US Army Corps
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Los Angeles District

Prado Basin Ecosystem Restoration and Water Conservation Study

APPENDIX M

Geotechnical

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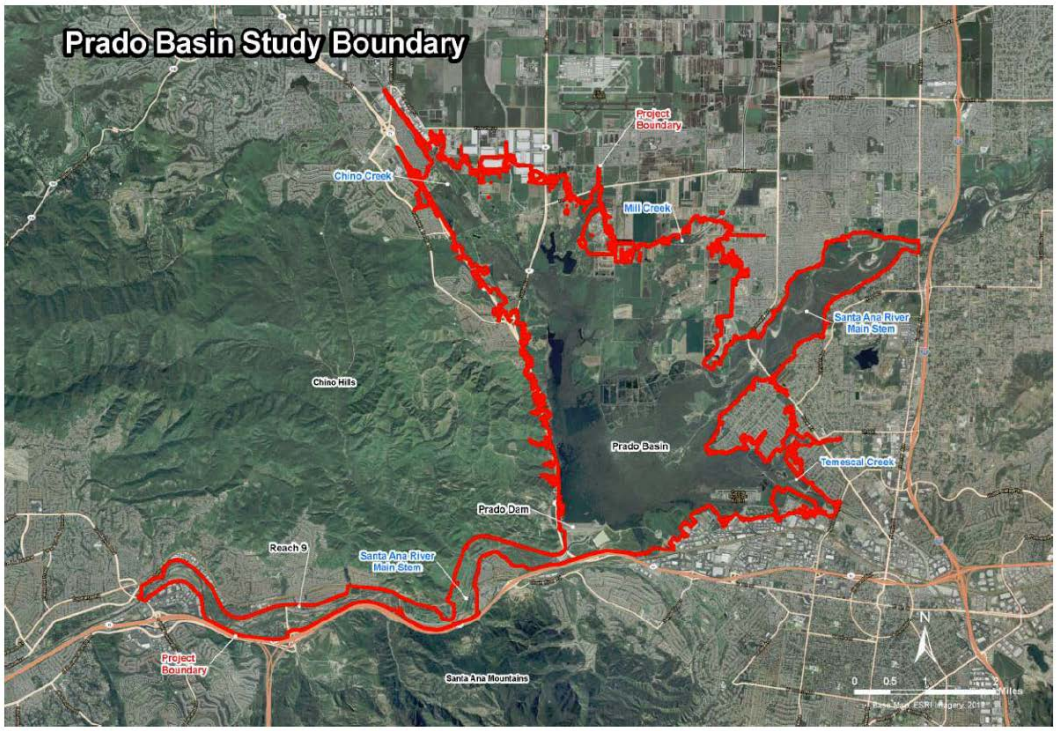
US Army Corps of Engineers

Los Angeles District
Geotechnical Branch

DRAFT Geotechnical Feasibility Study Report

Prado Basin Water Conservation & Ecosystem Restoration
Tentatively Selected Plan (TSP) Phase
Riverside, San Bernardino, and Orange Counties, California



June 2018

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1.0 INTRODUCTION

The Prado Basin feasibility study is a multi-purpose study that investigates opportunities primarily for improved water conservation and ecosystem restoration. The study also addresses opportunities to improve flood protection and recreation throughout the Basin and the Chino Creek and Mill Creek/Cucamonga Creek watersheds. This geotechnical report is an assessment of the existing study area conditions and the geotechnical considerations and constraints for the proposed alternatives.

1.1 Project Location

The feasibility study area includes portions of the Cities of Corona, Chino, Eastvale, and Yorba Linda at the borders of Riverside, San Bernardino, and Orange Counties, California. The Santa Ana River drainage area above Prado Dam encompasses about 2,500 square miles. The study area is approximately 50 square miles, and all storm water flows into Prado Dam. The Santa Ana River is the main watercourse to the study area, along with tributaries including Chino Creek, Mill Creek (known upstream as Cucamonga Creek), and Temescal Wash. The project area is approximately 45 miles southeast of downtown Los Angeles and includes both the upstream and downstream portions of Prado Dam and its auxiliary dike, as well as the impoundment area behind the dam (the basin) and the river channel roughly 8.3 miles downstream of the dam (Figure 1).

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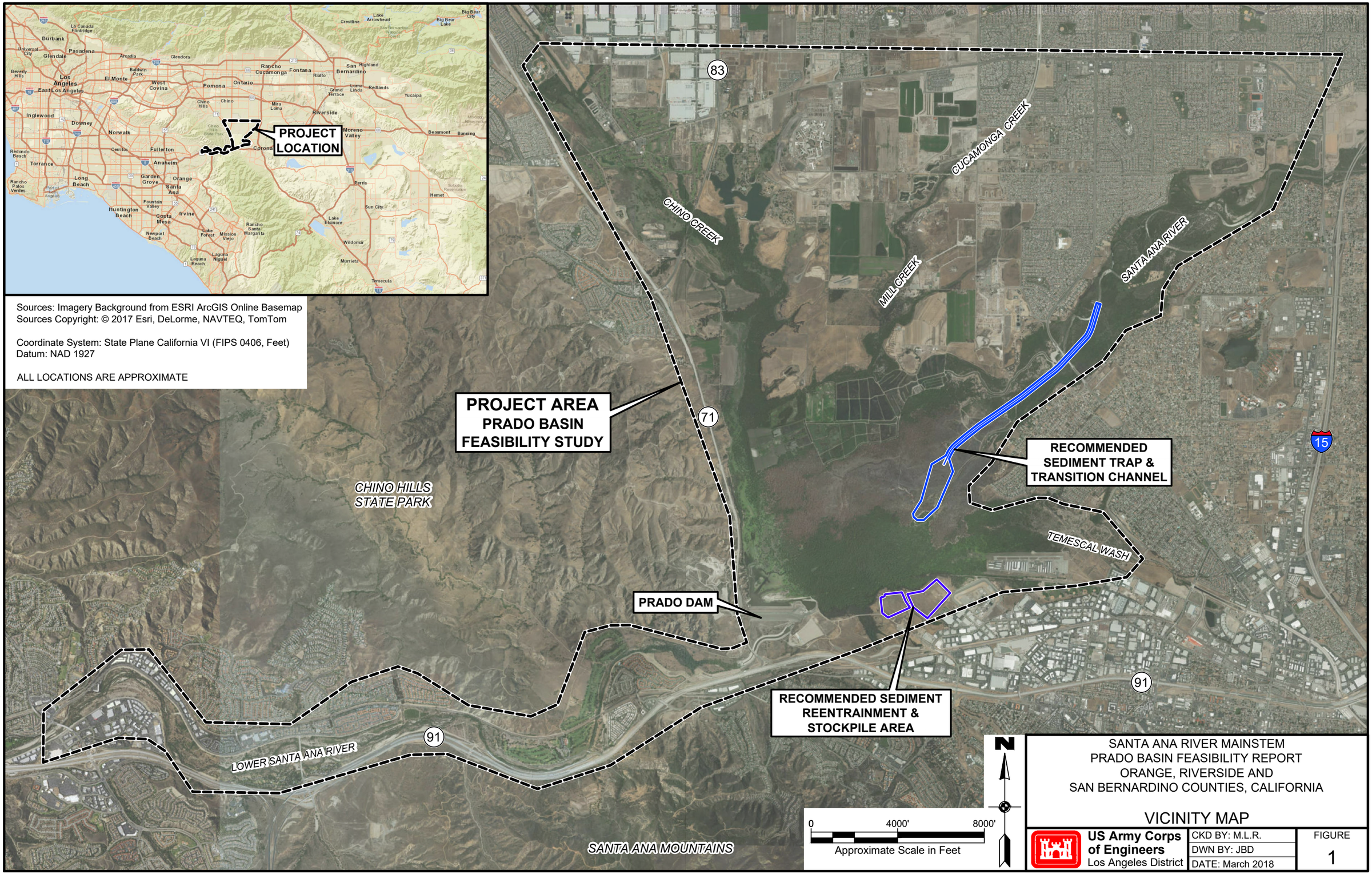

SANTA ANA RIVER MAINSTEM
PRADO BASIN FEASIBILITY REPORT
ORANGE, RIVERSIDE AND
SAN BERNARDINO COUNTIES, CALIFORNIA

VICINITY MAP

US Army Corps of Engineers
Los Angeles District

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Plot Date: 3/21/2018 11:18:25 AM, Plotted by: l1ed9jbd. File Name: SARM PBFS_B01_FIGURE 1_VICINITY MAP.DWG, Vicinity Map

1.2 Background

In its natural condition, the Santa Ana River carried sediment from its headwaters and various tributary areas through the Santa Ana Canyon and Orange County to the coast where sediments were deposited on the beaches or in the ocean. Prado Dam construction in 1941 by the U.S. Army Corps of Engineers, Los Angeles District (referred to as the USACE herein) disrupted the original natural sediment transport along the Santa Ana River Mainstem (SARM). Sediment-laden storm flows from the upstream watershed are now detained by the dam, which results in sediment deposition upstream of the dam.

Approximately 50,324 acre-feet (81,189,000 cubic yards) of sediment has deposited in Prado Basin below elevation 563 feet NGVD since the Dam's construction in 1941 through 2008 (Scheevel, 2018). This is an average sediment accumulate rate of more than one million cubic yards per year.

Since most of the sediment borne by flows in the Santa Ana River and its tributaries settles out in this basin, the flows released through the dam are relatively free of sediment, which tends to disrupt the balance of sediment transport downstream of the dam. The natural rate of sediment deposition downstream is thus reduced relative to the rate of scour along the creek bed, resulting in an imbalance toward a severe scouring condition there. This is an ongoing problem over the eight-mile long reach of the Lower Santa Ana River immediately downstream of Prado Dam (identified by USACE and Orange County as Reach 9).

1.3 Project Alternatives Considered During Plan Formulation

The project is intended to create opportunities for water conservation and ecosystem restoration. Specifically, the project is intended to address the following problems identified during the study:

- Sediment accumulation behind Prado dam (lack of sediment transport downstream due to the presence of the dam)
- Significant growth of non-native invasive plant and animal species
- Destabilization of the Santa Ana River Mainstem, Chino Creek, and Mill Creek due to impaired hydraulic and hydrologic processes (i.e. incision and erosion)
- Degraded riparian and aquatic ecosystems

Multiple project alternatives covering various combinations of nineteen measures were considered for this project. The suggested measures cover a variety of actions, some involving physical site modifications with engineering implications (such as excavating sediments), and others strictly ecological (such as feral pig management).

Twenty-five alternatives were considered during plan formulation, each consisting of various combinations of individual project features. After cost analyses, three alternatives/plans (Best Buy 9, 11, and 14, plus the No Action plan) were selected for further evaluation. Excluding the No Action Plan, all of the plans included a water conservation component. Two of the plans included a sediment trap. Sediment management is intended to address the available storage for water conservation behind the dam, supply sediment to reduce erosion of the Santa Ana River

channel downstream of the dam, and increase the efficiency of groundwater recharge operations by the Orange County Water District (OCWD).

Proposed improvements to address the identified issues included structural issues such as increased water conservation elevations and related dam operation changes, transportation of sediment around the dam, addressing scour and deposition, and eradication of non-native plant and animal species, as summarized in Table 1.

