Reservoir Reoperation Resource Management Strategy

CALIFORNIA WATER PLAN UPDATE 2023

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Acronyms and Abbreviations

CDFW	California Department of Fish and Wildlife
DWR	California Department of Water Resources
FIRO	forecast informed reservoir operations
FIRO-MAR	forecast informed reservoir operations and managed aquifer recharge
Flood-MAR	flood-managed aquifer recharge
RMS	resource management strategy
SGMA	Sustainable Groundwater Management Act
SRS	system reoperation study
SWP	State Water Project
USACE	U.S. Army Corps of Engineers
Water Supply Strategy	California's Water Supply Strategy: Adapting to a Hotter, Drier Future
WCM	water control manual
WCP	water control plan
WSWB Project	Willow Springs Water Bank Conjunctive Use Project

1. Introduction

California Water Plan Update 2018 describes system reoperation as a resource management strategy that for "water resources means changing existing operation and management procedures for a water resources system consisting of supply and conveyance facilities and end user demands with the goal of increasing desired benefits from the system." That resource management strategy (RMS) noted that reoperation of existing facilities usually serves one or more of three basic purposes:

1. Addresses a specific problem(s) or need(s).
2. Improves efficiencies.
3. Adapts facilities to anticipated future changes (e.g., changes in water demands, legal and regulatory constraints, and key physical variables such as climate).

The 2018 RMS explored and assessed reoperation concepts associated with one local, large reservoir and several large federal and State reservoirs. One of the reoperation elements described in the SRS was reoperation of multi-purpose reservoirs to facilitate improved performance in one or more of those purposes. This Reservoir Reoperation RMS focuses on this kind of reoperation specifically, describing several programs that facilitate consideration of reservoir reoperation and demonstrate mechanisms to advance and implement reoperation concepts in California.

California's Water Supply Strategy: Adapting to a Hotter, Drier Future (August 2022) makes a State commitment to, "work with the U.S. Army Corps of Engineers (USACE) leadership to accelerate the pace at which the manuals guiding reservoir operations are updated to reflect a changed climate." This commitment reflects a general acknowledgement that there is a continuing effort to improve forecasting, data, and management of water resources as plans are made for dealing with a changing climate future.

Action 7.1 of California's Water Resilience Portfolio (2020) makes a commitment to accelerate State permitting of projects that protect and enhance fish and wildlife and water supply reliability, such as those that were selected under the Water Storage Investment Program (Proposition 1). Several of the projects include reoperation elements that rely on conjunctive use of surface and groundwater storage.

Forecast Informed Reservoir Operations

One promising reservoir reoperation pathway is forecast informed reservoir operations (FIRO), a reservoir-operations strategy that better informs decisions to retain or release water by integrating additional flexibility in operation policies and rules with enhanced monitoring and improved weather and water forecasts (American Meteorological Society 2021). FIRO represents a relatively low-cost alternative to improving water management because, at most locations, it only seeks to modify the regulations for reservoir management and does not require the construction of any hard infrastructure. This allows more opportunistic capture of runoff without constructing additional surface storage facilities. Under USACE leadership, FIRO is progressing as a research and operations collaboration effort and has been successfully applied at Lake Mendocino in the Russian River Basin, showing nearly 20 percent more water storage with FIRO operations in Water Year 2020. Figure 1 shows operations with and without FIRO, indicating the potential scale of benefits, which will differ based on the reservoir and weather.

