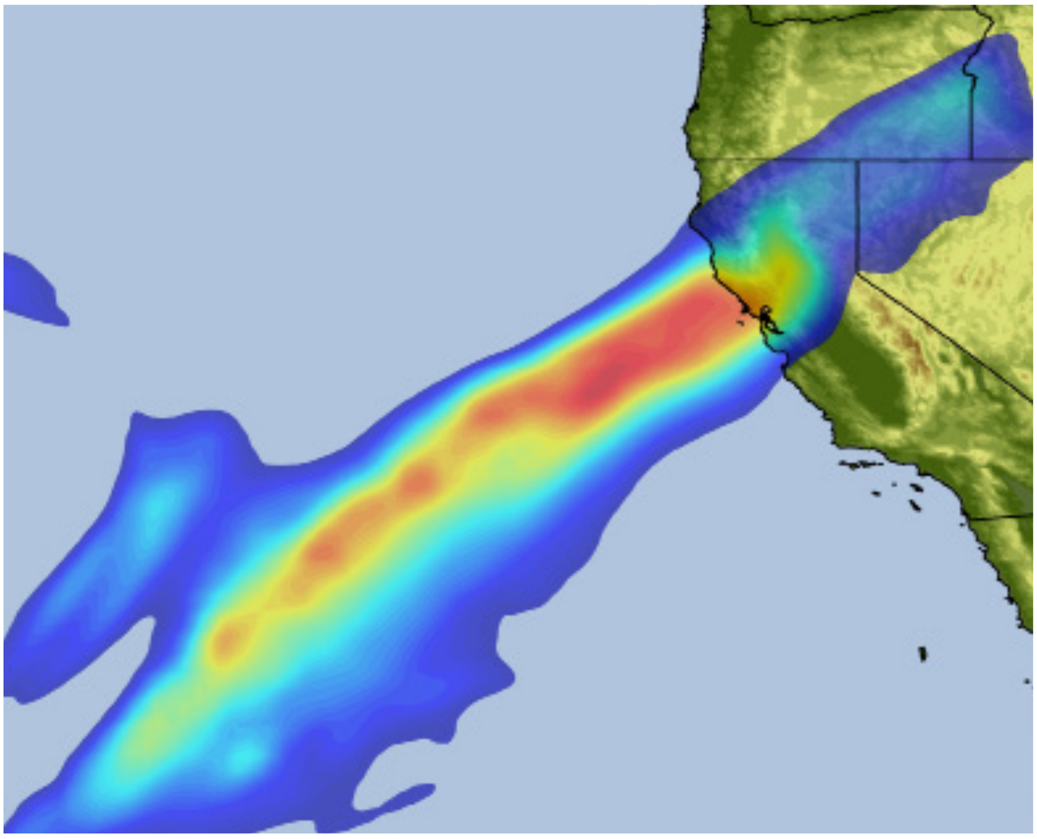
Work Plan for Seven Oaks Dam
FORECAST INFORMED RESERVOIR OPERATIONS (FIRO)

June 2024



Steering Committee

- **F. Martin Ralph:** CW3E (Co-chair)
- **Cary Talbot:** USACE, Engineer Research and Development Center (ERDC) (Co-chair)
- **Heather Dyer:** San Bernardino Valley (Co-chair)
- Tim Fairbank: USACE
- Jayme Laber: NOAA National Weather Service
- Michael Anderson: California Department of Water Resources
- Rollie White: USFWS
- Lisa Haney: Orange County Water District
- Joseph Forbis: ERDC
- James Tyler: Orange County Public Works
- Michael Fam: San Bernardino County Public Works
- Betsy Miller: San Bernardino Valley Water Conservation District
- Mallory O'Conor: Western Municipal Water District

Seven Oaks Dam Steering Committee Co-chairs

- **F. Martin Ralph:** Director, Center for Western Weather and Water Extremes (CW3E), Scripps Institution of Oceanography, UC San Diego
- **Cary Talbot:** National Lead, Forecast-Informed Reservoir Operations Program, Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers (USACE)
- **Heather Dyer:** Chief Executive Officer/General Manager, San Bernardino Valley Municipal Water District

Seven Oaks Dam Steering Committee Members

- **Tim Fairbank:** Chief, Hydrology & Hydraulics Branch, USACE Los Angeles District
- **Jayme Laber:** Hydrologist, National Oceanic and Atmospheric Administration (NOAA) National Weather Service; Analyze, Forecast, Support Office; Forecast Services Division; Water Resources Services Branch
- **Michael Anderson:** State Climatologist, California Department of Water Resources
- **Rollie White:** Assistant Field Supervisor, U.S. Fish and Wildlife Service (USFWS)
- **Lisa Haney:** Executive Director of Planning and Natural Resources, Orange County Water District
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- **Betsy Miller:** General Manager, San Bernardino Valley Water Conservation District
- **Mallory O'Conor:** Water Resources Specialist, Western Municipal Water District

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Abbreviations

For brevity, this document uses the following abbreviations:

Abbreviation	Definition
ac-ft	acre-feet
AR	atmospheric river
BO	Biological Opinion
cfs	cubic feet per second
CNRFC	California Nevada River Forecast Center
CW3E	Center for Western Weather and Water Extremes
DST	decision support tool
EIR	Environmental Impact Report
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
MAP	mean areal precipitation
NOAA	National Oceanic and Atmospheric Administration
PoT	peaks-over-threshold
PVA	Preliminary Viability Assessment
QPE	quantitative precipitation estimation
QPF	qualitative precipitation forecast
RAFSS	Riversidean alluvial fan sage scrub
RAOP	Research And Operations Partnership
RCP	representative concentration pathway
SARM	Santa Ana River Mainstem
SBVMWD	San Bernardino Municipal Water District
SBKR	San Bernardino kangaroo rat

Abbreviation	Definition
SOD	Seven Oaks Dam
SSC	Species of Special Concern
SSP	shared socioeconomic pathway
SWP	State Water Project
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
WCM	Water Control Manual
WCP	Water Control Plan
West-WRF	Western Weather Research and Forecasting
WRE	Water Resources Engineering
WSPA	Santa Ana River Woolly Star Preserve Area

Section 1. Introduction

California has one of the most variable climates in the United States, and it's 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. Long, narrow bands of concentrated moisture, ARs stretch thousands of miles across the Pacific Ocean. When ARs make landfall, they can release a staggering amount of rain and snow: for example, 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**).

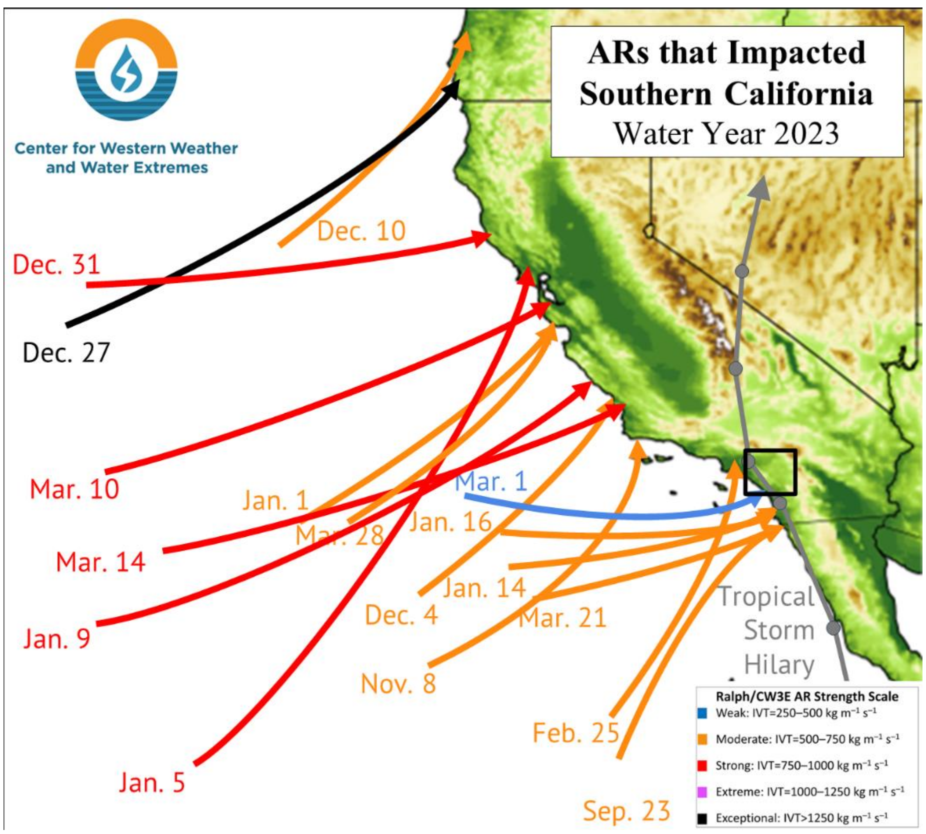

Figure 1-1*. Seventeen ARs and a tropical cyclone brought record-breaking snowfall to the region in water year 23. The ARs dropped more than 240 inches of snow at Big Bear. Note: ARs making landfall outside the Santa Ana watershed still affect the watershed, as they move along the coast.*

Since ARs are the main driver of floods, and the absence of ARs is often associated with droughts, improved AR forecasts are essential for Forecast Informed Reservoir Operations (FIRO). The Center for Western Weather and Water Extremes' (CW3E's) focused work to improve AR forecasts puts the "F" in FIRO. Recognizing the importance of ARs in a changing climate, the San Bernardino Valley Municipal Water District (San Bernardino Valley) initiated a project 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 to increase resilience to droughts and floods. This FIRO project's main objective is to explore options for increasing water conservation for habitat and water supply reliability, while maintaining or possibly improving flood risk management objectives.

Early FIRO results at Lake Mendocino show that reservoir operators can use forecast information and tools to store 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 1-2**), FIRO operations can result in 8 to 11 percent more recharge, on average.

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. Lessons learned in the Lake Mendocino and Prado Dam watersheds, where habitat was also a major consideration, will inform the Seven Oaks Dam FIRO viability assessment.

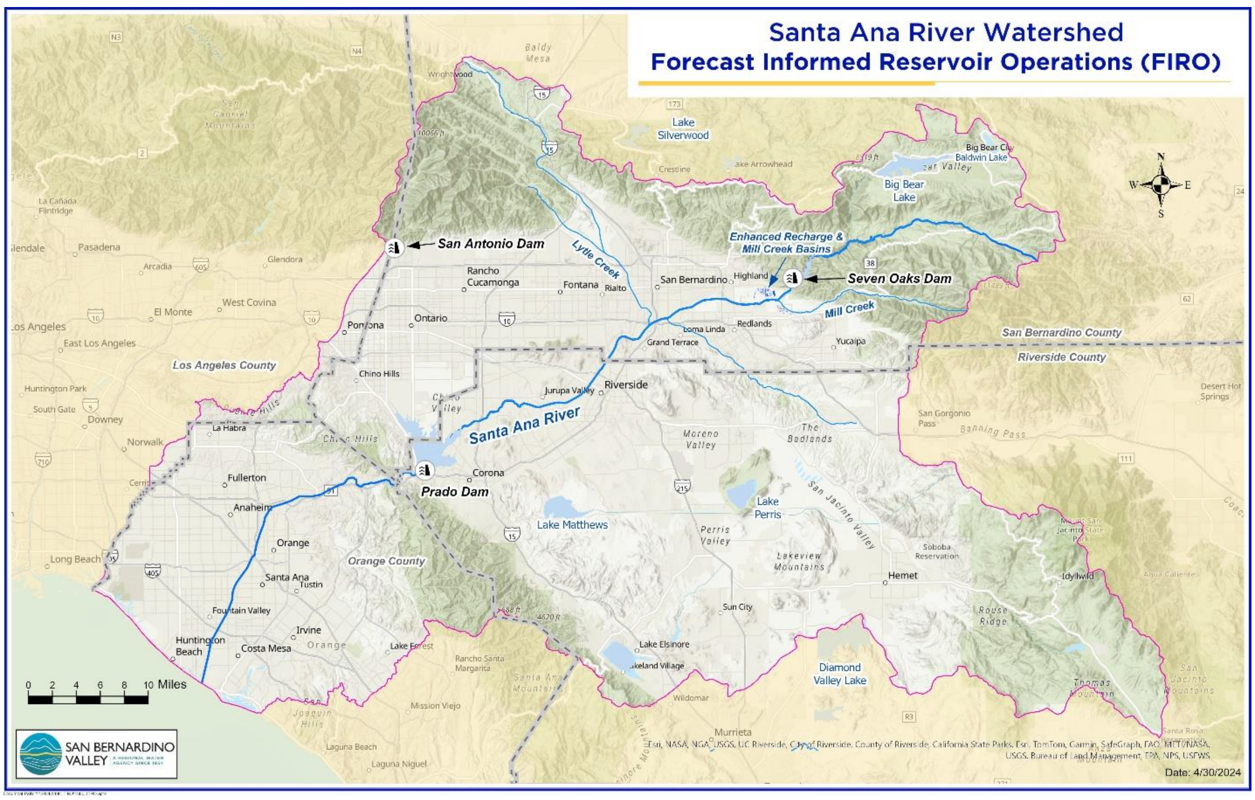

Figure 1-2. *Santa Ana River Watershed, showing the locations of Seven Oaks Dam in the upper watershed and Prado Dam in the lower watershed. (Credit: San Bernardino Valley.)*

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 for multiple benefits.

A Seven Oaks Dam FIRO Steering Committee was formed to represent these interests. Members are listed below.

Seven Oaks Dam FIRO Steering Committee

Co-Chairs:

- **F. Martin Ralph:** Director, CW3E, Scripps Institution of Oceanography, UC San Diego
- **Cary Talbot:** National Lead, FIRO Program, Engineer Research and Development Center (ERDC), United States Army Corps of Engineers (USACE)
- **Heather Dyer:** Chief Executive Officer/General Manager, San Bernardino Valley Municipal Water District

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The Steering Committee is supported by eight work teams, each addressing one of the following aspects of the FIRO workplan and viability assessment:

- Meteorology
- Hydrology
- Forecast verification
- Observations
- Environment
- Water resources engineering
- Decision support tools
- Communications

Steering Committee and work team members work together, as agreed upon in the Seven Oaks Dam FIRO Steering Committee Terms of Reference, to assess FIRO operations.

Their assessment includes two considerations particular to Seven Oaks Dam:

- While Seven Oaks Dam is currently not authorized for water conservation, this FIRO study will explore the potential for allowing water conservation to increase groundwater recharge for regional water reliability and to enhance habitat for protected species (see text box), while maintaining, if not enhancing, flood risk management.
- Unlike Prado Dam, on the lower Santa Ana River, Seven Oaks Dam has snow upstream. This project considers that important difference.

This workplan lays out a process and scope for assessing the viability of FIRO at Seven Oaks Dam (Figure **1-3**). This process seeks to answer a key question: Can current and improved forecasts of individual and series of landfalling atmospheric rivers and other storm types and their associated precipitation, temperature, and runoff be used to inform flexible reservoir operations at Seven Oaks Dam to increase water conservation and to enhance and protect habitat through strategic releases, while maintaining flood risk management objectives?

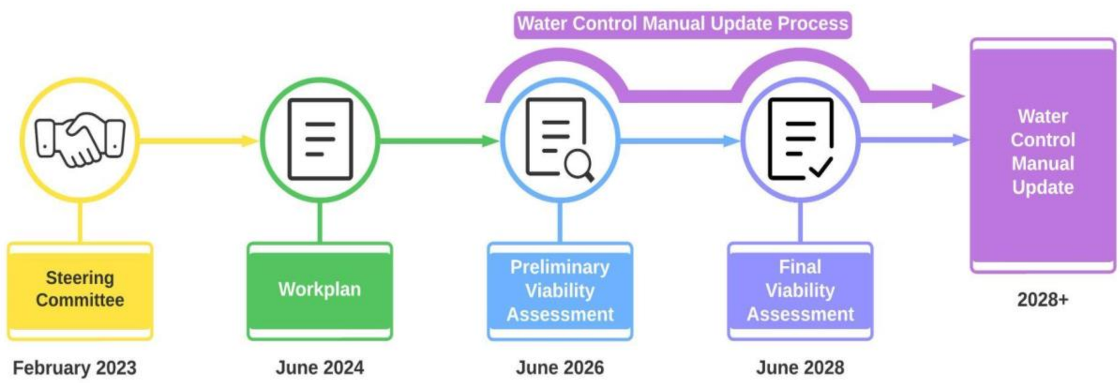

Figure 1-3*. FIRO viability is assessed according to a systematic process. If FIRO is viable, the body of work produced by this process will inform an update to the USACE Water Control Manual, which governs dam operations.*

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 2,700 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 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-elevation. Chaparral and coastal sage scrub are common in lower elevations, and riparian forest and marshes can be found along the riverbed.