Table 1: Study Measures & Alternatives Summary (Scheevel, 2018)

No Action	Plan 9	Plan 11	Plan 14	Study Measures	
x				NA - 0	No Action
	x			WC - 1	Water Conservation with Incidental Sediment Removal
		x	x	WC - 1	Water Conservation
	x	x	x	SU - 2	Invasive Plant Management Upstream SAR
	x	x	x	SD - 3	Invasive Plant Management Downstream SAR
	x	x	x	CC - 1	Invasive Plant Management Chino Creek
	x	x	x	MC - 1	Invasive Plant Management Mill Creek
	x	x	x	CC - 10	Native Plantings Chino Creek
	x	x	x	SU - 8	Native Plantings Upstream SAR
	x	x	x	MC - 7	Native Plantings Mill Creek
	x	x	x	CC - 2C	Chino Creek Channel Restoration
	x	x	x	CCMCSU	Cowbird Trapping
		x	x	SU - 6	Non-Native Aquatics Management Upstream SAR
		x	x	SU - 1A	Sediment Management
		x	x	SD - 2	Instream Habitat Features Downstream SAR
		x	x	SU - 3	Riparian Edge Management Upstream SAR
			x	SD - 4	Non-Native Aquatics Management Downstream SAR
			x	SU - 5	Instream Habitat Features Upstream SAR
			x	CCMCSU	Feral Pig Management

SARM or SAR = Santa Ana River Mainstem
US or SU = Upstream of Prado Dam
DS or SD = Downstream of Prado Dam
CC = Chino Creek
MC = Mill Creek
WC = Water Conservation

1.4 Tentatively Selected Plan

The tentatively selected plan (TSP) is one of five alternatives (alternative 15), including the "no action alternative," that make up the final array of alternatives (including alternatives 13, 18 and 20) for this project. The TSP includes measures for managing sediment, storing water, creating in-stream aquatic species habitat areas, mitigating invasive plant species, and managing wildlife within the basin.

The biggest engineering aspect of the project would be sediment management. This would include trapping sediments by means of a channel and basin, removing those sediments from the basin to a storage and dewatering area, and finally re-entraining some sediments from the storage

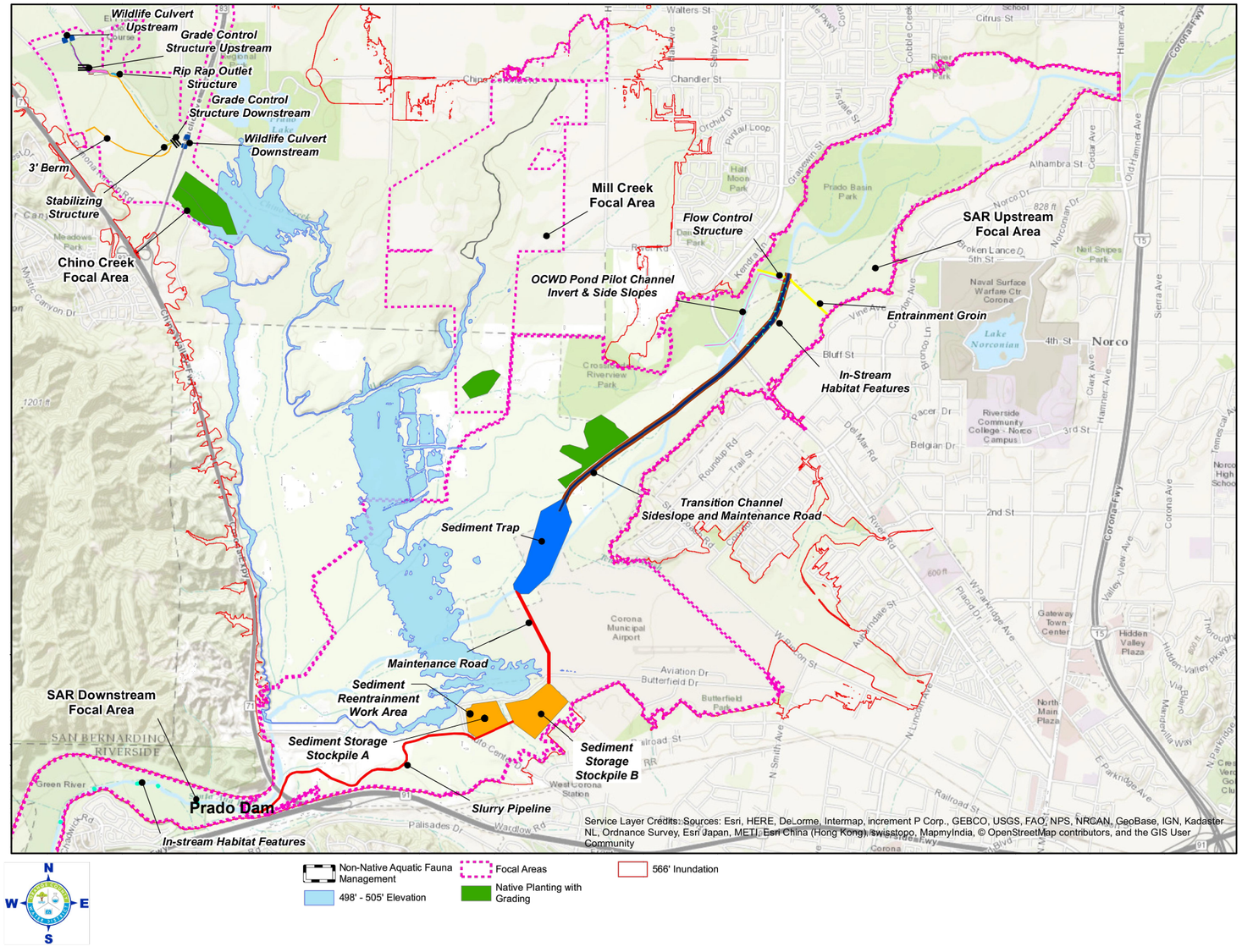
area and transporting them to the lower Santa Ana River by a pipe-slurry system around the dam. Sediments would only be delivered to the river below the dam seasonally and only when the hydrology is favorable (i.e. when there is sufficient outflow from Prado Dam to the river channel to adequately transport the sediments downstream).

Water conservation measures will consist of an updated reservoir regulation plan to allow year-round water storage up to elevation 505 feet above mean sea level (NGVD 1929). Wildlife management will include culverts to facilitate safe animal migration across roads. In-stream habitat creation will consist primarily of rock or gravel groins or mounds. Significant grading is recommended in some areas for native species planting. See Figure 2 for the locations of the main recommended engineering features. Other measures for invasive plant removal and wildlife management measures will be strictly biological and will not have engineering aspects. Briefly, the engineering aspects of the project include:

- A small sediment trap (Measure 15A) – a cut basin approximately 24 feet deep covering approximately 60 acres with a volume of almost two million cubic yards (CY)
- An alternative medium sediment trap (Measure 20) – a cut basin approximately 24 feet deep covering approximately 90 acres with a volume of about 3.2 million cubic yards (CY)
- A transition channel (part of both Measure 15A and 20) – an unlined cut trapezoidal channel of various widths and approximately 2 miles long parallel to the current natural Santa Ana River channel and leading to the sediment trap
- An “entrainment groin,” (part of both Measure 15A and 20) – a rock structure approximately 75 feet wide by 2400 feet long, at the upstream end of the transition channel to act as a grade-control structure and to direct flow into the channel
- A grade control structure (part of both Measure 15A and 20) – a concrete and/or rock structure at the downstream ends of the transition channel where it meets the sediment trap
- A “pilot channel” (part of both Measure 15A and 20) – earth channel leading from the upper Santa Ana river to the OCWD demonstration project
- A concrete flow control structure with “sluice gates” at the upstream end of the pilot channel
- A sediment re-entrainment work area (part of both Measure 15A and 20) - covering about 6 acres east of the Prado Dam spillway, west of the Auxiliary Dike and north of the 91 freeway in the approximate location of borrow area for Prado Dam, Auxiliary Dike, and Alcoa Dike
- Two sediment stockpile areas (part of both Measure 15A and 20) - Area A covering roughly 70 acres between the Prado Dam spillway and the Auxiliary Dike, and Area B covering roughly 100 acres northwest of the USACE Prado Office, also in the approximate location of borrow area for Prado Dam, Auxiliary Dike, and Alcoa Dike
- A maintenance road (part of both Measure 15A and 20) - road approximately 6,300 feet long for trucks to transport sediment from the trap to the stockpile and re-entrainment work area
- A set of three slurry pipes (part of both Measure 15A and 20) – 12-inch diameter pipes 10,000 feet long to transport water-borne sediment from the stockpile and re-entrainment

work areas between auxiliary dike and spillway to the river channel downstream of the dam

- A bike trail "fly-over" bridge (part of both Measure 15A and 20) – an elevated bridge through the sediment stockpile area with a clear span of about 50 feet, height of about 20 feet, and compacted fill approach ramps
- A grade control/diversion structure at Chino Creek (Measure 18) – concrete and/or rock structure where Chino Creek enters the Prado Basin.
- Earth berms (part of Measure 18) – berms up to three feet high to direct flows in the area of where Chino Creek enters the Prado Basin
- Culverts for wildlife passage (Measure 10) - two 48-inch reinforced concrete pipe (RCP) culverts to facilitate wildlife passage, one under Pine Avenue and the other under Euclid Avenue
- Grading for native plantings in three locations (Measures 2, 3, and 4) - more than 20,000 CY balanced cut/fill grading in each location
- Rock groins for in-stream aquatic species habitat (Measure 15b) – groins up to four feet high by 30 feet long consisting of rip-rap, cobbles, or gravel, and situated at various locations within the transition channel
- Rock groins for in-stream aquatic species habitat (Measure 15c) – groins up to four feet high by 30 feet long consisting of rip-rap, cobbles, or gravel, and situated at various locations in the lower Santa Ana River below Prado Dam



Reference: Basemap from "Prado Feasibility Study, Alternative 15 - Santa Ana River Upstream" Orange County Water District, USACE_Alt15Request.mxd, May 2017.

ALL LOCATIONS ARE APPROXIMATE

0 4000' 8000'

Approximate Scale in Feet

SANTA ANA RIVER MAINSTEM
PRADO BASIN FEASIBILITY REPORT
ORANGE, RIVERSIDE AND
SAN BERNARDINO COUNTIES, CALIFORNIA

PRADO BASIN FEASIBILITY
RECOMMENDED ENGINEERING FEATURES

US Army Corps of Engineers
Los Angeles District

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1.5 Geotechnical Scope of Work

This Geotechnical Study Report was authored by USACE, Los Angeles District, Engineering Division, Geotechnical Branch. The scope of the geotechnical study included the following tasks:

1. Reviewed referenced geotechnical reports and other available data pertaining to the geotechnical conditions at the site and vicinity.
2. Helped prepare a request for exception to USACE policy to study water conservation at Prado Dam (subsequently approved by Headquarters USACE).
3. Developed geotechnical input for the project risk register.
4. Helped develop a dam breach risk analysis.
5. Participated in several design workshops to develop alternatives and measures that would address the project's purpose.
6. Participated in a value engineering study.
7. Reviewed and commented on the Orange County Sediment Demonstration Project.
8. Attended and participated in project team meetings.
9. Prepared this report, documenting the proposed alternatives, site conditions, risks, geotechnical and geologic constraints, and recommendations for Preconstruction Engineering and Design (PED).

1.6 Prado Dam, Dikes, and River Channel

1.6.1 Main Embankment, Outlet and Spillway

The Prado Dam main embankment is a multi-zoned earth fill structure that provides flood control on the Santa Ana River. As initially constructed, it had a crest length of about 2,280 feet, a height of about 106 feet above the original streambed, and a crest width of 30 feet. The outlet works were originally located near the right abutment and consisted of a 195-foot long intake structure and a 366-foot long rectangular concrete outlet channel. The maximum capacity of the outlet works was 10,000 cubic feet per second (cfs). The original spillway is detached from the main embankment and constructed through the bluff forming the east (left) abutment. The spillway control section is a 12-foot high reinforced concrete ogee with a crest length of 1000 feet at elevation 543 feet.

