Final Work Plan for Viability Assessment of Forecast Informed Reservoir Operations (FIRO) at Prado Dam

September 2019

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Acronyms

AF	acre-feet
AR Recon	Atmospheric River Reconnaissance
ARs	atmospheric rivers
BNSF	Burlington North–Santa Fe
BOs	biological opinions
CEQA	California Environmental Quality Act
cfs	cubic feet per second
CHPS	Community Hydrologic Prediction System
CNRFC	California Nevada River Forecast Center
CW3E	Western Weather and Water Extremes
DM	Design Memorandum
DSAC	Dam Safety Action Classification
DSS	decision support system
DWR	California Department of Water Resources
EFO	Ensemble Forecast Operations
EIR	Environmental Impact Report
ERDC	Engineer Research and Development Center
FIRO	Forecast Informed Reservoir Operations
FY	fiscal year
GDM	General Design Memorandum
GEFS	Global Ensemble Forecast System
GFS	NCEP Global Forecast System
GPS	Global Positioning System
GSSHA	Gridded Surface Subsurface Hydrologic Analysis
HEC-FIA	Hydrologic Engineering Center’s Flood Impact Analysis
HEC-HMS	Hydrologic Engineering Center’s Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center’s River Analysis System
HEC-ResSim	Hydrologic Engineering Center’s Reservoir System Simulation
HEFS	Hydrologic Ensemble Forecast Service
IVT	integrated water vapor transport
IWCM	Interim Water Control Manual
IWCP	Interim Water Control Plan
LAD	Los Angeles District
LDY-S	Lomas De Yorba-South
MDL	minimum discharge line
MJO	Madden Julian Oscillation
MOA	6 Memorandum of Agreement
MSL	mean sea level
MWS	multilevel withdrawal system
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NOMADS	National Operational Model Archive and Distribution System

NRT	near real time
NWM	National Water Model
NWS	National Weather Service
OCFCD	Orange County Flood Control District
OCPW	Orange County Public Works
OCWD	Orange County Water District
PMF	probable maximum flood
PVPA	Pomona Valley Protective Association
QPF	qualitative precipitation forecast
RO	regulating outlet
ROC	Reservoir Operation Center
S2S	sub-seasonal to seasonal
SARI	Santa Ana River Interceptor
SARM	Santa Ana River Mainstem
SBCFCD	San Bernardino County Flood Control District
SC	steering committee
USFWS	U.S. Fish and Wildlife Service
WCM	water control manual
WES	Waterways Experiment Station
West-WRF	western United States
WRF	Weather Research and Forecasting
WRF-Hydro	WRF Hydrological modeling system
WSR-88D	Weather Surveillance Radar
WY	water year

1. Introduction

The U.S. Army Corps of Engineers (USACE) constructed Prado Dam, located on the Santa Ana River, in 1941 for the primary purpose of flood control. Authorization for the original Prado Dam and Reservoir project is contained in the Flood Control Act of June 22, 1936 (PL 74-738), which authorized the construction of reservoirs and related flood control works for the protection of the metropolitan area of Orange County, California. The USACE Los Angeles District (LAD) owns and operates the dam.

Prado Dam is also operated to help Orange County Water District (OCWD) recharge the Orange County Groundwater Basin in northern Orange County. Stormwater capture is an important groundwater recharge source that OCWD has been using since it began recharge operations in the Santa Ana River channel in 1936.

Since Prado Dam was constructed, USACE and OCWD have worked together to utilize up to 20,000 acre-feet (AF) of reservoir storage behind the dam for temporary stormwater capture to be released at a rate that OCWD can divert and spread for groundwater recharge. Figure 1 shows the elevations and volumes of the current conservation pool. In this scoping study, OCWD is working with USACE, the U.S. Fish and Wildlife Service (USFWS), the California Department of Water Resources (DWR), Orange County Public Works (OCPW), the National Oceanic and Atmospheric Administration (NOAA), and other key stakeholders to optimize current water conservation operations at Prado Dam and explore the potential to capture larger volumes of stormwater in the future.

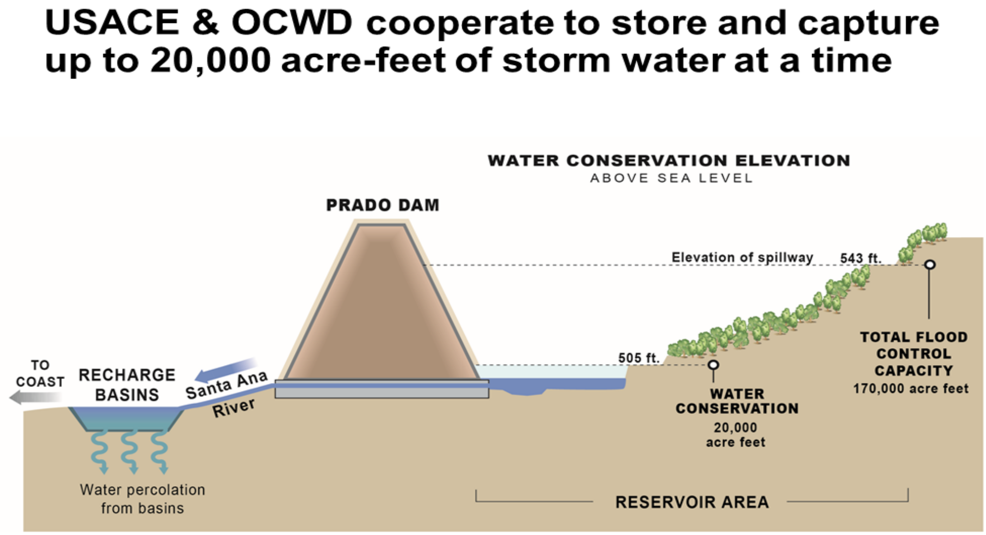

Figure 1. Schematic representation of Prado Dam water conservation elevation for stormwater storage and capture.

Over the past 25 years, OCWD has recharged an average of 55,000 AF of stormwater per year with a maximum of 117,000 AF in 1995. For planning purposes, OCWD assumes that 40,000 AF of stormwater will be captured and recharged in an average year. That is enough water for 320,000 people annually. If this water was not available, it would cost approximately $40 million to purchase imported water to replace it. In addition to economic considerations, imported water supplies are increasingly less reliable due to the fragile Bay-Delta, oversubscribed Colorado River, and changes in weather patterns.

Most of the stormwater recharged by OCWD originates as runoff in the Santa Ana watershed upstream of Prado Dam (Figure 2 and Figure 3). A majority of the upland and mountain areas upstream of Prado Dam are not urbanized. Most of the lower elevation portions of the tributary area to Prado Dam are urbanized, such as in the cities of Ontario, Riverside, and San Bernardino.

To increase the efficiency of stormwater capture at Prado Dam, OCWD is collaborating with the Center for Western Weather and Water Extremes (CW3E) at the Scripps Institution of Oceanography, University of California San Diego, to determine if Forecast Informed Reservoir Operations (FIRO) can be applied at Prado Dam in the Santa Ana River watershed. In December 2017, OCWD embarked on a multi-phase scoping study co-led by Dr. F. Martin Ralph, Director of CW3E, and Greg Woodside, Executive Director of Planning and Natural Resources for OCWD. A steering committee (SC) was formed (see Section 1.4), and the first meeting was held in March 2018. The scoping study includes preparing a work plan (this document) and should be completed by August 2019, followed by a preliminary viability assessment for FIRO at Prado Dam to be completed by October 2020. If FIRO is found to be a viable approach, additional phases of work will be considered to plan implementation.

Figure 2. Santa Ana River watershed and Prado Dam location.

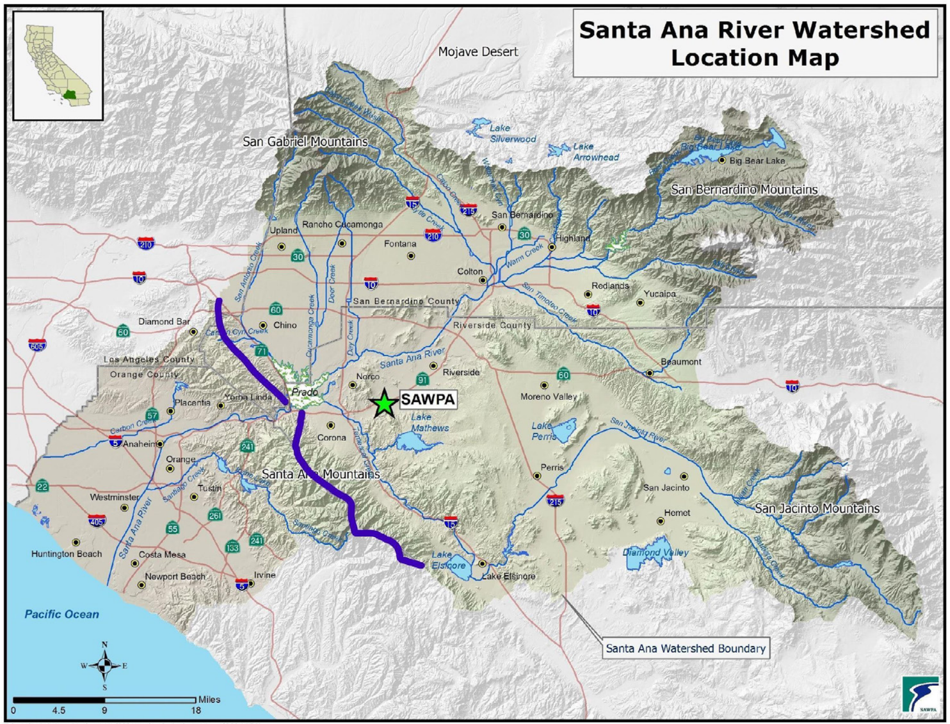

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Figure 3. Prado Dam's contributing area.

1.1 History of FIRO

California's water supplies rely on adequate precipitation, which largely depends on atmospheric rivers (ARs). ARs originate in the Pacific Ocean and can make landfall along the California coastline. The absence of AR storms often leads to drought in California, whereas strong ARs can cause flooding. Figure 4 shows an AR that impacted Southern California in 2005.

Currently, most reservoirs are operated without the benefit of AR forecasts. CW3E is developing skill in forecasting ARs. Predicting the timing and intensity of these critical precipitation events is essential to providing water managers and dam operators with the information they need and with enough lead time to operate reservoirs in anticipation of floods and drought. This cost-effective management approach, called FIRO, offers an opportunity to make better use of existing multi-purpose reservoirs across the state and region.

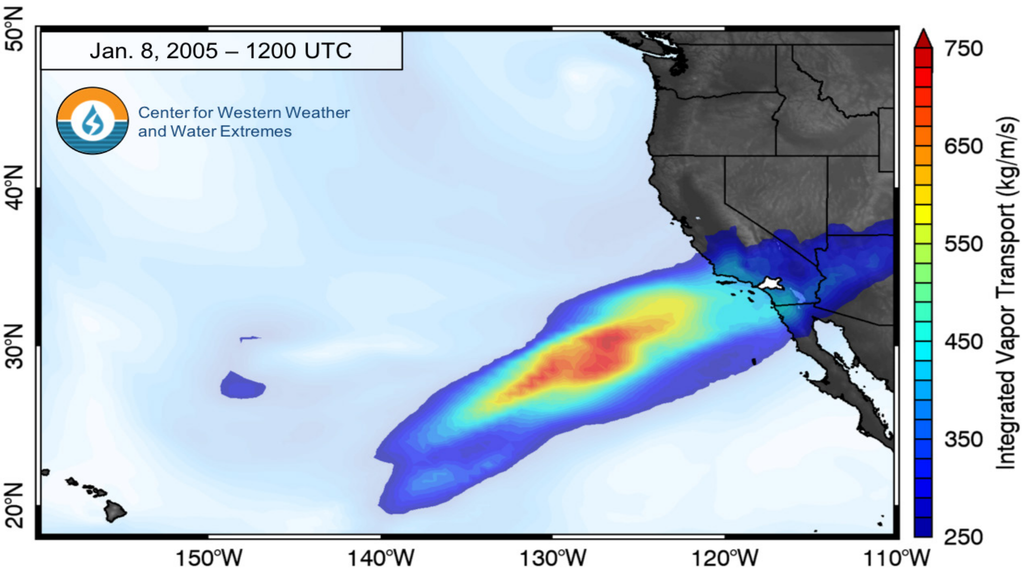

Figure 4. Landfalling AR that impacted the Santa Ana River watershed and Prado Dam in early January 2005.

FIRO uses data from watershed monitoring programs and improved weather and water runoff forecasting to help water managers selectively retain or release water from reservoirs in a flexible manner that more effectively reflects prevailing and anticipated conditions. FIRO represents an innovative use of emerging science and technology to optimize limited resources and adapt to changing climate conditions without costly reservoir infrastructure improvements.

FIRO was first initiated in 2014 by the creation of an SC to develop and test FIRO at the pilot reservoir, Lake Mendocino, in the Russian River watershed. The Lake Mendocino SC[1] determined FIRO to be viable during a preliminary viability assessment,[2] and the approach is currently being tested under a major deviation approval while the SC conducts the final viability assessment (expected to be completed by the end of 2020). The Lake Mendocino FIRO project is co-led by Dr. F. Martin Ralph, Director of CW3E, and Jay Jasperse, Chief Engineer at Sonoma Water.

Forecast-coordinated operations for the Yuba-Feather River system in Northern California also illustrate the potential benefits of FIRO. In this case, parallel reservoirs (Lake Oroville on the Feather River and New Bullards Bar Reservoir on the Yuba River) are operated for target flows at a common downstream location below the Yuba and Feather River confluence. By using forecasts and models of reservoir operation integrated into a decision support system (DSS), water managers from different agencies can assess potential release schedules and ensure coordinated operation so that the channel capacity is not exceeded at the downstream control point.

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[1] SC members include Jay Jasperse (Sonoma Water), Marty Ralph (CW3E), Michael Anderson (DWR), Levi Brekke (Bureau of Reclamation), Nick Malasavage (USACE), Michael Dettinger (U.S. Geological Survey), Joseph Forbis (USACE), Natalie Manning (NOAA), Cary Talbot (USACE), and Robert Webb (NOAA).

[2] FIRO SC (2017). Preliminary Viability Assessment of Lake Mendocino. Available from: http://escholarship.org/uc/item/66m803p2.

This Prado Dam FIRO work plan builds on past success and follows the process established by the Lake Mendocino pilot project.

1.2 Project Objectives

Prado Dam was chosen as a prime candidate for FIRO exploration based on:

- The impact of ARs in the Santa Ana watershed.
- The history of beneficial use of stormwater capture at Prado Dam for recharging OCWD's water supply (water conservation).
- Successful past practice increasing the maximum buffer pool elevation for water conservation.
- Dam improvements for flood risk management that are underway through the Santa Ana River Mainstem (SARM) project.
- The need for a water control manual (WCM) update (due to the upcoming completion of dam modifications).
- Cooperative relationships among the USACE LAD and South Pacific Division, NOAA National Weather Service (NWS), USFWS, OCPW, and OCWD.

USACE is working closely with OCWD on this work plan. OCWD's mission is to ensure a reliable supply of high-quality water for more than 2.5 million residents in north and central Orange County while protecting environmental habitats and natural resources. The Orange County Groundwater Basin managed by OCWD is the primary source of water in OCWD's boundary.

This collaborative scoping study will explore the potential application of FIRO at Prado Dam on the Santa Ana River. The Lake Mendocino experience in the upper Russian River watershed will inform the process, which will build on lessons learned about ARs as the source of heavy West Coast precipitation and runoff. As the owner and operator of Prado Dam, USACE has complete control regarding the dam's operation. If FIRO identifies potential modifications to the dam's operations, such modifications would be implemented only after USACE reviews and approves them. Additionally, this study may inform USACE in using weather forecasting technology at other USACE dams.

The purpose of this project is to answer the following question: Can current and improved forecasts of land-falling ARs and associated precipitation and runoff be sufficiently leveraged in Prado Dam operations to enhance water conservation (e.g., stormwater capture and subsequent groundwater recharge) while not compromising (or even improving) flood risk management and environmental objectives?

To answer this question, this draft work plan is being developed to determine the viability of FIRO at Prado Dam. The work plan objectives include:

1. Summarizing existing studies.
2. Identifying additional research, data, and analyses needed to demonstrate FIRO viability.
3. Developing a work process flow outline for a DSS.
4. Identifying scenarios where USACE can implement FIRO (including evaluating different reservoir target elevations).
5. Developing a strategy that will allow USACE to perform trial implementations of FIRO.

6. Establishing performance criteria from item v above to support USACE's integration of FIRO into a future version of the Prado Dam WCM.
7. Outlining a range of options to protect and enhance natural resources.

1.3 FIRO Viability Assessment Process

FIRO efforts at Prado Dam will involve both evaluating current forecasting technology as well as identifying and executing needs-based research. Figure 5 shows the general evaluation process that was used for the Lake Mendocino FIRO project. This tested process is fully applicable to the Prado Dam scoping study, and the FIRO team will follow this structure to conduct the study.

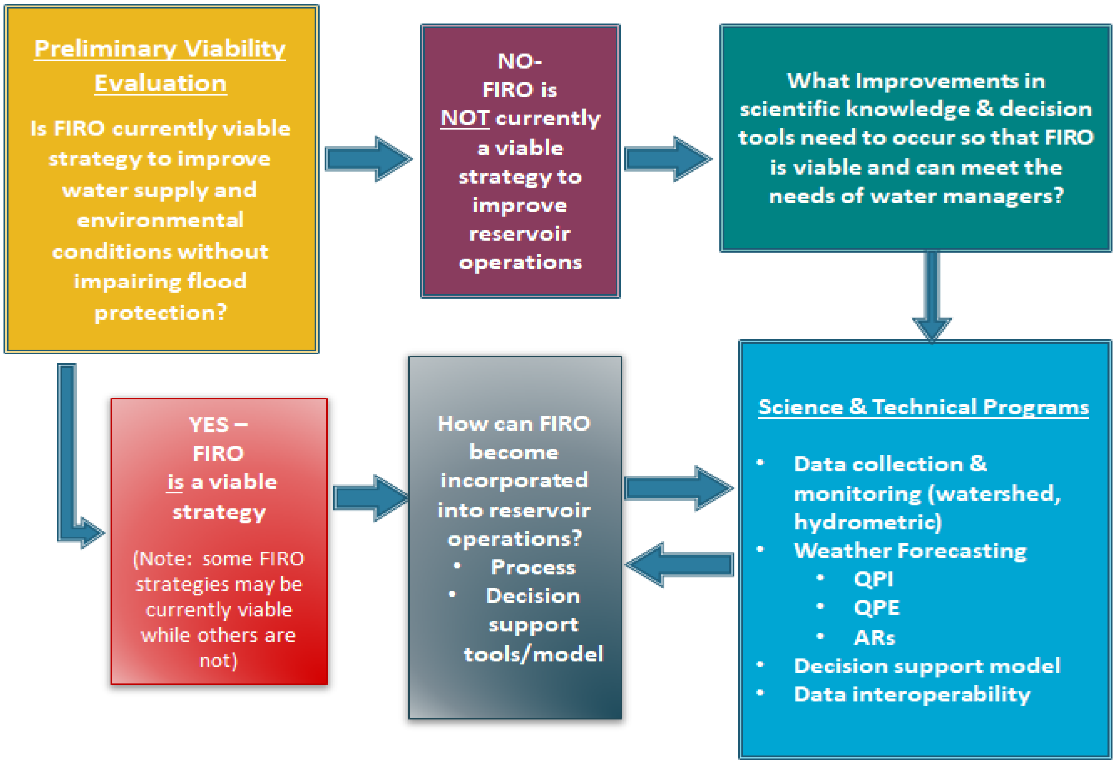


Figure 5. Preliminary viability assessment process.

The FIRO team will use established criteria to assess the ability of various strategies to improve the full spectrum of outcomes for Prado Dam operations. The team will identify and pursue research and development activities that have clear potential to improve FIRO outcomes while executing the work plan. The timeline for assessments and associated work will be established by agreement of the SC within the confines of available funding.

1.4 Prado Dam FIRO Steering Committee

The Prado Dam SC was formed in late 2017 and first met in March 2018. It is co-chaired by Dr. F. Martin Ralph, Director of CW3E, and Greg Woodside, Executive Director of Planning and Natural Resources at OCWD. Committee members were carefully selected to represent key organizations, and they bring together innovative leaders from those organizations that collaborate and contribute expertise and resources to accomplish common goals. Prado Dam SC and support staff membership are outlined below, followed by the SC's vision, mission, goals, and strategies.

