US Army Corps of Engineers®

LOWER CACHE CREEK, YOLO COUNTY, CA
CITY OF WOODLAND AND VICINITY

DRAFT FEASIBILITY REPORT FOR POTENTIAL FLOOD DAMAGE REDUCTION PROJECT

Cache Creek Levee Failure, January 27, 1983, looking south towards Woodland.

December 2019

Lower Cache Creek Draft Feasibility Study
Executive Summary

Introduction

This Feasibility Report (FR) describes the planning process followed to develop and evaluate an array of alternatives and identify the Tentatively Selected Plan (TSP) to address FRM problems and opportunities in Lower Cache Creek. This report (i) assesses the risk of flooding to the City of Woodland and surrounding agricultural areas; (ii) describes a range of alternatives formulated to reduce flood risk; and (iii) identifies a recommended plan for implementation. A standalone Supplemental Environmental Impact Statement (SEIS) accompanies this draft Feasibility Report.

This FR is being released for concurrent public review, internal policy review, Agency Technical Review (ATR), and Independent External Peer Review (IEPR). All comments received during the ATR, IEPR, and the 45-day public review period will be considered and incorporated into the final FR, as appropriate. The final FR will present the recommended plan for potential authorization by Congress.

Study Area

The study area is located along the lower portion of Cache Creek in Yolo County, California. The watershed is approximately 1,139 square miles and includes portions of Colusa, Lake, and Yolo Counties. The main stem of Cache Creek originates with the outflows of Clear Lake in the Coast Range Mountains of Northern California. Water flows from Clear Lake through the Clear Lake Outlet Channel, and then through the Cache Creek Dam approximately five miles downstream, which regulates flows and generates hydroelectricity. The north fork of Cache Creek is impounded by Indian Valley Dam and joins the main stem above Capay Valley before flowing out of the foothills into California’s Central Valley on an alluvial fan. The creek is ephemeral and water only reaches the Woodland area at certain times of year due to natural precipitation patterns, upstream retention, and diversions for water supply. Figure ES 1-1 provides a map of the watershed.

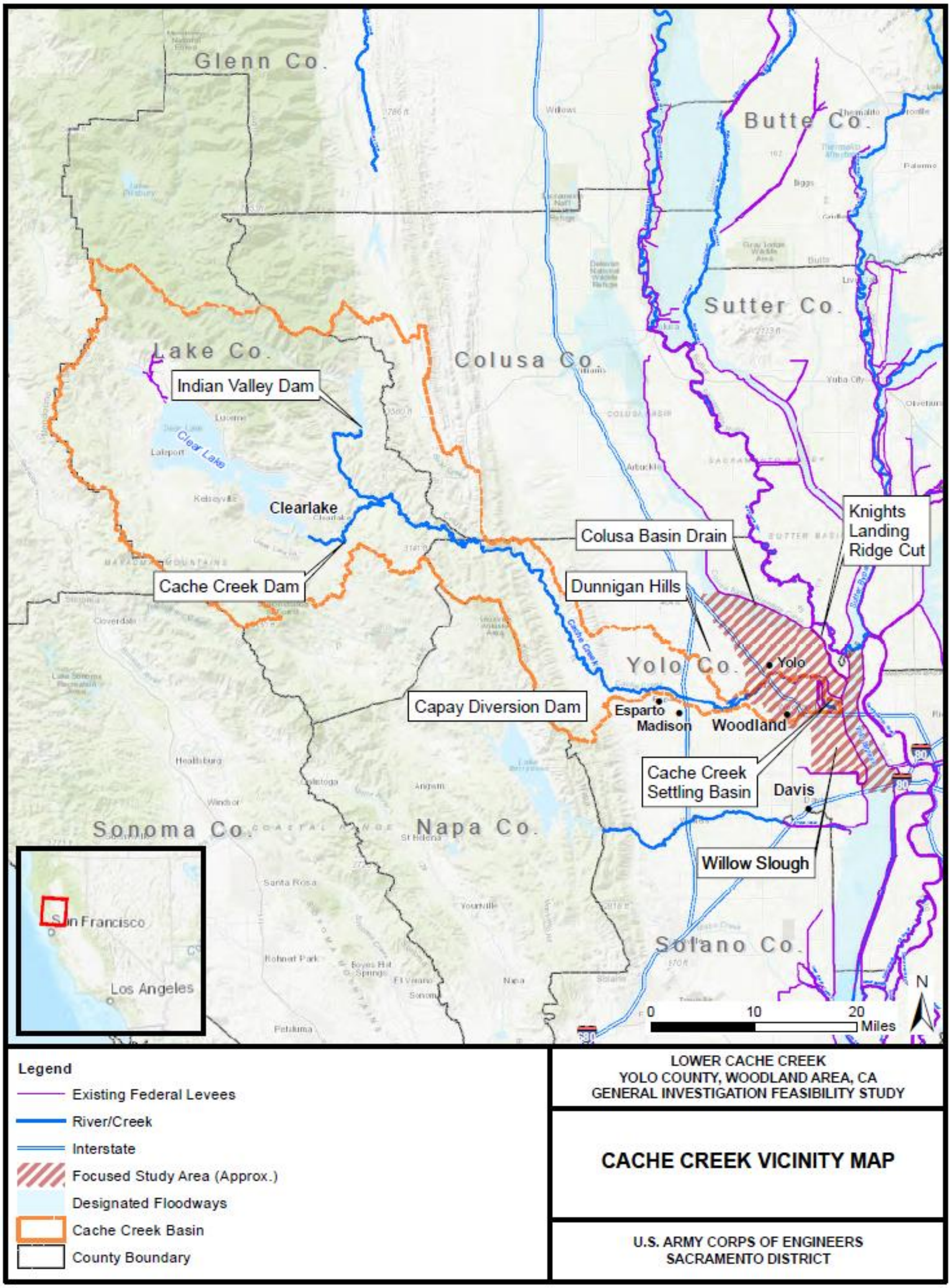


Figure ES 1-1. Cache Creek Watershed (Vicinity Map)

The focused study area encompasses the City of Woodland, town of Yolo, and surrounding agricultural areas, as shaded in red in Figure ES 1-1. The Cache Creek channel passes north of the City of Woodland through levees constructed by USACE as part of the Federally-authorized Sacramento River Flood Control Project (SRFCP). Construction began in 1918 and most facilities were completed by 1958. Design capacity of the Cache Creek levees was minimized at the time, as a flood storage reservoir was anticipated upstream (Wilson Valley Dam and Reservoir). However, the reservoir was never constructed due to seismic and environmental concerns. Given that the design of the Cache Creek levees assumed the construction of upstream flood protection measures that were never constructed, the existing FRM system has a relatively low level of performance relative to other levees in the Sacramento River Flood Control Project. The existing Cache Creek levee profile was designed to provide a freeboard of at least 3 feet above an adopted flood profile calculated using a project design flood of 30,000 cubic feet per second (cfs) (USACE, 1961). Based on current analysis presented in this report, the existing levee profile would pass a 10% (1/10) annual exceedance probability (AEP) event (30,000 cfs) with 90% assurance, if the levee is assumed to not fail prior to overtopping.

Purpose and Need

The purpose of the Lower Cache Creek Feasibility Study (LCCFS) is to investigate and determine the extent of Federal interest in a range of alternative plans that reduce flood risk to the City of Woodland and surrounding agricultural areas (study area). Lower Cache Creek has a history of flooding, and the study area experienced multiple flood events since the mid-1900s. Four major flood periods have been documented for the Cache Creek basin during the last half of the 20th century, and 20 severe floods have occurred since 1900. The most severe high water events of recent years in the Cache Creek basin downstream from Clear Lake occurred in 1939, 1955, 1956, 1958, 1964, 1965, 1970, 1983, 1995, 1997, 2005, and 2019.

Problems:

The following key problems were identified during the planning process by the study team and concerned stakeholders:

- There is risk to public health, safety, and critical infrastructure in the City of Woodland, town of Yolo, and surrounding agricultural areas from flooding from Lower Cache Creek.
- There is a significant risk of economic damages from flooding in the City of Woodland, town of Yolo, and surrounding agricultural areas.

Opportunities:

Opportunities for this study include the potential to:

- Increase public understanding of flood risk within the study area over the period of analysis.
- Leverage other existing or ongoing FRM initiatives, particularly the Central Valley Flood Protection Plan, within the study area and over the period of analysis.

Consideration of Alternative Plans

During the feasibility study, the Federal planning process for development of water resource projects was followed to identify a recommended plan for implementation. Following definition of flood-related problems and opportunities, specific planning objectives and planning constraints were identified. Then various management measures were identified to achieve the planning objectives and avoid the planning constraints. Management measures were screened based on how well they met the study objectives and cost effectiveness, and some measures were dropped from further consideration at that point. The retained management measures were combined to form the building blocks of alternative plans.

A preliminary array of alternatives was developed that encapsulated the identified measures to address flooding problems in the study area. These preliminary alternatives included strengthening the existing Cache Creek levee system, constructing setback levees, bypasses, levees near urban area of the City of Woodland, and various non-structural measures, some of which incorporated natural or nature-based approaches. The preliminary alternatives were developed to a level of detail to allow a basic comparison of the costs and benefits of each proposed plan. Many of these preliminary alternatives were eliminated based on efficiency and effectiveness. The PDT then developed more detailed cost estimates for a focused array of alternatives. Plans were compared to identify the plan that reasonably maximized Net Economic Development (NED) benefits. Due to the nature of flooding and concentrated areas of potential damages, most alternative plans would have generated similar benefits, but at significantly different costs. Plans were eliminated that required higher costs to achieve a similar level of benefits. The tentative NED plan is also the TSP.

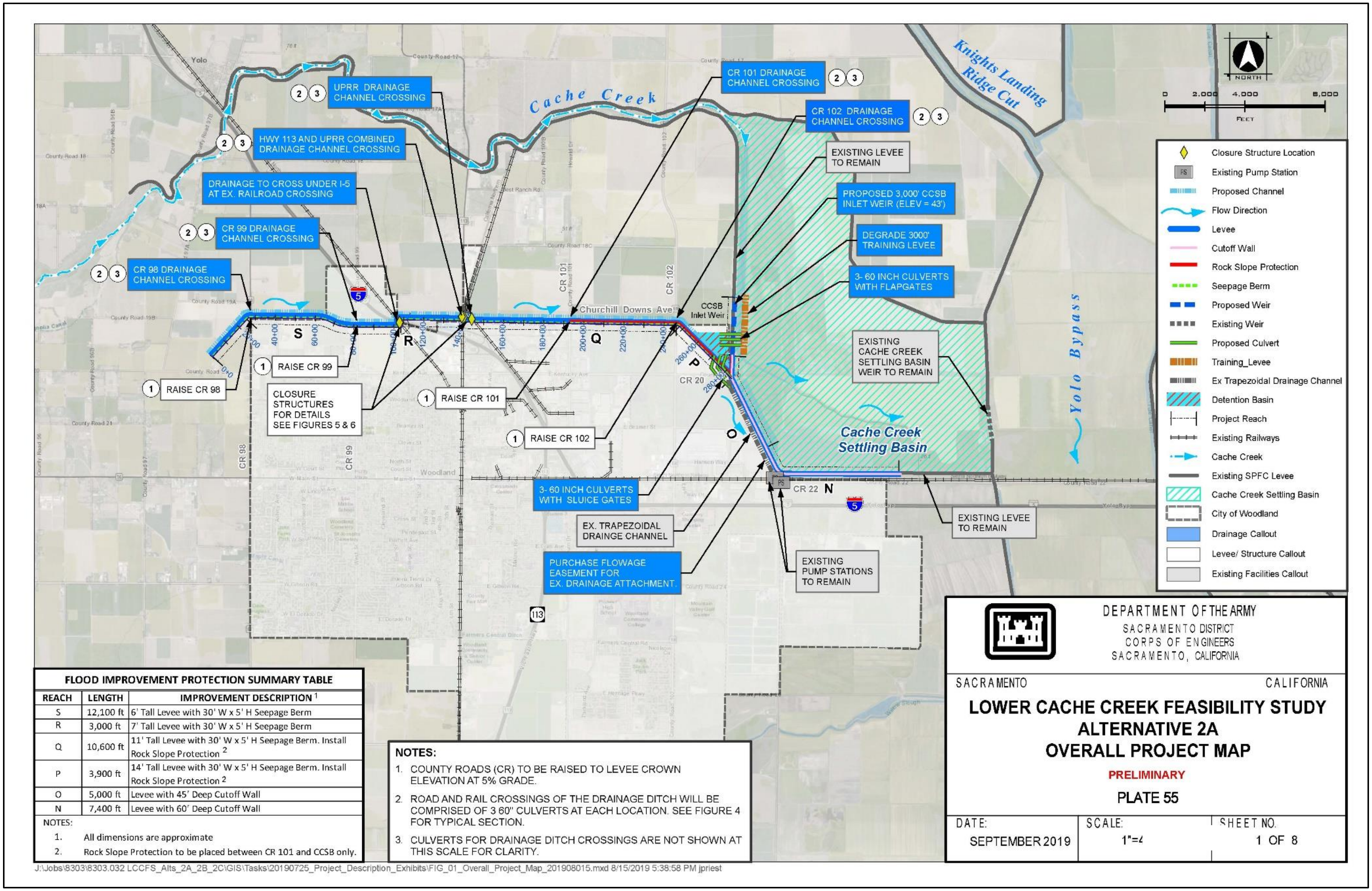
The Tentatively Selected Plan (Levee and Conveyance)

The TSP is Alternative 2A, Levee and Conveyance Plan. This plan meets the study objectives of reducing flood risk and flood damages in the study area. The plan significantly reduces flood risk to people and property in the City of Woodland and surrounding areas. With the TSP in place, areas in northeast Woodland, where damages are concentrated, would see a reduction in the annual chance of flooding from approximately 5.3% to 7.0%, depending on location, to about 0.1%.

Alternative 2A consists, overall, of improving existing levees and constructing a new levee north of the City of Woodland in order to prevent floodwaters emanating from Lower Cache Creek from reaching the built up portion of the City of Woodland. Proposed project features include levee embankment, seepage berms, drainage channel; cutoff walls; weir, and closure structures across roads and railways. Figure ES 1-2 shows the proposed project features.

Significant Environmental Effects

An evaluation of environmental effects determined that the proposed action has the potential for adverse effects on a variety of environmental resource areas. A summary of impacts, mitigation measures, and level of impacts with mitigation is provided in Figure ES 1-2.



FLOOD IMPROVEMENT PROTECTION SUMMARY TABLE

REACH	LENGTH	IMPROVEMENT DESCRIPTION [1]
S	12,100 ft	6' Tall Levee with 30' W x 5' H Seepage Berm
R	3,000 ft	7' Tall Levee with 30' W x 5' H Seepage Berm
Q	10,600 ft	11' Tall Levee with 30' W x 5' H Seepage Berm. Install Rock Slope Protection [2]
P	3,900 ft	14' Tall Levee with 30' W x 5' H Seepage Berm. Install Rock Slope Protection [2]
O	5,000 ft	Levee with 45' Deep Cutoff Wall
N	7,400 ft	Levee with 60' Deep Cutoff Wall

NOTES:

1. All dimensions are approximate
2. Rock Slope Protection to be placed between CR 101 and CCSB only.

NOTES:

1. COUNTY ROADS (CR) TO BE RAISED TO LEVEE CROWN ELEVATION AT 5% GRADE.
2. ROAD AND RAIL CROSSINGS OF THE DRAINAGE DITCH WILL BE COMPRISED OF 3 60" CULVERTS AT EACH LOCATION. SEE FIGURE 4 FOR TYPICAL SECTION.
3. CULVERTS FOR DRAINAGE DITCH CROSSINGS ARE NOT SHOWN AT THIS SCALE FOR CLARITY.

J:\Jobs\8303\8303.032 LCCFS_Alts_2A_2B_2C\GIS\Tasks\20190725_Project_Description_Exhibits\FIG_01_Overall_Project_Map_201908015.mxd 8/15/2019 5:38:58 PM jpriest

Figure ES 1-2. Tentatively Selected Plan and Design Features

Table ES-1-1. Comparative Summary of Environmental Effects, Mitigation, and Levels of Significance

	No-Action Alternative	**Alternative 2A Levee and Conveyance Alternative**
Socioeconomic Resources and Environmental Justice		
Effect	Landowners with Federally insured mortgages and some businesses within the FEMA 1 in 100 chance floodplain would be required to pay flood insurance. Flooding of residential areas and displacement of populations during a flood event.	The new levee would result in localized areas of slight increase in depth north of the levee and only impact approximately eight structures. An additional 14 structures north of the City will remain in the floodplain, but will not experience a change in depth or duration of flooding in frequency events less than or equal to 1/50 AEP. Temporary disruption to residents alongside construction sites from traffic, noise, and dust. Acquisition of properties for construction and staging easements. No long-term environmental injustices.
Significance	Significant.	Less than significant. Benefits to urban area.
Mitigation	None.	Landowner notification of potential disruptions and real estate acquisitions. Fair market value paid for acquisitions with implementation of appropriate BMPs.
Land Use and Agriculture		
Effect	Inconsistent with local land use policies requiring protection of the existing urban area from flood damages. Land use and future growth and development would continue as described in the City and County General Plans. Urban areas and farmlands would be susceptible to flooding during storm events.	The project would require approximately 370 acres of permanent project features and temporary haul roads and staging areas. Agricultural lands compose about 283 acres of the total land needs, 235 acres of which are Prime and Unique Farmland.
Significance	Significant.	Less than significant with mitigation.
Mitigation	None.	Compliance with Relocation Assistance and Real Property Acquisition Policies Act of 1970. Compliance with Farmland Policy Protection Act. Fair market value paid for acquisitions.
Transportation		

	No-Action Alternative	**Alternative 2A Levee and Conveyance Alternative**
Effect	The potential for flooding of local, county, and major transportation corridors like Interstate-5 (I-5) and State Route 113 would remain during major storm events. Damage to roadways during flood event. Emergency road repairs would increase traffic congestion.	The project would protect important roadway infrastructure from Woodland to Sacramento during flood events that would enable residents to leave flood affected areas and for emergency responders to enter.
Significance	Significant.	Minor and only occurring during construction.
Mitigation	None.	Preparation of a Traffic Control and Road Management Plan and implementation of BMPs. Culverts under roadways to redirect floodwaters off roads.
Noise		
Effect	Noise levels would be the same as existing conditions. Noise during flood-fighting and levee repairs may increase.	Local increase in noise levels during construction would occur that may exceed ambient noise thresholds. After construction concludes, noise levels would return to pre-project conditions.
Significance	Negligible, incremental short-term effects but no lasting increase in noise levels.	Significant. Moderate to major increases in noise levels during construction to adjacent receptors (residences and businesses).
Mitigation	None.	Coordination with local residents and compliance with City of Woodland noise ordinances. Work would occur during daylight hours.
Air Quality		
Effect	Woodland population expected to grow and corresponding increase in criteria pollutant emissions likely with-projected traffic volume increases. Increased emissions during emergency flood fighting activities without BMPs in place. Increased emissions during clean-up and reconstruction of the urban area.	Temporary emissions of criteria pollutants from construction equipment and haul trucks.
Significance	Significant.	Less than significant with mitigation.
Mitigation	None.	Implementation of YSAQMD Basic Construction Emission Control Practices and BMPs.
Climate Change		

	No-Action Alternative	**Alternative 2A Levee and Conveyance Alternative**
Effect	Inland hydrology models predict higher intensity storms which could lead to local pump stations being overwhelmed. Increased GHG emissions during flood fight.	Increased GHG emissions from construction equipment.
Significance	Significant.	Less than significant with mitigation.
Mitigation	None.	Implementation of YSAQMD Basic Construction Emission Control Practices and BMPs.
Water Quality		
Effect	Risk of contaminants entering the water from utilities, stored chemicals, septic systems, and flooded vehicles during flood event. Flood flows would increase bank erosion increasing turbidity. Climate change may create drought conditions and higher intensity wildfires in the watershed, leading to greater sediment deposit in Cache Creek.	Potential impacts include increased turbidity during drainage canal construction and tie-in to existing drainage ditch. Potential for storm water runoff from exposed soils and cement, slurry or fuel spills during construction.
Significance	Significant.	Less than significant with mitigation.
Mitigation	None.	Preparation of a Stormwater Pollution Prevention Plan, Spill Prevention Control and Countermeasure Plan, and a Bentonite Slurry Spill Contingency Plan and implementation of BMPs.
Vegetation and Wildlife		
Effect	Vegetation and wildlife that utilize the CCSB for habitat would continue to be affected by O&M of the existing levee system. Erosion during a flood event would cause vegetation and wildlife habitat loss. Future flood fighting and repairs would affect vegetation and wildlife. Wildlife that occupy farmlands would continue to be subject to agricultural practices.	The project would result in the loss of 0.05 acres of cottonwood willow riparian, 2 acres of valley oak woodland, 10 acres of seasonal marsh/wetland, and 8 acres of orchard habitat. 83 acres of non-native annual grassland would be also be temporarily lost.
Significance	Significant.	Less than significant with compensatory mitigation.
Mitigation	None.	Mitigation credits for riparian, wetland, and oak woodlands habitat would be purchased at a mitigation bank. Annual grasslands would be planted with a native forb/grass mix. Orchards would be mitigated by

	No-Action Alternative	**Alternative 2A Levee and Conveyance Alternative**
		purchasing equivalent oak woodland habitat at a bank. Additional analysis would be required for any on-site mitigation. Lands with the CCSB may accommodate habitat creation.
Special Status Species		
Effect	Habitat for special-status species is likely to affect by O&M of the existing levee system and CCSB. Flood event or flood fight could cause fatality to species.	The project would result in the loss of 0.85 acre of palmate-bracted bird’s beak, 6 elderberry shrubs, 0.82 acres of giant garter snake, and 0.65 acre of vernal pool fairy shrimp and vernal pool tadpole shrimp habitat.
Significance	Significant.	Less than significant with compensatory mitigation.
Mitigation	None.	Mitigation credits for the impacted special status species would be purchased from a bank. Additional analysis would be conducted to determine if on-site habitat restoration or creation could be constructed.
Cultural Resources		
Effect	Archaeological sites could be damaged from future flood events.	Potential for adverse effects to historic properties from construction of the project.
Significance	Significant.	Less than significant with mitigation.
Mitigation	None.	Cultural resources surveys would be conducted prior to construction, to identify historic properties that would be affected by the project. Adverse effects would be mitigated through measures described in a Programmatic Agreement executed pursuant to Section 106 of the NHPA.
Aesthetic and Visual Resources		
Effect	O&M needed to maintain existing levees would continue to degrade the visual character of Lower Cache Creek by removing or altering remaining riparian forest. A flood event could damage the visual character in the study area.	Temporary construction related interruption of visual resources. Views obstructed by the new levee would disrupt the rural, agricultural and sparsely populated visual conditions of the study area.
Significance	Not significant.	Significant.

	No-Action Alternative	**Alternative 2A Levee and Conveyance Alternative**
Mitigation	None.	New levee would be reseeded to match local conditions. Further analysis needed to determine feasibility of planting trees to provide a vegetation barrier between residents and travelers and proposed project.
Utilities		
Effect	In a flood event there could be significant damage to utility systems. Debris from flooded homes and properties could overwhelm solid waste disposal facilities.	Temporary disruptions to utility services possible, particularly during relocation of utilities that penetrate the new levee.
Significance	Significant.	Less than significant.
Mitigation	None possible.	Notification of potential interruptions would be provided to the appropriate agencies and landowners.
Hydrology and Hydraulics		
Effect	Emergency repairs during a flood event could result in the loss of channel capacity and alternation of current geomorphic processes.	During a large flood event (e.g. 1% AEP event) duration of flooding west of SR 113, near I-5 would be shorter than existing conditions, lasting only several days. Near SR 113, flood depths would decrease by up to 1 foot from existing conditions. Flood depths increase gradually to a maximum of 4-6 feet near the CCSB inlet weir during flood events greater than 2% AEP events. Induced flooding would impact industrial/agricultural area north of the city limit line.
Significance	Significant.	Less than significant.
Mitigation	None.	None needed.

Estimated Costs and Cost Sharing

Investment costs, annual costs, and annual benefits are displayed in Table ES-1-2 below.

Table ES-1-2. Estimated Annual Costs and Benefits for the Tentatively Selected Plan

Item	Cost ($1000's)[1]
Investment Costs:	
First Cost[2]	258,861
Interest During Construction	7,151
Total Project Investment Cost	266,012
Annual Costs:	
Annualized First Cost	9,853
Annual OMRR&R	180
Total Average Annual Cost	10,033
Average Annual Benefits	20,657
Net Benefits	10,623
Benefit to Cost Ratio	2.1

[1] Costs are October 2019 price levels at 2.75%, for a 50-year period of analysis.

[2] Does not include cultural resources data recovery.

Table ES-1-3 below shows the preliminary cost apportionment for Alternative 2A. The non-Federal sponsors are responsible for all Lands, Easements, Rights of Way, Relocations, and Disposal Sites (LERRDs) costs, a minimum of 5% cash, and any additional cash needed to reach a minimum of 35% of the total project cost. The maximum non-Federal share is 50% of the total project cost.

Table ES-1-3. Preliminary Cost-Share Apportionment for Tentatively Selected Plan[1]

Item	Federal	Non-Federal
Flood Risk Management	$168,852	$90,601
Total	$168,852	$90,601
Breakdown of Non-Federal		
LERRD		$20,687
5% Cash Requirement		$12,943
Remaining Cash		$56,971
Total		$90,601

[1]Costs ($1,000s) are October 2019 price levels at 2.75%, for a 50-year period of analysis.

Major Conclusions

The preliminary recommendation of the District Engineer of the Sacramento District, U.S. Army Corps of Engineers is that the report be finalized based on results of public review, internal policy review, ATR, and IEPR of this draft Feasibility Report, and if warranted, recommended for authorization for implementation as a Federal project. The estimated first cost of the tentatively selected plan is $258,861,000 and the estimated annual OMRR&R costs are $180,000. The Federal portion of the estimated first cost is $168,852,000. The non-Federal sponsor portion of the estimated first cost is $90,601,000.

The project would significantly reduce flood risk to people and property in the City of Woodland and surrounding areas. With the TSP in place, the annual chance of flooding in northeast Woodland—the most at risk area of the city—would decrease from between 5.3% and 7.1% depending on the specific area to about 0.1%. The plan would remove 636 structures from the 1/100 ACE event floodplain, of which 425 are residences, and would remove I-5 south of Woodland from the floodplain for up to the 1/500 ACE event. The existing Cache Creek levees would continue to reduce flood risk for areas adjacent to Lower Cache Creek. The average annual benefits from the project, estimated as a reduction in flood related damages, is $20,657,000.

Table of Contents

List of Appendices

List of Figures

List of Tables

List of Acronyms

ACRONYM	MEANING
ADM	Agency Decision Milestone
ARA	Abbreviated Risk Analysis
ARCF	American River Common Features
BCR	benefit to cost ratio
CAP	Continuing Authorities Program
CCSB	Cache Creek Settling Basin
CDEC	California Data Exchange Center
CDFW	California Department of Fish and Wildlife
CEQA	California Environmental Quality Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CFS	cubic feet per second
CH	fat clay
CL	lean clay
CPT	cone penetration test
CVFED	Central Valley Floodplain Evaluation and Delineation
CVFPB	Central Valley Flood Protection Board
CVFPP	Central Valley Flood Protection Plan
CVHS	Central Valley Hydrology Study
DFC	David Ford Consulting
DWR	Department of Water Resources
EAD	expected annual damage
EGM	Economic Guidance Memorandum
EIA	economic impact areas
EIR	Environmental Impact Report
EIS	Environmental Impact Statement
EMA	Emergency Management Action
EO	Executive Order
EPA	Environmental Impact Agency
EQ	Environmental Equality
ER	Engineer Regulation
ESA	Endangered Species Act
FCSA	Feasibility Cost Share Agreement
FDA	Flood Damage Analysis
FEMA	Federal Emergency Management Agency

FPS	feet per second
FR	Federal Register
FRM	flood risk management
FWCA	Fish and Wildlife Coordination Act
FWOP	future without-project condition
GDM	General Design Memorandum
H&H	hydrologic and hydraulic
HEC	Hydrologic Engineering Center
IDC	interest during construction
KLRC	Knights Landing Ridge Cut
LCCFS	Lower Cache Creek Feasibility Study
LERRD	Lands, Easements, Rights-of-Ways, Relocations and Disposal Areas
LPP	Locally Preferred Plan
ML	plastic silt
NAVD	North American Vertical Datum
NED	National Economic Development
NEMDC	Natomas East Main Drainage Canal
NEPA	National Environmental Policy Act
NFIP	National Flood Insurance Program
NFS	non-Federal sponsors
NOI	notice of intent
NRCS	Natural Resource Conservation Service
O&M	operations and maintenance
OLS	Ordinary Least Squares regression equation
OMRR&R	Operations, Maintenance, Repair, Rehabilitation, and Replacement
OSE	Other Social Effects
PA	Programmatic Agreement
PCET	Parametric Cost Estimating Tool
PDT	Product Delivery Team
PED	Preconstruction Engineering and Design
PPA	Project Partnership Agreement
RCC	Reinforced cement concrete
RE	Real Estate
RED	Regional Economic Development
REP	Real Estate Plan
ROW	Rights-of-way
SAFCA	Sacramento Area Flood Control Agency
SB	Senate Bill
SB	Soil-Bentonite
SCFRRP	Small Communities Flood Risk Reduction Program
SEIS	Supplemental Environmental Impact Statement
SHPO	State Historic Preservation Officer
SPFC	State Plan of Flood Control
SR 113	State Route 113

SRBPP	Sacramento River Bank Protection Project
SRFCP	Sacramento River Flood Control Project
TAC	Total Annual Cost
TMDL	Total Maximum Daily Load
TPCS	Total Project Cost Summary
TSP	tentatively selected plan
TUFLOW	Two-dimensional Unsteady FLOW
ULDC	Urban Levee Design Criteria
ULOP	Urban Level of Protection
UPRR	Union Pacific Rail Road
USACE	U.S. Army Corps of Engineers
USBR	U.S. Bureau of Reclamation
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VE	value engineering
WCM	Water Control Manual
WDL	Water Data Library
WY	water year

Chapter 1 – Study Information

1.1 Introduction

The U.S. Army Corps of Engineers, Sacramento District (USACE), in conjunction with the State of California's Central Valley Flood Protection Board (CVFPB) and the City of Woodland, conducted a flood risk management (FRM) feasibility study of the Lower Cache Creek watershed. Detailed investigations centered on the lower portion the Cache Creek and the Cache Creek Settling Basin, specifically, areas in the vicinity of the City of Woodland, town of Yolo and surrounding agricultural areas.

This study describes the Federal, State, and local interest in FRM along Lower Cache Creek based on input provided by multiple agencies and the interested public during prior and current phases of study. This chapter presents information on the study authority.

1.2 Study Authority

This study was authorized by Section 209 of the Flood Control Act of 1962, Pub. L. 87-874, § 209, 76 Stat. 1196 (1962), which states as follows for the Sacramento River Basin:

> "The Secretary of the Army is hereby authorized and directed to cause surveys for flood control and allied purposes, including channel and major drainage improvements, and floods aggravated by or due to wind or tidal effects, to be made under the direction of the Chief of Engineers, in drainage areas of the United States and its territorial possessions, which include the following named localities: Provided, That after the regular or formal reports made on any survey are submitted to Congress, no supplemental or additional report or estimate shall be made unless authorized by law except that the Secretary of the Army may cause a review of any examination or survey to be made and a report thereon submitted to Congress, if such review is required by the national defense or by changed physical or economic conditions: Provided further, That the Government shall not be deemed to have entered upon any project for the improvement of any waterway or harbor mentioned in this title until the project for the proposed work shall have adopted by law:...
>
> Sacramento River Basin and streams in northern California draining into the Pacific Ocean for the purposes of developing, where feasible, multiple-purpose water resource projects, particularly those which be eligible under the provisions of title III of Public Law 85-500…"

This study will only partially address the Sacramento River Basin authority. Therefore, the LCCFS will be called an "Interim Feasibility Report" to indicate that the study addresses the flood risk issues of a specific area within the authority, rather than the entire authorized area. This report does not rule out additional studies for this, or other areas, within the authorized study area at a future date.

Per Section 1203 of America's Water Infrastructure Act of 2018, Pub. L. 115-270, § 1203, 132 Stat 3803, the "Secretary shall expedite the completion of a feasibility study" for Lower Cache Creek, subject to the availability of funding.

1.3 Purpose and Need for the Project and Report

The purpose of the Lower Cache Creek Feasibility Study (LCCFS) is to investigate and determine the extent of Federal interest in a range of alternative plans that reduce flood risk to the City of Woodland and surrounding agricultural areas (study area). Lower Cache Creek has a history of flooding and the study area experienced multiple flood events since the mid-1900s. Four major flood periods have been documented for the Cache Creek basin during the last half of the 20th century, and 20 severe floods have occurred since 1900. The most severe high water events of recent years in the Cache Creek basin downstream from Clear Lake occurred in 1939, 1955, 1956, 1958, 1964, 1965, 1970, 1983, 1995, 1997, 2005, and 2019.

This report (i) assesses the risk of flooding to the City of Woodland and surrounding agricultural areas; (ii) describes a range of alternatives formulated to reduce flood risk; and (iii) identifies a recommended plan for implementation. A standalone Supplemental Environmental Impact Statement (SEIS) accompanies this draft Feasibility Report. This draft report will be circulated for review by the public and governmental agencies. USACE headquarters will review and approve the report, and then it will be transmitted to Congress for potential project authorization and funding of the Federal share of the project.

1.4 Study Location

The study area is located along the lower portion of Cache Creek in Yolo County, California. The watershed is approximately 1,139 square miles and includes portions of Colusa, Lake, and Yolo Counties. The main stem of Cache Creek originates with the outflows of Clear Lake in the Coast Range Mountains of Northern California. Water flows from Clear Lake through the Clear Lake Outlet Channel, and then through the Cache Creek Dam approximately five miles downstream, which regulates flows and generates hydroelectricity. The north fork of Cache Creek is impounded by Indian Valley Dam and joins the main stem above Capay Valley before flowing out of the foothills into California’s Central Valley on an alluvial fan. The creek is ephemeral and water only reaches the Woodland area at certain times of year due to natural precipitation patterns, upstream retention, and diversions for water supply. Figure 1-1 provides a map of the watershed.

The focused study area encompasses the City of Woodland, town of Yolo, and surrounding agricultural areas as indicated in Figure 1-2. The Cache Creek channel passes north of the City of Woodland through levees constructed by USACE as part of the Federally-authorized Sacramento River Flood Control Project (SRFCP). Construction began in 1918 and most facilities were completed by 1958. Design capacity of the Cache Creek levees was selected at the time in anticipation of the construction of an upstream flood storage reservoir (Wilson Valley Dam and Reservoir); however, the reservoir was never constructed due to seismic and environmental concerns. Given that the design of the Cache Creek levees assumed the construction of upstream flood protection measures that were never constructed, the existing FRM system has a relatively low level performance relative to other levees in the Sacramento River Flood Control Project. The existing Cache Creek levee profile was designed to provide a freeboard of at least 3 feet above an adopted flood profile calculated using a project design flood of 30,000 cubic feet per second (cfs) (USACE, 1961). Based on current analysis presented in this report, the existing levee profile would pass a 10% (1/10) annual exceedance probability (AEP) event (30,000 cfs) with 90% assurance, if the levee is assumed to not fail prior to overtopping. However, including the probability of geotechnical failure (i.e., collapse or ‘washout’ of a levee) prior to overtopping, the existing levee project would pass a 50% (1/2) AEP event (10,800 cfs) with 90% assurance.

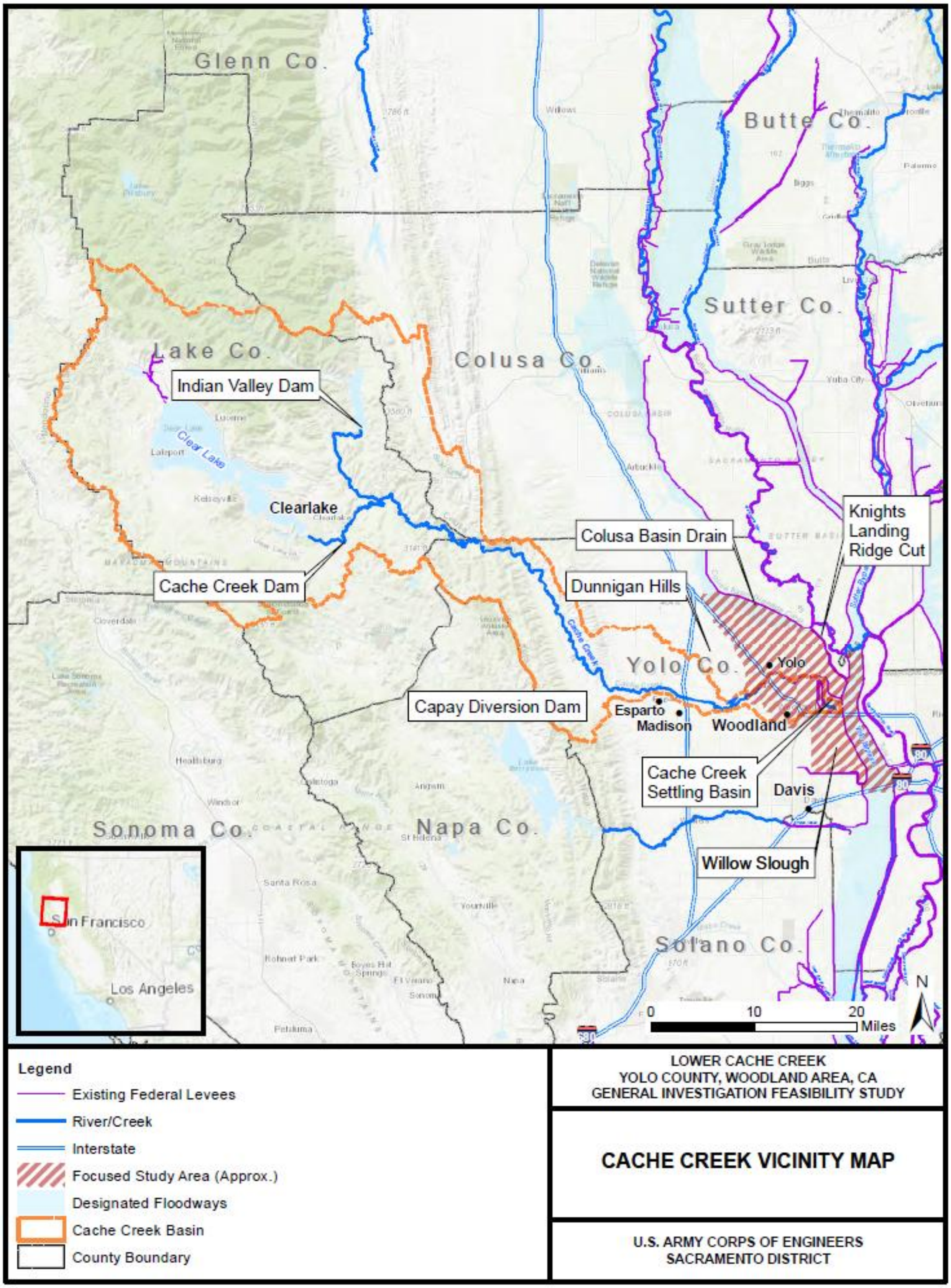


Figure 1-1. Cache Creek Watershed (Vicinity Map)

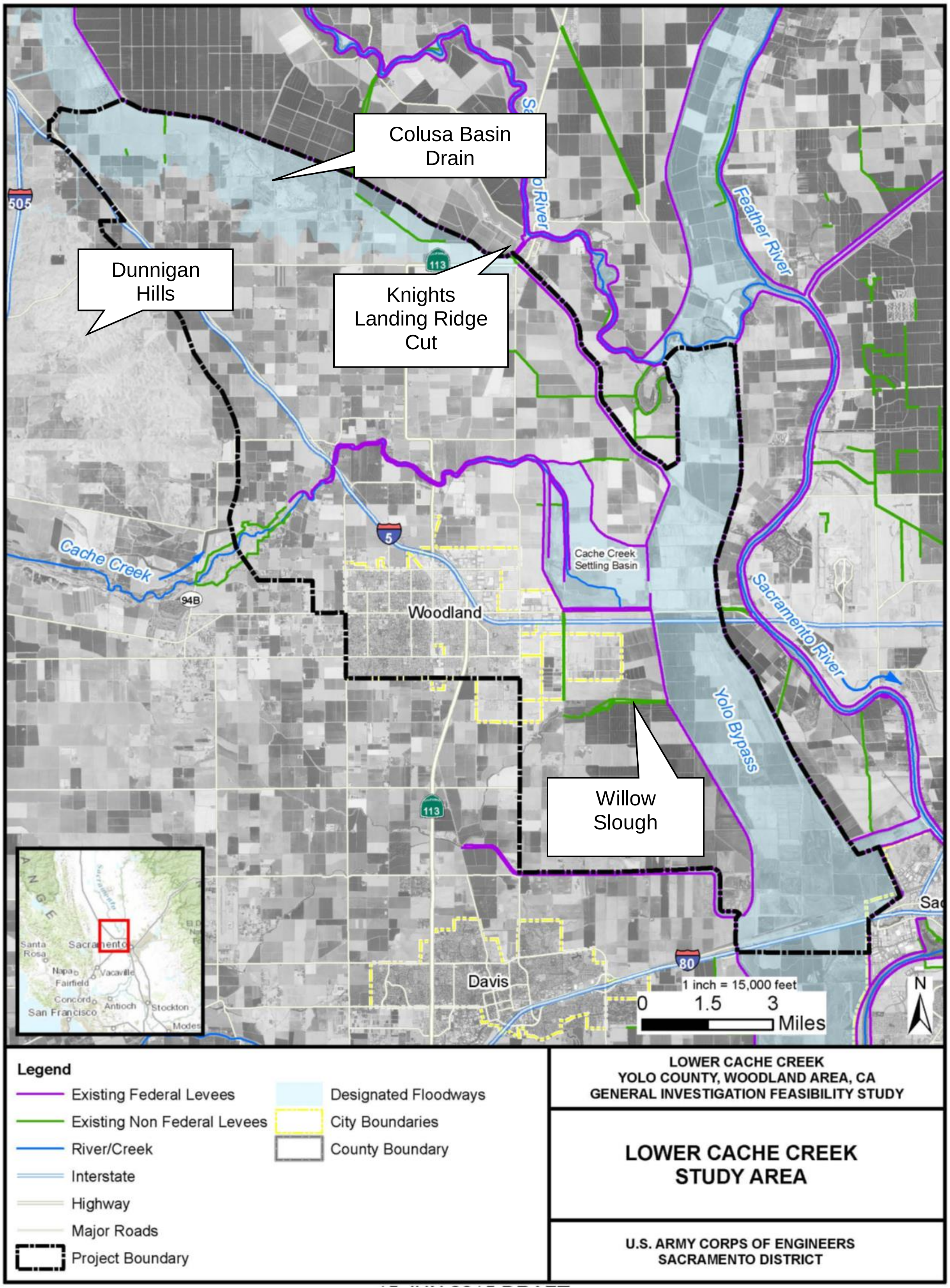


Figure 1-2. Lower Cache Creek Focused Study Area

The leveed portion of Cache Creek discharges into the Cache Creek Settling Basin (CCSB), which was constructed by USACE in 1937 and enlarged in 1993 as a separately authorized component of the SRFCP. Cache Creek carries a large sediment load that historically was distributed along the alluvial fan via small, braided channels prior to the creek emptying into the Yolo Bypass. The CCSB was constructed to reduce the volume of sediment carried by Cache Creek to the Yolo Bypass and reduce flood risk to the City of Sacramento. Coarse-grained sediment (sands, gravels) deposit in the CCSB, while silts and clays that do not increase the flood risk in receiving waters flow over a concrete weir into the Yolo Bypass.

Annual Exceedance Probability (AEP)

This report uses the term "Annual Exceedance Probability" (AEP) to describe the likelihood associated with storm and flood events. The AEP is expressed as a percentage that reflects the probability that a certain flow value will be equaled or exceed on any given year.

Flooding in the Cache Creek basin is principally caused by runoff of high-intensity rainstorms during the winter and spring. The flood threat to life and property in the study area is increased by the raised bed of I-5. The existing I-5 corridor diverts flood flows into the City of Woodland. The existing Cache Creek levee profile was designed to provide a freeboard of at least 3 feet above an adopted flood profile calculated using a project design flood of 30,000 cfs (USACE, 1961). Based on current analysis presented in this report, the existing levee profile would pass a 10% (1/10) AEP event (30,000 cfs) with 90% assurance, if the levee is assumed to not fail prior to overtopping. However, including the probability of geotechnical failure prior to overtopping, the existing levee project would pass a 50% (1/2) AEP event (10,800 cfs) with 90% assurance.

During the formation of the Central Valley, sediment deposition over time has resulted in a perched channel, where Lower Cache Creek sits at a slightly higher elevation than surrounding land. Consequently, any flows that break out of the channel quickly spread overland to the north and south of the creek and cover a large area. The resulting flooding is then prevented from releasing into the Sacramento River by the existing Yolo Bypass levees.

1.5 Study Sponsor and Participants

The non-Federal sponsors (NFS) for the study are the Central Valley Flood Protection Board (CVFPB, representing the State of California) and the City of Woodland. USACE is the lead National Environmental Policy Act (NEPA) agency; the CVFPB and the City of Woodland are the lead agencies for the California Environmental Quality Act (CEQA). Numerous other agencies, organizations, and individuals participated in the study, including local landowners, residents, the U.S. Fish and Wildlife Service (USFWS), Natural Resources Conservation Service (NRCS), and California Department of Fish and Wildlife (CDFW).

1.6 History of Lower Cache Creek Investigations

USACE has a lengthy history of involvement at Lower Cache Creek. A reconnaissance study completed in 1995 found sufficient potential Federal interest to proceed with a feasibility-level investigation of FRM along Lower Cache Creek. A feasibility study was undertaken from 2000 to 2003. A tentatively selected plan (TSP) was identified that included construction of an embankment at the northern city boundary, which increased flood depths between the urban limits and the creek. Public opposition to the plan led the NFS to request a pause in the study at that time. In 2009, the NFS expressed interest in restarting the feasibility study in response to renewed public interest in and support for FRM. A new Feasibility Cost Share Agreement (FCSA) was signed in May 2011. The TSP milestone was held in February 2019 after a series of financial pauses and a period of inactivity at the NFS's request to conduct further technical analysis and build public support.

1.7 Existing Programs, Projects, and Studies

There are several ongoing water resources related programs, studies, and projects that could affect FRM and ecosystem conditions in the Sacramento River Basin. The following list is not exhaustive, but highlights efforts that pertain to this feasibility study.

1.7.1 Programs

Federal Emergency Management Agency (FEMA), Flood Mitigation Assistance Program and the Hazard Mitigation Grant Program
These programs seek to reduce or eliminate loss of life and property damage due to natural and human-caused hazards. In order to qualify for these programs, a community must be enrolled in the National Flood Insurance Program (NFIP) and have a Flood Mitigation Plan approved by the FEMA Regional Director. This plan must include a description of the existing flood hazard and flood risk, including estimates of the number and type of structures at risk, repetitive loss properties and the extent of flood depth and damage potential. The City of Woodland and County of Yolo are enrolled in the NFIP. Yolo County's enrollment covers the unincorporated areas, which includes the study area outside the cities' limits.

Central Valley Flood Protection Plan (CVFPP)
The CVFPB approved the CVFPP in July 2012. SB 5 required that California Department of Water Resources and CVFPB address flooding problems in the Central Valley (Sacramento-San Joaquin Valley) and report to the Legislature with updates every 5 years. In response to SB 5, the State initiated the CVFPP to develop a comprehensive approach to FRM and related problems. The CVFPP proposed a State-wide investment approach for improving the State-Federal FRM system to meet the new standard, while addressing ecosystem and other water related objectives. This approach permits modification or improvement of existing facilities of the State Plan of Flood Control (SPFC), construction of new facilities and opportunities for ecosystem improvements within the SPFC. Further evaluations will continue and will be reported in the CVFPP 2022 update.

Designated Floodway Program
The CVFPB administers the Designated Floodway Program for California, which addresses land use management within the floodway. This program provides a nonstructural way to keep development from encroaching into flood-prone areas and reduces future potential flood damages by preserving the reasonable flood passage capacities of natural watercourses. The CVFPB adopts floodway boundaries, develops plans for modifications of boundaries and approves changes in acceptable use and types of structures within the floodways. Floodway areas in the study area are primarily limited to the areas between levees.

Yolo Small Communities Flood Risk Reduction
The Small Communities Flood Risk Reduction Program (SCFRRP) was created as part of the 2012 Central Valley Flood Protection Plan. The SCFRRP is a local assistance program whose objective is to reduce flood risk for small communities protected by State Plan of Flood Control facilities, as well as for legacy communities. In late 2017, Yolo County received a SCFRR Grant to complete a feasibility study for the town of Yolo. A draft feasibility report was prepared that recommends between 0 and 4 feet of levee raise above its current height near the town of Yolo and widening the levee at the base by as much as 10 to 15 feet in certain locations, particularly

along the downstream easterly portion of the levee system (Yolo County, 2019). Yolo County submitted a Draft Report to DWR in September 2019.

1.7.2 Projects

Development of water resources projects in the Sacramento Valley began in the 1850s and currently includes large, multipurpose reservoirs, extensive levee systems, and large bypasses. An array of Federal, state, and local entities are involved in water resources in the basin, including the USACE, United States Bureau of Reclamation (USBR), country irrigation districts, and local reclamation and levee districts.

Ongoing USACE projects in the basin include:

American River Common Features (ARCF), Natomas Basin Project
In 2007, the Natomas Levee Improvement Project was initiated by the Sacramento Area Flood Control Agency (SAFCA) in order to provide flood protection as an early implementation project to the Natomas Basin as quickly as possible. These projects consisted of improvements to the perimeter levee system of the Natomas Basin in Sutter and Sacramento Counties, as well as associated landscape and irrigation/drainage infrastructure modifications. SAFCA, DWR, CVFPB, and USACE initiated this effort with the aim of incorporating the Landside Improvements Project and the Natomas Levee Improvement Project into the Federally-authorized American River Common Features, Natomas Basin Project. Proposed improvement primarily involve constructing cutoff walls through the levees, or alternatively an adjacent levee in some reaches. Construction on the Natomas Basin Project is anticipated to continue through 2024.

American River Common Features 2016 Project
The ARCF 2016 project was fully funded by the Bipartisan Budget Act of 2018 and is scheduled for construction from 2019 through 2024. The purpose of this project is to reduce the risk of flooding for the city of Sacramento. The project will involve construction of levee improvements along the American and Sacramento River levees, as well as proposed improvements to the Natomas East Main Drainage Canal (NEMDC) east levee and Magpie Creek. The levee improvements scheduled for implementation include construction of cutoff walls, erosion protection, seepage and stability berms, relief wells, levee raises, and a small stretch of new levee. In addition, USACE would widen the Sacramento Weir and Bypass in order to divert additional flows into the Yolo Bypass. The project would also involve construction of a number of mitigation sites in the area.

Sacramento River Bank Protection Project
The Sacramento River Bank Protection Project (SRBPP) was authorized to protect the existing levees and flood control facilities of the Sacramento River Flood Control Project. The SRBPP was authorized in 1960 and initially consisted of the construction of 436,397 linear feet of bank protection from 1963 to 1975. In 1974, Congress authorized the SRBPP to continue into a Phase II with an additional 405,000 linear feet of bank protection. Construction proposed for 2019 includes a site at river mile 1.0 on the Feather River levee, which is located approximately 7.5 miles to the northeast of the LCCFS study area.

West Sacramento Project
The West Sacramento general reevaluation study determined the Federal interest in reducing the flood risk within the West Sacramento project area. The purpose of the West Sacramento Project is to bring the 50 miles of perimeter levees surrounding West Sacramento into compliance with applicable Federal and State standards for levees protecting urban areas. The West Sacramento

Project was authorized in WRDA 2016, and in the Fiscal Year 2019 work plan, the project received initial funding to begin preconstruction design. Construction of the project by USACE is estimated to begin in approximately 2021.

Folsom Dam Raise Project

The Folsom Dam Raise project includes raising the right and left wing dams, Mormon Island Auxiliary Dam and dikes 1-8 around Folsom Reservoir by 3.5 feet. Similar to the ARCF 2016 Project, the Folsom Dam Raise Project was fully funded by the Bipartisan Budget Act of 2018. Construction on the Folsom Dam Raise Project is scheduled to begin in 2019 with the Dike 8 construction, followed by Dike 7 in 2020, Dikes 1 through 3, the wing dams, and MIAD in 2021, and completing the project with Dikes 4 through 6 in 2022.

Folsom Dam Water Control Manual Update

The Folsom Dam Water Control Manual (WCM) was updated to reflect authorized changes to the flood management and dam safety operations at Folsom Dam to reduce flood risk in the Sacramento area. The WCM Update will utilize the existing and authorized physical features of the dam and reservoir, specifically the recently completed auxiliary spillway. Along with evaluating operational changes to utilize the auxiliary spillway, the WCM Update will assess the use of available technologies to enhance the FRM performance of Folsom Dam to include a refinement of the basin wetness parameters and the use of real time forecasting to inform dam operation. The study resulted in an Engineering Report as well as a Water Control Manual that implements the recommendations of the analysis. The WCM was finalized and approved in summer 2019. The WCM will be further revised in the future to reflect the capabilities to be provided by the Folsom Dam Raise Project and ARCF 2016, as appropriate.

Other activities in the basin include:

Off-Channel Gravel Mining

There are currently seven off-channel mining operations (Schwarzgruber, Syar, Solano, Teichert [Woodland], Teichert [Esparto], Granite Capay, and Granite Woodland) that are permitted along Cache Creek (Yolo County, January 2001). The gravel mining reach of the Cache Creek Basin extends approximately 14.5 miles along Cache Creek between Capay and Yolo. Facilities include sand and gravel processing plants, asphalt-concrete hot mix plants, concrete batch plants, material stockpiles, settling ponds, water wells, stationary and mobile equipment, and haul roads (USACE, 1995). In-stream mining is permitted by industry only as a flood control measure. This project began in 1996 and is expected to continue for 30 years.

Teichert/Yolo County Mining Reclamation Site

East of the 95B Bridge at Teichert (Woodland) above I-5, Yolo County reclaimed its old gravel extraction site previously used for county projects. The area was reclaimed as required in the original mining and reclamation plan (Yolo County, January 2001). Teichert Materials has requested approval of a new 30-year Mining Permit and Reclamation Plan, currently undergoing environmental review (Yolo County, June 2019).

2018 Water & Sewer Repair and Replacement Project

The City of Woodland launched this project as part of an annual program to replace water mains over 60 years old and repair sewer deficiencies. The project began in September 2018, repairing water mains and service laterals, as well as replacing sanitary sewer mains and laterals within city limits (City of Woodland, 2019).

North Regional Pond & Pump Station Project

North Regional Pond serves as a storm drainage mitigation feature for Spring Lake Area developments and was formerly the site of wastewater treatment operations in the mid-1980s. The site is centrally located with Woodland's Water Pollution Control Facility to the north, and the Regional Water Treatment Facility to the south. The City of Woodland recognizes the need to repurpose the area to meet population and housing increases. The project would include increasing detention capacity within the existing pond by 1,000 acre-feet, as well as constructing an additional storm drainage pumping plant on Main Street. Construction of this project is expected to begin in 2019.

Yolo Bypass/Cache Slough Partnership Improvement Projects

Huff's Corner and Wallace Weir Improvement Projects are part of the short-term improvements proposed in a joint program with CVFPB, USACE, and DWR. The Cache Creek Settling Basin Multi-Objective Project is incorporated into the long-term improvements plan of the joint partnership. The series of multi-benefit projects in the Yolo Bypass-Cache Slough Region incorporates Sacramento, Yolo, Solano, and Sutter Counties, with the regional objectives of flood risk reduction, ecosystem restoration, agricultural sustainability, and water supply reliability. The initiation request for project review is dated July 2019 by the CVFPB.

1.7.3 Studies

Cache Creek Area Plan Update

Yolo County adopted the Cache Creek Area Plan in 1996 for the 14.5 miles along Lower Cache Creek. Generally, the plan covers the area west of Capay Dam to the town of Yolo. The drafted update to the watershed management plan proposes increases to current in-channel material removal limits, modifications to in-channel boundaries, rezoned areas for future aggregate mining, and a 50 year program extension. The draft EIR was completed in May 2019 (Yolo County, 2019).

1.8 Planning Process and Report Organization

The organization and chapter headings in this report reflect the plan formulation process and broadly track the six steps of the USACE planning process. Environmental documentation is provided in the attached Supplemental EIS and in the Draft Environmental Impact Report (EIR) being prepared by the NFS. The balance of this report is organized as follows:

- Chapter 2, Problem Description and Planning Objectives, covers the first step in the planning process: specification of water resources and related land resources problems and opportunities. It also covers the second step of the planning process (inventory and forecast) to the extent necessary to establish the future without-project conditions prior to the development of the alternatives.
- Chapter 3, Plan Formulation, covers the third step in the planning process (formulation of alternative plans), the fifth step in the planning process (comparison of alternative plans), and the sixth step (selection of the recommended plan based upon comparison of the alternative plans).
- Chapter 4, Recommended Plan, describes the recommended plan in detail.
- Chapter 5, Public Involvement, Coordination, Consultation, and Compliance describes public involvement and coordination, as well as consultation and compliance with applicable law, policies, and plans.
- Chapter 6, Recommendations, presents the study recommendation.

This Feasibility Report also includes technical appendices that support the plan formulation and evaluation process. Technical appendices provide detailed information on studies related to the hydrologic, hydraulic analyses, geotechnical investigations, design and structural engineering, cost estimating, economic evaluation, and real estate investigations. Further detail about environmental impacts and compliance is provided in the SEIS.

Chapter 2 – Problem Description and Planning Objectives

2.1 Problems and Opportunities

A problem is an existing undesirable condition to be changed. An opportunity is a chance to create a future condition that is desirable. Within the context of solving problems, opportunities contribute to the overall beneficial outcome of the project. The difference between problems and opportunities is often indistinct, but in both cases a changed future condition is preferred. The feasibility study identifies, evaluates, and recommends to decision makers an appropriate, coordinated, and implementable solution to the identified water and land resources problems for the LCCFS area. The following key problems were identified during the planning process by the study team and concerned stakeholders.

2.1.1 Flooding

Problem: There is risk to public health, safety, and critical infrastructure in the City of Woodland, town of Yolo, and surrounding agricultural areas from flooding from Lower Cache Creek.

There is a risk to human life and safety in the City of Woodland, town of Yolo, and surrounding areas from flooding of Lower Cache Creek. Floodwaters from Lower Cache Creek create a significant life safety risk by inundating roadways from city streets to I-5, which create hazards for motorists and isolate citizens from critical facilities such as hospitals. I-5, a major economic artery and an evacuation route, passes through the northern portion of the City of Woodland and lies within the Lower Cache Creek floodplain, shown in Figure 2-3. The topography of the floodplain is shown in Figure 2-2. High water events have led to significant flood-fighting efforts, evacuations, swift water rescues, and road closures in the study area (see I-5 near Woodland in Figure 2-1).

Figure 2-1. I-5 Near Woodland Partially Submerged

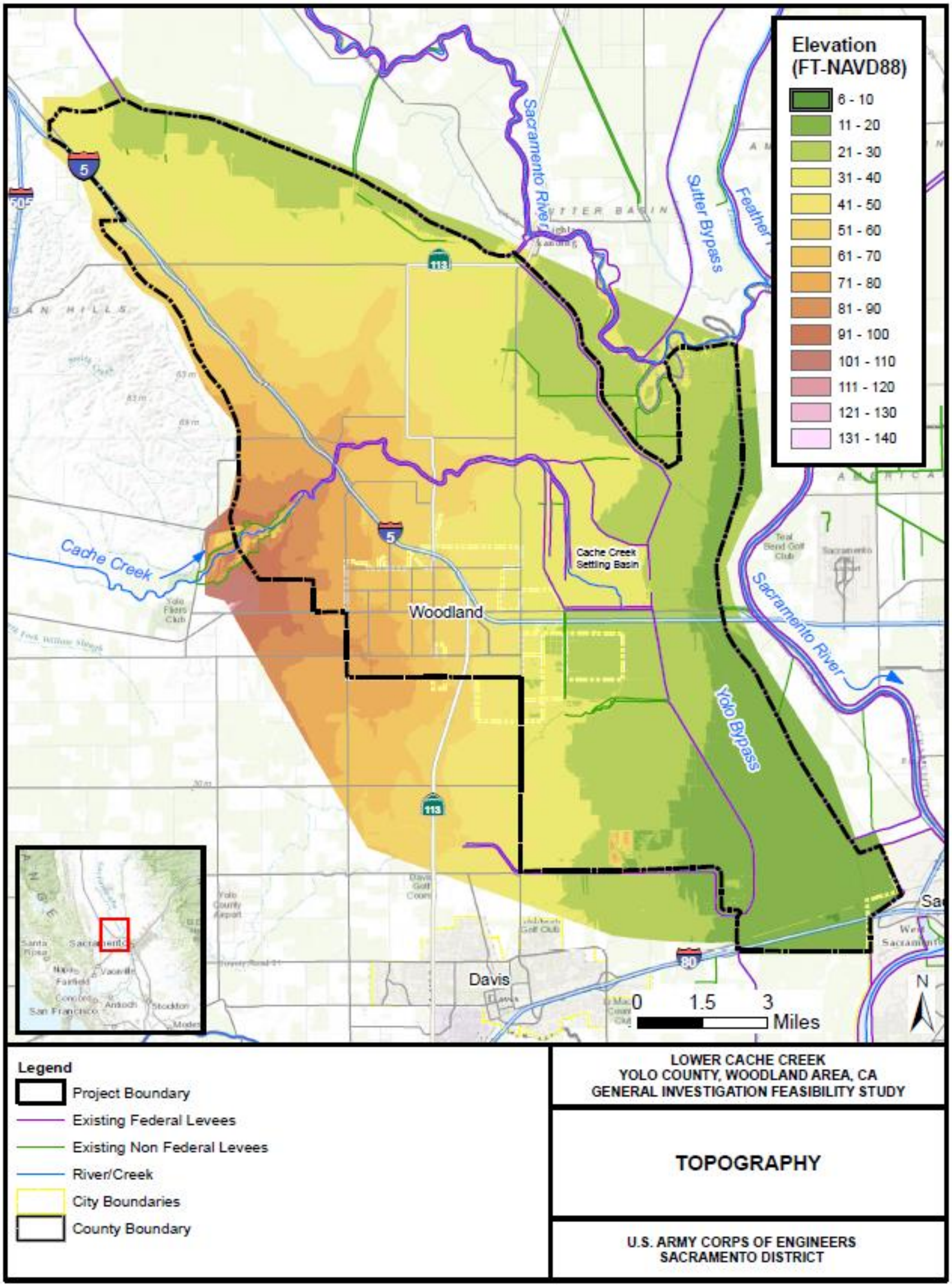


Figure 2-2. Topography of the Lower Cache Creek Floodplain

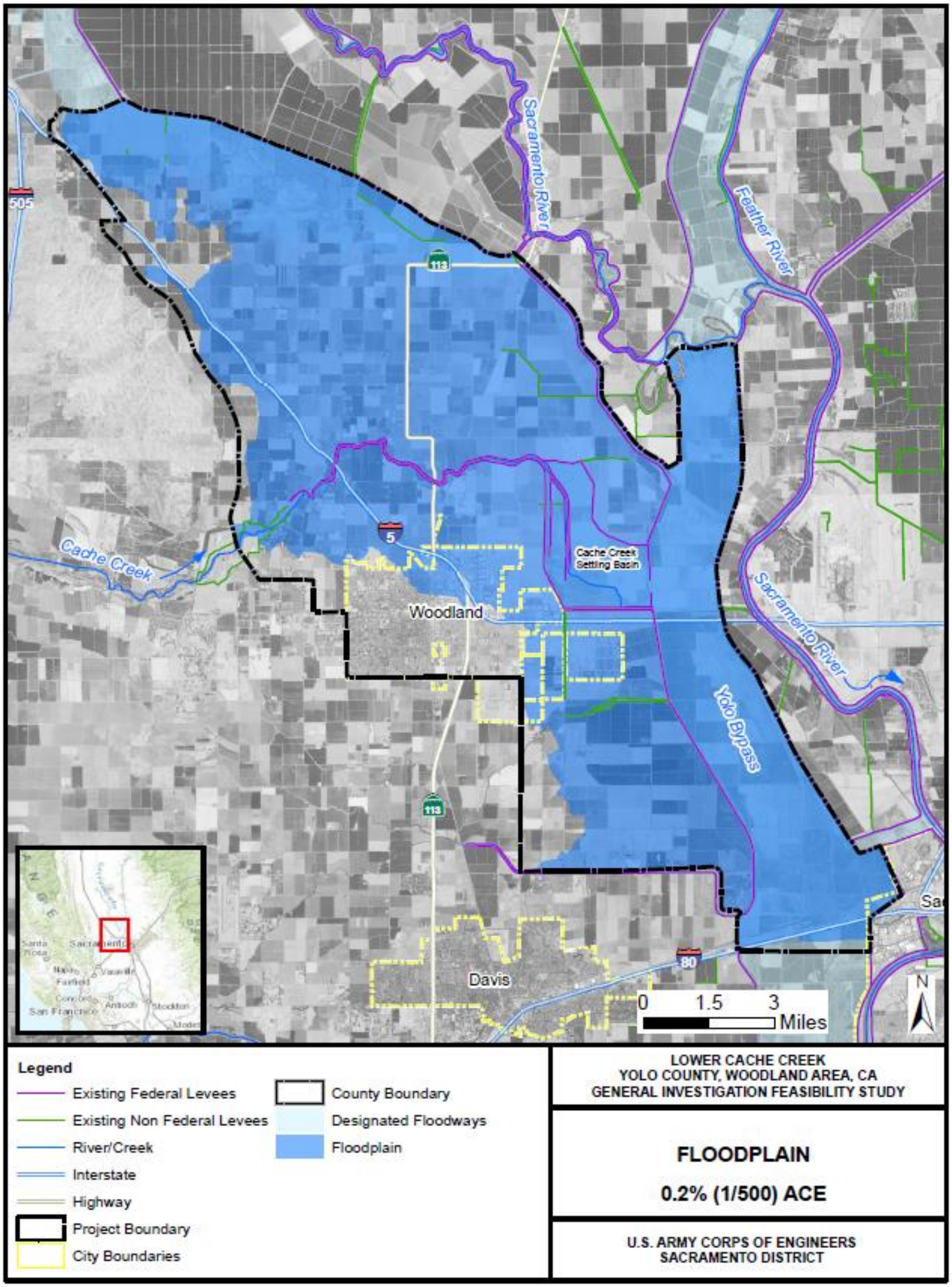


Figure 2-3. Lower Cache Creek 1/500 AEP Floodplain

Existing Hydraulic Infrastructure

An extensive levee system regulates water in and adjacent to the study area. There are 19 miles of Federal and non-Federal levees along Lower Cache Creek, which begin east of I-5 and continue to the CCSB. These levees accommodate 30,000 cfs, which corresponds to approximately a 1/10 AEP event, with 90% assurance before overtopping. However, including the probability of geotechnical failure prior to overtopping, the existing levee project would pass a 50% (1/2) AEP event (10,800 cfs) with 90% assurance. Natural banks between RD 94B and the town of Yolo begin to overtop between approximately 36,000 and 38,000 cfs, which are higher than the 1/10 AEP and lower than the 1/50 AEP event. There are nine miles of levee along the boundary of the CCSB. Seventeen miles of levees are along the Yolo Bypass. Ten miles are in the Colusa Basin Drain. Twelve miles are along the Knights Landing Ridge Cut, and 16 miles are along Willow Slough.

Existing Flood Behavior

Peak flows in Cache Creek at the upstream end of the project area (at County Road 94B) are 58,310 cfs for the 1/100 AEP event, and 74,233 cfs for the 1/500 AEP event. The primary source of flooding of the City of Woodland, town of Yolo, and surrounding areas is from overtopping of the Lower Cache Creek levees or flanking upstream of the levees. Flooding in the study area is driven by storms upstream in the Lower Cache Creek basin and not significantly influenced by flooding in the Sacramento River, Colusa Basin Drain, Knights Landing Ridge Cut, or Yolo Bypass.

Floodwaters begin to emanate from Lower Cache Creek northwest of central Woodland, near where I-5 crosses the Creek. Flows generally move in a southeasterly direction into the incorporated portion of Woodland. Flooding is sheet flow with average depths of about 3 feet and average velocity about 3 feet per second for the 1/100 AEP overtopping event. These sheet flows radiate from Lower Cache Creek until the floodwaters come against embankment features and levees of the CCSB and Yolo Bypass, where the flood depths can reach 10 to 16 feet and remain for days or weeks until it can be pumped out and into the Yolo Bypass. Figure 2-4 shows the approximate direction of flows as they emanate from Cache Creek and spread across the floodplain.

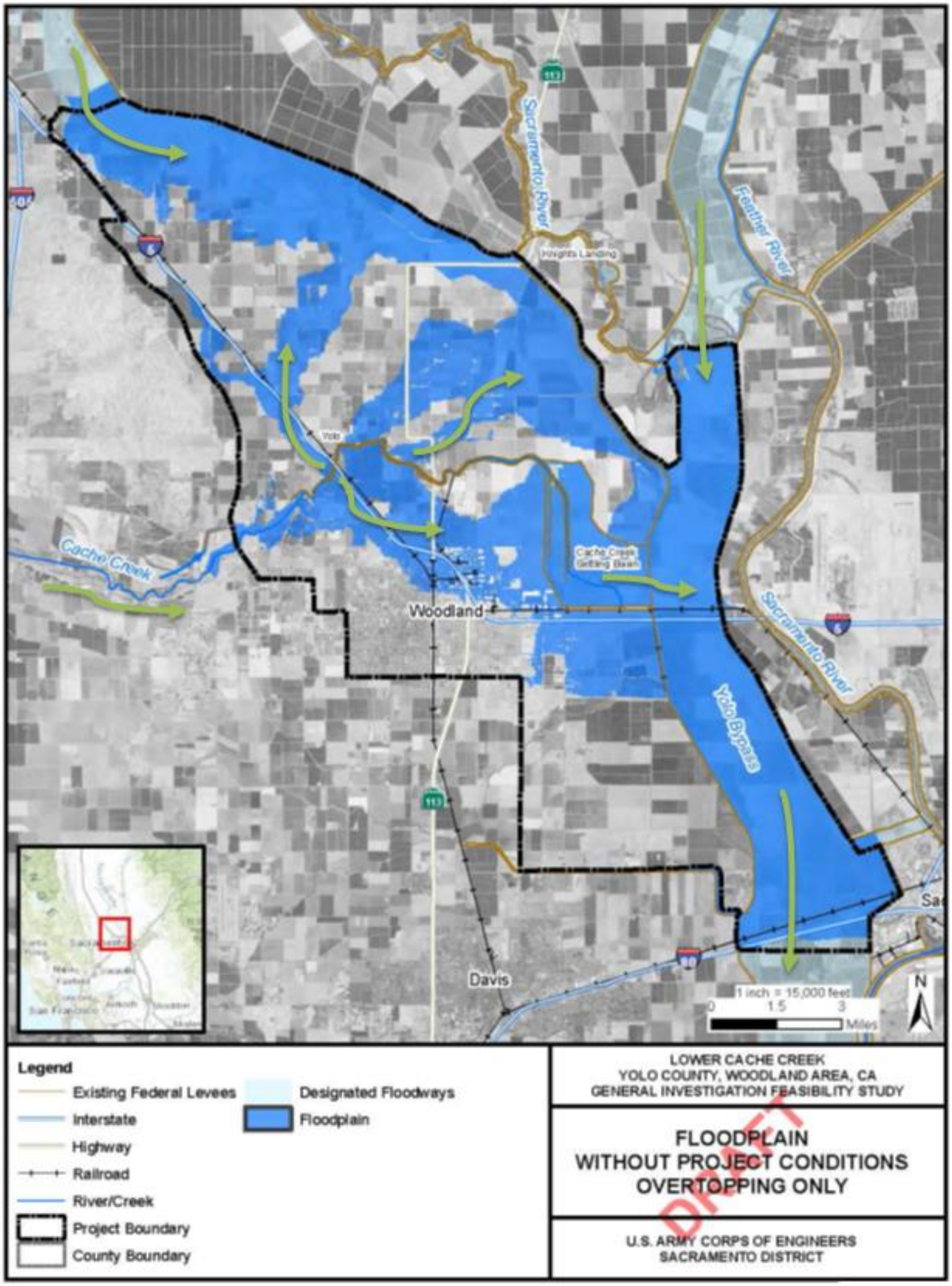
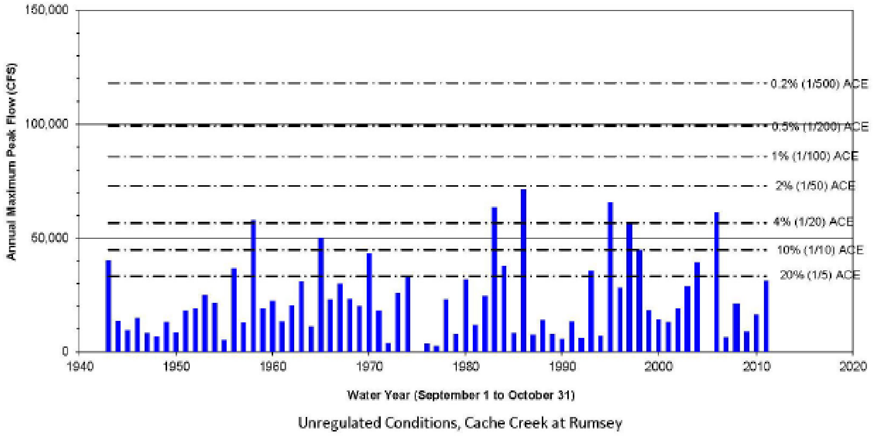


Figure 2-4. Without-Project Condition Floodplain

Flood Behavior

The primary source of flooding of the City of Woodland, town of Yolo, and surrounding areas is from overtopping of the Lower Cache Creek levees or flanking upstream of the levees. Overtopping of the existing levees, and subsequent breach due to water flowing quickly over the exposed soil of the levee, is a significant concern given the levee design height corresponds to an approximately 1/30 AEP event. Flooding in the study area is driven by storms upstream in the Lower Cache Creek basin and not significantly influenced by flooding in the Sacramento River, Colusa Basin Drain, Knights Landing Ridge Cut, or Yolo Bypass.

Lower Cache Creek has a history of flooding. Flood flows are most likely to occur between November and April; no known floods have occurred between June and August. Large floods result from rainstorm events. Four major flood periods have been documented for the Cache Creek basin during the last half of the 20th century, and 20 severe floods have occurred since 1900. The most severe high water events of recent years in the Cache Creek basin downstream from Clear Lake occurred in 1939, 1955, 1956, 1958, 1964, 1965, 1970, 1983, 1995, 1997, 2005, and 2019. Estimated unregulated annual peak discharges at the US Geological Survey (USGS) Cache Creek at Rumsey gage are provided in Figure 2-5.



Notes:

Unregulated conditions demonstrate the frequency of historical events for similar hydrologic conditions. Unregulated peak flows reflect flows unaffected by Indian Valley reservoir regulation. Regulated flows and regulated flow frequency estimates would be lower under current reservoir conditions.

1943-1965, 1972, 1974 based on translation from Cache Creek at Capay stream gage.

1978 to 2011 adjusted to remove the effects of Indian Valley reservoir regulation.

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ESTIMATED
UNREGULATED PEAK FLOWS
CACHE CREEK AT RUMSEY

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Prepared by PJB

Figure 2-5. Unregulated Peak Annual Flows from USGS Gage Cache Creek at Rumsey

Existing Levee Failure Modes

Based on analysis of the existing Lower Cache Creek embankments, the primary levee failure modes are through- and under-seepage (when water moves away from the river channel, either below or through the levee and surrounding land surface), as well as overtopping. In addition, the potential for a levee breach due to erosion also exists and is particularly relevant downstream of I-5 where the channel is incised, before flows enter into the CCSB. Past performance records support these findings and demonstrate the vulnerability of the existing Lower Cache Creek embankments with each high water event (see, for instance, a 1983 levee break in Figure 2-6 and 2019 flood fight pictured in Figure 2-7). The analysis in this report assumes that the flood source with the highest expected annual damage is representative of both without-project and residual risk in each damage area.

Figure 2-6. Cache Creek Levee Break, 1983

Figure 2-7. Flood Fight Along Existing Cache Creek Levees East of I-5, February 2019

The failure methods described above would result in large-volume flood flows at high velocities that would enter the City of Woodland suddenly and unpredictably. These failures have minimal warning and minimal time for effective implementation of evacuation and emergency plans. Study area flood events generally occur during winter months when colder air and water temperatures increase the risk of death by exposure. The risk of flooding from unexpected levee failure presents a continued threat to public health, safety, and critical infrastructure in the City of Woodland, town of Yolo, and surrounding areas.

Problem: There is a significant risk of economic damages from flooding in the City of Woodland, town of Yolo, and surrounding agricultural areas.

Flooding from Lower Cache Creek poses a risk of economic damage to property and critical infrastructure within the City of Woodland, town of Yolo, and surrounding areas. The anticipated damageable property (structures and contents) is $2.3 billion (October 2019 price levels) over the period of analysis. Damages are concentrated in an industrial area in northeastern Woodland, southwest of the CCSB. Additional information on the computation of economic damages is available in Appendix F: Economics.

Table 2-1. Number of Structures by Land Use

Land Use	Number of Structures	0.2% AEP Floodplain
Residential	12,929	588
Commercial	793	155
Industrial	366	242
Public	25	1
Total	14,113	986

Table 2-2. Damageable Property in 0.2% AEP Floodplain (in $1,000, October 2019 prices)

Land Use Type	Structure Value	Content Value	Total
Commercial	162,528	114,999	277,527
Industrial	662,080	1,045,810	1,707,890
Public	2,116	206	2,322
Residential	167,154	167,154	334,309
Total	993,879	1,328,169	2,322,048

2.1.2 Opportunities

Opportunities for this study include the potential to:

- Increase public understanding of flood risk within the study area over the period of analysis.
- Leverage other existing or ongoing FRM initiatives, particularly the Central Valley Flood Protection Plan, within the study area and over the period of analysis.

2.2 Objectives and Constraints

2.2.1 Federal Objectives

In the Flood Control Act of 1970, Congress identified four equal national objectives in water resources development planning. These objectives are: NED, Regional Economic Development (RED), Environmental Equality (EQ) and Social Wellbeing and Other Social Effects (OSE). These four categories are known as the System of Accounts, whereby each proposed plan can be easily compared to the No Action Plan and other alternatives. The Federal objective identified in the Economic and Environmental Principles for Water and Related Land Resources Implementation Studies (Principles and Guidelines) of February 3, 1983 (42 U.S.C. 1962 a-2 and d-1), is:

"The Federal objective of water and related land resources planning is to contribute to national economic development consistent with protecting the Nation's environment, pursuant to national environmental statues, applicable Executive Orders and other Federal planning requirements."

2.2.2 Non-Federal Objectives

The NFS has an additional objective to meet the California State Urban Level of Protection (ULOP) requirement defined in California Government Code 65007(I). In general, to comply, levees and floodwalls in the Sacramento-San Joaquin Valley are to provide FRM protection against a flood that has a 1-in-200 chance of occurring in any given year. The NFS is responsible for demonstrating a plan meets the ULOP objectives or requirements. The NFS would also seek FEMA accreditation of any new or strengthened levees. Neither the ULOP nor FEMA accreditation are Federal planning objectives or requirements. However, USACE and the NFS are sharing hydrologic and hydraulic modeling alternatives analyses and results, particularly associated with the NED plan, to allow the NFS to independently assess how the alternatives address ULOP or FEMA requirements.

2.2.3 Planning Objectives

Besides the national objective, which is to contribute to national economic development, the goal of the proposed project is to reduce flood risk to public health and safety, property, and critical infrastructure over the period of analysis in the City of Woodland, town of Yolo, and surrounding areas, in a manner consistent with national policy and to the degree that would meet Federal, state, and local objectives. The planning objectives of the study are:

- Reduce risk to public health, life, and safety from flooding of Lower Cache Creek in the City of Woodland, town of Yolo, and surrounding areas. This objective will be measured in terms of a reduction in expected annual damages.
- Reduce risk of damages to property from flooding of Lower Cache Creek in the City of Woodland, town of Yolo, and surrounding areas, to the fullest extent consistent with Federal participation and community financial capabilities.
- Reduce risk of damages to infrastructure from flooding of Lower Cache Creek in the City of Woodland, town of Yolo, and surrounding areas, to the fullest extent consistent with Federal participation and community financial capabilities.

2.2.4 Planning Constraints

Planning constraints represent restrictions that limit the extent of the planning process. They are statements of things that alternative plans must avoid. Constraints are designed to avoid undesirable changes between without and with-project conditions. The planning constraint for this study is:

- Under existing conditions, mercury deposits into the CCSB from mercury-laden sediment in Lower Cache Creek become methylated as a result of natural processes. Methylmercury is a potential hazard to downstream receptors in the Sacramento/San Joaquin delta. This feasibility study does not seek to remedy the methylmercury situation in CCSB. Proposed alternatives must avoid or mitigate any interference with the State of California's obligation to maintain compliance with the Total Maximum Daily Load (TMDL) of mercury-laden sediment in the Yolo Bypass, as mandated by the Environmental Policy Agency (EPA) in accordance with the Clean Water Act. USACE will follow all applicable Federal, State, and local law and policies (including TMDLs for pollution and sediment), as stated in ER1105-2-100.

2.3 Inventory and forecast of future without-project conditions

The future without-project condition (FWOP) is the most likely condition expected to exist in the future in the absence of the proposed water resource project. The FWOP defines the benchmark against which alternative plans are evaluated. While most of the documentation of affected resources is located in the SEIS, a few critical assumptions that affect plan formulation are highlighted below.

Critical assumptions in defining the FWOP condition include:

- Based on the condition of the existing levee system, the risk of economic damages and the risk to human life and safety from floodwater from Lower Cache Creek will remain.
- The existing Lower Cache Creek levee system will continue to provide flood protection for the City of Woodland, town of Yolo, and surrounding areas for events up to about 1/10 AEP.
- All existing levees will continue to be maintained as per current practices. Erosion protection, including the practice of placing rock revetment as needed, will continue as part of regular operations and maintenance.
- The sediment aggradation and degradation processes occurring within the channel will continue to impact the hydraulic capacity of the creek resulting in changes to the floodplain patterns as related to overbank flooding, levee overtopping, and breaching locations.
- Sedimentation in the CCSB will continue. DWR will maintain the CCSB per O&M manual. Future sedimentation below the maintenance threshold was not considered significant for hydraulic modeling.
- Lands within the unincorporated areas of the study area are primarily zoned agricultural. Lands within the incorporated areas of Woodland and Yolo are primarily zoned Residential or Industrial. The City of Woodland and Yolo County both have policies intended to limit urban development and preserve agricultural land.
- Recreation facilities will remain limited along Lower Cache Creek and in the CCSB.
- The CCSB will likely continue to be a point source of methylmercury for the period of performance of any project alternative.

2.3.1 Existing Non-Structural Features

The Yolo County Office of Emergency Services, in coordination with the City of Woodland, administers a warning system that notifies residents of potential flood threats or evacuations via phone, email, and text message (Yolo County, 2016). It is assumed that this warning system would remain in place under the FWOP condition.

There are several small FRM features that were constructed by private landowners or local or regional governments to reduce the consequences of flooding in the study area. These features include small berms, diversion structures, and drainage canals. It is assumed that all of these features will remain in place under the FWOP condition.

Chapter 3 – Plan Formulation

The formulation, evaluation, and comparison of alternative plans comprises the third, fourth, and fifth steps of the USACE planning process, referred to collectively as Plan Formulation. Plan Formulation is a structured and highly iterative process to develop and refine a reasonable range of alternative plans, then narrow down to a final array of feasible plans, from which a single plan may be recommended for authorization and implementation.

3.1 Flood Risk Management Measures

Measures are the building blocks that are grouped together to form alternative plans. Alternative plans are developed by grouping dependent and independent measures together to address the planning objectives. A measure is a feature or an activity that can be implemented at a specific geographic area to address one or more planning objectives. Various measures were identified to achieve the planning objectives and avoid planning constraints. The measures were screened to determine whether they should be retained for use in the formulation of alternative plans based on the following criteria:

- Effective – Measure meets planning objectives.
- Implementable – Measure is technically implementable (sound) and is feasible within the context of the study area.
- Efficient – The potential benefits/outcome of the measure are greater than what could be provided by another measure of equal or greater cost.

Screening for effective and implementable used a graduated rating of “high”, “medium”, or “low”. This is based on a qualitative assessment, using professional judgment, to rate the extent that a measure may satisfy these criteria. Screening for efficiency used rough order costs to screen out measures that were clearly inefficient. Table 3-1 presents the measures considered, the screening process, and shades dropped measures in red.

Table 3-1. Summary of Management Measures Retained or Dropped

Measures	Effective	Implementable	Efficient	Result	Notes
Non-Structural Measures					
Enhance Educational Outreach: This measure would consist of enhancing the existing flood educational outreach program for the public and policy makers.	Medium	High	High	Retained	
Reservoir Reoperation: This measure would consist of revising the operation procedures at Clear Lake and/or Indian Valley dam reservoirs to reduce the timing of peak flows in the watershed.	Low	Low	Medium	Dropped	Limited improvement possible. Clear Lake operations strictly governed by existing Court Decrees and modification would cause damages to numerous structures around lake. Operations for Indian Valley Dam established by USACE in 1974 are effective for reducing peak flood flow.
Flood Warning System: This measure includes an enhanced flood warning system, or components of a system, such as gages, software, and threat recognition system.	Low	High	High	Dropped	The Yolo County Office of Emergency Services, in coordination with the City of Woodland, administers a warning system that notifies residents of potential flood threats or evacuations via phone, email, and text message (Yolo County, 2016).
Flood Response Plans: This measure would develop or enhance plans for flood response actions for Woodland and/or Yolo.	High	High	High	Dropped	Yolo County has an existing Multijurisdictional Hazard Mitigation Plan (Yolo County, 2018) which negates the need to include one in this study.
Flood Proofing: This measure would reduce damages to structures and contents by applying wet or dry flood proofing techniques.	High	High	Medium	Retained	This includes flood proofing existing pump stations to maintain operability during a flood event.
Raising Structures: This measure would reduce the risk to structures and content by elevating structures above the base flood elevation.	High	High	Medium	Retained	Number of structures would vary from plan to plan, though would likely be in the dozens.

Measures	Effective	Implementable	Efficient	Result	Notes
Removing Flood Prone Structures (Buyout): This measure would reduce the risk to life and property damage by removing/buying out structures, creating open space with no damageable property.	High	High	Medium	Retained	This measure would contribute to restoration of the floodplain and enable more natural movement of water. Number of structures would vary from plan to plan, though would likely be in the dozens.
Relocating Structures: This measure would reduce the risk to life and property by moving (relocating) structures and residents to locations outside of the floodplain.	High	High	Medium	Retained	This measure would contribute to restoration of the floodplain and enable more natural movement of water. Number of structures would vary from plan to plan, though would likely be less than ten.
Preserve Floodplain: This measure would include setting aside property/land that is used for containing/conveying floodwater by acquiring flowage easements or fee title in floodplain lands.	High	High	Medium	Retained	These nature-based measures would contribute to the natural movement of water across the floodplain, enabling ecosystem benefits such while reducing flood risk to life and property.
Floodplain Management: This measure includes revising existing floodplain management policies, such as zoning or land use planning in an attempt to limit or avoid future development in areas subject to flooding.	High	High	High	Retained	
Structural Measures					
Containment					
Strengthen Existing Levees: This measure strengthens the existing levees, or portions of existing levees.	High	High	High	Retained	Appropriate seepage control measures will be employed. This measure includes levees along Cache Creek and the CCSB.

Measures	Effective	Implementable	Efficient	Result	Notes
Raise Existing Levees: This measure raises the existing levees, or portions of levees, to contain higher flow than is currently possible. This considers the larger footprint to account for an increased base wide for a higher levee (levee prism requirements).	High	High	High	Retained	Appropriate seepage control measures will be employed. This measure includes levees on the creek and the CCSB and may be considered around the existing I-5 bridge.
New Levees: This measure would replace existing levees or build new levees, including setback levees, using current engineering methods. This potentially includes removal of existing levees, or potions of, prior to replacement.	High	High	High	Retained	Appropriate seepage control measures will be employed. This measure is not limited to levees along the creek alignment and could include new setback levees located away from the channel. Setback levees favor ecosystem health by allowing the creek to meander within a defined area and for high flows to deposit nutrients within the levee corridor, while also reducing flood risk beyond the levees.
Floodwalls: This measure would build floodwalls to contain floodwaters in a channel or provide a line of defense around the urban area or critical infrastructure.	High	High	High	Retained	Floodwalls were considered in areas with limited available real estate for FRM features, however floodwalls increase construction cost.
Upstream Detention: This measure would include a large upstream detention facility.	Medium	Medium	Medium	Retained	
In-channel Retention: This nature-based measure would entail one or more retention facilities, such as a constructed wetland, mid-watershed or along the channel to reduce peak flows in Cache Creek.	Medium	Low	Medium	Dropped	The perched channel of Cache Creek limits the usefulness of near channel retention, such as constructed wetlands, given that flows that leave the channel are prone to spread across the floodplain.

Measures	Effective	Implementable	Efficient	Result	Notes
Stormwater Detention: This measure would retain local stormwater in one or more small detention/retention facilities.	Low	Low	Medium	Dropped	Local stormwater ordinance exists; the volume of flow is from outside these municipalities. Not effective at meeting objectives.
Channel Modification					
Vegetation Clearing: This measure would increase flow conveyance capacity by removing riparian vegetation from the channel. The cleared area would be reseeded with grass, and rock slope protection would be placed where required.	Low	Low	Low	Dropped	Would significantly affect the existing environment. Not effective at meeting FRM objectives. Overgrowth does not strongly contribute to flooding and thus clearing would offer little change to flood behavior.
Sediment Removal/Channel Deepening: This measure would increase conveyance capacity by removing sediment deposits from the channel.	Low	Low	Low	Dropped	Channel is largely sediment starved, little improvement could be gained. Would require to be combined with vegetation clearing.
Channel Straightening: This measure would replace selected winding courses in the creek and replace them with straight cuts.	Medium	Low	Low	Dropped	There are few locations along the creek that would provide a reduction in flooding. The effort and cost to straighten these sections of the creek are greater than the small benefit that could be realized. Additionally, potentially significant adverse environmental impacts.
Channel Widening: This measure would increase channel capacity by increasing the width of the channel at selected locations, but not for the full channel. This also includes channel benching.	High	Low	Low	Dropped	There are few locations along the creek that would provide a reduction in flooding. The effort and cost to widen specific sections of the channel are greater than the benefit that could be realized.

Measures	Effective	Implementable	Efficient	Result	Notes
Bank and/or Bed Protection: This measure would consist of rock slope protection of the water-side banks of levees and/or the bed of the creek to prevent or reduce erosion due to high flows or to provide grade control.	Medium	High	High	Retained	New and strengthen levees include bank protection. The PDT will consider different bank protection approaches, including rock revetment and nature-based methods.
Transportation Infrastructure					
Raise I-5 Roadbed: This measure would raise the portion of I-5 south of the CCSB to reduce the potential for damage to the roadbed and motorists. It would also reduce the potential for closing this major interstate during flooding.	High	High	Low	Dropped	Potentially provides FRM benefits, though cost is significant and could induce flooding in other areas.
Lower I-5 Roadbed: This measure would lower portions of I-5 in vicinity of Yolo, north of Woodland. The intent is to allow floodwater to overtop the roadway, thus removing the constriction that currently results in backflow flooding.	High	Low	Low	Dropped	This measure could reduce backflow flooding, though is very costly and could increase risk to motorists and damage to transportation infrastructure, as well as lengthen closures of I-5.
Raise Railroad Bed: This measure would raise portions of the railroad bed in select locations to reduce ponding of floodwater.	Medium	Low	Low	Dropped	It was eliminated due to high costs, low efficiency and low implementability.
Bridging/Culverts: This measure would include raising, protecting, or otherwise modifying bridges and	Medium	High	Medium	Retained	This measure contributes to opening of the floodplain and more natural movement of floodwaters. This measure

Measures	**Effective**	**Implementable**	**Efficient**	**Result**	**Notes**
roads within the floodplain to reduce constriction points in the channel that cause channel bank or levee overtopping; for example, adding large scale culverts under select locations of I-5, Union Pacific Rail Road (UPRR), and county roads to reduce ponding of floodwater.					could be combined with other structural or non-structural features.
Use Existing Floodplains					
Bypass/floodway: This measure would channel floodwater (from levee overtopping upstream out of bank flow, or levee breach) away from urban areas into one of several locations.	High	High	Medium	Retained	The bypass or floodway may include features such as weirs or flap gates to allow water to move from the existing channel into another channel. The bypass may follow the natural floodplain or may require levees or floodplain contouring. Flood easements could be required in the bypasses as well.
Floodplain Contouring: This measure would consist of modifications to the floodplain to contain or direct flow.	Medium	High	Medium	Retained	This measure would be combined with bypass or floodway features to direct flow.
Modification of outlet weir: Increase the height of the existing CCSB outlet weir into the Yolo Bypass.	Low	Medium	Low	Dropped	Sedimentation of the CCSB has not reached the level where a modification of the weir would be necessary.

These measures preliminarily achieve FRM objectives in the study area. FRM measures can be structural or non-structural. Non-structural measures reduce flood damages without altering the nature or extent of the flooding and are accomplished by changing the use of the floodplains or by adapting existing uses to the flood hazard. In contrast, structural measures alter the nature or extent of the flooding by modifying the magnitude, direction, extent, or timing of the flooding. Several measures incorporate natural or nature-based approaches, which is the intentional alignment of natural and engineering processes to efficiently and sustainably deliver benefits.

Early screening measures that considered opportunities to apply FRM measures in the study area used a coarse estimate of the basic magnitude of construction costs compared to the maximum potential FRM benefits possible. Reduction in flood damages translates into monetary benefits, which in turn help determine if the Federal government can participate in the project (i.e., the Federal interest).

3.2 Plan Formulation Strategy

At this stage in the planning process, the PDT identified broad alternatives to address flood risk in the City of Woodland: non-structural approaches, diverting floodwater to the north of Cache Creek, diverting floodwater to the south of Cache Creek and north of the City of Woodland, diverting floodwater south of the City of Woodland, retaining water upstream, several levee configurations to keep water in or near the channel, and various combinations of the above. An initial array of FRM alternatives was developed, evaluated, and compared to identify a plan that reasonably maximizes net benefits (benefits minus costs). The alternatives were formulated to address specific flooding sources using measures to reduce the consequences to the maximum extent possible. The initial array of 11 alternative plans primarily consists of various levee configurations to prevent floodwaters from Cache Creek from entering the City of Woodland, and to strengthen the CCSB.

The retained measures generally need to be combined with other retained measures in order to develop complete alternative plans. Table 3-2 illustrates which measures were combined to form the various alternative plans. The initial array broadly groups potential plans as bypass alternatives or containment alternatives. While each individual measure contributes to one or more of the FRM objectives, most need to be applied in combination with the others in order to provide a complete plan that achieves the multiple objectives identified by the study. A description of each of the preliminary alternative plans follows Table 3-2.

Table 3-2. Inclusion of Measures in Initial Alternative Plans

Retained Measures	Alternatives											
	No Action	Bypass Alternatives				Containment Alternatives					Non-Structural Alternatives	
	0	1	2	3	4	5	6	7	8	9	10	11
Enhance educational outreach		X	X	X	X	X	X	X	X	X	X	X
Flood proofing		X	X	X	X			X	X	X	X	X
Raising structures		X	X	X	X			X	X	X	X	X
Removing structures / buyout		X	X	X		X		X	X	X	X	X
Relocating Structures		X	X	X		X		X	X	X	X	X
Flowage Easements		X	X	X	X	X	X	X	X			
Strengthen Existing Levees		X	X		X		X	X		X		
Raise Existing Levees							X					
New Levees		X	X			X	X	X	X	X		
Floodwalls			X									
Upstream Detention						X						
Bank / Bed Protection		X	X	X	X	X	X	X	X	X		
Bridging / culverts		X	X	X	X							X
Bypass/floodway		X	X	X	X		X	X	X			
Floodplain contouring		X										

3.2.1 Alternative 0: No Action Plan

The No Action Plan is the existing and future without-project condition, which is described in Chapter 2. This plan serves as the baseline against which the effects and benefits of the action plans are evaluated. The Federal Government would take no action to implement a specific plan to reduce flooding of the city of Woodland under the No-Action Plan; and the Cache Creek levee system, with continued maintenance and repairs/rehabilitation, would continue to provide for the reliable conveyance of the 1/20 AEP event. Larger events would continue to pose significant flood risk for the City of Woodland and surrounding areas. Annual damages to real property from overflows from Cache Creek would be expected to continue to be about $22.7 million. Other losses or adverse effects would continue to include the potential for flood-related loss of life, contamination from sanitary sewage and hazardous materials, and the extended closure of the section of I-5 east of the city of Woodland.

Bypass Alternatives

3.2.2 Alternative 1: North Bypass

This alternative would allow flow over approximately 30,000 cfs to leave the creek and flow north either following the natural floodplain or by being somewhat contained by subtle floodplain contouring or new levees. The new bypass, represented by areas A and B in Figure 3-1, would convey high flows into either the Colusa Basin Drain or Knights Landing Ridge Cut, depending on configuration, and from there into the Yolo Bypass. The new bypass would likely require rights of way, likely flood easements. There are different possible alignments for this alternative: one alignment could follow the natural floodplain into the Colusa Basin Drain, one could follow the natural floodplain into the Knights Landing Ridge Cut, or both alignments can be used. Further analysis may find that new levees are needed along both sides of I-5 to County Road 94B; this will depend on the alignment of the bypass. This alternative includes bridging (large culverts) of I-5 and possibly UPRR, as well as strengthening portions of the existing Lower Cache Creek and CCSB levees to reduce breach potential. This alternative includes flood-proofing structures and property buyouts, where needed, as well as enhanced educational outreach.

3.2.3 Alternative 2: South Bypass

This alternative consists of diverting flows over approximately 30,000 cfs from the right overbank by constructing a bypass, or conveyance channel, to the south of Cache Creek and to the north of the City of Woodland, represented by area C in Figure 3-1. High flows would pass through or from the CCSB into the Yolo Bypass. Construction of a flood barrier (levee and floodwall combination) north of Woodland will provide an urban line of defense from flood surges. This alternative includes bridging (large culverts) of I-5, county roads, and possibly UPRR. There are two different alignment possibilities with this alternative. A wide bypass alignment removes a portion of the existing CCSB (southern portion of basin), rebuilding the south levee, and expanding the basin geographically to mitigate for the portion of the basin that is removed. The intent is to continue agricultural production in this bypass. The second alignment is a narrow bypass located to the south of the CCBS (and thus does not impact the CCSB). The narrow alignment would require relocation of major warehouses. Either alignment includes strengthening portions of the existing Lower Cache Creek and CCSB levees to reduce breach potential. This alternative includes flood-proofing structures and property buyouts, where needed, as well as enhanced educational outreach.

3.2.4 Alternative 3: West Bypass

This alternative consists of a bypass, with easements, diverting flows over approximately 30,000 cfs from Cache Creek, downstream of I-505, with an outlet to Yolo Bypass near Willow Slough, north of the City of Davis, as represented by area D in Figure 3-1. The alignment would cross several county roads, thus bridge/culvert improvements might be required. This alternative includes flood-proofing structures and property buyouts, where needed, as well as enhanced educational outreach.

3.2.5 Alternative 4: North and South Bypass

This alternative includes two bypasses, a south bypass into Yolo Bypass and a north bypass following one of two possible alignments described in Alternative 1, represented by areas A, B, and C in Figure 3-1. The alternative consists of diverting flows over approximately 30,000 cfs from the right overbank and left overbank by constructing two bypasses downstream of County Road 94B to convey flows away from the City of Woodland and into the Yolo Bypass. This alternative also includes bridging/culverts under UPRR, I-5, and county roads. This alternative includes flood-proofing structures and property buyouts, where needed, as well as enhanced educational outreach.

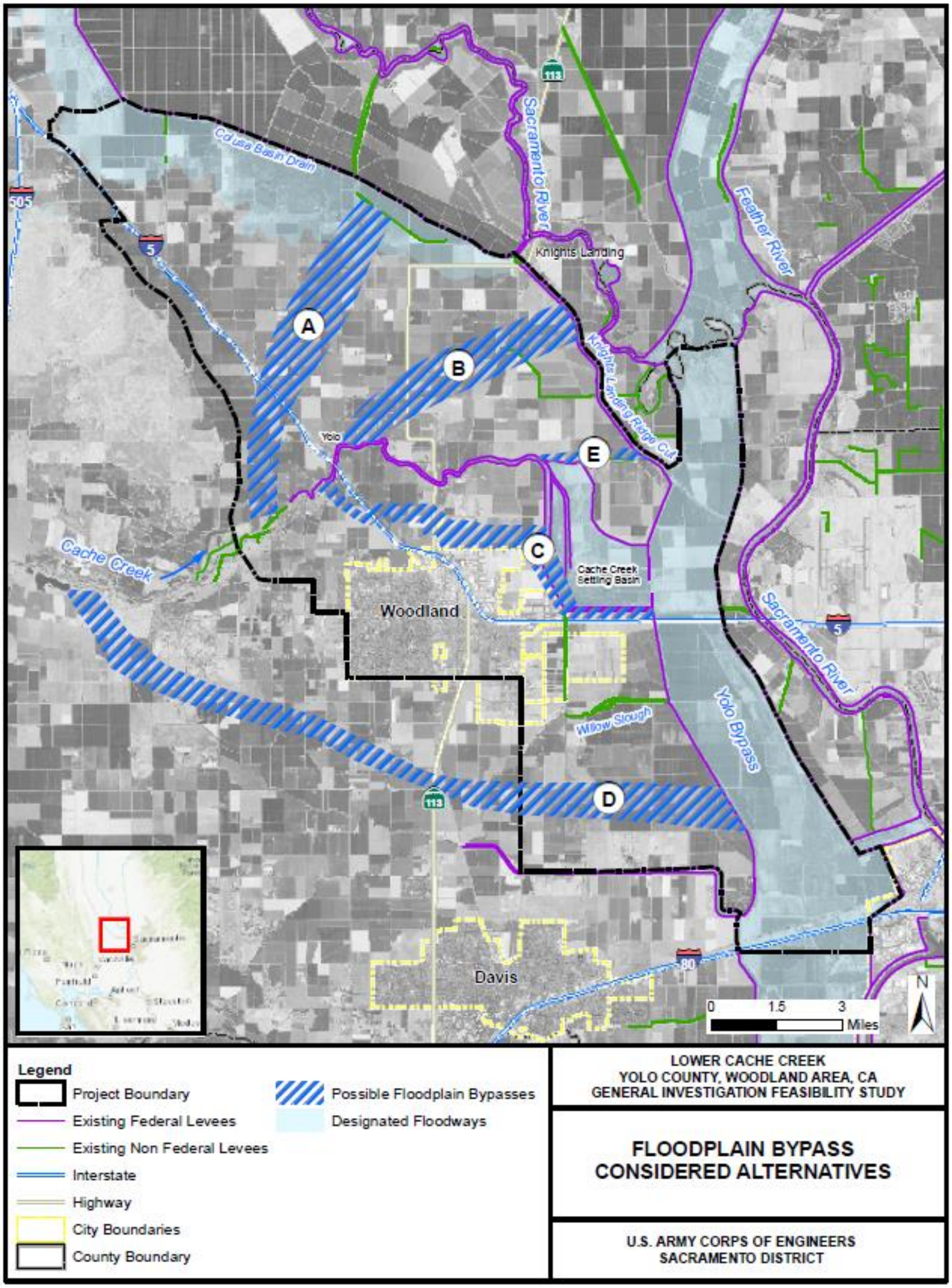


Figure 3-1. Bypass Alternatives

3.2.6 Alternative 5: Upstream Detention/Retention

This alternative consists of constructing a new detention site/reservoir in the upper watershed or one or more retention basins in the mid watershed to capture and hold large volumes of water and thus decrease flow and potential flooding in the downstream communities. The detention/retention basin(s) would likely include levees, buyout, or relocations of structures. Potential sites include: Bear Creek approximately 11 miles upstream of its confluence with Cache Creek; Wilson Valley; and Blue Ridge, located between Rumsey and Clear Lake along State Highway 16.

3.2.7 Alternative 6: Levee Fix in Place

The purpose of this alternative is to contain flow within the levee system where possible, primarily by strengthening and/or raising existing levees, as illustrated in Figure 3-2. Levee work would consist of: levees east of I-5 will be raised or strengthened to the northernmost portion of the CCSB on the right and left banks; levees from the northernmost portion of the CCSB to the Yolo Bypass will be strengthened to mitigate and prevent seepage concerns; and new levees will be added upstream of I-5 to prevent overtopping in this location. In areas where the existing levees are eroding, the levee will be slightly set back from the existing location. The alternative would also require either a geographic expansion of the CCSB to accommodate increased inflow of water or controlled overtopping of levees with a small floodway to the Yolo Bypass. Bridging/culverts under I-5 and UPRR might be required. This alternative includes flood-proofing structures and property buyouts, where needed, as well as enhanced educational outreach.

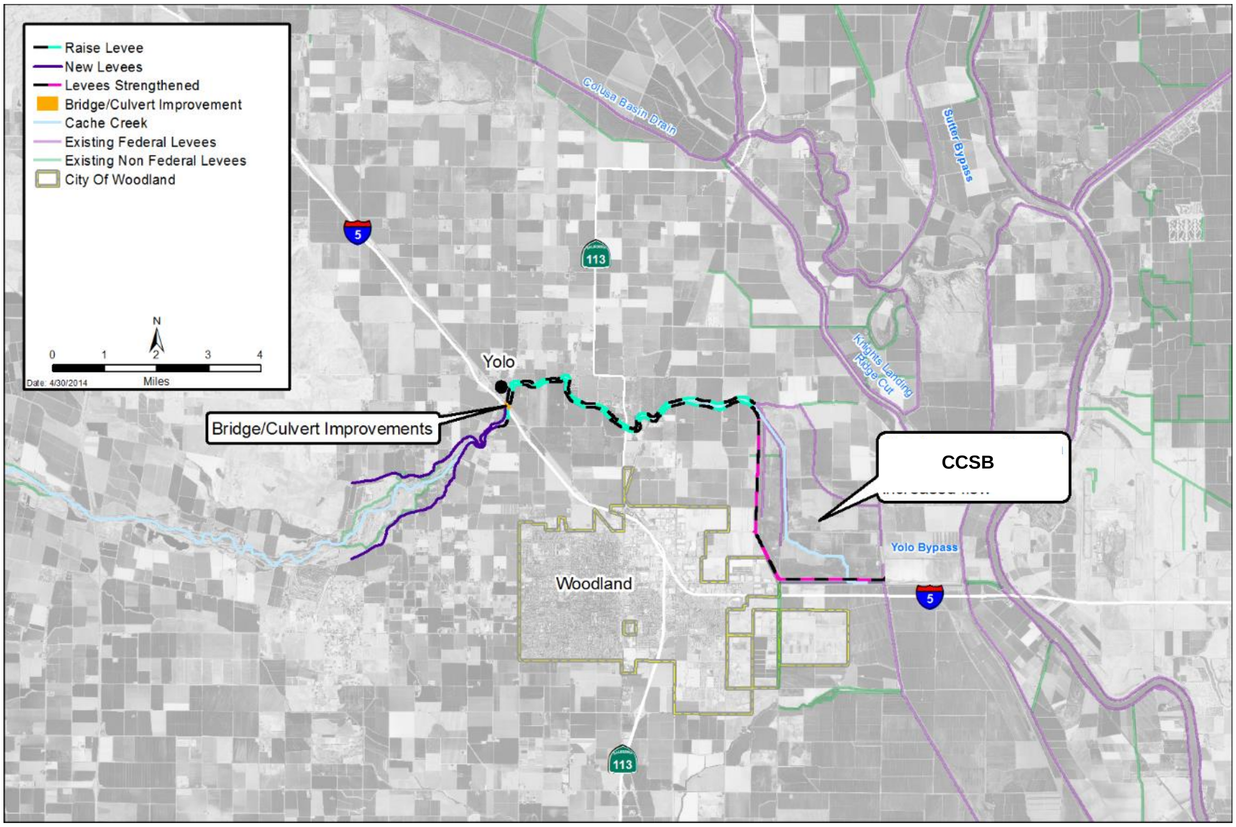


Figure 3-2. Alternative 6: Levee Fix in Place

3.2.8 Alternative 7: Partial Setback Levees

The purpose of this alternative is to contain flow within a levee system. New levees would be built upstream (West) of I-5 to prevent overtopping in this location, as illustrated in Figure 3-3. Setback levees would be added to the right and left banks in advantageous locations to prevent flooding due to overtopping of the existing levee. Areas where setback levees will not be built would be strengthened. This includes levees from the northernmost portion of the CCSB to the Yolo Bypass to mitigate and prevent seepage concerns. Lands or rights of way will be required (either easement or fee). The alternative will also require either a geographic expansion of the CCSB to accommodate increased inflow of water or controlled overtopping of levees with a small floodway to the Yolo Bypass, or a construction of a new bypass north of the CCSB into the Yolo Bypass, as indicated in area E of Figure 3-2. Bridging/culverts under I-5 and UPRR might be required. This alternative includes flood-proofing structures and property buyouts, where needed, as well as enhanced educational outreach.