The following modifications have been made to the dam or are planned:

- Raise Prado Dam's main embankment (completed in June 2008)
- Replace Prado Dam's original outlet works with new outlet works capable of 30,000 cfs flows (completed in June 2008)
- Raise Prado Dam's spillway crest 20 feet to elevation 563 (currently planned for 2021)
- Construct channel improvements downstream of Prado Dam in Reach 9 (currently ongoing)

1.6.2 Interior Dikes Within Prado Basin

Raising the dam and the spillway crest (and associated maximum pool elevation of 566 feet) will result in inundating much of the Prado Basin, including most of the proposed project features. Dikes have been constructed to protect major development features around the perimeter of Prado Basin, including the Corona Sewage Treatment Plant, Corona Housing Tract, California Institution for Women, and the Yorba Slaughter Adobe Museum. Also, the Auxiliary Embankment and California State Route 71 (SR-71) dikes were constructed to provide flood protection for the development east of the spillway and at the SR-71, near the right (west) abutment just upstream of the dam, respectively. Dikes are currently proposed at the Alcoa Aluminum plant and at residential areas in southwestern Eastvale (known as River Road Dike). All of these dikes/embankment are within and/or adjacent to the future Prado Basin (post planned spillway raise).

1.6.3 Channel Improvement Downstream of Prado Dam

The portion of the Santa Ana River located immediately downstream of Prado Dam to Weir Canyon Road (referred to as Reach 9) is included in the project study area. Several phases of flood control improvement have been completed, three are currently underway, and at least three more phases are planned. In general, the channel improvements within this reach consist of a combination of different slope protection improvements such as soil cement, rip rap, grouted rip rap, and anchored sheet piles. These improvements are constructed to withstand the maximum conveyance of 30,000 cubic feet per minute (CFM) based on the new outlet works.

1.7 Available Information

Available information pertinent to the proposed project includes feasibility and water conservation studies by USACE and by other entities. With regard to geologic and geotechnical information, USACE has conducted geotechnical investigations for Prado Dam and its associated features, the channel downstream of the dam, dikes within the basin, and other features around Prado Basin. Available information by other entities includes basin-wide studies of groundwater and hydrogeology, geotechnical investigations for pipelines and other utilities within the basin, and a geotechnical investigation conducted specifically for OCWD’s sediment demonstration project. The available information is described in the following sections of this report.

1.7.1 Prado Dam Reports by USACE

The following reports address the dam and recent improvements to the embankment and outlet works.

- U.S. Engineer Office, Los Angeles California, Definite Project Report for Prado Retarding Basin, December 21, 1936
- U.S. Engineer Office, Los Angeles California, Basis for Design, Santa Ana River Improvement, April, 1938
- U.S. Army Corps of Engineers, South Pacific District, Prado Dam Foundation Analysis, July 1976

- U.S. Army Corps of Engineers, South Pacific District, Santa Ana River – Design Memorandum for Major Rehabilitation Volumes 1 and 2, Prado Dam, July 1985
- U.S. Army Corps of Engineers, South Pacific District, Santa Ana River – Design Memorandum for Major Rehabilitation Volume 2, Prado Dam, July 1985
- U.S. Army Corps of Engineers, South Pacific District, Santa Ana River – Phase II General Design Memorandum, Prado Dam, August 1988

1.7.2 USACE Reports for Water Conservation in Prado Basin or Vicinity

The following USACE reports address Prado Basin water conservation.

- U.S. Army Corps of Engineers, South Pacific District, Prado Dam Water Conservation Study, January 1987
- U.S. Army Corps of Engineers, South Pacific District, Prado Dam Water Conservation Study, Geotechnical Appendix for AFB Documentation, August 1999
- U.S. Army Corps of Engineers, South Pacific District, Prado Basin Water Conservation Feasibility Study, Main Report and Draft Environmental Impact Statement/ Environmental Impact Report, July 2004

1.7.3 Scheevel Engineering 2017a and 2017b

These reports summarize the features included in the array of project alternatives, including the TSP, and provides earthwork volumes and other engineering quantities associated with the plan.

1.7.4 RBF Technical Memorandum 2014

This report outlined five alternatives to collect and transport the sediments from the basin to the Santa Ana River downstream of the dam. All of the alternatives in the RBF report have a sediment capture area proposed along the alignment of the Santa Ana River and just downstream of River Road Bridge with a combination of different methods to excavate and transport the material downstream. After undergoing a weighted selection process, RBF concluded that the preferred alternative for further consideration was one which included a sediment capture system and a slurry pipeline carrying the sediment downstream to sediment storage facilities located just east of the Prado Dam spillway.

1.7.5 HDR Report 2014

This report by HDR Inc. addresses the OCWD Prado Basin Sediment Management Demonstration Project and includes a detailed geotechnical appendix (Appendix C, prepared by Golder Associates, Inc., November 2010) described later in this report.

1.7.6 USACE Prado Dam Water Conservation Study (1987)

This report presented the technical feasibility of having a proposed permanent water conservation pool at Elevation 514 feet behind Prado Dam. The report included geotechnical assessment of water storage at various pool elevations under three scenarios: 1) under seepage

through the dam foundation, 2) stability of the abutments, and 3) static and dynamic stability of the embankment.

It was concluded that the abutment stability should not be significantly affected by the proposed water conservation pool elevation. The assessment of the proposed water conservation alternatives for Prado Dam concluded that there were no serious deficiencies which would preclude implementation of the alternatives that were presented. Therefore, no remedial treatment of the embankment or foundation was recommended.

1.7.7 USACE Prado Dam Water Conservation Study (1999)

This report presents the technical feasibility of a proposed permanent water conservation pool at Elevation 508 feet behind Prado Dam. The report addressed the liquefaction potential of the embankment and foundation material under seismic motions and included a two dimensional finite element analysis. Based on the ground motions expected at the dam during a maximum credible event (MCE) or operational basis event (OBE), shallow saturated zones in the foundation under the upstream pervious zone and in the vicinity of the upstream toe were potentially liquefiable.

The post-earthquake stability of the embankment slopes was evaluated and earthquake-induced permanent deformation analyses were conducted. The estimated deformation for the upstream slope for the MCE and OBE events was approximately 5 feet and less than 1 foot, respectively. Based on the proposed water conservation pool of Elevation 508 feet and a crest elevation of 594.4 feet, an initial freeboard of 86 feet would make this deformation tolerable.

1.7.8 USACE Prado Dam Water Conservation Feasibility Study (2004)

This report updated the hydrology and other data, and presented five reformulated alternatives with increasing flood pool elevations and increasing maximum discharges. The report included no geotechnical evaluation or geology data.

2.0 GEOTECHNICAL FIELD AND LABORATORY STUDIES

2.1 General

Field and laboratory study programs were performed for the USACE Lower Santa Ana River and Prado Dam improvement projects. There is a large amount of data regarding the subsurface conditions within the vicinity of Prado Dam.

2.2 USACE Investigations

Geotechnical field and laboratory investigations by USACE for the dam embankment, spillway, outlet works, and borrow area (the proposed stockpiling area for the sediment trap area) are summarized in Table 2.

Table 2: USACE geotechnical investigations at Prado Dam prior to 1988

Date Conducted	Purpose of the Investigation
Late 1930s	Design of Prado Dam
1971	Possible Spillway Modification
1972, 1974, and 1975	Seismic Evaluation
1980	Local faulting investigation
1982, 1983, and 1987	Outlet Works Relocation

Geotechnical field and laboratory investigations by USACE for other features in the vicinity of Prado Basin are summarized in Table 3.

Table 3: Other USACE geotechnical investigations in the vicinity of Prado Basin

Date Conducted	Purpose of the Investigation
1954	Chino Creek Channel
1973	Cucamonga Creek (Mill Creek) Channel
1993	State Route 71 Dike
2007	Corona Sewage Treatment Plant Dike
1994	Corona Housing Tract Dike
2011	Yorba Slaughter Adobe Museum Dike
2014	Women’s Prison Dike

Geotechnical field and laboratory investigations by USACE for the lower Santa Ana River channel downstream of Prado Dam are summarized in Table 4.

Table 4: USACE geotechnical investigations in the Lower Santa Ana River Reach 9

Date Conducted	Purpose of the Investigation
2011	Reach 9 Phase 2
2011	Reach 9 Phase 3
2015	Reach 9 Phase 4
2013-2014	Reach 9 Phase 5A
2014-2015	Reach 9 Phase 5B
2011-2012	BNSF Bridge

These investigations included a combination of test holes/borings and test trenches to map the various geologic formations, to determine the nature and extent of the soil and bedrock materials, and evaluate the character of local faults. The following reports include geotechnical information from reports other than USACE studies.

2.3 Golder Associates, Inc. 2010

As part of the OCWD Prado Basin Sediment Management Demonstration Project, Golder Associates Inc. conducted a field exploration program in March and May of 2010 consisting of three mechanically drilled boreholes and two hand auger boreholes within the Prado Basin to depths of 15 to 30 feet. This report provides the geologic and geotechnical basis for the HDR 2014 report on the OCWD's Demonstration Project. It also includes logs of four borings drilled within the Basin by Ninyo and Moore in 2009. Sample testing from the field exploration showed the predominant material within the drilled depth range is sandy-silt material with sand interbeds. The material is medium plasticity with the plasticity index ranging from 16 to 27.

2.4 Ninyo and Moore 2009

This report by Ninyo and Moore was prepared for the Santa Ana Watershed Project Authority (SAWPA) as part of a project to repair the Santa Ana Regional Interceptor (SARI) wastewater line that traverses Prado Basin.

2.5 AMEC-Geomatrix Seismic Hazard Report 2009

This report provides detailed seismic ground motion data for both Prado Dam and the Women's Prison Dike which is north of Prado Basin. Therefore, its findings are applicable to most of the study area.

2.6 Wildermuth 2005

This report, prepared for the Chino Basin Watermaster, contains extensive geology, hydrogeology, and groundwater data for the Prado Basin including water well locations and well boring logs.

2.7 SAWPA 1977

This internal document is a collection of data relating to eleven test wells drilled and installed within Prado Basin in March 1977, and includes drillers' logs and water sampling and testing data.

3.0 SITE CONDITIONS

3.1 Surface Conditions and Topography

The Prado Basin Feasibility Study area is situated in the southwesterly corner of the broad alluvial-filled Chino Basin and is bounded by the Puente Hills and the foothills of the Santa Ana Mountains to the west and south, respectively. The topography of the Prado Basin is characterized by relatively broad and gently sloping terrain formed by the coalescence of alluvial fans that emanate from the San Gabriel Mountains to the north and the relatively broad floodplain of the Santa Ana River from the northeast. Within the immediate area behind the dam, the terrain is dominated by Holocene sediment deposits associated with the active flood plain of the Santa Ana River. This deposition process is on-going. The very young and relatively flat alluvial sediments have buried much of the older alluvial sediment and bedrock beneath the Prado Basin. The few exposures of bedrock within or on the periphery of the basin include Miocene marine sediments of the Puente formation at both dam abutments, the spillway and the west side of the Prado Dam, further south downstream of the dam along the Santa Ana River, and a small hill of Mesozoic Granite at the U.S. Naval Weapons Station and the Norco Hills just southeast of the reservoir. The older sediment within the basin exists as terrace and fan deposits that are positioned at slightly higher elevations to the north of the Santa Ana River. Remnants of these terraces and fan deposits can be seen exposed around the perimeter of the reservoir area, near the center of the reservoir, and in an extensive area adjacent to the spillway.

The very young and relatively flat lying sediment generally consists of silts and sands in the proximate area of the proposed sediment trap. The Prado Basin Study area is fed by the Santa Ana River, Chino Creek, and Mill Creek. Each of these tributaries are discussed below.

The Santa Ana River is the largest river entirely in Southern California, draining to the Pacific Ocean. The watershed overlies the two largest groundwater basins in Southern California available for conjunctive use. The river drainage area upstream of Prado encompasses about 2,650 square miles making it the largest in Southern California. The Santa Ana River watershed possesses Southern California's largest freshwater wetland, which is the Prado Basin located behind Prado Dam. The basin accumulates nearly all bed material loads and a large portion of the wash load supplied from the contributing drainage area. Within the Prado Basin, OCWD has constructed more than 400 acres of wetlands. The basin's inundation area includes critical habitat for several special status species and vegetation. Downstream of Prado Dam, the Santa Ana River runs through Orange County and drains into the Pacific Ocean.