Co-Chairs

- Greg Woodside: Executive Director of Planning and Natural Resources, OCWD
- F. Martin Ralph: Director, CW3E, Scripps Institution of Oceanography, University of California San Diego

Members

- Jay Jasperse: Chief Engineer, Sonoma Water
- Michael Anderson: State Climatologist, DWR
- Cary Talbot: Chief, Flood and Storm Protection Division, USACE Engineer Research and Development Center
- Alan Haynes: NOAA NWS, Hydrologist-in-Charge, California Nevada River Forecast Center (CNRFC)
- Rene Vermeeren: Chief, Hydrology and Hydraulics Branch, Engineering Division, USACE LAD
- Jon Sweeten: Hydraulic Engineer, Reservoir Regulation Section, USACE LAD
- James Tyler: Manager, Real Estate/Finance and Engineering, OCPW
- Ken Corey: Assistant Field Supervisor, USFWS, Palm Springs

Support Staff

- Adam Hutchinson: Recharge Planning Manager, OCWD
- John Spencer, Civil Engineer, OCPW
- Arleen O'Donnell: Civil Engineer, Eastern Research Group, Inc.
- Robert Hartman: Hydrologist, Robert K. Hartman Consulting Services
- Dr. Forest Cannon: Project Scientist, CW3E

Figure 6. May 17, 2018, photo of Prado Dam Steering Committee members and support staff at Prado Dam.

(From left: Rob Hartman, Jon Sweeten, Mike Anderson, Jay Jasperse, John Spencer, Forest Cannon, Marty Ralph, Greg Woodside, Cary Talbot, Cuong Ly, Rene Vermeeren, Van Crisostomo, James Tyler, Arleen O'Donnell)

SC Vision, Mission, Goal, and Strategies

- **Vision:** Develop robust forecast data and tools that support increased flexibility in reservoir operations, improving water conservation, flood control, and habitat management outcomes.
- **Mission:** Guide a highly collaborative engagement process to ensure that deliverables reflect interdisciplinary perspectives and interagency input.
- **Goal:** Develop clear pathways for assessing the viability of FIRO at Prado Dam.
- **Strategies:** Draft a work plan outlining tasks, roles, schedule, and requirements for assessing FIRO viability; conduct preliminary technical studies; and develop a preliminary viability assessment based on current forecast skill and a final viability assessment based on potential improvements in forecast skill.

Process for Achieving Mission

- Hold quarterly SC meetings, at least two of which are in person each year.
- Develop meeting agendas and circulate meeting notes; document and track action items.
- Conduct conference calls, site visits, small working group meetings, and other means of coordination.
- Hold an annual workshop to engage/coordinate with and learn from each other.
- Pursue communication and outreach opportunities.
- Develop a strategy for launching the work plan, including funding and implementation commitments.

2. Project Background and Description

2.1 Santa Ana River Watershed

2.1.1 Physical Characteristics

The Santa Ana River, more than 90 miles long, is the longest river entirely within Southern California. The effective contributing drainage of the entire river is approximately 2,450 square miles, 2,255 square miles (92 percent) of which are captured behind Prado Dam. The river originates in the San Bernardino Mountains and flows southwesterly through San Bernardino, Riverside, and Orange counties before terminating at the Pacific Ocean. The Santa Ana River watershed is ringed by the rugged San Gabriel, San Bernardino, and San Jacinto Mountains, each containing at least one peak greater than 10,000 feet in elevation. These mountains and their foothills represent about one-third of the total drainage area.

Principal tributaries above Prado Dam (listed clockwise) include San Antonio/Chino Creek, Cucamonga Creek, Lytle Creek, Mill Creek, San Timoteo Creek, and the San Jacinto River, which flows into Temescal Creek. The Lytle, Mill, and San Timoteo Creeks converge with the Santa Ana River just above the city of Riverside. The others discharge directly into Prado Reservoir. Santiago Creek is the largest tributary to the lower Santa Ana River downstream from Prado Dam.

The Santa Ana River has an average gradient of 240 feet/mile in the mountains and about 20 feet/mile closer to Prado Reservoir. The average gradient of the principal tributaries in the mountains is 700 feet/mile and 30 feet/mile in the valleys.

Prado Dam is the principal flood risk management dam in the watershed. Two other flood risk management dams receive runoff from relatively small areas of the mountainous upper watershed: San Antonio Dam on San Antonio Creek (drainage area 27 mi^2) and Seven Oaks Dam, located on the Santa Ana River (drainage area 177 mi^2). See Figure 7 for locations of dams in the Santa Ana River watershed.

This section of the work plan will also describe the climatology and runoff characteristics of the watershed, including the range in annual precipitation rates across the watershed, maximum observed historical rainfall events, and runoff statistics such as the 25-year and 50-year event peak inflow rates into Prado Basin.

The FIRO team will add physical characteristics relevant to the study to the work plan as they are identified during the analysis and evaluations.

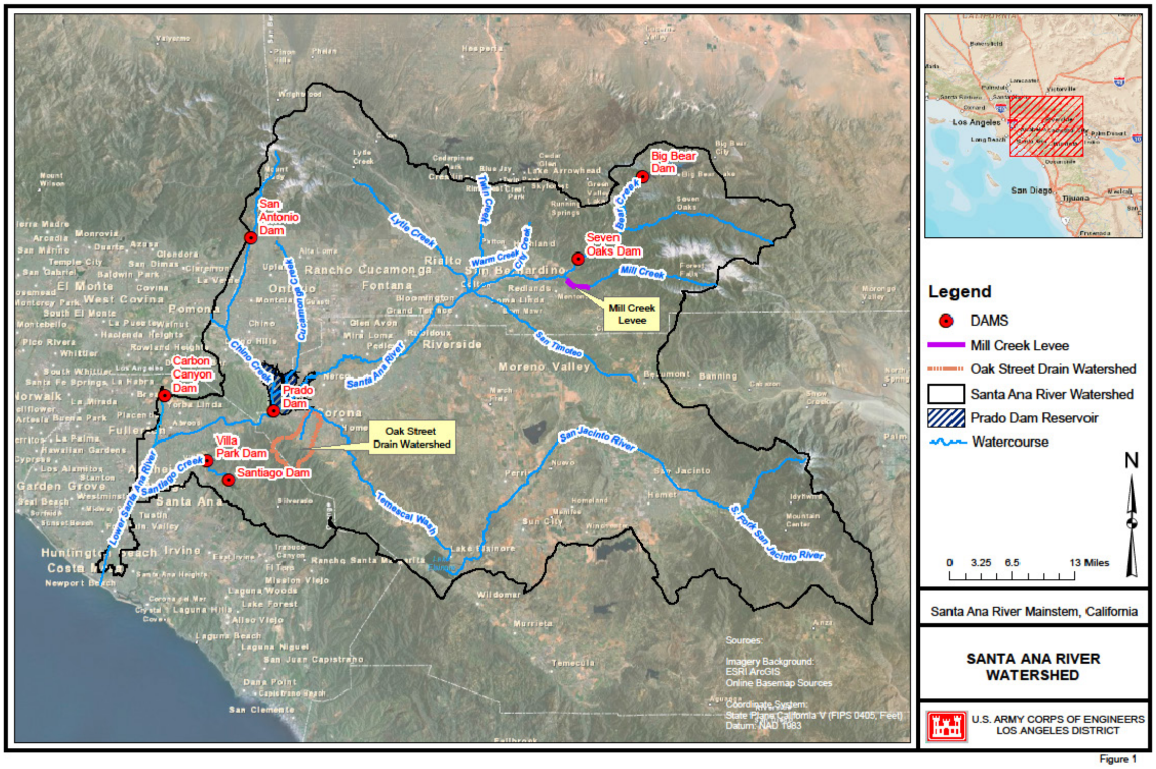


Figure 7. Location of dams in the Santa Ana River watershed.

2.1.2 Environmental Assets and Considerations

This section of the work plan characterizes the ecological resources of the area, highlighting threatened and endangered species, species of special concern, and the implications of habitat health for these species in relation to reservoir operations.

2.1.2.1 Threatened and Endangered Species

This section discusses the occurrence, habitat characteristics, and related information for each federal and state listed threatened/endangered species and state "Special Status Species" found in Table 1. The evaluation will also include pond turtles, which are under review for federal listing. Maps will show the designated critical habitat for each species. The work plan will also map habitats of the Prado Basin and describe the areal extent and dominant species.

Table 1. Threatened and Endangered Species in the Santa Ana River Watershed

Species	Endangered Species Act Listing
Least Bell's vireo	Endangered
Southwestern willow flycatcher	Endangered
Santa Ana sucker	Threatened
Western yellow-billed cuckoo	Threatened
Coastal California gnatcatcher	Threatened

Prado Basin supports a major population of the least Bell's Vireo (see Figure 8), *Vireo belli pusillus*. The vireo is a small, insectivorous, migratory songbird that breeds in riparian habitat in California and northern Baja, Mexico. The vireo is listed as an endangered species by the state of California and the USFWS. The vireo population in the Prado Basin has been monitored since 1986. Vireo occur in southern Baja Mexico in the winter and migrate to Southern California in late winter, typically arriving in Prado Basin and the greater Santa Ana watershed in March. Vireo territories occur in Prado Basin at various locations, as illustrated in Figure 9. Year 2018 locations in Figure 9 illustrate vireo occupying lower elevations of Prado Basin (e.g., below elevation 498 feet) because 2018 was a dry year with minimal inundation. During a year with greater precipitation and more inundation than 2018, vireo territories will generally not be observed to the same degree in the lower elevations but will redistribute to higher elevations.

Figure 8. Photo of least Bell's vireo with chicks (Courtesy of B. Peterson, USFWS)

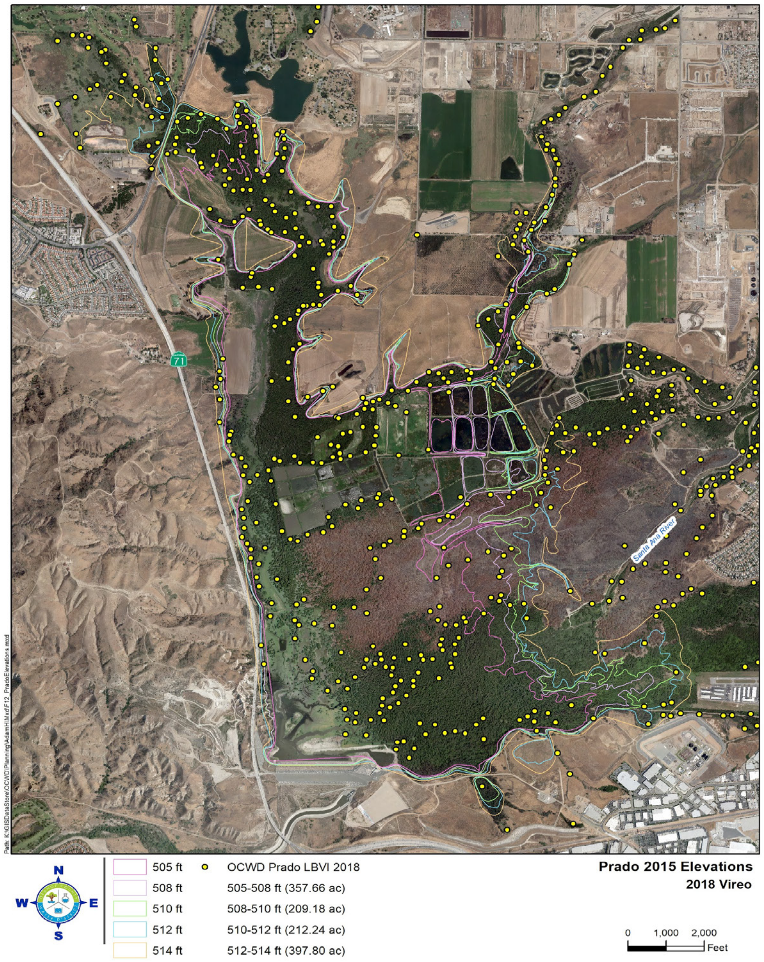


Figure 9. Location of least Bell's vireo territory (yellow dots represent nesting sites) and topography.

2.1.2.2 Governing Documents, Biological Opinions

Governing documents to be incorporated in the work plan include habitat conservation plans, species recovery plans, designations of critical habitat, and relevant biological opinions (BOs). Conditions for the existing stormwater capture program are outlined in BOs issued by the USFWS. BOs associated with USACE/OCWD requests for water conservation include BO 1-6-95-F-28, issued in 1995 for non-flood season water conservation to elevation 505 feet; BO FWS-WRIV-2102.3, issued in 2002 for flood season water conservation to elevation 498 feet; and BO FWS-WRIV-09B0192-18F0101, issued in 2018 for a 5-year flood season deviation to 505 feet.

2.1.2.3 Goals

The environmental goals for water conservation in the Prado Basin are to maintain and enhance natural resources in concert with temporary stormwater capture; this section will describe the environmental goals in detail. Environmental goals will be incorporated into the overall FIRO program goals.

2.1.2.4 Relationships with Water Level (Frequency, Duration, and Time of Year)

If FIRO implementation recommends water conservation to higher elevations than the existing operations, the team will need to evaluate impacts from additional days of habitat inundation. Other impacts to assess include increased sediment deposition, the effect of changes in sedimentation on habitat and wildlife movement and impacts to the channel downstream of the dam. For example, the FIRO project team will assess potential effects to Santa Ana sucker habitat due to changes in flow velocity. The team would prepare National Environmental Policy Act (NEPA)/California Environmental Quality Act (CEQA) documentation, but the work plan outlines issues that may require analysis separate from NEPA/CEQA documentation. Potential impacts from increased inundation may occur infrequently, and to date, there are limited data to assess the impacts of infrequent increased inundation of riparian habitat. From calendar year 2001 through 2019, there were eight years when the water elevation in Prado Basin exceeded 498 feet. There were five years when the water elevation exceeded 498 feet for 20 days or more. Inundation will be less frequent if a higher elevation of stormwater capture is implemented, with less opportunity to collect data regarding potential impacts. Attachment 1 describes a proposed scope of work to address these issues.

2.2 Water Management

2.2.1 Prado Dam

This section includes key information about Prado Dam, including owner, purpose, and storage capacity, as well as how it is operated for flood risk management and managed for water conservation. Temporary capture of stormwater at Prado Dam is referred to as “water conservation” because it conserves water that would otherwise flow to the ocean and distinguishes it from “water supply,” which triggers additional conditions in USACE projects.

2.2.1.1 History and Authorizations

Authorization for the original Prado Dam and Reservoir project is contained in the Flood Control Act of June 22, 1936 (PL 74-738), which authorized the construction of reservoirs and related flood control works for the protection of the metropolitan area of Orange County, California.

On March 12, 1937, the Chief of Engineers approved the report titled *Definite Project for the Construction of Reservoirs and Related Flood Control Works in Orange County, California,* which included

Prado Dam. Paragraph 5 of the definite project report gives the following general description of the approved project:

> ***General:*** *The Prado Retarding Basin is located on the Santa Ana River in Riverside County, California, about two miles north of the Orange County line. Its primary purpose is flood protection for those residents of Orange County whose lands have previously been subject to the destructive action of uncontrolled flood waters. There is also a water conservation feature to be utilized in connection with the automatic release of flood waters. Due to the high absorptive qualities of the material underlying the riverbed below the dam, and the large natural underground storage characteristics of the valley, it will be possible through automatic regulation to conserve a large portion of the flood flows heretofore wasted to the ocean.*

Paragraph 9 reads further:

> *… The storage capacity of the retarding basin below spillway crest elevation is 180,000 acre-feet. The Orange County Flood Control District has estimated that the practical capacity of the Santa Ana River below Prado Retarding Basin is approximately 6,000 cfs. In order to limit the outflow to this quantity it is necessary to provide the storage capacity of 180,000 acre-feet with the retarding basin operated for flood control and conservation as described below. The Orange County Flood Control District has assumed that the channel downstream from the proposed Prado Dam site will absorb by percolation flows from 1,000 to 2,000 cfs. It is further assumed that the retarding basin could safely be operated for conservation to elevation 507.5 (capacity of 54,000 acre-feet). The remaining net storage capacity of 126,000 acre-feet is to be reserved for flood control. It is proposed to secure the conservation operation by omitting the gate on the one of the 4 ft by 8 ft conduits.*

With the authorization found in the Flood Control Act of 1936 and in accordance with the definite project report approved by the Office of the Chief of Engineers on March 12, 1937, the original Prado Dam and Reservoir project was constructed in accordance with the May 1938 report titled *Analysis of Design—Prado Dam.* Construction was completed in April 1941 at a cost of about $9,450,000.

Further modifications to the original project authorization are contained in the Water Resources Development Act of 1986 (PL 99-662). The purpose of this modification was to provide additional capacity for storage of flood waters and sediment by enlarging the existing Prado Dam and Reservoir and to take advantage of increased downstream channel capacity by increasing the release capacity of the outlet works. Congress authorized the modification, which was based on a plan recommended by the USACE LAD, as described in the document titled *Design Memorandum (DM) No. 1, Phase II General Design Memorandum (GDM) on the Santa Ana River Mainstem including Santiago Creek, Volume 2—Prado Dam*, dated August 1988. The environmental justification for this modification is provided within the report titled *Supplemental EIS and Project Environmental Impact Report (EIR) for Prado Basin, Including Stabilization of the Bluff Toe at Norco Bluffs*, dated December 2001. The details of the SARM project are provided in Section 2.4.

Table 2 summarizes the water storage volume at selected elevations based on the year 2015 topographic survey.

Table 2. Water Storage Volume at Select Elevations

Water Surface Elevation (ft, NGVD 29)	Volume (AF)
498	9,369
505	19,469
508	25,374
510	29,823
514	39,900
516	45,675
543	172,758

This section of the work plan will also describe how Prado Dam is operated in tandem with upstream dams. Historical operations, such as inflows, storage levels, and outflow levels, will provide context for evaluating future operations.

2.2.1.2 Interim Water Control Plan (IWCP) and Manual (IWCM)

Prado Dam and Reservoir are congressionally authorized to provide flood protection to the metropolitan area of Orange County. Protecting the downstream floodplain takes priority over protecting reservoir lands and leaseholders from inundation. The IWCP regulation objectives, in addition to flood risk management, include 1) minimizing adverse environmental impacts, 2) minimizing impacts to endangered species, 3) minimizing maintenance costs to the dam and downstream channel, 4) minimizing impacts to reservoir lands and activities (i.e., to leaseholders), 5) maintaining public health and safety, and 6) minimizing water quality problems.

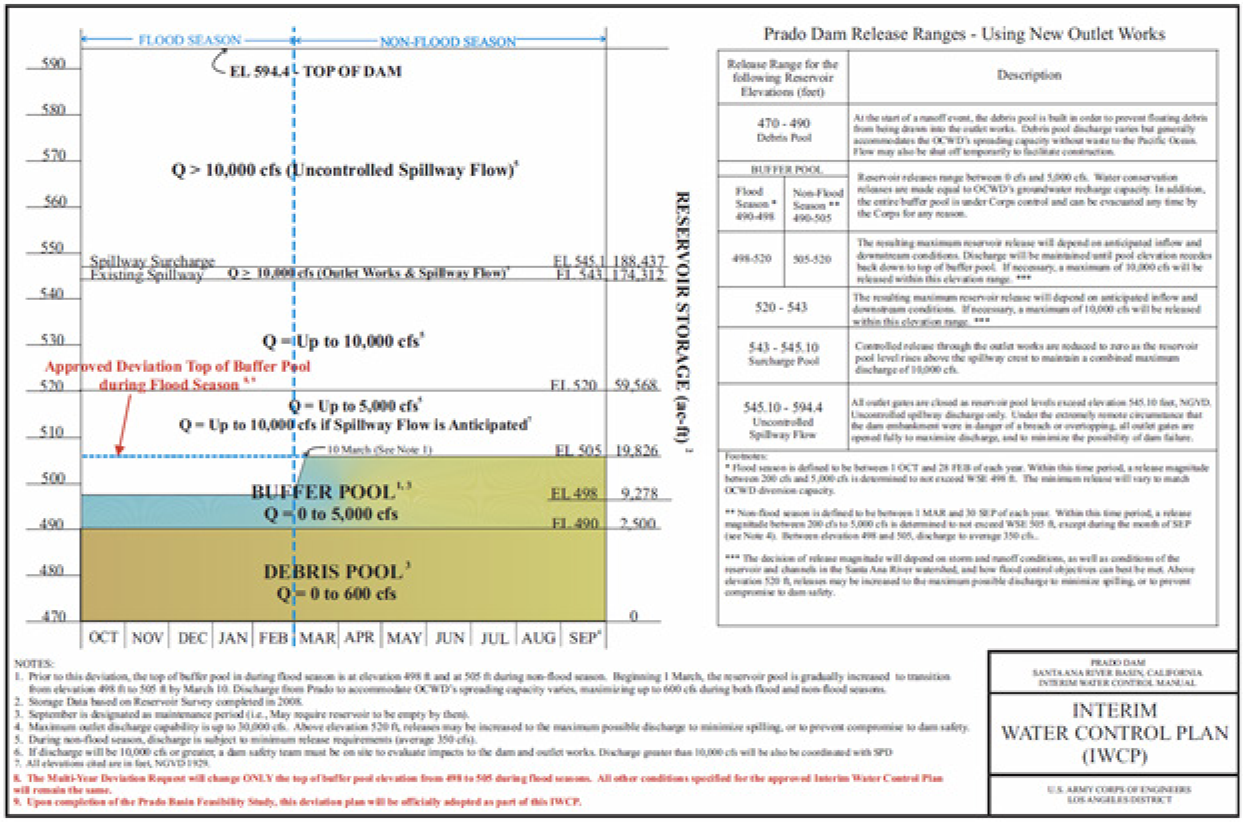
The IWCP contained in the IWCM is a hybrid plan consisting of the last approved WCP provided in the *Interim Water Control Plan (during construction), Prado Dam and Reservoir, Santa Ana River, Orange County, California,* dated May 2003 (2003 IWCP), and the recently approved 5-year planned major deviation to the 2003 IWCP. The planned major deviation allows for a higher water conservation buffer pool during the flood season. The 2003 IWCP was previously developed to update only the WCP contained in the last approved WCM—the *Prado Dam Water Control Manual,* dated September 1994 (1994 WCM). Together with the 1994 WCM, the 2003 IWCP was implemented while the original outlet works was still operational and the new larger capacity outlet works was under construction. After the dam's embankment was raised to 594.4 feet and a new larger discharge capacity outlet works was installed, it became necessary to develop a water control document that properly describes existing project conditions while still implementing an IWCP during the ongoing construction at and downstream of Prado Dam. The IWCM containing the IWCP replaces both the 2003 IWCP and the 1994 WCM documents.

