USACE, the Prado Dam WCM does not explicitly leverage weather and water forecasts. Nonetheless, USACE water management staff consider precipitation and streamflow forecasts in their decision process while adhering to WCM guidelines and procedures. As part of the FIRO viability assessment process at this site, the Prado Dam FIRO Steering Committee conducted and published a Preliminary Viability Assessment (PVA) in July 2021 which tested and determined the range of possible FIRO scenarios that could be supported by current operational constraints, current forecast skill and other relevant factors.

The Prado Dam PVA evaluated current forecasting technology and incorporated research to understand and therefore better predict precipitation processes in the Santa Ana River Watershed. The Ensemble Forecast Operations (EFO) model, which was used to assess FIRO at

Lake Mendocino, was successfully generalized and applied to Prado Dam for the simulation of operations needed to assess strategies for implementation in the updated WCM. The EFO model operates without a traditional guide curve and uses the 15-day ensemble streamflow forecasts to identify required flood releases. The Steering Committee's preliminary assessment of FIRO was based on five operational strategies, described in Table 1.

The EFO model was successful in simulating the reservoir operations strategies listed in Table 1 over the hindcast period of record (1985–2011) and for three large events scaled to 100- and 200-year return frequency levels. Hindcast period of record simulations for all alternatives remained well below the spillway crest, and higher buffer pools led to greater groundwater recharge, averaging nearly 7,000 ac-ft per year. The scaled events, which generated spillway flow for all FIRO alternatives, exhibited slightly lower spill rates than the baseline. The upper limit of the buffer pool is largely a function of community and environmental tolerance for more frequent flood pool inundation than operational constraints of the dam. Land and easement purchases coordinated by USACE and Orange County Public Works are required for the spillway raise and will be critical to easing impacts of more frequent inundation. At the highest pool elevation assessed (512 feet), the use of forecasts is needed to avoid increased flood risk.

The PVA also concluded that, while precipitation gages are adequate to support FIRO, improvements are needed at two stream gage locations to support operations and model calibration and development. In addition, the hydrologic engineering management plan (HEMP) initial assessment was found to provide a consistent framework within which Water Control Plan (WCP) alternatives can be simulated and compared. Identified refinements will improve the quality of the FVA.

Table 1. Alternative Water Control Plan strategies assessed for the Prado Dam FIRO PVA.

ID	Alternative Strategy	Description
1	Unrestricted: 505 feet (baseline)	Buffer pool* allowed to extend up to 505 feet without a seasonal restriction. Releases when pool is ≤ 505 feet at maximum recharge rate. Releases above 505 feet are at the maximum scheduled rate. No forecasts were used.
2	EFO-508 feet	Buffer pool allowed to extend up to 508 feet. Uses ensemble inflow forecast to determine release required to mitigate risk of exceeding spillway crest.**
3	EFO-512 feet	Buffer pool allowed to extend up to 512 feet. Uses ensemble inflow forecast to determine release required to mitigate risk of exceeding spillway crest.**
4	No Forecast-512 feet	Buffer pool allowed to extend up to 512 feet. Releases when pool is ≤ 512 feet at maximum recharge rate. Releases above 512 feet are at the maximum scheduled rate. No forecasts were used.
5	Perfect Forecast-512 feet	Buffer pool allowed to extend up to 512 feet. Uses observed inflows as forecasts (perfect forecasts) to determine releases that avoid exceeding spillway crest.**

* "Buffer pool" is a USACE Los Angeles District term used to describe an acceptable temporary encroachment into the flood pool for water conservation purposes.

** A spillway crest of 543 feet was evaluated for period of record simulations, and spillway crests of 543 and 563 feet were evaluated for 100-year and 200-year scaled hydrologic events.