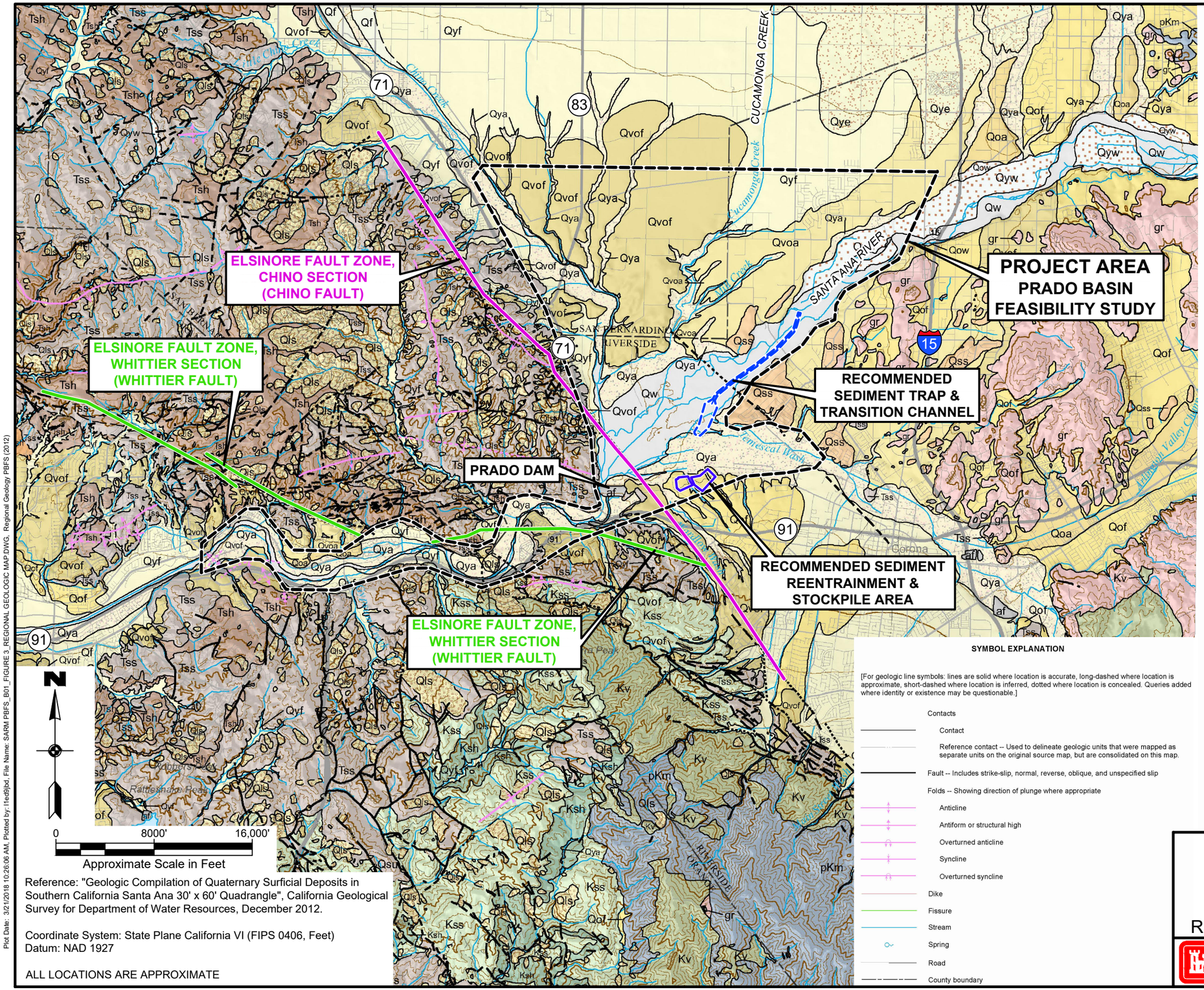
Chino Creek is a tributary to Prado Basin and is lined with concrete along most of the channel length, and so introduces little sediment into the basin. This condition is a major factor contributing to erosion of the creek bed. Residential and commercial developments are situated immediately adjacent to the creek upstream of Pine Avenue, and a historical shooting range and a golf course are located downstream of Pine Avenue. Downstream of Euclid Avenue, the creek is bounded by dense vegetation. Upstream of Euclid Avenue, quality habitat is found within the creek bed and bank slopes.

Mill Creek is a tributary to the Prado Basin and is situated just east of Chino Creek. Upstream of Hellman Avenue, Mill Creek is a concrete lined channel known as Cucamonga Creek;

downstream of Hellman Avenue, Mill Creek is a sandy, soft-bottom channel with vegetation. The short segment between Chino Corona Road and Hellman Avenue is heavily vegetated with the Ontario Wetlands projects adjacent to it on the western side. The creek introduces little sediment inflows into the basin which is a factor contributing to erosion of the creek bed.

3.2 Local Geology

The local geology of the basin consists predominantly of a thick layer of unconsolidated sediment (alluvium) of Quaternary age. The alluvium is derived from the San Bernardino and San Gabriel Mountains to the north and, to a lesser degree, from the Chino Hills to the northwest. The subsurface of the basin is predominantly Quaternary younger river deposited sediment that has dissected or cut through older sediments of the adjacent alluvial fans. Both the fan and river sediment consist of unconsolidated sand, silt, gravel, cobble, and some clay. Figure 3 shows the geologic features within the vicinity of the project area.



Reference: "Geologic Compilation of Quaternary Surficial Deposits in Southern California Santa Ana 30' x 60' Quadrangle", California Geological Survey for Department of Water Resources, December 2012.

Coordinate System: State Plane California VI (FIPS 0406, Feet)
Datum: NAD 1927

ALL LOCATIONS ARE APPROXIMATE

MAP UNITS

Late Holocene (Surficial Deposits)

- af — **Artificial Fill** - deposits of fill resulting from human construction, mining, or quarrying activities; includes engineered fill for buildings, roads, dams, airport runways, harbor facilities, and waste landfills
- Qsu — **Undifferentiated Surficial Deposits** - includes colluvium, slope wash, talus deposits, and other surface deposits of all ages; generally unconsolidated but locally may contain consolidated layers
- Qls — **Landslide Deposits** - may include debris flows and older landslides of various earth material and movement types; unconsolidated to moderately well-consolidated
- Qb — **Beach Deposits** - unconsolidated marine beach sediments consisting mostly of fine- and medium-grained, well-sorted sand
- Qw — **Alluvial Wash Deposits** - unconsolidated sandy and gravelly sediment deposited in recently active channels of streams and rivers; may contain loose to moderately loose sand and silty sand
- Qf — **Alluvial Fan Deposits** - unconsolidated boulders, cobbles, gravel, sand, and silt recently deposited where a river or stream issues from a confined valley or canyon; sediment typically deposited in a fan-shaped cone; gravelly sediment generally more dominant than sandy sediment
- Qa — **Alluvial Valley Deposits** - unconsolidated clay, silt, sand, and gravel recently deposited parallel to localized stream valleys and/or spread more regionally onto alluvial flats of larger river valleys; sandy sediment generally more dominant than gravelly sediment
- Ql — **Lacustrine, Playa, and Estuarine (Paralic) Deposits** - mostly unconsolidated fine-grained sand, silt, mud, and clay from fresh water (lacustrine) lakes, saline (playa) dry lakes that are periodically flooded, and estuaries; deposits may contain salt and other evaporites
- Qe — **Eolian and Dune Deposits** - unconsolidated, generally well-sorted wind-blown sand; may occur as dune forms or sheet sand

Holocene to Late Pleistocene (Surficial Deposits)

- Qyw — **Young Alluvial Wash Deposits** - unconsolidated to slightly consolidated, undissected to slightly dissected sandy and gravelly stream bed sediments in marginal parts of active and recently active washes and river channels
- Qyf — **Young Alluvial Fan Deposits** - unconsolidated to slightly consolidated, undissected to slightly dissected boulder, cobble, gravel, sand, and silt deposits issued from a confined valley or canyon
- Qya — **Young Alluvial Valley Deposits** - unconsolidated to slightly consolidated, undissected to slightly dissected clay, silt, sand, and gravel along stream valleys and alluvial flats of larger rivers
- Qye — **Young Eolian and Dune Deposits** - unconsolidated to slightly consolidated, undissected to slightly dissected wind-blown sands

Late to Middle Pleistocene (Surficial Deposits)

- Qow — **Old Alluvial Wash Deposits** - slightly to moderately consolidated, moderately dissected sand and gravel; typically elevated above modern washes
- Qof — **Old Alluvial Fan Deposits** - slightly to moderately consolidated, moderately dissected boulder, cobble, gravel, sand, and silt deposits issued from a confined valley or canyon
- Qoa — **Old Alluvial Valley Deposits** - slightly to moderately consolidated, moderately dissected clay, silt, sand, and gravel along stream valleys and alluvial flats of larger rivers
- Qol — **Old Lacustrine, Playa, and Estuarine (Paralic) Deposits** - slightly to moderately consolidated, moderately dissected fine-grained sand, silt, mud, and clay from lake, playa, and estuarine deposits of various types

Middle to Early Pleistocene (Surficial Deposits)

- Qvof — **Very Old Alluvial Fan Deposits** - moderately to well-consolidated, highly dissected boulder, cobble, gravel, sand, and silt deposits issued from a confined valley or canyon
- Qvoa — **Very Old Alluvial Valley Deposits** - moderately to well-consolidated, highly dissected clay, silt, sand, and gravel along stream valleys and alluvial flats of larger rivers; generally uplifted and deformed
- Qvol — **Very Old Lacustrine, Playa, and Estuarine (Paralic) Deposits** - moderately to well-consolidated, highly dissected fine-grained sand, silt, mud, and clay from lake, playa, and estuarine deposits of various types

Quaternary (Bedrock)

- Qss — **Coarse-grained formations of Pleistocene age and younger** - primarily sandstone and conglomerate
- Qsh — **Fine-grained formations of Pleistocene age and younger** - includes fine-grained sandstone, siltstone, mudstone, shale, siliceous and calcareous sediments

Tertiary (Bedrock)

- Tss — **Coarse-grained Tertiary age formations** - primarily sandstone and conglomerate
- Tsh — **Fine-grained Tertiary age formations** - includes fine-grained sandstone, siltstone, mudstone, shale, siliceous and calcareous sediments
- Ty — **Tertiary age formations of volcanic origin**

Mesozoic and Older (Bedrock)

- Kss — **Coarse-grained Cretaceous age formations of sedimentary origin**
- Ksh — **Fine-grained Cretaceous age formations of sedimentary origin**
- Kv — **Cretaceous age formations of volcanic origin**
- pKm — **Cretaceous and pre-Cretaceous metamorphic formations of sedimentary and volcanic origin**
- sp — **Serpentinite of all ages**
- gr — **Granitic and other intrusive crystalline rocks of all ages**

SYMBOL EXPLANATION

[For geologic line symbols: lines are solid where location is accurate, long-dashed where location is approximate, short-dashed where location is inferred, dotted where location is concealed. Queries added where identity or existence may be questionable.]

Contacts

- Contact
- Reference contact -- Used to delineate geologic units that were mapped as separate units on the original source map, but are consolidated on this map.