The ongoing *Prado Basin Feasibility Study* may be completed during the implementation period of the IWCP. One of this study's alternatives proposes to formally increase the maximum flood season water conservation buffer pool elevation from 498 feet to 505 feet. During IWCP implementation, it is anticipated that the *Prado Basin Feasibility Study* could be completed, which will officially modify the last approved 2003 IWCP only with respect to the regulation of the flood season water conservation buffer pool. The IWCP "hybrid plan," therefore, can serve as the official regulating/operating plan through the remaining construction improvements projects. The final WCP and WCM will supersede the IWCP and IWCM, documenting the final regulation plan and final project conditions.

If the 5-year planned major deviation expires before the *Prado Basin Feasibility Study* is completed, the top of the water conservation pool will revert to the last approved flood season buffer pool elevation of 498 feet, as specified in the 2003 IWCP. This will be the case until the study is completed and its findings are integrated into the IWCP.

2.2.1.3 Overall Plan for Water Control

Figure 10 illustrates the IWCP for Prado Dam as described in Section 2.2.1.2 and is in force at the time of this document's preparation.



Prado Dam Release Ranges - Using New Outlet Works

Release Range for the following Reservoir Elevations (feet)		Description
470 - 490 Debris Pool		At the start of a runoff event, the debris pool is built in order to prevent floating debris from being drawn into the outlet works. Debris pool discharge varies but generally accommodates the OCWD's spreading capacity without waste to the Pacific Ocean. Flow may also be shut off temporarily to facilitate construction.
BUFFER POOL		
Flood Season * 490-498	Non-Flood Season ** 490-505	Reservoir releases range between 0 cfs and 5,000 cfs. Water conservation releases are made equal to OCWD's groundwater recharge capacity. In addition, the entire buffer pool is under Corps control and can be evacuated any time by the Corps for any reason.
498-520	505-520	The resulting maximum reservoir release will depend on anticipated inflow and downstream conditions. Discharge will be maintained until pool elevation recedes back down to top of buffer pool. If necessary, a maximum of 10,000 cfs will be released within this elevation range. ***
520 - 543		The resulting maximum reservoir release will depend on anticipated inflow and downstream conditions. If necessary, a maximum of 10,000 cfs will be released within this elevation range. ***
543 - 545.10 Surcharge Pool		Controlled release through the outlet works are reduced to zero as the reservoir pool level rises above the spillway crest to maintain a combined maximum discharge of 10,000 cfs.
545.10 - 594.4 Uncontrolled Spillway Flow		All outlet gates are closed as reservoir pool levels exceed elevation 545.10 feet, NGVD. Uncontrolled spillway discharge only. Under the extremely remote circumstance that the dam embankment were in danger of a breach or overtopping, all outlet gates are opened fully to maximize discharge, and to minimize the possibility of dam failure.

Footnotes:

* Flood season is defined to be between 1 OCT and 28 FEB of each year. Within this time period, a release magnitude between 200 cfs and 5,000 cfs is determined to not exceed WSE 498 ft. The minimum release will vary to match OCWD diversion capacity.

** Non-flood season is defined to be between 1 MAR and 30 SEP of each year. Within this time period, a release magnitude between 200 cfs to 5,000 cfs is determined to not exceed WSE 505 ft, except during the month of SEP (see Note 4). Between elevation 498 and 505, discharge to average 350 cfs.

*** The decision of release magnitude will depend on storm and runoff conditions, as well as conditions of the reservoir and channels in the Santa Ana River watershed, and how flood control objectives can best be met. Above elevation 520 ft, releases may be increased to the maximum possible discharge to minimize spilling, or to prevent compromise to dam safety.

NOTES:

1. Prior to this deviation, the top of buffer pool in during flood season is at elevation 498 ft and at 505 ft during non-flood season. Beginning 1 March, the reservoir pool is gradually increased to transition from elevation 498 ft to 505 ft by March 10. Discharge from Prado to accommodate OCWD's spreading capacity varies, maximizing up to 600 cfs during both flood and non-flood seasons.
2. Storage Data based on Reservoir Survey completed in 2008.
3. September is designated as maintenance period (i.e., May require reservoir to be empty by then).
4. Maximum outlet discharge capability is up to 30,000 cfs. Above elevation 520 ft, releases may be increased to the maximum possible discharge to minimize spilling, or to prevent compromise to dam safety.
5. During non-flood season, discharge is subject to minimum release requirements (average 350 cfs).
6. If discharge will be 10,000 cfs or greater, a dam safety team must be on site to evaluate impacts to the dam and outlet works. Discharge greater than 10,000 cfs will be also be coordinated with SPD
7. All elevations cited are in feet, NGVD 1929.
8. The Multi-Year Deviation Request will change ONLY the top of buffer pool elevation from 498 to 505 during flood seasons. All other conditions specified for the approved Interim Water Control Plan will remain the same.
9. Upon completion of the Prado Basin Feasibility Study, this deviation plan will be officially adopted as part of this IWCP.

Figure 10. Prado Dam IWCP.

The Seven Oaks Dam project, located approximately 30 miles northeast of the Prado Basin, is jointly owned by the local sponsors (Orange, Riverside, and San Bernardino Counties). Please see Section 2.2.2 below for a description of Seven Oaks Dam operations. Releases from Seven Oaks Dam, in addition to local runoff downstream of Seven Oaks Dam, are captured and temporarily stored behind Prado Dam.

The primary objective of the IWCP is to limit the damaging flows that could result from large runoff events. Normal maximum flood risk management discharge is up to 5,000 cubic feet per second (cfs); however, it may also be maximized up to 10,000 cfs, if warranted by hydrometeorological conditions at the project. Discharge anticipated to be in excess of 5,000 cfs will be closely coordinated with the OCPW, OCSD, OCWD, and USFWS (when applicable).

The IWCP differs from the last approved 2003 IWCP only with respect to water conservation regulation. Therefore, the IWCP's maximum flood risk management discharge will still be up to 5,000 cfs, whenever possible. In addition, if there are concerns related to hydrometeorological conditions near the project, dam safety, or an emergency situation that warrant a need to exceed the normal maximum discharge of 5,000 cfs, steps may be taken to coordinate a larger controlled discharge up to 10,000 cfs before all Reach 9 construction activities have been completed. Discharge from the dam may also be curtailed or shut off completely to accommodate maintenance activities or inspections within the downstream channel, during an emergency situation in cooperation with local authorities, or when there are impacts to safety at the Burlington North–Santa Fe (BNSF) bridge due to construction-related activities.

The IWCP will be typically implemented as follows. At the start of a storm runoff event, a debris pool is formed up to elevation 490 feet. The purpose of the debris pool is to allow excess sediment and debris that collects in the reservoir to settle so that they do not get pulled into the outlet works. While building the debris pool, discharge from the dam may also be coordinated with OCWD for water conservation benefits.

While it does not interfere with flood risk management, runoff into the reservoir can be stored in the buffer pool for water conservation. When storage exceeds or is anticipated to exceed the top of the buffer pool elevation, discharge from the dam may be increased up to 5,000 cfs. When the reservoir recedes below the top of the buffer pool elevation, and if there are no conflicts with flood risk management objectives, discharge from the dam will resume coordination with OCWD to benefit water conservation efforts.

The regulation/operation decision process provided above is also part of the "normal communications conditions," where regulation responsibility lies solely with USACE LAD's Reservoir Operation Center (ROC). The dam tenders that physically operate the project make no independent regulation decisions or move any outlet gates without permission from the ROC.

The ROC's nominal discharge decisions typically take into account, but are not limited to, the following available information:

- Current pool elevation behind the dam.
- Maximum available downstream channel capacity.
- Current calculated inflow into the dam's reservoir.
- Weather forecast information from the NWS and CNRFC.[3]

The following sections describe in detail the typical regulation for these various pool elevation ranges:

a. Debris pool (elevation 470 feet to 490 feet).

The debris pool ranges from elevation 470 feet (project invert) up to 490 feet. During runoff events, discharge from the dam is kept at a minimum to create an impoundment so that excess debris and trash that wash into the reservoir can settle out and do not get pulled into the outlet works. The rate of discharge while within the debris pool elevation can range from 0 to 600 cfs, and it is often coordinated

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[3] As weather and runoff forecasts are rarely 100 percent accurate with respect to timing and intensity anticipated, quantitative precipitation forecasts are currently NOT used as input for any kind of USACE runoff modeling for determining runoff volume.

with OCWD so that they can divert the flow into their spreading grounds for groundwater recharge and water conservation. Proper operation of the dam and outlet works is improved when the pool is at or above 490 feet.

b. Buffer pool for water conservation (elevation 490 feet to 498/505 feet).

The nominal release range for the buffer pool can range from 0 cfs to 5,000 cfs. Discharges from within the buffer pool elevations are also coordinated with OCWD to support their groundwater recharge operations for water conservation, or to coordinate preparation for the project's flood risk management regulation. As the pool elevation rises toward the top of the buffer pool elevation, the regulation/operation at Prado Dam transitions from water conservation to flood risk management.[4]

While the water surface elevation is within the buffer pool, discharge from the dam may be gradually increased before achieving the top of buffer pool elevation to have a better handle on inflow. Discharge can be up to 5,000 cfs and could be maintained long-term with minimal or no concerns of damage within the downstream channel. Channel observers—as coordinated with San Bernardino County and Riverside County Flood Control Districts and/or LAD's Hydraulics Section—will be necessary to ensure channel safety and no outbreak of channel flow onto urban surroundings or overtopping of diversion structures set up to protect the ongoing Reach 9 construction.

Due to the presence of the endangered least Bell's vireo within the Prado Reservoir, there is also a seasonal regulation/operation for the buffer pool with respect to the flood season (winter) and the non-flood season. Details of the seasonal regulation are as follows:

- Flood season is from October 1 through the end of February of the following year. During the implementation of the IWCP, the top of buffer pool elevation could be either 498 feet or 505 feet depending upon the status of the 5-year major deviation and the *Prado Dam Feasibility Study* described earlier. The drawdown release rates below the top of buffer pool elevation are normally coordinated with OCWD to assist with water conservation through their groundwater recharge. However, if a significant storm event is forecasted, the reservoir may be drawn down as low as the top of debris pool elevation (490 feet) to prepare the reservoir for storm runoff. This drawdown will be performed as quickly as safely possible and may begin before the start of the forecasted storm event if deemed necessary. Discharge rates can be 5,000 cfs or greater if necessary. The maximum safe discharge will be evaluated considering the existing downstream channel conditions. The maximum discharge capacity of the new outlet works is 30,000 cfs.
- The non-flood season spans from March 1 through September 30 of each year. As with flood season operations, the reservoir can be drawn down to the top of the debris pool (490 feet) as needed to prepare the project to meet flood risk management objectives. The same release limits and considerations apply. Between March 1 and March 10, the buffer pool may be allowed to increase up to 505 feet. From March 10 on, the buffer pool may be maintained up to 505 feet through August 31, per the 2006 Memorandum of Agreement (MOA) for water conservation between the LAD and OCWD. The month of September is designated for project maintenance activities, and the reservoir should be dry or near dry by the end of August. Should runoff volume be received late in the season, the project can be regulated/operated for water

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[4] LAD has complete operational discretionary authority of this impoundment, so it can be drained completely at any time, as needed, for the purposes of flood risk management, environmental concerns, or for concerns relating to dam safety.

conservation up to elevation 505 feet through the end of September. Priority consideration for project maintenance, construction, or USFWS requirements may also be given, as necessary, over support for water conservation during September.

c. Flood control pool (elevation 498/505 feet to 543 feet).

As the reservoir pool elevation approaches the top of buffer pool elevation, the regulation/operation of the dam will transition from water conservation to flood risk management. A flood risk management release is a gradual increase of discharge to match the calculated inflow to the reservoir, which could also be 5,000 cfs or more if necessary. This regulation allows for maintaining controlled releases from the dam to avoid spillway flows (above 543 feet).

OCPW received a certification letter in 1999 stating that a 100-year level of protection on the lower Santa Ana River from Weir Canyon Road to the Pacific Ocean will be maintained during all construction activities. This certification was contingent upon 1) the operation of Seven Oaks Dam with the latest approved WCP; 2) the lower Santa Ana River channel improvements from Reaches 1–7 being completed, and the existing OCPW channels being fully entrenched and capable of safely conveying the 100-year flood; and 3) Prado Dam's ability to release up to 9,200 cfs from the outlet works during large runoff events.

The decision to implement this "100-year level of protection" regulation/operation will consider the following factors:

- Current water surface elevation within the reservoir.
- Latest qualitative precipitation forecast (QPF) information.
- Quantity of observed rainfall.
- CNRFC inflow forecast.
- Progress of Reach 9 construction activities and available channel capacity.

If it is determined that the pool elevation behind Prado Dam could rise up to elevation 520 feet, proactive measures may be taken to draft the reservoir as low as 490 feet. At elevation 520 feet, approximately half of the storage capacity below the spillway crest (543 feet) is filled. Additionally, if the CNRFC inflow forecast is significant enough to indicate potential storage up to spillway crest, discharge may be increased up to 10,000 cfs.

All flood risk management releases are made as safely as possible following a rate of release change schedule. Channel observers will be dispatched to monitor downstream conditions, especially if releases are 5,000 cfs or greater. Constant coordination between the channel observers and the ROC are made to ensure that releases from Prado Dam are kept within the downstream channel limits. When the opportunity exists during flood risk management operations, a performance test may be implemented on Prado Dam's new RO and low flow gates to ensure that each gate can pass the design maximum of 5,000 cfs and 300 cfs, respectively.

d. Spillway flow (elevation 543 feet and higher).

Flood risk management releases through the outlet works are gradually reduced as the reservoir pool rises above the spillway crest to keep the combined spillway and outlet works flow within the downstream channel capacity. This activity requires close coordination between the LAD ROC and onsite personnel. Plate 2-21b shows the spillway rating curve for the existing unmodified spillway structure. As the dam operation transitions completely to an uncontrolled spillway flow, all outlet gates are closed. Under extreme circumstances, such as the safety of dam operation being threatened, the outlet gates are reopened fully to maximize discharge and evacuate storage as quickly as possible.

2.2.1.4 Operational Constraints

The IWCP release schedule developed for Prado Dam considers available downstream channel capacity before implementing the release decision. Currently, the safe maximum discharge from Prado Dam is limited to 5,000 cfs during Reach 9 construction. If necessary, discharge in excess of 5,000 cfs may be made for flood risk management or dam safety purposes. Before making releases exceeding 5,000 cfs from Prado Dam, channel observers from both the LAD and OCPW will be called out to observe the performance of the downstream channel and to report any concerns. Prior notifications and coordination with the local government, public, and private constituents impacted by such discharge will also be made.

a. Existing spillway at elevation 543 feet.

The updated design storm analysis showed increased runoff resulting from urbanization of the watershed. This led to the modification of the Prado Dam and Reservoir project's existing features, including raising the spillway crest elevation. Before modifications, the project could handle an approximately 70-year runoff event, although originally designed for a 200-year event. With an operational Seven Oaks Dam and a controlled discharge from Prado Dam of 9,200 cfs, the developments around the lower Santa Ana River in Orange County now have at least a 100-year level of protection. The 100-year level of protection certification letter to Orange County is provided as Exhibit G in the IWCM. Still, an independent updated analysis of the existing conditions at Prado Dam and Reservoir (i.e., raised embankment, new outlet works, and unraised spillway) must be completed to understand what level of protection this project alone can provide without Seven Oaks Dam. This analysis is currently scheduled to take place during mid to late fiscal year (FY) 2019.

The spillway modification construction will begin when Orange County has acquired all lands within the new taking line (566 feet) in fee/easement. The spillway modification work is currently in the design phase. While the spillway structure remains at 543 feet, a major flood runoff event that exceeds the current reservoir capacity could cause catastrophic damages in an area downstream inhabited by about 2 million people. A design event of this nature would inundate over 110,000 acres of highly urbanized land and directly involve hundreds of thousands of homes, businesses and factories, and hundreds of schools; the direct damages from a flood of this magnitude are estimated at about $15 billion.

b. Inundation within the reservoir.

There are numerous environmental, public, and private concerns with developments located within the Prado Reservoir. In addition, there are remaining construction activities that include modification to Prado dikes (Alcoa and River Road) and Norco Bluffs. Because flood risk management is the primary authorized purpose, developments and upstream construction sites located within the reservoir boundary up to the top of dam elevation are subject to inundation during operations. During runoff events, the LAD's ROC will remain aware of high water impoundment impacts to these developments and upstream constructions sites; however, the ROC will not give priority consideration to avoid inundating these sites when considering flood risk management decisions. The following are a few notable concerns with regulating the dam during significant storm runoff events:

- **Least Bell's vireo nesting habitat, BO, and MOA**. Please see Section 2.2.2.
- **Corona Municipal Airport.** This is a recreational airport managed by the city of Corona and used primarily for small private planes. The airport is located between elevations 514 feet and 536 feet. The LAD's ROC gives a rising water surface notification to the city of Corona if privately owned aircraft and other movable airport facilities could be inundated.
- **Corona percolation ponds.** The city of Corona leases land from the federal government for an effluent spreading area (10 ponds covering approximately 60 acres) and effluent pipeline and access road, spanning elevations 534 feet to 540 feet. The spreading grounds are designed to handle 5 million gallons per day (7.7 cfs) of treated effluent. In recent years, the ponds have not been used for percolation. In the past, the City of Corona has alleged that the high water surface elevations within Prado Reservoir have resulted in a detrimental reduction in the percolation rate of the ponds.

c. Lower Santa Ana River Channel Improvements Project (Reach 9).

Reach 9 construction is ongoing during the implementation of the IWCP. Remaining work for Reach 9 includes Phase 5B and the BNSF railroad bridge improvements. The channel capacity due to these construction activities remains limited and will vary depending on their completion progress. Critical outflow rates from the dam will be evaluated during each phase of the downstream construction and adjustments to the Prado Dam releases may be made, if necessary, as long as they do not compromise Prado Dam's flood risk management objectives.

Before the start of Reach 9 construction, it was observed that a long-term release of 5,000 cfs from the dam, in addition to local runoff, can be tolerated with little or no downstream concerns. The Reach 9 contractors were advised that they should be able to provide a water diversion capacity of up to 5,000 cfs, plus local runoff, while working in the channels. In addition, the Santa Ana River from Prado Dam to Weir Canyon Road has historically experienced a peak flow discharge of 10,000 cfs from Prado Dam, and the IWCP will allow for discharge up to that maximum if necessary. Releases up to 10,000 cfs will more than likely result in severe damage to the existing conditions of Reach 9 and surrounding areas of the channel. If a discharge that exceeds 10,000 cfs should become necessary, this regulation decision will be discussed with the District Engineer and the water control managers at USACE South Pacific Division prior to coordination with pertinent local entities and implementation of the action.

- **BNSF railroad bridge.** Part of the ongoing Reach 9 construction will be to reinforce the BNSF railroad bridge piers and the channel embankment to withstand a release of 30,000 cfs from Prado Dam. To prevent damage to the site during construction, Prado Dam releases are limited to 10,000 cfs. Improvements include bank armoring, sheet piling, and bridge pier nose modification. The BNSF Bridge Protection construction contract was awarded in October 2017 and is anticipated to take approximately two to three years to complete. In addition, during this construction, the contractors' maximum diversion capacity is estimated to be around 1,100 cfs. A larger capacity diversion structure could not be constructed due to size limitations from the existing channel, which cannot accommodate both the larger diversion structure and access for construction activities. Prado Dam's flood risk management discharge plan will continue adhere to the IWCP. When it does not compromise flood risk management objectives, discharge from the dam may also consider the maximum available diversion capacity to limit structural impacts to the bridge itself during construction.