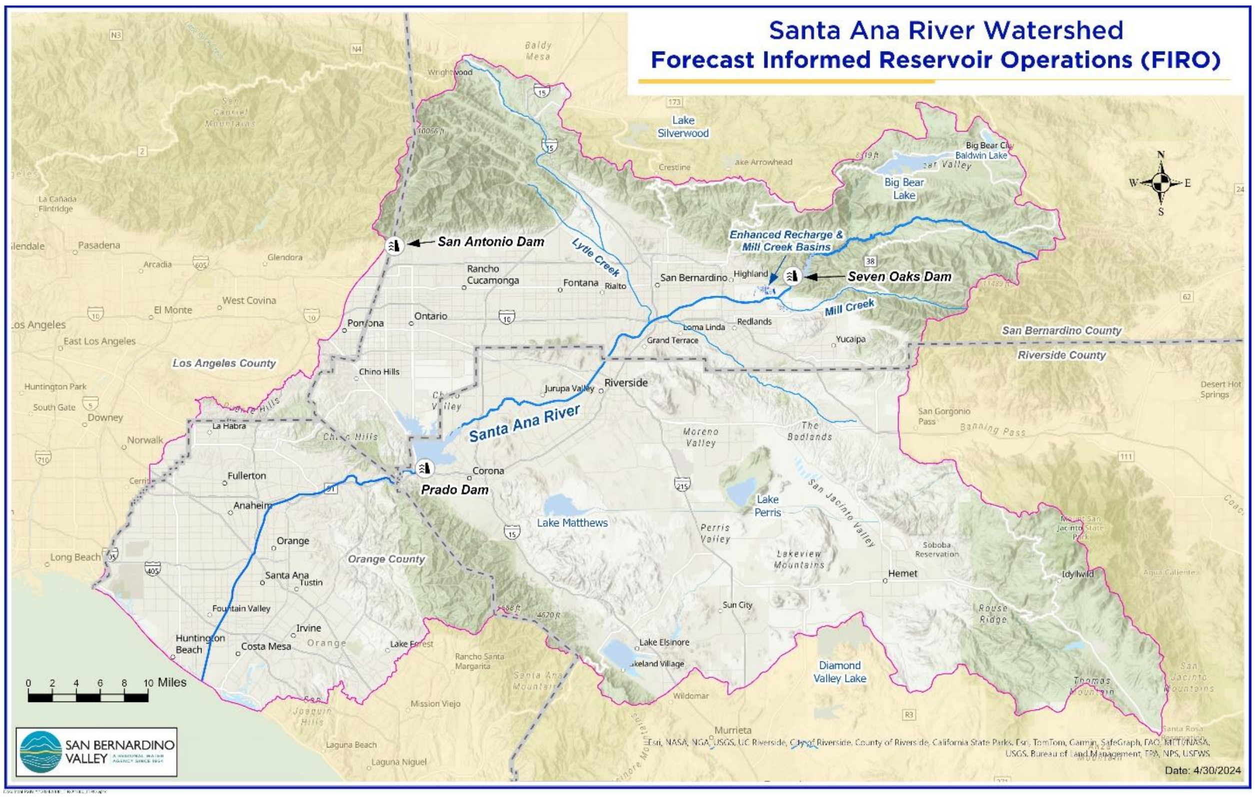

***Figure 2-1**. The Santa Ana River Watershed. Seventy-four percent of the watershed area above Seven Oaks Dam is at an elevation higher than 1,900 meters (6,234 feet) above mean sea level. (Credit: San Bernardino Valley.)*

About 6 million people live in the Santa Ana River watershed. Water supply reservoirs within the watershed include Lake Mathews, Lake Perris, Lake Skinner, Diamond Valley Lake, and Irvine Lake. In addition, Prado Dam, 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 non-storm season is dominated by effluent from nine wastewater treatment plants. Stormwater runoff in the lower basin is collected in the Prado Dam Basin. Below Prado Dam, Orange County Water District diverts, on average, approximately 150,000 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 San Bernardino Valley Municipal Water District

San Bernardino Valley Municipal Water District (San Bernardino Valley) is a wholesale water and groundwater management agency; its service area covers over 350 square miles and serves around 714,000 customers. The service area covers the eastern two-thirds of the San Bernardino Valley, Crafton Hills, and part of the Yucaipa Valley (including the cities of San Bernardino, Colton, Loma Linda, Redlands, Rialto, Highland, Grand Terrace, and Yucaipa, part of the city of Fontana, and unincorporated areas in San Bernardino County, including Bloomington and Mentone). San Bernardino Valley obtains water from the State Water Project (SWP) from the east branch of the state aqueduct via Lake Silverwood. In addition to other water rights holders, San Bernardino Valley and the Western Municipal Water District (Western Water) have water rights permits to divert and use up to 198,000 ac-ft per year of water from the Santa Ana River. San Bernardino Valley and Western Water also have rights to store up to 50,000 ac-ft of Santa Ana River water at Seven Oaks Dam.

A portion of the Santa Ana River flows released from Seven Oaks Dam are recharged into the groundwater basin directly downstream of the dam by the San Bernardino Valley Water Conservation District. The groundwater basin is identified by the California Department of Water Resources as Basin 8-002.06, the "Upper Santa Ana Valley–San Bernardino Subbasin" (Department of Water Resources Bulletin 118). The subbasin, together with adjacent subbasins, is referred to as the San Bernardino Basin Area.

San Bernardino Valley, Western Water, the city of Riverside, and other entities in Riverside County are parties to the judgment in the case of *Western Municipal Water District v. East San Bernardino County Water District, et al.,* Riverside Superior Court No. 78426, which established water rights and responsibilities for management of the San Bernardino Basin Area. The judgment is administered and enforced by a court-appointed watermaster, consisting of a committee of two persons—one representative nominated by San Bernardino Valley and one by Western Water. About a million people in Riverside and San Bernardino Counties rely on the San Bernardino Basin Area for their principal water supply.

In 1960, San Bernardino Valley signed an agreement with the California Department of Water Resources to contract for SWP supplies. San Bernardino Valley's allocation of SWP supplies is 102,600 ac-ft per year. The amount of water provided by the SWP to the San Bernardino Valley each year varies, based on hydrologic conditions, environmental considerations, and other factors. In years when northern California is wet, 70 to 100 percent of the allocation of SWP may be available to San Bernardino Valley. In dry years, the allocation has historically been as low as 5 percent.

The population of San Bernardino and Riverside Counties is projected to grow by 15–20 percent by 2045 (California Department of Finance 2024). This will increase demand for water. **Table 2-1** shows sources and volumes of water supply to meet existing and future needs within the San Bernardino Valley service area.

Table 2-1. *Water supply sources in the San Bernardino Basin Area.*

Sources of Supply	Range in Current Supply (ac-ft/Year)	Range in Estimated Future Water Supply (ac-ft/Year)
SWP: groundwater recharge	0 to 70,000	0 to 70,000
SWP: delivery to treatment plants	5,000 to 33,000	5,000 to 33,000
Groundwater pumping	190,000 to 220,000	190,000 to 270,000
Direct delivery of treated local surface water	5,000 to 20,000	5,000 to 30,000
Direct delivery of surface water to irrigation	1,000 to 10,000	1,000 to 10,000
Groundwater recharge from Santa Ana River water released from Seven Oaks Dam (sustains groundwater pumping)	Up to about 100,000 in a wet year	Up to 200,000 in a wet year
Notes: Groundwater pumping is sustained by recharging Santa Ana River water, other local recharge, and SWP supplies. Values are ranges and not intended to be summed.		

2.3 Seven Oaks Dam and Reservoir

2.3.1 History and Authorized Uses

Orange County suffered major damage during the historic 1938 flood. In response, Prado Dam was built in 1941. The Corps later determined that another dam was needed at the base of the San Bernardino Mountains, as part of the Santa Ana River Mainstem (SARM) project, authorized by Congress in 1986. The SARM project extends about 75 miles from the upper Santa Ana River Canyon in the San Bernardino Mountains downstream to its confluence with the Pacific Ocean at Newport Beach. The $2 billion project provides flood protection for over two million people and hundreds of square miles of developed lands within Orange, Riverside and San Bernardino Counties. It includes construction of Seven Oaks Dam, raising Prado Dam, improving channels downstream of Prado Dam, and acquiring land and land easements.

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

Table 2-2. *Seven Oaks Dam quick facts from Orange County Public Works.*

Storage	
Height	550 feet
Top width	40 feet
Base width	Over 2,200 feet
Crest length	2,760 feet
Slope	Upstream slope = 1:2.2 (vertical to horizontal) Downstream slope = 1:1.8 (vertical to horizontal)
Embankment volume	37,626,983 cubic yards
Drainage area	177 square miles
Spillway type	Trapezoidal rock cut with concrete sill; total width 500 feet

Debris capacity	3,128 ac-ft
At spillway	147,970 ac-ft
At top of dam	174,609 ac-ft
Spillway	
Crest elevation	2,580 feet
Crest length	500 feet
Elevation of max. water surface	2,604 feet
Intake elevation	2,265 feet
Reservoir	
Area at spillway	780 acres
Gross capacity (at spillway crest)	145,600 ac-ft.
Storage Allocation Below Spillway Crest	
Flood control	113,600 ac-ft
Sedimentation (100-year storage)	32,000 ac-ft
Reservoir Design (General Storm)	
Total volume	115,000 ac-ft
Peak inflow	85,000 ft/sec
Peak outflow	7,000 ft/sec
Design Flood (350-year Recurrence)	
Total volume (four-day)	115,000 ac-ft
Peak inflow	85,000 cubic feet per second (cfs)
Peak outflow (no spillway)	7,000 cfs

Maximum Probable Flood	
Total volume	326,000 ac-ft
Peak inflow	185,000 cfs
Peak outflow	180,000 cfs

Construction of Seven Oaks Dam began in 1993 and was completed in 2000. The 550-foot high earth and rockfill embankment dam, 35 miles upstream of Prado Dam in the upper portion of the watershed, was built at a cost of about $450 million; 764 acres of habitat were set aside for three protected species, Santa Ana River woolly-star, the San Bernardino kangaroo rat (SBKR), and slender-horned spineflower. USACE's non-federal project sponsors included Orange County Flood Control District, San Bernardino Flood Control District, and Riverside County Flood Control and Water Conservation District. Since it was built, San Bernardino Valley and Western Water have been interested in operating the dam to capture and release water for recharge during or after storm events to enhance water reliability in the basin for human use and for habitat enhancement.

Currently, the dam is authorized for flood risk management only. A feasibility study by USACE, a Section 203 report, or an act of Congress would be required to authorize the dam for water conservation. In 1997, a feasibility study concluded that water could be seasonally stored at Seven Oaks Dam without impairing flood risk management. However, implementation stalled during the National Environmental Policy Act process because the Environmental Impact Report did not fully address potential project impacts on the then-newly federally listed endangered SBKR.

The Water Control Manual [USACE 2003, page 8-06) briefly mentions incidental water conservation:

> *The Water Control Plan currently does not include or preclude regulation for water supply purposes. The plan may be modified in the future to accommodate water conservation. The contemplated operation of the dam within the debris pool was negotiated with the downstream water users during the preparation of the Phase II General Design Memorandum (GDM) to address the impacts of the flood control operation on those users. Releases made from the debris pool during the flood season, and the draining of the debris pool during the summer months, are anticipated to address the impacts to downstream water users caused by building the debris pool during the flood season. Above the debris pool, temporary impoundment of water occurs during wet years. This water, which would have discharged from the canyon at much larger rates under natural conditions, could also incidentally enhance water conservation.*

2.3.2 Existing Operations

Seven Oaks Dam is operated and maintained by the abovementioned project sponsors (Orange County Flood Control District, San Bernardino County Flood Control District, and Riverside

County Flood Control and Water Conservation District). Operations are conducted by Orange County Flood Control District staff, in accordance with the USACE 2003 Water Control Manual.

The dam can function to store "incidental" water within the intermediate pool. When water is in this pool, releases can be delayed, and the release rates modified if hydrologic conditions warrant, to support downstream habitat mitigation and enhancement plans. This allows San Bernardino Valley and Western Water to opportunistically capture and recharge as much water as possible as it is released from the dam, within the constraints of the current Water Control Manual. The amount of water captured for groundwater recharge varies yearly, depending on precipitation and runoff generated and downstream water levels.

See **Figure 2-3** for a simplified storage allocation diagram from the Seven Oaks Dam Water Control Plan (USACE 2003, plate 7-01A).

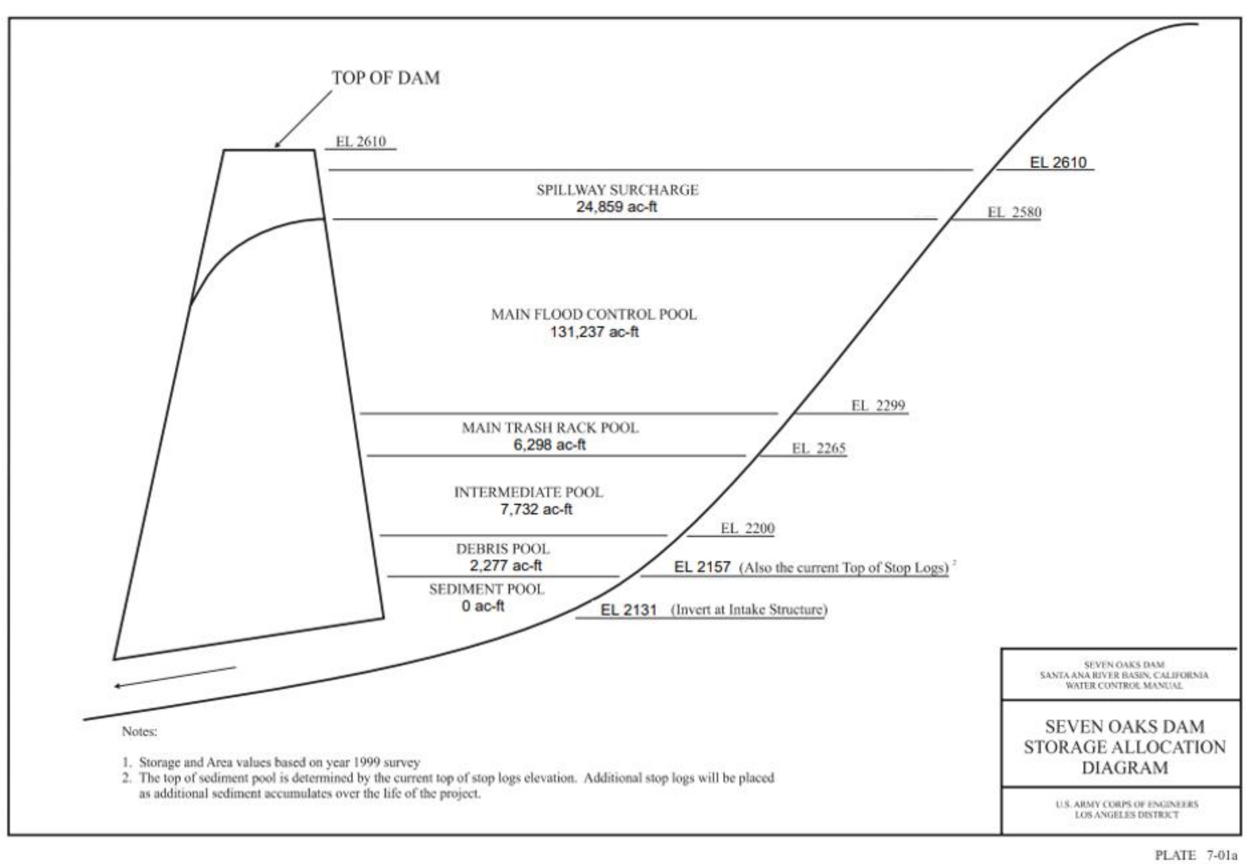

Figure 2-3. *Simplified storage allocation diagram from the Seven Oaks Dam Water Control Plan (plate 7-01A). Volumes shown here were based on prior surveys. Current storage volumes have changed due to sediments from recent storms and will be updated after completion of a new reservoir and sediment survey. (Credit: USACE Los Angeles District.)*

Currently, Orange County Flood Control District uses forecasts provided by the National Weather Service to inform future releases. Reasonably accurate precipitation forecasts are generally available within a week before the storm event, and release decisions are adjusted as the storm event approaches to lower the water surface elevation for as much effective storage as possible within the available time to prepare. Release flow rates are dictated according to the schedule shown in the appendix (Section 6.1), but releases at 500 cfs or less are optimal for recharge, and 3 cfs is needed for downstream minimum flow requirements. To maximize recharge, slow-release rates over a long time during the winter and into spring are most effective, but current operations do not yet follow this practice. Discharges can be adjusted to meet public safety concerns, environmental mitigation, and/or maintenance requirements. Typically, the operational goal is to allow the water surface elevation to build up during the storm season (November to April). Then, from April to September, the goal is to empty the reservoir below the intermediate pool by September 1. Once the storm season ends, the operational goal shifts to emptying the reservoir to the sediment pool, to provide the required dry conditions for any maintenance; this drawdown should begin directly after the storm season ends, and no later than September 1 to allow at least a month and a half for maintenance work.

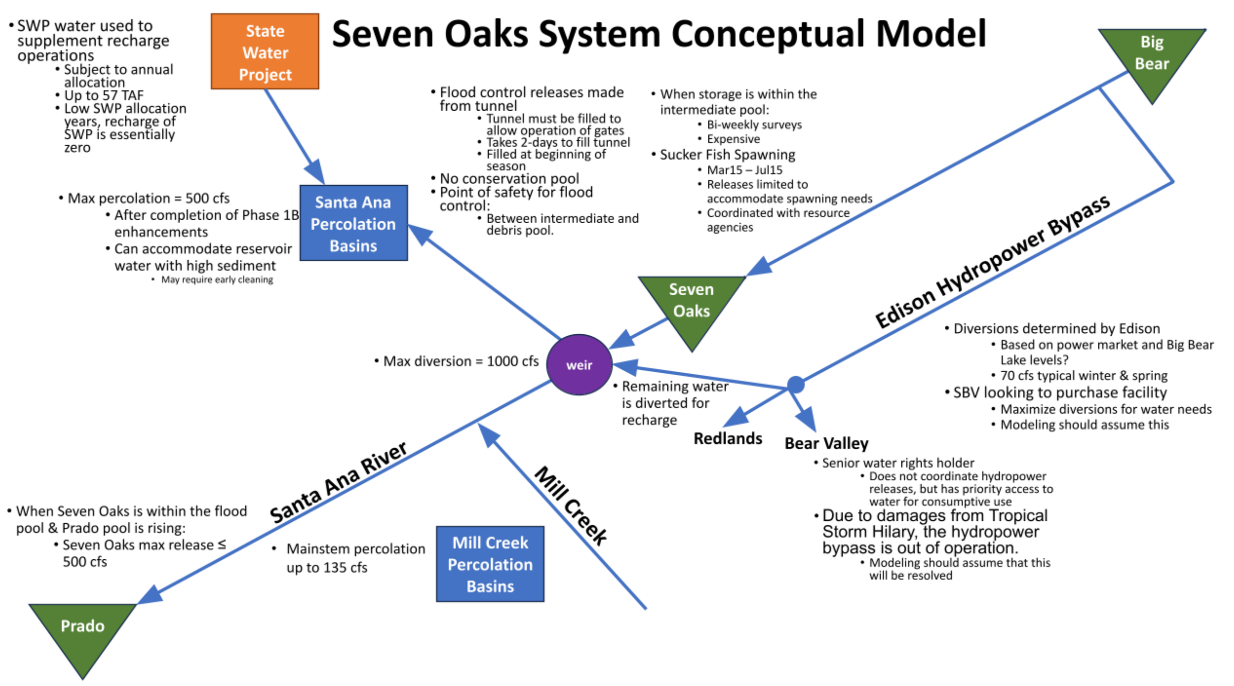

Figure 2-4. *Seven Oaks system conceptual model. (Hydropower bypass is non-consumptive use. SWP recharge is a secondary priority; Santa Ana River water is the priority for recharge basins.)*

2.3.3 Seven Oaks and Prado Dam Coordinated Operations

When the water level is low enough that water stays within the main flood control pool, releases from Seven Oaks Dam must be coordinated with Prado Dam. During flood events, Seven Oaks Dam will store water if the reservoir pool at the Prado reservoir is rising and the pool at Seven Oaks Dam is not approaching the spillway. When Prado Dam water is rising, releases from Seven Oaks Dam are capped at 500 cfs. Once water levels in the Prado Dam pool begin to recede, release rates from Seven Oaks can vary but are capped at 7,000 cfs.