Fault -- Includes strike-slip, normal, reverse, oblique, and unspecified slip

Folds -- Showing direction of plunge where appropriate

- Anticline
- Antiform or structural high
- Overturned anticline
- Syncline
- Overturned syncline

Dike

Fissure

Stream

Spring

Road

County boundary

SANTA ANA RIVER MAINSTEM
PRADO BASIN FEASIBILITY REPORT
ORANGE, RIVERSIDE AND
SAN BERNARDINO COUNTIES, CALIFORNIA

REGIONAL GEOLOGIC MAP AND FAULTS

US Army Corps of Engineers
Los Angeles District

CKD BY: M.L.R.	FIGURE
DWN BY: JBD	3
DATE: March 2018	

Plot Date: 3/21/2018 10:26:06 AM, Plotted by: 1fed9jbd, File Name: SARM PBFS_B01_FIGURE 3_REGIONAL GEOLOGIC MAP.DWG, Regional Geology PBFS (2012)

3.3 Sediment Stratigraphy

The sediment within Prado Basin is early Quaternary alluvium that extends south from the foothills of the San Gabriel and San Bernardino mountains into the Prado Basin. The alluvial fan deposit is shaped by the Santa Ana River and its tributaries, and the younger alluvium has been deposited atop this fan deposit. The alluvium deposit materials consist of unconsolidated heterogeneous mixtures of silt, sand, gravel, cobbles, and some clay.

A three dimensional sediment model was developed using the computer software Groundwater Modeling System (GMS) – Borehole Module version 9.3 and data from a variety of borings and wells (locations shown on Figure 4). The model is based on the stratigraphy data provided by the OCWD, which included water well and geotechnical borehole data from local utilities and municipal agencies such as the OCWD and Santa Ana Watershed Project Agency. The modeled area is within Prado Basin, immediately upstream of Prado Dam and extending northeast upstream along the Santa Ana River, ending at the River Road bridge crossing.

Figures 5, 6, and 7 show the results of modeling sediment within the basin. The sediment model developed from the GMS program showed the coarse sediments being located from River Road Bridge to the upper middle end of the basin behind Prado Dam. The model simulates the heterogeneous mix of existing sediment types within Prado Basin for the uppermost 20 to 50 feet thickness of depth. It models this mixture into three basic types based on grain size. These sediment types are seen as solid colored layers within the model and as shown on the figures as yellow for sand, pink for clay, and blue for silt. The resulting output of the models shows the coarser sand material (shown yellow on the Figures) is present from River Road Bridge to approximately central portion of Prado Basin, which includes much of the area modeled. The thickest portion of this sand layer extends from River Road Bridge to the middle of the modeled area and then it thins out appreciably beneath and above the finer clay and silt layers in the central and west central portions of the modeled Basin area. The clay and silt layers are thinly dispersed from the narrow eastern neck portion of the modeled area and become thicker in the central and western extends of the modeled area. These clay and silt fine grained sediments are concentrated mostly within the proximity of the dam's abutment.

This depositional sequence is consistent with the sedimentation behind a dam. The finer incoming sediments from the Santa Ana River would settle out last and deposit further away from the coarser sand deposits. The sand is heavier and settles out first where it deposits as a thicker layer further upstream between the dam and River Road Bridge, which is upstream of the immediate areas behind the dam. This deposition is traditionally described as a delta deposit, occurring when a river meets a still body of water. The newer sediment gradually covers the older sediment with each new incoming depositional event at this still water boundary forming foreset beds. Foreset beds and delta deposits are much more pronounced when the river bed gradient is steeper behind a dam. This is not quite the case for the Prado Basin Study area, in which the river bed gradient is gentler. Also, the dam operates at low water levels during flood events, causing most of the incoming sediment from the Santa Ana River to be carried immediately into the area close behind the dam. The depositional sequence behind Prado resembles more of a combination Delta to Wedge deposit. This is why there is an abrupt and thick layer of finer sediment just behind the Prado dam bounded by a coarser sand which thickens upstream from this wedge. The wedge shaped depositional process exhibited within the

basin is similar to other sequences behind flood control structures that maintain relatively low pool levels for short durations.

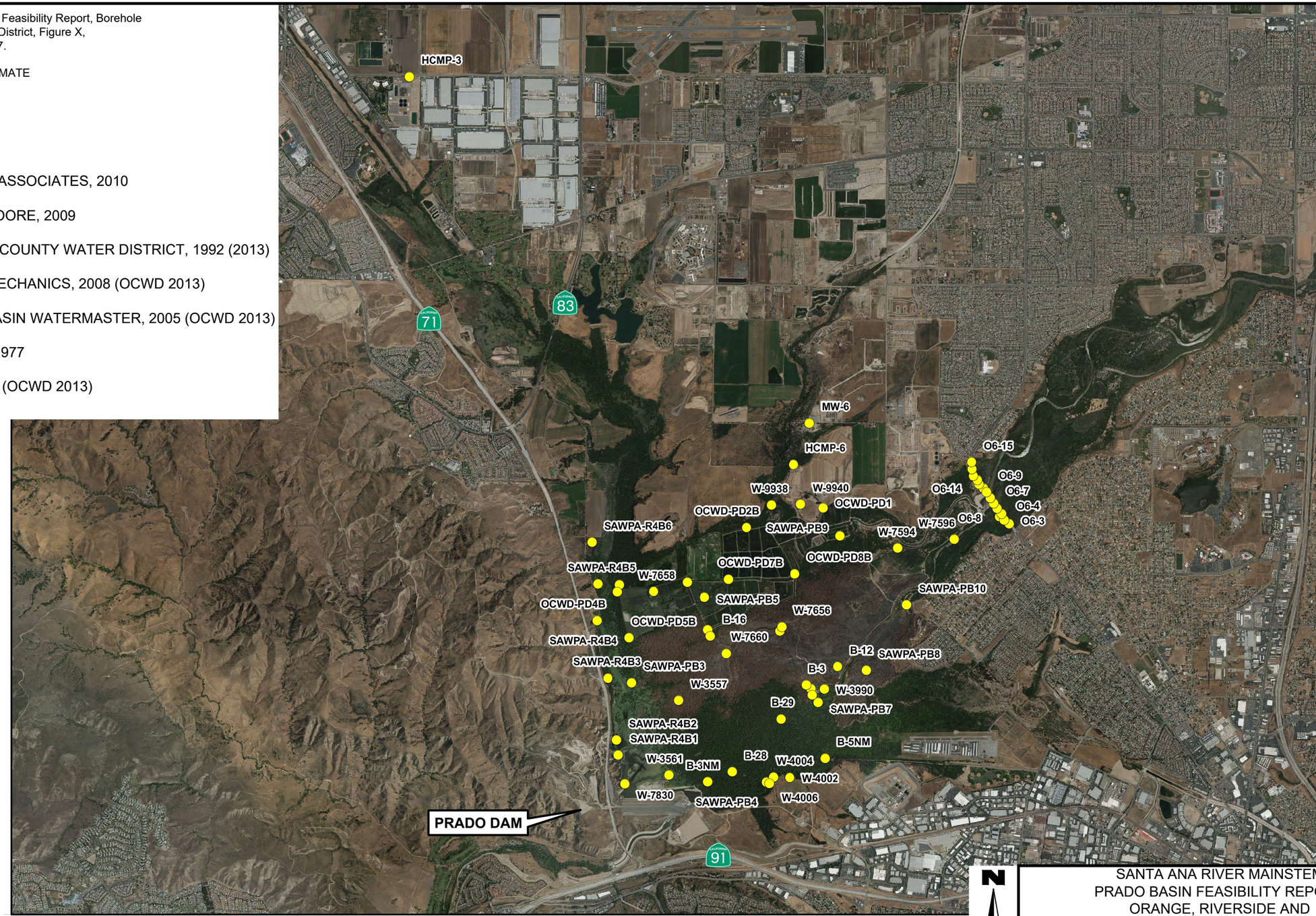
Based on the modeling, the coarser sediment (sand) is found throughout the basin and is more predominant closer to the ground surface and at the upstream portion of the Santa Ana River within the basin. Also, the model indicates two major depths of occurrence for the sandy material. The upper sandy deposit is encountered from the ground surface to depths that vary from 6.5 to 33 feet, extending from the upper reaches of the basin to the Santa Ana River to the bridge crossing at River Road. This upper sandy deposit is not present at areas within the Prado Basin adjacent to the dam. The lower sandy deposit is encountered at an approximate elevation range of 439 to 488 feet and is 6.5 to 16 feet thick, covering most of the basin. The upper and lower layers contain a total sandy sediment volume of approximately 45,149,750 and 35,655,000 cubic yards, respectively as of December 2014. The geographic limits of the layers are shown in Figures 5, 6, and 7.

Reference: Basemap from "Prado Feasibility Report, Borehole Locations" Orange County Water District, Figure X, BoreholeLocations.mxd, May 2017.

ALL LOCATIONS ARE APPROXIMATE

BOREHOLE LEGEND

B-3	GOLDER ASSOCIATES, 2010
B-3NM	NINYO MOORE, 2009
OCWD-PD1	ORANGE COUNTY WATER DISTRICT, 1992 (2013)
O□-4	EARTH MECHANICS, 2008 (OCWD 2013)
HCMP-3	CHINO BASIN WATERMASTER, 2005 (OCWD 2013)
SAWPA-R4B□	SAWPA, 1977
MW-□ W-7830	VARIOUS (OCWD 2013)



Borehole Locations

0 4000' 8000'
Approximate Scale in Feet

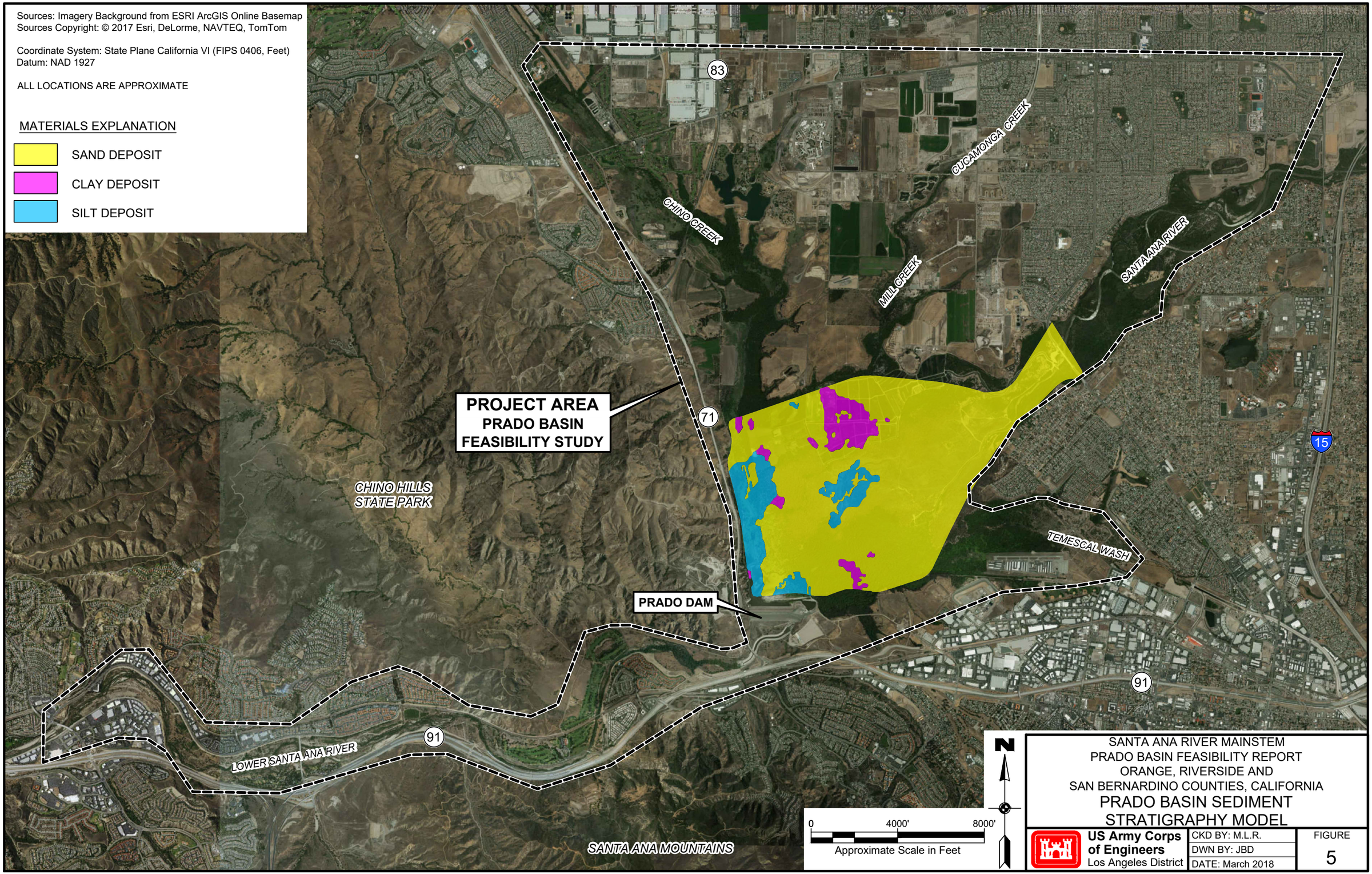
SANTA ANA RIVER MAINSTEM
PRADO BASIN FEASIBILITY REPORT
ORANGE, RIVERSIDE AND
SAN BERNARDINO COUNTIES, CALIFORNIA