2.2.2 Seven Oaks Dam

Seven Oaks Dam is in the foothills of the San Bernardino Mountains, approximately 2 miles north of Redlands. Seven Oaks Dam is owned by the Orange County Flood Control District (OCFCD), San Bernardino County Flood Control District (SBCFCD) and Riverside County Flood Control and Water Conservation District. OCFCD staff are responsible for making water control management decisions and directing the Seven Oaks Dam reservoir operations. SBCFCD provides the dam tenders and performs most of the operation and maintenance. Seven Oaks Dam is a zoned earth and rockfill dam with a maximum height of 550 feet above the existing streambed. The dam crest is 40 feet wide and 2,760 feet long. The main flood control pool has a maximum capacity of 147,946 AF. The dam is operated for flood control purposes by temporarily retaining water and attenuating peak flow until the downstream flood threat has passed. The hydrologic effect of Seven Oaks Dam is to reduce peak flood flows downstream to Prado Dam, which controls flood flows downstream to the Pacific Ocean.

Seven Oaks Dam was designed to be operated in conjunction with Prado Dam to protect the areas along the lower Santa Ana River from floods. Because the operation of Seven Oaks Dam will affect the operation of Prado Dam, the Seven Oaks Dam water control managers must notify the USACE LAD ROC of any changes in releases from Seven Oaks Dam that are beyond releases made for downstream water users. The ROC can also be reached for regulation consultation, if necessary, via telephone or by radio using the USACE radio system.

The WCP for Seven Oaks Dam is designed to achieve flood control objectives. When significant flood inflow into the dam reservoir occurs, flood waters are temporarily retained while a small release (500 cfs or less) is made until the reservoir pool level at Prado Dam begins to recede. Water retained at Seven Oaks Dam is then released at higher rates to evacuate the reservoir pool in a controlled manner to regain retention capacity for subsequent flood events. Storing water for longer periods for the purpose of water conservation is not currently authorized or proposed. Additional details on Seven Oaks Dam operations are provided in Attachment 2.

The highest pool elevation achieved at Seven Oaks Dam was on March 3, 2005, at 2,392.40 feet NGVD. The largest hourly inflow calculated since 2002 was 8,158.8 cfs on January 11, 2005 between 0300 hrs and 0400 hrs. The largest release achieved at the dam was calculated to be 6,210 cfs on March 1, 2011, during a test of the outlet works.

2.2.3 San Antonio Dam

San Antonio Dam is a flood control and water conservation project constructed and operated by USACE LAD. The San Antonio Flood Control Project, including the San Antonio and Chino Creek Channels Improvements Project, was authorized (as part of the Santa Ana River Basin flood protection program) by the Flood Control Act of June 22, 1936 (PL 74-738), and the Flood Control Act of June 28, 1938 (PL 75-761). The construction of the dam was initiated in April 1952 and completed on May 1, 1956. The construction of the San Antonio and Chino Creek Channels was initiated in 1956 and completed in 1960.

The San Antonio Flood Control Project is located approximately 30 miles east of Los Angeles in the Santa Ana River Basin. The dam is situated on San Antonio Creek about 10.5 miles upstream from its confluence with Chino Creek, which is a tributary to the Santa Ana River. San Antonio Creek originates in the San Gabriel Mountains on the south slopes of San Antonio Peak at elevation 10,064 feet NGVD. It flows in a southerly direction approximately 11 miles into San Antonio Reservoir, draining an area of 26.7 square miles. The San Antonio Reservoir lies mostly in San Bernardino County with only a small portion falling within the Los Angeles County boundary line. The dam is sited at the mouth of the canyon where San Antonio Creek emerges from the San Gabriel Mountains.

The gate "standby" position is one gate open at 0.3 feet with the remaining two gates closed. During the initial stages of an inflow event, the three gates remain at the "standby" setting to form a debris pool until the water surface elevation rises above elevation 2,164 feet NGVD. From water surface elevation 2,164 feet NGVD to 2,170 feet NGVD, outlet gates are raised to increase releases from 80 cfs to 5,030 cfs. When water surface elevation rises above 2,170 feet NGVD, an average release of 7,500 cfs is maintained, with the maximum release capped at 8,000 cfs. When the water surface rises to elevation 2,238 feet NGVD, uncontrolled spillway flows will begin. During the initial spillway flows, releases from the outlet gates are adjusted so that the combined spillway flow and the outlet gates outflow will not exceed 8,000 cfs. When the uncontrolled releases exceed 8,000 cfs, the controlled releases from the outlets are shut off. Flood releases from San Antonio Dam plus local downstream runoff are discharged into the Prado Reservoir, another project operated by USACE in the Santa Ana River Basin downstream from the San Antonio Dam.

During the falling stages, the operational schedule is followed in reverse until the water surface level falls to elevation 2,176 feet NGVD. When the water surface elevation falls below 2,176 feet, a decision can be made to continue flood control releases or go off-schedule for water conservation operation. During the water conservation operations, releases from San Antonio Dam are coordinated with the city of Pomona’s Water Operations Division. Most of the releases, if not all, coming out of San Antonio Dam are diverted for spreading operations by the city of Pomona as part of the Pomona Valley Protective Association (PVPA). Any excessive flow going down the San Antonio Creek can be diverted by the Mountain View Water Company, the Chino Basin Municipal Water District, and the Chino Basin Water Conservation District.

The 15.7-mile San Antonio and Chino Creek Channels Improvements Project provides the following channel capacities: 1) channel capacity is 8,000 cfs immediately downstream of the dam; 2) channel capacity increases from 8,000 cfs at the dam to 17,000 cfs at the Chino Creek confluence; and 3) channel capacity increases from 17,000 cfs at the Chino Creek confluence to 29,000 cfs at the discharge point to the Prado Reservoir. Diversions for water conservation were provided in the improved channel for the PVPA, the Mountain View Water Company, and the SBCFCD.

The current WCM for San Antonio Dam was approved in July 1991.

2.2.4 Groundwater Recharge

This section will describe the surface water recharge system that OCWD has developed downstream of Prado Dam, including the number and types of recharge facilities, diversion capacities, storage capacities, and recharge capacities, and how these capacities change with time during the storm season and in the springtime after the storm season. This section will also present estimates of how stormwater capture and recharge varies with the water conservation pool volume at Prado Dam. Although OCWD has developed a system capable of capturing and recharging large quantities of stormwater, there are limits to the flows that can be diverted from the Santa Ana River. Prado Dam is critical to capturing these high-flow events that otherwise would be lost to the ocean.

2.2.5 Upper Santa Ana Watershed Stormwater Recharge

This section will describe the existing and planned stormwater recharge activities of agencies upstream of Prado. This includes onsite infiltration of stormwater required in municipal separate storm sewer system permits. The recent work in preparation of the Upper Santa Ana River Habitat Conservation Plan will be used to assess potential ranges in the amount of stormwater that may be captured upstream of Prado Dam.

2.3 Water Management Context and Challenges

2.3.1 History of OCWD/USACE Collaboration and Agreements

This section describes the history of OCWD's collaboration with USACE, which dates back to the construction of Prado Dam (completed in 1941). Some key dates are as follows:

- **1991:** USACE and OCWD begin to formalize water conservation (stormwater capture) operations at Prado Dam though MOAs.
- **1993:** MOA provides for flood season (October–February) and non-flood season conservation pool elevations of 494/505 feet above mean sea level (MSL), respectively.
- **2006:** MOA provides for flood season conservation pool elevation increase from 494 to 498 feet above MSL (no change to non-flood conservation pool elevation).
- **2018:** Deviation provides for 505 feet above MSL in flood season for the next five years. It is anticipated that a new MOA may make this conservation pool permanent in the near future (pending completion of *Prado Basin Ecosystem Restoration and Water Conservation Feasibility Study*).

Stormwater conserved at Prado Dam is temporarily held in the buffer pool. USACE coordinates with OCWD to drain the stormwater temporarily captured at the dam as quickly as possible for recharge into the Orange County Groundwater Basin. OCWD does not have a dedicated water supply pool at Prado Dam. Prado Dam's primary purpose is flood risk management, and USACE has complete authority and discretion to operate Prado Dam and release water held in the buffer pool as it deems necessary.

This section will summarize the key features that led to successful implementation of the current USACE-OCWD stormwater capture program at Prado Dam.

2.3.2 Improving Water Conservation, Flood Risk Management, and Environmental Objectives

Prado FIRO water conservation objectives are to:

- Maximize the use of available storage space at Prado Dam for stormwater capture and downstream groundwater recharge.
- Minimize the occurrence of water released from the buffer pool before a storm not being captured for downstream groundwater recharge due to an over-forecast of Prado inflow.
- Operate the dam in the flood season with flexibility for small, short-term exceedance of buffer pool maximum elevation (five days or less) so that the water surface elevation can be adjusted after the peak stormflow rate subsides in a manner that maximizes downstream groundwater recharge.
- Provide analysis and framework for potentially higher temporary storage space in the future.

Prado FIRO flood risk management objectives are to:

- Ensure that, at a minimum, any FIRO alternative must not negatively impact the flood risk management capacity of Prado Dam. During this work, the flood risk management capacity of Prado Dam will increase (see Section 2.4). Evaluations will take this shifting capacity into account. In the process of developing and evaluating alternatives, it is entirely possible that the flood control capacity of Prado Dam can be improved.

Prado FIRO environmental objectives are to:

- Explore habitat enhancement options that could offer environmental co-benefits.
- Avoid and, where avoidance is not possible, minimize and mitigate negative impacts on natural resources.

The total amount of Prado Dam's additional storage volume that may be used for temporary stormwater capture is 15 percent of the total storage below the spillway crest or 50,000 AF, whichever is less. USACE policy provides that the volume may be less than 15 percent based on various factors (USACE ER 1105-2-100, April 2000). For the current spillway elevation of 543 feet, 15 percent of the available volume is 26,000 AF (508 feet water surface elevation). For the future spillway upon completion of SARM, 15 percent of the available volume is 50,100 AF (the cap of 50,000 AF would apply). A storage volume of 50,000 AF corresponds to a water surface elevation of 517 feet. A potential increase in the maximum elevation of temporary stormwater capture will need to assess USACE ER 1105-2-100, other USACE policies, land uses within the Prado Basin, potential environmental impacts, and potential infrastructure impacts.

2.4 SARM Project Phases and Timelines

The SARM project consists of seven major features, including constructing a 550-foot earth and rock fill dam, raising the embankment of Prado Dam by 28 feet, widening and deepening the 23-mile river channel between Prado Dam and the Pacific Ocean outlet in Orange County, creating a water holding reservoir on Santiago Creek, and widening and deepening three major flood channels (Oak Street Drain in Riverside County and San Timoteo Creek and Mill Creek Levees in San Bernardino County).

2.4.1 Phase A: Reach 9 Construction, BNSF Railroad Bridge, Reach 9 Channel Modifications → 2021

2.4.1.1 Reach 9 Channel Improvements—Phases 2A, 2B, 3, 4, 5A, 5B, and BNSF bridge

Reach 9 begins just downstream of the Prado Dam Outlet channel to the Weir Canyon Road bridge crossing. The Reach 9 project, when completed, will be able to convey long-term controlled releases from Prado Dam up to a maximum of 30,000 cfs.

The Reach 9 project segments for improvements are located at the 1) Green River Housing Estate, 2) Green River Mobile Home Park, 3) lower State Route 91 embankment, and 4) car wash and strip mall just north of Weir Canyon Road. Improvements to these segments were performed in phases, namely Phases 2A, 2B, and 3, which were completed by October 2014. Construction on Phase 4, 5A, 5B, and the BNSF bridge is on-going.

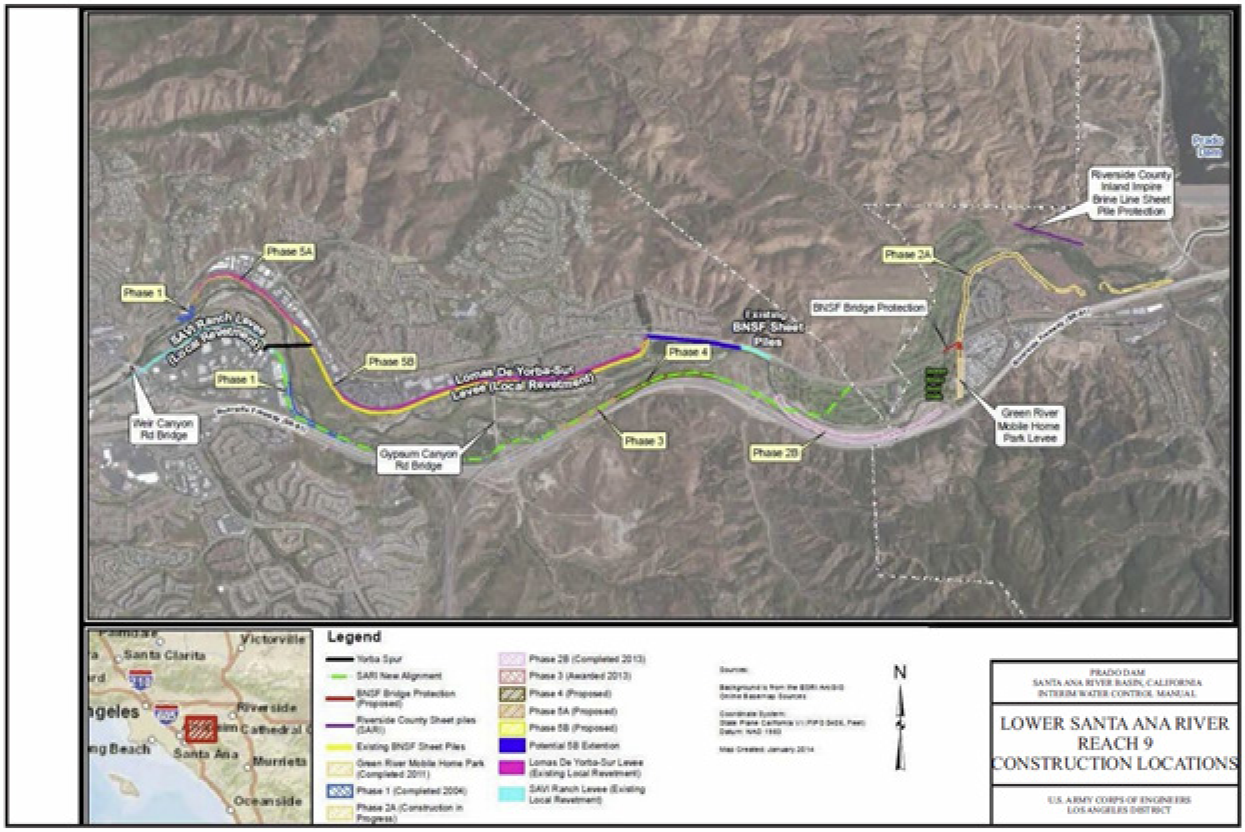

Figure 11. Santa Ana River Reach 9 construction locations.

Figure 11 provides the locations of all Reach 9 project phases, and the following paragraphs provide more detail for each completed phase.

a. Phase 2A (State Route 91 embankment). Immediately downstream from the Prado Dam concrete outlet channel and drop structure below Prado Dam, the slope of State Route 91 on the left bank of the Santa Ana River had been unprotected. Following the winter storm events of water year (WY) 2005, the stabilization measures originally planned for this segment as part of the Reach 9 project were deemed insufficient for long-term high-volume releases following a large release (10,000 cfs) from Prado Dam. The Phase 2A project was redesigned to make use of more robust bank protection options. The design now includes grouted stone revetment, launchable derrick stone toe, driven sheet pile, and combinations of these three to protect State Route 91 and the housing tracts on the left bank of the Santa Ana River. All work was completed by October 2014.

b. Phase 2B (Green River Golf Course). The original channel through the Green River Golf Course included a concrete lined low flow channel. To protect State Route 91 from flood discharges, the California Department of Transportation (Caltrans) improved the left bank of the channel with soil-cement protection with a toe depth of 5 feet. However, the increased release rates of WY 2005 (10,000 cfs) from Prado Dam proved these improvements to be inadequate for increased rates of release. The Phase 2B project coupled a small amount of driven sheet pile with grouted stone bank protection to shield State Route 91 (and indirectly the mobile home park) from increased release rates from Prado Dam. The plan also allowed for environmental restoration, providing aeration, adequate substrate, and stone structures designed to increase the habitat of the protected Santa Ana sucker. All work was completed by June 2014.

c. Phase 3 (Gypsum Canyon Road to Coal Canyon Road). Phase 3 is located on the south bank of Reach 9 downstream of Phase 4. The existing soil cement bank was built by Caltrans and extends 5 feet below the surface. Based upon the results of the hydraulic analysis and sediment transport study for the Santa Ana River Interceptor (SARI) sewer line in 2010, it was determined that the existing protected reach length and depth of toe-down was not sufficient to keep the bank from eroding and potentially impacting the freeway. New soil cement bank protection 10 feet thick was proposed, which will provide protection below the estimated maximum potential scour depths. This protection alignment extends approximately 300 feet downstream beyond where the historic low flow channel alignment migrates away from the bank and toward the center of the channel. To avoid impacting the relocated SARI line between the bank protection and State Route 91, the downstream terminus incorporated a flare-out. The river also widens to nearly 2,000 feet in this portion of the reach. The anticipated scour and the adjacent low flow channel in this area establish the need for bank protection. The construction contract for this portion of the project was awarded in September 2013; construction was completed in March 2015.

d. Phase 4 (between Gypsum Canyon Road and Coal Canyon Road). The Phase 4 bank protection project is on the south bank along State Route 91. Phase 4 is approximately 3,900 feet in length and extends upstream from approximately 3,500 feet upstream of Gypsum Canyon Road Bridge to approximately 1,500 downstream of Coal Canyon. Phase 4 bank stabilization continues the Phase 3 improvements upstream and ties into existing high ground at the upstream extent. The upstream extent of Phase 4 ties into a bluff on Chino Hills State Park land that has experienced discharges exceeding 100,000 cfs and has not historically eroded. The project elements for Phase 4 consist of soil cement slope protection, bank stabilization construction, and improvements of numerous interior drainage systems. The project elements will protect the existing south bank and slope from sustained releases up to and including the design discharge of 30,000 cfs from Prado Dam. This will include interior drainage and result in a design discharge at the project of approximately 35,500 cfs. It is essential that the project is fully functional for a range of sustained flows because the historical meandering flow patterns within Reach 9, especially for intermediate discharge releases, may allow for the horizontal migration of flows and increase the potential for impingement upon the banks. Construction is ongoing with completion within the next two years.

e. Phase 5A (Weir Canyon Road to Via Lomas De Yorba West Road). The Phase 5A bank protection project is on the north bank along a portion of the existing alignment of the Lomas De Yorba-South (LDY-S) Levee. Phase 5A bank stabilization continues the Phase 1 improvements on the north bank to just upstream of Via Lomas De Yorba West Road, where Phase 5A will tie into the existing bank and eventually the proposed Phase 5B bank protection in the future. The project elements for Phase 5A consist of grouted riprap slope protection, sheet pile bank stabilization construction, and improvements of numerous interior drainage systems. The project elements will protect the existing north bank and slope from sustained releases up to and including the design discharge of 30,000 cfs from Prado Dam. This will include interior drainage and result in a design discharge at the project of approximately 36,500 cfs. It is essential that the project is fully functional for a range of sustained flows because the historical meandering flow patterns within Reach 9, especially for intermediate discharge releases, may allow for the horizontal migration of flows and increase the potential for impingement upon the banks. Construction is ongoing with completion within the next two years.

f. Phase 5B (via Lomas De Yorba West Road to Coal Canyon Road). The Phase 5B bank protection project is on the north bank, immediately upstream of Phase 5A, beginning near Via Lomas De Yorba West Road and running upstream along the alignment of the existing LDY-S Levee for approximately 3 miles. The bank protection may be extended an additional 3,000 feet upstream. The recommended revetment type is grouted stone or a comparable revetment material, such as soil cement. Under the grouted stone alternative, approximately 3 miles of grouted stone would replace the existing levee and the river bank upstream of the levee that is currently unprotected. The new bank protection would have a toe depth of 5 feet for scour protection and provide erosion control and subsequent flood protection. In addition, the upstream limit of Phase 5B would be set at the same alignment and limit of the existing bank protection. Upon further evaluation, it may also be extended upstream to the BNSF sheet pile wall to protect the BNSF rail line. Construction is ongoing with expected completion with the next two years.

g. BNSF railway bridges. The BNSF railway bridges are located just downstream from the end of the Phase 2A project. These three bridges cross the Santa Ana River and are an operational constraint to Prado Dam's maximum release capability of 30,000 cfs. The bridge abutments are within the river and are subject to scour, and it is estimated that the maximum tolerable discharge from Prado Dam is 10,000 cfs. The BNSF bridge protection construction contract was just recently awarded and should be completed within the next two years.

2.4.2 Phase B: Completion of Interior Dikes in Reservoir, Raise Spillway → 2023

2.4.2.1 Dikes Within the Reservoir with Raised Spillway Structure

It is anticipated that the future enlarged Prado Dam and Reservoir would provide a total storage allocation below spillway crest (elevation 563 feet) of about 362,000 AF, including a 70,000 AF, 100-year sediment allowance.

As part of the Prado Dam's modification contract, dikes have been constructed to protect some of the government and privately owned developments within and around the reservoir (Figure 12).