2.4 Infrastructure

2.4.1 Existing Infrastructure

Facilities located upstream of the dam, within the reservoir and watershed, include service roads that provide access for the U.S. Forest Service, Southern California Edison, U.S. Fish and

Wildlife Service (USFWS), and water operators. Southern California Edison owns two hydroelectric powerhouses, and associated flume system and transmission lines, in the watershed. Several gauging stations with associated infrastructure are also located upstream of the dam. The dam facility itself has several operational components, as shown in **Figure 2-5**.

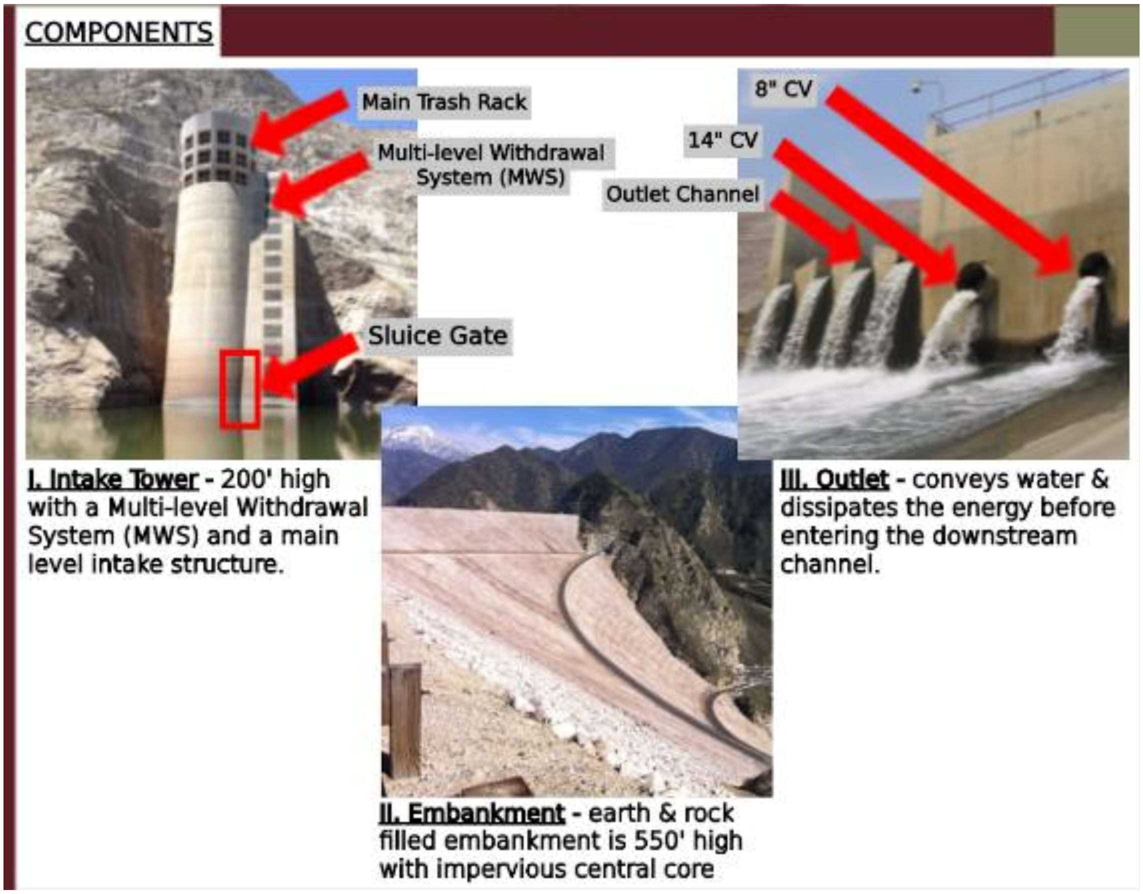

Figure 2-5. *Components of the Seven Oaks Dam system. (Credit: Orange County Public Works.)*

Downstream infrastructure (**Figure 2-6**) consists of a main intake structure, a tunnel, an additional minimum discharge line and gate system with control valves, and a plunge pool that water passes through before discharging to the Santa Ana River below the dam. The system is designed to regulate reservoir levels and downstream flows according to the USACE Water Control Plan, which requires a minimum pool elevation of 2,200 feet be maintained from October 15 through April 15 and dictates seasonal cfs limitations on releases to empty the debris pool by August 31. The 100-year debris pool target elevation is 2,200 feet. Flood control releases are restricted to a maximum of 500 cfs at elevations between 2,200 and 2,265 feet but can vary from 50 cfs to 2,000 cfs as specified in the release flow rate schedule (see Section 6.1 for more information). Typically, from October through April (and when no major floods are occurring), releases are made up to 500 cfs. Flood control releases can vary over a wider range depending on conditions. During flood events, releases can increase up to 7,000 cfs to meet the target elevation. Under Main Flood Control Pool conditions, Seven Oaks Dam operations are coordinated with elevations at downstream Prado Dam, and Seven Oaks releases are held at 500 cfs until the flood peak passes Prado Dam. For more information on the system hydrology and engineering, refer to Sections 4.3 and 4.5, respectively.

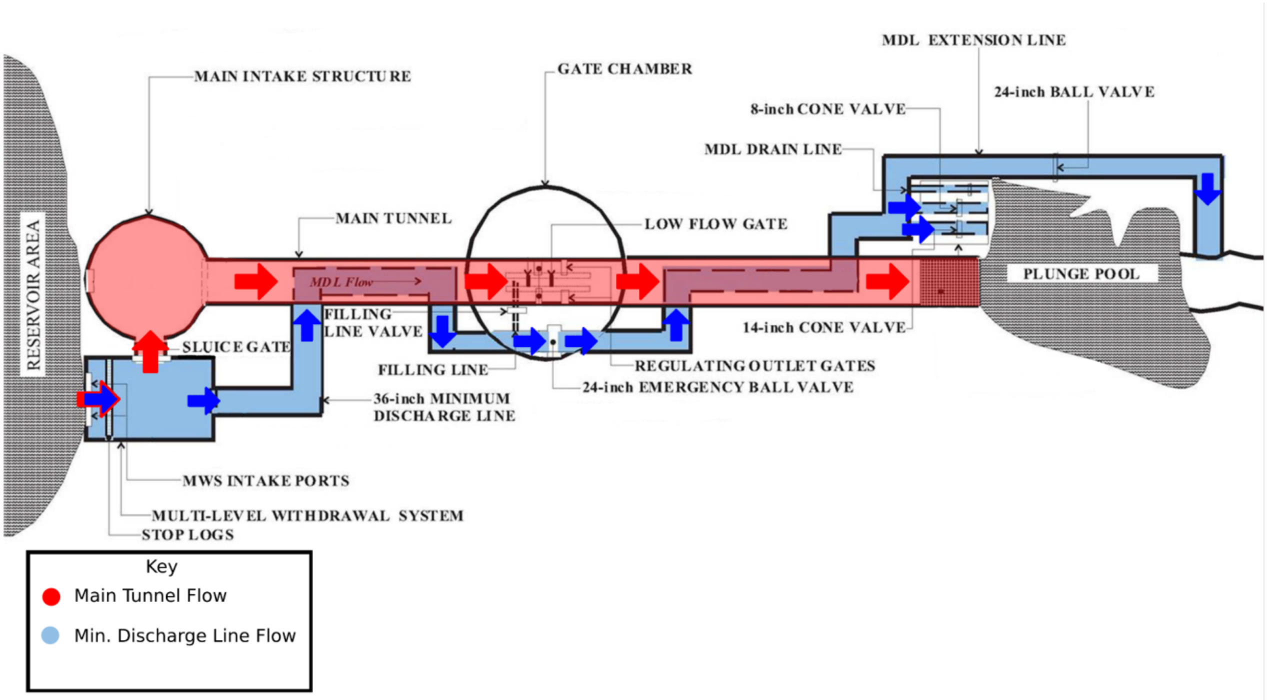

Figure 2-6. *Seven Oaks Dam reservoir downstream infrastructure. (Credit: Orange County Public Works.)*

The San Bernardino Valley Water Conservation District recharges Santa Ana River water released from Seven Oaks Dam. The capacity of the existing recharge facilities is 195 cfs, which can decrease by half due to sediment accumulation and/or groundwater mounding following high recharge years. The Conservation District conducts facilities maintenance to optimize recharge capacity during dry periods, typically in the summer and fall. The facilities used to recharge Santa Ana River flows released from Seven Oaks Dam are shown in **Figure 2-8**.

2.4.2 Future Infrastructure and Enhancements

The Seven Oaks Dam water conservation feasibility report (USACE 1997) considered four alternatives (in addition to a "no action" alternative) for increasing water conservation at Seven Oaks Dam (see Section 4.5 for more information). While increasing the elevation of the intermediate pool may be an option considered in the FIRO viability assessment, it may also be possible to increase groundwater recharge by varying the release rate and/or keeping water levels in the intermediate pool later in the season. Certain infrastructure improvements would likely be needed for additional storage regardless of how that is achieved. The Santa Ana River draft Environmental Impact Report (EIR) (San Bernardino Valley Municipal Water District & Western Municipal Water District 2004) shows several improvements that may be needed to retain water at elevations above 2,265 feet (**Figure 2-7**).

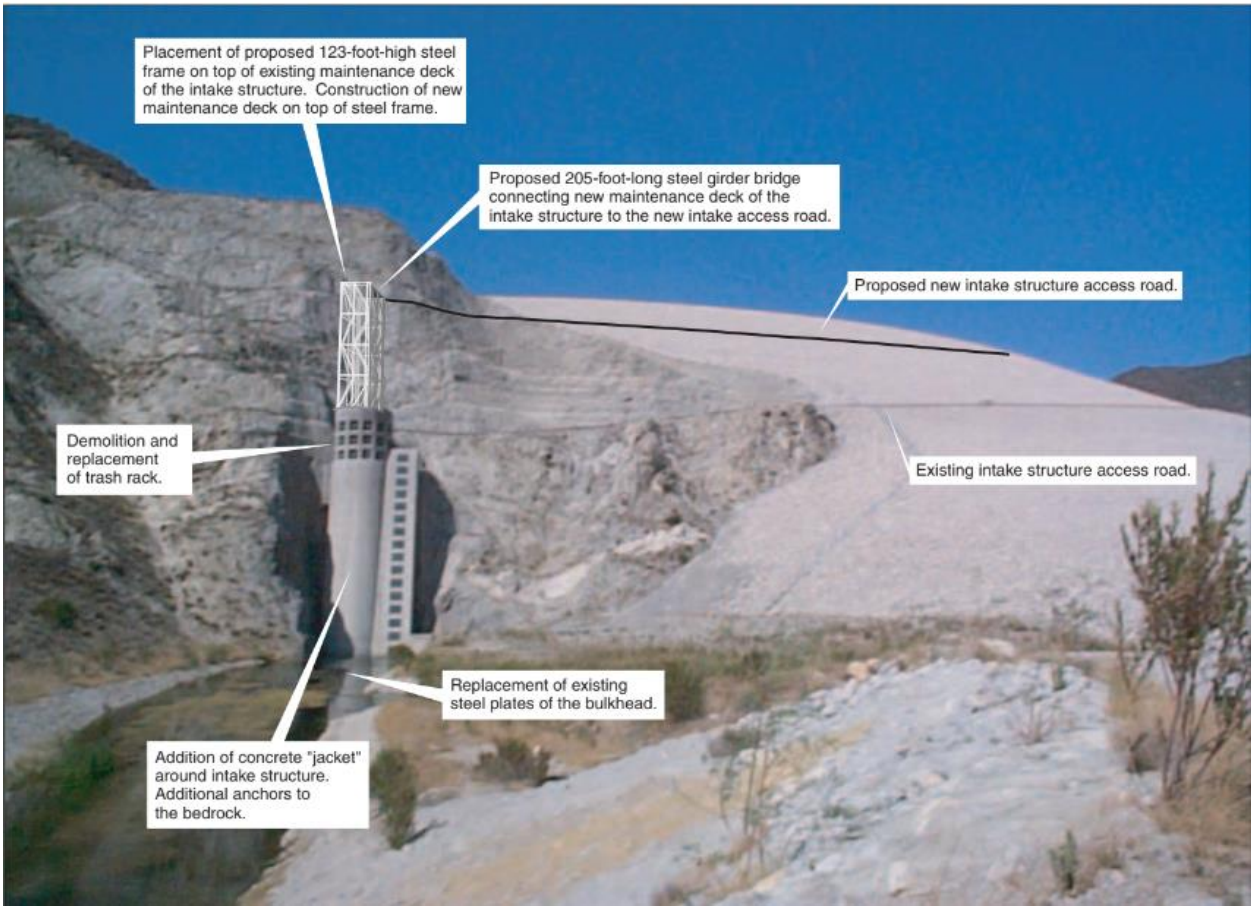

Figure 2-7. *Visual simulation of modifications to Seven Oaks Dam intake structure and access road needed to accommodate additional water storage behind the dam. (Figure from San Bernardino Valley Municipal Water District & Western Municipal Water District 2004.)*

Efforts are underway to expand the recharge basin capacity to capture additional runoff. San Bernardino Valley, in collaboration with Western Water, is constructing the Enhanced Recharge Project Phase 1B, which will add 80 acres of new recharge basins to the existing facilities. These recharge basins are being constructed on Conservation District land and will be operated by the Conservation District upon completion. The addition of the new recharge basins will expand the recharge capacity from 195 cfs to 500 cfs, allowing the expanded facility to recharge up to an additional 80,000 ac-ft per year when enough water is available. The construction of the new recharge basins is projected to be completed by the end of 2024 (**Figure 2-8**). In addition, system enhancements from the Enhanced Recharge project allow San Bernardino Valley to convey Santa Ana River water from the Phase 1A sedimentation basin afterbay through their existing system for spreading at San Bernardino County Flood Control's Waterman Basins.

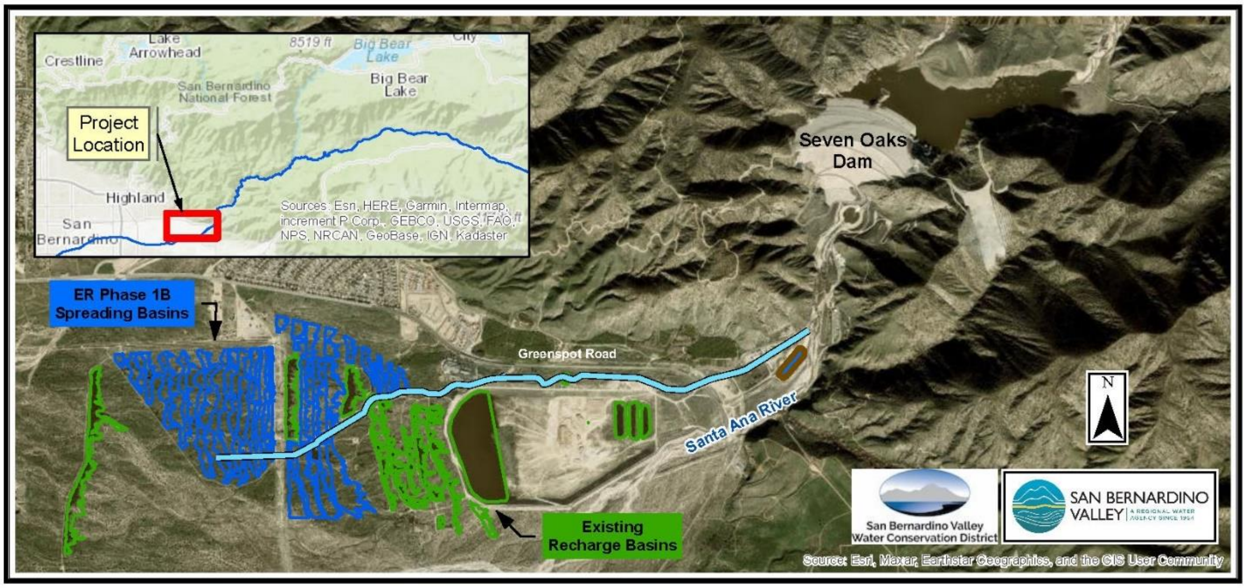

***Figure 2-8**. Map of existing and expanded recharge basins. (Credit: San Bernardino Valley.)*

2.5 Environmental Objectives

Habitat protection and enhancement are central to the Seven Oaks Dam FIRO project, and the FIRO viability assessment will explore a range of operational modifications that could provide additional water conservation and habitat benefits, in accordance with governing documents and management plans described below.

2.5.1 Governing Documents

Environmental impacts and mitigation associated with construction of the SARM project, including Seven Oaks Dam, were addressed in the 1988 Supplemental Environmental Impact Statement associated with the Phase II General Design Memorandum on the SARM (USACE 1988). USACE prepared biological assessments and consulted with USFWS pursuant to section 7(a)(2) of the Federal Endangered Species Act to account for federally listed species and critical habitat within the project area.

USFWS Biological Opinions (BOs) in 1989 and 2002 determined that the SARM and operation of Seven Oaks Dam would not jeopardize the continued existence of the least Bell's vireo, Santa Ana River woolly-star, slender-horned spineflower, or SBKR or adversely modify SBKR critical habitat with compensatory mitigation and conservation measures.

The 1989 BO addresses compensation, reasonable and prudent measures, and conservation recommendations specific to Santa Ana River woolly-star and least Bell's vireo. As a result of the 1989 BO, 764 acres were purchased by USACE's non-federal project sponsors (Orange County Flood Control District, San Bernardino Flood Control District, and Riverside County Flood Control & Water Conservation District) and set aside in perpetuity as the Santa Ana River Woolly Star Preserve Area (WSPA) to mitigate potential impacts of Seven Oaks Dam (Figure 2-9).

The 2002 BO addresses impacts from Seven Oaks Dam operations on additional federally listed species and included conservation measures to sustain SBKR, slender-horned spineflower, and

Santa Ana River woolly-star on WSPA lands (USFWS 2002). The 2002 BO also included a requirement to enable large releases from Seven Oaks Dam when and if necessary to sustain endangered species habitat within the WSPA, which was incorporated in the 2003 Water Control Manual.

USACE prepared a Multi-Species Habitat Management Plan in 2012 to coordinate and adaptively manage WSPA lands to sustain the three covered species and their habitats during the life of the SARM project. The management plan identifies a detailed strategy and plan of action, including monitoring the covered species' populations, monitoring habitat conditions, and taking management measures as appropriate (which may include "environmental enhancement releases" from Seven Oaks Dam).

