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Seven Oaks Dam Forecast Informed Reservoir Operations Preliminary Viability Assessment

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et al.

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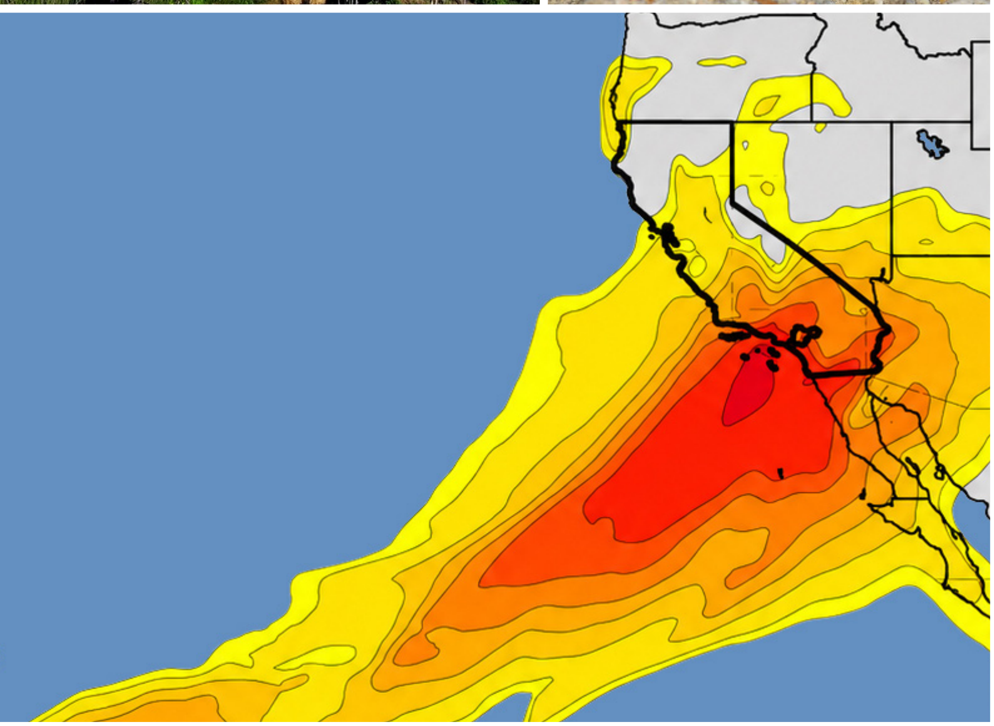
Seven Oaks Dam

FORECAST INFORMED RESERVOIR OPERATIONS

Preliminary Viability Assessment

July 2026



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Abbreviations

For brevity, this document uses the following abbreviations:

Abbreviation	Definition
ac-ft	acre-feet
AR	atmospheric river
cfs	cubic feet per second
CNRFC	California Nevada River Forecast Center
CW3E	Center for Western Weather and Water Extremes
EFO	Ensemble Forecast Operations
ERDC	Engineer Research and Development Center
FIRO	Forecast Informed Reservoir Operations
FVA	Final Viability Assessment
HEFS	Hydrologic Ensemble Forecast System
HEMP	hydrologic engineering management plan
IVT	integrated vapor transport
LAD	Los Angeles District
MAP	mean areal precipitation
MCSG	Mill Creek spreading grounds
MPC	Model Predictive Control
MWDSC	Metropolitan Water District of Southern California
NOAA	National Oceanic and Atmospheric Administration
PVA	Preliminary Viability Assessment
RAFSS	Riversidean alluvial fan sage scrub
RAOP	Research And Operations Partnership
RDF	reservoir design flood
SARSG	Santa Ana River spreading grounds
SBCFCB	San Bernardino County flood control basins
SFO	Summary Forecast Operations
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WCM	Water Control Manual
WCP	Water Control Plan
West-WRF	Western Weather Research and Forecasting
WFR	Weighted Forecast Release
WRE	Water Resources Engineering

Executive Summary

Built in 1999, Seven Oaks Dam is a 550-foot-high earth and rock fill dam that impounds the Santa Ana River (Figure ES-1) in the San Bernardino National Forest. It was constructed as part of a larger approximately $2 billion flood control effort called the Santa Ana Mainstem Project.

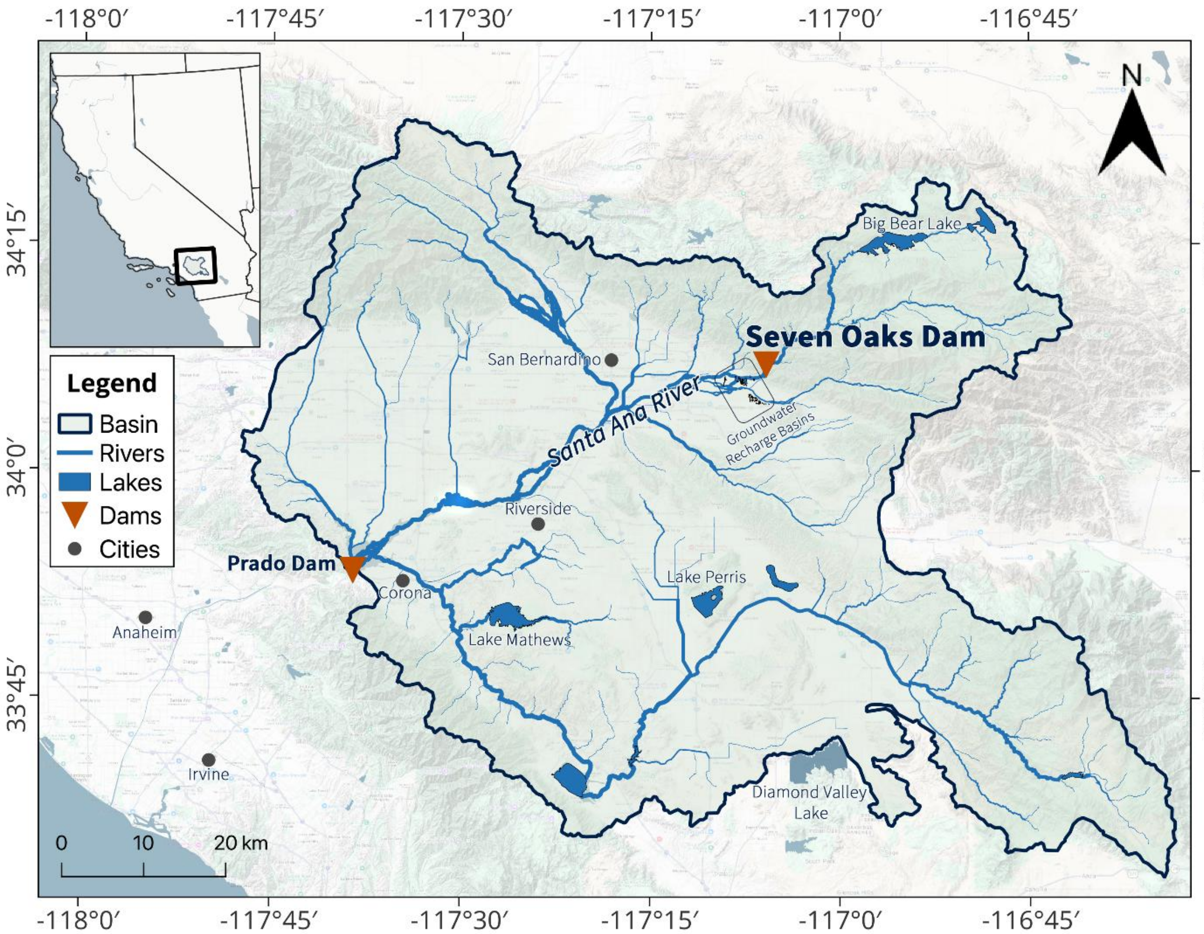

Figure ES-1. *The Santa Ana River watershed.*

Seven Oaks Dam is operated and maintained by Orange County Flood Control District, Riverside County Flood Control and Water Conservation District, and San Bernardino County Flood Control District. Currently, the dam is authorized for flood risk management (FRM).

This Preliminary Viability Assessment (PVA), initiated by San Bernardino Valley Municipal Water District and undertaken by an interagency Steering Committee (page ii), explores possibilities for water conservation to increase groundwater recharge for regional water reliability and to enhance habitat for protected species, while maintaining or enhancing FRM using improved monitoring, as well as improved weather and runoff forecasts. The steering committee includes key decision makers and stakeholders that have the authority to commit time and resources. The steering committee guides the Forecast Informed Reservoir Operations (FIRO) viability assessment process to develop a full understanding of the watershed and the project features, identify analyses and data needs, and scope a host of variables and constraints associated with managing water resources in the basin. The Steering Committee meets regularly and actively contributes to the project work, with a key goal of establishing collaboration amongst the agencies.

What is FIRO?

FIRO is a flexible water management approach that uses data from watershed monitoring and improved weather forecasting to help water managers selectively retain or release water from reservoirs for increased resilience to droughts and floods. FIRO applies emerging science and technology to optimize water resources and adapt to climate change without costly infrastructure.

The PVA, which builds on the Seven Oaks FIRO workplan (Ralph et al. 2024), assessed 16 alternative water resources operational scenarios to determine their efficacy relative to a set of environmental, water supply availability, and FRM metrics. Key findings and recommendations are presented below. A full list of findings and recommendations can be found in Sections 3–5.

Key Findings

- Preliminary analyses suggest FIRO is viable for Seven Oaks Dam.
- Forecast skill for extreme events is ranked in the top 10 percent nationally, making Seven Oaks Dam an excellent candidate for FIRO.
- FIRO alternatives that simulated FIRO Spaces at less than 2,299 feet (compared to current operations at an elevation of 2,220 feet) showed no impact to FRM metrics, while higher FIRO Spaces need further examination to better assess FRM and groundwater recharge outcomes.
- FIRO can increase groundwater recharge across all facilities, with the largest improvements coming in wetter than average years and with higher winter storage in the reservoir. Differences in recharge outcomes across FIRO alternatives are driven by the top of the FIRO Space, with higher FIRO Spaces enabling higher recharge.
- Indicators to explore potential environmental changes showed little variation between FIRO alternatives and Water Control Manual (WCM) operations for downstream conditions. Variations between alternatives for upstream conditions are influenced by the FIRO Space.

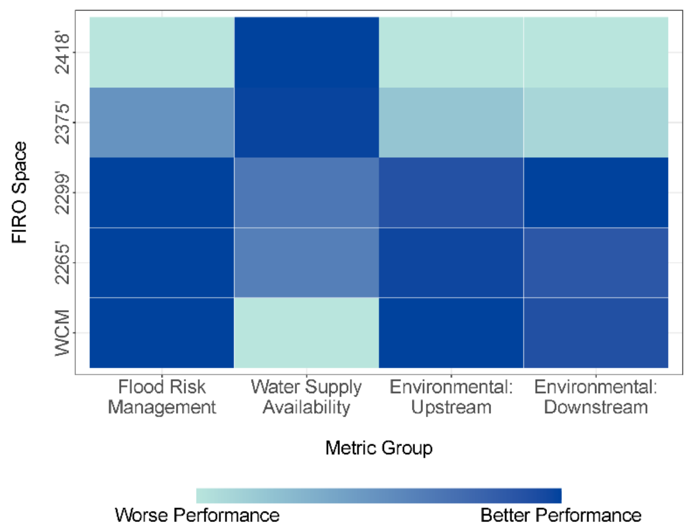

Figure ES-2. *Comparison of baseline conditions (WCM) and four alternative FIRO spaces according to key performance metrics assessed in the PVA.*

Key Recommendations

- Refine FIRO Spaces below 2,299 feet (top of trash rack) and explore the elevation tradeoff point below 2,375 feet (25 percent of gross pool) for FRM and groundwater recharge outcomes.
- Refine reservoir operations and groundwater recharge modeling framework for a more granular assessment of metric performance.
- Install additional sensors to improve snow observations.
- Translate the environmental indicators into metrics to assess the environmental impacts or benefits of alternative reservoir operations.
- Assess options to provide authority to implement water conservation as a secondary purpose, subordinate to FRM.
- Pursue a planned deviation to the WCM to test FIRO on a relatively small scale.

Next Steps

The results of this PVA support advancing FIRO at Seven Oaks Dam into a Final Viability Assessment (FVA). The FVA will build on the PVA by prioritizing additional analyses, engaging work teams, and continuing coordination with the Steering Committee to support decision making. Consideration should be given to coordinating with the local sponsors to process a U.S. Army Corps of Engineers (USACE)-approved planned deviation from the current WCM to test FIRO. FIRO Spaces between approximately 2,220 feet and 2,265 feet are candidates for interim testing through a deviation, given demonstrated water supply benefits, without compromising FRM. If a deviation is approved, the local sponsors will have more operational flexibility, while retaining discretion to operate the dam in accordance with the WCM.

Implementing FIRO will require continued coordination with local sponsors and USACE regarding the authority for water conservation as a secondary purpose of Seven Oaks Dam. Decision support tools will be further evaluated and enhanced during the FVA to ensure operators have the situational awareness and modeling capabilities needed for forecast-informed operations. The FVA is expected to be completed by 2028, with the ultimate goal of updating the WCM to formally incorporate FIRO operations, subject to USACE approval.

Section 1. Introduction

California has one of the most variable climates in the United States, and it is getting more extreme—increasingly marked by long periods of warm, dry conditions punctuated by stronger and wetter atmospheric river (AR) storms.

ARs are responsible for more than half of all beneficial precipitation and over 90 percent of flood damage in California. These long, narrow bands of concentrated moisture stretch thousands of miles across the Pacific Ocean. When ARs make landfall, they can release a staggering amount of rain and snow: during a particularly active AR season from November 2022 to April 2023, 17 ARs produced an average of 29 inches of precipitation in the Santa Ana River watershed (Figure 1-1).

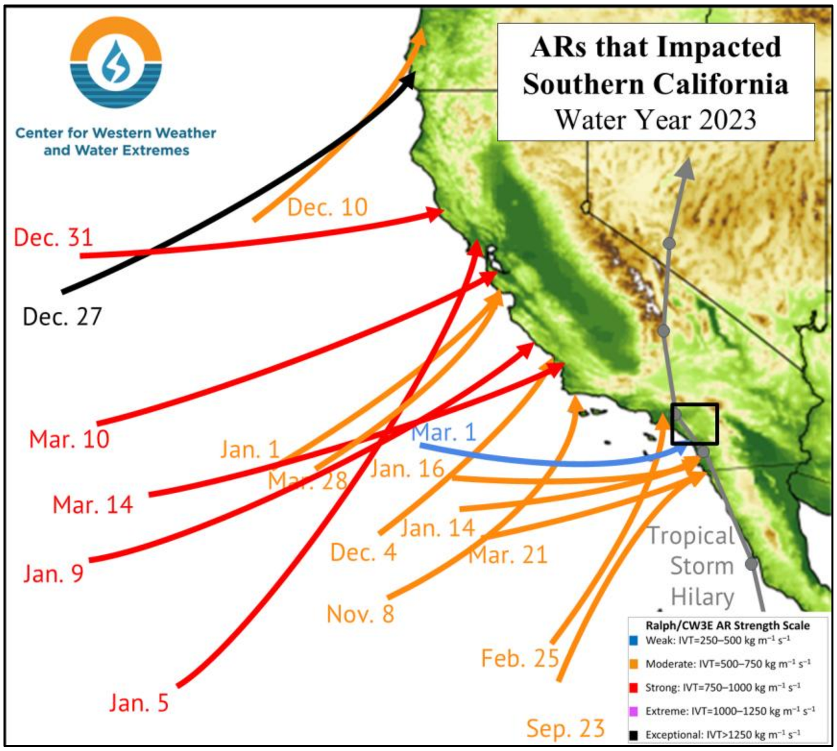

Figure 1-1. *Seventeen ARs and a tropical cyclone brought record-breaking snowfall to the area in 2023. The ARs dropped more than 240 inches of snow at Big Bear. Note: ARs making landfall outside the Santa Ana River watershed affect the watershed as they move along the coast.*

Since ARs are the main drivers of floods, and the absence of ARs is often associated with droughts, improved AR forecasts are essential for Forecast Informed Reservoir Operations (FIRO). Recognizing the importance of ARs in a changing climate, the San Bernardino Valley Municipal Water District (San Bernardino Valley) and Western Municipal Water District (Western Water) have partnered with the Center for Western Weather and Water Extremes to explore the potential for FIRO at Seven Oaks Dam. FIRO is a flexible water management strategy that uses improved weather and runoff forecasts to help water managers retain or release reservoir water for increased resilience to weather extremes.

FIRO results at Lake Mendocino show that reservoir operators can use forecast information and tools to plan for storing up to 20 percent more water when forecasts indicate low risk of flooding. At Prado Dam, about 35 miles downstream of Seven Oaks Dam (Figure 2-1), FIRO operations can result in 8 to 11 percent more groundwater recharge, on average.

Seven Oaks Dam is operated and maintained by the project sponsors: Orange County Flood Control District, San Bernardino County Flood Control District, and Riverside County Flood Control and Water Conservation District. Reservoir regulation for Seven Oaks Dam is conducted by the Orange County Flood Control District staff following the approved Water Control Plan (WCP), contained in a Water Control Manual (WCM; USACE 2003) provided by the U.S. Army Corps of Engineers Los Angeles District.

The Seven Oaks Dam FIRO project is the first FIRO project that (1) is significantly snowmelt-fed, (2) includes habitat enhancement as a primary objective, and (3) incorporates consideration for several protected species.

FIRO at Seven Oaks Dam is a Research and Operations Partnership (RAOP), a term coined for FIRO projects to convey the symbiotic relationship between research and water operations. Research is driven by water managers' needs; research findings inform, and feed directly into, operational decisions. RAOP consists of researchers, water managers, dam operators, and environmental scientists with vested interests in improving dam operations to achieve multiple benefits. A Seven Oaks Dam FIRO Steering Committee (members listed on page i) was formed to represent these interests and to answer a key question: *Can current and improved forecasts of precipitation, temperature, and runoff associated with landfalling ARs and other storms be used to employ flexible reservoir operations at Seven Oaks Dam to increase water conservation and enhance and protect habitat through strategic releases, while continuing to meet flood risk management objectives?*

To help answer this question, the project team has developed this Preliminary Viability Assessment (PVA). The PVA is an early, science-based evaluation that uses existing forecast skill, historical and simulated hydrologic data, and current operational constraints to examine whether FIRO could be feasible and beneficial at Seven Oaks Dam. It identifies the most promising opportunities for increasing water conservation and habitat benefits; highlights potential limitations or risks; and outlines the additional analyses, tools, or infrastructure that would be needed for full FIRO implementation. The PVA provides a structured foundation for deciding whether and how FIRO could advance to later phases of development at Seven Oaks Dam. It is the third step of a process culminating in a WCM update (Figure 1-2).

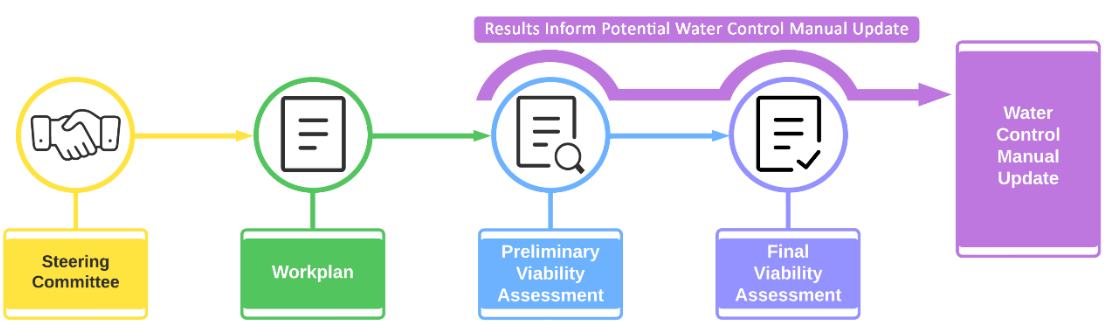

Figure 1-2. *The FIRO process steps.*

Section 2. Background and Context

2.1 Santa Ana River Watershed

The Santa Ana River watershed is the largest in Southern California's coastal region. It encompasses about 2,650 square miles and parts of San Bernardino, Riverside, Orange, and Los Angeles counties. The upper watershed is ringed by the San Gabriel, San Bernardino, and San Jacinto mountain ranges, with elevations over 10,000 feet. These mountains form a barrier to atmospheric river (AR) storms that originate in the Pacific Ocean and make landfall in Southern California, forcing moist flow upward and generating clouds and precipitation. Lowlands consist mainly of dry alluvial valleys. The watershed has over 10 vegetation zones, including alpine and subalpine areas in high elevations and pine, lodgepole, and oak forests at mid-elevations. Chaparral and coastal sage scrub are common in lower elevations, and riparian forest and marshes can be found along the riverbed. Figure 2-1 shows a map of the watershed.

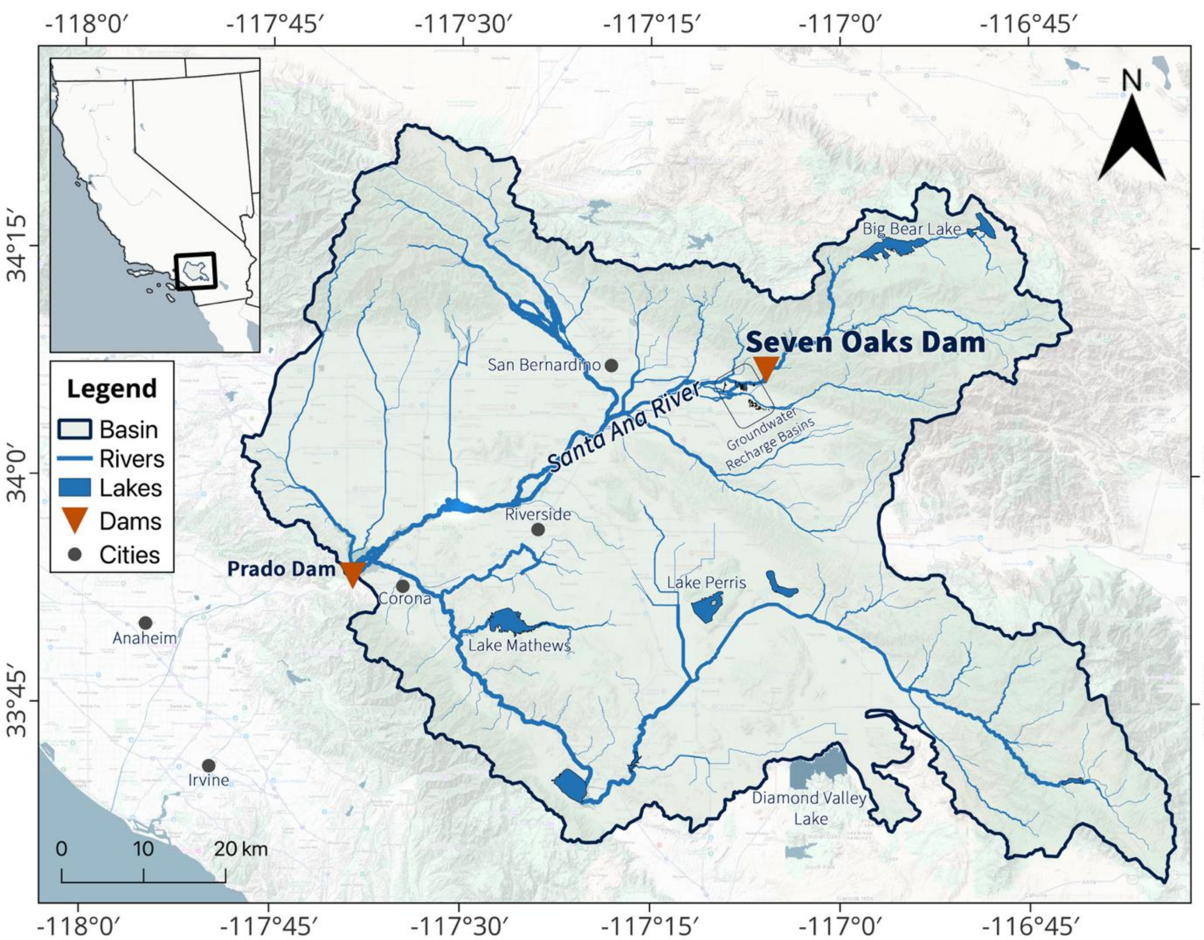

Figure 2-1. *Santa Ana River watershed. Seventy-four percent of the watershed area above Seven Oaks Dam is at an elevation higher than 6,234 feet (1,900 meters) above mean sea level. (Credit: San Bernardino Valley Municipal Water District.) The groundwater recharge basins shown on the map are the primary basins included in the PVA analysis. However, there are additional recharge facilities throughout the basin not considered in this analysis.*

Approximately 6 million people live in the Santa Ana River watershed. Water supply reservoirs within the area include Lake Mathews, Lake Perris, Lake Skinner, Diamond Valley Lake, and Irvine Lake. In addition, Prado Dam, which was constructed for flood risk management, is also operated to facilitate groundwater recharge under certain conditions, providing valuable water supply for Orange County Water District.