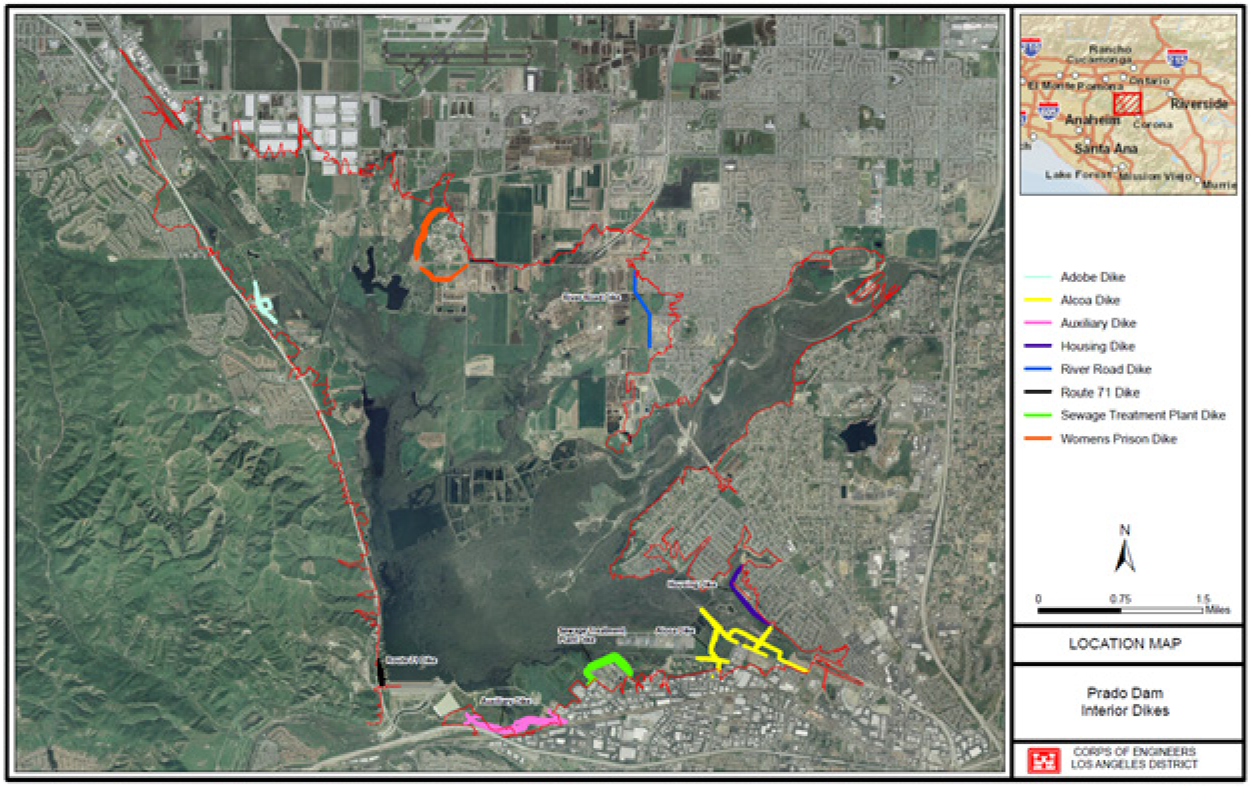

Figure 12. Prado Dam interior dikes.

There is a dike along the Corona Expressway (State Route 71 Dike) and four other completed interior dikes that have a final elevation of 566 feet, which coincides with the new taking line elevation of the completed Prado Dam modification project. Two additional interior dikes will be constructed at the Alcoa Aluminum Plant and River Road.

a. Dike at Corona Expressway. The Corona Expressway (State Route 71) is located along the western edge of the reservoir area of Prado Dam. The top of road elevation has been raised to elevation 594.4 feet to contain the probable maximum flood (PMF) elevation of 589.9 feet. This high point is also located approximately 2,200 feet north of the dam embankment—not at the axis of the dam—to avoid necessary modifications to the highway bridge that crosses the Santa Ana River as well as the interchange with the Riverside Freeway (State Route 91). The Corona Expressway dike also has a top elevation of 594.8 feet along the east side of State Route 71 between the abutment of the dam and the highest point. The dike is approximately 2,130 feet in length, and its slope surface on the reservoir side is revetted with 24 inches of stone. Construction was completed in 2012.

b. Auxiliary Dike and Floodwall. The compacted earth fill dike wall extends from the south side of the spillway to the west side of Serfas Club Drive and is approximately 5,370 feet long. The top width of the dike is 20 feet at elevation 594.8 feet. The maximum height of the dike above the existing ground is approximately 74 feet, with an average height of about 30 feet. The dike embankment has side slopes of 1 vertical on 2.25 horizontal, and the slope revetment consists of 24-inch stone over 9 inches of bedding material and 6 inches of filter on the reservoir side. About 600 lineal feet of dike are being built to connect to the city of Corona's grade separator project. The concrete floodwall is located along the north side of the railroad track, currently 120 feet from the east of Serfas Club Drive to a point 1,000 feet east of Serfas Club Drive where the existing ground is at elevation 595 feet. The floodwall is constructed within a 20-foot wide dedicated easement located approximately 100 feet north of the existing railroad track. Wall heights will range from 16 feet at the western end to 2 feet at the eastern terminus, and 120 remaining lineal feet of floodwall will be built to connect to the city of Corona's grade separator project. Construction is expected to be completed in FY 2020.

c. Yorba Slaughter Adobe Dike. The design for the Yorba Slaughter Adobe Dike was not originally part of the Prado Dam modification project, as provided in the 1988 Phase II GDM. The dike will protect the Yorba and Slaughter Families Adobe, a California State Historical Landmark and one of the oldest standing adobe residences in San Bernardino County. The dike is in the northwestern part of the basin approximately 3.5 miles north of Prado Dam. It is a compacted fill with a 15-inch riprap face on the waterside and is earthen on the landside. The top of dike elevation is 566 feet and is up to 30 feet above the existing ground. Construction is ongoing and expected to be completed in FY 2020.

d. Dike at Corona Sewage Treatment Plant. The city of Corona owns the existing sewage treatment plant, which is located on 49 acres of reservoir land owned by the U.S. government. The land has been leased to the city since 1967. The treatment facility, which consists of sedimentation tanks, aeration tanks, digesters, and the control buildings, occupies approximately 20 percent of the leased land. The sludge drying beds occupy the majority of the remaining space. The treatment facility and about half of the drying beds are below elevation 566 feet. A ring dike was constructed on the outside boundary of the facility. The dike is approximately 3,810 feet long with a maximum height of 53 feet above the existing ground surface. Construction was completed in 2018.

e. Dikes at the California Institution for Women. Approximately 75 percent of the California Institution for Women site is below the proposed taking line at elevation 556 feet. The newdikes are located on the western and southern border of the facility with a 16.3 AF ponding area between elevations 551 feet and 557.6 feet. The dike on the western side of the facility is approximately 2,860 feet long with a top elevation varying from 566 feet to 568.6 feet. The dike along the southern side of the facility is 2,910 feet long, 1,130 feet of which will be on privately owned land. The top of dike elevation varies from 556 feet to 570.7 feet. The dikes were completed in 2016.

f. Dike and Floodwall at Corona National Housing Tract. The housing tract is located within the city limits of Corona adjacent to the southeastern portion of the Prado Dam Reservoir. Approximately 20 homes along Meadowview Street and Greenbriar Avenue are located within the proposed taking line at elevation 566 feet. A dike was built along the southwestern side of the housing tract, and a floodwall was built on the northwestern boundary of the tract where there is not adequate space for a dike. The floodwall is 1,080 feet long, 6 feet tall, and constructed using reinforced concrete. The dike is approximately 1,870 feet long with a 15-foot top width. The maximum height is 24 feet with an average height of approximately 17 feet above the existing ground surface. Construction was completed in 2018.

g. Dike at Alcoa Aluminum Plant. The privately-owned Alcoa Aluminum Plant is located just outside of the existing right-of-way in the southeastern part of the reservoir. The entire plant is located within the proposed reservoir taking line at elevation 566 feet. However, other privately-owned developments in the proximity of the aluminum plant fall below that elevation. It was more economical to construct a dike around the aluminum plant and these other properties, rather than acquire them for flood risk management purposes. The proposed dike will be located on government land, adjacent to existing Smith Avenue and Rincon Street. This alignment minimizes impacts on existing facilities such as streets, utilities, sludge drying beds, and other industrial and commercial developments. The dike will be 5,550 feet long, with its top elevation varying between 556 feet and 569.8 feet, in accordance with freeboard design. It will have a top width of 15 feet and an average height of 30 feet above the existing ground surface. The maximum top levee height is 30 feet. The reservoir side of the slopes are protected with 18 inches of stone over a layer of filter cloth. A 55.5 AF ponding area is located between elevations 554.7 feet and 550.7 feet, as well as a 36-inch culvert with a flap gate at the outlet structure to handle interior drainage. Construction began in June 2018 and will be completed by October 2019. The dike will be constructed in two phases.

h. River Road Dike. Similar to the Yorba Slaughter Adobe Dike, the design for the River Road Dike was not included in the previous design memorandums. The River Road Dike will be located along the westerly side of River Road, between Bluff Street and Trail Street, approximately 3 miles northeast of Prado Dam. The dike is the recommended alternative from a value engineering proposal prepared by Orange County that consists of constructing an earthen dike 4,500 feet long, ranging in height from 0 to approximately 14 feet. Constructing a dike would be more economical than real estate acquisition of six affected properties. Construction is expected to begin in late FY 2019 or FY 2020.

2.4.2.2 Raising the Existing Spillway from Elevation 543 to 563 Feet

The *Phase I GDM on the Santa Ana River Mainstem Including Santiago Creek*, dated September 1980, recommended the existing spillway be widened from 1,000 feet to 1,300 feet. A 1988 spillway embankment optimization study superseded this recommendation and indicated that the most economical design was to maintain the existing length. The existing spillway structure, however, needs to be raised from its current elevation at 543 feet to elevation 563 feet.

The water surface profile for a spillway crest that is 20 feet higher was based on the results of the hydraulic model testing conducted by the hydraulic engineering staff at USACE's Waterways Experiment Station (WES) in Vicksburg, Mississippi, while completing the *Prado Dam Major Rehabilitation Report* for the Dam Safety Assurance Program. Modification of the spillway will begin after Orange County acquires all real estate required for flood easements up to elevation 566 feet. Until then, the flood risk management pool will remain at the current spillway crest elevation of 543 feet.

One proposed modification to the spillway would raise the existing concrete ogee section (the spillway crest) by 20 feet with the addition of a concrete cap. Spillway walls would also be extended by adding either concrete or vertical inclined walls, depending on the location and terrain conditions in the vicinity of the existing structure. WES's model study of the spillway indicated that the floodwater flows at the approach of the spillway would be erratic unless training dikes are provided on both banks of the approach channel. These dikes will extend 300 feet upstream from the spillway crest and be earthfill structures with 18 inches of grouted stone revetment. At elevation 589.9 feet on the east side of the spillway, the top width of the dike will be 16 feet. Due to the location of the west dike near the entrance of the new outlet works, the top of the dike will be limited to elevation 553 feet. A concrete training wall will be constructed between elevations 553 feet and 589.9 feet.

The current status of the spillway design is in flux due to an updated PMF and other dam safety concerns regarding the spillway concrete apron.

2.4.3 Phase C: SARM Project Complete → 2023

2.4.3.1 Re-evaluation of Prado Dam Safety Action Classification (DSAC) Rating and Changes to WCM

Prado Dam DSAC 2 changed to DSAC 1 due to the existing spillway's erodible foundation and concrete slab condition. Consequences are very high—up to 1.4 million people are at risk and the economic impacts could be severe. Furthermore, 28 cities in four counties could be impacted. The spillway may need to be redesigned/re-evaluated for the updated PMF values.

The Prado Dam IWCM is currently under review. The latest update of the IWCM will assume the major deviation elevation of 505 feet for water conservation.

3. Catalog and Assessment of Existing Monitoring Programs

3.1 Surface Observations

The NWS collects precipitation data from approximately 80 stations in the Santa Ana River watershed. About 25 of these stations are quality controlled and ingested for hydrologic modeling. Several agencies operate and maintain these stations, including the Bureau of Land Management (one station), the U.S. Forest Service (seven stations), the California Department of Forestry and Fire (two stations), the counties of San Bernardino and Riverside (12 stations combined), the USGS (two stations), and USACE (one station). The stations are situated primarily in the 1,000- to 5,000-foot elevation range, with the lowest elevation at 640 feet MSL and the highest at 6,903 feet MSL. Precipitation measured at these stations is aggregated into six- and 24-hour blocks and quality controlled at the NWS CNRFC. These data are then spatially distributed using a tool employing a PRISM climatology background and distance weighting to form mean areal precipitation values for each of the sub-basins used in the CNRFC's hydrologic modeling. Subsets of the gages that report precipitation also report temperature (four stations). The CNRFC uses these stations to collect and quality control six-hour mean temperatures and 24-hour maximum and minimum temperatures similarly to how it quality controls precipitation data, ultimately producing mean areal temperatures for each of the sub-basins used in the CNRFC's hydrologic modeling.

The CNRFC uses seven USGS stream gages as part of its hydrologic modeling system for the Santa Ana basin. San Bernardino County and Riverside County operate and maintain additional ALERT stream gaging stations in the basin.

3.2 Remote Sensing

The NWS operates a Weather Surveillance Radar (WSR-88D) in the Santa Ana Mountains at 3,106 feet MSL. The radar detects precipitation and winds aloft over the watershed.

A few elements of the California DWR/NOAA Environmental Research Laboratory AR observing system can contribute to the monitoring effort for the Prado Dam FIRO. An AR observatory on the coast is located at the Santa Barbara Airport. This observing system can be used to determine the onshore flux of water vapor associated with ARs making landfall in the region. Snow-level radar in Devil's Canyon and provides freezing elevation (elevation where rain turns to snow). A number of GPS-Met stations are in the region and quantify water vapor concentration related to precipitation amounts in AR storms.

3.3 Environmental

This section describes existing environmental monitoring programs. OCWD, USACE, the Santa Ana Watershed Association, and other stakeholders implement environmental monitoring programs in the Prado Basin. OCWD intensively monitors vireo nesting, vegetation health, and other natural resources. OCWD, the Chino Basin Watermaster, and the Inland Empire Utilities Agency also acquire aerial photography of Prado Basin each year, while stakeholders collect data on natural resources in the Santa Ana Canyon downstream of Prado Dam.

This section will also identify shortcomings, if any, in the existing environmental monitoring programs and identify future environmental monitoring needs for potential implementation of FIRO.

3.4 Gaps and Potential Enhancements

The CNRFC has judged that the network of precipitation and temperature gages throughout the Santa Ana River watershed is adequate for the current hydrologic forecasting services the agency provides. Temperature tends to be relatively smooth when analyzed spatially, primarily varying due to elevation, and is exclusively used in the snow model portion of the CNRFC suite of hydrologic forecasting tools. Thus, a much smaller set of temperature gages can adequately capture the spatial variability in temperature. If forecast demands change during this work, enhancements to the gaging network to support CNRFC forecasting may be required.

The existing gaging network is adequate for the operational decisions that USACE and OCWD currently make. The exploration of FIRO alternatives may place additional demands on observations. This study will consider additional observations.

While surface-based meteorological observations in the watershed are sufficient for CNRFC hydrologic forecasting services, deploying additional instrumentation to observe precipitation mechanisms is essential to identifying sources of event-to-event variability in the spatiotemporal distribution of precipitation and precipitation rate across the watershed. A CW3E-coordinated field campaign to enhance observations of the physical processes that drive precipitation (microphysics, water vapor transport, orographic forcing, etc.) is expected to include two to three field sites in and around the Santa Ana River watershed. The sites will deploy instrumentation similar to that in the Russian River for current FIRO investigations, including a laser disdrometer, a micro-rain-radar, and atmospheric sounding equipment. These sites will additionally leverage the existing network of NEXRAD and radiosonde locations to enable novel studies of the mechanisms that drive event-to-event variability in precipitation rate and accumulation throughout the region. Additional discussion of the proposed field campaign, including a map of potential field sites and instrumentation, is found in Section 6.6 (Figure 10).

4. Catalog and Review of Existing Models

This section presents an overview of the models used in the Santa Ana River watershed (see Table 3). Subsections will describe key models in more detail. The FIRO team will consider and leverage available models while exploring and resolving this study's questions. Some of the key models are further described below.

Table 3. Models Used in the Santa Ana River Watershed

Model (Source)	Purpose	Model Category
Surface Water Model (Wildermuth Environmental)	Support water supply/water quality as part of SAWPA task force.	Hydrologic/ Hydraulic
Surface Water Model (Geoscience Support Services)	Update of Wildermuth model.	Hydrologic/ Hydraulic
CHPS: Community Hydrologic Prediction System (NOAA/NWS/CNRFC)	Use of multiple models to generate Prado inflow forecast.	Hydrologic/ Hydraulic
Integrated Surface/Groundwater Model (Geoscience Support Services)	Integrate five groundwater basin models (probably not relevant to FIRO).	Groundwater
Corps Water Management System: CWMS (USACE)	Interface that allows the use of multiple USACE models (e.g., HEC-RAS, HEC-ResSim, etc.)	CWMS
LAD Prado Reservoir Model (USACE)	Spreadsheet model used to inform reservoir operations during storm periods.	Hydrologic/ Hydraulic
Recharge Facilities Model (OCWD, Jacobs)	Simulates operation of OCWD groundwater recharge facilities.	Hydrologic/ Hydraulic
Groundwater Basin Model (OCWD)	MODFLOW model of OCWD groundwater basin	Groundwater
Climate Change Analysis for the Santa Ana River Watershed (U.S. Bureau of Reclamation, VIC model)	Downscaled climate modeling for Santa Ana River watershed. https://www.usbr.gov/lc/socal/basinstudies/OWOWReferences/FinalReport/TM%201%20Climate%20Change.pdf	Weather/Climate
Five Year (2017 to 2022) Planned Deviation to the Prado Dam Water Control Plan and Sediment Management Demonstration Project Biological Assessment (USACE, HEC-RAS)	Contains analysis of sediment transport and Prado Dam hydrology. https://www.spl.usace.army.mil/Portals/17/docs/publicnotices/AppendixD_BA_wTech_Repts.pdf?ver=2017-08-21-170237-623	Hydrologic/ Hydraulic

4.1 Hydrologic/Hydraulic

4.1.1 CHPS—Community Hydrologic Prediction System (NOAA/NWS/CNRFC)

CHPS provides the structure for running multiple rainfall-runoff models above Prado Dam. The Prado watershed inflow forecast model is currently divided into eight basins. Each basin has components for simulating and forecasting rain-snow elevation, snow accumulation and melt (SNOW-17), soil runoff (SAC-SMA), and hydrograph routing (LAG/K). Forcing input includes a 10-day temperature forecast, six-day QPF, and six-day freezing-level forecast. While most model components are run on a six-hour time step, some tributaries (Lytle Creek, San Timoteo Creek, and Temescal Creek) are run on an hourly time step.

CHPS also produces probabilistic inflow hydrographs using the Hydrologic Ensemble Forecast Service (HEFS). HEFS forecasts include both short-range (15-day) and long-range (365-day) simulations. Short-range probabilities are produced from hourly hydrographs based on a hybrid of both CNRFC QPF forecasts and the Global Ensemble Forecast System (GEFS) forcings. Long-range products are produced on a daily time step based on climatological forcings beyond 15 days.

The CHPS model continuously produces forecasts 365 days per year. During flood events, forecasts are produced every six hours. CHPS allows hydrologic forecasters to make real-time adjustments to the model during flood events. Forecasts for the Prado Reservoir are run from the Joint Operations Center in Sacramento, where both NWS forecasters and California DWR forecasters collaborate in operational forecasting.

The current operational Prado inflow model was last updated in 2014. Additional detail could be added to the model by forecasting San Antonio Creek, Cucamonga Creek, and Chino Creek.

More information about CNRFC modeling can be found at https://www.cnrfc.noaa.gov/about/.

4.1.2 CWMS—Corps Water Management System

CNRFC provides the current inflow predictions for the combined inflow from all contributing areas into Prado Dam twice daily and four times daily during forecasted extreme events upon request from USACE. From this information, a simple spreadsheet program is used to predict the water level behind Prado Dam. USACE's direction is to incorporate the QPF into the CWMS Santa Ana River Basin model and determine the overall flood risk within the basin, with emphasis on the flooding potential downstream of the dam. Enhanced rainfall forecasts associated with ARs and developed with FIRO, especially five-day forecasts, will be incorporated into the CWMS to develop alternative Prado inflow estimates. This additional information would help USACE water managers for both water conservation and flood operations. Background information on CWMS can be found at https://www.hec.usace.army.mil/cwms/cwms.aspx.

The CWMS team has developed the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS), River Analysis System (HEC-RAS), Reservoir System Simulation (HEC-ResSim), and Flood Impact Analysis (HEC-FIA) models for the Santa Ana River watershed. Figure 13 shows the area covered by CWMS.