Figure 1 Lake Mendocino Storage

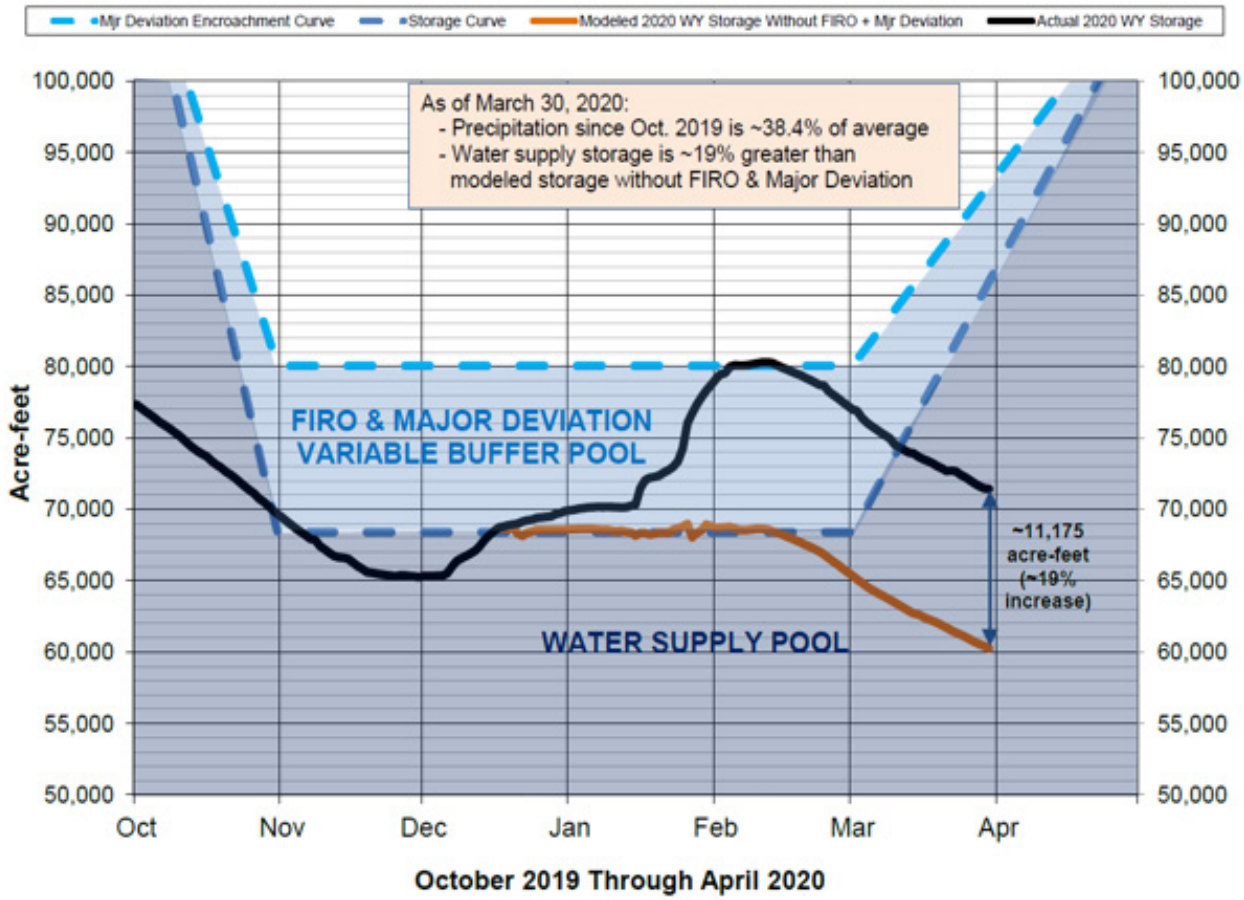


Figure 1 illustrates that the water control manual (WCM) for Lake Mendocino allows the reservoir to be operated at or below 68,000 acre-feet during the wet season, then fill to as much as 100,000 acre-feet during the dry season, with some transition. A FIRO deviation allowed the lake to be filled to as much as 80,000 acre-feet during the wet period based on forecasts, resulting in the 11,175 acre-feet improved water supply pool at the end of March 2020. This kind of flexibility can be accomplished based on forecasts, including the accuracy of those forecasts.

Lake Mendocino is a reservoir in the Russian River Watershed located in Northern California and is the first FIRO pilot project. To date, FIRO projects have followed a certain pathway for the development of documents and deliverables. Over time this may change, but for the time being, this pathway has proven to be very successful and is based on the Lake Mendocino project experience and lessons learned.

There may be opportunities to implement FIRO-like concepts at reservoirs that are not USACE-related facilities, but for discussion purposes here, focus is on the USACE FIRO efforts. The number of FIRO projects with USACE is being expanded in the Russian River Basin (Lake Sonoma), in the Santa Ana River Basin (Prado Dam and Seven Oaks Dam), and the Yuba-Feather River Basin (New Bullards Bar Dam and Oroville Dam). New Bullards Bar and Oroville are combined in one study and update because their WCMs have shared responsibility to coordinate reservoir releases to meet specific flood flow targets on the Feather River. Each of these FIRO projects is engaging experts and stakeholders in civil engineering, hydrology, meteorology, biology, economics, and climate from federal, State, and local agencies. Scripps Institution of Oceanography's Center for Western Weather and Water Extremes is an essential partner in these efforts, advancing understanding of extreme weather events, including atmospheric rivers, and developing tools and science to enable multipurpose reservoir operators to use the best available science to inform their actions, including forecasts. USACE is assessing FIRO suitability at other appropriate sites throughout the U.S. The keys to FIRO success reside in:

- A local champion.
- Intentional collaboration.
- Research and operations partnership.
- A shared vision for implementation.