Additionally, the PVA provided the following high-level findings that support FIRO viability at Prado Dam:

- Evaluation of FIRO WCP alternatives suggests that higher buffer pools can enhance groundwater recharge, averaging nearly 7,000 ac-ft per year, while not impacting and perhaps enhancing flood risk management outcomes.
- Much progress has been made to improve AR forecasts and AR tools. Evaluation of the AR landfall tool for Prado Dam showed full internal agreement at three-day lead times and a high degree of reliability at greater than five days' lead time, which is sufficient for dam operators to make timely releases.
- Studies of least Bell's vireo (a federally listed endangered species of bird that nests in the water conservation space behind the dam) indicate tolerance to inundation, but further studies are needed to assess prolonged inundation at higher elevations. An adaptive management approach with planned mitigation measures will be pursued.

Based on these findings, the FIRO Steering Committee recommended continued research and monitoring to further improve potential FIRO outcomes, coordination with and support of the USACE WCM update process, development of operational decision support tools designed specifically for FIRO implementation, refinement of the HEMP for evaluating the WCP alternatives, and interim operational testing through USACE's deviation process. In particular, the Steering Committee recommended submitting a multi-year deviation beginning in water year 2023 (October 2022) to gain operational experience with a FIRO maximum buffer pool greater than 505 feet. This deviation request was submitted in 2022 and is currently under evaluation.

The PVA concludes that it is an opportune time to consider FIRO at Prado Dam. With improvements underway to raise the Prado Dam spillway crest and upgrade downstream infrastructure (Santa Ana River Mainstem Project), a very high level of flood risk management will be achieved. Based on the recommendations from the PVA, an FVA workplan has been developed and is currently being conducted with expected completion in 2024.

Yuba-Feather System: In addition to Prado Dam, a third pilot was added that consists of a two-dam system in one large watershed where snowpack is a vital water supply, and floods are strongly influenced by how much of the watershed experiences rain vs snow in a storm. This system, the Yuba-Feather System, consists of New Bullards Bar (NBB), owned and operated by the Yuba Water Agency (Yuba Water) on the Yuba River and Lake Oroville (ORO), owned and operated by the California Department of Water Resources (DWR), on the Feather River (see Figure 3). Releases from NBB and ORO converge in Yuba City, CA which requires that operations between these two reservoirs be coordinated. The primary objective of the Yuba-Feather FIRO project is to reduce flood risk; a secondary objective is to achieve water supply benefits where possible, while supporting environmental needs (Ralph et al., 2022).