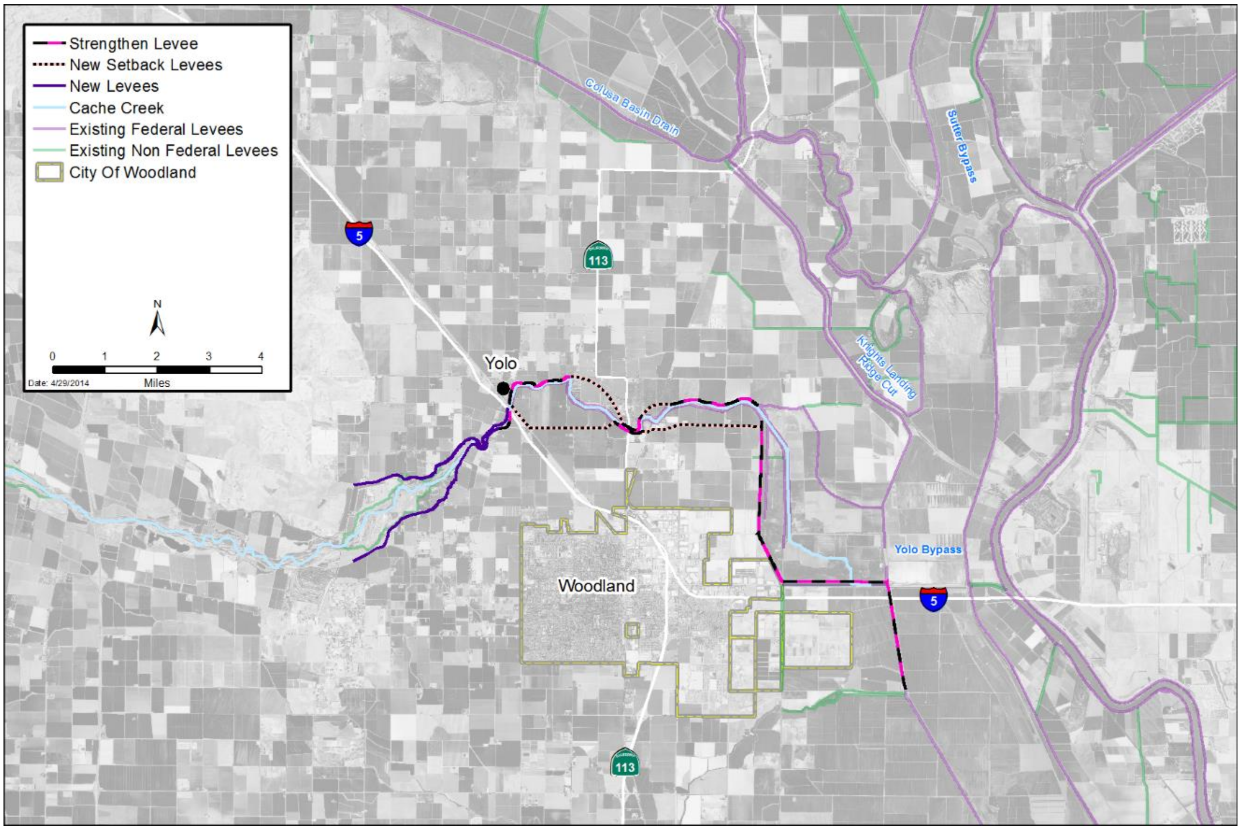


Figure 3-3. Alternative 7: Partial Setback Levees

3.2.9 Alternative 8: Continuous Setback Levees

The purpose of this alternative is to build setback levees to contain flow within the levee system. Different alignments are possible. The first alignment would follow the existing river channel, on both the right and left banks. This consists of approximately 19 miles of levees along the creek and would require increasing the capacity of the CCSB. The second alignment would include a continuous right bank setback levee closely following the alignment of the urban area and would extend south to parallel the Yolo Bypass. This would provide a line of defense for the city of Woodland. Lands or rights of way would be required (either easement or fee). This alignment would have an outlet into the Yolo Bypass and would require new levees upstream, west of I-5, to prevent overtopping in that location. Bridging/culverts under the UPRR might be required. This alternative includes flood-proofing structures and property buyouts, where needed, as well as enhanced educational outreach.

3.2.10 Alternative 9: Yolo Flood Risk Reduction

This alternative consists of strengthening the left bank levees from I-5 to CCSB to reduce breach potential and building new levees, where needed, to reduce flood risk in the town of Yolo. This alternative includes flood-proofing structures and property buyouts, where needed, as well as enhanced educational outreach.

Non-Structural Alternatives

3.2.11 Alternative 10: Raise, Flood-proof, Buyout

This alternative is a combination of non-structural measures aimed at removing or reducing risk to people and property in the floodplain. This would include raising and flood-proofing structures in-place, where possible. Other structures would be considered for relocation or buyout. The plan also incorporates enhanced educational outreach.

3.2.12 Alternative 11: Bridging with Raise, Flood-proof, Buyout

This alternative is a combination of non-structural measures with structural roadway improvements. Bridging/culverts under known roadway constriction points, I-5, railroad, and county roads would alleviate some backwater flow into the urban area. Structures that are still at risk would be considered for flood-proofing or raising in-place where possible. Other structures would be considered for buyout or relocation. The plan also incorporates enhanced educational outreach.

3.3 Initial Alternatives Analysis

Alternative plans were screened during a series of workshops with the USACE, DWR, and the City of Woodland (the California Department of Transportation participated on a limited basis). Screening criteria were developed in the first workshop and later refined. The second workshop focused on screening alternatives using a graduated rating of “high”, “medium”, or “low” for each criterion. This is based on qualitative assessment, using professional judgment, to rate the extent that an alternative satisfies these criteria. The No Action Plan was carried forward in order to serve as the baseline against which all retained alternative plans are compared.

- High indicates the alternative meets planning objectives, is technically implementable, and is considered efficient.
- Medium indicates the alternative somewhat meets objectives, is technically implementable, and is considered efficient.
- Low indicates the alternative does not meet objectives, is not technically implementable, and/or is not considered efficient.

Coarse cost estimates were identified using information from the sponsor and previous studies, as needed, for screening. Several similar alternatives were combined.

Results of the initial array screening using the criteria below are shown in Table 3-3, which shades dropped alternatives in red:

- Complete – The extent to which the plan provides and accounts for all necessary investments or other actions. To be complete, a plan must not reply on other activities to function.

- Effective – The extent to which the plan meets planning objectives.
- Efficient – The extent to which the benefits of a plan are likely to exceed the costs. (Even though costs were developed, the uncertainty was such that the team elected not to use cost for screening; rather, the criterion of "efficient" was based on professional judgment of how plans compared to each other.)
- Implementable – The extent to which an alternative is technically sound and feasible to implement in the context of the study area.
- Acceptable – The extent to which an alternative is environmentally, economically, politically, and socially acceptable. The acceptability criterion also captures the extent to which the alternative is consistent with the CVFPP and SB 5.

The "Effective" score is a composite of the following parameters and represents the extent of how each alternative meets study objectives of:

- Reduces Risk to Public Health, Life, Safety – The extent to which the alternative reduces risk to life (life safety) for the City of Woodland and town of Yolo.
- Risk Reduction to Property – The extent to which the alternative reduces risk to property in the City of Woodland and town of Yolo.
- Risk Reduction to Infrastructure – The extent to which the alternative reduces risk to critical infrastructure in the City of Woodland and town of Yolo.

Alternatives were also screened based on the following criteria:

- Encourages Wise Use of Floodplains – The extent to which the alternative conveys water away from urban area, is compliant with Executive Order 11988, and does not increase development in floodplains subject to a 1% or greater chance of flooding in any given year.
- Environmental Justice – The extent to which the alternative provides fair treatment of all people in the study area.
- Opportunities – Whether or not the alternative achieves the opportunities of increasing public understanding of flood risk and leveraging other ongoing FRM initiatives.
- Constraints – The extent to which the alternative avoids or mitigates any interference with the State of California's obligation to maintain compliance with the TMDL of mercury-laden sediment in the Yolo Bypass and adheres to Laws/Policies.

Alternative plans were eliminated if a rating of "Low" was identified for the criteria of complete, effective, efficient, or implementable. All criteria were considered during screening; however, decisions were weighted toward alternatives being complete, effective, efficient, and implementable. The initial screening was undertaken prior to the development of hydraulic and economic modeling efforts that would provide quantitative benefits, and also prior to the development of alternative-specific costs. Thus, the qualitative screening effort was based on professional judgment. The retained preliminary alternatives were later evaluated and compared with a greater level of detail to identify the National Economic Development (NED) plan.

Table 3-3. Screening of Initial Array of Alternatives

Alternative	Complete	Effective	Efficient	Implementable	Acceptable	Result	Reason for Dropping
1. North Bypass	High	High	High	High	Medium	Retained	
2. South Bypass	High	High	Medium	Medium	Medium	Retained	
3. West Bypass	Medium	High	Medium	Low	Low	Dropped	This alternative was eliminated as it transferred risk to the city of Davis.
4. North and South Bypass	High	High	Low	High	Medium	Dropped	This alternative was eliminated as it is likely less efficient than other bypass alternatives—it would generate similar benefits but at a higher cost. Other bypass alternatives are more efficient as they accomplish the same reduction in risk with a single bypass.
5. Upstream Detention	High	High	High	Low	Low	Dropped	Previous studies investigated the possibility for upstream detention in the study area. A few sites were previously identified as suitable, but later found to be unsuitable due to Seismic and environmental concerns rule out most potential sites. Topography of the upstream area does not provide any other suitable location for detention/retention basins of a suitable size that would provide adequate flood risk reduction to the downstream communities. This alternative was eliminated as it is not implementable.
6. Levee Fix in Place	High	Medium	High	Medium	Medium	Retained	
7. Partial Setback	High	High	High	High	Medium	Retained	

Alternative	Complete	Effective	Efficient	Implementable	Acceptable	Result	Reason for Dropping
Levees							
8. Continuous Setback Levees	High	High	Low	High	Medium	Dropped	The PDT eliminated this alternative because it was less efficient than other containment alternatives. The buyouts and easements required for this alternative would be significant, in comparison to other options, and there would need to be significant improvements to increase the capacity of the CCSB. Despite the higher costs, it would not generate higher benefits than other alternatives.
9. Yolo Flood Risk Reduction	Medium	High	High	Medium	High	Retained	
10. Raise, Flood-proof, Buyout	Low	Medium	Medium	Medium	High	Dropped	The PDT considered various approaches to flood-proofing structures with the highest damages, such as wrapping the building in plastic and closing off openings for depths less than 3 feet. However, this approach was not considered feasible because the flood warning time is likely to be less than the time required to deploy the flood proofing for individual structures. These methods are not considered feasible for depths greater than 3 feet because hydrostatic forces could cause the walls to collapse inward. Individual ring levees or floodwalls

Alternative	Complete	Effective	Efficient	Implementable	Acceptable	Result	Reason for Dropping
							surrounding each structure were considered for depths greater than 3 feet. However, to address the requirements of ECB 2016-01 the levees and floodwalls are not considered non-structural methods and would have to meet USACE design criteria for levees and floodwalls (e.g. patrol roads, real estate, etc.)-These methods are unlikely to be economically justified. Other alternatives incorporate non-structural elements considered under this alternative. Raises and buyouts for all structures in the floodplain were dropped on account of high costs (low efficiency), limited effectiveness, and low acceptability.
11. Bridging with Raise, Flood-proof, Buyout	Low	Medium	Medium	Medium	High	Dropped	The PDT considered various approaches to flood-proofing structures with the highest damages, including the construction of small ring levees or floodwalls to reduce risk on individual structures or adjacent groups of structures. Flood-proofing was not economically viable (the construction cost of small flood risk reduction measures to USACE design standards outweighed the benefits). Bridging does not significantly reduce flood

Alternative	Complete	Effective	Efficient	Implementable	Acceptable	Result	Reason for Dropping
							risk in the study area. Other alternatives incorporate non-structural elements considered under this alternative. Raises and buyouts for all structures in the floodplain were dropped on account of high costs (low efficiency), limited effectiveness, and low acceptability.

3.4 Focused Array of Alternatives

Based on the screening process of the initial array described above, the no action and four action alternatives were carried forward to the focused array: Alternative 1: North Bypass, Alternative 2: South Bypass, Alternative 6: Levee Fix in Place, and Alternative 7: Partial Setback Levees. The PDT developed and evaluated several configurations of each alternative in the focused array based on a qualitative assessment of inflection points in the costs and/or benefits of alternatives, as described below. Letters following the alternative number (i.e., 1A, 1B, 1C) represent various performance options of each alternatives. A value engineering (VE) study conducted on the focused array further informed the screening of alternatives and lead to the inclusion of alternatives 1D, 7A, and 7B. The following provides a description of the focused array of alternatives.

3.4.1 Alternative 1A: North Bypass A

This alternative includes strengthening the right bank of the existing levees from downstream of I-5 to the CCSB, as well as the left bank near the town of Yolo. In addition, this alternative includes a grade control structure and a right bank levee extension upstream of I-5, to accommodate excess flows. Figure 3-4 shows the project features. These features would increase the stage upstream of I-5, resulting in floodwaters overtopping the left bank and flowing north towards the Colusa Basin Drain. This alternative would include seepage mitigation and rock bank protection along most of its length.

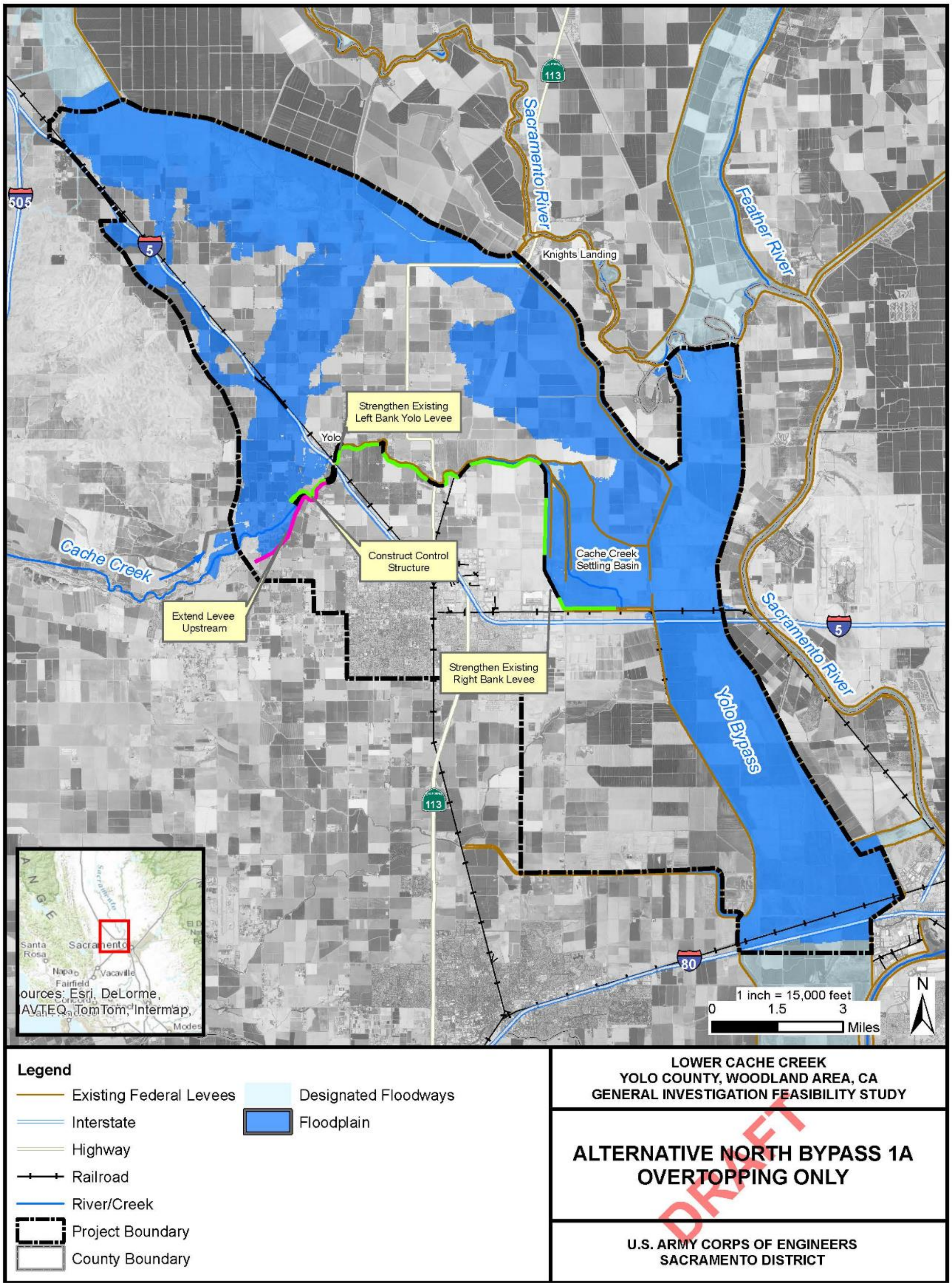


Figure 3-4. Alternative 1A: North Bypass A

3.4.2 Alternative 1B: North Bypass B

This alternative consists of the same structural features as Alternative 1A, though it adds the purchase of flowage easements on the land that would convey floodwaters to the Colusa Basin Drain. This alternative would include seepage mitigation and rock bank protection along most of its length. A map of this alternative is shown in Figure 3-5.

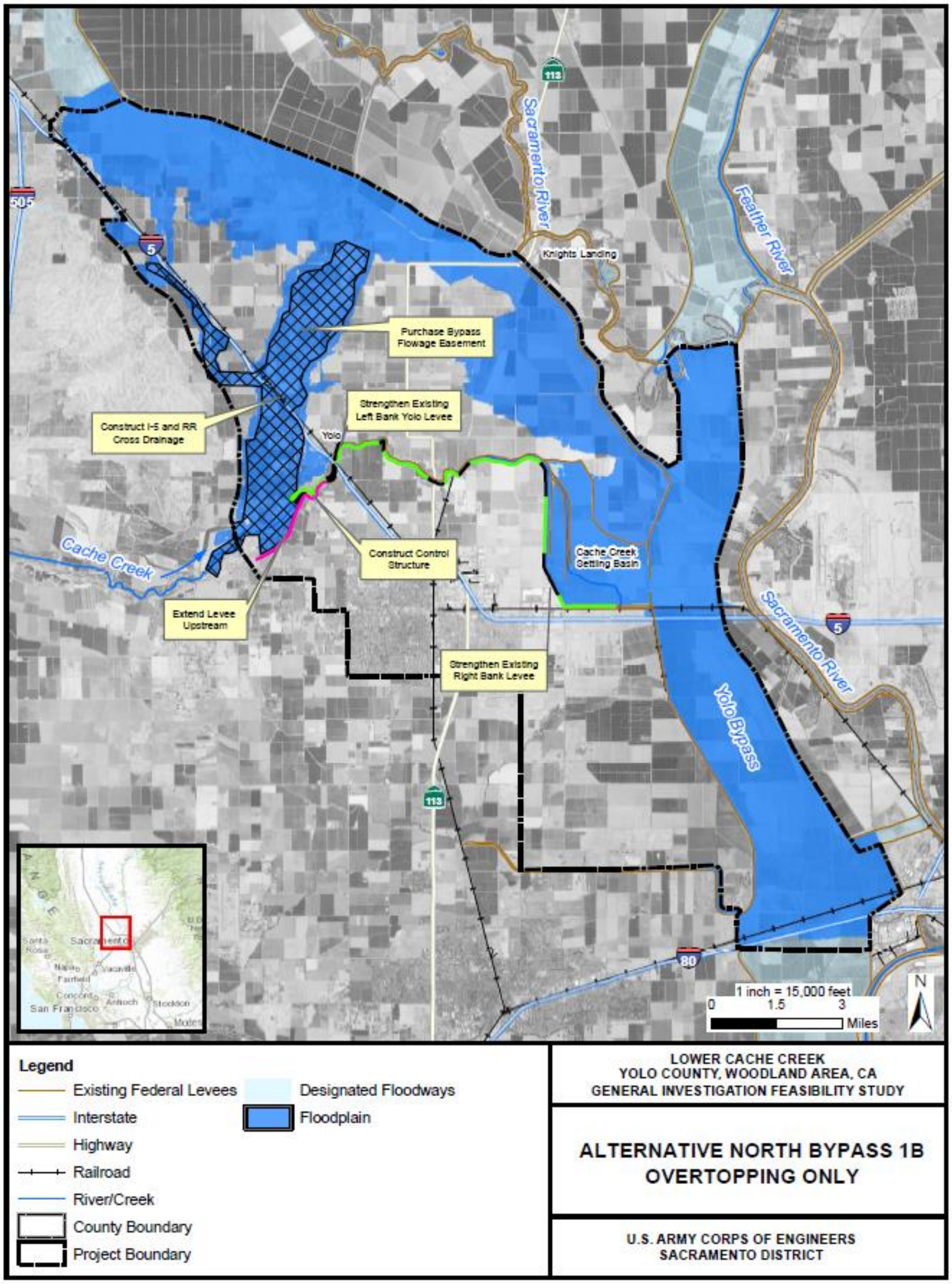


Figure 3-5. Alternative 1B: North Bypass B

3.4.3 Alternative 1C: North Bypass C

This alternative includes strengthening the right bank of the existing levees from downstream of I-5 to the CCSB, similar to the structural features in Alternatives 1A and 1B. However, it includes the construction of bypass levees to ensure the floodwaters are conveyed to the Colusa Basin Drain. This alternative would include seepage mitigation and rock bank protection along most of its length. A map of this alternative is shown in Figure 3-6.

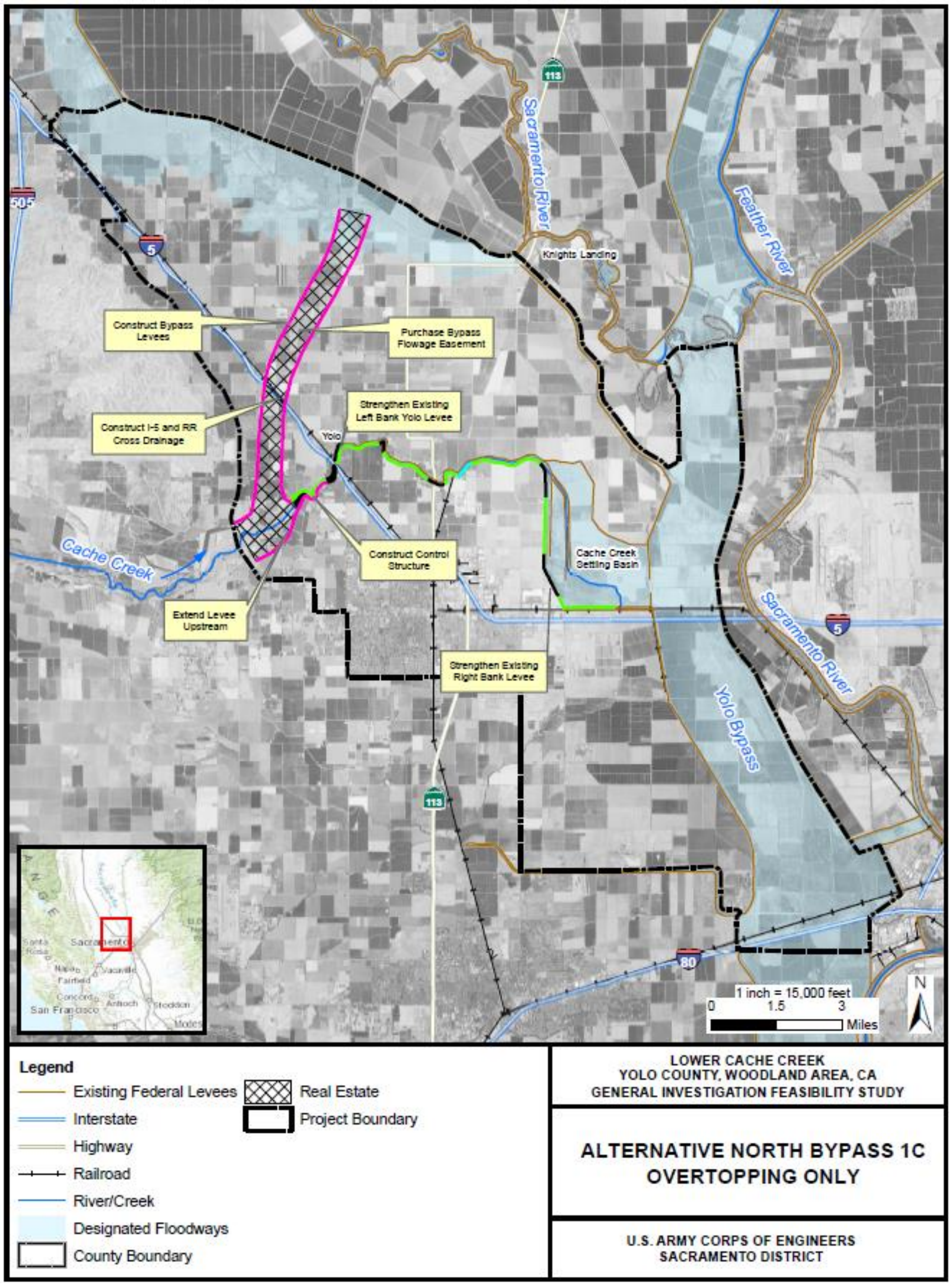


Figure 3-6. Alternative 1C: North Bypass C[1]

---

[1] Focused array alternatives that were screen out early on in the planning process due to cost analysis did not undergo a full hydraulic analysis. This alternative was expected to provide similar benefits as 1A and 1B, but was found to have higher costs, and therefore was eliminated. This map includes designated floodways, but not floodplains.

3.4.4 Alternative 1D: North Bypass D

This alternative is similar to Alternative 1A. However, it replaces the grade control structure and a right bank levee extension upstream of I-5 with a smaller extension of the right bank, a degrading of the left bank levee upstream of I-5, a new levee segment adjacent to I-5, and no strengthening of levees on the right bank of Cache Creek downstream of I-5. A map of this alternative is shown in Figure 3-7.

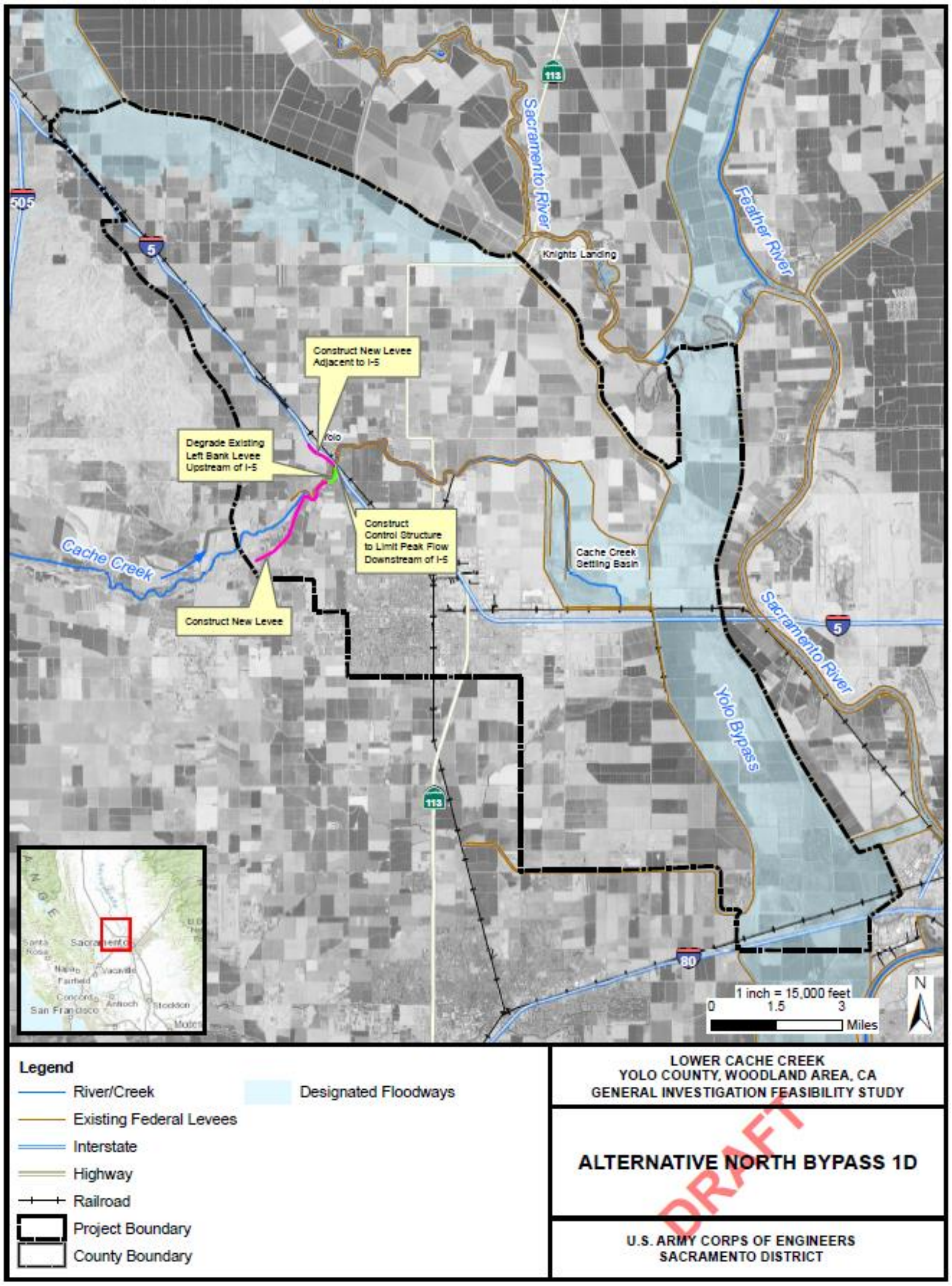


Figure 3-7. Alternative 1D: North Bypass D[2]

---

[2] Focused array alternatives that were screen out early on in the planning process due to cost analysis did not undergo a full hydraulic analysis. This alternative was expected to provide similar benefits as 1A and 1B, but was found to have higher costs, and therefore were eliminated. This map includes designated floodways, but not floodplains.

3.4.5 Alternative 2A: South Bypass A, or Levee and Conveyance Alternative

This alternative would consist of a levee that would direct floodwaters that would otherwise enter the urban area of the City of Woodland east towards the Cache Creek Settling basin. The floodwaters would then pass into the CCSB through a new inlet weir. The new inlet weir in the western levee of the CCSB would allow the floodwater to enter the CCSB while reducing the probability that Cache Creek floodwaters would escape the CCSB during smaller flood events. The inlet weir reduces stages west of the CCSB and is less costly than flowage easements that would have been required due to frequent flooding in the absence of the inlet weir. A portion of the floodwaters overtopping the south bank of Cache Creek would be conveyed by a channel created by the borrow area adjacent to the proposed levee. The channel would divert flows to the CCSB or to the City of Woodland pumping plant which would then discharge to the Yolo Bypass. The alternative also includes removal of a portion of a sediment training levee inside the CCSB so it does not obstruct the inlet weir. A map of this alternative is shown Figure 3-8.

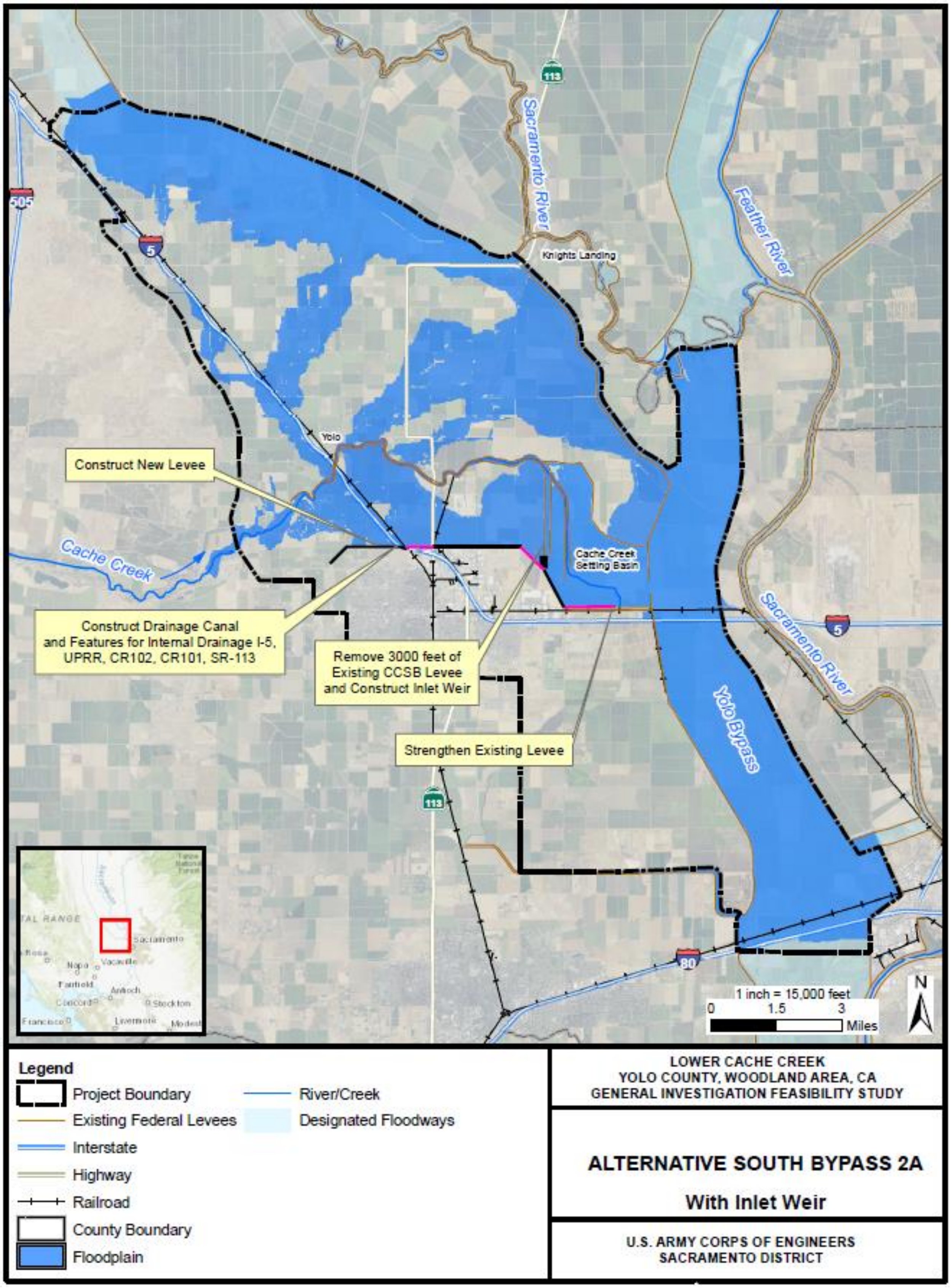


Figure 3-8. Alternative 2A: South Bypass A (Levee and Conveyance)

3.4.6 Alternative 2B: South Bypass B

This alternative would consist of a levee that would direct floodwaters that would otherwise enter the urban area of the City of Woodland east towards the Cache Creek Settling basin, similar to Alternative 2A. However, rather than constructing an inlet weir to convey the water into the CCSB, a channel would convey floodwaters to the south of the CCSB and into the Yolo Bypass. This channel would involve moving a portion of the CCSB west levee further to the east to avoid a large industrial complex. Based on additional qualitative analysis, including of real estate requirements in an industrial complex adjacent to the CCSB, this alternative was screened out of the focused array. Alternative 2C incorporates some of the proposed features of Alternative 2B. A map of this alternative is shown in Figure 3-9.

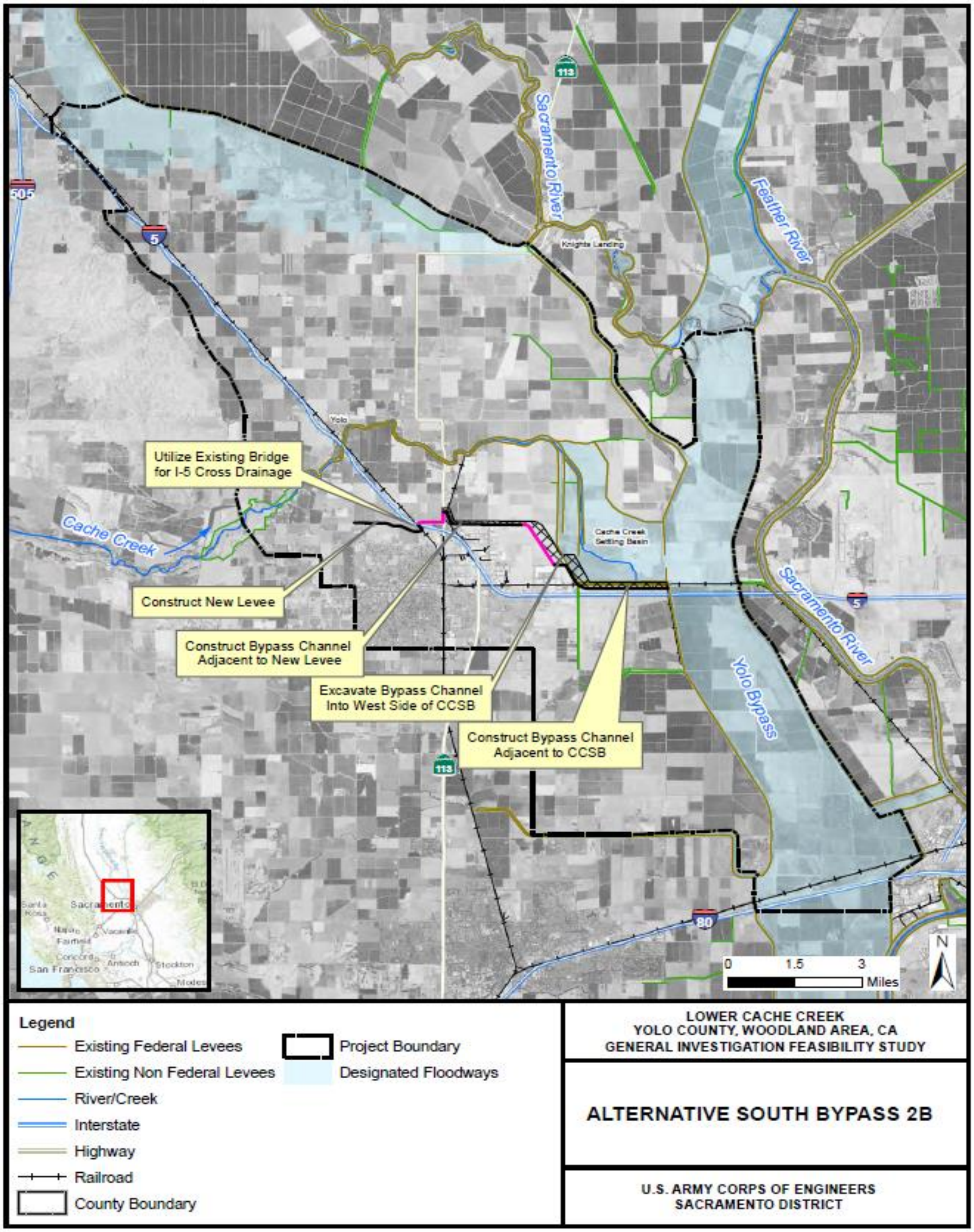


Figure 3-9. Alternative 2B: South Bypass B[3]

---

[3] Focused array alternatives that were screen out early on in the planning process due to cost analysis did not undergo a full hydraulic analysis. This alternative was expected to provide similar benefits as 2A, but was found to have higher costs, and therefore was eliminated. This figure includes designated floodways, but not floodplains.

3.4.7 Alternative 2C: South Bypass C

This alternative would consist of a levee that would direct floodwaters that would otherwise enter the urban area of the City of Woodland east towards the Cache Creek Settling basin, similar to Alternative 2A and 2B, but rather than constructing an inlet weir to accommodate excess flows to the west of the CCSB, a channel would convey floodwaters to the south of the CCSB and into the Yolo Bypass. The railroad line along the south side of the CCSB would also require extensive modifications to allow for the flood conveyance channel. A map of this alternative is in Figure 3-10.

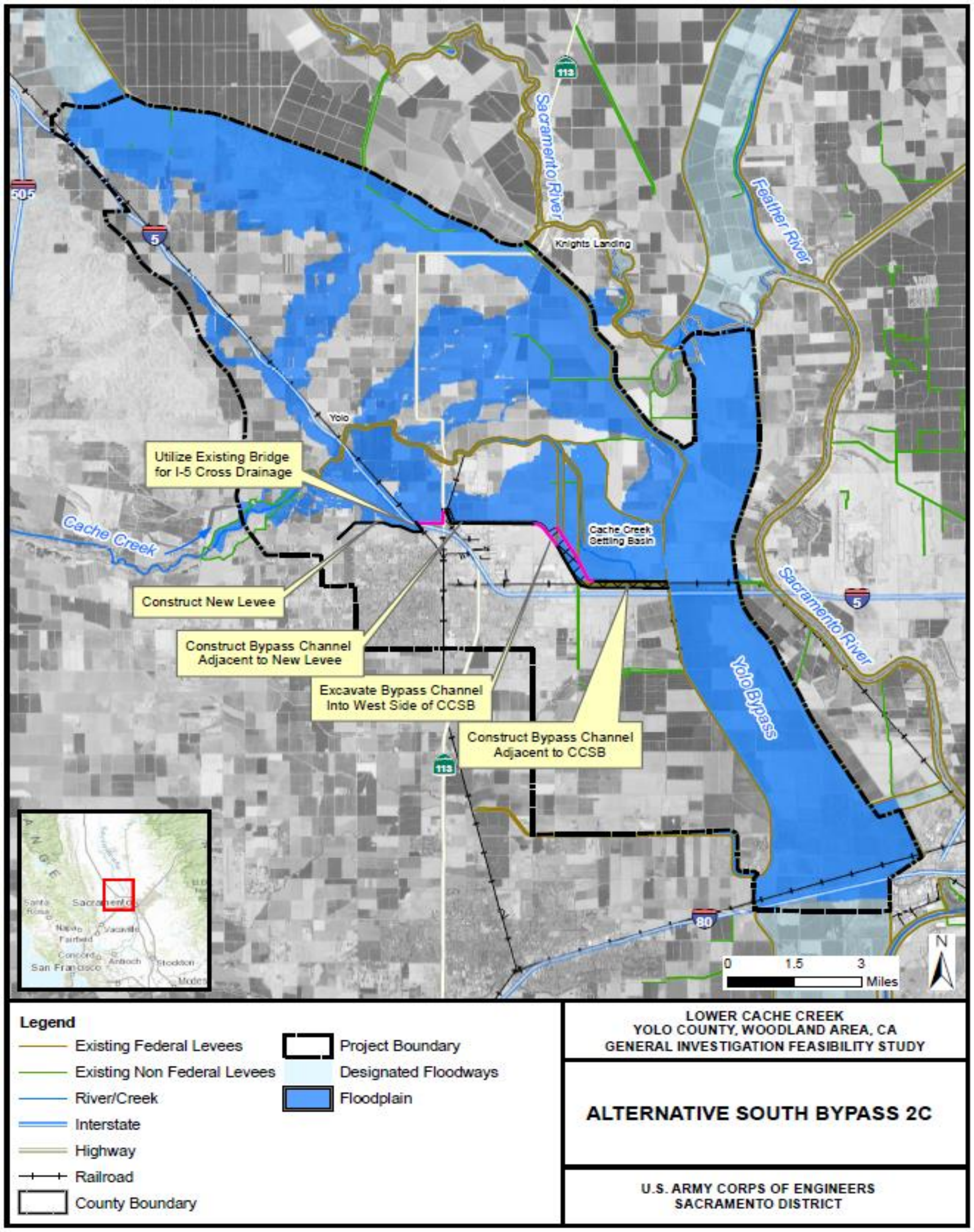


Figure 3-10. Alternative 2C: South Bypass 2

3.4.8 Alternative 2D: South Bypass D

This alternative would consist of a levee that would direct floodwaters that would otherwise enter the urban area of the City of Woodland east towards the CCSB, similar to Alternative 2C. However, it would also include strengthening the right bank levee of Cache Creek to reduce flooding north of the City of Woodland and strengthen the left bank levee of Cache Creek adjacent to the town of Yolo. This alternative includes seepage mitigation and rock bank protection along most of right bank of Cache Creek. A map of this alternative is shown in Figure 3-11.

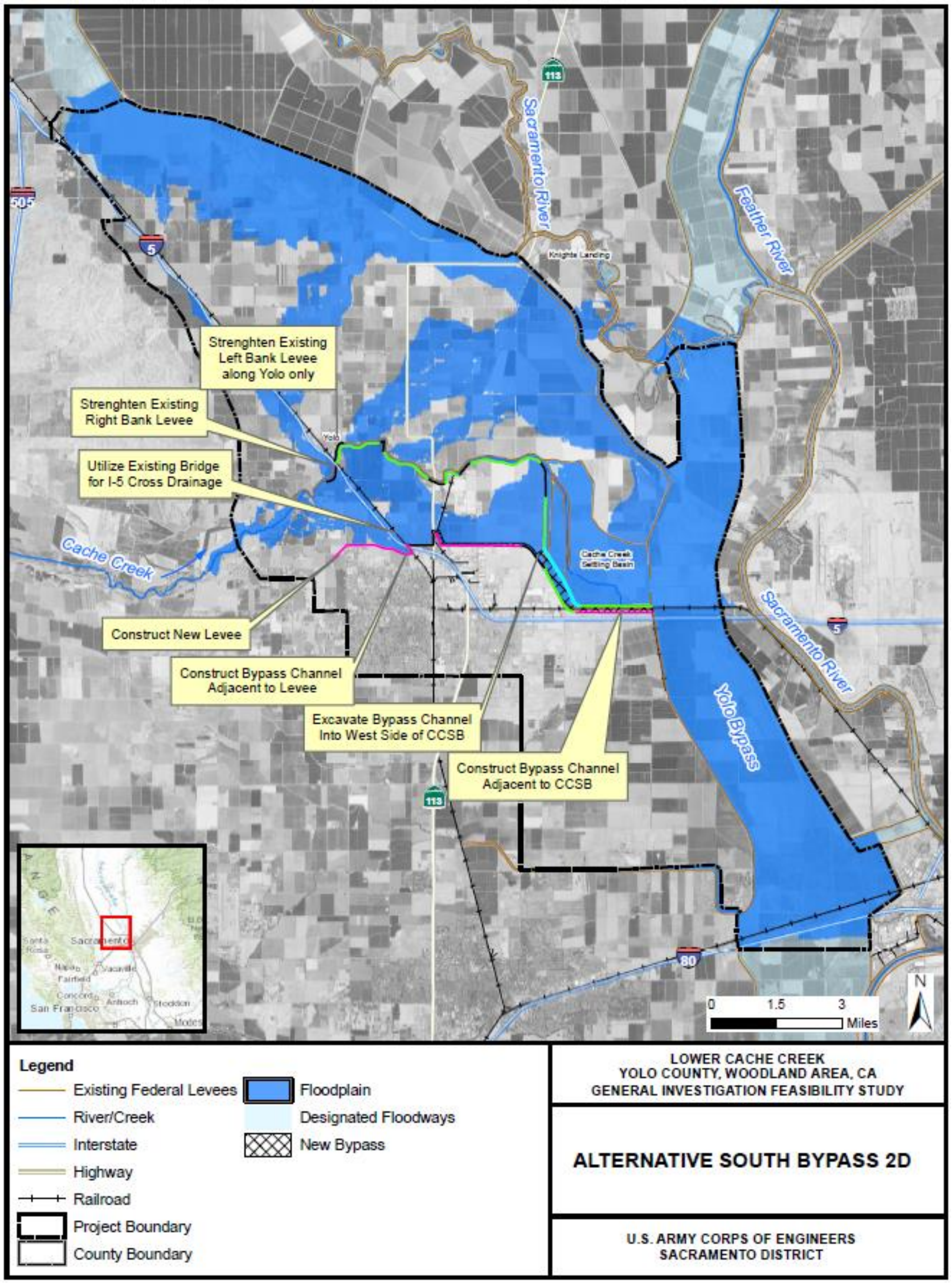


Figure 3-11. Alternative 2D: South Bypass D

3.4.9 Alternative 6A: Strengthen In Place A

This alternative would involve strengthening the right bank levee of Cache Creek. The alternative would also include strengthening the left bank levee of Cache Creek along the town of Yolo. This alternative reduces the risk of flooding associated with geotechnical related failures (e.g. through- and under-seepage). However, the hydraulic capacity (overtopping) related failure probability would remain the same. This alternative includes seepage mitigation and rock bank protection along most of its length. A map of this alternative is shown in Figure 3-12.

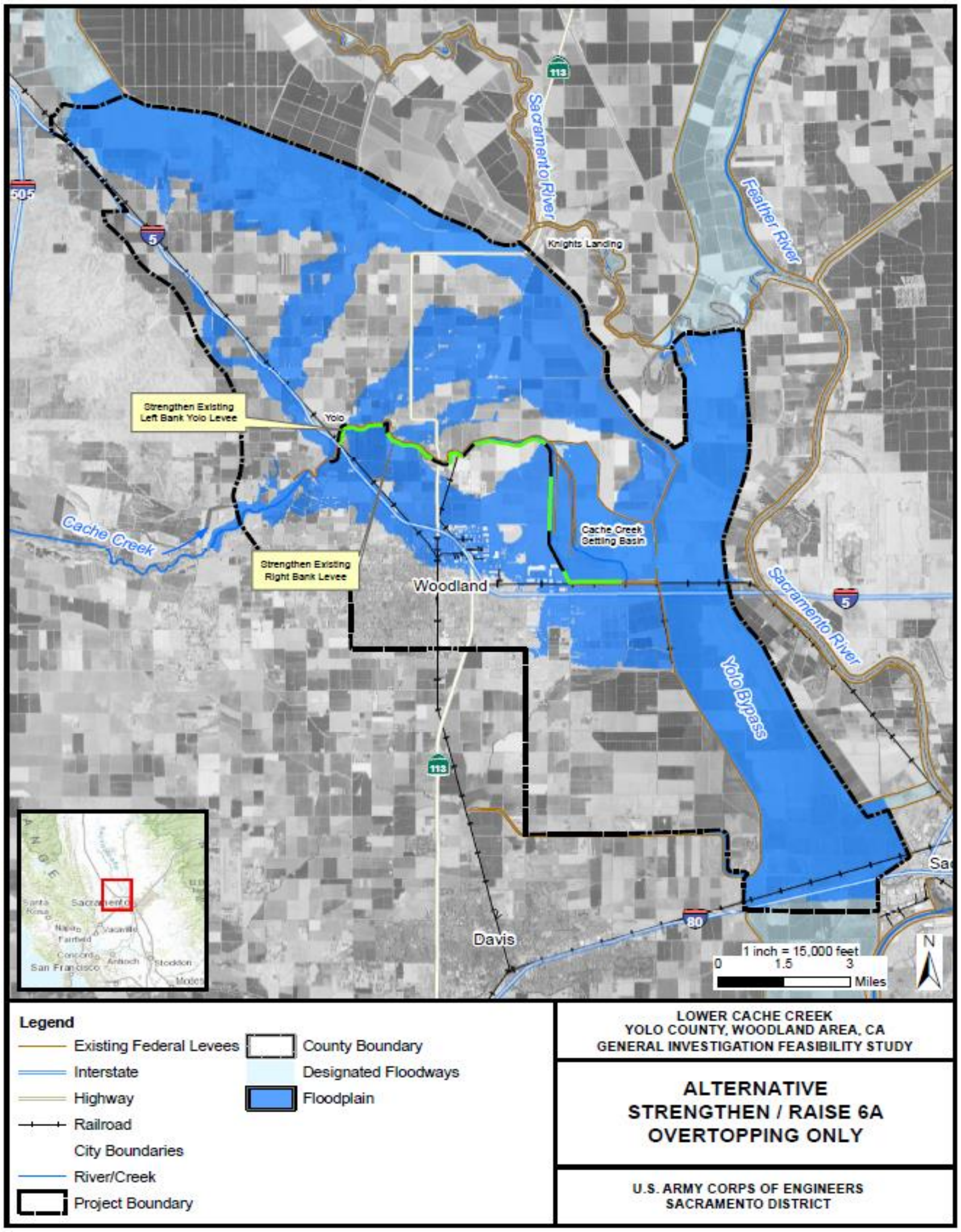


Figure 3-12. Alternative 6A: Strengthen/Raise in Place A

3.4.10 Alternative 6B: Strengthen/Raise In Place B

This alternative strengthens and increases the height of the right bank levee and the left bank levee near Yolo. Floodwaters would flow overland to the Colusa Basin Drain and Knights Landing Ridge Cut before draining into the Yolo Bypass. This alternative includes seepage mitigation and rock bank protection along most of its length. A map of this alternative is shown in Figure 3-13.

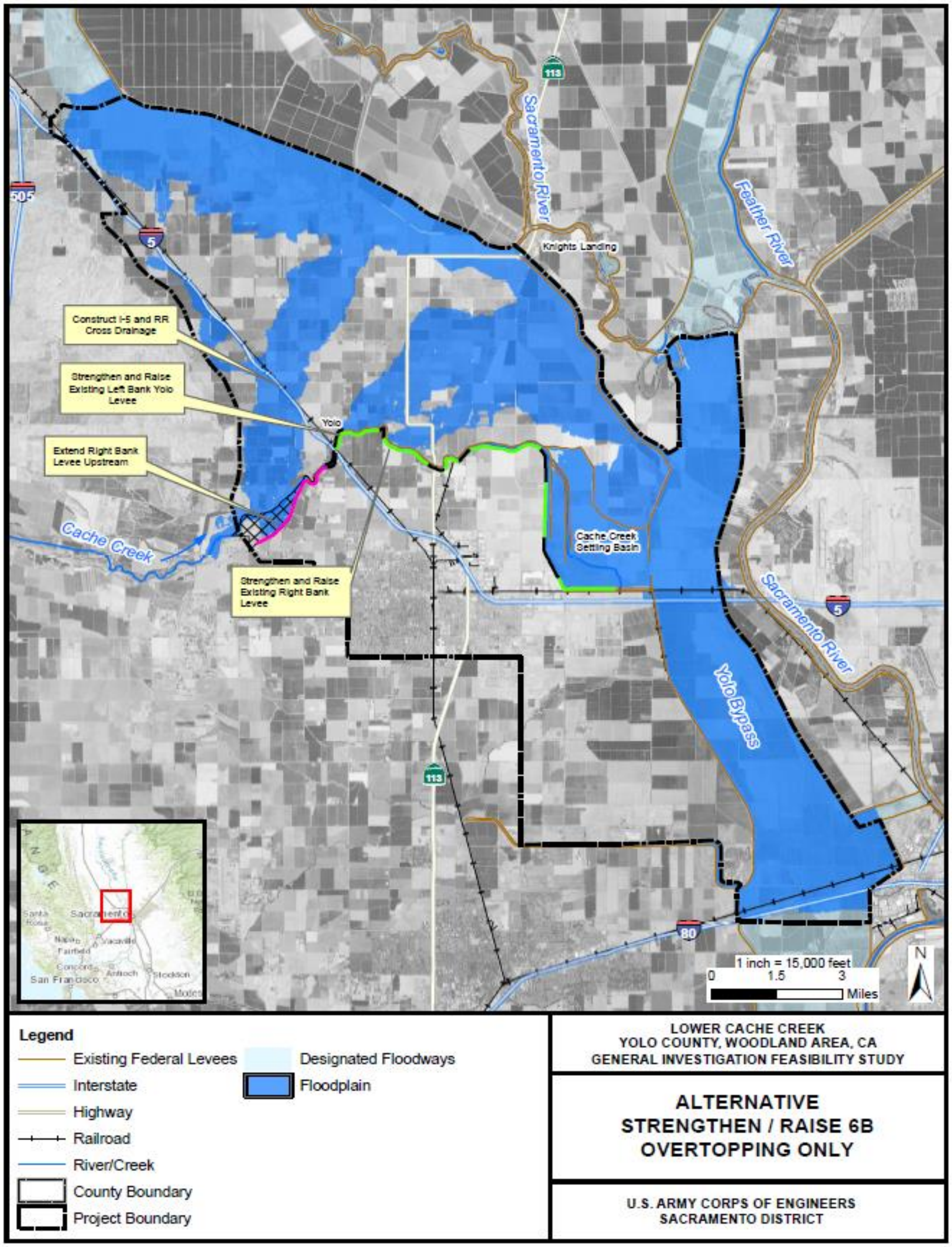


Figure 3-13. Alternative 6B: Strengthen/Raise in Place B

3.4.11 Alternative 6C: Strengthen/Raise In Place C

This alternative includes strengthening or increasing the height of existing left and right bank levees to contain flow in the existing levee alignment. The left bank levee upstream of I-5 would be removed and a new levee would be constructed adjacent to I-5, to force the floodwaters to the north where they would be conveyed across I-5 through a bank of culverts. This alternative would include seepage mitigation and rock bank protection along most of its length. A map of this alternative is shown in Figure 3-14.

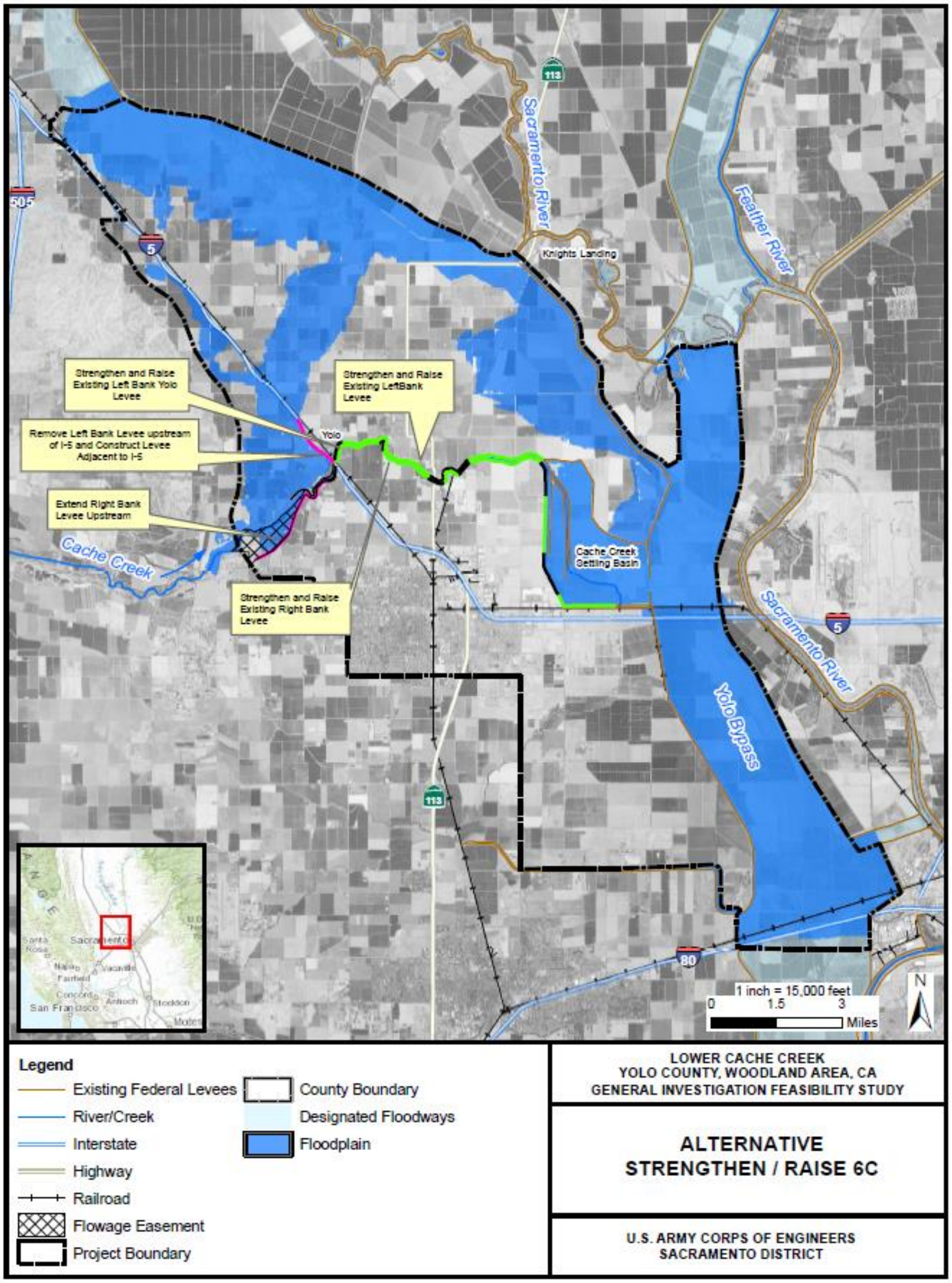


Figure 3-14. Alternative 6C: Strengthen/Raise in Place C

3.4.12 Alternative 7A: Partial Setback Levee A

This alternative would involve building levees set back from Cache Creek on the right bank to contain flow within an expanded levee system, reducing the probability of flooding in the City of Woodland. The channel dimensions for the setback levee configuration would be designed to maintain the same water surface profile as existing condition but with additional flow. The additional flow would be based on maintaining the same left bank overflow upstream of I-5 as the No Action Plan. At bridges, culverts would be included in the overbank area to eliminate constrictions. The alternative would modify the existing CCSB outlet weir into the Yolo Bypass to accommodate the increased flow. A map of this alternative is shown in Figure 3-15.

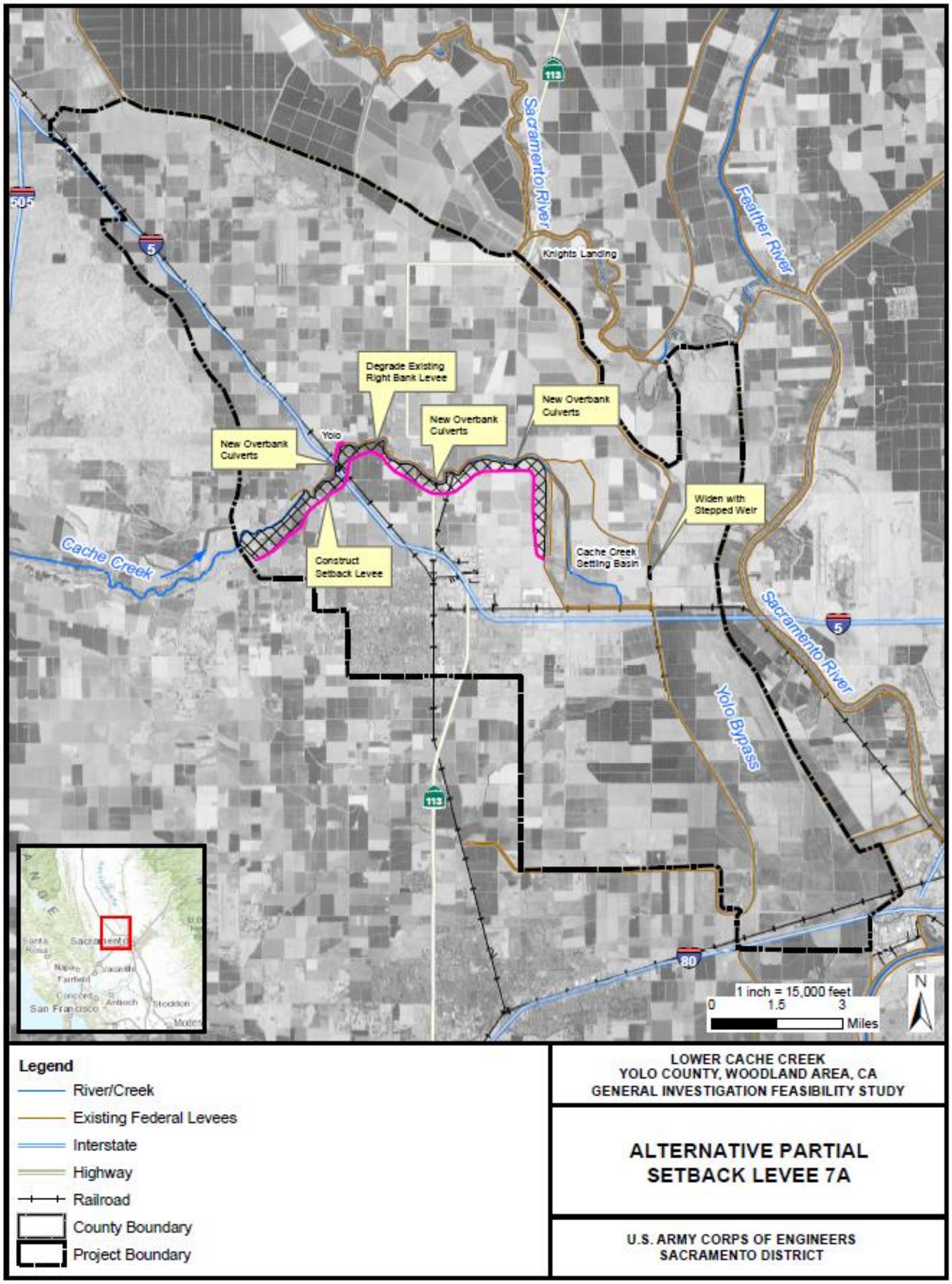


Figure 3-15. Alternative 7A: Partial Setback Levee A[4]

---

[4] Focused array alternatives that were screen out early on in the planning process due to cost analysis did not undergo a full hydraulic analysis. This alternative is expected to provide similar benefits as 7B, but was found to have higher costs, and therefore eliminated as described below.

3.4.13 Alternative 7B: Partial Setback Levee B

This alternative would involve building levees set back from Cache Creek on the right bank as well as culverts under I-5, UPRR and other utilities, similar to Alternative 7A. However, it also includes a bypass channel to the north of the CCSB. Measures include excavation of material to accommodate flow through the North Channel, flowage easements on inundated lands, and a new inlet weir north of the CCSB to allow flows to enter the Yolo Bypass. A map of this alternative is shown in Figure 3-16.

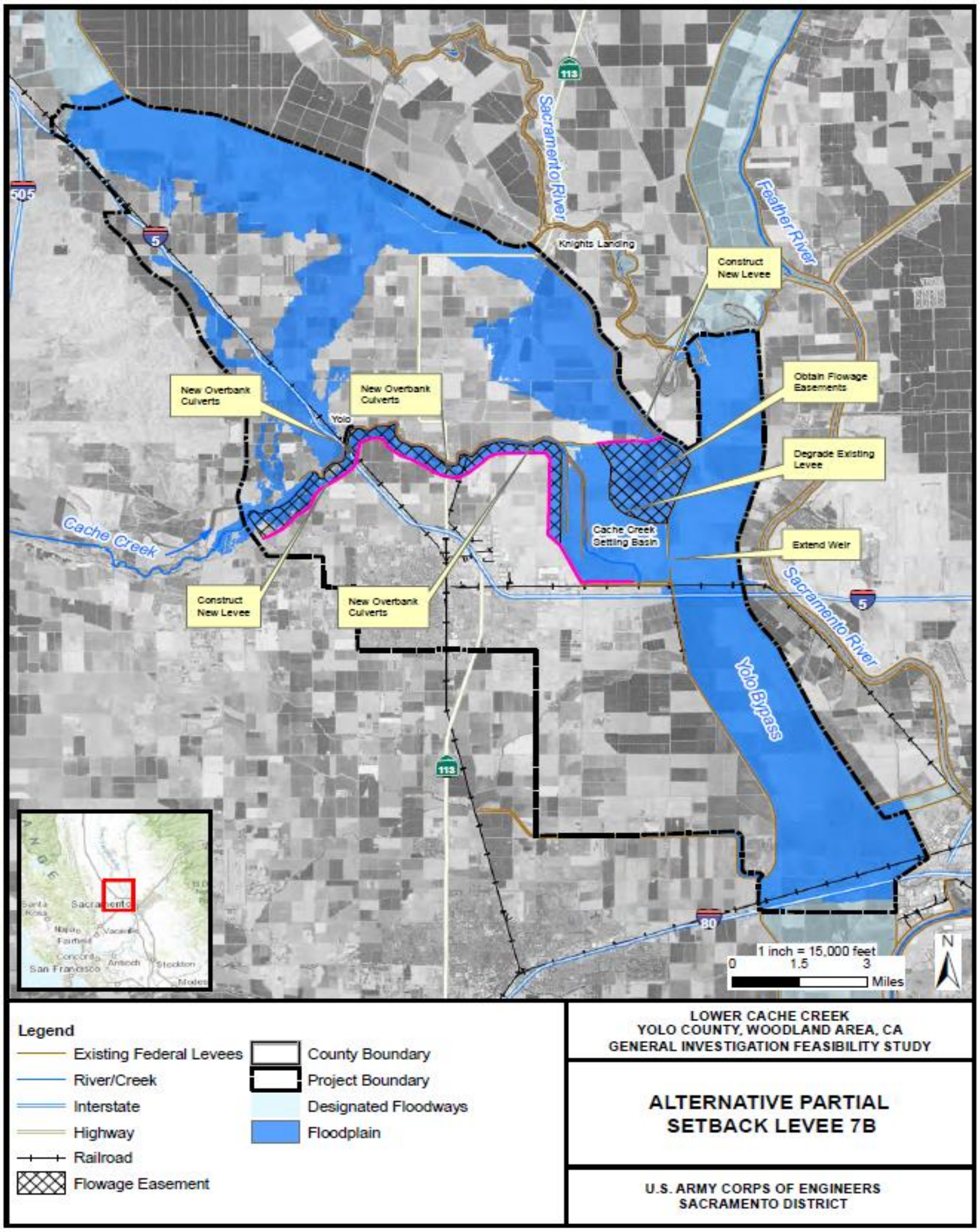


Figure 3-16. Alternative 7B: Partial Setback Levee B

Town of Yolo
The PDT considered several configurations of FRM measures to reduce flood risk in the town of Yolo. Alternatives 1A-D, 2D, and 6A-C incorporate various configurations of these measures. The one potentially feasible plan involves strengthening the existing Cache Creek levee adjacent to the town of Yolo and relies on the existing I-5 embankment to prevent overland flood flows from entering the town from the west. There is a high degree of uncertainty related to the performance of the existing embankment that could impact the feasibility of the Yolo approach. The envisioned strengthening of the levee adjacent to the town of Yolo would have no significant impact on depths against the I-5 embankment.

FRM measures for the town of Yolo would constitute a separable element: they are not hydraulically linked to FRM measures for the City of Woodland and one can be implemented independent of the other. The benefits and costs are independent of an intervention in Yolo and the TSP focused on the City of Woodland. The PDT will evaluate the potential plan in greater detail ~~following ADM~~ and consider other USACE authorities that could potentially support design and construction, including the Continuing Authorities Program (CAP). Additionally, Yolo County is preparing a feasibility study independent of this report that proposes FRM measures for the town of Yolo as described in Chapter 1 of this report. This effort will inform future USACE analysis.

3.5 Evaluation and Comparison of Alternatives

The following paragraphs and tables present the evaluation and comparison of alternatives and the analysis process to identify the NED plan.

The PDT evaluated each of the alternatives in the focused array based the following criteria: Flood Risk to Property, Flood Risk to Critical Infrastructure, Life Safety, Wise Use of Floodplains, Environmental Impacts, Climate Change, and Net Economic Benefits. While other factors such as RED OSE have been considered, they were not used in the evaluation of the Focused Array. The following paragraphs describe how each criterion applied to the screening process.

3.5.1 Life Safety

Life safety risk related to flooding was considered but not estimated for each alternative. Given the expected flood warning times, shallow flood depths in developed areas, and small population at risk, the life loss from flooding in this area is fairly small and is not expected to be significantly different between alternatives.

As the Lower Cache Creek study is a FRM study seeking to reduce flood risk along the Lower Cache Creek, the recommended alternative is a structural measure that can potentially induce two types of impacts that may affect life risk: 1) possible increased development that may lead to an increased population subjected to flood risk and 2) transform the current condition of a relatively slow and steady rise of flood risk to a potentially more severe and immediate flood risk associated with a failure of the new levee. It is the study team’s determination that the tentatively selected plan will lower the overall life-safety risk for the Lower Cache Creek Study Area as compared to the without project condition. Even though the consequences of with-project failure may be higher as compared to the without project condition, the probability of a with-project failure is very low. To ensure compliance with Planning Bulletin, PB 2019-04, life safety may be considered further in post Agency Decision Milestone (ADM) efforts.

3.5.2 Flood Risk to Property

Flood risk to property represents the risk within the study area after construction of an alternative. The risk to property is a consideration in the development for the residual Expected Annual Damages for the No Action and alternative conditions. Flood risk to property did not vary significantly across action alternatives (with the exception of Alternative 6A, which implies higher residual risk). The estimation of economic benefits below captures the value associated with flood risk to property.

3.5.3 Flood Risk to Critical Infrastructure

Critical infrastructure facilities are assets essential for the functioning of society and the economy. For each alternative, the risk to critical infrastructure was described by comparing the number of critical infrastructure facilities within an economic impact area to the expected AEP within the economic impact area. Critical infrastructure for the Lower Cache Creek study is divided into two categories: life safety and regional economic infrastructure. Most of the critical infrastructure assets are located in Economic Impact Area S8, and regional economic infrastructure is concentrated in Economic Impact Areas S8 and S9 (Figure 3-17.).

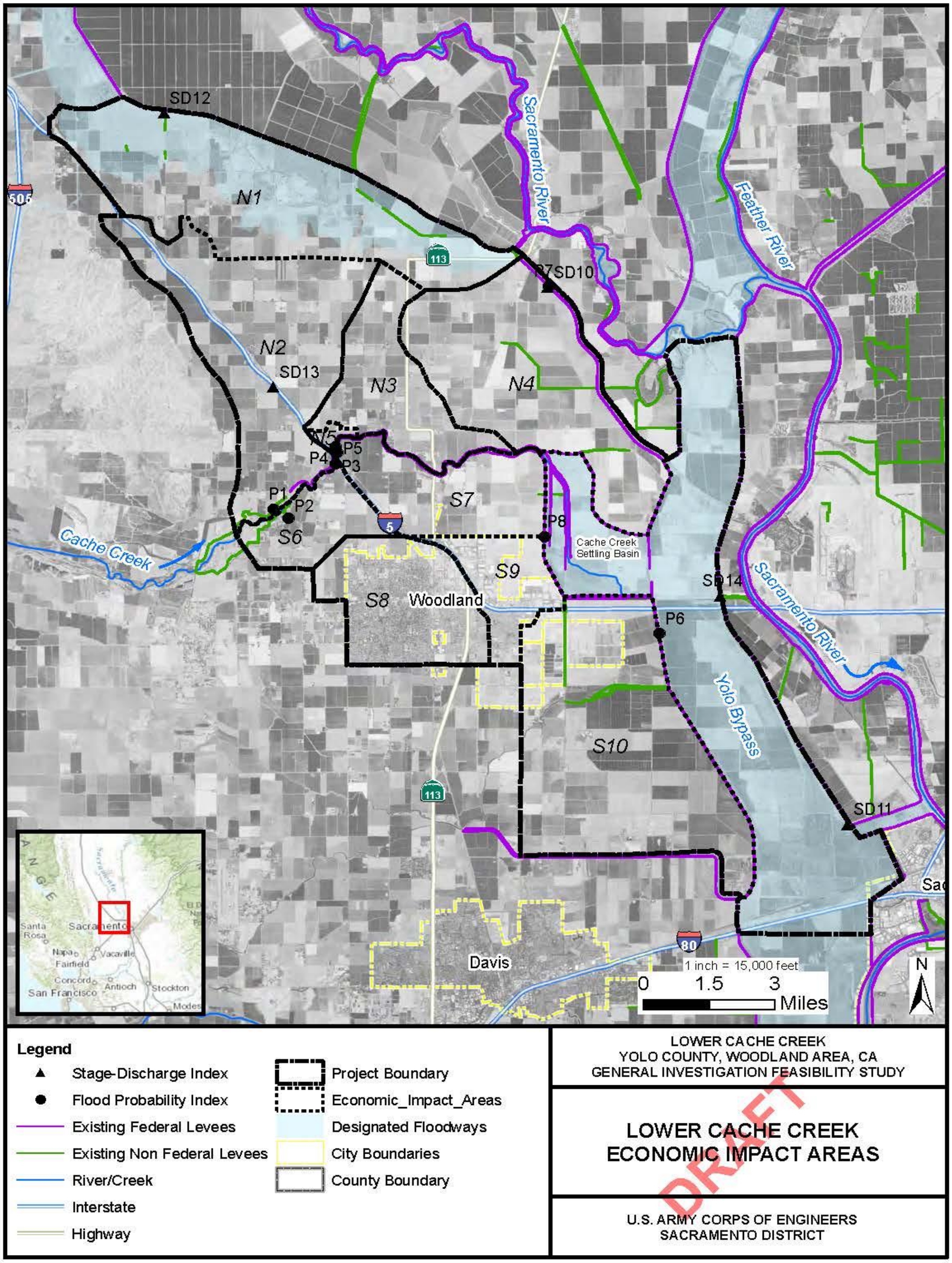


Figure 3-17. Economic Impact Areas Map

3.5.4 Wise Use of Floodplains and EO 11988 Analysis

Compliance with Executive Order 11988 and the wise use of floodplains were considered throughout the plan formulation process but not used as a screening criteria for the focused array. The objective of this Executive Order (EO) is the avoidance, to the extent possible, of long-and short-term adverse effects associated with the occupancy and modification of the base floodplain (1 in 100 annual event) and the avoidance of direct and indirect support of development in the base floodplain wherever there is a practicable alternative. Under the Order, USACE is required to provide leadership and take action to:

a) Avoid development in the base flood plain unless it is the only practicable alternative;
b) Reduce the hazard and risk associated with floods;
c) Minimize the impact of floods on human safety, health and welfare; and
d) Restore and preserve the natural and beneficial values of the base flood plain.

The developable (i.e. not yet built or zoned for residential or industrial use) acres of floodplain for each alternative were included in this evaluation. All alternatives in the focused array comply with the provisions of EO 11988. The criteria and associated eight-step process are described in more detail for the Tentatively Selected Plan (see Chapter 4).

3.5.5 Environmental Impacts

The estimated environmental mitigation costs developed for each alternative provide a comparison of the environmental impacts of each alternative. Higher environmental mitigation costs indicate greater environmental impacts.

3.5.6 Climate Change

Interpretations of observed and projected climate-altered hydrology indicate that future conditions will likely be warmer and possibly wetter in the Sacramento River Watershed of which Cache Creek is a major tributary. This means that the area could be subject to larger flood events because of the increase in moisture content of the storms impacting the region. Additionally, droughts could be more severe and longer lasting and this could increase frequency of large wildfires in the watershed thereby causing additional increases in runoff from burn scars. These factors are anticipated to impact all plans in the focused array to a similar degree, and thus do not impact plan selection. Additional information on climate change is available in Appendix A: Hydrology.

3.5.7 Net Economic Benefits

Net economic benefits were estimated for each alternative to describe the performance relative to the NED objective. The Lower Cache Creek Feasibility Study is a single purpose, FRM study. NED is the scale of a flood damage reduction alternative that reasonably maximizes expected net benefits (expected benefits less expected costs). The net benefits are computed as the annualized flood damage reduction benefits gained minus the annualized cost of construction and Operations Maintenance Repair Rehabilitation and Replacement (OMRR&R). Expected Annual Damages were estimated using the HEC-FDA computer program. Net Benefit computations were evaluated based on October 2019 price levels. The annualized cost was derived using a 50-year period of analysis at a rate of 2.875%.

Table 3-4 provides a summary of the costs, benefits, net benefits (benefits minus costs), and benefit to cost ratios (BCRs) for comparison of alternatives. The preliminary annual net benefits range from -$44.8 million (that is, costs exceed benefits -$44.8 million on an annual basis) to $9.6 million (that is, benefits exceed costs by $9.6 million on an annual basis). Based on this comparison, Alternative 2A is shown to be the alternative which maximizes net benefits and is therefore carried forward for further analysis. It is highlighted in green in the table below along with the No Action Plan.

Table 3-4. Benefit-Cost Summary (monetary units in October 2019 $1,000s)

Alternative	Annual Benefits	Estimated Project First Costs	Annual Costs	Net Benefits	BCR	Carried Forward?	Notes
No Action							
No Action	$ -	$ -	$ -	$ -	-	Yes	Damages continue to accrue, no benefits area realized.
Alternative 1: North Bypass Sub-Alternatives							
1A	$19,511	$560,892	$21,285	-$1,774	0.9	No	All increments of the North Bypass were eliminated from further consideration, as the other alternatives reduce risk for a similar amount of property—and thus yield similar benefits—though at a substantially lower cost. All increments imply significant construction costs, and Alternatives 1B and 1C add significant flowage easements.
1B	$19,511	$727,497	$27,607	-$8,096	0.7	No	
1C	$19,638	$751,006	$28,499	-$8,861	0.7	No	
1D	Same as 1A	Greater than 1A	Greater than 1A	Less than 1A	Less than 1A	No	Alt 1D was added as a result of the Value Engineering study. It would entail similar construction costs to Alternative 1A, though would require additional flowage easements at a higher total cost. Given the higher cost, detailed costs and benefits were not estimated.
Alternative 2: South Bypass Sub-Alternatives							
2A	$17,848	$216,625	$8,221	$9,627	2.2	Yes	This alternative reduces risk for a similar value of damageable property as the North Bypass, Strengthen in Place, or Setback Levee Alternatives, but does so with fewer miles of levee and/or a

Alternative	Annual Benefits	Estimated Project First Costs	Annual Costs	Net Benefits	BCR	Carried Forward?	Notes
							reduction in environmental mitigation. It provides a similar level of benefits to other alternatives, but at a lower cost.
2B	Lower than 2C	Similar to 2C	Similar to 2C	Less than 2C	Less than 2C	No	This alternative includes the construction of a bypass to the south of the CCSB. It would entail significant real estate costs and lower benefits (several structures in the highest damage area would be acquired to make way for civil works and thus no benefits would be generated by protected them). Given the high costs and lower benefits, detailed costs and benefits were not estimated. Some measures incorporated into 2C.
2C	$17,848	$550,129	$20,876	-$3,028	0.9	No	Not economically justified. Benefits very similar to the benefits of Alternative 2A, but at a higher cost.
2D	$19,031	$745,910	$28,306	-$9,275	0.7	No	Right bank strengthening in place of existing levee not economically justified (costs exceed benefits).
Alternative 6: Strengthen In Place Sub-Alternatives							
6A	$5,108	$226,171	$8,583	-$3,475	0.6	No	Does not address overtopping and thus generates lower benefits than all other action alternatives.
6B	$19,511	$355,428	$13,488	$6,023	1.4	No	Includes significant environmental mitigation costs. Delivers slightly higher benefits than Alternative 2A but at nearly double the cost (net

Alternative	Annual Benefits	Estimated Project First Costs	Annual Costs	Net Benefits	BCR	Carried Forward?	Notes
							benefits less than ~~approximately half~~ of 2A).
6C	$19,608	$1,694,650	$64,309	-$44,700	0.3	No	Plan would deliver the highest new benefits of those considered, but carried the highest cost. Includes significant environmental mitigation costs. Left bank raise not economically justified. Net benefits are negative (i.e., annualized costs exceed net benefits).
Alternative 7: Setback Levee Sub-Alternatives							
7A	$19,511	$1,694,650	$64,309	-$44,798	0.3	No	Includes significant costs for TMDL mitigation associated with CCSB and flowage easements between setback levees and Cache Creek. Generates similar benefits to Alternative 2A at markedly higher cost.
7B	$19,511	$521,579	$19,793	-$282	1.0	No	Includes costs for TMDL mitigation associated with CCSB and extensive flowage easements between setback levees and Cache Creek, and northeast of CCSB. Generates similar benefits to Alternative 2A at higher cost.

[1] Benefits and Costs shown in table are preliminary estimates from early iteration of the planning process. Information provided is used for alternatives comparison purposes only. Relevant information on updated costs and benefits for plans carried forward are shown in the Executive Summary and subsequent chapters.

Table 3-4 shows that most action alternatives, except Alternative 6A, would deliver a similar level of benefits—that is, each alternative is expected to reduce flood damages to a comparable total value of damageable property. Alternative 6A is expected to deliver significantly lower benefits. However, the costs varied significantly across alternatives.

Given that most plans deliver a similar level of benefits, cost became the primary driver in identifying the NED plan. Many plans were screened out as they provided a similar level of benefits but at a higher cost.

Alternative 2A has the highest net benefits of the alternatives in the focused array, with approximately $9.6 million in annual net benefits and a BCR of 2.2. The PDT conducted an analysis of several smaller, lower cost increments of Alternative 2A, as described in detail in the Appendix F: Economics. This exercise indicated that smaller increments of Alternative 2A yield lower net benefits than the full Alternative 2A. Alternative 2A thus maximizes net benefits.

3.6 The Tentatively Selected Plan

The Tentatively Selected Plan is Alternative 2A. It consists of constructing a new levee that would prevent floodwaters from Lower Cache Creek from entering the built-up areas of the City of Woodland as well as improving existing CCSB levees. This plan would reduce the flood flows that drive the risk of economic damages, as well as decrease the flooding of roadways that creates a hazard for motorists, cuts residents off from essential services, and ultimately generates a risk to human life and safety.

It is unclear at this point in the planning process if Alternative 2A will meet the NFS objective of SB 5 compliance. However, the NFS elected not to pursue a Locally Preferred Plan (LPP) and will continue to work with the USACE and CVFPB if additional local actions are required to meet SB 5 once the project is better defined during PED phase.

Chapter 4 – Tentatively Selected Plan

This chapter describes the TSP as well as procedures and cost sharing required for implementation of the plan if it becomes the plan recommended to, and authorized by, Congress. A schedule and a list of further studies are also included.

4.1 Tentatively Selected Plan

The TSP is Alternative 2A (Figure 4-1). The features of the plan as described below were further refined from the cost and benefit estimation used in the focused array (described in Chapter 3 of this report). It is economically justified, has a benefit to cost ratio of 2.1, and provides annual flood damage reduction benefits of $20,657,000, as shown in Table 4-1. Estimated Annual Costs and Benefits for the Tentatively Selected Plan Table 4-1. There is a residual risk of flooding north of the City of Woodland that the TSP would not reduce.

Table 4-1. Estimated Annual Costs and Benefits for the Tentatively Selected Plan

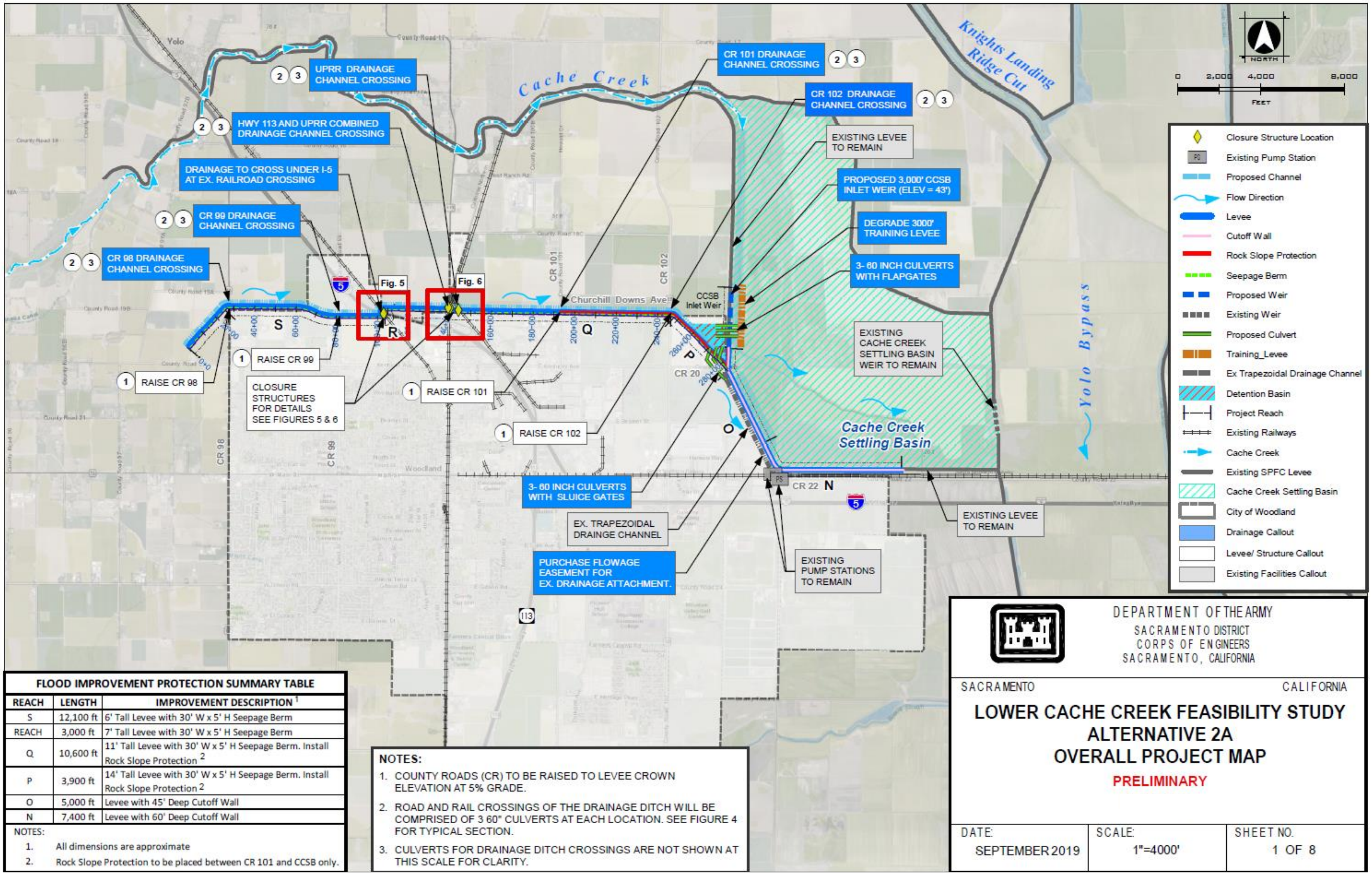
Item	Cost ($1000's)[1]
Investment Costs:	
First Cost[2]	258,861
Interest During Construction	7,151
Total Project Investment Cost	266,012
Annual Costs:	
Annualized First Cost	9,853
Annual OMRR&R	180
Total Average Annual Cost	10,033
Average Annual Benefits	20,657
Net Benefits	10,623
Benefit to Cost Ratio	2.1

[1] Costs are October 2019 price levels at 2.75%, for a 50-year period of analysis.
[2] Does not include cultural resources data recovery.

The TSP is described in detail below, including the specific cost share requirements associated with approved policy. For additional information, refer to the appendices and supporting documentation.

4.2 Features and Accomplishments

Alternative 2A consists, overall, of improving existing levees and constructing a new levee north of the City of Woodland in order to prevent floodwaters emanating from Lower Cache Creek from reaching the built up portion of the City of Woodland. Proposed project features include levee embankment, seepage berms, drainage channel; cutoff walls; weir, and closure structures across roads and railways. Figure 4-1 shows the proposed project features. Possible design refinements could incorporate sponsor-built recreational features that are compatible with the FRM facilities.



FLOOD IMPROVEMENT PROTECTION SUMMARY TABLE

REACH	LENGTH	IMPROVEMENT DESCRIPTION [1]
S	12,100 ft	6' Tall Levee with 30' W x 5' H Seepage Berm
REACH	3,000 ft	7' Tall Levee with 30' W x 5' H Seepage Berm
Q	10,600 ft	11' Tall Levee with 30' W x 5' H Seepage Berm. Install Rock Slope Protection [2]
P	3,900 ft	14' Tall Levee with 30' W x 5' H Seepage Berm. Install Rock Slope Protection [2]
O	5,000 ft	Levee with 45' Deep Cutoff Wall
N	7,400 ft	Levee with 60' Deep Cutoff Wall

NOTES:
1. All dimensions are approximate
2. Rock Slope Protection to be placed between CR 101 and CCSB only.

NOTES:
1. COUNTY ROADS (CR) TO BE RAISED TO LEVEE CROWN ELEVATION AT 5% GRADE.
2. ROAD AND RAIL CROSSINGS OF THE DRAINAGE DITCH WILL BE COMPRISED OF 3 60" CULVERTS AT EACH LOCATION. SEE FIGURE 4 FOR TYPICAL SECTION.
3. CULVERTS FOR DRAINAGE DITCH CROSSINGS ARE NOT SHOWN AT THIS SCALE FOR CLARITY.

DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

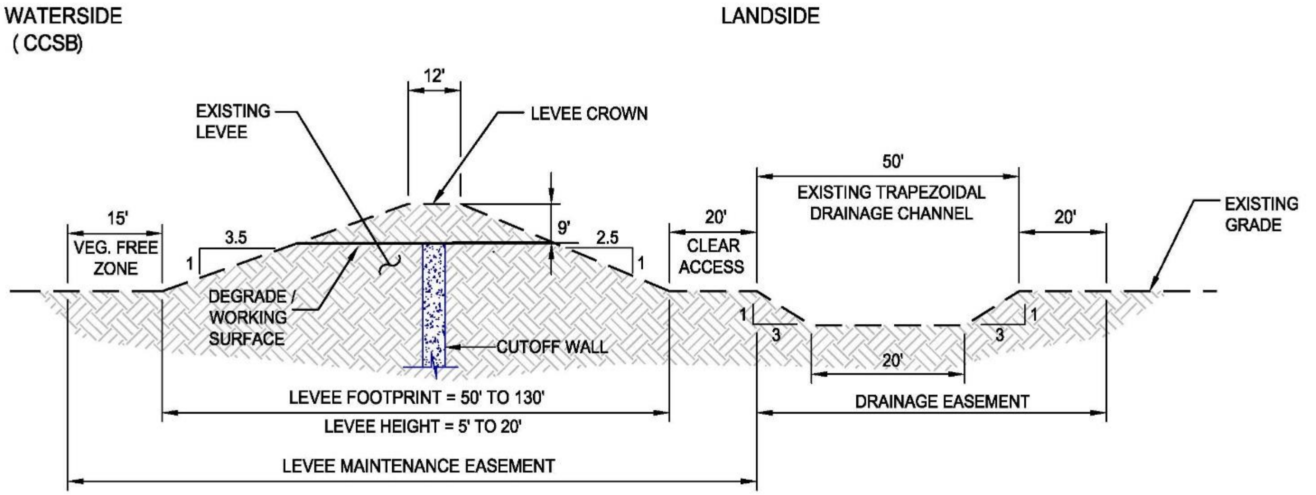
SACRAMENTO CALIFORNIA

LOWER CACHE CREEK FEASIBILITY STUDY
ALTERNATIVE 2A
OVERALL PROJECT MAP
PRELIMINARY

DATE:	SCALE:	SHEET NO.
SEPTEMBER 2019	1"=4000'	1 OF 8

Figure 4-1. Tentatively Selected Plan and Design Features

Alternative 2A would rehabilitate a portion of the southern levee (Reach N) of the CCSB by constructing a 60-foot-deep cutoff wall through the levee (Figure 4-2) and the southwest levee (Reach O) of the CCSB by constructing a 45-foot-deep cutoff wall. Along with this cutoff wall installation, a 3,000-foot-long section of the west levee of the settling basin would be degraded to an elevation of 43 feet to accommodate a reinforced cement concrete (RCC) weir with a height of approximately nine feet above existing adjacent grade (Figure 4-3). The weir would serve to accept floodwater emanating from Cache Creek west of the CCSB and would prevent backflow from the CCSB to the west during smaller, more frequent flood events. Additionally, the southernmost 3,000-foot portion of the CCSB training levee would be degraded in order to improve the distribution of sediment within the basin. The existing outlet weir on the east side of the CCSB would remain unchanged. Please note that all elevations are given in the North American Vertical Datum of 1988 (NAVD 88).



DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

SACRAMENTO CALIFORNIA

LOWER CACHE CREEK FEASIBILITY STUDY
ALTERNATIVE 2A
TYPICAL CUTOFF WALL SECTION (REACH N & O)
PRELIMINARY

DATE:	SCALE:	SHEET NO.
AUGUST 2019	NOT TO SCALE	2 OF 8

Figure 4-2. Typical Cutoff Wall Section (Reaches N & O)

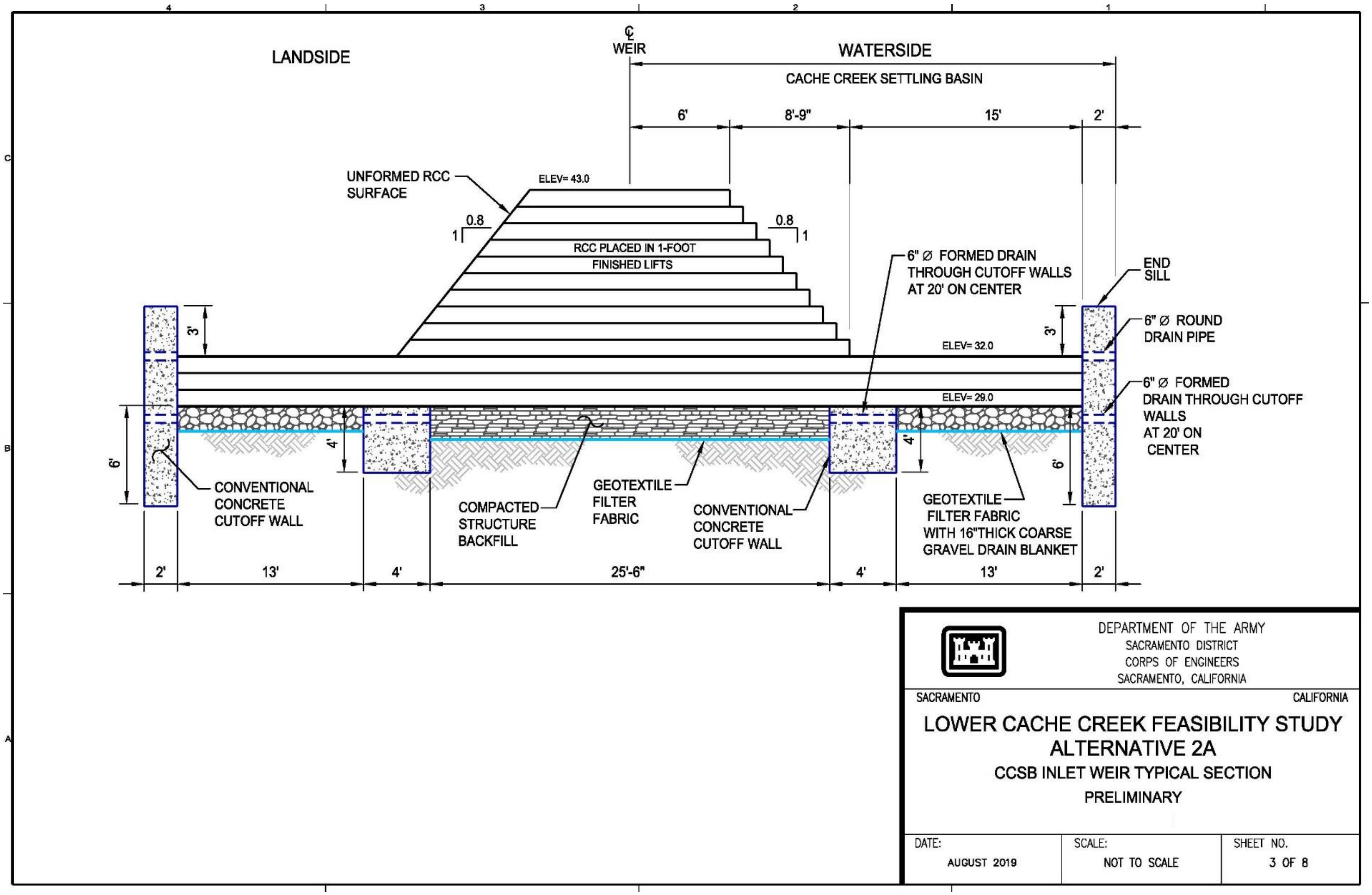


Figure 4-3. CCSB Inlet Weir Typical Section

New Levees and Other Proposed Project Features
A new levee with a 20-foot-wide crest and a 30-foot-wide landside seepage berm would begin near the intersection of County Road 20 and County Road 98 and extend east to the CCSB (Figure 4-4). The alignment of the levee would generally follow the northern city limit line west of State Route 113 (SR 113) and Churchill Downs Avenue east of SR 113. The height of the new levee would vary from six feet near County Road 98 to 14 feet at its intersection with the existing west levee of the CCSB. Rock slope protection is proposed on the waterside slope of the new levee from County Road 101 east to the southern end of the proposed inlet weir near County Road 20.

A trapezoidal drainage channel with a design capacity of approximately 350 cfs would be constructed north (waterward) of the new levee in Reaches P through S in order to capture smaller, more frequent events and discharge them to the CCSB, and also to provide the necessary fill material for the project. This drainage channel may vary in width during subsequent design phases in order to balance earthwork for the project.

A total of four closure structures (gates that are assembled by O&M personnel prior to the flood) would be constructed where the embankment crosses the UPRR tracks near I-5, the UPRR tracks west of SR 113, SR 113, and the UPRR tracks east of SR 113. Due to the limited distance between the closure structures, short sections of floodwall would be constructed to connect the closure structure at the I-5 crossing to the existing roadway embankment and to connect the closure structures at the SR 113 crossing and the adjacent UPRR crossing to the west.

Internal Drainage
Water impounded by the proposed levee and the west levee of the CCSB would be drained via proposed culverts into the CCSB and to the City’s interior drainage system. A detention basin would be located at the downstream end of the proposed drainage channel along Reach P. The detention basin would include an east outlet and a south outlet. The east outlet would provide for gravity drainage into the CCSB and consist of three 60-inch diameter culverts fitted with flap gates. This would allow gravity flow from the detention basin into the CCSB after stages subside below the weir elevation, with reverse flow from the CCSB into the detention basin being prevented by the flap gates. The south outlet would consist of a set of three 60-inch diameter culverts fitted with sluice gates. The culverts would discharge to an existing ditch that terminates at a pump station owned and operated by the City. The sluice gates would control the discharge flow to the pump station until capacity was available to discharge the flows to the Yolo Bypass. The design and operation of these systems has not been fully developed yet and will be optimized during later phases of the project.

Roadway Improvements
The new levee would require the raising of County Road 98, County Road 99, County Road 101, and County Road 102. Culverts would be installed at each of these raised crossings as well as under SR 113 and the two UPRR crossings along the alignment. An existing railroad underpass at I-5 would be used to convey flood waters under the interstate. In order to prevent erosion due to high velocities in this area, those portions of the area found to have velocities of over five feet per second (fps) would be lined with concrete. This protection would be installed across the entire project footprint area where flood flows velocities exceed the five fps limit. This area includes the existing slopes of the I-5 roadway embankment, the slopes of the proposed Reach R and Reach S levees, the proposed channel (both bottom and slope), and the existing UPRR railway.

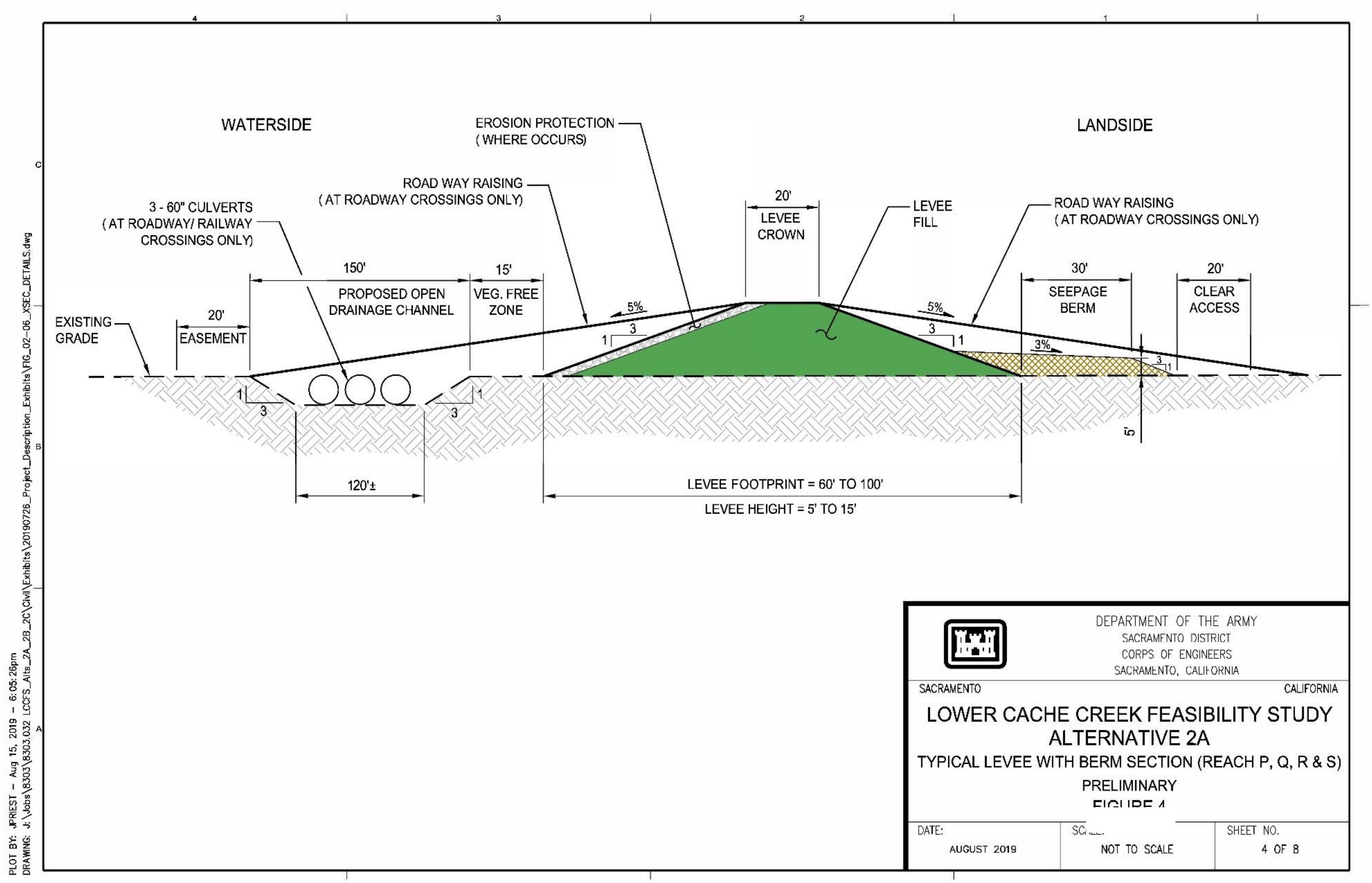


Figure 4-4. Typical Levee with Berm Section (Reach P, Q, R & S)

Summary
Table 4-2 summarizes the features and improvements discussed previously.