HISTORIC GEOTECHNICAL AND WATER WELL BOREHOLE LOCATIONS

US Army Corps of Engineers
Los Angeles District

CKD BY: M.L.R.	FIGURE
DWN BY: JBD	4
DATE: March 2018	

Plot Date: 3/21/2018 10:34:35 AM, Plotted by: l1ed9jxd, File Name: SARM PBFS_B01_FIGURE 4_BOREHOLE LOCS.DWG, Bor Locs (pdf)



SANTA ANA RIVER MAINSTEM
PRADO BASIN FEASIBILITY REPORT
ORANGE, RIVERSIDE AND
SAN BERNARDINO COUNTIES, CALIFORNIA

PRADO BASIN SEDIMENT
STRATIGRAPHY MODEL

US Army Corps of Engineers
Los Angeles District

CKD BY: M.L.R.
DWN BY: JBD
DATE: March 2018

FIGURE
5

Plot Date: 3/21/2018 11:11:07 AM, Plotted by: l1ed9jbd, File Name: SARM PBFS_B01_FIGURE 5_STRAT MODEL-SEDIMENT.DWG, Sediment (4k)

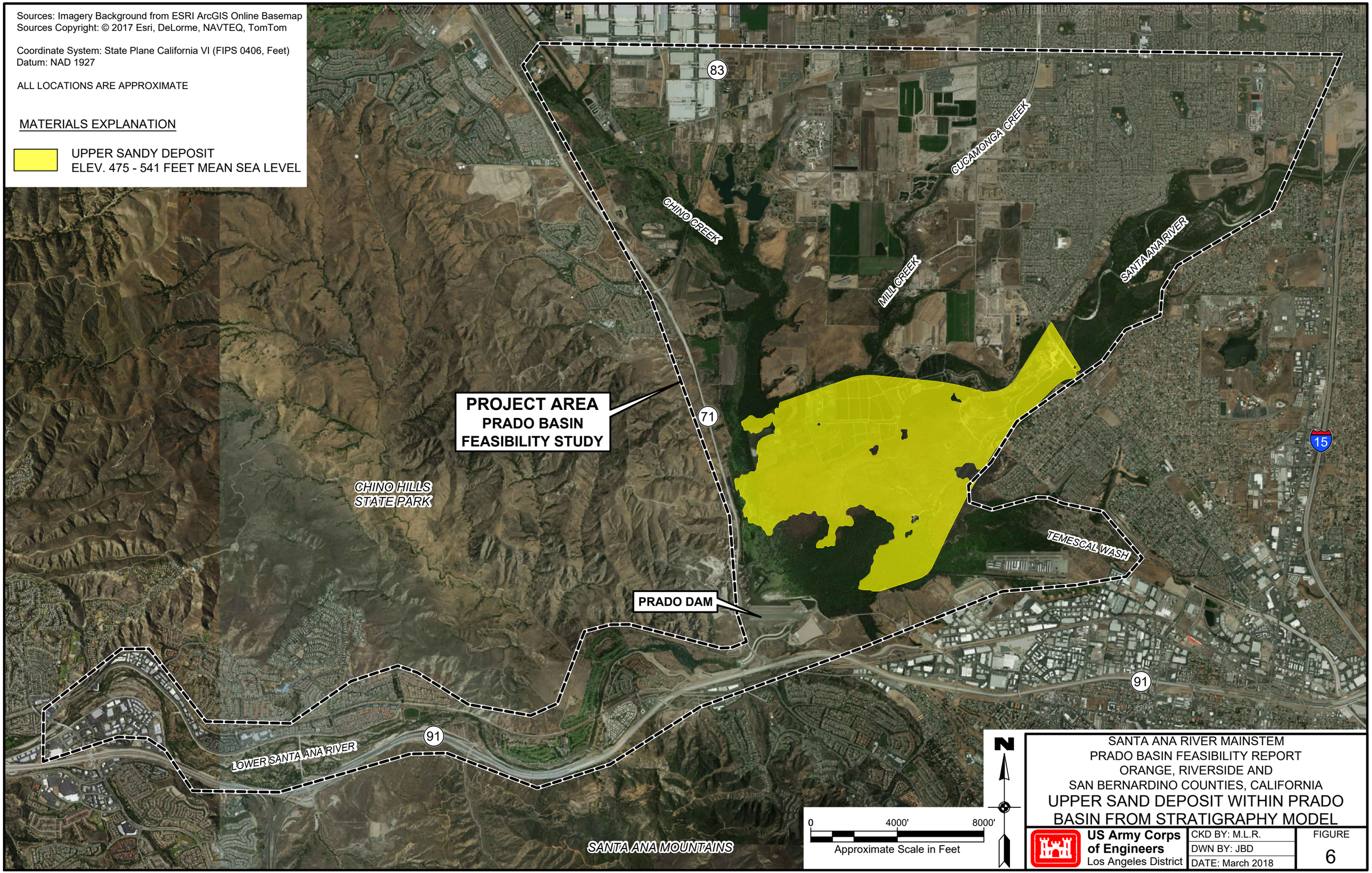
Sources: Imagery Background from ESRI ArcGIS Online Basemap
Sources Copyright: © 2017 Esri, DeLorme, NAVTEQ, TomTom

Coordinate System: State Plane California VI (FIPS 0406, Feet)
Datum: NAD 1927

ALL LOCATIONS ARE APPROXIMATE

MATERIALS EXPLANATION

UPPER SANDY DEPOSIT
ELEV. 475 - 541 FEET MEAN SEA LEVEL



SANTA ANA RIVER MAINSTEM
PRADO BASIN FEASIBILITY REPORT
ORANGE, RIVERSIDE AND
SAN BERNARDINO COUNTIES, CALIFORNIA

UPPER SAND DEPOSIT WITHIN PRADO BASIN FROM STRATIGRAPHY MODEL

US Army Corps of Engineers
Los Angeles District

CKD BY: M.L.R.
DWN BY: JBD
DATE: March 2018

FIGURE
6

Plot Date: 3/21/2018 11:14:36 AM, Plotted by: l1ed9jkd, File Name: SARM PBFS_B01_FIGURE 6_STRAT MODEL-UPPER.DWG, Upper Sandy (4k)

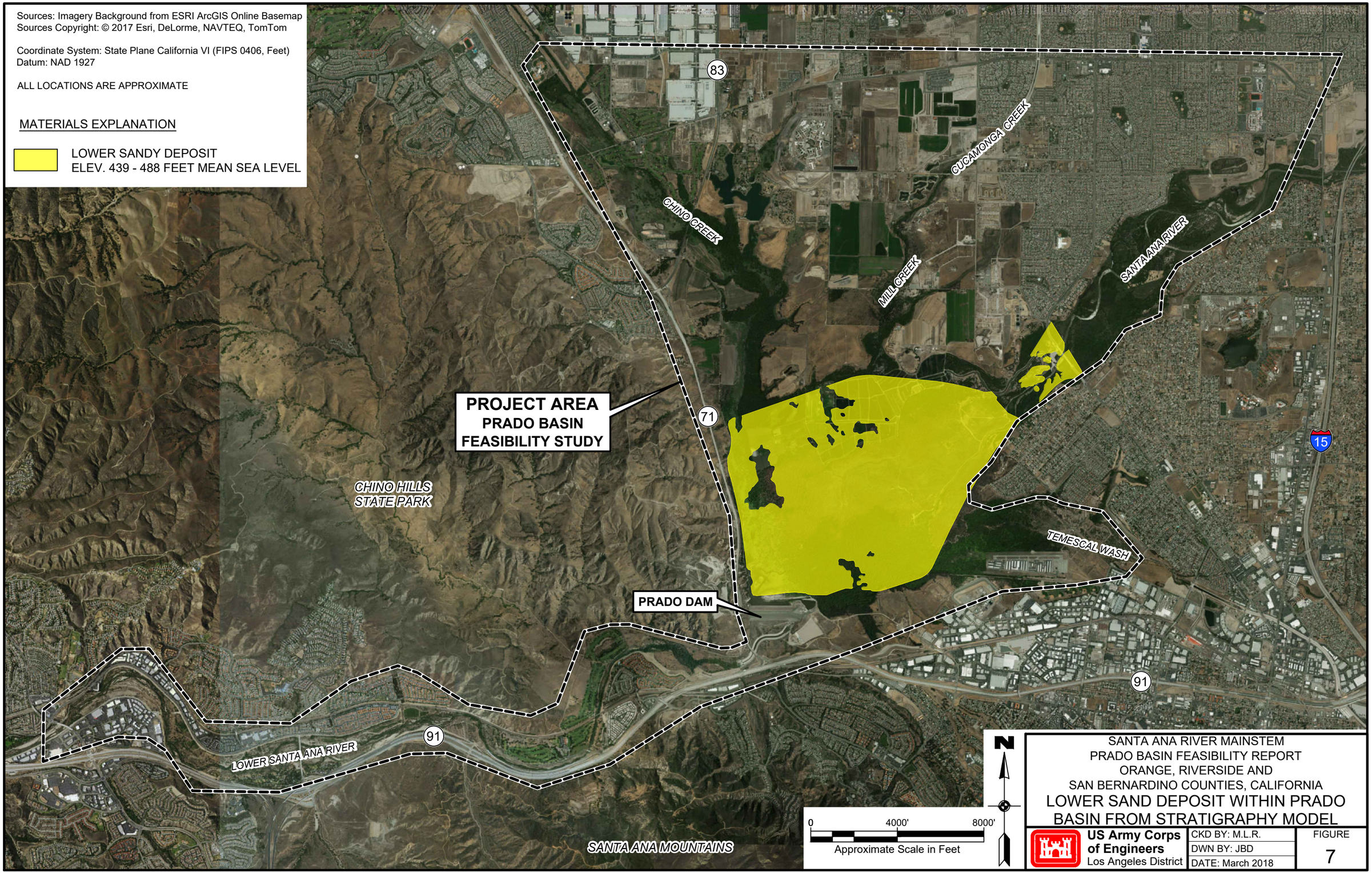
Sources: Imagery Background from ESRI ArcGIS Online Basemap
Sources Copyright: © 2017 Esri, DeLorme, NAVTEQ, TomTom

Coordinate System: State Plane California VI (FIPS 0406, Feet)
Datum: NAD 1927

ALL LOCATIONS ARE APPROXIMATE

MATERIALS EXPLANATION

LOWER SANDY DEPOSIT
ELEV. 439 - 488 FEET MEAN SEA LEVEL



SANTA ANA RIVER MAINSTEM
PRADO BASIN FEASIBILITY REPORT
ORANGE, RIVERSIDE AND
SAN BERNARDINO COUNTIES, CALIFORNIA

LOWER SAND DEPOSIT WITHIN PRADO BASIN FROM STRATIGRAPHY MODEL

US Army Corps of Engineers
Los Angeles District

CKD BY: M.L.R.
DWN BY: JBD
DATE: March 2018

FIGURE
7

Plot Date: 3/21/2018 11:15:34 AM, Plotted by: l1ed9jbd, File Name: SARM PBFS_B01_FIGURE 7_STRAT MODEL-LOWER.DWG, Lower Sandy (4k)

3.4 Groundwater

Prado Dam and its reservoir area fall within the Chino Groundwater Basin and form the downstream southerly portion of the basin. Numerous wells for production of domestic water have been installed and operate in the reservoir area. The water-bearing sediments of Chino Basin are composed of interbedded, discontinuous layers of gravel, sand, silt, and clay. These layers and their geometries are too numerous and complex to characterize on a basin-wide scale. The base of the freshwater aquifer beneath the Prado Dam reservoir area ranges from roughly Elevation 300 feet to Elevation 400 feet. The groundwater surface in the vicinity of Prado Basin is roughly around Elevation 500 feet, but varies seasonally. Depth to water ranges from ground surface to 20+ feet below grade. Portions of the Chino Basin to the west along Chino Creek historically had artesian groundwater conditions (Wildermuth Environmental, 2005).