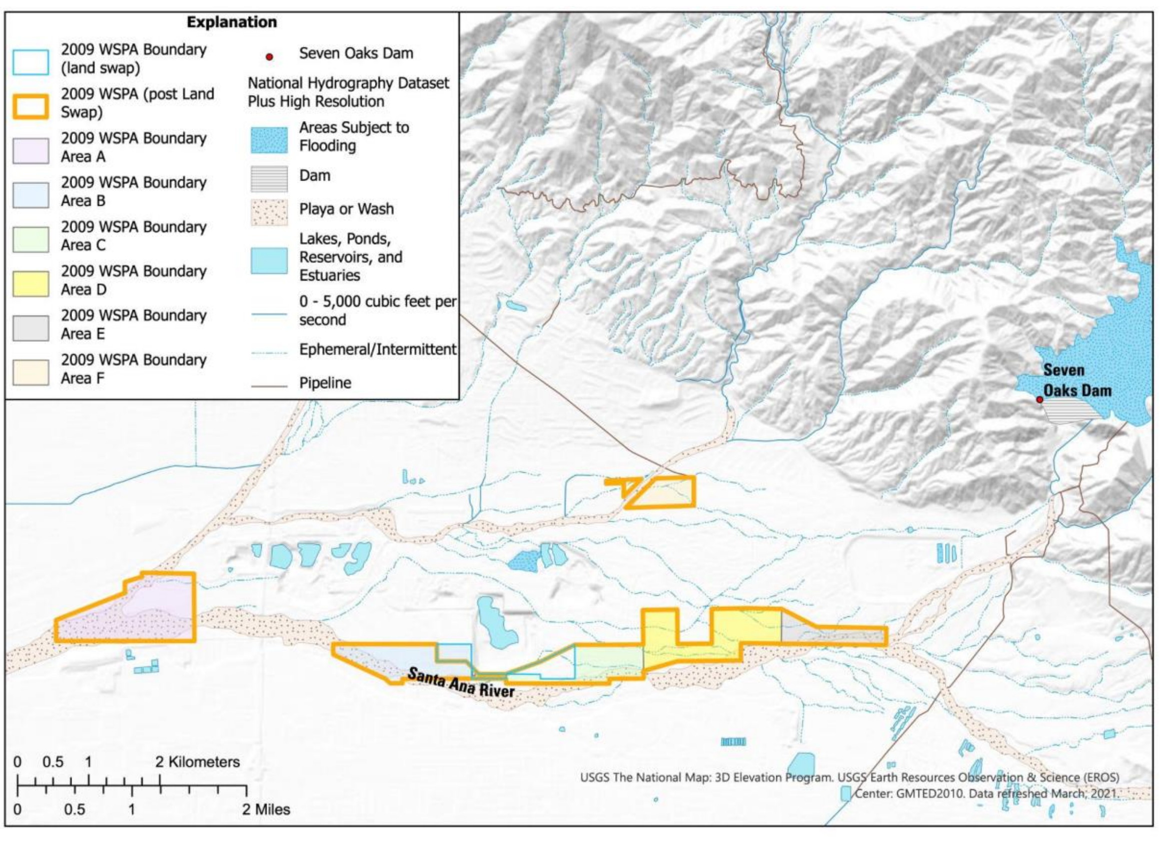

Figure 2-9. The Santa Ana River Woolly Star Preserve Area.

2.5.2 Water Quality

After construction of Seven Oaks Dam, water agencies that treat water released from the dam for delivery as potable water reported changes in water quality. A report from Camp Dresser & McKee (2005) indicates that the quality of water entering treatment plants downstream of the dam deteriorated with respect to turbidity and other constituents including overall organic content, algal blooms, iron, and manganese.

The USACE Engineer Research and Development Center (ERDC) conducted water quality studies related to this issue. ERDC produced a series of interim reports, including *Water Quality in Seven Oaks Reservoir and Influences on Receiving Waters of the Santa Ana River, California*

(ERDC 2011). This report monitored water quality during a year when flood water was purposefully held in order to test dam functionality during a high-flow release. The report states:

> *The Seven Oaks Dam [SOD] flood control project on the Santa Ana River has unavoidably altered the hydrology and water quality of the river. Turbid storm water that used to pass downstream in a matter of days, with destructive effects downstream, is now retained for several weeks or months in the SOD reservoir pool before being released in accordance with an established regulation schedule. The overall effect of impounding flood water by SOD is to remove (by settling) a large fraction of the flood-related sediment (and associated material) that enters the pool from upstream. Because the project attenuates the peaks of flood discharges and traps sediment, the total mass of material and turbidity transported downstream of the impoundment is greatly reduced. This is particularly evident when comparing reservoir discharges to historic peak flood levels. However, as a tradeoff, turbidity in the downstream release may be elevated above low-flow, background levels for extended periods (e.g., weeks) after a flood. The dam and its pool of impounded river water also create an opportunity for biological processes in the impounded water to process (biochemically transform) organic matter and nutrients associated with the flood waters, and to create chemical conditions that mobilize undesirable constituents from the bottom sediments of the reservoir. However, none of these effects or processes had been quantitatively evaluated in SOD prior to 2006 and therefore, to better identify and quantify the various potential effects on water quality of the SOD impoundment and to explore possible approaches to improve downstream water quality at SOD, staff of the ERDC in 2006 began collecting water quality field data in collaboration with San Bernardino County Flood Control Staff and conducted numeric model simulations of water quality in the SOD system.*

USACE's Los Angeles District also investigated water quality issues and published a draft report titled Post-authorization Change Report, Santa Ana River Mainstem Project, Seven Oaks Dam Water Quality Study, San Bernardino County, California (USACE 2010). The purpose of the report was "to investigate any post-construction water quality issues related to the construction of Seven Oaks Dam." The report also evaluates alternatives and presented a Tentatively Selected Plan. The Tentatively Selected Plan in the draft report was modification of the Water Control Plan to eliminate the "full-time" debris pool during the flood season. The work to complete the interim report was not conducted and no changes were made to the Water Control Plan.

The EIR for San Bernardino Valley and Western Water's Santa Ana River Water Rights Application also discusses the water quality issue (San Bernardino Valley Municipal Water District & Western Municipal Water District 2007). The EIR states:

> *The quality of water impounded in the Debris Pool for flood control was impaired during the summer of 2004 by the development of anaerobic conditions. Water impounded in the reservoir for flood control purposes in 2005 contained high levels of suspended solids and was unsuitable for use.*

The State Water Resources Control Board issued water rights permits to San Bernardino Valley and Western Water to recharge water in the Santa Ana River below Seven Oaks Dam and to store up to 50,000 ac-ft of water in the reservoir. The permits issued by the board include the following terms:

- To prevent degradation of the quality of water released to the Santa Ana River from storage at Seven Oaks Dam, the board may modify the permits to set conditions that apply water quality objectives to any release from storage.
- No water shall be released from storage of Seven Oaks Dam for re-diversion by the permittee until the permittee has consulted with the Chief Deputy Director for Water Quality or their delegate and the Chief Deputy Director has determined that the releases will be consistent with applicable water quality objectives. The releases shall be consistent with any conditions the Chief Deputy Director determines are necessary to ensure compliance with applicable water quality objectives.

2.5.3 Habitat Restoration and Conservation

The Western Riverside County Multiple Species Natural Community Conservation Plan and Habitat Conservation Plan (WRC MSHCP), a comprehensive regional natural community conservation plan/habitat conservation plan, was adopted in June 2003. The WRC MSHCP provides mitigation for future county projects, particularly transportation and development projects in the covered area of western Riverside County. There are 146 covered species in the WRC MSHCP, including the four covered by the 2002 BO.

USFWS permitted the Upper Santa Ana River Wash HCP in 2020. This plan has a planning area of 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, and SBKR, among others.

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

The Upper Santa Ana River Habitat Conservation Plan (Upper SAR HCP), which encompasses about 862,966 acres in San Bernardino and Riverside Counties, is currently being developed to protect, enhance, and restore habitat, while streamlining Federal Endangered Species Act permitting for water resource management projects at a regional scale. Covered activities under this plan include diversions for groundwater recharge, water infrastructure development, and flood control. The Upper SAR HCP covers 20 species, including the four covered by the 2002 BO.

All three habitat conservation plans (shown in **Figure 2-10**) have, or will have, restoration projects and monitoring programs intended to track metrics related to restoration success, relevant geophysical processes, and covered species.

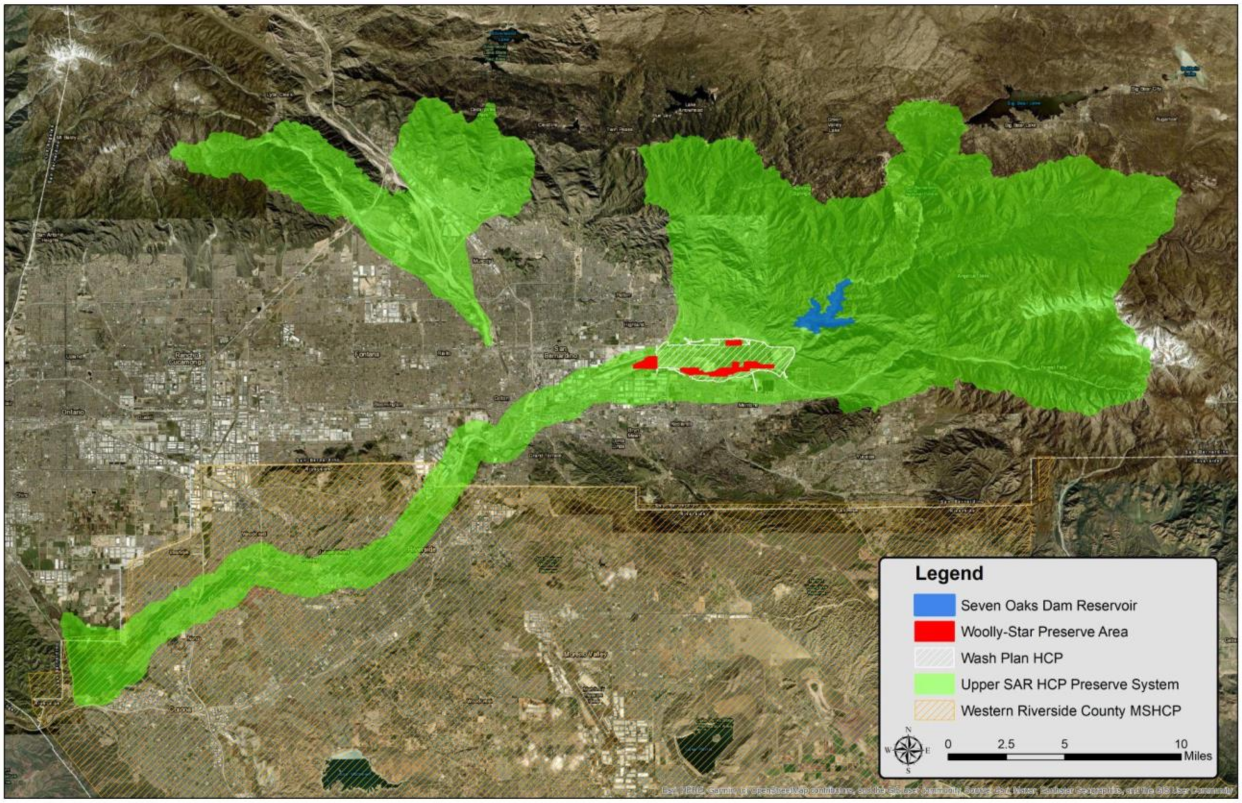

Figure 2-10. *Habitat conservation plans relevant to FIRO at Seven Oaks Dam. (Credit: San Bernardino Valley.)*

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Section 3. Preliminary Technical Studies Plan

The Forecast Informed Reservoir Operations (FIRO) concept fundamentally requires an understanding of forecast skill as it relates to reservoir operations at Seven Oaks Dam. The overarching goal of the preliminary technical studies is to understand the role of atmospheric reiver (AR) storms impacting Santa Ana River watershed. The results of these studies will be important to understanding forecast errors and being able to forecast extreme precipitation events and their impact on runoff within the Seven Oaks Dam watershed. This evolution of forecast errors will motivate future work targeted at minimizing these errors, and hence improve forecast skill. In addition, results will further the understanding of how ARs contribute to projected changes in precipitation frequency at the Santa Ana River watershed under the "business-as-usual" climate change scenario. As water managers adapt to climate change, it is important that they gain insights into how the effects of climate change may manifest as event occurrences within the Santa Ana River watershed. The preliminary technical studies will be complete in October 2024. Sections 3.1 and 3.2 briefly describe the methodology and preliminary results of these studies.

3.1 Extreme Precipitation Events and Their Impact on Runoff

Preliminary technical studies related to extreme precipitation events in the Seven Oaks basin will seek to evaluate the storm characteristics responsible for variability in forecast error. These characteristics can drive variability in and impact on streamflow and runoff in the basin. Studies of storm characteristics were divided into two categories: to better understand both the processes associated with extreme precipitation and its forecast skill (Section 3.1.1), and to analyze freezing level uncertainty and its forecast skill (Section 3.1.2).

3.1.1 Better Understand Extreme Precipitation and Forecast Skill

In order to better understand extreme precipitation and its forecast skill, the FIRO team aims to utilize a dataset developed for the Santa Ana River watershed containing data spanning watershed mean areal values of quantitative precipitation forecasts (QPF), quantitative precipitation estimates (QPE), and the near-coastal characteristics of landfalling ARs. After confirming a strong correlation between the precipitation over the upper portion of the Santa Ana River watershed containing the Seven Oaks catchment compared to the mean areal precipitation (MAP) for the entire basin (**Figure 3-1**), a methodology was constructed to identify AR-related storms during water years 2012–2022 that featured large cool-season (i.e., October–April) QPF errors at several lead times during landfalling ARs (**Figure 3-2**).

The dates associated with storms that were forecast as too wet or too dry as a function of lead time were analyzed to find 23 storms that were incorrectly forecast in three or more lead times, as shown in **Figure 3-2**. The FIRO team plans to next assess the characteristics of these 23 storms to determine processes that influenced the relatively poor forecast skill. In the following list of three items to be investigated for these storms, both (1) and (2) have experienced significant progress over the last decade, with (3) remaining for additional study through the period of performance:

1. Landfalling AR characteristics, including intensity, duration, and orientation relative to terrain features.

2. Small-scale features responsible for spatial and/or temporal variability in precipitation and its prediction, such as narrow cold frontal rainbands or convection.

3. Large-scale features responsible for spatial and/or temporal variability in precipitation and its prediction related to landfalling ARs, such as intensity, duration, and landfall location.

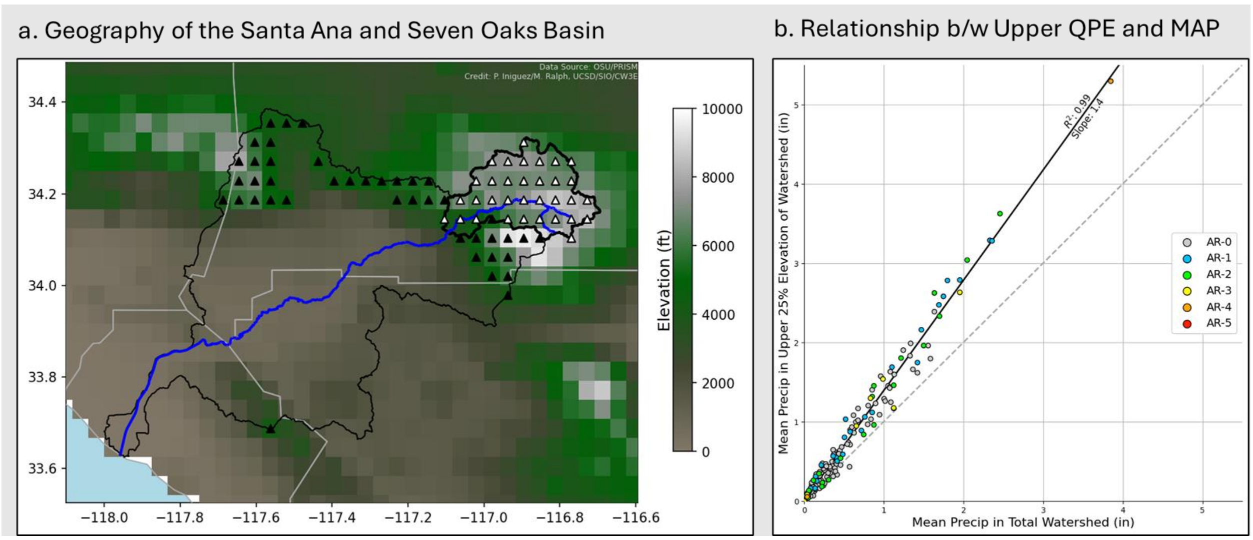

***Figure 3-1**. Left: Panel (a) shows the geography of the Santa Ana (thin black line) and Seven Oaks (thick black line) basins with topography shaded at the 4-kilometer grid resolution. The grids in the upper 25 percent elevation of the Santa Ana basin are black and white triangles, whereas the grids in the Seven Oaks basin are white triangles. Right: The relationship between the MAP for the entire Santa Ana basin as compared to the upper 25 percent elevation is shown in panel (b) with a correlation (r^2) of 0.99.*

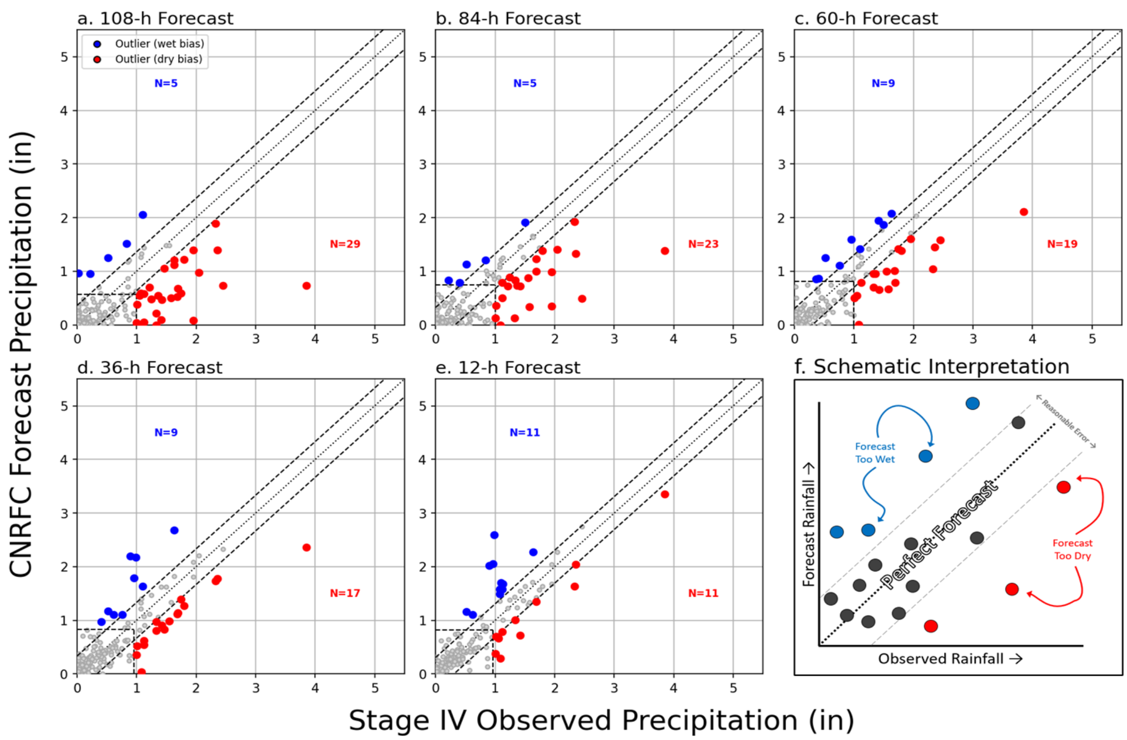

***Figure 3-2**. Comparison of the California Nevada River Forecast Center (CNRFC) precipitation forecast (in; y-axis) with the observed Stage IV precipitation (in; x-axis) as a function of lead time (a) 108 hours through (e) 12 hours. Blue circles represent forecasts that were too wet relative to a "reasonable margin of error" and red circles represent forecasts that were too dry as depicted by the schematic interpretation in panel (f). The reasonable margin of error was an 80 percent confidence interval relative to overall QPF bias.*

3.1.2 Better Understand Freezing Level Uncertainty and Its Forecast Skill

Freezing level uncertainty within a watershed is often associated with uncertainty in expected runoff generation rates when the precipitation is falling as rain or snow. When more of the watershed is exposed to freezing temperatures, the resulting snow often has a slower runoff generation response. In turn, the timelines associated with reservoir fill can be impacted due to different runoff volumes occurring at different rates (e.g., Sumargo et al. 2021). This task aims to support the investigations of forecasted freezing level uncertainty as it pertains to runoff generation.