Table 4-2. Project Feature Summary

Feature	Improvement Description	Applicable Reaches	Quantity
New Levee	New Levee with Seepage Berm	Q (Partial), R, S	3.9 Miles
New Levee with RSP	New Levee with Seepage Berm and Rock Slope Protection	P, Q (Partial)	1.7 Miles
Improve Existing Levee	Improve existing levee with cutoff wall	N, O	2.3 Miles
Drainage Channel	New drainage channel and culverts. Also serves as borrow source for levee fill.	P, Q, R, S	5.6 Miles
Elevated Roadways	Elevate Roadway over levee at CR98, CR99, CR101, and CR102	P, Q, R, S	4
Gated Roadway Closure Structure	Gate at SR 113	Q, R	1
Gated Railroad Closure Structures	Gate for Railroad at I-5, West of SR 113, East of SR 113	Q, R, S	3
Cache Creek Settling Basin Inlet Weir	Concrete Inlet Weir	CCSB Inlet Weir	3,000 Feet
Degrade Training Levee	Degrade 3,000 feet of Existing Cache Creek Settling Basin Training Levee	Training Levee	3,000 Feet
Detention Basin and Outlets	New Detention Basin and Outlets	P	1
Improve Existing Drainage Ditch	Utilize Existing drainage ditch from Detention Basin to City of Woodland Pump Station.	O	1 Mile

Performance
The plan significantly reduces flood risk to people and property in the City of Woodland and surrounding areas. With the TSP in place, economic impact areas (EIAs) S8 and S9 in northeast Woodland, where damages are concentrated, would see a reduction in the annual chance of flooding which ranges from approximately 5.3% to 7.0%, respectively, to about 0.1% in both EIAs. The EIA S8 and S9 assurance values improve under the with-project condition. For example, in EIA S8, the assurance value for the one-percent AEP event is 8% in the without project condition and improves to 98% with-project. This 98% assurance value indicates that under the with-project condition, there is a 98% chance of safely passing a one percent AEP event in EIA S8. In EIA S9, one percent AEP event assurance improves from 83% without project to 98% with-project. In the with-project condition, I-5 south of Woodland is removed from the floodplain, but I-5 immediately north of the city would remain in the floodplain.

4.3 Environmental Summary

The effects to the natural environment have been considered throughout the planning process, and refinements have been identified to reduce effects to resources within the study area. Since the Levee and Conveyance Alternative does not include features adjacent to the Lower Cache

Creek channel, environmental effects are minimized. Impacts to Federally listed species and vegetation communities that provide habitat, including grassland, orchards, and regulated wetlands, and compensation for the loss of habitat, are shown below in Table 4-3. During the design phase of the project, design refinements that minimize effects to the CCSB, which provides the majority of wildlife habitat in the study area, will be identified.

Mitigation for air quality and cultural resources is also shown below. Additional information on environmental effects is located in Section 3.3, and mitigation is located in Section 4.7 in the accompanying Supplemental Draft EIS.

Table 4-3. Environmental Effects of and Proposed Mitigation for the TSP

Impact Type	Potential Impacts	Duration of Impact	Mitigation	Cost
Environmental				
Palmate-Bracted Bird's Beak	0.15 acres (Indirect)	Permanent	2.25 acres - Education/Habitat Enhancement at Woodland Regional Park	$50,000
	0.7 acres (Direct)			
Valley Elderberry Longhorn Beetle	4 elderberry shrubs	Permanent	4 VELB credits - $5,000 per credit	$20,000
Giant Garter Snake	1.04 acres (Aquatic)	Permanent	30 acres - $22,500 per acre	$660,000
	8.78 acres (Upland)			
Oak Woodland	6 acres	Permanent	18 acres - $55,000 per acre	$1,015,000
Orchard	8 acres	Permanent	8 acres - $55,000 per acre	$450,500
Seasonal Wetland	7 acres	Permanent	7 acres - $150,000 per acres	$1,050,000
Grassland	67 acres	Single Construction Season	67 acres Hydroseed with native mix	No additional environmental cost
Air Quality				
NOx (Oxides of Nitrogen)	1 ton per Construction Season	Permanent	2 tons - $25,000 unit	$50,000
Cultural				
Historic Properties Treatment Plan				$58,000
Data Recovery/Mitigation Field Work				$259,000

Impact Type	Potential Impacts	Duration of Impact	Mitigation	Cost
Laboratory Analyses for Data Recovery Fieldwork				$151,000
Data Recovery Report				$110,000
Sub-Total				**$3,873,500**
Contingency				**$1,355,725**
Total				**$5,229,225**

Water and sediment quality were evaluated for the final array, and adverse impacts are not anticipated based on the results of Phase 1 Environmental Site Assessment, a UC Davis sediment trap efficiency study, and consideration of impaired water bodies under the Clean Water Act. Project construction will not cause adverse environmental impacts relative to the future without project conditions.

4.4 Real Estate

A fee title will be obtained for areas beneath the physical project features (i.e. embankment, seepage berm, drainage channel, etc.) and for the area 15 feet beyond the toe of waterside features and 20 feet beyond the toe of landside features. A summary of real estate requirements is included in Table 4-4.

Table 4-4. Estimated Real Estate Requirements

Ownership	Quantity	Acres
Private Ownerships	24	257.8
Public Ownerships	8	45.8
Railroad	1	0.6
Estates	**Quantity**	**Acres**
Permanent Easement Estates	40	314.4
Temporary Work Areas	11	32.6
Fee	0	0
Number of PL-91-646	0	0

Existing trees and encroachments will be removed to the extent necessary to facilitate construction of the project and to support long-term operation and maintenance. It may be the case that some trees and other encroachments are not removed from the rights-of-way (ROW). These encroachments will be addressed on a case-by-case basis during final design of the project.

4.5 Plan Economics and Cost Sharing

The project first cost, estimated on the basis of 2019 price levels, amounts to $259,453,000. Table 4-5 displays each cost by project feature. Estimated average annual costs of approximately $10,033,000 were based on a 2.75 percent interest rate, a period of analysis of 50 years, and construction ending in 2027. Table 4-6 shows the project first costs. The total average annual flood damage reduction benefits are $20,657,000 with a benefit to cost ratio of 2.1 to 1.0.

Table 4-5. Estimated Costs of Tentatively Selected Plan (Alternative 2A)

ACCOUNT	DESCRIPTION	Total First Cost ($1000's)
01	Lands and Damages	$20,687
02	Relocations	$45,952
06	Fish And Wildlife Facilities	$4,567
09	Channels & Canals	$6,092
11	Levees & Floodwalls	$128,340
18	Cultural Resource Preservation	$592
30	Planning, Engineering and Design	$37,324
31	Construction Management	$15,899
	Total[1]	*$259,453*

~~[1] Does not include cultural resources data collection.~~

Table 4-6. Summary of Cost Sharing Responsibilities for the TSP

Item	Federal	Non-Federal
Flood Risk Management	$168,852	$90,601
Total	$168,852	$90,601
Breakdown of Non-Federal		
LERRD		$20,687
5% Cash Requirement		$12,943
Remaining Cash		$56,971
Total		$90,601

[1]Costs ($1,000s) are October 2019 price levels at 2.75%, for a 50-year period of analysis.

4.6 Risk and Uncertainty

In general, the ability of the plan to provide the expected accomplishments depends on the following: the validity of pertinent assumptions, base data, and analytical techniques used in this study; the successful completion of future studies, designs, and construction; and appropriate OMRR&R after construction.

The uncertainty in the stage-discharge estimates is not expected to change for the focused array of alternatives. The stages are relatively insensitive to discharges and the flow conditions and conveyance are expected to remain similar to the without project conditions. Therefore, it is estimated that uncertainty in stages associated with the proposed focused array will be same as for the existing conditions.

The economic analysis described in this report includes uncertainties in the valuation of residential and non-residential structures and contents along with automobile losses. Uncertainty in the valuation of structures and contents stems from several factors, including uncertainty in the first floor elevation and in the damages associated with specific depths of flooding. Several factors contributed to the uncertainty associated with automobile damages. These factors include the average unit value, the number of vehicles per residence, and the evacuation rate. The Economic and Risk Appendix describes these uncertainties further and how they were incorporated in the model.

4.7 Residual Risk

The TSP greatly reduces the risk of flooding within the urban area of the City of Woodland. Even with the project in place, a slight residual risk of flooding within the city would remain. The TSP does not propose structural measures on the left bank of Cache Creek and would not change the risk of flooding north of Cache Creek, including in the town of Yolo.

The long-term risk, which indicates the percentage chance of flooding over a given period of time, improves for EIAs S8 and S9 (Figure 3-17.) under the with-project condition. In EIA S8, the 10-year, 30-year, and 50-year chance of flooding improves from 42 percent, 80 percent and 93 percent to 1 percent, 3 percent, and 4 percent, respectively. For EIA S9, the 10-year, 30 year, and 50-year chance of flooding improves under the with-project condition from 51 percent, 89 percent and 97 percent to 1.0 percent, 3 percent, and 4 percent, respectively.

It is expected that the engineering performance of the project will deteriorate over time, especially 50-100 years beyond construction. There are many reasons for this, such as overall area subsidence, climate change, and other uncertain future hydrologic and hydraulic conditions.

4.8 Executive Order 11988

The Water Resources Council Floodplain Management Guidelines for implementation of EO 11988, as referenced in USACE ER 1165-2-26, require an eight-step process that agencies should carry out as part of their decision-making on projects that have potential impacts to or within the floodplain. The eight steps reflect the decision-making process required in Section 2(a) of the EO. The eight steps and project-specific responses to them are summarized below.

1. Determine if a proposed action is in the base floodplain (that area which has a one percent or greater chance of flooding in any given year).
The proposed action is located entirely within the base floodplain.

2. If the action is in the base floodplain, identify and evaluate practicable alternatives to the action or to location of the action in the base floodplain.
Flood storage in the upper watershed was initially considered and screened out due to seismic and environmental concerns. Since the primary objective of the study and the plan is FRM, there are no practicable alternatives completely outside of the base floodplain that would achieve this objective.

3. If the action must be in the floodplain, advise the general public in the affected area and obtain their views and comments.
Because the primary objective of the study and plan is FRM, the action must be in the floodplain. The general public, governmental agencies, organizations and interested stakeholders have been involved in the study process since public outreach on FRM concepts began in 2000 with multiple public meetings, as detailed in Chapter 5, and release of a Draft Environmental Impact Statement (DEIS) and Draft Feasibility Report in March 2003.

Numerous comments were received on the DEIS and Draft Feasibility Report, which have been included and responded to in this updated Supplemental EIS and 2019 Draft Feasibility Report. Public opposition to the tentative plan at that time led to the request by the NFS to stop work and pause the study. The study was restarted in 2011 to account for additional Sponsor-led community engagement.

4. Identify beneficial and adverse impacts due to the action and any expected losses of natural and beneficial floodplain values. Where actions proposed to be located outside the base floodplain but will affect the base floodplain, impacts resulting from these actions should also be identified.

While construction of TSP features would result in mostly minor and temporary adverse impacts to the natural environment, there are no anticipated long term adverse impacts or benefits to floodplain values in association with the construction and OMRRR of the TSP.

5. If the action is likely to induce development in the base floodplain, determine if a practicable non-floodplain alternative for the development exists.
The TSP will not induce development in the floodplain.

6. As part of the planning process under the Principles and Guidelines, determine viable methods to minimize any adverse impacts of the action including any likely induced development for which there is no practicable alternative and methods to restore and preserve the natural and beneficial floodplain values. This should include reevaluation of the "no action" alternative.
The TSP would not induce development in the floodplain.

7. If the final determination is made that no practicable alternative exists to locating the action in the floodplain, advise the general public in the affected area of the findings.
The general public will be provided the opportunity to comment on the draft feasibility report and draft SEIS during the 45-day public comment period. Responses will be prepared to all comments received during that time and will be included in the final feasibility report and SEIS.

8. Recommend the plan most responsive to the planning objectives established by the study and consistent with the requirements of the Executive Order.
The TSP is the most responsive to all of the study objectives, and it is consistent with the requirements of EO 11988.

4.9 Environmental Operating Principles

USACE has reaffirmed its commitment to the environment by formalizing a set of "Environmental Operating Principles" applicable to all of its decision-making and programs. The principles are described in Engineering Circular 1105-2-4040 "Planning Civil Work Projects under the Environmental Operating Principles," 1 May 2003. The Environmental Operating Principles are:

1. Foster sustainability as a way of life throughout the organization.

2. Proactively consider environmental consequences of all Corps activities and act accordingly.

3. Create mutually supporting economic and environmentally sustainable solutions.

4. Continue to meet our corporate responsibility and accountability under the law for activities undertaken by the Corps, which may impact human and natural environments.

5. Consider the environment in employing a risk management and systems approach throughout the life cycles of projects and programs.

6. Leverage scientific, economic and social knowledge to understand the environmental context and effects of Corps actions in a collaborative manner.

7. Employ an open, transparent process that respects views of individuals and groups interested in Corps activities.

The Environmental Operating Principles are met by the TSP in the following ways:

Environmental balance and sustainability (EOP 1,2,3 &4)

- Project avoids or minimizes environmental impacts while maximizing future safety and economic benefits to the community.
- Monitoring will be used to implement adaptive management measures to meet and sustain the targeted Lower Cache Creek FRM objectives.
- NEPA, Fish and Wildlife Coordination Act (FWCA), and Endangered Species Act (ESA) requirements will be met.

Planning with the environment (EOP 1,2 4, and 5)

- Worked with resource agencies during planning phase to minimize impacts to the environment.
- Minimize impacts on surrounding habitats through adaptive management.

Integrate scientific, economic and social knowledge base (EOP 6)

- Sought advice from experts on the latest principles and science on levee construction.

Seeks public input and comments (EOP 7)

- Held stakeholder meetings and public workshops throughout the process
- Worked with local groups to achieve a balance of project goals and public concerns

4.10 Plan Implementation

This section describes the remaining steps to potential authorization of the project by Congress.

4.10.1 Report Completion

The draft Feasibility Report and draft SEIS will be circulated for public and agency review for 45 days. A public meeting will be held to obtain comments from the public, agencies, and other interested parties. After completion of the public review period, comments will be considered and incorporated into the Feasibility Report and SEIS, as appropriate. Comments received during the public comment period, as well as responses to them, will be presented in an appendix. The final Feasibility Report and SEIS will be provided to any public agency that provides comments on the Draft Report. The NFS is responsible for certifying that the Final EIR has been prepared in compliance with CEQA.

4.10.2 Report Approval

The final Feasibility Report and SEIS will be circulated for 30 days to agencies, organizations, and individuals who have an interest in the proposed project. All comments received will be considered and incorporated into the final Feasibility Report as appropriate. This study is being coordinated with all appropriate Federal, state, and local government agencies. USACE Headquarters coordinates compilation and response to comments from affected Federal and State agencies, and completes its own independent review of the final report.

After its review of the final Feasibility Report and SEIS, including consideration of public comments, USACE Headquarters prepares the Chief of Engineers' Report. This report is then submitted to the Assistant Secretary of the Army for Civil Works ASA(CW), who coordinates with the Office of Management and Budget and submits the report to Congress.

4.10.3 Project Authorization and Construction

Once the final report is approved by the Chief of Engineers and the project is authorized by Congress, construction funds must be appropriated by Congress before a Project Partnership Agreement (PPA) can be signed by USACE and sponsor to begin construction.

4.10.4 Division of Responsibilities

Federal Responsibilities

USACE would conduct the PED studies. Once the project is authorized and funds are appropriated, a PPA would be signed with the non-Federal sponsor. After the sponsor provides the cash contribution, lands, easements, rights-of-way, relocations, and disposal areas, the Federal Government would begin construction of the project.

Non-Federal Responsibilities

Specific items of local cooperation are identified in Chapter 6, *Recommendations*.

Views of Non-Federal Sponsor

The non-Federal sponsors, City of Woodland and the CVFPB, support the TSP. Throughout development of this feasibility report, there has been significant coordination with the City of Woodland, the State of California, and other stakeholders.

Financial Capability of Sponsor

The total estimated non-Federal first cost of the project is $90,808,591 including LERRDs using 2019 price levels. Actual costs may be slightly greater at the time of construction due to inflation. The total estimated value for the project lands, including LERRDs is $8,284,000. The non-Federal sponsor(s) will be required to provide self-certification of financial capability for the final report as required by USACE guidance.

Project Cost-Sharing Agreements

A Design Agreement must be executed between USACE and the non-Federal sponsor in order to cost share the development of detailed plans and specifications. Before construction is started, the Federal Government and the non–Federal sponsor would execute a Project Partnership Agreement. This agreement would define responsibilities of the non-Federal sponsor for project construction as well as operation, maintenance, repair, replacement, and rehabilitation and other assurances.

4.11 Schedule

If the project is authorized in 2022, construction could start in 2025. Table 4-7 contains a notional schedule showing the approval and construction phases of the project.

Table 4-7. Notional Project Schedule

Phase	Scheduled Dates
Division Commander’s Transmittal to HQUSACE	2021
Chief of Engineers Report	2021
Potential Authorization	2022
USACE and Sponsor Sign Design Agreement	2022
Preconstruction Engineering and Design	2022-2024
USACE and Sponsor Sign Project Partnership Agreement	2024
Initiate Construction	2025
Complete Physical Construction	2027

4.12 Further Studies

During the PED phase, several additional studies would be conducted as part of developing detailed designs for the project. These studies include:

- Additional geotechnical analysis of underlying substrates.
- Additional hydraulic analysis including most current modeling data.
- Topographic and ground surveys for project design.
- Preconstruction surveys to avoid direct impacts to nesting birds and other sensitive species.
- Water quality analysis of construction activities and methods.
- Intensive cultural resources surveys, evaluations, and mitigation as appropriate, in consultation with the State Historic Preservation Officer (SHPO), and Native American Tribes; as specified in the Programmatic Agreement (PA).

As mentioned in Chapter 1, this study would only partially address the Sacramento River Basin Study Authority, and is therefore, called an “Interim Feasibility Report” which indicates that the study is addressing the water resource issues of a specific area within the authority, rather than the entire area authorized for study. Additional studies to address other water resource issues within the Sacramento River Basin could be initiated based on Congressional direction.

Chapter 5 – Public Involvement, Review, and Consultation

5.1 Public Involvement Program

To announce the start of the Lower Cache Creek Feasibility Study, a notice of intent (NOI) to prepare an integrated Feasibility Report/ Draft Supplemental Environmental Impact Statement (FR/SEIS) for the Lower Cache Creek Feasibility Study was posted in the Federal Register (Vol. 80, No. 165) on August 26, 2015. The recipients were invited to comment on the scope of analysis as well as potential alternatives. The notice in 2015 announced a public workshop where the public was given the opportunity to comment.

The meeting location, date, and time were as follows:

- September 3, 2015, Woodland Community Center—2001 East St., Woodland, CA (4-7 pm)

5.2 Public Feedback

There were 18 people who provided comments resulting from the September 3, 2015 scoping meeting. Comments were solicited through the use of court reporters at the meeting. Additional comments could be submitted through mail or electronic mail. Oral and written comments were made through a series of meetings by 6 local, state, and Federal agencies, 3 community organizations, and 9 individuals. The comments and the responses to them are summarized in the Public Involvement Section of the Supplemental Environmental Impact Statement (Appendix J of the EIS).

5.3 Other Public Involvement

To help the community stay informed about current study activities, information is provided in a variety of ways:

- The City of Woodland held a public scoping meeting as part of its CEQA requirements at Woodland City Hall on September 11, 2019.
- SPK website
- Citizens Advisory Committee

5.4 Institutional Involvement

5.4.1 Project Delivery Team

During the study, staff from the City of Woodland, DWR, and the CVFPB participated along with USACE as members of the PDT.

5.4.2 Agency Participation

Coordination with USFWS is being conducted in accordance with the Fish and Wildlife Coordination Act. The project is also coordinating with the CDFW.

5.5 Additional Required Coordination

Additional coordination will be summarized in the final report.

5.6 Public View and Responses

Public views and responses to comments on the draft report will be summarized in the final report.

5.7 Impact on Recommendations

Any impacts on the recommendations due to public views will be summarized in the final report.

Chapter 6 – Recommendations

I recommend that the Tentatively Selected Plan (Alternative 2A) be authorized for implementation, as a Federal project, with such modifications thereof as in the discretion of the Commander, U.S. Army Corps of Engineers, may be advisable. The estimated first cost (2019 price level) of the Tentatively Selected Plan is $259,453,000 with an estimated Federal cost of $168,852,000 and an estimated non-Federal cost of $90,601,000. The estimated annual OMRR&R cost is $180,000 (2019 price levels). Federal implementation of the Tentatively Selected Plan would be subject to the non-Federal sponsor agreeing to comply with applicable Federal laws and policies, including but not limited to:

a. Provide a minimum of 35 percent, but not to exceed 50 percent, of total project costs as further specified below:

    1. Provide 35 percent of design costs in accordance with the terms of a design agreement entered into prior to commencement of design work for the project;

    2. Provide during the first year of construction, any additional funds necessary to pay the full non-Federal share of design costs;

    3. Provide, during construction, a contribution of funds equal to 5 percent of total project costs;

    4. Provide all lands, easements, and rights-of-way, including those required for relocations, the borrowing of material, and the disposal of dredged or excavated material; perform or ensure the performance of all relocations; and construct all improvements required on lands, easements, and rights-of-way to enable the disposal of dredged or excavated material all as determined by the Government to be required or to be necessary for the construction, operation, and maintenance of the project;

    5. Provide, during construction, any additional funds necessary to make its total contribution equal to at least 35 percent of total project costs;

b. Shall not use funds from other Federal programs, including any non-Federal contribution required as a matching share therefore, to meet any of the non-Federal obligations for the project unless the Federal agency providing the Federal portion of such funds verifies in writing that expenditure of such funds for such purpose is authorized;

c. Not less than once each year, inform affected interests of the extent of protection afforded by the project;

d. Agree to participate in and comply with applicable Federal flood plain management and flood insurance programs;

e. Comply with Section 402 of the Water Resources Development Act of 1986, as amended (33 U.S.C. 701b-12), which requires a non-Federal interest to prepare a flood plain management plan within one year after the date of signing a project cooperation agreement, and to implement such plan not later than one year after completion of construction of the project;

f. Publicize flood plain information in the area concerned and provide this information to zoning and other regulatory agencies for their use in adopting regulations, or taking other actions, to prevent unwise future development and to ensure compatibility with protection levels provided by the project;

g. Prevent obstructions or encroachments on the project (including prescribing and enforcing regulations to prevent such obstructions or encroachments) such as any new developments on project lands, easements, and rights-of-way or the addition of facilities which might reduce the level of protection the project affords, hinder operation and maintenance of the project, or interfere with the project's proper function;

h. Comply with all applicable provisions of the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970, Public Law 91-646, as amended (42 U.S.C. 4601-4655), and the Uniform Regulations contained in 49 CFR Part 24, in acquiring lands, easements, and rights-of-way required for construction, operation, and maintenance of the project, including those necessary for relocations, the borrowing of materials, or the disposal of dredged or excavated material; and inform all affected persons of applicable benefits, policies, and procedures in connection with said Act;

i. For so long as the project remains authorized, operate, maintain, repair, rehabilitate, and replace the project, or functional portions of the project, including any mitigation features, at no cost to the Federal Government, in a manner compatible with the project's authorized purposes and in accordance with applicable Federal and State laws and regulations and any specific directions prescribed by the Federal Government;

j. Give the Federal Government a right to enter, at reasonable times and in a reasonable manner, upon property that the non-Federal sponsor owns or controls for access to the project for the purpose of completing, inspecting, operating, maintaining, repairing, rehabilitating, or replacing the project;

k. Hold and save the United States free from all damages arising from the construction, operation, maintenance, repair, rehabilitation, and replacement of the project and any betterments, except for damages due to the fault or negligence of the United States or its contractors;

l. Keep and maintain books, records, documents, or other evidence pertaining to costs and expenses incurred pursuant to the project, for a minimum of three years after completion of the accounting for which such books, records, documents, or other evidence are required, to the extent and in such detail as will properly reflect total project costs, and in accordance with the standards for financial management systems set forth in the Uniform Administrative Requirements for Grants and Cooperative Agreements to State and Local Governments at 32 Code of Federal Regulations (CFR) Section 33.20;

m. Comply with all applicable Federal and State laws and regulations, including, but not limited to: Section 601 of the Civil Rights Act of 1964, Public Law 88-352 (42 U.S.C. 2000d) and Department of Defense Directive 5500.11 issued pursuant thereto; Army Regulation 600-7, entitled "Nondiscrimination on the Basis of Handicap in Programs and Activities Assisted or Conducted by the Department of the Army"; and all applicable Federal labor standards requirements including, but not limited to, 40 U.S.C. 3141- 3148 and 40 U.S.C. 3701 – 3708 (revising, codifying and enacting without substantial change the provisions of the Davis-Bacon Act (formerly 40 U.S.C. 276a et seq.), the Contract Work Hours and Safety Standards Act (formerly 40 U.S.C. 327 et seq.), and the Copeland Anti-Kickback Act (formerly 40 U.S.C. 276c et seq.);

n. Perform, or ensure performance of, any investigations for hazardous substances that are determined necessary to identify the existence and extent of any hazardous substances regulated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), Public Law 96-510, as amended (42 U.S.C. 9601-9675), that may exist in, on, or under lands, easements, or rights-of-way that the Federal Government determines to be required for construction, operation, and maintenance of the project. However, for lands that the Federal Government determines to be subject to the navigation servitude, only the Federal Government shall perform such investigations unless the Federal Government provides the non-Federal sponsor with prior specific written direction, in which case the non-Federal sponsor shall perform such investigations in accordance with such written direction;

o. Assume, as between the Federal Government and the non-Federal sponsor, complete financial responsibility for all necessary cleanup and response costs of any hazardous substances regulated under CERCLA that are located in, on, or under lands, easements, or rights-of-way that the Federal Government determines to be required for construction, operation, and maintenance of the project;

p. Agree, as between the Federal Government and the non-Federal sponsor, that the non-Federal sponsor shall be considered the operator of the project for the purpose of CERCLA liability, and to the maximum extent practicable, operate, maintain, repair, rehabilitate, and replace the project in a manner that will not cause liability to arise under CERCLA; and

q. Comply with Section 221 of Public Law 91-611, Flood Control Act of 1970, as amended (42 U.S.C. 1962d-5b), and Section 103(j) of the Water Resources Development Act of 1986, Public Law 99-662, as amended (33 U.S.C. 2213(j)), which provides that the Secretary of the Army shall not commence the construction of any water resources project or separable element thereof, until each non-Federal interest has entered into a written agreement to furnish its required cooperation for the project or separable element.

The recommendations contained herein reflect the information available at this time and current Departmental policies governing formulation of individual projects. They do not reflect program and budgeting priorities inherent in the formulation of a national Civil Works construction program nor the perspective of higher review levels within the Executive Branch. Consequently, the recommendations may be modified before they are transmitted to the Congress as proposals for authorization and implementation funding. However, prior to transmittal to the Congress, the sponsor, the States, interested Federal agencies, and other parties will be advised of any modifications and will be afforded an opportunity to comment further.

____
Date

James J. Handura
Colonel, U.S. Army
Corps of Engineers
District Engineer

Chapter 7 – References

Bernacchi, L. 2018. Farms serve as natural experiment site for large-scale groundwater recharge. Dr. Helen Dahlke's research contributes to restoring California's water reserves. UCWater. Accessed 11-7-2019 from http://ucwater.org/news/onfarm-groundwater-recharge. UC Davis, CA.

Bureau of Land Management. 1993. "Coordinated Resource Management Plan (CRMP),"

Busch, T. Personal communication. 2019. City of Woodland Public Scoping Meeting for the EIR. Woodland, CA.

California Environmental Protection Agency. 1980-1998 Air Resources Board; "Ozone Data Summaries for California Air Basins," http://arbis.arb.ca.gov/aqd/ozone/ozgeosel.htm

California Environmental Protection Agency; Air Resources Board. 1988-1997. "PM10 Data Summaries for California Air Basins http://arbis.arb.ca.gov/aqd/pm10/pmgeosel.htm

California Demographic Research Unit Report. 2000. "E-1 City/County Population Estimates with Annual Percentage Change," http://www.dof.ca.gov/html/demograp/repndat.htm

CalTrans. 2017. Traffic Volumes: Route 5-6. Retrieved from https://dot.ca.gov/programs/traffic-operations/census/traffic-volumes/2017/route-5-6.

(CDOC) California Department of Conservation. 2014-2016. Yolo County Important Farmland. Division of Land Resource Protection, Farmland Mapping and Monitoring Program. Vector digital data. Accessed November 14, 2019 from https://www.conservation.ca.gov/dlrp/fmmp/Pages/Yolo.aspx.

City of Woodland. General Plan Background Report, Woodland, California. 1996.

City of Woodland. 2014. Average Daily Traffic Volumes 2015. Public Works Department Engineering Division. Woodland, CA.

City of Woodland. 2016. Lower Cache Creek Feasibility Study Alternatives Analysis Report. Prepared by Wood Rodgers.

City of Woodland. 2017a. General Plan Update 2035. Prepared by Dyett & Bhatia, Urban and Regional Planners. Woodland, CA.

City of Woodland. 2017b. Final 2035 Climate Action Plan. Prepared by City of Woodland Public Works Department and Community Development Department. Woodland, CA.

City of Woodland. 2018. Public Review Draft Municipal Service Review and Sphere of Influence Study for the City of Woodland. MSR/SOI for the City of Woodland. LAFCo Project No. 049. Conducted by C. Crawford. Yolo Local Agency Formation Commission. Woodland, CA.

County of Yolo. 2009. 2030 Countywide General Plan Resolution No. 09-189. Planning and Public Works Department; Woodland, CA. Received August 12, 2019 from https://www.yolocounty.org/general-government/general-government-departments/county-administrator/general-plan

County of Yolo. 2018a. Cache Creek Parkway Plan: Open Space Inventory and Baseline Improvements. Prepared by Tchudin Consulting Group and Callander Associates Landscape Architecture.

Cost Estimating Guide for Civil Works. 1993. “Sacramento District Corps of Engineers,” including Code of Accounts.

Cunningham Engineering. 1993. “Annual In-Channel Mining Report,” Spring 1993, Topographic Maps

Dames & Moore. 1991. “Draft Program Environmental Impact Report, Cache Creek Aggregate Resources, Mining Activities and Policy Alternatives,”

Department of Water Resources (State of California). 1968. Investigation of Alternative Plans for Control of Sediment From Cache Creek - Memorandum Report

Department of Water Resources. 2014. Summary of Recent, Historical, and Estimated Potential for Future Land Subsidence in California.

Department of Water Resources. 2018a. Cache Creek Settling Basin Trap Efficiency Study Final Report. Prepared by A. Ercan, K. Carr, T. Tu, and M.L. Kavvas. UC Davis J.A. Hydraulics Laboratory, Department of Civil and Environmental Engineering. University of California, Davis.

EIP Associates. 1995. Technical Studies and Recommendations for the Lower Cache Creek Resource Management Plan for Yolo County Community Development Agency

Energy and Water Development Appropriations Act of 1993 (Public Law 102-377).

Federal Emergency Management Agency (FEMA). 1998. “Flood Insurance Study, Yolo County, California, Incorporated Areas,”

Federal Emergency Management Agency (FEMA). 1998. “Flood Insurance Study, City of Woodland,California,”

Federal Emergency Management Agency (FEMA). 2012. FEMA’s National Flood Hazard Layer (NFHL) Viewer. Accessed from https://hazards-fema.maps.arcgis.com/apps/webappviewer/index.html.

Federal Emergency Management Agency (FEMA). (2015). Environmental Planning and Historic Preservation Program: Executive Order 12898, Environmental Justice for Low Income & Minority Populations, 1994. Retrieved from: https://www.fema.gov/executive-order-12898-environmental-justice-low-income-minority-populations-1994#0

Federal Highway Administration (FWA). 1988. Visual Impact Assessment for Highway Projects. (FHWA-HI-88-054). USDOT (US Department of Transportation).

Flood Control Act of 1962 (Public Law 87-874).

Jennings, C.W. 1994. Fault Activity Map of California and Adjacent Areas With Locations and Ages of Recent Volcanic Eruptions. California Division of Mines and Geology, Geologic Data Map No. 6, Scale 1:750,000.

Lake County, History of Clear Lake. Retrieved from http://www.lakecountyca.gov/Government/Directory/WaterResources/ClearLake/History.htm

MBK Engineers. 2019. Technical Memorandum Subject: Flood Risk to Community to Yolo. Prepared by B. Brown for J. Twitchell of GEI Consultants.

Miller, R. 2018. Summary of Mining Operations, Approved Mining Operations (West to East along Cache Creek). Prepared by R. Miller, Senior Mining Planner for the Yolo County. Retrieved from https://www.yolocounty.org/home/showdocument?id=58661.

National Oceanic and Atmostpheric Administration (NOAA). 2019. California Nevada River Forecast Center. Accessed from https://www.cnrfc.noaa.gov/

NRCS. Soil Survey of Yolo County, California. 2019. Retrieved from: https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Rivertech, Inc. 1989. “Assessment of Impact of Proposed Mining on Bank Protection and Erosion Control for Cache Creek,” Parcels 49-470-10, 49-470-11, 49-140-11 and 48-140-20,

Roger Foott Associates. , Inc. “Geotechnical Assessment of Levees in the Mid-Valley Area, Sacramento River Flood Control System Evaluation,”

Sacramento River Watershed Program. 2010. The Sacramento River Basin: A Roadmap to Watershed Management. Accessed from sacriver.org.

Simons, Li & Associates Inc. 1987. “Geomorphic Analysis of Cache Creek Between Rumsey and Madison, Yolo County, California,” Phase I Final Report

Soil Conservation Service, U.S. Department of Agriculture. 1972 “Soil Survey of Yolo County,” California

State of California, Department of Water Resources. 1961. “Bulletin No. 90; Clear Lake – Cache Creek Basin Investigation,” State of California, Department of Water Resources. 1968. “Investigation of Alternative Plans for Control of Sediment From Cache Creek,” Memorandum Report

State of California, Department of Water Resources. 1994 “State Water Project Conjunctive Water Use – Eastern Yolo County,”

State of California. 1998. “Mercury Concentrations and Loads from the Sacramento River and from Cache Creek to the Sacramento-San Joaquin Delta Estuary,”

Toppozada, T., D. Branum, M. Petersen, C. Hallstrom, C. Cramer, and M. Reichle. 2000. Epicenters of and Areas Damaged by M>5 California Earthquakes, 1800-1999. California Division of Mines and Geology, Map Sheet 49.

U.S. Army Corps of Engineers (USACE). 1961. Unit No.126 Cache Creek Levees and Settling Basin Yolo Bypass to High Ground. Supplement to Standard Operation and Maintenance Manual; Sacramento River Flood Control Project. Sacramento, CA.

USACE. 2003. Draft Environmental Impact Statement/Environmental Impact Report for Potential Flood Damage Reduction Project: Lower Cache Creek, Yolo County, CA, City of Woodland and Vicinity. Sacramento, CA.

USACE. 2007. Operation and Maintenance Manual. Cache Creek Basin, California: Cache Creek Settling Basin Enlargement. USACE, Sacramento District: Sacramento, CA.

USACE. 2014a. Environmental Site Assessment, Lower Cache Creek, Phase 1. Sacramento District, Sacramento, CA.

USACE. 2014b. USACE Climate Preparedness and Resilience Policy Statement. Climate Change Adaptation Plan. Prepared by USACE Climate Preparedness and Resilience Steering Committee. Washington, D.C.

USACE and West Sacramento Area Flood Control Agency (WSAFCA). 2015. West Sacramento Project General Reevaluation Report: Final Environmental Impact Statement/Environmental Impact Report. Sacramento, CA.

USACE. 2017. Guidance for Detection of Nonstationarities in Annual Maximum Discharges. ETL 1100-2-3. CECW-CE. Washington, D.C.

U.S. Census. (2010, 2017, 2018). QuickFacts. Yolo County, California. Retrieved from: https://www.census.gov/quickfacts/fact/table/yolocountycalifornia,CA/PST045218

U.S. Census. (2019). Poverty Thresholds. Poverty Thresholds for 2018 by Size of Family and Number of Related Children Under 18 Years. Accessed September 17, 2019 from https://www.census.gov/data/tables/time-series/demo/income-poverty/historical-poverty-thresholds.html.

U.S. Department of the Army, Corps of Engineers. 1992. “Reconnaissance Report – Yolo Bypass, California,”

U.S. Department of the Army, Corps of Engineers. 1992. “Sacramento Metropolitan Area, Final Feasibility Report, California,”

U.S. Department of the Army, Corps of Engineers. 1991. “Sacramento River Flood Control System Evaluation, Initial Appraisal Report – Mid-Valley Area,”

U.S. Department of the Army, Corps of Engineers. 1991. “Sacramento River Flood Control System Evaluation, Initial Appraisal Report – Lower Sacramento Area, Phase IV,”

U.S. Department of the Army, Corps of Engineers. 1995. “Sacramento River Flood Control System Evaluation, Design Memorandum Report – Mid-Valley Area, Phase III, California,”

U.S. Department of the Army, Corps of Engineers. “Sedimentation Investigations of Rivers,” EM 1110-2-4000.

U.S. Department of the Army, Corps of Engineers. “Surveys and Design Manual,” DM 4-805-10.

U.S. Department of the Army, Corps of Engineers. 1994. “Westside Tributaries to Yolo Bypass, California Reconnaissance Study,”

U.S. Department of the Army, Corps of Engineers. 1998. “Yolo County, California – Unincorporated Areas, Flood Insurance Study,”

U.S. Department of the Interior, Fish and Wildlife Service. 1993. Reconnaissance Planning Report, “Fish and Wildlife Resource Management options for Lower Putah Creek, California,”

U.S. Department of the Interior, U.S. Geological Survey. 1989. “Streamflow, Sediment Discharge, and Streambank Erosion in Cache Creek, Yolo County, California, 1953-86,”

U.S. Geological Survey. 1995-1998 “National Water Quality Assessment of the Sacramento River Basin, California: Water-Quality, Sediment and Tissue Chemistry, and Biological Data,” http://infotrek.er.usgs.gov/pls/nawqa/nawqa.home

UC-Davis. 2016. "Amendment to the Cache Creek Settling Basin Trap Efficiency Study for the City of Woodland's Urban Flood Risk Reduction (UFRR) Study and Preliminary Design."

Wahler Associates. 1982. Geologic Report, Cache Creek Aggregate Resources, Yolo County, California. For: Aggregate Resources Advisory Committee, County of Yolo, Community Development Agency.

Water Engineering and Technology, Inc. 1989. “Cache Creek Erosion Mitigation Alternatives Report to the U.S. Army Corps of Engineers, Sacramento District, Contract No. DACW05-88-D-0044, Delivery Order 0003,”

Wirth, G.F., A.I.A & Associates/Architects, Inc. 1982. Woodland Historical Resource Inventory Final Report 1981-82: City of Woodland.

Yolo County. 2007a. Guinda Bridge Replacement Project on County Road 57 (Bridge 22C-0074) over Cache Creek. Negative Declaration. Yolo County Planning and Public Works Department. Woodland, Ca.

Yolo County. 2007b. Oak Woodland Conservation and Enhancement Plan. Prepared by Yolo County Parks and Natural Resources Management Division and Planning, Resources, and Public Works Department. Woodland, CA.

Yolo County. 2013. County of Yolo Bicycle Transportation Plan: Bicycle Routes and Priorities. Prepared by Yolo County Transportation Advisory Committee.

Yolo County. 2018b. Draft Revised Cache Creek Resources Management Plan (CCRMP) for Lower Cache Creek. Accessed September 14, 2019 from https://www.yolocounty.org/home/showdocument?id=54404.

Yolo Habitat Conservancy. 2018. "Yolo Habitat Conservation Plan/Natural Community Conservation Plan Volume 1."

Yolo County, 2019a. Cache Creek Parkway Plan: Open Space Inventory and Baseline Improvements, Financial Feasibility Study. Prepared by Bae Urban Economics.

Yolo County. 2019b. GIS Open Data – Administration. General Plan Land Use from the 2030 General Plan. Vector digital data. Retrieved from https://yodata-yolo.opendata.arcgis.com/datasets.

Yolo County. 2019. Draft Small Community Flood Risk Reduction Feasibility Study. Prepared by the Community of Yolo.

Yolo County. 1996 “Final Off-Channel Mining Plan for Lower Cache Creek, Yolo County,”

Yolo County. 1996. “Final Cache Creek Resources Management Plan for Lower Cache Creek, Yolo County,”

Yolo County. 1995 “Technical Studies and Recommendations for the Lower Cache Creek Resource Management Plan (Technical Studies),”

Yolo County. 2001. “Evaluation of Giant Garter Snake Habitat for Lower Cache Creek Flood Damage Reduction Study,” Yolo County, CA, Sycamore Env. Consultants, Inc.,

Yolo County. 2001. “Botanical Survey Report for a Federal and State Endangered Plant Species: Cordylanthus Palmatus (Palmate – Bracted Birds – Beak) for the Lower Cache Creek Flood Red. Study,” Yolo County, CA, Sycamore Env. Consultants, Inc.

CACHE CREEK WATERSHED HYDROLOGIC ANALYSIS

APPENDIX A

LOWER CACHE CREEK FEASIBILITY STUDY

Yolo County, CA

November 2019

United States Army Corps of Engineers
Sacramento District

Table of Contents

Executive Summary

Situation

The California Department of Water Resources (DWR) and the US Army Corps of Engineers, Sacramento District (Corps) are involved in a collaborative effort, the Central Valley Hydrology Study (CVHS), to develop flood flow frequency relationships at various analysis points in California's Central Valley. In most cases, these flow-frequency relationships can be defined through analyses that use historical streamflow data. However, for some streams where historical streamflow data are poor or unavailable, rainfall-runoff modeling must be used to characterize flood flow-frequency. These locations and their respective watersheds are listed in Table 1 of *Central Valley Hydrology Study: Ungaged watershed analysis procedures*, dated November 14, 2011. The *Ungaged watershed analysis procedures* document also outlines the analysis approach used to develop frequency curves at these locations. In addition, FloodSafe Yolo, which includes the city of Woodland, has entered into a cost sharing agreement with the U.S Army Corps of Engineers (USACE) to evaluate flood damage reduction alternatives for lower Cache Creek. This is called the Lower Cache Creek Feasibility Study.

This report describes our analysis of the Cache Creek watershed (ungaged watershed 11 of Table 1 from the *Ungaged watershed analysis procedures*).

Task

Wood Rodger's developed the Cache Creek HEC-HMS model and peak unregulated flow frequency curve at the Rumsey gage. The U.S Army Corp of Engineer's Hydrology Section is tasked to review their hydrology model and frequency curve to determine if the work performed could be adopted for the CVHS study and/or the USACE feasibility study. The final product produced for both studies are the regulated annual exceedence probability (AEP) hydrographs for the two analysis points. Changes to the frequency curve and the hydrology model are made providing sufficient reasons and documented in this report. Plate 1 shows a map of the watershed and location of the analysis points.

Action

To develop the required flow frequency curves, the following steps are followed:

1. Review the Wood Rodgers report, unregulated peak flow frequency curve, and HEC-HMS model
2. Derive an independent, unregulated peak flow frequency curve
3. Perform additional analyses to include 1-day and 3-day unregulated flow frequencies curves.
4. Revise the hypothetical storm duration, temporal pattern, and precipitation depth such that the hydrographs produced matches the AEP peak, 1-day, and 3-day frequency curves at Rumsey gage
5. Simulate the design storms
6. Adopt the resulting regulated flow hydrographs and regulated flow frequency curves at analysis points CAC-12 and CAC-14.

Yolo FloodSafe contracted with Wood Rodgers to analyze the flow frequency on Cache Creek in 2009 (Yolo FloodSafe, 2009). Although their procedures did not utilize CVHS procedures, it does use the Rumsey unregulated flow frequency curves to adjust the model, which can produce acceptable hydrographs for CVHS and the USACE Feasibility Study. In this study, adherence to the CVHS procedures is of secondary importance.

After reviewing the Yolo FloodSafe peak flow frequency curve, USACE has concerns with the methodology used to unregulate the peak flows. In addition, large floods in the Central Valley, California tend to be the result of several days of rain. Therefore, to ensure proper peak flows and volume in the hydrographs, the USACE has decided to derive its own peak, 1-day, and 3-day curves.

The task for this study is summarized in Figure 1

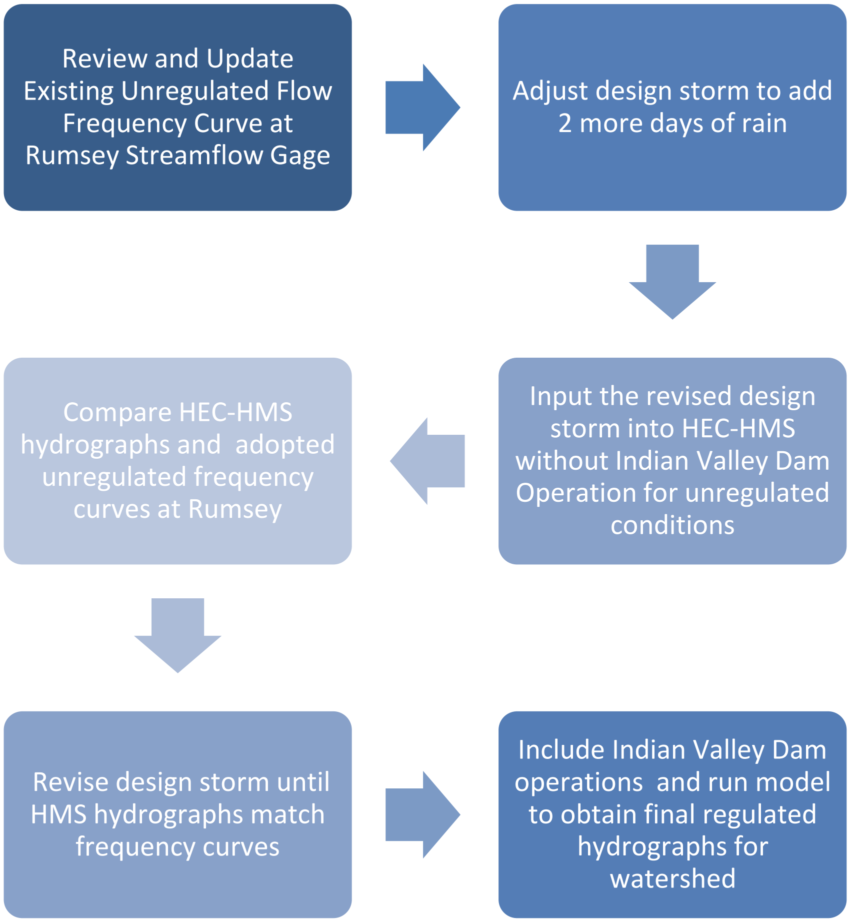


Figure 1 Overview of Method for developing unregulated –regulated flow frequency curves

Results
The USACE unregulated peak flow frequency curve is similar to the Yolo FloodSafe curve for the 10% through 0.2% AEP events at the Rumsey gage, as seen in Plate 2. The adopted unregulated and regulated AEPs at Road 94b are presented in Table 1 and Table 2.

Table 1 Unregulated runoff peak at each analysis point (flow, in cfs)

AEP	**CAC-12** **Cache Creek at Road 94B** **(Drainage Area 1,130 sq mi)**			**CAC-14** **Cache Creek near Capay** **(Drainage Area 1,074 sq mi)**		
	Peak	**1-Day**	**3-Day**	**Peak**	**1-Day**	**3-Day**
0.1	39,700	29,600	21,500	39,700	29,200	21,000
0.02	63,400	46,900	33,700	63,400	46,200	32,800
0.01	74,200	54,800	39,200	74,200	54,000	38,300
0.005	83,000	61,700	45,400	82,600	60,500	44,000
0.002	94,300	70,100	51,500	93,800	68,600	49,900

Table 2 Regulated runoff peak at each analysis point (flow, in cfs)

AEP	**CAC-12** **Cache Creek at Road 94B** **(Drainage Area 1,130 sq mi)**			**CAC-14** **Cache Creek near Capay** **(Drainage Area 1,074 sq mi)**		
	Peak	**1-Day**	**3-Day**	**Peak**	**1-Day**	**3-Day**
0.1	31,500	24,500	18,700	32,100	24,200	18,200
0.02	49,900	38,600	29,200	50,900	38,000	28,400
0.01	58,300	45,000	34,000	59,500	44,300	33,000
0.005	65,400	50,800	39,300	66,300	49,700	38,000
0.002	74,200	57,500	45,000	75,300	56,300	43,400

Study Purpose

The document *Central Valley hydrology study: Ungaged watershed analysis procedures* dated November 14, 2011, describes the procedures to be used for locations in which rainfall-runoff modeling must be used to characterize flood flow-frequency. The watersheds that contain analysis points that fall into this analysis category are listed in Table 1 of the *Ungaged watershed analysis procedures* document. The Cache Creek watershed is one of the identified ungaged watersheds. Thus, the purpose of this study is to review Wood Rodger's HEC-HMS model and peak frequency curve, and compute flood flow-frequency relationships for the Cache Creek watershed at 2 analysis points for floods of various exceedence probabilities and durations. A third analysis point, CAC-0, will have its exceedence probabilities calculated through HEC-RAS since the river section is bounded by levees with a limited channel capacity of 36,000 to 38,000 cfs. The routing is beyond the scope of the current hydrologic analysis.

Watershed Description

Watershed Overview

Cache Creek basin is located approximately 100 miles northeast of San Francisco in the coastal mountain ranges and drains about 1,139 square miles. Clear Lake, the most prominent feature of the basin, is the largest natural body of fresh water within California. Cache Creek originates at the outlet of Clear Lake, which flows generally northeast about 8.5 miles to the confluence with its North Fork, through Capay Valley, south to the irrigation dam at Capay, north past the town of Yolo, and east and south into the Cache Creek settling basin before finally flowing into the Yolo Bypass. The watershed contains many diversion dams and reservoirs of various sizes. Clear Lake Reservoir and Indian Valley Dam contain the two largest bodies of water in the watershed and have a significant influence on the flows on Lower Cache Creek.

The outlet of Clear Lake is the start of Cache Creek and is a narrow, confined channel that meanders approximately five miles before reaching Clear Lake Dam. Clear Lake Dam began storing water in 1915. Even before the dam was built, the outflow from Clear Lake had always been limited to less than 10% of the potential Clear Lake inflow due to a natural “weir-like” structure called the “Griggsby Riffles,” seen in Plate 3. During large inflows, the constrained outflow causes the shallow lake to rise rapidly, sometimes resulting in flooding along the rim of the lake.

Clear Lake Dam can release more water than can physically pass over the riffles. The riffles control the volume of water that can reach the dam and consequently, long-duration maximum outflow. The maximum flow passing over the riffles during large floods has been about 5,000 cfs. There is no designated flood control space upstream of Clear Lake Dam, although the limited channel capacity of Griggsby Riffles in combination with the considerable storage capacity of Clear Lake provides significant flood damage reduction benefits to downstream communities.

Indian Valley Dam lies on the North Fork of Cache Creek and is operated by the Yolo County Flood Control and Water Conservation District. The reservoir serves dual purposes for both irrigation supply and flood control. Flood control releases are made in accordance with rules and regulations determined by the U.S. Army Corps of Engineers in the authorized Water Control Manual. The total volume of space set aside for flood control is 40,000 ac-ft. Two major objectives of the reservoir are to a.) Release no more than 10,000 cfs immediately downstream of the dam b.) Maintain a downstream objective flow of no more than 20,000 cfs at the Rumsey gage (combined outflow and downstream local runoff)

Watershed Properties

The general description of the properties of the Cache Creek watershed, such as climate, elevation information, vegetation, land use, and geology, are presented in Table 3

Table 3 Cache Creek Watershed General Properties

Watershed Characteristics	Description
Climate	The climate of the Cache Creek Basin is characterized by cool wet winters and hot dry summers. Temperatures range from slightly below freezing in winters to highs of over 100 degrees Fahrenheit at times during the summer. Normal annual precipitation varies from a minimum of about 17 inches near the community of Yolo, and averages about 32 inches over the watershed. The major portion of the annual rainfall occurs from October through April. Snowfall is very rare and has no significant effect on the streamflow in the basin.
Elevation Range	The topography of the basin varies from steep, rugged hill slopes of the Coast Ranges to the gentle slopes of the valley floor, beginning near Capay, located on the western edge of a large alluvial plain. The elevation ranges from 6,120 feet at Goat Mountain on the northern basin perimeter to nearly sea level near Yolo.
Vegetation	Vegetation in upper Cache Creek consists mainly of deciduous trees and brush, such as blue oaks and chaparral. In middle elevations, riparian forest and valley oaks predominate.
Land Use	Irrigated crops, orchards, and vineyards occupy the lower elevations. Most of the basin is undeveloped. Primary land use includes national forest, recreation, grazing and agriculture. Future development of the watershed is not expected to be significant.
Geology	The geology of the basin consists of the Franciscan formation, which forms the core of much of the Coast Ranges. Rock outcrops of this formation can only be found in the upper part of Cache Creek Basin and consist of marine sedimentary and volcanic rock. To the east of Clear Lake and in the central portion of the basin, rocks are predominantly of

	massive sandstone with imbedded conglomerates and silty shales. Continental deposits in the lower portion of the basin consist of clay, sand, and gravel, and occur as discreet units and heterogeneous mixtures. The younger overlying alluvium is similar and generally not as coarse as the continental deposits. Underground aquifers underlie the valley portion of the basin downstream from Rumsey. The size and extent of these aquifers are not known. Intensive agriculture, and to a lesser degree the seasonal recreation industry, comprise the main economic features of the basin. State Highways 16, 20, 29, 53 and Interstate Highway 5 are the main traffic arteries.

(USACE, 2001)

Table 4 Previous Studies of the Cache Creek Watershed

Cache Creek Basin, California; Standard Project Floods (USACE, May 1974)	The purpose of this report is to present the standard project floods computed for streams at selected index points in Cache Creek Basin. The document describes the criteria and procedures used to develop the standard project flood. Contains subbasin map of Cache Creek
Cache Creek Basin, California: Hydrology Review Report (USACE, March 1985)	This report reviews the results presented in the Cache Creek Basin California, Feasibility Report, dated February 1979. The review includes: an update of historical stream flow data, an evaluation of the January 1983 storm and flood, a check on the storm centering, and an evaluation of the standard project centering based on the January 1983 storm
Hydrology for Cache Creek Yolo County, California; Reconnaissance Study Office Report (USACE, August 1995)	The purpose of this study was to provide hydrographs to support an evaluation of potential flooding and environmental restoration on Cache Creek. Existing hydrologic data and the Cache Creek HEC-1 model is reviewed. 50, 100, 200, and 500 year flood hydrographs were computed for Cache Creek at Rumsey and Capay.
Appendix C Hydrology Appendix for Lower Cache Creek Feasibility Study Yolo County, California (USACE, March 2001)	The purpose of this appendix is to provide a feasibility level analysis of the hydrology for Lower Cache Creek, Yolo County, California. The study reach extends from Cache Creek at Road 94B down to the Cache Creek Settling Basin, where Cache Creek has its confluence with the Yolo Bypass of the Sacramento River, about 17 river miles. Key products of the analysis include: a) a family of regulated frequency curves for Cache Creek at Road 94B, and b) synthetic hydrographs of the 2%-, 1%-, 0.5%-, and 0.2%-chance flows (50-, 100-, 200-, and 500-year) on Cache Creek at Road 94B.
Cache Creek Hydrology Study Review; City of Woodland (DFC, 2007)	This report reviews the USACE storm centering location, which was used in the 2001 Cache Creek feasibility study, and determines whether the location of the centering was appropriate.
Cache Creek Hydrology Update: Flood Safe Yolo Pilot Program (Wood Rodgers, October 2009)	This report was tasked under the floodSAFE YOLO Pilot Program and provides an update to the Cache Creek hydrology.

Development of Flow Frequency Curve

Overview

Wood Rodgers developed an unregulated peak flow frequency curve for the Cache Creek basin at the Rumsey gage, which is used to validate the peak hydrographs produced from the HEC-HMS model. The Yolo FloodSafe report (Yolo FloodSafe, 2009) describes the development of the peak flow frequency curve. However, Wood Rodgers did not develop duration flow frequency curves, which are used to validate computed hydrograph volumes. Flow volumes, such as the 1-day and 3-day, are important to flood analyses since it determines the amount of water that may cause flooding to a city in reaches with extensive, flat floodplain storage areas. For this reason, the U.S Army Corps of Engineers Hydrology Section will update their 2001 unregulated peak, 1-day, and 3-day flow frequency curves to validate the hydrograph peak and volume.

Flow Frequency Development Strategy

Since the 2001 study, an additional 11 years of annual maximum flows are incorporated into the new unregulated flow frequency statistics. The Capay station (USGS, 11452000, 1,044 sq. mi – inactive) located approximately 8 miles downstream of Rumsey, is combined with the Rumsey station (DWR, RUM, 955 sq. mi) to extend the flow record for the peak, 1-day, and 3-day volumes at Rumsey gage. This is done by applying a MOVE1 regression for the overlapping period between the two stations (1961-1971).

Since Indian Valley Dam started operating June of 1974, for flows after 1974 the incremental "change in storage" at Indian Valley Dam (converted to cfs) is added to the observed, regulated annual maximum daily flows. Recorded instantaneous peak flows are not available at Indian Valley Dam, except for the 1997 event. Previous USACE studies, using a calibrated HEC-1 model, estimated peak unregulated flow at Rumsey for the 1983 and 1995 floods (USACE, 2001). The remainder of the peak flows are estimated using the Ordinary Least Squares regression equation (OLS) which is developed to describe the relationship between unregulated 1-day flows (determined by the volume estimate using incremental storage) to unregulated peak flows.

The 2001 study did not incorporate regional skews in the weighting of the adopted skews in the final unregulated flow frequency curves. Additionally, the USGS recently published peak and duration regional skews ((USGS, 2010), (USGS, 2011)), respectively and will be incorporated into the weighting of the skews for this study.

Flow Data Collection

Rumsey, Capay, and Indian Valley Dam data are collected from the U.S Geological Survey (USGS), California Data Exchange Center (CDEC), Water Data Library (WDL), and US. Army Corp of Engineer's data server. Rumsey gage began operating in 1961 and is maintained by the Department of Water Resources (DWR). The Capay gage had been maintained by the USGS from 1943 to 1976; however, the gage is no longer operating. Indian Valley Dam began storing water June 1974 and is operated by the Yolo County Flood Control and Water Conservation District. Daily storage flows are available from 1974 to present.

Regression Equation

The MOVE1 regression equation maintains the variance and mean between the overlapping water years and is appropriate to use when correlating between two gage stations in the same watershed. The Move1 regression equation is as follows:

$$\hat{y}(i) = m(y_1) + \frac{S(y_1)}{S(x_1)} * (x(i) - m(x_1)\ )$$

Where: $\hat{y}(i)$ = short record station
$m(y_1)$ = mean short record
$S(y_1)$ = standard deviation short record
$S(x_1)$ = standard deviation base record
$x(i)$ = base record station
$m(x_1)$ = mean of base station

The Ordinary Least Squared regression equation minimizes the squared errors of the predicted value and is used to estimate the unregulated peak flows from unregulated daily maximum flows. The OLS equation is as follows:

$$\hat{y}(i) = m(y_1) + r * \frac{S(y_1)}{S(x_1)} * (x(i) - m(x_1)\ )$$

Where: r = correlation coefficient

Regional Skew

Bulletin 17B recommends that at-site skews calculated from recorded data be weighted with regional skews (USACE, 2010). The generalized skew (the station skew weighted with the regional skew) is the final skew used for the frequency curve. The variance of prediction, which corresponds to the mean square error (MSE), describes the precision of the generalized skew and is part of the final skew calculation. The following equations calculate the peak and duration regional skews given the average basin elevation of 2,050 ft.:

Peak Regression Equation: $\hat{\gamma} = \beta_0 + \beta_2\{1 - \exp[-\left(\frac{ELEV}{6,500}\right)^2\}\hat{\gamma} = \beta_0 + \beta_2\{1 - \exp[-\left(\frac{ELEV}{6,500}\right)^2]$

Where β_0 β_0= -0.62

β_2 β_2= 1.3

ELEV = Average elevation of watershed

Duration Regression Equation: $\hat{\gamma} = \beta_0 + \beta_1[1 - \exp\left\{-\left(\frac{ELEV}{3,600}\right)^{12}\right\}]$

Where β_0 = -0.7346 for 1-Day and -0.6905 for 3-Day durations

$\beta_1\beta_1$ = 0.6859 for 1-Day and 0.6822 for 3-Day durations

Table 5 and Table 6 list the peak and duration Variance of prediction (VPnew) for different elevations:

Table 5 Variance of Prediction for Peak Skews

Elevation (ft)	VPnew
0	0.14
1,000	0.14
2,000	**0.14**
3,000	0.13
4,000	0.13
5,000	0.13
6,000	0.14
7,000	0.14
8,000	0.15
9,000	0.16
10,000	0.16
11,000	0.17

*Variance of Prediction (VPnew) for peak skews

* Table is obtained from Peak Regional Skew USGS report (USGS, 2010)

*bolded value is used as MSE

Table 6 Variance of Prediction for Duration Skews

Elevation	1-Day	3-Day
<2,500	**0.058**	**0.059**
3,000	0.055	0.056
3,200	0.052	0.053
3,400	0.047	0.049
3,600	0.043	0.044
3,800	0.04	0.042
4,000	0.039	0.041
>4,500	0.039	0.04

*Variance of Prediction (VPnew) for 1-Day and 3-Day skews
*Table is obtained from Duration Regional Skew USGS report (USGS, 2011)
*Bolded values used as MSE

Flow Frequency Results

The Move1 and OLS regression inputs are listed in Table 7. The statistics are developed from the overlapping period (WY 1961-1973) between Rumsey and Capay gage. WY 1965 peak is removed from the regression calculations since the flow may have been overestimated as stated in the 1985 Hydrology report (USACE, 1985), which notes that the 1965 high flow is possibly due to the "extension of low flow rating table and slope-area measurements" (USACE, 1985). Although the 2001 study incorporates the 1965 flow, due to the uncertainty of this value, the 1965 peak flow is removed from the regression analysis. The final annual maximum flows used to compute the frequency curve statistics are listed in Table 8.

Table 7 MOVE1 and OLS Statistical Values

Statistics	Move1	OLS
r	0.94	0.91
$m(x_1)$	20,461	34,772
$m(y_1)$	24,600	17,449
$S(y_1)$	9,114	19,138
$S(x_1)$	8,545	9,406

*overlapping years from WY 1961-1973, OLS includes 1983, 1995, and 1997
*missing WY 1962, 1963, 1964, 1972
*WY 1965 removed from correlation
*WY 1977 low outlier across durations

Table 8 Unregulated Peak, 1-day, and 3-day Annual Maximum Flows at Rumsey

WATER YEAR	PEAK	1-DAY	3-DAY
1943	**40,106**	**17,388**	**12,819**
1944	**13,443**	**6,386**	**3,733**
1945	**9,390**	**5,020**	**3,828**
1946	**14,936**	**7,319**	**5,966**
1947	**8,217**	**2,653**	**1,511**
1948	**6,510**	**3,488**	**2,188**
1949	**13,059**	**6,926**	**5,083**
1950	**8,441**	**4,195**	**3,411**
1951	**17,922**	**7,957**	**5,125**
1952	**18,989**	**12,181**	**9,103**
1953	**24,855**	**14,048**	**9,570**
1954	**21,655**	**12,771**	**5,759**
1955	**5,156**	**1,886**	**944**
1956	**36,693**	**24,068**	**19,598**
1957	**12,867**	**6,562**	**4,753**
1958	**57,810**	**21,317**	**17,495**
1959	**19,095**	**9,598**	**8,444**
1960	**22,402**	**10,060**	**7,256**
1961	13,200	3,420	2,197
1962	**20,482**	13,000	8,570
1963	**30,827**	**15,030**	**10,775**
1964	**11,000**	**4,725**	**2,382**
1965	**50,238**	**20,433**	**17,110**
1966	23,000	11,600	7,610
1967	30,000	17,800	9,260
1968	23,200	8,970	5,433
1969	20,200	15,600	10,710
1970	43,400	23,600	16,800
1971	18,000	10,200	7,313
1972	**3,787**	677	546
1973	25,800	12,300	9,033
1974	**32,960**	**15,816**	**11,070**
1975	-	-	-
1976	*3,415*	513	375
1977	*2,582*	63	47
1978	*22,927*	11,051	9,327
1979	*7,877*	2,923	2,483
1980	*31,555*	15,711	13,397
1981	*11,938*	5,116	3,933
1982	*24,586*	11,947	9,309
1983	63,321*	27,088	20,137
1984	*37,682*	19,020	13,328
1985	*8,360*	3,184	1,951
1986	*71,326*	37,191	25,794
1987	*7,455*	2,695	1,990
1988	*14,054*	6,259	3,856
1989	*7,796*	2,879	1,968
1990	*5,618*	1,703	1,288
1991	*13,147*	5,769	3,402
1992	*6,107*	1,967	1,571
1993	*35,588*	17,889	12,013
1994	*7,063*	2,483	1,398
1995	65,820*	-	-
1996	*27,981*	13,781	8,533
1997	56,556	27,645	17,039
1998	*44,727*	22,825	17,801
1999	*18,314*	8,560	5,229
2000	*14,139*	6,305	4,515
2001	*13,128*	5,759	4,433
2002	*18,905*	8,879	-
2003	*28,746*	14,194	-
2004	*39,354*	19,923	-
2005	-	-	-
2006	*61,150*	31,695	17,888
2007	*6,437*	2,145	1,693
2008	*21,207*	10,122	6,941
2009	*9,003*	3,531	2,895
2010	*16,378*	7,514	5,850
2011	*31,151*	15,493	10,958

Bolded values estimated from MOVE1, Italics values estimated from OLS, "" estimated from HEC-1and underlined values unregulated from Indian Valley Dam. WY 1977 low outlier

The peak, 1-day, and 3-day annual maximum flows are input into Statistical Software Program (HEC-SSP) (USACE, 2012) to calculate mean, standard deviation, and station skew. The regional skew and VPnew (Mean Squared Error) values are also entered into SSP. Table 9 list the computed statistics while Table 10 shows the AEP flows for the 0.50 to 0.002. Plate 4 shows the peak, 1-day, and 3-day flow frequency curves.

Table 9 Bulletin 17B Flow Frequency Statistics at Rumsey gage

Statistics	Peak	1-Day	3-Day
Mean	4.243	3.868	3.669
Std Dev	0.327	0.418	0.446
Skew	-0.291	-0.758	-0.699

Table 10 AEP Flows Extracted from Frequency Curves at Rumsey gage

AEP	Peak (cfs)	1-Day (cfs)	3-Day (cfs)
0.5	18,200	8,300	5,300
0.2	33,300	16,800	11,300
0.1	44,800	22,800	15,700
0.05	56,600	28,500	20,100
0.02	72,900	35,400	25,800
0.01	85,800	40,300	29,900
0.005	99,200	44,800	33,800
0.002	118,000	50,300	38,700

Plate 2 compares the USACE peak flow frequency curve with the Wood Rodgers curve, which shows similarity toward the lower frequency events but divergence toward the higher frequency events. The peak frequency curves do not exactly match since the unregulated peak flows are calculated differently. Wood Rodgers added daily annual maximum change in storage flows from Indian Valley Dam to the regulated peak flows recorded at Rumsey gage (Yolo FloodSafe, 2009), while USACE computed unregulated peak flows using the HEC-1 model and the OLS regression equation.

Watershed delineation for Modeling

The watershed and subbasin have been delineated during the development of the HEC-1 model. A subbasin map, found in the Cache Creek Standard Project Flood report (USACE, 1974), does show where the subbasins originated from, but does not describe how the subbasins have been delineated. Efforts have been made by Wood Rodgers, David Ford Consulting (DFC), and USACE to match the subbasin areas. The watershed has been digitally re-created by DFC and can be seen in Figure 2 of the Yolo FloodSafe report (Yolo FloodSafe, 2009).

Required Model Parameters, Transforms, and Routings

The following steps below were performed by Wood Rodgers for the 2009 Study.

Runoff Volume

The initial and constant loss rates have been transferred from the 2004 USACE HEC-1 model

Channel Losses

Wood Rodgers determined Cache Creek "…loses significant water after it reaches the channel along some creek reaches…due to a significant groundwater/surface water interface downstream of Rumsey…mostly coinciding with large gravel deposits and gravel mining operations…" (Yolo FloodSafe, 2009). Wood Rodgers used the WRIME program to evaluate potential channel losses due to infiltration. Flow diversions have been established in the HEC-HMS model to account for the infiltrative losses. More information can be found in the Yolo FloodSafe report (Yolo FloodSafe, 2009).

Transform

The unit hydrographs have been initially copied from the HEC-1 model but have been shown to "…delay[ing] and suppress[ing] the peak flow as well as produce[ing] fatter shaped hydrographs" which do not reflect observed conditions (Yolo FloodSafe, 2009). Wood Rodgers revised the unit hydrograph using the U.S Bureau of Reclamation's Dimensionless Unit Hydrograph, which resulted in a faster runoff response.

Flow Routing

The routing inputs have been transferred over from the 2004 HEC-1 model.

Computation Time Step

The computation time step for the HEC-HMS model is 1 hour

Reservoir Regulation

The regulating affect of Clear Lake Dam during large floods has been modeled in the 2004 HEC-1 with a stage-rating curve for the Griggsby Riffles. The starting elevation used for Clear Lake in the HEC-1 model has been the same elevation that occurred just one day prior to the March 9, 1995 storm (one of the two largest floods of record on Lower Cache Creek since 1941, assuming no regulation from Indian Valley Dam). This starting storage is suitable for simulating large storm events such as the 0.01 AEP since it accounts for the antecedent saturated soil condition typically associated with large storms. The Clear Lake HEC-1 stage-rating curve and starting elevation have been imported into HEC-HMS.

The starting storage at Indian Valley Dam has been set to the bottom of the flood control space (260,000 ac-ft). An elevation-storage discharge curve, imported from the HEC-1, has been used to model operations at Indian Valley Dam; however, the dam is removed from the HEC-HMS model to simulate unregulated flow conditions.

Calibration of Model using Historical Data

Calibration Strategy

Wood Rodgers calibrated the model using the 2006 flood event and validated the model using the 1997 flood event. The Rumsey gage, maintained by the California Department of Water Resources (DWR), provides flow records during the selected storm events and is used to calibrate and check the model. The 2006 flood event, which occurred from December 30th, 2005 to January 1st, produced a peak of 34,876 cfs at Rumsey gage. The peak is the fourth largest recorded flow event within the last 32 years and "considered statistically infrequent[cy] and large enough for use in calibration" (Yolo FloodSafe, 2009). More information on model calibration can be found in the Yolo FloodSafe report and HEC-HMS model.

Hydro-meteorological Data Collection

For the 2006 event, Wood Rodgers obtained radar rainfall data through OneRain (www.onerain.com), while for the 1997 event Wood Rodgers collected surrounding hourly rainfall gages from the California Data Exchange Center (CDEC). A map of the rainfall gages used in the validation can be seen in Figure 15 of the Wood Rodgers report. OneRain provided 32 days of rainfall data from December 7th, 2005 to January 8, 2006 in gridded 2 km x 2 km resolution in 15 minute time steps.

Calibration Simulations

The 2006 calibration storm event has been defined between midnight December 30, 2005 and noon January 1, 2006. The antecedent conditions have been characterized as wet since there has been rainfall recorded days prior to the event (Yolo FloodSafe, 2009). The initial and constant loss values, unit hydrographs, and routing parameters from the HEC-1 model have been used as the initial input into the model. Changes have been made to the input parameters to match observed flows at Rumsey gage during the flood event.

Calibration Results

As stated in the "Transform" section, the HEC-1 unit hydrographs produced hydrographs that delayed and suppressed the observed peak flow. The unit hydrographs have been revised using the U.S Bureau of Reclamation's Dimensionless Unit Hydrograph, which resulted in a faster runoff response. Routing parameters have been "…slightly adjusted to match the timing of the peak flow measured at Rumsey..." (Yolo FloodSafe, 2009). The initial and constant loss rates have been lowered for some of the subbasins to match the observed peak and volume. Table 1 in the Wood Rodgers report compares the initial and constant loss for the HEC-1 model and the calibrated HEC-HMS model. Figure 14 in the Yolo FloodSafe report shows the 2006 calibrated HEC-HMS flow compared to the observed flow (Yolo FloodSafe, 2009).

Wood Rodgers ran the 1997 storm through the 2006 calibrated HEC-HMS model. Results showed that the parameters calibrated for the 2006 storm have been reasonable and no further calibrations have been necessary to the HEC-HMS model (Yolo FloodSafe, 2009).

Development of Design Precipitation

Overview

Wood Rodgers developed a 24-hr, 48-hr, and 96-hr temporal rainfall distribution and calculated AEP rainfall depths using DFC's precipitation depth analysis (Yolo FloodSafe, 2009). Storm pattern, depth calculations, and results can be viewed in the Wood Rodgers report and Cache Creek HEC-HMS model (Yolo FloodSafe, 2009). Depths used in this study are compared to NOAA 14 precipitation frequency depths with applied aerial reduction factor at subbasin 805 and INDVLY for the 0.01 AEP event. The DFC depths at 805 are 1.054 inches, 1.864 inches, 2.269 inches, and 3.890 inches for the 1HR, 3HR, 6HR, 24HR durations, respectively, while NOAA 14 depths at 805 are 0.801 inches, 1.384 inches, 1.980 inches, and 4.309 inches for the 1HR, 3HR, 6HR, and 24HR durations, respectively. DFC depths are greater than NOAA 14 depths by as much as 26% except for the 24 HR depth where NOAA 14 depths were greater by 11%. At higher elevations near Indian Valley Dam, the DFC depths are 1.384 inches, 2.449 inches, 2.982 inches, and 5.111 inches for the 1HR, 3HR, 6HR, and 24HR durations, respectively, while the NOAA 14 depths are 1.007 inches, 1.760 inches, 2.610 inches, and 5.953 inches for the 1HR, 3HR, 6HR, and 24HR durations, respectively. Again, DFC depths are greater than NOAA 14 depths for the 1 to 6 HR durations, but less than the 24HR duration.

The 24-hr storm pattern has been designed using the SCS Type IA storm imbedded in the HEC-HMS software. The 24-hr storm pattern and 0.01 AEP depth produced a hydrograph peak flow that matched well with the 2012 USACE peak and 1-day unregulated flow frequency curve. However, since the design storm lasted only 24 hours, the resulting hydrograph volume fell short of the 3-day frequency curve. To add additional flow volume to the analysis, this study added two days of precipitation at the end of the Wood Rodger's 24-hour storm. The two days of precipitation are patterned after Wood Rodger's 48 hr temporal storm pattern. The temporal pattern and 3-day storm depths are adjusted such that the 3-day hydrograph volumes matched closely to the 3-day unregulated flow frequency curve. For the above effort, Indian Valley Dam operation is removed in HEC-HMS to mimic unregulated watershed conditions. Since Clear Lake Dam operation mimics historic outflows from Clear Lake before the dam had been built, no modifications are done to Clear Lake Dam operations. The constant loss rates for each subbasin are increased by 27.5% such that the 0.01 hydrograph peak matches the 0.01 peak flow frequency curve.

Design Storm Adjustments

As stated above, an additional 48 hours of precipitation is added to Wood Rodger's 24 hour design storm. The additional rain uses the same pattern as the Wood Rodger's 48-hour design storm, but the actual depths are lower. The rising limb of the Wood Rodger's 48-hour hyetograph in the 2009 report, seen in Figure 2, is adjusted iteratively such that the resulting1-day hydrograph volume produced in HEC-HMS stays within 10-15% of the 1-day unregulated flow frequency value, and the resulting 3-day volume has a good match to the 3-day frequency curve value. The final 72-hr design storm combines the 24-hr rainfall pattern with the 48-hr pattern, as seen in Figure 3. The 0.01 and 0.005 AEP 24 hour precipitation depths are calculated using DFC's AEP depth analysis (DFC, 2007), while the 0.01 and 0.005 AEP 72 hour depths are adjusted until the computed hydrograph's 3-day volume matches the 3-day frequency curve; consequently, the storms are no longer the 0.01 and 0.005 AEP 72 hr design storms. The 0.01 AEP 72 hr is adjusted to 89% of the original depth while the 0.005 AEP 72 hr is adjusted to 90% of the original depth. The final 24- hr and 72-hr precipitation depths are presented in Table 11.

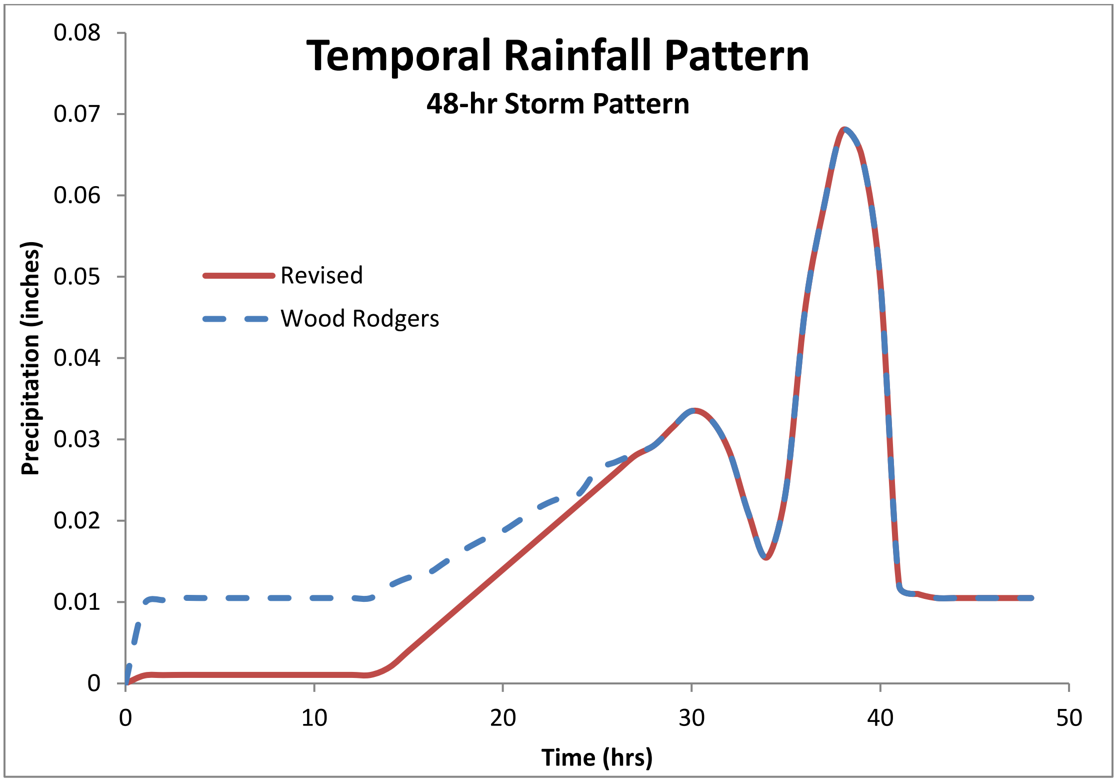


Figure 2: 48-hr Adjusted Rainfall Pattern

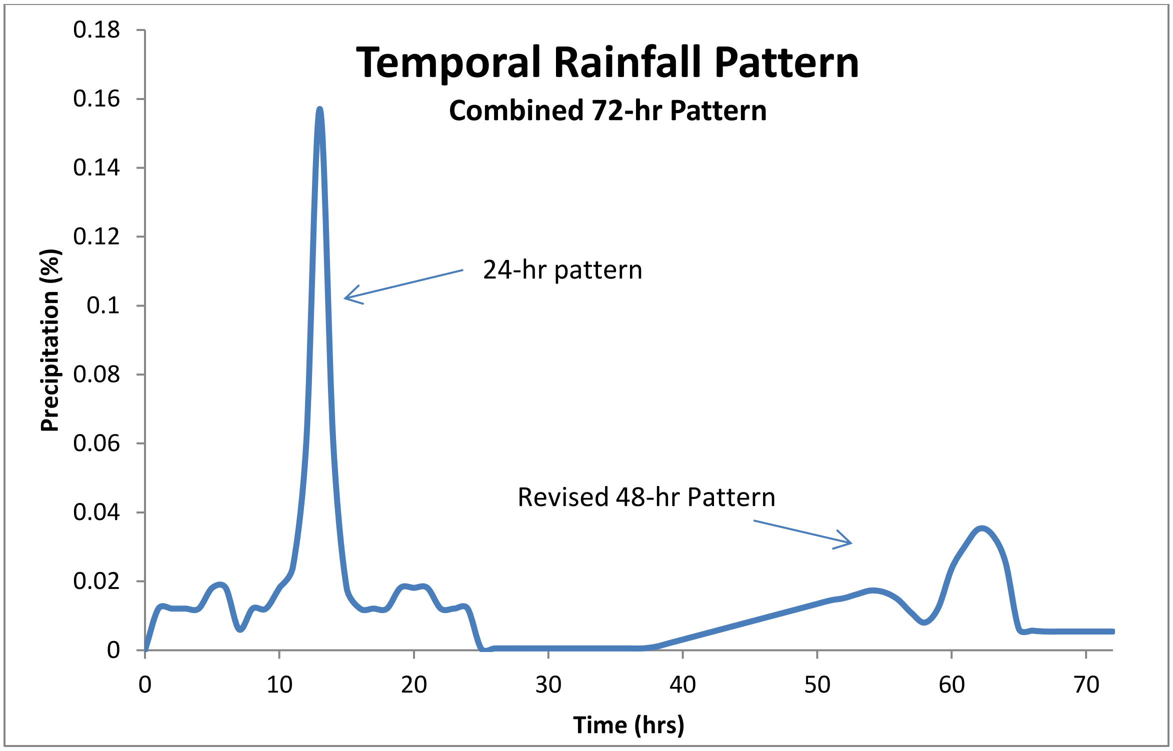


Figure 3: USACE 72-hr Rainfall Pattern

Table 11 24-hr AEP design and modified 72-hr storm precipitation depths

Subbasin	**100 yr 24 hr**	**200 yr 24 hr**	**89% of 100yr 72 hr**	**90% of 200yr 72 hr**
101	5.789	6.275	9.800	10.850
102	5.720	6.201	9.684	10.721
1041	5.720	6.201	9.684	10.721
1042	5.720	6.201	9.684	10.721
1031	5.720	6.201	9.684	10.721
1032	5.720	6.201	9.684	10.721
1033	5.720	6.201	9.684	10.721
1034	5.720	6.201	9.684	10.721
1052	5.720	6.201	9.684	10.721
1051	5.720	6.201	9.684	10.721
106	5.720	6.201	9.684	10.721
107	5.720	6.201	9.684	10.721
108	5.720	6.201	9.684	10.721
109	5.720	6.201	9.684	10.721
100	5.720	6.201	9.684	10.721
201	6.466	7.009	10.947	12.120
202	5.720	6.201	9.684	10.721
203	5.720	6.201	9.684	10.721
200	5.720	6.201	9.684	10.721
CLEAR	4.758	5.158	8.055	8.918
4012	4.942	5.357	8.366	9.263
403	4.942	5.357	8.366	9.263
4567	4.942	5.357	8.366	9.263
501	5.248	5.689	8.884	9.836
502	5.248	5.689	8.884	9.836

500	5.248	5.689	8.884	9.836
301	7.119	7.717	12.052	13.343
302	5.248	5.689	8.884	9.836
303	5.248	5.689	8.884	9.836
300	5.248	5.689	8.884	9.836
304	5.248	5.689	8.884	9.836
305	5.248	5.689	8.884	9.836
306	5.248	5.689	8.884	9.836
4890	5.649	6.123	9.563	10.588
4110	5.649	6.123	9.563	10.588
4234	5.649	6.123	9.563	10.588
701	5.649	6.123	9.563	10.588
702	5.427	5.883	9.188	10.173
700	4.658	5.050	7.886	8.731
800	5.324	5.772	9.014	9.980
801	5.063	5.488	8.571	9.490
804	4.052	4.392	6.860	7.595
805	4.874	5.284	8.252	9.136
806	3.610	3.913	6.111	6.766
807	3.687	3.997	6.242	6.911
808	3.077	3.336	5.210	5.768

Results

Hypothetical model results are often inconsistent with actual stream gage results for common events. Possible reasons for inconsistencies include 1) the starting storage assumptions at reservoirs can vary 2) the model strictly follows flood control reservoir operation rules while operators may deviate from operation rules during easily controlled events 3) possible agricultural diversions to water crops. To produce a more realistic 0.5 through 0.05 AEP (2-yr through 20-yr) events, a graphical regulated frequency curve is produced from historic data (post-Indian Valley Dam construction) at the Cache Creek at Yolo gage, shown in Plate 5. For events more rare than a 0.05 AEP (20-yr), the HEC-HMS model results are adjusted to provide a good match with the Cache Creek at Rumsey gage unregulated peak, 1-day and 3-day curve quantiles.

Overall, the AEP computed hydrographs match well with the duration frequency curve flows at Rumsey. Table 12 compares the computed HEC-HMS flows with extracted AEP frequency flows. Additionally, Table 13 compares the regulated HMS model computed flows at the outlet of Cache Creek with the graphical frequency curve at Yolo gage. The 1-day maximum flows from the hydrologic model are expected to be slightly higher than the maximum 1-day flows in the unregulated frequency curve since the flows from the hydrologic model is a 24-hr maximum flow. The flows used to compute the 1-day frequency curve are obtained from gages that measure flow from 12AM to 12AM, which can effectively cut off some portion of the maximum 24 hours of a hydrograph.

The computed 0.01 event hydrographs are scaled by 0.15, 0.36, 0.52, 0.58, and 0.85 in HEC-HMS to get the 0.5, 0.2, 0.1, 0.05, and 0.02 AEP hydrographs, respectively, while the 0.005 hydrographs are scaled by 1.14 to get the 0.002 hydrographs. Scaling the 0.005 AEP hydrographs to produce a 0.002 AEP hydrographs resulted in a better match to the peak, 1-day, and 3-day volumes of the Rumsey gage frequency curve when compared to scaling the .01 AEP event. The less common event ratios (0.02, 0.01, 0.005, and 0.002) are adjusted to match the unregulated frequency curve at Rumsey while the more common event ratios (0.5, 0.2, 0.1, and 0.05) are adjusted to match the regulated frequency curve at the Yolo gage. The Cache Creek at Yolo gage reflects actual regulated flow values, which is of interest to this study; therefore, the hydrographs for the more common events are calibrated to the regulated Yolo curve. However, the limited channel capacity leading to the Yolo gage confines the calibration to just the common events. The less frequent events are calibrated to the unregulated Rumsey gage since the channel contains flows greater than 38,000 cfs and statistics can be calculated to determine the 0.005, and 0.002 AEPs. Although the peak 0.005 and 0.002 AEPs do not exactly match the peak flow frequency curve, the computed volumes are within reason to the duration curves. More confidence is given to the duration curves than the peak flow frequency curve for such rare frequencies.

Table 12 AEP flows extracted from the unregulated Rumsey frequency curves and simulated hydrographs

AEP	Duration	Frequency Curve	HEC-HMS Hydrograph	% Difference
0.50	**Peak**	**18,200**	**14,915**	**-18%**
	1-Day	**8,300**	**9,068**	**9%**
	3-Day	**5,300**	**6,420**	**21%**
0.20	**Peak**	**33,300**	**32,411**	**-3%**
	1-Day	**16,800**	**18,395**	**9%**
	3-Day	**11,300**	**12,129**	**7%**
0.10	**Peak**	**44,800**	**45,742**	**2%**
	1-Day	**22,800**	**25,510**	**12%**
	3-Day	**15,700**	**16,508**	**5%**
0.05	**Peak**	**56,600**	**50,741**	**-10%**
	1-Day	**28,500**	**28,180**	**-1%**
	3-Day	**20,100**	**18,151**	**-10%**
0.02	Peak	72,900	73,240	0%
	1-Day	35,400	40,201	14%
	3-Day	25,800	25,574	-1%

0.01	Peak	85,800	85,748	0%
	1-Day	40,300	46,881	16%
	3-Day	29,900	29,721	-1%
0.005	Peak	99,200	93,891	-5%
	1-Day	44,800	51,595	15%
	3-Day	33,800	33,452	-1%
0.002	Peak	118,000	106,709	-10%
	1-Day	50,300	58,500	16%
	3-Day	38,700	37,854	-2%

*0.50 through 0.05 chance events shown in bold font were adjusted to match regulated frequency curve at Yolo gage as shown in Table 13.

Table 13 regulated Yolo gage at Woodland peak flow frequency curve and simulated hydrograph

Regulated AEP	Duration	Frequency Curve	HEC-HMS Hydrograph	% Difference
0.50	Peak	9,900	10,700	8%
0.20		22,000	22,400	2%
0.10		30,000	31,200	4%
0.05		34,000	34,600	2%

Lower Cache Cr Residual Floodplain Analysis:

Because high stages and flows in the lower Cache Creek watershed can be the result of high flow on any of the three major tributaries, Cache Creek, Colusa Drain or the Yolo Bypass, thus a coincident flow and residual floodplain analysis of the Lower Cache Cr Watershed is performed. A detailed description and results of this analysis is found in Attachment 1: Hydrographs for Residual Floodplain Mapping.

2001 USACE Feasibility Study

Table 14 compares the AEP flows computed in the 2001 Feasibility with the flows computed in the 2012 update. Table 15 shows the percent difference in flow.

Table 14 AEP Simulated Regulated Flow Comparisons between previous study to current study at Road 94b

AEP (1)	Peak flow (cfs)(2) USACE 2001	Peak flow (cfs)(2) USACE 2012	24-hour flow (cfs)(3) USACE 2001	24-hour flow (cfs)(3) USACE 2012	72-hr flow (cfs)(4) USACE 2001	72-hr flow (cfs)(4) USACE 2012
0.02	53,000	49,900	43,500	38,600	29,500	29,200
0.01	63,000	58,300	54,500	45,000	36,500	34,000
0.005	70,000	65,400	62,000	50,800	41,500	39,300
0.002	78,500	74,200	72,500	57,500	48,000	45,000

*USACE 2001 statistics obtained from 2001 Feasibility report

Table 15 AEP Regulated Percent Flow Difference

AEP (1)	Difference (%)(2)		
	Peak	24-hour	72-hour
0.02	-6%	-11%	-1%
0.01	-7%	-17%	-7%
0.005	-7%	-18%	-5%
0.002	-5%	-21%	-6%

*Difference = (current study – 2001 study)/2001 study x 100

For the peak and 3-day, the difference in flows are no greater than 10%, while the 24-hr differences range from 12% to 22%. The large differences in the 1-day AEP flows are a result of the changes made to the 1-day flow frequency curve, which incorporates the regional skew. Results show a more negative skew value reducing the flow towards the upper end of the curve. Table 16 compares the 2001 and 2012 frequency statistics. The 2001 unregulated flow frequency curve can be seen in the 2001 Cache Creek Feasibility report on Chart 12 (USACE, 2001).

Table 16 Bulletin 17B Frequency Statistics at Rumsey gage

	Mean		Standard Deviation		Skew	
Duration	2001	2012	2001	2012	2001	2012
Peak	4.233	4.243	0.355	0.327	-0.6	-0.291
1-day	3.895	3.868	0.426	0.418	-0.6	-0.758
3-day	3.741	3.669	0.410	0.446	-0.6	-0.699

*2001 period of record WY 1943-2000
*2012 period of record WY 1943-2012

Possible Impacts of Climate Change on Floods and Droughts

Projections of observed and climate altered hydrology indicate that future conditions will likely be warmer and possibly wetter in the Sacramento River Watershed of which Cache Creek is a major tributary. This means that the area could be subject to larger flood events because of the increase in moisture content of the storms impacting the region. Additionally, droughts could be more severe and longer lasting and this could lead increase frequency of large wildfires in the watershed thereby causing additional increases in runoff from burn scars. More detailed information is presented in the Climate Change Assessment in Attachment 2.

Adoption of Regulated Flow Frequency Curves

After matching the AEP hydrographs to the updated unregulated flow frequency curves at Rumsey, Indian Valley Dam is placed back in operation in the HEC-HMS model and the hydrographs are routed downstream to the selected analysis points to obtain AEP regulated flows. The AEP regulated flows computed at those points are adopted as the flow frequency curves for Central Valley Hydrology Study. The flows at those locations will be further routed downstream through an HEC-RAS model to estimate the AEP flows at the outlet to the Yolo Bypass. The unregulated-regulated flow frequency curves for the 2 analysis points are presented in Table 1 and Table 2 in the Executive Summary for this report.

Equivalent Record Length for Risk Analysis

EM 1110-2-1619 Table 4-5 (in Table 17 below) provides guidance for equivalent record lengths to be used in FDA (Flood Damage Analysis). Equivalent record length provides information needed to create confidence limits to the flow frequency curves. The flow frequency curves with confidence limits are sampled in Monte Carlo simulations in FDA along with stage and damage relationships. The equivalent record lengths for the main index points in the current study are shown in Table 18. A map of the index point location is provided in the Economic Appendix to the Lower Cache Creek Feasibility Study Report. The Cache Creek at Rumsey Frequency unregulated flow frequency curve was computed from 67 years of record. The runoff below the Rumsey gage does not typically add much flow to the peak in the lower watershed. As such, the equivalent record length is assigned as 67 years. The Yolo Bypass downstream of Putah Creek and the Colusa Basin at KRC-7 are assigned equivalent record lengths of 102 years and 25 years, respectively based on Table 4-5 below.

Table 17 Equivalent Record Length Guidelines from EM 1110-2-1619 table 4-5.

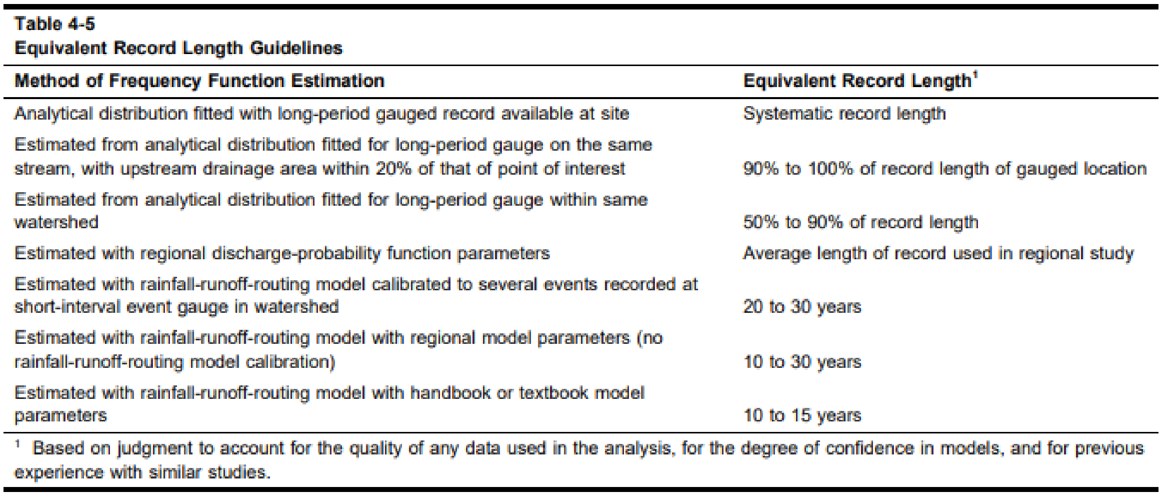


Table 4-5
Equivalent Record Length Guidelines

Method of Frequency Function Estimation	Equivalent Record Length[1]
Analytical distribution fitted with long-period gauged record available at site	Systematic record length
Estimated from analytical distribution fitted for long-period gauge on the same stream, with upstream drainage area within 20% of that of point of interest	90% to 100% of record length of gauged location
Estimated from analytical distribution fitted for long-period gauge within same watershed	50% to 90% of record length
Estimated with regional discharge-probability function parameters	Average length of record used in regional study
Estimated with rainfall-runoff-routing model calibrated to several events recorded at short-interval event gauge in watershed	20 to 30 years
Estimated with rainfall-runoff-routing model with regional model parameters (no rainfall-runoff-routing model calibration)	10 to 30 years
Estimated with rainfall-runoff-routing model with handbook or textbook model parameters	10 to 15 years

[1] Based on judgment to account for the quality of any data used in the analysis, for the degree of confidence in models, and for previous experience with similar studies.

Table 18 Index points and Equivalent Record Lengths used in the FDA Models.

Index Point	Analysis Location	Equivalent Record Length
P1	Cache Cr at Rumsey	67
P2	Cache Cr at Rumsey	67
P3	Cache Cr at Rumsey	67
P4	Cache Cr at Rumsey	67
P5	Cache Cr at Rumsey	67
P6	Yolo Bypass downstream of Putah Cr	102
P7	Colusa Basin Drain at point KRC-7	25
P8	Cache Cr at Rumsey	67

References

David Ford Consulting Engineers (DCF), 2007. “Cache Creek Hydrology Study Review, City of Woodland.”

Department of Water Resources (DWR), California Data Exchange Center (CDEC), http://cdec.water.ca.gov/ (accessed July 2012)

Department of Water Resources (DWR), Water Data Library (WDL). http://www.water.ca.gov/waterdatalibrary/ (accessed July 2012)

HEC, 2012. “HEC-SSP, Statistical Software Program. “Software Program, Version 2.0. Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, CA

U.S. Army Corps of Engineers (USACE), 1974. “Cache Creek Basin, Standard Project Floods: Office Report.”

U.S. Army Corps of Engineers (USACE), 1985. “Cache Creek Basin, Hydrology Review Report.”

U.S. Army Corps of Engineers (USACE), 1995. “Hydrology for Cache Creek, Yolo County, California, Appendix B: Office Report, Reconnaissance Study.”

U.S. Army Corps of Engineers (USACE, 2001). “Lower Cache Creek Feasibility Study, Yolo County, California, Appendix C.”

U.S Geological Survey (USGS), 1982. “Comparison of Four Streamflow Record Extension Techniques: U.S Geological Survey Water Resource Research,” Vol 18, No.4, PG 1081-1088

U.S. Geological Survey (USGS), 2010. “Regional Skew for California, and Flood Frequency for Selected Sites in the Sacramento–San Joaquin River Basin, Based on Data through Water Year 2006,” U.S. Geological Survey Scientific Investigations Report 2010–5260.

U.S Geological Survey (USGS), 2011. “Development of regional skews for selected flood durations for the Central Valley Region, California, based on data through water years 2008-09,” U.S. Geological Survey Scientific Investigations Report.

U.S Geological Survey (USGS). Current Water Data for USA. http://waterdata.usgs.gov/nwis/rt (accessed July 2012)

Yolo FloodSafe, 2009. “Cache Creek Hydrology Update, Flood SAFE Yolo Pilot Program.”

Attachment 1: Hydrographs for Residual Floodplain Analysis.

Memorandum for Record

Date: April 3, 2014

Study: Lower Cache Creek Feasibility Study (LCCFS)

Subject: Hydrographs for residual floodplain mapping

This memo documents the development of upstream boundary hydrographs to support hydraulic modeling of residual floodplains. The hydrographs were developed with the goal of being sufficient to support the study needs while adopting an analysis level of detail consistent with the Corps 3x3x3 framework.

Based on coordination with the Hydraulic Analysis section, hydrographs were needed for the following 3 reaches: Cache Creek, Colusa Drain, and Yolo Bypass. At each location, hydrographs were needed to support development of residual floodplains corresponding to the following annual exceedence probability (AEP) values: 0.5, 0.20, 0.10, 0.05, 0.02, 0.01, 0.05, and 0.02.

High stages in the study area can result from high flow on a tributary, Cache Creek or Colusa Drain, or from a high flow in the Yolo Bypass. The level of effort that would be required to 1) develop relations of coincidence between the bypass and tributaries, and 2) generate composite residual floodplains representing these flow combinations, was considered unnecessary to satisfy the level of detail needed to adequately define the residual floodplains. Therefore, a simplification was made in developing the boundary hydrographs: the peak regulated flows occurring on each of the 3 reaches would have the same AEP. In other words, to support development of the 0.01 residual floodplain, an event having 0.01 peak flow on each of the boundary reaches would be developed.

Hydrographs developed as part of the Central Valley Hydrology Study (CVHS) served as a starting point for developing LCCFS residual floodplain hydrographs. The CVHS had available system-wide simulations of 4 storm patterns, for a wide range of scale factors applied to each event. The scaled events were routed through ResSim in the upper reaches and HEC-RAS in the lower (main stem) portions of the system. At the time, only the ULOP/ULDC levee condition had been simulated. This condition consists of urban levees which do not fail and do not overtop, and non-urban levees which have been restored to design height and overtop without failure.

The general steps for developing LCCFS hydrographs for residual floodplain analysis consisted of:

1. Select one CVHS storm pattern for definition of hydrograph shape at all 3 reaches. The December 1964 event pattern was selected as it provided a simple single-wave shape in both the Yolo Bypass and tributaries (Cache Creek & Colusa Drain).
2. Identify target quantile flows in each reach based on flow-frequency curves obtained from previous or in-process studies.
3. For each location and each target AEP, select CVHS scale factor event hydrograph having peak flow nearest to the target flow.
4. If necessary, further scale the selected hydrographs to provide an improved match to the target (quantile) AEP peak flows.

Details on how these 4 steps were implemented at each for each of the 3 reaches are described below. Flow-frequency curves, which are used here to define the AEP flows on each reach, were developed prior to this effort. The source of each flow-frequency curve is noted.

Location: Cache Creek at Yolo

Source hydrograph: HEC-ResSim hydrographs for 1964 event pattern from CVHS.
Frequency curve: From CVHS rainfall-runoff analysis of Cache Creek, location CAC-12 (Road 9Bb).

Table 1 – Cache Creek at Yolo peak flow summary

1/AEP	Peak flow frequency curve (cfs)	CVHS 1964 event scale factor	Further scaling for LCCFS	Boundary hydrograph peak flow (cfs)
2	9,900[1]	0.60	1.00	10,085
5	22,000[1]	1.30	1.00	19,055
10	31,500[2]	2.40	1.00	30,802
20	35,300[1]	2.60	1.00	38,205
50	49,900[2]	3.40	1.00	49,463
100	58,300[2]	3.40	1.20	59,357
200	65,400[2]	3.40	1.34	66,282
500	74,200[2]	3.40	1.52	75,186

1) Peak flow frequency curve for Yolo gage (Table 13 of 2014 Cache Creek report).
2) Peak flow frequency curve for Cache Creek at Road 94B (Table 2 of 2014 Cache Creek report).

Location: Knights Landing Ridge Cut Slough (upstream end)

Source hydrograph: CVHS local flow hydrographs for 1964 event pattern from CVHS.

Frequency curve: From draft CVHS rainfall-runoff analysis of Colusa Basin, location KRC-7

Table 2 – Knights Landing Ridge Cut Slough peak flow summary

1/AEP	Peak flow frequency curve (cfs)	CVHS 1964 event scale factor	Further scaling for LCCFS	Boundary hydrograph peak flow (cfs)
2	14,246	0.40	0.66	14,174
5	20,041	0.40	1.00	21,476
10	24,827	0.40	1.16	24,912
20	30,213	0.60	0.89	28,670
50	33,804	0.60	1.00	32,214
100	37,541	0.60	1.17	37,690
200	41,262	0.80	1.00	42,951
500	46,135	0.85	1.00	45,636

Location: Yolo Bypass – downstream of Fremont Weir

Source hydrograph: HEC-RAS ULOP hydrographs (STA 56.76) for 1964 event pattern.

Frequency curve (1/AEP = 2 through 50): from draft graphical curve at Yolo Bypass near Woodland.

Frequency curve (1/AEP = 100 through 500): CVHS regulated frequency curve for Yolo Bypass at Putah Creek (PUC-0, HEC-RAS STA 38.522).

Table 3 – Yolo Bypass downstream of Fremont Weir peak flow summary

1/AEP	Peak flow frequency curve (cfs)	Hydrograph peak flow at frequency curve location (cfs)	CVHS 1964 event scale factor	Further scaling for LCCFS	Boundary hydrograph peak flow (cfs)
2	33,266	30,990	0.20	0.789	30,990
5	165,959	156,458	0.40	1.185	156,458
10	228,034	213,682	0.60	1.127	213,682
20	239,883	223,840	0.80	0.870	223,840
50	357,273	332,424	1.00	1.000	332,424
100	532,467	576,423	1.45	1.000	429,231
200	594,769	667,369	1.65	1.000	479,382
500	762,183	753,270	1.80	1.000	534,785

Location: Sacramento Bypass (downstream end)

These hydrographs were scaled to be consistent (same scaling) with hydrographs developed for Yolo Bypass downstream of Fremont Weir. In so doing, a consistent total flow at Yolo Bypass at Putah Creek is preserved. Including this hydrograph is advised if the hydraulic model extends to this location.

Table 4 – Sacramento Bypass peak flow summary

1/AEP	Peak flow frequency curve (cfs)	CVHS 1964 event scale factor	Further scaling for LCCFS	Boundary hydrograph peak flow (cfs)
2	n/a	0.20	0.789	228
5	n/a	0.40	1.185	44,897
10	n/a	0.60	1.127	65,561
20	n/a	0.80	0.870	72,849
50	n/a	1.00	1.000	100,477
100	n/a	1.45	1.000	123,453
200	n/a	1.65	1.000	162,553
500	n/a	1.80	1.000	193,675

Boundary hydrographs to support mapping of LCCFS residual floodplains were provided in HEC-DSS file “Lower Cache resid flood flows 12-19-2013 update.dss”.

Brad Moore, PE

REFERENCES:

CVHS ULOP frequency curve for analysis location PUC-0, April 11, 2013.

CVHS Cache Creek Watershed Hydrologic Analysis, February 27, 2014.

(draft) CVHS Colusa Basin Drain Watershed Hydrologic Analysis, December 30, 2011.

Attachment 2: Climate Change Impact Assessment.