Ultimately, in these watersheds, FIRO is implemented by USACE with WCM updates. When federal funds are used to construct a dam that includes flood mitigation as an authorized purpose, the USACE becomes responsible for managing that purpose pursuant to Section 7 of the U.S. Flood Control Act of 1944. A primary mission of the

USACE is flood risk reduction, including operating and maintaining dams and other flood risk management infrastructure. Given the consequences of dam failure, the USACE takes their responsibility very seriously. A WCM is developed for each Section 7 or USACE dam that includes flood control as an authorized purpose. The WCM guides water release decisions for the dam. WCMs are generally completed within a year of project completion and are updated if conditions or the physical attributes of the project change. The prescribed regulations comprise the water control plan (WCP). The WCP is found in the WCM along with other pertinent information about the dam and reservoir. The WCP guides aspects of reservoir operations such as storage requirements and water release decisions for the dam. USACE guidance states that WCPs "should be reviewed no less than every 10 years and shall be revised…as necessary to conform with changing requirements resulting from developments in the project area and downstream, improvements in technology, improved understanding of ecological response and ecological sustainability, new legislation, reallocation of storage, new regional priorities, changing environmental conditions and other relevant factors." But many WCPs and WCMs have not been updated for several decades, often because of a lack of USACE appropriations. A WCM update will consider FIRO if the appropriation includes language regarding FIRO. Updating the WCMs can make California's reservoirs more resilient to climate change, as indicated in California's Water Supply Strategy: Adapting to a Hotter, Drier Future (Water Supply Strategy).

Forecast skill has improved during recent decades. At the same time, climate change has induced changes in California's hydrology. Reservoirs and water resource projects were developed and implemented, including operation rules and guidance, based on historical hydrology that was available when many of California's reservoirs began operation. This means that many of the state's reservoirs reflect operation rules that are based on basin hydrologies that are at least 50 years old. In the past, this approach was based on the idea that the hydrologic record was a good predictor of future hydrology. But with climate change science advancing, there is an understanding that past hydrology is often an inadequate predictor of future hydrology. The effects of climate change on hydrology in California are already being observed.

Storage for reservoir purposes and priorities — capacity dedicated to flood, water supply, ecosystem support, and hydropower generation — may become increasingly inadequate, as droughts and floods intensify under the effects of climate change. Each reservoir in the state possesses a certain amount of storage, frequently shared by multiple purposes, including flood management, water supply for agriculture,

urban and environmental deliveries, instream environmental needs, power production, and recreation. In many cases, climate change effects will lead to increased flood risk, decreased water supply reliability, continued decline of aquatic species that rely on instream flows, and other uses with decreased reliability. While there is great value in these multi-purpose projects generally, in practice reservoir operations are becoming increasingly rigid (i.e., lacking flexibility) often because of additional requirements or commitments from each reservoir, so that an improvement or increase in commitment to one water management sector comes at some cost to other sectors. Reservoir reoperation may provide some additional operational flexibility for various water management purposes.

Reservoir reoperation, particularly FIRO, is expanding rapidly and gathering attention from water management agencies. In 2016, USACE updated Engineer Regulation 1110-2-240 to allow forecasted conditions to be used for planning future operations and opening the door for the FIRO program. The Lake Mendocino FIRO project has released a report, referred to as the Final Viability Assessment for Forecast-Informed Reservoir Operations (FIRO) at Lake Mendocino, produced by a partnership of federal, State, and local agencies and led by Sonoma Water and the Center for Western Weather and Water Extremes at Scripps Institution of Oceanography at UC San Diego. The Lake Mendocino FIRO project "is an example of how multiple agencies can collaborate to collectively explore the potential of emerging technologies in observations and forecasts and create an adaptive strategy with multiple benefits for water management in a changing climate," said Michael Anderson, State climatologist with DWR.