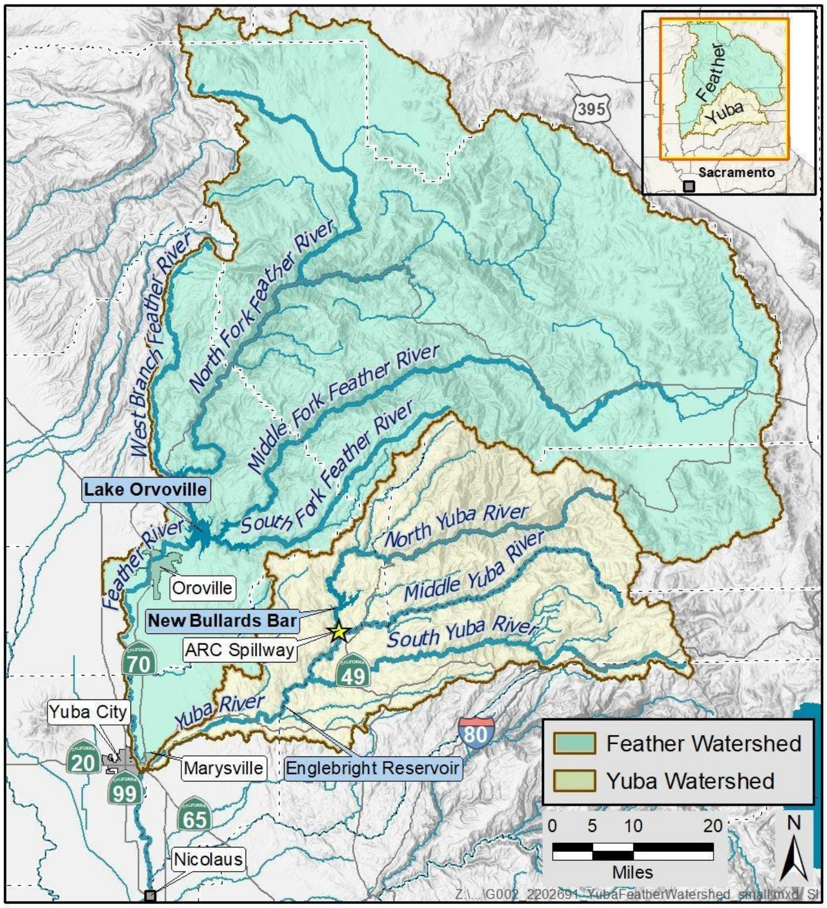

Figure 3. Map of the Yuba and Feather River watersheds.

As with the previous FIRO pilot efforts at Lake Mendocino and Prado Dam, a PVA was conducted for the Yuba-Feather system with the report detailing the findings published in December 2022.

Begun in 2019, the Yuba-Feather FIRO effort has two primary elements: improving precipitation and runoff forecasts, especially for large AR events, and integrating improved forecasts into new reservoir operations to improve operational flexibility. Data driving FIRO include weather data collected from reconnaissance flights over the Pacific Ocean, weather balloons launched during AR storms, and a growing network of weather stations that collect continuous real-time data to ground-truth conditions, including soil moisture, which is critical for more accurate runoff predictions. A robust AR research program is central to improving precipitation forecast accuracy and lead times and to meet FIRO objectives over time.

The Yuba-Feather PVA assessed whether improved precipitation and runoff forecasts can reduce flood risk below the NBB and ORO reservoirs, based on multiple flood risk metrics. The primary flood risk reduction method is reservoir releases ahead of large storm events (i.e., pre-releases), which creates additional temporary flood storage space for anticipated inflows. However, there are limitations on downstream flows, so flood storage volume, elevation to spillway crest, and peak downstream flows were all considered in the analysis.

FIRO evaluation considered current operations and two FIRO alternatives that were assessed within the context of Forecast-Coordinated Operations, the system DWR and Yuba Water use to coordinate releases from ORO and NBB. Based on the PVA experience, refinements will be made for the FVA to determine how best to meet the objectives for each reservoir, as well as points downstream.

Overall, the Yuba-Feather FIRO PVA indicates strong potential for FIRO to be a viable water management strategy for reducing flood risk in the Yuba and Feather River watersheds. Some key findings of the PVA include:

- FIRO has the potential to enhance flood risk management without impacting water supply
- Frequency of exceeding key pool elevations, outflows, and downstream flows is generally reduced with the preliminary FIRO alternatives when compared to existing operations
- End-of-event storage, a cursory indication of water supply reliability, is generally increased

To better leverage forecasts, Yuba Water is designing a second spillway, called the Atmospheric River Control (ARC) Spillway for NBB that allows for greater forecast-informed pre-releases at lower reservoir elevations. Using FIRO with the planned spillway will enable the management of up to an additional 117,000 acre-feet of reservoir space and the potential to reduce water levels on levees near Marysville by 2 to 3 feet.

The FVA, to be completed in 2023, will further refine and assess the alternatives and test them against projected climate change hydrology, with the FIRO implementation phase beginning in 2024. USACE is updating its WCMs, which govern reservoir flood operations for both reservoirs, in parallel with the FVA to ensure FIRO integration into reservoir operations by 2026.

Howard Hanson Dam: A fourth FIRO pilot site was selected at Howard Hanson Dam on the Green River upstream from Seattle. This pilot study has experienced some delays in the Steering Committee formation due to various factors, including the effects of the COVID-19 pandemic, but recent progress is being made that is moving this effort forward once again. While the exact goals of the application of FIRO at this site will yet be decided by the Steering Committee once it is fully formed, a FIRO viability assessment in a much wetter Pacific Northwest watershed presents some interesting FIRO application opportunities. In discussions with the various stakeholders including the Seattle District of the USACE, Tacoma Water and the King County Flood Control District, a proposed goal of application of FIRO at Howard Hanson Dam is to improve water availability for fisheries without increasing downstream flood risk. This would be accomplished by exploring the use of modern forecast methods to enable earlier reservoir refill and later draw down to the flood pool, under current and future climate conditions, including droughts, so that more water is available for higher spring and later season flows that better mimic natural river flows. Additional secondary goals could be to improve water availability.