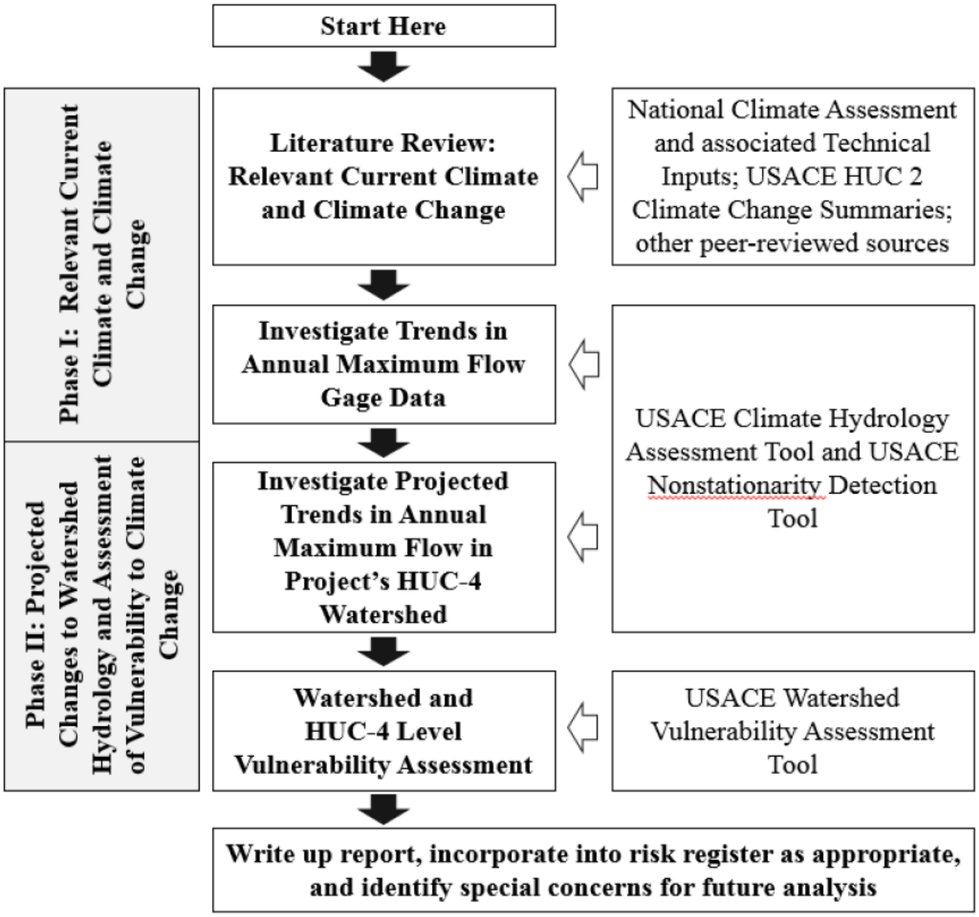
Climate Change Impacts

Overview:

Introduction: ECB No. 2016-252018-14 requires Corps planning studies to provide a qualitative description of climate change impacts to inland hydrology. The objective of ECB 2016-25 is to enhance USACE climate preparedness and resilience and reduce vulnerabilities by incorporating relevant information about climate change impacts in hydrologic analyses for new and existing USACE projects. The purpose of this section is to meet the requirements as set forth in the ECB. This includes applying the qualitative analysis guidance to inland hydrology of the Sacramento River Valley including the Cache Creek Watershed, and facilitating the incorporation of climate change impacts on hydrologic analyses in plans and designs for the Lower Cache Creek Flood Control Project (See Figure 1). Up to the present time, USACE projects and operations have generally proven to be robust in the face of natural climate variability over their operating life spans. However recent scientific evidence shows, that in some geographic locations and for some impacts relevant to USACE operations, climate change is shifting the climatological baseline about which natural climate variability occurs and the range of the variability may be changing as well (USACE 2015, USGCRP 2014). Climate change information for hydrologic analyses includes direct changes to hydrology through changes in temperature, precipitation, evaporation rates, and other climate variables, as well as dependent basin responses to climate drivers, such as sedimentation loadings.

Two phases are required to conduct the qualitative analysis required by the ECB (Figure 1). The analysis includes consideration of both past (observed) changes as well as potential future (projected) changes to relevant hydrologic inputs. The qualitative approach on its own will not produce binding numerical outputs or alter the numerical results of the calculations made for other, non-climate aspects of the required hydrologic analyses. However, the qualitative analysis can inform the decision process related to future without project conditions, formulation and evaluation of the performance of alternative plans, and other decisions related to project planning, engineering, operation, and maintenance. Some examples of how a qualitative assessment may affect a project design include considering whether the project could be modified in the future, whether a strategy should be considered to accommodate projected future conditions, or whether one project alternative can be judged to reduce vulnerabilities or enhance resilience more than the others.

At the time of this study, the methods for incorporating climate change into the planning process are still developing. Additional guidance documents will be published in the future to support quantitative analyses of climate threats and impacts, including the detection of trends, attribution of these trends to climate change, and projections of future trends.


Start Here
Phase I: Relevant Current Climate and Climate Change
Literature Review: Relevant Current Climate and Climate Change
National Climate Assessment and associated Technical Inputs; USACE HUC 2 Climate Change Summaries; other peer-reviewed sources
Investigate Trends in Annual Maximum Flow Gage Data
USACE Climate Hydrology Assessment Tool and USACE Nonstationarity Detection Tool
Phase II: Projected Changes to Watershed Hydrology and Assessment of Vulnerability to Climate Change
Investigate Projected Trends in Annual Maximum Flow in Project's HUC-4 Watershed
Watershed and HUC-4 Level Vulnerability Assessment
USACE Watershed Vulnerability Assessment Tool
Write up report, incorporate into risk register as appropriate, and identify special concerns for future analysis

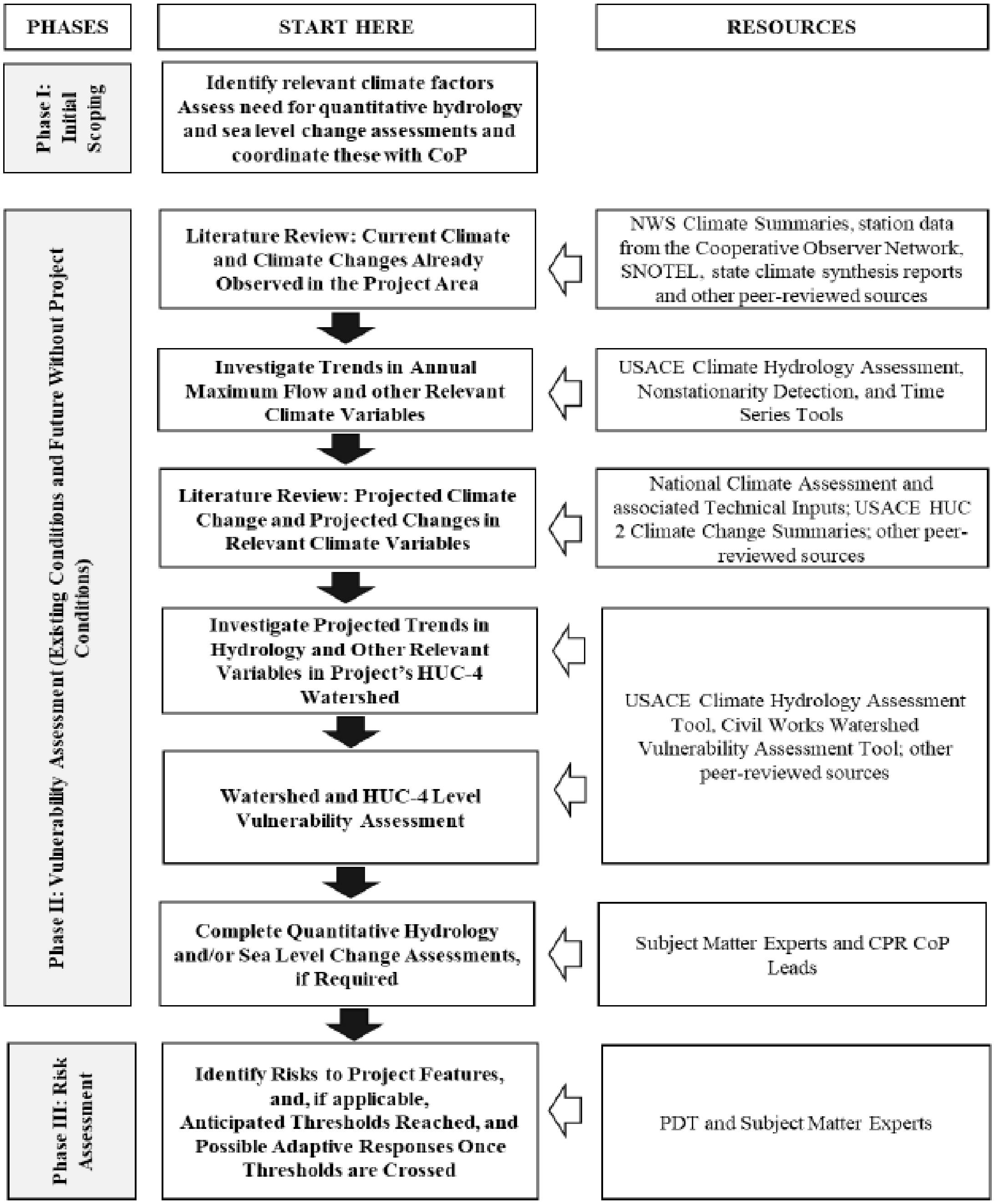


Figure 23. Flow Chart describing the qualitative climate change assessment to be used in Hydrology studies for Corps projects. From ECB 2016-252018-14, Attachment B

Project Description:

The area addressed in this report includes the entire Cache Creek watershed from the eastern foothills of the Coast Range Mountains to the western levees of the Yolo Bypass. (See Figure 2.) The area includes parts of Yolo, Colusa, and Lake Counties. The focus of the report is flood damage reduction opportunities specific to the problem/study area, the city of Woodland, and areas north and east of Woodland. The purpose of this study is to identify economically feasible and environmentally sensitive methods to reduce flood-related damages to Woodland and adjacent areas. Without a flood damage reduction project, average annual flood damages to real property from overflows from Cache Creek are expected to be about $12.4 million, most of which would be in Woodland. Other adverse effects and losses would include the potential for flood-related loss of life, contamination from sanitary sewage and hazardous materials, and the extended closure of the section of Interstate 5 (I-5) east of Woodland.

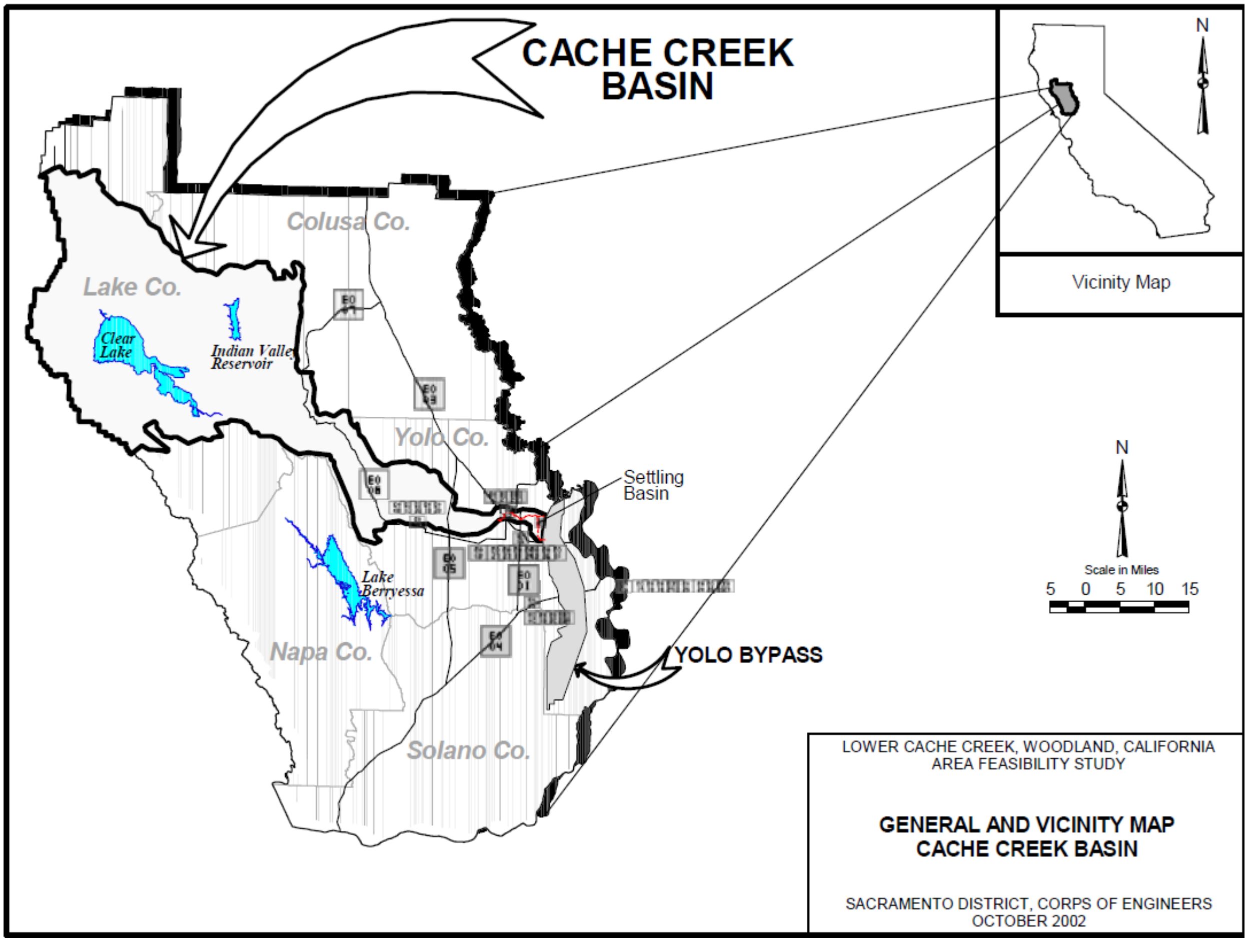


Figure 45. Map of the Study Area showing major reservoirs and watersheds (from USACE 2003).

Literature Synthesis:

Recent surface observations of temperature and precipitation in the southwest United States including the Central Valley of California indicate a significant warming trend starting about 1970 (NOAA, 2013, Goodrich, 2007). This recent warming trend is especially noticeable in the minimum temperatures during the interval from 1990 to about 2005. This warming is in addition to more general warming trends from about 1890 to the present. The reasons cited among scientists include natural multi-decadal oscillations, increased greenhouse gases in the atmosphere, land use changes, and urban heat island effects (NOAA, 2013; Levi, 2008; Barnett et al. 2008; Das et al., 2011). Current reported temperature trends and future climate projections indicate warmer winter temperatures and some changes in precipitation in the Central Valley, and this leads to an increased risk of flooding from large storms (CH2M Hill 2014, NOAA 2013).

Projected changes in future climate contain significant uncertainties related to our understanding and modeling of the earth's systems, as well as our ability to forecast future development and greenhouse gas emission pathways. There are also a great deal of uncertainties associated with simulating changes at a local scale and at a time-step relevant to hydrologic analysis (USACE 2015, USGRP 2014).

USACE Climate Preparedness and Resilience Community of Practice Literature Review:

A 2015 USACE climate literature report synthesizes literature for HUC-2 Region 18 (California Region; **Error! Reference source not found.**), focusing on the identification and detection of climate trends (USACE 2015). The approach at USACE is to consider the questions in need of climate change information at the geospatial scale where the driving climate models retain the climate change signal. As of 2015, USACE judged that the regional, sub-continental climate signals projected by the driving climate models were coherent and useful at the scale of the 2-digit HUC and that confidence in the driving climate model outputs declines below the level of a reasonable trade-off between precision and accuracy for areas smaller than the watershed scale of the 4-digit HUC.

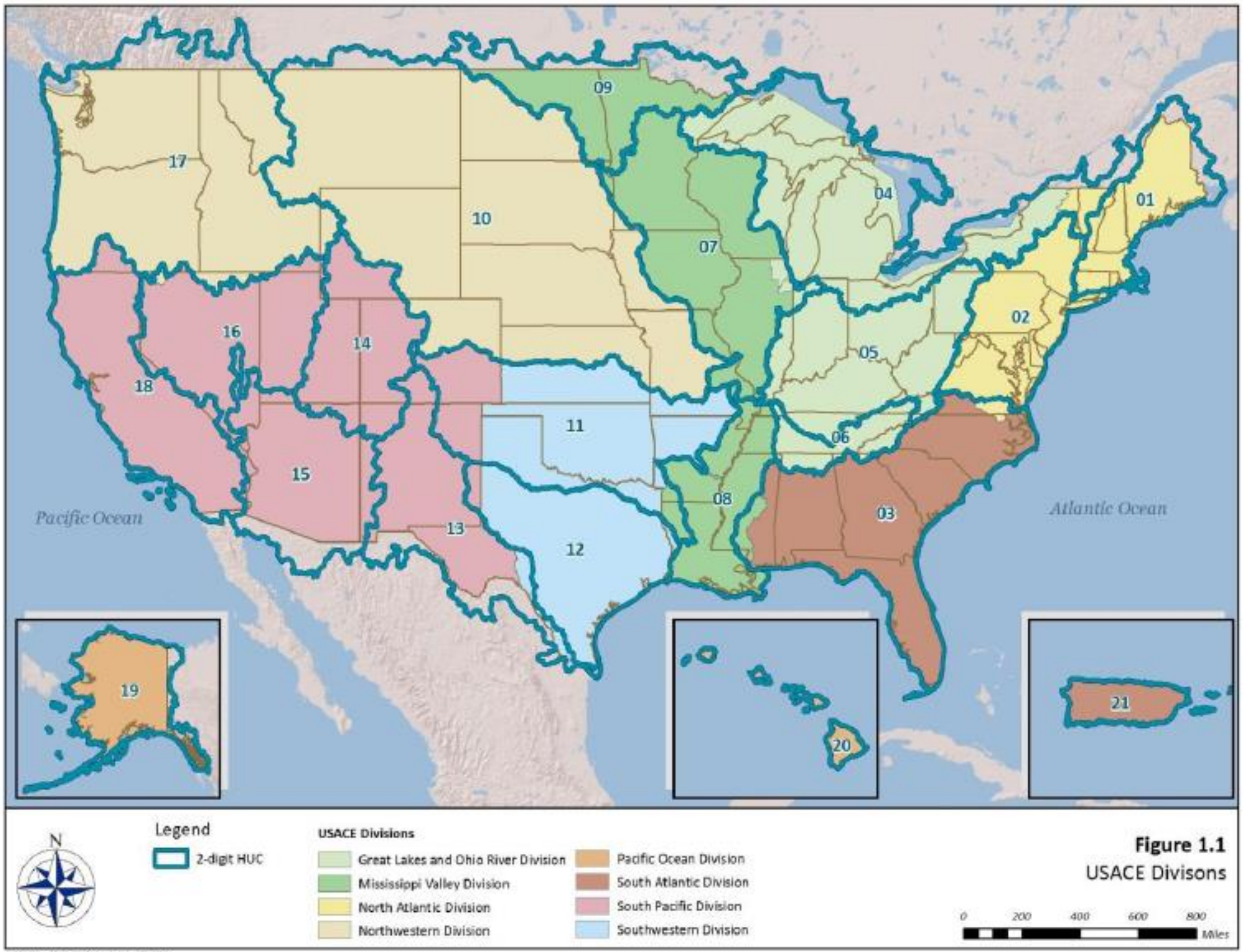


Figure 3: HUC-2 Region for USACE Literature Synthesis (USACE 2015)

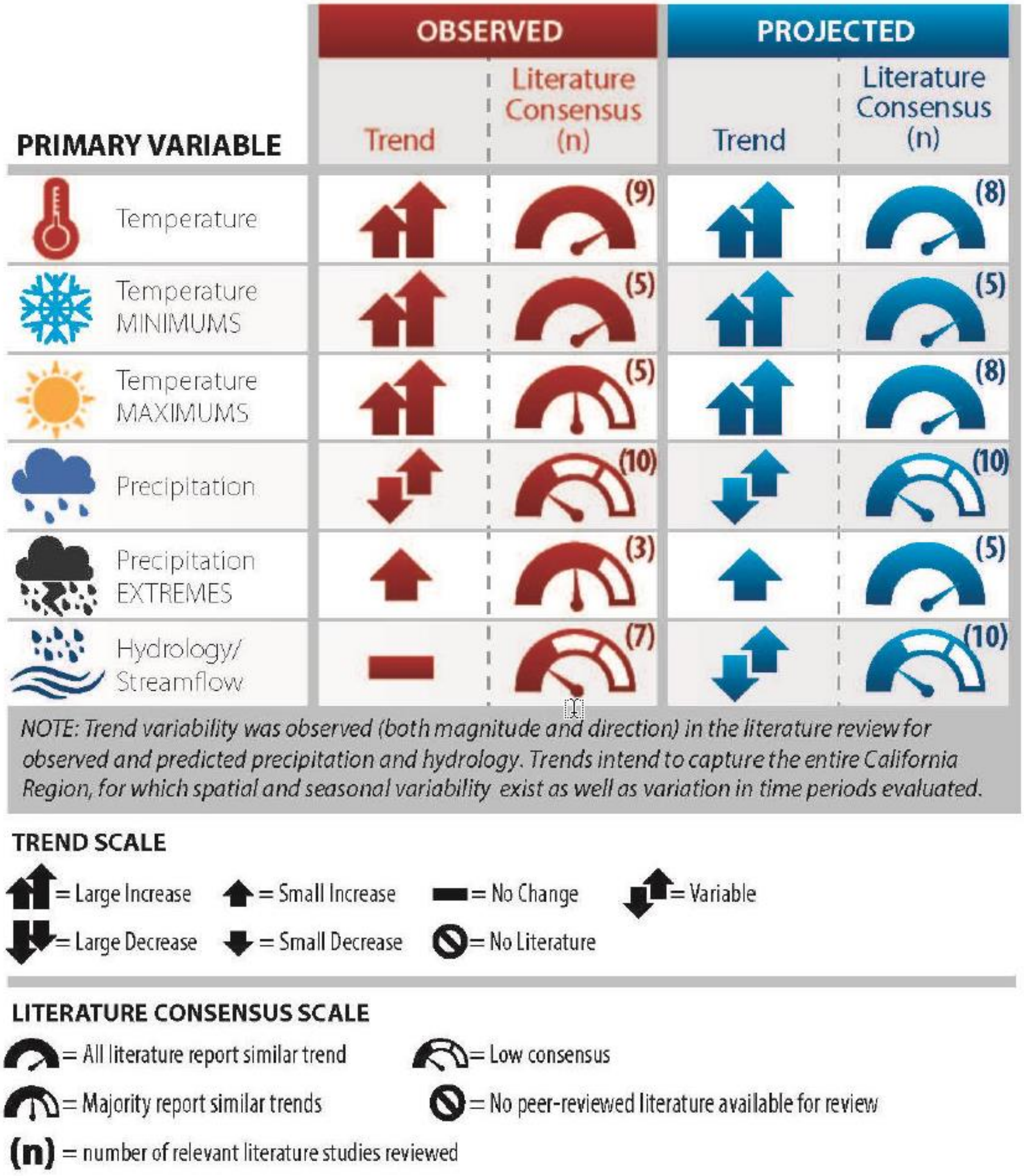
Key findings of the USACE literature review are listed below. Figure 4 summarizes the key variables identified in the report and variables for which consensus exists about current or projected trends.

- In general, there appears to be an increasing trend in both minimum and maximum historical temperatures in the California Region with relatively strong consensus in the literature.
- Strong consensus exists in the literature that projected mean, minimum, maximum, and extreme temperatures in the study region show an increasing trend over the next century.
- No consistent trend has been identified in the region’s historical precipitation data, with little consensus across the literature.
- Large variability exists, spatially, and across model projections, for future precipitation trends within the California Region. There is little consensus across the literature as to how precipitation trends will change, although many studies recognize this variability.
- Despite the low consensus in precipitation trends, extreme precipitation events are projected to increase in intensity.
- Literature on observed streamflow trends in the California Region have very low consensus. The majority of studies suggest that no statistically significant trends have been identified in the

region’s streamflow data for the latter half of the 20th century, although advances in the timing of spring runoff and reductions in April 1 SWE were observed.

The USACE literature synthesis also summarizes potential climate impacts by line of business. For the ecosystem restoration line of business in the California Region, the report lists the following impacts:

- Increased ambient air temperatures and heat wave days will result in increased water temperatures. This may lead to water quality concerns, particularly for the dissolved oxygen levels, which are an important water quality parameter for aquatic life. Increased air temperatures are associated with the growth of nuisance algal blooms and influence wildlife and supporting food supplies.
- Increased storm intensities and frequencies may pose complications to planning for ecosystem needs and lead to variation in flows. This may be particularly true during dry years, when water demands for conflicting uses may outweigh water supply.



PRIMARY VARIABLE	OBSERVED Trend	OBSERVED Literature Consensus (n)	PROJECTED Trend	PROJECTED Literature Consensus (n)
Temperature	⇈	(9)	⇈	(8)
Temperature MINIMUMS	⇈	(5)	⇈	(5)
Temperature MAXIMUMS	⇈	(5)	⇈	(8)
Precipitation	⇅	(10)	⇅	(10)
Precipitation EXTREMES	▲	(3)	▲	(5)
Hydrology/ Streamflow	▬	(7)	⇅	(10)

NOTE: Trend variability was observed (both magnitude and direction) in the literature review for observed and predicted precipitation and hydrology. Trends intend to capture the entire California Region, for which spatial and seasonal variability exist as well as variation in time periods evaluated.

TREND SCALE

⇈ = Large Increase ▲ = Small Increase ▬ = No Change ⇅ = Variable
⇊ = Large Decrease ▼ = Small Decrease ⊘ = No Literature

LITERATURE CONSENSUS SCALE

◠ = All literature report similar trend ◠ = Low consensus
◠ = Majority report similar trends ⊘ = No peer-reviewed literature available for review
(n) = number of relevant literature studies reviewed

Figure 4. Summary of USACE Literature Synthesis (USACE 2015)

Climate models suggest the projected temperature signal is strong and temporally consistent. It has been projected that air temperatures will increase by over 3 degrees Fahrenheit by the middle of the current century. All projections are consistent in the direction of the temperature change, but vary in terms of other hydrometeorological variables (precipitation, streamflow, seasonality, variability, extremes etc.). For example, annual precipitation projections are not directionally consistent. Multi-decadal variability complicates period precipitation analysis. Regional trends indicate that it is more likely for the upper Sacramento Valley to experience equal or greater precipitation. Extreme precipitation is likely to increase (Das et al., 2013; NOAA, 2013; CH2M HILL, 2014).

Simulations with Global Climatic Models (GCMs) are mostly consistent in predicting that future climate change will cause a general increase in air temperatures in California during the critical months when the most precipitation falls. November through March is the period when the most significant and damaging storms hit this region. The American River, which flows through Folsom, has many high elevation mountains with peaks ranging from 5,000 to 11,000 feet above sea level. Significant portions of these watersheds are covered in snowpack during the winter months. As temperatures warm during the century, it is expected that the snowpack line (demarcation between bare ground and snowpack-covered ground) will recede to higher elevations, and a greater percentage of the drainage area of individual watersheds will incur rainfall, as opposed to snowfall (DWR 2017,USACE, 2015, USGRP 2014, NOAA 2013). This trend is expected to cause significant increases in runoff volume in the high elevation watersheds for large storms. Another impact of warmer air temperatures on the seasonality of flooding in the study area is that the spring snowpack will melt earlier, thus increasing reservoir inflows at a time when spring storms still threaten the region and empty space is still required to attenuate flood inflows. In other words, flood control operations at reservoirs could become more difficult in the spring months. The snowpack typically begins to melt in late March or early April. With the projected increase in temperatures during the coming decades, the snowpack will begin to melt earlier in the year (i.e. early to mid-March or sooner). This will overlap the time in which large atmospheric river storms normally hit the region. Therefore, more rain on snow events are likely to occur. Additionally, more of the watershed will be exposed to rainfall runoff processes because the snowlines on average will be higher than during the base period. The trend towards earlier spring snowmelt has already been observed in the Sierra Nevada Mountains over the last century (DWR 2017, USACE 2015, USGRP, 2014, NOAA 2013).

With less certainty than above, some global climate models indicate that future conditions may increase the amount of moisture in the storms, since warmer air holds more moisture than cold air. When air cools, condensation occurs, which causes precipitation. It is possible that due to increasing temperatures, atmospheric rivers will have higher precipitation depths in the future because the warmer air can hold more moisture than cooler air, and this will lead to an increase in the size of runoff peaks and volumes. The largest storms that typically impact the west coast of the United States are termed “pineapple express” or more recently “atmospheric rivers” by meteorologists. This type of event occurs when a long plume of saturated air moves northeastward from the low-latitudes of the Pacific Ocean and mixes with cold dense air moving southward from the arctic. The mixing of cold and warm air causes a storm front. As these very moist storms move eastward over the Sierra Mountain Range, the air is pushed to higher elevations where more cooling occurs, thus increasing condensation and precipitation. Historically, the largest and most damaging floods in the Central Valley of California are caused by atmospheric rivers (USACE 2015, USGRP 2014, CH2M HILL 2014, NOAA 2013).

Climate projections (CMIP5) consistent with the most recent Intergovernmental Panel on Climate Change (IPCC) Assessment Report 5 (AR5) are available to evaluate future, projected climate (Taylor et al., 2012). Three on-going, DWR-supported research studies were initiated in 2013, which apply CMIP5 data to hydrologic analysis. These include the Climate Variability Sensitivity Study (completed by the Corps in 2014) which evaluated the effects of increasing temperature only (not precipitation) on flood runoff on selected watersheds in the San Joaquin River Valley. The results from this study indicate that warmer temperatures would reduce the volume of the antecedent snowpack and increase the storm runoff due to more precipitation falling as rain and larger portions of the watersheds contributing runoff. The other two include the Atmospheric River Study (led by Scripps Institute of Oceanography/USGS) investigating indices and future projections of the major flood-producing atmospheric processes, and the Watershed Sensitivity Study (led by UC Davis) investigating the atmospheric and watershed conditions that contribute to the extreme flows on several Central Valley watersheds. This study shows that annual runoff and event runoff will occur earlier in the season as a result of increasing temperatures and declining snowpack. The California Department of Natural Resources (DWR) has invested millions of dollars to study climate impacts on the flood control system in the Central Valley. Results were recently published in the *Draft 2017 CVFPP Update– Climate Change Analysis Technical Memorandum* dated March 2017. The results are based on downscaled outputs from a subset of the Coupled Model Intercomparison Project – Phase 5 (CMIP5) global climatic models, which DWR has determined are most suitable for modeling climate change on the west coast of California. The downscaled results are fed into a calibrated variable infiltration capacity (VIC) rainfall runoff model of the Sacramento and San Joaquin River watersheds. The DWR analysis relies upon existing, available climate projections and hydrologic modeling to represent a range of potential future changes to unregulated flow volumes due to climate change. The draft results provided by DWR have projections of volume change for 1-day and 3-day durations at many index points throughout the Sacramento River, including the American River Watershed. DWR results indicate the potential for an increase in 1-day and 3-day streamflow peaks within the study area.

Phase I Current Climate Observations:

Historical Precipitation and Temperature Data

Historical temperature, precipitation, and drought index data for 1895-2018 are available from NOAA National Centers for Environmental Information (Figure 5 - Figure 10). California Climate Division 2 represents Sacramento Drainage (HUC 1802) which includes the Yuba River Watershed (NOAA NCEI 2018).

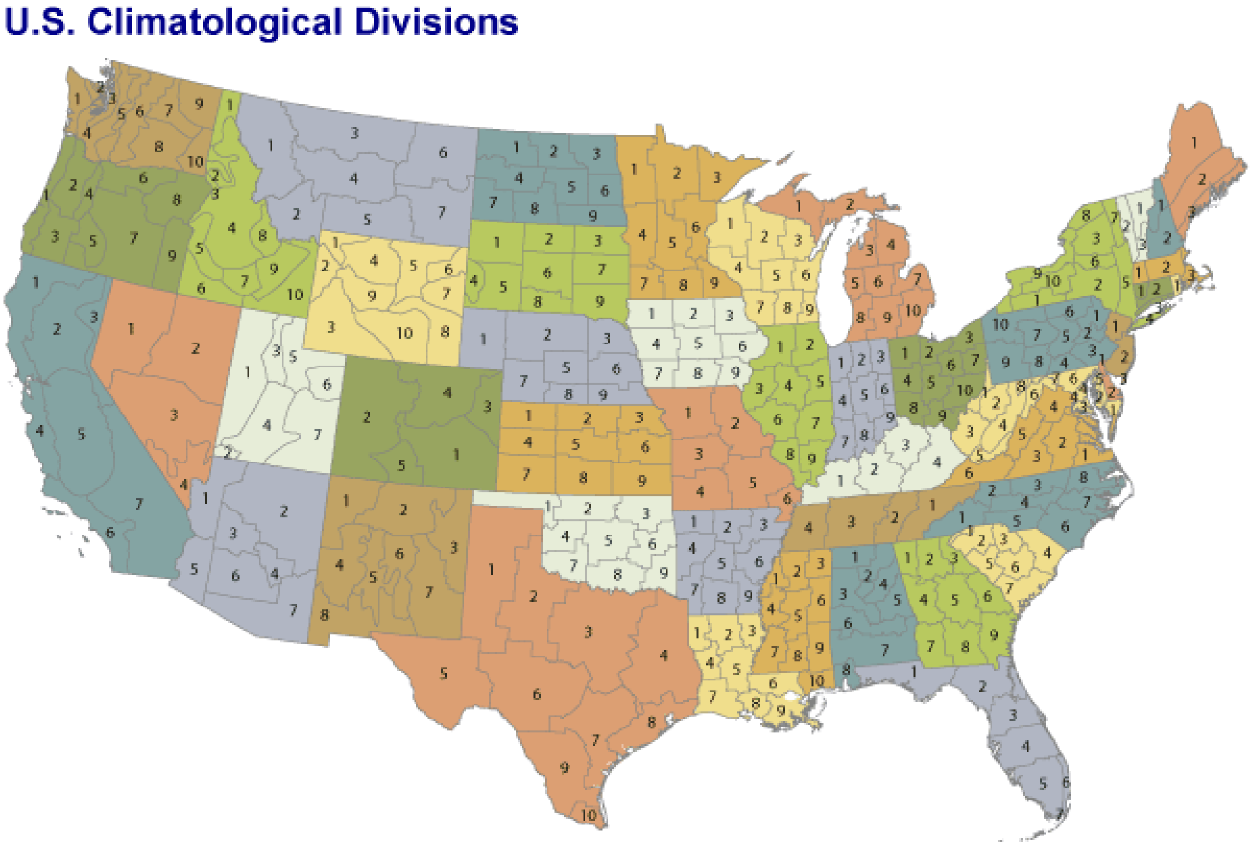


Figure 5 US Climatological Divisions (NOAA NCEI 2018)

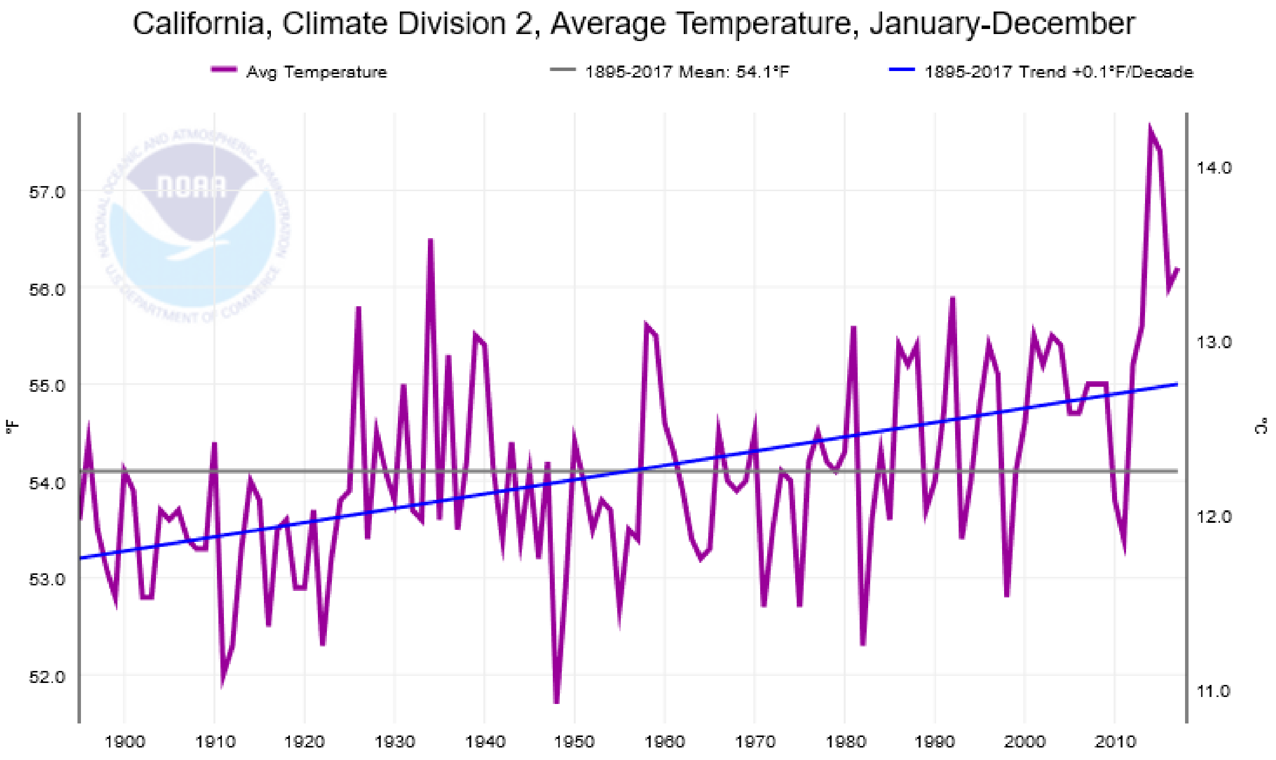


Figure 6: Average Annual Temperature for Sacramento HUC 1802 Watershed

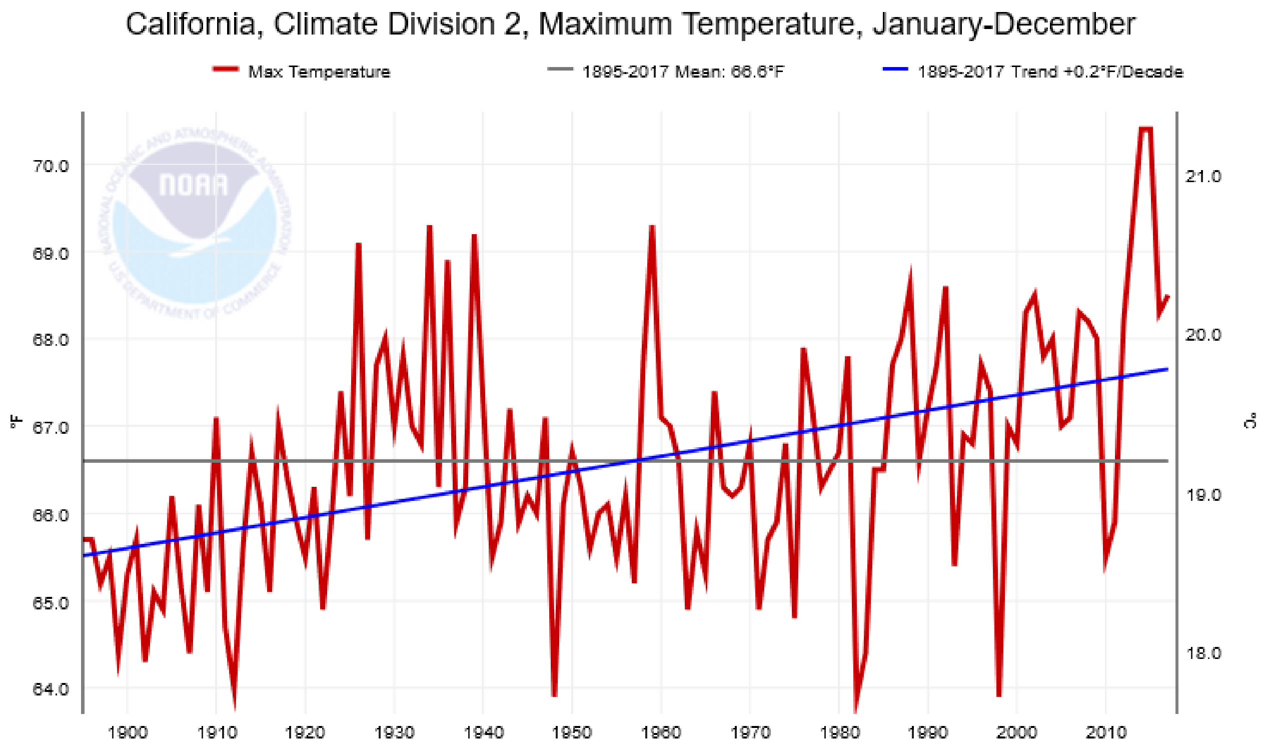


Figure 7: Annual Maximum Temperature for the Sacramento Watershed.

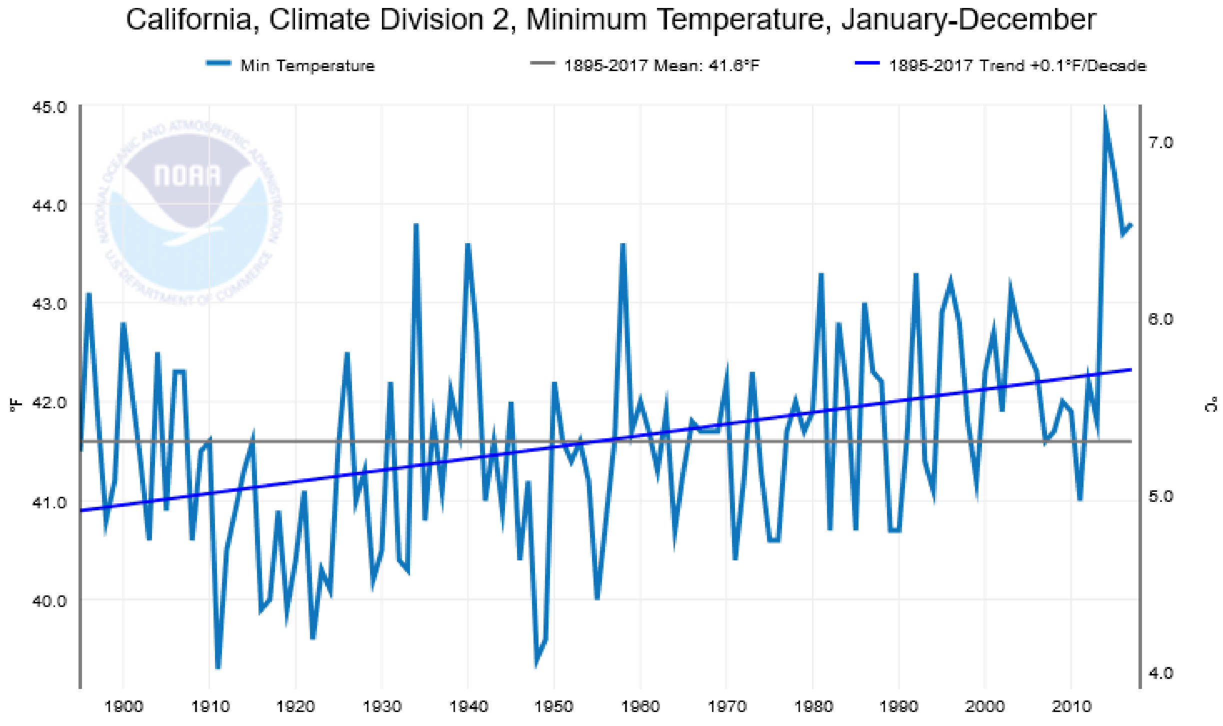


Figure 8: Annual Minimum Temperature for Sacramento Watershed.

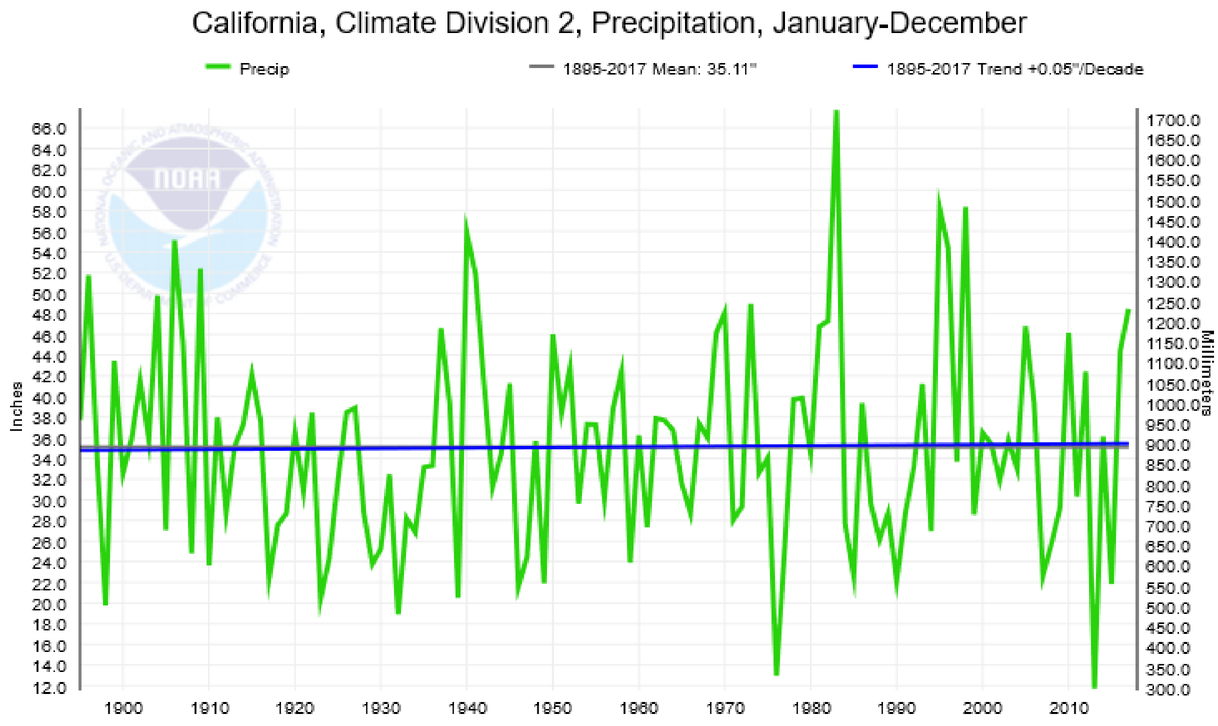


Figure 9: Annual Precipitation in the Sacramento Watershed.

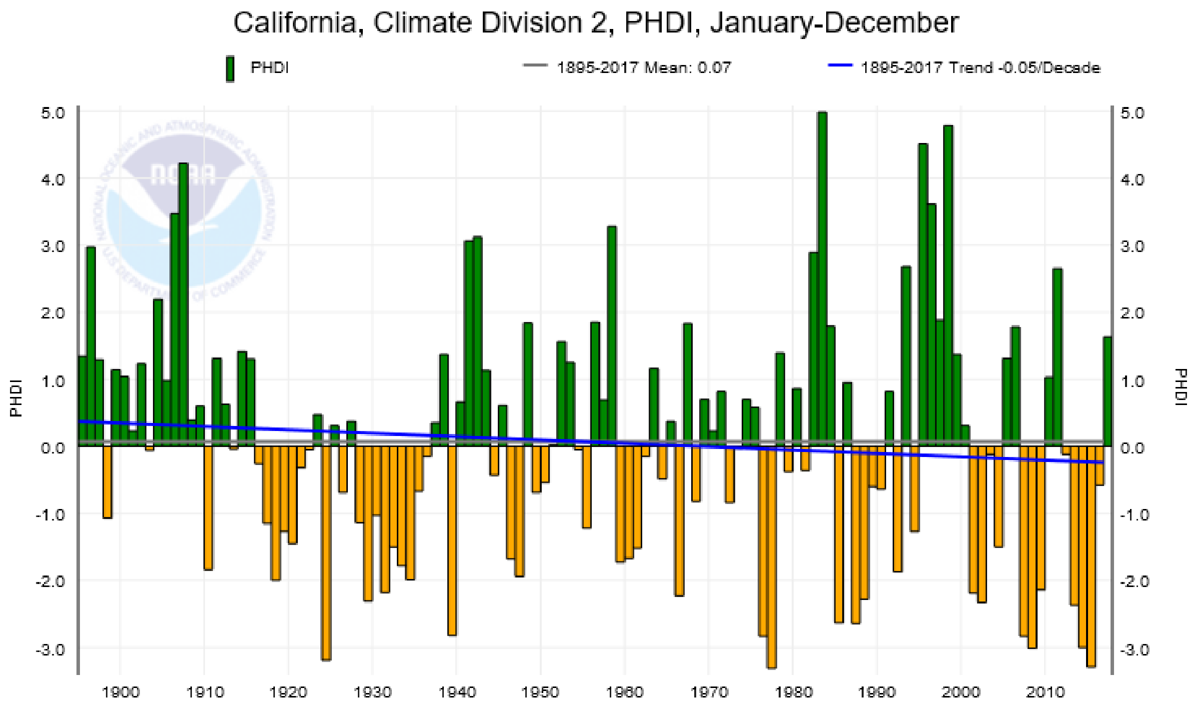


Figure 10: Palmer Hydrologic Drought Index (PHDI) for the Sacramento Watershed.

Annual Maximum Flow Data:

Trends in Annual Peak StreamflowsClimate Hydrology Assessmentand Non-Stationarity Detection:

For the Climate Hydrology and non stationarity analyses, two analysis points were selected: USGS gauge 11451100 North Fork Cache Creek at Hough Spring near Clearlake Oaks, drainage area (DA): 60.20 square miles and USGS gauge 11449500 Kelsey Cr at Kelseyville, DA: 36.60 square miles. These two locations were chosen because they have long periods of record (42 years at the Hough spring gauge and 71 years for the Kelseyville gauge) and because the flow is unregulated and the watershed upstream of each location is primarily rural with no significant land use change during the period of record. Annual maximum flows are examined in this study because the project involves modification of and use of levees in flood risk management. Figures 11 and 12 show the period of record of annual maximum flows at both gages, as well as a linear trend assessment for these two sites.

Neither the North Fork Cache Creek at Hough Spring gauge, nor the Kelsey Creek at Kelseyville guage show a significant trend in peak flows over time. The significance of the trends is determined by the p-values computed for the stations: 0.475 for Hough Spring and 0.647 for Kelseyville. Smaller p-value values indicate greater statistical significance of trends. In practice, a p-value of 0.05 is often used as a threshold for significance. A p-value of 0.05 indicates that there is a 5% chance of type I errors or false positives (USACE, 2016 b).

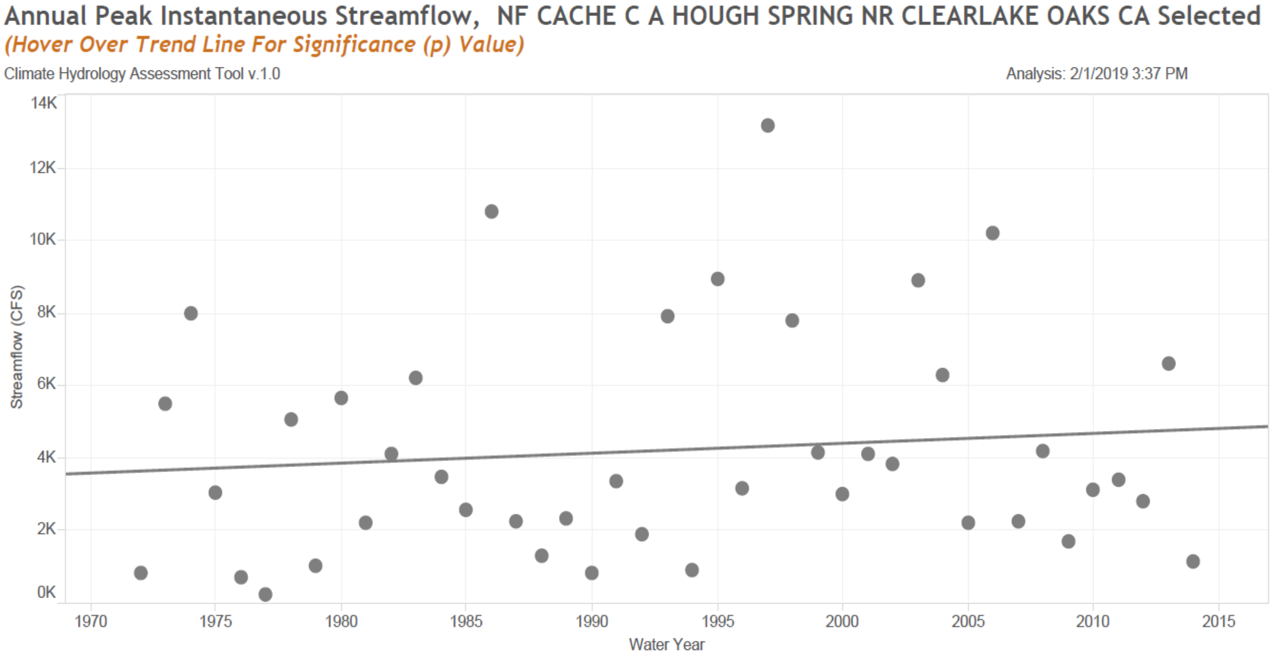


Figure 11 Annual Maximum Flow at the North Fork Cache Cr at Hough Springs Gauge near Clearlake Oaks, CA.

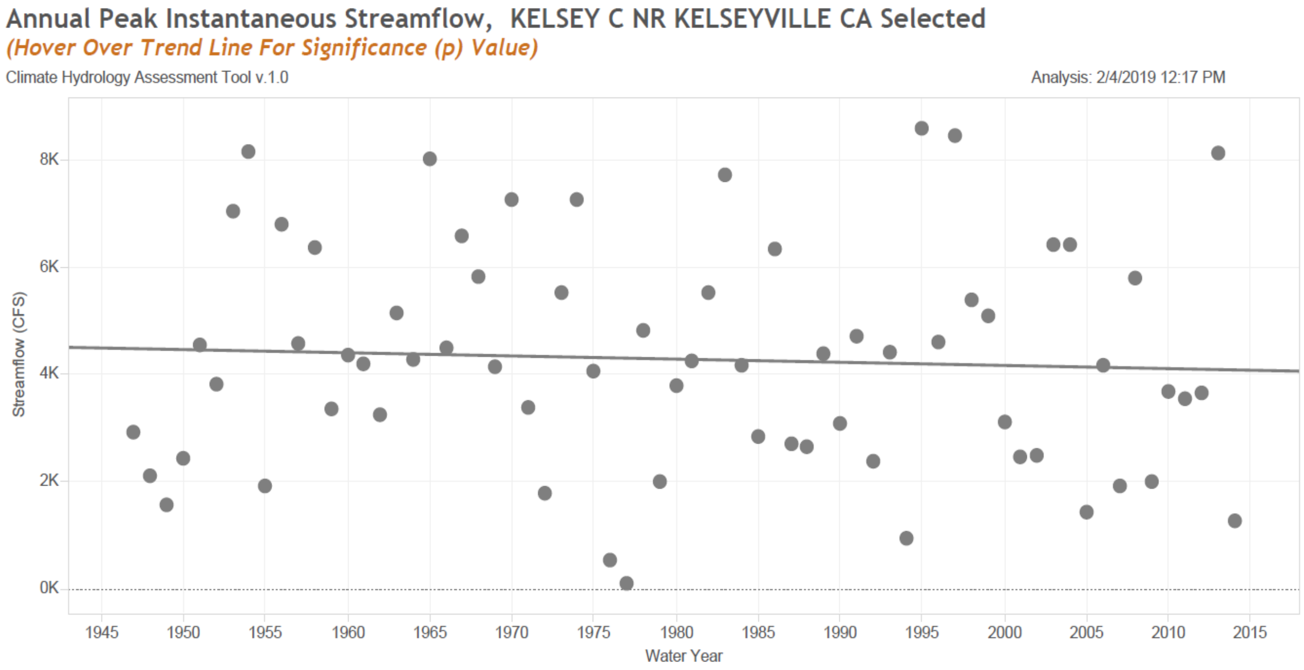


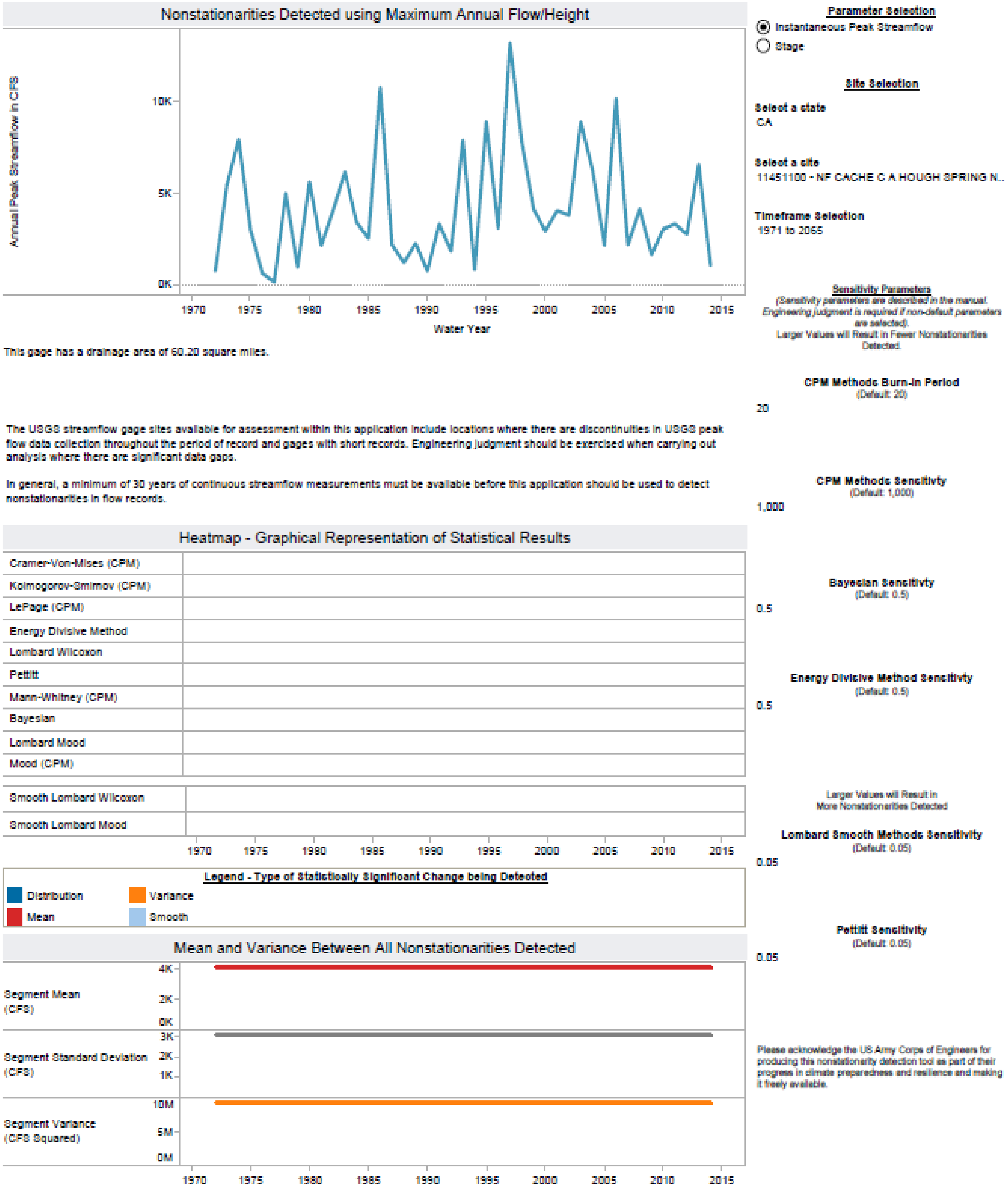
Figure 12 Annual Maximum Flow at the Kelsey Creek near Kelseyville Gauge.

Non-Stationarity Detection

The analysis of trends in observed data continues with an assessment of non-stationarities in annual peak streamflow data carried out in accordance to ETL 1100-2-3 (*Guidance for Detection of Non-stationarities in Annual Maximum Discharges,* USACE 2017) using the USACE Nonstationarity Detection Tool (USACE 2016 c)(http://corpsmapu.usace.army.mil/cm_apex/f?p=257:10:0::NO). This web based tool uses a series of statistical tests to detect changes in the trends (mean, variation and distribution) of the recorded, USGS annual instantaneous peak flow data at each gage. The tests include the Lombard model which identifies breaks in the mean and / or variance; the energy based divisive (ecp) method, a nonparametric test that detects multiple change points in the distribution; and other statistical tests. The levels of significance for each test can be controlled by the user- default setting were applied for this analysis. The same analyses points were selected, as were used for the Climate Hydrology Assessment Tool: North Fork Cache Creek at Hough Spring and Kelsey Creek at Kelseyville, CA. No non-stationarities were detected at either location (See figures 13 and 14). In order for a non-stationarity to be considered strong or robust, a minimum of three methods targeting changes in mean, distributional characteristics or variance are required to detect a non-stationarity during a five year period (at minimum two tests indicating a change in the same statistical property and an additional test indicating a change in a different statistical property). Magnitude of the change is also an indicator of a strong non-stationarity if the difference between the component means and variances before and after the change point is significant (USACE 2017).

Changes in hydrologic processes can occur either abruptly (e.g., through construction of a dam) or gradually (e.g., through watershed development over time) depending on the characteristics of the nonstationarity factors affecting physical processes. Engineering Technical Letter (ETL) 1100-2-3 provides guidance on detecting abrupt and slowly varying changes in annual maximum discharge records that could impact future without-project-condition.

Monotonic trend analysis can be conducted after the change point detection tests have been applied. The change point detection tests divide the record into a series of statistically homogenous subsets. If no abrupt changes were detected, the presence of monotonic trends should be examined using the entire record. Tests for monotonic patterns indicate whether the statistical properties within subsets of data are relatively constant, increasing or decreasing, and provide the user with insight into whether or not the trends exhibited within the dataset are likely to persist. If trends are detected within the identified subsets of flow data, the user should apply engineering judgment when using methods that rely on the stationarity assumption (USACE 2017). Monotonic trend analyses detected no statistically significant trends in either station.



This gage has a drainage area of 60.20 square miles.

The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

In general, a minimum of 30 years of continuous streamflow measurements must be available before this application should be used to detect nonstationarities in flow records.

Parameter Selection

● Instantaneous Peak Streamflow
○ Stage

Site Selection

Select a state
CA

Select a site
11451100 - NF CACHE C A HOUGH SPRING N..

Timeframe Selection
1971 to 2065

Sensitivity Parameters
(Sensitivity parameters are described in the manual. Engineering judgment is required if non-default parameters are selected).
Larger Values will Result in Fewer Nonstationarities Detected.

CPM Methods Burn-In Period
(Default: 20)
20

CPM Methods Sensitivty
(Default: 1,000)
1,000

Bayesian Sensitivity
(Default: 0.5)
0.5

Energy Divisive Method Sensitivty
(Default: 0.5)
0.5

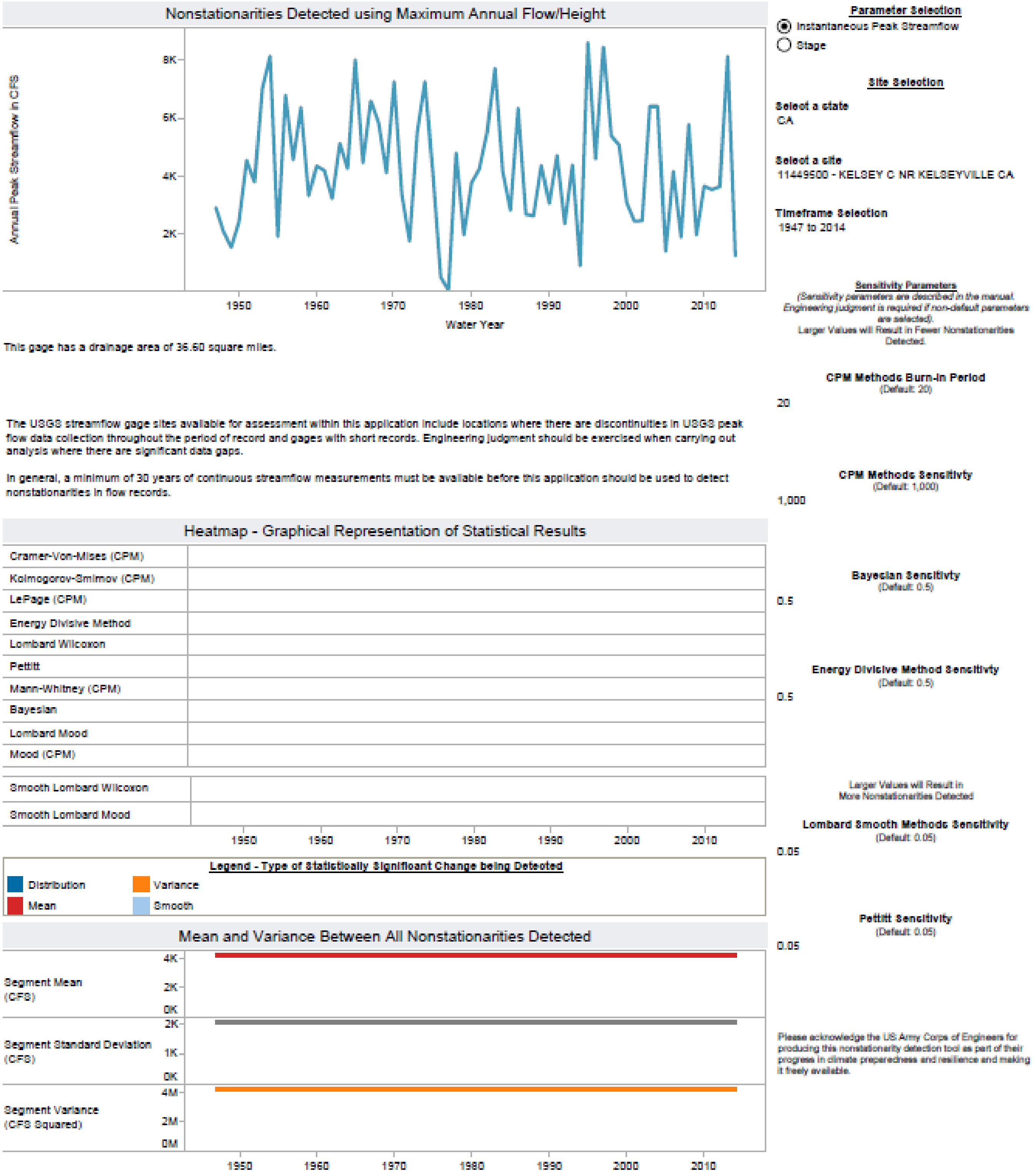
Larger Values will Result in More Nonstationarities Detected

Lombard Smooth Methods Sensitivity
(Default: 0.05)
0.05

Pettitt Sensitivity
(Default: 0.05)
0.05

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 13 NF Cache Cr at Hough Spring, CA non-stationarity detection. No non-stationarities are detected.



This gage has a drainage area of 36.60 square miles.

The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

In general, a minimum of 30 years of continuous streamflow measurements must be available before this application should be used to detect nonstationarities in flow records.

Parameter Selection

● Instantaneous Peak Streamflow

○ Stage

Site Selection

Select a state
CA

Select a site
11449500 - KELSEY C NR KELSEYVILLE CA

Timeframe Selection
1947 to 2014

Sensitivity Parameters
(Sensitivity parameters are described in the manual. Engineering judgment is required if non-default parameters are selected).
Larger Values will Result in Fewer Nonstationarities Detected.

CPM Methods Burn-In Period
(Default: 20)
20

CPM Methods Sensitivty
(Default: 1,000)
1,000

Bayesian Sensitivty
(Default: 0.5)
0.5

Energy Divisive Method Sensitivty
(Default: 0.5)
0.5

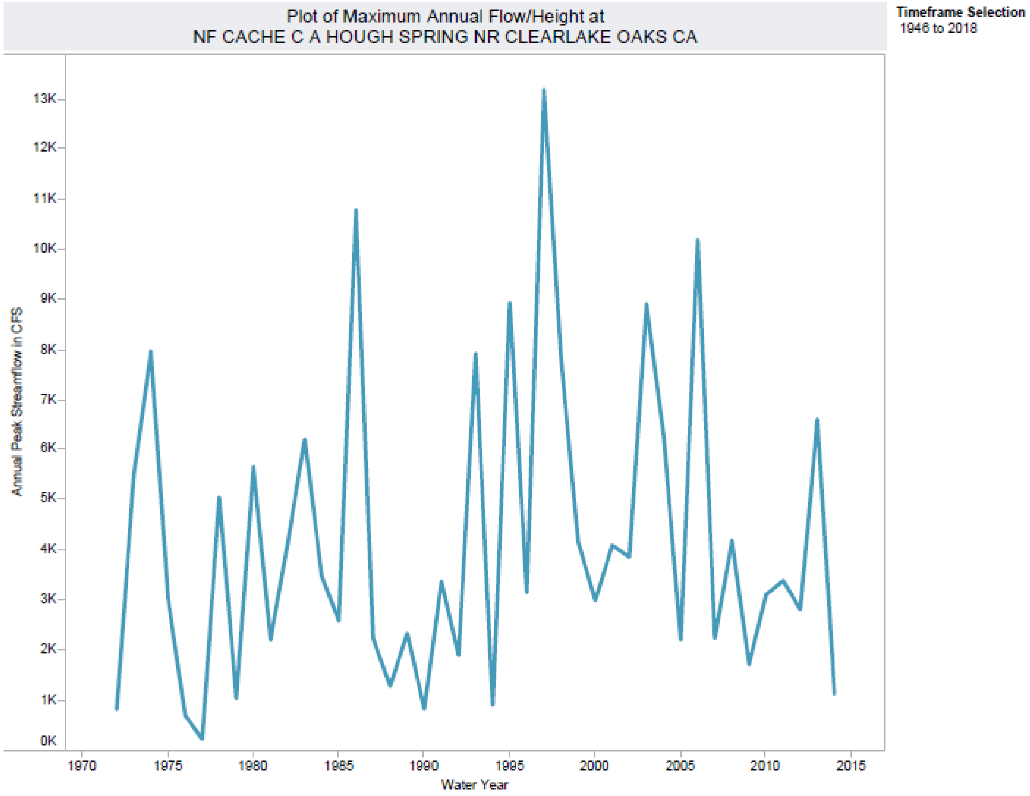
Larger Values will Result in More Nonstationarities Detected

Lombard Smooth Methods Sensitivity
(Default: 0.05)
0.05

Pettitt Sensitivity
(Default: 0.05)
0.05

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 14 Kelsey Creek at Kelseyville non-stationarity detection results. No non-stationarities were detected.



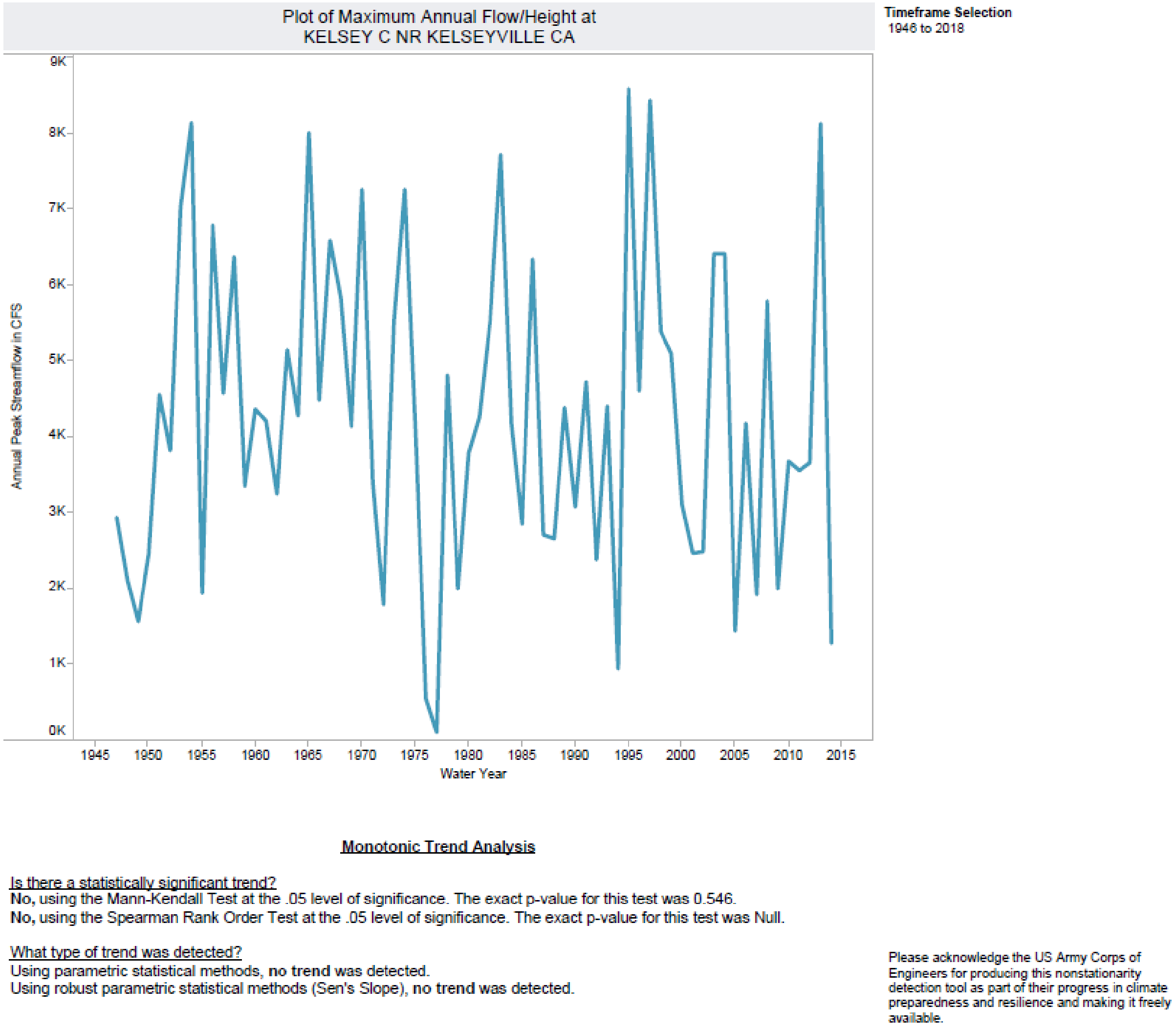
Monotonic Trend Analysis

Is there a statistically significant trend?
No, using the Mann-Kendall Test at the .05 level of significance. The exact p-value for this test was 0.414.
No, using the Spearman Rank Order Test at the .05 level of significance. The exact p-value for this test was Null.

What type of trend was detected?
Using parametric statistical methods, **no trend** was detected.
Using robust parametric statistical methods (Sen's Slope), **no trend** was detected.

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 615 Monotonic Trend analysis at NF Cache Cr at Hough Spring near Clearlake Oaks, CA.



Is there a statistically significant trend?
No, using the Mann-Kendall Test at the .05 level of significance. The exact p-value for this test was 0.546.
No, using the Spearman Rank Order Test at the .05 level of significance. The exact p-value for this test was Null.

What type of trend was detected?
Using parametric statistical methods, **no trend** was detected.
Using robust parametric statistical methods (Sen's Slope), **no trend** was detected.

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

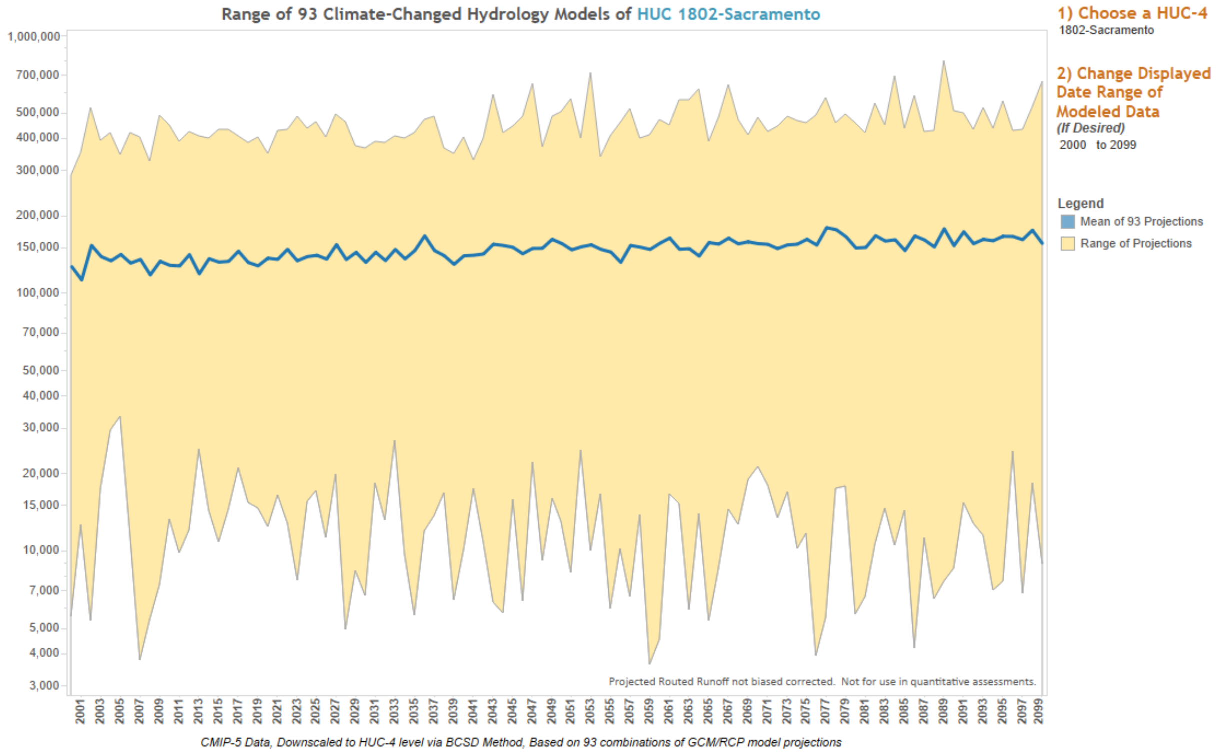
Figure 7 16 Monotonic Trend Analysis of Kelsey Cr near Kelseyville gauge.

Phase II Future Climate Scenarios:

Projected changes in future climate contain significant uncertainties due to limitations in our understanding and modeling of the earth’s systems, estimated projections of future development and greenhouse gas emission pathways. Uncertainties are also associated with hydrologic modeling, and translating global climate model outputs to a temporal and spatial scale applicable to hydrologic analysis.

Projected Streamflow Trends in the Sacramento HUC-4 Watershed:

The Corps Climate Hydrology Assessment Tool was used to examine observed and projected trends in watershed hydrology to support the qualitative assessment. As expected, there is considerable and consistent spread in the projected annual maximum monthly flows (Figure 15). The overall projected trend in mean projected annual maximum monthly flows (**Error! Reference source not found.**) increases over time and this trend is statistically significant (p-value <0.0001), suggesting that there may be potential for an increase in flood risk in the future relative to the current time. The tool uses climate data projected by global circulation models translated using a Variable Infiltration Capacity (VIC) model developed for the entire United States. The VIC model does not capture regulatory impacts. The assessment tool facilitates an overall assessment of probable projected trends in climate changed hydrology, but does not provide much insight into the magnitude of these trends. The VIC model is not calibrated to historical values at a study specific scale thus it may not replicate exact historic streamflow within a high degree of accuracy and this adds to the uncertainty with the projected climate changed hydrology.


Range of 93 Climate-Changed Hydrology Models of HUC 1802-Sacramento

Projected Routed Runoff not biased corrected. Not for use in quantitative assessments.

CMIP-5 Data, Downscaled to HUC-4 level via BCSD Method, Based on 93 combinations of GCM/RCP model projections

Figure 15 Range of 92 Climate-Altered Hydrology Model Projections of Annual Maximum Monthly Average Flow in HUC 1802 Sacramento. The range itself is indicated by the yellow shading and the mean of the projections is indicated by the blue curve.

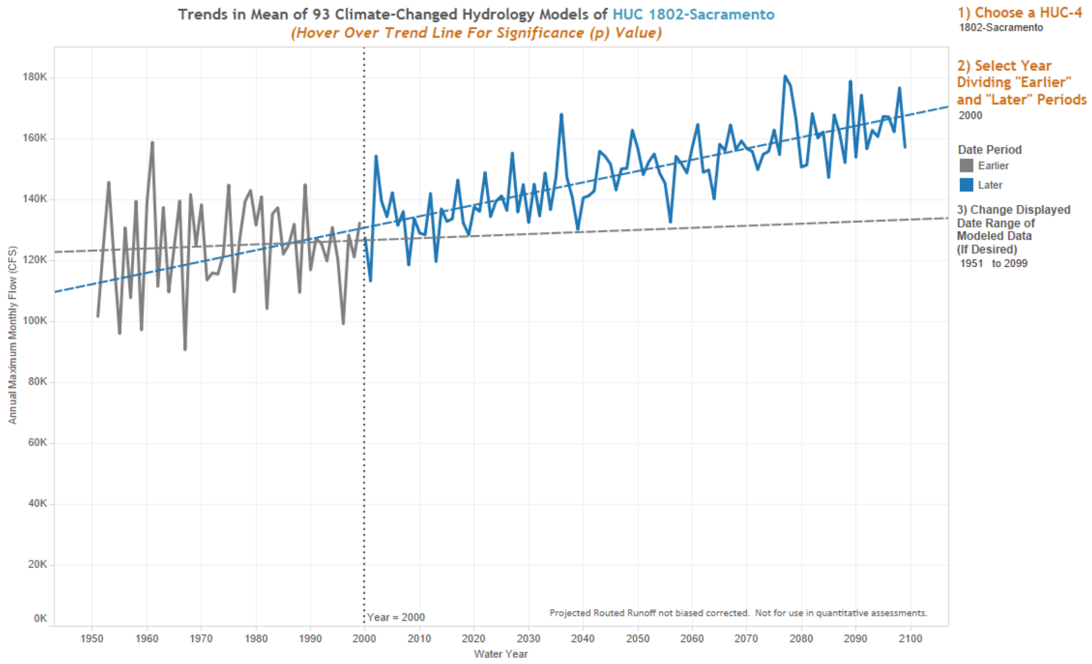


Figure 16 Projected Trend in Annual Maximum Flow for HUC-1802 Sacramento. Dotted line indicates year 2000, grey dashed line indicates present trend from 1950 to 2000 and the blue dashed line indicates projected climate altered trend in streamflow from 2000 to 2100.

Vulnerability Assessment:

The Corps Watershed Vulnerability Assessment Tool (VA Tool) provides nationwide screening level assessment of climate change vulnerability relative to USACE mission, operations, programs and projects (Corps, 2106). The VA tool was used to examine the vulnerability of the project area to future flood risk across the primary business line for which The Lower Cache Creek Flood Protection Project is designed. That business line is flood risk reduction. However because this is a feasibility study, all eight business lines are considered. Like the Climate Hydrology Assessment Tool, this tool uses climate data projected by GCMs translated into runoff using a VIC model, and the vulnerability assessment for inland Hydrology is only qualitative at this time. The results for the Sacramento River watershed are relative to those of the other 201 watersheds in the United States. This vulnerability assessment uses 27 different variables (indicators) and eight business lines to develop vulnerability scores specific to each of the 202 HUC-4 watersheds in the United States for each of the business lines. Indicators reflect stressors related to climate, demographic changes, ecological changes, and other factors relevant to a particular business line. Five of these indicators are relevant to the Flood Risk Management business line (Table). A subjective weight can be used to give more weight to indicators that are more relevant to the issues affecting the vulnerability of a given business line. The least relevant/important indicator is assigned an importance weight of 1, while all other indicators are assigned an importance weight relative to that (e.g., an indicator that is considered 50% more relevant/important is given an importance weight of 1.5).

Table 1: Indicators and Importance Weights for Flood Risk Reduction Business Line.

Indicator Short Name	Indicator Description	Default Importance Weights
175C_ANNUAL_COV	Long-term variability in hydrology: ratio of the standard deviation of annual runoff to the annual runoff mean. Includes upstream freshwater inputs (cumulative).	1.25
277_RUNOFF_PRECIP	Median of: deviation of runoff from monthly mean times average monthly runoff divided by deviation of precipitation from monthly mean times average monthly precipitation.	1.00
568C_FLOOD_MAGNIFICATION	Change in flood runoff: ratio of indicator 571C (monthly runoff exceeded 10% of the time, including upstream freshwater inputs) to 571C in base period.	1.8
568L_FLOOD_MAGNIFICATION	Change in flood runoff: Ratio of indicator 571L (monthly runoff exceeded 10% of the time, excluding upstream freshwater inputs) to 571L in base period.	1.4
590_URBAN_500YRFLOODPLAIN_AREA	Acres of urban area within the 500-year floodplain.	1.75

Table 2: Indicators and Importance Weights for Ecosystem Restoration.

Indicator Short Name	Indicator Description	Default Importance Weights
65L_MEAN_ANNUAL_RUNOFF	Mean runoff: average annual runoff, excluding upstream freshwater inputs (local).	1.3
156_SEDIMENT	The ratio of the change in the sediment load in the future to the present load.	1.5
221C_MONTHLY_COV	Measure of short-term variability in the region's hydrology: 75th percentile of annual ratios of the standard deviation of monthly runoff to the mean of monthly runoff. Includes	1.75
277_RUNOFF_PRECIP	Median of: deviation of runoff from monthly mean times average monthly runoff divided by deviation of precipitation from monthly mean times average monthly precipitation.	1.75
297_MACROINVERTEBRATE	The sum (ranging from 0-100) of scores for six metrics that characterize macroinvertebrate assemblages: taxonomic richness, taxonomic composition, taxonomic diversity, feeding	2
568C_FLOOD_MAGNIFICATION	Change in flood runoff: ratio of indicator 571C (monthly runoff exceeded 10% of the time, including upstream freshwater inputs) to 571C in base period.	1.5
568L_FLOOD_MAGNIFICATION	Change in flood runoff: Ratio of indicator 571L (monthly runoff exceeded 10% of the time, excluding upstream freshwater inputs) to 571L in base period.	1
700C_LOW_FLOW_REDUCTION	Change in low runoff: ratio of indicator 570C (monthly runoff exceeded 90% of the time, including upstream freshwater inputs) to 570C in base period.	1
8_AT_RISK_FRESH LANT	Percentage of wetland and riparian plant communities that are at risk of extinction, based on remaining number and condition, remaining acreage, threat severity, etc.	2

Table 3 Emergency Management Business Line Indicators and Importance Weights.

Indicator Short Name	Indicator Description	Default Importance Weights
65C_MEAN_ANNUAL_RUNOFF	Mean runoff: average annual runoff, including upstream freshwater inputs (cumulative).	1
65L_MEAN_ANNUAL_RUNOFF	Mean runoff: average annual runoff, excluding upstream freshwater inputs (local).	2
130_FLOODPLAIN_POPULATION	Population within the 500-year floodplain.	1.3
156_SEDIMENT	The ratio of the change in the sediment load in the future to the present load.	1.2
175C_ANNUAL_COV	Long-term variability in hydrology: ratio of the standard deviation of annual runoff to the annual runoff mean. Includes upstream freshwater inputs (cumulative).	1.4
175L_ANNUAL_COV	Long-term variability in hydrology: ratio of the standard deviation of annual runoff to the annual runoff mean. Excludes upstream freshwater inputs (local).	1.6
192_URBAN_SUBURBAN	Land area that is urban or suburban as a percentage of the total U.S. land area.	1.85
221C_MONTHLY_COV	Measure of short-term variability in the region's hydrology: 75th percentile of annual ratios of the standard deviation of monthly runoff to the mean of monthly runoff. Includes	1.2
221L_MONTHLY_COV	Measure of short-term variability in the region's hydrology: 75th percentile of annual ratios of the standard deviation of monthly runoff to the mean of monthly runoff. Excludes	1.9
450_FLOOD_INSURANCE_COMMUNITIES	Number of communities enrolled in the National Flood Insurance Program (NFIP).	1.8
568C_FLOOD_MAGNIFICATION	Change in flood runoff: ratio of indicator 571C (monthly runoff exceeded 10% of the time, including upstream freshwater inputs) to 571C in base period.	1.4

Table 4 Regulatory Business Line Indicators and Importance Weights.

Indicator Short Name	Indicator Description	Default Importance Weights
65C_MEAN_ANNUAL_RUNOFF	Mean runoff: average annual runoff, including upstream freshwater inputs (cumulative).	1.4
65L_MEAN_ANNUAL_RUNOFF	Mean runoff: average annual runoff, excluding upstream freshwater inputs (local).	1.3
156_SEDIMENT	The ratio of the change in the sediment load in the future to the present load.	1.5
175C_ANNUAL_COV	Long-term variability in hydrology: ratio of the standard deviation of annual runoff to the annual runoff mean. Includes upstream freshwater inputs (cumulative).	1.7
221C_MONTHLY_COV	Measure of short-term variability in the region's hydrology: 75th percentile of annual ratios of the standard deviation of monthly runoff to the mean of monthly runoff. Includes	1.75
277_RUNOFF_PRECIP	Median of: deviation of runoff from monthly mean times average monthly runoff divided by deviation of precipitation from monthly mean times average monthly precipitation.	1.25
297_MACROINVERTEBRATE	The sum (ranging from 0-100) of scores for six metrics that characterize macroinvertebrate assemblages: taxonomic richness, taxonomic composition, taxonomic diversity, feeding	1.8
568C_FLOOD_MAGNIFICATION	Change in flood runoff: ratio of indicator 571C (monthly runoff exceeded 10% of the time, including upstream freshwater inputs) to 571C in base period.	1.6
568L_FLOOD_MAGNIFICATION	Change in flood runoff: Ratio of indicator 571L (monthly runoff exceeded 10% of the time, excluding upstream freshwater inputs) to 571L in base period.	1.1
700C_LOW_FLOW_REDUCTION	Change in low runoff: ratio of indicator 570C (monthly runoff exceeded 90% of the time, including upstream freshwater inputs) to 570C in base period.	1.5

Table 5 Recreation Indicators Importance Weights

Indicator Short Name	Indicator Description	Default Importance Weights
95_DROUGHT_SEVERITY	Greatest precipitation deficit: The most negative value calculated by subtracting potential evapotranspiration from precipitation over any 1-, 3-, 6-, or 12-month period.	2
156_SEDIMENT	The ratio of the change in the sediment load in the future to the present load.	1
221C_MONTHLY_COV	Measure of short-term variability in the region's hydrology: 75th percentile of annual ratios of the standard deviation of monthly runoff to the mean of monthly runoff. Includes	1.2
277_RUNOFF_PRECIP	Median of: deviation of runoff from monthly mean times average monthly runoff divided by deviation of precipitation from monthly mean times average monthly precipitation.	1
568C_FLOOD_MAGNIFICATION	Change in flood runoff: ratio of indicator 571C (monthly runoff exceeded 10% of the time, including upstream freshwater inputs) to 571C in base period.	1.4
568L_FLOOD_MAGNIFICATION	Change in flood runoff: Ratio of indicator 571L (monthly runoff exceeded 10% of the time, excluding upstream freshwater inputs) to 571L in base period.	1
570L_90PERC_EXCEEDANCE	Low runoff: monthly runoff that is exceeded 90% of the time, excluding upstream freshwater inputs (local).	1.5
571C_10PERC_EXCEEDANCE	Flood runoff: monthly runoff that is exceeded 10% of the time, including upstream freshwater inputs (cumulative).	1
700L_LOW_FLOW_REDUCTION	Change in low runoff: ratio of indicator 570L (monthly runoff exceeded 90% of the time, excluding upstream freshwater inputs) to 570L in base period.	1.3

Table 6 Navigation Indicators and Importance Weights.

Indicator Short Name	Indicator Description	Default Importance Weights
95_DROUGHT_SEVERITY	Greatest precipitation deficit: The most negative value calculated by subtracting potential evapotranspiration from precipitation over any 1-, 3-, 6-, or 12-month period.	1.5
192_URBAN_SUBURBAN	Land area that is urban or suburban as a percentage of the total U.S. land area.	1
221C_MONTHLY_COV	Measure of short-term variability in the region's hydrology: 75th percentile of annual ratios of the standard deviation of monthly runoff to the mean of monthly runoff. Includes	1
277_RUNOFF_PRECIP	Median of: deviation of runoff from monthly mean times average monthly runoff divided by deviation of precipitation from monthly mean times average monthly precipitation.	1.5
441A_0.2AEPFLOODPLAIN_AREA	Area in the 0.2% Annual Exceedance Probability floodplain	1
568C_FLOOD_MAGNIFICATION	Change in flood runoff: ratio of indicator 571C (monthly runoff exceeded 10% of the time, including upstream freshwater inputs) to 571C in base period.	2
570C_90PERC_EXCEEDANCE	Low runoff: monthly runoff that is exceeded 90% of the time, including upstream freshwater inputs (cumulative).	1.75
570L_90PERC_EXCEEDANCE	Low runoff: monthly runoff that is exceeded 90% of the time, excluding upstream freshwater inputs (local).	1.25
700C_LOW_FLOW_REDUCTION	Change in low runoff: ratio of indicator 570C (monthly runoff exceeded 90% of the time, including upstream freshwater inputs) to 570C in base period.	1.5

Table 7 Water Supply Indicators and Importance Weights

Indicator Short Name	Indicator Description	Default Importance Weights
95_DROUGHT_SEVERITY	Greatest precipitation deficit: The most negative value calculated by subtracting potential evapotranspiration from precipitation over any 1-, 3-, 6-, or 12-month period.	2
130_FLOODPLAIN_POPULATION	Population within the 500-year floodplain.	2
156_SEDIMENT	The ratio of the change in the sediment load in the future to the present load.	1.5
192_URBAN_SUBURBAN	Land area that is urban or suburban as a percentage of the total U.S. land area.	1
221C_MONTHLY_COV	Measure of short-term variability in the region's hydrology: 75th percentile of annual ratios of the standard deviation of monthly runoff to the mean of monthly runoff. Includes	1.3

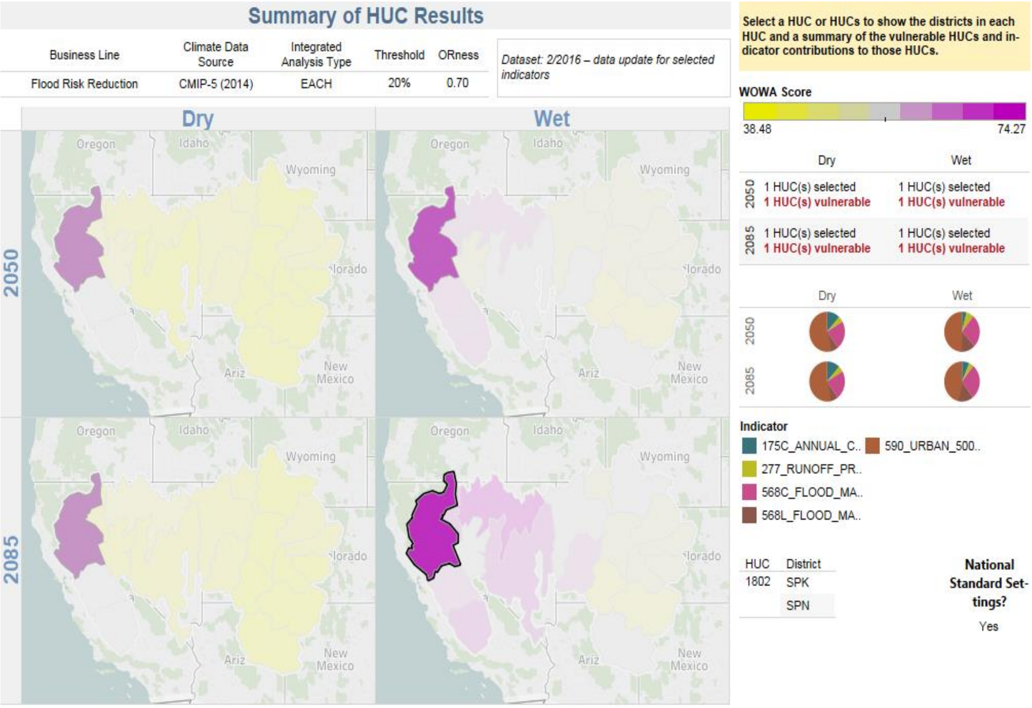
Table 8 Hydropower Indicators and Importance Weights.

Indicator Short Name	Indicator Description	Default Importance Weights
95_DROUGHT_SEVERITY	Greatest precipitation deficit: The most negative value calculated by subtracting potential evapotranspiration from precipitation over any 1-, 3-, 6-, or 12-month period.	2
156_SEDIMENT	The ratio of the change in the sediment load in the future to the present load.	1.2
175C_ANNUAL_COV	Long-term variability in hydrology: ratio of the standard deviation of annual runoff to the annual runoff mean. Includes upstream freshwater inputs (cumulative).	1.5
221C_MONTHLY_COV	Measure of short-term variability in the region's hydrology: 75th percentile of annual ratios of the standard deviation of monthly runoff to the mean of monthly runoff. Includes	1.6
277_RUNOFF_PRECIP	Median of: deviation of runoff from monthly mean times average monthly runoff divided by deviation of precipitation from monthly mean times average monthly precipitation.	1.5
568C_FLOOD_MAGNIFICATION	Change in flood runoff: ratio of indicator 571C (monthly runoff exceeded 10% of the time, including upstream freshwater inputs) to 571C in base period.	1.4
568L_FLOOD_MAGNIFICATION	Change in flood runoff: Ratio of indicator 571L (monthly runoff exceeded 10% of the time, excluding upstream freshwater inputs) to 571L in base period.	1
700L_LOW_FLOW_REDUCTION	Change in low runoff: ratio of indicator 570L (monthly runoff exceeded 90% of the time, excluding upstream freshwater inputs) to 570L in base period.	1

The tool provides an indication of how vulnerable a given HUC-4 watershed is to the potential impacts of climate change relative to the other 201 HUC-4 watersheds in the United States. The business lines are the prisms for the evaluation of vulnerability in a given watershed. The VA tool gives assessments using two scenarios or subsets of traces (wet and dry) for two of three epochs assessed within the tool, 2035-2064 (centered on 2050) and 2070-2099 (centered on 2085). The remaining epoch (base period) covers the current time and uses modeled flows generated from the GCM outputs from the base period (1950-1999). The subset with the lower cumulative runoff projections is used to compute values for the dry scenario and the subset with the higher runoff projections is used to compute values for the wet scenario. These are all equally likely projections of the future and the dry projection could be wetter than the base epoch. For the Sacramento River Watershed (HUC 1802), this tool shows that the area is highly vulnerable to increased flood risk during the twenty-first century for all wet and dry projected scenarios when compared to the other 201 HUC-4 watersheds in the nation. The Vulnerability Assessment Tool uses the following parameters to compute the results: ORness, Integrated Analysis Type (IAT) and Vulnerability Threshold. The ORness parameter describes the level of risk-aversion/risk-tolerance assumed for the analysis. Values range from .5 to 1.0. At the lowest value of ORness, indicators are aggregated using a simple average. At the highest value of ORness, the highest-valued indicator is weighted as 100% and all other indicators are weighted as 0%. The national standards settings uses an ORness of 0.7. The Integrated Analysis Type (IAT) specifies how the vulnerability scores will be calculated. The national standard setting uses an IAT of “each” meaning that a score is calculated for each business line during each scenario and epoch thus there are four sets of WOWA scores for each of the business lines. The assessment was carried out using the national standard settings (ORness set to 0.7, all 202 HUC-4 watersheds are considered, Analysis type is set to “Each” and vulnerability threshold is set at 20%).

Results Based on National Standard Settings:

Figures 17-22 and tables 9-16 show the breakout of indicators for each scenario and epoch combination for each of the eight business lines. For the Flood Risk Management business line, in both the wet and dry subsets, the increase in the area of the 0.002 (1/500) annual exceedance probability (AEP), particularly in urban areas, is the dominant indicator contributing to the flood risk vulnerability score, followed by changes in the size and timing of flood runoff. This analyses along with the studies discussed in the literature synthesis indicates that in the future warming climate, floods could increase in magnitude over time and that much of the population and economic activity will be in areas which will be vulnerable to floodwaters (at least the 0.002 (1/500) AEP floodplain). Floods could be larger and more damaging than in previous times.



Summary of HUC Results

Business Line	Climate Data Source	Integrated Analysis Type	Threshold	ORness
Flood Risk Reduction	CMIP-5 (2014)	EACH	20%	0.70

Dataset: 2/2016 – data update for selected indicators

Select a HUC or HUCs to show the districts in each HUC and a summary of the vulnerable HUCs and indicator contributions to those HUCs.

WOWA Score

	Dry	Wet
2050	1 HUC(s) selected **1 HUC(s) vulnerable**	1 HUC(s) selected **1 HUC(s) vulnerable**
2085	1 HUC(s) selected **1 HUC(s) vulnerable**	1 HUC(s) selected **1 HUC(s) vulnerable**

Indicator

- 175C_ANNUAL_C..
- 590_URBAN_500..
- 277_RUNOFF_PR..
- 568C_FLOOD_MA..
- 568L_FLOOD_MA..

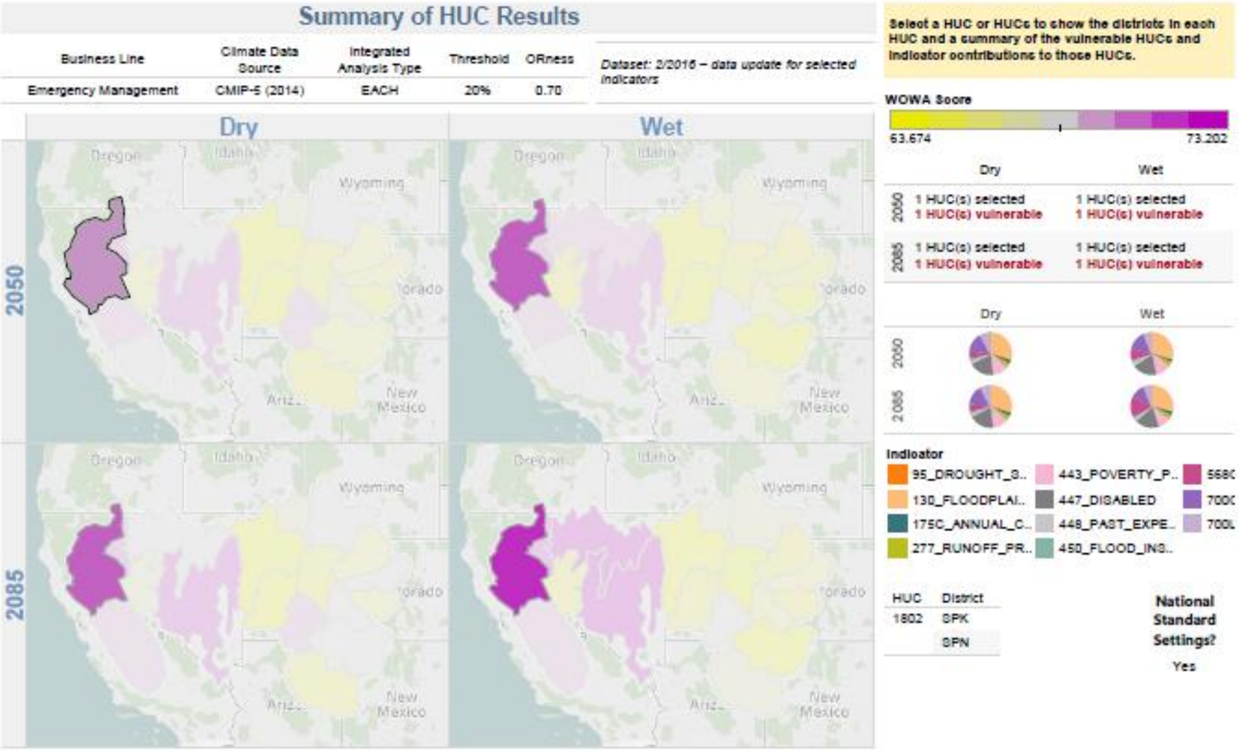
HUC	District
1802	SPK
	SPN

National Standard Settings?

Yes

Figure 17 Summary of Flood Risk Reduction Business Line Vulnerability of the Assessment for HUC 1802 – Sacramento River Watershed. **Note: This area is vulnerable to increased flood risk primarily due to increases in the area of the 0.002 (1/500) AEP floodplain and changes in the magnitude of floods as shown in the pie charts on the right of the figure. The Weighted Order Weighted Average (WOWA) scores are in the range of 59-67 which indicates a high overall vulnerability relative to all other HUC-4 watersheds in the United States. WOWA scores can range from 0 to 100.**

.



Summary of HUC Results

Business Line	Climate Data Source	Integrated Analysis Type	Threshold	ORness
Emergency Management	CMIP-5 (2014)	EACH	20%	0.70

Dataset: 2/2016 – data update for selected indicators

Select a HUC or HUCs to show the districts in each HUC and a summary of the vulnerable HUCs and indicator contributions to those HUCs.

WOWA Score

63.674 73.202

	Dry	Wet
2050	1 HUC(s) selected 1 HUC(s) vulnerable	1 HUC(s) selected 1 HUC(s) vulnerable
2085	1 HUC(s) selected 1 HUC(s) vulnerable	1 HUC(s) selected 1 HUC(s) vulnerable

Indicator

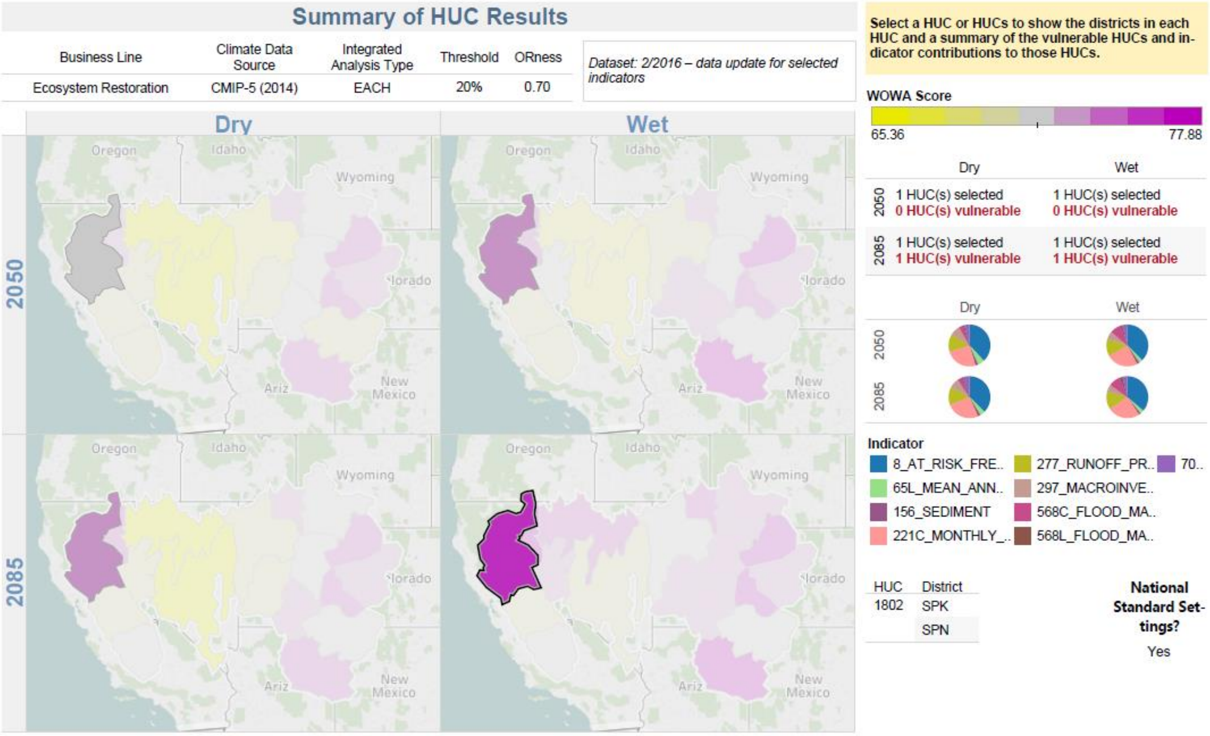
🟧 95_DROUGHT_S..	▨ 443_POVERTY_P..	🟥 568
🟧 130_FLOODPLAI..	⬛ 447_DISABLED	🟪 700
🟦 175C_ANNUAL_C..	▨ 448_PAST_EXPE..	🟪 700L
🟩 277_RUNOFF_PR..	🟩 450_FLOOD_INS..	