Most of the watershed area above Seven Oaks Dam is within the San Bernardino National Forest. The Santa Ana River above Seven Oaks Dam is free flowing, with a steep gradient (300 feet per mile) and highly erodible soil. Below Seven Oaks Dam, as the river enters the lower basin, much of the flow is diverted for municipal and agricultural water supply and groundwater recharge. Flow downstream of San Bernardino during the dry season (referred to as "the perennial stream") is dominated by effluent from nine wastewater treatment plants. Stormwater runoff in the lower basin is collected behind Prado Dam. Below Prado Dam, Orange County Water District diverts an average of approximately 55,000 acre-feet (ac-ft) per year from Prado Dam releases into recharge basins, which provides about one-third of its municipal water supply yearly.

2.2 Local Agency Partnerships

The San Bernardino Valley Municipal Water District (San Bernardino Valley) is a wholesale water and groundwater management agency serving approximately 714,000 people across more than 350 square miles in the eastern San Bernardino Valley, Crafton Hills, and parts of Yucaipa Valley. Its service area includes the cities of San Bernardino, Redlands, Loma Linda, Rialto, Colton, Highland, Grand Terrace, Yucaipa, and portions of Fontana, as well as nearby unincorporated communities.

The Western Municipal Water District (Western Water) is one of the largest public agencies in Riverside County, providing water, wastewater (sewer), and recycled water services to nearly 1 million people, both wholesale and retail customers, across 527 square miles in western Riverside County. Western Water represents several entities in Riverside County under a 1969 court ruling, including the City of Riverside, Riverside Highland Water Company, Meeks & Daley Water Company, and the University of California.

Together, San Bernardino Valley and Western Water hold rights to divert up to 198,000 ac-ft per year from the Santa Ana River and store up to 50,000 ac-ft annually at Seven Oaks Dam. A 1969 groundwater adjudication (Western-San Bernardino Judgment) established the rights and obligations for San Bernardino Valley and Western Water entities in the San Bernardino Basin Area and adjacent groundwater basins. The provisions of the Western-San Bernardino Judgment are enforced and administered by a court-appointed Watermaster consisting of one member nominated by San Bernardino Valley and one member nominated by Western Water, to represent the interests of the San Bernardino County entities and San Bernardino Basin Area pumpers that export water to Riverside County, respectively.

Water released from Seven Oaks Dam is recharged by San Bernardino Valley into the Upper Santa Ana Valley–San Bernardino subbasin, which is also referred to as the San Bernardino Basin Area and supplies water to roughly 1 million people in San Bernardino and Riverside counties. Water released from the dam can also be conveyed to flood control basins operated by San Bernardino County Public Works for groundwater recharge. Western Water is a member agency of the Metropolitan Water District of Southern California (MWDSC) and is initiating discussions with MWDSC to develop the required agreements to divert releases from Seven Oaks Dam to MWDSC reservoirs. See Section 3.2.1.a for more information.

In additional to locally available water, San Bernardino Valley also imports water from the State Water Project via the East Branch aqueduct through Lake Silverwood. San Bernardino Valley's annual State Water Project allocation is 102,600 ac-ft, though deliveries vary from 70–100 percent in wet years to as low as 5 percent in dry years. Regional population growth of 15–20 percent projected by 2045 will increase future demand for water. Current and future supplies are expected to come from a combination of State Water Project imports, local surface and recycled water, groundwater pumping, and Santa Ana River flows released at Seven Oaks Dam, which can contribute up to 100,000 ac-ft in a wet year and as much as 200,000 ac-ft under future estimated water supply conditions (Appendix 2.1; Table 2-1).

2.3 Seven Oaks Dam and Reservoir

2.3.1 History and Authorized Uses

Following the devastating 1938 flood, Prado Dam was built in 1941. To further improve regional flood protection, Congress authorized the Santa Ana River Mainstem project in 1986, which included constructing Seven Oaks Dam (Figure 2-2). Completed in 1999, the 550-foot-high earth and rockfill dam cost about $450 million and provides protection for communities across Orange, Riverside, and San Bernardino counties. As part of construction, 764 acres of open space were permanently set aside to protect three federally listed species: the Santa Ana River woolly-star, San Bernardino kangaroo rat, and slender-horned spineflower.

Figure 2-2. *Seven Oaks Dam. (Credit: Steve Schumaker via Wikimedia Commons, released under CC BY-SA 1.0.)*

2.3.2 Existing Operations

While Seven Oaks Dam is currently authorized for flood risk management, San Bernardino Valley and Western Water are interested in adding water conservation as a secondary purpose of the dam. The dam is jointly operated by the Orange, San Bernardino, and Riverside County Flood Control Districts following the U.S. Army Corps of Engineers' (USACE's) 2003 Water Control Manual (WCM), as amended. Water stored in the intermediate pool and the debris pool provide incidental benefits, allowing operators to adjust release timing to support downstream habitat and groundwater recharge when conditions permit. Releases are typically kept below 500 cubic feet per second (cfs) but may increase to 7,000 cfs during flood events if the reservoir pool impoundment reaches the main flood control pool. Seven Oaks Reservoir is drawn down each summer (by September 1) to allow time for annual maintenance and ensure it is ready for the next flood season.

Operational goals are seasonal: Build the debris pool beginning October 1 and maintain the debris pool throughout the storm season (October–April), then draw the entire reservoir down to the top of the sediment pool by September 1.

FRM operations at Seven Oaks require close coordination with Prado Dam during a significant flood runoff event. During these times, if water levels are rising at Prado, Seven Oaks discharge is limited to 500 cfs until downstream conditions and inflow conditions at Prado Dam stabilize, after which flows are increased to maximize FRM benefits at Seven Oaks Dam and lower the water surface elevation. Slower, extended releases through winter and spring would improve recharge efficiency, but this approach is not yet standard practice.

Currently, the Orange County Flood Control District follows the 2003 Water Control Plan (WCP), using National Weather Service forecasts and consulting with the USACE Reservoir Regulation Section, as needed, to manage Seven Oaks Dam releases. If the water surface elevation at Seven Oaks Dam is above the debris pool, dam operators may lower reservoir levels in advance of a storm to create storage capacity and adjust releases as conditions evolve. During the storm season, operations generally aim to return the reservoir to the top of the debris pool. Section 3.1.3.a provides detailed information on Seven Oaks Dam operations.

Figure 2-3 shows a simplified storage allocation diagram from the Seven Oaks Dam WCP. Elevations in the figure have not yet been finalized by Orange County Public Works and USACE Los Angeles District.

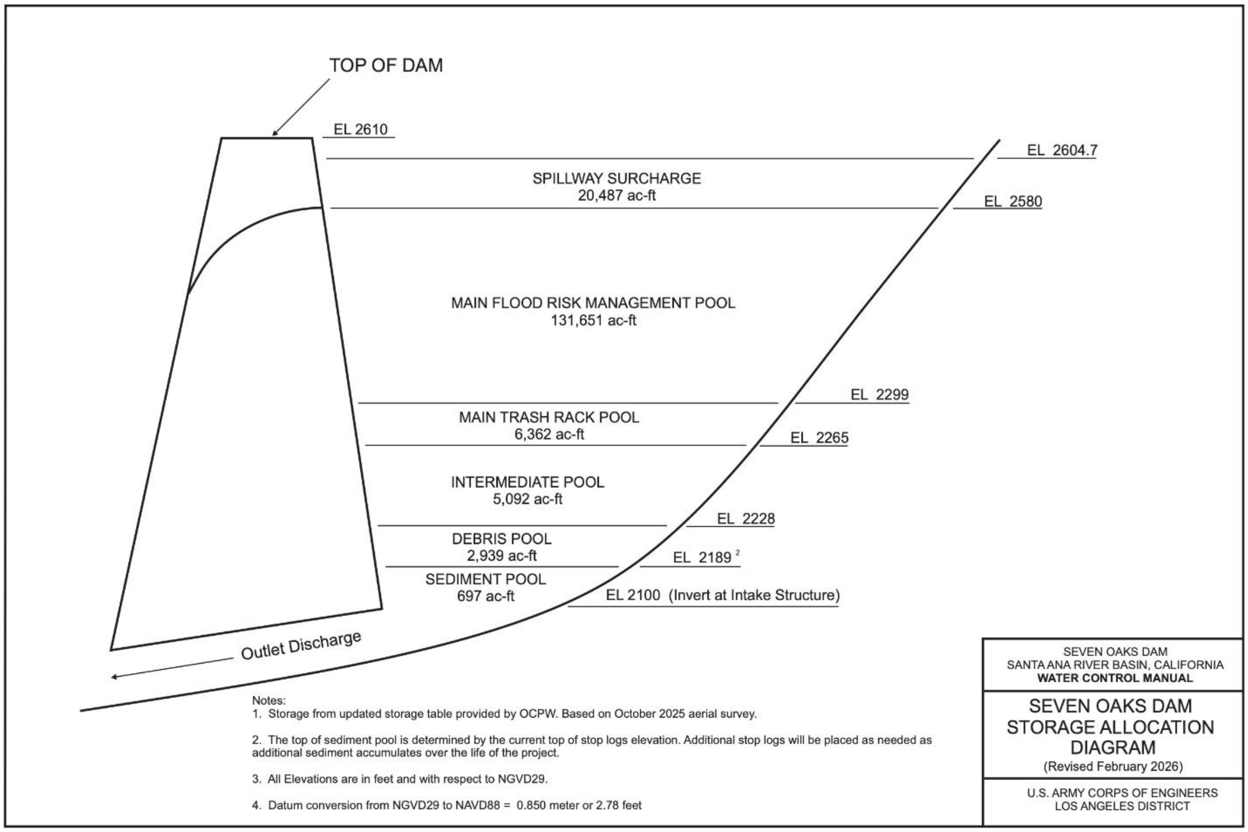

Figure 2-3. *Simplified storage allocation diagram from the Seven Oaks Dam WCP. Revised February 2026 (plate 7-01). (Source: USACE Los Angeles District.)*

2.4 Infrastructure

Facilities in the Seven Oaks Dam watershed support flood management, hydropower, and groundwater recharge, including access roads and two hydroelectric powerhouses recently acquired by San Bernardino Valley. The dam system consists of an intake structure, tunnel, discharge gates, and a plunge pool that releases water to the Santa Ana River, with operations governed by the USACE Seven Oaks WCP. Water released from the dam is recharged into the San Bernardino Basin Area by San Bernardino Valley. In 2024, San Bernardino Valley and Western Water (representing the Riverside County entities that pump from the San Bernardino basin area) completed Phase 1B of the Santa Ana River Enhanced Recharge Project, expanding recharge capacity and enabling up to 78,500 ac-ft of additional recharge in wet years.

2.5 Environmental Objectives

2.5.1 Governing Documents

Environmental requirements for Seven Oaks Dam were established through a series of documents developed during the Santa Ana River Mainstem project review process. Biological Opinions issued by the U.S. Fish and Wildlife Service in 1989 and 2002 concluded that project operations would not jeopardize federally listed species—including the Santa Ana River woolly-star, slender-horned spineflower, and San Bernardino kangaroo rat (Figure 2-4)—if specific mitigation measures were implemented. The 1989 Biological Opinion resulted in the creation of the 764-acre Woolly Star Preserve Area to offset project impacts. The 2002 Biological Opinion added further conservation measures and required that Seven Oaks Dam allow occasional large releases when needed to maintain habitat within the preserve, a provision incorporated into the 2003 WCM. To support long-term stewardship, USACE completed a Multi-Species Habitat Management Plan in 2012 (USACE 2012) that outlines ongoing monitoring and adaptive management actions, including potential environmental enhancement releases, to sustain species and habitats in the preserve.

Figure 2-4. *Least Bell's Vireo, Slender-horned spineflower, Santa Ana River woolly star, and San Bernardino kangaroo rat. (Credit: U.S. Geological Survey, public domain; California Department of Fish and Wildlife, photo by Susan Cochran; Steve Schumaker via Wikimedia Commons, CC BY-SA 1.0; U.S. Fish and Wildlife Service, public domain.)*

2.5.2 Water Quality

After construction finished on Seven Oaks Dam, water agencies that treat water released from the dam and deliver it as potable water reported changes in water quality, prompting several studies. Camp Dresser & McKee (2005) reported increased turbidity, organic materials, algal blooms, iron, manganese, among other constituents. The USACE Engineer Research and Development Center conducted additional studies (USACE 2014) to support modifying the 2003 WCP to discontinue the seasonal debris pool maintenance by building a debris pool only in response to forecasted rain events and then draining the debris pool entirely when the rainfall runoff event has passed. This change would have addressed concerns about seasonal retention of winter flood season's turbid runoff and other water quality degradation concerns. Ultimately, however, the 2003 WCP was not updated with findings from the study.

Water quality concerns were also described in the Environmental Impact Report for San Bernardino Valley and Western Water's Santa Ana River water rights application. To address these concerns, the State Water Resources Control Board added requirements that any releases from storage intended for re-diversion must meet applicable water quality objectives and be coordinated with the California Department of Water Resources Chief Deputy Director for Water Quality. See Appendix 5.7.1 for more information.

2.5.3 Habitat Restoration and Conservation

Several regional habitat conservation plans guide environmental protection in areas influenced by Seven Oaks Dam operations and downstream recharge activities. The Western Riverside County Multiple Species Habitat Conservation Plan (County of Riverside 2003) covers 146 species and provides mitigation for major development and infrastructure projects in western Riverside County, including the four species addressed in the 2002 Biological Opinion.

The U.S. Fish and Wildlife Service approved the Upper Santa Ana River Wash Habitat Conservation Plan in 2020 (San Bernardino Valley Water Conservation District 2023). This plan includes 4,892 acres in the alluvial plain downstream of Seven Oaks Dam. Its primary goal is to balance the ground-disturbing effects of groundwater recharge and other activities with the conservation of natural communities and populations of Santa Ana River woolly-star, slender-horned spineflower, San Bernardino kangaroo rat, and other sensitive species.

A third plan, the Upper Santa Ana River Habitat Conservation Plan, is currently being developed and will cover nearly 863,000 acres in San Bernardino and Riverside counties. This plan will facilitate permitting water management and flood control activities while protecting and restoring habitat for 20 species. San Bernardino Valley is working with the U.S. Fish and Wildlife Service to complete the Upper Santa Ana River Habitat Conservation Plan. All three plans include restoration actions and monitoring programs that will help track habitat conditions and species responses over time.

Protected Species of Interest to FIRO at Seven Oaks Dam

- Cactus wren
- Coastal California gnatcatcher
- Least Bell's vireo
- Southwestern willow flycatcher
- Yellow-breasted chat
- San Bernardino kangaroo rat
- Los Angeles pocket mouse
- Western spadefoot toad
- Arroyo chub
- Santa Ana sucker
- Slender-horned spineflower
- Santa Ana River woolly-star

Habitat protection and enhancement are central to the Seven Oaks Dam Forecast Informed Reservoir Operations (FIRO) project. Section 5.7 of this Preliminary Viability Assessment (PVA) presents preliminary environmental indicators to compare FIRO alternatives with respect to potential changes for habitat and protected species across three geographic focus areas: the upstream inundation zone, the alluvial fan and Santa Ana River Wash, and the perennial stream reach extending to Prado Dam. These indicators provide a means to assess how operational changes may enhance, maintain, or impact ecological resources within these areas.

More detailed background information is presented in the workplan for Seven Oaks Dam FIRO (Ralph et al. 2024) and references below.

2.6 References

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Section 3. How FIRO Viability Was Assessed

The Seven Oaks Dam Forecast Informed Reservoir Operations (FIRO) Steering Committee collaboratively developed and finalized a multiyear workplan to assess the viability of FIRO for Seven Oaks Dam operations in June 2024 (Ralph et al. 2024). Specifically, the plan called for assessing the potential of existing weather and water forecasts to improve San Bernardino Valley Municipal Water District's ability to recharge groundwater without compromising flood risk management outcomes for the U.S. Army Corps of Engineers (USACE).

Section 3.1 describes the framework used to objectively assess a selection of alternative Water Control Plans (WCPs). Currently, Seven Oaks Dam is regulated in accordance with the USACE 2003 Water Control Manual (WCM) (USACE LAD 2003). Figure 3-1 shows the simplified WCP, and the full WCP is shown in Appendix 3.1. Unlike traditional USACE WCPs, FIRO WCP alternatives leverage streamflow forecasts to inform release decisions. All WCPs (non-FIRO and FIRO) are subject to the same operational and physical constraints specified in the 2003 WCP. Each WCP alternative is evaluated with metrics representing flood risk management (FRM), water supply availability, and environmental outcomes. The coupled reservoir and downstream diversion model is described in Section 3.2. The process used to generate the streamflow forecasts and a description of the forecasts used to evaluate the WCP alternatives are provided in the simulation plan (Section 3.3).

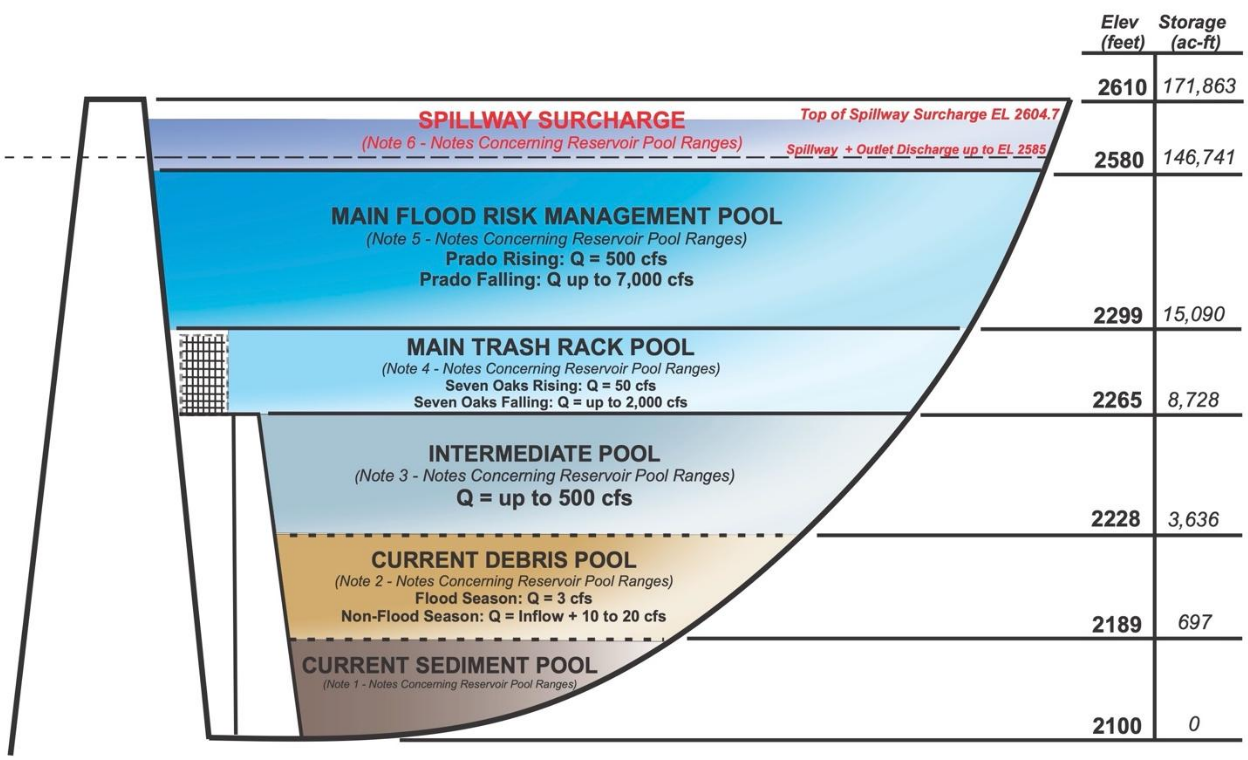

Figure 3-1. *Simplified WCP for Seven Oaks Dam (plate 7-01) (USACE LAD 2003). Pool elevations were updated by a survey completed in October 2025 (revised February 2026) by Orange County Public Works. (Storage values revised February 2026.) The Preliminary Viability Assessment (PVA) modeling took place before this survey. The elevations used in the PVA modeling for the top of sediment pool and debris pool were 2,190 feet and 2,220 feet, respectively. The full WCP is shown in Appendix 3.1.*

3.1 Evaluation Framework

The study team used an established USACE framework called a hydrologic engineering management plan (HEMP) to evaluate the effectiveness of WCP alternatives. The plan provides a systematic, defensible, and reproducible way to compare alternatives with the existing baseline and with one another. The full HEMP can be found in Appendix 3.2. This section provides a summary and describes adjustments made during the evaluation process.

3.1.1 System Constraints

The constraints for the modeling analysis are provided in Table 3-1. These are hard constraints that must be explicitly followed by each of the alternative WCPs.

Table 3-1. *Operational constraints that all FIRO alternatives must satisfy. Release units are in cubic feet per second (cfs).*

ID	Limiting Condition	Description
1	Must accommodate maximum release schedule	The maximum release schedule as defined in the USACE 2003 WCM.
2	Must meet instream minimum flow requirements	Minimum release set at 3 cfs.
3	Must satisfy limits on release rate of change	Limits on release rate of change are provided in the WCM for releases up to 7,000 cfs.
4	Must meet requirements for annual maintenance	All alternatives must draw down the reservoir to the top of the sediment pool (2,190 feet) as quickly as possible starting on August 1 for annual maintenance beginning on September 1.

The maximum release schedule detailed in the WCM (USACE LAD 2003) is a function of current pool elevation, downstream conditions at Prado Dam, and time of year. The maximum release schedule is summarized in Table 3-2. Releases from the debris pool are limited to 3 cfs during the flood season to build up and maintain the pool. Maximum releases from the intermediate pool are constrained by the release capability of the low-flow gate (500 cfs). Maximum releases from the trash rack pool depend on whether the water surface elevation (WSE) of Seven Oaks Dam is rising or falling. There are operational concerns with holding the WSE within the trash rack pool for extended periods of time due to potentially clogging the intake structure with debris floating on the pool's water surface.

Table 3-2. *Maximum release schedule at Seven Oaks Dam.*

Date	Debris Pool	Intermediate Pool	Trash Rack Pool	Flood Control Pool
Flood season (10/1–4/14)	3 cfs	500 cfs	Seven Oaks rising: 50 cfs Seven Oaks falling: 500–2,000 cfs	Prado rising: 500 cfs Prado falling: 2,000–7,000 cfs

Date	Debris Pool	Intermediate Pool	Trash Rack Pool	Flood Control Pool
Non-flood season (4/15–9/30)	500 cfs	500 cfs	Seven Oaks rising: 50 cfs Seven Oaks falling: 500–2,000 cfs	Prado rising: 500 cfs Prado falling: 2,000–7,000 cfs

The trash rack intake structure in relation to the dam is shown in Figure 3-2. When Seven Oaks Dam is rising and the WSE is within the trash rack pool, releases are limited to 50 cfs so the WSE can continue to rise without pulling in any floating debris into the intake structure. The intake structure clogging is primarily a concern when the WSE is rising. Releases from the trash rack pool when the WSE is falling vary from 500 cfs to 2,000 cfs and are a function of the Seven Oaks Dam WSE. When the WSE is within the flood control pool, releases are limited based on whether the Prado Dam WSE is rising or falling. If the Prado Dam WSE is rising, releases from Seven Oaks Dam are limited to 500 cfs to provide downstream flood control relief. Otherwise, releases vary from 2,000 cfs to 7,000 cfs depending on physical maximum release, which is a function of the Seven Oaks Dam WSE.