Figure 3-3 below shows the relationship between freezing level distributions and the Seven Oaks basin elevation distribution over an 11-year period of record using CNRFC gridded observations and forecasts. During periods of precipitation near Seven Oaks Dam, the freezing level (i.e., 0 °C isotherm height) spans 450 meters to 3,900 meters. This range exceeds the minimum and maximum elevations found in the Seven Oaks basin, indicating that freezing level can impact all extents of the basin. More importantly, over half the time when precipitation is falling near Seven Oaks Dam, 75 percent of the watershed is exposed to freezing temperatures. In other words, freezing level often impacts most of the basin during precipitation events. This analysis indicates that freezing level is a key meteorological factor for Seven Oaks and should be investigated for its impact on precipitation partitioning and reservoir volume generation.

Using freezing level forecasts to identify the amount of water volume falling as snow versus rain is another key aspect of the technical studies effort. Gridded precipitation totals can be converted into total water volume falling within the basin and compared to water only falling within the area of basin above the freezing level elevation. Figure 3-4 (left) shows an example of the comparison between the observed 24-hour total precipitation volume within the Seven Oaks basin and precipitation falling within the bounds of the observed freezing level elevation valid at 00Z 2021-12-29. This analysis assumes all precipitation falling above the freezing level is snow. The total basin volume is approximately 2,300 acre-feet (ac-ft) and 75.7 percent of the total volume is falling at an elevation higher than the freezing level. A large ensemble regional forecast model can also show the 24-hour forecast variability of the daily basin volume and the fraction of volume above the freezing level to quantify the uncertainty in the volume partitioning.

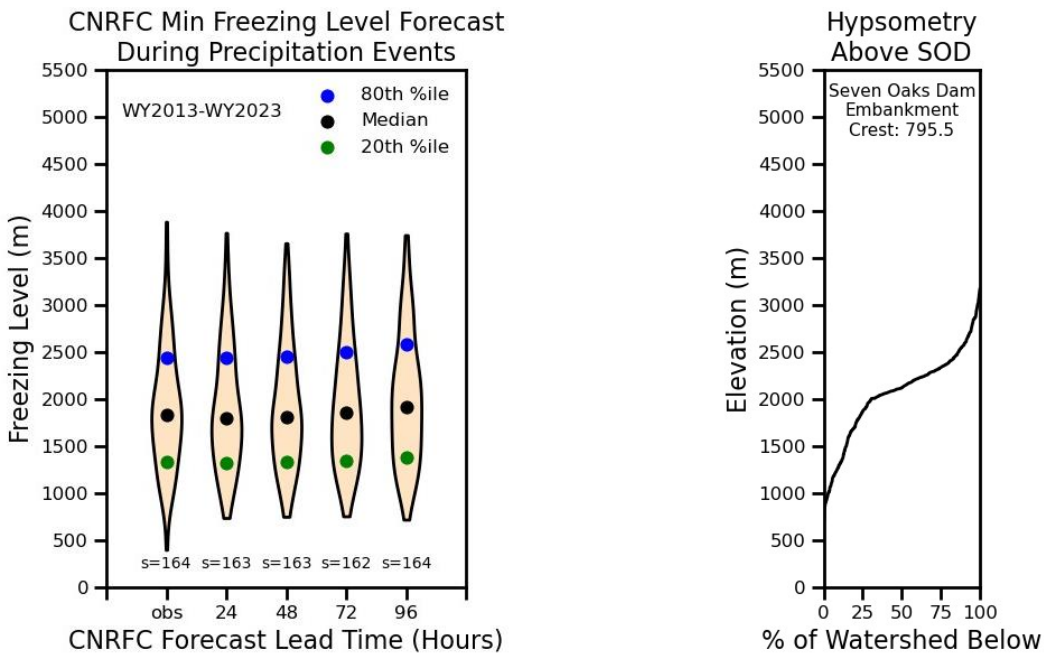

***Figure 3-3**. Left: Distributions of freezing level (i.e., 0 °C isotherm heights) using CNRFC gridded observations and forecasts at lead times of 24, 48, 72, and 96 hours using data between 2013–2023 at times when precipitation was falling near Seven Oaks Dam. The yellow shaded area represents the density of the freezing level distribution where the height of the edges represents the minima and maxima, respectively. The blue dot corresponds to the 80th percentile value of the distribution, the black dot to the 50th percentile (i.e., median), and the green dot to the 20th percentile value of the distribution. Right: Elevation hypsometry above Seven Oaks Dam. The height of the dam embankment is given in the upper corner of the plot.*

The right panel of **Figure 3-4** below shows that the 200 different ensemble 24-hour forecasts from the Center for Western Weather and Water Extremes' (CW3E's) Western Weather Research and Forecasting (West-WRF) ensemble was predicting total basin volumes between 1,000 and 6,000 ac-ft, with the vast majority (72–89 percent) of that precipitation volume falling above the freezing level elevation. The FIRO team will continue to evaluate this metric for robustness and analyze if freezing level forecasts depend on volume partitioning. In addition, the FIRO team will also utilize alternative observations to the CNRFC, namely the vertical profiling radar data that estimate the rain-snow elevation and quantify the difference between the observation types.

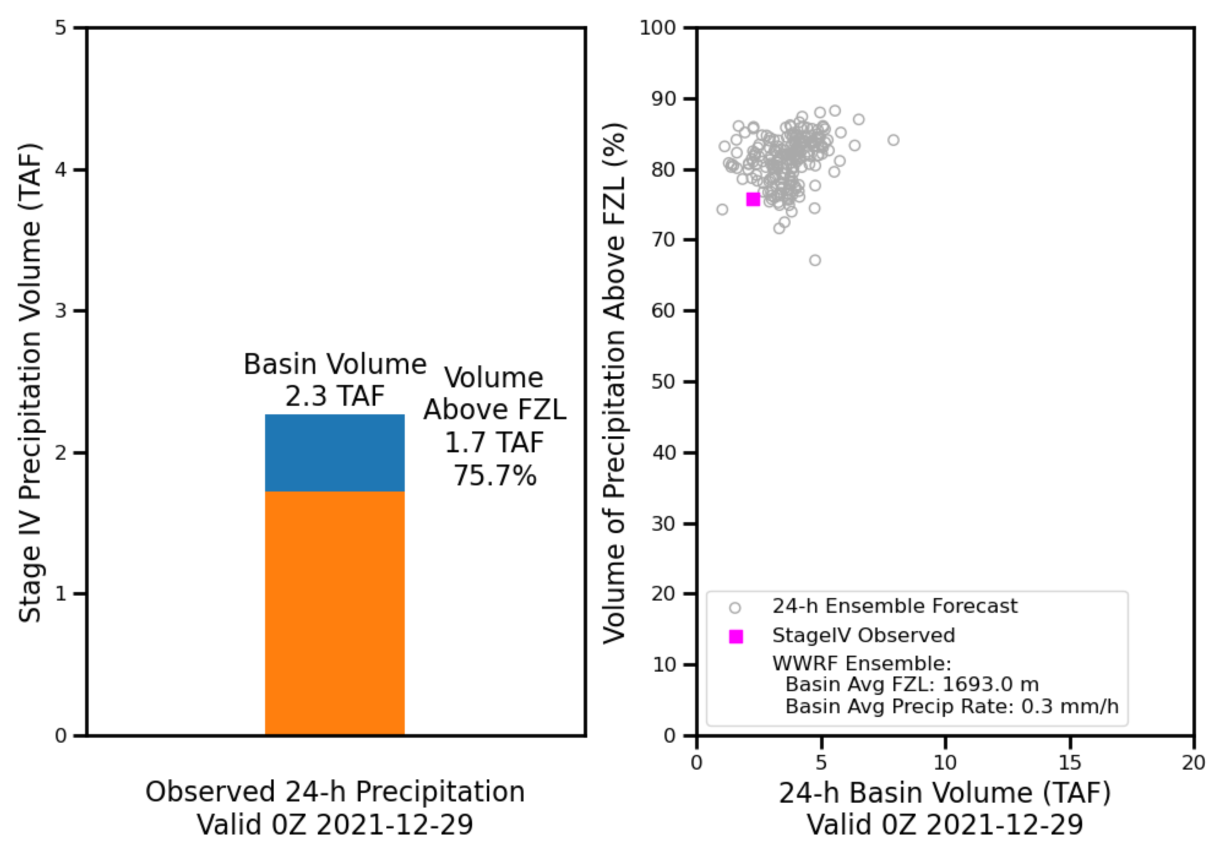

Figure 3-4. *Left: Observed basin 24-hour total precipitation volume within the Seven Oaks basin (height of blue bar) and precipitation that falling within the bounds of the observed freezing level elevation (height of orange bar) valid at 00Z 2021-12-29. The percentage of the volume falling above the freezing level elevation is given in the inset as FZL. Right: Scatter plot of the daily basin volume (thousands of ac-ft) versus the percent of volume above the freezing level using observations (pink square) and 24-hour forecasts from CW3E's 200-member West-WRF ensemble (gray circles).*

The technical studies on freezing level forecast skill and uncertainty will continue to address and investigate:

1. Variability in observed volume partitioning across several case studies of ARs impacting the Seven Oaks basin.
2. How to identify freezing level variability and skill across case studies using ensembles.
3. Differences between measures to quantify the rain-snow elevation (i.e., differences between 0°C isotherm and observations made by vertical profiling radars).

3.1.3 Assessment of Existing Meteorological and Hydrological Observation Sites

Observations are a critical component to forecast verification, model evaluation, and in situ decision support tools to support FIRO objectives. Reliable and accurate observations available in near real-time are required to support these efforts. To better understand the spatial distribution, temporal coverage, and reliability of existing observations in the network, the observations team aims to conduct an observations network analysis. As of this writing, the Seven Oaks basin has few active monitoring stations.

The network analysis for this study will focus on observation types most relevant to FIRO objectives. For the watershed above Seven Oaks Dam, the network analysis will include precipitation amount, precipitation phase, snow depth and snow water equivalent, soil moisture, and discharge. The observations team will compile an inventory of all active and online stations measuring the observation types of interest from MesoWest and the California Data Exchange Center and include notes on inactive or discontinued stations. In addition to summarizing station metadata, the team will conduct a spatial cluster analysis of watershed characteristics, including elevation, slope, aspect, climatological precipitation (from PRISM), and land use. The spatial cluster analysis uses K-means clustering to classify different areas of the watershed based on relevant watershed characteristics. The number and type of monitoring stations in each cluster will help identify under-represented regions or characteristics of the watershed. The team will also evaluate the elevation distribution of monitoring stations relative to the hypsometry of the basin to ensure monitoring station coverage is proportional to the distribution of elevations in the basin. Data quality and reliability are a significant consideration for how well the monitoring network represents the landscape.

To assess the quality of the current observations network, the team will use a select number of precipitation events to determine monitoring station reliability, availability, and data quality during events with different precipitation amounts and phases. Data quality and reliability will also be cross-referenced with forecast verification analyses for areas with the largest precipitation forecast errors and freezing level forecast errors. These analyses aim to identify strengths and weaknesses of the existing monitoring network, particularly how well the network can support FIRO goals. The results can then inform where additional observations are needed, what types of observations are needed, and suggestions to improve existing monitoring stations.

3.1.4 Key Findings and Summary

Key Findings

- Thirty-six storms were identified that contained large forecast errors across multiple lead times during water years 2012–2022.
- Freezing level has often impacted most of the Seven Oaks basin during precipitation events over the last 11 years.
- Ensemble forecasts can be used to quantify the uncertainty in predicted partitioning of the precipitation volume between totals of rain versus snow.
- Limited observations of relevant snow, soil, and discharge measurements are available in the watershed.

Summary:

- Methods have been developed to analyze precipitation forecast skill for events over the Seven Oaks basin.
- The FIRO team will explore landfalling AR and precipitation characteristics, terrain blocking, and upstream storm evolution in more detail to identify the sources of forecast error.
- Methods have been developed to quantify the partitioning of precipitation volume between totals of rain versus snow to account for potential runoff into Seven Oaks.

3.2 Projected Changes in Precipitation Frequency Under the "Business-as-Usual" Climate Change Scenario

3.2.1 Data

3.2.1.1 Historical Observations:

Daily precipitation totals from rain gauges (Menne et al. 2012) are interpolated to a 6-by-6-kilometer grid (Pierce et al. 2021) across the entire conterminous United States in a manner that respects topography and daily volatility. The FIRO team considers the observations to be reliable from the year 1948 onwards.

3.2.1.2 Downscaled Model Output:

Statistical downscaling of the most recent generation of global climate models, CMIP6, has recently been completed for three climate change scenarios: shared socioeconomic pathway (SSP) 245 (moderate anthropogenic forcing), SSP 370 (moderate to high anthropogenic forcing), and SSP 585 (high anthropogenic forcing). There are 27 models, some with up to 10 realizations in each scenario. Model runs are about 150 years spanning the years 1950–2100 (Pierce et al. 2023).

3.2.2 Methods

For most analysis, the FIRO team will aggregate over the Santa Ana River watershed by averaging over the 6-by-6-kilometer grid cells, which are at least partially contained by the Santa Ana River watershed, according to the tributary area spatial extent selection method of the Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections download page.

3.2.2.1 Traditional Peaks-Over-Threshold (PoT) Extreme Value Analysis

The probability distribution of daily precipitation on days with heavy precipitation (those above the locally determined 75th percentile of nonzero precipitation) will be reviewed in terms of a standard PoT analysis (Coles 2001). In the study region, daily precipitation is volatile as described in Kozubowski et al. 2008: exceedance probabilities of large values decay with a power law (i.e., heavy) tail, so large "outliers" are common.

3.2.2.2 Holistic Extreme Event Analysis

The FIRO team will extend traditional PoT analysis to consider precipitation events of random durations, as described in (Weyant et al., in preparation). "Precipitation events" are runs of consecutive time steps—in this case, days—in which heavy precipitation is observed. The team will summarize these events in terms of their duration, maximum daily intensity, and total accumulation. A trivariate probability distribution with four parameters is fit to these event summaries.

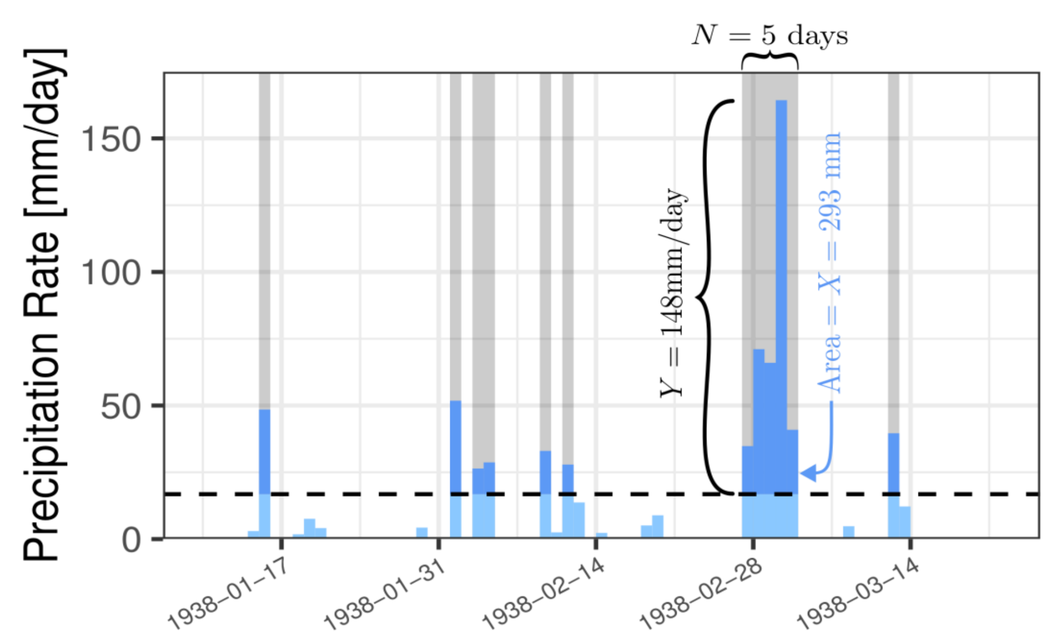

Figure 3-5. *Schematic showing how precipitation events are defined and identified in a series of daily precipitation accumulations at San Gabriel Canyon Pumphouse, California. Accumulations above a threshold are shown in dark blue. Seven separate events are visible, each with its own duration (width of gray shaded region), maximum intensity (maximum height of dark blue region), and magnitude (area of the dark blue region). (Credit: Weyant et al., in preparation.)*

3.2.3 A First Look at Projections

The effects of climate change may manifest as a change in the frequency of event occurrences and/or changes in any of the four parameters of the trivariate distribution. Figure **3-6** below shows the inconclusive results from our first-look projections, which utilized previous generation LOCA-downscaled climate models (CMIP5) with only a single realization of each model downscaled.