3.5 Engineering Seismology

3.5.1 Regional Seismology

Prado Basin is located along the southern corner of Chino Basin. The Chino Basin lies approximately 40 miles east of Los Angeles and covers an area of about 230 square miles. It is a geologically young (Quaternary) sedimentary basin bounded by major faults and resistant hills within the northern reaches of the northwest-trending Peninsular Ranges where they terminate against the east-west trending Transverse Ranges. The Transverse Ranges, with their numerous east-west trending active thrust faults and associated folds, are the results of the compressional forces caused by the big bend in the strike slip boundary between North American and Pacific plates, where the crust is converging at rates that range from 0.2 to 0.8 inches per year. The result is an east-west trending belt of rugged mountains that is marked by frequent moderate to large earthquakes. The most recent event from the system is the Northridge event that occurred approximately 65 miles northwest of the Prado Basin.

3.5.2 Local Faulting

The dominant fault system for the project area is the Elsinore fault system, due to its proximity to Prado Basin. The Elsinore fault system is predominantly a right-lateral strike slip fault with some reverse displacement along secondary faults. The Elsinore fault system extends for about 190 miles (306 km) southeast along the northeastern side of the Santa Ana Mountains, with segments terminating at the north near the cities of Pomona and Whittier and into Baja California. The estimated horizontal fault slip rate is 0.16 inches per year.

Immediately south of the Prado Basin, the Elsinore fault system splits into two segments: the Chino and Whittier Faults. Between these two faults, numerous minor faults exist, trending either northwest-southeast (normal to the major faults) or northeast-southwest (parallel to the major faults). The Chino fault is a right-reverse fault with a length of 13 miles. The estimated horizontal fault slip rate is 0.04 inches per year. The Whittier fault is right-lateral strike-slip fault with some reverse slip with a length of 25 miles. The estimated horizontal fault rate is 0.11 inches per year.

The Chino Hills and the Puente Hills to the northwest are part of a structural unit that has been uplifted between the Whittier faults, which form the east margin of these hills. Uplift of the region occurred during the past 2 to 3 million years (Quaternary time) and deformed the Puente Formation with extensive warping and faulting. The warping generally trends northwest-southeast, paralleling major faults. Several very pronounced folds known as the Mahala anticline, Arena Blanca anticline, and the Arena Blanca Syncline project through the Chino Hills near Prado Dam. There are numerous minor faults between the Whittier and Chino faults which trend in two general directions: northwest-southeast (parallel to the major faults) and northeast-southwest (normal to the major faults). Figure 3 shows the seismic faulting conditions within the vicinity of the project area.

4.0 GEOTECHNICAL AND GEOLOGIC CONSIDERATIONS

4.1 General

As discussed under section 1.4 Tentatively Selected Plan (TSP), the proposed project has multiple purposes, primarily water conservation and ecosystem restoration within the Prado Basin.

The largest geotechnical concern for this project is the effect of the project on the stability and performance of the Prado Dam embankment, outlet works, and spillway. There is sufficient high-quality geotechnical data around the dam, outlet, and spillway to perform the necessary risk assessments and evaluations described in the following paragraphs.

The other geotechnical concerns are for design of the various physical project features listed in Section 1.4 (ecological project features are not a geotechnical concern except where they involve large grading volumes). Although some geotechnical data is available from several sites within the basin and many sites along the lower Santa Ana River channel, there is limited geotechnical information at the precise locations of most of the proposed project features, so site-specific investigations will be needed. Geotechnical concerns for design of the various physical project features include slope stability (both long-term and during construction), settlement, foundation type and foundation bearing capacity for structures such as the bicycle bridge and culverts, erodibility, stone quality, and other concerns.

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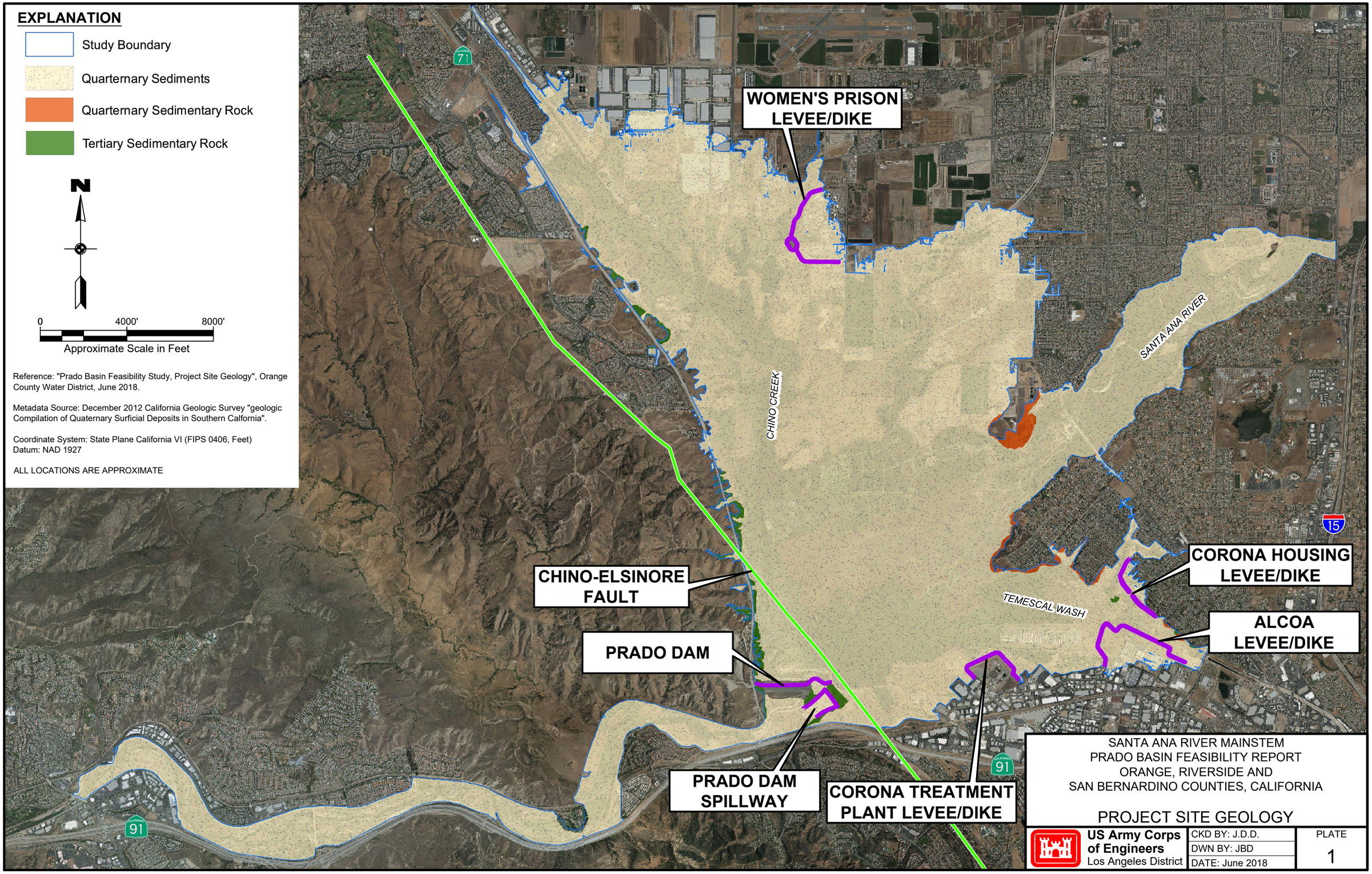

Plot Date: 6/18/2018 12:59:55 PM, Plotted by: l1ed5jbd, File Name: DNU-NAP_SARM PBFS_B01_SEDIMENT.DWG, Prado Basin_Site Geology

4.2 Design Constraints

The following issues will impact the proposed water conservation plan and sediment management systems and will be constraints to the project design:

- Dam Safety: Prado Dam is a critical flood risk reduction structure. Negative impacts to the functionality of the dam from the proposed designs are prohibited. The proposed sediment storage stockpiles will be very large and may cause settlement at the spillway or the auxiliary dike. The proposed slurry pipelines to transport sediment from the basin to the river downstream of the dam may need to be routed over the surface of portions of the auxiliary dike, but no penetrations of the main dam embankment or auxiliary dike embankment should be made. Neither the old nor new outlet works, nor the SARI pipeline should be used as a conduit to transport sediment beneath or through the embankment.

- Basin sediment inflow volumes: While sizing the sediment trap, the inflow volumes will need to be accounted for as the sediment's volume inflow fluctuates on a year to year basis. From historical data, the drier years provided small amount of sediment inflows, while the wetter years provided large amounts, capable of overwhelming the capacity of the trap if it is not designed properly.

- Availability of suitable sediments: The desirable sediments to transport downstream of the dam are considered to be silty sand to sand material. The location and depths for the desired material for re-entrainment is discussed above under "Sediment Stratigraphy Models."

- Environmental Disturbance: Although it is not a geotechnical issue, this factor is important because the project area is located in an environmentally sensitive area. Regulatory agencies such as the U.S. Fish & Wildlife Service (USFWS) want a sediment trap that has a minimal environmental footprint.

4.3 Geotechnical Aspects of Sediment Management Plan

4.3.1 Sediment Collection and Removal

The stratigraphy data and models within the basin indicate that the location of the proposed sediment trap contains the desirable sandy material for delivery to the river below Prado Dam. New annual deposits of sediment into the trap are also expected to be mostly sandy material. OCWD estimates that, once the system is constructed, up to one million CY of sediment will be removed from the trap and transition channel annually.

Although a significant amount of geotechnical data is available from several sites within the basin which may provide general insight as to the expected material characteristics, there is limited information regarding the in-situ geotechnical parameters of the existing material in the proposed sediment trap and transition channel areas. So site-specific investigations will be needed for the sediment trap, channel, and related features. Based on available information, the soils in those areas are expected to be readily excavatable using conventional earth-moving

equipment. However, if the sediment trap area is very wet, dredging equipment could be advantageous. The sediment trap is expected to capture generally wet coarse-grained material (sands and gravels). Based on consultation with coastal engineers, it is expected that sediment accumulated within the trap below the river water surface could be removed using cutter head dredges, thus avoiding the need for construction dewatering.

The OCWD is planning a demonstration project for 2018 or 2019 to excavate a limited sediment trap using both conventional earth moving equipment and a dredge. The excavated wet sediments will be placed in a bermed area for storage and drainage. The results of that demonstration project will help evaluate the feasibility of the larger sediment collection and removal system proposed in this study.

The design specifics for the proposed sediment trap, transition channel, entrainment groin, pilot channel, and flow control and grade control structures will need to be developed in the PED phase. Earlier feasibility studies for this project discussed side slopes of 5H:1V for the sediment trap, but 3H:1V side slopes for the trap and transition channel are discussed in current OCWD documents (Scheevel Engineering, 2017).

4.3.2 Sediment Delivery System

After sediment is collected at the trap, it would be transported to the designated stockpiling and processing area by conventional trucking according to the current plan.