Screening Process: Using lessons learned from the transferability of FIRO to additional pilot sites in Phase II, a FIRO Screening Process has also been designed and developed to scale up the implementation of FIRO. The Screening Process maintains the same level of rigor and quality to the process as demonstrated at the original pilot sites but at a screening level which can be executed more rapidly than full viability assessments, enabling FIRO benefits to be accessible at more reservoir sites.

The goal of the screening process is to develop a broadly usable tool for water management agencies to determine sites where FIRO may be appropriate, including evaluating entire portfolios of reservoirs. The Screening Process is meant to be an adaptable, easy-to-use process that empowers more local ownership over FIRO implementation.

As depicted in Figure 4, the FIRO Screening Process has been designed as a three-stage process with the first Stage A being an initial screening with "weed out" criteria to eliminate dams that have little potential or no FIRO potential due to any one of a number of criteria, such as not having a controlled outlet or no WCM. Stage B delves into the specifics of each candidate site and is designed to produce a spectrum of less to more suitable for FIRO scoring. This "suitability index" can be used by a water resources agency to decide where further FIRO investigation is warranted, given limited time and resources. The third Stage C involves a more thorough assessment and dialog with those sites that are prioritized in Stage B. As depicted in Figure 4, a variety of outcomes are possible from this Stage C assessment. Possible outcomes of Stage C include FIRO appears to be possibly viable but the potential benefits are minimal and would not warrant a full viability assessment. Other Stage C outcomes might be that more research and improvements in forecast skill, for example, could be needed or possibly an in-depth viability assessment before a determination could be made. Finally, Stage C could also reveal sites where all indications are that FIRO suitability is high and a full viability assessment would yield positive, meaningful benefits.

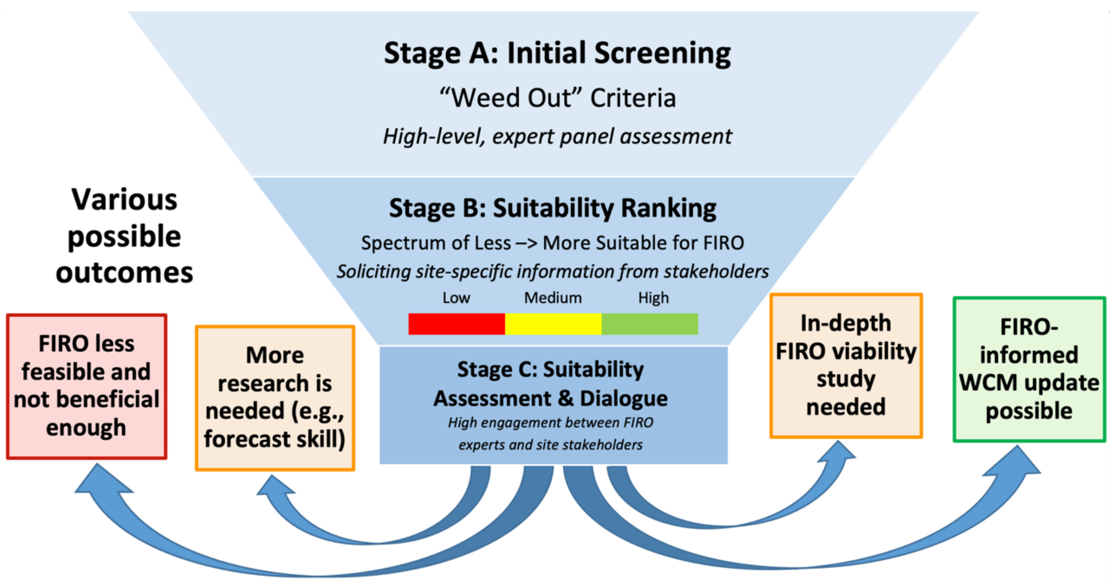

Figure 4. Stages of the FIRO Screening Process with potential outcomes.