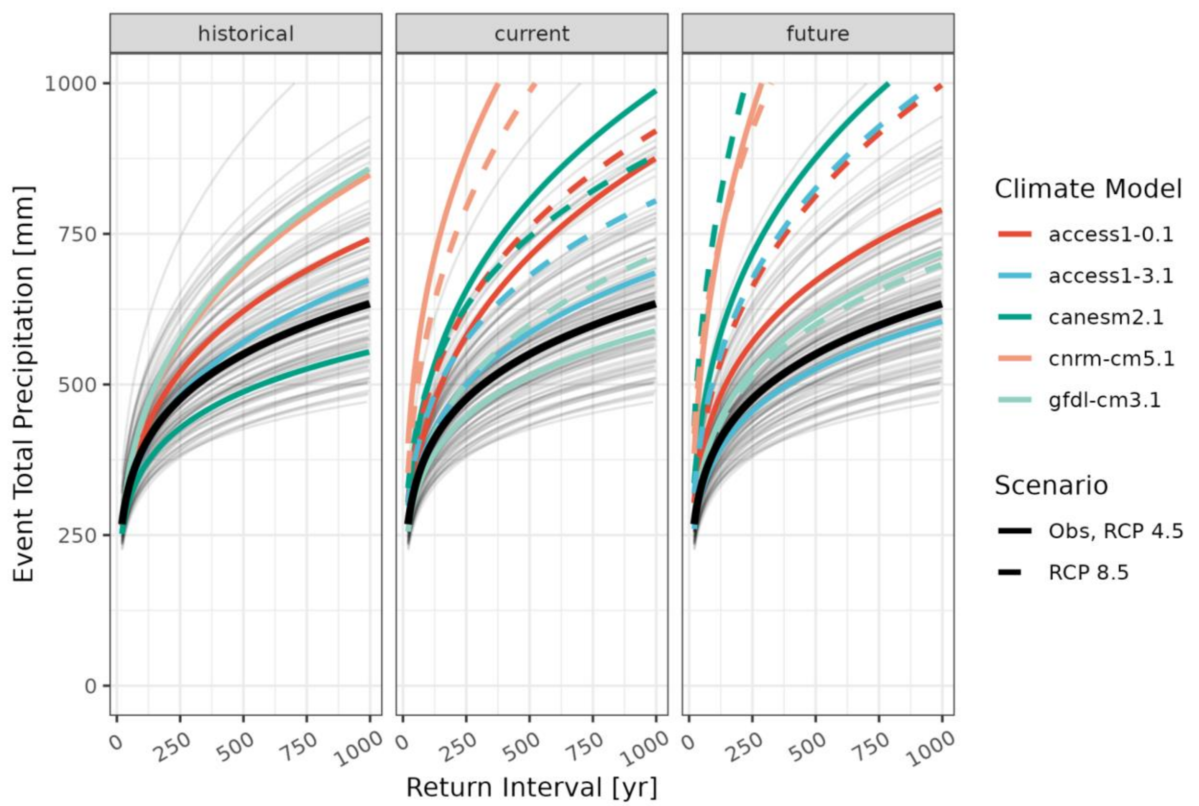

Figure 3-6. *Return levels of event total precipitation estimated from observations and five CMIP5 models, selected for their ability to realistically simulate ARs (Gershunov et al. 2019). Estimates are based on maximum likelihood estimation of the parameters of the trivariate event distribution (Weyant et al., unpublished), and panels show 50-year periods over which parameters are estimated: historical (1950, 1999), current (2000, 2049), and future (2050, 2099). Two emissions scenarios, representative concentration pathway (RCP) 4.5 and RCP 8.5, are compared to observations from the historical period. Sampling uncertainty in the observations is shown in the gray curves, which are the result of bootstrapping (i.e., sampling with replacement) the events, then re-estimating the parameters of the trivariate distribution 500 times. In this study, the FIRO team used atmospheric models (ACCESS1-0.1, ACCESS1-3.1, CANESM2.1, CNRM-CM5.1 and GFDL-CM3.1) to develop additional climate simulations to provide an ensemble of model runs on future climates under different scenarios.*

Running the downscaled CMIP6 ensemble will provide a clearer look at the actual signal within each model. To reiterate, the key difference between this analysis and the previous analysis is the use of the small ensemble of each model, which was previously unavailable. Using new and more sophisticated methods is also possible. Work by the FIRO team's statistician colleagues is well underway to develop a generalized linear model of these parameters (a nontrivial problem), which will help better explain any local changes in terms of larger-scale phenomena (such as El Niño–Southern Oscillation).

3.2.4 Preliminary Results

The LOCA-downscaled CMIP5 model runs of the historical period provide a reasonable description of precipitation events. Durations of model runs of days with heavy precipitation as well as totals over these runs are reasonable and well within the envelope of uncertainty gleaned from observations. However, there is only one downscaled realization of each CMIP5 model run for each emissions scenario, and Figure 3-6 shows that the presence or magnitude of projected changes vary too much for the FIRO team to draw conclusions. In addition, the drastic changes in the frequency of massive precipitation event totals projected by climate models CNRM-CM5.1 and CANESM2.1 are concerning. Furthermore, the level of forcing (i.e., the severity of the emissions scenario) does not always correspond to a stronger response. A small sample has not given clear results, so the next step is to look at an ensemble of similarly downscaled CMIP6 model projections.

3.2.5 Key Findings and Immediate Next Steps

Key Findings

- Downscaled CMIP5 historical simulations reasonably describe the probability distribution of multiday precipitation events.
- Projections from the same models do not all seem reasonable, there is not a convincing monotonic relationship between forcing strength, and response magnitude is lacking.

Immediate Next Steps

- Look at a downscaled CMIP6 ensemble in the same manner.
- Construct a statistical model of the trivariate event distribution parameters to gain more information from the small ensemble (if theoretical development within the project period allows).

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Section 4. Preliminary Viability Assessment Scoping

The objective of the Preliminary Viability Assessment (PVA) is to conduct technical studies that describe meteorological, hydrological, water resource engineering, and environmental work, as well as develop enhanced monitoring, decision support tools, and communication materials for the U.S. Army Corps of Engineers (USACE) and water agency partners to consider using for Forecast Informed Reservoir Operations (FIRO) testing and operationalization. This section develops key questions and recommended tasks for the Preliminary Viability Assessment (PVA), with the expected outcome of producing sufficient analyses and supporting documentation to assist with a deviation request to the local sponsors and USACE to implement FIRO at Seven Oaks Dam.

4.1 Observations

4.1.1 Context

The watershed above Seven Oaks Dam encompasses an elevation range of 2150 - 11240 feet. The mountainous terrain creates high gradients in precipitation amount and precipitation phase that is difficult to monitor with the observations available in the watershed. Observations are a critical component to forecast verification, model evaluation, and in-situ decision support tools to support FIRO objectives. Reliable and accurate observations available in near real-time are required to support these efforts. The main observation types targeted in the Technical Studies include: precipitation amount and phase, snow depth and snow water equivalent, soil moisture, and discharge. Preliminary results of the Technical Studies highlight existing gaps in the observations network including snow, soil, and discharge measurements (**Figure 4-1**). Historically, the watershed included six snow survey locations with periods of record of three to 31 years, all ending operation by the mid-1990s. There are currently no publicly available snow surveys or near real time stations measuring snow depth or snow water equivalent. Additionally, there are no publicly available soil moisture or discharge stations in the watershed. **Figure 4-1** shows the stations available online and in near real time, including a Center for Western Weather and Water Extremes (CW3E) station that measures snow level, precipitation amount, and precipitation phase that was installed as part of FIRO for at Prado Dam.

The results from the observations network analysis are required to understand watershed characteristics currently represented by observations, quality of existing observations, and identify specific gaps to be filled.

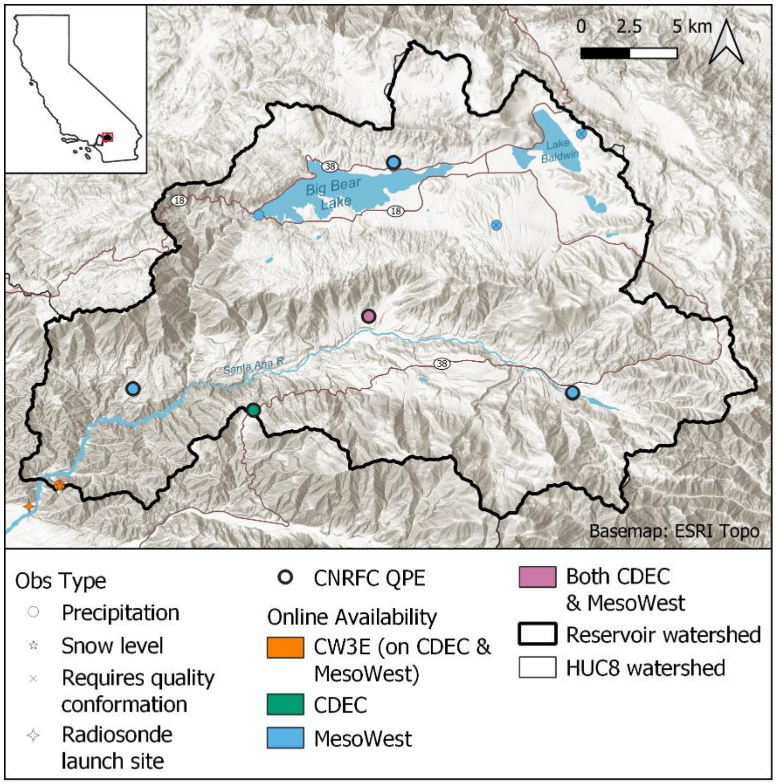

Figure 4-1. *Map of existing stations in the Santa Ana River watershed above Seven Oaks Dam. Symbols represent observations type and status, while colors show where the data are available online. Not shown are the reservoir storage observations at Big Bear Lake and Seven Oaks Dam and monthly precipitation measurements from Big Bear Lake.*

Watershed characteristics considered in the observations network analysis include elevation, slope, aspect, climatological precipitation (from PRISM), and land use. As discussed in Section 0, the FIRO team will use these inputs in a spatial cluster analysis to classify different areas of the watershed and summarize what characteristics the current observations represent. The team will assess data quality and reliability for a select number of precipitation events and will cross-reference the data with forecast verification analyses for areas with the largest precipitation and freezing level forecast errors. These analyses are underway as a part of the Technical Studies (see Section 0) and will inform where, what kind, and how many additional observations are needed to address identified gaps.

4.1.2 List of Key Questions and Tasks

The following key questions and tasks will be addressed by the observations section within the PVA:

Key Questions

Based on the gaps identified in the Technical Studies:

- Where will new hydrometeorological observations have the most impact?
- What type of observations (e.g., discharge, soil moisture) are needed to support FIRO goals?
- Are there additional gaps, either in observation type or location, that still need to be addressed?

Recommended Tasks:

1. Scout locations and install two new hydrometeorological stations.
    a. Determine station locations based on gaps identified in the network analysis conducted in partnership with the meteorology and forecast verification teams and operational forecasters. Acquire permits for installation as needed. These stations will include a standard suite of hydrometeorological sensors to measure precipitation, temperature and relative humidity, wind speed and direction, incoming solar radiation, air pressure, and soil moisture and temperature.
    b. Install stations.
    c. Disseminate data in near real-time to partner platforms, including the California Data Exchange Center, MesoWest, and the National Oceanic and Atmospheric Administration (NOAA) Physical Sciences Laboratory.
2. Scout location and install one new enhanced hydrometeorological station.
    a. Determine station locations based on gaps identified in the network analysis and freezing level verification findings, and acquire permits for installation as needed. This station will include a standard suite of hydrometeorological sensors to measure precipitation, temperature and relative humidity, wind speed and direction, incoming solar radiation, air pressure, and soil moisture and temperature, as well as a disdrometer to measure hydrometeor drop size and velocity to derive precipitation phase.
    b. Install station.
    c. Disseminate data in near real-time to partner platforms, including the California Data Exchange Center, MesoWest, and the NOAA Physical Sciences Laboratory.
3. Scout location and install one new discharge station.
    a. Determine station location based on gaps identified in network the analysis and acquire permits for installation as needed. This station will include pressure transducers to measure river stage and will require manual discharge measurements to establish a rating curve to derive discharge.
    b. Install station.
    c. Survey stream channel for developing rating curve.
    d. Create a sampling plan for manual discharge measurements to develop the rating curve.
4. Report on gaps filled and summarize remaining gaps in the observations network.
5. Engage with forecast verification and meteorology work teams to align available observations with model evaluations and storm characteristics.

4.1.3 Expected Outcomes

The observations section of the PVA aims to fill identified gaps in the observation network to better represent watershed characteristics and hydrometeorological conditions with reliable, near real-time monitoring stations. Filling key gaps in observations will support efforts undertaken by the meteorology and forecast verification work teams by providing additional hydrometeorological data along with data not previously available within the watershed such as soil moisture and soil temperature. Data from these stations will be leveraged for multiple sections of the Final Viability Assessment (FVA) to report on preliminary data collected and provide additional data for forecast verification and meteorology. Longer term, the period of record for these stations will help better represent the climatology of the watershed and provide valuable information for decision support and situational awareness.

The Technical Studies and PVA will inform additional observations or areas of interest that might be initially out of scope but will inform future observational needs. These needs can be addressed in the FVA or as post-FIRO activities to continue expanding and improving the observation network.

4.2 Meteorology

4.2.1 Introduction

Southern California precipitation depends on a relatively small number of extreme events each year. For example, 42 percent of the annual precipitation falls on days with extreme precipitation (defined as the top 5 percent of wet days), and 50 percent of the annual precipitation falls on average in just seven days in the Santa Ana River watershed (Ricciotti and Cordeira 2020). Landfalling ARs in Southern California are responsible for approximately two-thirds of these extreme precipitation events, with the remaining precipitation related to other processes such as cutoff cyclones and convection storms (i.e., severe thunderstorms) (Cannon et al. 2018).

The overarching goal of the meteorology effort is to identify the physical processes associated with precipitation extremes across the upper portion of the Santa Ana River watershed, and to evaluate their predictability to help understand the potential viability of FIRO in the Seven Oaks Reservoir. This section is related to Section 4.4 on Forecast Verification.

4.2.2 Precipitation Extremes and ARs

4.2.2.1 Background

Landfalling ARs are important to both annual and extreme precipitation in the Santa Ana River watershed (Cannon et al. 2018, Ricciotti and Cordeira 2020, Ralph et al. 2024). The purpose of these tasks is to further summarize the relationships among landfalling ARs and extreme precipitation, specifically over the upper portion of the Santa Ana River watershed in the Seven Oaks basin, as well as to evaluate the AR-related and non-AR-related forecast skill for precipitation events over the basin.

In addition to climatological analyses of the influence of ARs and non-ARs on extreme precipitation events and their skill over a long period of record, additional tasks will investigate case studies of high-impact events that contained large amounts of precipitation (i.e., inflow), including events with forecast errors. These analyses will leverage in situ observations collected by the CW3E field team and other local data.

4.2.2.2 Key Questions and Tasks

The following key questions related to precipitation extremes and ARs will be addressed by the meteorology team in coordination with the forecast verification team, as part of the PVA:

- What fraction of extreme precipitation events over the Seven Oaks basin is associated with landfalling ARs?
- What meteorological processes influence spatial and temporal variability in precipitation during landfalling ARs or other non-AR events?
- How does the precipitation forecast skill differ between AR-related and non-AR-related events over the Seven Oaks basin?
- What meteorological processes produce challenges to precipitation forecast skill during extreme events?
- How do in situ observations help scientific understanding and model validation of extreme precipitation events?

The following tasks will be conducted by the meteorology team during the PVA:

1. Create and summarize an hourly, event-based catalog of precipitation events for the Seven Oaks basin.
2. Create and summarize both a coastal and inland catalog of landfalling ARs based on the Ralph et al. (2019) AR scale for the Seven Oaks basin.
3. Evaluate and summarize relationships between precipitation extremes and landfalling ARs using the precipitation and AR catalogs.
4. Quantify and summarize precipitation forecast skill as a function of lead time for AR-related and non-AR-related precipitation events over the Seven Oaks basin using a re-forecast dataset.
5. Investigate meteorology processes responsible for non-AR-related precipitation events such as cutoff cyclones or convection.
6. Conduct case studies of high-impact events to the Seven Oaks basin—including at least one AR-related and one non-AR-related event that contained low precipitation forecast skill—by leveraging in situ observations.

4.2.2.3 Expected Outcomes

The tasks investigating the physical processes responsible for extreme precipitation and their influence on precipitation forecast skill over the Seven Oaks basin, specifically related to both landfalling ARs and other drivers, will provide context for evaluating the predictability of large inflow and streamflow events into the Seven Oaks Reservoir.

4.3 Hydrology

4.3.1 Context

The hydrology task primarily focuses on meeting the data and informational requirements of the Water Resources Engineering (WRE) task. For this project, the hydrology team will review and assess the current streamflow modeling implemented by the California Nevada River Forecast Center (CNRFC) and make recommendations for improvements where appropriate.

They hydrology task primarily focuses on meeting the data and information requirements of the WRE analysis of alternative Water Control Plans that leverage streamflow forecasts.

4.3.2 Tasks

1. **Team charter and collaboration with other work teams.** The hydrology team will develop a team charter with specific tasks as described below. They will collaborate significantly with the WRE team to ensure the work products effectively meet the WRE team's requirements for the PVA.
2. **Historical observations of inflow.** Diversions and water use upstream of Seven Oaks Dam impact inflows and can compromise the quality of the calibrated streamflow model if not properly accounted for. The hydrology team will ensure the historical inflow records used in PVA analyses are well understood and provide the best possible representation of "unimpeded" or "full natural flow" conditions.
3. **Review of the CNRFC's Seven Oaks Dam inflow model.** WRE work relies upon the quality of the CNRFC's inflow model for Seven Oaks Dam. As an initial step, the hydrology team will review the ability of the inflow model to simulate historical observations. The team will address and correct identified gaps and deficiencies if feasible within the project timeline.
4. **Critical duration analysis.** The hydrology team will evaluate historical precipitation and streamflow records to estimate the most appropriate critical duration for inflow to Seven Oaks Dam. The critical duration will be used for the frequency analysis and is needed for the scaling of individual large events within the hindcast period of record.
5. **Frequency analysis.** The hydrology team will conduct a frequency analysis for the critical duration to ensure the range of scaling factors used in the hindcast preparation adequately covers the extremes needed for robustness testing (e.g. 500-year, three-day inflow event).
6. **Hydrologic Ensemble Forecast System (HEFS) hindcasts.** The hydrology team will work with the CNRFC to develop the HEFS hindcasts needed for the WRE evaluation of Water Control Plan (WCP) alternatives. To the greatest extent possible, hindcasts will be consistent with the CNRFC's real-time operations so the WRE evaluation results are representative of expected operations. HEFS hindcasts will be generated for:
    a. Period of record (1980–2022).
    b. Scaled events (two to three selected events incrementally scaled to cover 100- to 500-year recurrence intervals.
    c. Synthetic events outside of the HEFS period of record (if available).
7. **Collaboration with other teams.** As stated above, the hydrology team will work closely with the WRE team to ensure delivered products and information meet the defined needs. In collaboration with the verification team (Section 4.4), the hydrology team will assess and document the quality and uncertainty of the CNRFC's Seven Oaks Dam inflow model and collaborate with the observations team (Section 4.1) to ensure that sufficient monitoring supports decision support.