HUC	District
1802	SPK
	SPN

National Standard Settings?

Yes

Figure 89 Emergency Management Sumary of Results. Watershed is vulnerable in all epochs and scenarios. Population in floodplain is the dominant indicator.



Summary of HUC Results

Business Line	Climate Data Source	Integrated Analysis Type	Threshold	ORness
Ecosystem Restoration	CMIP-5 (2014)	EACH	20%	0.70

Dataset: 2/2016 – data update for selected indicators

Select a HUC or HUCs to show the districts in each HUC and a summary of the vulnerable HUCs and indicator contributions to those HUCs.

WOWA Score

65.36 – 77.88

	Dry	Wet
2050	1 HUC(s) selected 0 HUC(s) vulnerable	1 HUC(s) selected 0 HUC(s) vulnerable
2085	1 HUC(s) selected 1 HUC(s) vulnerable	1 HUC(s) selected 1 HUC(s) vulnerable

Indicator

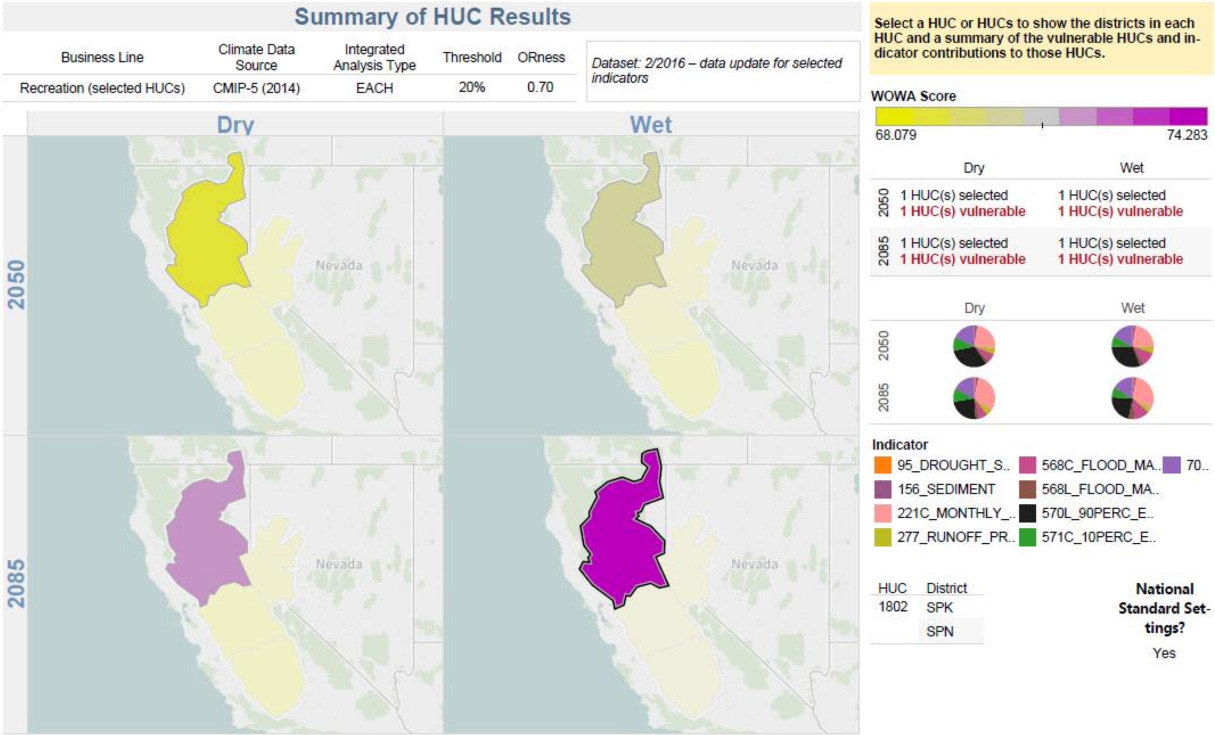
- 8_AT_RISK_FRE..
- 65L_MEAN_ANN..
- 156_SEDIMENT
- 221C_MONTHLY_..
- 277_RUNOFF_PR..
- 297_MACROINVE..
- 568C_FLOOD_MA..
- 568L_FLOOD_MA..
- 70..

HUC	District
1802	SPK
	SPN

National Standard Settings?

Yes

Figure 1011 Summary of Vulnerability to the Ecosystem Restoration Business Line in the Sacramento River HUC-4 Watershed. The watershed is not vulnerable relative to other watersheds during the 2050 epoch but becomes vulnerable in this business line relative to the other watersheds during the 2085 epoch. The dominant indicator appears to be the presence of at risk freshwater plant communities.



Summary of HUC Results

Business Line	Climate Data Source	Integrated Analysis Type	Threshold	ORness
Recreation (selected HUCs)	CMIP-5 (2014)	EACH	20%	0.70

Dataset: 2/2016 – data update for selected indicators

Select a HUC or HUCs to show the districts in each HUC and a summary of the vulnerable HUCs and indicator contributions to those HUCs.

WOWA Score

68.079 74.283

	Dry	Wet
2050	1 HUC(s) selected **1 HUC(s) vulnerable**	1 HUC(s) selected **1 HUC(s) vulnerable**
2085	1 HUC(s) selected **1 HUC(s) vulnerable**	1 HUC(s) selected **1 HUC(s) vulnerable**

Indicator

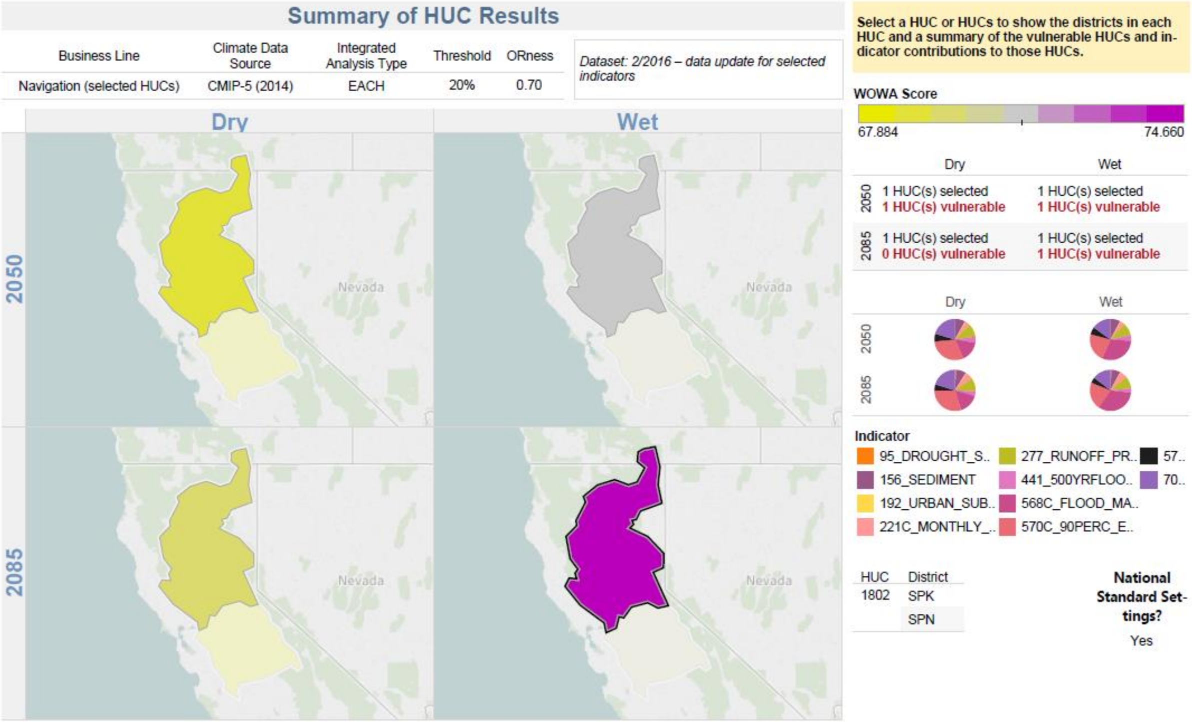
- 🟧 95_DROUGHT_S..
- 🟪 156_SEDIMENT
- 🟥 221C_MONTHLY_..
- 🟨 277_RUNOFF_PR..
- 🟪 568C_FLOOD_MA..
- 🟫 568L_FLOOD_MA..
- ⬛ 570L_90PERC_E..
- 🟩 571C_10PERC_E..
- 🟪 70..

HUC	District
1802	SPK
	SPN

National Standard Settings?

Yes

Figure 20 . Relative Vulnerability of the Recreation business line in the Sacramento River HUC-4 watershed. The watershed is vulnerable due to the possibility of decreasing runoff into the rivers as indicated by the change in low flow , monthly covariance and drought severity indicators.



Summary of HUC Results

Business Line	Climate Data Source	Integrated Analysis Type	Threshold	ORness
Navigation (selected HUCs)	CMIP-5 (2014)	EACH	20%	0.70

Dataset: 2/2016 – data update for selected indicators

Select a HUC or HUCs to show the districts in each HUC and a summary of the vulnerable HUCs and indicator contributions to those HUCs.

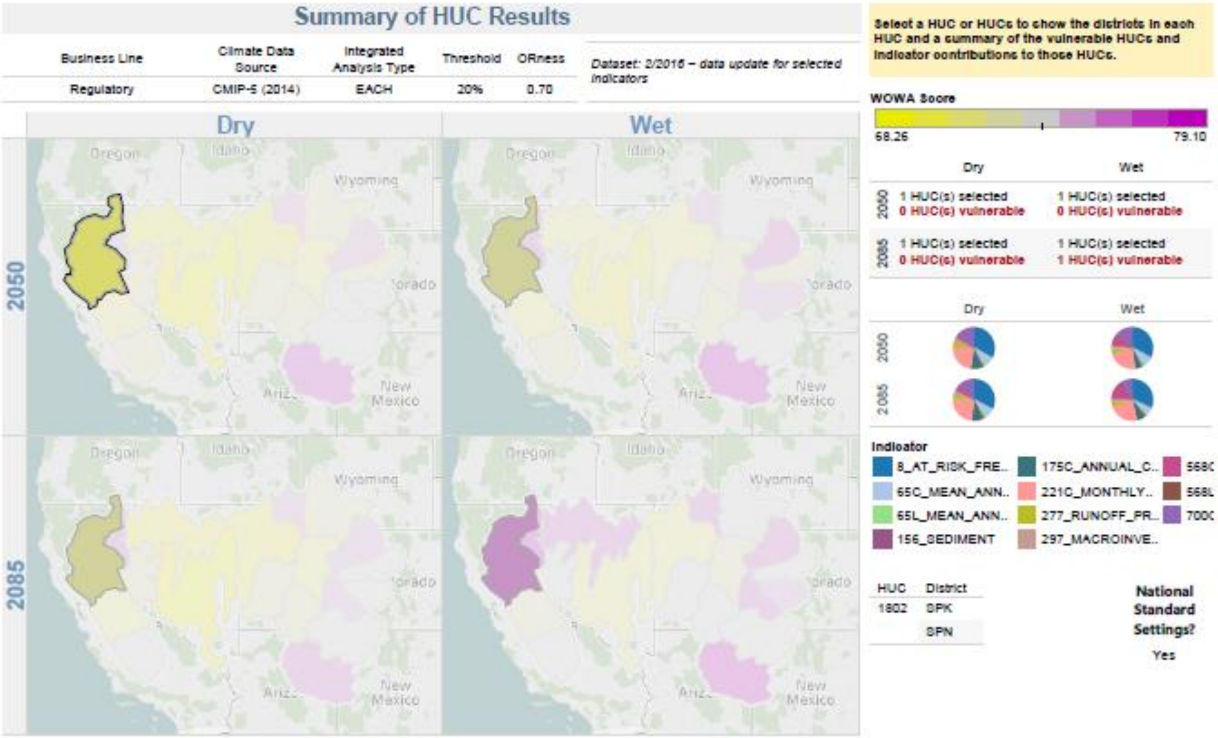
	Dry	Wet
2050	1 HUC(s) selected **1 HUC(s) vulnerable**	1 HUC(s) selected **1 HUC(s) vulnerable**
2085	1 HUC(s) selected **0 HUC(s) vulnerable**	1 HUC(s) selected **1 HUC(s) vulnerable**

HUC	District
1802	SPK
	SPN

National Standard Settings?

Yes

Figure 21 Relative vulnerability of the Navigation business line in the Sacramento River HUC-4 Watershed. The watershed is vulnerable relative to the other watersheds in the nation. Dominant indicators are flood magnification in wet scenarios and decreased runoff in dry scenarios.



Summary of HUC Results

Business Line	Climate Data Source	Integrated Analysis Type	Threshold	ORness
Regulatory	CMIP-5 (2014)	EACH	20%	0.70

Dataset: 2/2016 – data update for selected indicators

Select a HUC or HUCs to show the districts in each HUC and a summary of the vulnerable HUCs and indicator contributions to those HUCs.

	Dry	Wet
2050	1 HUC(s) selected 0 HUC(s) vulnerable	1 HUC(s) selected 0 HUC(s) vulnerable
2085	1 HUC(s) selected 0 HUC(s) vulnerable	1 HUC(s) selected 1 HUC(s) vulnerable

HUC	District
1802	SPK
	SPN

National Standard Settings?

Yes

Figure 22 Summary for the Regulatory Business Line. Watershed is vulnerable in the 2085 wet scenario due to changes in monthly and annual covariance.

Note : Water Supply and Hydropower graphical information is not supplied for the Sacramento River Watershed (HUC-1802) in the Vulnerability Assessment Tool.

Table 9 Flood Risk Reduction Vulnerability Scores for the Sacramento Watershed. Flood Risk Reduction is the Primary Business Line for this Project.

Business Line	Flood Risk Reduction									
Epoch and Scenario	Base Period		Dry 2050		Wet 2050		Dry 2085		Wet 2085	
Indicator Short Name	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	%WOWA	Raw WOWA	% WOWA
175C_ANNUAL_COV	4.06	7.24%	7.05	11.88%	2.69	4.16%	6.99	11.77%	4.53	6.70%
277_RUNOFF_PRECIP	2.51	4.47%	2.77	4.67%	4.32	6.68%	2.87	4.83%	2.86	4.23%
568C_FLOOD_MAGNIFICATION	12.42	22.15%	13.53	22.77%	17.31	26.75%	13.74	23.15%	19.30	28.58%
568L_FLOOD_MAGNIFICATION	6.27	11.19%	4.44	7.48%	8.74	13.52%	4.51	7.60%	9.75	14.44%
590_URBAN_500YRFLOODPLAIN_AREA	30.81	54.96%	31.61	53.21%	31.62	48.89%	31.25	52.65%	31.08	46.04%
Total WOWA	56.07	100.00%	59.41	100.00%	64.69	100.00%	59.35	100.00%	67.51	100.00%

Table 10 Ecosystem Restoration Vulnerability Scores.

Business Line	Ecosystem Restoration									
Epoch and Scenario	Base Period		Dry 2050		Wet 2050		Dry 2085		Wet 2085	
Indicator Short Name	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	%WOWA	Raw WOWA	% WOWA
156_SEDIMENT	2.01	2.94%	1.55	2.17%	1.55	2.13%	1.55	2.13%	1.20	1.59%
221C_MONTHLY_COV	15.97	23.39%	17.83	24.95%	17.85	24.45%	18.78	25.72%	18.98	25.15%
277_RUNOFF_PRECIP	8.78	12.85%	9.66	13.52%	9.81	13.43%	10.02	13.73%	10.08	13.36%
297_MACROINVERTEBRATE	5.64	8.26%	5.64	7.90%	4.36	5.97%	5.66	7.76%	4.37	5.79%
568C_FLOOD_MAGNIFICATION	1.54	2.25%	2.16	3.02%	6.08	8.32%	2.20	3.02%	6.84	9.06%
568L_FLOOD_MAGNIFICATION	0.79	1.15%	0.85	1.20%	1.10	1.50%	0.87	1.19%	1.60	2.12%
65L_MEAN_ANNUAL_RUNOFF	3.67	5.38%	3.72	5.20%	2.15	2.95%	2.86	3.92%	2.15	2.85%
700C_LOW_FLOW_REDUCTION	2.67	3.91%	2.83	3.97%	2.82	3.86%	3.74	5.13%	2.84	3.77%
8_AT_RISK_FRESHWATER_PLANT	27.22	39.85%	27.22	38.09%	27.31	37.40%	27.32	37.41%	27.39	36.31%
Total WOWA	68.29	100.00%	71.46	100.00%	73.04	100.00%	73.01	100.00%	75.44	100.00%

Table 19 Vulnerability Assessment Scores for Emergency Management in the Sacramento Watershed.

Business Line	Emergency Management									
Epoch and Scenario	Base Period		Dry 2050		Wet 2050		Dry 2085		Wet 2085	
Indicator Short Name	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	%WOWA	Raw WOWA	% WOWA
130_FLOODPLAIN_POPULATION	23.73	33.53%	20.87	29.84%	20.69	29.43%	20.84	29.60%	20.56	28.89%
175C_ANNUAL_COV	1.41	2.00%	1.98	2.84%	1.43	2.03%	1.96	2.79%	1.94	2.73%
277_RUNOFF_PRECIP	2.40	3.40%	2.65	3.79%	2.66	3.78%	2.74	3.90%	2.71	3.81%
443_POVERTY_POPULATION	8.03	11.35%	8.19	11.71%	8.12	11.55%	8.17	11.61%	6.48	9.11%
447_DISABLED	13.50	19.07%	13.54	19.36%	13.43	19.09%	13.54	19.23%	13.36	18.77%
448_PAST_EXPERIENCE	1.82	2.57%	1.47	2.10%	1.81	2.58%	1.47	2.08%	1.45	2.03%
450_FLOOD_INSURANCE_COMMUNITIES	1.13	1.60%	1.13	1.62%	1.12	1.60%	1.13	1.61%	1.12	1.57%
568C_FLOOD_MAGNIFICATION	3.57	5.05%	3.88	5.55%	6.13	8.72%	3.94	5.60%	10.59	14.89%
700C_LOW_FLOW_REDUCTION	10.10	14.27%	10.74	15.36%	10.57	15.03%	10.88	15.45%	8.49	11.93%
700L_LOW_FLOW_REDUCTION	5.07	7.17%	5.39	7.71%	4.26	6.06%	5.46	7.76%	4.26	5.99%
95_DROUGHT_SEVERITY	0	0%	0.09	0.12%	0.10	0.14%	0.26	0.36%	0.19	0.27%
Total WOWA	70.77	100.00%	69.94	100.00%	70.32	100.00%	70.40	100.00%	71.15	100.00%

Table 20 Vulnerability Sores for Navigation in the Sacramento Watershed.

Business Line	Navigation									
Epoch and Scenario	Base Period		Dry 2050		Wet 2050		Dry 2085		Wet 2085	
Indicator Short Name	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	%WOWA	Raw WOWA	% WOWA
156_SEDIMENT	1.89	3.04%	1.87	2.91%	1.83	2.79%	1.87	2.85%	1.82	2.69%
192_URBAN_SUBURBAN	0.46	0.75%	0.51	0.80%	0.50	0.76%	0.41	0.62%	0.40	0.59%
221C_MONTHLY_COV	3.73	6.01%	4.12	6.42%	4.02	6.14%	5.48	8.37%	5.40	7.95%
277_RUNOFF_PRECIP	5.07	8.17%	8.90	13.84%	6.93	10.58%	9.18	14.02%	7.09	10.44%
441_500YRFLOODPLAIN_AREA	2.89	4.67%	2.87	4.46%	2.80	4.28%	2.86	4.37%	2.80	4.12%
568C_FLOOD_MAGNIFICATION	6.47	10.44%	6.95	10.81%	13.99	21.34%	7.04	10.75%	15.66	23.06%
570C_90PERC_EXCEEDANCE	20.81	33.58%	20.81	32.37%	20.32	31.00%	20.81	31.78%	20.30	29.89%
570L_90PERC_EXCEEDANCE	8.57	13.82%	5.33	8.30%	5.21	7.94%	4.21	6.42%	4.10	6.04%
700C_LOW_FLOW_REDUCTION	12.09	19.51%	12.71	19.77%	9.71	14.82%	12.85	19.61%	9.75	14.35%
95_DROUGHT_SEVERITY	0.00	0%	0.21	0.33%	0.24	0.36%	0.79	1.20%	0.59	0.87%
Total WOWA	61.98	100.00%	64.28	100.00%	65.55	100.00%	65.50	100.00%	67.92	100.00%

Table 21 Vulnerability Results for Recreation in the Sacramento Watershed.

Business Line	Recreation									
Epoch and Scenario	Base Period		Dry 2050		Wet 2050		Dry 2085		Wet 2085	
Indicator Short Name	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	%WOWA	Raw WOWA	% WOWA
156_SEDIMENT	1.79	2.80%	1.37	2.04%	1.36	1.98%	1.39	1.98%	1.38	1.90%
221C_MONTHLY_COV	14.60	22.91%	16.29	24.17%	16.12	23.45%	22.52	32.03%	22.44	30.95%
277_RUNOFF_PRECIP	3.05	4.79%	3.36	4.98%	3.37	4.90%	3.52	5.00%	2.68	3.70%
568C_FLOOD_MAGNIFICATION	4.19	6.57%	4.54	6.73%	7.47	10.87%	4.67	6.64%	11.01	15.18%
568L_FLOOD_MAGNIFICATION	1.36	2.14%	1.92	2.85%	2.43	3.54%	1.98	2.81%	3.59	4.95%
570L_90PERC_EXCEEDANCE	21.32	33.46%	21.57	32.00%	21.36	31.07%	16.88	24.01%	16.64	22.95%
571C_10PERC_EXCEEDANCE	7.27	11.41%	7.32	10.86%	5.71	8.30%	7.43	10.57%	5.83	8.04%
700C_LOW_FLOW_REDUCTION	10.15	15.93%	10.76	15.96%	10.59	15.40%	11.05	15.72%	8.29	11.43%
95_DROUGHT_SEVERITY	0.00	0%	0.29	0.43%	0.33	0.48%	0.86	1.23%	0.65	0.90%
Total WOWA	63.72	100.00%	67.42	100.00%	68.74	100.00%	70.31	100.00%	72.51	100.00%

Table 22 Regulatory Business Line Vulnerability Scores for Sacramento Watershed (HUC-1802).

Business Line	Regulatory									
Epoch and Scenario	Base Period		Dry 2050		Wet 2050		Dry 2085		Wet 2085	
Indicator Short Name	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	%WOWA	Raw WOWA	% WOWA
156_SEDIMENT	1.18	1.73%	1.18	1.65%	0.95	1.32%	1.18	1.63%	0.95	1.27%
175C_ANNUAL_COV	4.43	6.48%	6.18	8.63%	3.62	5.00%	6.13	8.43%	4.92	6.61%
221C_MONTHLY_COV	14.62	21.40%	16.30	22.76%	16.30	22.53%	17.13	23.56%	17.21	23.09%
277_RUNOFF_PRECIP	2.50	3.66%	3.42	4.77%	2.78	3.85%	3.54	4.86%	2.84	3.81%
297_MACROINVERTEBRATE	3.27	4.79%	2.62	3.67%	2.11	2.92%	2.11	2.90%	2.11	2.83%
568C_FLOOD_MAGNIFICATION	1.56	2.28%	2.10	2.93%	6.45	8.92%	2.66	3.65%	8.97	12.04%
568L_FLOOD_MAGNIFICATION	0.69	1.01%	0.75	1.05%	1.19	1.65%	0.76	1.05%	1.66	2.23%
65C_MEAN_ANNUAL_RUNOFF	5.82	8.52%	4.71	6.58%	4.63	6.40%	4.71	6.47%	3.70	4.96%
65L_MEAN_ANNUAL_RUNOFF	1.98	2.91%	1.61	2.25%	1.57	2.17%	1.61	2.21%	1.25	1.68%
700C_LOW_FLOW_REDUCTION	8.39	12.29%	8.89	12.42%	8.84	12.22%	9.02	12.40%	7.12	9.55%
8_AT_RISK_FRESHWATER_PLANT	23.86	34.93%	23.84	33.29%	23.89	33.02%	23.87	32.83%	23.79	31.93%
Total WOWA	68.30	100.00%	71.61	100.00%	72.34	100.00%	72.72	100.00%	74.51	100.00%

Table 23 Vulnerability Results for Hydropower. Note that there are no CORPS projects in the Sacramento Watershed (HUC-1802) which are under this business line.

Business Line	Hydropower									
Epoch and Scenario	Base Period		Dry 2050		Wet 2050		Dry 2085		Wet 2085	
Indicator Short Name	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	%WOWA	Raw WOWA	% WOWA
156_SEDIMENT	2.36	4.09%	2.36	3.70%	1.76	2.70%	2.36	3.56%	1.76	2.53%
175C_ANNUAL_COV	7.80	13.49%	8.76	13.70%	5.91	9.06%	8.68	13.07%	6.49	9.33%
221C_MONTHLY_COV	24.73	42.80%	27.61	43.19%	27.46	42.14%	28.97	43.63%	29.11	41.87%
277_RUNOFF_PRECIP	12.39	21.43%	13.63	21.32%	13.75	21.09%	14.09	21.22%	14.08	20.26%
568C_FLOOD_MAGNIFICATION	3.65	6.32%	3.96	6.19%	9.02	13.84%	4.02	6.05%	10.11	14.55%
568L_FLOOD_MAGNIFICATION	1.46	2.53%	1.58	2.48%	2.70	4.14%	1.61	2.42%	3.03	4.35%
700C_LOW_FLOW_REDUCTION	5.40	9.34%	5.72	8.95%	4.24	6.50%	5.80	8.73%	4.26	6.13%
95_DROUGHT_SEVERITY	0.00	0%	0.30	0.47%	0.34	0.53%	0.88	1.33%	0.68	0.97%
Total WOWA	57.79	100.00%	63.93	100.00%	65.16	100.00%	66.41	100.00%	69.51	100.00%

Table 24 Water Supply vulnerability results. Note that there are no CORPS projects in California which have Water Supply as a project purpose.

Business Line	Water Supply									
Epoch and Scenario	Base Period		Dry 2050		Wet 2050		Dry 2085		Wet 2085	
Indicator Short Name	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	% WOWA	Raw WOWA	%WOWA	Raw WOWA	% WOWA
156_SEDIMENT	21.76	45.75%	15.51	27.60%	15.51	27.82%	15.51	26.38%	15.51	26.45%
175C_ANNUAL_COV	4.95	10.40%	6.10	10.86%	5.51	9.89%	6.04	10.28%	6.06	10.33%
221C_MONTHLY_COV	13.01	27.36%	24.52	43.65%	24.47	43.90%	25.74	43.78%	25.94	44.24%
277_RUNOFF_PRECIP	7.85	16.49%	9.47	16.86%	9.58	17.19%	9.79	16.66%	9.81	16.74%
95_DROUGHT_SEVERITY	0.00	0%	0.58	1.03%	0.67	1.20%	1.71	2.90%	1.31	2.23%
Total WOWA	47.56	100.00%	56.18	100.00%	55.73	100.00%	58.78	100.00%	58.62	100.00%

Conclusions:

The literature synthesis summarizing trends in observed and projected meteorology and climate changed hydrology indicate that future conditions will be warmer and possibly wetter then present conditions. This lends itself to a possible increased likelihood of large runoff events due to increases in the moisture content of storms. Note: The Cache Cr watershed does not have a significant snowpack and changes in the snowline (demarcation between where precipitation falls as rain versus snow) is not expected to have any significant impact on the hydrology. However, the impact that of the increased moisture content of storms will have on flooding in the Cache Cr Basin is uncertain. At this point, the USACE Nonstationarity Detection Tool is not identifying any significant nonstationarities in either of the datasets analyzed as part of this study, and the Climate Hydrology Assessment Tool is not detecting any trends in the recorded peak flow data at either gage location assessed. However, statistically significant increasing trends are identified in the projected, climate-changed annual maximum monthly streamflow values projected for the HUC 1802 Sacramento River Watershed as part of this analysis. The vulnerability assessment conducted as part of this study indicates that the main indicators of vulnerability in terms of flood damage reduction are flood magnification (ratio of the annual runoff exceeded 10% of the time during the given epoch to the same during the base period) and the urban development in the 0.2% exceedance floodplain. The Sacramento River Watershed is identified as being relatively vulnerable to increased flood risk due to climate change across all subsets of traces and epochs of time analyzed. Droughts are expected to become more common and severe, which could increase the chances of fires and the burning of significant acreage in the watershed in the future. This could lead to increased runoff from the burn areas.

The study evaluated a focused array of alternatives. Including the effects of climate change in the economic analysis would increase the estimated net benefits of all alternatives in the focused array. Alternative 2A is likely to be the least sensitive to climate change because the height is less sensitive to increased water surfaces related to climate change. Alternative 2A is a levee that runs on the north side of the urbanized portion of the City of Woodland. The levee runs through mainly rural areas and could be raised in height to accommodate larger floods if the hydrology changes in the coming decades. The team should consider and evaluate whether there are any further actions that can be taken in the context of the current study to make the community more resilient to higher future flows. Such actions might include flood proofing or acquiring structures, developing evacuation plans, land use planning, changes to levees and levee alignment and adjusting elevation or spacing of mechanical features (e.g., pump stations), among other actions. Climate change risks should be detailed in the project risk register.

References

USACE, Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects: ECB No. 2016-25 Dated September 2016.

USACE, Climate Hydrology Assessment Tool (ECB 2016-25), http://corpsmapu.usace.army.mil/cm_apex/f?p=313 dated November 2016.

USACE, Nonstationarity Detection Tool (NSD), http://corpsmapu.usace.army.mil/cm_apex/f?p=257 dated November 2016.

USACE, Vulnerability Assessment (VA) Tool, https://maps.crrel.usace.army.mil/apex/f?p=201 dated November 2016.

CH2M HILL , Preliminary Climate Change Analysis for the CVFPP - Phase IIA, CH2M HILL Technical Memorandum. Dated September 25, 2014.

Barnett, T.P., D.W. Pierce, H. Hidalgo, C. Bonfils, B. Santer, T. Das, G. Bala, A. Wood, T. Nozawa, A. Mirin, D. Cayan and M. Dettinger. 2008. Human-induced changes in the hydrology of the western United States. Science, 316, 1080-1083.

NOAA, NOAA Technical Report NESDIS 142-5: Regional Climate Trends and Scenarios for the U. S. National Climate Assessment: Part 5 Climate of the Southwest U.S. Washington D.C. dated January 2013.

Dettinger M.D., Ralph F.M., Hughes M., Das T., Neiman P., Cox D., Estes G., Reynolds D., Hartman R., Cayan D.R., and Jones L. 2011a. Design and quantification of an extreme winter storm scenario for emergency preparedness and planning exercises in California. Natural Hazards, doi: 10.1007/s11069-011-9894-5.

Dettinger, M.D., Ralph F.M., Das T., Neiman P.J., and Cayan D.R. 2011b. Atmospheric Rivers, Floods and the Water Resources of California. Water 3 (2), 445-478.

Das T., Maurer E.P., Pierce D.W., Dettinger M.D., and Cayan D.R. 2013. Increases in Flood Magnitudes in California under Warming Climates. Journal of Hydrology. http://dx.doi.org/10.1016/j.jhydrol.2013.07.042.

Das T., Dettinger M.D., Cayan D.R., and Hidalgo H.G. 2011a. Potential increase in floods in Californian Sierra Nevada under future climate projections. Climatic Change, doi: 10.1007/s10584-011-0298-z.

Das, T., D.W. Pierce, D.R. Cayan, J.A. Vano, and D.P. Lettenmaier. 2011b. The Importance of Warm Season Warming to Western U.S. Streamflow Changes. Geophys. Res. Lett., DOI: 10.1029/2011GL049660.

Taylor, Karl E., Ronald J. Stouffer, Gerald A. Meehl. 2012. An Overview of CMIP5 and the Experiment Design. Bull. Amer. Meteor. Soc., 93, 485–498.

Goodridge, J., Persistence in California Weather Patterns, unpublished, Dated July 28, 2007.

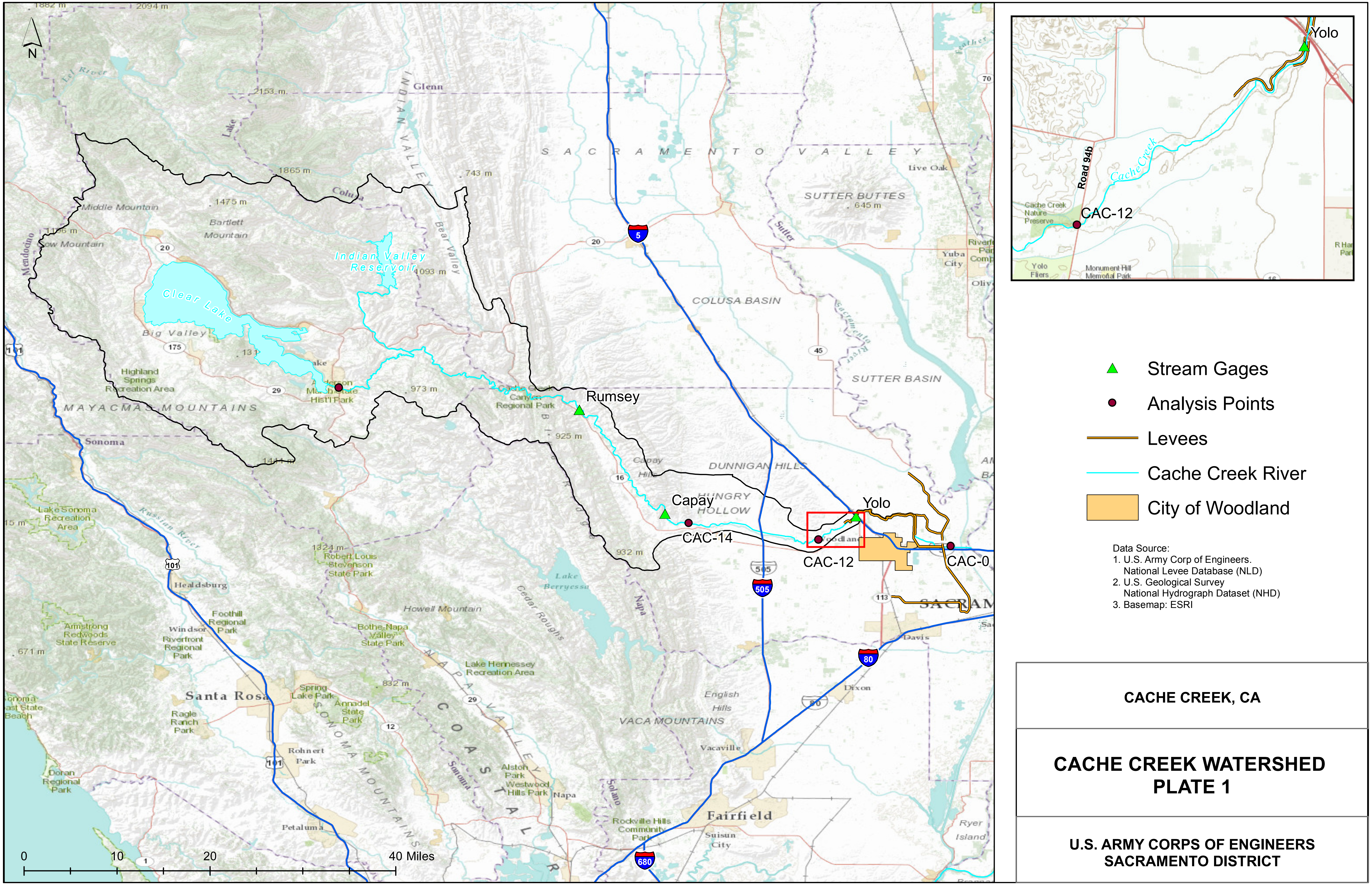
National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI), Climate at a Glance: Divisional Time Series, published February 2018, retrieved on March 13, 2018 from http://www.ncdc.noaa.gov/cag/

National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI), US Climate Divisions, retrieved on March 13, 2018 from https://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php

USACE (SPK). 2015. Central Valley Climate Variability Sensitivity Study, USACE, Sacramento District (SPK).

U.S. Bureau of Reclamation (US BoR). 2014. West-Wide Climate Risk Assessment for the Sacramento and San Joaquin Basins. Downloaded 18 March 2018. https://www.usbr.gov/watersmart/wcra/docs/ssjbia/ssjbia.pdf

USGCRP, 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018.



Stream Gages

Analysis Points

Levees

Cache Creek River

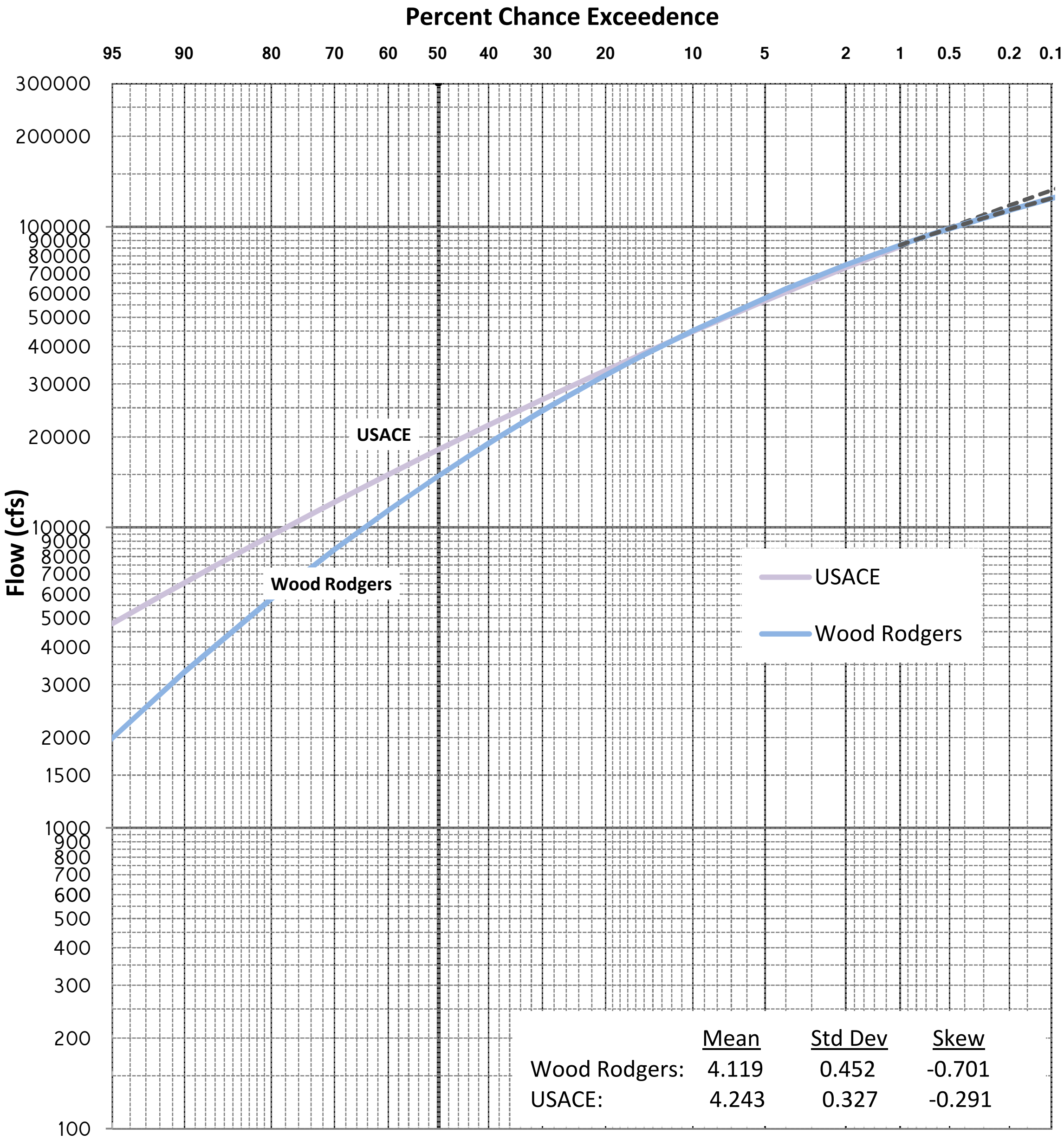
City of Woodland

Data Source:
1. U.S. Army Corp of Engineers.
National Levee Database (NLD)
2. U.S. Geological Survey
National Hydrograph Dataset (NHD)
3. Basemap: ESRI

CACHE CREEK, CA

CACHE CREEK WATERSHED
PLATE 1

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



	Mean	Std Dev	Skew
Wood Rodgers:	4.119	0.452	-0.701
USACE:	4.243	0.327	-0.291

NOTES:

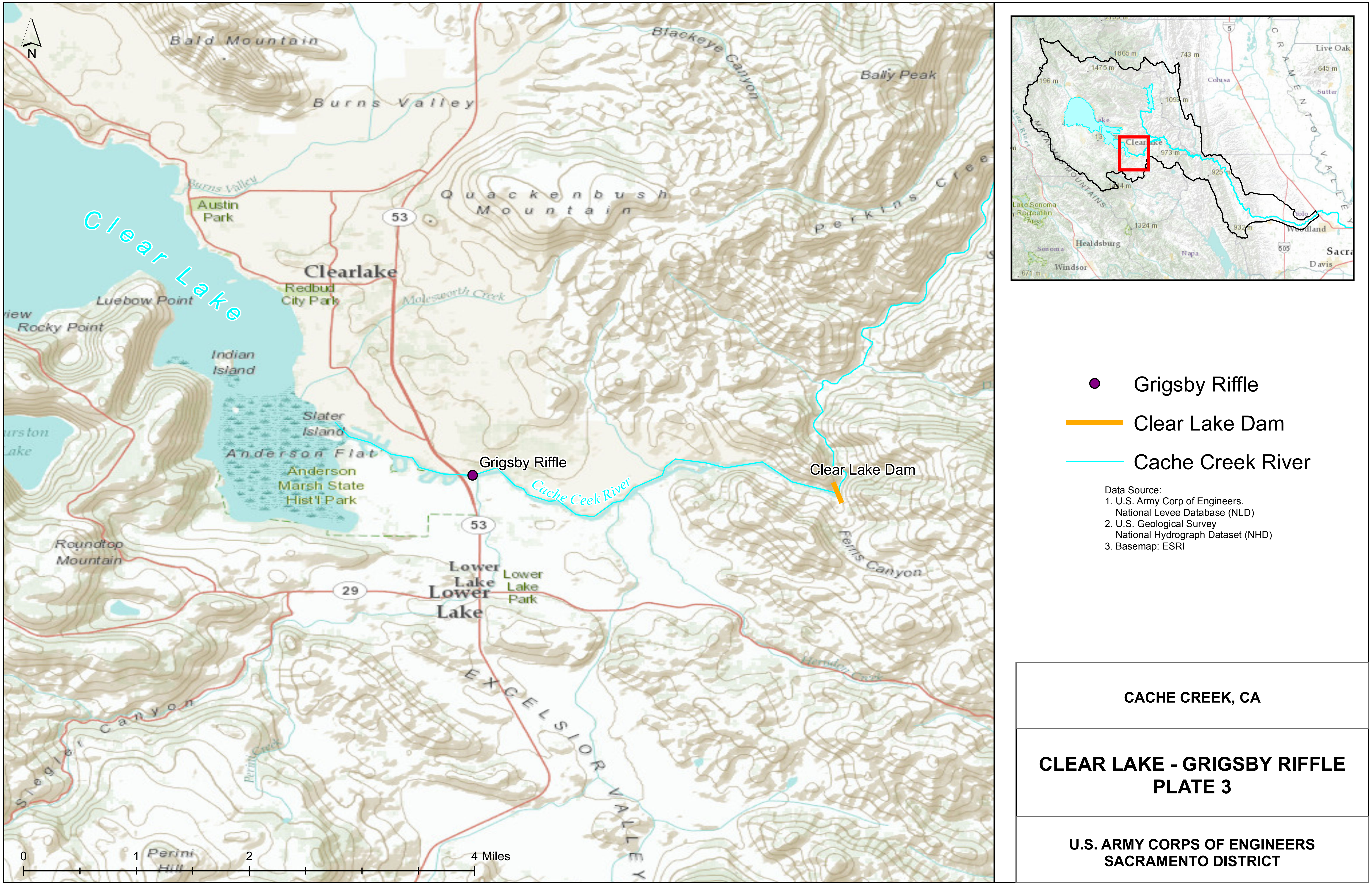
1. Computed Probability
2. Drainage area: 955 sq. mi.
3. Wood Rodger's curve: WY 1943-2008
4. USACE's curve: 1943-2011

CACHE CREEK STUDY
CACHE CREEK, CALIFORNIA

UNREGULATED PEAK FLOW FREQUENCY CURVES
COMPARISON AT RUMSEY
PLATE 2

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

22-Feb-13



● Grigsby Riffle

━ Clear Lake Dam

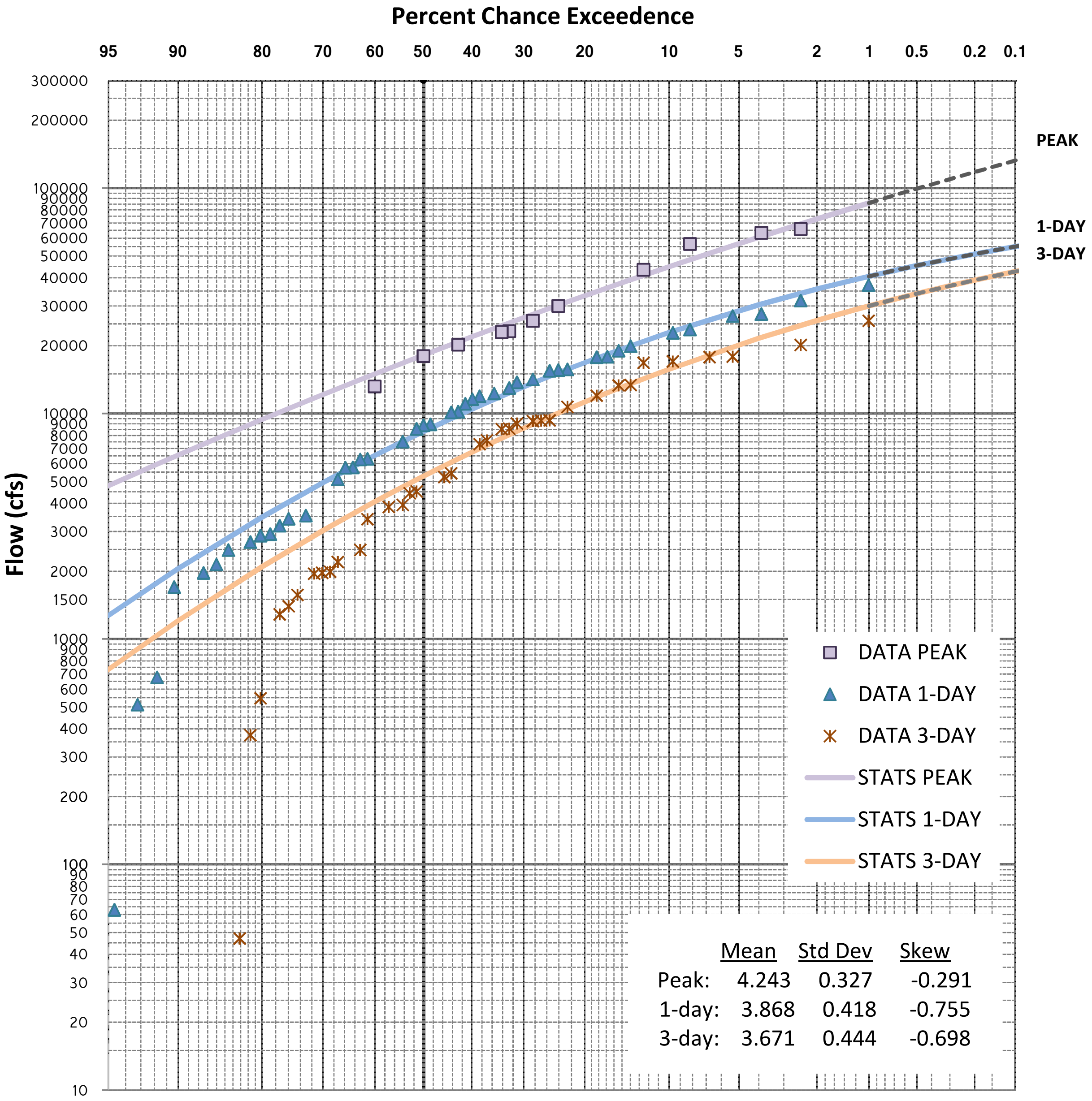
─ Cache Creek River

Data Source:
1. U.S. Army Corp of Engineers.
National Levee Database (NLD)
2. U.S. Geological Survey
National Hydrograph Dataset (NHD)
3. Basemap: ESRI

CACHE CREEK, CA

CLEAR LAKE - GRIGSBY RIFFLE
PLATE 3

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



	Mean	Std Dev	Skew
Peak:	4.243	0.327	-0.291
1-day:	3.868	0.418	-0.755
3-day:	3.671	0.444	-0.698

NOTES:

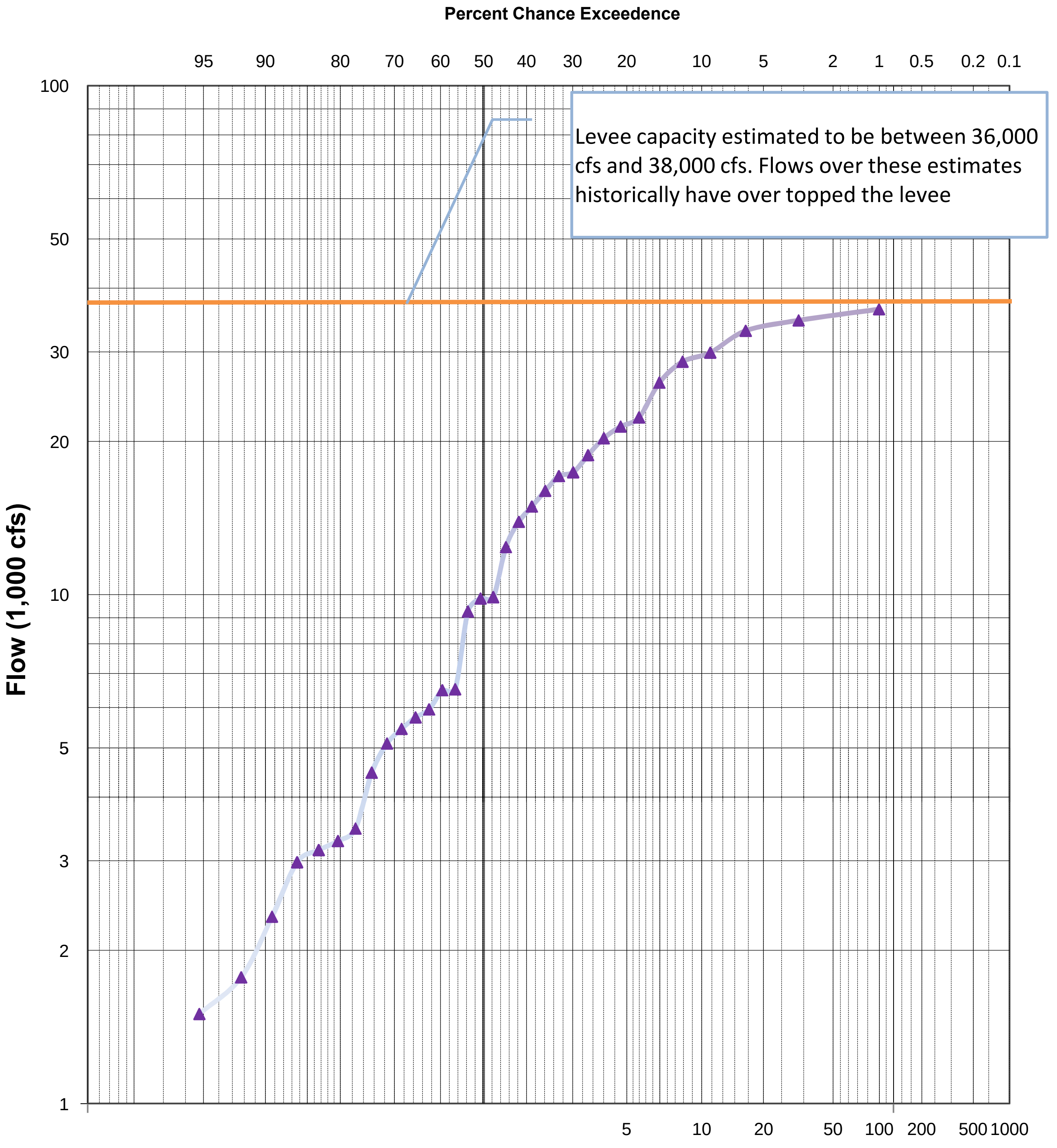
1. CDEC ID: RUM
2. Median plotting positions.
3. Computed Probability
4. Drainage area: 955 sq. mi.
5. Historical Maximum Discharge: WY 1943-2011.
6. WY 1977 low outlier

CACHE CREEK STUDY
CACHE CREEK, CALIFORNIA

UNREGULATED FREQUENCY CURVES
CACHE CREEK AT RUMSEY
PLATE 4

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

25-Feb-13



NOTES:

1. Drainage Area: 1,139 sq mi.
2. Period of Record: 1978-2010.
3. Historical Record: 1943-2012
4. 1995 Historical Peak: 34,600 cfs
5. USGS #: 11452500.
6. Median plotting position

CACHE CREEK STUDY
YOLO, CALIFORNIA

PLATE 5

CACHE CREEK AT YOLO

REGULATED FREQUENCY CURVES

1978-2010

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

3/4/2013

HYDRAULIC ANALYSIS AND CIVIL DESIGN

APPENDIX B

LOWER CACHE CREEK DRAFT FEASIBILITY STUDY

Yolo County, CA

December 2019

United States Army Corps of Engineers

Sacramento District

Contents

TABLES

PLATES

1.0 Introduction

1.1 Purpose and Scope

The purpose of the hydraulic appendix is to describe the hydraulic analysis conducted in support of the Lower Cache Creek Feasibility Study. This hydraulic appendix is an addendum to the main feasibility study report. The appendix provides a description of the existing conditions and sources of potential flooding. The appendix also documents the analysis of the focused array and final array of alternatives aimed to reduce flood risk in the affected communities.

1.2 Background

The Lower Cache Creek Feasibility Study (LCCFS) is being conducted under the authority of the Flood Control Act of 1962. The goal of the study is to identify a cost effective, technically feasible and locally acceptable project that best reduces flood risk and flood damages and complies with all Federal, State, and local laws and regulations.

The Cache Creek Feasibility Study is utilizing the process of risk informed decision making during plan formulation. Within this process, an initial analysis is conducted prior to detailed analysis. Based on sensitivity to these initial assumptions, more detailed analyses may be conducted as plans are refined and formulated. Further, more detailed analysis would likely occur during project engineering and design phase depending on the sensitivity of the design.

All alternatives are designed to meet all USACE design requirements.

1.3 Location

The study area is located along the lower portion of Cache Creek in Yolo County, California. The main stem of Cache Creek originates with the outflows of Clear Lake in the Coast Range Mountains of Northern California. The north fork of Cache Creek joins the main stem of Cache Creek above Capay Valley before flowing out of the foothills into California's Central Valley.

The focused study area encompasses the City of Woodland, town of Yolo, and surrounding agricultural areas as indicated in Plate 1. The channel passes north of the City of Woodland through levees improved by USACE in 1958 as part of the Federally-authorized Sacramento River Flood Control Project (SRFCP).

1.4 Plan Formulation

The focused and final array of plans described in this report are selected through a risk informed plan formulation process involving multi-disciplinary analysis using an appropriate level of detail for decision making. At each level of screening and analysis the level of detail was improved and the relative uncertainty was assessed. A measure or alternative was carried forward if the level of detail was insufficient to screen it out. Throughout this process the concept of absolute accuracy versus relative accuracy was considered in alternative comparisons. Although it would appear that every plan should be compared to the most accurate assessment of existing conditions, this is not necessary because the relative accuracy between plans is sufficient to select the most optimal plans to move forward. The plan formulation and evaluation process is summarized below. The comparison and selection of plans is described in the feasibility report.

1.5 Formulation and Evaluation Approach for Focused Array

A focused array of alternatives was formulated from an initial array of alternatives described in the feasibility study report. The focused alternatives were evaluated using qualitative and quantitative engineering analyses. Analyses included floodplain hydraulic modeling, geotechnical evaluations, cost estimating, and economic benefit estimations. The level of detail was limited to that required to decide which plans to carry forward. Results were evaluated at a combined Value Engineering (VE) study and planning charette attended by the project sponsors and subject matter experts. At the conclusion of the VE study and planning charette, refinements to the focused array of alternatives were identified for further, more detailed analysis.

Each feature of the alternatives was designed following USACE design criteria: EM 1110-2-1913, Design and Construction of Levees; and ETL 1110-2-583 Guidelines for Landscape Planting and Vegetation Management at Levees. The performance of each alternative was then evaluated by adjusting inputs in the USACE FDA program to reflect the features of the alternative. The approach of simulating an alternative's performance by changing FDA inputs is described in Section 9 of EM 1110-2-1619, Risk Analysis for Flood Damage Reduction Studies. Inputs to the FDA program were unregulated flow frequency, unregulated flow versus regulated flow, regulated flow versus stage, levee fragility, and stage-damage relationships and their uncertainties. The results of the economic and risk analysis are described in the Economic and Risk Appendix of the feasibility report.

1.6 Evaluation Approach for Final Array

Final alternatives were selected from the focused alternatives to be studied in increased detail. The level of detail was increased by included additional qualitative and quantitative engineering analyses. Analyses included refined cost estimating, economic benefit estimates, and impacts analysis. The level of detail was limited to that required to decide which plan to carry forward as the Tentatively Selected Plan.

1.7 Feasibility Level Design of Tentatively Selected Plan

It is anticipated that additional refinements will be made to the Tentatively Selected Plan after the Agency Decision Milestone. The refinements would be described in the final feasibility report and appendices.

1.8 Datum

As required by ER 1110-2-8160 all elevation data provided herein are referenced to the NAVD88 vertical datum in US Survey Foot. All horizontal data provided herein are referenced to the North American Horizontal Datum of 1983 (NAD83) in US Survey Foot. All horizontal coordinates are projected UTM 10 coordinate system.

Historical elevation data were converted to NAVD88 from their original legacy reference datum. The method of conversion followed the requirements in ER 1110-2-8160 and the uncertainty in the conversion was accounted for in the study results.

2.0 Study Area

2.1 Overview

The study area encompasses the city of Woodland and town of Yolo, California, as shown in Plate 1. It also includes the communities of Zamora and unincorporated areas of Yolo County. The principal sources of flooding to the study area are Cache Creek, Colusa Basin Drain, Yolo Bypass, and Willow Slough. The study area is drained by the Yolo Bypass, a major structural feature of the regional Sacramento River Flood Control Project which diverts water around the major urbanized areas of Sacramento, West Sacramento, Woodland, and Davis. Although the flood control system has significantly reduced risk to urban and agricultural lands within the study area, residual risk of structural failures remains throughout the system. The residual risks relate primarily to the potential of events exceeding the system design and known and the performance of levees in the system.

Cache Creek is a west side tributary of the Sacramento River near Sacramento, California. Cache Creek flows southeast out of Clear Lake, through Capay Valley and the eastern foothills of the Coast Range Mountains through the Cache Creek Settling Basin (CCSB) and the western levees of the Yolo Bypass. The creek is ephemeral and typically water only reaches the lower reaches of the creek near Woodland during the winter season due to natural precipitation patterns, upstream retention, and diversions for water supply.

There are two large lakes within the watershed. Clear lake is a natural lake located on the main stem of Cache Creek upstream of the North Fork. The lake has no allocated flood control storage. Indian Valley Dam and Reservoir, completed in 1971 is located on the North Fork of Cache Creek. Indian Valley Reservoir capacity at gross pool is 300,600 acre-feet, of which 40,000 acre-feet is allocated during flood seasons for flood control storage (USACE, 1971).

The existing Cache Creek levee profile was designed to provide a freeboard of at least 3 feet above an adopted flood profile calculated using a project design flood of 30,000cfs (USACE, 1961). Based on current analysis presented in this report, the existing levee profile would pass a 10% (1/10) AEP event (30,000 cfs) with 90% assurance, if the levee is assumed to not fail prior to overtopping. However, including the probability of geotechnical failure prior to overtopping, the existing levee project would pass a 50% (1/2) AEP event (10,800cfs) with 90% assurance.

The Cache Creek Settling basin is a detention basin located at the downstream end of Cache Creek just upstream from the Yolo Bypass. The purpose of the CCSB is to detain sediment that would otherwise deposit in the Yolo Bypass and reduce the conveyance area of the Yolo Bypass and thereby increase the flood risk to the city of Sacramento.

2.2 Topography

The study area is located on the alluvial fan of Cache Creek. A topographic map of the study area is provided as Plate 2. The general terrain slopes downward from the Capay Valley towards the Sacramento River. Cache Creek is perched on a ridge of higher ground radiating outward from the Capay Valley towards the Sacramento River. This ridge was formed through the historical deposition of fine grained sediment along the channel banks during out of bank flow events. Historical alignments of Cache Creek are evident as several similar ridges of higher ground radiating from the Capay Valley. Floodwaters that overtop the natural banks or levees flow away from the main channel of Cache Creek to the valleys between the ridges. This natural floodplain topography is interrupted by multiple linear embankments that can significantly influence the direction and depth of flooding. For example the linear embankments of railroads, highways, and levees can significantly impact the direction of floodwaters.

2.3 Principal Sources of Flooding

The principal source of flooding to the study area is Cache Creek. However, portions of the study area are subject to comingled flooding from other sources described below.

Colusa Basin Drain conveys floodwaters from the eastern slopes of the Coastal Range and area west of the Sacramento River to the Knights Landing Ridge Cut (KLRC). The Colusa Basin Drain has a drainage area of approximately 1800 square miles; all flood water from the Colusa Basin Drain flows into the KLRC and then into the Yolo Bypass. Flows in Colusa Basin Drain watershed are unregulated.

Knights Landing Ridge Cut (KLRC) is a channel that was excavated through a ridge of high ground near the town of Knights Landing. The KLRC conveys floodwaters of the Colusa basin drain to the Yolo Bypass.

Yolo Bypass is a flood bypass of the Sacramento River Flood Control Project. The Yolo bypass begins at the Fremont Weir and conveys flood waters from the Sacramento River and Sutter Bypass to the Sacramento River Delta near the town of Rio Vista. The Yolo Bypass has a design capacity of 343,000 cfs.

Willow Slough conveys runoff from the eastern slopes of the Coastal Range to the Yolo Bypass. The levees along the downstream portion of Willow Slough are designed to account for the backwater from the Yolo Bypass.

2.4 Stream gages

Stream gages on Lower cache Creek include the DWR Cache Creek at Rumsey gage, USGS Cache Creek at Yolo gage, and USGS Cache Creek at Capay gage. The Cache Creek at Capay gage which is 20 miles upstream of Highway 5 had been maintained by the USGS from 1943 to 1976; however the gage is no longer operating. The Cache Creek at Rumsey gage which is 36 miles upstream of Highway 5 began operating in 1961 and is maintained by the Department of Water Resources (DWR). The Cache Creek at Rumsey gage provided flow records and was used to calibrate and check the hydrologic models. The Cache Creek at Yolo gage which is located at Highway 5 Bridge crossing is operated by USGS since 1907 and was used for calibrating hydraulic models. The gage only measures flows in the Cache Creek channel and does not account for flow outflanking the gage when flows exceed 30,000 to 35,000 cfs.

2.5 Historical Flood Events

Flood flows are most likely to occur between November and April, no known floods have occurred between June and August. Large floods results from rainstorm events. Lower Cache Creek has a history of flooding. Four major flood periods have been documented for the Cache Creek basin during the last half of the 20th century, and 20 severe floods have occurred since 1900. The most severe floods of recent years in the cache Creek basin downstream from Clear Lake occurred in 1939, 1955, 1956, 1958, 1964, 1965, 1970, 1983, 1995, 1997, 2005. Recorded annual peak discharges at the USGS Cache Creek at Yolo gage are provided in Plate 3.

The largest five flow events based on USGS gage Cache Creek at Yolo are presented in Table 1.

Table 1. Largest Top Five Flow Events 1903 to 2019, USGS 11452500 Cache Creek at Yolo, CA

Year	Channel Flow (cfs)	Date
1958	41,400	February 25, 1958
1940	38,700	February 28, 1940
1965	37,800	January 06, 1965
1995	36,400	March 09, 1995
1970	36,600	January 24, 1970

The city of Woodland was incorporated in 1871 and never been flooded. However, historical flooding does not mean there is no flood risk. Some of the factors are discussed as below:

Lower Cache Creek has not experienced a 1% (1/100) AEP flood since the city was built. It is possible that a 1% (1/100) AEP flood may not occur within a hundred-year period. Statistically, there is only a 63% chance that a flood of this magnitude will occur in any given century.

Conditions in the creek and in the City of Woodland have changed over the years. The footprint of developed land has grown. Areas that flooded in the past, such as in 1983, are now inside the city limits. It is also likely that in the early part of the century, flows might have overtopped the channel farther upstream and followed a path that took it away from the city of Woodland, such as the drainage path of the Willow Slough to the south or the natural swale to the north, upstream of the area that is now crossed by Interstate 5. In addition, gravel pit mining and streambed erosion have increased the carrying capacity of the creek so that more water reaches lower Cache Creek during big storms than occurred in the past. It is also known that the first half of this century was relatively dry while the last half has been relatively wet. While out-of-bank flows just upstream of the town of Yolo used to flow eastward into the Yolo Bypass, they are now partially diverted south into the city by Interstate 5. Additionally, out-of-bank flows that reach the Cache Creek Settling Basin are forced south into the east side of the city by the new (1990) west levee of the Cache Creek Settling Basin (CCSB).

The potential for flooding in Woodland has occurred numerous times and even though the city of Woodland has no recorded history of flooding, in 1958, 1983, and 1995, Cache Creek rose to the top of both levees and overflowed its banks toward Woodland. The fact that the city hasn't is also due to circumstance and flood-fighting efforts.

The following are descriptive accounts of some of the major flood events:

2.5.1 February 28, 1940

The north levee west of the Woodland-Knights Landing Bridge broke, causing extensive flooding. The 1940 flood produced the largest peak flow on the adjoining watershed of Putah Creek for the unregulated period prior to the building of Monticello Dam. The peak flow was 81,000 cfs on Putah Creek at Winters (547 mi^2 drainage area).

2.5.2 January 27, 1983

Early in the morning, the south levee of Cache Creek failed about 2 miles east of Woodland and north of Interstate 5. Following the break, 12 flood fighters were stranded for a few hours between the break site and the stub end of the levee system. The flood crews were rescued by a California Highway Patrol helicopter. About 600 acres of agricultural land was flooded. Protective measures were taken to save the town of Yolo. The peak flow at the Rumsey gage was estimated at 53,500 cfs ((2% (1/50) AEP). Despite intense flood- fighting and sandbagging efforts, the January 1983 flood caused the south levee to break to the east of Road 102. Six hundred acres of farmland were flooded to the east of the city, but the damages might have been worse if the levee had failed farther upstream, putting the water in a more direct path towards the City of Woodland. Federal, state, and local agencies patched levee boils at that time to prevent additional levee breaks along both sides of the levee system.

2.5.3 March 9, 1995

High flows in January were followed by an even larger event in March. The estimated peak flows at Rumsey were 33,000 and 52,000 cfs in January and March, respectively. Heavy bank erosion and debris endangered the Capay Bridge and buildings along the creek. Rock was dumped at the bridge to stabilize the banks. Farther downstream, sandbagging and bank protection measures were used to protect the Cache Creek levees. In this event, overbank flow is estimated to have started at 36,500 cfs. The levees were originally designed to convey about 30,000 cfs (not including the additional levee freeboard). Although the levees did not fail, overtopping did occur. Large tracts of land were flooded (mostly undeveloped land and agricultural areas). Fortunately, there was not enough volume in this event to reach the City of Woodland. The hydrograph was spiked in shape (high peak flow but less volume). At Rumsey, the peak was a 2% (1/50) AEP and the 24-hour and 72-hour volume was approximately a 5% (1/20) AEP. An analysis of a high water mark at Road 94B indicated a peak flow of about 48,000 cfs (about a 2.5% (1/40) AEP). The March 1995 flood overtopped the levee upstream of the Interstate 5 Bridge and resulted in the city declaring a State of Emergency and advising voluntary evacuation of properties north of Woodland Avenue. The water moved south along Highway 5, flooding hundreds of acres before the water came to a stop at the edge of a developed portion of the city. The extent of flooding would have been worse if the south levee had failed rather than just being overtopped because this would have decreased channel capacity from 36,000 cfs to between 20,000 - 25,000 cfs (as determined by MBK Engineers). In addition, while the peak flow at Road 94B had a 22.5% (1/40) AEP, the 72-hour volume was determined to only be a 5% (1/20) AEP. More volume would have resulted in Woodland being flooded.

2.5.4 January 1997

42,000 cfs had been recorded at Rumsey gage which resulted in the flooding of agricultural land.

2.5.5 February 2019

The most recent high flow event was on February 27, 2019. A flow of 26,400 cfs resulted in overtopping of left bank levee downstream of Yolo upstream and overtopping of the right banks upstream of the project levees. Though there was overtopping upstream and downstream of the community of Yolo, the peak stage was 4-5 feet below the top of levee adjacent to the community. During this event there were also numerous boils and seepage concerns along both banks of the Cache Creek levees downstream to CA 113. DWR and local agencies performed emergency flood fight sandbagging to raise the top of levee along Cache Creek.

3.0 Existing and Future without Project Conditions

The existing and future without project conditions were assumed to be similar. The upstream watershed is remote and urban development is unlikely to change runoff characteristics. There are no authorized yet unconstructed USACE projects planned in the watershed that would alter the hydrology.

The existing and future without project conditions analysis reflects the topographic conditions of the study area in 2008. Due to regional land subsidence in the area, water surface elevations may not accurately reflect conditions after 2008. However, the resulting change in channel slope is not considered significant enough to impact plan selection.

Based on an evaluation of the existing and future without project Hazardous, Toxic, and Radioactive Waste (HTRW), water quality, and sediment transport and trapping, there are no adverse impacts expected for any of the design alternatives as discussed in the relevant EIS sections. Sediment trapping efficiency is expected to increase based on an a study conducted by UC Davis, and a Phase 1 Environmental Site Assessment concluded no increased adverse impacts are likely from project construction.

3.1 Hydrology

Hydrology for the study is detailed in the Hydrology Appendix. The Cache Creek hydrology was adopted by DWR for the 2012 Central Valley Hydrology Study (CVHS) and into the Central Valley Floodplain Evaluation and Delineation (CVFED) Program. This adopted hydrology was used as the basis for analyzing flood frequencies for Lower Cache Creek hydraulic analysis. Peak flows are provided in Table 2.

Table 2. Model Boundary Conditions/Peak Flows

Annual Chance Exceedance (AEP)	Cache Creek at Road 94B (cfs)	Colusa Basin Drain at Oat Creek (cfs)	Yolo Bypass at Fremont Weir (cfs)	Sacramento Bypass At Sacramento Weir (cfs)
2006 Calibration Event	29,900	Not included	Not included	Not included
50% (1/2)	10,800	14,200	31,000	200
20% (1/5)	22,500	21,500	156,500	44,900
10% (1/10)	31,500	24,900	213,700	65,600
5% (1/20)	34,800	28,700	224,500	72,800
2% (1/50)	49,900	32,200	332,400	100,500
1% (1/100)	58,300	37,700	429,200	123,500
0.5% (1/200)	65,400	43,000	479,400	162,600
0.2% (1/500)	74,200	45,600	534,800	193,700

For the purposes of hydraulic analysis for the existing conditions and project alternatives, flows in the Colusa Basin Drain, Yolo Bypass, and Sacramento Bypass have been assumed to be coincident with the same frequency as Cache Creek. This simplification was determined to be reasonable because the timing of peak runoff is significantly offset Cache Creek and these other channels. The offset of hydrographs for Colusa basin drain, Yolo Bypass, and Sacramento Bypass were based on the relative timing of the 1964 Cache Creek flood.

To confirm the reasonableness of the coincident flow assumption, the calibrated hydraulic model adopted for the study was used to perform a coincident flow sensitivity analysis by testing several coincident flow scenarios.

The following scenarios were analyzed to determine the sensitivity of the system for a range of event probabilities from 50% (1/2) AEP to 0.2% (1/500) AEP (Referred to as n-AEP) hydrological events:

a. Scenario 1: No inflow in Cache Creek; 0.5% (1/200) AEP flooding in Colusa Basin Drain, Yolo Bypass, and Sacramento Bypass.
b. Scenario 2: 0.5% (1/200) AEP flow in Cache Creek, with 10% (1/10) AEP flows in Yolo Bypass and Sacramento Bypass.
c. Scenario 3: 10% (1/10) AEP flows in Cache Creek; 0.5% (1/200) AEP flooding in the Colusa Basin Drain, and Sacramento Bypass.
d. Scenario 4: 0.5% (1/200) AEP inflows coincident in all parts of the system.

The boundary conditions coincident sensitivity analysis indicates the sensitivity of different locations within the floodplain to coincident flooding. Flooding in the Colusa Drain and Knights Landing Ridge Cut is predominantly governed by local inflows and tailwater influences from the Yolo Bypass and is not significantly influenced by the contributions from Cache Creek inflows. Flooding in the Yolo Bypass is predominantly governed by contributions from the main system and is not significantly influenced by outflow from Cache Creek Settling Basin. Flooding within the city of Woodland is predominantly governed by Cache Creek overflows, and is not impacted by coincident flooding in the Colusa Basin Drain, Knights Landing Ridge Cut, or the Yolo Bypass. By design, the performance of the Cache Creek Settling Basin outlet weir is not significantly influenced by flooding in the Yolo Bypass and will flow in a state of free discharge even when the stages in the Yolo Bypass are relatively high. Assuming the timing of flooding in Cache Creek is coincident with flooding in the Yolo Bypass, the results of 0.2% (1/500) AEP flood analysis indicate a maximum submergence ratio of approximately 75 percent at the Cache Creek Settling Basin outlet weir. Therefore, the weir will discharge freely for all conditions being evaluated, and the model results within the Cache Creek settling Basin will not be significantly influenced by conditions in the Yolo Bypass, even during extreme flood conditions.

The adjacent floodplains of Cache Creek which directly impact the communities of Woodland and Yolo are governed primarily by flooding from Cache Creek and are not significantly influenced by flooding conditions in the Colusa Basin Drain, Knights Landing Ridge Cut, or Yolo Bypass.

Generally speaking, many parts of the system are hydraulically independent from one another and will not be significantly influenced by the timing of peak flows. Therefore, it is reasonable to use coincident n-AEP flows for the system wide analysis.

3.2 Hydraulic Model

TUFLOW hydraulic computer program has been used to simulate depth-averaged, one and two dimensional free-surface flows and associated hydraulic analysis for the existing and the project conditions. The one dimensional channel components of the model are based on HEC-RAS geometry. The model consists of high resolution 25-foot grid in the vicinity of the breach locations and 100-foot grid for other portions of the model domain. When simulating a levee breach in the TUFLOW, the model adjusts the elevation of the two-dimensional grid over time. The hydraulic model domain is presented in Plate 4. The Cache Creek River Miles are presented in Plate 5.

3.3 Terrain and Survey Data

LiDAR data collected in 2008 by the California Department of Water Resources Central Valley Floodplain Evaluation and Delineation (CVFED) study was used to develop the geometry for the hydraulic models. The horizontal datum is the 1983 California Coordinate System Epoch 2010.00 (2011.00 realization), Zone 2, US Survey Feet. The vertical datum is Geoid 12b based on North American Vertical Datum of 1988 derived from the ellipsoid height. The LiDAR data was compiled to meet 1 foot contour vertical accuracy (0.6 foot vertical accuracy at the 95 percent confidence level in open areas and 1.2 foot at the 95 percent confidence level in all other than open or obscured areas). Additionally, the data was compiled to meet 3.5 feet horizontal accuracy at the 95 percent confidence level (RMSE * 1.96). Portions of Cache Creek that were underwater and obscured during the time the LiDAR was flown were later field surveyed as part of the CVFED Program. The channel configuration in the TUFLOW model is based on the bathymetric surveys collected in 2010 by West Yost Associates on behalf of Yolo County Flood Control and Water Conservation District.

Land subsidence caused by groundwater extraction has occurred historically and continues to occur in portions of the Sacramento Valley (DWR, 2018). A 2017 high precision GPS study by the California Department of Water Resources (DWR) concluded that portions of the study area have undergone regional ground subsidence since the 2008 topographic surveys were conducted. A map of the findings is presented in Figure ES-1 of the DWR report. The study indicates that subsidence rates from 2008 to 2017 were greatest on the west side of the Lower Cache Creek feasibility study area (-1.1 feet) and lowest on the east side of the study area (-0.1 feet). During the time of the 2017 survey, groundwater levels in the Sacramento Valley were recovering from the severe drought of 2012-16 (DWR, 2018). During the drought, groundwater levels hit historic lows in most wells in the Sacramento Valley with maximum decreases in Glenn and Colusa Counties of 58 ft. and 43 ft., respectively, compared to 2011 pre-drought conditions. During the survey field work in 2017, groundwater levels had recovered about 7 ft. on average since 2015 (DWR, 2018). Since the severe drought occurred over the observation period, it is possible the observed rate does not reflect an average future rate.

3.4 Roughness coefficients

Land use survey data from DWR and the Sacramento Area Council of Governments was used for land use classifications in rural and urbanized areas respectively. Roughness coefficients for the rural and agricultural portions of the model domain were developed using guidance from United States geological Survey (USGS) Water Supply Paper 2339, “Guide for Selecting Manning’s Roughness Coefficients for Natural Channels and Flood Plains”. For the urbanized classifications the roughness coefficients were adjusted using the methodology described in H.R. Hejl, Jr’s “A Method for Adjusting Values of Manning’s Roughness Coefficients of Flooded Urban Areas” (Hejl, 1977). Table 3 shows the model roughness values for different land uses.

Table 3. TUFLOW Overland Roughness Coefficient by Land Use Type

Land Use Type	Manning's "n" Values
Barren and Wasteland	0.04
Citrus and Subtropical	0.05
Commercial	0.1
Deciduous Fruits and Nuts	0.05
Field Crops	0.05
Grain and Hay Crops	0.04
Idle	0.04
Industrial	0.1
Native Vegetation	0.05
Pasture	0.04
Residential	0.1
Rice	0.035
Riparian Vegetation	0.045
Semi-agricultural and Incidental to Agriculture	0.04
Truck, Nursery, and Berry Crops	0.045
Urban	0.021
Urban Landscape	0.045
Vacant	0.04
Vineyards	0.05
Water Surface	0.03

3.4.1 Hydraulic Structures

Hydraulic structures in the TUFLOW computer model include bridges, weirs, and culverts. The Cache Creek Settling Basin outlet weir is modeled using the design elevation (35 ft NAVD88) of the existing concrete spillway. Other elevated floodplain features such as levees, railroads, and roadway embankments are modeled in TUFLOW using breakline data digitized from the LiDAR data. Features that are considered critical for influencing the direction and depth of flooding within the model domain are input in the model as breaklines. Openings through embankments are simulated by leaving gaps in the breakline definitions.

3.4.2 Hydrologic and Hydraulic Boundary Conditions

The downstream model boundary is located south of where Union Pacific Railroad line and Interstate 80 cross the Yolo Bypass. Normal depth has been used for the boundary condition to achieve hydraulic modeling stability for the low flow conditions.

The model domain includes portions of the Colusa Basin Drain, Yolo Bypass, and Sacramento Bypass. The upstream boundary conditions are inflow hydrographs Cache Creek at Road 94B, Colusa Basin Drain at Oat Creek, Yolo Bypass at Fremont Weir, and Sacramento Bypass at Sacramento Weir. The Cache Creek at Road 94B hydrographs for 50% (1/2) AEP, 20% (1/5) AEP, 10% (1/10) AEP, 5% (1/20) AEP, 2% (1/50) AEP, 1% (1/100) AEP, 0.5% (1/200) AEP, and 0.2% (1/500) AEP (n-AEP events), are presented in Plate 6.

3.4.3 Model calibration

In order to reduce uncertainty in model results, the one-dimensional hydraulic model has been calibrated to the January 1, 2006 event on Cache Creek using high-water mark data compiled by DWR for the CVFED Program. It should be noted that the peak flow recorded during the 2006 storm event was 29,900 cfs which is slightly less than the design capacity of Cache Creek downstream of County Road 102. Therefore, the 2006 storm represents a condition that is essentially bankfull, making it useful for calibrating the one-dimensional model.

3.4.4 Results

The results of the hydraulic model for the n-AEP simulations, including maximum depths and velocities are presented in Plates 7 through 15. Water surface profiles for the existing conditions are presented in Plate 16.

Based on TUFLOW hydraulic modeling analysis, the levees of the Lower Cache Creek start overtopping upstream of I-5 prior to overtopping further downstream. The overtopping flow splits into multiple flow paths that follow the topography away from the Cache Creek Channel banks. The northern overtopping flow splits into couple of flow paths, eventually reaching Colusa Drain and Knights Landing Ridge Cut where it eventually drains into the Yolo Bypass. The southern overtopping flow also splits in two flow paths, eastward of I-5 and westward of I-5. The flow path east of I-5 inundates agricultural areas between Cache Creek and City of Woodland. The flow path west of I-5 of propagates south and inundates City of Woodland. The flooding in the overbank areas is shallow and unconfined by distinct topographic boundaries. The estimated maximum depths of the flooding for a 0.2% (1/500) AEP event range 2 feet to 5 feet in the urban areas of Woodland. The boundary of 0.2% (1/500) AEP floodplain extends southeast to the Willow Slough levee.

The flow velocity in most of the overbank areas and in the floodplain range from 2 fps to 3 fps on average. There are some localized areas of velocities up to 5 feet per second near roadways and intersections.

3.5 Flood Warning Time

The principle sources of flood warnings are advisories by the National Weather Service (NWS) and river stage forecasts by the California Nevada River Forecast Center (CNRFC). The flood warning time would likely be greater for an overtopping related breach than a geotechnical failure type breach.

Flood warnings/small river and stream flood warnings are issued by the NWS when flooding of main stem rivers is occurring or imminent (CNRFC, 2019). Main stem river flooding refers to flooding of gauged and forecasted rivers (CNRFC, 2019). The product can also be used to issue Small River and Stream Flood Warnings for smaller rivers/streams which do not have forecast points.

Flash Flood Warnings are issued when flooding is reported; when precipitation capable of causing flooding is observed by radar and/or satellite; when observed rainfall exceeds flash flood guidance or criteria known to cause flooding; or when a dam or levee failure has occurred or is imminent (CNRFC, 2019). A flash flood is defined as a flood caused by heavy or excessive rainfall in a short period of time, and occurring generally within 6 hours of the causative event (CNRFC, 2019).

In addition to the advisories described above, the NWS in coordination with the California Department of Water Resources issues forecasts and guidance for river flows through the CNRFC. In general, river forecasts are based on modeled runoff from observed precipitation, snowmelt estimates, and actual reservoir operations. The forecast length varies depending on the location. River guidance is based on modeled runoff from forecasted precipitation, snowmelt estimates, and forecasted reservoir operations. The forecasts and guidance are issued for a forecast site in a graphical format that compares the future river stage to a monitor stage, flood stage, and danger stage. The combined forecast and guidance are made 5 days into the future but the uncertainty increases significantly the farther into the future.

Flooding from a levee overtopping event along the Lower Cache Creek would result from a large regional storm event in the Cache Creek Watershed. CNRFC river flood forecast points on the Cache Creek are located at Cache Creek, Yolo. It is assumed that an overtopping flood would be preceded by a flood warning and river guidance issued by the NWS and CNRFC five days in advance. However, it would be highly uncertain. A more accurate warning of potential levee overtopping, based on river forecasts, would likely be made 6 hours in advance. This estimate was based on a review of the flood guidance plots for February 2019 flood which indicate the forecasted peak flow was similar to the observed flow approximately 6 hours prior.

3.6 Geomorphic and Channel Stability Assessment

In 2001, a qualitative geomorphic and channel stability assessment of Lower Cache Creek was conducted for the feasibility study (USACE, 2003). The objective of the study was to identify key geomorphic processes affecting channel morphology and river dynamics of Lower Cache Creek from Road 94B to the Yolo Settling Basin. The Lower Cache Creek was divided into 6 geomorphically distinct reaches described from downstream to upstream. Plate 23 shows the reaches. A descriptive narrative of the reaches is presented in the following paragraphs.

Reach 1 (station 140+00 to station 260+00) is 12,000 ft in length, Cache Creek flows south in an artificially constructed channel that directs Cache Creek flows into the settling basin. Reach 1 showed no apparent bank erosion sites.

Reach 2 (station 260+00 to station 415+00) is 15,500 ft in length and located between CA113 and Reach 1. Channel banks in Reach 2 appeared stable and no areas of significant bank erosion were observed.

Reach 3 (station 415+00 to station 480+00) is 6,500 ft in length and forms a transitional reach between the wider Reach 2 downstream and the narrower Reach 4 upstream. Some areas that were devoid of tree cover exhibited significant areas of bank erosion and instability.

Reach 4 (station 480+00 to station 580+00) is 10,000 ft in length. The frequency of bank erosion in this reach is greater than downstream reaches.

Reach 5 (station 580+00 to station 670+00) is 9,000 ft in length and characterized by large meander bends that exhibit severe bank erosion along high vertical banks over hundreds of lineal feet.

Reach 6 (station 670+00 to station 780+00) is 11,000 ft long and located in a historically gravel mined section of the project reach.

In general, the frequency and severity of bank erosion and bank instability increases from Reach 1 (downstream) to Reach 5 (upstream).

Reach 1 has low flow velocities, sediment transport capacity, and shear stress. Future channel bed aggradation due to ongoing sedimentation is expected. The future bank erosion in Reach 2 is generally low with two exceptions which are located near the meanders and are narrow sections. The potential for future bank erosion in Reach 3 and Reach 4 is generally moderate due to a narrow channel width, entrenchment, and steep banks. Reach 5 has high potential for future bank erosion due to river meanders, entrenchment, and nearly vertical, high unstable banks in several areas. Bank erosion and instability in Reach 6 are not a significant issue to due to levee setback project in this area.

4.0 Inputs to Economic and Risk Analysis

The following describes the development of hydraulic inputs to the flood risk assessment and performance analysis conducted using the HEC-FDA program described in the Economic Appendix. Index locations reflect the performance of a channel reach. Engineering inputs for index locations include discharge frequency estimates, stage-discharge relationships, and levee performance curves (geotechnical appendix). Economic Impact Areas (EIA) reflect the consequences if the channel capacity was exceeded within the reach represented by the index point. Engineering inputs for the Economic Impact Areas are inundation depths for levee breach simulations.

4.1 Index Locations

Index locations reflect the performance of a channel reach. Engineering inputs for index locations include discharge frequency estimates, stage-discharge relationships, and levee performance curves (geotechnical appendix). Plate 24 shows the index points and damage areas. The peak stage-discharge relationships are generated from the TUFLOW model results at all index points for with and without levee breach scenarios.

4.2 Economic Impact Areas

Economic impact areas (EIA) are defined based on hydrologic separability. Separable element is defined as a portion of the project that is physically separable from other portions of the project and achieves hydrologic effects and or produces physical or economic benefits which are separately identifiable from those produced by other portions of the project.
While not specific to “hydrologically separableness,” “separable element” is defined in 33 United States Code (U.S.C.) Section 2213(f) as a portion of the project that (1) is physically separable from other portions of the project; and (2)(a) achieves hydrologic effects, or (b) produces physical or economic benefits, which are separately identifiable from those produced by other portions of the project.

An evaluation of how the Lower Cache Creek study area meets 33 United States Code (U.S.C.) Section 2213(f) requirement is described below:

Within the Lower Cache Creek study area, the floodplain has a relatively low gradient (approximately 0.1%) and the hydrologically separable areas are not clearly defined by basic topographic features alone, therefore the physical separation is best understood by analyzing the hydrologic and hydraulic characteristics of the levee breaches throughout the study. The separation is more evident in the levee breach simulations conducted for the study and the functionality of the alternatives. Damage areas were defined based on 0.2% (1/500) AEP inundation simulations.

Flood damages are computed for each of these impact areas from each major source of potential flooding using FDA. The change of damages within these areas are used to evaluate alternatives.

4.2.1 Economic Impact Area N1

N1 is on the right bank of Colusa Drain. The area is susceptible to comingled flooding from left bank overtopping and levee failures from Lower Cache Creek and the Colusa Basin Drain. The flooding in this area is susceptible to levee failures at index locations P1 and P4 on Cache Creek.

4.2.2 Economic Impact Area N2

N2 is on the left bank of Lower Cache Creek upstream of I-5.   This area is susceptible to flooding from index locations P1 and P4 but not susceptible to flooding by the Colusa Basin Drain. A breach or an overtopping at the index location P1 and or P4 on the left bank of the Cache Creek will impact the N2 Economic Impact Area.

4.2.3 Economic Impact Area N3

N3 is on the left bank of Cache Creek downstream of I-5 excluding the town of Yolo.   This area is susceptible to flooding from index location P4 but not the Colusa Basin Drain.   A breach at the index location P4 on the left bank of the Cache Creek will impact N3.

4.2.4 Economic Impact Area N4

N4 is susceptible to levee failure at index locations P4 and P7 on Cache Creek and Knights Landing Ridge Cut at the index location P7.

4.2.5 Economic Impact Area N5

N5 is on the left bank of Cache Creek downstream of I-5 and is associated with town of Yolo. The flooding in this area is related to index location P4. A breach at the index location P4 on the left bank of the Lower Cache Creek will impact N5.

4.2.6 Economic Impact Areas S6 and S8

S6 and S8 are on the right bank of Lower Cache Creek upstream of I-5. S8 consists of urbanized Woodland upstream of I-5. The flooding in these areas is related to breaches represented by index locations P2 and P3 which ever will yield the highest EAD. A breach at the index location P2 or P3 on the right bank of the Lower Cache Creek will impact S6 and S8.

4.2.7 Economic Impact Area S7

S7 is on the right bank of Lower Cache Creek downstream of I-5 and north of Woodland.   This area is susceptible to damages resulting from Index location P5 and P8 and damages will be defined based on which ever index location inundation will yield the highest EAD. A breach at the index location P5 and/or P8 on the right bank of the Lower Cache Creek will impact S7.

4.2.8 Economic Impact Area S9

S9 is on the right bank of Cache Creek downstream of I-5 and south of economic impact area S7 and consists of mostly urban areas of city of Woodland.   The area is susceptible to damages resulting from Index location P2, P3, P5, and P8 and damages will be defined based on which ever index location inundation will yield the highest EAD. A breach at the index location P2, P3, P5, and P8 on the right bank of the Lower Cache Creek will impact S9.

4.2.9 Economic Impact Area S10

S10 is on the right bank of Yolo Bypass downstream of Lower Cache Creek Settling Basin. The flooding in this area is impacted by P2, P3, P5, P8, and P6. The flooding depths and extents along the Yolo Bypass levee will be impacted by the flows and overtopping in Yolo Bypass, and any potential levee breach along this feature.

4.3 Levee Breach Analysis

Levee breaches are simulated for the flood risk evaluation described in the economic and risk appendix of the feasibility report. Whereas economic index point reflects the performance of a levee reach at a single point, the breach simulation location reflects a representative inundation pattern if a breach were to occur within that levee reach. Levee breach simulations were conducted at eight index locations along Cache Creek, Cache Creek Settling Basin, Knights Landing Ridge Cut, and Yolo Bypass. The breach simulations were used to develop economic damage areas discussed in detail in Section 4.1. Plate 24 shows the breach locations. Hydraulic modeling breach locations and corresponding economic index points are presented in Table 4.

Table 4. TUFLOW Model Breach Locations

TUFLOW Model Breach Location	Economic Index Point	Flood Source
1	P1	Cache Creek
2	P2	Cache Creek
3	P3	Cache Creek
4	P4	Cache Creek
5	P5	Cache Creek
6	P6	Yolo Bypass
7	P7	Knights Landing Ridge Cut
8	P8	Cache Creek Settling Basin

Index points 1 and 2 are on the natural bank of Cache Creek (no levee), therefore, no levee breach analysis was performed for these two locations. For locations 3, 4, and 5, flood events smaller than 10% (1/10) AEP do not rise above the landside toe of the levee. Consequently, only breach analysis for events equal and higher than 10% (1/10) AEP were performed. A detailed narrative of the breach analysis and associated results are presented in Reference 24. To limit the number of plates in this report, only a representative suite of the inundation maps for a 2% (1/50) AEP event are presented in Plate 17 through Plate 22 for breach locations 3(P3) through index location 8(P8). However, additional breach inundation maps are available in the project files.

4.4 Hydraulic Uncertainty

Hydraulic uncertainty is the uncertainty in the stage-discharge relationship. Hydraulic uncertainty is attributed to natural variation and modeling uncertainty. Modeling uncertainty is primarily related to the accuracy and precision of the topographic data, hydraulic computational assumptions, channel roughness coefficients, and sedimentation.

The natural uncertainty is the uncertainty caused by the natural variation in physical characteristics of the stream and errors that occur in the stage and discharge measurements. The standard deviation of total stage uncertainty is calculated using the following equation:

$$SD_{total} = S_t = (S^2\ natural + S^2 model)^{1/2}$$

*S**t*** is the total standard deviation, (ft)

*S**natural*** is the uncertainty associated with the variability of the physical characteristics of the stream and errors in measurement, (ft)

*S**model*** is the water surface profile uncertainty associated with the estimation of the hydraulic roughness and debris loading on bridges, (ft)

4.5 Model Uncertainty *Smodel*

Model uncertainty was estimated by evaluated the sensitivity of the hydraulic model to changes in roughness values and compared to the minimum standard deviation of error in stages based on roughness coefficients and topographic information presented in Table 5-2 of EM 1110-2-1619. The highest value was then selected.

Model uncertainty related to Manning's n roughness coefficients was estimated using the TUFLOW hydraulic model. A description of the assumptions, methodology and results of the sensitivity analysis is provided in Wood Rodgers, Inc. (WRI), 2015. Table 5 shows the computed stages uncertainty associated with the model for the four index points. Uncertainty analysis for stage-discharge relationships was conducted for a high stage event contained by the channel (including levees). For the uncertainty analysis a 10% (1/10) AEP event was used for Lower Cache Creek and 1% (1/100) AEP event for the other index points.

The model uncertainty related to Manning's roughness was calculated using Eqn. 5-7 in EM 1619:

$$S = Emean / 4$$

Where:

Emean = mean stage difference between the upper and lower limit water surface profiles, (ft). The mean stage difference between the upper and lower limit is considered to encompass 95% of the projected range and equate to four standard deviations. Therefore, *Emean* is assumed to be the difference between the upper and lower limit of the model runs and one standard deviation is calculated by dividing *Emean* by four.

Table 5. Stage Uncertainty Associated with Model Roughness

	Cache Creek at Yolo Gage	**Yolo Bypass at Woodland Gage**	**Settling Basin At Index Location P8**	**Knights Landing At Index Location P7**	**CA 113**
Annual Exceedance Probability used for evaluation	10%	1%	10%	1%	1%
Water Surface Elevation with 30% Increase in Channel Roughness (Ft-NAVD 88)	83.98	37.55	44.95	40.36	55.73
Mean Water Surface elevation (Ft-NAVD 88)	80.67	35.53	43.93	38.9	55.59
Water Surface Elevation with 30% Decrease in Channel Roughness (Ft-NAVD 88)	76.69	32.85	42.98	37	55.48
E/4 (Feet)	1.82	0.3	0.5	0.23	0.1

Modeling uncertainty based on roughness values in Table 5 are compared to the minimum standard deviation of error in stages based on roughness coefficients and topographic information presented in Table 5-2 of EM 1110-2-1619. Topo Uncertainty (*Stopo*) is inclusive in the uncertainty values in Table 5-2. Research at the Hydrologic Engineering Center and the U.S. Army Engineer Waterways Experiment Station provides this information when using a gradually varied flow model. The standard deviation of the normally distributed errors in the estimated stages are based on topographic information and confidence in estimated Manning's n value.

For index points on Lower Cache Creek, there is fair reliability related to fair to good model adjustment/validation for which some, but limited, high-water mark data are available. The cross-sections are based on field survey and aerial spot elevation. Therefore, minimum standard deviation associated with these two conditions is about 0.7 feet (Fair). The same applies to the index location on Yolo Bypass.

For index points on Knights Landing Ridge Cut, there is no channel topographic information and also there is no calibration data for Manning's n. Therefore, poor reliability equates to poor model adjustment/validation or essentially no data for model adjustment/validation. The minimum standard deviation associated with these two conditions is 1.5 feet (Poor).

For index point CA 113, aerial spot elevation topographic information has been used to develop hydraulic model, however, there is no calibration data available. Therefore, the minimum standard deviation associated with these two conditions is 1.3 feet (Poor).

The stage uncertainty related to model roughness was compared to minimum standard deviation of uncertainty in Table 5-2 of EM-1110-2-1619 and the highest values were adopted. Table 6 provides the results.

Table 6. Adopted Model Uncertainty (Feet)

Computation Location	Minimum Standard Deviation (EM-1110-2-1619) (Feet)	Uncertainty related to Model Roughness (Feet)	Adopted Model Uncertainty (Feet)
Cache Creek at Yolo Gage	0.7	1.82	1.82
Yolo Bypass at Woodland Gage	0.7	0.3	0.7
Settling Basin At Index Location P8	0.7	0.5	0.7
Knights Landing At Index Location P7	1.5	0.23	1.5
CA 113	1.3	0.1	1.3

4.6 Natural Uncertainty *Snatural*

Equation 5-5 as described in EM 11619 is used to calculate natural uncertainty.

$$S\boldsymbol{natural}=[0.07208 + 0.04936IBed - 2.2626x10\text{-}7ABasin + 0.02164HRange + 1.4194x10\text{-}5Q100]^{2}$$

Where:

IBed = streambed identifier

ABasin = drainage area at stream gage (km2)
HRange = maximum expected or observed stage range (m)
Q100 = 1% (1/100) AEP event discharge (m3/sec)

Sediment uncertainty is also evaluated as part of natural uncertainty. The report, "Qualitative Geomorphic and Channel Stability Assessment of Lower Cache Creek" in the 2003 Feasibility study report (USACE, 2003) was reviewed to estimate the uncertainty in stages due to sediment.

Section 4.0 (Future Channel Stability) of the report documents that channel aggradation will affect the entire creek invert profile but the channel invert is not expected to return to its former historical profile within the life of the project. Based on this, uncertainty due to sedimentation is not applicable for Lower Cache Creek. For the index locations at Yolo Bypass and Knights Landing Ridge Cut, it is assumed that sediment transport is not characteristic of these reaches.

Table 7 presents the inputs to the equations for the four index locations and resulting natural uncertainty.

Table 7. Natural Uncertainty using Equation 5-2 (EM 1110-2-1619)

Computation Location	Drainage Area (Square	Discharge (cfs)	Depth (feet)	I*Bed* (Bed) (Sands	Natural Uncertainty (Feet)

	Miles)			**and Gravel)**	
Cache Creek at Yolo Gage	1130	58,300	40	3.5	0.9
Yolo Bypass at Woodland Gage	25000	429,200	20	3.5	0.9
Settling Basin At Index Location P8	1130	31,000	16	3.5	0.4
Knights landing	1800	8,400	15	3.5	0.4
CA 113	1130	18,000	6	3.5	0.95

4.7 Total Estimated Hydraulic Uncertainty

The calculated stage uncertainties S***natural*** and S***model***, discussed above are used to compute the total hydraulic uncertainty as follows:

$$\mathrm{SD}_{\mathbf{total}} = S_t = (S^2 \, natural + S^2 model)^{1/2}$$

Table 8. Total Estimated Hydraulic Uncertainty

Computation Location	**Total Hydraulic Uncertainty (ft)**
Cache Creek at Yolo Gage	2.03
Yolo Bypass at Woodland Gage	1.14
Settling Basin At Index Location P8	0.8
Knights Landing At Index Location P7	1.55
CA 113	1.6

Table 9 presents the uncertainty recommendation for all index locations for the range of events evaluated within the study area. The total hydraulic uncertainty does not appear to vary by discharge. Therefore, based on the evaluation of measured stage discharge curve, we recommend applying the uncertainty consistently throughout the rating curve.

Table 9. Total Hydraulic Uncertainty (in Feet) Recommendation

Index Locations	**.2%**	**0.5%**	**1%**	**2%**	**5%**	**10%**	**20%**	**50%**
CA113	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
P1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
P2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
P3	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
P4	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
P5	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
P6	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
P7	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
P8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

5.0 Focused Array Alternative Analysis

An initial array of alternatives was identified in the preliminary stages of the study as documented in the main feasibility report. Based on the screening of an initial array, the no action and four with action alternatives were retained. Several configurations of each alternative were developed. Table 10 shows the major differences in the action alternatives and the associated engineering features.

Engineering assumptions, criteria, and details of hydraulic analysis for the focused array of alternatives are discussed in the following sections of this chapter. Several simplifying assumptions were made for the evaluation of the focused array of plans. These assumptions are expected to all of the alternatives in a similar way. Therefore they would be unlikely to influence the selection of the final array. It was assumed that future hydrologic and hydraulic conditions would be similar to the existing conditions and any changes in those conditions over the 100-year project life are accounted for in the hydrologic and hydraulic uncertainty estimates. It was assumed land subsidence would impact the performance of all alternatives in a similar way over the 100-year project life.

5.1 No Action Alternative

The no action plan is the same as the future without project conditions. The future conditions were assumed to be similar to the existing conditions hydraulic analysis described in preceding chapter. Therefore, no further hydraulic analysis was performed for this alternative.

5.1.1 General Design

Since this is the future without project condition, there are no design features.

5.1.2 Levee Design Height

All existing levees are assumed to be maintained to the existing height or federally authorized height (federal project levees) whichever is higher. The design top of existing levee is based on the authorized design water surface profiles and the minimum freeboard specified in the Operations and Maintenance Manuals.

5.1.3 Upstream Reservoir Operation

There are no anticipated changes to upstream reservoir operations as compared to the existing conditions. Therefore, the hydrologic inflows are based on existing conditions.

5.1.4 Interior Drainage Facilities

The interior drainage is not a major factor in the selection of alternatives. Therefore, it was not considered and the models do not account for interior drainage facilities.

Table 10. Action Alternatives and Associated Features

Features	ALT 1A	ALT 1B	ALT 1C	ALT 1D	ALT 2A	ALT 2B	ALT 2C	ALT 2D	ALT 6A	ALT 6B	ALT 6C	ALT 7A	ALT 7B
Flowage Easement		×	×	×	×								×
Raise Left Bank Levee										×	×	×	×
Raise Right Bank Levee										×	×		
Strengthen Existing Left bank Levees	×	×	×	×				×	×	×	×	×	×
Strengthen Existing Right Bank Levees	×	×	×		×	×	×	×	×	×	×		
New Levees	×	×	×	×	×	×	×	×		×	×	×	×
Inlet Weir and Training Levee Removal					×								
Control Structure for Flow Diversion	×	×	×										
Drainage Channel					×	×	×	×					
Widen CCSB Outlet Weir												×	

5.1.5 Operation and Maintenance

All project features will be maintained with similar conditions as existing hydraulic conditions as defined in USACE Operation and Maintenance manuals and designs.

5.1.6 Levee Superiority

The original Cache Creek Levees Flood Control project includes levee superiority. The design allows the overtopping and flanking of the upstream levees resulting in inundation of agricultural overbank areas. Thereby, resulting lesser damage to the downstream urban areas as compared if a levee failure to occur.

5.1.7 Erosion Protection

Erosion protection will be added to existing project as regular operations and maintenance.

5.1.8 Cache Creek Settling Basin

The 1987 CCSB General Design Memorandum (GDM) states that the future diminishing trap efficiency will necessitate the accommodation of increased volume in the CCSB. The authorized plan of improvement described in the GDM included raising the weir by six feet at year 25 of the project life, or when the basin fills with sediment such that the trap efficiency decreases to less than 30 percent. At that time, it was estimated that this efficiency would fall below 30% on or around the year 2018. Currently, the trap efficiency is at approximately 50%. The City of Woodland has expressed concern regarding the planned raise. It is assumed that the DWR will continue to operate and maintain the CCSB, including the CCSB levees as described in the Operation and Maintenance Manual. It is assumed that any future changes to the CCSB will not exacerbate flood risk to this study area.

It is the assumption of this study that the CCSB outlet weir to Yolo Bypass will not be raised, because in order to do so, the western and southern levees bounding the CCSB would need to be strengthened, and there is no authorized project to include this levee work.

5.1.9 Bridges

There are six existing bridges across Lower Cache Creek. Any future bridges will be designed by accounting minimum adverse hydraulic impacts to the authorized project as directed by USACE guidelines and protocols.

5.1.10 Climate Change

The current analysis does not account for changes in hydrology due to climate change.

5.1.11 Performance

The Economics Appendix discusses the project performance for the alternative.

5.1.12 Results

No hydraulic model simulation is performed for this alternative, as the no action alternative is assumed to include only those features that are same as future without project conditions. The future without project condition is represented by the existing conditions.

5.2 Alternative 1A: North Bypass A

This alternative includes strengthening the right bank of the existing levees from downstream of I-5 to the CCSB, as well as the left bank near the town of Yolo. In addition, this alternative includes a grade control structure and a right bank levee extension upstream of I-5, to accommodate excess flows. These features would increase the stage upstream of I-5, resulting in floodwaters overtopping the left bank and flowing north towards the Colusa Basin Drain. This alternative would include seepage mitigation and rock bank protection along most of its length. Plate 25 shows the project features for this alternative.

5.2.1 TUFLOW Modeling Methodology

This alternative will allow flood flows in excess of approximately 30,000 cfs to leave the creek upstream of I-5 be conveyed by following the naturally existing floodplain footprint, north east towards Colusa Drain and Knights Landing. The Cache Creek flood flows would intermingle with flood flows of the Colusa Basin Drain. The flood flows would then be conveyed by the Knights Landing Ridge cut to the Yolo Bypass. Basically, the alternative will force the excess floodwaters naturally upstream before flooding the City of Woodland downstream of I-5. However, in practice, some sort of physical engineering is needed to direct the waters exceeding the channel capacity of 30,000 cfs. So, a couple of techniques are used to develop a functioning alternative which are stated below:

a. Grade Control Structure
b. Raising/Extending the right bank levee

Hydraulic modeling is performed for the A version of Natural North Bypass that included levees on the right bank and a flood and grade control structure modeled by selecting the methodology of increased roughness upstream of I-5, exceeding the channel capacity of approximately 29,000 cfs -30,000 cfs. This was accomplished by assigning infinite levees on both right and left bank and artificially increasing the roughness values as high as 0.12 upstream of I-5 crossing.   For TUFLOW modeling purpose, the levees on the right bank upstream of I-5 are raised to an elevation of 100 feet NAVD 88. These features would increase the stage upstream of I-5 resulting in floodwaters overtopping the left bank and flowing north towards the Colusa

Basin Drain. The modeled increased roughness will be a project feature that will involve a flood and grade control structure design. Bridges are not modified for the alternative analysis. The resulting water surface elevations within the channel, upstream of I-5 are used to determine the height of the project levee on the right bank.