The Screening Process is currently being tested and refined through application to all 85 reservoirs under the purview of USACE South Pacific Division. The testing process is scheduled for completion in the Fall of 2023.

FIRO Phase III: "National Expansion Pathfinder"

Phase III Overview

Fiscal Year (FY) 2023 is the final year of FIRO Phase II as well as the first year of Phase III, the "National Expansion Pathfinder". Phase III accelerates FIRO assessments substantially by: expanding to systems of dams and to other regions nationally where extreme precipitation and flooding is influenced by different storm types; applying the screening process to all USACE dams; completing the FIRO viability assessments underway in Phase II; and expanding the research into improving forecast skill, particularly in areas of the U.S. that are impacted by atmospheric rivers and/or other major storm types, specifically tropical storms/hurricanes, clusters of thunderstorms, and Nor'Easters. Phase III will complete core elements of the FIRO National Expansion Pathfinder as described below.

Forecast Skill Assessment and Improvement for Multiple Types of Flooding Storms: FIRO is not viable at reservoirs where forecasts of extreme precipitation and associated floods do not have adequate skill. Although meteorology has largely struggled to improve quantitative precipitation forecasts (QPF), FIRO Phases I and II have found that atmospheric rivers are the key storm type in the west coast flood season (fall/winter). Additionally, FIRO research has found that there is adequate skill to support FIRO operations at Lake Mendocino with additional positive PVA results at Prado Dam, ORO and NBB. Research to improve forecasts have benefitted from focusing on the storms that predominantly produce the precipitation at these reservoirs, i.e., atmospheric rivers. FIRO viability has also been favored by the fact that watersheds along the west coast are relatively short and steep, leading to short travel times for water released from a dam to move beyond flood prone areas. AR forecast skill at lead times of even just a few days is often sufficient for FIRO to be viable at many reservoirs.

FIRO viability in other regions nationally, where other very different storm types dominate flooding, will hinge on the forecast skill for these storms and on the watershed sizes and travel times for water released from dams. Slopes are likely much shallower and thus water travel times longer in places like much of the southeast and Great Plains. Also, convection, a frequent storm type in many parts of the country, especially in the summer, is notoriously difficult to predict accurately, while the track and intensity of landfalling tropical storms/hurricanes can also be difficult to predict, including whether or not they stall (e.g., hurricanes Harvey and Florence). Studies have found that forecast skill for extreme daily precipitation is best in the west (due to ARs) followed by New England, and suggests the need for improvement in QPF for these storm types may be needed for FIRO to be viable.

Precipitation prediction skill is tied to the dynamical processes in the major storm types, and to the models and forecast tools that have been developed to predict them. As with atmospheric rivers in the west, a key to identifying the causes of errors in predictions of extreme precipitation in these storm types is understanding the meteorological attributes of the storms that make them capable of producing the extreme precipitation. This also leads to fruitful research pathways for improving these predictions. By analogy, the hydrologic differences in regions affected by these storms need to be considered.

Finally, a key recommendation from FIRO Phases I and II is that water control manual updates include attributes that allow for expedited increases in reservoir operations flexibility (i.e., the size of the "FIRO space" or amount of flexibility granted to water managers) as precipitation and inflow forecast skill improves. This is referred to as "FIRO 2.0" and represents a potentially efficient way to enhance reservoir operations over time, while also motivating continuing improvement in forecast skill and use of that skill to deal with increasingly extreme weather and water events anticipated to be characteristic of the future. Essentially, the concept of FIRO 2.0 is to build update WCMs at FIRO-viable sites in such a way that they incorporate FIRO for current forecast skill but also allow provision for the size of the FIRO space to increase if forecast skill improves in the future.