4.3.3 Expected Outcomes

Through the process of performing the tasks identified above, the hydrology team expects to develop substantial insight on the predictability of Seven Oaks Dam inflows and refine the process for delivering analysis and hindcasts to support WRE team tasks.

4.4 Forecast Verification

4.4.1 Introduction

Weather and water forecast verification is paramount to FIRO, where forecast information could be leveraged for water management decisions. Water managers need confidence in the forecast information and context for predicted weather and hydrologic conditions to utilize forecasts to the maximum extent.

The goal of the forecast verification effort is to provide forecast skill analyses for multiple components of the hydrometeorological system impacting operations at Seven Oaks Dam. The evaluation will focus particularly on the scales that dictate the development of meteorological mechanisms responsible for precipitation generation, localized orographic patterns, rain-snow partitioning, and resulting streamflow or inflow into the reservoir. It will also serve as a pathway to identify opportunities for advancing AR prediction, such as physical process identification, model analysis and improvement, and observation quality and spatial distribution.

4.4.2 Baseline Assessment Using Historical Forecast Information for Precipitation and Inflow

4.4.2.1 Context

Long-term forecast skill assessments ultimately provide users with knowledge on how well and at what lead times models can predict different magnitudes and characteristics of extreme events using long periods of data records (typically between 10–30 years). This effort provides a baseline for forecast skill of precipitation and inflow predictions on relevant time scales and spatial bounds associated with operations at Seven Oaks Dam. Ultimately, it serves as the starting point for further partitioning the meteorological and hydrologic characteristics that could affect predictability of precipitation and runoff generation.

4.4.2.2 List of Key Questions and Tasks

The verification team will address the following key questions for long-term forecast skill evaluations as part of the PVA:

- What is the skill of precipitation and inflow forecasts within the Seven Oaks basin?
- What are the relationships between precipitation and inflow forecast skills?

The verification team will conduct the following tasks during the PVA:

- Identify relevant basin information (e.g., regulations, diversions, important tributary locations) to better approximate the operational basin extent.
- Obtain observations of precipitation and inflow for Seven Oaks Reservoir and relevant location information relative to the dam and important tributaries.

- Compute mean areal precipitation forecast skill from archived or re-forecasted global and high-resolution models and determine lead times where there is evidence of skill. Precipitation totals can be examined on sub-daily, daily, and multiday timescales.
- Compute skill of multi-volume totals of inflows into Seven Oaks Reservoir using re-forecasted and archived inflow forecasts generated from (or simulated from a matching configuration of) the CNRFC Hydrologic Modeling System.
- Identify pathways to intercompare links between atmospheric and hydrologic forecast skill.

4.4.2.3 Expected Outcomes

The expected outcome of this effort will be a series of statistical skill measures of precipitation and inflow for Seven Oaks Reservoir using several metrics, models, and aggregation times relevant for operations.

4.4.3 Post-Event Precipitation Verification to Provide Context of Forecast Evolution for Impactful Events

4.4.3.1 Context

Each winter season, ARs can bring considerable rainfall and runoff to the Seven Oaks basin that vary alongside the duration, intensity, position, and life cycle evolution of ARs. Understanding the variability in forecast evolution will allow the verification team to study and rectify how different scales of variability and uncertainty impact the decision-making process and actionable timelines. This understanding is especially important when AR forecasts are highly uncertain (e.g., forecasts of an AR look significantly different from that of the previous day's forecast). When forecasts were particularly challenging, it is important to analyze what components of the forecast were correct and which were highly variable. To provide added value of forecast utility, the verification team will provide post-event and post-season verification statistics of precipitation. These statistics will also guide future science investigations and case study analysis that will ultimately improve understanding of AR predictability and variability.

4.4.3.2 List of Key Questions and Tasks

The following key questions for long-term forecast skill evaluations will be addressed by the verification team as part of the PVA:

1. What were the forecast errors of precipitation of several high-impact events in the Seven Oaks basin?
2. What were the overall seasonal errors of precipitation forecasts in the Seven Oaks basin for the last several years?
3. How do individual AR storms and their forecast errors contribute to the overall seasonal error?

The verification team will conduct the following tasks during the PVA:

- Analyze several water years of seasonal and event-total precipitation errors in the Seven Oaks basin and compute the percentage of seasonal error for each AR occurring during the season.

- Provide list of poorly forecasted (i.e., bust) case studies and their precipitation error tendencies.

4.4.3.3 Expected Outcomes

The expected outcome of this effort will be a report on a series of water year evaluations of precipitation on daily, event, and seasonal time scales. The report will include a quantitative evaluation of the fraction of ARs to the seasonal total error of precipitation, as well as findings on any relevant trends in forecast tendencies.

4.4.4 Identification and Alignment of Storm Characteristics Associated with Forecast Errors

4.4.4.1 Context

Precipitation errors can be influenced by meteorological and hydrological mechanisms that span scales from localized to synoptic in nature. After identifying precipitation error in Section 4.4.3, the verification team will look at key influencing factors potentially affecting the predictability of precipitation and inflow, and their associated skill. Factors include large-scale ones such as landfall, intensity, and duration of ARs, as well as localized influences like freezing level. This section will provide forecast assessments of the key factors provided to the meteorological team for further processing, review, and study.

4.4.4.2 List of Key Questions and Tasks

The following key questions for long-term forecast skill evaluations will be addressed by the verification team as part of the PVA:

1. What is the landfall, intensity, and position forecast skill for ARs making landfall near the Seven Oaks basin?
2. What is the forecast skill of the volume of precipitation falling as rain or snow during key events?
3. What are other scales of factors influencing precipitation and runoff predictability?

The following tasks will be conducted during the PVA:

- Provide assessments of landfall, intensity, and position skill of forecasts for ARs making landfall near the Seven Oaks basin.
- Calculate the forecast skill of volumetric precipitation in areas with sub-freezing temperatures.
- Iterate with the meteorology team to subset the above characteristics to identify related patterns of forecast errors.

4.4.4.3 Expected Outcomes

The expected outcome of this task will include a report that summarizes the characteristics of ARs (and other features) that influence forecast skill over a relevant time period.

4.4.5 Coordination of Verification with Regional Model Development and Forecasting

4.4.5.1 Context

Identifying systematic model forecast errors is a goal of the verification group. Understanding the source of these errors takes coordination with the modeling team to identify unresolved physical processes and/or dynamical features to target for improvement. This task is aimed at building pathways between model development and verification to iterate on findings associated with integrating AR and precipitation predictions and models.

4.4.5.2 List of Key Questions and Tasks

1. What are some key differences between regional and global forecast errors associated with ARs impacting the Seven Oaks basin?
2. What are some pathways for exploring improvements to precipitation and AR forecasting using regional models?

4.4.5.3 Expected Outcomes

The expected outcome from this effort will be identifying priorities for model development based on verification outcomes.

4.5 Water Resources Engineering

4.5.1 Context

The Water Resources Engineering (WRE) task seeks to gain insight toward the rigorous assessment of FIRO for Seven Oaks Dam. The PVA serves as a testing ground where the team learns the complexities of the system and how to effectively and accurately simulate candidate reservoir operations that integrate forecasts into their decision logic. Experience with previous FIRO projects has shown that the lessons learned through the PVA contribute to a significantly better and more robust FVA.

The WRE tasks associated with the PVA are also intentionally "exploratory." While practical considerations are both primary and necessary, there is room to try less conventional and even novel approaches that may not be immediately targeted for a Water Control Manual. This research approach pushes the limits of conventional approaches and provides opportunities to advance the state of the science and practice of reservoir management.

4.5.2 Tasks

4.5.2.1 Organizational Approach: Hydrologic Engineering Management Plan (HEMP).

The WRE team will develop a HEMP to demonstrate FIRO viability at Seven Oaks Dam, in accordance with the process developed by previous FIRO projects. The HEMP will describe both the process and components of the assessment.

The goal of the HEMP is to create an evaluation framework whereby alternative WCPs that use streamflow forecasts can be compared with existing (i.e., baseline) operations as well as each other.

The HEMP will be developed by the WRE team and vetted with the Seven Oaks Dam Steering Committee. The HEMP contains the following sections:

- Objective and overview of technical analysis process.
- WCP alternative requirements, constraints, and considerations.
- WCP alternatives to be evaluated (baseline and FIRO).
- Metrics for evaluating viability and efficiency of alternatives.
- Tasks and subtasks.
- Project delivery team members and their roles.
- Schedule for completion of technical analyses.
- Risks to success.

4.5.2.2 Modeling and Simulations.

A modeling framework will be established to account for how the movement of water affects the operations of Seven Oaks Dam.

4.5.2.3 Water Accounting

As shown in Figure **2-4**, the movement of water associated with Seven Oaks Dam is quite complex. It includes activities within the Seven Oaks Dam watershed and activities below the dam, including imports from the State Water Project. The simulation framework will strive to account for the structure of water movement to the greatest extent feasible. Where detailed data are not available, the WRE team will make reasonable estimations based on well-informed guidance.

4.5.2.4 Reservoir Operations

The WRE team will model reservoir operations for each of the selected FIRO alternatives (and the non-FIRO baseline) through a combination of the USACE Water Management System and research applications (e.g., Ensemble Forecast Operations model). Reservoir operations models will be configured to simulate storage and releases while providing the information needed to quantitatively assess the performance metrics identified in the HEMP. The time step of reservoir operations simulations will be determined during the study. It may be possible to simulate the system at a daily time step, although an hourly time step may be required during flood operations.

4.5.2.5 Groundwater Recharge

Groundwater recharge will be modeled to adequately represent the process's complexities while running efficiently enough to permit extensive simulation (across the record period and scaled events). The WRE team will leverage existing recharge models, such as the Integrated Santa Ana River Model developed by the San Bernardino Valley Municipal Water District. Simulations will represent the envisioned recharge facilities currently under development and construction.

4.5.2.6 Simulation Plan

The WCP alternatives identified in the HEMP will be simulated using water accounting, reservoir operations, and groundwater recharge over a lengthy period of record (~30 years) and for a collection of extreme events representing return intervals up to 500 years (0.002 percent annual probability of exceedance). The WRE team will collect and process the information from the simulations to compute the performance metrics identified in the HEMP.

4.5.2.7 Coupling to Prado Dam Operations

The potential impacts of FIRO at Seven Oaks Dam on the performance of Prado Dam operations are of interest to the Steering Committee. As the WRE team develops the simulation and modeling framework for the PVA, efforts will be made to ensure that Prado Dam operations can be effectively coupled at the appropriate time.

4.5.2.8 Collaboration with Other Teams.

The WRE team will rely upon the hydrology team (see Section 4.3) for the following information:

a. Curated inflow observations that consider water management activities by upstream entities.
   i. Daily time step for the period of record.
   ii. Hourly time step for significant or scaled events.
b. Consensus on the critical duration for reservoir operations.
c. Frequency analysis of reservoir inflows.
d. Potential recalibration of the Seven Oaks Dam inflow model used and provided by the CNRFC.
e. Generation of period of record hindcasts using HEFS.
f. Generation of scaled HEFS hindcasts for alternative testing outside the period of record.
g. Potential generation of synthetic HEFS hindcasts.

The WRE team will rely upon the verification team (see Section 4.4) for the following information:

a. Assessment of CNRFC reservoir inflow simulation modeling. The WRE team will use this modeling to assess the need to recalibrate the inflow model.

The WRE team will collaborate with the decision support team (see Section 4.6) to ensure candidate alternatives are appropriately supported with established tools and near real-time data.

4.5.3 Expected Outcomes

Through the process of performing the tasks identified above, the WRE team expects to develop substantial insight on the potential for Seven Oaks Dam to benefit from FIRO. In addition, the experience gained through the PVA process is expected to sharpen and improve the WRE assessment associated with the FVA and eventual Water Control Manual update.

4.6 Decision Support

4.6.1 Context

The decision support team is focused on activities that identify, collect, refine, and develop data and technology transfer applications that benefit reservoir operations decision making. The decision support team will leverage experience gained with other FIRO viability studies (PVA and FVA) but will be tailored to the specific needs and decision-makers associated with Seven Oaks Dam and its beneficiaries.

Decision support is a key pillar of FIRO, and the process of identifying and improving the informational system cuts across all disciplines and partner agencies.

4.6.2 Tasks

4.6.2.1 Develop a team charter.

The decision support team will develop a team charter with the specific tasks described below. Additional tasks may be added while developing the PVA.

4.6.2.2 Identify and document key decision-makers.

4.6.2.3 Catalog existing decision support tools (DSTs) used by Seven Oaks Dam operations and partner agencies.

4.6.2.4 Conduct DST workshop(s).

4.6.2.5 Identify additional DSTs that may support FIRO operations.

4.6.2.6 Develop a FIRO-specific needs assessment.

4.6.2.7 Work with developers to prototype new information sources identified in the needs assessment.

4.6.2.8 Collaborate with other work teams.

The decision support team will work closely with nearly every PVA work team. The closest collaboration will take place with the observations, meteorology, WRE, and environmental teams.

4.6.3 Expected Outcomes

By performing the tasks identified above, the decision support team expects to develop substantial insight on the informational needs of reservoir operations, as well as downstream recharge facility operations. The team will work toward prototyping new informational environments that provide cross-cutting data and forecasts in an intuitive fashion. Experience and progress gained during the PVA will be carried forward and refined during the FVA effort.

4.7 Communications

4.7.1 Context

The communications team supports the project's communications and outreach needs as identified by the Steering Committee. Tasks focus on translating technical information into accessible terminology and messaging that capture the key milestones, accomplishments, and challenges of this project in a way that audiences will quickly and easily understand. This translation is essential to ensure that elected officials, agency representatives, advocacy groups, taxpayers, and other stakeholders are aware of, and can support, all steps of the FIRO process, leading to improved reservoir operations for multiple benefits.

Communication is an essential function of FIRO to ensure project objectives are clear and stakeholders are engaged throughout the FIRO process.

4.7.2 Tasks

4.7.2.1 Review and revise team charter as needed.

The Communications team has developed a team charter for the workplan, which it will review for any revisions as the FIRO project transitions from the workplan to the PVA.

4.7.2.2 Prepare fact sheets as the FIRO team reaches key milestones; then, introduce the next step of the process.

4.7.2.3 Identify opportunities to communicate progress, benefits, and other unique aspects of the Seven Oaks Dam FIRO project, including public events, major milestones, inquiries, and conferences or workshops.

4.7.2.4 Create communication products as needed (e.g., fact sheets, YouTube videos, infographics, other visuals) and distribute them via social media, websites, press releases, and other outlets as directed by the Steering Committee co-chairs.

4.7.2.5 Oversee production of the PVA, FVA, and all other FIRO documents—including formatting, editing, and presentation of materials and visuals—to ensure the documents succinctly convey important information with a single voice and unified look and feel.

4.7.2.6 Collaborate with other teams.

The communications team will work closely with other PVA work teams, particularly the WRE and environmental teams, to ensure the information they produce is accurately and concisely translated.

4.7.3 Expected Outcomes

The communications team expects the Seven Oaks Dam FIRO objectives, major milestones, operational alternatives, and possible outcomes will be easily understood by audiences and stakeholders.

4.8 Environment

A key goal for FIRO at Seven Oaks Dam is to explore the potential to enhance and protect habitat through flexible reservoir operations. Modifying reservoir management under FIRO may allow for changes to reservoir water surface elevations, pool duration and timing, and release regimes. These changes may help enhance habitat for special-status (federally or state-listed) species in riparian, alluvial fan sage scrub and perennial stream habitats.

4.8.1 Special Status Species Consideration

The biological resources of the area surrounding Seven Oaks Dam can be characterized by three biogeographical focal areas of importance (**Figure 4-2**). This section will describe the habitats within these focal areas, occurrence of special-status species that may be impacted by changes to hydrologic regimes under FIRO (Table **4-1**, **Figure 4-3**), and implications of habitat health for these species in relation to reservoir operations.