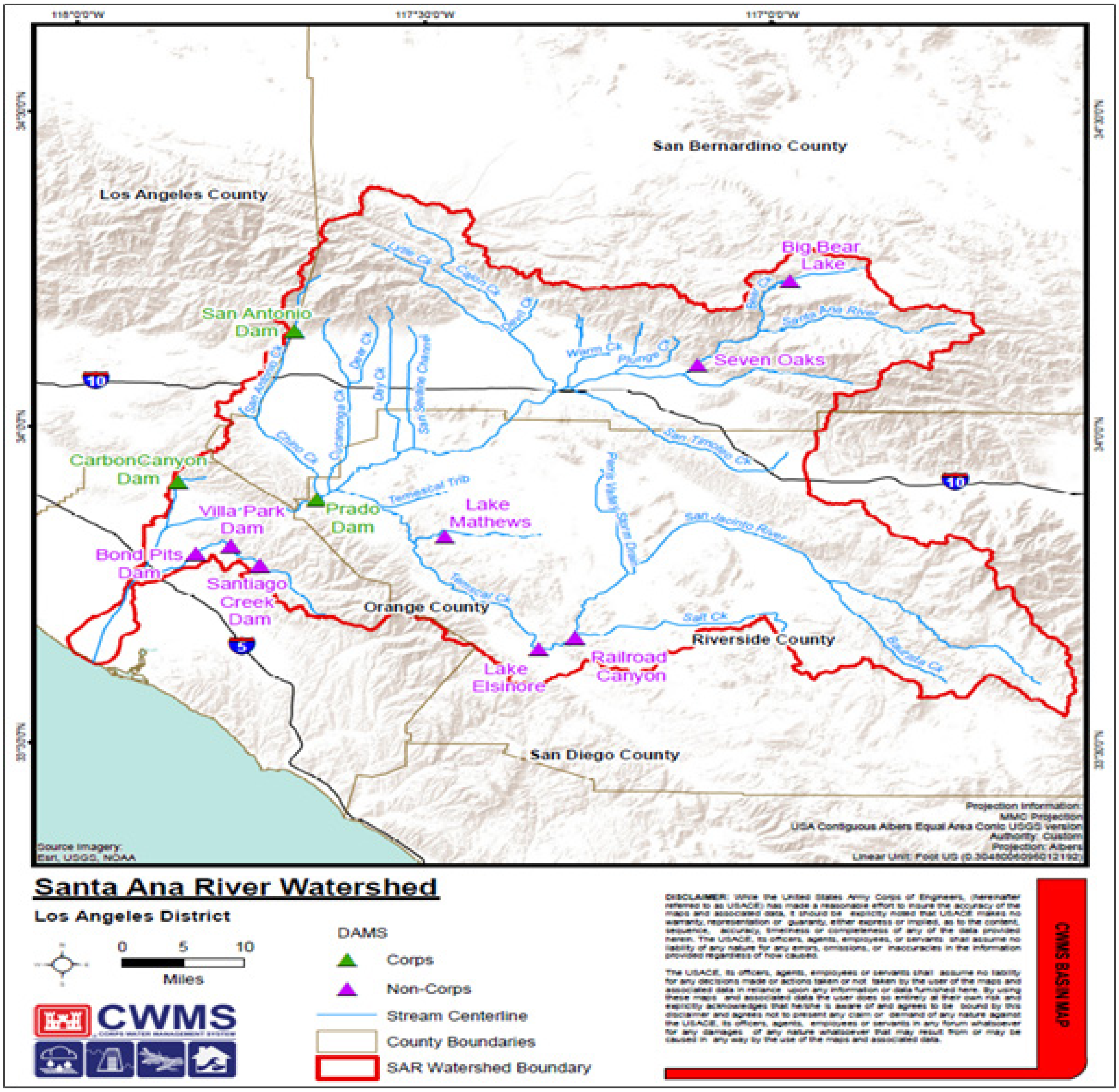

Figure 13. Santa Ana River watershed CWMS.

The HEC-HMS model simulates rainfall-runoff processes within the watershed. Additional verification and calibration of this model, however, will be necessary. This will be pursued further during the CWMS model implementation phase. Further, additional historic observed flow data should be collected to better define realistic flow contribution into the system due to other surrounding projects' regulation/operation.

The completed HEC-RAS model has undergone extensive stress testing to address stability and significant functioning issues. During development, it was found that the supercritical reaches and the lateral structures that connect the 1D model to the 2D areas create instabilities within the RAS model. A holistic calibration and verification of the model is still required, which will be further developed during the CWMS model implementation phase. OCWD may also want to consider including additional reaches such as Mill Creek, Santiago Creek, and San Timoteo Creek to enhance model accuracy.

The completed HEC-ResSim model also had extensive testing performed to verify all reservoir operation rules. Further verification will be required as the model contains two reservoirs with multiple operation sets. A script may be developed during the implementation phase to simplify operational setup by reducing the number of operation-sets within the ResSim model.

The HEC-FIA model was developed and adjusted using best available data that reasonably represent the flood impact population within the basin. While no unresolved issues were observed during the development of the FIA model, it can be further calibrated with additional updated economic data. Additionally, the FIA model can also be improved with updated flood impact tables, an updated structural inventory where additional tributaries may be added and updated critical infrastructure and census data as they become available.

The CWMS models are currently in the implementation phase, during which they will be extensively calibrated and regularly tested for use in reservoir operations. Expected completion is FY 2020.

4.1.3 OCWD RFM—Recharge Facilities Model

The OCWD RFM simulates the operation of both Prado Dam and OCWD's downstream recharge facilities. The model uses GoldSim software and incorporates multiple features, such as linking Prado Dam release rates to recharge system capacity on a daily time step. Recharge system capacity is dynamic in that clogging of the facilities and cleaning operations are tracked every day. Key model outputs for comparing various scenarios are the total volume of water recharged over a study period and the amount of water lost to the ocean.

4.1.4 Sediment Model

USACE is currently developing a 1D HEC-RAS sediment model for the SARM. The model consists of two parts—the Santa Ana River from Seven Oaks Dam to just upstream of Prado Basin and from the Prado Dam outlet through Reach 9. The model will determine a 40-year sediment trend in the mainstem river to determine impacts to the Santa Ana sucker. Expected completion is FY 2020.

4.2 Groundwater

The Integrated Surface/Groundwater Model (Geoscience Support Services) simulates groundwater flow near Prado Dam. The model is scheduled to be completed and available for use in October 2019. It is not likely that this model will be relevant on the FIRO timescales.

Within Orange County, OCWD staff developed and calibrated a basin-wide, transient, three-layer groundwater flow model (basin model) in 2000. In 2012, the model was subsequently converted from three to five layers by explicitly modeling the intervening aquitards rather than using leakance. The basin model was developed as a predictive tool to test future basin management strategies and their impacts (e.g., inland well fields and new recharge projects). The model has also been a valuable learning tool for determining how the groundwater basin responds to various natural and human-induced stressors.

The basin model is capable of simulating groundwater flow between model layers in addition to flow within each layer. The three aquifer layers conceptually represent the shallow, principal, and deep aquifer systems in the basin. The top model layer (layer 1) includes the uppermost 300± feet of the basin. The middle layer (layer 3) represents the principal aquifer system where approximately 90 percent of basin groundwater production occurs. The bottom layer (layer 5) represents the deep aquifer system, which includes zones containing colored water in the coastal areas of the basin. Model layers 2 and 4 represent the intervening aquitards. These aquitards are partially absent in the Anaheim Forebay area near the OCWD recharge facilities.

The basin model encompasses the entire Orange County groundwater basin and extends westward approximately 3 miles into the Central Basin of Los Angeles County to help reduce boundary effects within the Orange County portion of the model. Identifiable aquifer units were correlated across the basin into the Central Basin, indicating that the county line is a political boundary with no hydrogeological significance.

Coverage of the modeled area is accomplished with a uniform grid consisting of cells having horizontal dimensions of 500 feet by 500 feet (approximately 5.7 acres) and vertical dimensions that vary from cell to cell based on the defined aquifer system thickness at that grid cell location for each model layer. The five model layers make up a network of over 130,000 active grid cells. The widely accepted computer program MODFLOW, developed by USGS, is the base modeling code.

Both the development and calibration of the basin model have depended heavily on information gathered from OCWD's basin-wide monitoring well network. Defining the aquifer geometry for each model layer and for the intervening aquitards would not have been possible to the level of detail accomplished without the historical depth-specific groundwater level and quality data from these strategically located wells, as well as the lithological and geophysical data gathered during well drilling.

The transient calibration period for the original three-layer basin model was 1990–1999. Throughout the calibration process, model results were peer-reviewed by a model advisory panel comprising four groundwater modeling experts, culminating in a letter of acceptance from the panel.

Recently, the current five-layer basin model has been extended through 2017 and calibration refinement for the later years from 1999 to 2017 is currently in progress.

4.3 Weather and Climate

In addition to standard forecast tools available to the NWS, including global forecasts from the National Centers for Environmental Prediction (NCEP), European Centre for Medium-Range Weather Forecasts, and other centers, CW3E maintains an AR research and forecasting website that contains archived and real-time observations, gridded analyses, and gridded numerical weather prediction forecasts of AR-related information over the northeast Pacific and western United States (http://cw3el.ucsd.edu). The gridded analyses and forecasts on the site are created from NCEP Global Forecast System (GFS) and GEFS data provided by the NOAA National Operational Model Archive and Distribution System (NOMADS). These forecast products focus on identifying and tracking ARs over the northeast Pacific with attention to their structure, intensity, and orientation at landfall along the U.S. West Coast. Displays of integrated water vapor transport (IVT) and other gridded forecast parameters are computed from the deterministic GFS and 20-member GEFS data.

The GEFS IVT forecast probability-over-threshold maps over the northeast Pacific can provide essential uncertainty analysis for AR landfall potential. For example, Figure 14 shows a 16-day forecast time-latitude (following the U.S. West Coast) depiction of the fraction of GEFS members ensemble (including the control member) with IVT magnitudes > 250 kg/m/s for the period six days before an extreme event that impacted the Santa Ana River watershed. The vertical dashed black lines denote the time after model initialization on February 13, 2017, at 00Z (right to left), whereas the dashed horizontal line denotes the latitude corresponding to the U.S. West Coast map between 32° and 42°N.

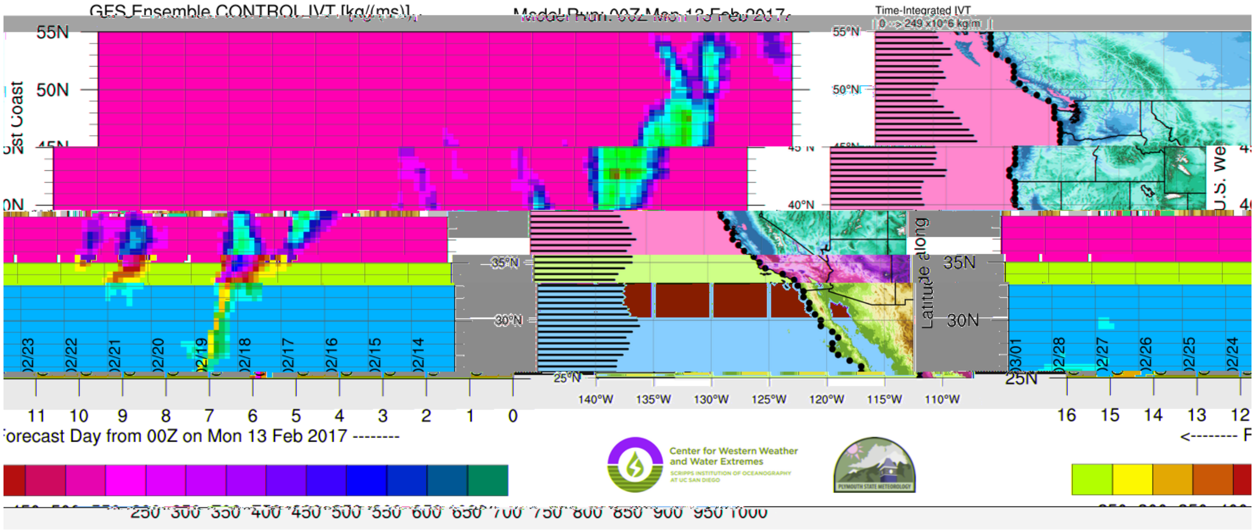

Figure 14. Depiction of the fraction of GEFS ensemble members with IVT magnitudes > 250 kg/m/s for the period six days before an extreme event that impacted the Santa Ana River watershed.

While global numerical weather prediction models, such as GFS, can explicitly simulate the largest weather scales on Earth and resolve some mesoscale fluid dynamic features, they do not explicitly resolve the smallest orographic uplift, surface flux, or cloud microphysics scales. Thus, to generate the best forecast possible, simulating the unresolved physical processes that are key to AR evolution and impacts requires a regional numerical weather prediction model that is specifically tailored to West Coast precipitation.

CW3E has invested in developing an optimal version of the Weather Research and Forecasting (WRF) model that is configured for AR precipitation in the western United States (West-WRF) and runs at 3 km resolution. The *Journal of Hydrometeorology* has published a manuscript summarizing West-WRF forecast performance (Martin et al., 2018) and detailing its advantages relative to global-scale forecasts or other regional-scale models not specifically developed for ARs. The manuscript introduces a systematic evaluation of West-WRF and GFS forecasts relative to the dedicated network of observations, explores the sources of forecast errors in QPF and atmospheric state variables, and investigates the role that explicitly modeled scales or sub-grid parameterized scales play in driving these errors. West-WRF forecasts were also used to demonstrate the benefit of high-resolution simulation to freezing level height prediction during the 2017 WY (Henn et al., *submitted*) and have led to additional publications and conference presentations over the course of the study. Over 600 unique West-WRF near real time (NRT) forecasts have been produced over the past three winter seasons. AR diagnostic output from West-WRF is hosted on the CW3E website alongside GFS forecasts.

5. Identification, Review, and Assessment (Comparison with Operational Baseline) of Contemporary Hydrologic Forecast Modeling

5.1 WRF-Hydro (National Water Model)

The WRF Hydrological modeling system (WRF-Hydro), which was developed by the National Center for Atmospheric Research (NCAR) and its research partners, simplifies the coupling of terrestrial hydrological models with the WRF model. WRF-Hydro accounts for physical processes, including surface and subsurface flow, soil moisture, and streamflow routing, and has been used to successfully forecast streamflow. In WRF-Hydro, the Noah Land Surface Model is enhanced with overland and river flow routing via the NCAR Distributed Hydrological Modeling System. WRF-Hydro is computationally suitable for investigating the role of a physically enhanced description of terrestrial hydrology on land-atmosphere feedbacks in a multi-month simulation. WRF-Hydro is also the core model of the National Water Center's operational hydrologic model, the National Water Model (NWM). The NWM provides high-resolution forecasts (of soil moisture, surface runoff, snow water equivalent, etc.) at 2.7 million stream locations nationwide (http://water.noaa.gov/map#forecast-chart), including the Santa Ana River streamflow. The NWM has the potential for regional improvement. One example is to consider soil moisture observation data for calibrating the WRF-Hydro model, which is an ongoing project at CW3E for Lake Mendocino and can be considered for the current study area as well.

5.2 GSSHA (USACE Engineer Research and Development Center)

The need for hydrologic simulations in non-Hortonian and mixed watersheds prompted USACE to invest in developing the Gridded Surface Subsurface Hydrologic Analysis (GSSHA) model. GSSHA is a fully distributed, physical-process-based, gridded hydrologic numerical tool suitable for engineering analysis and design that simulates the hydrologic response of a watershed subject to given hydrological and atmospheric inputs. GSSHA can simulate the following physical processes: precipitation distribution, precipitation interception, infiltration, evapotranspiration, surface water retention, surface runoff routing, unsaturated zone modeling, saturated groundwater flow, overland sediment erosion, transport and deposition, and constituent fate and transport for overland flows. The USACE Engineer Research and Development Center (ERDC) has built and calibrated multiple spatial-resolution GSSHA models of the Russian River watershed for the Lake Mendocino FIRO pilot project to test the applicability and benefit of using this next-generation hydrologic model in water management operations. CW3E is using these GSSHA models to investigate uncertainty in forecasting runoff by examining atmospheric forcing data.

The FIRO team will investigate the application of this approach in the Santa Ana River watershed and its benefit to operations at Prado Dam. The Santa Ana River watershed provides an opportunity for the GSSHA model to demonstrate meaningfully different results than current empirically derived watershed models, given the combination of high-elevation headwaters; snow melt-driven flows; and flat, highly urbanized watershed. GSSHA can model these factors with high accuracy over a wide range of hydrologic conditions, enabling effective operational decision-making. Unlike the Russian River watershed, the Santa Ana River watershed has a low frequency of storm events, meaning that empirical watershed models have a high degree of uncertainty. Forecasting flows using a physics-based distributed model like GSSHA will provide more forecast certainty. The modeling effort for this work will demonstrate these differences and describe the usefulness of

NOAA scientists are looking at the GSSHA model's ability to simulate soil moisture in the Lake Mendocino watershed, along with the effort to do the same with the NWM. GSSHA is applicable across various scales, from small watersheds to large river basins. Fine-resolution inset models can be constructed around features of interest in large basins. This flexibility in application lets GSSHA be tailored to the individual study area and for the simulation's exact purpose—be it river flows, groundwater stages, soil moistures, or reservoir water levels. GSSHA has been verified to be able to simulate all these physical states. Coupling the model with weather forecasts enables forecasting of a variety of hydrologic parameters, contributing to better management decisions. ERDC has contracted with NCAR to couple GSSHA with its existing ensemble and data assimilation methods, increasing the potential utility of its forecasts. While the NWM provides hydrologic forecasting for the entire continental United States, the application of GSSHA will be specific to each study.

5.3 Gaps and Potential Enhancements

This section addresses the informational and technological gaps that affect the application and performance of WRF-Hydro and GSSHA. Researchers will contribute to this section during the implementation, testing, and evaluation of these models in the Santa Ana River watershed.

5.4 Plan of Assessment

The hydrologic simulation models identified above will be assessed for their potential to provide more accurate and/or more precise streamflow forecasts in support of the project objectives. The baseline against which the models will be measured is the operational CHPS system supported by the CNRFC. CHPS is described in Section 4 of this work plan. Both WRF-Hydro and GSSHA require a great deal more information about the weather and environment than CHPS. As such, their performance can only be judged over the period that these more detailed observations are available.

Model output will be evaluated from both a "simulation" and "forecast" perspective. Simulation refers to the model's ability to generate results consistent with observations and key variables (e.g., precipitation, air temperature, multi-spectral radiation, wind speed, humidity). Forecast refers to the ability of the model to generate results consistent with future observations, given forecasts of the forcing variables. The ultimate value of the model output in the FIRO context is limited to the forecast results, but the simulation results will provide insight on the source of forecast errors.

Time and space scales will also be considered in assessing the ability of these models to meet FIRO project objectives. CHPS forecasts are limited to larger watersheds, and while information may be available at an hourly time step, the fundamental computational time step is six hours. Some project objectives may require or benefit from hydrologic forecasts for smaller areas and at more refined time steps.

Comparative statistics will be generated across common time periods and special analysis and focus will be trained on flood events that more significantly affect the operation of Prado Dam.

6. Meteorological Analysis, Assessment, and Research

6.1 AR Climatology for Santa Ana River

Research performed in the first year of the Prado FIRO scoping study led to the publication of a study diagnosing regional meteorological influences on extreme precipitation based upon case studies and the full record of 107 extreme precipitation events from 1981 to 2017 (Cannon et al., 2018). This study was performed under Tasks 4.1 and 4.2 of Phase 1, and addressed the following primary science goals:

- Use global forecast models and observational data to investigate the large-scale event conditions that produced ARs, their mechanisms for extreme precipitation, and subsequent differences in precipitation intensity and timing over the Santa Ana River watershed.
- Investigate mesoscale precipitation processes, including orographic enhancement, embedded convection, and cloud microphysics, which contributed to the spatiotemporal variability of precipitation within he watershed during each event. These analyses utilize precipitation observations from a dense network of rain gages and NEXRAD radar data within the watershed as well as high-resolution regional weather model output (West-WRF).

Cannon et al. (2018) found that Southern California water resources depend on a small number of extreme precipitation events each winter season, which dictate the highly variable interannual accumulations in the region. In the Santa Ana River watershed, 107 extreme events contributed nearly half of total precipitation between 1981 and 2017. Two-thirds of these extreme events occurred in association with landfalling ARs, though all events featured enhanced moisture transport into the watershed. The synoptic-scale conditions and precipitation mechanisms associated with these events were highly variable, as demonstrated by the orientation of moisture transport into the Santa Ana River watershed and the position of each event's attendant cyclone. Figure 15 shows a schematic of surface low pressure centers and the axis of enhanced IVT magnitude for 107 extreme precipitation events at the time of the maximum IVT over the Santa Ana River watershed. The central low pressure and IVT orientation for the two case studies discussed in Cannon et al. (2018) and the Prado years 1 and 2 scoping proposals are labeled in black.