Figure 3-2. *Aerial photograph of Seven Oaks Dam and Reservoir. (Credit: Orange County Water District and EcoFlight.)*

The WRE team developed and simulated two configurations of operational constraints for this analysis to better understand the impacts of operations within the trash rack pool on groundwater recharge. The first configuration (C1) follows all the hard constraints outlined in Table 3-1. The second configuration (C2) ignores the maximum release schedule when the Seven Oaks Dam WSE is within the track rack pool and the WSE is rising. For C2, the maximum release within the trash rack pool is the physical outlet maximum (500–2,000 cfs) for both rising and falling conditions. It is important to note that C2 is not currently implementable at the Seven Oaks Dam. However, the simulation of C2 seeks to quantify any reductions in FIRO benefits for groundwater recharge due to current operational constraints that could potentially be addressed or removed with infrastructural changes in the future.

3.1.2 Operational Considerations and Performance Metrics

Table 3-3 provides the operational considerations for Seven Oaks Dam. These considerations establish the basis for the performance metrics used in this assessment.

Table 3-3. *Operational considerations evaluated by the alternatives.*

ID	Operational Consideration	Description
1	Meet downstream diversion capacity	Meet the downstream demand, which is the sum of the capacity of all diversion facilities.
2	Flows in excess of downstream diversion capacity	Water not recharged in the San Bernardino Basin Area, which is quantified to assess potential opportunities for recharge and to enhance habitat on the alluvial fan (AF).
3	Environmental impacts to downstream species	Releases that are not diverted can travel downstream, which is quantified for further assessment of potential benefits and impacts.
4	Emergency spillway flow	Emergency spillway releases raise dam safety concerns.

Table 3-4 shows the metrics evaluated for each WCP alternative. The development and modeling of the water supply availability and environmental metrics are described in more detail in Sections 5.6 and 5.7, respectively.

Table 3-4. *Performance metrics used for evaluation and comparison of the baseline WCM and proposed FIRO WCP alternatives.*

ID	Metric	Category	Method of Calculation
FRM-1	Annual maximum discharge frequency from Seven Oaks Dam	FRM	Frequency curve. Simulate 30-year hindcast period and extend with seven event-based simulations.
FRM-2	Annual maximum pool elevation frequency function of Seven Oaks Dam	FRM	Frequency curve. Simulate 30-year hindcast period and extend with seven event-based simulations.
WS-1	Annual diversion below Seven Oaks Dam to each facility (e.g. recharge basin)	Water supply availability	Net annual average. Simulate 30-year hindcast period.
WS-2	Annual release in excess of downstream diversion capacity (i.e., water not captured)	Water supply availability	Net annual average. Simulate 30-year hindcast period.
US-1	Number of days per year where inundation occurs above the following WSEs: 2,265 feet, 2,299 feet, 2,350 feet, and 2,400 feet	Environment	Days per year. Simulate 30-year hindcast period.
AF-1a	Number of days flow in the river at Alabama Street exceeds 100, 200, 300, 400, 500, 1,000, 1,500, 2,000, and 2,500 cfs in the river channel[a]	Environment	Days per year. Simulate 30-year hindcast period.
AF-1b	Number of times[b] flow in the river at Alabama Street exceeds 100, 200, 300, 400, 500, 1,000, 1,500, 2,000, and 2,500 cfs in the river channel[a]	Environment	Times[b] per year. Simulate 30-year hindcast period.
PS-1a	Number of days flow in the river at the perennial stream section exceeds 100, 200,	Environment	Days per year. Simulate 30-year hindcast period.

ID	Metric	Category	Method of Calculation
	300, 400, 500, 1000, 1,500, 2,000, and 2,500 cfs in the river channel[a]		
PS-1b	Number of times[b] flow in the river at the perennial stream section exceeds 100, 200, 300, 400, 500, 1,000, 1,500, 2,000, and 2,500 cfs[a]	Environment	Times[b] per year. Simulate 30-year hindcast period.

[a] After accounting for all downstream diversions.
[b] Number of unique occurrences (i.e., non-consecutive days).

FRM metrics pertain to Seven Oaks Dam releases and WSEs. There are no downstream flow control points that Seven Oaks Dam must consider. However, any releases that exceed 500 cfs trigger notifications for downstream interests (FRM-1). WSEs that result in discharging water through the emergency spillway (FRM-2) cause dam safety and long-term infrastructure concerns (e.g., erosion of spillway). Better performance is measured as minimizing downstream flows over 500 cfs (FRM-1) and minimizing use of the emergency spillway (FRM-2).

The water supply availability metrics measure the amount of water sent to the downstream diversion facilities for groundwater recharge and for storage in Metropolitan Water District of Southern California (MWDSC) reservoirs (WS-1). An additional water supply availability metric (WS-2) quantifies the amount of water not captured for recharge or for other uses in the San Bernardino Basin Area. This amount is defined as releases from Seven Oaks Dam that flow down the Santa Ana River past Alabama Street and exit the San Bernardino Basin Area before being diverted for recharge or storage. Better performance across FIRO alternatives is defined as maximizing WS-1 and minimizing WS-2.

The environmental work team developed environmental metrics to track model outputs and compare performance of the FIRO alternatives regarding environmental considerations. These metrics are not intended to assess environmental impacts nor quantify environmental benefits. The environmental metrics focus on three locations: one upstream of Seven Oaks Dam and two downstream of the dam on the Santa Ana River. The upstream metric (US-1) is based on the Seven Oaks Dam pool elevation. The first downstream location of interest is the alluvial fan, which is measured where Alabama Street crosses the Santa Ana River (AF-1a and AF-1b). The second downstream location is where water treatment plant effluent is discharged into the Santa Ana River near Rialto, California (PS-1a and PS-1b). While much of the Santa Ana River from the dam to just upstream of the treatment plant is ephemeral, effluent discharged by the treatment plant causes the section downstream of the treatment plant to be perennial. This reach is referred to as the perennial stream section of the Santa Ana River.

3.1.3 Reservoir Operations

The WRE team developed and simulated 17 alternatives for this study (Table 3-5), including 16 FIRO alternatives and one alternative capturing current operations under the WCM (USACE LAD 2003). Simulated outcomes under the existing WCM serve as a baseline with which to compare the performance of the simulated FIRO alternatives. This section summarizes operations under the WCM as well as the 16 FIRO alternatives.

Table 3-5. *WCP alternatives (16 FIRO and baseline WCM) simulated in the Seven Oaks Dam PVA.*

FIRO Space		Operating Strategy				
Elevation (feet)	% of Gross Storage	WCM	Summary Forecast Operations (SFO)	Ensemble Forecast Operations (EFO)	Weighted Forecast Release (WFR)	Model Predictive Control (MPC)
2,220	3%	WCM-2220	–	–	–	–
2,265	7%	–	SFO-2265	EFO-2265	WFR-2265	MPC-2265
2,299	11%	–	SFO-2299	EFO-2299	WFR-2299	MPC-2299
2,375	25%	–	SFO-2375	EFO-2375	WFR-2375	MPC-2375
2,418	35%	–	SFO-2418	EFO-2418	WFR-2418	MPC-2418

3.1.3.a WCM Operations

Orange County Public Works staff operate Seven Oaks Dam in accordance with the WCM (USACE LAD 2003), which is summarized in Figure 3-1. The only operating objective of the Seven Oaks Dam WCM is FRM. At the beginning of each flood season (October 1), releases are limited to a minimum flow (Table 3-2) to form the debris pool (2,220 feet). Once the debris pool is formed, releases generally follow the inflow up to the maximum release capability of the project (i.e., maximum release schedule) throughout the remainder of the flood season. When the storm season ends (April 15), the operational goal shifts to emptying the reservoir to the top of the sediment pool (2,190 feet) for annual maintenance. The drawdown begins directly after the storm season ends and must be completed by September 1 to allow time for maintenance work. Appendix 3.3 shows a table of the full release schedule prescribed by the WCM.

3.1.3.b FIRO Alternatives

A FIRO alternative is defined as the combination of reservoir operating strategy (i.e. FIRO strategy) and top of allowable storage (i.e. FIRO Space). A total of 16 FIRO alternatives were included for testing in this analysis. Releases prescribed from each FIRO alternative are limited by the operational constraints in Table 3-1. The FIRO alternatives also include an additional minimum release rule for downstream demand. The downstream demand rule is the sum of the diversion capacity of all the downstream facilities, described in Section 3.2.1. This rule ensures that if there is available water in the reservoir storage and releases are not constrained by a higher priority rule, then the downstream demand will be released instead of being stored within the reservoir. The FIRO strategies and FIRO Spaces are described in more detail below.

<u>FIRO Strategies</u>

The WRE team modeled four FIRO operating strategies for simulation in this study: SFO, EFO, WFR, and MPC. Each strategy receives identical ensemble streamflow forecast information as input. However, the method to transform forecast information to release decisions varies for each strategy, which results in different prescribed releases. The strategies are summarized below with more details in the corresponding appendices.

1) Summary Forecast Operations

SFO, formerly Simpler Forecast Operations, was developed by the USACE Hydrologic Engineering Center for testing during the Prado Dam Final Viability Assessment (FVA) (Ralph et al. 2023). SFO leverages a time-varying percentile of the forecasted cumulative inflow volume over a five-day forecast horizon and a target storage threshold to calculate releases.

For a given forecast, a release with the SFO strategy is calculated as follows:

1. Retrieve ensemble forecast of reservoir inflows. Use five-day forecast horizon.
2. Calculate cumulative inflow volume for each ensemble member at each lead time.
3. Take the *nth* percentile of cumulative inflow for each lead time. The percentile is a function of the initial reservoir WSE.
4. Calculate excess volume over target storage (e.g., top of FIRO Space, spillway crest) to release.
5. Normalize each release by the corresponding lead time.
6. Set maximum as release.

More detail on the SFO strategy and parameterization is provided in Appendix 3.4.1 and in Section 4.2.1 of the Prado Dam FVA.

2) Ensemble Forecast Operations

EFO is a methodology that determines flood control releases based on a probability index curve, formerly risk tolerance curve (Delaney et al. 2020), which is calibrated to balance FRM and water supply availability at Seven Oaks Dam. EFO has been evaluated as a FIRO strategy in previous viability assessments including the Lake Mendocino FVA (Jasperse et al. 2020), Prado Dam FVA (Ralph et al. 2023), and Yuba-Feather FVA (Ralph et al. 2025). EFO prescribes a release schedule using all ensemble members, to ensure the full range of uncertainty is considered, and a key assumption here is that all ensemble members are equally likely. Physical and operational constraints are considered in estimating EFO-prescribed flood control releases, which allows EFO to adapt to future limitations caused by such constraints. For example, if releases at a future time step are expected to be constrained, EFO can use this information to adapt and release more at the current timestep to account for future constraints.

For a given forecast, the process to calculate a release with the EFO strategy is as follows:

1. Retrieve the ensemble forecast of reservoir inflows. Use a 14-day forecast horizon.
2. Calculate the cumulative inflow volume for each ensemble member over forecast horizon.
3. Count the number of ensemble members that exceed target storage (i.e. top of FIRO Space) at each lead-time.
4. Compare the number of exceeding members to the probability index curve (calibrated parameter set).
5. Calculate the maximum volume to release to satisfy the probability index curve at each lead time.
6. Normalize each release by the corresponding lead time.
7. Set the maximum value as the release.

More detail on the EFO strategy is provided in Appendix 3.4.2 and in Delaney et al. (2020). Details on calibrating the probability index curve are available in Appendix 3.4.3.

3) Weighted Forecast Release

WFR is a flood control strategy that uses a non-exceedance percentile of the ensemble inflow forecast and lead time–specific release weights to calculate flood control releases. The WRE team selected and calibrated the non-exceedance percentile and lead time–specific release weights for this study to maximize system performance. The release weights decrease as lead time increases because forecast uncertainty increases with lead time, which can result in unnecessarily large flood control releases. Smaller weights for longer lead times act as a countermeasure against over forecasts of reservoir inflows. Physical and operational constraints are considered by the strategy in estimating the release schedule, which allows WFR to adapt and react to potential future release constraints. In such cases, WFR uses this information to adjust the release schedule accordingly.

For a given forecast, the process to calculate a release with the WFR strategy is as follows:

1. Retrieve the ensemble forecast of reservoir inflows. Use a 14-day forecast horizon.
2. Calculate the cumulative inflow volume for each ensemble member.
3. Take the *nth* percentile of cumulative inflow for each lead time.
4. Calculate the excess volume over the target storage (i.e., top of FIRO Space) to release.
5. Normalize each release by lead time.
6. Adjust the normalized value by the corresponding release weights (calibrated parameter set) for each lead time.
7. Set the maximum value as the release.

More detail on the WFR strategy is provided in Appendix 3.4.4 and in Erfani et al. (*in preparation*). Details on the calibration of the release weights are available in Appendix 3.4.3.

4) Model Predictive Control

MPC is a control technique that optimizes releases at each decision time step (i.e., daily) by simulating system performance over a forecast horizon (Castelletti et al. 2023). MPC is an online control strategy, meaning that it reoptimizes the release sequence for each new forecast issuance. Traditional MPC approaches leverage single-value forecasts. However, newer MPC methods have emerged to leverage ensemble forecasts in decision making, such as tree-based MPC (Raso et al. 2013, 2014; Schwanenberg et al. 2015; Uysal et al. 2018). This study develops and evaluates tree-based MPC as a FIRO strategy. Tree-based MPC leverages forecast information via a scenario tree that is generated from the individual ensemble members. For computational efficiency, the original ensemble undergoes scenario reduction to reduce dimensionality (Growe-Kuska et al. 2003). Scenario reduction decreases redundant information present in similar ensemble members, often near the projected mean, while preserving the spread of the original ensemble members. This process also preserves the probability distribution of the original ensemble members.

For a given forecast, the process to calculate a release with the MPC strategy is as follows:

1. Retrieve the ensemble forecast of reservoir inflows. Use a 14-day forecast horizon.
2. Perform a scenario reduction on the ensemble.

3. Generate a scenario tree from the reduced ensemble.
4. Optimize releases over each branch of the scenario tree to minimize exceeding the top of the FIRO Space and minimize water not captured (WS-2).
5. Select the release sequence that best balances flood control and water supply, subject to selection criteria (calibrated parameter set). Selection criteria is a function of initial WSE and forecasted storage.
6. Set the first release in the selected sequence.

More detail on the MPC strategy is provided in Appendix 3.4.5 and Semmendinger-Raney et al. (*in preparation*). Details on the selection criteria development are available in Appendix 3.4.6.

FIRO Spaces

The FIRO team selected four FIRO Spaces at Seven Oaks Dam for this study: 2,265 feet, 2,299 feet, 2,375 feet, and 2,418 feet, as shown in Figure 3-3. The two lower FIRO Spaces correspond with the top of intermediate pool (2,265 feet) and top of trash rack pool (2,299 feet), and the two higher FIRO Spaces are located within the main flood control pool (2,375 and 2,418 feet). Table 3-5 shows the percentage of gross storage for each FIRO Space. The selection of the four FIRO Spaces was informed by a water conservation feasibility study conducted by USACE in 1997 (USACE LAD 1997). However, the feasibility study was neither finalized nor approved for implementation at Seven Oaks Dam. The two FIRO Spaces located within the main flood control pool (2,375 feet and 2,418 feet) are modeled in this PVA as exploratory FIRO Spaces to test the robustness of Seven Oaks Dam and stress test its system. The inclusion of these two FIRO Spaces is meant to evaluate at what elevation FRM outcomes degrade, which helps promote a better understanding of the system dynamics.

The FIRO Spaces follow the same temporal fill and drawdown pattern as the operational WCM guide curve, as shown in Figure 3-3. During the flood season, the target storage of Seven Oaks Dam is set to the top of the FIRO Space. The FIRO strategies calculate a release when the Seven Oaks Dam WSE exceeds (or is forecasted to exceed) the top of FIRO Space elevation. At the end of flood season, the FIRO Spaces are drained, typically at a rate of downstream diversion capacity, to empty the reservoir to an elevation of 2,190 feet for annual maintenance by September 1. The reservoir remains empty (i.e., outflows are equal to inflows) for the rest of September for maintenance purposes before the flood season begins.

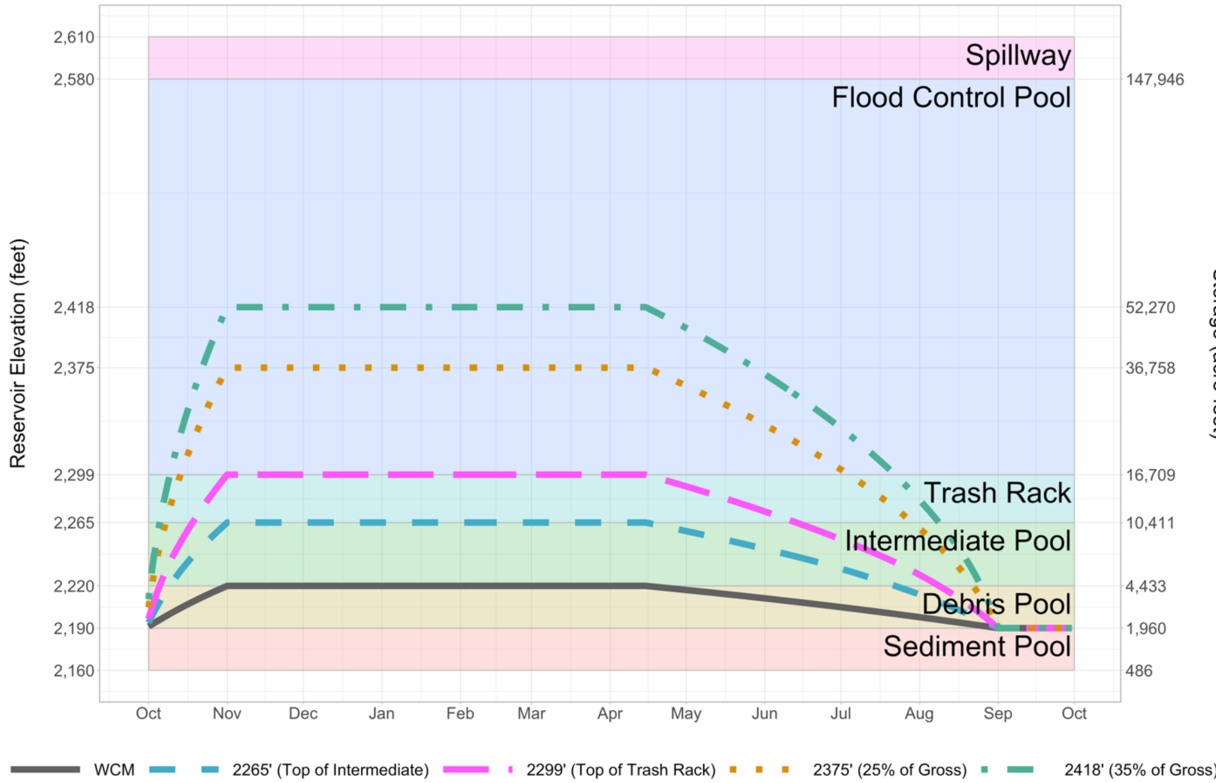

Figure 3-3. *The operational WCM guide curve and the four simulated tops of FIRO Spaces (2,265 feet, 2,299 feet, 2,375 feet, and 2,418 feet) assessed in the Seven Oaks Dam PVA.*

3.2 System Modeling Plan

The WRE team developed a network model to simulate coupled reservoir and groundwater operations. Ideally, reservoir releases are made at a rate that can be fully diverted for groundwater recharge or municipal use. However, there are times when more releases than downstream demand are needed for FRM or for annual maintenance. This section describes the development of a system network model for Seven Oaks Dam and the integrated downstream demand modeling that guides releases associated with water supply use.

3.2.1 Network Model

The simulation framework foundation is a network model that is consistent across FIRO alternatives and the baseline WCM. Figure 3-4 shows a schematic of the network model. Observed and forecasted reservoir inflows for FIRO alternatives are used to calculate a release from Seven Oaks Dam, which differs between FIRO alternatives. The release is routed to the downstream point of diversion, the Cuttle Weir. From there, flows can be diverted to the Santa Ana River spreading grounds (SARSG), Mill Creek spreading grounds (MCSG), San Bernardino County flood control basins (SBCFCB), and/or MWDSC reservoirs. Additionally, flows can continue down the Santa Ana River for percolation along the main river channel. The recharge capacity (or the conveyance capacity) across these locations is summed to calculate the release for downstream demand. The downstream diversion facilities and allocation scheme are described in more detail in Section 5.6.

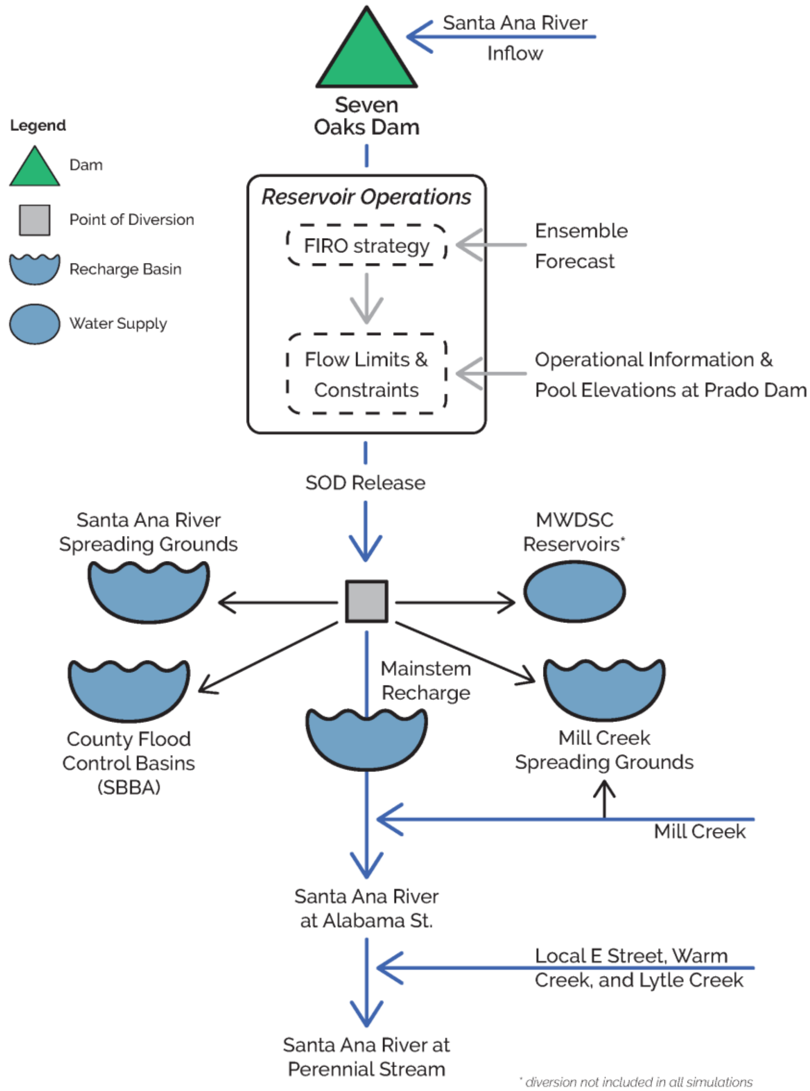

Figure 3-4. *Network model schematic of Seven Oaks Dam and downstream diversion points.*

3.2.1.a Network Scenarios for Evaluation

The FIRO team configured two scenarios in the network model for this study. The first scenario (S1) includes diversions to SARSG, MCSG, SBCFCB, and the Santa Ana River channel. The second scenario (S2) has all the diversions from S1 and includes an additional diversion to MWDSC reservoirs. S1 serves as the default network for analysis. The joint water right between San Bernardino Valley and Western Water permits up to 198,000 acre-feet (ac-ft) per year of diversions to and storage in the MWDSC reservoirs. Western Water requested the FIRO modeling be consistent with the permit language, and thus diversions to MWDSC reservoirs are included as a series of explorative simulations and will be evaluated in the FVA. Diversions to MWDSC reservoirs are not currently operational due to a lack of institutional and infrastructural agreements. However, Western Water is initiating discussions MWDSC to develop the required agreements to divert to MWDSC reservoirs as demonstrated in S2. S2 seeks to quantify how much water could potentially be diverted to MWDSC reservoirs under FIRO operations.