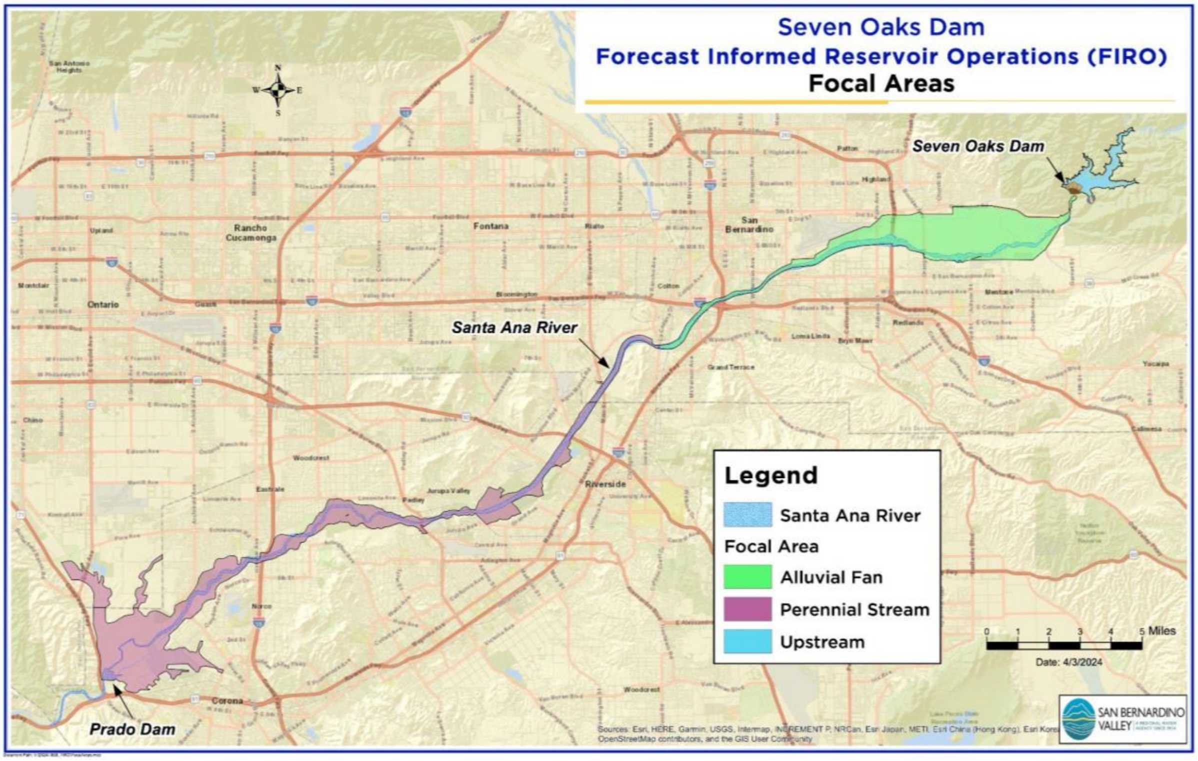

Figure 4-2. *FIRO at Seven Oaks Dam biogeographical focal areas. (Credit: San Bernardino Valley Municipal Water District.)*

Table 4-1. *Special-Status Species Relevant to FIRO at Seven Oaks Dam*

Common Name	Scientific Name	Focal Area	Federal Status	State Status
Southwestern willow flycatcher	*Empidonax traillii extimus*	Upstream, perennial stream (riparian)	Endangered	Endangered
Least Bell's vireo	*Vireo bellii pusillus*	Upstream, perennial stream (riparian)	Endangered	Endangered
Cactus wren	*Campylorhynchus brunneicapillus*	Alluvial fan	None	Species of Special Concern (SSC)
San Bernardino kangaroo rat	*Dipodomys merriami parvus*	Alluvial fan	Endangered	Endangered

Common Name	Scientific Name	Focal Area	Federal Status	State Status
Slender-horned spineflower	*Dodecahema leptoceras*	Alluvial fan	Endangered	Endangered
Santa Ana River woolly-star	*Eriastrum densifolium* ssp. *sanctorum*	Alluvial fan	Endangered	Endangered
Los Angeles pocket mouse	*Perognathus longimembris brevinasus*	Alluvial fan	None	SSC
Coastal California gnatcatcher	*Polioptila californica californica*	Alluvial fan	Threatened	SSC
Western spadefoot toad	*Spea hammondii*	Alluvial fan	Proposed Threatened	SSC
Santa Ana sucker	*Catostomus santaanae*	Perennial stream	Threatened	None
Arroyo chub	*Gila orcuttii*	Perennial stream	None	SSC
Yellow-breasted chat	*Icteria virens*	Perennial stream (riparian)	None	SSC

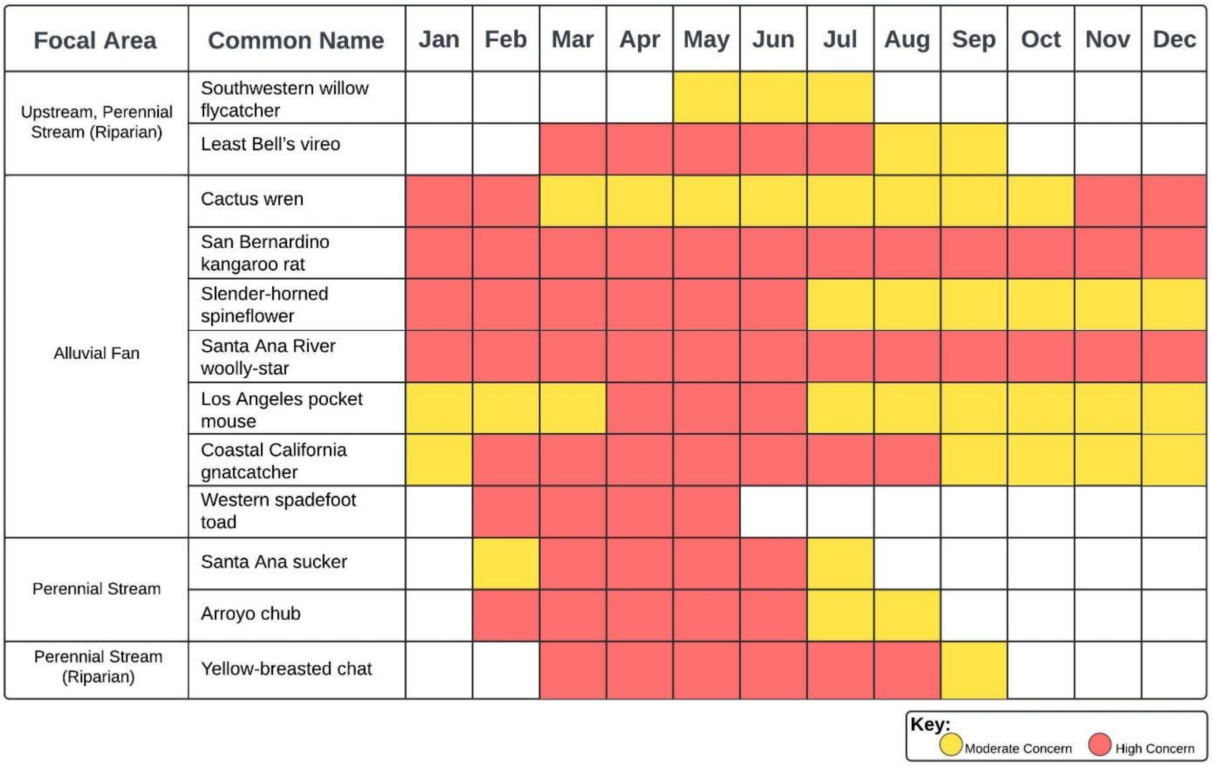

Figure 4-3. *Special-status species occurrence throughout the calendar year and associated level of concern. High concern indicates species' breeding season and potential presence. Moderate concern indicates non-breeding season and potential presence.*

4.8.2 Upstream

Biological resources upstream of Seven Oaks Dam are primarily associated with chaparral intergrading to riparian habitats. Riparian scrub habitat is found above the flood inundation elevation upstream of the Warm Springs tributary and just below the Alder Creek confluence. Patches of moderately dense riparian scrub vegetation are present and can support a variety of riparian species including least Bell's vireo and southwestern willow flycatcher; however, no breeding has been detected for these species above Seven Oaks Dam. The U.S. Fish and Wildlife Service (USFWS) has designated Critical Habitat for southwestern willow flycatcher at and above Seven Oaks reservoir.

Fluctuations in the reservoir size and depth, as well as changes to pool duration and timing with FIRO, may alter the distribution and quality of riparian habitat suitable for these species. The 1988 Supplemental Environmental Impact Statement provided mitigation for the loss of all vegetation within the 50-year flood pool elevation of 2,425 feet. No new mitigation would be required if potential FIRO operations do not exceed this pool elevation. In the PVA, the FIRO team will further analyze potentially introducing non-native aquatic species due to changes in pool elevation and/or duration.

4.8.3 Alluvial Fan

Riversidean alluvial fan sage scrub (RAFSS) is the dominant vegetation community found downstream of Seven Oaks Dam in the Santa Ana River Wash. RAFSS is a mediterranean shrubland type that occurs in washes and on gently sloping alluvial fans. Special-status species known to occur in RAFSS habitat downstream of Seven Oaks Dam include the Santa Ana River woolly-star, slender-horned spineflower, and San Bernardino kangaroo rat.

Seven Oaks Dam affects flood magnitude and depositional characteristics in overbank floodplain areas downstream. Current dam operations interfere with flood cycles needed for healthy habitat in large portions of the Santa Ana River wash. Natural fluvial processes (or other mechanisms that mimic these processes), whereby cycles of overbank flooding and dry periods result in dynamic fluctuations and rejuvenation of RAFSS habitat, are crucial for these species. Extensive studies have been completed and a successful pilot project constructed to better understand the ability of land managers to replicate these natural processes using small-scale flows.

4.8.4 Perennial Stream

For this project's purposes, the perennial stream focal area of the Santa Ana River begins at the La Cadena drop structure, about 15 miles downstream of Seven Oaks Dam. The perennial stream and associated willow-cottonwood riparian forest and scrub habitats support special-status species including the Santa Ana sucker, Southwestern willow flycatcher, and least Bell's vireo. Santa Ana sucker inhabit small streams with coarse substrates, consistent flow, and water temperature typically below 72 ºF. USFWS-designated Critical Habitat for Santa Ana sucker includes the Santa Ana River within the perennial stream focal area. Southwestern willow flycatchers have historically bred in Prado Basin, where suitable habitat for this species is well distributed and maintained through conservation programs by the Orange County Water District. However, no breeding pairs of this species have been detected in Prado Basin since 2013. Least Bell's vireo are a migratory, riparian obligate species commonly observed within the perennial stream focal area, with the highest concentration located in Prado Basin.

Seven Oaks Dam modifies the historical flow regime of the upper Santa Ana River. Reductions in peak flows have reduced both the amount and size of sediment that is transported downstream, affecting the prevalence of coarse sediment (USACE 2000). Furthermore, the dam creates a discontinuity in sediment transport because it traps the bedload transported into Seven Oaks Reservoir, reducing sediment supply downstream. Occasional moderate- and high-velocity flows from Seven Oaks Dam and/or other tributaries or sources are critical for maintaining and enhancing habitat conditions in the perennial stream focal area for species such as the Santa Ana sucker. Potential benefits of these flows may include flushing fine sediments downstream and exposing or relocating coarse sediment substrates for spawning and foraging.

4.8.5 Potential Species Translocations

The Upper Santa Ana River Habitat Conservation Plan includes programs for translocating species including the Santa Ana sucker, Santa Ana speckled dace, and mountain yellow-legged frog as a component of its conservation strategy. Translocations of these three species are being contemplated in areas upstream of Seven Oaks Dam within the San Bernardino Mountains. Translocations of Santa Ana sucker could also occur in the perennial reaches of the Santa Ana River or its tributaries downstream. The environmental team will consider the potential translocation of additional species during the analysis of FIRO at Seven Oaks Dam.

4.8.6 Key Questions and Tasks

The following section describes key questions to be explored by the environmental team in the PVA, and the associated tasks.

Key Questions

- What are the habitat goals for special-status species that may be achieved with FIRO operations?
- What changes to the dam operations could enhance the habitat of special-status species within all focal areas?
- What metrics will help the FIRO team track progress toward these habitat goals, and what metrics should the team propose to compare FIRO operational alternatives?

4.8.6.1 Recommended Tasks:

1. Define specific environmental goals to achieve with FIRO at Seven Oaks Dam.
    a. Hold a workshop to discuss and define these goals.
    b. Present the proposed goals to the FIRO Seven Oaks Dam Steering Committee for concurrence.
2. Define quantifiable metrics that will help track progress toward environmental goals and FIRO operational alternatives.
3. Perform an analysis of current environmental monitoring projects in the area, including identifying gaps in environmental monitoring needs for potential FIRO implementation.
4. Explore opportunities to aggregate environmental monitoring data into a dashboard or other reporting format.

4.8.7 Expected Outcomes

The work in the PVA will define the environmental opportunities and constraints in relation to potential FIRO operations at Seven Oaks Dam. The environmental team will identify quantifiable metrics it can use to assess progress toward environmental goals and FIRO operational alternatives. The team will analyze current environmental monitoring projects and identify potential gaps, as well as exploring opportunities for a dashboard or other system used to track and report on environmental metrics relating to FIRO. In close collaboration with the WRE team, the environmental team will begin working toward a method of analysis to assist with evaluating environmental metrics in the PVA.

4.9 References

Cannon, F., Cordeira, J. M., Norris, J. R., Hecht, C. W., Demirdjian, R., Michaelis, A., & Ralph, F. M. (2020). GPM satellite radar observations of precipitation mechanisms in atmospheric rivers. *Monthly Weather Review, 148*(4), 1449–1463.

Ralph, F. M., Dettinger, M., Rutz, J. J., Cordeira, J. M., Schick, L., Anderson, M., Smallcomb, C., & Reynolds, D. (2019). A scale to characterize the strength and impacts of atmospheric rivers. *Bulletin of the American Meteorological Society, 100*(2), 269–289.

Ricciotti, J. A., & Cordeira, J. M. (2021). Summarizing relationships among landfalling atmospheric rivers, integrated water vapor transport, and California watershed precipitation 1982–2019. *Journal of Hydrometeorology, 23*(9), 1439–1454.

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Section 5. FIRO Implementation Strategy

5.1 From FIRO Viability Assessment to Water Control Manual Update

This workplan serves to provide context and the scoping document for the rest of the Forecast Informed Reservoir Operations (FIRO) viability assessment process, shown in **Figure 5-1**. After finalizing the workplan, the Steering Committee will pivot to the Preliminary Viability Assessment (PVA). The FIRO team will develop a detailed PVA outline, including a list of tasks and assignments, at a technical workshop, after which all work teams will transition into the next step of the process. The PVA will outline meteorological, hydrologic, engineering, and environmental parameters related to FIRO operationalization for Local Sponsors and the U.S. Army Corps of Engineers (USACE) to consider including in the Water Control Manual (WCM). The PVA will determine FIRO viability at Seven Oaks Dam and specify additional analyses needed to develop the Final Viability Assessment (FVA) and WCM update.

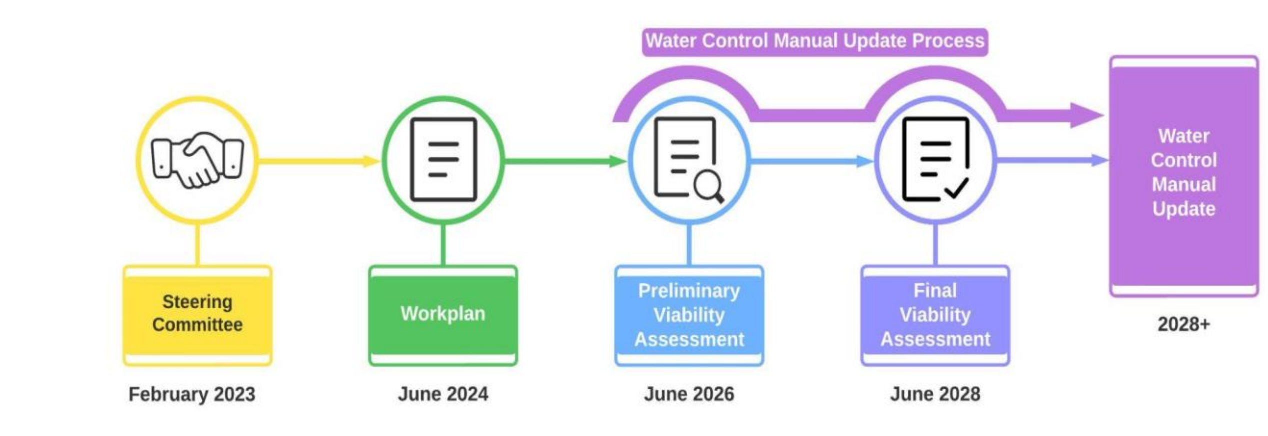

Figure 5-1. *FIRO and WCM update timeline at Seven Oaks Dam.*

5.1.1 Potential Planned Deviation

The FIRO process typically tests FIRO operations via approved minor (or major) deviations to the Water Control Plan (WCP). As the PVA is developed, information will become available to determine if a deviation to the WCP may be feasible to test FIRO. If the information indicates a deviation may be feasible from a technical standpoint, the Steering Committee will likely consider making a recommendation to the Local Sponsors and USACE regarding initiating an assessment of a deviation. This process would involve scoping out the technical analyses involved in assessing the deviation, preparing environmental documentation, and conducting related work.

5.2 Implementation Timeline

Ideally, the WCM update process will either overlap with, or begin toward the end of, the FIRO viability assessment process, as shown in Figure 5-1 above, to ensure efficient FIRO implementation. FIRO implementation includes an array of efforts that are introduced during the PVA and subsequently developed in the FVA to support FIRO outcomes into the future. Specific findings and recommendations within the research areas of forecast skill assessment and enhancement, water resources engineering, observations, weather forecasting, hydrologic modeling, and an understanding of environmental objectives are all fundamental components of the viability assessment process. Following this foundational work, FIRO implementation is pursued through deviation requests to the USACE Los Angeles District before being permanently implemented through updating the WCM. One of the central needs for FIRO implementation is a WCP that utilizes forecasts to inform reservoir release decisions. This process will require the support of Local Sponsors and USACE.

5.3 FIRO 2.0

USACE has not been regularly funded to update WCMs. It is fundamental to make the WCPs in WCMs as adaptive as possible, with the ability to integrate better forecast products as forecast skill improves. FIRO 2.0 is a concept that defines water management methodologies that consider improvements in weather and water forecast technology that can be applied to WCMs. It is a framework for WCPs that supports the future incorporation of improvements to forecast skill and reservoir operations modeling by developing sufficiently flexible WCP language and a forecast skill assessment process.

Section 6. Appendices

6.1 Background and Context—Appendix

	Release Flow Rate (cfs) based on pool Elevation							
Date	Debris Pool 2149.72 to 2200'	Intermediate Pool 2200' to 2265'	Main Trash Rack Pool 2265' to 2299'		Main Flood Control Pool	2299' to 2400'	2400' to 2500'	2500' to 2580'
Oct 1 - Mar 14	3 cfs	3 to 500 cfs	Seven Oaks Rising	50 cfs	Prado Rising	500	500	500
			Seven Oaks Falling	500 - 2000 cfs	Prado Falling	2000 - 4340	4340 - 6560	6560 - 7000
Mar 15 - Apr 15	3 cfs	3 to 250 cfs	Seven Oaks Rising	50 cfs	Prado Rising	500	500	500
			Seven Oaks Falling	1000 cfs	Prado Falling	2000	4340	6560
Apr 16 - May 31	Min = 3 cfs	Min = 3 cfs	Seven Oaks Rising	50 cfs	Prado Rising	500	500	500
	Max = Inflow	Max = 250 cfs	Seven Oaks Falling	1000 cfs	Prado Falling	2000	4340	6560
Jun 1 - Jun 30	Min = 3 cfs	Min = Inflow + 10	Min = Inflow + 10		Min = Inflow + 10			
	Max = Inflow + 10 cfs	Max = 250 cfs	Max = 250 cfs		Max = 250 cfs			
Jul 1 - Jul 15	Min = 3 cfs	Min = Inflow + 20	Min = Inflow + 20		Min = Inflow + 20			
	Max = Inflow + 20 cfs	Max = 250 cfs	Max = 250 cfs		Max = 250 cfs			
Jul 16 - Aug 31	Min = 3 cfs	3 to 500 cfs	Seven Oaks Rising	50 cfs	Prado Rising	500	500	500
	Max = Inflow + 20 cfs		Seven Oaks Falling	500 - 2000 cfs	Prado Falling	2000 - 4340	4340 - 6560	6560 - 7000
Sep 1 - Sep 30	Min = 3 cfs	3 to 500 cfs	Seven Oaks Rising	50 cfs	Prado Rising	500	500	500
	Max = Inflow + 20 cfs		Seven Oaks Falling	500 - 2000 cfs	Prado Falling	2000 - 4340	4340 - 6560	6560 - 7000

Figure 6-1. *Seven Oaks Dam release flow rate schedule based on pool elevation. (Credit: Orange County Public Works.)*

Note: Discharges can be modified based on unforeseen and unique hydrologic conditions to meet public safety concerns, environmental mitigation, and/or maintenance deadlines.

* Typically, the operational goal is to allow the water surface elevation to build up during the storm season (November to April). Then, from April to September, the operational goal is to be fully out of the intermediate pool by September 1.