An economic assessment, funded in part by the U.S. Bureau of Reclamation, completed to quantify the benefits of FIRO for dam operations, water supply, fisheries, recreation, and hydropower found that FIRO will lead to positive benefits in all these areas except hydropower, resulting in total estimated annual benefits of $9.4 million.

The final viability assessment at Lake Mendocino creates a precedent within USACE for how FIRO can be safely and effectively implemented within the context of USACE's flood risk management mission. The Lake Mendocino project sets a great pattern for bringing together individual stakeholder perspectives in a steering committee comprised of State, local, and federal agencies to assess viability, a model which could be used by any agency that wants to evaluate the applicability of FIRO.

Many dams in the West are strictly regulated by USACE-issued WCMs based on historical long-term averages of winter storms and spring runoff. These manuals do not rely on forecasts and have traditionally operated on directives to "manage water on the ground" and typically specify lower reservoir levels in the fall to make room to prevent winter storm runoff floods and raise levels in the late spring. The variability of when rainfall occurs from year to year is not directly considered. Many WCMs were developed prior to modern technology such as satellites, radar, and numerical models that have led to significant improvements in forecasting skill.

After a viability assessment, a final step in FIRO implementation, such as at Lake Mendocino, is a WCM update by USACE that formally facilitates inclusion of these operations based on forecasts in an update for the WCM. For Lake Mendocino, development of the WCM update leveraging FIRO is on-going. The effort is the culmination of the USACE's first reservoir to implement FIRO. The new paradigm and associated decision support tools will make permanent multiple techniques developed in research and development, and during major deviations. This approach has already shown several efficiencies in the protection of downstream communities (flood risk management) and water security and supply.

Conjunctive Use Recharge and Reservoir Reoperation

A second pathway for reoperation is demonstrated by California's Water Storage Investment Program, which includes three projects that have a reservoir reoperation component. California's Water Supply Strategy directs the State to work with local proponents to complete the seven Proposition-1-supported storage projects and to consider funding other viable surface storage projects. Of the seven continuing Water Storage investment Program projects, three are explicitly formulated to employ conjunctive use of surface and groundwater and then facilitate a reservoir reoperation that would provide ecosystem benefits downstream of Lake Oroville:

- Chino Basin Conjunctive Use Environmental Water Storage/Exchange Program.
- Kern Fan Groundwater Storage Project.
- Willow Springs Water Bank Conjunctive Use Project.

Each of these reoperation projects would require agreements with one or more State Water Project (SWP) partners, DWR, and the California Department of Fish and Wildlife (CDFW) to reoperate Oroville Dam and manage the water to provide an ecosystem benefit.

For example, the Southern California Water Bank Authority is proposing the Willow Springs Water Bank Conjunctive Use Project (WSWB Project). The Willow Springs Water Bank is an existing facility located in the adjudicated Antelope Valley Groundwater Basin. The WSWB Project is proposed as a conjunctive use and reservoir reoperation project that would integrate the SWP reservoir and conveyance system with south-of-Delta groundwater storage. The WSWB Project will leverage 500 thousand acre-feet (taf) of existing groundwater storage facilities and operate conjunctively with the SWP and provide ecosystem benefits north of the Delta. Operations of the WSWB Project to provide ecosystem benefits would require agreements with one or more SWP partners to forego SWP delivery in exchange for receiving WSWB Project water, and agreements with DWR and CDFW to reoperate Oroville reservoir and manage the water to provide the ecosystem benefit.

These examples point to a growing opportunity for reoperation in the Sustainable Groundwater Management Act (SGMA) era. Operating reservoirs in conjunction with groundwater is not new. For example, Santa Clara Valley has explicitly managed its reservoirs, surface water sources, and aquifers together to store and deliver water. But operating with an explicit connection of surface and groundwater has been geographically limited. With the passage of SGMA in 2014, groundwater sustainability agencies are looking to untapped surface water sources to provide some assistance in recharging aquifers to help achieve groundwater sustainability. This is potentially another stressor on California's surface water systems, and by extension, reservoirs. In addition, groundwater sustainability agencies now have authority to implement projects and manage the recharge and extractions in their basins so that re-management of surface water flows can be used for recharge. Reservoir reoperation will be an important part of more formal integrated operations of groundwater and surface water systems.