After stockpiling and processing, selected sediments would be re-entrained downstream of the dam seasonally at appropriate times depending on multiple factors, including environmental restrictions, seasonal tributary flows into the Prado Basin, and Prado Dam's flood risk management operations. A more specific and detailed re-entrainment plan will be developed in the PED phase. Slurry pumps and slurry pipelines are proposed to transport and re-entrain the sediments. Previously considered conveyor belt systems tend to have higher operation and maintenance costs. Although a slurry system requires significant amounts of water, it was considered preferable to the conveyor belt alternative.

The slurry pipe, or a previously considered conveyor belt system, would be at the ground surface and would be considered portable and temporary. Anchoring where the pipe or conveyor traverses slopes would be the only geotechnical concern with these portable temporary features.

The current array of alternatives and the TSP all proposed temporary above-grade slurry pipelines routed around the dam along access roads but potentially routed partly over the auxiliary embankment. Previous concepts of routing slurry pipelines through the dam embankment or spillway, possibly through former outlet works, are not incorporated into the current plan and should not be permitted in any future project design due to dam safety concerns. The slurry pipelines will require anchoring systems of some sort to keep them in place on sloping ground. Where slurry pipelines cross access roads and maintenance roads, they may need culverts to allow them to pass beneath the road or bridge structures to allow them to pass over the roads. Specific geotechnical investigations would be necessary to address those features.

The alternatives analysis report by RBF (2014) assumed a 20 percent and 1 percent concentration of the sediment load by weight for transporting the sediments to the stockpile area and for re-

entrainment downstream of the dam, respectively. The amount of water needed to complete these tasks would pose a concern because: (1) it would require a fairly substantial, consistently available water source and (2) the vicinity of the stockpile area to the Prado Dam's spillway and the Sewage Treatment Plant Dike could pose problems.

4.3.3 Sediment Stockpiles and Re-entrainment Work Area

Two stockpiles for storing sediment are proposed that would have 5H:1V side slopes and be up to 80 feet tall when completely full. Area A would cover up to 70 acres and be just east of the Prado Dam spillway, just north of the Auxiliary Dike, and just west of the USACE Prado Dam Resident Office. Area B would cover up to 100 acres and would be just northeast of the USACE office and just northwest of private properties occupied by structures. The stockpile locations are generally in the areas formerly used as a borrow source for the Prado Dam and Auxiliary Dike projects and currently designated for the upcoming Alcoa Dike project.

At the estimated rates of sediment accumulation, the stockpiles would not reach their maximum dimensions for many years (likely decades). However, since these stockpiles are projected to become very large and very high, their effect on the site and adjacent sites must be considered. They would induce significant vertical stresses in the ground. Such large induced stresses would likely cause settlement on the order of multiple feet beneath the stockpiles and for a significant radius around each stockpile. The potential for settlement caused by the stockpiled soil in Area A to negatively impact the performance of the spillway and auxiliary dike should be evaluated. The potential for settlement caused by stockpile B to negatively impact adjacent private properties should be evaluated.

Other engineering concerns for the stockpiles include: stability of temporary stockpile slopes; drainage of runoff from rainfall and stockpiled saturated soils; erosion from stockpile side slopes; dust control; and compaction control. Although the stockpiles will not be used to support structures or pavements, stockpiled soils should be at least minimally compacted (85% of modified Proctor maximum density should be sufficient for stockpiles).

The proposed re-entrainment work area would be for processing, spreading, and dewatering sediment prior to stockpiling, but also for re-entraining sediment for delivery by pipeline to the Santa Ana River channel below Prado Dam. The re-entrainment work area would be situated at the west edge of stockpile area A, west of the existing USACE Prado Dam Resident Office near the Prado Dam spillway. The location of the re-entrainment work area in the proposed plan means there would be a significant amount of water near an existing critical flood control structure. The potential for this water to negatively impact the performance of the spillway should be evaluated, such as the potential for an increased risk of under-seepage due to local groundwater rise as a result of the nearby re-entrainment slurry operation.

4.3.4 Bicycle "Fly-over" Bridge

The proposed elevated bicycle bridge ("fly over" bridge) through the stockpile area would require foundations for two abutments and possibly one or more piers. Bridge abutment foundations are typically conventional shallow footings, but pier foundations are commonly deep foundations (typically CIDH piles). Earthen approach ramps for the bridge would consist of

compacted fill and may require retaining walls. A site-specific geotechnical investigation would be necessary for bridge design.

4.4 Geotechnical Concerns for Water Conservation

The current Water Control Plan for Prado Dam allows impoundment for water conservation within the buffer pool elevations. The buffer pool elevations range from the top of the debris pool, elevation 490 feet, up to elevation 498 feet during the flood season (1 October through 28/29 February), and up to elevation 505 feet during the non-flood season (1 March through 30 September). The current study evaluates the feasibility of raising the water conservation pool to Elevation 505 feet during the flood season to allow year-round water storage at that elevation. This would increase the potential water conservation by about 10,500 acre-feet, which would eventually be captured in OCWD's spreading grounds for groundwater recharge, located downstream of Prado Dam.

4.4.1 Screening for Portfolio Risk Assessment

The Screening for Portfolio Risk Assessment (SPRA) conducted by USACE Headquarters in December 2009 on Prado Dam identified four issues. Three are related to the spillway capacity and will be addressed when the improvements to Prado Dam are completed. The fourth issue is related to the liquefaction potential of the dam's foundation. The dam was preliminarily rated as a Dam Safety Action Classification (DSAC) 3.

4.4.2 Waiver to Study Water Conservation

Conducting a water conservation study on a DSAC 3 or lower rated dam is not in compliance with Chapter 24 of Engineering Regulation (ER) 1110-2-1156. The three primary issues that contributed to Prado Dam's current DSAC rating are related to the dam's spillway capacity. Those issues will be addressed and the DSAC rating will improve once the ongoing improvements within Prado Basin and along the Santa Ana River Reach 9 are complete. The currently estimated completion date for all the Prado Basin flood risk improvement is 2021. A request for waiver of the pertinent requirements of Chapter 24 of ER 1110-2-1156 was submitted and subsequently approved by USACE Headquarters as of July 15, 2014.

4.4.3 Dam Breach Assessment

A dam breach risk assessment should be conducted to evaluate whether the downstream channel could handle the resulting flows from a dam breach. The analysis should document the time necessary to evacuate the water conservation pool and regain full flood control capacity of 171,848 acre-feet. The assessment should include the following:

- Identify the non-damaging pool; the flows from the corresponding dam breach at the pool elevation would not flow out of the downstream channels
- Evaluate the probability of the non-damaging pool exceedance under the existing dam operation
- Estimate the flow rate for each elevation and associate flood map for these rates
- Calculate the loss of life and economic consequences

A facilitated probable failure mode analysis would support the risk assessment and should be done beforehand.

4.4.4 Probable Failure Mode Analysis

The proposed re-operation of the reservoir pool for water conservation purposes would require a probable failure mode analysis (PFMA) to be conducted. The PFMA is the first step in evaluating the risk assessment with an existing dam. During this process, the analysis hypothesizes particular defects and conditions that would initiate methods of failures. These methods of failure, potential failure modes (PFMs), would be identified, described, and evaluated on their credibility and significance, which would include the following:

- Factors, data, or conditions that suggest the potential failure mode is more likely or less likely to occur
- The breach scenario and potential consequences of failure
- Additional data and information needed for a risk analysis and supplemental interim risk reduction measures (data gaps)

The PFMs thought to be credible would then undergo further review. Prioritization of the PFMs would be done to determine which of the PFM(s) would be the “risk drivers” for the water conservation study.

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5.0 CONCLUSIONS AND RECOMMENDATIONS

Based on available data, the TSP appears to be feasible from a geotechnical perspective. Impacts to the stability and operation of Prado Dam and its associated features must be carefully considered. Settlement of nearby spillway, dike, and private buildings resulting from the proposed sediment stockpiles may be the most significant geotechnical concern. The various project features within the basin area will mostly be founded on relatively soft and loose sediments in areas of generally shallow groundwater. Difficulty in excavation is not anticipated, but slope stability, settlement, liquefaction, and construction dewatering will likely be serious geotechnical concerns for most of the proposed features. Detailed geotechnical investigations will be necessary for design of each of the many project features.

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6.0 RECOMMENDED ADDITIONAL GEOTECHNICAL STUDIES

Site-specific geotechnical investigations will prescribe during the PED phase for most of the proposed project features. For the proposed sediment trap, transition channel, and pilot channel, a project-specific field exploration program will be required within the Prado Basin to verify that the data provided by OCWD is a current representation of the basin subsurface conditions at the proposed project location. Site specific geotechnical investigations will be necessary at the proposed sediment stockpile areas, at the Chino Creek features, at the proposed wildlife passage culvert locations, and at the proposed grading areas for native planning to provide geotechnical parameters for civil and structural design of those features. The investigation program would generally consist of exploratory borings and test trenches with appropriate soil sampling. Geotechnical laboratory tests would be conducted on the samples collected from the investigations to characterize the subsurface materials.

Settlement due to the sediment storage stockpiles would necessitate detailed engineering evaluation including laboratory compressibility (consolidation) testing. The stability of sediment trap and channel slopes would be part of the engineering evaluation including slope and seismic stability. Foundation design for the slurry pipe supports would be required, as necessary, depending on the proposed design.

The current plan to construct the slurry pipe between the spillway and auxiliary dike will need to be checked against the spillway design and the as-built plans for the auxiliary dike.

The water conservation study would need to include a PFMA for the full dam operations and dam breach analysis to evaluate the risk associated with the proposed water conservation measure. The findings of the previous geotechnical studies supporting an increase in water conservation pool (1987, 1999, and 2014) should be updated to support the current proposal.

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7.0 LIMITATIONS AND RISK

As part of the project study, several issues were identified and considered as a risk to the ultimate completion of the proposed measures and alternatives. Many of these risks have been discussed previously in this report and are discussed below for completeness.

The findings, conclusions, and recommendations for this study are based on the current knowledge. There are constraints regarding Prado Dam as both project purposes will at least indirectly impact Prado Dam. Its primary function is to serve as a flood control structure. Design of alternatives for secondary purposes such as sediment re-entrainment and water conservation shall consider the dam's primary function.

Prado Dam is rated as a DSAC 3, which means it is conditionally unsafe with moderate to high risk and consequence from an economical, life, and environmental standpoint. Per USACE Engineering Regulation 1110-2-1156, a reallocation that would require raising the conservation pool is not permitted while a project is classified as DSAC 1, 2, or 3. The rating is due to four issues associated with the dam: three are related to the spillway capacity and the fourth is liquefaction of the foundation material underlying the dam. The spillway capacity issues will be addressed with the completion of the Lower Santa Ana River Improvement projects and ongoing improvements to Prado itself, including interior dikes and the spillway raise which are still remaining. However, the liquefaction issue is not scheduled to be addressed until all of the dams in the nation with DSAC 1 and 2 ratings have been studied. Also, the dam's DSAC rating may never change from a DSAC 3 to a DSAC 4 due to the potentially high consequences. These scenarios would either prohibit any proposed changes to the conservation pool and/or delay the project schedule.

Since the project is largely dependent on the risk and consequence evaluation of Prado Dam, future engineering studies including seismic evaluation, PFMA, and its spillway design could identify additional engineering studies not stated in the sections above.

Penetrations of the dam and auxiliary embankment or use of old or new outlet works for sediment conveyance are no longer included in the selected alternatives. The risks of penetrating the embankments or otherwise compromising or modifying dam performance and operation should be kept in mind during project design.

Lack of appropriate geotechnical data for many of the smaller proposed features in the basin area is a significant risk for this project. The project includes many disparate features over a wide geographic area. Although site-specific geotechnical investigations are recommended at each feature location, cost and time constraints may limit the amount of geotechnical data obtained. The risk of lack of information to project design and construction costs should be understood.

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