5.2.2 Levee Design Height

All existing levees are assumed to be maintained to the existing height or federally authorized height (federal project levees) whichever is higher. The design top of levee is based on the authorized design water surface profiles and the minimum freeboard specified in the Operations and Maintenance Manuals.

5.2.3 Upstream Reservoir Operation

Alternative 1A does not include any modifications to upstream reservoirs.
There are no changes to upstream reservoir operations as compared to existing conditions. Therefore, the hydrologic inflows are based on existing conditions.

5.2.4 Interior Drainage Facilities

The models do not account for interior drainage facilities.

5.2.5 Operation and Maintenance

All project features will be maintained.

5.2.6 Levee Superiority

Designs using levee superiority can force initial overtopping in the least hazardous locations. Superiority in overtopping is a concept dealing with adjacent levees or levee reaches designed to overtop one before the other. Superiority may simply mean providing higher levees at all points except where initial overtopping is desired.

Although, alternative Alt 1A is not formulated to incorporate levee superiority, the hydraulic modeling results of the alternative exhibit intrinsic accommodation of overtopping in the least hazardous areas associated with life loss and economic damages. The alternative allows flood waters to take the course of natural north bypass, upstream of I-5, eventually draining into the Yolo Bypass.

5.2.7 Erosion Protection

Erosion protection was considered to be added to the proposed alternative.

5.2.8 Cache Creek Settling Basin

The 6 feet raise of the settling basin weir is not incorporated in the Alt 1A as described previously.

5.2.9 Bridges

There are six existing bridges across Lower Cache Creek. Any future bridges will be designed by accounting minimum adverse hydraulic impacts to the authorized project as directed by USACE guidelines and protocols.

5.2.10 Climate Change

The current hydraulic analysis does not account for changes in hydrology due to climate change.

5.2.11 Project Performance

The Economics Appendix discusses the project performance for the alternative.

5.2.12 Results

The results of the hydraulic model for n-AEP simulations are presented in Plate 26 and Plate 27. Plate 26 shows maximum depths and Plate 27 shows maximum velocities. Plate 28 shows the differential maximum depth for this alternative as compared to the existing conditions.

5.3 Alternative 1B: North Bypass B

This alternative consists of the same structural features as Alternative 1A, though it adds the purchase of flowage easements on the land that would convey floodwaters to the Colusa Basin Drain. This alternative would include seepage mitigation and rock bank protection along most of its length. Plate 29 shows the project features for this alternative.

5.3.1 TUFLOW Modeling Methodology

This alternative is similar to the North Natural Bypass Version A with an added real estate increment of purchasing flowage easements for the excess flood impacted areas.
No further hydraulic analysis is needed for this alternative.

5.3.2 Levee Design Height

All existing levees are assumed to be maintained to the existing height or federally authorized height (federal project levees) whichever is higher. The design top of levee is based on the authorized design water surface profiles and the minimum freeboard specified in the Operations and Maintenance Manuals.

5.3.3 Upstream Reservoir Operation

Alternative 1B does not include any modifications to upstream reservoirs. There are no changes to upstream reservoir operations as compared to the existing conditions. Therefore, the hydrologic inflows are based on existing conditions.

5.3.4 Interior Drainage Facilities

The models do not account for interior drainage facilities.

5.3.5 Operation and Maintenance

All project features will be maintained.

5.3.6 Levee Superiority

Designs using levee superiority can force initial overtopping in the least hazardous locations. Superiority in overtopping is a concept dealing with adjacent levees or levee reaches designed to overtop one before the other. Superiority may simply mean providing higher levees at all points except where initial overtopping is desired.

Although, alternative Alt 1B is not formulated to incorporate levee superiority, the hydraulic modeling results of the alternative exhibits intrinsic accommodation of overtopping in the least hazardous areas associated with life loss and economic damages. The alternative allows flood waters to take the course of natural north bypass, upstream of I-5, eventually draining into the Yolo Bypass.

5.3.7 Erosion Protection

Erosion protection was considered to be added to the proposed alternative.

5.3.8 Cache Creek Settling Basin

The 6 feet raise of the settling basin weir is not incorporated in the Alt 1B as described previously.

5.3.9 Bridges

There are six existing bridges across Lower Cache Creek. Any future bridges will be designed by accounting minimum adverse hydraulic impacts to the authorized project as directed by USACE guidelines and protocols.

5.3.10 Climate Change

The current analysis does not account for changes in hydrology due to climate change.

5.3.11 Project Performance

The Economics Appendix discusses the project performance for the alternative.

5.3.12 Results

No hydraulic analysis was performed for this alternative as described in the previous section.

5.4 Alternative 1C: North Bypass C

This alternative includes strengthening the right bank of the existing levees from downstream of I-5 to the CCSB, similar to the structural features in Alternatives 1A and 1B. However, it includes the construction of bypass levees to ensure the floodwaters are conveyed to the Colusa Basin Drain. This alternative would include seepage mitigation and rock bank protection along most of its length. Plate 30 shows the project features for this alternative.

5.4.1 TUFLOW Modeling Methodology

This alternative is similar to North Natural Bypass Version A with an added increment of constructing levees/berms. The construction of levees/berms is performed to reduce the flood footprint of excess flows from Cache Creek, upstream of I-5, through Colusa basin Drain. However, the extent of this is currently being evaluated. It is anticipated that this alternative will be screened out using rough order of magnitude costs compared to the benefits. Therefore, for the VE Study Conference, no hydraulic analysis has been conducted for this alternative.

5.4.2 Levee Design Height

All existing levees are assumed to be maintained to the existing height or federally authorized height (federal project levees) whichever is higher. The design top of levee is based on the authorized design water surface profiles and the minimum freeboard specified in the Operations and Maintenance Manuals.

5.4.3 Upstream Reservoir Operation

Alternative 1C does not include any modifications to upstream reservoirs. There are no changes to upstream reservoir operations as compared to existing conditions. Therefore, the hydrologic inflows are based on existing conditions.

5.4.4 Interior Drainage Facilities

The models do not account for interior drainage facilities.

5.4.5 Operation and Maintenance

All project features will be maintained.

5.4.6 Levee Superiority

Designs using levee superiority can force initial overtopping in the least hazardous locations. Superiority in overtopping is a concept dealing with adjacent levees or levee reaches designed to overtop one before the other. Superiority may simply mean providing higher levees at all points except where initial overtopping is desired.

Although, alternative Alt 1C is not formulated to incorporate levee superiority, the hydraulic modeling results of the alternative exhibits intrinsic accommodation of overtopping in the least hazardous areas associated with life loss and economic damages. The alternative allows flood waters to take the course of natural north bypass, upstream of I-5, eventually draining into the Yolo Bypass.

5.4.7 Erosion Protection

Erosion protection was considered to be added to the proposed alternative.

5.4.8 Cache Creek Settling Basin

The 6 feet raise of the settling basin weir is not incorporated in the Alt 1C as described previously.

5.4.9 Bridges

There are six existing bridges across Lower Cache Creek. Any future bridges will be designed by accounting minimum adverse hydraulic impacts to the authorized project as directed by USACE guidelines and protocols.

5.4.10 Climate Change

The current analysis does not account for changes in hydrology due to climate change.

5.4.11 Project Performance

The Economics Appendix discusses the project performance for the alternative.

5.4.12 Results

No hydraulic analysis was performed for this alternative as described in the previous section.

5.5 Alternative 1D: North Bypass D

This alternative includes strengthening the right bank of the existing levees from downstream of I-5 to the CCSB, similar to the structural features in Alternatives 1A and 1B. This alternative includes purchase of flowage easements.

5.5.1 TUFLOW Modeling Methodology

This alternative is similar to North Natural Bypass Version 1A. However, it replaces the grade control structure and a right bank levee extension upstream of I-5 with a smaller extension of the right bank, a degrading of the left bank levee upstream of I-5, a new levee segment adjacent to I-5, and no strengthening of levees on the right bank of Cache Creek downstream of I-5. Alt 1D was added as a result of the Value Engineering study. It would entail similar construction costs to Alternative 1A, though would require additional flowage easements at a higher total cost. Given the higher total cost, the alternative was not carried forward, therefore, no hydraulic analysis was performed for 1D.

5.5.2 Levee Design Height

All existing levees are assumed to be maintained to the existing height or federally authorized height (federal project levees) whichever is higher. The design top of levee is based on the authorized design water surface profiles and the minimum freeboard specified in the Operations and Maintenance Manuals.

5.5.3 Upstream Reservoir Operation

Alternative 1D does not include any modifications to upstream reservoirs. There are no changes to upstream reservoir operations as compared to existing conditions. Therefore, the hydrologic inflows are based on existing conditions.

5.5.4 Interior Drainage Facilities

The models do not account for interior drainage facilities.

5.5.5 Operation and Maintenance

All project features will be maintained.

5.5.6 Levee Superiority

Designs using levee superiority can force initial overtopping in the least hazardous locations. Superiority in overtopping is a concept dealing with adjacent levees or levee reaches designed to overtop one before the other. Superiority may simply mean providing higher levees at all points except where initial overtopping is desired.

Although, alternative Alt 1D is not formulated to incorporate levee superiority, the hydraulic modeling results of the alternative exhibits intrinsic accommodation of overtopping in the least hazardous areas associated with life loss and economic damages. The alternative allows flood waters to take the course of natural north bypass, upstream of I-5, eventually draining into the Yolo Bypass.

5.5.7 Erosion Protection

Erosion protection was considered to be added to the proposed alternative.

5.5.8 Cache Creek Settling Basin

The 6 feet raise of the settling basin weir is not incorporated in the Alt 1D as described previously.

5.5.9 Bridges

There are six existing bridges across Lower Cache Creek. Any future bridges will be designed by accounting minimum adverse hydraulic impacts to the authorized project as directed by USACE guidelines and protocols.

5.5.10 Climate Change

The current analysis does not account for changes in hydrology due to climate change.

5.5.11 Project Performance

The Economics Appendix discusses the project performance for the alternative.

5.5.12 Results

No hydraulic analysis was performed for this alternative as described in the previous section.

5.6 Alternative 2A: South Bypass A, or Levee and Conveyance Alternative

This alternative would consist of a levee that would direct floodwaters that would otherwise enter the urban area of the City of Woodland east towards the Cache Creek Settling basin. The floodwaters would then pass into the CCSB through a new inlet weir. The new inlet weir in the western levee of the CCSB would allow the floodwater to enter the CCSB while reducing the probability that Cache Creek floodwaters would escape the CCSB during smaller flood events. The inlet weir reduces stages west of the CCSB and is less costly than flowage easements that would have been required due to frequent flooding in the absence of the inlet weir. A portion of the floodwaters overtopping the south bank of Cache Creek would be conveyed by a channel created by the borrow area adjacent to the proposed levee. The channel would divert flows to the CCSB or to the City of Woodland pumping plant which would then discharge to the Yolo Bypass. The alternative also includes removal of a portion of a sediment training levee inside the CCSB so it does not obstruct the inlet weir. Plate 31 shows the project features for this alternative.

5.6.1 TUFLOW Modeling Methodology

Alternative 2A includes a levee north of City of Woodland with a portion of west levee removed along the eastern direction for the inlet of the floodwater into the settling basin. The levee is about 6 miles long and ties into the west levee of settling basin. For TUFLOW modeling purpose, an infinitely high levee was coded into the modeled. The resulting water surface elevations against the levee are used to determine the height of the levee to be designed. To simulate the inlet weir 3000-feet of the west levee of the settling basin assigned an elevation of 45-feet NAVD88. About 5,000 feet of southern portion of the training levee in the settling basin was also removed from the model to simulate its removal.

5.6.2 Levee Design Height

The proposed plan includes construction of a new levee north of the urban area of Woodland. The levee would be approximately 6 miles in length, originate near the intersection of County

Road 19B and County Road 96B and extend easterly to the Cache Creek Settling Basin. The dimensions of the new levee are as follows: levee crown is a uniform 12 feet; waterside slope is 1V:3H and landside slope is 1V:3H; height of the levee varies from 2 feet near CR 96B to 18 feet at its intersection with the existing west levee of the Cache Creek Settling Basin. The south side of the new levee would include a 30 foot wide x 5 foot high seepage berm along its length. Along the north side of the new levee, an open trapezoidal drainage ditch is planned to include rock slope protection. Deep cutoff wall depths are as follows: Reach F – 45 feet deep; Reach E – 60 feet deep. Depending on further analysis and design during PED, a cutoff wall may be required in some reaches where a seepage berm is not feasible. Depending on further analysis and design during PED, a cutoff wall may be required in some reaches where a seepage berm is not feasible. The levee design height was selected to be 3 feet above the 0.5% (1/200) AEP water surface profile.

All existing levees are assumed to be maintained to the existing height or federally authorized height (federal project levees) whichever is higher. The design top of levee is based on the authorized design water surface profiles and the minimum freeboard specified in the Operations and Maintenance Manuals.

5.6.3 Upstream Reservoir Operation

Alternative 2A does not include any modifications to upstream reservoirs. There are no changes to upstream reservoir operations as compared to existing conditions. Therefore, the hydrologic inflows are based on existing conditions.

5.6.4 Interior Drainage Facilities

The models do not account for interior drainage facilities.

5.6.5 Operation and Maintenance

All project features will be maintained**.**

5.6.6 Levee Superiority

The original Cache Creek Levees Flood Control project includes levee superiority. The design allows the overtopping and flanking of the upstream levees resulting in inundation of agricultural overbank areas. Thereby, resulting lesser damage to the downstream urban areas as compared if a levee failure to occur.

5.6.7 Erosion Protection

Erosion protection was considered to be added to the proposed alternative.

5.6.8 Cache Creek Settling Basin

The 6 feet raise of the settling basin weir is not incorporated in the Alt 2A as described previously.

5.6.9 Bridges

There are six existing bridges across Lower Cache Creek. Any future bridges will be designed by accounting minimum adverse hydraulic impacts to the authorized project as directed by USACE guidelines and protocols.

5.6.10 Climate Change

The current analysis does not account for changes in hydrology due to climate change.

5.6.11 Project Performance

The Economics Appendix discusses the project performance for the alternative.

5.6.12 Results

The results of the hydraulic model for n-AEP simulations are presented in Plates 32 through Plate 33. Plate 34 shows the differential maximum depth for this alternative as compared to the existing conditions.

5.7 Alternative 2B: South Bypass B

This alternative would consist of a levee that would direct floodwaters that would otherwise enter the urban area of the City of Woodland east towards the Cache Creek Settling basin, similar to Alternative 2A. However, rather than constructing an inlet weir to convey the water into the CCSB, a channel would convey floodwaters to the south of the CCSB and into the Yolo Bypass. Based on additional qualitative analysis, including of real estate requirements in an industrial complex adjacent to the CCSB, this alternative was screened out of the focused array. Alternative 2C incorporates some of the proposed features of Alternative 2B. Plate 35 shows the project features for this alternative.

5.8 Alternative 2C: South Bypass C

This alternative would consist of a levee that would direct floodwaters that would otherwise enter the urban area of the City of Woodland east towards the Cache Creek Settling basin, similar to Alternative 2A and 2B, but rather than constructing an inlet weir to accommodate excess flows to the west of the CCSB, a channel would convey floodwaters to the south of the CCSB and into the Yolo Bypass. This channel would involve moving a portion of the CCSB west levee further to the east to avoid a large industrial complex. The railroad line along the south side of the CCSB would also require extensive modifications to allow for the flood control channel. Plate 36 shows the project features for this alternative.

5.8.1 TUFLOW Modeling Methodology

TUFLOW hydraulic model for Alternative 2C incorporated all features described in Section 5.8.

5.8.2 Levee Design Height

The proposed plan includes construction of a new levee north of the urban area of Woodland. The levee would be approximately 6 miles in length, originate near the intersection of County Road 19B and County Road 96B and extend easterly to the Cache Creek Settling Basin. The height of the levee varies from 2 feet near CR 96B to 18 feet at its intersection with the existing west levee of the Cache Creek Settling Basin. The levee design height was selected to be 3 feet above the 0.5% (1/200) AEP water surface profile.

All existing levees are assumed to be maintained to the existing height or federally authorized height (federal project levees) whichever is higher. The design top of levee is based on the authorized design water surface profiles and the minimum freeboard specified in the Operations and Maintenance Manuals.

5.8.3 Upstream Reservoir Operation

Alternative 2C does not include any modifications to upstream reservoirs.
There are no changes to upstream reservoir operations as compared to existing conditions. Therefore, the hydrologic inflows are based on existing conditions.

5.8.4 Interior Drainage Facilities

The models do not account for interior drainage facilities.

5.8.5 Operation and Maintenance

All project features will be maintained.

5.8.6 Levee Superiority

The original Cache Creek Levees Flood Control project includes levee superiority. The design allows the overtopping and flanking of the upstream levees resulting in inundation of agricultural overbank areas. Thereby, resulting lesser damage to the downstream urban areas as compared if a levee failure to occur.

5.8.7 Erosion Protection

Erosion protection was considered to be added to the proposed alternative.

5.8.8 Cache Creek Settling Basin

The 6 feet raise of the settling basin weir is not incorporated in the Alt 2C as described previously.

5.8.9 Bridges

There are six existing bridges across Lower Cache Creek. Any future bridges will be designed by accounting minimum adverse hydraulic impacts to the authorized project as directed by USACE guidelines and protocols.

5.8.10 Climate Change

The current analysis does not account for changes in hydrology due to climate change.

5.8.11 Project Performance

The Economics Appendix discusses the project performance for the alternative.

5.8.12 Results

The results of the hydraulic model for n-AEP simulations are presented in Plate 37 and Plate 38. Plate 37 shows depths and Plate 38 shows maximum velocities. Plate 39 shows the differential maximum depth for this alternative as compared to the existing conditions.

5.9 Alternative 2D: South Bypass D

This alternative would consist of a levee that would direct floodwaters that would otherwise enter the urban area of the City of Woodland east towards the Cache Creek Settling basin, similar to Alternative 2C. However, it would also include strengthening the right bank levee of

Cache Creek to reduce flooding north of the City of Woodland and strengthen the left bank levee of Cache Creek adjacent to the town of Yolo. This alternative includes seepage mitigation and rock bank protection along most of right bank of Cache Creek. A map showing the project features and flood inundation are shown on Plate 40.

5.9.1 TUFLOW Modeling Methodology

This alternative would be similar to South Bypass Version C. As there are no hydraulic features added to this alternative, no hydraulic modeling analysis was performed for this alternative.

5.9.2 Levee Design Height

The proposed plan includes construction of a new levee north of the urban area of Woodland. The levee would be approximately 6 miles in length, originate near the intersection of County Road 19B and County Road 96B and extend easterly to the Cache Creek Settling Basin. The height of the levee varies from 2 feet near CR 96B to 18 feet at its intersection with the existing west levee of the Cache Creek Settling Basin. The levee design height was selected to be 3 feet above the 0.5% (1/200) AEP water surface profile.

All existing levees are assumed to be maintained to the existing height or federally authorized height (federal project levees) whichever is higher. The design top of levee is based on the authorized design water surface profiles and the minimum freeboard specified in the Operations and Maintenance Manuals.

5.9.3 Upstream Reservoir Operation

Alternative 2D does not include any modifications to upstream reservoirs.
There are no changes to upstream reservoir operations as compared to the existing conditions. Therefore, the hydrologic inflows are based on existing conditions.

5.9.4 Interior Drainage Facilities

The models do not account for interior drainage facilities.

5.9.5 Operation and Maintenance

All project features will be maintained.

5.9.6 Levee Superiority

The original Cache Creek Levees Flood Control project includes levee superiority. The design allows the overtopping and flanking of the upstream levees resulting in inundation of agricultural overbank areas. Thereby, resulting lesser damage to the downstream urban areas as compared if a levee failure to occur.

5.9.7 Erosion Protection:

Erosion protection was considered to be added to the proposed alternative.

5.9.8 Cache Creek Settling Basin

The 6 feet raise of the settling basin weir is not incorporated in the Alt 2D as described previously.

5.9.9 Bridges

There are six existing bridges across Lower Cache Creek. Any future bridges will be designed by accounting minimum adverse hydraulic impacts to the authorized project as directed by USACE guidelines and protocols.

5.9.10 Climate Change

The current analysis does not account for changes in hydrology due to climate change.

5.9.11 Project Performance

The Economics Appendix discusses the project performance for the alternative.

5.9.12 Results

As discussed previously no hydraulic modeling was performed for this alternative.

5.10 Alternative 6A: Strengthen in Place A

This alternative would involve strengthening the right bank levee of Cache Creek. The alternative would also include fixing the left bank of Cache Creek along the town of Yolo. This alternative reduces the risk of flooding associated with geotechnical related failures. However, the hydraulic capacity (overtopping) related failure probability would remain the same. This alternative includes seepage mitigation and rock bank protection along most of its length. The project features for this alternative are shown in Plate 41.

5.10.1 TUFLOW Modeling Methodology

This alternative reduces the risk of flooding associated with geotechnical related failures. As the hydraulic capacity (overtopping) related failure probability would remain the same. Therefore, no hydraulic analysis is performed for this alternative.

5.10.2 Levee Design Height

The alternative does not incorporate any changes to the height of existing levees. All existing levees are assumed to be maintained to the existing height or federally authorized height (federal project levees) whichever is higher. The design top of existing levee is based on the authorized design water surface profiles and the minimum freeboard specified in the Operations and Maintenance Manuals.

5.10.3 Upstream Reservoir Operation

Alternative 6A does not include any modifications to the upstream reservoirs.
There are no changes to upstream reservoir operations as compared to existing conditions. Therefore, the hydrologic inflows are based on existing conditions.

5.10.4 Interior Drainage Facilities

Alternative 6A does not include any modifications to interior drainage facilities.

5.10.5 Operation and Maintenance

All project features will be maintained.

5.10.6 Levee Superiority

The levee superiority for this alternative will not change from what is inherent in the existing system which is described in previous section of future without project conditions.

5.10.7 Erosion Protection:

Erosion protection was considered to be added to the proposed alternative.

5.10.8 Cache Creek Settling Basin

The 6 feet raise of the settling basin weir will not be incorporated for Alternative 6A as described in previous section.

5.10.9 Bridges

There are six existing bridges across Lower Cache Creek. Any future bridges will be designed by accounting minimum adverse hydraulic impacts to the authorized project as directed by USACE guidelines and protocols.

5.10.10 Climate Change

The current analysis does not account for changes in hydrology due to climate change.

5.10.11 Project Performance

The Economics Appendix discusses the project performance for the alternative.

5.10.12 Results

As discussed in Section 5.2.1., hydraulic modeling simulation is not performed for this alternative.

5.11 Alternative 6B: Strengthen/Raise In Place B

This alternative strengthens and increases the height of the right bank levee and the left bank levee near Yolo. Floodwaters would flow overland to the Colusa Basin Drain and Knights Landing Ridge Cut before draining into the Yolo Bypass. This alternative includes seepage mitigation and rock bank protection along most of its length. The project features for this alternative are shown in Plate 42.

5.11.1 TUFLOW Modeling Methodology for Alt 6B

The alternative has an added increment to Strengthen in Place Version A. The added increment consists of raising elevations of right levee and a small stretch of left bank levee in the vicinity of town of Yolo. The hydraulic modeling and analysis have been accomplished by assigning infinite levees in the TUFLOW on the right bank and extending it further upstream until it daylights the natural ground. The new right bank levee, upstream of I-5, is modeled with a line shape file and associated point shape file in GIS. The existing right levee was raised by simply reassigning the elevations of the existing levee point file to values of infinite height. Bridges are not modified for the alternative analysis. Manning’s “n” developed for the existing conditions are not changed for this alternative.

5.11.2 Levee Design Height

The proposed plan includes raising the existing levee and the installation of deep cutoff walls. The dimensions of the levee raise are as follows: levee crown varies between 10 feet and 12 feet; waterside slope is 1V:4H and landside slope is 1V:3H; height of the levee raise varies from 2 feet west of the project to 13 feet. The south side of the new levee would include a 60 foot wide x 5 foot high seepage berm along its length. Deep cutoff wall depths are as follows: Reach H - 18 feet deep; Reach F – 45 feet deep; Reach E – 60 feet deep. Depending on further analysis and design during PED, a cutoff wall may be required in some reaches where a seepage berm is not feasible. The levee design height was selected to be 3 feet above the 0.5% (1/200) AEP water surface profile. All existing levees are assumed to be maintained to the existing height or federally authorized height (federal project levees) whichever is higher. The design top of existing levee is based on the authorized design water surface profiles and the minimum freeboard specified in the Operations and Maintenance Manuals.

5.11.3 Upstream Reservoir Operation

Alternative 6B does not include any modifications to upstream reservoirs.
There are no changes to upstream reservoir operations as compared to existing conditions. Therefore, the hydrologic inflows are based on existing conditions.

5.11.4 Interior Drainage Facilities

The models do not account for interior drainage facilities.

5.11.5 Operation and Maintenance

All project features will be maintained.

5.11.6 Levee Superiority

Designs using levee superiority can force initial overtopping in the least hazardous locations. Superiority in overtopping is a concept dealing with adjacent levees or levee reaches designed to overtop one before the other. Superiority may simply mean providing higher levees at all points except where initial overtopping is desired.

Although, alternative Alt 6B is not formulated to incorporate levee superiority, the hydraulic modeling results of the alternative exhibits the intrinsic accommodation of overtopping in the least hazardous areas associated with life loss and economic damages. The alternative allows flood waters to take the course of natural north bypass, upstream of I-5, and the left overbank, eventually draining into the Yolo Bypass.

5.11.7 Erosion Protection

Erosion protection was considered to be added to the proposed alternative.

5.11.8 Cache Creek Settling Basin

The 6 feet raise of the settling basin weir is not incorporated in the Alt 6B as described previously.

5.11.9 Bridges

There are six existing bridges across Lower Cache Creek. Any future bridges will be designed by accounting minimum adverse hydraulic impacts to the authorized project as directed by USACE guidelines and protocols.

5.11.10 Climate Change

The current hydraulic analysis does not account for changes in hydrology due to climate change.

5.11.11 Project Performance

The Economics Appendix discusses the project performance for the alternative.

5.11.12 Results

The results of the hydraulic model for n-AEP simulations are presented in Plate 43 and Plate 44. Plate 43 shows depths and Plate 44 shows maximum velocities. Plate 45 shows the differential maximum depth for this alternative as compared to the existing conditions.

5.12 Alternative 6C: Strengthen/Raise In Place C

This alternative includes strengthening or increasing the height of both left and right levees along their entire length, to contain flow in the current creek. The left bank levee upstream of I-5 would be removed and a new levee would be constructed adjacent to I-5, to force the floodwaters to the north where it would be conveyed across I-5 through a bank of culverts. This alternative would include seepage mitigation and rock bank protection along most of its length. Plate 46 shows the project features for this alternative.

5.12.1 TUFLOW Modeling Methodology

This alternative has an added increment to Strengthen in Place Version B. The increment essentially consists of raising the elevations of the left levees in parity with the right levee raises. This version of alternative includes levee raises on both left and right bank downstream of I-5, new levee on right bank upstream of I-5, new levee along the I-5 on the left bank, and degrading existing levee on the left bank upstream of I-5. Hydraulic modeling for levee raises is accomplished using the same methodology as was discussed for Strength in Place Version B. Bridges are not modified for the alternative analysis. Manning’s n developed for the existing conditions are not changed for this alternative. The resulting water surface elevations from the hydraulic modeling analysis are used to determine the levee heights for this alternative.

5.12.2 Levee Design Height

The levee design height was selected to be 3 feet above the 0.5% (1/200) AEP water surface profile. All existing levees are assumed to be maintained to the existing height or federally authorized height (federal project levees) whichever is higher. The design top of existing levee is based on the authorized design water surface profiles and the minimum freeboard specified in the Operations and Maintenance Manuals.

5.12.3 Upstream Reservoir Operation

Alternative 6C does not include any modifications to upstream reservoirs.
There are no changes to upstream reservoir operations as compared to existing conditions. Therefore, the hydrologic inflows are based on existing conditions.

5.12.4 Interior Drainage Facilities

The models do not account for interior drainage facilities.

5.12.5 Operation and Maintenance

All project features will be maintained.

5.12.6 Levee Superiority

Designs using levee superiority can force initial overtopping in the least hazardous locations. Superiority in overtopping is a concept dealing with adjacent levees or levee reaches designed to overtop one before the other. Superiority may simply mean providing higher levees at all points except where initial overtopping is desired.

Although, alternative Alt 6C is not formulated to incorporate levee superiority, the hydraulic modeling results of the alternative exhibits some level of overtopping in the least hazardous areas associated with life loss and economic damages. The alternative allows flood waters to take the course of natural north bypass, upstream of I-5, eventually draining into the Yolo Bypass. However, impacts of additional floodwaters to the levees of CCSB will need to be evaluated for TSP alternative**.**

5.12.7 Erosion Protection

Erosion protection will be added to the proposed project.

5.12.8 Cache Creek Settling Basin

The 6 feet raise of the settling basin weir is not incorporated in the Alt 6C as described previously.

5.12.9 Bridges

There are six existing bridges across Lower Cache Creek. Any future bridges will be designed by accounting minimum adverse hydraulic impacts to the authorized project as directed by USACE guidelines and protocols.

5.12.10 Climate Change

The current analysis does not account for changes in hydrology due to climate change.

5.12.11 Project Performance

The Economics Appendix discusses the project performance for the alternative.

5.12.12 Results

The results of the hydraulic model for n-AEP simulations are presented in Plate 47 and Plate 48. Plate 47 shows floodplain maps and Plate 48 shows maximum velocities. Plate 49 shows the differential maximum depth for this alternative as compared to the existing conditions.

5.13 Alternative 7A: Partial Setback Levee A

This alternative would involve building levees set back from Cache Creek on the right bank to contain flow within an expanded levee system, reducing the probability of flooding in the City of Woodland. The channel dimensions for the setback levee configuration would be designed to maintain the same water surface profile as existing condition but with additional flow. The additional flow would be based on maintaining the same left bank overflow upstream of I-5 as the no-action plan. At bridges, culverts would be included in the overbank area to eliminate constrictions. The alternative would modify the existing CCSB outlet weir into the Yolo Bypass to accommodate the increased flow. A map showing the project features are shown on Plate 50.

5.13.1 TUFLOW Modeling Methodology

The hydraulic analysis for this alternative was not performed as based on cost analysis it was concluded that the alternative likely will not be a feasible solution for further consideration. Specifically, the expansion of CCSB outlet weir was resulting in a significant increase in the cost of the project.

5.13.2 Levee Design Height

The levee design height was selected to be 3 feet above the 0.5% (1/200) AEP water surface profile. All existing levees are assumed to be maintained to the existing height or federally authorized height (federal project levees) whichever is higher. The design top of existing levee is based on the authorized design water surface profiles and the minimum freeboard specified in the Operations and Maintenance Manuals.

5.13.3 Upstream Reservoir Operation

Alternative 7A does not include any modifications to upstream reservoirs.
There are no changes to upstream reservoir operations as compared to existing conditions. Therefore, the hydrologic inflows are based on existing conditions.

5.13.4 Interior Drainage Facilities

The models do not account for interior drainage facilities.

5.13.5 Operation and Maintenance

All project features will be maintained.

5.13.6 Levee Superiority

Designs using levee superiority can force initial overtopping in the least hazardous locations. Superiority in overtopping is a concept dealing with adjacent levees or levee reaches designed to overtop one before the other. Superiority may simply mean providing higher levees at all points except where initial overtopping is desired.

Although, alternative Alt 7A is not formulated to incorporate levee superiority, the hydraulic modeling results of the alternative exhibits some level of overtopping in the least hazardous areas associated with life loss and economic damages. The alternative allows flood waters to take the course of natural north bypass, upstream of I-5, eventually draining into the Yolo Bypass.

5.13.7 Erosion Protection

Erosion protection will be added to the proposed project.

5.13.8 Cache Creek Settling Basin

The 6 feet raise of the settling basin weir is not incorporated in the Alt 7A as described previously. The alternative would modify the existing CCSB outlet weir into the Yolo Bypass to accommodate the increased flow.

5.13.9 Bridges

There are six existing bridges across Lower Cache Creek. Any future bridges will be designed by accounting minimum adverse hydraulic impacts to the authorized project as directed by USACE guidelines and protocols.

5.13.10 Climate Change

The current analysis does not account for changes in hydrology due to climate change.

5.13.11 Project Performance

The Economics Appendix discusses the project performance for the alternative.

5.13.12 Results

The hydraulic analysis was not performed for this alternative as described before.

5.14 Alternative 7B: Partial Setback Levee B

This alternative would involve building levees set back from Cache Creek on the right bank as well as culverts under I-5, UPRR and other utilities, similar to Alternative 7A. However, it also includes a bypass channel to the north of the CCSB. Measures include excavation of material to accommodate flow through the North Channel, flowage easements on inundated lands, and a new inlet weir north of the CCSB to allow flows to enter the Yolo Bypass. A map showing the project features and flood inundation are shown on Plate 51.

5.14.1 TUFLOW Modeling Methodology

For TUFLOW modeling purpose, an infinitely high setback levee was selected with an elevation of about 200 feet NAVD 88. The resulting water surface elevations against the setback levee are used to determine the height of the levee to be designed.

5.14.2 Levee Design Height

The levee design height was selected to be 3 feet above the 0.5% (1/200) AEP water surface profile. All existing levees are assumed to be maintained to the existing height or federally authorized height (federal project levees) whichever is higher. The design top of existing levee is based on the authorized design water surface profiles and the minimum freeboard specified in the Operations and Maintenance Manuals.

5.14.3 Upstream Reservoir Operation

Alternative 7B does not include any modifications to upstream reservoirs.
There are no changes to upstream reservoir operations as compared to existing conditions. Therefore, the hydrologic inflows are based on existing conditions.

5.14.4 Interior Drainage Facilities

The models do not account for interior drainage facilities.

5.14.5 Operation and Maintenance

All project features will be maintained.

5.14.6 Levee Superiority

Designs using levee superiority can force initial overtopping in the least hazardous locations. Superiority in overtopping is a concept dealing with adjacent levees or levee reaches designed to overtop one before the other. Superiority may simply mean providing higher levees at all points except where initial overtopping is desired.

Although, alternative Alt 7B is not formulated to incorporate levee superiority, the hydraulic modeling results of the alternative exhibits some level of overtopping in the least hazardous areas associated with life loss and economic damages. The alternative allows flood waters to take the course of natural north bypass, upstream of I-5, eventually draining into the Yolo Bypass.

5.14.7 Erosion Protection

Erosion protection will be added to the proposed project.

5.14.8 Cache Creek Settling Basin

The 6 feet raise of the settling basin weir is not incorporated in the Alt 7B as described previously.

5.14.9 Bridges

There are six existing bridges across Lower Cache Creek. Any future bridges will be designed by accounting minimum adverse hydraulic impacts to the authorized project as directed by USACE guidelines and protocols.

5.14.10 Climate Change

The current analysis does not account for changes in hydrology due to climate change.

5.14.11 Project Performance

The Economics Appendix discusses the project performance for the alternative.

5.14.12 Results

The results of the hydraulic model for n-AEP simulations are presented in Plates 52 and Plate 53. Plate 54 shows the differential maximum depth for this alternative as compared to the existing conditions.

5.15 Hydraulic Uncertainty for Focused Array of Alternative Conditions

The uncertainty in the stage-discharge estimates is not expected to change for the focused array of alternatives. The stages are relatively insensitive to discharges and the flow conditions and conveyance are expected to remain similar to the without project conditions.
Therefore, it is estimated that uncertainty in stages associated with the proposed focused array will be same as of the existing conditions.

6.0 Final Array

The final array was selected from the focused array of alternatives. Focused alternatives are describes in Chapter 5. The final array includes no action alternative and Alternative 2A with inlet weir.

6.1 No Action Plan

No further refinements for the no action alternative were deemed necessary.

6.2 Alternative 2A Levee and Conveyance Plan

Alternative 2A from the Focused Array was selected to be in the final array of plans. The name was changed to Alternative 2A - Levee and Conveyance Plan to provide more clarity to the public. Comparison and selection of the tentatively selected plan from the final array is described in the feasibility study report. The sections below describe the alternative in more detail including refinements made to the plan to address design requirements and support a more detailed Class 4 cost estimate. A map of the project features and levee segments of the updated Alternative 2A is provided in Plates 55 through 61.

6.2.1 Design Features

The design includes new levees, improvement of existing levees, interior drainage facilities, and railway and roadway relocations. A list of the project features is provided in Table 11.

Table 11. Alternative 2A Project Features

Feature	Description	Applicable Reaches	Quantity
New Levee	New Levee with Seepage Berm	Q (Partial), R, S	3.9 Miles
New Levee with RSP	New Levee with Seepage Berm and Rock Slope Protection	P, Q (Partial)	1.7 Miles
Improve Existing Levee	Improve existing levee with cutoff wall	N, O	2.3 Miles
Drainage Channel	New drainage channel and culverts. Also serves as borrow source for levee fill.	P, Q, R, S	5.6 Miles
Elevated Roadways	Elevate Roadway over levee at CR98, CR99, CR101, and CR102	P, Q, R, S	4
Gated Roadway Closure Structure	Gate at SR 113	Q, R	1
Gated Railroad Closure Structures	Gate for Railroad at I-5, West of SR 113, East of SR 113	Q, R, S	3
Cache Creek Settling Basin Inlet Weir	Concrete Inlet Weir	CCSB Inlet Weir	3,000 Feet
Degrade Training	Degrade 3,000 feet of Existing	Training Levee	3,000 Feet

Levee	Cache Creek Settling Basin Training Levee		
Detention Basin and Outlets	New Detention Basin and Outlets	P	1
Improve Existing Drainage Ditch	Utilize Existing drainage ditch from Detention Basin to City of Woodland Pump Station.	O	1 Mile

New Levees and Other Proposed Project Features: A new levee with a 20-foot-wide crest and a 30-foot-wide landside seepage berm would begin near the intersection of County Road 20 and County Road 98 and extend east to the CCSB. The alignment of the levee would generally follow the northern city limit line west of CA 113 and Churchill Downs Avenue east of CA 113. The height of the new levee would vary from six feet near County Road 98 to 14 feet at its intersection with the existing west levee of the CCSB. Rock slope protection is proposed on the waterside slope of the new levee from County Road 101 east to the southern end of the proposed inlet weir near County Road 20.

A trapezoidal drainage channel, 150 feet wide, with a design capacity of approximately 350 cubic feet per second (cfs) would be constructed north (waterward) of the new levee in Reaches P through S in order to capture smaller, more frequent events and discharge them to the CCSB, and also to provide the necessary fill material for the project. This drainage channel may vary in width during subsequent design phases in order to create a balanced earthwork for the project.

A total of four closure structures (gates that are assembled by operations and maintenance (O&M) personnel prior to the flood) would be constructed where the embankment crosses the Union Pacific Railroad (UPRR) tracks near Interstate 5 (I-5), the UPRR tracks west of CA 113, CA 113 and the UPRR tracks east of CA 113. Due to the limited distance between the closure structures, short sections of floodwall would be constructed to connect the closure structure at the I-5 crossing to the existing roadway embankment and to connect the closure structures at the CA 113 crossing and the adjacent UPRR crossing to the west.

Modifications to Existing Levees / Cache Creek Settling Basin: Alternative 2A would rehabilitate a portion of the southern levee of the Cache Creek Settling Basin (CCSB) by constructing a 60-foot-deep cutoff wall through the levee and the southwest levee of the CCSB by constructing a 45-foot-deep cutoff wall. Along with this cutoff wall installation, a 3,000-foot-long section of the west levee of the settling basin would be degraded to an elevation of 43 feet to accommodate a concrete weir with a height of approximately nine feet above existing adjacent grade. The weir would serve to accept floodwater emanating from Cache Creek west of the CCSB, and would prevent backflow from the CCSB to the west during smaller, more frequent flood events. Additionally, the southernmost 3,000-foot portion of the CCSB training levee would be degraded in order to improve the distribution of sediment within the basin before construction begins. The existing outlet weir on the east side of the CCSB would remain unchanged.

Internal Drainage: Water impounded by the proposed levee and the west levee of the CCSB would be drained via proposed culverts into the CCSB and to the City's interior drainage system. A detention basin would be located at the downstream end of the proposed drainage channel. The detention basin would include an east outlet and a south outlet. The east outlet would provide for gravity drainage into the CCSB and consist of three 60-inch diameter culverts fitted with flap gates. This would allow gravity flow from the detention basin into the CCSB after stages subside below the weir elevation, with reverse flow from the CCSB into the detention basin being prevented by the flap gates. The south outlet would consist of a set of three 60-inch diameter culverts fitted with sluice gates. The culverts would discharge to an existing ditch that terminates at a pump station owned and operated by the City. The sluice gates would control the discharge flow to the pump station until capacity was available to discharge the flows to the Yolo Bypass. The design and operation of these systems has not been fully developed yet, and will be optimized during later phases of the project.

Roadway Improvements: The new levee would require the raising of County Road 98, County Road 99, County Road 101, and County Road 102. Culverts would be installed at each of these raised crossings, as well as under CA 113 and the two UPRR crossings along the alignment. An existing railroad underpass at I-5 would be used to convey flood waters under the interstate. In order to prevent erosion due to high velocities in this area, those portions of the area found to have velocities of over five feet per second (fps) would be lined with concrete. This protection would be installed across the entire project footprint area where flood flows velocities exceed the five fps limit. This area includes the existing slopes of the I-5 roadway embankment, the slopes of the proposed Reach R and Reach S levees, the proposed channel (both bottom and slope), and the existing UPRR railway. A soil bentonite cutoff wall would be constructed along the center of the levee to address seepage design criteria.

6.3 California State Urban Levee Design Criteria

Although the California State Urban Levee Design Criteria (ULDC) is not a federal objective of the study, it is a local sponsor objective. Two options are offered in the ULDC requirements for determining if a levee meets the urban and urbanizing area levee system design. The freeboard option (option 1) requires 3 feet of freeboard above the mean 0.5% (1/200) AEP flood event. The risk and uncertainty option (option 2) allows for a lesser amount of freeboard (2 feet) if a high level of assurance (95%) can be demonstrated. For Lower Cache Creek, option 1 was adopted.

6.4 TUFLOW Modeling Methodology

The updated Alternative 2A was modeled using the focused array ALT2A with inlet weir TUFLOW model as described in Section 5.6.1. The refinements to the model included lowering the inlet weir elevation to 43 feet NAVD 88 and degrading training levee for a length of 3000 feet. The elevation of the weir was selected so that the 1% (1/100) AEP flows crest the weir, thereby eliminating the flows going through the City of Woodland interior drainage system. It reduces the floodplain extent north of County Road 18C and facilitates drainage of impounded floodwaters. Furthermore, degrading the inlet weir to an elevation of 43 feet reduces the water surface near CA 113, thus reducing hydraulic impacts due to the alternative.

6.5 Climate Change

The current analysis does not account for changes in hydrology due to climate change.

6.6 HTRW and Water Quality

Water and sediment quality were evaluated for the final array, and adverse impacts are not anticipated based on the results of Phase 1 Environmental Site Assessment, a UC Davis sediment trap efficiency study, and consideration of impaired water bodies under the Clean Water Act. Project construction will not cause adverse environmental impacts relative to the future without project conditions.

6.7 Project Performance

The Economics Appendix discusses the project performance for the TSP.

6.8 Results

The results of the hydraulic model for n-AEP simulations are presented in Plates 62 through Plate 94. Plate 62 shows the 0.5% (1/200) AEP water surface elevations along the proposed levee. Plates 63 though Plate 70 show maximum depths. Plates 71 through Plate 78 show maximum velocities for n-AEP simulations for the tentatively selected updated Alt2A. Plates 79 through Plate 94 show the differential maximum depths and differential velocities for this tentatively selected plan as compared to the existing conditions. Plate 95 shows a zoomed view of changes in depth for 1% (1/100) AEP. Stage and flow frequency curves are provided in Plates 96 through Plate 104. Index points P1, P2, and P3 will not be impacted by the tentatively selected plan. Therefore, results at those locations are not presented.

6.9 Managed Overtopping

The proposed TSP levee is designed for 0.5% (1/200) AEP flow as described in Section 6.2. In case of significantly larger event like 0.1% (1/1000) AEP, the design probably will allow controlled overtopping upstream of the new levee near Road 98B per USACE ECB 2017-15. A flowage easement for the probable inundated area resulting from flanking will be considered for final feasibility design to manage the controlled overtopping. This will result in lesser damage to the downstream urban areas and levee sections.

6.10 Hydraulic Impacts

A potential adverse hydraulic impact would be induced flooding or significant increase in velocities within the system or both. Induced flooding could result from a project increasing the depth, duration, or frequency of flooding. The potential for induced flooding was evaluated by comparing with-project and no action plans throughout the system. Increases and decreases to flood depths within the model domain are provided in Plates 79 through 86. Differential changes to the velocities due to the proposed alternative are presented in Plates 87 through 94.

CA 113 demarks a significant change in the duration of flooding and any induced flooding. The duration of flooding west of CA 113 would be similar as existing conditions but would be higher or lower depths depending on location. East of CA 113, the duration and depth of flood impacts would increase, with the highest depth increases and longest duration being near the inlet weir. It is estimated that the duration of flooding west of CA 113 is less than on 1 week and the duration of flooding at the inlet weir would be around 1 month. A major factor for the duration of flooding near the inlet weir is the availability and capacity of the city pump station that would be used to pump the water into the Yolo Bypass.

6.11 Geomorphic Assessment

The proposed plan is similar to the 2003 Feasibility study plan in terms of geomorphic assessment. Therefore, conclusions based on Reference 16 can be applied for the selected plan as well. The alternative will allow the channel to function as it currently does with flows overtopping the levee and leaving the channel and flowing out on the wide floodplain. Channel topping flows are routed over the floodplain south of the Creek to the Settling Basin. Future channel stability issues remain identical to those discussed in Section 3.6.2. The alternative will maintain the current channel capacities.

In 2016, City of Woodland conducted a sediment transport study to evaluate the relative sediment capture performance and relative flood inundation for the settling basin for the proposed Alternative 2A as compared to the existing conditions. Reference 26 details the study. The trap efficiencies in the settling basin is based on total load entering the settling basin at Road 102 and exiting the system at the overflow weir near Yolo Bypass. The results of the study indicate a small increase in the trap efficiency of the settling basin, thereby indicating settling basin will fill at a slightly faster rate as compared to the future without project conditions.

Table 12. Trap Efficiencies of Cache Creek Settling Basin for the Current Conditions and Alternative 2A with Inlet Weir

Flow Event	Current Condition	Alternative 2A
10%(1/10)AEP	31%	41%
2%(1/50)AEP	56%	58%
1%(1/100)AEP	57%	63%
0.5%(1/200)AEP	66%	71%

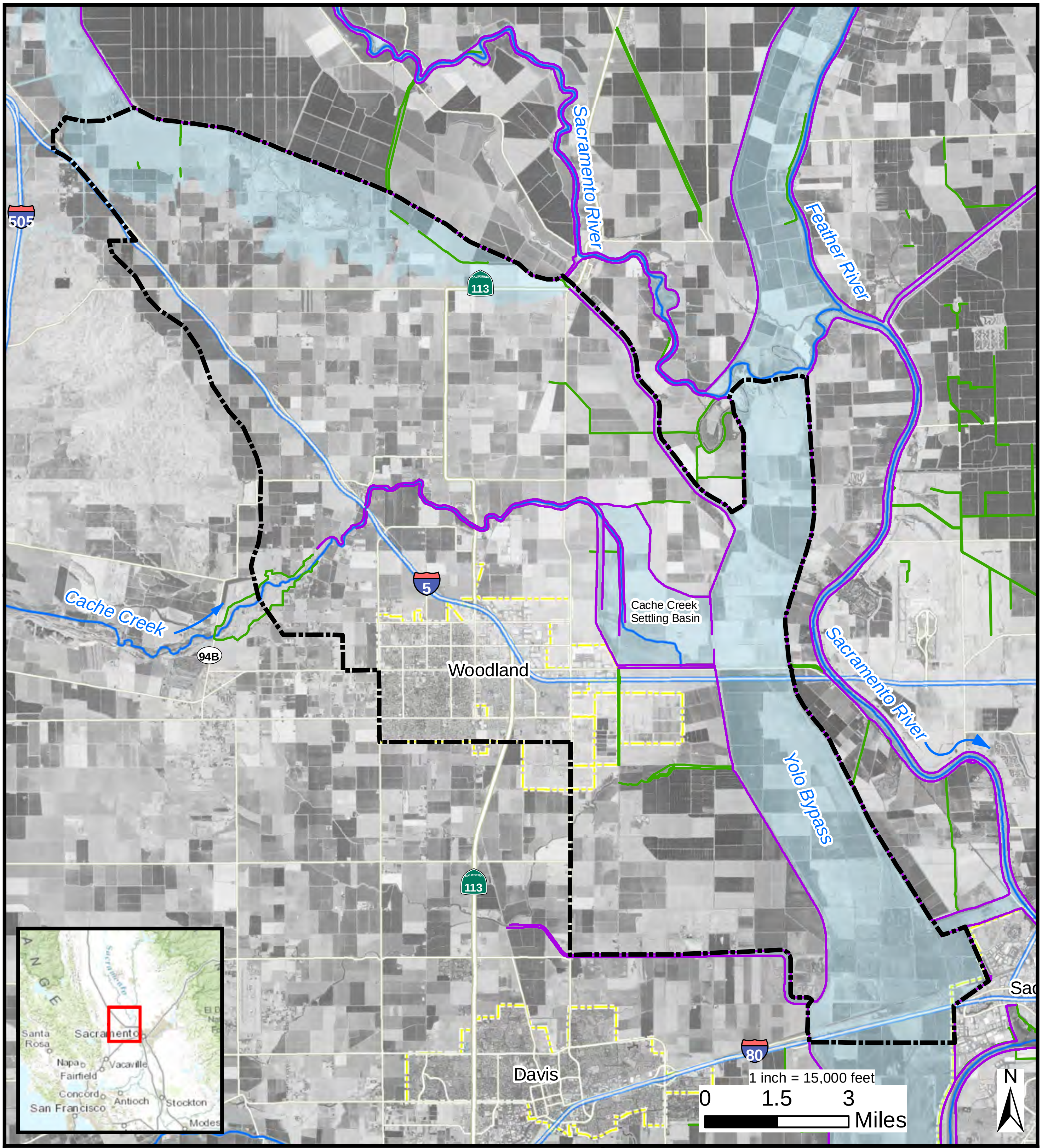
6.12 Flood Warning Time

Alternative 2A will not result in increase or decrease of the flood warning time to the affected communities due to overtopping failures from Cache Creek. A description of flood warning time is provided in Section 3.4. The proposed TSP levee is a second line of defense for flooding to occur in Woodland. In case of failure of the existing Cache Creek levees or upstream overtopping the flood warning time will be the same as for the current existing conditions.

7.0 References

1. California Department of Water Resources (DWR), 2018. 2017 GPS Survey of the Sacramento Valley Subsidence Network, December 2018.
2. Chow, 1959. “Open Channel Hydraulics.” McGraw Hill, 1959.
3. CNRFC, 2019. Weather Forecast Office (WFO) Hydrologic Products, California Nevada River Forecast Center.
4. HEC, 2008. Hydrologic Engineering Center, HEC-RAS River Analysis Program, version 4.0.0, March, 2008.
5. Hejl, 1977, USGS, A Method for Adjusting Values of Manning’s Roughness Coefficients of Flooded Urban Areas.
6. MBK Engineers (MBK), 2016. “Hydraulic Analysis for Lower Cache Creek Feasibility Study Alternatives.” Draft, prepared for the Sacramento District, Sacramento, CA.
7. TUFLOW Model, BMT WBM Group Inc., Version 2013-04-AC-Dev, 2013.
8. U.S. Army Corps of Engineers (USACE), 1960. “Levee Construction, Cache Creek, Yolo Bypass to High Ground.” Flood control project as-built drawing, file no. 50-4-3227, Sacramento District, Sacramento, CA.
9. U.S. Army Corps of Engineers (USACE), 1962. “Unit No. 126, Cache Creek Levees and Settling Basin, Yolo Basin to High Ground.” Supplement to Standard Operation and Maintenance Manual, Sacramento River Flood Control Project, Sacramento District, Sacramento, CA.
10. U.S. Army Corps of Engineers (USACE), 1984. “General Design Conference, Cache Creek Basin, California.” Information Pamphlet, Sacramento District, Sacramento, CA.
11. U.S. Army Corps of Engineers (USACE), 1985. “Cache Creek Basin, California, Sediment Engineering Investigation.” Existing Field Conditions at “Active” Bank Erosion Sites, notes to file, Sacramento District, Sacramento, CA.
12. U.S. Army Corps of Engineers (USACE), 1987. “Design Memorandum No. 1, Cache Creek Settling Basin, California.” Final General Design Memorandum, Sacramento District, Sacramento, CA.
13. U.S. Army Corps of Engineers (USACE), 1993. “Engineering and Design: River Hydraulics.” Engineer Manual EM 1110-2-1415, Washington, DC.
14. U.S. Army Corps of Engineers (USACE), 1995. “Engineering and Design: Sedimentation Investigations.” Engineering Regulation ER 1110-2-8153, Washington, DC.
15. U.S. Army Corps of Engineers (USACE), 1996. “Engineering and Design: Risk-Based Analysis for Flood Damage Reduction Studies.” Engineer Manual EM 1110-2-1619, Washington, DC.
16. U.S. Army Corps of Engineers (USACE), 2003. “Draft Environmental Impact Statement/Environmental Impact Report for Potential Flood Damage Reduction Project.” Lower Cache Creek, Yolo County, CA, City of Woodland and Vicinity. State Clearinghouse #2000062064.
17. U.S. Army Corps of Engineers (USACE), 2007. “Operation and Maintenance Manual.” Cache Creek Settling Basin Enlargement, Sacramento District, Sacramento, CA.
18. U.S. Army Corps of Engineers (USACE), 2012. “Central Valley Hydrology Study.” Cache Creek Watershed Hydrologic Analysis, Sacramento District, Sacramento, CA.
19. U.S. Army Corps of Engineers (USACE), 2015a. “Lower Cache Creek Feasibility Study, Future Without-Project Condition Assumption for Cache Creek Settling Basin Weir Raise.” Draft Memorandum for File, Sacramento District, Sacramento, CA.

20. U.S. Army Corps of Engineers (USACE), 2015b. “Lower Cache Creek Feasibility Study.” Documentation of Levee Breach Simulations and Breach Width Uncertainty Analysis.” Draft Technical Memorandum, Sacramento District, Sacramento, CA.
21. U.S. Army Corps of Engineers (USACE), 2017. “Managed Overtopping of Levee Systems.” Engineering Construction Bulletin ECB 2017-15, Washington, DC.
22. Wood Rodgers, Inc. (WRI), 2012. “Cache Creek Hydraulic Model Development.” Technical Memorandum, task order 24, subtask 10. Prepared for the California Department of Water Resources.
23. Wood Rodgers, Inc. (WRI), 2013a. “Central Valley Floodplain Evaluation and Delineation: Two-Dimensional Overland Hydraulic Model Construction.” Technical Memorandum, contract number 4600007989, task order no. 23, subtask 7. Prepared for the California Department of Water Resources, Floodplain Management Branch, Floodplain Mapping Section.
24. Wood Rodgers, Inc. (WRI), 2013b. “USACE Lower Cache Creek Feasibility Study.” Documentation of Levee Breach Simulations and Breach Width Uncertainty Analysis.” Draft Technical Memorandum. Prepared for the City of Woodland.
25. Wood Rodgers, Inc. (WRI), 2015. “USACE Lower Cache Creek Feasibility Study.” Documentation of Manning’s Roughness Coefficient Uncertainty Analysis, Draft Technical Memorandum. Prepared for the City of Woodland.
26. Wood Rodgers, Inc. (WRI), 2016. “City of Woodland, Lower Cache Creek Feasibility Study, Alternatives Analysis Report.” Prepared for the City of Woodland.
27. Wood Rodgers, Inc. (WRI), 2019. “Lower Cache Creek Feasibility Study, City of Woodland.” Draft Project Description. Prepared for the Sacramento District, Sacramento, CA.



Legend

- Existing Federal Levees
- Existing Non Federal Levees
- River/Creek
- Interstate
- Highway
- Major Roads
- Project Boundary
- Designated Floodways
- City Boundaries
- County Boundary

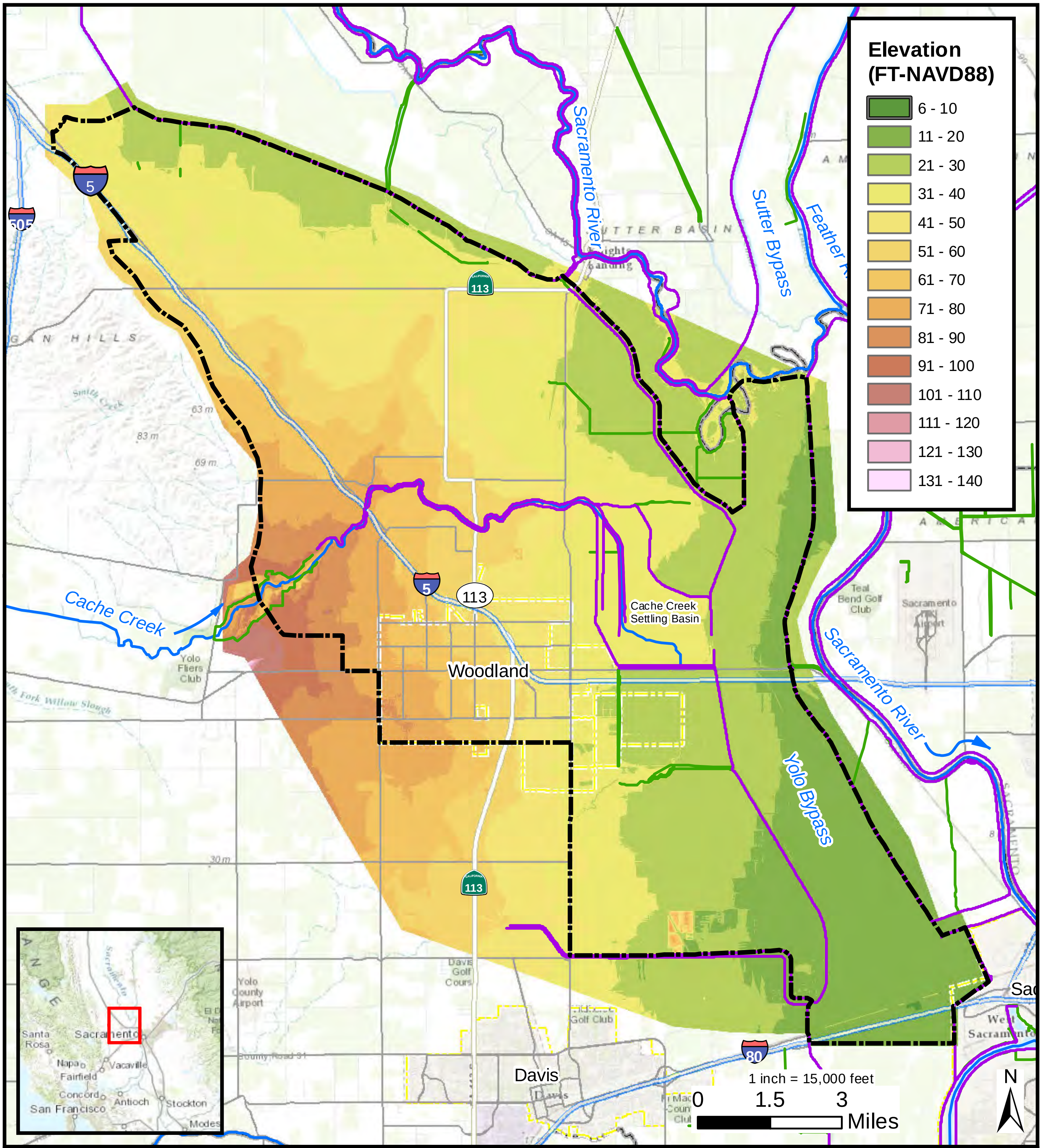
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

LOWER CACHE CREEK
STUDY AREA

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019

PLATE 1



Legend

- ▭ Project Boundary
- Existing Federal Levees
- Existing Non Federal Levees
- River/Creek
- City Boundaries
- County Boundary

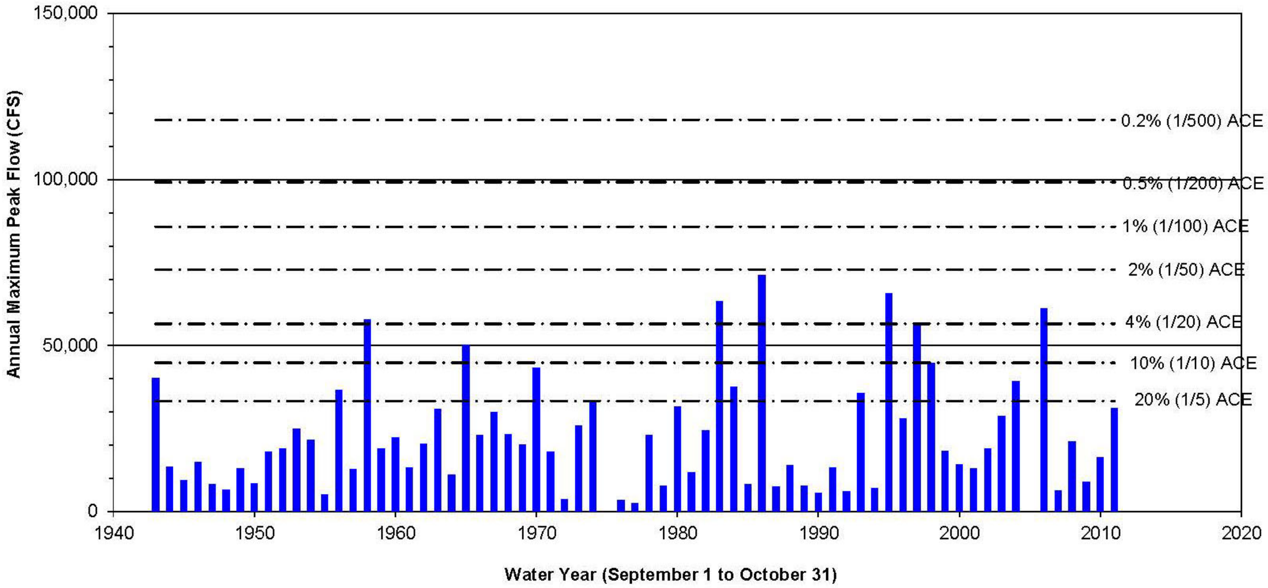
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

TOPOGRAPHY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019

PLATE 2



Unregulated Conditions, Cache Creek at Rumsey

Notes:

Unregulated conditions demonstrate the frequency of historical events for similar hydrologic conditions. Unregulated peak flows reflect flows unaffected by Indian Valley reservoir regulation. Regulated flows and regulated flow frequency estimates would be lower under current reservoir conditions.

1943-1965, 1972, 1974 based on translation from Cache Creek at Capay stream gage.

1978 to 2011 adjusted to remove the effects of Indian Valley reservoir regulation.

Prepared by PJB

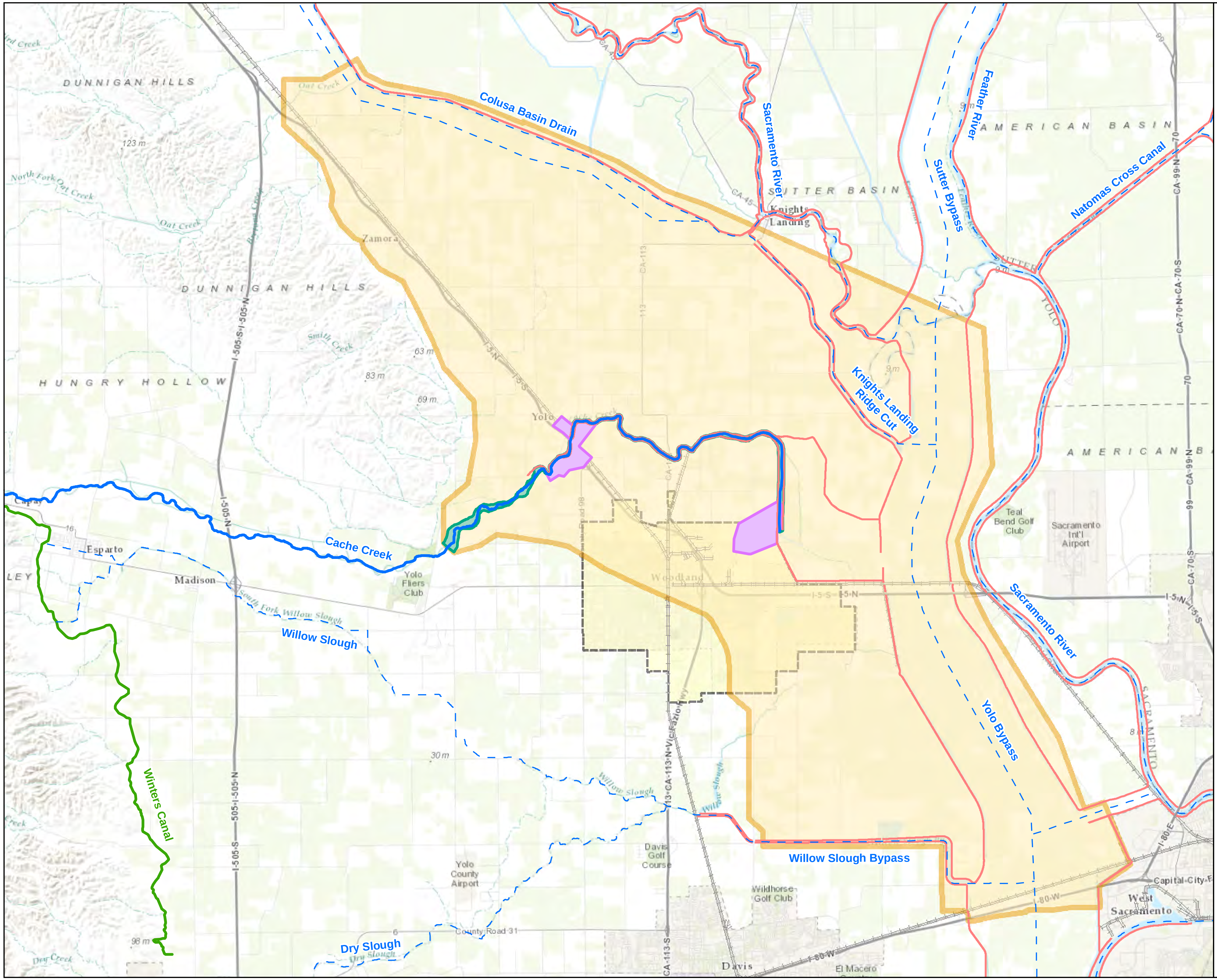
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ESTIMATED UNREGULATED PEAK FLOWS CACHE CREEK AT RUMSEY

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

AUG 2019

PLATE 3



🟧 TUFLOW Model Domain - Low Resolution 2D

🟩 1D Domain

🟪 High Resolution 2D Domain

▨ City of Woodland

— State Plan of Flood Control Levees

— Cache Creek

- - Stream Centerlines

— Winters Canal

┼┼┼ Railways

Sources:

1. Cache Creek hydrology based upon the "Central Valley Hydrology Study - Cache Creek Watershed Hydrologic Analysis," developed by U.S. Army Corps of Engineers, Sacramento District, 2012. Supplemental inflow data for Knights Landing Ridge Cut, Yolo Bypass, and Sacramento Bypass provided in .dss file format by the USACE Sacramento District April 2014.
2. California Department of Water Resources, CVFED Program LiDAR
3. Esri Online Imagery sources: Esri, DeLorme, NAVTEQ, Tom Tom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community.

NORTH

0 6,000 12,000

Feet

WOODLAND
City of Trees
CALIFORNIA

LOWER CACHE CREEK FEASIBILITY STUDY

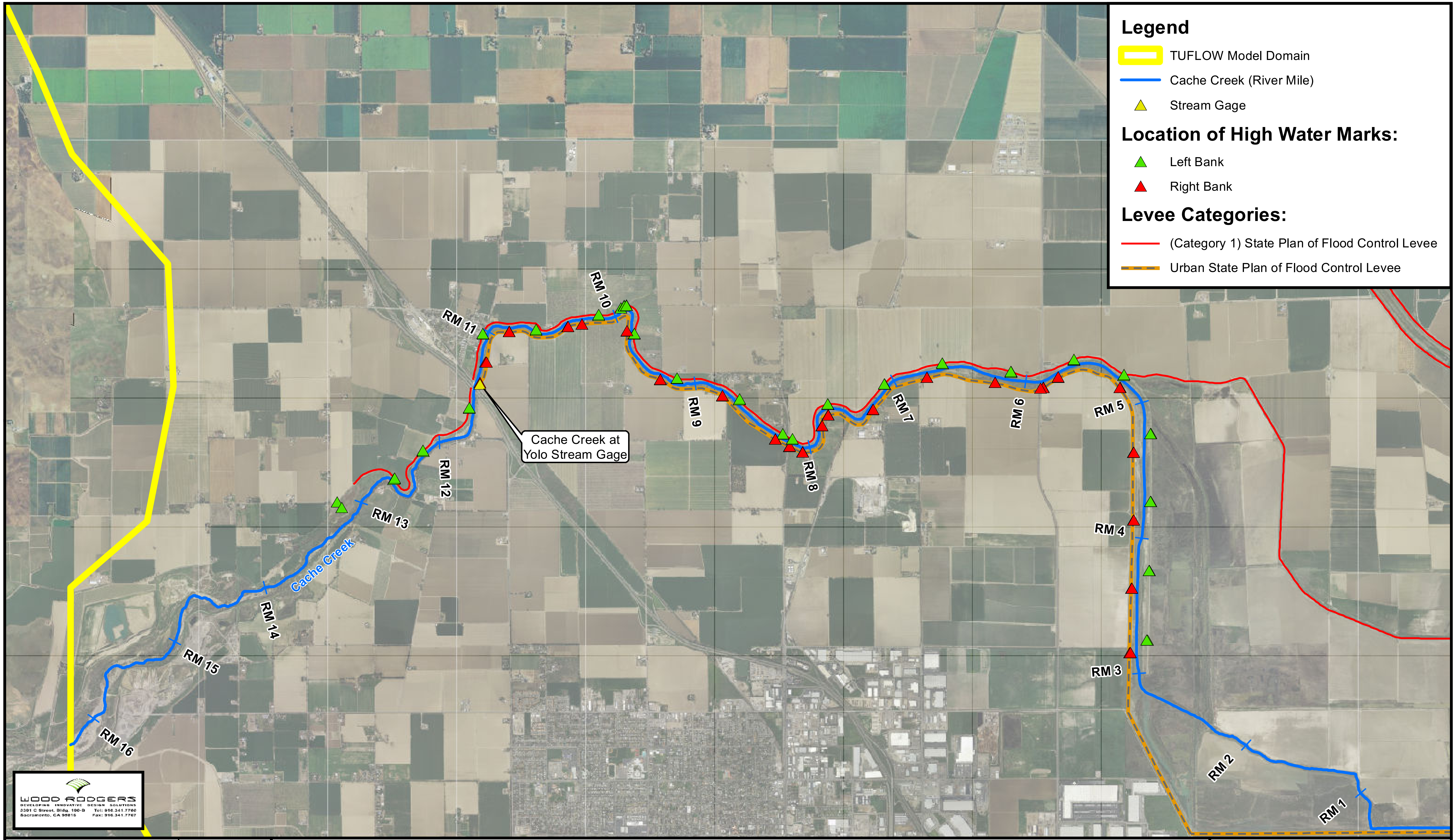
TUFLOW MODEL DOMAIN LAYOUT

WOOD RODGERS
DEVELOPING INNOVATIVE DESIGN SOLUTIONS

J:\Jobs\8303\8303.020\GIS\Tasks\Milestone_2_Maps\3_1-3_Calib_NoFailure_TM\F02_CAC_MS02_TUFLOW_Model_Domain_Layout_Map_20150107_V3.mxd 1/15/2015 3:39:41 PM cmilligan

September 2019

PLATE 4

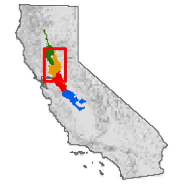


WOOD RODGERS
DEVELOPING INNOVATIVE DESIGN SOLUTIONS
3301 C Street, Bldg. 100-B
Sacramento, CA 95816
Tel: 916.341.7760
Fax: 916.341.7767

1 " = 3,600 '
0 3,600 Feet

N

Datum: NAD83
Zone: 10N
Projection: UTM
Units: US Feet
Sources: California Levee Database



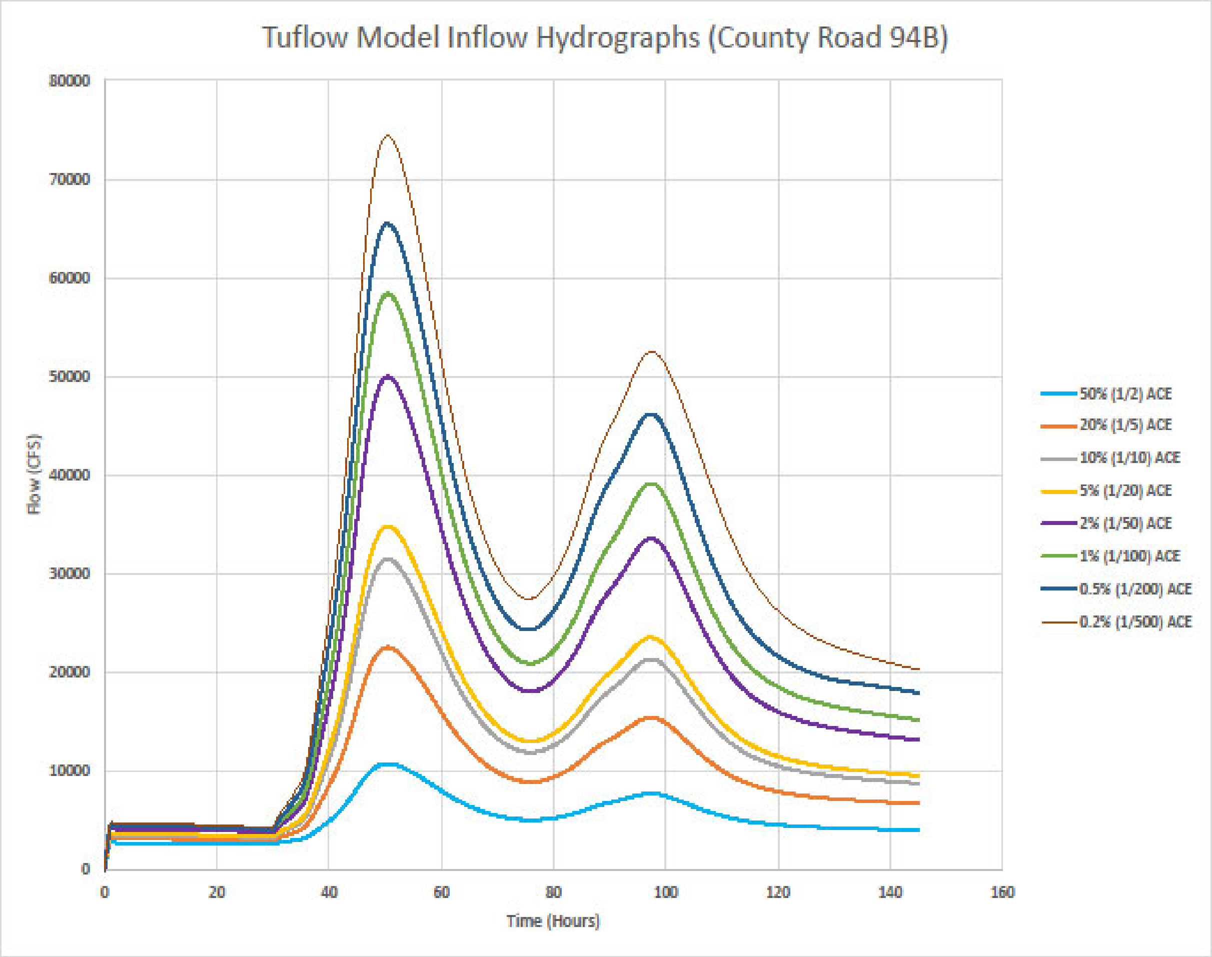
Central Valley Floodplain Evaluation and Delineation Program
Lower Sacramento River Basin

TASK ORDER NO. 23
CACHE CREEK
2006 CALIBRATION DATA LOCATION MAP

FloodSAFE CALIFORNIA DEPARTMENT OF WATER RESOURCES

Prepared By: Wood Rodgers	Figure: 9
Job No.: 8338.023	Date: Jan 27, 2013
Fig_09_CAC_2006_Calibration_Data_20130110_V1	

J:\Jobs\8338_DWR\8338_023_TaskOrder-23\GIS\Tasks\Subtask_7_TechMemo\CAC\Fig_09_CAC_2006_Calibration_Data_20130110_V1.mxd 01/27/2013 02:09:54 PM schaoka

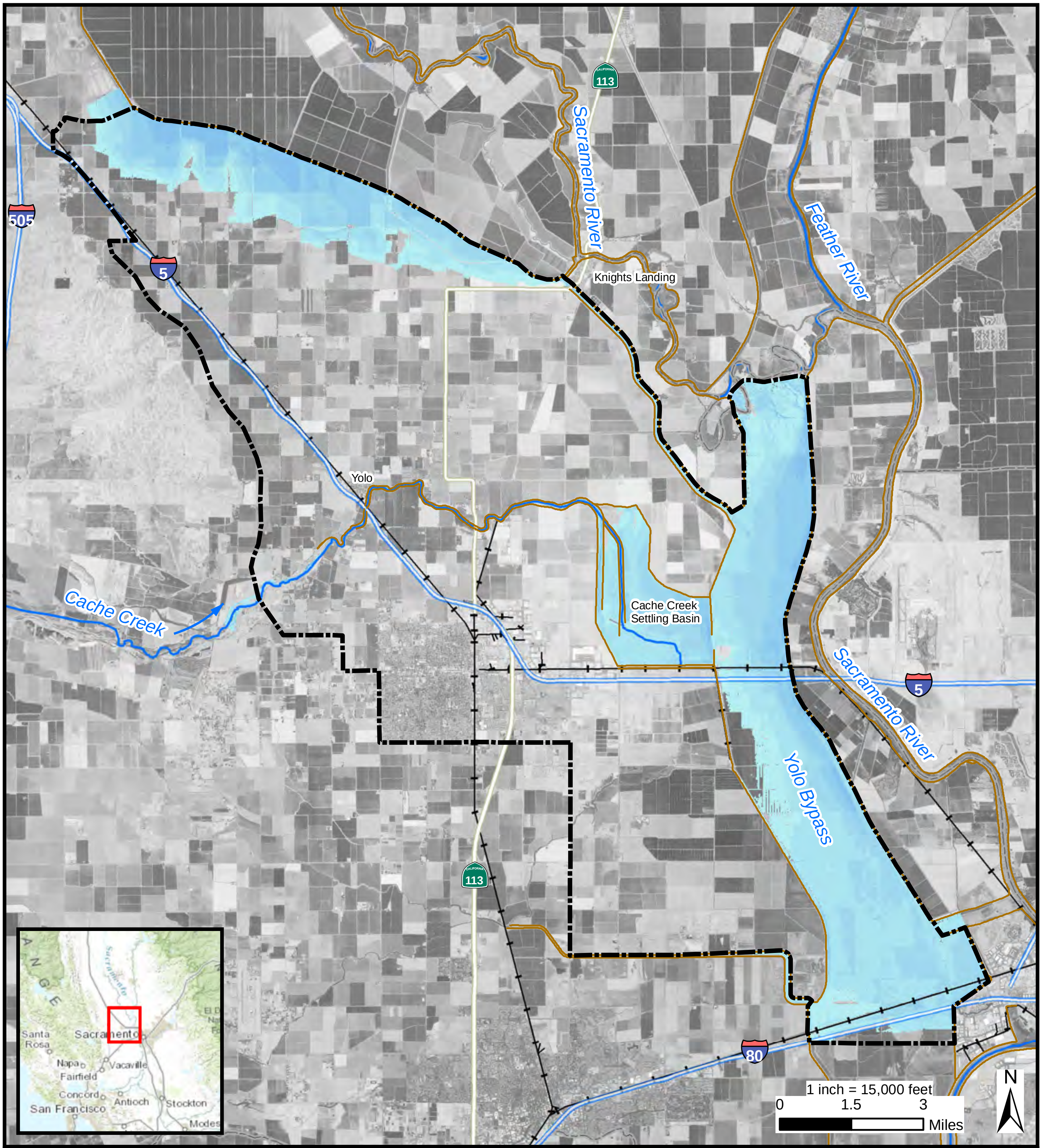


Prepared by SRS

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

INFLOW HYDROGRAPHS
CACHE CREEK AT ROAD 94B

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



Legend

- Existing Federal Levees
- Interstate
- Highway
- Railroad
- River/Creek
- Project Boundary
- County Boundary

Max Depth (Feet)

0 to 2	24 to 26
2 to 4	26 to 28
4 to 6	28 to 30
6 to 8	30 to 32
8 to 10	32 to 34
10 to 12	34 to 36
12 to 14	36 to 38
14 to 16	38 to 40
16 to 18	40 to 42
18 to 20	42 to 44
20 to 22	44 to 46
22 to 24	

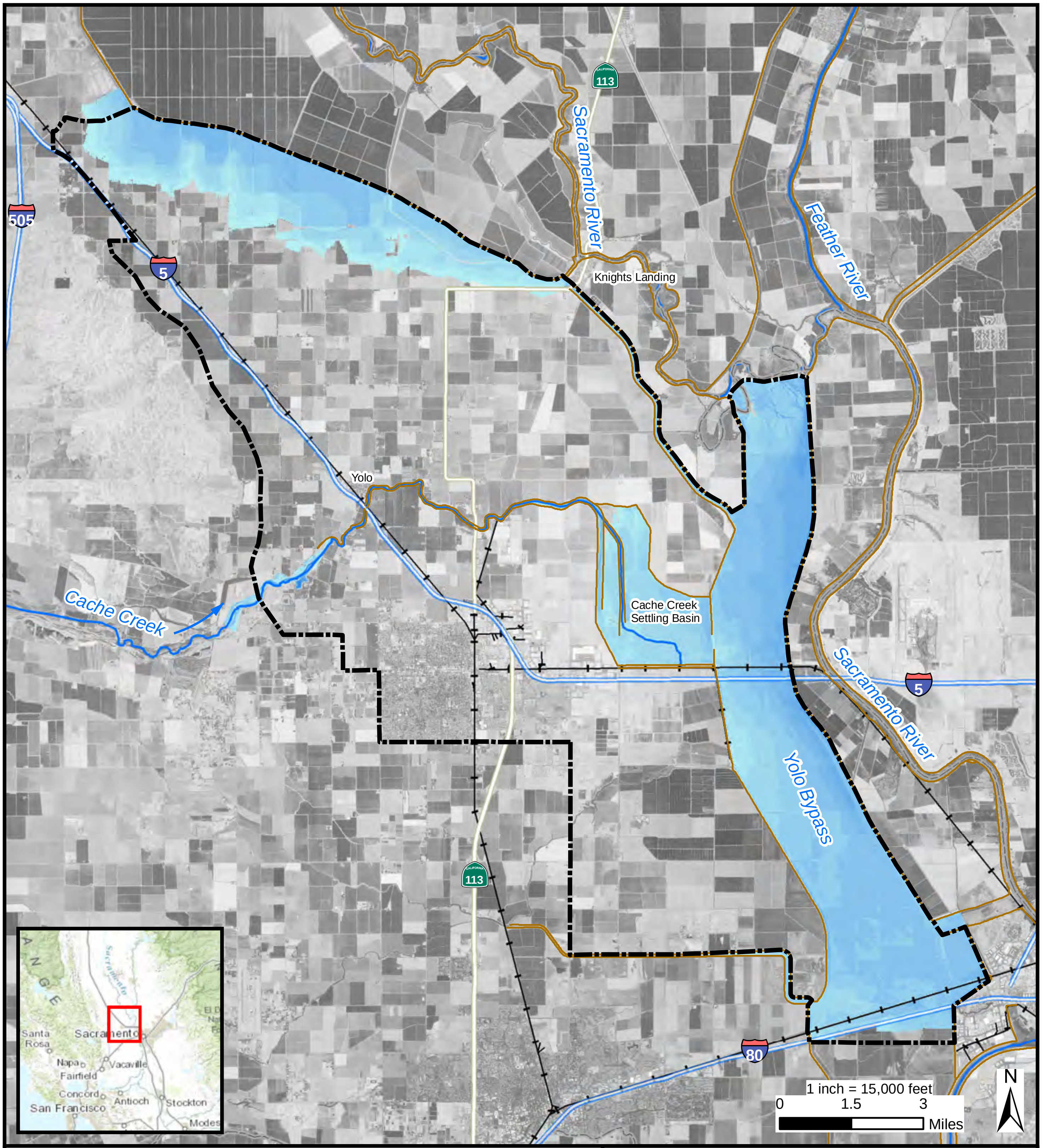
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

50% (1/2) ACE FLOODPLAIN WITHOUT PROJECT CONDITIONS OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019

PLATE 7



Legend

- Existing Federal Levees
- Interstate
- Highway
- Railroad
- River/Creek
- Project Boundary
- County Boundary

Max Depth (Feet)

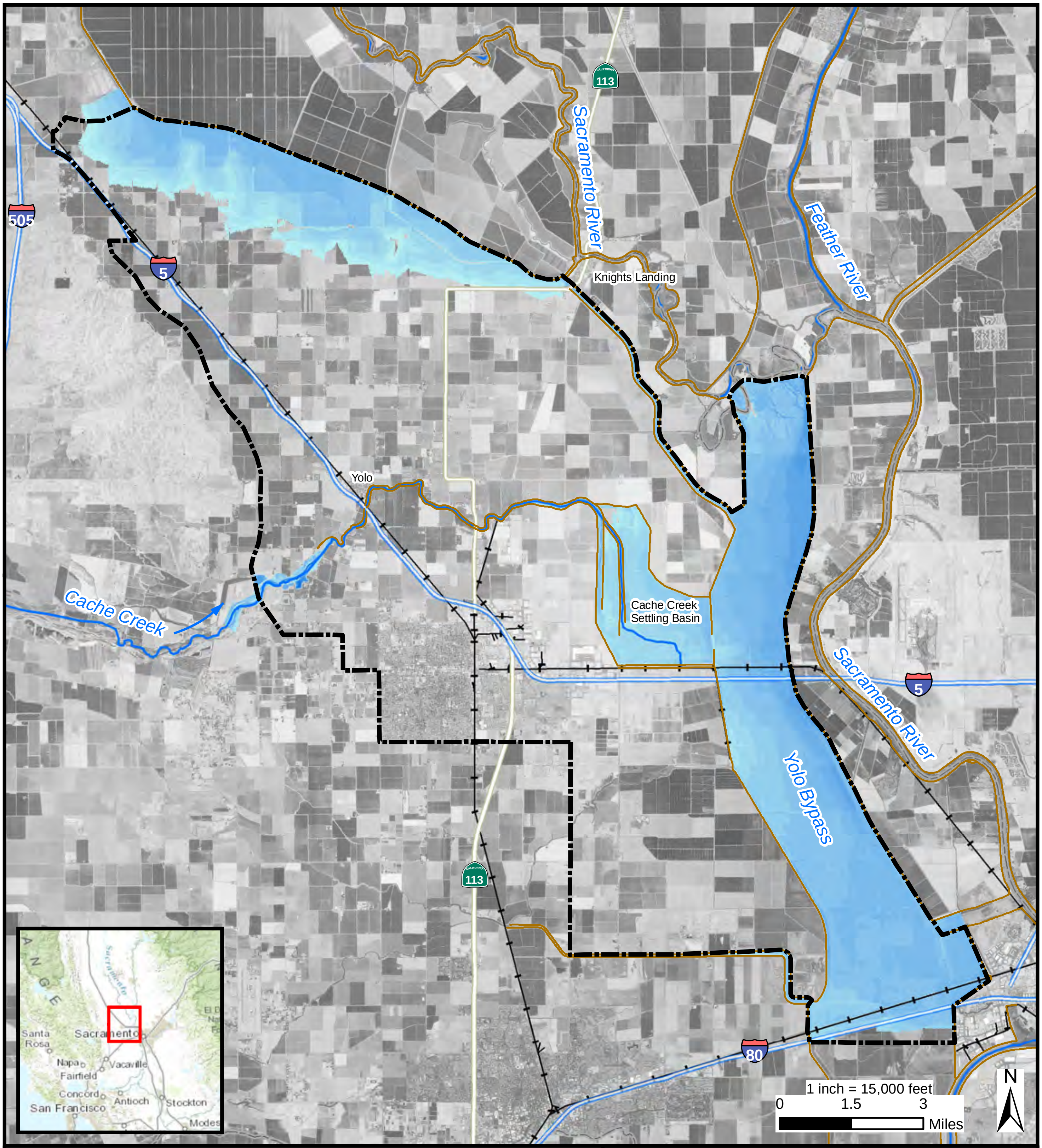
0 to 2	24 to 26
2 to 4	26 to 28
4 to 6	28 to 30
6 to 8	30 to 32
8 to 10	32 to 34
10 to 12	34 to 36
12 to 14	36 to 38
14 to 16	38 to 40
16 to 18	40 to 42
18 to 20	42 to 44
20 to 22	44 to 46
22 to 24	

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

20% (1/5) ACE FLOODPLAIN WITHOUT PROJECT CONDITIONS OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



Legend

- Existing Federal Levees
- Interstate
- Highway
- Railroad
- River/Creek
- Project Boundary
- County Boundary

Max Depth (Feet)

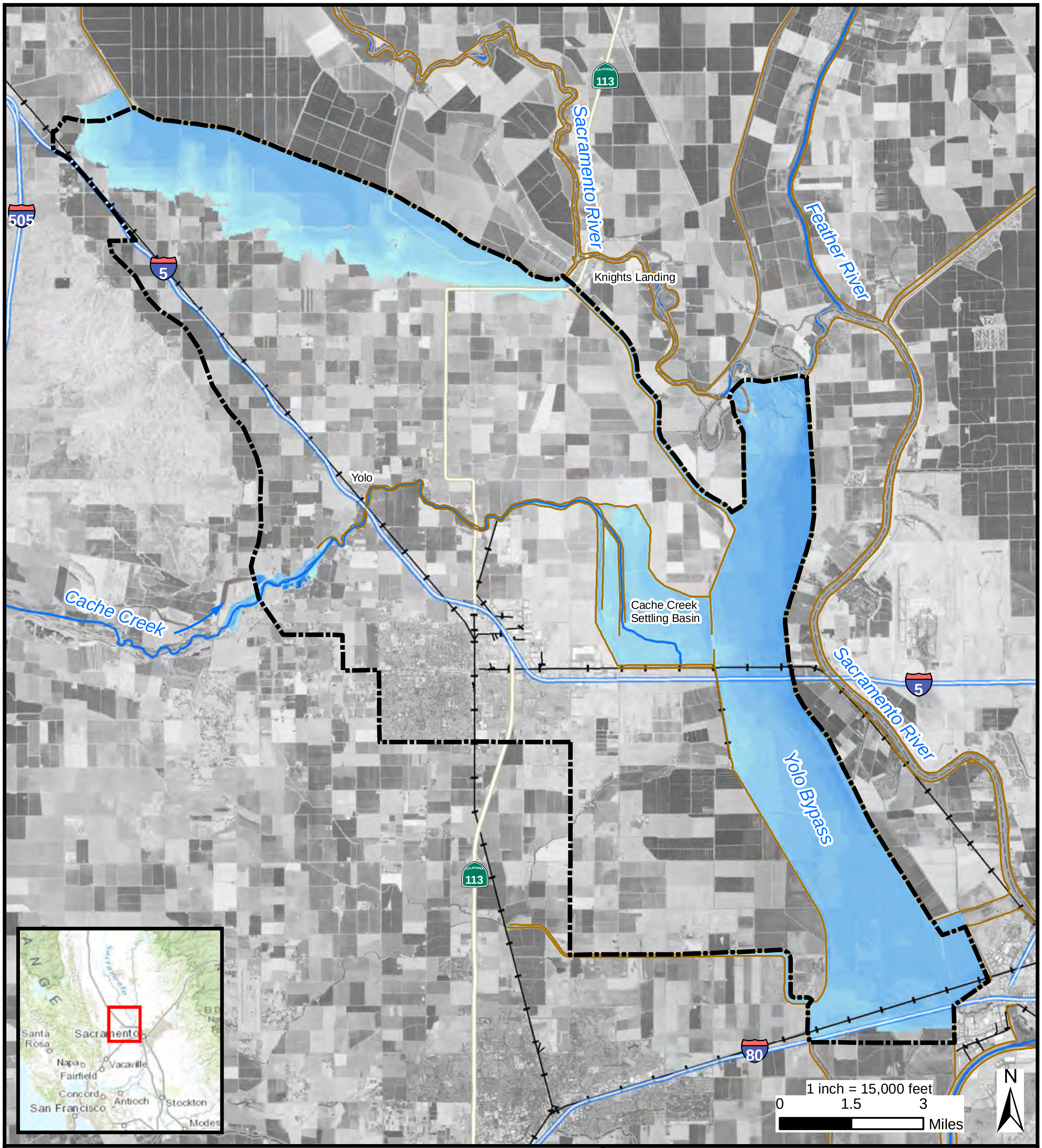
0 to 2
2 to 4
4 to 6
6 to 8
8 to 10
10 to 12
12 to 14
14 to 16
16 to 18
18 to 20
20 to 22
22 to 24
24 to 26
26 to 28
28 to 30
30 to 32
32 to 34
34 to 36
36 to 38
38 to 40
40 to 42
42 to 44
44 to 46

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

10% (1/10) ACE FLOODPLAIN WITHOUT PROJECT CONDITIONS OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



Legend

- Existing Federal Levees
- Interstate
- Highway
- Railroad
- River/Creek
- Project Boundary
- County Boundary

Max Depth (Feet)

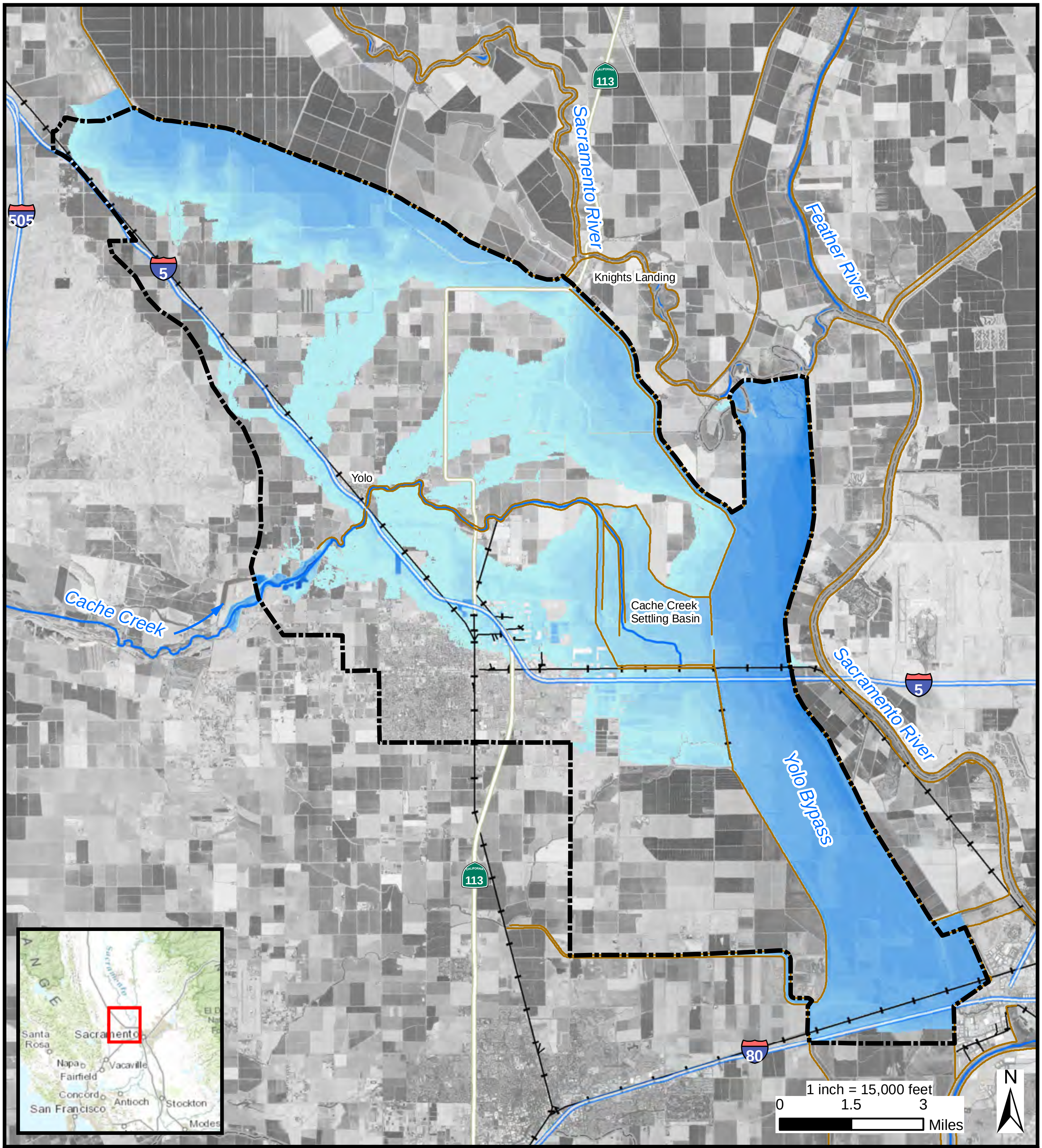
- 0 to 2
- 2 to 4
- 4 to 6
- 6 to 8
- 8 to 10
- 10 to 12
- 12 to 14
- 14 to 16
- 16 to 18
- 18 to 20
- 20 to 22
- 22 to 24
- 24 to 26
- 26 to 28
- 28 to 30
- 30 to 32
- 32 to 34
- 34 to 36
- 36 to 38
- 38 to 40
- 40 to 42
- 42 to 44
- 44 to 46

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

5% (1/20) ACE FLOODPLAIN WITHOUT PROJECT CONDITIONS OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



Legend

- Existing Federal Levees
- Interstate
- Highway
- Railroad
- River/Creek
- Project Boundary
- County Boundary

Max Depth (Feet)

0 to 2	24 to 26
2 to 4	26 to 28
4 to 6	28 to 30
6 to 8	30 to 32
8 to 10	32 to 34
10 to 12	34 to 36
12 to 14	36 to 38
14 to 16	38 to 40
16 to 18	40 to 42
18 to 20	42 to 44
20 to 22	44 to 46
22 to 24	

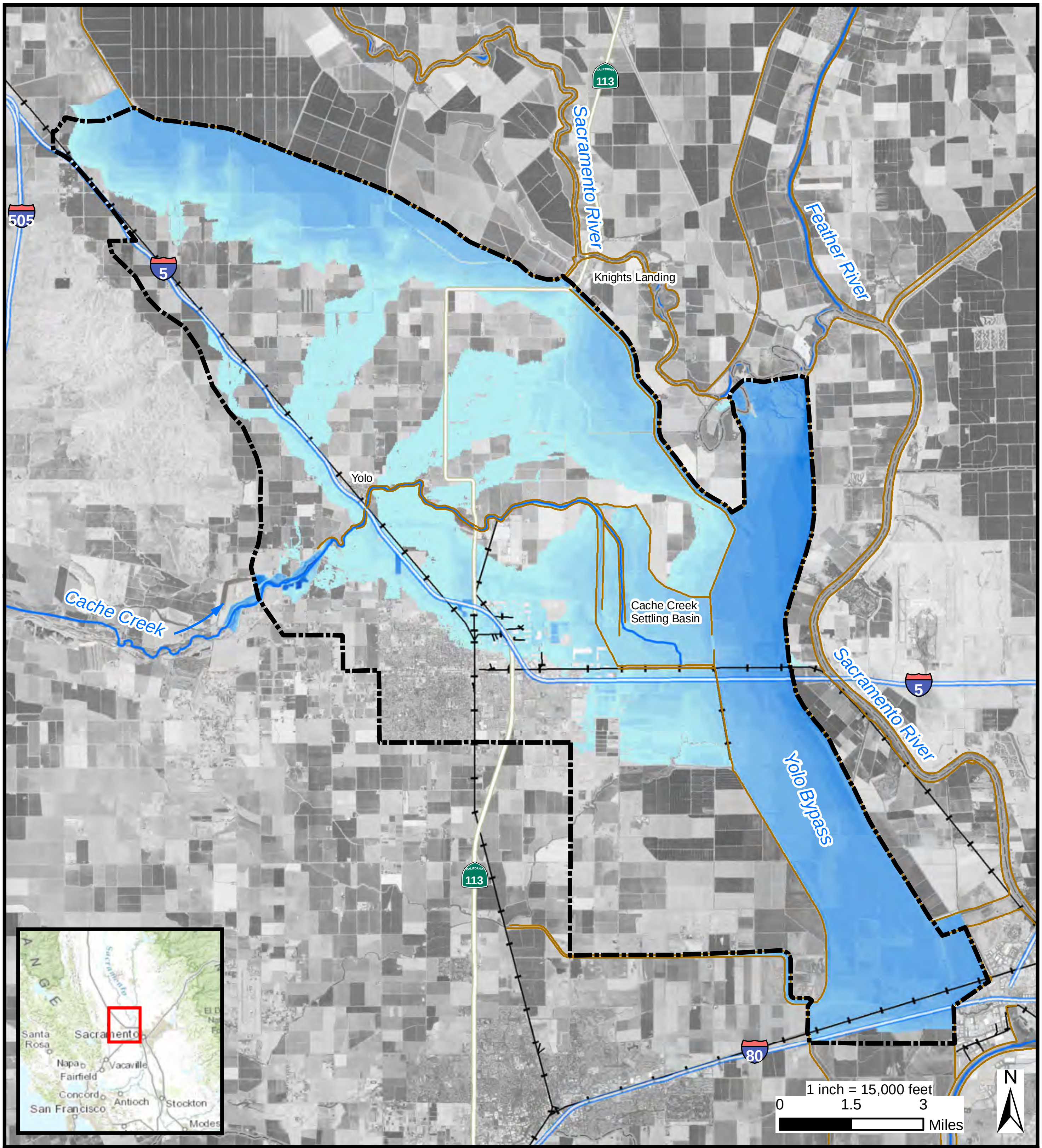
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

2% (1/50) ACE FLOODPLAIN WITHOUT PROJECT CONDITIONS OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019

PLATE 11



Legend

- Existing Federal Levees
- Interstate
- Highway
- Railroad
- River/Creek
- Project Boundary
- County Boundary

Max Depth (Feet)

- 0 to 2
- 2 to 4
- 4 to 6
- 6 to 8
- 8 to 10
- 10 to 12
- 12 to 14
- 14 to 16
- 16 to 18
- 18 to 20
- 20 to 22
- 22 to 24
- 24 to 26
- 26 to 28
- 28 to 30
- 30 to 32
- 32 to 34
- 34 to 36
- 36 to 38
- 38 to 40
- 40 to 42
- 42 to 44
- 44 to 46

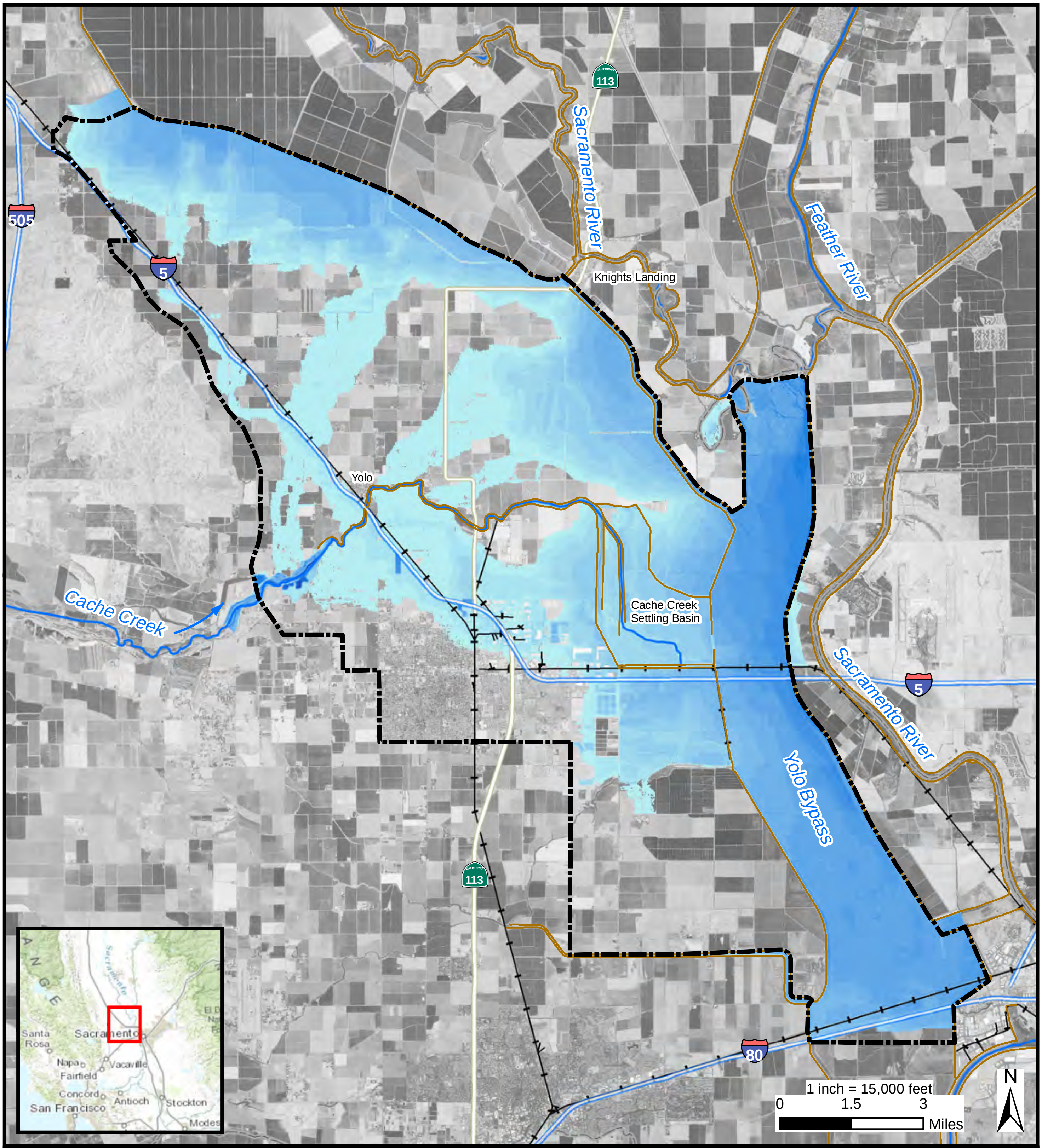
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

1% (1/100) ACE FLOODPLAIN WITHOUT PROJECT CONDITIONS OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019

PLATE 12



Legend

- Existing Federal Levees
- Interstate
- Highway
- Railroad
- River/Creek
- Project Boundary
- County Boundary

Max Depth (Feet)

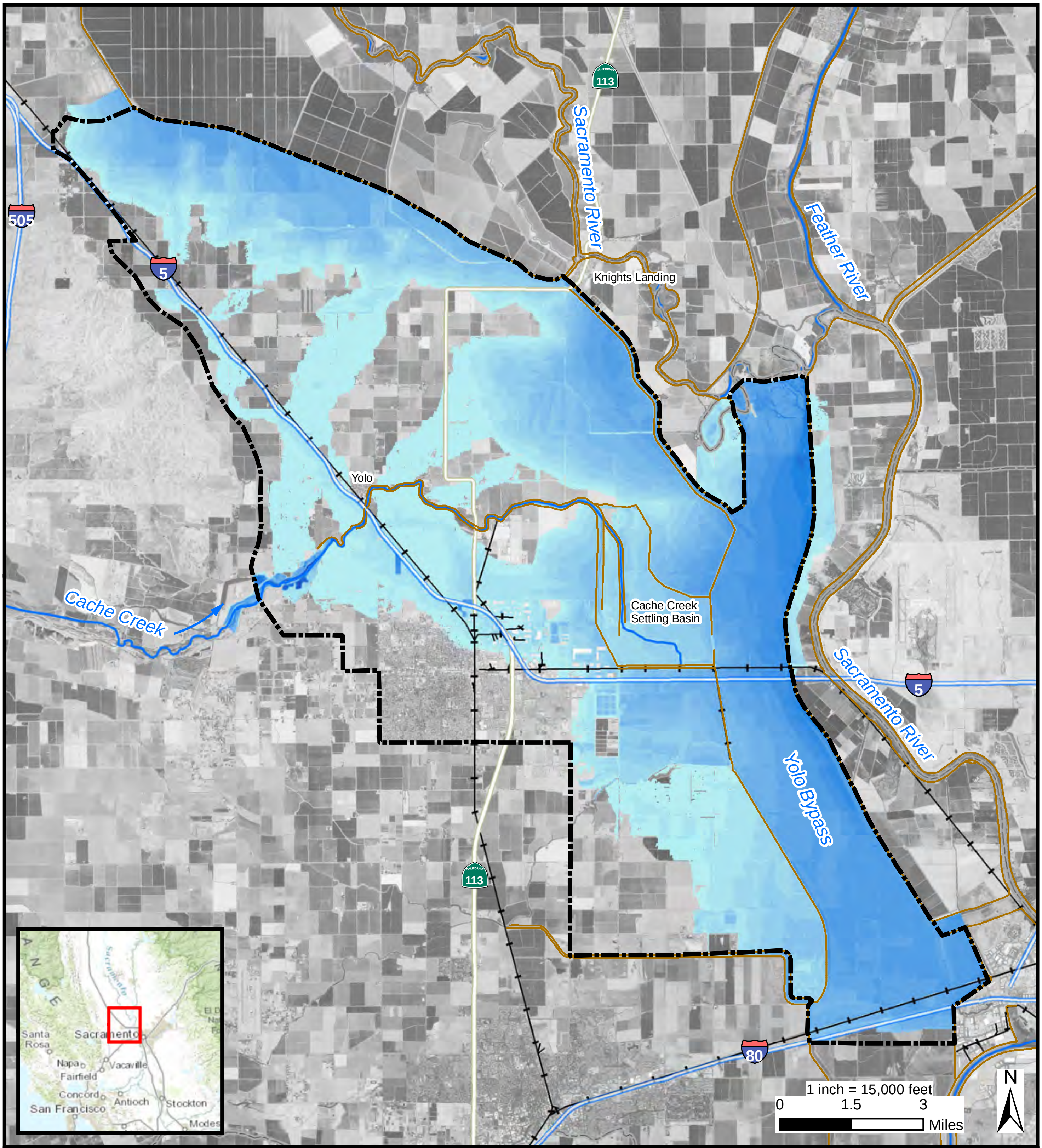
0 to 2
2 to 4
4 to 6
6 to 8
8 to 10
10 to 12
12 to 14
14 to 16
16 to 18
18 to 20
20 to 22
22 to 24
24 to 26
26 to 28
28 to 30
30 to 32
32 to 34
34 to 36
36 to 38
38 to 40
40 to 42
42 to 44
44 to 46

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

0.5% (1/200) ACE FLOODPLAIN WITHOUT PROJECT CONDITIONS OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



Legend

- Existing Federal Levees
- Interstate
- Highway
- Railroad
- River/Creek
- Project Boundary
- County Boundary

Max Depth (Feet)

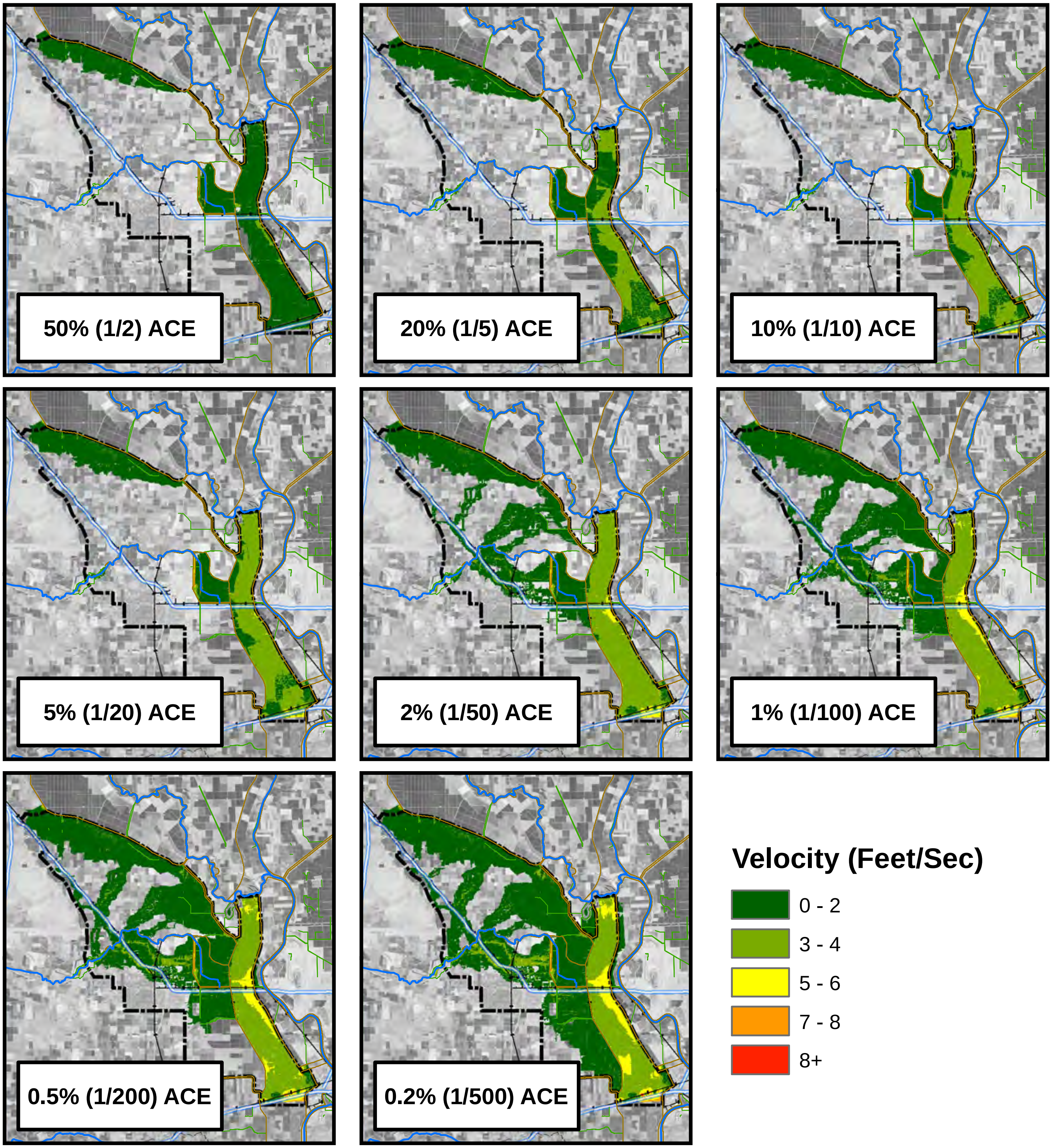
- 0 to 2
- 2 to 4
- 4 to 6
- 6 to 8
- 8 to 10
- 10 to 12
- 12 to 14
- 14 to 16
- 16 to 18
- 18 to 20
- 20 to 22
- 22 to 24
- 24 to 26
- 26 to 28
- 28 to 30
- 30 to 32
- 32 to 34
- 34 to 36
- 36 to 38
- 38 to 40
- 40 to 42
- 42 to 44
- 44 to 46

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

0.2% (1/500) ACE FLOODPLAIN WITHOUT PROJECT CONDITIONS OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



Legend

River/Creek

Existing Federal Levees

Existing Non Federal Levees

Interstate

Railroad

Project Boundary

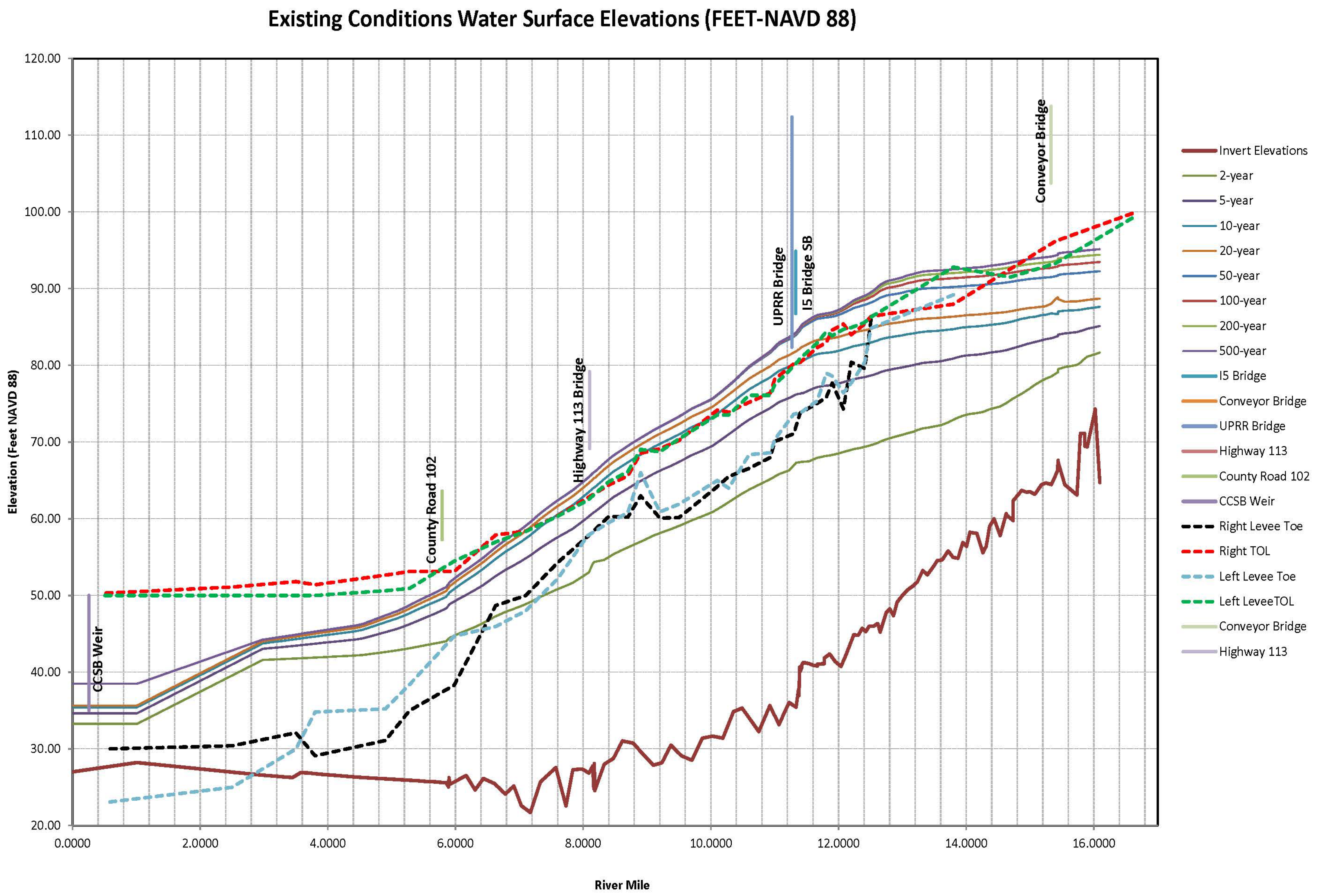
Note: Maps depict overtopping without failure

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

EXISTING CONDITIONS OVERTOPPING NO FAILURE MAX VELOCITY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

Longitudinal Profiles, Cache Creek

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

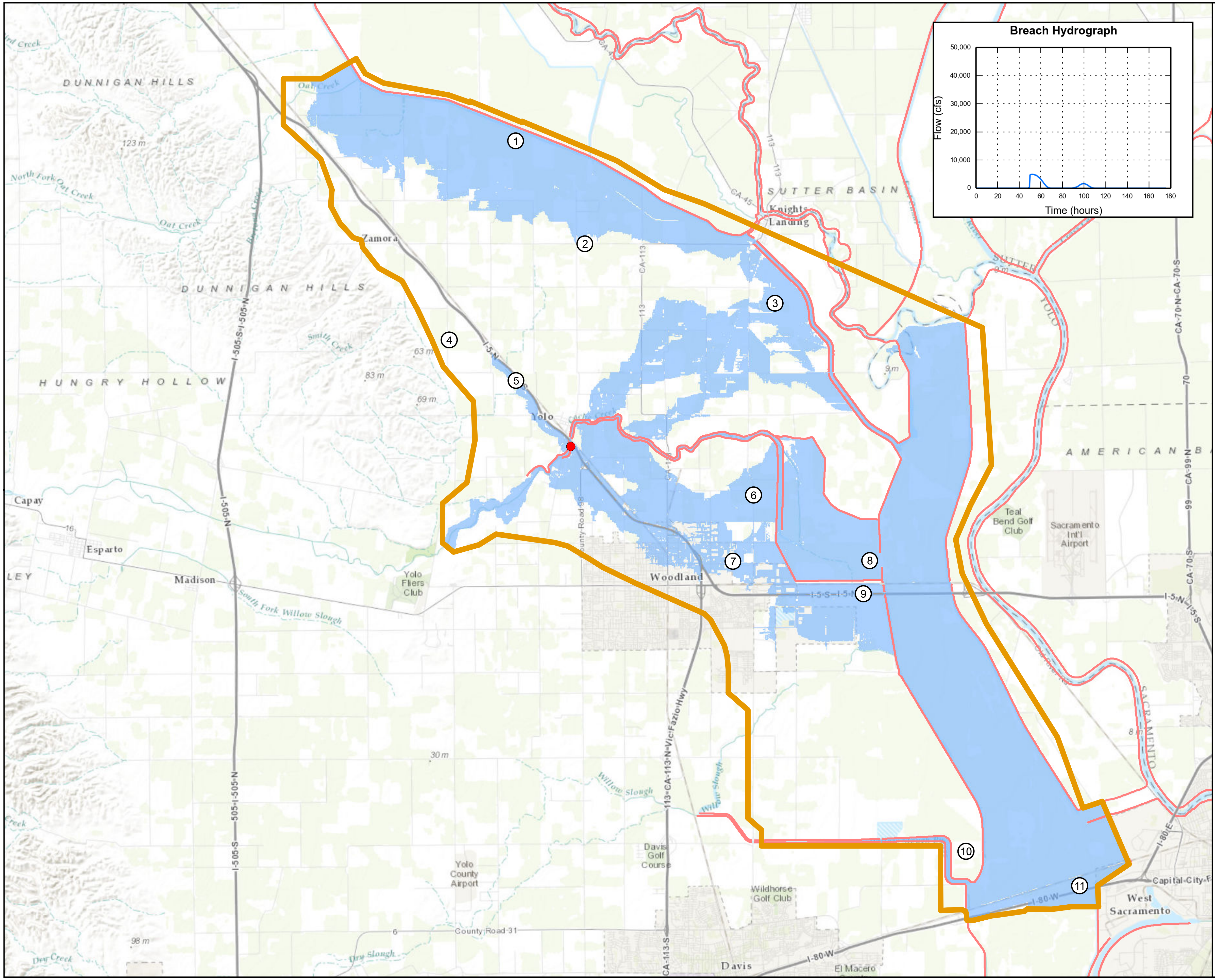
Annual Chance Exceedance flows based on total flow in channel and floodplain.