FIRO and Recharge

A related integrated opportunity can be developed by combining the reoperation elements described above — conjunctive use of surface and groundwater using recharge and FIRO. The Orange County Water District (Prado Dam) is already integrating aquifer recharge and FIRO. The San Joaquin Basin Flood-Managed Aquifer Recharge (Flood-MAR) Watershed Studies assess adaptation strategies that include the elements described above — FIRO and managed aquifer recharge (i.e., FIRO-MAR). These studies emphasize planning at the watershed scale, identifying water management challenges and opportunities for three water management sectors: flood, ecosystems, and water supply. They include up to four components: conjunctive use of surface and groundwater, providing flexibility in reservoir

operation rules by integrating FIRO, changed or additional downstream infrastructure, and improved ecosystem flows and actions. Expanding from reservoir reoperation of a single reservoir to a system reoperation of multiple reservoirs may capture more benefits. This type of multiple reservoir FIRO-MAR operation will be tested by the San Joaquin watershed studies described above.

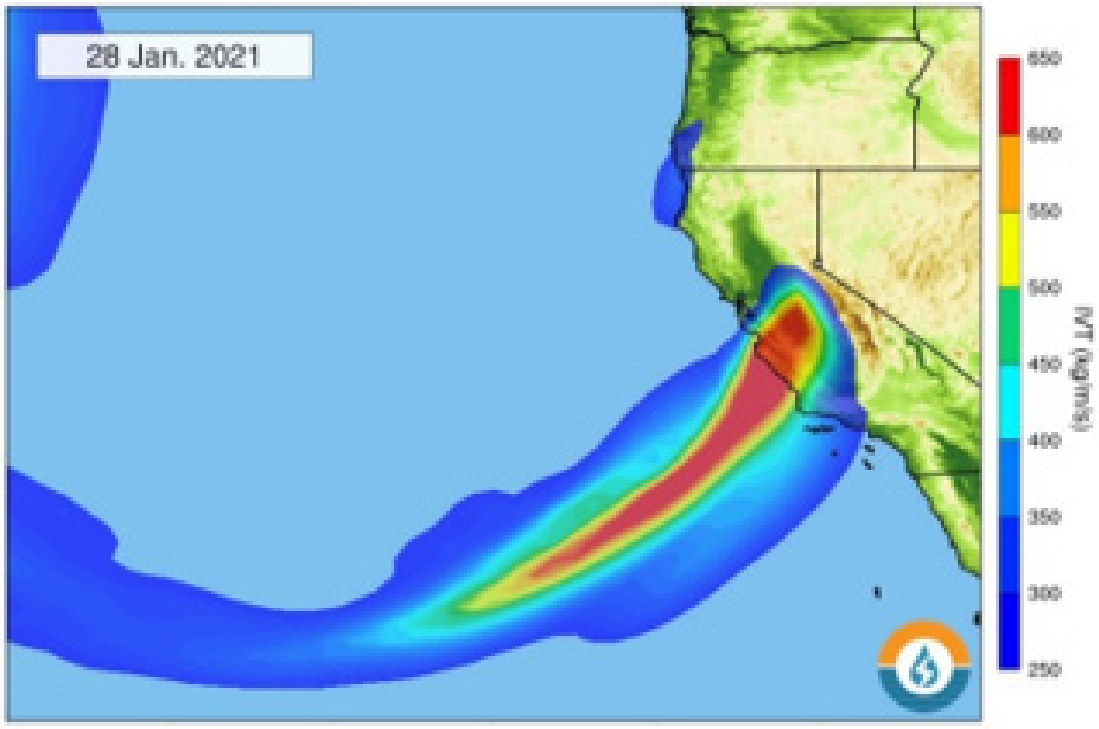
A pilot study initiated for the Merced River watershed includes a study partnership of DWR and the Merced Irrigation District. This initial Flood-MAR watershed study is now complete, and the *Merced River Watershed Flood-MAR Reconnaissance Study* (March 2024) illustrates the significant multi-sector vulnerabilities – flood, water supply and ecosystems - resulting from climate change and the compelling performance of Flood-MAR strategies. The report specifically notes that, "Flood-MAR strategies, especially those incorporating reservoir reoperation such as FIRO, can significantly reduce flood risk, improve water supply through conjunctive use, and enhance conditions for aquatic and terrestrial species." Flood-MAR provides a flexible framework for greater collaboration and integration across water management sectors. DWR is completing similar studies for the Calaveras, Stanislaus, Tuolumne, and Upper San Joaquin watersheds. These studies provide assessments of climate change vulnerability for flood, ecosystems, and water supply (surface and groundwater) as well as performance of Flood-MAR related adaptations, including combinations of FIRO and MAR.