3.3 Simulation Plan

The simulation plan defines and provides the observations and forecasts needed to simulate reservoir operations for each WCP alternative in Table 3-5. This study includes two types of simulations: (1) a 30-year continuous simulation and (2) seven event-based simulations. The two simulation types within the simulation plan are summarized in Table 3-6 and further described in Sections 3.3.1 and 3.3.2, respectively.

Table 3-6. *Simulation plan for each WCP alternative.*

Simulation Type	Continuous			Event-based	
Simulation Period	30-year period of record (POR)			Six historical events	Reservoir design flood
Constraint Configuration / Network Scenario	C1/S1	C1/S2	C2/S1	C1/S1	C1/S1

3.3.1 Continuous POR Simulation

A continuous POR of coupled reservoir and groundwater operations was simulated from October 1, 1990, to September 30, 2019. The input datasets (Section 3.3.1.a) and modeling assumptions (Section 3.3.1.b) for the POR simulation are described below.

3.3.1.a Hydrologic Inputs

Several input hydrologic datasets are needed to run the reservoir and groundwater operations model. The datasets used in the 30-year POR simulation are:

- Observed reservoir inflows.
  - Reservoir inflows were compiled from two datasets. The pre-dam period uses Santa Ana River streamflow observations from U.S. Geological Survey (USGS) gage #11051501 (i.e., natural flows). The post-dam period uses inflows calculated with historical pool elevations and release records. For more information, see Section 5.5.2.a.
- Ensemble forecast of reservoir inflows.
  - Historical ensemble forecasts (i.e., hindcasts) were generated for the National Weather Service’s Hydrologic Ensemble Forecast System (HEFS). HEFS hindcasts are inputs to the FIRO alternatives that inform flood control releases. HEFS hindcasts are available from October 1, 1990, to September 30, 2019. For more information, see Section 5.5.2.b.
- Mill Creek streamflow.
  - Observed streamflow at Mill Creek is from USGS gage #11055000.
- Santa Ana River downstream tributary streamflow contributions.
  - Simulated flows using the California Nevada River Forecast Center’s hydrologic model are used for local flows at E Street (with the Mill Creek contribution removed). Additional tributary flows for Warm Creek and Lytle Creek use observed streamflow from USGS gage nos. 11060400 and 11065000. See Appendix 3.5 for more detail.
- Prado Dam pool elevations.

- Prado Dam WSE is needed to determine the maximum flood control release from Seven Oaks Dam. The dataset used for Prado Dam WSE is from the Prado Dam FVA (Ralph et al. 2023) for the simulated EFO alternative with a 508-foot buffer pool.

3.3.1.b Model Setup

Each WCP alternative started with the same initial condition (an initial reservoir elevation of 2,190 feet) and was simulated for the 30-year POR. Releases from Seven Oaks Dam are modeled based on the input hydrology described above for each FIRO alternative. The release is then diverted to the downstream facilities described in Section 3.2.1. Any water that is not diverted is routed downstream along the Santa Ana River.

For the historical simulation, the WRE team modeled three combinations of constraint configurations (C1 and C2) and network scenarios (S1 and S2): C1/S1, C1/S2, and C2/S1. Note that C2/S2 was not simulated since both the operational constraint configuration and baseline network scenario are changed, which would not provide results for the isolated effects of C2 and S2. The FIRO alternatives are evaluated based on the FRM, water supply, and environmental metrics described in Table 3-4.

3.3.2 Event-Based Simulation

Outside of the POR, the WRE team simulated an additional seven flood events. Six historical events outside of the POR (pre-1990) and the synthetically generated reservoir design flood (RDF) were simulated to provide a more robust analysis for FRM outcomes. Table 3-7 shows the seven events, estimated return periods, and critical inflow volumes. See Section 5.5 for more detail on the flow frequency analysis. The input datasets and modeling setup for the six historical events and RDF event are described in the following subsections.

The historical flood events were selected based on the events with the highest two-day critical duration volume. For Seven Oaks Dam, the hydrology team identified the two-day inflow volume as the critical duration, which also aligns with the critical volume that was used in the Prado Dam FVA (Ralph et al. 2023).

Table 3-7. *Details for the event-based simulations for six historical and one synthetic floods.*

Event	Type	Estimated Return Period	Maximum Cumulative Two-Day Inflow Volume (ac-ft)
January 27, 1916	Historical	75-year	38,678
March 2, 1938	Historical	100-year	46,770
December 6, 1966	Historical	25-year	18,129
January 25, 1969	Historical	25-year	13,587
February 25, 1969	Historical	25-year	17,256
February 21, 1980	Historical	15-year	13,428
RDF	Synthetic	350-year	99,828

The RDF is the maximum flood that the reservoir was originally designed to control under assumed conditions of operation according to the WCM. The RDF is based on a scaled standard project flood, which "represents the flood that would result from the most severe combination of meteorologic and hydrologic conditions considered reasonably characteristic of the geographical area" (USACE LAD 2003). The RDF was scaled up from the standard project flood based on a benefit-cost analysis to determine the optimal level of protection. More details on how USACE developed the standard project flood and RDF are available in the WCM (USACE LAD 2003; Section 8. pp. 1–3).

3.3.2.a Hydrologic Inputs

Several input hydrologic datasets are needed to run the reservoir and groundwater recharge operations model for each event-based simulation. The datasets used in the event-based simulations are:

- Observed reservoir inflows.
    - Historical: Observed streamflow from USGS gage #11051501 (i.e., natural Santa Ana River flow).
    - RDF: The RDF event uses an inflow trace included in the WCM (USACE LAD 2003; Plate 8-02). The five-day trace was digitized and expanded using average wintertime baseflow conditions.
- Ensemble forecast of reservoir inflows.
    - HEFS hindcasts were not available for the event-based simulations. The FIRO team used a methodology developed in Brodeur et al. (2024, 2025) to generate synthetic streamflow forecasts that emulate the current HEFS forecast skill for periods that fall outside of the POR. Since these synthetically generated ensemble forecasts are stochastic by nature, a total of 100 random forecast sets were generated and used as input to the FIRO alternatives for each event. The reservoir outcomes presented in the following section are shown as distributions of outcomes across the 100 randomly generated samples. More details and the verification metrics for the synthetic forecasts are available in Appendix 3.6.
- Prado Dam pool elevations.
    - Prado Dam WSEs are assumed to begin rising four days before peak inflows through two days after peak inflows.

Note that Mill Creek streamflow and Santa Ana River downstream tributary streamflow contributions are not applicable in the event-based simulation because the network does not model downstream conditions.

3.3.2.b Model Setup

Each simulation starts 15 days before peak inflows and ends 15 days after peak inflows. Simulations for each alternative are started with a reservoir elevation at the corresponding top of FIRO Space in order to capture how holding water at the top of each FIRO Space impacts FRM outcomes. Downstream diversions are not modeled for the flood event simulations, so the simulations do not include the downstream demand rule for minimum release (described in Section 3.1.3.b). The event-based simulations track Seven Oaks Dam releases and WSE to measure FRM-1 and FRM-2 from Table 3-4.

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Section 4. Assessment Results

This section presents the simulation results of the 16 Forecast Informed Reservoir Operations (FIRO) alternatives and baseline Water Control Manual (WCM) (USACE LAD 2003) using the evaluation framework presented in Section 3. The 17 Water Control Plan (WCP) alternatives (16 FIRO alternatives and baseline WCM) are shown in Table 3-5. The results for the 30-year period of record (POR) simulation and seven event-based simulations for the metrics outlined in Table 3-4 are described in Section 4.1.

The goals of this assessment were to:

- Refine the process through which FIRO alternatives could be simulated and evaluated for the Final Viability Assessment (FVA).
- Gain insight on the viability of FIRO for Seven Oaks Dam.
- Gain insight on the type of WCP alternatives that should be evaluated for the FVA.

As such, the analysis and results shown are not intended to yield a recommendation for a specific FIRO WCP alternative for Seven Oaks Dam. Instead, they provide information for a follow-up study that will include an implementation recommendation.

The simulations and assessments performed generated significant insight into the viability of FIRO at Seven Oaks Dam. The results shown in Section 4.1 indicate that FIRO is viable at Seven Oaks Dam. Overall, the 2,265-foot (top of intermediate pool) and 2,299-foot (top of trash rack pool) FIRO Spaces improve water supply availability without compromising flood risk management (FRM) outcomes. The potential impacts to environmental metrics and water quality outcomes need further examination.

The key findings for this analysis are:

- There are no FRM impacts for FIRO alternatives tested against historically observed event simulations (30-year POR and six historical flood events).
- Alternatives with FIRO Spaces of 2,265 feet or 2,299 feet (slightly higher winter storage levels than current operations) result in similar FRM compared WCM operations (2,220 feet) when simulated with inflows from the reservoir design flood (RDF).
- Alternatives with higher FIRO Spaces of 2,375 feet or 2,418 feet could incur additional risk against unobserved, but plausible, exceptionally extreme flood events, as shown in the RDF simulation.
- Differences in recharge outcomes across FIRO alternatives are attributable to the top of FIRO Space rather than the FIRO strategy. Higher winter storage, especially in wet years, increases the amount of water available for recharge.
- Indicators to explore potential environmental changes showed little variation in between FIRO alternatives and WCM operations for downstream flow conditions.

4.1 Simulation Results

The simulation results for each WCP alternative, constraint configuration (C1 and C2), and network scenario (S1 and S2) support the evaluation of impacts to flood risk management, water supply, and environmental metrics. The FIRO alternatives are described in Table 3-5, and the performance metrics are described in Table 3-4. The results are presented below by FRM

(Section 4.1.1), water supply (Section 4.1.2), and environmental (Section 4.1.3) metric performance. Additional results and figures are in the corresponding appendices.

4.1.1 FRM Metrics

Results are based on the POR simulations (1990–2019) and seven flood-event simulations (six pre-1990 flood events and the RDF event). The inclusion of specific flood events in the simulation plan serves to provide more robust tests for FRM outcomes. This section will present flood frequency curves that include the seven flood event simulations with the 30-year POR results. These results are based on the C1 constraint configuration (operational trash rack flow constraint). The event-based simulations do not simulate downstream conditions of Seven Oaks Dam (see Section 3.3.2.b), and the POR simulation is based on the S1 network scenario (without Metropolitan Water District of Southern California [MWDSC] diversion).

4.1.1.a Aggregated Annual Exceedance Probability Analysis

The annual exceedance probabilities of Seven Oaks Dam water surface elevations (WSEs) are shown in Figure 4-1, and the annual exceedance probabilities of Seven Oaks Dam releases are shown in Appendix 4.1, Figure 4-1. Note that the flood event simulations (six historical flood events and the RDF event) use the synthetically generated ensemble forecasts described in Section 3.3.2. A total of 100 randomly generated synthetic forecast sets were used to ensure the results were not overly sensitive to a particular forecast sample. Figure 4-1 and Appendix 4.1 show the average WSEs and releases that occur across the 100 random forecast samples that were simulated.

The expected maximum annual WSEs and releases are similar between WCM operations and FIRO alternatives with the 2,265-foot and 2,299-foot FIRO Spaces. FIRO alternatives with 2,375-foot and 2,418-foot FIRO Spaces produce higher maximum annual releases and WSEs than the baseline WCM operations. The RDF event simulation produced the highest release and WSE of all FIRO alternatives. The next six highest releases and WSEs produced for all FIRO alternatives were results of the six historical event simulations. Inflows over the 30-year POR were fairly small in terms of the full observational record (1912–present). The annual maxima over the POR did not test the ability of FIRO alternatives to navigate FRM.

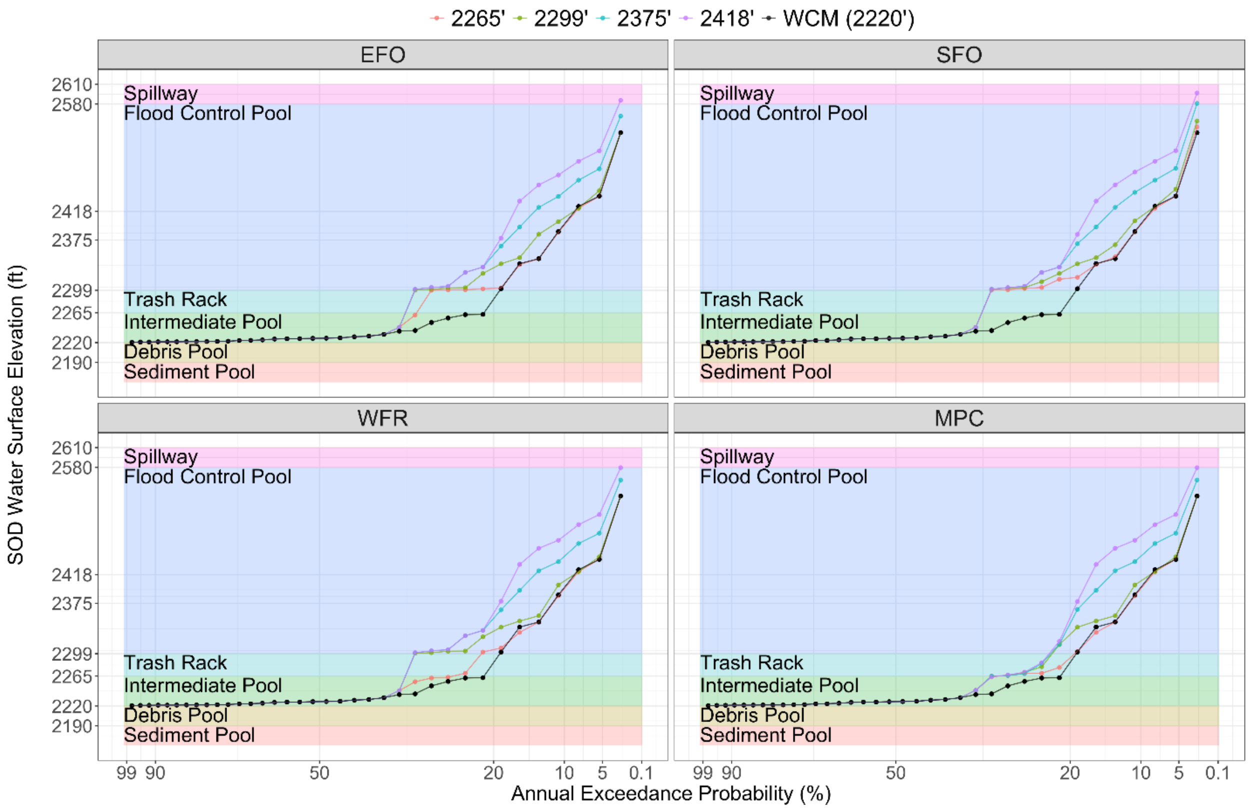

Figure 4-1. *Annual exceedance probability for Seven Oaks Dam WSEs based on the 16 FIRO alternatives and baseline WCM. Results are categorized by FIRO strategy. The lines in the faceted plots are colored by FIRO Space. Baseline WCM WSEs are included for comparison as the solid black line in each facet. The shaded background regions of each plot show the five reservoir pool areas and the emergency spillway.*

4.1.1.b Reservoir Design Flood Event Analysis

The RDF simulation was the only simulated event that triggered emergency spillway releases for any FIRO alternative. Since flood control is the primary operating objective of Seven Oaks Dam, FIRO alternatives must not result in worse FRM outcomes than those of the baseline WCM. The simulated WSEs for the RDF event are shown in Figure 4-2. The results show the distribution of WSE outcomes for each FIRO alternative across the 100 random forecast samples simulated.

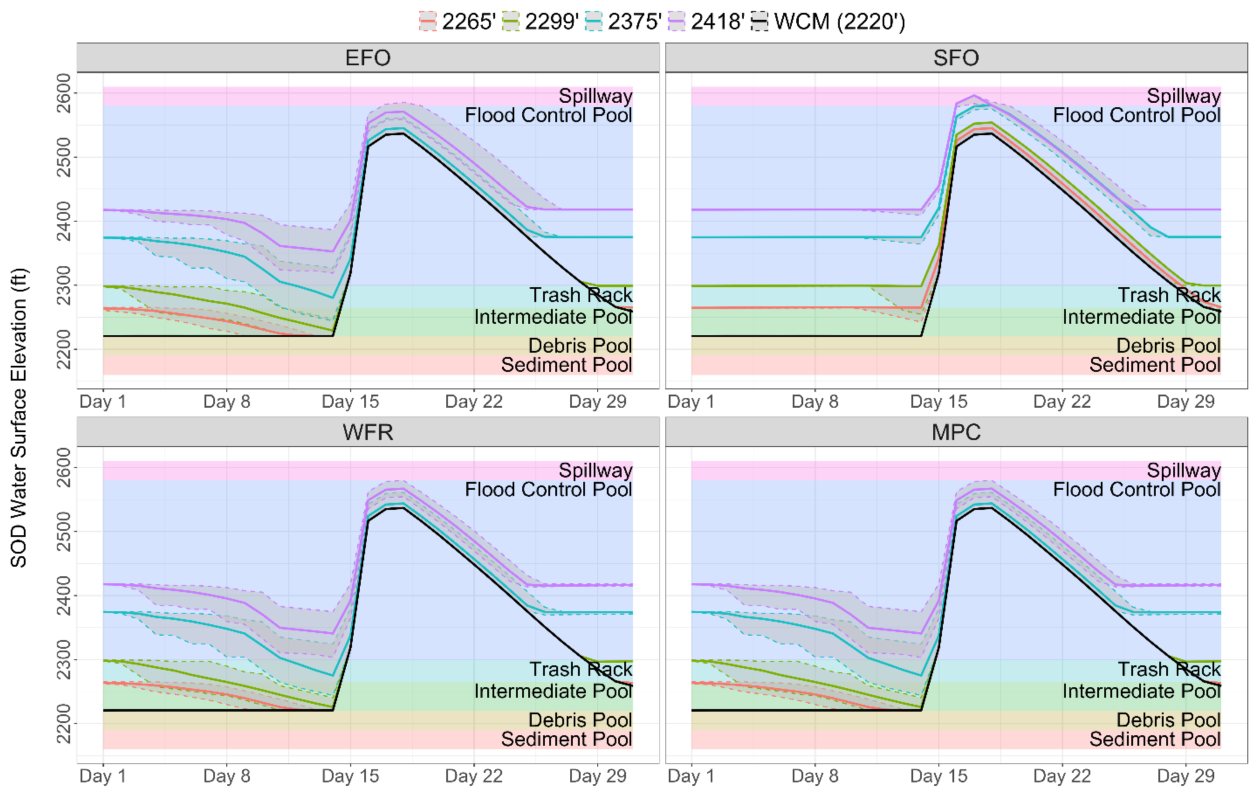

Figure 4-2. *The distribution of WSEs for the RDF event simulation for the 100 forecast samples. Results are categorized by FIRO strategy. Lines are colored by the corresponding FIRO Space. The solid line shows the average WSE, and the dashed lines show the minimum and maximum WSEs at each time step. The solid black line on each plot is the baseline WCM WSE time series. The shaded background regions show the five reservoir pool areas and the emergency spillway.*

FRM outcomes are sensitive to the top of FIRO Space. No FIRO alternatives with a FIRO Space of 2,266 feet or 2,299 feet resulted in spillway releases for any FIRO strategy. Furthermore, the maximum simulated WSEs for the 2,266-foot and 2,299-foot FIRO Spaces were the same as the baseline WCM for three FIRO strategies (Ensemble Forecast Operations [EFO], Weighted Forecast Release [WFR], and Model Predictive Control [MPC]). Only the Summary Forecast Operations (SFO) strategy produced larger peak WSEs for the 2,266-foot and 2,299-foot FIRO Spaces.

Results for FRM outcomes were more varied at the 2,375-foot and 2,418-foot FIRO Spaces. All FIRO alternatives with the 2,375-foot and 2,418-foot FIRO Spaces produced larger peak WSEs than the baseline WCM. A total of four FIRO alternatives resulted in use of the emergency spillway, one with a 2,375-foot FIRO Space and three with a 2,418-foot FIRO Space (SFO-2375, SFO-2418, EFO-2418, and MPC-2418). SFO-2375 had 98 of 100 forecast samples reach the emergency spillway. SFO-2418 had 100 of 100 forecast samples reach the emergency spillway. EFO-2418 had five of 100 forecast samples reach the emergency spillway. MPC-2418 had one of 100 forecast samples reach the emergency spillway. No WFR alternatives resulted in use of the emergency spillway.

The variability in WSE outcomes across the 100 random forecast samples for the SFO strategy is much smaller than for other FIRO strategies. This is likely due to the shortened forecast horizon (i.e., five days) that SFO uses to prescribe flood control releases. Prado Dam pool elevations were assumed to begin rising four days prior to peak inflows (see Section 3.3.2.b), which limits releases from Seven Oaks Dam to 500 cubic feet per second (cfs). Therefore, the ability of SFO to pre-release prior to peak inflows is limited to the fifth day before peak inflows. This differs from the EFO, WFR, and MPC strategies, which use a forecast horizon of 14 days, so pre-releases can occur before releases are constrained for downstream flood control at Prado Dam.

Overall, these results indicate that storing water at 2,265 feet and 2,299 feet has little to no impact on FRM outcomes (maximum release and peak WSE). Based on the results from this study, storing water at 2,375 feet and 2,418 feet may increase expected FRM outcomes for events of RDF or larger. Exploring FIRO Spaces between 2,299 feet and 2,375 feet is recommended for the FVA to better assess the FIRO Space elevation at which FRM outcomes begin to degrade for exceptionally extreme events.

4.1.2 Water Supply Availability Metrics

The results described below are based on the 30-year POR simulation for each FIRO alternative for the C1 constraint configuration and S1 network scenario unless otherwise noted. The net annual average recharge summed at all downstream facilities and the net annual average water not captured for the 16 FIRO alternatives over the 30-year POR are shown in Figure 4-3. Better performance for a FIRO alternative is defined as higher values for water recharged and lower values for water not captured. The net annual average recharge at individual recharge facilities for each FIRO alternative is shown in Appendix 4.2.

There is minimal variation in water recharged (Figure 4-3a) and water not captured (Figure 4-3b) for the same FIRO Space across the four FIRO strategies. However, the performance of water supply availability metrics is much more sensitive to the top of FIRO Space elevation. Generally, as the top of FIRO Space increases, the performance for the water supply availability metrics also increases (i.e., groundwater recharge increases and water not captured decreases).