Gage only measures channel flow. Above 30,000cfs gage may not include floodplain flow

After 1971 peak flows and Annual Chance Exceedance flows affected by regulation at Indian Valley Reservoir

September 2019

PLATE 16



TUFLOW Model Domain

State Plan of Flood Control Levees

⑧ Reporting Locations

● Index Point

▨ Floodplain Extents

Sources:
1. Cache Creek hydrology based upon the "Central Valley Hydrology Study - Cache Creek Watershed Hydrologic Analysis," developed by U.S. Army Corps of Engineers, Sacramento District, 2012. Supplemental inflow data for Knights Landing Ridge Cut, Yolo Bypass, and Sacramento Bypass provided in .dss file format by the USACE Sacramento District April 2014.
2. California Department of Water Resources, CVFED Program LiDAR
3. Esri Online Imagery sources: Esri, DeLorme, NAVTEQ, Tom Tom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community.

NORTH

0 6,000 12,000
Feet

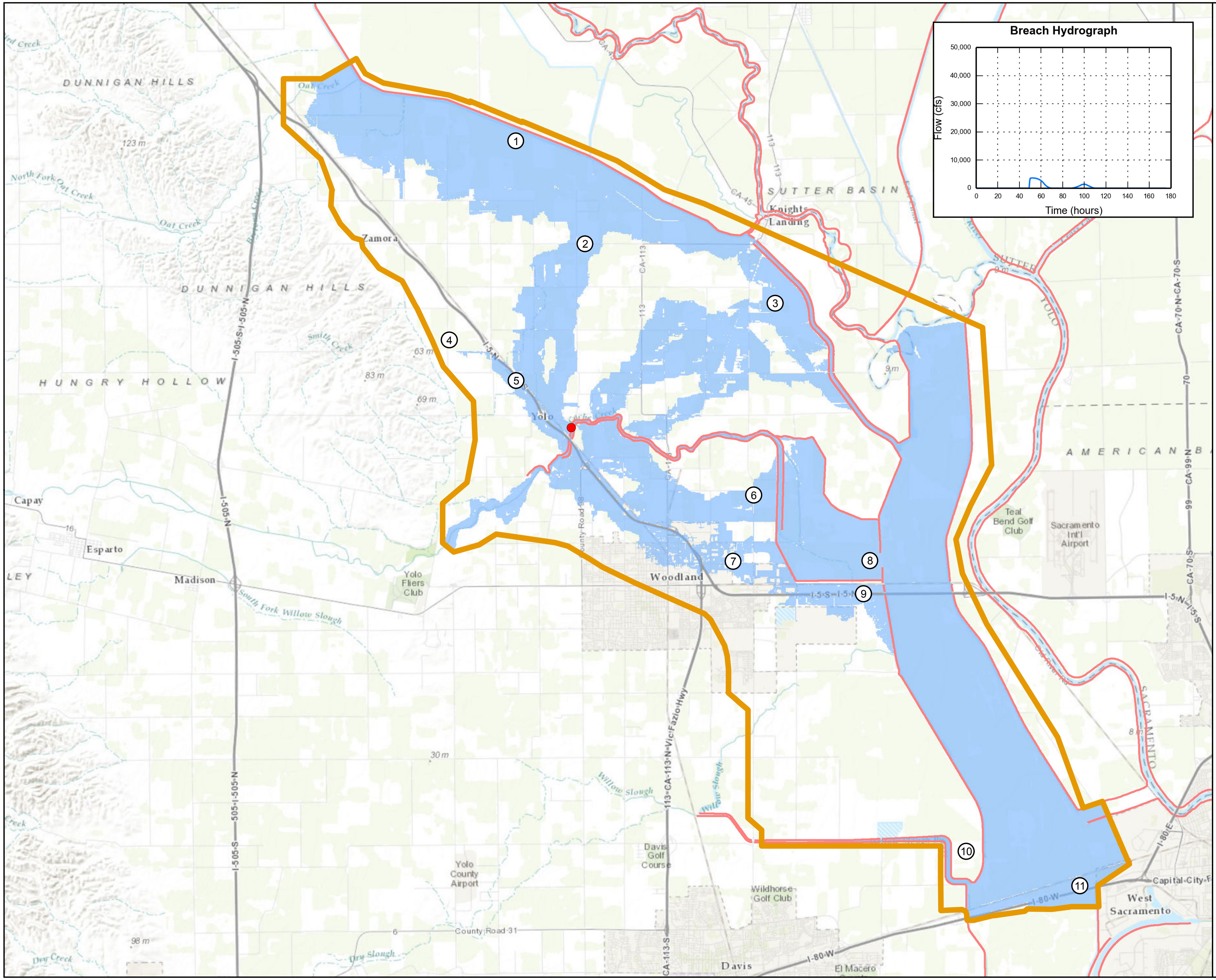
WOODLAND
City of Trees
CALIFORNIA

BREACH WIDTH UNCERTAINTY ANALYSIS
FLOODPLAIN EXTENTS
2% ACE
INDEX POINT 3 BREACH NO ADJUSTMENT

WOOD RODGERS
DEVELOPING INNOVATIVE DESIGN SOLUTIONS

J:\Jobs\8303\8303.020\GIS\Tasks\Milestone_2_Maps\3_6-7_Breach_Sim_and_Uncert_TM\Appendix_A\Fig_3_050_YR_FP_Extents_INDEX_POINT_3_BREACH_NO_ADJUSTMENT.mxd 3/8/2015 2:23:54 PM cmilligan

September 2019



TUFLOW Model Domain

State Plan of Flood Control Levees

⑧ Reporting Locations

● Index Point

🟦 Floodplain Extents

Sources:
1. Cache Creek hydrology based upon the "Central Valley Hydrology Study - Cache Creek Watershed Hydrologic Analysis," developed by U.S. Army Corps of Engineers, Sacramento District, 2012. Supplemental inflow data for Knights Landing Ridge Cut, Yolo Bypass, and Sacramento Bypass provided in .dss file format by the USACE Sacramento District April 2014.
2. California Department of Water Resources, CVFED Program LiDAR
3. Esri Online Imagery sources: Esri, DeLorme, NAVTEQ, Tom Tom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community.

NORTH

0 6,000 12,000
Feet

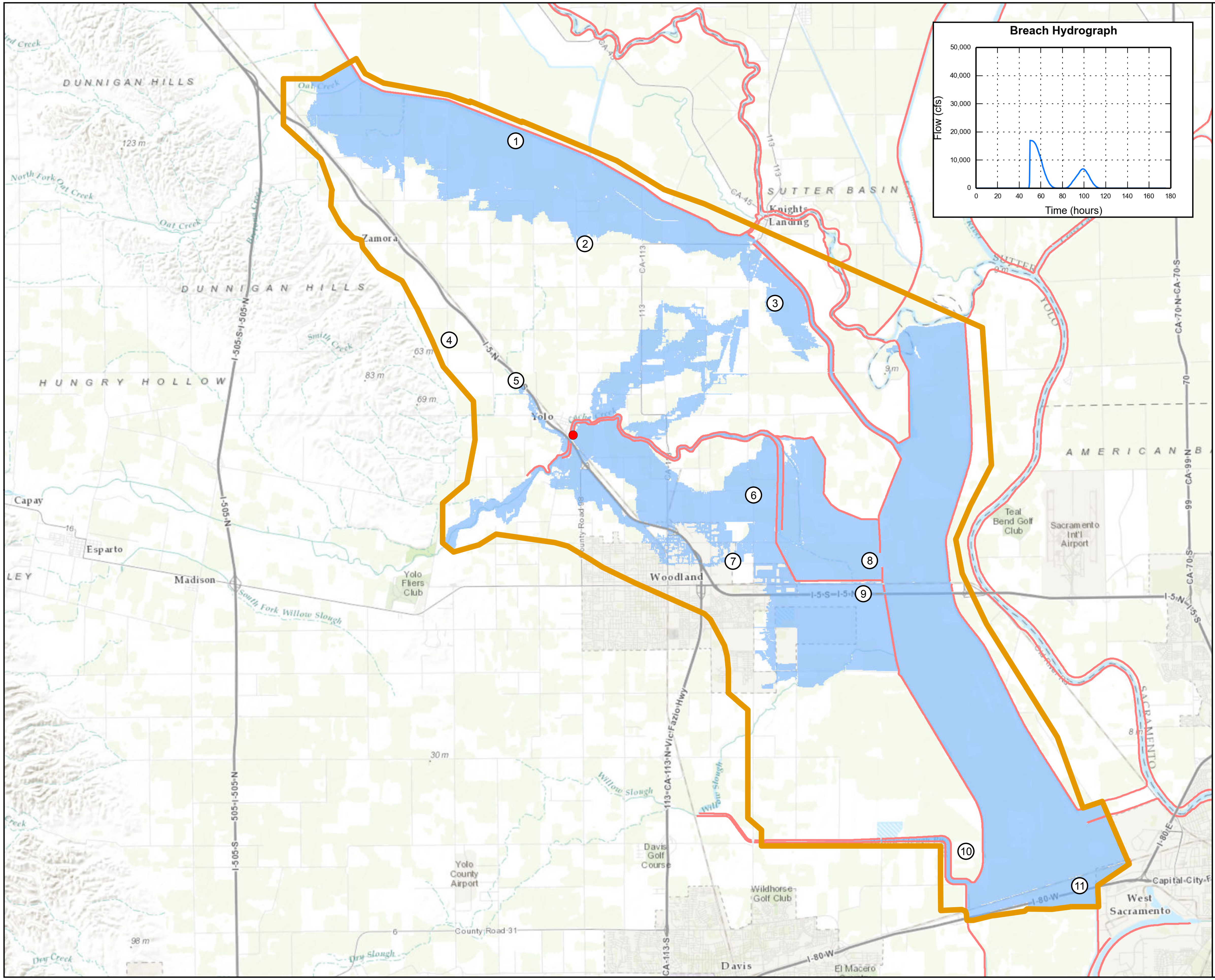
WOODLAND
City of Trees
CALIFORNIA

BREACH WIDTH UNCERTAINTY ANALYSIS
FLOODPLAIN EXTENTS
2% ACE
INDEX POINT 4 BREACH NO ADJUSTMENT

WOOD RODGERS
DEVELOPING INNOVATIVE DESIGN SOLUTIONS

J:\Jobs\8303\8303.020\GIS\Tasks\Milestone_2_Maps\3_6-7_Breach_Sim_and_Uncert_TM\Appendix_A\Fig_9_050_YR_FP_Extents_INDEX_POINT_4_BREACH_NO_ADJUSTMENT.mxd 3/8/2015 2:24:05 PM cmilligan

September 2019



TUFLOW Model Domain

State Plan of Flood Control Levees

⑧ Reporting Locations

● Index Point

🟦 Floodplain Extents

Sources:
1. Cache Creek hydrology based upon the "Central Valley Hydrology Study - Cache Creek Watershed Hydrologic Analysis," developed by U.S. Army Corps of Engineers, Sacramento District, 2012. Supplemental inflow data for Knights Landing Ridge Cut, Yolo Bypass, and Sacramento Bypass provided in .dss file format by the USACE Sacramento District April 2014.
2. California Department of Water Resources, CVFED Program LiDAR
3. Esri Online Imagery sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community.

NORTH

0 6,000 12,000
Feet

WOODLAND
City of Trees
CALIFORNIA

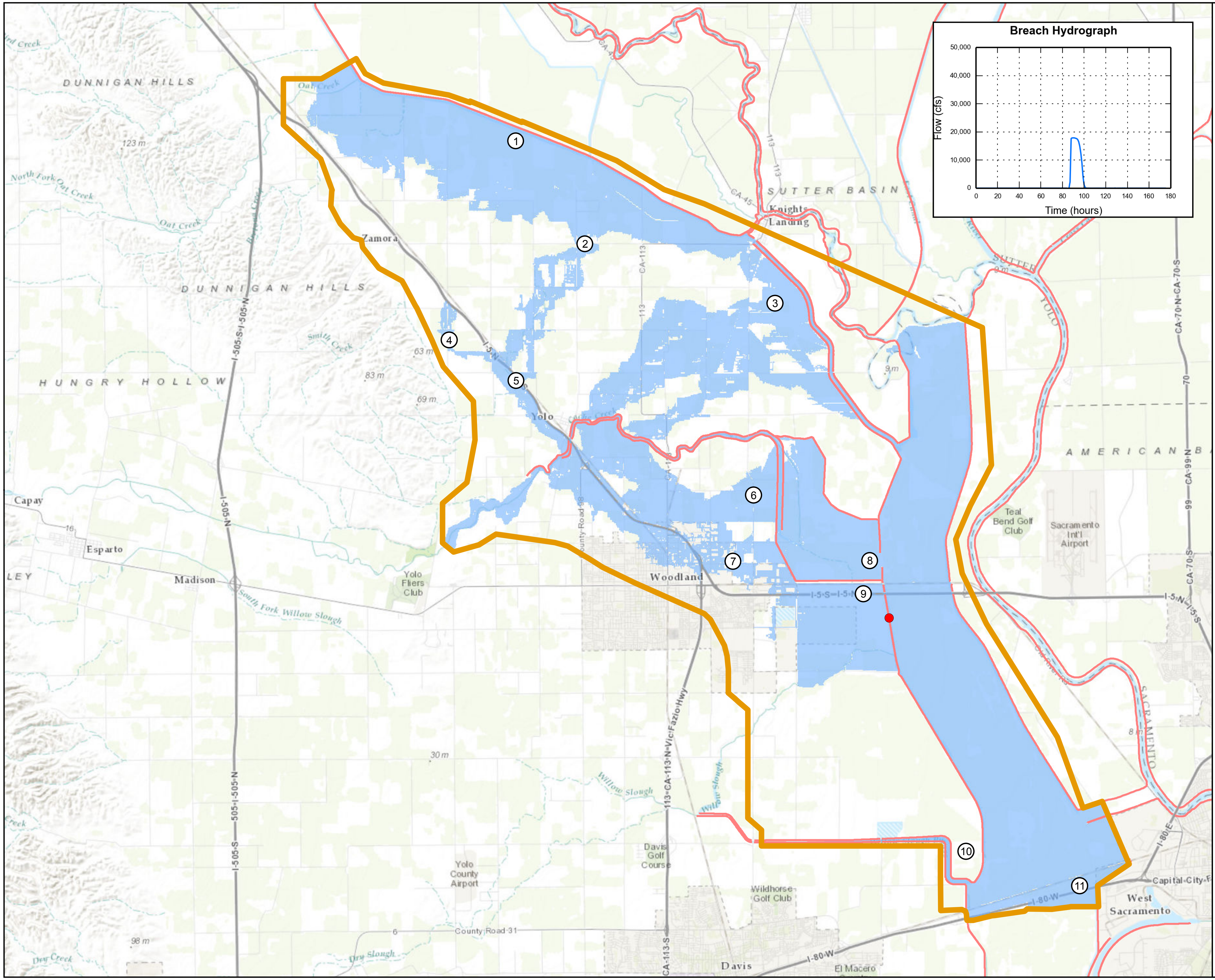
BREACH WIDTH UNCERTAINTY ANALYSIS
FLOODPLAIN EXTENTS
2% ACE
INDEX POINT 5 BREACH NO ADJUSTMENT

WOOD RODGERS
DEVELOPING INNOVATIVE DESIGN SOLUTIONS

J:\Jobs\8303\8303.020\GIS\Tasks\Milestone_2_Maps\3_6-7_Breach_Sim_and_Uncert_TM\Appendix_A\Fig_15_050_YR_FP_Extents_INDEX_POINT_5_BREACH_NO_ADJUSTMENT.mxd 3/8/2015 2:24:16 PM cmilligan

September 2019

PLATE 19



TUFLOW Model Domain

State Plan of Flood Control Levees

⑧ Reporting Locations

● Index Point

Floodplain Extents

Sources:

1. Cache Creek hydrology based upon the "Central Valley Hydrology Study - Cache Creek Watershed Hydrologic Analysis," developed by U.S. Army Corps of Engineers, Sacramento District, 2012. Supplemental inflow data for Knights Landing Ridge Cut, Yolo Bypass, and Sacramento Bypass provided in .dss file format by the USACE Sacramento District April 2014.
2. California Department of Water Resources, CVFED Program LiDAR
3. Esri Online Imagery sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community.

NORTH

0 6,000 12,000

Feet

WOODLAND

City of Trees

CALIFORNIA

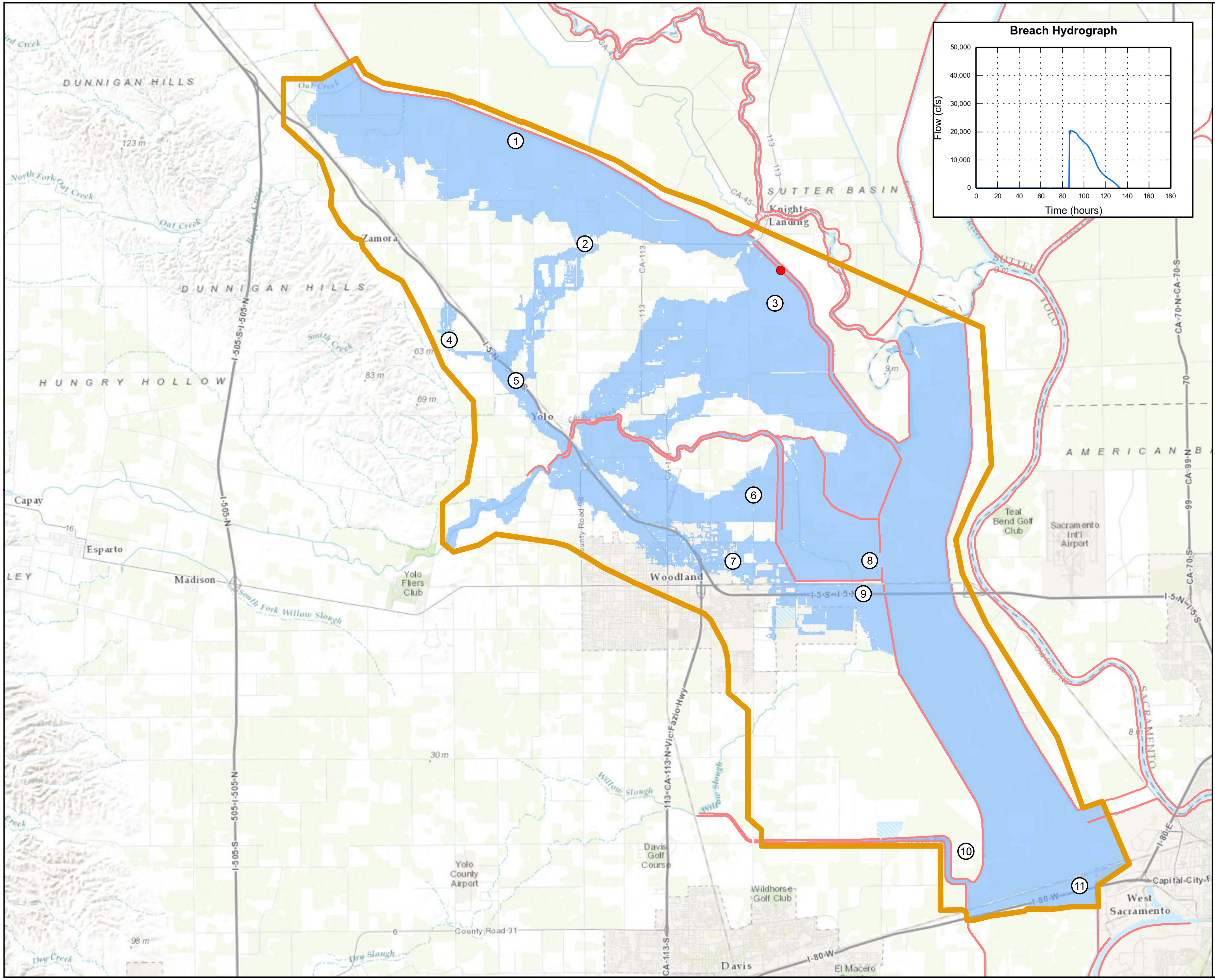
BREACH WIDTH UNCERTAINTY ANALYSIS
FLOODPLAIN EXTENTS
2% ACE
INDEX POINT 6 BREACH NO ADJUSTMENT

WOOD RODGERS

DEVELOPING INNOVATIVE DESIGN SOLUTIONS

J:\Jobs\8303\8303.020\GIS\Tasks\Milestone_2_Maps\3_6-7_Breach_Sim_and_Uncert_TM\Appendix_A\Fig_23_050_YR_FP_Extents_INDEX_POINT_6_BREACH_NO_ADJUSTMENT.mxd 3/8/2015 2:24:26 PM cmilligan

September 2019



▭ TUFLOW Model Domain

— State Plan of Flood Control Levees

⑧ Reporting Locations

● Index Point

🟦 Floodplain Extents

Sources:
1. Cache Creek hydrology based upon the "Central Valley Hydrology Study - Cache Creek Watershed Hydrologic Analysis," developed by U.S. Army Corps of Engineers, Sacramento District, 2012. Supplemental inflow data for Knights Landing Ridge Cut, Yolo Bypass, and Sacramento Bypass provided in .dss file format by the USACE Sacramento District April 2014.
2. California Department of Water Resources, CVFED Program LiDAR
3. Esri Online Imagery sources: Esri, DeLorme, NAVTEQ, Tom Tom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community.

NORTH

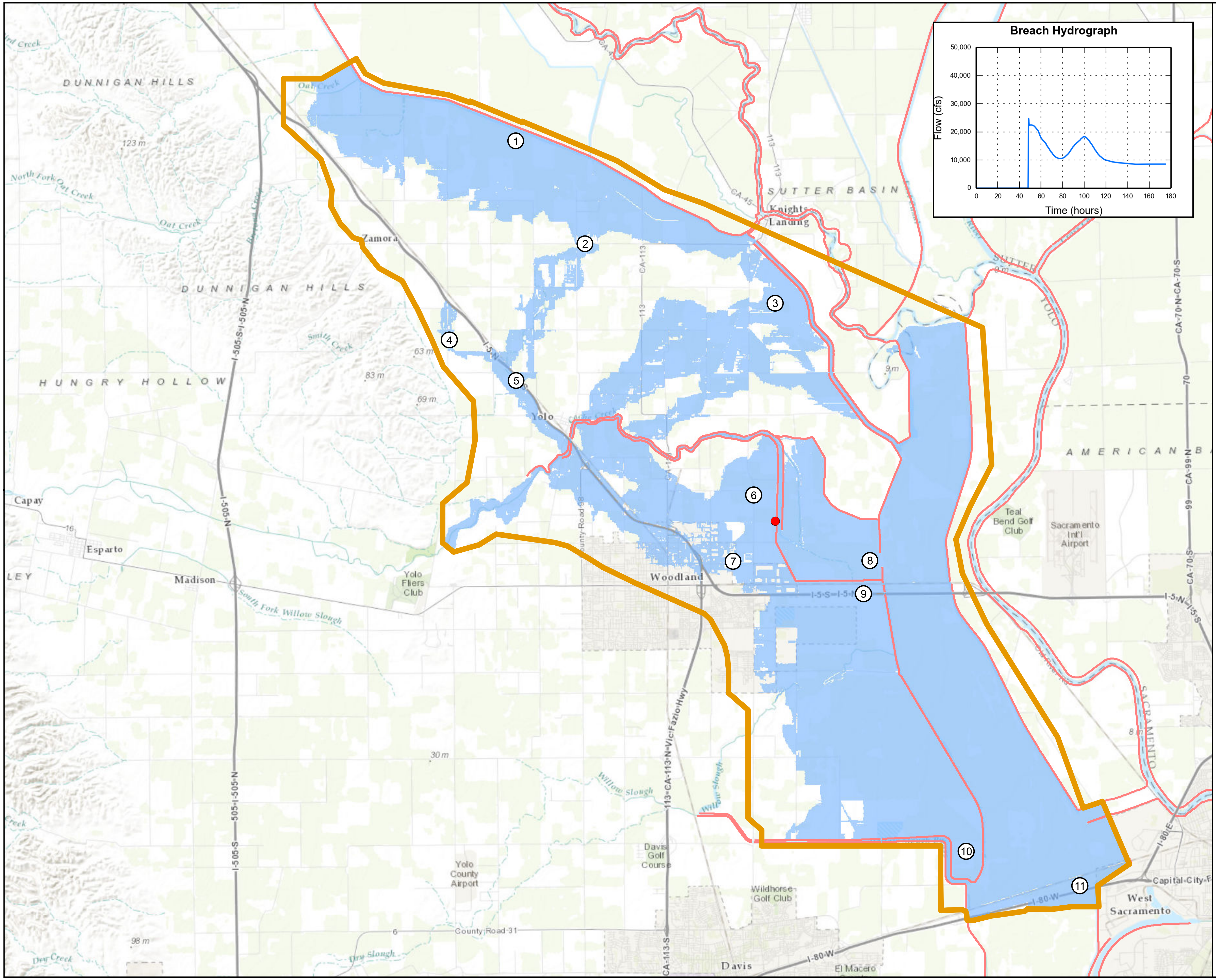
0 6,000 12,000
Feet

BREACH WIDTH UNCERTAINTY ANALYSIS
FLOODPLAIN EXTENTS
2% ACE
INDEX POINT 7 BREACH NO ADJUSTMENT

WOOD RODGERS
DEVELOPING INNOVATIVE DESIGN SOLUTIONS

J:\Jobs\8303\8303.020\GIS\Tasks\Milestone_2_Maps\3_6-7_Breach_Sim_and_Uncert_TM\Appendix_A\Fig_31_050_YR_FP_Extents_INDEX_POINT_7_BREACH_NO_ADJUSTMENT.mxd 3/8/2015 2:24:37 PM cmilligan

September 2019



TUFLOW Model Domain

State Plan of Flood Control Levees

⑧ Reporting Locations

● Index Point

Floodplain Extents

Sources:
1. Cache Creek hydrology based upon the "Central Valley Hydrology Study - Cache Creek Watershed Hydrologic Analysis," developed by U.S. Army Corps of Engineers, Sacramento District, 2012. Supplemental inflow data for Knights Landing Ridge Cut, Yolo Bypass, and Sacramento Bypass provided in .dss file format by the USACE Sacramento District April 2014.
2. California Department of Water Resources, CVFED Program LiDAR
3. Esri Online Imagery sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community.

NORTH

0 6,000 12,000
Feet

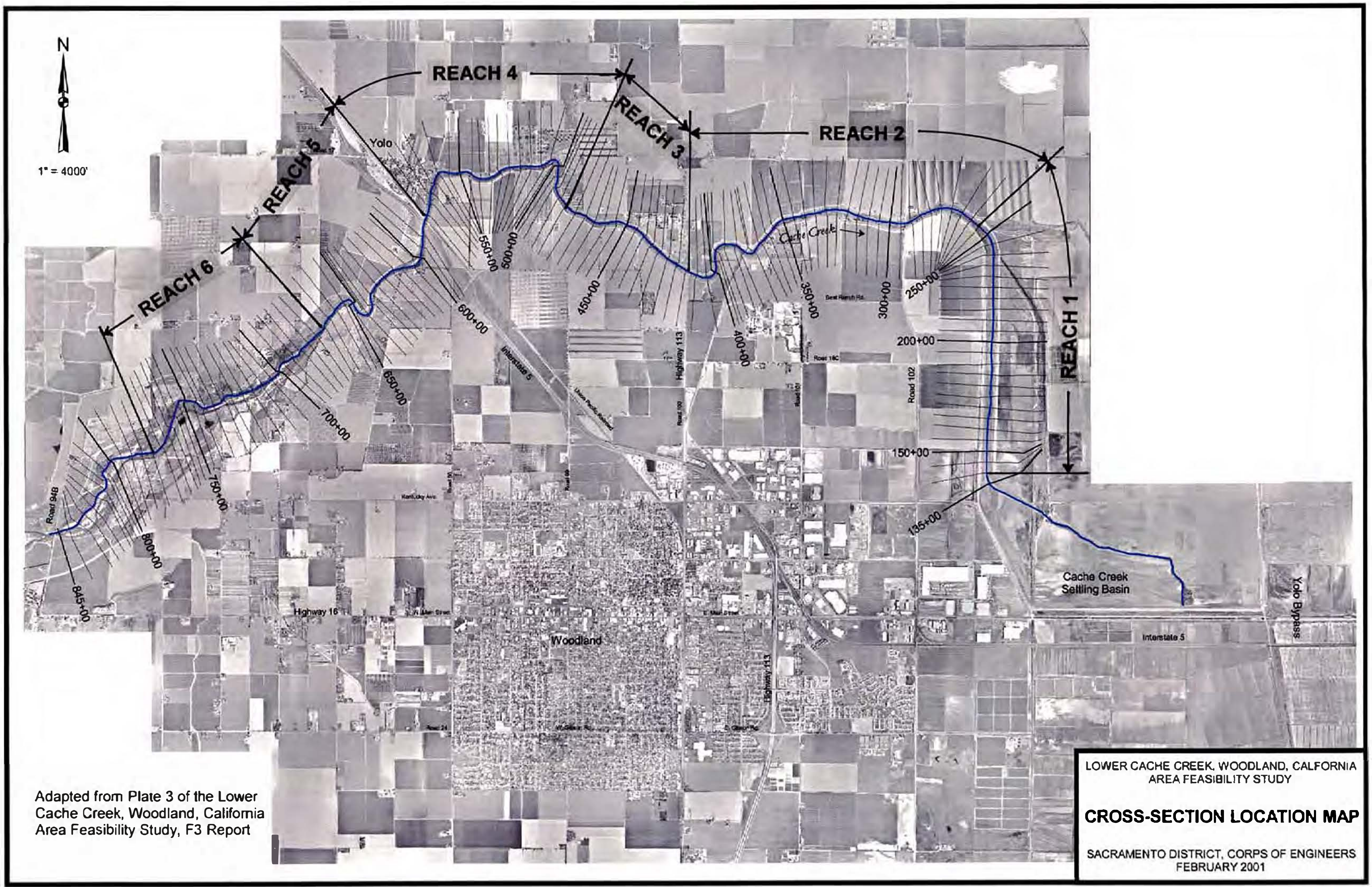
WOODLAND
City of Trees
CALIFORNIA

BREACH WIDTH UNCERTAINTY ANALYSIS
FLOODPLAIN EXTENTS
2% ACE
INDEX POINT 8 BREACH NO ADJUSTMENT

WOOD RODGERS
DEVELOPING INNOVATIVE DESIGN SOLUTIONS

J:\Jobs\8303\8303.020\GIS\Tasks\Milestone_2_Maps\3_6-7_Breach_Sim_and_Uncert_TM\Appendix_A\Fig_39_050_YR_FP_Extents_INDEX_POINT_8_BREACH_NO_ADJUSTMENT.mxd 3/8/2015 2:24:48 PM cmilligan

September 2019

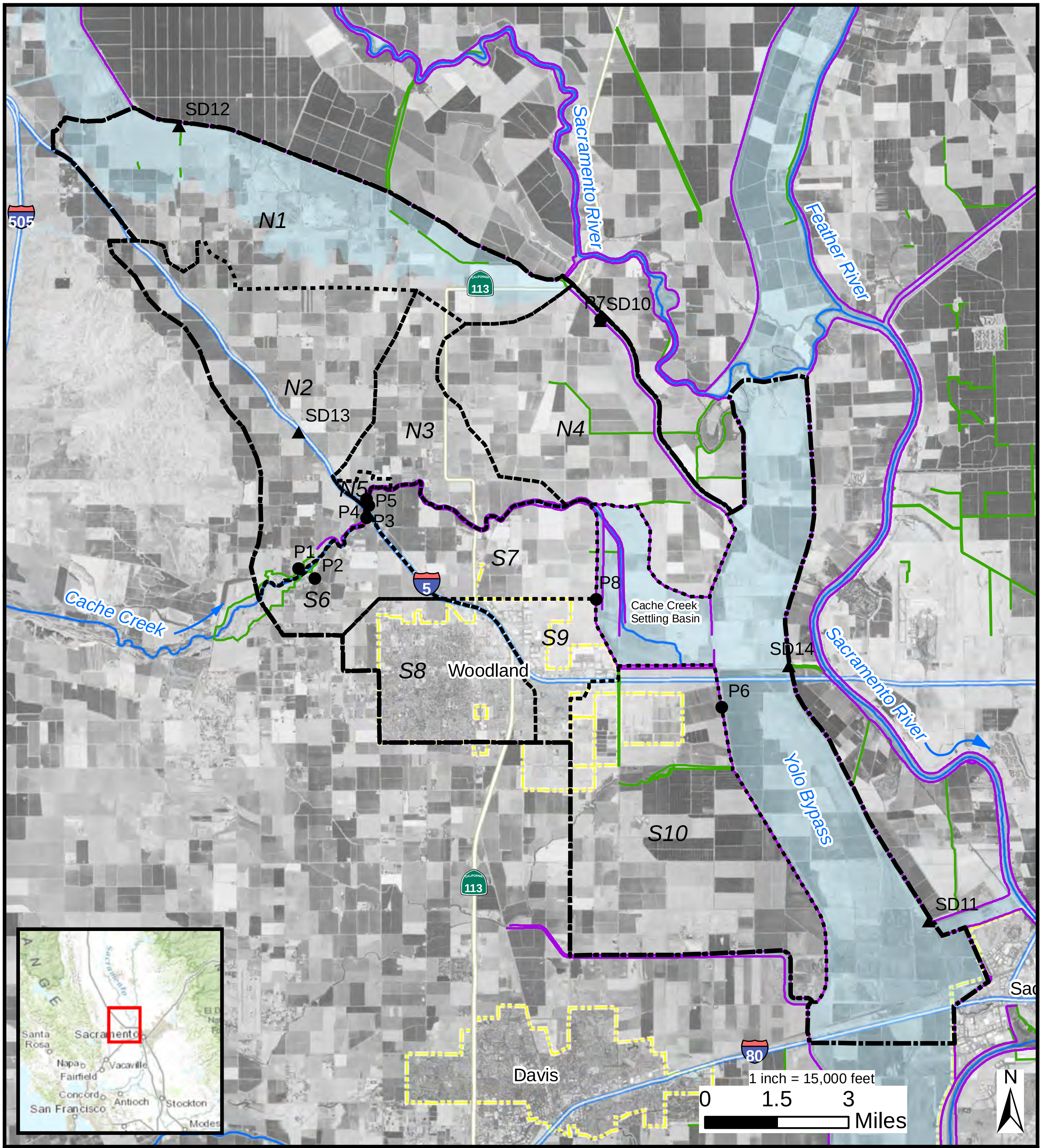


Adapted from Plate 3 of the Lower Cache Creek, Woodland, California Area Feasibility Study, F3 Report

LOWER CACHE CREEK, WOODLAND, CALIFORNIA
AREA FEASIBILITY STUDY

CROSS-SECTION LOCATION MAP

SACRAMENTO DISTRICT, CORPS OF ENGINEERS
FEBRUARY 2001



Legend

▲ Stage-Discharge Index

● Flood Probability Index

Existing Federal Levees

Existing Non Federal Levees

River/Creek

Interstate

Highway

Project Boundary

Economic_Impact_Areas

Designated Floodways

City Boundaries

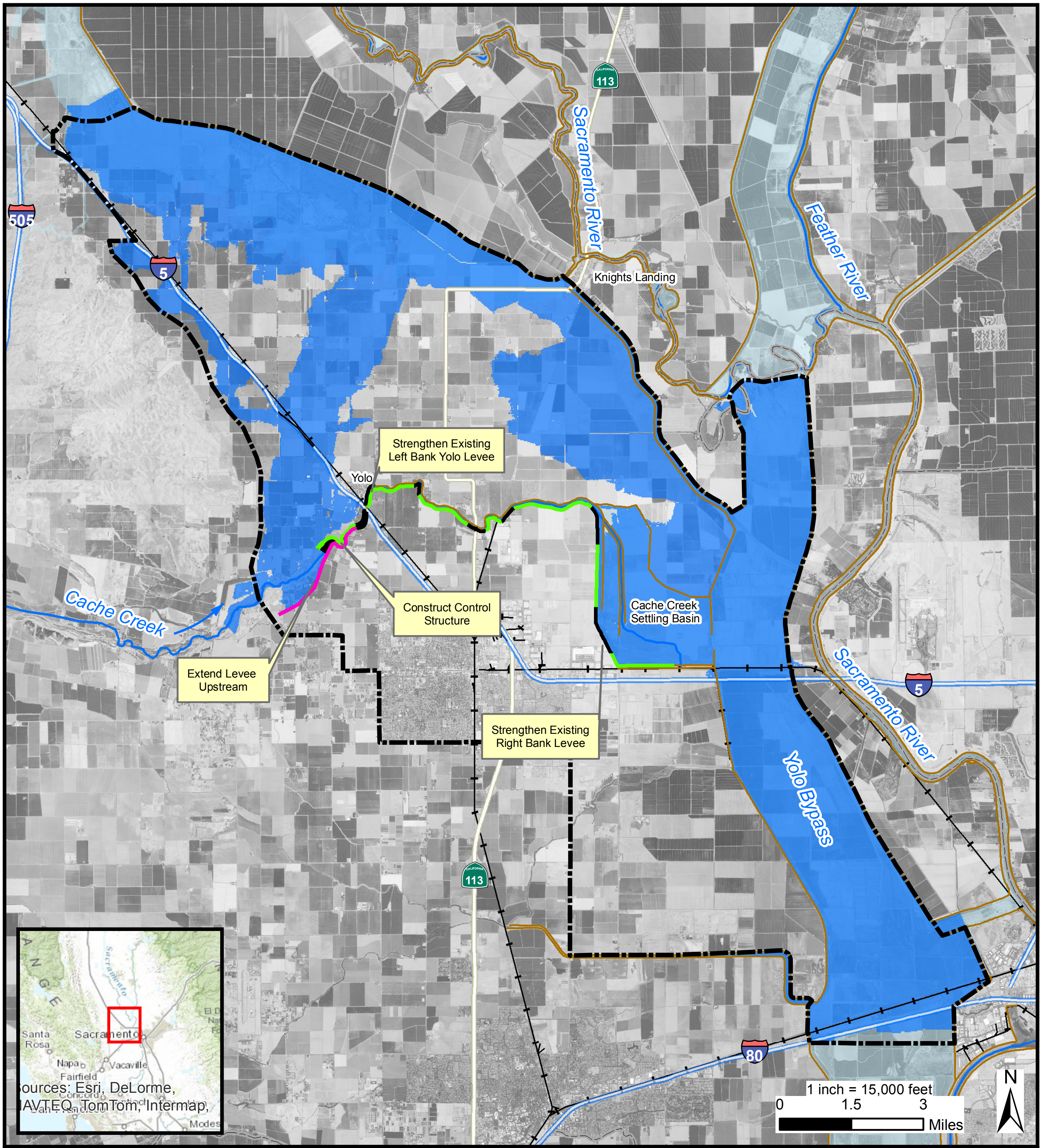
County Boundary

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

LOWER CACHE CREEK ECONOMIC IMPACT AREAS

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



Legend

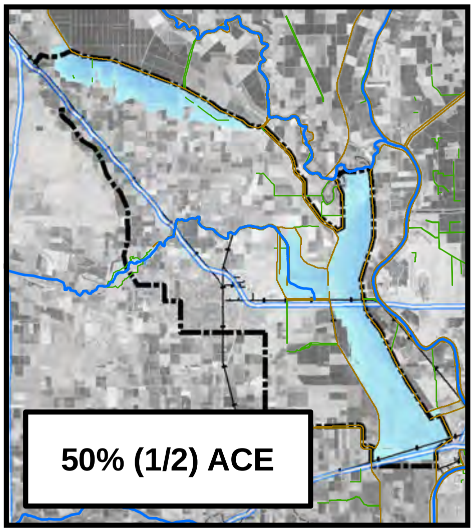
— Existing Federal Levees
— Interstate
— Highway
—+— Railroad
— River/Creek
▭ Project Boundary
▭ County Boundary
▭ Designated Floodways
▭ Floodplain

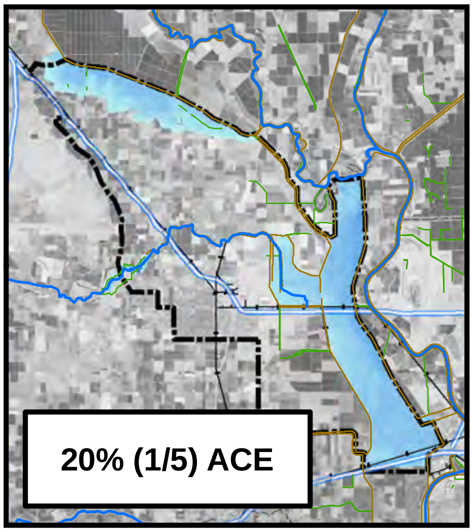
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

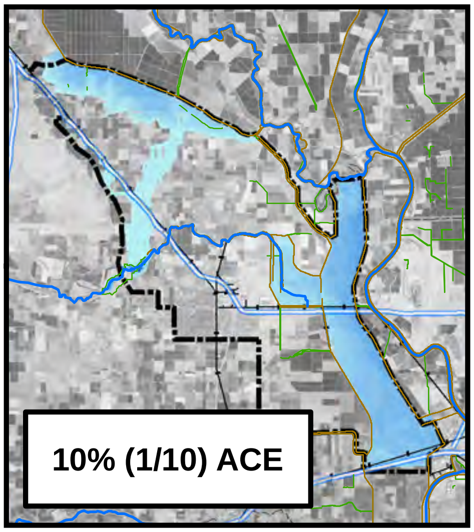
ALTERNATIVE NORTH BYPASS 1A OVERTOPPING ONLY

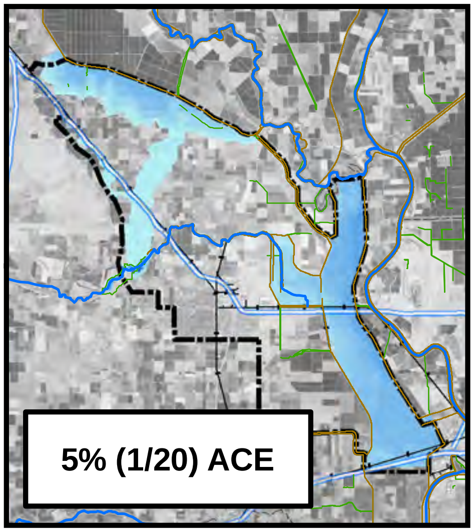
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

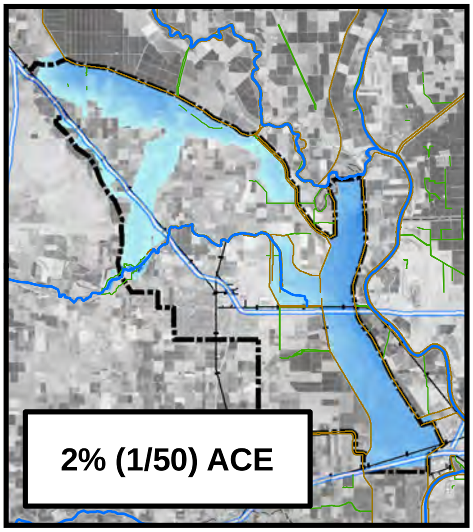
September 2019

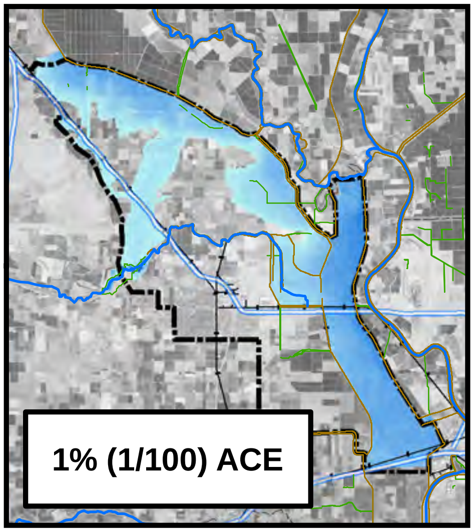

50% (1/2) ACE

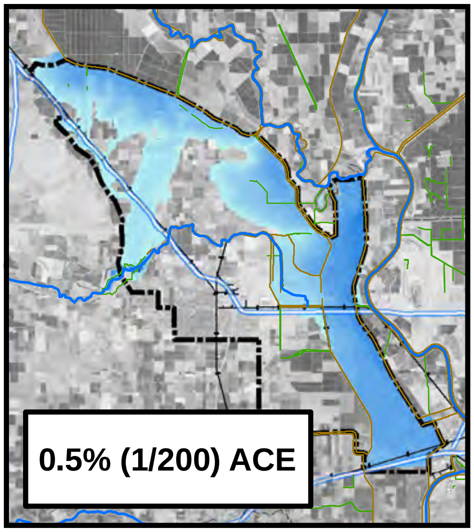

20% (1/5) ACE

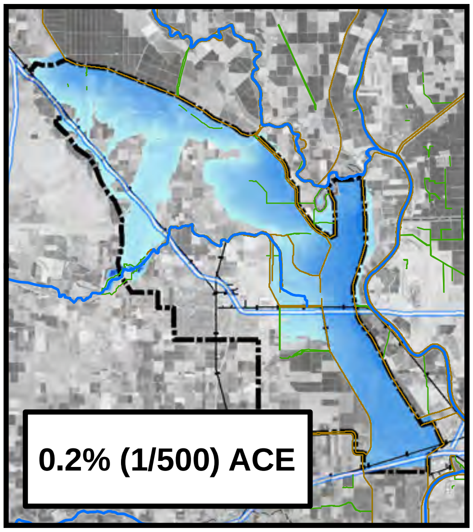

10% (1/10) ACE


5% (1/20) ACE


2% (1/50) ACE


1% (1/100) ACE


0.5% (1/200) ACE


0.2% (1/500) ACE

Depth (FEET)

- ▨ 0 - 2
- ▨ 3 - 4
- ▨ 5 - 6
- ▨ 7 - 8
- ▨ 9 - 10
- ▨ 11 - 12
- ▨ 13 - 14
- ▨ 15 - 16
- ▨ 17 - 18
- ▨ 19 - 20
- ▨ 21 - 22
- ▨ 23 - 24
- ▨ 25 - 26
- ▨ 27 - 28
- ▨ 29 - 30
- ▨ 31 - 32
- ▨ 33 - 34
- ▨ 35 - 36
- ▨ 37 - 38
- ▨ 39 - 40
- ▨ 41 - 42
- ▨ 43 - 44
- ▨ 45 - 46

Legend

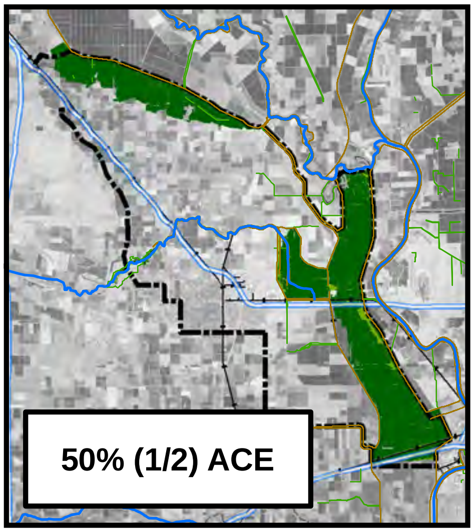
- River/Creek
- Existing Federal Levees
- Existing Non Federal Levees
- Interstate
- Railroad
- Project Boundary

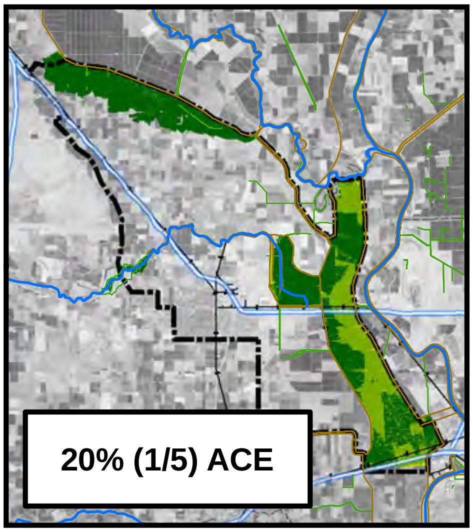
Note: Maps depict overtopping without failure

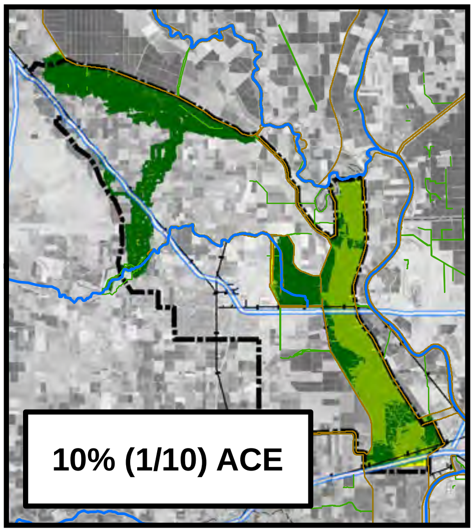
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

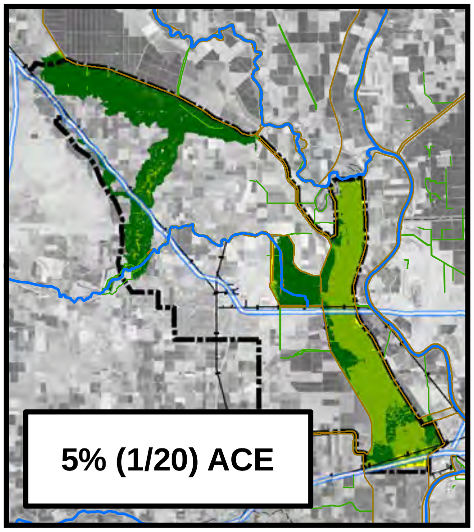
ALTERNATIVE NORTH BYPASS 1A
OVERTOPPING NO FAILURE
INUNDATION

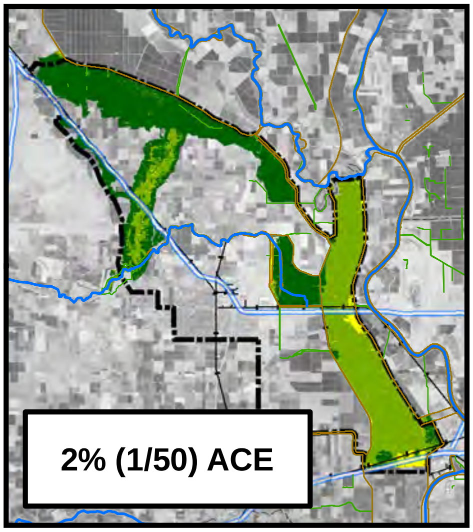
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

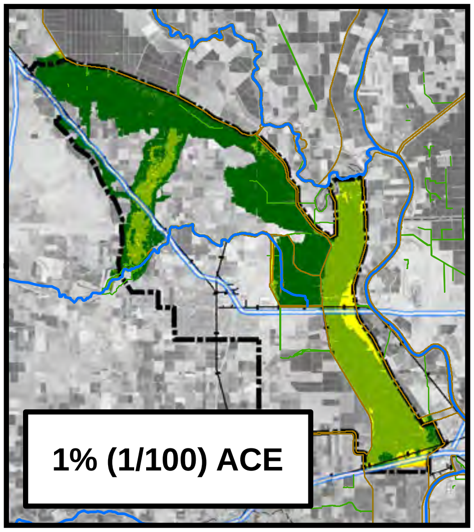


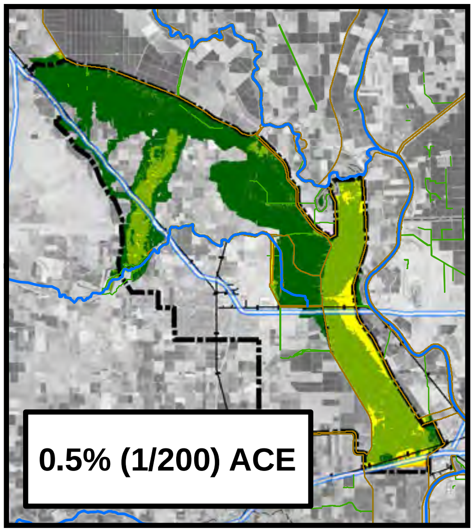


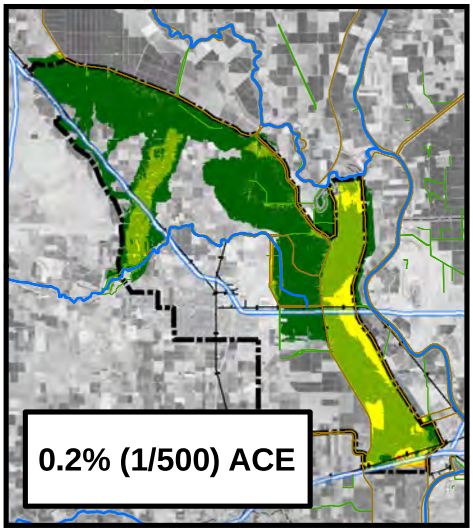












Velocity (Feet/Sec)

- 🟩 0 - 2
- 🟩 3 - 4
- 🟨 5 - 6
- 🟧 7 - 8
- 🟥 8+

Legend

- River/Creek
- Existing Federal Levees
- Existing Non Federal Levees
- Interstate
- Railroad
- Project Boundary

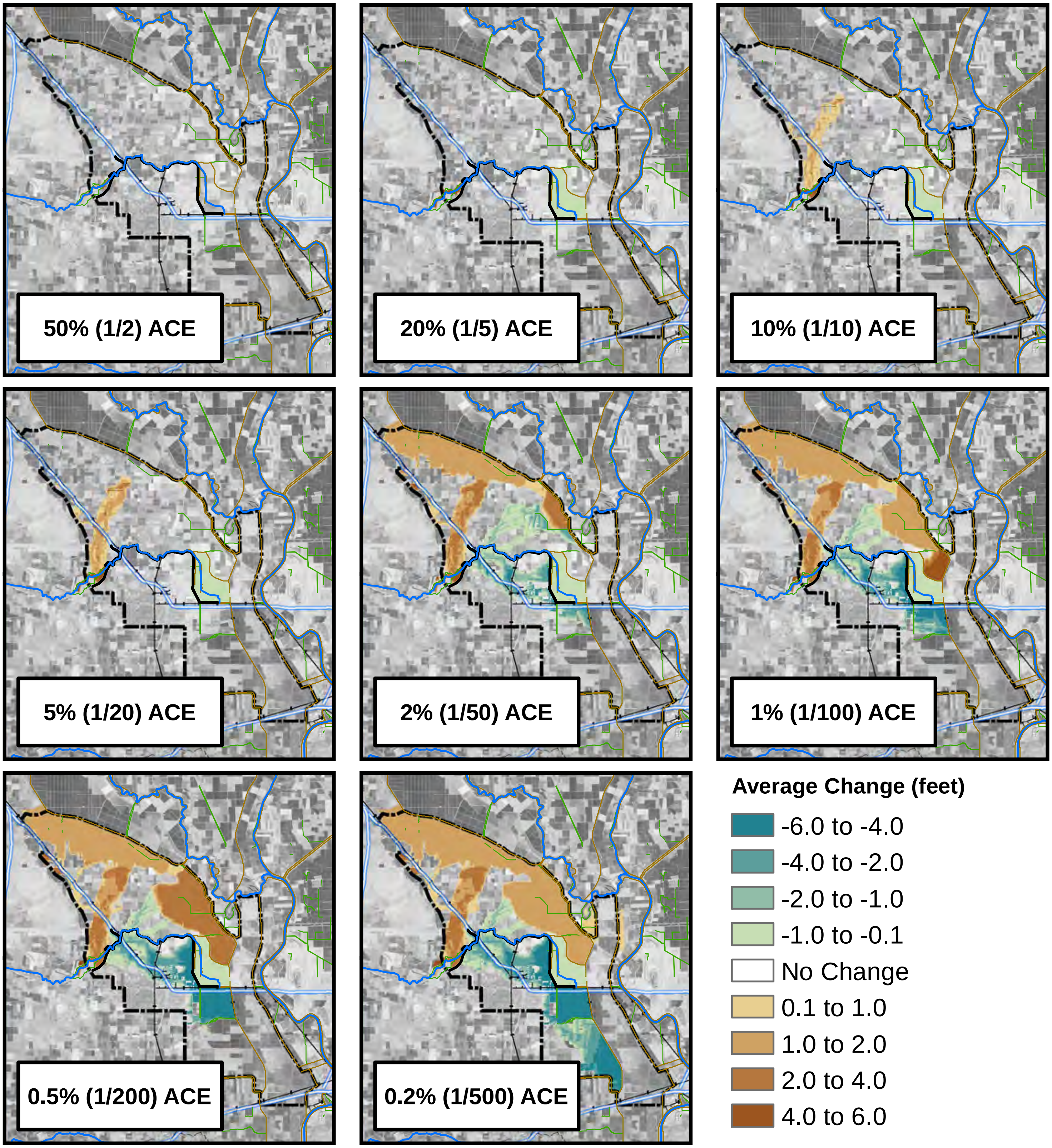
Note: Maps depict overtopping without failure

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE NORTH BYPASS 1A OVERTOPPING NO FAILURE MAX VELOCITY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



Legend

River/Creek

Existing Federal Levees

Existing Non Federal Levees

Interstate

Railroad

Project Boundary

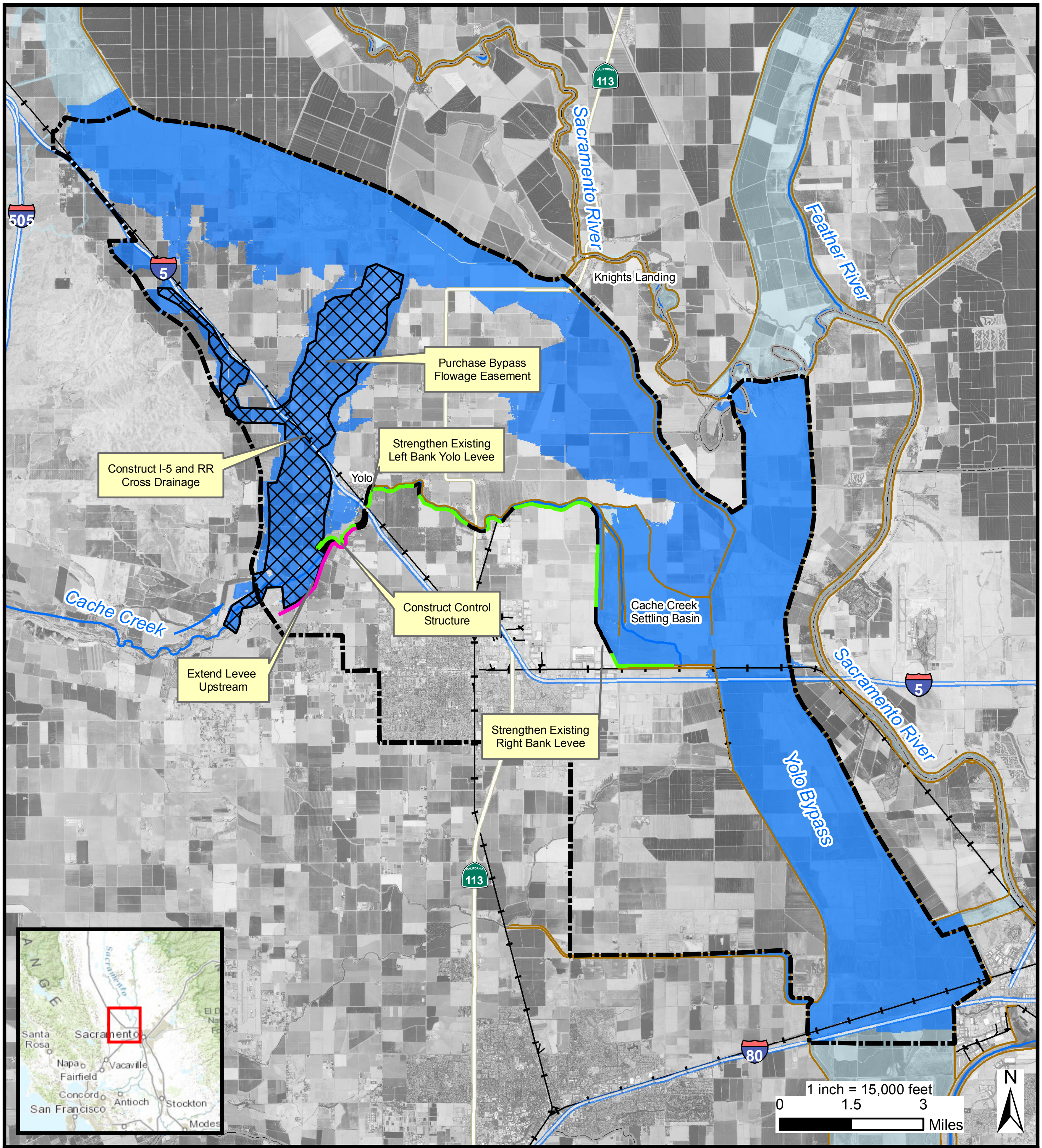
Note: Maps depict overtopping without failure

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE NORTH BYPASS 1A AVERAGE CHANGE IN FLOOD DEPTH

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



Purchase Bypass Flowage Easement

Strengthen Existing Left Bank Yolo Levee

Construct I-5 and RR Cross Drainage

Construct Control Structure

Extend Levee Upstream

Strengthen Existing Right Bank Levee

Legend

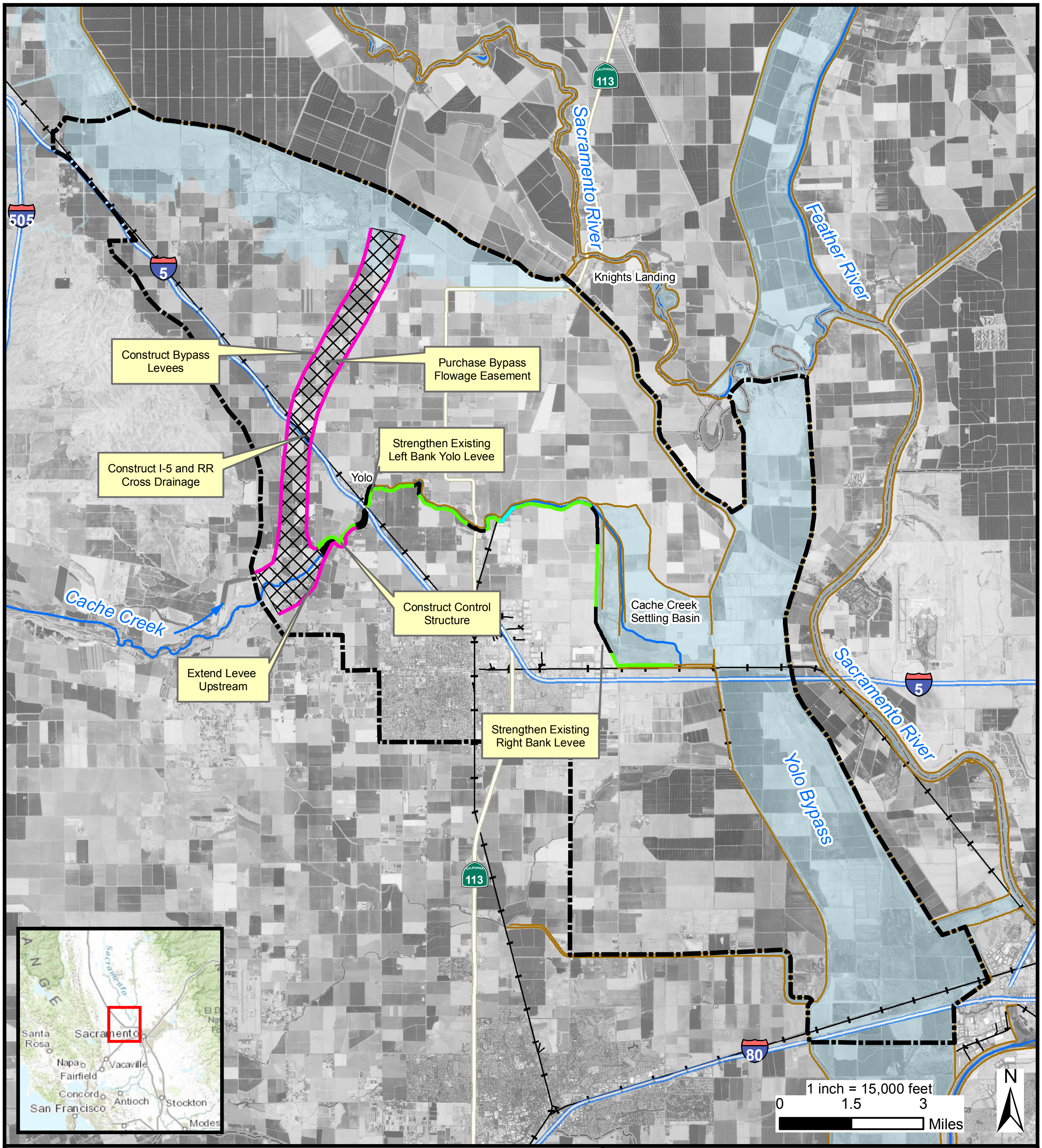
Existing Federal Levees	Designated Floodways
Interstate	Floodplain
Highway	
Railroad	
River/Creek	
County Boundary	
Project Boundary	

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE NORTH BYPASS 1B
OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



Legend

- Existing Federal Levees
- Interstate
- Highway
- Railroad
- River/Creek
- Designated Floodways
- County Boundary
- ▨ Real Estate
- Project Boundary

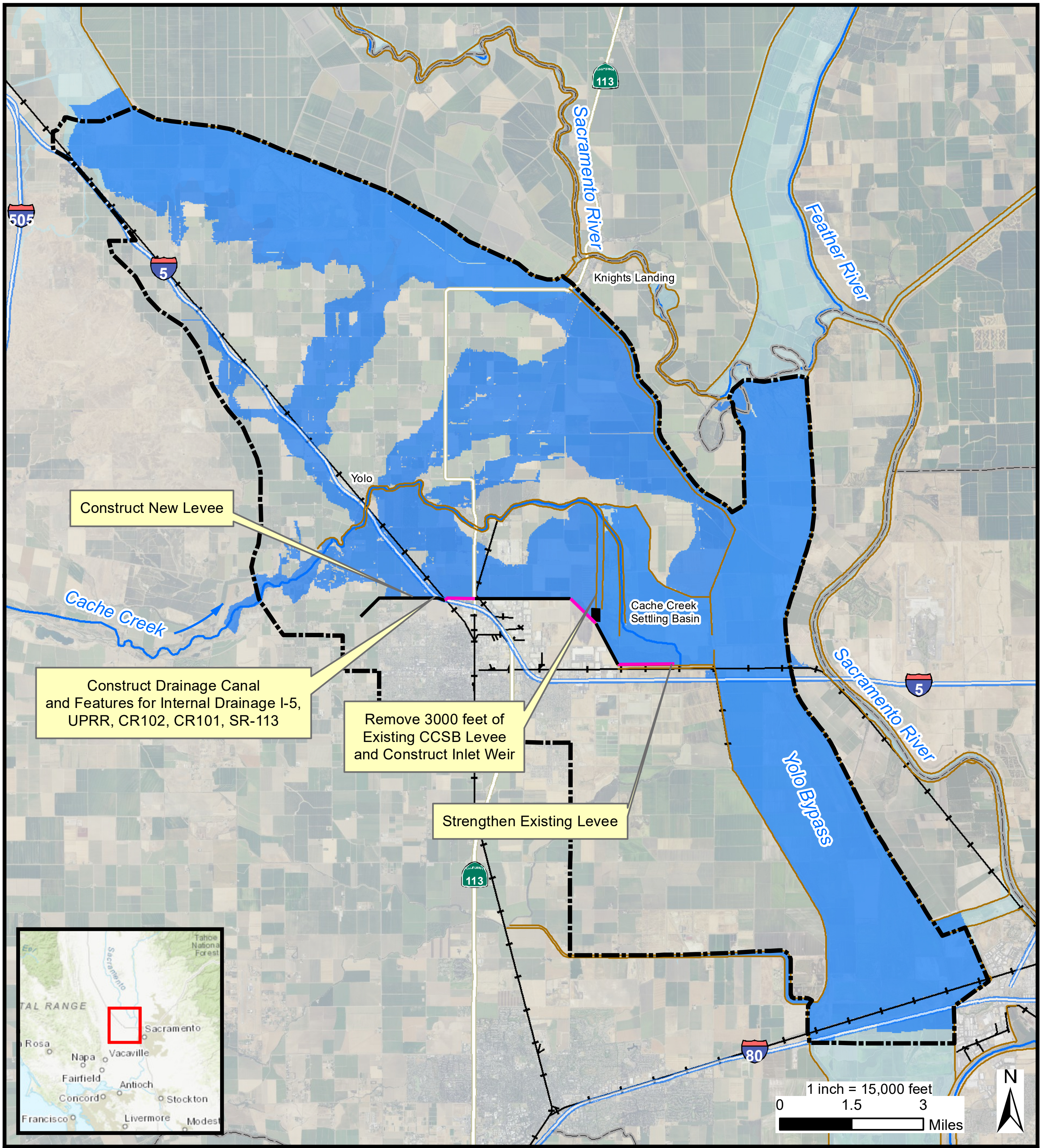
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE NORTH BYPASS 1C
OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019

PLATE 30



Legend

- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- Floodplain
- River/Creek
- Designated Floodways

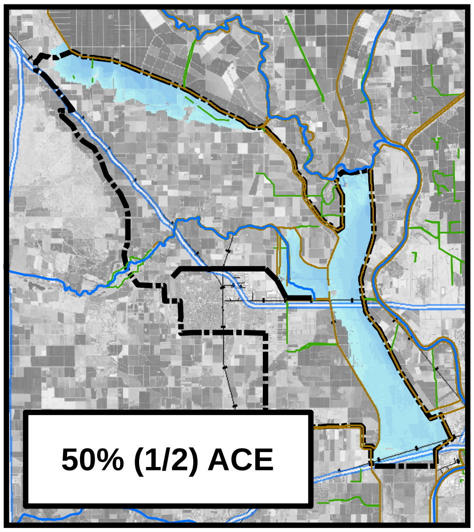
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE SOUTH BYPASS 2A

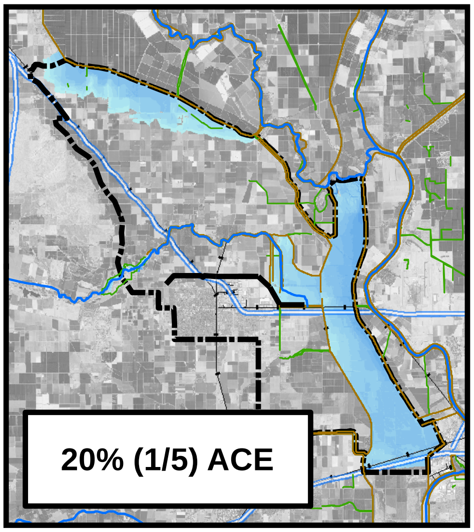
With Inlet Weir

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

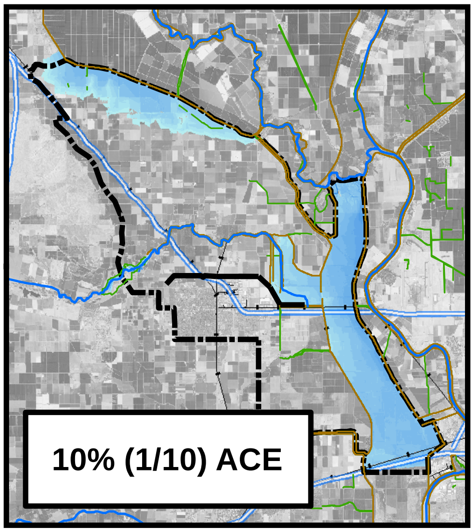
September 2019



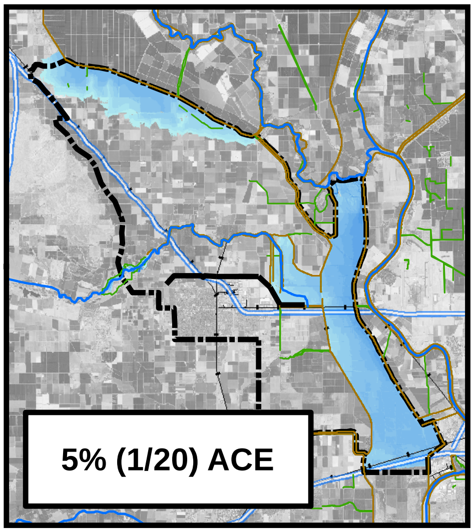
50% (1/2) ACE



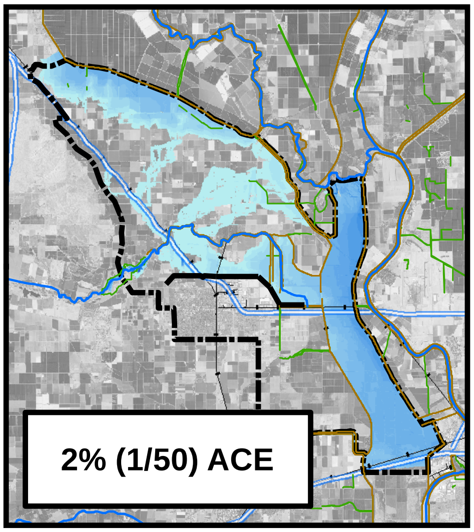
20% (1/5) ACE



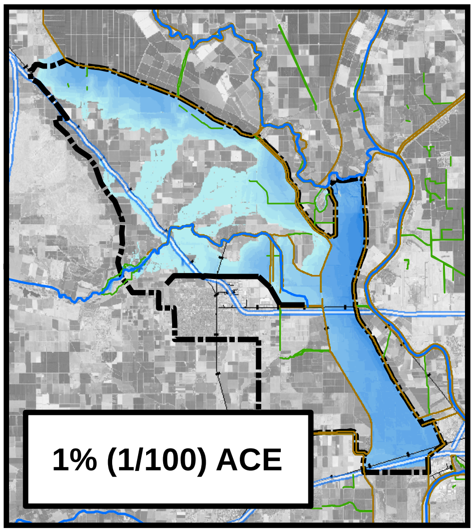
10% (1/10) ACE



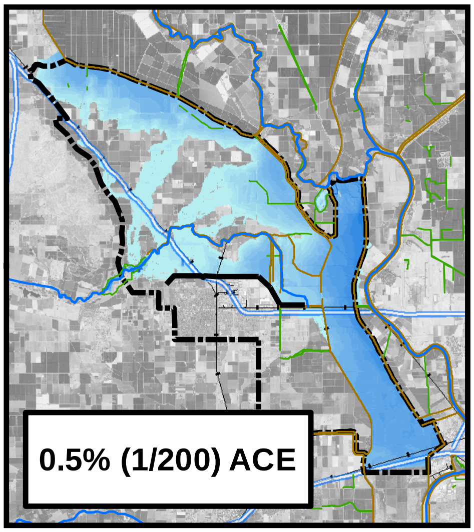
5% (1/20) ACE



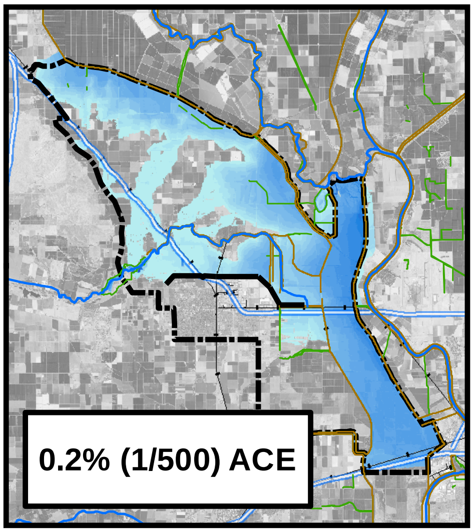
2% (1/50) ACE



1% (1/100) ACE



0.5% (1/200) ACE



0.2% (1/500) ACE

Depth (FEET)

▭	0 - 2	▭	25 - 26
▭	3 - 4	▭	27 - 28
▭	5 - 6	▭	29 - 30
▭	7 - 8	▭	31 - 32
▭	9 - 10	▭	33 - 34
▭	11 - 12	▭	35 - 36
▭	13 - 14	▭	37 - 38
▭	15 - 16	▭	39 - 40
▭	17 - 18	▭	41 - 42
▭	19 - 20	▭	43 - 44
▭	21 - 22	▭	45 - 46
▭	23 - 24		

Legend

- New Levee
- River/Creek
- Existing Federal Levees
- Existing Non Federal Levees
- Project Boundary
- Interstate
- Railroad

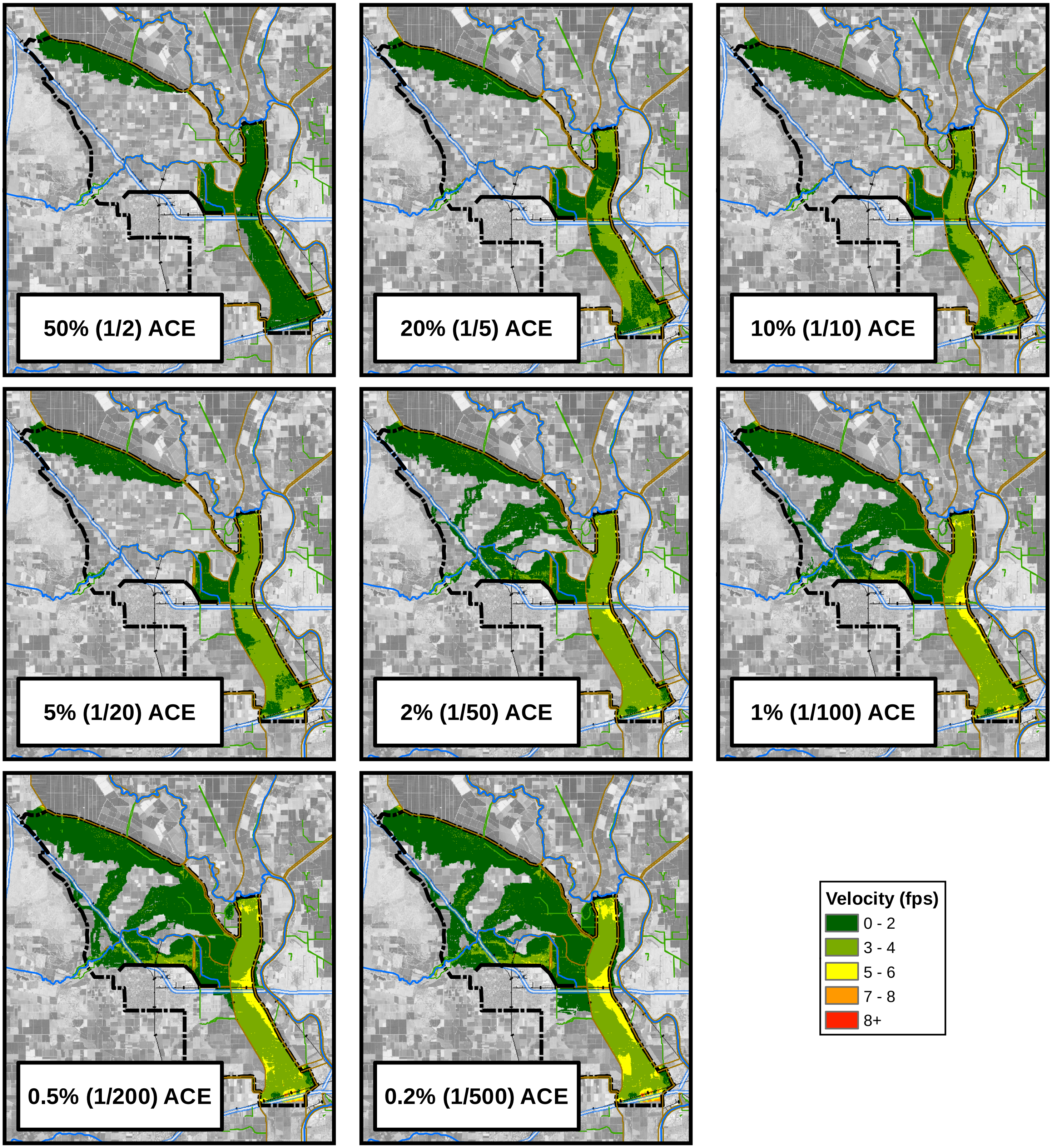
Note: Maps depict overtopping without failure

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE SOUTH BYPASS 2A with INLET WEIR OVERTOPPING NO FAILURE INUNDATION

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

24 SEP 2019



Legend

New Levee

River/Creek

Existing Federal Levees

Existing Non Federal Levees

Project Boundary

Interstate

Railroad

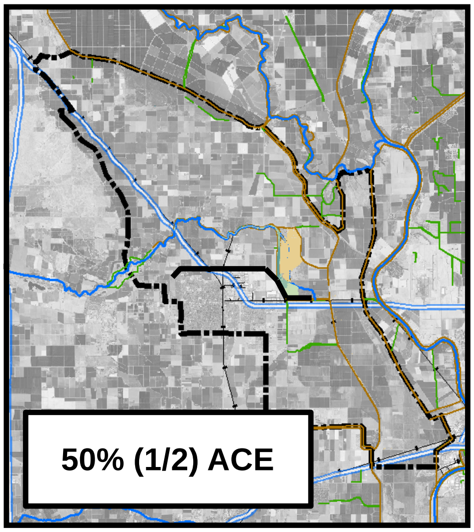
Note: Maps depict overtopping without failure

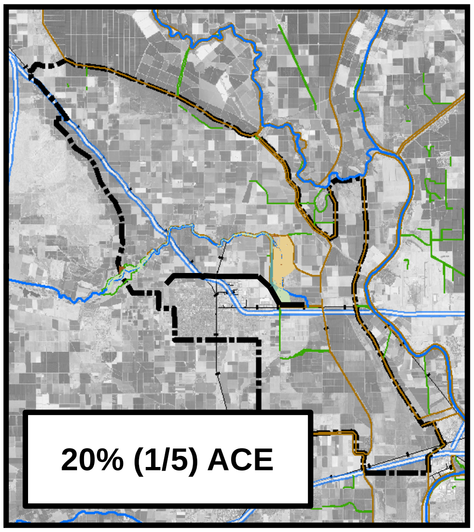
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

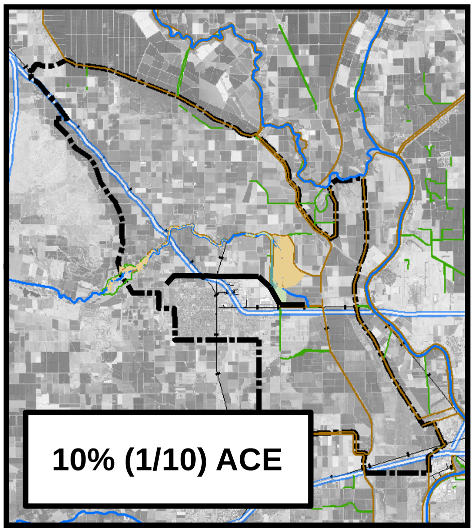
ALTERNATIVE SOUTH BYPASS 2A with INLET WEIR NO FAILURE MAX VELOCITY

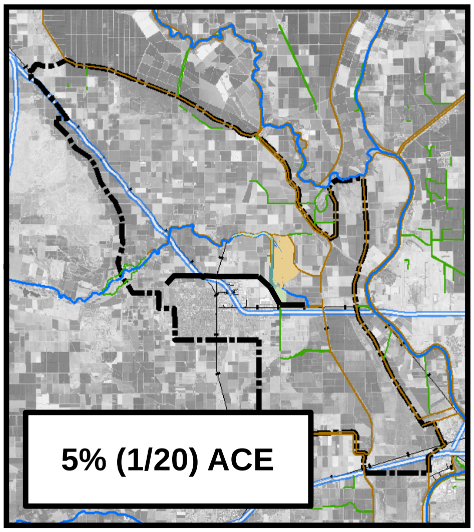
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

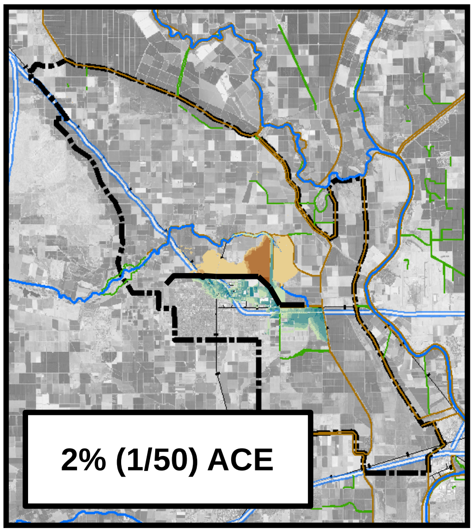
24 SEP 2019

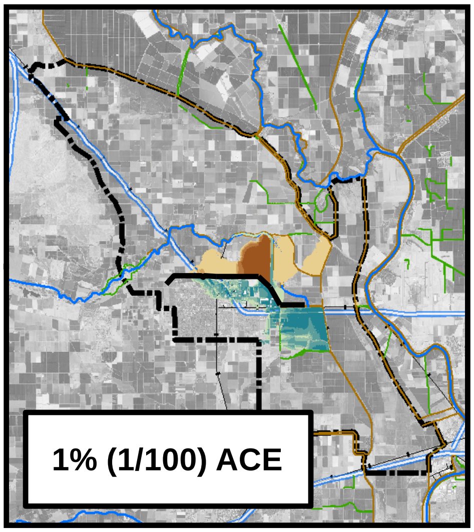

50% (1/2) ACE

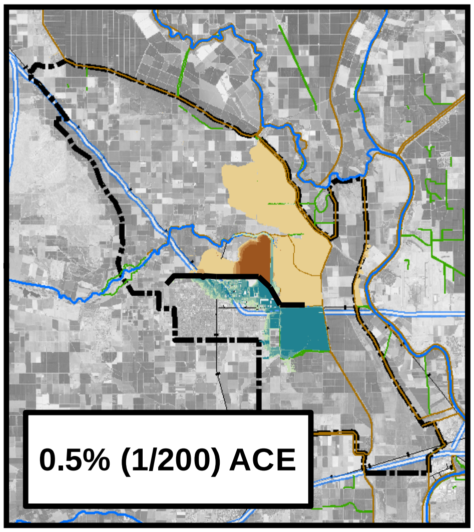

20% (1/5) ACE

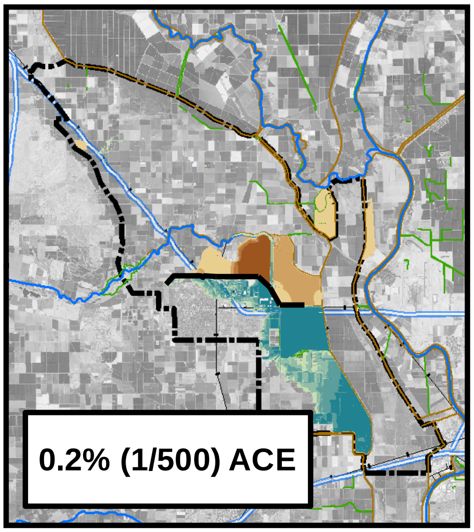

10% (1/10) ACE


5% (1/20) ACE


2% (1/50) ACE


1% (1/100) ACE


0.5% (1/200) ACE


0.2% (1/500) ACE

Avg Change (feet)

🟦	-6.0 to -4.0
🟦	-4.0 to -2.0
🟩	-2.0 to -1.0
🟩	-1.0 to -0.1
☐	No Change
🟨	0.1 to 1.0
🟧	1.0 to 2.0
🟫	2.0 to 4.0
🟫	4.0 to 6.0

Legend

New Levee
River/Creek
Existing Federal Levees
Existing Non Federal Levees
Project Boundary
Interstate
Railroad

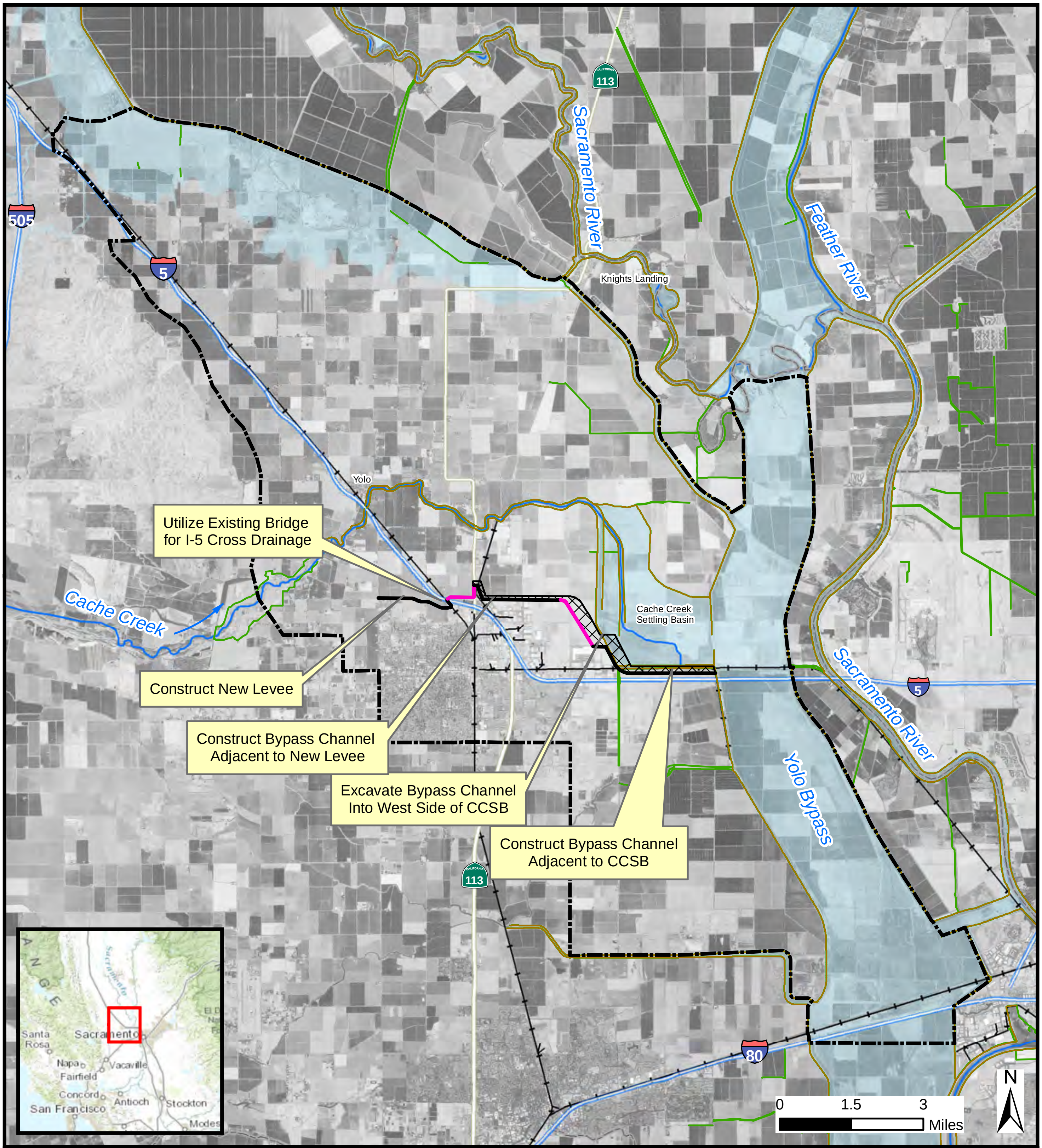
Note: Maps depict overtopping without failure

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE SOUTH BYPASS 2A with INLET WEIR AVERAGE CHANGE IN FLOOD DEPTH