Completion of Final Viability Assessments at Western Reservoirs Started in Phase II: Several efforts from Phase II will not be complete at the end of Phase II in FY23 and will therefore need to be carried to completion in Phase III including:

- FVA for NBB and ORO to be completed in FY24
- Viability assessment for Howard Hanson Dam. The workplan will be developed in FY23 with the PVA in FY24 and FVA in FY25
- Viability assessment for Lake Sonoma which was added in FY22 as a sibling dam to Lake Mendocino in the Russian River valley
- Viability assessment for Seven Oaks Dam which was added in FY22 as an upstream dam to Prado Dam.

Conduct Full Viability Assessment of System of 14 Dams in the Willamette River Basin: Phase III will assess two major systems of dams (representing at least 8 dams in each system), for which coordination across several dams in an entire larger watershed is required. The first of these will be the Willamette watershed system, with its 14 reservoirs, where atmospheric rivers are the main drivers of floods and a leading source of water supply, and where lessons from Phases I and II can efficiently be applied and the skill of atmospheric river prediction can be utilized.

Conduct Full Viability Assessment of System of 8+ Dams in another region nationally: Building on the lessons learned from conducting a FIRO viability assessment in the Willamette valley, Phase III will explore a system in a region where different storm types are key to heavy rain and flooding, and where longer forecast lead times may be required. The second system of at least 8 dams to be examined in Phase III will be in one of these regions where non-AR storm types are a key factor. This is to be located in a region where extreme precipitation is dominated by tropical storms/hurricanes, clusters of long-lived thunderstorms, or Nor'Easters. Atmospheric rivers may also be an important storm type in this region.

Conduct Full Viability Assessments on Two Single Dams in Other Regions Nationally: Two additional non-system viability assessments are to be conducted in regions of the country where extreme precipitation is dominated by weather systems other than ARs, e.g., tropical storms/hurricanes, large clusters of long-lived thunderstorms, or Nor'Easters. These dams will not be located in the same regions explored in the assessment of system of dams.

FIRO Screening-Level Process – Preliminary National Assessment: All or parts of the Western states are impacted by atmospheric river events, some to greater degrees than others. The FIRO Screening Process was developed from lessons learned by applying FIRO to Lake Mendocino (rural, coastal, flood and supply), Prado Dam (urban, coastal, flood and groundwater recharge), Oroville and New Bullards Bar (rural, Sierra Nevada mountains, flood and major water supply for California), and Howard Hanson (urban, Washington cascade Mountains, flood and water supply, fisheries). The Screening Process was then tested by being applied to all 85 USACE South Pacific Division dams. Additionally, the other aspects of Phase III will explore FIRO in regions characterized by other storm types and reservoir operations strategies, constraints and methods, allowing the systematic growth of the scientific and engineering knowledge base needed to perform well-founded future assessments of FIRO applicability across a much broader range of conditions than has been explored in the first pilot reservoir, Lake Mendocino, and the transferability study basins in the West. The Screening Process will be applied to the nationwide portfolio of USACE dams and reservoirs, the result being an index of FIRO suitability across the portfolio, helping the USACE to prioritize future viability assessments and WCM updates based on FIRO.

Final Report: The full viability assessments for several reservoirs across different regions nationally, as well as results of applying the FIRO screening-level process across all USACE dams will be documented in a concluding report for the FIRO National Expansion Pathfinder that will be made available to the public and agencies as a guide for how assessments for FIRO viability can be conducted at reservoirs across the United States and beyond.

Conclusions

With the key policy update in May 2016, the USACE has entered a new phase of water management where forecasts can be officially incorporated into WCMs and other water management practices. The FIRO research and operations partnership has defined how this can safely and effectively be done and codified in WCM updates. The PVA and FVA studies conducted to date indicate from 5-20% increased water availability as well as improvements in flood risk management and ecosystem benefits at the reservoirs where FIRO has been studied. The results of Phases I and II of FIRO have demonstrated the value of assessing FIRO viability at candidate reservoirs and Phase III will continue to explore how these benefits can be realized in other parts of the country and at an accelerated pace. Results to date clearly indicate that FIRO provides an effective means of increasing the efficiency and resiliency of existing water resources infrastructure to achieve multi-purpose benefits and provide increased flexibility demanded by climate change, all without costly construction projects.

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