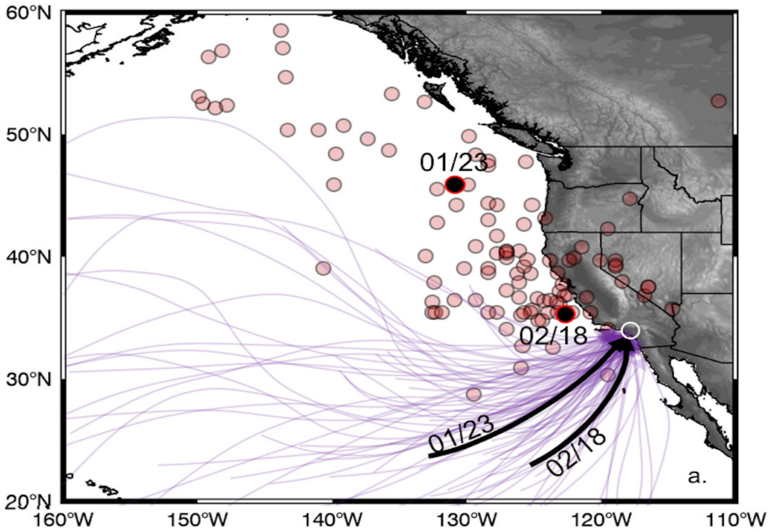

Figure 15. Schematic of surface low pressure centers and the axis of enhanced IVT magnitude for 107 extreme precipitation events at the time of the maximum IVT over the Santa Ana River watershed.

The influence of orographic lift, synoptic-scale forcing for ascent, and convective instability on precipitation were evaluated using an "ingredients-based" approach across the record of 107 extreme events. While terrain-normal water vapor flux explains a majority of the observed precipitation variance during landfalling ARs, large-scale dynamics that support the development of non-orographic and convective precipitation also strongly influenced the variance among extreme events in the Santa Ana River watershed. Event-to-event variability in these mechanisms is an important area of continued research toward better understanding precipitation mechanisms and their predictability.

Ongoing research also includes the development of diagnostic tools that guide the development of key storm mechanisms in forecast models. This effort includes expanding the set of extreme event case studies to include the largest precipitation events in recent years (e.g., December 16–23, 2010, and 2006). Furthermore, it will be necessary to perform detailed analyses of forecasted events that did not materialize (e.g., February 27, 2017) and to place these in a climatological context to understand the conditions that most frequently lead to false alarm forecasts.

6.2 Predictability of Extreme Precipitation Events

Tasks 4.3 and 4.4 in Phase 2 of the OCWD funding proposal will yield insight into the viability of FIRO at Prado Dam by 1) evaluating the predictability of identified meteorological influences in extreme events and 2) defining inflow uncertainty at Prado according to USACE and OCWD lead time requirements. These tasks include the following:

- Explore forecast skill for each 2017 case study and the record of 107 extreme events. AR forecast tools developed at CW3E will be leveraged to understand how each event's dominant precipitation influences affected its forecast skill. This task will additionally investigate QPF error in relation to findings from Tasks 4.1 and 4.2.
- Evaluate forecast skill over lead time in collaboration with USACE and OCWD to ensure that scientific advancements address current operations and needs for FIRO at Prado. This task identifies the probabilistic skill of inflow forecasts for the record of extreme events according to the lead times necessary for FIRO at Prado, as determined by operational constraints.

These analyses will provide key information regarding current forecast skill, challenges to improved predictability, and operational needs for FIRO at Prado. Results from Phase 2 will serve as the foundation for research toward improving prediction of water conservation and hazards in the Santa Ana River watershed, and they will support the transferability of West-WRF regional mesoscale forecasting in NRT to Prado interests. Section 6.3 below describes West-WRF development for FIRO at Lake Mendocino and transferability to Prado. Additionally, Section 6.4 details a major AR monitoring program to improve predictability through airborne reconnaissance and data assimilation, and Section 6.5 describes the development of an augmented AR monitoring network for Southern California.

6.3 West-WRF Transferability to Prado

The development of high-resolution numerical weather prediction models for accuracy during ARs is crucial to improved QPF skill and water supply prediction. The proposed work includes using West-WRF modeling capabilities to benefit meteorological understanding and improved forecast skill in the Santa Ana River watershed. A key step will be identifying the primary sources of QPF errors in West-WRF NRT in Southern California and targeting those physical mechanisms for continued model development. An important focus of understanding the sources of West-WRF QPF error during ARs (Martin et al., 2018) will be the development of ensemble simulations to account for uncertainty in the model's initial state, unresolved physical processes, and parameterization errors. Ensemble generation in West-WRF represents a significant advancement toward quantifying and understanding individual sources of uncertainty and mitigating initial condition errors in forecasts of western U.S. weather for water resource conservation and hazard mitigation. These efforts will potentially improve the forecasts associated with the full range of storm magnitudes impacting the Santa Ana River watershed.

The expansion of West-WRF for the Santa Ana watershed will additionally benefit from ongoing development of a West-WRF reforecast that will enable an unprecedented ability to post-process high-resolution NRT precipitation forecasts. This effort, in collaboration with USACE and CNRFC, is focused on downscaling the entire record of the GEFS Reforecast control member data (1986–2019), using the NRT West-WRF configuration. The data set will enable bias correction of forecasts and will provide guidance on forecast uncertainty.

6.4 Assessment of AR Recon Benefits and Application

The Atmospheric River Reconnaissance (AR Recon) project is exploring the use of dropsonde measurements in and around ARs over the northeast Pacific Ocean to improve the prediction of landfalling ARs on the U.S. West Coast, including their associated precipitation and streamflow. Previous research has shown that AR forecasting is more skillful at long lead times than precipitation alone (Lavers et al., 2016) and can be leveraged to increase forecast lead time of high-impact events. However, it is also understood that initial condition errors in and around ARs offshore at one to three days lead time are the leading source of model error. To provide increasingly skillful forecasts of ARs and their associated impacts, improved observations ahead of landfall are required, including through airborne observation campaigns (Doyle et al., 2014; Ralph et al., 2014a; Neiman et al., 2016; Cordeira et al., 2017).

In 2016, 2018, and 2019, AR Recon targeted improved predictions of landfalling ARs on the U.S. West Coast by supplementing conventional global forecast model data assimilation with dropsonde observations of the full atmospheric profile within ARs. During the 2019 season, three ARs with significant impacts in Southern California were sampled ahead of landfall as part of AR Recon, including a record-setting precipitation event on February 13, 2019. The offshore sampling of this AR ahead of impacts in the Santa Ana watershed is the subject of several ongoing studies focused on understanding precipitation mechanisms, forecast uncertainty, and the impact of added upstream observations.

6.5 Observation-Based Studies (Field Campaign)

Augmented observations of atmospheric profiles via ground-based radars and radiosondes within the watershed, as well as observations of microphysical properties in clouds and precipitation, will enable investigation of precipitation mechanisms and their contribution to event-to-event variability in the spatiotemporal distribution of precipitation (Ralph et al. 2014b). A proposed field campaign includes the deployment of instrumentation at three strategic field sites. Micro-rain-radars, disdrometers and radiosondes deployed at Santa Catalina Island, upstream of the Santa Ana River watershed, will yield observations of water vapor transport and precipitation characteristics of the storm ahead of landfall. Observations from sites with similar instrumentation in the foothills of the San Gabriel and San Bernardino Mountains will be used to determine the impact of regional topography on precipitation processes, such as seeder-feeder precipitation and barrier jet development.

Suggested sites were chosen to create two individual transects that will allow the observation of multiple precipitation mechanisms that are hypothesized to impact the watershed. The first transect, spanning from Santa Catalina to the San Bernardino foothills and crossing the NEXRAD location in the

Santa Ana Mountains, will utilize vertical micro-rain-radar profiles to validate NEXRAD coverage over the field sites. The proposed configuration will enable error quantification in the use of range-height indicator scans along this transect for evaluating the upstream evolution of precipitation in flow orthogonal to the San Bernardino Mountains. This information, paired with radiosonde observations of meteorological conditions and disdrometer observations of microphysical processes in the upwind and mountain locations, will be useful in developing radar precipitation diagnostics for the watershed.

The second transect, including the San Bernardino site and a second foothill location in the San Gabriel Mountains, will additionally leverage the Goleta Atmospheric River Observatory to create a transect of meteorological profiles along the transverse ranges. These will enable physical process studies, including the influence of barrier jet development on orographic precipitation.

Figure 16 shows the locations of existing and proposed instrumentation to support AR precipitation studies.

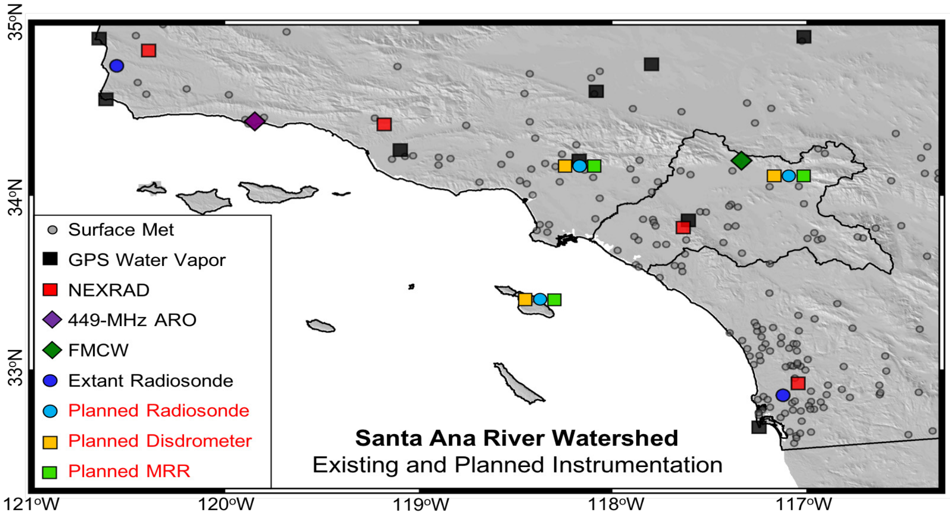

Figure 16. Locations of existing and proposed field instrumentation to support AR precipitation process studies.

6.6 Sub-Seasonal to Seasonal Predictability

Ongoing research suggests that sub-seasonal to seasonal (S2S) forecasts could predict the onset, evolution, and decay of some large-scale extreme events several weeks in advance (DeFlorio et al. 2019). For instance, S2S models often display skill in predicting higher probabilities of landfalling AR IVT two to three weeks before extreme events. Continued efforts to establish forecast skill beyond two weeks are focusing on synoptic-scale circulation patterns that are conducive to the development of extreme (e.g., > 95th percentile IVT events) and/or multiple large events in succession. Ideally, S2S forecasts of extreme events could be integrated into FIRO at Prado by providing an early warning of high probabilities of extreme events a few weeks in advance. Finally, S2S forecasts can also be used to investigate the causality of some extreme events (e.g., El Niño and Madden Julian Oscillation [MJO] teleconnections). Planned work includes an S2S-focused evaluation of the extreme events that were identified in Cannon et al. (2018), including an evaluation of the impact of both El Niño and the MJO, among other teleconnections.

7. Evaluation Framework, Scenarios, and Criteria

7.1 Evaluation Framework

The Prado Dam FIRO viability assessment must demonstrate a compelling case for integrating weather and streamflow forecasts into routine operations for the project. Assessment requires goals and metrics for measurement. The project objectives are fairly straightforward, as described in Section 1. That is:

> *Improve opportunities for stormwater recharge below Prado Dam by appropriately using the "buffer space" within the flood control pool while maintaining or enhancing the flood mitigation capacity of the project and maintaining or enhancing the environmental benefits associated with listed threatened or endangered species.*

Metrics and criteria will be drawn from these three objectives: 1) stormwater recharge, 2) flood management capacity, and 3) environmental benefits and outcomes. The project team will take the baseline condition from current practices by OCWD, USACE/LAD, and USFWS as of 2018. The team will also develop specific metrics for each objective in collaboration with agency personnel and representatives.

7.2 Validation of Precipitation and Inflow Forecasts

An underlying premise of FIRO is that the precipitation and streamflow forecasts are skillful. To establish expectations and a baseline for project investment improvements, the project team will assess the skill of CNRFC's contemporary forecasts. The CNRFC has issued and archived QPFs and inflow forecasts. These forecasts will be validated over the period of record for which they are available, understanding that the underlying technology (and most likely the skill) is not stationary over this period. Similar to the Lake Mendocino preliminary viability assessment, this work will statistically analyze the forecasts to characterize their skill and reliability in the FIRO process.

7.3 Assessment of Lead Time Requirement(s)

Applying forecasts to the operation of Prado Dam requires an understanding of how and when the forecasts impact decision-making. Factors that affect the lead time requirement may include:

- The time needed for water to flow from the dam to the ocean.
- The time needed to draft the reservoir down to a specific level.
- The time needed to issue evacuation notices and remove people and resources from harm's way.

The project team will assess the operational profile for Prado Dam and suggest forecast lead-time requirement(s). These lead-time requirements will be used to focus the forecast validation (above) and research needed to improve weather and streamflow forecasts.

7.4 Modeled Evaluation Scenarios

This work will demonstrate the value of forecasts in an objective decision model. The SC will finalize a decision model of the approaches, but it is envisioned that they will apply Sonoma Water's Ensemble Forecast Operations (EFO) model as well as USACE's HEC toolset (CWMS, HEC-WAT). Both approaches will include "bookend" studies that characterize the system benefits with 1) no forecasts and 2) perfect forecasts. Each will also attempt to estimate the system benefits using forecasts that are consistent with those operationally available at the current time. If properly defined, this analysis should describe the potential for research investments to improve system outcomes.

7.4.1 1985–2017 GEFS Hindcast Period Performance

7.4.1.1 Existing WCM Operations

a. No inflow forecast
b. Perfect inflow forecasts
c. Approximation of current forecast skill

7.4.1.2 EFO-Type

a. No inflow forecast
b. Perfect inflow forecasts
c. Approximation of current forecast skill

7.4.2 HEC CWMS/WAT (Period of Record, Monte Carlo)

7.4.2.1 Existing WCM Operations

a. No inflow forecast
b. Perfect inflow forecasts
c. Approximation of current forecast skill

7.4.2.2 Revised Rule Curve Operations

a. No inflow forecast
b. Perfect inflow forecasts
c. Approximation of current forecast skill

The engineering of the EFO-type application for Prado Dam will require the consideration of project objectives and operational boundaries. Because the project does not have a traditional conservation pool, the evaluation of a set of potential "buffer pools" at and above 505 feet water surface elevation are likely to be considered. In addition, the SC will need to develop and vet the WCM alternative(s) considered in the HEC-type evaluation.

7.5 Development of Evaluation Criteria

SC members will collaboratively develop evaluation criteria based on anticipated system outcomes and project goals. Examples include:

- Average annual change in downstream stormwater recharge.
- Frequency and duration of critical habitat inundation during specific seasons.
- Frequency and duration of inundation features within the flood pool (e.g., Euclid Avenue, Corona Airport, recreational uses).

The contemporary historical record of observations does not include storm events that challenge the operations of Prado Dam with its current physical attributes. This creates a problem when attempting to demonstrate the robust nature of a selected management alternative. This challenge will be even greater when the SARM flood risk management project is completed and downstream flow constraints are removed. To address this, the project team will employ two techniques to create storm events “extreme enough” to establish confidence in the robustness of a selected management alternative. The first approach involves the “scaling” of observed events by a factor needed to achieve the desired frequency (e.g., 200-year). The second involves current development work that will provide synthetic single-value or ensemble forecasts associated with design events.

8. Assessment of Potential Socioeconomic Benefits

8.1 Municipal/Government Services

8.1.1 Water Supply

Municipal water demand is expected to rise slowly over time with population growth. Water demand has exceeded local supply in the OCWD area since before 1950. The shortfall is primarily made up for by costly and energy-intensive imports from the Colorado River and the California State Water Project. Santa Ana River water flows primarily by gravity to OCWD recharge facilities. FIRO may allow reservoir operators to maintain higher water levels as well as greater control over release rates. Less water will be lost to the ocean and more water will go into aquifer recharge, increasing Santa Ana River yields to the groundwater recharge system. This will decrease reliance on water imports, increasing water supply reliability and yielding economic benefits that can be quantified directly. The value of increased recharge and increased water supply reliability can be calculated based on the value of the water to OCWD and, ultimately, to all water consumers. FIRO may also decrease greenhouse gas emissions associated with Orange County’s water supplies by reducing the demand for imported water.

8.1.2 Flood Risk Management

Since the construction of Prado Dam, the flood risk in the lower Santa Ana River watershed has been largely due to local topography, not to the flooding of the Santa Ana River, which is constrained in a concrete channel and rated to provide protection against a 100-year flood. Nonetheless, the impacts of a major urban flood below Prado Dam would be staggering. Moderating this risk is the basis of the USACE investments described in Section 2.4. In addition, the impacts of climate change on flooding represent another source of risk. FIRO represents a potential tool that USACE can use to improve flood risk management and adapt to a changing climate.

8.2 Environmental Services

The extent of ecological issues downstream of the dam is affected by the high degree of modification of the river for flood risk management purposes. The reach below the dam to Weir Canyon Road is confined within a channel, but there is a relatively wide area for the riverbed to migrate and this reach provides riparian habitat. Downstream of Weir Canyon Road and thence to the ocean, the river is confined to a narrow channel. Downstream of Prado Dam, there is generally poor quality habitat for the Santa Ana sucker, and sucker fish are rarely found. USACE has constructed a sucker fish habitat restoration project downstream of the dam. A portion of the river through Santa Ana and Garden Grove has a concrete bottom. Upstream of the dam, the Prado Reservoir itself provides critical habitat for the endangered least Bell’s vireo and other species. The habitat protection benefits that Prado Reservoir provides can be estimated under existing reservoir operations and with FIRO to estimate the benefit of improved reservoir operations in terms of ecosystem services. Methods would need to be evaluated to determine the best approach for valuing the least Bell’s vireo population, supporting habitat, and other relevant environmental values.

8.3 Business: Commercial/Industrial

Quantifying the benefits to commercial and industrial water users downstream of Prado Dam will follow a similar method for quantifying these benefits to residential users, as decreased reliance on water imports will lower water prices for all users. Similarly, benefits in terms of improved flood control for extreme flood events will accrue to commercial and industrial interests for residential properties in the lower Santa Ana River watershed. Many businesses operate within or near Prado Reservoir. Existing damage functions that estimate losses to these businesses at select water elevations within the reservoir can be used to quantify potential FIRO benefits.

9. Implementation Strategies and Timeline

9.1 Pathway

Potential implementation pathways must account for initial implementation on a test basis and new technology incorporation on an ongoing basis. The initial implementation could be formulated as a deviation to the Prado Dam WCM for one or two flood seasons, depending on hydrology; a WCM update could be proposed to permanently incorporate FIRO into Prado Dam operations. The WCM update should include a framework to allow future technology developments to be incorporated without requiring a formal re-update of the manual.

9.2 Santa Ana River FIRO DSS

Collected and developed FIRO technologies will be combined into an interactive DSS that facilitates testing and evaluation and provides a test bed for proposed new Prado Dam operations. It is envisioned that the platform will rely upon the foundation established by the California DWR’s Forecast Coordinated Operations DSS, as implemented for the Yuba-Feather project and subsequently expanded to the San Joaquin and Russian Rivers. The DSS will collect data and streamflow forecasts, run selected reservoir models, and provide options for release decisions along with impacts. The selected release will be routed to the CNRFC for use in downstream forecasts. Mock operations will simulate multiple operational approaches to develop a sense of the relative benefits of different strategies.

The DSS development will be a combined effort involving the California DWR (California Data Exchange Center), CW3E, and contracting support. Deployment will include training for the Prado FIRO community, with specific focus on LAD for operational decision support.

9.3 Timeline and Relationship with Project Phases (A, B, C)

Section 2.4 defines the approximate timelines for completing elements of the SARM flood risk management project. Phase A is the current condition and extends until the Reach 9 construction features are completed. Phase B extends from the end of Phase A to the completion of the SARM project. Phase C starts after completion of the SARM project. During Phase A, the Prado Dam release rates are limited due to construction in the channel downstream of the dam. During Phase B, the release rate limitations associated with downstream construction will no longer apply, but dam operations may be limited due to construction of remaining SARM features. It is anticipated that Phase C will provide the greatest flexibility to implement FIRO.

10. Technical and Scientific Programs for Viability Assessment

The FIRO process combines application development and research. A series of questions arose during the development of the work plan outline. The answers to these questions will impact how FIRO is structured and performed for Prado Dam. In addition, as work continues, there will undoubtedly be additional questions that arise and are worthy of team assessment. The Prado SC will discuss, consider, and prioritize these assessments as they arise. The preliminary viability assessment scope should include the following:

Background and Purpose

1. Purpose of Prado FIRO effort and the preliminary viability assessment.
    a. Comparison with Lake Mendocino project.
2. Climatology and runoff characteristics of the Santa Ana River watershed.
    a. Precipitation.
    b. Temperature.
    c. Runoff.
3. Physical characteristics of Santa Ana River watershed.
    a. Soils.
    b. Vegetation.
    c. Urbanization.
    d. Special features.