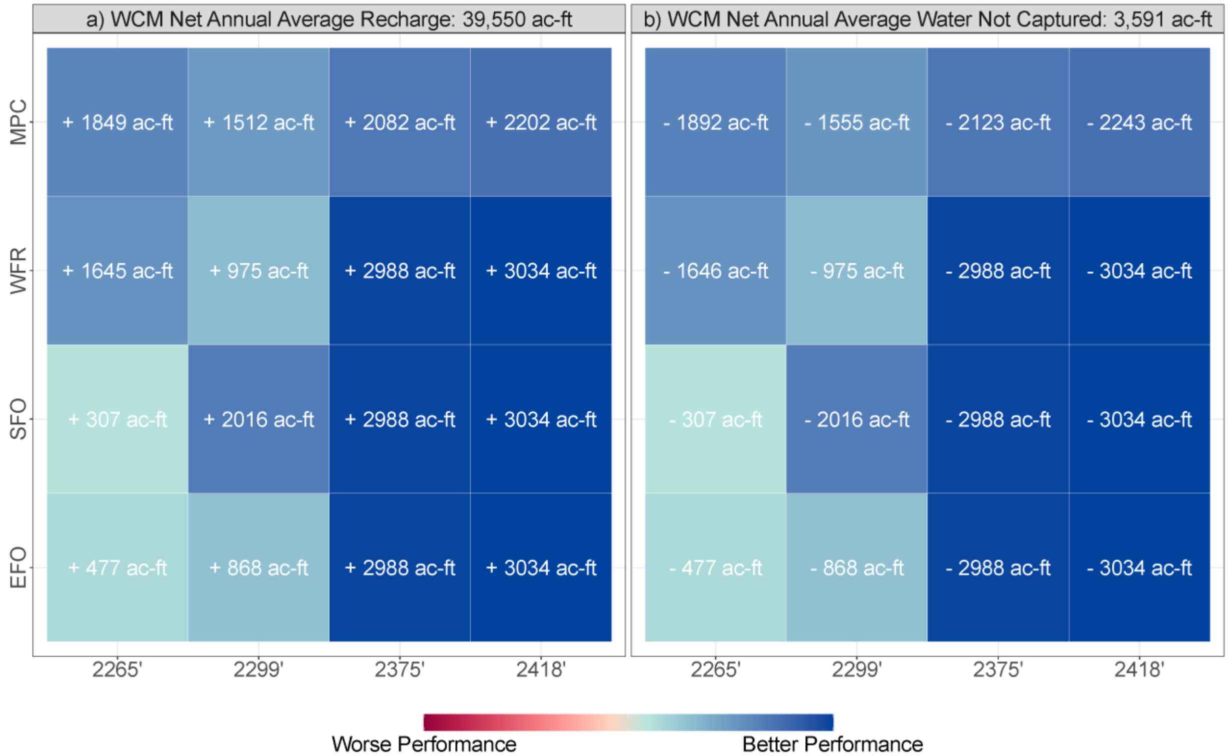

Figure 4-3. *Improvement in net annual average a) groundwater recharge and b) water not captured for the 16 FIRO alternatives compared to baseline WCM operations for the 30-year POR simulation. FIRO alternatives are arranged by FIRO strategy (rows) and FIRO Space (columns). Tiles are shaded by performance where darker blue corresponds to better performance (i.e., higher recharge values and lower values of water not captured).*

While the FIRO alternatives improve water supply availability outcomes compared to baseline WCM operations, the magnitude of water supply benefits varies from year to year. Figure 4-4 shows the total recharge by water year for each year in the POR (1990–2019). In 24 out of 30 years (80 percent), recharge outcomes for the 16 FIRO alternatives were the same as the baseline recharge. The six years (20 percent) where FIRO alternatives outperformed the baseline WCM had higher than average inflows (i.e., wet years). This indicates that in average or drier than average years, there is not enough inflow to the reservoir for FIRO alternatives to store more water during the flood season. FIRO benefits are greatest in wet years when FIRO alternatives can temporarily store more water in the reservoir that would otherwise be immediately released under baseline WCM operations. The water stored in the reservoir under FIRO operations is then released post-event at a rate corresponding to the capture capacity of downstream facilities.

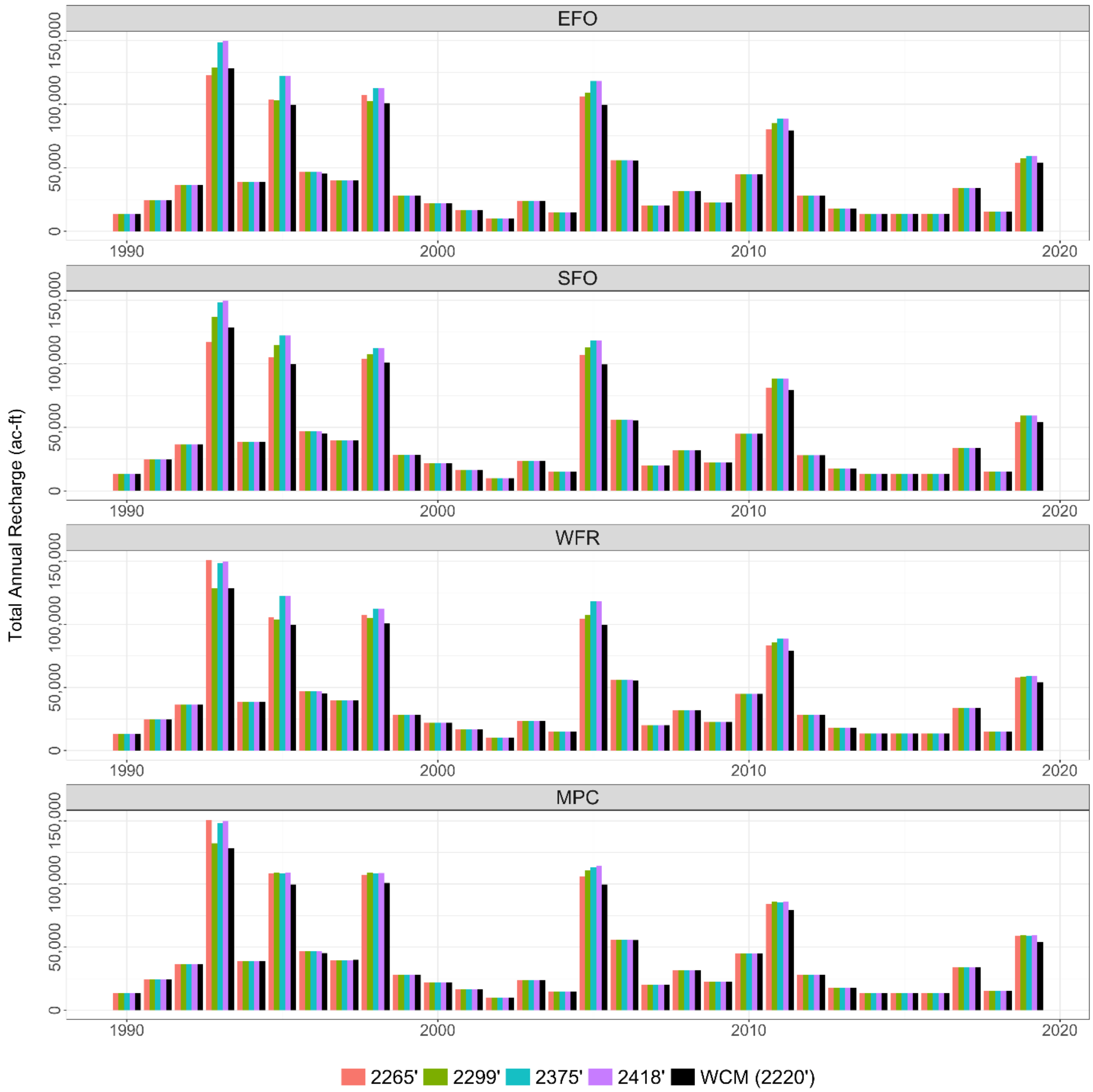

Figure 4-4. *Total annual recharge for each water year in the 30-year POR. Results are categorized by FIRO strategy, and the bars in the faceted plots are colored by FIRO Space. Baseline WCM releases are included for comparison as the solid black bar in each facet.*

4.1.2.a Impacts of Trash Rack Operations on Water Supply Outcomes

The two constraint configurations (C1 and C2) were run for the S1 network scenario to quantify the impacts of the trash rack constraint on water supply metrics. The total recharge for the 30-year POR between the two constraint configurations and their difference for the four FIRO Spaces with the EFO FIRO strategy are shown in Table 4-1. While only results for the EFO control strategy are shown, results are similar for the other three FIRO strategies. At the two lower FIRO Spaces (2,265 feet and 2,299 feet), trash rack operations result in a reduction of groundwater recharge. However, at the two higher FIRO Spaces (2,375 feet and 2,418 feet), trash rack operations have little impact on recharge. The reduction in recharge at the 2,265-foot and 2,299-foot FIRO Spaces is due to their increased frequency of entering the trash rack pool compared to the 2,375-foot and 2,418-foot FIRO Spaces. Once the 2,375-foot and 2,418-foot FIRO Spaces rise above the trash rack pool, the WSE often does not fall back into the trash rack pool until the late summer drawdown. The 2,265-foot and 2,299-foot FIRO Spaces enter the trash rack pool more frequently, albeit in slightly different ways.

During periods of increased inflows, the 2,265-foot alternatives may pre-release water to make room for forecasted inflows. However, if not enough water is released, the WSE will rise above the top of FIRO Space and enter the trash rack. Once the WSE enters the trash rack, releases are limited to 50 cfs, which causes the WSE to quickly rise above the trash rack. Then, once peak inflows have passed, the 2,265-foot alternatives prescribe releases exceeding downstream recharge capacity to bring the WSE back down to the top of FIRO Space as quickly as possible.

The 2,299-foot alternatives behave differently since the top of FIRO Space corresponds with the top of the trash rack pool. To pre-release water, the WSE of 2,299-foot alternatives must dip down into the trash rack pool. However, as soon as the WSE enters the trash rack pool, releases are limited to 50 cfs to bring the WSE back up to 2,299 feet. Then, when peak inflows enter the reservoir, the WSE rises above the top of FIRO Space, and the 2,299-foot alternatives prescribe releases to bring the WSE back down to the top of FIRO Space as quickly as possible. These releases often exceed downstream recharge capacity. Generally put, the 2,299-foot alternatives cannot pre-release water based on the forecasted inflows given the operational trash rack constraints.

Table 4-1. *Total recharge over the POR for the EFO FIRO strategy for the two simulated constraint configurations, shown in acre-feet (ac-ft). The C1 configuration (second column) includes the operational trash rack release constraint, and the C2 configuration (third column) does not include the operational trash track release constraints. The difference in groundwater recharge between C1 and C2 is shown in the fourth column.*

FIRO Alternative	C1 Recharge (ac-ft)	C2 Recharge (ac-ft)	Difference (C2 – C1)
EFO-2265	605,409	617,218	11,809
EFO-2299	611,314	629,256	17,942
EFO-2375	643,383	644,772	1,389
EFO-2418	644,072	645,461	1,389

The C2 constraint configuration was included for simulation in the Preliminary Viability Assessment (PVA) to investigate whether current trash rack operations have any impact on water supply availability metrics. These preliminary simulation results indicate that current trash rack operations may result in a lost opportunity to recharge water within the SBBA due to releases that exceed downstream diversion capacity. The FVA should further refine this evaluation process to better understand more granular impacts of trash rack operations and identify pathways to address potential losses in recharge opportunities.

4.1.2.b Exploratory Simulation with MWDSC Diversions

The joint water right between San Bernardino Valley and Western Water permits for up to 198,000 ac-ft per year contemplates diversions to, and storage in, the MWDSC reservoirs. To be consistent with the permit language, Western Water requested the inclusion of diversions to

MWDSC reservoirs in the modeling analysis, and the MWDSC reservoirs were thus simulated as a separate scenario (S2). MWDSC reservoir diversions were not included in the original network model due to the need for institutional and operational arrangements that are required to implement this diversion in Seven Oaks Dam operations. Western Water and Metropolitan Water District are initiating discussions of the required agreements, and the exploratory simulation (S2) with MWDSC diversions includes a refined priority scheme to better incorporate the reservoirs. Appendix 4.3 shows the change in net annual average total groundwater recharge, MWDSC reservoir diversion, and water not captured for all FIRO alternatives compared to the baseline WCM for the 30-year POR.

For most FIRO alternatives, there is minimal change from baseline operations for groundwater recharge (Appendix 4.3.1) and diversions to MWDSC reservoirs (Appendix 4.3.2). WFR-2266 and MPC-2266 increase diversions to MWDSC reservoirs. However, EFO-2266 and SFO-2266 result in reductions. There is a minimal decrease at the 2,299-foot, 2,375-foot, and 2,418-foot FIRO Spaces for the EFO, WFR, and MPC FIRO strategies. Diversions increase for SFO-2299 and SFO-2375.

The inclusion of diversions to MWDSC reservoirs (S2) results in a reduction of water not captured (Appendix 4.3.3) compared to S1 (Figure 4-3b) in all except in one FIRO alternative (SFO-2266). This is primarily because the MWDSC reservoirs increase downstream demand compared to S1. Therefore, when a FIRO alternative prescribes a flood control release, more water is diverted to downstream interests with the additional demand of MWDSC reservoirs. While diversions to MWDSC reservoirs cannot be accomplished in current operations, institutional and infrastructural arrangements should be considered and evaluated in the FVA to leverage the additional diversion capacity of MWDSC reservoirs.

4.1.3 Environmental Metrics

Results are based on the 30-year POR simulation for each FIRO alternative for the C1 constraint configuration and S1 network scenario unless otherwise noted. Results are presented below for the three environmental focal areas: upstream of Seven Oaks Dam (upstream focal area [US]; 4.1.3.a), Santa Ana River wash (alluvial fan focal area [AF]; 4.1.3.b), and the perennial stream section (perennial stream focal area [PS]; 4.1.3.c). The metrics are described in Table 3-4.

4.1.3.a Performance of Upstream Focal Area Metrics

The average number of days per year that exceed the WSE thresholds for the US-1 metric are shown in Figure 4-5. Results for all FIRO alternatives are shown in Appendix 4.4.1. Over the 30-year POR, performance for US-1 varies between FIRO alternatives due to the top of FIRO Space rather than the FIRO strategy, so results are presented as the change in number of days above each elevation threshold averaged across the FIRO strategies for each FIRO Space. The 2,265-foot threshold is exceeded most frequently, with the frequency of exceedance increasing as FIRO Space increased. A similar pattern emerges for the 2,299-foot and 2,350-foot thresholds; however, the frequency of exceedances is smaller than for 2,265 feet. There are no exceedances of 2,400 feet over the 30-year POR.

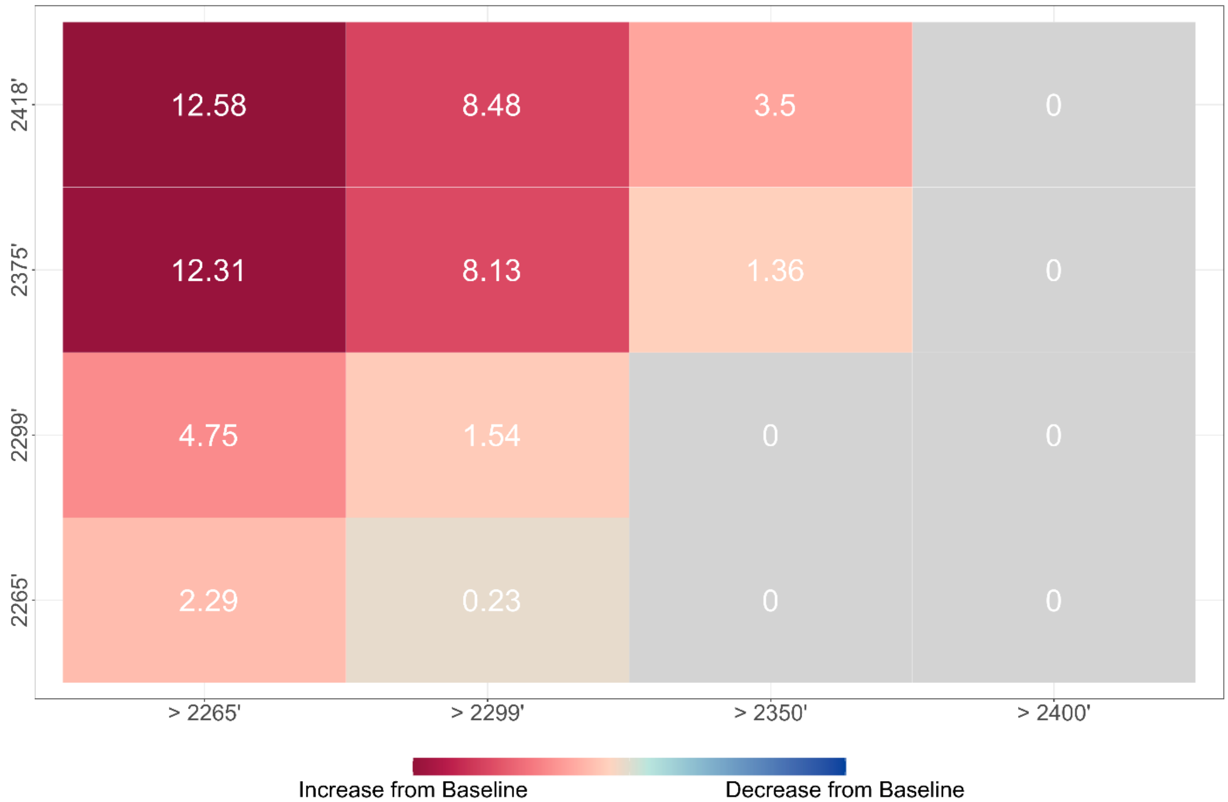

Figure 4-5. *Average number of days per year that Seven Oaks Dam WSE exceeds 2,265; 2,299; 2,350; and 2,400 feet (US-1) over the 30-year POR. Results are presented as the change in days averaged across the four FIRO strategies from baseline WCM operations. Tiles are shaded by performance where darker blue corresponds to fewer exceedances and darker red corresponds to more exceedances compared to baseline operations.*

4.1.3.b Performance of Alluvial Fan Focal Area Metrics

The number of days and times per year that exceed the flow thresholds for the AF-1 metric averaged across the FIRO Spaces is shown in Figure 4-6. The AF-1a and AF-1b metrics do not represent environmental thresholds but rather track opportunities for potential environmental enhancements. There is little variation in performance across the WCP alternatives for AF-1a and AF-1b. The results for all 16 FIRO alternatives are included in Appendices 4.4.2 and 4.4.3. The range of AF-1a (Figure 4-6a) performance across FIRO alternatives would decrease the number of days per year that exceed the flow thresholds by an average of less than two days compared to the baseline WCM. Overall, there are minimal changes from baseline operations for the AF-1b metric (Figure 4-6b). There is a slight increase in lower flows for the two lower FIRO Spaces and a slight decrease in higher flows for higher FIRO Spaces.

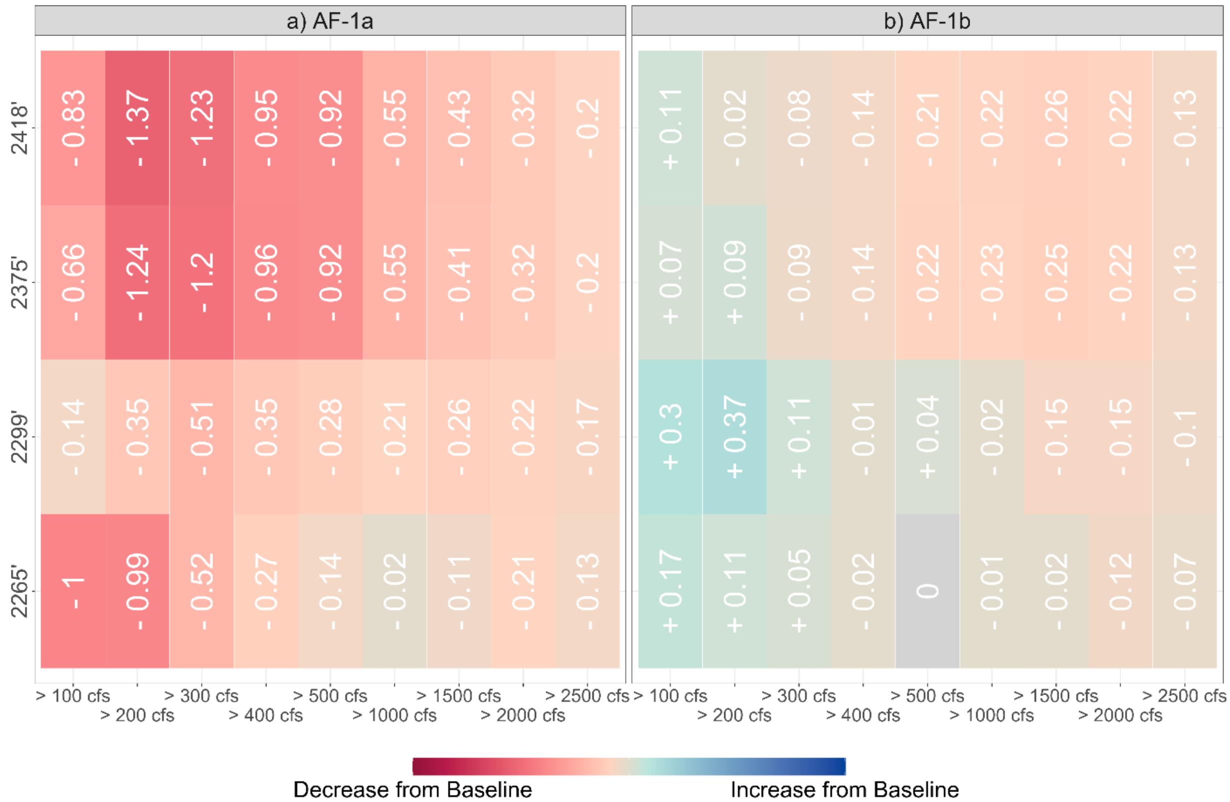

Figure 4-6. *Average number of a) days and b) times per year the flow in the river at Alabama Street exceeds 100; 200; 300; 400; 500; 1,000; 1,500; 2,000; and 2,500 cfs over the 30-year POR. Results are presented as the change from baseline WCM operations averaged across the four FIRO strategies. Tiles are shaded by performance where darker red corresponds to fewer exceedances and darker blue corresponds to more exceedances of the flow thresholds compared to baseline operations.*

4.1.3.c Performance of Perennial Stream Focal Area Metrics

The average number of days and times per year that exceed the flow thresholds for the PS-1 metric across FIRO Spaces is shown in Figure 4-7. The PS-1 metrics do not represent environmental thresholds but rather track occurrences of downstream flow. Like the AF metrics, there is little variation in performance across the WCP alternatives for PS-1a and PS-1b. The results for each FIRO alternative are included in Appendices 4.4.4 and 4.4.5. The range of PS-1a (Figure 4-7a) performance across FIRO alternatives would decrease the number of days per year that exceed the flow thresholds by an average of less than one day compared to the baseline WCM

There are minimal changes from baseline operations for the PS-1b metric (Figure 4-7b). There is a slight decrease in higher flows across all FIRO Spaces. The potential benefits and impacts of downstream Santa Ana River flow quantified by PS-1a and PS-1b will be assessed in the FVA.

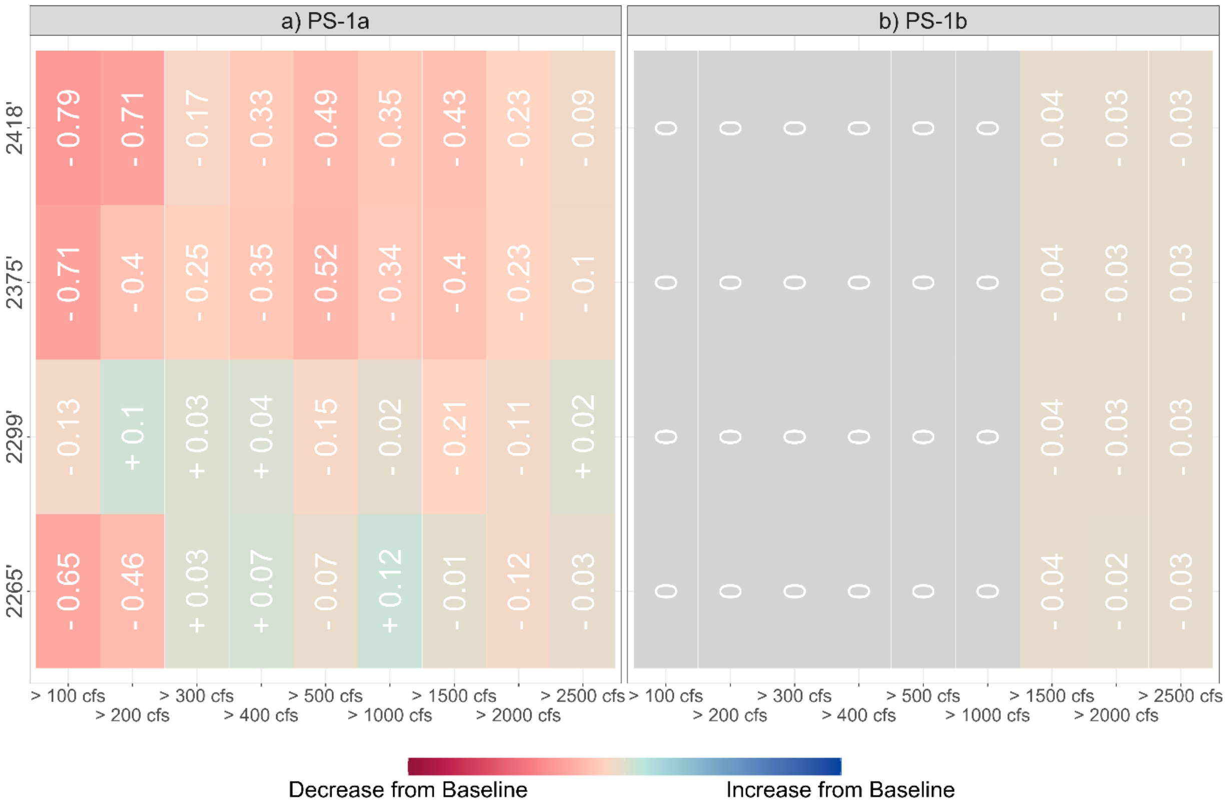

Figure 4-7. *Average number of a) days and b) times per year flow in the river at the perennial stream section exceeds 100; 200; 300; 400; 500; 1,000; 1,500; 2,000; and 2,500 cfs over the 30-year POR. Results are presented as the change from baseline WCM operations averaged across the four FIRO strategies. Tiles are shaded by performance where darker red corresponds to fewer exceedances and darker blue corresponds to more exceedances of the flow thresholds compared to baseline operations.*

4.1.3.d Summary of Impacts Across Environmental Metrics

Overall, the FIRO alternatives slightly reduce the frequency of releases that exceed the flow thresholds for the AF and PS metrics. This is because the FIRO alternatives temporarily store more water in the reservoir, which reduces the amount of water that flows to downstream sections of the system. However, as demonstrated in Section 4.1.2, FIRO alternatives generally increase water availability. While the modeling framework presented here only considers using available water for groundwater recharge and diversions to MWDSC reservoirs, available water could also be used in operations to support environmental outcomes. This would require developing operational rules into the FIRO alternatives that monitor and prescribe releases to support downstream environmental concerns. That was not considered in the scope of the PVA. The FVA will assess potential changes to the metrics to account for potential negative and positive impacts associated with the FIRO alternatives.