2. Benefits of Reservoir Reoperation

If implemented, reservoir reoperation would increase the resilience of California's flood and water systems. The examples above of reservoir reoperation share a common attribute: expanding the effective storage of the existing water management system.

By using the gains in weather forecasting for example, reservoir reoperation can safely provide more flexibility. This approach adaptively expands the capacity of existing reservoirs for flood and supply purposes. Climate change will increase storm and drought intensity, and FIRO can help reservoirs prepare for both.

Figure 2 Path of Only Major Atmospheric River to make California Landfall in 2021



A WCM update that includes FIRO can give reservoir operators updated forecasting information to optimize how the reservoir can be operated with current weather forecasting skill. More accurate predictions of incoming weather events, especially atmospheric river storms – the leading cause of floods in California – can mitigate flood risk by releasing water in advance of a storm or, conversely, can mitigate drought impacts by holding water back when no storms are in sight. FIRO

implementation through WCM updates allows reservoir operators to adapt to climate change impacts on their systems. The viability assessment for Lake Mendocino showed that FIRO will result in significant benefits for water supply reliability, flood risk management, dam operations, recreation, and fish habitat. The benefits to endangered salmonids are achieved by higher reservoir elevations that retain cooler water temperature at depth, and then downstream, for improved fish success.

The Water Storage Investment Program includes concepts related to public and non-public investments associated with public and non-public benefits. Public benefits eligible for public funding associated with WSIP include ecosystem improvements, water quality improvements, recreational benefits, flood control benefits, or emergency response. Non-public benefits are generally associated with water supply. The conjunctive use and Lake Oroville reservoir reoperation projects discussed above include a combination of public and non-public benefits; public benefits include ecosystem improvements, water quality improvements, and emergency response.

The reservoir reoperation strategy that combines FIRO and conjunctive use recharge (FIRO-MAR) facilitates integrated storage benefits by deploying more formal coordination of surface (reservoir) and groundwater storage. Additional water stored from FIRO and MAR can be dedicated to a variety of downstream purposes. In DWR's Merced Watershed Flood-MAR Watershed Study, which includes a FIRO-MAR adaptation strategy, additionally stored water improved instream salmonid spawning habitat and seasonally inundated off-channel juvenile rearing habitat, in addition to recharging some of the opportunistically stored water. The Merced study and the San Joaquin Basin Watershed studies are demonstrating that combining reservoir reoperation (e.g., FIRO) with managed aquifer recharge can provide multi-sector benefits, including flood, ecosystems, and water supply (surface and groundwater). These multi-sector solutions may provide an important climate change resilience opportunity for several watersheds in the state that have demonstrated vulnerability across those water management sectors. More specific benefits demonstrated with these adaptations include peak flood flow reduction, mitigation of groundwater overdraft, mitigation of subsidence, improved groundwater elevations associated with groundwater dependent ecosystems and disadvantaged communities, improved stream-aquifer interactions, shorebird and managed multi-benefit habitat.

The benefits from reservoir reoperation may be even more extensive if these concepts were applied more broadly to include systems similar to the FIRO studies of Oroville and New Bullards Bar in the Yuba-Feather Basin, or Lake Mendocino and

Lake Sonoma in the Russian River Basin. For example, in the San Joaquin Valley, the reservoirs operate somewhat independently for water supply; but for flood management, flood operations are coordinated by necessity, indicating some advantages of an integrated water management system. The flexibility benefits and potential for flood management and additional groundwater recharge may be enhanced if those reservoirs were operated together.

In addition, the electric grid might be considered in integrated, system-wide reviews, especially as reoperations may affect power contracts and repayment schedules. There may also be an opportunity to coordinate reoperations with the periodic reviews of the subset of reservoirs and dams with FERC hydropower licenses.

3. Economic Benefits of Implementation

Studies have been conducted to estimate the benefits of FIRO, which is a viable alternative to the more expensive option of infrastructure expansion.

The benefits of FIRO at Lake Mendocino were estimated to be more than $9 million annually, including benefits to fisheries, water supply, recreation, and agriculture.

FIRO at Prado Dam could recharge 7,000 acre-feet per year of additional water, saving Orange County more than $6 million annually and avoiding costly alternatives.