Operations and Constraints

1. Functional description of Prado Dam operations.
    a. Purpose.
    b. Capacity.
    c. Upstream and downstream constraints and considerations.
    d. History and historical operations.
    e. Current operational profile.
        i. 5-year major deviation and path forward.
2. Functional description of San Antonio Dam and Seven Oaks Dam operations.
    a. Purpose.
    b. Capacity.
    c. Historical operations.
    d. Relationship with Prado operations.
3. SARM project phases. Clarify key features of each phase (A, B, C), limitations that exist before each is completed, and each phase's final capacity.
    a. Phase A.
    b. Phase B.
    c. Phase C.
    d. Groundwater recharge information. Details needed on flow capacity as a function of date and any other information that may enhance or limit the volume that can be accepted.
4. Environmental considerations.

   a. Define the relationship between allowable raises in water surface elevation once the vireos begin to arrive and nest.
   b. Others.
   c. Mitigation opportunities.
5. Additional constraints that affect the evaluation of alternatives (e.g., Euclid Avenue, Corona Municipal Airport, recreational activities) and potential offsets.

Technical Studies

1. Assess adequacy of stream gages. How reliable are the key USGS stream gages such as Santa Ana River at MWD Crossing and Santa Ana River below Prado Dam? Can anything be done to improve observations? Are additional locations needed?
2. Document the magnitude and impact of increased sedimentation associated with periodic increases in water surface above 505 feet.
3. Model the local contributing flow between Prado Dam and the OCWD recharge facilities. If needed, develop a scheme to produce observations and forecasts.
4. Develop and evaluate WCP alternatives.
   a. Develop and execute Hydrologic Engineering Management Plan.
      i. Develop full set of evaluation metrics from the following categories:
         1. Stormwater recharge.
         2. Flood management capacity.
         3. Environmental benefits and outcomes.
      ii. Define required data and methodologies.
      iii. Define process for alternative selection/recommendation.
      iv. Approximate existing forecast skill (precipitation and runoff) using:
         1. CNRFC single-value archive.
         2. HEFS reforecasts (1985–2017).
      v. Analyze options for each phase (A,B,C) of the SARM project, including:
         1. Perfect forecasts.
         2. No forecasts.
         3. Current forecast skill.
      vi. Develop alternatives for each phase (A,B,C) of the SARM project and each analysis option, including:
         1. Existing operations (498 feet and under 505 feet MDL).
         2. Full EFO at different maximum buffer pool elevations (e.g., 508, 510, 512, 515, etc.)
         3. Folsom-like.
         4. Other?
   b. Develop framework for adaptive water control plan implementation.
5. Evaluate the adequacy of existing CWMS implementation for the Santa Ana River.
   a. Has HEC-HMS been properly calibrated?
   b. Are all features adequately represented to allow for operational decision support?
6. Leverage OCWD RFM so it can be coupled with WCP alternatives in the evaluation. (See Section 4.1.3).

7. Document lead-time[5] requirements for Prado Dam operations. Examples include:
    a. Time needed for water to flow to the ocean.
    b. Time needed for channel activities (e.g., construction) to be stopped and resources removed.
    c. Time needed to draft the reservoir to a specific level.
    d. Time needed to issue evacuation notices and move people and resources from harm's way (both in the pool and in the downstream channel).
    e. Time needed to move aircraft and resources from the Corona Municipal Airport.
8. Develop a basic economic assessment framework for estimating the benefits and costs of implementing or not implementing FIRO.

Scientific Investigations—Meteorology

1. Develop climatology of precipitation events in the Santa Ana River watershed and perform a formal assessment of current forecast skill for AR IVT and precipitation predictability across zero- to seven-day lead times (GFS, GEFS [use FV3 when reforecast is finished], West-WRF, CNRFC). Specific lead-time focus will eventually depend upon USACE outflow limitations and storage.
2. Identify meteorological processes that are responsible for poorly forecasted events and identify limitations in current understanding, observation, and predictability across different event types. These include the roles of ARs, mesoscale frontal waves, narrow cold-frontal rainbands, varying microphysics, barrier jets, and snow level.
3. Design a field campaign to supplement existing observation networks with a specific focus on improved observation of poorly forecast precipitation mechanisms (e.g., co-located disdrometer and micro-rain-radar instrumentation for precipitation microphysics).
4. Continue West-WRF development with specific focus on Southern California extreme precipitation events and relevant meteorology. Utilize field campaign data for model development. Utilize West-WRF reforecast to post-process mesoscale model data in partnership with CNRFC.
5. Focus AR Recon data assimilation experiments on well-sampled AR events that impacted the Santa Ana River during the 2019 field campaign. Establish the impact of supplemental dropsonde observations on precipitation forecast skill in those events.
6. Develop improved material to communicate probabilistic risk of extreme events, types of events, and expected advanced warning of each event type.
7. Develop forecast skill metrics tailored to specific requirements of FIRO for Prado Dam.

Scientific Investigations—Environmental

1. Develop guidelines on the relationship between inundation depth and duration and recovery of riparian vegetation such as mule fat in Prado Basin.
    a. See Attachment 1 at the end of this document for the draft scope of work.
2. How do we better predict the arrival of the vireo population each spring? Can we do better than just assuming March 15? Are there environmental pressures in the winter range and the local range?

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[5] Lead time is the period of time between when forecast information is available and the forecast event is expected to take place. Operational lead time is the time required to implement a specific activity (e.g., remove equipment, evacuate residents, place barriers).

3. Determine seasonality of extreme events to establish challenges in late-season storage at Prado (e.g., overlap of extremes with vireo nesting season).
4. What are the reservoir conditions that affect vireo population maintenance and growth?
    a. Insect production.
    b. Other environmental enhancements.
5. What are the opportunities for vireo habitat mitigation?

Scientific Investigations—Hydrology

1. Configure and calibrate WRF-Hydro for the Santa Ana River watershed. Evaluate its performance compared to existing operational models.
2. Configure and calibrate GSSHA for the Santa Ana River watershed. Evaluate its performance compared to existing operational models.
3. Develop joint probability distribution of observed streamflow given CNRFC ensemble streamflow forecast.
4. Inventory and assess soil moisture observations in the basin. Is the distribution of sites adequate to characterize the spatial variability across the watershed? Can the existing network serve the GSSHA and WRF-Hydro calibrations and evaluations?
5. Couple GSSHA model to West-WRF for potential forecasting capability. Assess performance relative to existing methods.
6. Drive GSSHA with downscaled (time and space) CNRFC six-hour observed precipitation and compare to other models and rainfall sources (i.e., West-WRF, observed network, radar).
7. Utilize the GSSHA model to investigate hydrologic processes in the watershed, including mass balance.
8. To the extent possible, integrate hydrologic modeling efforts.

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Attachment 1 –

Scope of Work for Study of Effects of Inundation on Riparian Habitat and Nesting Birds in Prado Basin to Determine Strategies for Future Management

The proposed study would examine the hydrological history of the Prado Basin, current climatic conditions and models incorporating runoff trends, and potential habitat management actions that might hasten and support forest recovery under future conditions. The forest in the lowest elevations of Prado Basin is dominated by Black Willows that have been subjected to periodic structural damage by partial inundation for flood risk management and water conservation; recruitment of trees may also have been affected. Recent larger inundation events have occurred once or twice per decade and the habitat has recovered in between to support a major population of the least Bell's vireo (*Vireo belli pusillus*). Under dry conditions, forest and dependent wildlife productivity is lowered; under wetter conditions, there can be structural damage to the forest, but foliage and food resources are high. How can this forest and its bird populations be best managed under potential future scenarios?

The vireo is a small, insectivorous, long-distance migratory songbird that breeds in riparian habitat in California and northern Baja, Mexico. The vireo was listed as an endangered species by California in 1980 and by the U.S. Fish and Wildlife Service in 1986, when only 300 pairs were estimated. Critical habitat was designated for the vireo in February 1994. The vireo was formerly described as common to abundant in riparian habitats from Tehama County, California, to northern Baja California, Mexico, but currently occupies a small fraction of its former range and is a rare and local breeder. The vireo's dramatic decline is attributed to the combined effects of the widespread loss of riparian habitat and brood parasitism by the brown-headed cowbird (*Molothrus ater*). The vireo population in the Prado Basin has been monitored since 1986 and in the rest of the watershed since 2000. Table A1-1 shows the number of vireo territories per year. With riparian restoration and cowbird management, the vireo population in the Prado Basin grew from 12 pairs in the early 1980s to 665 breeding territories in 2018, with an additional 1,347 territories in the Santa Ana River watershed outside the basin. Combined, this is the largest vireo population in existence. Table A1-2 shows the number of vireo territories in specific elevation ranges.

Flood risk management and water conservation commenced in the Prado Basin in 1941, leading to proliferation of obligate riparian habitat and subsequent intermittent habitat inundation. Submergence of riparian trees and shrubs has caused structural damage to those specimens, even death, depending upon the extent, timing, and duration of inundation and interplay of sedimentation. OCWD has planted hundreds of acres of mitigation areas above elevation 505 feet to offset previously estimated impacts from water conservation below elevation 505 feet. However, in dry years, dozens of vireo occupy territories below elevation 505 feet.

The proposed study would examine the parameters of past inundation events, apparent effects on habitat based on aerial photo interpretation, and vireo response based upon historic monitoring data collected during those years. The study would also examine forest recovery timing and extent between wet periods, as well as collect field data on the effect of temporary inundation of riparian habitat through control experiments or other means. The study model would then predict probable future inundation frequency and duration given currently observed local runoff changes from historic and likely future changes based upon climate models and possible future water conservation levels. Restoration potential along and above particular elevations would be explored. The likely response of the vireos would be integrated along with management prescriptions to aid recovery of riparian elements, particularly in the lower elevations, to benefit nesting birds.

Table A1-1. Total Vireo Territories Reported Within Prado Basin 2000–2017

Year	2000	2001	2002	2003*	2004*	2005*	2006*	2007	2008
Vireos Reported	357	432	440	409	584	589	392	418	463
Year	**2009**	**2010***	**2011***	**2012**	**2013**	**2014**	**2015**	**2016**	**2017***
Vireos Reported	543	569	515	449	560	520	530	511	549

Data sources: OCWD vireo data (2000–2017); USACE Prado Dam water elevation data (2000–2017)

Notes:

*Years when Prado water elevation exceeded 498 feet during nesting season.

Vireo counts about River Road are excluded.

Table A1-2. Elevation Distribution of Vireos in Prado Basin

Calendar Year	466 to 490 ft. elevation range	490 to 494 ft. elevation range	494 to 498 ft. elevation range	498 to 505 ft. elevation range	505 to 566 ft. elevation range	Total vireo (within 566 ft., excluding above River Road)	Number of days Prado water elevation exceeded 498 ft. in vireo nesting season
2001	6%	9%	9%	16%	61%	432	0
2002	12%	12%	10%	14%	52%	440	0
2003*	4%	6%	11%	17%	62%	409	44
2004*	8%	7%	8%	15%	63%	584	9
2005*	4%	6%	9%	12%	69%	589	125
2006*	1%	1%	8%	16%	74%	392	78
2007	2%	1%	11%	14%	72%	418	0
2008	3%	2%	8%	18%	69%	463	0
2009	3%	2%	12%	17%	67%	543	0
2010*	1%	2%	12%	18%	68%	569	18
2011*	1%	1%	9%	20%	70%	515	74
2012	1%	1%	11%	23%	63%	449	0
2013	4%	2%	13%	21%	61%	560	0
2014	7%	2%	13%	19%	59%	520	0
2015	6%	4%	11%	19%	60%	530	0
2016	8%	3%	14%	17%	58%	511	0
2017*	5%	2%	13%	17%	63%	549	17

Data sources: OCWD vireo data (2001–2017); USACE Prado Dam water elevation data (2001–2017)
Notes:
*Years when Prado water elevation exceeded 498 feet during nesting season.

Percentages of vireo in topographic ranges from 2001 to 2005 were calculated based on 1989 topographic survey.
Percentages of vireo data from 2006 to 2017 were calculated based on 2008 topographic survey.
All calculations use State Plane NAD83, Vertical Datum NGVD 29.
Vireo counts above River Road are excluded.

Attachment 2 –
Seven Oaks Dam Information

1. Reservoir Regulation Overview

The counties of San Bernardino, Orange, and Riverside are responsible for the operation and maintenance of the dam. The operation, maintenance, repair, replacement, rehabilitation, and inspections of the dam and appurtenances, the reservoir, and related facilities are to be performed in accordance with regulations and directions prescribed by the Secretary of the Army.

These counties are represented by their flood control agencies. As project regulators, the local sponsors are required to regulate the project in accordance with the WCM. By agreement, San Bernardino County undertakes dam tender responsibilities and Orange County is responsible for water control manager duties. The dam tender observes water surface elevations, piezometer readings, and gate settings and logs the information. These readings are reported to the water control managers via telephone (or radio). During the non-flood season (April 15–November 15), these readings may be taken as often as once a week on a designated day. During the flood season (November 15–April 15), they are taken daily, Monday–Friday. During flood operations, they are taken as often as the water control managers deem necessary.

If the water control managers require an operation such as a change in discharge, the dam tenders will perform the operation and then report back to the water control managers to confirm that the operation is complete. This confirmation will also be accompanied by a new gate setting and water surface elevation report. Any gate operation, for whatever reason, must be reported to the water control managers before the operation. No gate operation will be performed without the permission of the water control managers.

At any time of the day or year, if based upon weather or hydrologic forecasts, the water control managers expect significant inflow into the reservoir, they shall request the presence of a dam tender. A dam tender is required to be present at the dam, furnish reports, and perform operations any time the water control managers request it. During flood events, the dam tenders perform the above-described observations and operations and report them by radio or telephone to the water control managers, as often as required by the water control managers. All reports called in by the dam tenders should be documented on a reservoir operation report.

Communication between the Seven Oaks Dam water control managers and the dam tenders is accomplished via telephone or radio. If all communications between the water control managers and the dam tenders are interrupted, a set of "Standing Instructions to the Project Operator for Water Control" have been compiled and included in the WCM.

The Seven Oaks Dam water control managers are responsible for calling various in-house sections, county agencies, city authorities, private party stakeholders, or any entity with a legitimate need for the information when any operations at Seven Oaks Dam may impact people or property.

2. Overview of Pool Levels and Reservoir Operation

Long-Term Operation Plan for Flood Control

Long-term flood control operations at Seven Oaks Dam include the following main elements.

a. Sediment pool.

At the beginning of each flood season, stop logs are added, as necessary, to block the lower inlet ports of the multilevel withdrawal system (MWS) wet well. This wet well leads to the minimum discharge line (MDL). The stop logs block the ports to a point about 20 to 30 feet above the active sediment level to prevent sediment from entering the intake structure and either blocking or damaging the MDL. The stop logs form a "dead pool" and no operation is possible, other than leakage through the stop logs when the water surface elevation is within the sediment pool. Additional stop logs may be installed during the flood season if sediment accumulation is greater than expected. During the initial years of operation, stop logs had been installed to block the bottom two rows of intake ports at the MWS, making the invert elevation for the open row of ports to be at 2,120.24 feet NGVD. As sediment accumulates and more stop logs are added, the sediment pool will shift upward. The current elevation of the top of the sediment adjacent to the intake structure is approximately 2,131 feet. The current top of the sediment pool is 2,157 feet, coincident with the top elevations of the stop logs as currently installed. While the water surface is within the sediment pool, outflow passes through the MDL. Beginning October 1 of each year, release from the dam within the sediment pool will be limited to a maximum of 3 cfs to allow the formation of the debris pool. Since this release rate can only be made through the MDL, the sluice gate is kept closed to prevent sediment from entering the main tunnel.

b. Debris pool.

At the beginning of the project life, the design documents call for a debris pool up to elevation 2,200 feet NGVD. Throughout the project life, the allotted storage for sediment accumulation will be filled, and a new top of debris pool elevation will be established. Toward the end of the project life, sediments will have accumulated up to the final invert elevation of the reservoir, which is 2,265 feet NGVD. The final top of debris pool elevation at the end of the project life will be the top of the trash rack structure elevation, which is at 2,300 feet NGVD. Water stored within the debris pool is not available for environmental mitigation and enhancement plans. Current elevation of the top of the debris pool is 2,200 feet.

As stated in the previous section, releases from the dam are reduced to a maximum of 3 cfs to form the debris pool starting October 1 of each year. This rate is to continue until the water surface elevation reaches the top of the debris pool elevation. During the first major storm of the year, if the water surface is expected to exceed the top elevation of the debris pool, preparation for releases through the main tunnel shall be made. This would entail equalizing the pressure between the main wet well and the MDL wet well, opening the sluice gate, and seating the regulating outlet (RO)and low flow gates. Once opened, the sluice gate may remain open through the remainder of the flood season.

The debris pool is held until the end of the flood season, when it is drained on a schedule established in cooperation with the downstream water agencies during the development of the Phase II General Design Memorandum, dated August 1988. During the month of June, releases will equal inflow plus 10 cfs; during the months of July and August, releases will equal inflow plus 20 cfs. Regular adjustments may be needed to accommodate varying inflow rates. By September 1, the debris pool shall be completely drained, using higher than calculated release rates, if needed.

c. Intermediate pool.

The intermediate pool elevations occur between the current top of the debris pool and the sill of the main intake, which is at elevation 2,265 feet NGVD. The intermediate pool is the portion of the flood control pool that lies below the sill of the main intake. The releases within this range should match inflow up to the maximum release capability of the project. The combined release capability of the low flow gate and the MDL in this range is approximately 400 to 500 cfs. If hydrologic conditions warrant (i.e., no forecasts indicating significant rainfall), releases can be modified/delayed to support environmental mitigation and enhancement operations.

d. Main trash rack pool (elevation 2,265 to 2,299 feet NGVD).

The trash racks protecting the main intake are located between elevations 2,265 and 2,292.5 feet NGVD. Within this range, releases are based only on the rising and falling pool elevations at Seven Oaks Dam. As the pool is rising, releases (if required) will be cut back to the maximum safe rate through the MDL, when the water surface elevation is between elevations 2,265 and 2,299 feet NGVD. The reason for this is to avoid drawing floating debris into the trash racks and possibly rendering the main outlets inoperative. The 2,299 feet elevation allows for adequate submergence of the trash rack to avoid vortex formation. The maximum safe release rate when the pool is rising will be determined by project operating experience but is theoretically on the order of 50 cfs. During falling stages, releases will be made in accordance with the project design schedule from Plate 7-01 of the WCM, as shown below.

@2,265 ft. NGVD	Q = 500 cfs
@2,269 ft. NGVD	Q = 1,000 cfs
@2,273 ft. NGVD	Q = 1,500 cfs
@2,299 ft. NGVD	Q = 2,000 cfs

These are theoretical maximum safe rates ranging up to 2,000 cfs. If project experience indicates that floating debris is less of a problem than anticipated, the falling pool release rates may be increased. Conversely, if operational experience indicates that floating debris is more of a problem than anticipated, then falling pool rates may be decreased. If hydrologic conditions warrant, releases can be modified/delayed in order to support environmental mitigation and enhancement operations.

e. Flood control pool (elevation 2,299 to 2,580 feet NGVD).

This is the pool between elevations 2,299 feet NGVD and the spillway crest at elevation 2,580 feet NGVD. Within the flood control pool, release rates from Seven Oaks Dam are based on concurrent conditions at Prado Dam. During flood events, Seven Oaks Dam will store water destined for Prado Dam as long as the reservoir pool at Prado Reservoir is rising and the pool at Seven Oaks Dam is not approaching the spillway. Once the reservoir water surface elevation at Prado Dam reaches its peak and starts to recede, Seven Oaks Dam releases will be made based upon the Seven Oaks Dam pool elevation, ranging from a minimum of 2,000 cfs at elevation 2,299 feet NGVD up to the maximum rate of 7,000 cfs at elevation 2,580 feet NGVD. The portion of Plate 7-01 below identifies the release schedule within this elevation range.

@2299 ft. NGVD	Q = 2,000 cfs
@2300 ft. NGVD	Q = 2,030 cfs
@2400 ft. NGVD	Q = 4,340 cfs
@2500 ft. NGVD	Q = 7,000 cfs

It is important to note that within most of this range, the intake structure deck at elevation 2,302 feet NGVD, which is where the sluice gate control is located, will be submerged. If hydrologic conditions warrant, releases can be modified/delayed to support environmental mitigation and enhancement operations.

f. Spillway surcharge (elevation 2,580 to 2,604 feet NGVD).

Above elevation 2,580 feet NGVD, uncontrolled releases over the spillway occur. During rising stages, when uncontrolled releases are less than 7,000 cfs, releases from the outlet works will be adjusted so that the total project release (combination of spillway and outlet works releases) equals 7,000 cfs. When uncontrolled releases are greater than 7,000 cfs, no outlet works releases will be made. The maximum spillway design discharge is 180,000 cfs at elevation 2,604.4 feet NGVD, a surcharge depth of 24.4 feet. During falling stages, the outlet works gates can be adjusted to maintain the maximum spillway release rate during the event and to ensure the quickest evacuation of the remaining surcharge volume in anticipation of another significant flood.

3. Historical Reservoir Regulation Operations

Seven Oaks Dam was turned over to the local sponsors in 2002 for operation and maintenance. USACE directed the dam to be operated per the WCM; however, if there were particularly wet storm seasons, USACE directed the sponsors to hold back enough water to test the dam's outlet works. The main flood control pool was achieved in 2005, 2010, and 2011. Each of those years, large releases were made to test the outlet works. Since 2011, the dam has been operated per the WCM.