4.2 FVA Recommendations

There are several recommended refinements to the FIRO simulation and evaluation process to enhance the FVA study:

- Simulate coupled reservoir and groundwater operations on an hourly time step to better capture peak inflows and releases.
- Simulate a longer continuous record than the 30-year POR using synthetic forecasts for more robust water supply and environmental outcomes.
- Update reservoir storage elevation curves with survey data from November 2025.
- Develop and simulate hydrologic traces that better capture extreme events and their variability within the range of the largest historical event (100-year event) and the RDF (350-year event).
- Extend the downstream extent of the network model to couple operations at Prado Dam rather than using a static input dataset of pool elevations at Prado Dam.
- Explore FIRO Spaces between 2,299 feet (top of trash rack) and 2,375 feet (25 percent of gross pool) to understand the tradeoff elevation for FRM and groundwater recharge outcomes.
- Refine the process to quantify the impacts of current trash rack operations on water supply availability metrics.
- Investigate the optimal forecast horizon to inform reservoir operations in FIRO alternatives. The 14-day forecast horizon was chosen for most FIRO strategies. Assess whether a shorter forecast horizon can better navigate FRM and forecast uncertainty.
- Parameterize the SFO model for the Seven Oaks system and take advantage of recent enhancements by U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center.
- Develop a scenario that minimizes the amount of stored water that needs to be released in excess of the diversion capacity in the July–August period during wet years.
- Include water diversions to senior water rights holders not associated with groundwater recharge.
- Consider development of operational rules to support improved environmental outcomes.
- Develop an approach to account for relevant water quality considerations in reservoir operations.
- Identify next steps for coordination of dam safety considerations with USACE and the California Department of Water Resources Division of Safety of Dams.

4.3 References

USACE LAD (U.S. Army Corps of Engineers Los Angeles District). (2003). *Water Control Manual: Seven Oaks Dam and Reservoir*.

Section 5. Work Team Technical Studies

5.1 Overview and Purpose

Technical studies were conducted as part of the Preliminary Viability Assessment (PVA) to build the scientific foundation needed to test Forecast Informed Reservoir Operations (FIRO) for potential implementation at Seven Oaks Dam. Because FIRO depends on using forecasts to inform release and storage decisions, the studies evaluate whether the watershed can be monitored and forecasted well enough to support safe, effective operations, and what improvements are needed to get there.

Each work team addresses a critical and interconnected component of FIRO, as shown in Figure 5-1 and Table 5-1. The observations work team identifies gaps in monitoring precipitation, snow, soil moisture, streamflow, and discharge, and identifies station installations to improve situational awareness and support model validation. The meteorology and forecast verification work teams conduct studies that characterize storm types that drive extreme precipitation, quantify forecast skill and common error patterns, and identify the processes and conditions that impact forecast reliability at different lead times. The hydrology team completes analyses to improve the inflow record, assess and improve the operational inflow model and hindcasts used in simulation, and provide the data and information needed to support the Water Resources Engineering (WRE) tasks. The WRE team integrates these inputs to simulate baseline and FIRO alternatives and compare performance across the FIRO objectives.

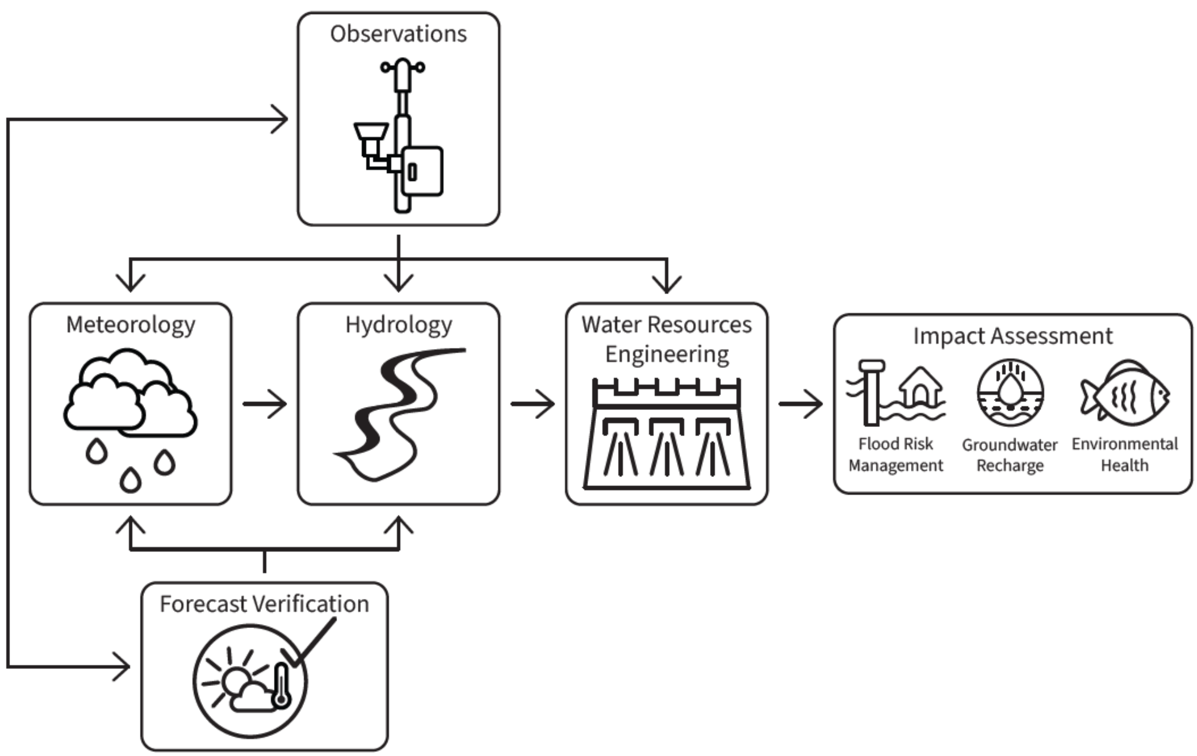

Figure 5-1. *Workflow of FIRO technical work team modeling and interactions in the PVA.*

Table 5-1. *Summary of technical work teams, their roles in the PVA, and why their contributions are essential to evaluating FIRO feasibility at Seven Oaks Dam.*

Work Team	Role in the PVA	Why This Matters for FIRO
Forecast verification and skill	Quantifies forecast skill (e.g., accuracy)	Establishes confidence in forecasts for decision-making at lead times needed to inform operations
Observations	Identifies and addresses gaps in watershed monitoring; improves measurements of precipitation, snow, soil moisture, and streamflow	Provides baseline data needed to evaluate forecast performance, calibrate models, and provide situational awareness
Meteorology	Assesses storm types driving precipitation in the watershed	Determines which weather conditions have the most impact on FIRO operations
Hydrologic modeling	Evaluates and improves inflow data and models	Translates forecasts into inflow estimates used to test different operating parameters
WRE[a]	Simulates different FIRO alternatives using forecasts and inflows within system constraints	Provides the formal feasibility evaluation of FIRO alternatives
Groundwater recharge and dam diversion modeling	Develops models to simulate groundwater recharge operations coupled with reservoir operations	Establishes modeling framework to assess FIRO benefits for groundwater recharge
Environmental Resources	Develops metrics to evaluate ecological habitat impacts and benefits for FIRO alternatives	Ensures operational changes are evaluated against regulatory requirements and identifies potential ecological benefits

[a] Presented in Section 3: How FIRO Viability Was Assessed and Section 4: Assessment Results.

During the workplan phase of the FIRO viability assessment process, select work teams conducted preliminary studies to support the PVA. The preliminary technical studies report is included in Appendix 5.1. The following sections summarize the technical studies completed during the PVA, which form an integrated evidence base to guide potential deviation requests and evaluate FIRO feasibility.

5.2 Forecast Verification and Skill

5.2.1 Role of Forecast Verification Work Team and Questions Addressed

The verification component of the PVA evaluates the skill, reliability, and clarity of meteorological and hydrologic forecast information to support operational decision making at Seven Oaks Dam. The assessment focuses on quantifying the skill of precipitation and inflow forecasts, understanding how errors evolve in time, and identifying the atmospheric–hydrologic linkages that drive performance. This work provides the exploratory evidence base needed to suggest when, and to what extent, forecasts could be used for FIRO-related operations.

Key questions guiding the skill assessment include precipitation and inflow forecast skill within the Seven Oaks basin, as well as post-event and seasonal verification of impactful atmospheric river (AR) storms and freezing level. This section analyzes event- and seasonal-scale precipitation errors, storm-evolution variability, and freezing level uncertainty to assess predictability and its impact on operations and future AR research.

Accomplishments in support of FIRO:

- Evaluated an operational reforecast model for precipitation forecast skill of top 5 percent of events from 2000 to 2019.
- Evaluated inflow forecast skill at Seven Oaks Dam using the California Nevada River Forecast Center (CNRFC) hindcast and a suite of metrics from 1989 to 2019.
- Evaluated the sensitivity of rain–snow partitioning with observational uncertainty from snow level.

Key findings:

- The Santa Ana River watershed benefits from high predictability of extreme precipitation, a low number of false alarms, and strong dry-forecast reliability—all advantageous conditions for FIRO.
- Historical forecast skill of extreme events in the area containing the Seven Oaks basin is ranked amongst the top 10 percent nationally.
- Dry forecasts that mask extreme events (e.g., missing a top 20th-percentile event) are extremely rare.
- Inflows associated with large events (≥ 80th percentile) demonstrate higher skill than smaller events, consistent with positive Brier skill scores.
- Analysis of the 10 largest inflow errors (absolute error) shows that seven of our 10 events were underpredicted, with the largest error being –19.39 thousand acre-feet.
- The largest observational uncertainty in rain–snow partitioning is approximately ±7 percentage points across three water years examined. In practice, this corresponds to uncertainty in the rain fraction ranging from about 53.7 percent to 67.5 percent.

5.2.2 Results

5.2.2.a Precipitation Forecast Skill

The forecast verification team evaluated the skill of quantitative precipitation forecasts (QPFs) for extreme precipitation over the Santa Ana River watershed from a global operational model reforecast (GEFSv12). See Appendix 5.2.1 for more information.

Results show that the Santa Ana basin consistently ranks among the highest-skill watersheds in the nation for predicting extreme 24-hour precipitation, placing in the top 10 percent nationwide at all lead times (one to 10 days). Forecast skill was measured using the critical success index (CSI), where 0 is no skill and 1 is perfect skill. CSI for the top 5 percentile events remains better than random (i.e., CSI > 0.33) out to three to four days, providing multiple days of potentially usable guidance for extreme mean areal precipitation (MAP) related to FIRO decision timelines. Even by the eighth or ninth day, when national skill typically collapses, the Santa Ana River watershed still retains marginal but non-negligible predictability of top 5 percent events.

False alarm behavior and dry-forecast reliability further reinforce this performance. The false alarm ratio in the Santa Ana basin is among the lowest 10 percent nationally, meaning forecasts rarely predict extreme rainfall that does not occur—an important consideration for avoiding risks associated with unnecessary preemptive releases. Similarly, the dry forecast failure ratio is exceptionally low: 0 percent at day 1 and below 1 percent even at days 8 and 9, indicating that forecasted dry periods almost never mask extreme events. This supports reservoir operators' confidence that dry forecasts—particularly beyond the first several days—rarely underestimate risk. The meteorology team also evaluated the predictability of AR and non-AR events (see Section 5.4).

Overall, the findings show that the Santa Ana River watershed benefits from high predictability of extreme precipitation, low number of false alarms, and strong dry-forecast reliability—all advantageous conditions for FIRO. These characteristics suggest that reservoir operators can leverage short- to medium-range QPF to support dynamic storage, risk-based decision thresholds, and operational flexibility during major storms, especially when guided by AR-aware forecasting strategies.

5.2.2.b Inflow Forecast Skill

The inflow forecast skill at Seven Oaks Dam was examined with a focus on lead times and flow conditions most relevant to FIRO. See Appendix 5.2.2 for more information.

Using ensemble inflow forecasts from the National Weather Service Hydrologic Ensemble Forecast System (HEFS), the analysis assessed deterministic and probabilistic forecast performance across lead times ranging from one to 10 days and accumulation periods of 24, 72, and 120 hours. Emphasis was placed on elevated inflow conditions associated with meteorologically significant events, such as ARs, which pose the greatest operational risk.

Results showed that HEFS forecasts provide meaningful skill for moderate to high inflow thresholds (i.e., 80th and 90th percentile events) that are most relevant for FIRO decision making. Probabilistic performance, measured using Brier skill score, is consistently positive for these percentile inflow thresholds across lead times, indicating reliable exceedance guidance for elevated flows. Although deterministic accuracy degrades with increasing lead time, forecast correlations remain sufficiently high to explain a substantial portion of inflow variability at short- to medium-range horizons, particularly when flows are evaluated over multiday accumulation windows. This indicates that forecasts retain useful information about the timing and relative magnitude of inflow events, even as uncertainty increases.

In contrast, forecast skill for low-flow thresholds is poor, with negative Brier skill scores at the 10th percentile, reflecting limited predictability and reduced value for low-flow applications. HEFS provides substantially greater value for flood risk management (FRM) than for low-flow forecasting, consistent with its calibration and design. Evaluation of a hindcast simulation driven by observed meteorological forcings demonstrates that hydrologic model performance is generally robust, and that forecast skill in the operational system is primarily constrained by atmospheric predictability rather than hydrologic model limitations.

Together, these findings support the use of HEFS ensemble inflow forecasts as a decision-support tool for FIRO operations at Seven Oaks Dam, particularly for anticipating elevated inflows and managing flood risk. The identification of the largest inflow events and largest forecast errors further provides a targeted foundation for forecast value assessment, enabling deeper investigation of predictability limits and sources of uncertainty during the events that matter most for FIRO decision making.

5.2.2.c Other AR Characteristics and Their Predictability

Freezing-level forecasts are critical for water management because they influence the rain–snow partitioning and subsequent runoff during extreme precipitation events. See Appendix 5.2.3 for more information. In the Seven Oaks basin, elevations range from 2,600 to 11,500 feet, while freezing levels vary between 2,600 and 13,125 feet, often impacting precipitation phases across the basin. Accurately assessing forecast skill for freezing levels provides essential context for hydrologic predictions. Freezing levels can be approximated by the 0°C isotherm (Z0C) from models or by bright band heights (BBH) from vertical profiling radar. Observational uncertainty in these measurements was accounted for by sampling the mean difference and standard deviation between Z0C and BBH, allowing a probabilistic estimate of rain–snow partitioning.

By incorporating observational uncertainty through random sampling of snow level displacements, the study distinguished between errors arising from model forecasts versus observational variability. Results show that mean displacements between Z0C and BBH vary by location (e.g., 250 meters at Seven Oaks Dam, 350 meters at San Bernardino), and standard deviations often exceed the mean, highlighting substantial real-world variability. Analysis of water years 2022–2024 indicates that 54 to 62 percent of precipitation fell below the snow level, with uncertainties quantified from observational variability. The largest observational uncertainty range of rain–snow partitioning is on the order of 9 percent across three different water years.

CNRFC forecasts demonstrate an approximately 95 percent probability of detection within observational uncertainty. Center for Western Weather and Water Extremes’ (CW3E’s) 200-member ensemble forecasts further characterize the uncertainty in freezing levels. Preliminary decision-support analyses suggest that ensemble-based approaches provide valuable information for rain–snow partitioning, supporting improved hydrologic forecasting and operational water management in the Seven Oaks basin.

In addition to the work in this section, the meteorology team also explored further mechanism attribution and case studies that are summarized in Section 5.4.

5.2.3 Recommendations for the Final Viability Assessment (FVA)

- Continue to identify mechanisms impacting the predictability of extreme events, high inflow events, and linkages between ARs and non-AR predictability.
- Refine inflow verification for additional clarity on high-flow events.
- Determine relationships between meteorological input uncertainty and hydrologic forecast errors.
- Continue to develop probabilistic assessments of extreme precipitation and rain–snow partitioning across the Seven Oaks basin.

5.3 Observations

5.3.1 Role of Observations Work Team and Questions Addressed

Meteorological and hydrological observations provide empirical data needed to validate forecasts, evaluate model skill, and refine decision-support tools used in reservoir operations that are central to FIRO. Observing precipitation amount and phase, snow depth, soil moisture, freezing level, and discharge allows researchers to compare predicted versus observed conditions, diagnose the causes of precipitation and runoff forecast errors, and evaluate the performance of hydrologic and atmospheric models used for operational decision making. These data also feed in situ decision-support tools that provide real-time situational awareness of storm evolution, watershed response, and runoff generation.

The Seven Oaks FIRO technical studies identified major observational gaps in the Seven Oaks watershed, especially for snow, soil moisture, and discharge, that limit the ability to evaluate forecast skill and model performance. The PVA identified new stations to close gaps and answered core questions from the workplan, such as where additional observations will have the greatest impact, what measurement types are most needed, and what observations gaps remain.

Accomplishments in support of FIRO:

- Scouted prospective station locations to fill meteorological and hydrological observational gaps identified through the technical studies report and discussion with work teams and FIRO partners.
- Secured permits for two hydrometeorological stations and one stream gage and began permitting for one disdrometer station.
- Installed two hydrometeorological stations and began the process to disseminate the data to partner websites.
- Prepared all other station components (stream gage and disdrometer station) for deployment to deliver near real-time data to support forecast verification, model evaluation, and decision-support tools.

Key findings:

- Persistent precipitation forecast biases in the one- to five-day lead time Western Weather Research and Forecasting (West-WRF) reforecast align with sparsely observed areas, underscoring the need for expanded coverage of precipitation observations.
- There are insufficient mid-elevation rain-snow observations; small freezing-level shifts strongly affect rain–snow partitioning and runoff, and targeted monitoring can improve understanding of freezing levels in the basin.
- There are currently no active stream gages in the Seven Oaks watershed. A former U.S. Army Corps of Engineers (USACE) gage monitored inflows during dam construction. The proposed new gage would capture flows from 86 to 92 percent of the reservoir’s contributing area, providing valuable monitoring coverage and improving reservoir inflow estimates.

5.3.2 Results

Existing hydrometeorological stations (Figure 5-2) and historical gage (Appendix 5.3.5) and snow survey data (Appendix 5.3.4) provided context for current observation needs. The technical studies identified major gaps (summarized in Appendix 5.3.1), including sparse upper-elevation coverage, insufficient mid-elevation rain–snow observations, and lack of near real-time soil moisture and streamflow data. Subsequent analyses and partner discussions refined these findings and guided the selection of priority monitoring sites.

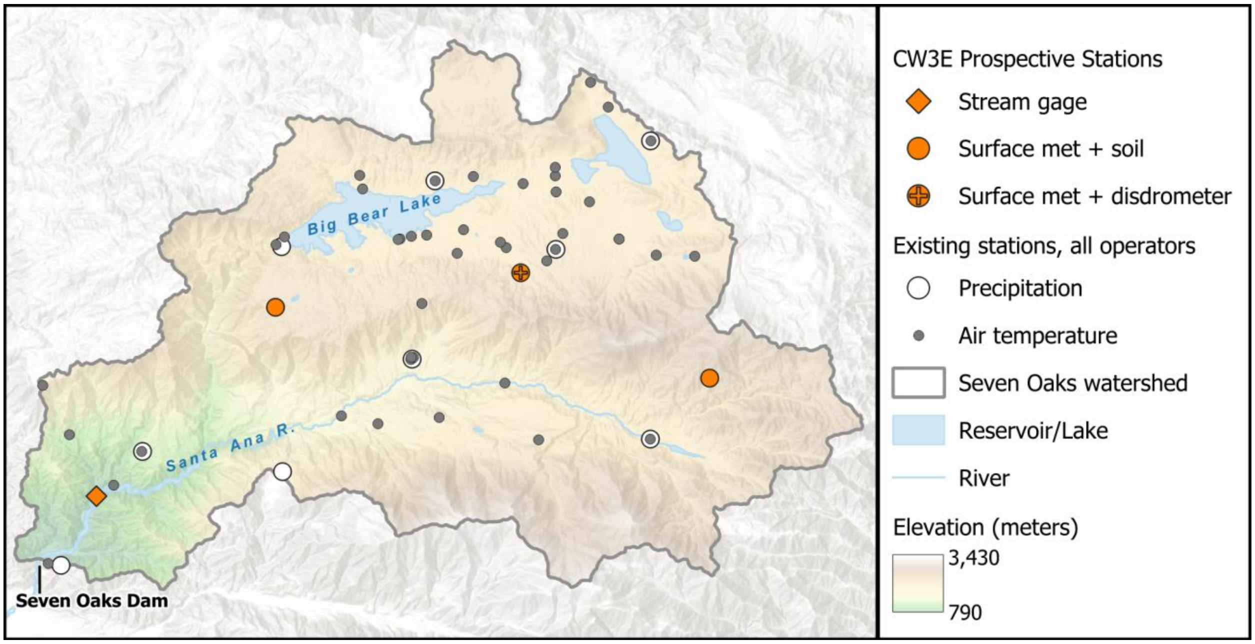

Figure 5-2. *Map of prospective station additions to the Seven Oaks watershed (orange diamond = stream gage location; orange circles = two hydrometeorological stations; and orange circle with plus sign = disdrometer station) and existing stations in the watershed (white circles = station with precipitation measurements; grey circles = station with air temperature measurements).*

Analysis of 24-hour West-WRF reforecast precipitation (2008–2019) revealed systematic west–east bias patterns that aligned with areas lacking station coverage (see Appendix 5.3.2), informing where additional precipitation observations could resolve uncertainty in the spatial distribution of precipitation. Prospective locations for two new hydrometeorological stations aim to close the gap in the western region of the basin where precipitation is over-forecasted and the eastern region of the basin where precipitation is under-forecasted (Figure 5-2; summary of station components and siting effort in Appendix 5.3.6).

No stations in the basin currently provide near real-time soil moisture or snow depth observations. Snowpack and soil moisture are key controls on runoff timing and magnitude, representing water stored in snow and soil, respectively. The planned hydrometeorological stations incorporate soil moisture and snow depth measurements to address these gaps.