In the Yuba-Feather watershed, if FIRO had been in place during the devastating flood of 1997, reservoir releases could have started sooner and flooding may have been reduced by 2 to 3 feet, saving millions of dollars in flood damage.

Challenges to Implementation

Despite considerable interest in the water management community, there remain legal, technical, and managerial challenges to implementation.

Legal, Bureaucratic, and Administrative Challenges

The process used by Sonoma Water and partners to implement FIRO at Lake Mendocino began with FIRO viability assessment, which included interim FIRO operations via USACE-approved deviations to the WCP, and finally implementation of FIRO operations via a WCM update (currently underway). Comprehensive WCM updates that include revisions to WCPs require a National Environmental Policy Act analysis. Depending on the complexity of the current operations, the potential impacts to the environment, and other factors, the time required to update a WCM could take several years.

A reservoir operations partner agency with USACE that wants a WCM updated with FIRO concepts should first consult with the appropriate USACE district office. All reservoirs in California regulated by USACE are being screened for FIRO suitability, and this information should be consulted first. FIRO viability assessments typically take as long as five years and include meteorology, additional observations, hydrology, water resources engineering, modelling, and forecast skill assessment. Examples of FIRO assessments are available on the FIRO website.

Some research has noted that routine operations at dams and reservoirs are largely protected from litigation precisely because they are routine and do not deviate from the status quo. Conversely, reoperation may attract attention and conflict, giving dam operators a "strong perverse incentive to avoid considering any meaningful change, thus perpetuating environmental harms caused by established operations" (Benson 2017). But an open and inclusive approach to reoperation may help avoid litigation, especially over compliance with federal environmental laws (Benson, 2017); models can be found in Canada, Colorado, and elsewhere. One recent study (Turley et al. 2022) notes that "institutional innovation" underpinned many of the reservoir reoperations in Colorado in the last several decades; actors negotiated, adapted, and deviated from prior policy arrangements in creating coherent arrangements — and even new institutions entirely — to meet new demands and users. The authors detail a reoperation initiated by Denver Water that was marked by extensive negotiation, institution-building, and efforts to resolve differences cooperatively.

Reservoir reoperation also provides an opportunity for greater clarity regarding the many functions of multipurpose reservoirs. Authorizing legislation and other documents can sometimes be ambiguous, particularly in describing which purposes are primary and which are secondary. For example, hydropower may be formally considered to be secondary or incidental, but revenues from power production are often essential for loan repayment or for operations and maintenance of more than just the hydropower facilities. Similarly, preliminary research at the Bureau of Mines explores how reservoirs may be operated to support water uses that are not formally required (e.g., to support rafting or to protect the habitat of species not [yet] listed as endangered). Reoperation documents can more clearly convey the hierarchy and interrelationships of reservoirs and dams' multiple functions, including the ways in which uses may be complementary or conflicting (Benson 2017). Although there may be concerns that such clarity may restrict operators' flexibility, such flexibility can be built-in explicitly rather than left unstated and ambiguous.

Technical Challenge — Forecasting

Forecasting weather events is becoming more accurate. An important skill for FIRO is the ability to forecast an atmospheric-river-driven event. Improved forecasting skill may provide additional flexibility for reservoir operators. The Center for Western Weather and Water Extremes is running a regional forecast model, West-WRF, that is focused on improvements in forecasting atmospheric rivers. Through integrating new research and technologies, West-WRF has shown improvement in the atmospheric forecasts such that five-day forecast errors for integrated water vapor transport (IVT;

kg m-1 s-1, a measurement of an atmospheric river's strength) are as good as a three-day forecast prior to Water Year 2018.

Financial Challenge

To get the benefit of water that is conserved through FIRO, dam operators and downstream agencies may need to install additional infrastructure, including new downstream recharge facilities. This new infrastructure may not be used every year, making it relatively more expensive.

Costs If Not Implemented

The alternative to reservoir reoperation is continued use of existing operations (e.g., continued use of the current WCM) and the costs associated with the existing operations. Existing WCMs determine the allocation of storage that can be used at the reservoir for water supply and flood protection. This allocation is written into law by Congressional approval. Without a WCM update or a FIRO study, there will be no new flexibility incorporated into the reservoir operations rules. Without a WCM update or FIRO study, reservoir operators lose the chance to improve operations based upon better weather forecasting and adaptions to changing hydrology.

Similarly, the cost of not implementing a Water Storage Investment Program recharge and reservoir reoperation would be continued operations using existing operations and consequently existing outcomes.