Accurate precipitation-phase measurements, such as those provided by a disdrometer, are critical for understanding shifts in the freezing level, which affect runoff timing and flood risk. Continuous, high-resolution precipitation phase observations within the basin's primary elevation band (approximately 6700 to 7700 feet) will strengthen forecast verification, model validation, and situational awareness for decision support (see Appendix 5.3.3).

Streamflow observations are a priority for improving hydrologic model performance. Re-establishing a gage near the former USACE site, or at a nearby upstream location (Figure 5-2), would capture flows from approximately 86 to 92 percent of the basin area, improving inflow characterization and model validation. The planned gage measures water level, or stage, and requires manual discharge measurements to establish a rating curve (see Appendix 5.3.6 for station components and siting effort). Preliminary site assessments indicated that river morphology may hinder manual discharge measurements during high flows, limiting the ability to develop a rating curve representative of the full range of flow. A non-contact gage measuring velocity is recommended to help overcome these challenges by enabling continuous monitoring of velocity to further constrain rating curve development.

5.3.3 Recommendations for the FVA

- Continue to interface with other work teams to ensure existing and new observations are integrated into analyses and workflows.
- Consider additional stream gaging methods such as velocity or slope-based techniques to complement the current stage-based technique and better account for the flashy hydrology and dynamic nature of the Santa Ana River channel.
- Renew snowpack monitoring efforts.
- Maintain ongoing evaluation of observation network performance to identify evolving gaps and optimize station placement.

5.4 Meteorology

5.4.1 Role of Meteorology Work Team and Questions Addressed

Understanding the meteorological phenomena that modulate precipitation and influence forecast skill is essential for successfully implementing FIRO. Flexibility in reservoir operations relies on accurate forecasts of precipitation and the storms that produce said precipitation at sufficiently long lead times. The meteorology team assessed the contribution of ARs and other storm types to total precipitation in the Seven Oaks basin, as well as their role in precipitation extremes. The team also investigated the factors that influence precipitation forecast skill and potential sources of forecast error.

Accomplishments in support of FIRO:

- Created precipitation and AR event catalogs specific to the Seven Oaks basin.
- Analyzed relationships between ARs and precipitation in the basin.
- Investigated non-AR sources of precipitation in the basin.
- Evaluated forecast skill for AR-related and non-AR-related precipitation.
- Conducted case studies of AR-related and non-AR-related events with low forecast skill.

Key findings:

- ARs are the primary source of precipitation in the basin; 70 percent of total precipitation fell on days with an AR over the basin, and ARs were present during 85 percent of extreme events.
- Closed lows (i.e., areas of low pressure aloft with well-defined cyclonic circulations) frequently contribute to precipitation in the basin but rarely produce extreme precipitation in the absence of an AR.
- Forecast skill for the top 5 percent of wet days is higher on AR days versus non-AR days at lead times of one to five days, suggesting that the presence of ARs increases predictability of extreme precipitation.

5.4.2 Results

The Seven Oaks basin receives a substantial portion of its precipitation from a small number of relatively infrequent events. Between water years 2003 and 2024, precipitation occurred during only 18 percent of all days, and 50 percent of the total precipitation fell within < 2 percent of days. Extreme precipitation events, here defined as events exceeding the 95th percentile of daily precipitation (approximately 34 millimeters), accounted for 53 percent of total precipitation. Like other basins in Southern California, precipitation varies seasonally, with 60 percent of total precipitation and 73 percent of extreme events occurring in December–February, and only 7 percent of total precipitation and 1 percent of extreme events occurring in June–August (Appendix 5.4.2, Figure 5-38).

On average, ARs were detected over the Seven Oaks basin on 47 days per year during water years 2003–2024. The highest frequency of ARs was observed during December, and the lowest frequency was observed during July–September (Appendix 5.4.2, Figure 5-39). Of the 788 unique AR events identified over the basin, 79 received an AR Scale ranking of AR 0, 72 received a ranking of AR 1, 26 received a ranking of AR 2, and only 3 received a ranking of AR 3 following a modified version of the Ralph et al. (2019) AR Scale (Appendix 5.4.2, Figure 5-40). Higher AR Scale rankings are indicative of stronger and/or longer-duration ARs and tend to be associated with more extreme hazards and increased severity of impacts (Corringham et al. 2019). Most AR events did not meet the duration and/or integrated vapor transport (IVT) magnitude criteria to be assigned an AR Scale ranking. AR events in the basin tend to be short-lived; 76 percent of unique AR events lasted < 24 hours, and only 4 percent of events lasted ≥ 48 hours (Appendix 5.4.2, Figure 5-39). Compared to coastal locations in Southern California, the more inland location and relatively high elevation of the Seven Oaks basin limits moisture transport in the basin.

Results from the precipitation and AR event catalogs confirm that ARs are the primary source of both total and extreme precipitation in the basin. While ARs were present on only 13 percent of all days, 70 percent of total precipitation fell on AR days, and the number of AR days explains 48 percent of the variance in annual precipitation. ARs were present during 87 percent of the top 10 percent nonzero precipitation days and 85 percent of extreme precipitation events (Figure 5-3). Besides event duration, IVT magnitude and direction differentiated extreme events from non-extreme events. A majority of extreme events featured maximum IVT ≥ 250 kg/m/s and mean IVT directions between 180° (southerly) and 240° (west-southwesterly; Appendix 5.4.2, Figure 5-41). Non-extreme events were much more likely to occur without an AR and generally featured weaker IVT magnitudes and a broader range of IVT directions. A comparison of daily MAP and IVT on AR days revealed that the component of IVT along 202° (south-southwesterly) was most strongly correlated with MAP, but the component of IVT along 184° (southerly) yielded the largest increase in MAP with respect to IVT magnitude.

In addition to ARs, closed lows frequently contribute to precipitation in the basin. These features are often difficult to forecast, especially when they become separated from the background large-scale flow. Closed lows were present during 41 percent of all precipitation days and were the largest source of precipitation during March–May. It is not unusual for ARs and closed lows to impact the basin simultaneously; 35 percent of total precipitation fell on days when both an AR and a closed low were present, 35 percent fell on days when only an AR was present, and 17 percent fell on days when only a closed low was present (Figure 5-3). When closed lows and ARs occur in tandem, the combination of dynamical forcing for ascent ahead of the closed low and upslope moisture flux within the AR can enhance precipitation. More than 50 percent of extreme events featured both a closed low and an AR. Closed lows rarely produce extreme precipitation in the absence of an AR; only 12 percent of extreme events featured a closed low and no AR. The relatively small contributions of ARs and closed lows to June–August precipitation suggests that other sources, such as the North American monsoon and tropical cyclones, are important drivers of summer precipitation.

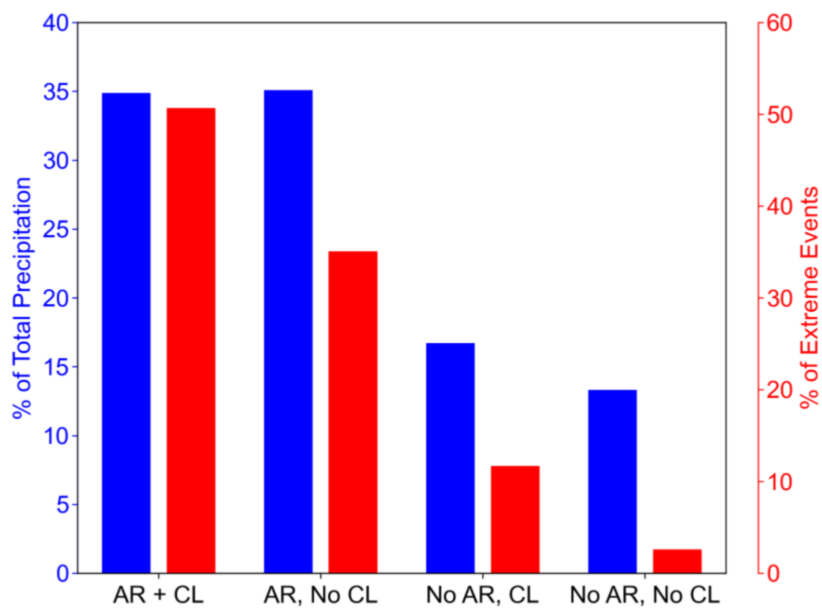

Figure 5-3. *Blue bars: percent of total precipitation falling on days with both an AR and a closed low (AR + CL), days with an AR but no closed low (AR, No CL), days with a closed low but no AR (No AR, CL), and days with neither an AR nor a closed low (No AR, No CL). Red bars: percent of extreme precipitation events featuring both an AR and a closed low, an AR but no closed low, a closed low but no AR, and neither an AR nor a closed low.*

A QPF skill assessment of 24-hour periods exceeding the top 5 percent of nonzero precipitation days in the Santa Ana HUC-8 watershed found much higher forecast skill on AR days than on non-AR days at lead times of one to five days (Appendix 5.4.2, Figure 5-42). The CSI on AR days was > 0.5 at one-day lead time and did not drop below 0.33 until day 5, whereas the CSI on non-AR days consistently remained below 0.25. Lower CSI scores on non-AR days may be influenced by small sample sizes of forecast precipitation above the top 5 percent threshold. At lead times of six to nine days, there were fewer than 10 forecasts above the top 5 percent threshold on non-AR days, and the CSI was not calculated. Even at lower thresholds (e.g., top 10 percent of precipitation days), the CSI scores for AR days exceeded those for non-AR days at all lead times.

Case studies of an extreme AR event in February 2019 and a non-extreme, non-AR event in December 2021 were leveraged to investigate sources contributing to precipitation forecast error. Both events were previously identified in the technical studies as cases with persistently large operational precipitation forecast biases in the Santa Ana River watershed. The February 2019 event featured a strong AR (AR 3 over the basin) that transported tropical moisture into California and produced 150 millimeters of MAP in the Seven Oaks basin. Both the Global Ensemble Forecast System (GEFS) and European Centre for Medium-Range Weather Forecasts (ECMWF) ensembles struggled to forecast the amplification, timing, and phasing of an upstream 500-hPa trough over the Northeast Pacific. Forecasts at lead times ≥5 days exhibited large spread in the depth and position of the trough, which translated into major uncertainty in the strength and landfall timing of the AR (Appendix 5.4.2, Figure 5-43). Models also failed to capture the intensity of a 250-hectopascal (hPa) jet streak over the Pacific Northwest and the resulting secondary cyclogenesis at lead times ≥ three days. These forecast errors led to a persistent underestimation of precipitation amounts in the Santa Ana River watershed. The December 2021 case featured a slow-moving 500-hPa shortwave trough west of California in the absence of a well-defined AR or tropical/subtropical moisture source. Observed precipitation in the basin was modest (13 millimeters of MAP in 48 hours), with the heaviest precipitation (>100 millimeters) occurring west of Cajon Pass. At lead times of one to three days, models struggled to predict the orientation, amplitude, and propagation speed of the trough and an associated weak surface low-pressure system. Poor prediction of these features in the GFS model translated into an eastward displacement of the regions of strongest upward vertical motion and low-level moisture flux, resulting in significant overestimation of precipitation in the Seven Oaks basin and underestimation of precipitation over Ventura and Los Angeles counties (Appendix 5.4.2, Figure 5-44). CW3E's West-WRF ensemble also incorrectly predicted intense precipitation (> 50 percent probability of > 2.5 inches in a 24-hour period) over the basin at just a two-day lead time.

5.4.3 Recommendations for the FVA

- Explore how the background large-scale circulation pattern modulates precipitation and storm characteristics in the basin using a catalog of historical weather regimes.
- Investigate meteorological processes that produce short-duration, high-intensity rainfall over the basin.
- Coordinate with the forecast verification team to leverage precipitation and AR event catalogs to identify meteorological sources of QPF error in the Seven Oaks basin.
- Consider how future changes in storm activity and temperature, precipitation, streamflow, and snowpack conditions may affect management of the Seven Oaks Dam.

5.5 Hydrologic Modeling

5.5.1 Role of Hydrologic Modeling Work Team and Questions Addressed

Recent hydrologic modeling work to support FIRO at Seven Oaks Dam focused on rebuilding a high-quality historical inflow data record, generating new historical streamflow forecasts to support the WRE team, and demonstrating the improved reliability of CNRFC operational capabilities over previous methods. Because past inflow data were sparse, inconsistent, and based on problematic pool elevation measurements, the team reconstructed a much longer and cleaner inflow record by merging corrected post-2000 reservoir data with pre-dam U.S. Geological Survey (USGS) streamflow records extending back to the late 1800s. This expanded record confirms that very large runoff events (much larger than have occurred in recent decades) have occurred in the distant past but are rare, which helps explain why forecasting them remains difficult and why better historical data are essential for model calibration. Using this improved record, the team collaborated with the CNRFC to generate new ensemble hindcasts (1990–2023) with modern HEFS methods, replacing older hindcasts that lacked sufficient predictability. Together, these efforts highlight the need for continued improvements—such as upgraded pool elevation sensors, recalibrated hydrologic models, and better precipitation and precipitation-type inputs—to strengthen FIRO evaluations and future forecast performance.

Accomplishments in support of FIRO:

- Located, consolidated, and curated historical observations that support natural inflow calculations across the period of record (late 1800s to 2023).
- Reviewed historical inflows in the context of existing characterizations of hydrologic events (using critical duration estimates and flow frequency analyses from USACE).
- Generated ensemble streamflow hindcasts (1990 to 2023) using the CNRFC HEFS modeling infrastructure that formed the basis of streamflow forecast evaluation work and the production of synthetic ensembles (for the WRE alternatives analysis).

Key findings:

- Historical inflow data were previously sparse and inconsistent, and this likely affects the performance of the CNRFC hydrologic model for the Seven Oaks Dam. Inflow calculations for the post-dam period (2000 to 2023) were improved and expanded to include the pre-dam period (late 1800s to 1994) using historical USGS streamflow data.
- Although very large runoff events have occurred in the expanded historical record (e.g., daily inflows exceeding 15,000 cubic feet per second [cfs] in 1916 and 1938), these are very infrequent (i.e., 75th percentile of inflows is approximately only 500 cfs). This underscores the importance of improving and expanding the historical inflow record (mentioned above).
- Recent recalibration efforts by the CNRFC have improved ensemble streamflow predictions for the Santa Ana River, but predicting large runoff events in this basin remains a challenge. This is likely a consequence of 1) the previous lack of historical inflow records to support model calibration (mentioned above), 2) the relatively small size and topographic variability of the Seven Oaks Dam catchment (which creates

challenges for weather models), and 3) the infrequency of large events (also mentioned above).

5.5.2 Results

5.5.2.a Developing and Characterizing Historical Inflows

During the calibration of the current operational hydrologic model for Seven Oaks Dam, the CNRFC leveraged inflow data computed for 2009 to 2023. This period only contains two events that exceeded daily inflows of 1,000 cfs (corresponding to approximately a five-year return period). Further, the pool elevation data used to compute this previous inflow data set were found to be spuriously problematic, resulting in low biases at both high and low flows. Through the PVA, a longer, higher quality inflow data set was developed (spanning the 2000 to 2023 period with consistent inputs and computations and extended back to the late 1800s using pre-dam construction streamflow data). This process relied upon several data sources:

- The USGS gage downstream of Seven Oaks Dam (#11051501) that reports the combined outflow plus the Southern California Edison canal diversion. These data were used to estimate natural inflows to Seven Oaks Dam.
- The USACE automated pool elevation gage for Seven Oaks Dam.
- The USACE daily manual pool elevation reading archive, to provide quality control for the automated pool readings.
- Storage-elevation curves for the reservoir.

Manual quality control of the automated pool elevation gage data was performed, and the cleaned data were merged with the manual pool readings prior to storage calculations. A linear weighting scheme was used to estimate storage values between storage-elevation survey dates (1999 and 2012). Daily inflows were then computed across 2000 to 2023 (previously limited to 2009) using change in storage at Seven Oaks Dam and data from USGS gage #11051501. Refer to Appendix 5.5.1 for more information on the data sources, quality control process, and inflow calculations.

Note that Big Bear Lake is situated upstream of Seven Oaks Dam, and this system is partially regulated by the local water district. However, using release data provided by the water district for 1998 to 2024, it was determined that any impacts of the upstream regulation to Seven Oaks Dam inflows are minimal and only apply at low flows (on the order of approximately 5 to 10 percent of total flow) because the lake passes inflows during events. Thus, the Seven Oaks Dam inflow calculations discussed above are assumed to represent natural inflows to the system.

In a 1988 report (USACE 1988), the Santa Ana River at the long-standing USGS gage near Mentone (#15051499) just downstream of the dam today was shown to experience very large runoff events (based on the historical record of this gage, which extends back to the late 1800s). The volume frequency curves summarized in this report illustrate that 24-hour inflows could approach 40,000 cfs. However, as shown in Figure 5-4, 24-hour inflows have only exceeded 1,000 cfs a few times (with a maximum in 2005 of approximately 4,000 cfs). Thus, since the dam was built (using specifications outlined in the 1988 report), no events of real consequence to the reservoir have occurred. To help populate the historical inflow data record with as many events as possible, the computed data (2000 to 2023) were merged with the long-standing USGS gage data prior to construction of Seven Oaks Dam, expanding the period of record back to the late 1800s. Note that years 1994 to 2000 were set missing, however, because dam construction occurred throughout this period and natural streamflows could not be reliably computed.

The decision was made to align the critical duration with the preceding Prado FVA, which used a two-day duration. Since the largest events in the historical record occurred prior to 1980, the decision was made to leverage the existing volume frequency analysis from the 1988 report mentioned above, which included return periods for two-day volumes. Additionally, exploration of the updated inflow data set (i.e., records through 2023) revealed similar statistics (e.g., 100-year event for 24-hour inflows of approximately 20,000 cfs, which aligns with the 1988 report).

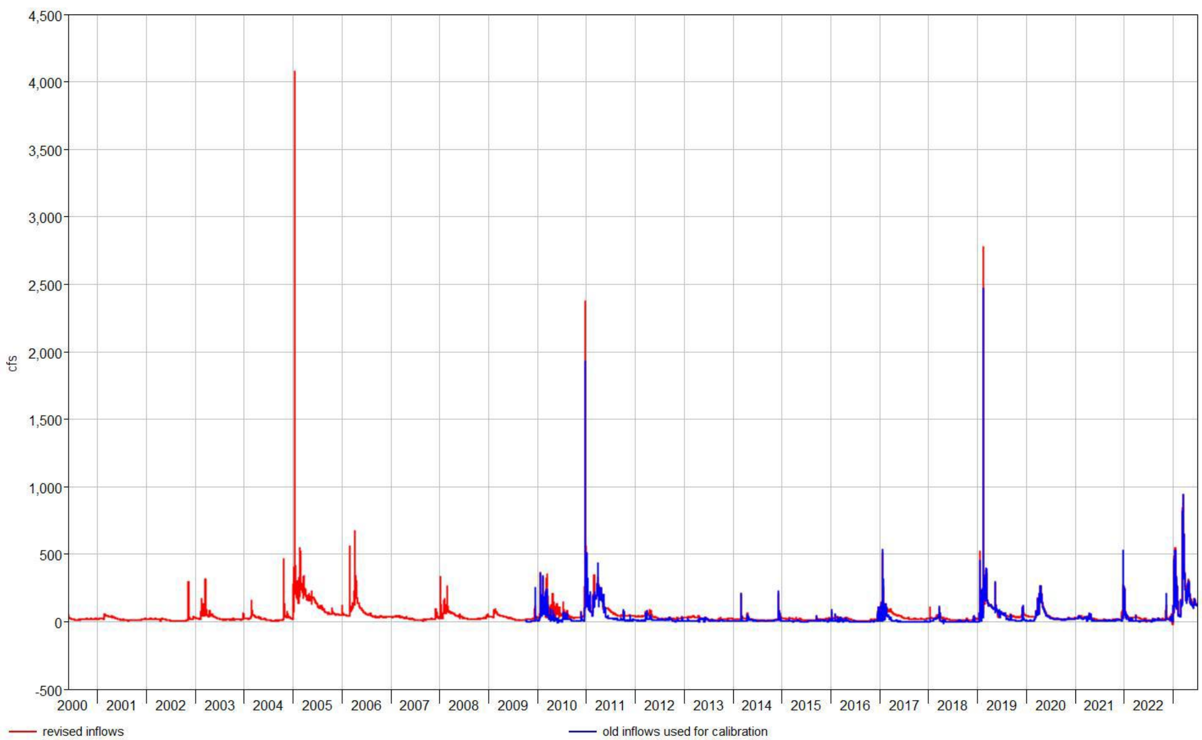

Figure 5-4. *Historical inflow data for Seven Oaks Dam. The recently extended data (red) now span the 2000–2023 period and improve upon the high and low flow calculations using quality-controlled pool elevation data.*

5.5.2.b Generating and Evaluating Ensemble Streamflow Hindcasts

Forecasts of historical runoff conditions, created using today's technology and methods but for periods in the past, are called hindcasts. For FIRO viability assessments, hindcasts of ensemble streamflows are typically generated using RFC HEFS capabilities to 1) assess the predictability of runoff conditions of the recent past using operational hydrologic forecasting methods, and 2) represent uncertainty in the predictions by outputting many different streamflow hydrographs that together account for the variability in the input weather information (e.g., precipitation, temperatures). For this PVA, HEFS hindcasts were produced and evaluated for Seven Oaks Dam inflows across the 1990–2023 period (based on the availability of input weather forecast, or reforecast, information).

Although hindcasts for Seven Oaks Dam inflows were also produced as part of the Prado FVA (across years 1990 to 2019), only observed Seven Oaks Dam outflows and downstream contributions were modeled for this earlier work. As such, the quality of the Seven Oaks Dam inflow hindcasts was not fully assessed during this Prado effort. The original intent was to make use of these previously developed hindcasts for Seven Oaks Dam, but it was ultimately determined that they lacked the predictability required to support the WRE work for this PVA (see Appendix 5.5.2). Thus, in close collaboration with the CNRFC, new HEFS hindcasts were generated for this effort using the latest hydrologic model and HEFS parameters, which are currently used in operations. This is described in more detail in Appendix 5.5.2.

5.5.3 Recommendations for the FVA

- Improve automated pool elevation data quality (e.g., install new station/sensor) to ensure more accurate inflow data.
- Recalibrate the Seven Oaks Dam hydrologic model using an extended and improved inflow data record and regenerate HEFS hindcasts using the recalibrated hydrology models.
- Produce synthetic streamflow ensembles for events within and outside the hindcast period (both scaled and unscaled). These synthetic hindcasts will help provide more rigorous evaluation of candidate FIRO alternatives.
- Explore emerging ensemble prediction capabilities for precipitation and precipitation typing to improve streamflow forecasts for impactful but infrequent events.

5.6 Groundwater Recharge and Dam Diversion Modeling

5.6.1 Role of Recharge and Diversion Work Team and Questions Addressed

An objective of the study at Seven Oaks Dam is to assess how FIRO may improve water supply availability through diversions to groundwater recharge basins and surface water reservoirs. There are several groundwater recharge facilities downstream of Seven Oaks that can divert releases from the dam to be recharged to the San Bernardino basin area. Metropolitan Water District of Southern California (MWDSC) reservoirs may also be available for storage of Santa Ana River water released from the dam. The facilities included in this analysis are described in more detail below.

Accomplishments in support of FIRO include:

- Developed diversion and recharge modeling logic for the four recharge facilities.
- Identified an exploratory modeling framework to assess potential benefits through diversions to MWDSC reservoirs.
- Collaborated with the WRE team to integrate recharge diversion logic with reservoir operations.

Key findings:

- FIRO can increase groundwater recharge across all facilities, with the largest improvements coming in years that are wetter than average.
- A lack of institutional and infrastructural agreements limits current diversion capacity to MWDSC reservoirs.

5.6.2 Results

A modeling framework was developed to simulate how water released from Seven Oaks Dam can be diverted for groundwater recharge and reservoir storage. The framework represents operational and physical constraints of each facility, along with the priorities that determine how flows are allocated.

The framework reflects conditions expected in 2028, the year identified for completion of the FVA. Under these conditions, several groundwater recharge facilities can receive Santa Ana River water released from the dam when they have unused capacity. The framework also incorporates an exploratory scenario in which Santa Ana River water may be diverted to MWDSC reservoirs. Diversions to MWDSC reservoirs are included as a series of explorative simulations due to infrastructural limitations and a lack of necessary institutional agreements that constrain the amount of water that can currently be diverted. The framework identifies two scenarios: (A) diversion to groundwater recharge facilities and (B) diversions to groundwater recharge facilities and MWDSC reservoirs.

5.6.2.a Facilities Included in the Diversion Model

Water released from Seven Oaks Dam can be diverted to the following facilities, shown in Figure 5-5:

- Santa Ana River spreading grounds (SARSG)
- Mill Creek spreading grounds (MCSG)
- San Bernardino County flood control basins (SBCFCB)
- Santa Ana River channel downstream of Seven Oaks Dam (Santa Ana River Channel)
- MWDSC reservoirs[1]

Flows to SARSG, MCSG, and CFCB are diverted from the Santa Ana River downstream of the dam outlet for recharge. Releases not diverted continue to flow in the Santa Ana River and can percolate up to the maximum recharge capacity of the river channel. Any water that is not diverted flows out of the system and is not recharged within the San Bernardino Basin Area. Each facility has a defined diversion capacity and operational constraints.

<u>Santa Ana River Spreading Grounds</u>

SARSG is specifically designed to recharge Santa Ana River water and has the highest recharge capacity of the facilities. The maximum recharge capacity and diversion rate to SARSG is approximately 500 cfs. The model incorporates the variable recharge capacity throughout the water year by simulating reduced recharge rates as the recharge basins become clogged with accumulated sediment over time. More information on the SARSG recharge model is available in Appendix 5.6.1.

<u>Mill Creek Spreading Grounds</u>

These facilities primarily serve to recharge Mill Creek water. They can accept Santa Ana River releases when (1) there is unused capacity and (2) Santa Ana River diversions do not interfere with Mill Creek recharge operations. The maximum recharge capacity of the MCSG is

[1] Diversions to MWDSC reservoirs are included in a separate series of exploratory simulations.

approximately 115 cfs. However, the maximum conveyance rate that can be diverted to the MCSG from Seven Oaks Dam is 60 cfs. An exponential decay function is used to reduce the maximum recharge capacity throughout the water year as percolation occurs to account for clogging. More information on the MCSG recharge model is available in Appendix 5.6.2.

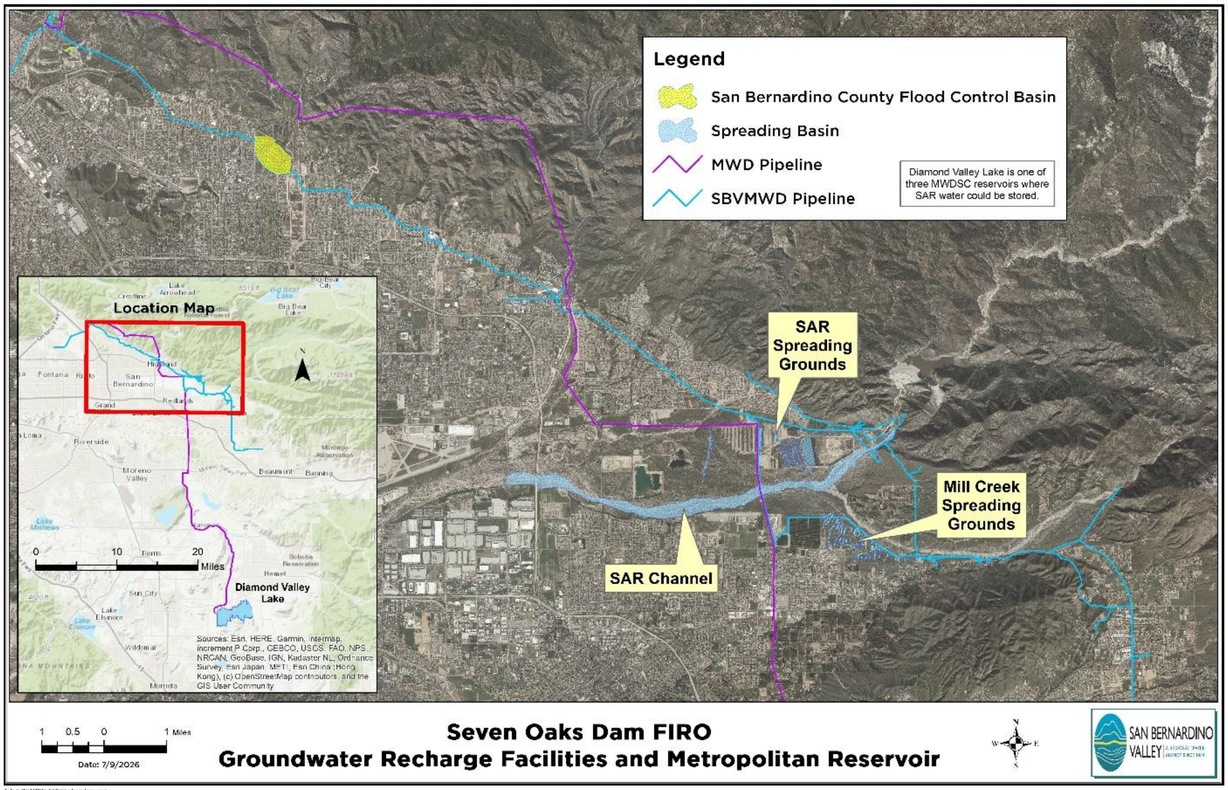

Figure 5-5. *Map of recharge and diversion facilities in the San Bernardino Basin Area. (Credit: San Bernardino Valley Municipal Water District.)*

San Bernardino County Flood Control Basins

The flood control basins owned by the San Bernardino County Flood Control District are used for groundwater recharge only during seasons when the basins are not required for flood risk management (April 1–September 30). The maximum diversion rate to the basins is assumed to be a constant 40 cfs.

Santa Ana River Channel

The channel downstream of the dam provides in-channel recharge. The river channel is assumed to have a constant percolation rate of 30 cfs.

MWDSC Reservoirs

Diversions to MWDSC reservoirs will require completion of institutional agreements with MWDSC. In the modeling framework, the diversion to MWDSC reservoirs is informed by the current water right shared by Westen Water with San Bernardino Valley. The maximum permitted diversion is 1,250 cfs with annual maximum diversions of 100,000 acre-feet. The model assumes demand diversions will not exceed 10 percent of the maximum permitted diversion (10 percent of 1,250 cfs = 125 cfs).

5.6.2.b Priority and Allocation Framework

The framework applies a priority-based allocation system to determine how available Santa Ana River water is distributed among facilities. Two scenarios were analyzed, as shown in Table 5-2 and Table 5-3.

Table 5-2. *Network Scenario 1: Diversions to groundwater recharge.*

Facility	Priority	Percent Allocation
SARSG	1	100%
MCSG	2	50%
Santa Ana River channel	2	50%
SBCFCB	3	100%

Under Scenario 1 (Table 5-2), SARSG receives water first until its operational capacity is reached. MCSG and the Santa Ana River channel equally share second priority and receive any remaining water until their operational capacities are met. Any remaining water is diverted to the CFCB up to the maximum capacity.

Table 5-3. *Network Scenario 2: Diversions to groundwater recharge and MWDSC reservoirs.*

Facility	Priority	Percent Allocation
SARSG	1	100%
MCSG	2	40%
Santa Ana River channel	2	40%
MWDSC reservoirs	2	10%
SBCFCB	3	100%

Scenario 2 expands on Scenario 1 and redistributes second-priority flows among three facilities: MCSG, the Santa Ana River channel, and MWDSC reservoirs. The introduction of MWDSC reservoirs slightly reduces the percentage allocated to the other second-priority facilities.

5.6.3 Recommendations for the FVA

- Update the SARSG model with observational data from recent operations for better representation of recharge rates and impacts of groundwater mounding, especially during back-to-back wet years.
- Improve diversion logic for the MCSG based on available capacity after water from Mill Creek has been diverted.
- Include water diversions to senior water rights holders not associated with groundwater recharge.
- Explore a variable percolation rate model in the Santa Ana River channel.
- Develop a more detailed model of diversion capacity for MWDSC reservoirs.
- Include more detailed representation of basin cleaning and maintenance in the late summer–early fall time frame.
- Develop a scenario that minimizes the amount of stored water that needs to be released in excess of the diversion capacity in the July–August period during wet years.

5.7 Environmental Resources

5.7.1 Role of Environmental Resources Work Team and Questions Addressed

Environmental resources form the foundation of ecosystem health, biodiversity preservation, and sustainable community development. These resources, including water, soil, vegetation, and wildlife, support essential ecological services such as water filtration and erosion control. The maintenance of natural hydrologic processes, native plant communities, and soil stability support both ecological integrity and the long-term resilience of human systems.

Accomplishments in support of FIRO:

- Developed metrics to assess the impacts of FIRO at Seven Oaks Dam on environmental outcomes.

Identified gaps in the current modeling framework to consider water quality operations and Riversidean alluvial fan sage scrub (RAFSS) habitat support.

Key findings:

- Focused metrics on threatened and endangered species habitats, and how FIRO could benefit (or impact) them. The requirements for these species are intended to protect others within the focal area.
- Established metrics for each focal area to account for their differing requirements.
- Incorporated temporal and spatial factors into the metrics.

5.7.2 Results

The environmental team developed metrics to assess environmental benefits across FIRO alternatives. Metrics were identified for the three focal areas being considered by the environmental team. Each focal area is shown in Figure 5-6 and described below:

- Upstream focal area: The area within the maximum water surface elevation possible at Seven Oaks Dam, which is approximately 2,604 feet.
- Alluvial fan focal area: Extends from Seven Oaks Dam downstream along the Santa Ana River, through and including the Santa Ana River Wash, to the La Cadena drop structure.
- Perennial stream focal area: Stretches from the La Cadena drop structure downstream along the Santa Ana River to Prado Dam.

The three focal areas were chosen because multiple threatened and endangered species reside within these areas. Figure 5-7 lists several of these key species, the focal areas they might inhabit, and the times of year when they could be impacted by operations of the dam.

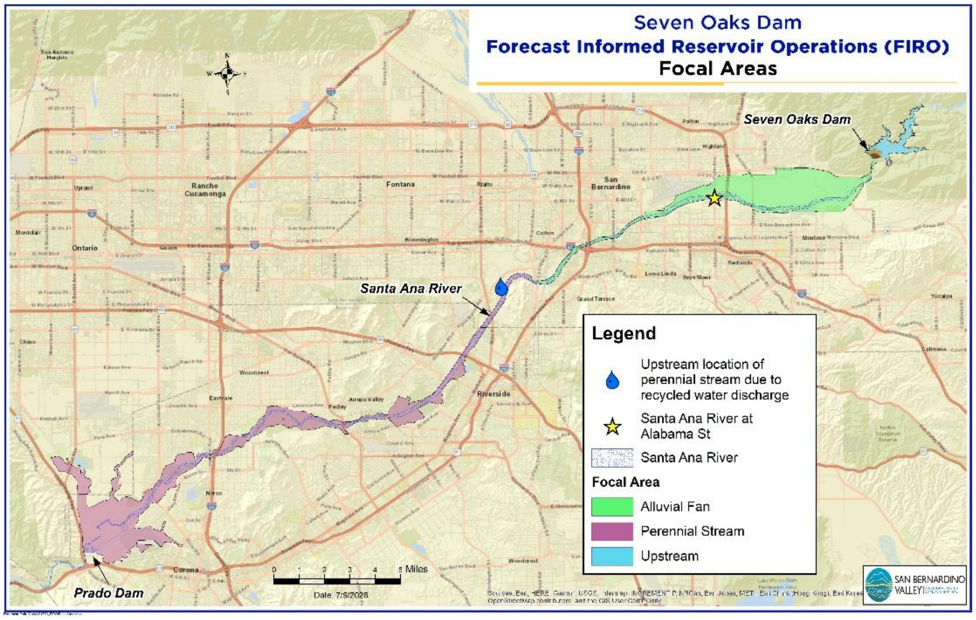

Figure 5-6. *Focal areas considered by the environmental team for FIRO at Seven Oaks Dam. (Credit: San Bernardino Valley Municipal Water District.)*

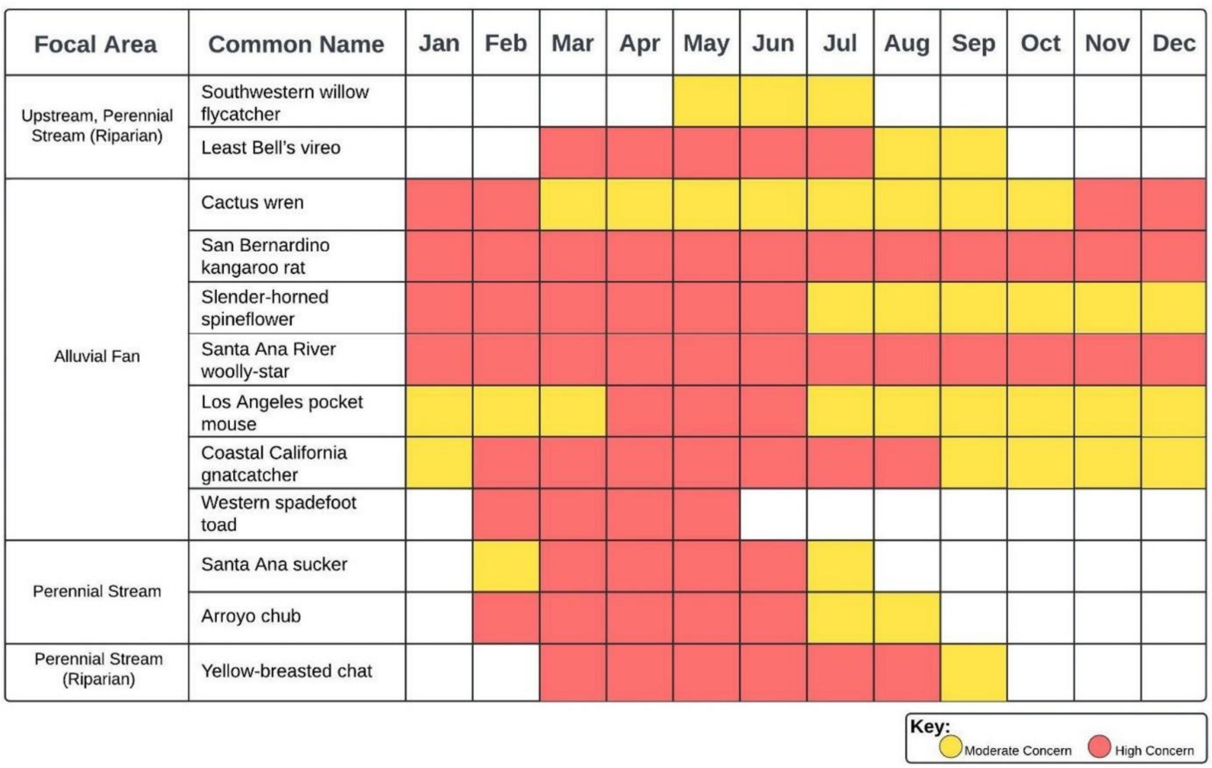

Figure 5-7. *Special-status species occurrence within the focal areas throughout the calendar year and associated level of concern. High concern indicates species' breeding season and potential presence. Moderate concern indicates non-breeding season and potential presence, or within breeding season but concern is lower. (Credit: San Bernardino Valley Municipal Water District.)*

The focal areas are the basis of environmental metrics evaluated in the PVA, shown in Table 5-4. Metrics for the upstream focal area are focused on potential impacts from the temporal and spatial extent of holding water in the reservoir at various elevations (US-1). Metrics associated with the alluvial fan and perennial stream focal areas facilitate comparison of potential impacts from the duration and amount of water released from Seven Oaks Dam that is not diverted for groundwater recharge and travels downstream (AF-1a, AF-1b, PS-1a, and PS-1b). These environmental metrics were established to track model outputs and do not necessarily define environmental impacts or benefits.

Additional metrics were developed that quantify the effects of FIRO on potential water quality changes (US-2, PS-2, PS-3a, and PS-3b) and RAFSS habitat support (AF-2a and AF-2b). Modeling approaches employed during the PVA do not currently support the calculation of these metrics. However, metrics regarding water quality changes and RAFSS habitat support are planned to be evaluated in future phases of FIRO assessment.

Table 5-4. *Environmental metrics developed to assess the impacts of FIRO at Seven Oaks Dam.*

No.	Location	Metric	Modeled in PVA
US-1	Upstream of Seven Oaks Dam	Number of days in a given water year where inundation occurs above water surface elevations of top of intermediate pool (2,265 feet), trash rack pool (2,299 feet), 2,350 feet, and 2,400 feet.	Yes
US-2	Upstream of Seven Oaks Dam	Number of times in a water year that water quality parameters exceed acceptable thresholds during temporary storage in the pool (e.g., harmful algal blooms, turbidity).	No
AF-1a	Santa Ana River Wash	Number of days flow in the river exceeds 100, 200, 300, 400, 500, 1000, 1500, 2000, or 2500 cfs or greater in river channel after all diversions are accounted for.	Yes
AF-1b	Santa Ana River Wash	Number of times flow in the river exceeds 100, 200, 300, 400, 500, 1000, 1500, 2000, or 2500 cfs or greater in river channel after all diversions are accounted for in a given water year.	Yes
AF-2a	Santa Ana River Wash	Number of times during simulation period flow is available for discharge out of enhanced recharge to maintain RAFSS habitat.	No
AF-2b	Santa Ana River Wash	Number of days during simulation period flow is available for discharge out of enhanced recharge to maintain RAFSS habitat.	No
PS-1a	Santa Ana River Wash / Perennial Stream	Number of days flow in the river exceeds 100, 200, 300, 400, 500, 1000, 1500, 2000, or 2500 cfs or greater in river channel at the upstream end of the perennial stream focal area when releases are being made from Seven Oaks Dam per water year.	Yes
PS-1b	Santa Ana River Wash / Perennial Stream	Number of times in a given water year that flow in the river exceeds 100, 200, 300, 400, 500, 1000, 1500, 2000, or 2500 cfs or greater in river channel at the upstream end of the perennial stream focal area when releases are being made from Seven Oaks Dam.	Yes
PS-2	Perennial Stream	Turbidity, pH, temperature and dissolved oxygen levels for water released from the dam that would remain in the river after diversions and recharge potential are accounted for.	No

No.	Location	Metric	Modeled in PVA
PS-3a	Perennial Stream	Number of days a release reaches the perennial stream that is driven by maintenance needs, need to evacuate pool to accommodate a pending storm, or when water quality is unsuitable for recharge purposes.	No
PS-3b	Perennial Stream	Number of times a release reaches the perennial stream that is driven by maintenance needs, need to evacuate pool to accommodate a pending storm, or when water quality is unsuitable for recharge purposes.	No

5.7.3 Recommendations for the FVA

- Translate the “monitoring” environmental metrics into performance metrics to elucidate the environmental impacts or benefits of alternative reservoir operations.
- Assess how to best use environmental metrics.
- Assess how to use flows in excess of the diversion capacity to improve environmental outcomes on the alluvial fan.
- Develop an approach to account for relevant water quality considerations.

5.8 References

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Section 6. FIRO Implementation and Final Viability Assessment (FVA) Roadmap

6.1 Recommendations To Be Considered in the FVA

The execution of this Preliminary Viability Assessment (PVA) involved an array of analyses and Forecast Informed Reservoir Operations (FIRO) alternatives to address the feasibility of FIRO at Seven Oaks Dam. As the project transitions from the PVA to the FVA, efforts will focus on selecting and evaluating the most promising FIRO alternatives identified in the PVA. Overarching recommendations listed in the Executive Summary will be implemented during the FVA. Recommendations in Section 4 and Section 5 provide additional guidance that will be considered and prioritized as the FVA is scoped. Work teams will continue to carry out the necessary tasks to complete the FVA, updating the Steering Committee regularly and seeking guidance as needed.

6.2 Possibility for Planned Deviation and Interim Operations

Seven Oaks Dam is currently operated for flood risk management. San Bernardino Valley and Western Water are working with local sponsors (Orange County Flood Control District, San Bernardino County Flood Control District, and Riverside Flood Control and Water Conservation District) to develop an approach for water conservation to be implemented as a secondary purpose of Seven Oaks Dam. As a secondary purpose, water conservation would be subordinate to the primary purpose of flood risk management, like the framework for water conservation at Prado Dam.

Testing FIRO alternatives is done through interim operations: reservoir operations that are allowed to be tested at the dam through a deviation to the Water Control Manual (WCM), prior to completion of a WCM update. U.S. Army Corps of Engineers (USACE) approval is required for a planned deviation from the current WCM if changes to the current Water Control Plan (WCP) are proposed. FIRO spaces within the range of 2,220 feet to 2,265 feet (top of debris and intermediate pools, respectively) will be explored for interim operations, given the results of the preliminary assessment, which demonstrated that water supply availability improvements are possible without compromising flood risk management (FRM).

As part of the process of analyzing a proposed deviation, the local sponsors will coordinate with USACE to determine the scope of work to assess the proposed deviation. This scoping effort will identify relevant factors to evaluate during interim operations. Such topics include dam safety, environmental considerations, operations and maintenance, and other topics identified by USACE and the local sponsors.

The deviation period would ideally be in place, or modified, from the time of approval until FIRO WCP operations are formally approved by USACE for implementation in an updated WCM. It should be noted that in a potential WCM update process, USACE and the local sponsors are informed by the FIRO viability assessment but are not bound to the FIRO operations assessed in the FVA or the interim operations.

Planned deviations, approved at or below the USACE division level, can be minor or major, depending upon the magnitude of the requested deviation from the existing WCP. The USACE guidelines for planned deviations are described in USACE EM-1110-2-240, with additional guidance provided by USACE's South Pacific Division. Requests for a planned deviation can come from the owner of the dam or from the Steering Committee.

6.3 Decision Support Tools

Decision support is a key component of implementing any forecast-informed WCP. Decision support tools are necessary to provide (1) situational awareness of current and expected weather and watershed conditions, and (2) the ability to process forecast inflows and streamflows through reservoir storage and release models. A decision support tools work team will be established during the FVA to assess any gaps in current decision support tools and recommend additional tools to support FIRO operations during interim operations and eventually under an updated WCM. Additionally, reservoir operations for FIRO alternatives may be simulated in real time during the FVA process. These virtual operations demonstrate what may have been achieved if a deviation were in place.

6.4 Timeline

The timeline below (Figure 6-1) shows the sequence of activities that will be conducted between completion of the PVA (August 2026) through completion of the FVA (2028) and additional activities in parallel with and following the FVA. Goals of the additional activities include pursuing a deviation to the WCM to test FIRO in interim operations and, ultimately, developing an updated WCM. The updated WCM would be prepared based on information and experience developed during the deviation period.

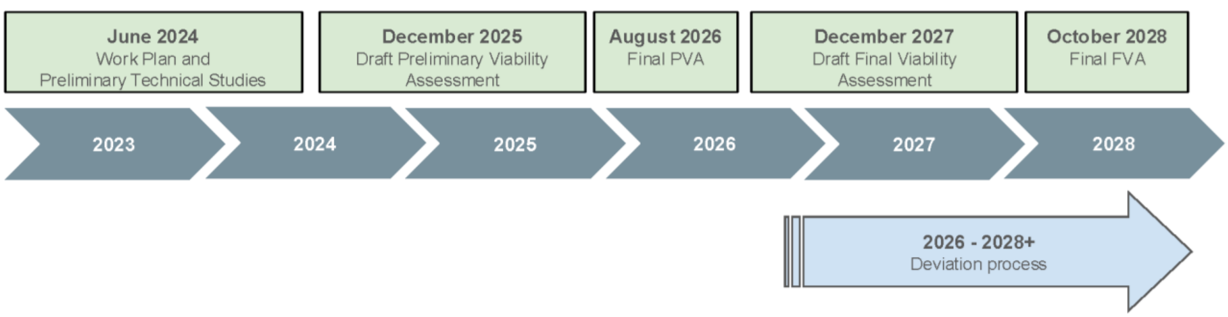

Figure 6-1. *Timeline for the FIRO viability assessment process at Seven Oaks Dam.*