4. Climate Change Adaptation

Implementation of reservoir reoperation strategies can support resilience to climate change, as described above. Action 27.3 of the California Water Resilience Portfolio directs State agencies, "in cooperation with USACE and reservoir owners, evaluate the potential for implementing forecast-informed reservoir operations in watersheds where improved weather forecasting capabilities would allow reservoir operators to improve flood control and surface and ground water supply storage." This provides a clear connection between reservoir reoperation and climate change adaptation considerations.

Climate Change Mitigation

The potential for reservoir reoperation greenhouse gas reductions is feasible but will depend on existing conditions and potential implementation. For example, recharge of aquifers will relatively decrease pumping heads associated with groundwater extraction. But some energy would likely be expended conveying water to recharge locations.

One of the potential benefits of FIRO is more water in storage for hydropower generation, which also supports greenhouse gas mitigation. This needs to be evaluated at each reservoir independently. Reoperation can provide increased reliability of hydropower supply when it's needed the most: to offset generation from nonrenewable resources. Conserving water during winter and spring allows electric utility operators great flexibility later in the season to dispatch hydropower instead of natural gas or other firm resources. Moreover, all such resources are often much more expensive during heavy load periods, yet hydropower's marginal cost can be near zero and is much more predictable. FIRO can increase the likelihood that all other constraints on water can be met, and then, discretionary hydropower can be planned for expected higher-load periods. FIRO can allow reservoir operators to conserve less water in the rainy season, making more room in the reservoirs when refill is likely, perhaps seizing hour-by-hour opportunities to generate hydropower when market prices are high, rather than curtail hydrogeneration in anticipation of the possibility of a drought.

5. Reservoir Reoperation and the Water Resilience Portfolio

Action 27.3 of the Water Resilience Portfolio directs DWR to cooperate with the U.S. Army Corps of Engineers and reservoir owners, to evaluate the potential for implementing FIRO in watersheds where improved weather forecasting capabilities would allow reservoir operators to improve flood control and surface and ground water supply storage.

Action 27.1 directs State agencies to support regional decision-making with watershed scale climate vulnerability and adaptation assessments that include strategies to address water management risks, an approach employed in the San Joaquin Basin Flood-MAR Watershed studies.

6. Recommendations

1. As noted in the *Water Resilience Portfolio* and Water Supply Strategy, California should continue to support FIRO assessments and WCM updates with USACE. In some cases, such as the on-going Yuba-Feather example, multiple reservoirs can, and should be, considered together.
2. State and federal agencies should continue to support research and tools that improve forecast precision, facilitating improved use of reservoir storage.
3. Water managers should continue to explore and implement conjunctive use opportunities that effectively leverage integrated surface and groundwater storage, as demonstrated with the three Water Storage Investment Program conjunctive use projects.
4. State, federal, and local agencies should continue to improve their collaborative abilities, bringing together water and resource managers, operators, scientists, and researchers, as exemplified by the FIRO sub-committee approach.
5. FIRO, conjunctive management of surface and groundwater storage, and combining these approaches (i.e., FIRO-MAR) should all be pursued where feasible to provide resilient solutions for California's water management future.

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8. Useful Web Links

California Water Plan Update 2018
https://water.ca.gov/Programs/California-Water-Plan/Previous-Updates/Update-2018

California's Water Supply Strategy: Adapting to a Hotter, Drier Future
https://resources.ca.gov/-/media/CNRA-Website/Files/Initiatives/Water-Resilience/CA-Water-Supply-Strategy.pdf

Forecast Informed Reservoir Reoperation (FIRO) website
https://cw3e.ucsd.edu/firo/

Merced River Flood-MAR Reconnaissance Study
https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Flood-Management/Flood-MAR/230410_Merced-R_FloodMAR-Reconnaissance-Study_Division-Report_v7.pdf

Sustainable Groundwater Management Act
https://water.ca.gov/Programs/Groundwater-Management/SGMA-Groundwater-Management

Water Resilience Portfolio
https://resources.ca.gov/Initiatives/Building-Water-Resilience/portfolio

Water Storage Investment Program
https://cwc.ca.gov/Water-Storage

Willow Springs Water Bank Conjunctive Use Project
https://cwc.ca.gov/Water-Storage/WSIP-Project-Review-Portal/All-Projects/Willow-Springs-Water-Bank-Conjunctive-Use-Project


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