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

24 SEP 2019



Utilize Existing Bridge for I-5 Cross Drainage

Construct New Levee

Construct Bypass Channel Adjacent to New Levee

Excavate Bypass Channel Into West Side of CCSB

Construct Bypass Channel Adjacent to CCSB

Legend

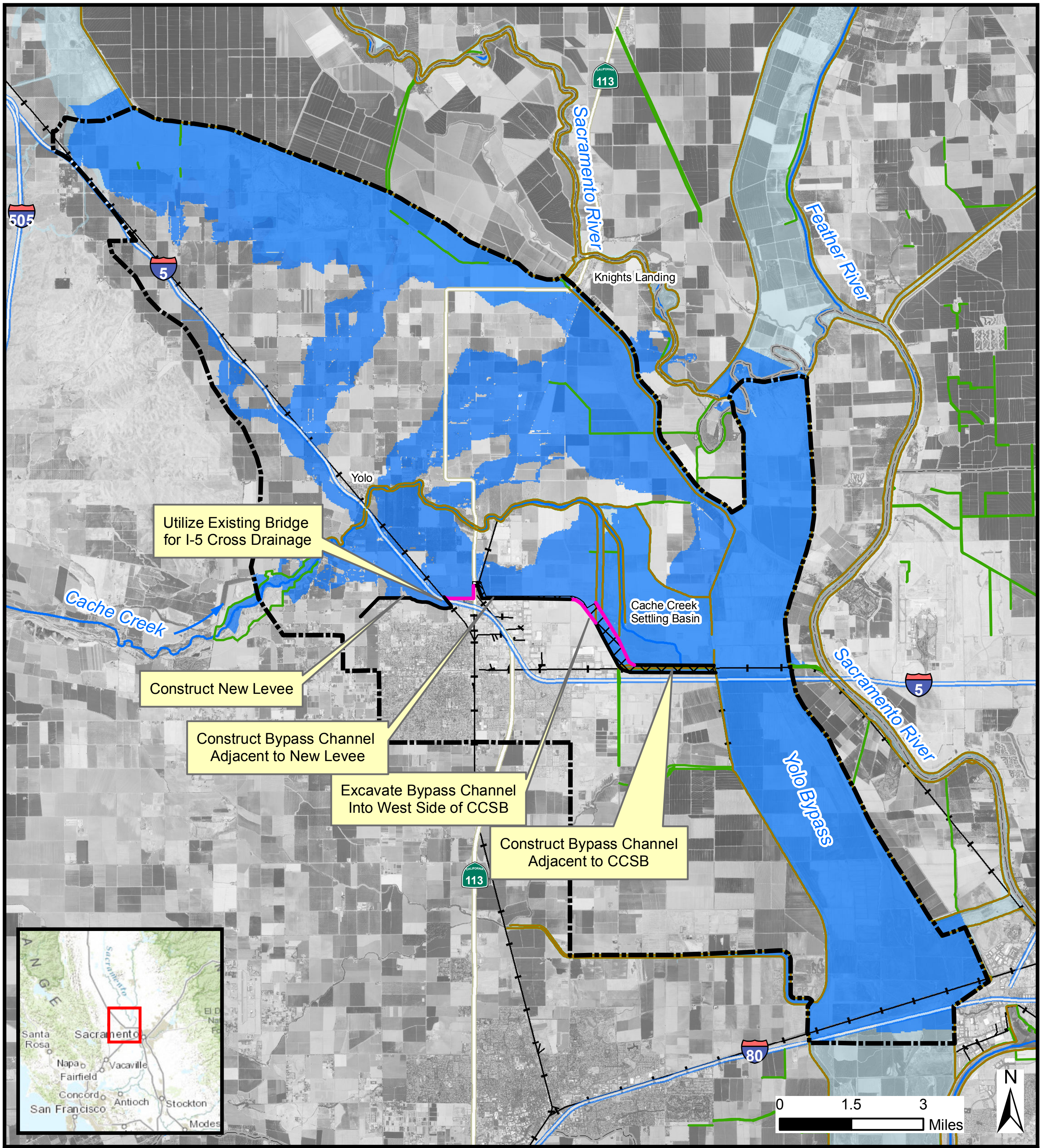
- Existing Federal Levees
- Existing Non Federal Levees
- River/Creek
- Interstate
- Highway
- Railroad
- County Boundary
- Project Boundary
- Designated Floodways

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE SOUTH BYPASS 2B

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



Utilize Existing Bridge for I-5 Cross Drainage

Construct New Levee

Construct Bypass Channel Adjacent to New Levee

Excavate Bypass Channel Into West Side of CCSB

Construct Bypass Channel Adjacent to CCSB

Legend

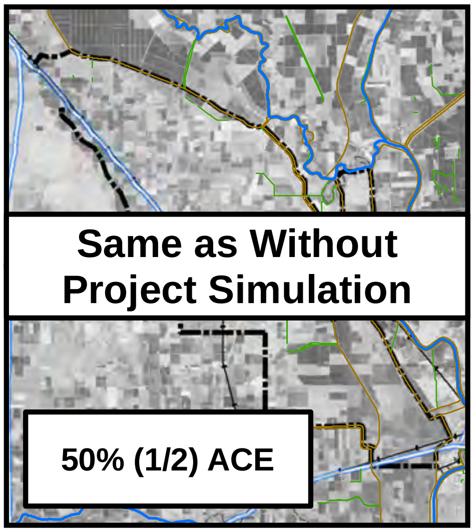
—	Existing Federal Levees
—	Existing Non Federal Levees
—	River/Creek
═	Interstate
═	Highway
┼	Railroad
☐	County Boundary
▭	Project Boundary
▭	Designated Floodways
▭	Floodplain

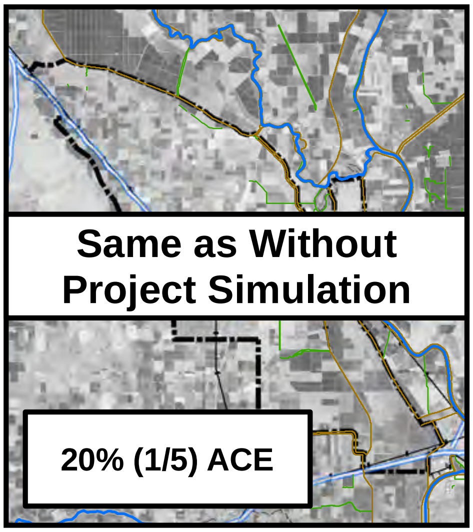
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

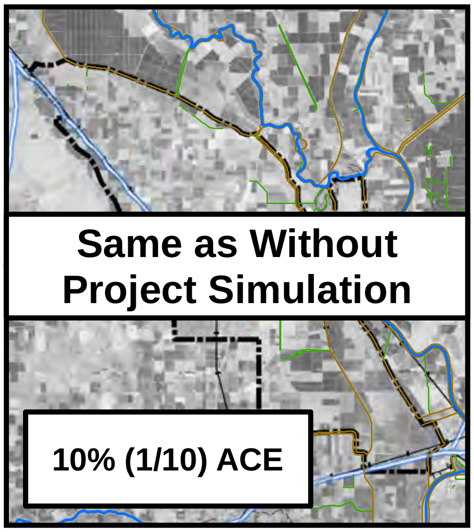
ALTERNATIVE SOUTH BYPASS 2C

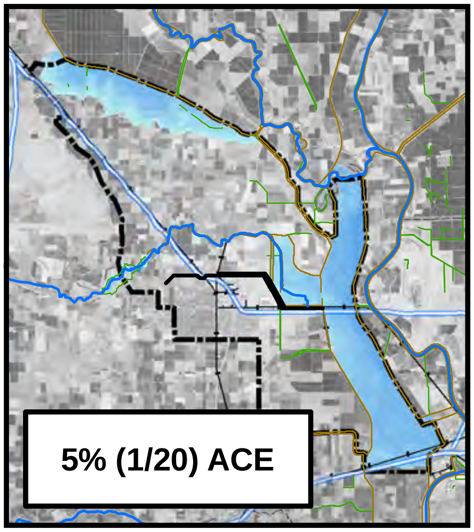
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

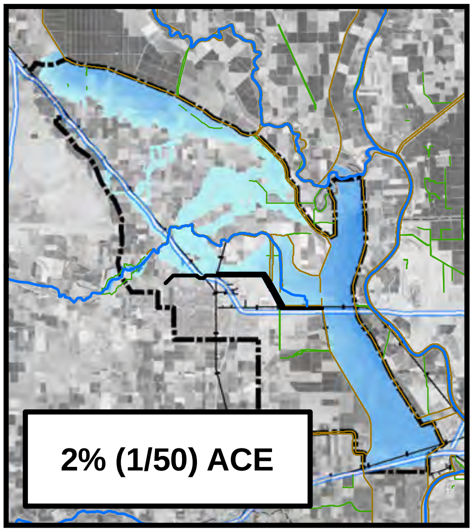
September 2019

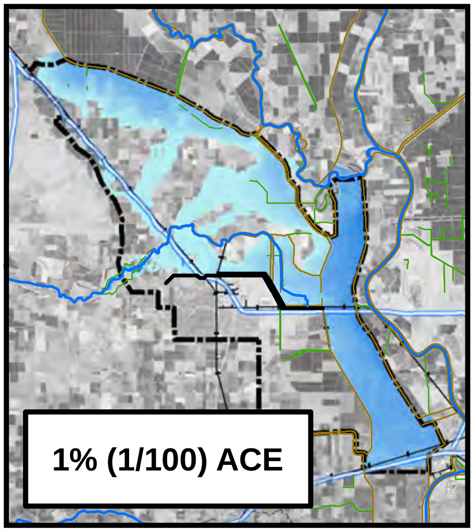


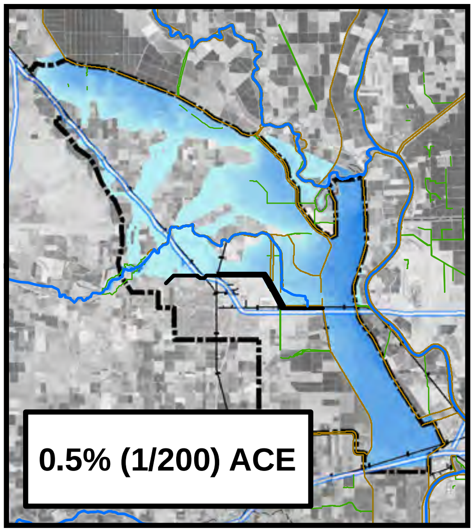


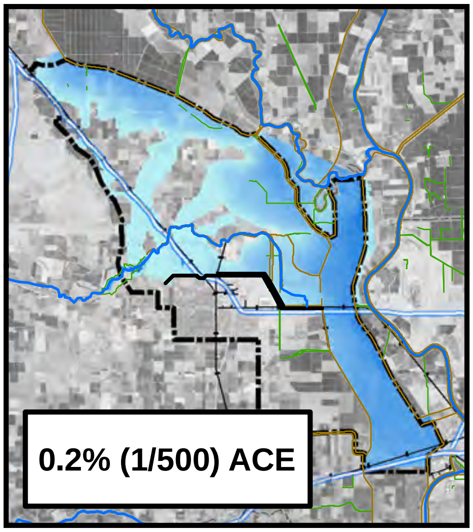












Depth (FEET)

🟦	0 - 2	🟦	25 - 26
🟦	3 - 4	🟦	27 - 28
🟦	5 - 6	🟦	29 - 30
🟦	7 - 8	🟦	31 - 32
🟦	9 - 10	🟦	33 - 34
🟦	11 - 12	🟦	35 - 36
🟦	13 - 14	🟦	37 - 38
🟦	15 - 16	🟦	39 - 40
🟦	17 - 18	🟦	41 - 42
🟦	19 - 20	🟦	43 - 44
🟦	21 - 22	🟦	45 - 46
🟦	23 - 24		

Legend

— River/Creek

— Existing Federal Levees

— Existing Non Federal Levees

═ Interstate

+—+ Railroad

▭ Project Boundary

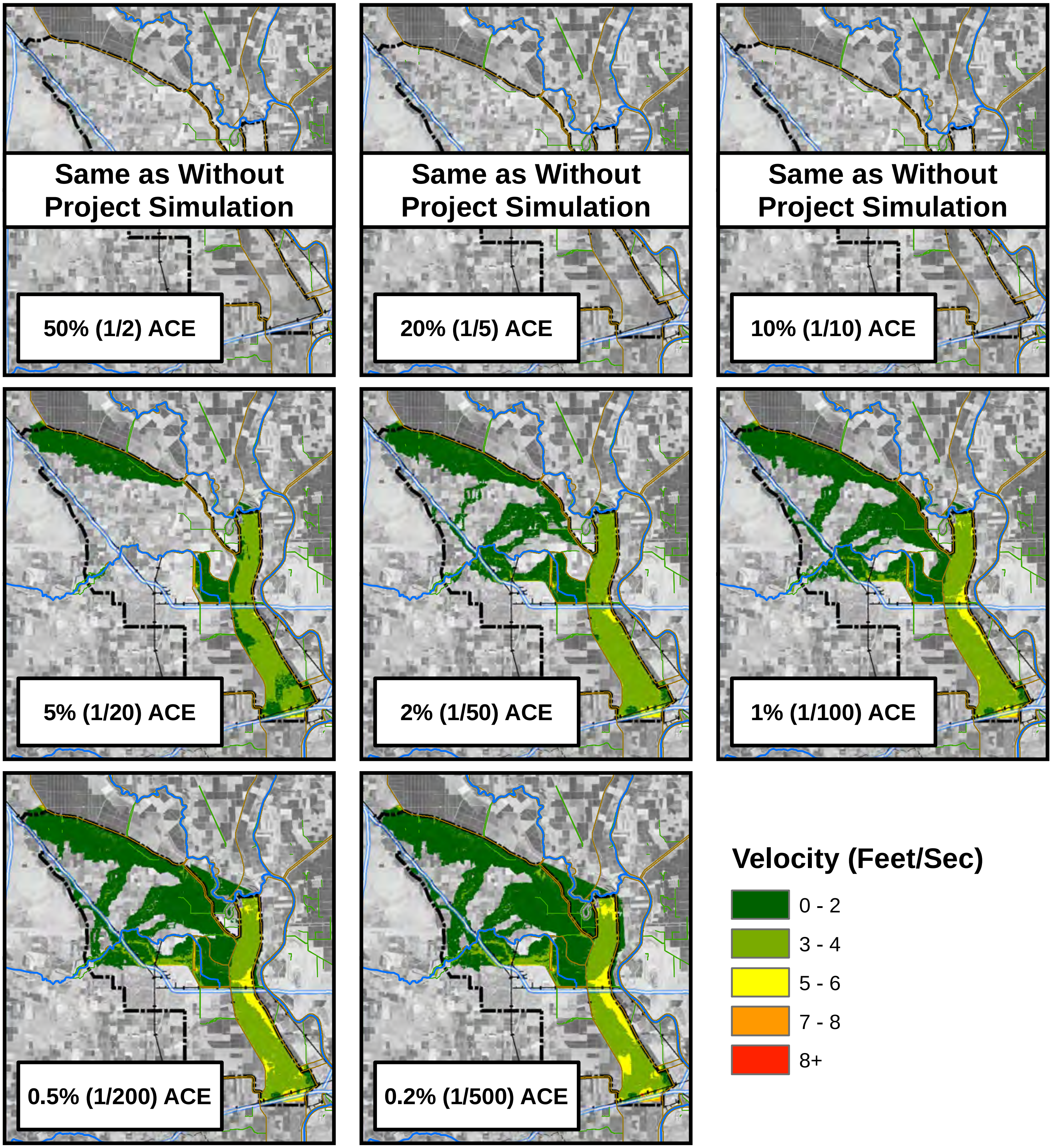
Note: Maps depict overtopping without failure

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE SOUTH BYPASS 2C OVERTOPPING NO FAILURE INUNDATION

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



Legend

- River/Creek
- Existing Federal Levees
- Existing Non Federal Levees
- Interstate
- Railroad
- Project Boundary

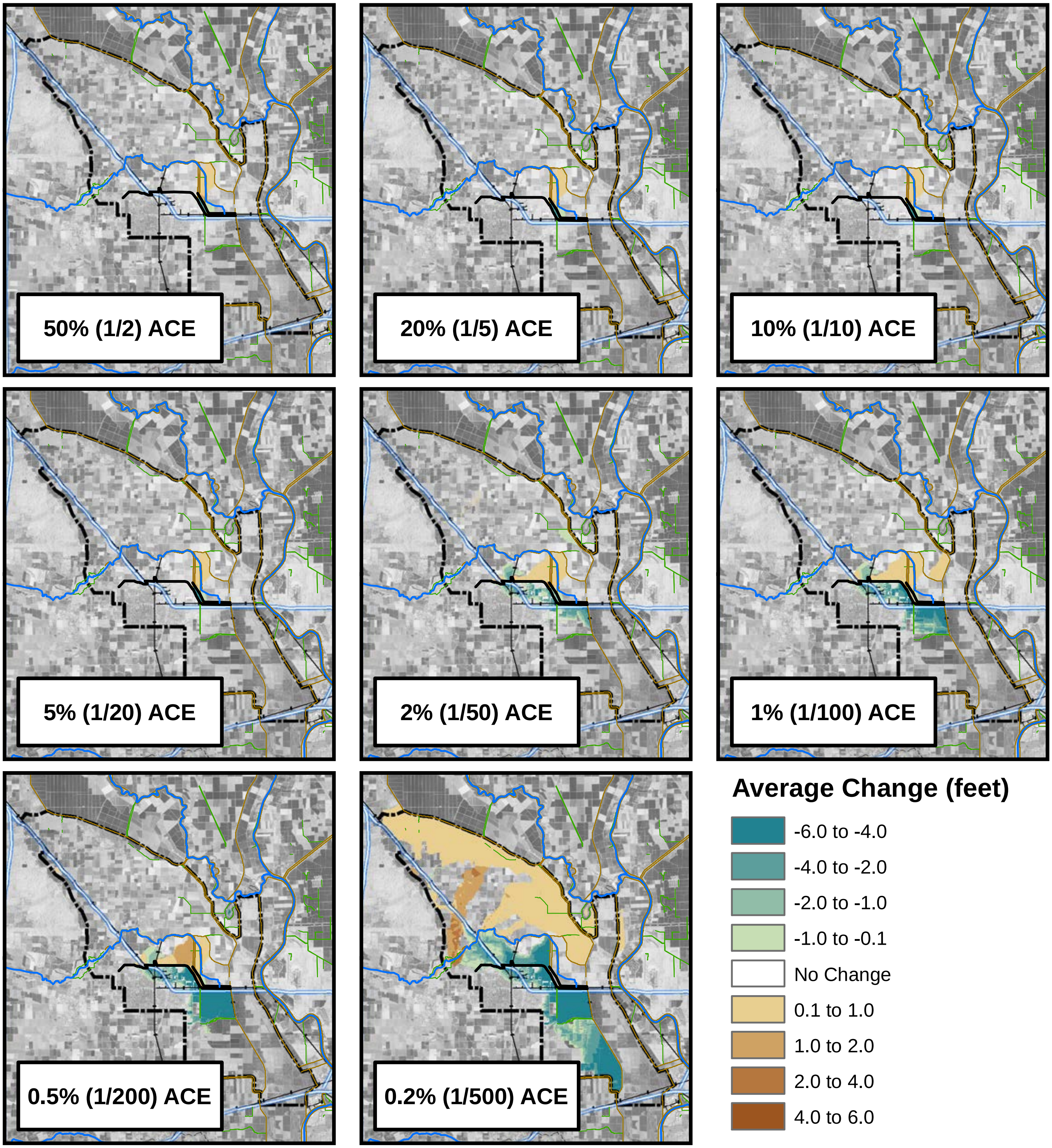
Note: Maps depict overtopping without failure

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE SOUTH BYPASS 2C OVERTOPPING NO FAILURE MAX VELOCITY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



Legend

- River/Creek
- Existing Federal Levees
- Existing Non Federal Levees
- Interstate
- Railroad
- Project Boundary

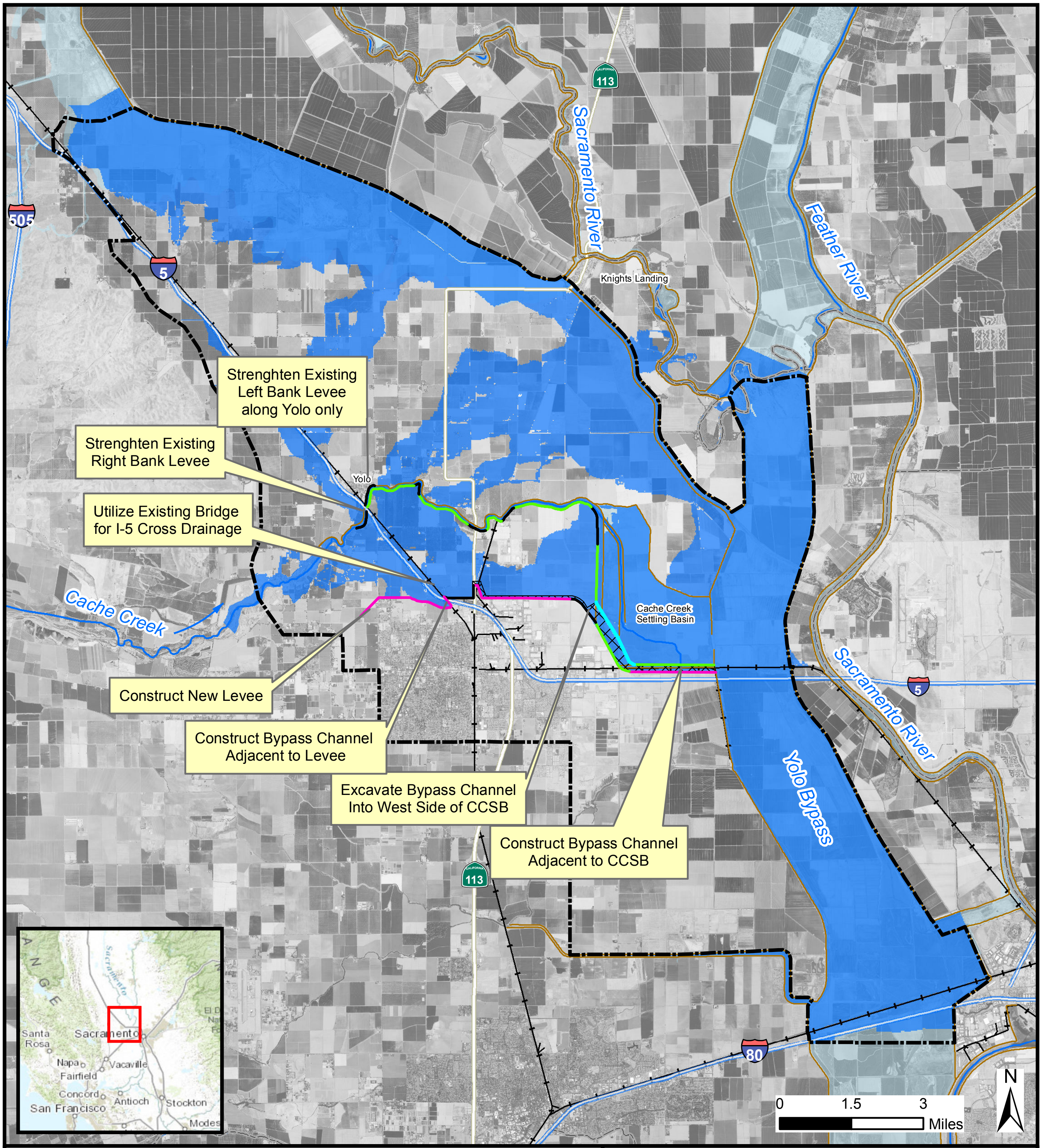
Note: Maps depict overtopping without failure

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE SOUTH BYPASS 2C AVERAGE CHANGE IN FLOOD DEPTH

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



Legend

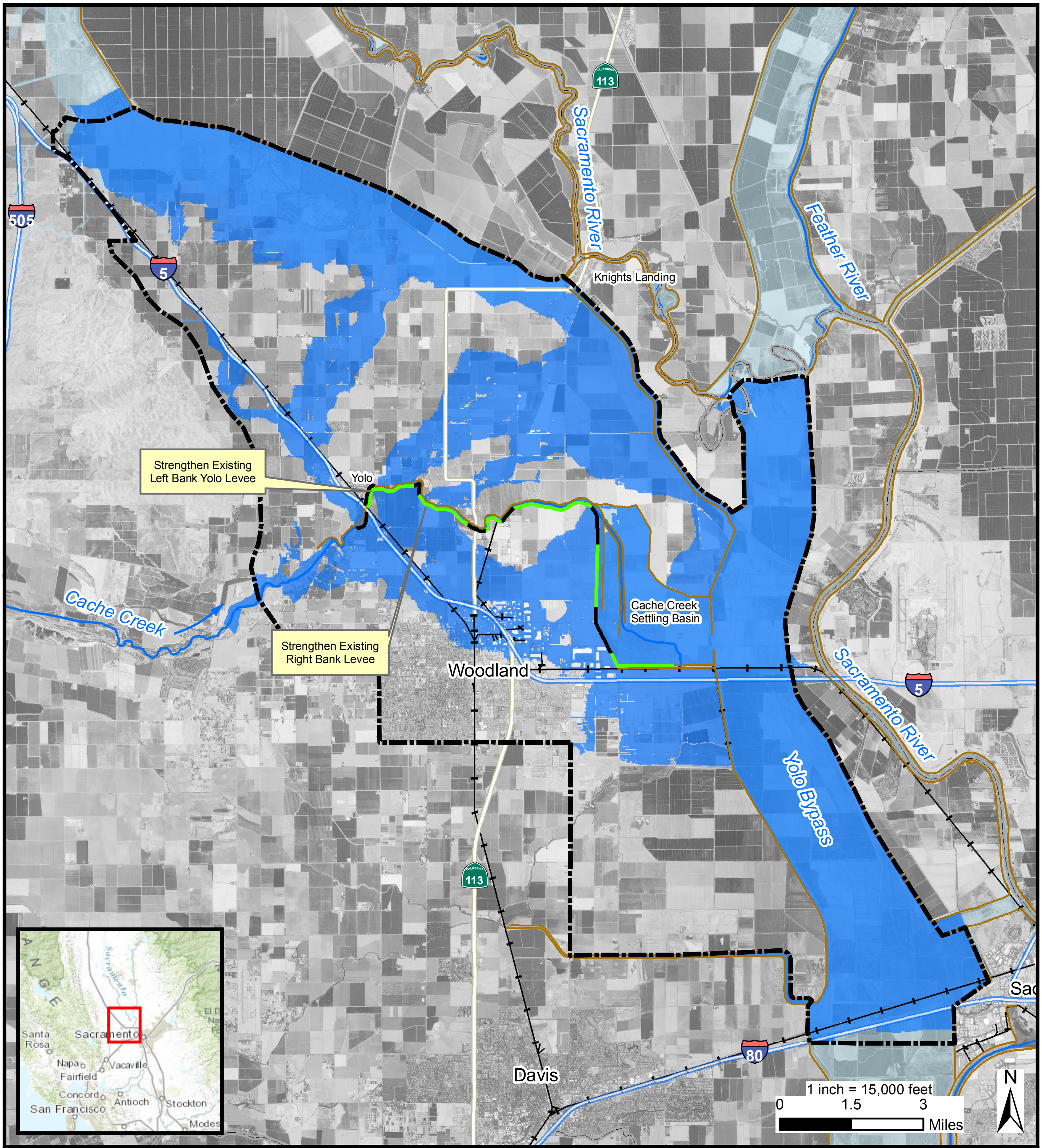
Existing Federal Levees
River/Creek
Interstate
Highway
Railroad
Project Boundary
County Boundary
Floodplain
Designated Floodways
▨ New Bypass

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE SOUTH BYPASS 2D

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



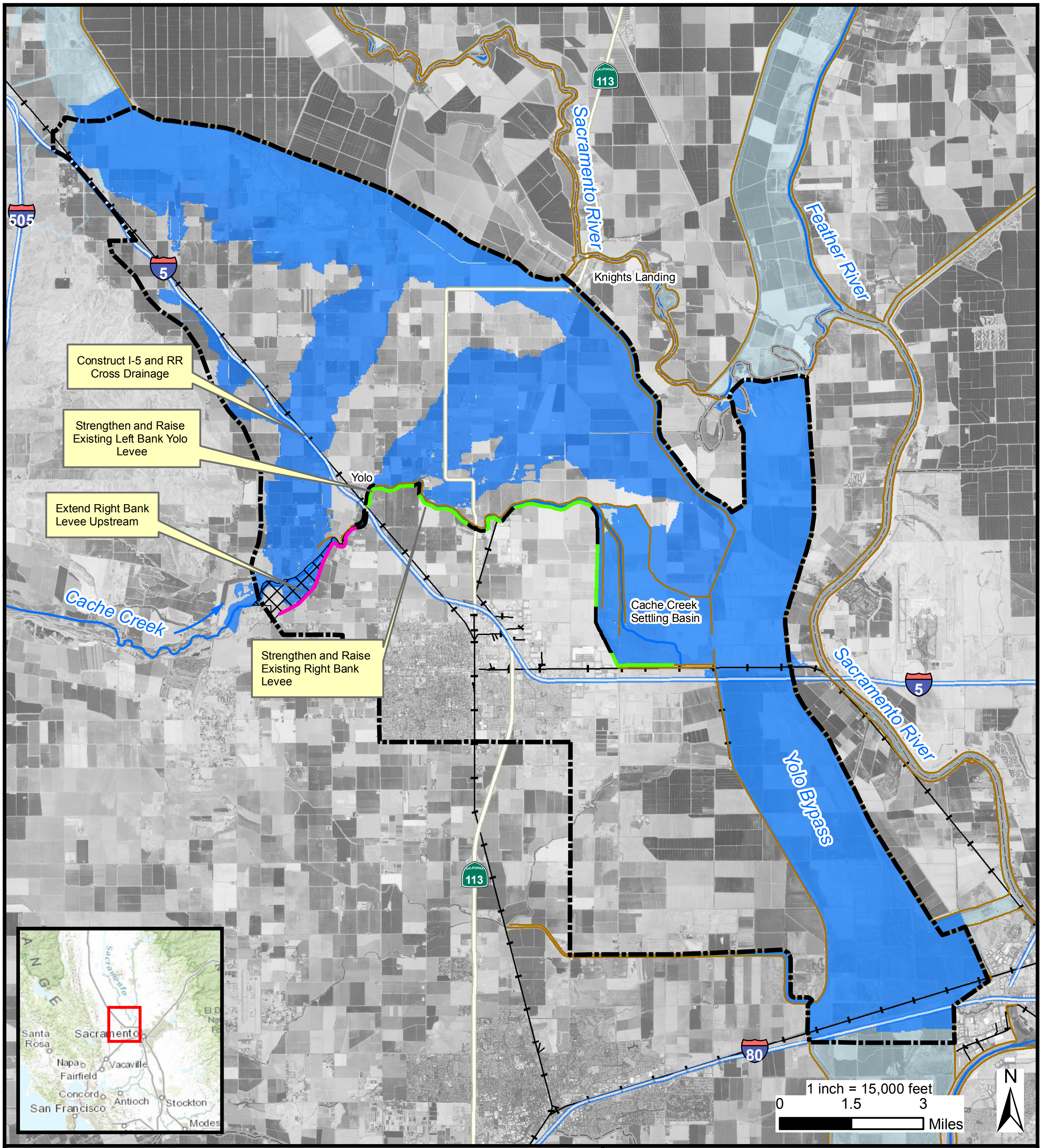
Legend

Existing Federal Levees
Interstate
Highway
Railroad
City Boundaries
River/Creek
Project Boundary
County Boundary
Designated Floodways
Floodplain

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE STRENGTHEN / RAISE 6A OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



Legend

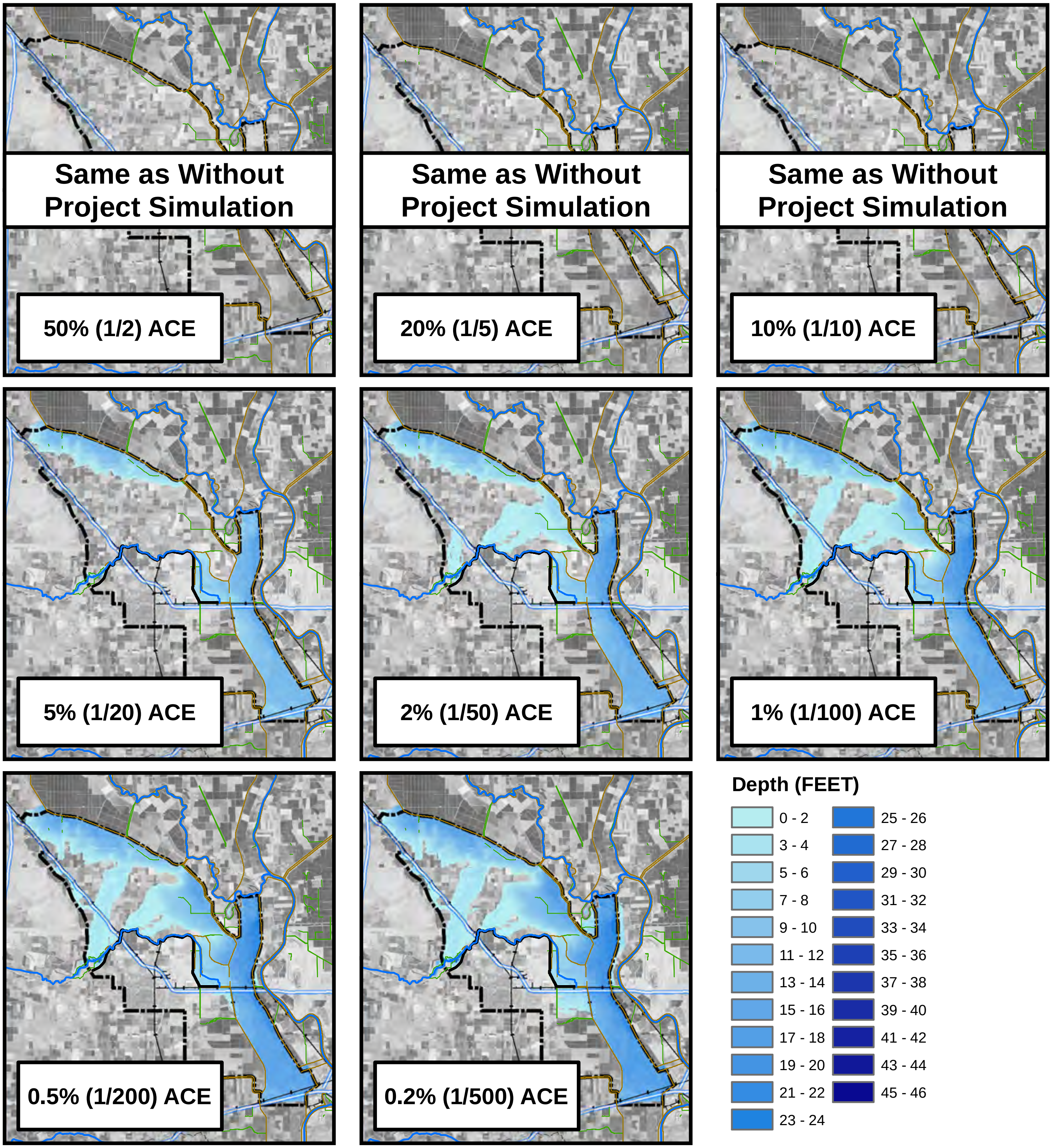
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- River/Creek
- County Boundary
- Project Boundary
- Designated Floodways
- Floodplain

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE STRENGTHEN / RAISE 6B OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



Legend

River/Creek

Existing Federal Levees

Existing Non Federal Levees

Interstate

Railroad

Project Boundary

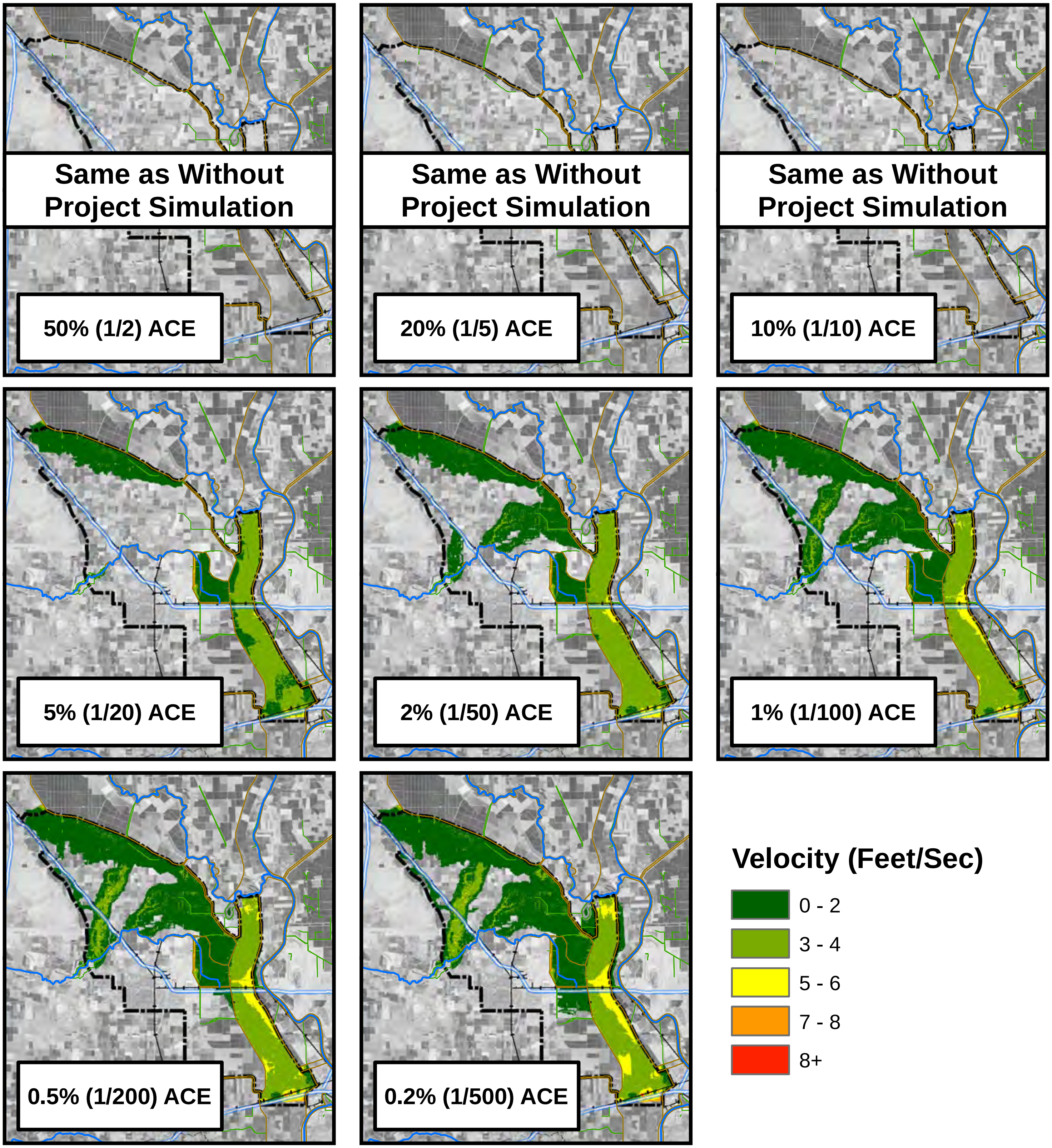
Note: Maps depict overtopping without failure

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE STRENGTHEN/RAISE 6B OVERTOPPING NO FAILURE INUNDATION

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



Legend

- River/Creek
- Existing Federal Levees
- Existing Non Federal Levees
- Interstate
- Railroad
- Project Boundary

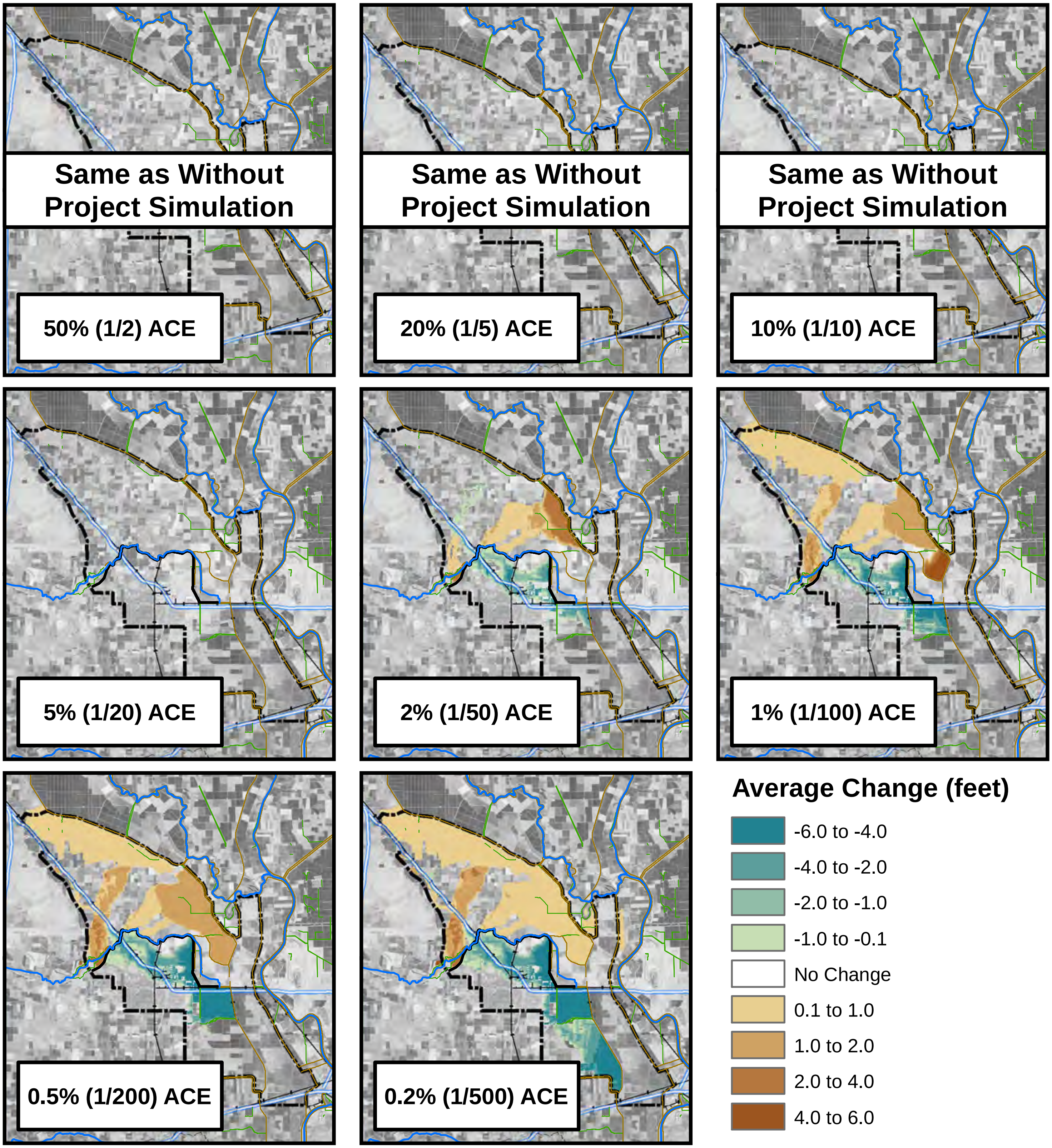
Note: Maps depict overtopping without failure

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE STRENGTHEN/RAISE 6B OVERTOPPING NO FAILURE MAX VELOCITY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



Average Change (feet)

■	-6.0 to -4.0
■	-4.0 to -2.0
■	-2.0 to -1.0
■	-1.0 to -0.1
□	No Change
■	0.1 to 1.0
■	1.0 to 2.0
■	2.0 to 4.0
■	4.0 to 6.0

Legend

- River/Creek
- Existing Federal Levees
- Existing Non Federal Levees
- Interstate
- Railroad
- Project Boundary

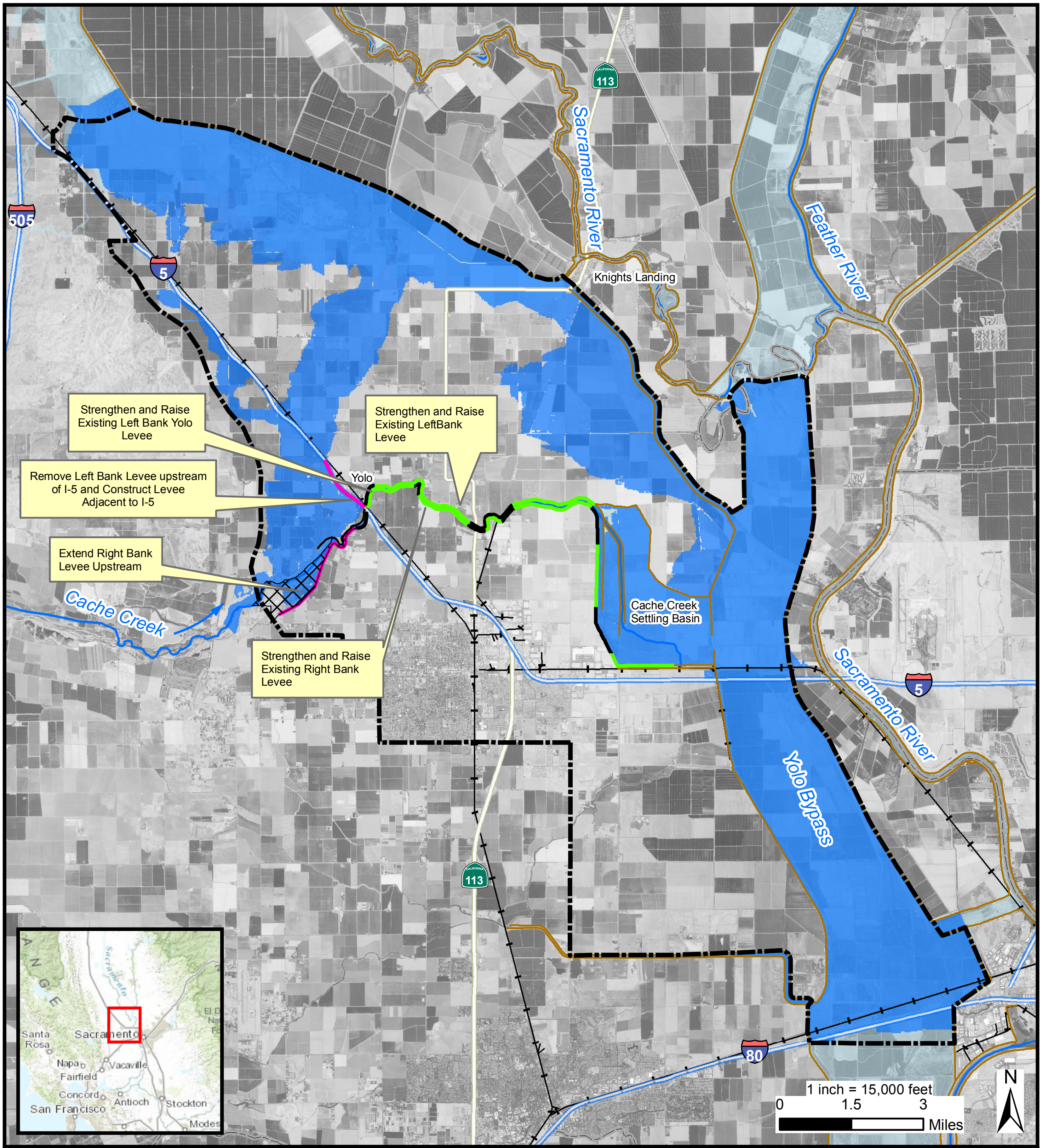
Note: Maps depict overtopping without failure

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE STRENGTHEN/RAISE 6B AVERAGE CHANGE IN FLOOD DEPTH

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



Legend

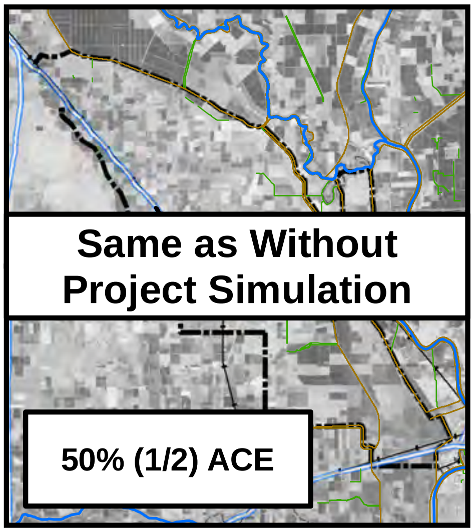
- Existing Federal Levees
- River/Creek
- Interstate
- Highway
- Railroad
- ▨ Flowage Easement
- Project Boundary
- ☐ County Boundary
- Designated Floodways
- Floodplain

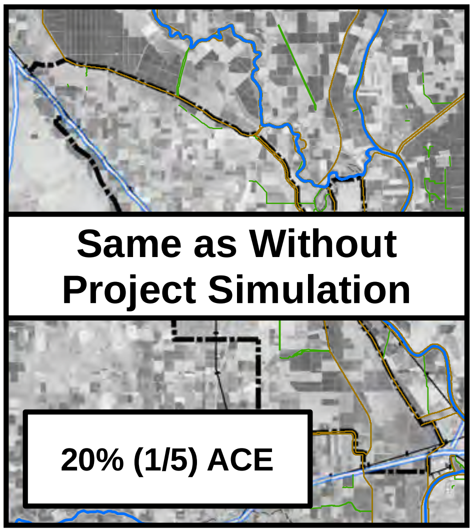
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

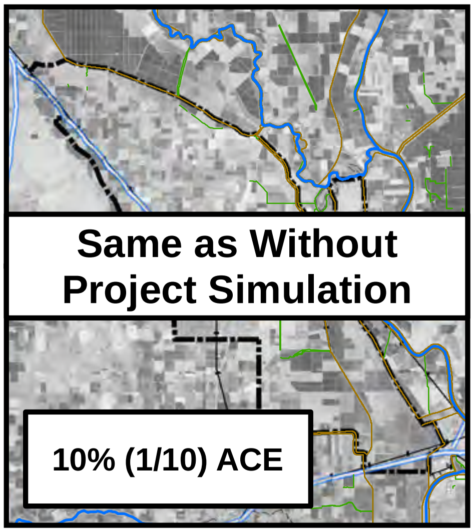
ALTERNATIVE STRENGTHEN / RAISE 6C

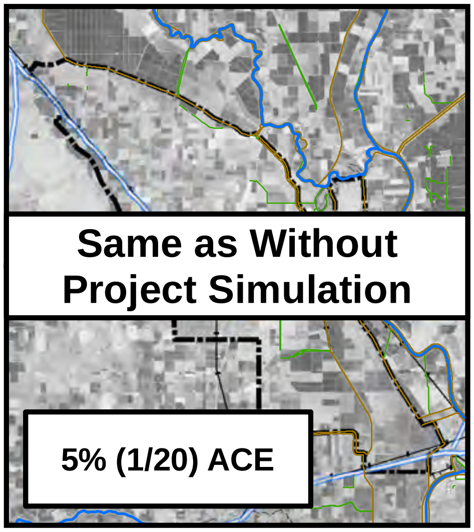
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

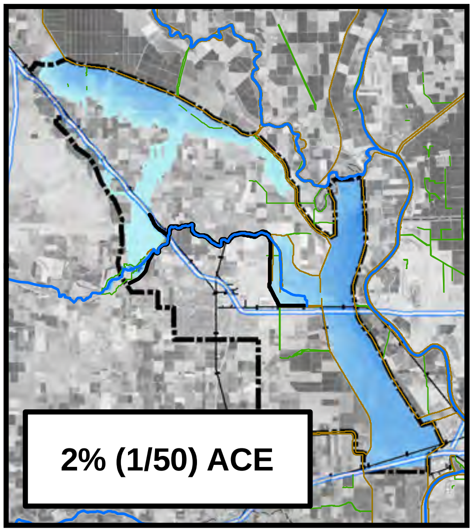
September 2019

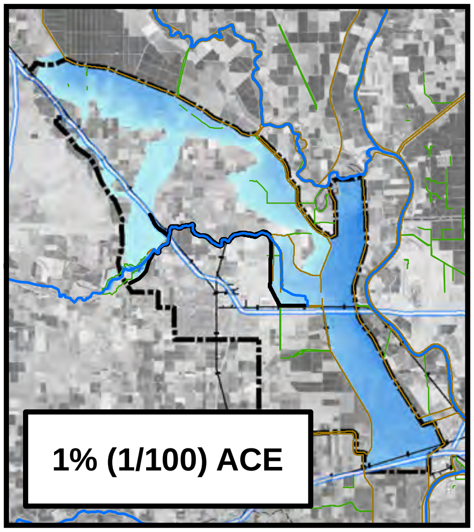


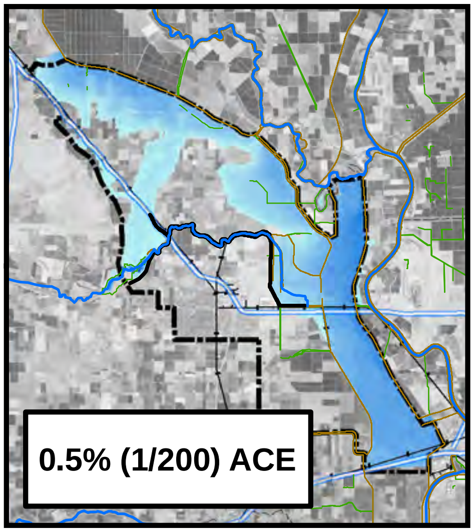


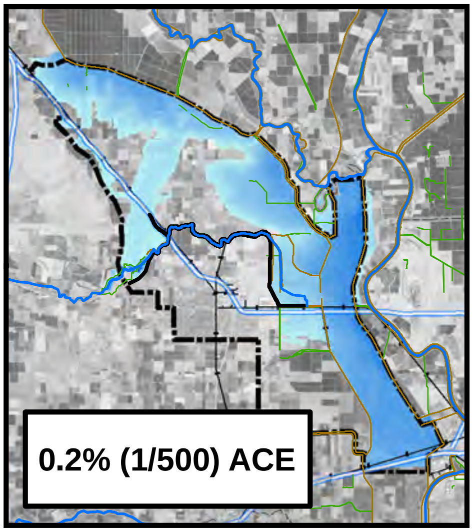












Depth (FEET)

0 - 2	25 - 26
3 - 4	27 - 28
5 - 6	29 - 30
7 - 8	31 - 32
9 - 10	33 - 34
11 - 12	35 - 36
13 - 14	37 - 38
15 - 16	39 - 40
17 - 18	41 - 42
19 - 20	43 - 44
21 - 22	45 - 46
23 - 24	

Legend

River/Creek

Existing Federal Levees

Existing Non Federal Levees

Interstate

Railroad

Project Boundary

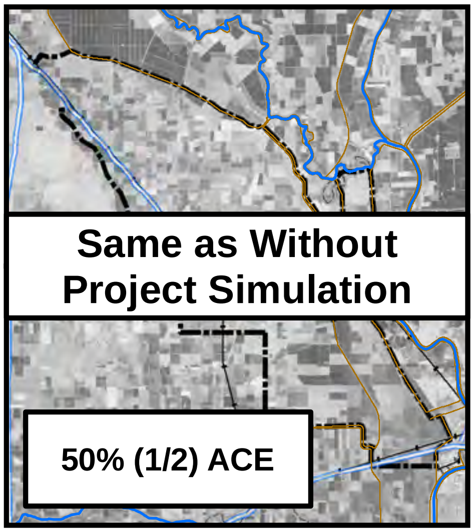
Note: Maps depict overtopping without failure

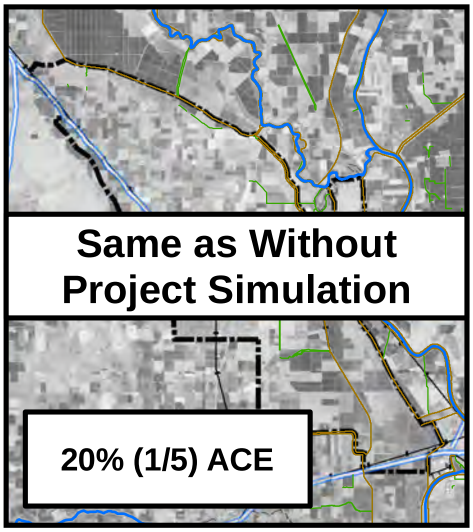
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

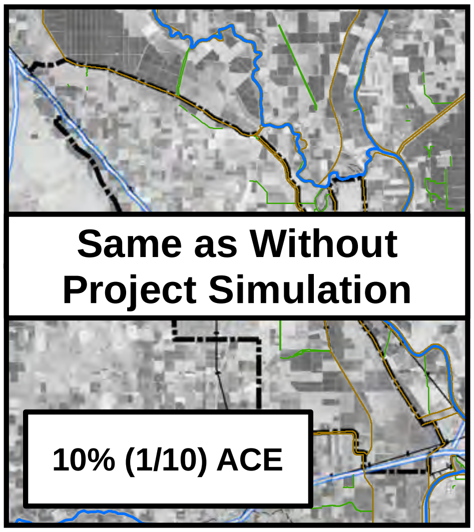
ALTERNATIVE STRENGTHEN/RAISE 6C OVERTOPPING NO FAILURE INUNDATION

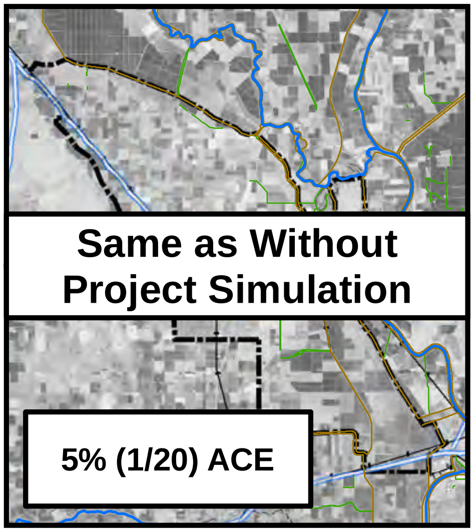
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

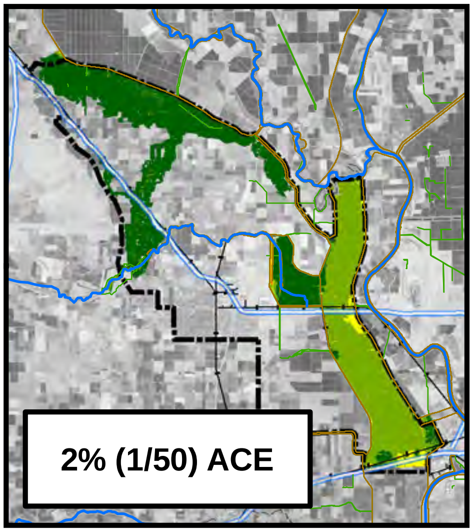
September 2019

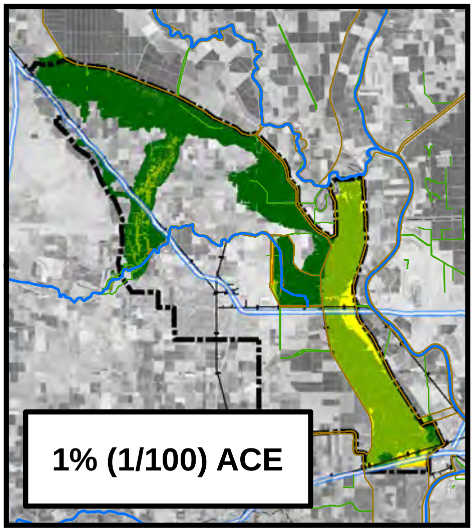


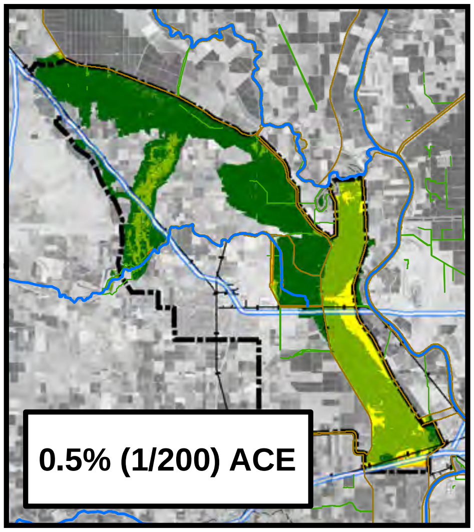


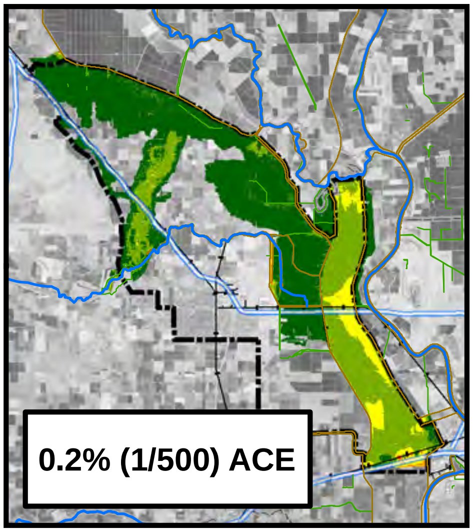












Velocity (Feet/Sec)

- 🟩 0 - 2
- 🟩 3 - 4
- 🟨 5 - 6
- 🟧 7 - 8
- 🟥 8+

Legend

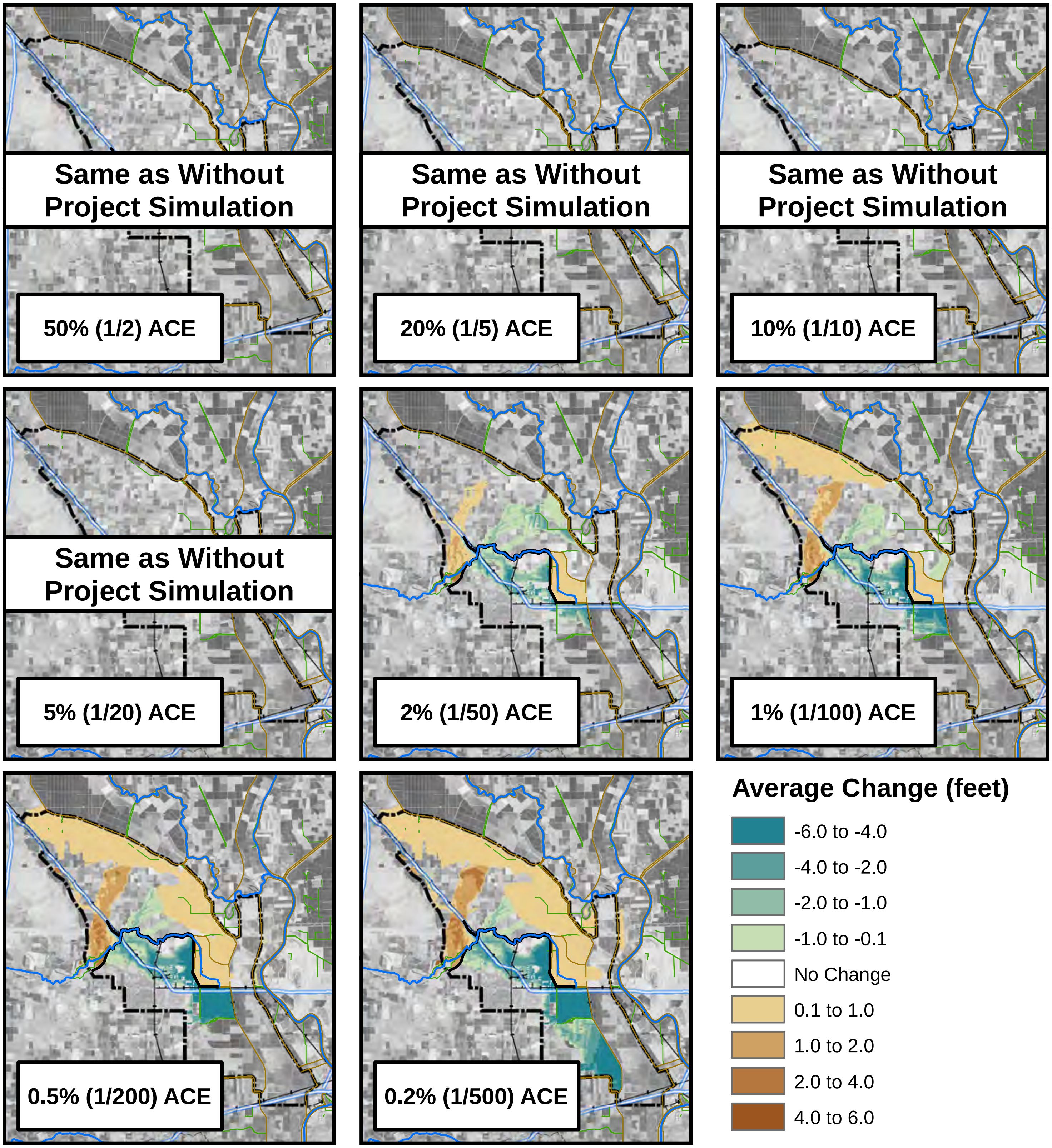
- River/Creek
- Existing Federal Levees
- Existing Non Federal Levees
- Interstate
- Railroad
- Project Boundary

Note: Maps depict overtopping without failure

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE STRENGTHEN/RAISE 6C OVERTOPPING NO FAILURE MAX VELOCITY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



Legend

River/Creek
Existing Federal Levees
Existing Non Federal Levees
Interstate
Railroad
Project Boundary

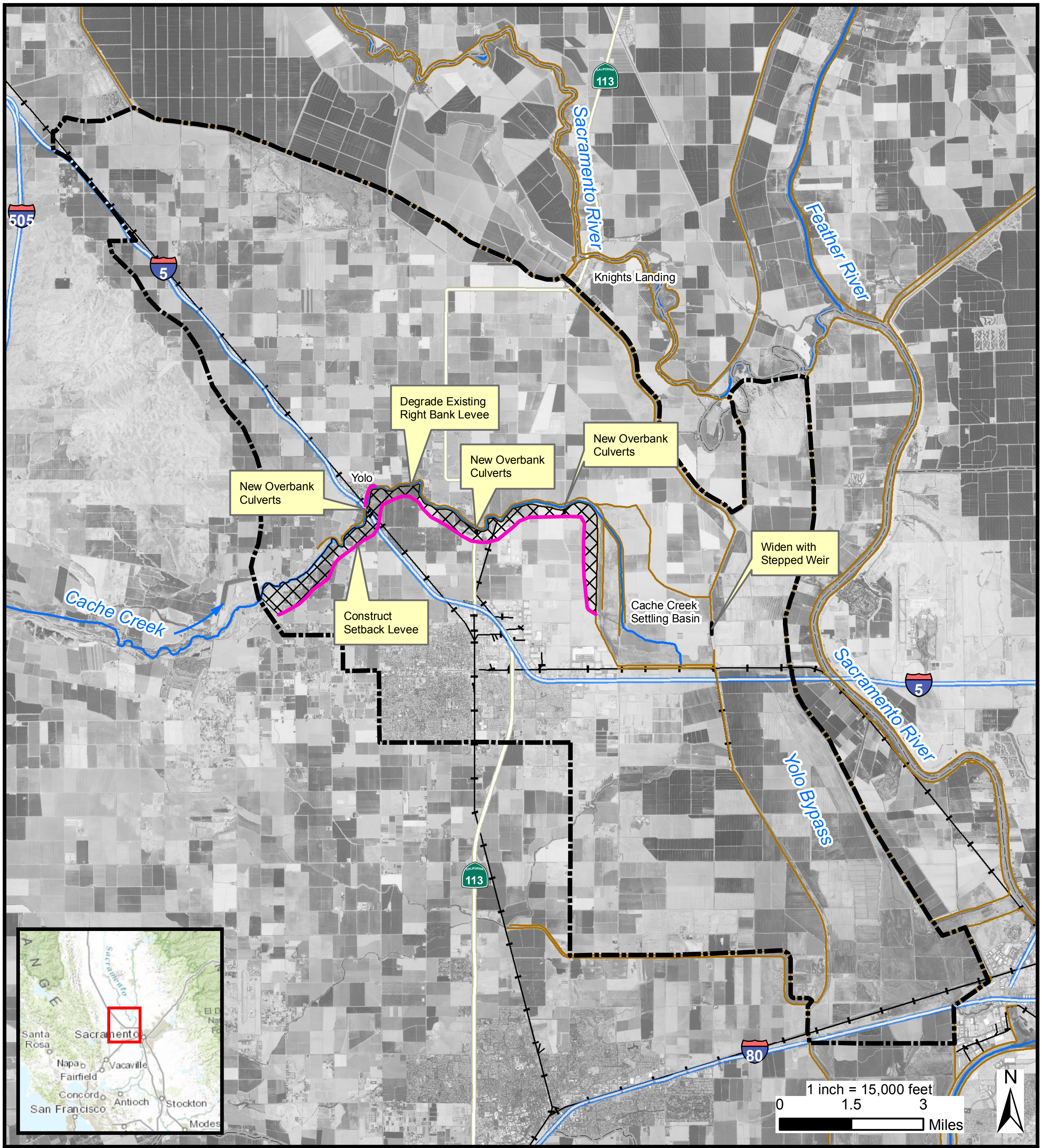
Note: Maps depict overtopping without failure

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE STRENGTHEN/RAISE 6C AVERAGE CHANGE IN FLOOD DEPTH

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



Legend

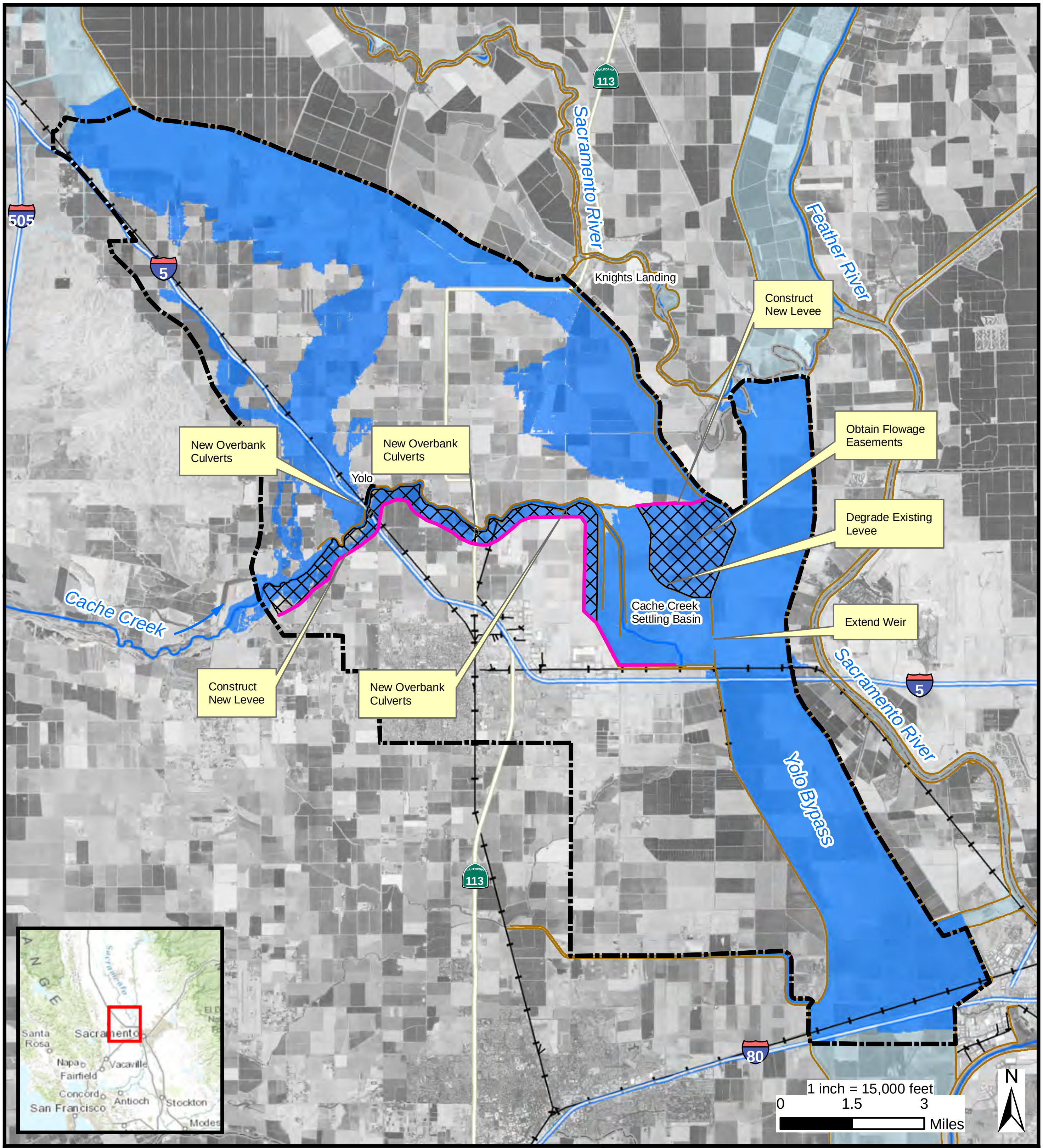
- River/Creek
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- Project Boundary

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE PARTIAL SETBACK LEVEE 7A

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



Legend

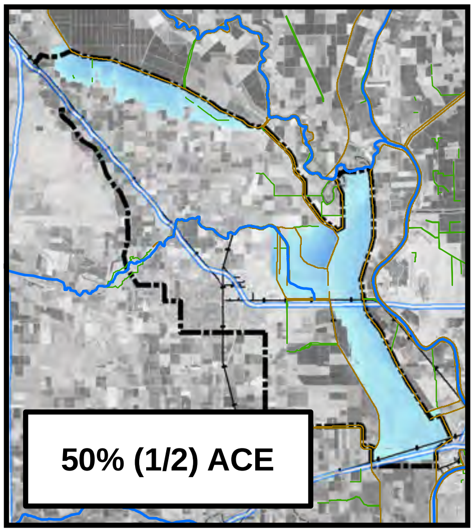
—	Existing Federal Levees
—	River/Creek
═	Interstate
═	Highway
─┼─	Railroad
▨	Flowage Easement
☐	County Boundary
☐	Project Boundary
☐	Designated Floodways
■	Floodplain

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

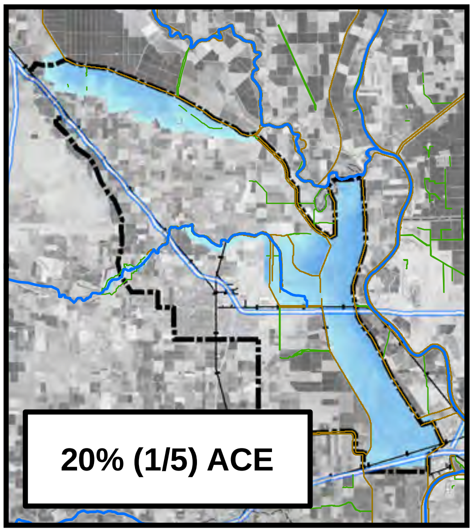
ALTERNATIVE PARTIAL SETBACK LEVEE 7B

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

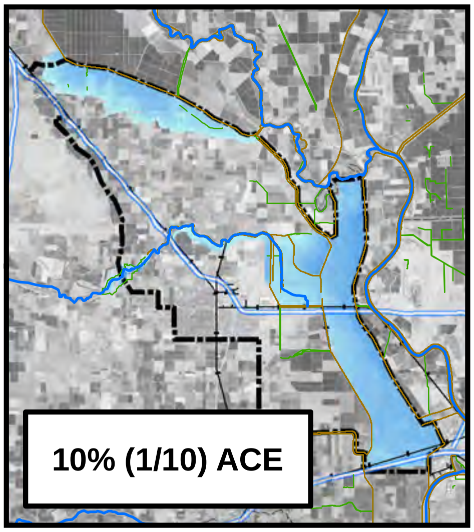
September 2019



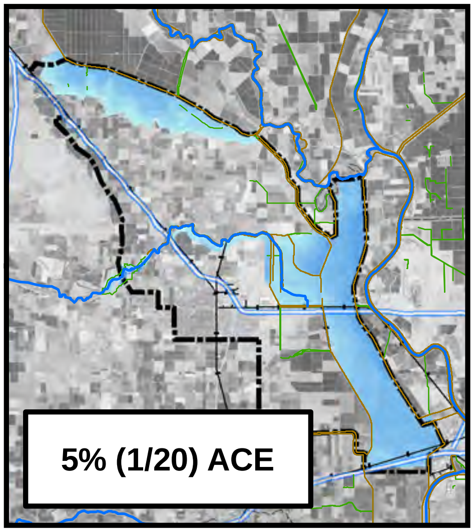
50% (1/2) ACE



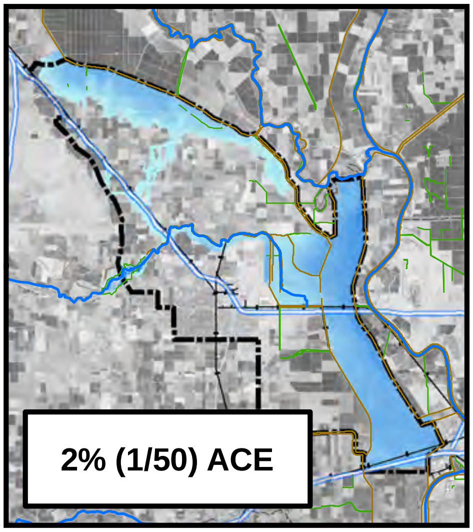
20% (1/5) ACE



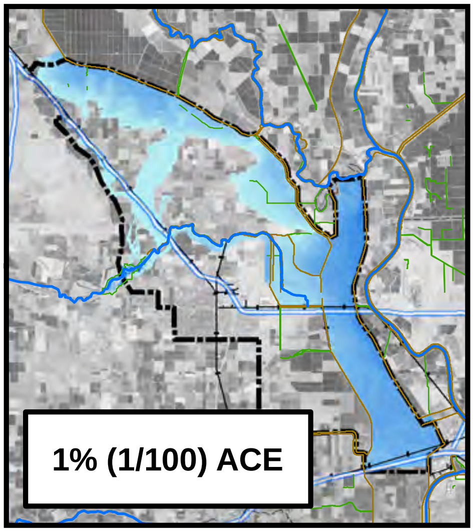
10% (1/10) ACE



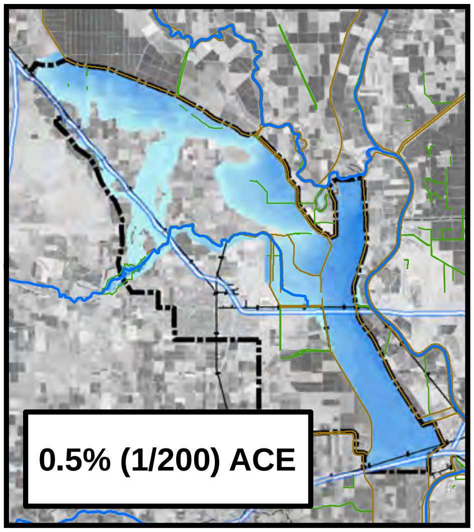
5% (1/20) ACE



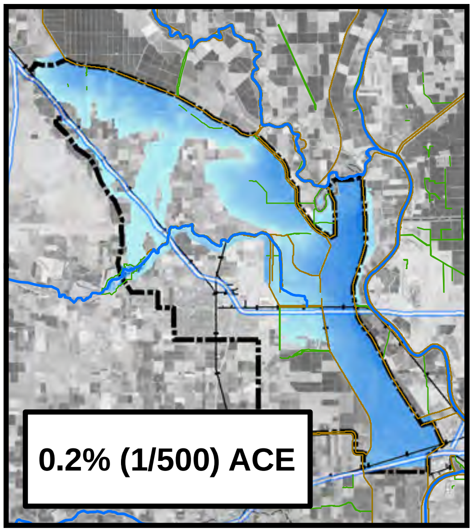
2% (1/50) ACE



1% (1/100) ACE



0.5% (1/200) ACE



0.2% (1/500) ACE

Depth (FEET)

▨ 0 - 2	▨ 25 - 26
▨ 3 - 4	▨ 27 - 28
▨ 5 - 6	▨ 29 - 30
▨ 7 - 8	▨ 31 - 32
▨ 9 - 10	▨ 33 - 34
▨ 11 - 12	▨ 35 - 36
▨ 13 - 14	▨ 37 - 38
▨ 15 - 16	▨ 39 - 40
▨ 17 - 18	▨ 41 - 42
▨ 19 - 20	▨ 43 - 44
▨ 21 - 22	▨ 45 - 46
▨ 23 - 24	

Legend

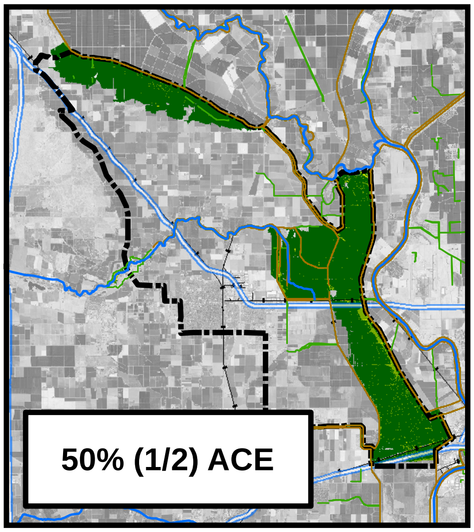
— River/Creek
— Existing Federal Levees
— Existing Non Federal Levees
═ Interstate
—+— Railroad
▭ Project Boundary

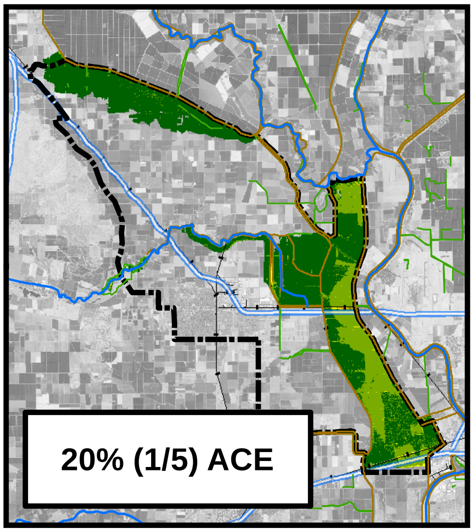
Note: Maps depict overtopping without failure

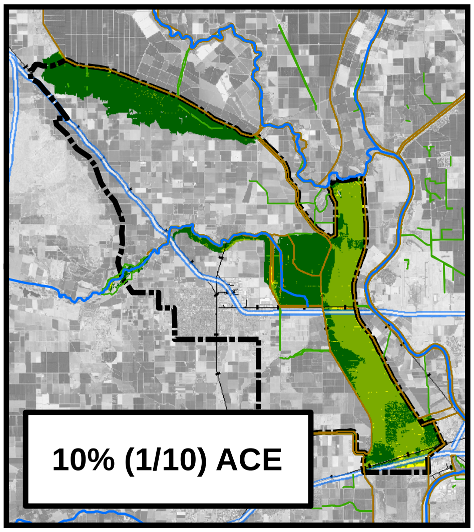
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

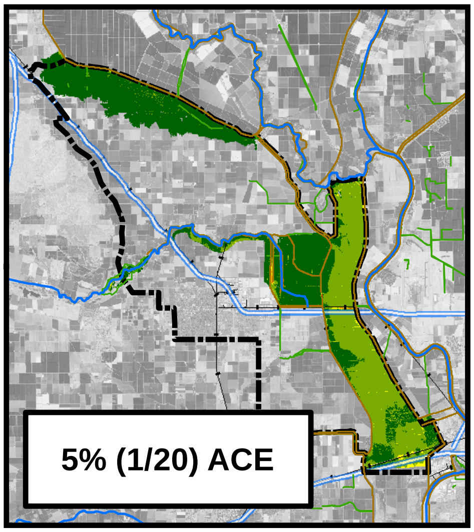
ALTERNATIVE SETBACK 7B OVERTOPPING NO FAILURE INUNDATION

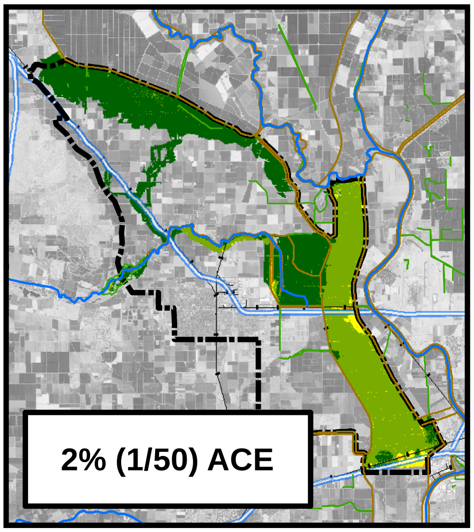
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

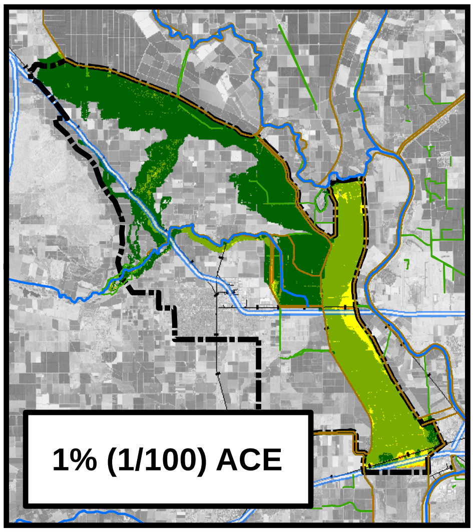


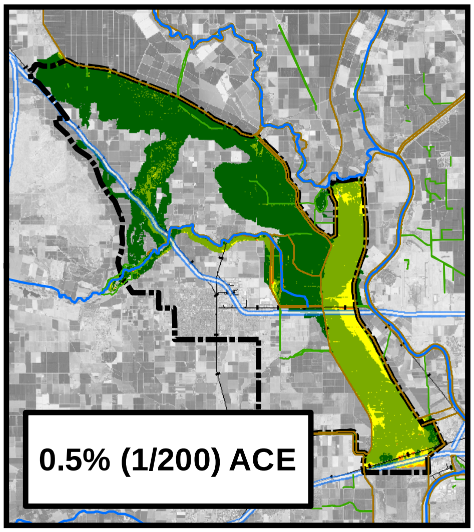


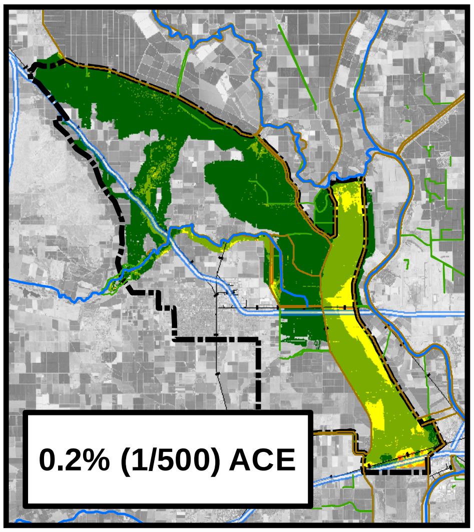












Velocity (fps)
- 🟩 0 - 2
- 🟩 3 - 4
- 🟨 5 - 6
- 🟧 7 - 8
- 🟥 8+

Legend
- River/Creek
- Existing Federal Levees
- Existing Non Federal Levees
- Project Boundary
- Interstate
- Railroad

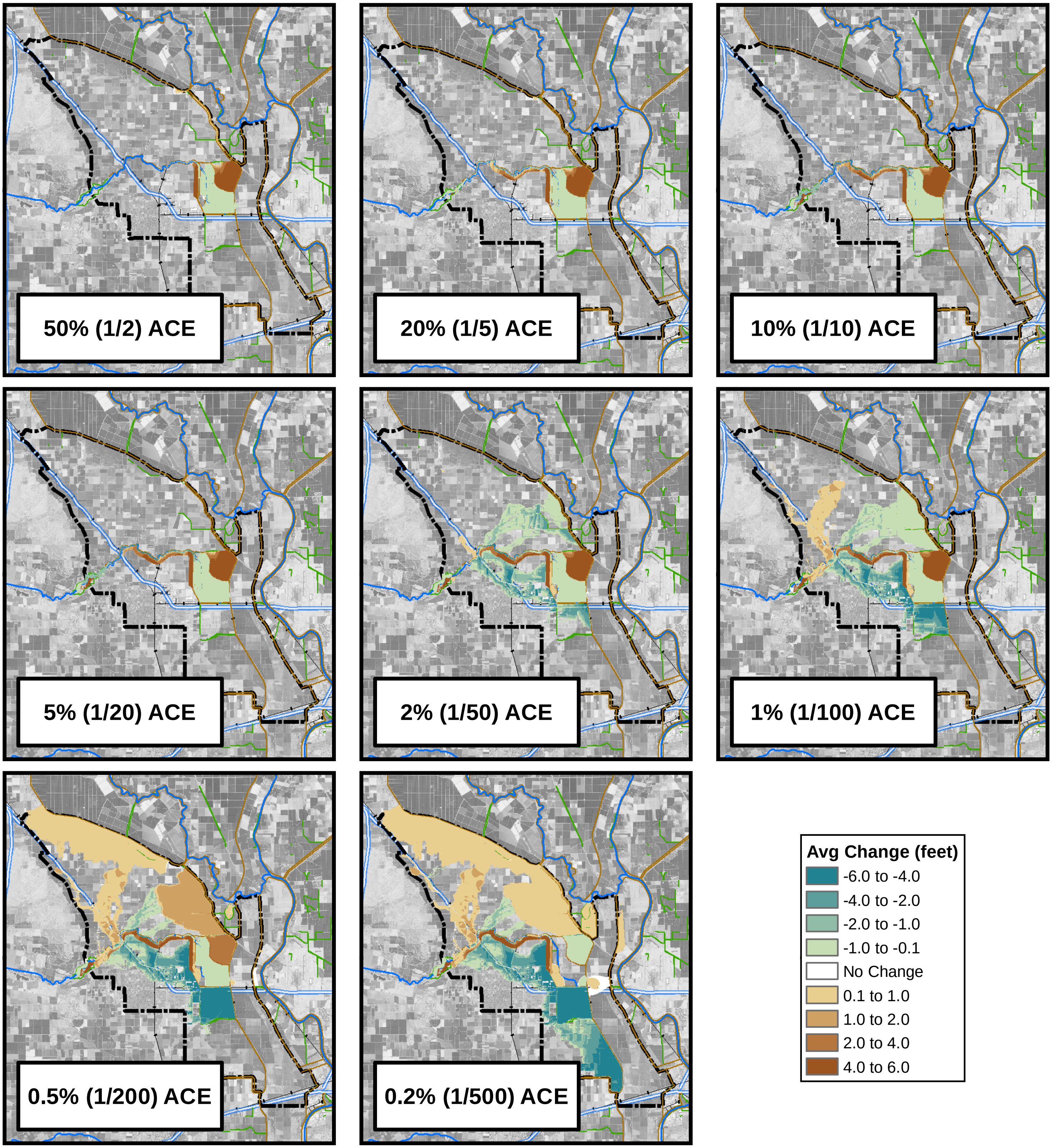
Note: Maps depict overtopping without failure

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE 7B
NO FAILURE MAX VELOCITY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

24 SEP 2019



Legend

River/Creek

Existing Federal Levees

Existing Non Federal Levees

Project Boundary

Interstate

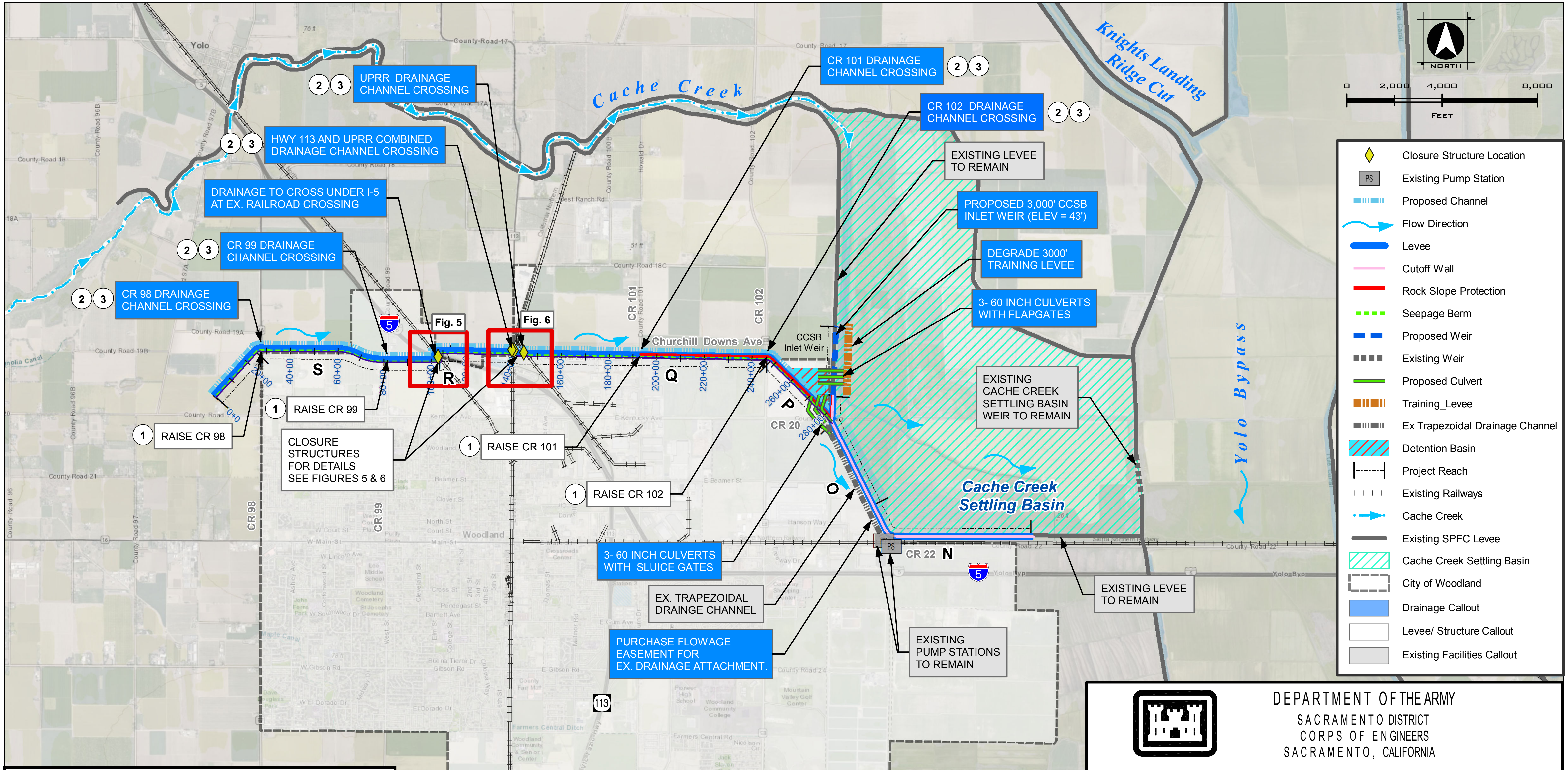
Railroad

Note: Maps depict overtopping without failure

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE 7B
AVERAGE CHANGE IN FLOOD DEPTH

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



FLOOD IMPROVEMENT PROTECTION SUMMARY TABLE

REACH	LENGTH	IMPROVEMENT DESCRIPTION [1]
S	12,100 ft	6' Tall Levee with 30' W x 5' H Seepage Berm
REACH	3,000 ft	7' Tall Levee with 30' W x 5' H Seepage Berm
Q	10,600 ft	11' Tall Levee with 30' W x 5' H Seepage Berm. Install Rock Slope Protection [2]
P	3,900 ft	14' Tall Levee with 30' W x 5' H Seepage Berm. Install Rock Slope Protection [2]
O	5,000 ft	Levee with 45' Deep Cutoff Wall
N	7,400 ft	Levee with 60' Deep Cutoff Wall

NOTES:

1. All dimensions are approximate
2. Rock Slope Protection to be placed between CR 101 and CCSB only.

NOTES:

1. COUNTY ROADS (CR) TO BE RAISED TO LEVEE CROWN ELEVATION AT 5% GRADE.
2. ROAD AND RAIL CROSSINGS OF THE DRAINAGE DITCH WILL BE COMPRISED OF 3 60" CULVERTS AT EACH LOCATION. SEE FIGURE 4 FOR TYPICAL SECTION.
3. CULVERTS FOR DRAINAGE DITCH CROSSINGS ARE NOT SHOWN AT THIS SCALE FOR CLARITY.

DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

SACRAMENTO CALIFORNIA

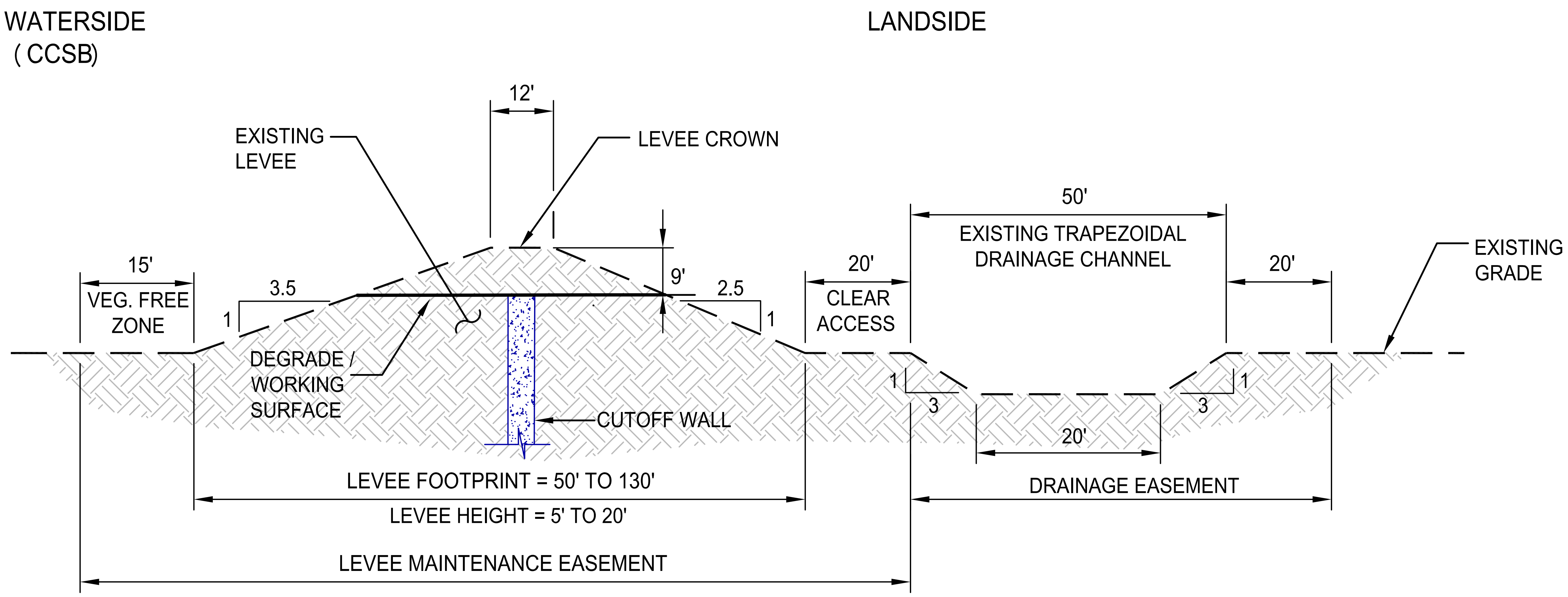
LOWER CACHE CREEK FEASIBILITY STUDY ALTERNATIVE 2A OVERALL PROJECT MAP

PRELIMINARY

PLATE 55

DATE:	SCALE:	SHEET NO.
SEPTEMBER 2019	1"=4000'	1 OF 8

J:\Jobs\8303\8303.032 LCCFS_Alts_2A_2B_2C\GIS\Tasks\20190725_Project_Description_Exhibits\FIG_01_Overall_Project_Map_201908015.mxd 8/15/2019 5:38:58 PM jpriest



DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

SACRAMENTO CALIFORNIA

LOWER CACHE CREEK FEASIBILITY STUDY
ALTERNATIVE 2A

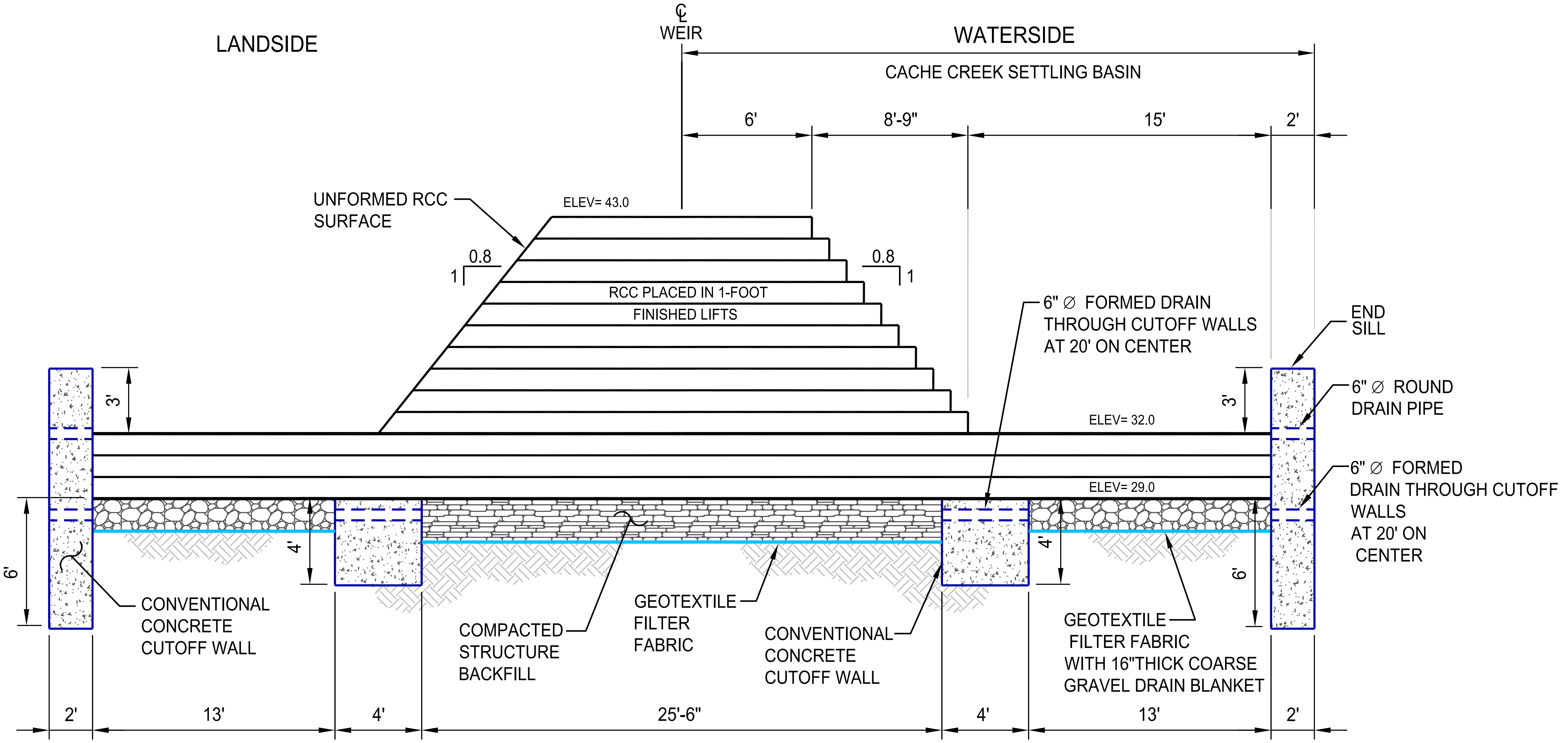
TYPICAL CUTOFF WALL SECTION (REACH N & O)

PRELIMINARY

PLATE 56

DATE:	SCALE:	SHEET NO.
SEPTEMBER 2019	NOT TO SCALE	2 OF 8

PLOT BY: JPRIEST – Aug 15, 2019 – 5:59:12pm
DRAWING: J:\Jobs\8303\8303.032 LCCFS_Alts_2A_2B_2C\Civil\Exhibits\20190726_Project_Description_Exhibits\FIG_02-06_XSEC_DETAILS.dwg



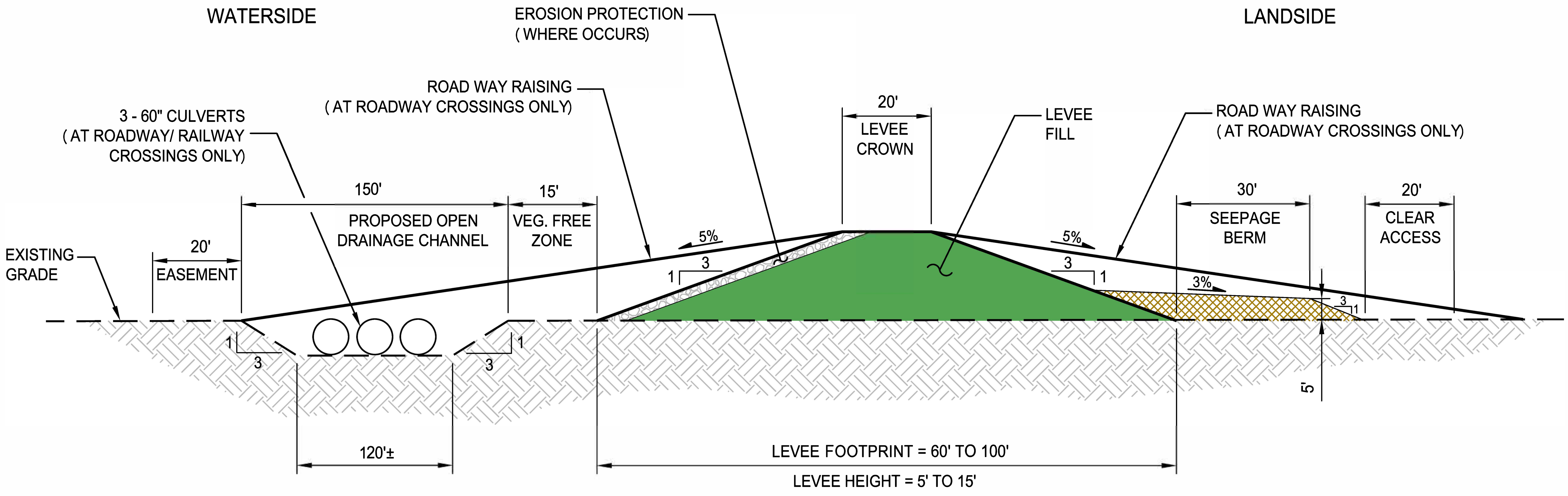
DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

SACRAMENTO CALIFORNIA

LOWER CACHE CREEK FEASIBILITY STUDY
ALTERNATIVE 2A
CCSB INLET WEIR TYPICAL SECTION
PRELIMINARY
PLATE 57

DATE:	SCALE:	SHEET NO.
September 2019	NOT TO SCALE	3 OF 8

PLOT BY: JPRIEST – Aug 15, 2019 – 6:00:05pm
DRAWING: J:\Jobs\8303\8303.032 LCCFS_Alts_2A_2B_2C\Civil\Exhibits\20190726_Project_Description_Exhibits\FIG_02-06_XSEC_DETAILS.dwg



DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

SACRAMENTO CALIFORNIA

LOWER CACHE CREEK FEASIBILITY STUDY
ALTERNATIVE 2A

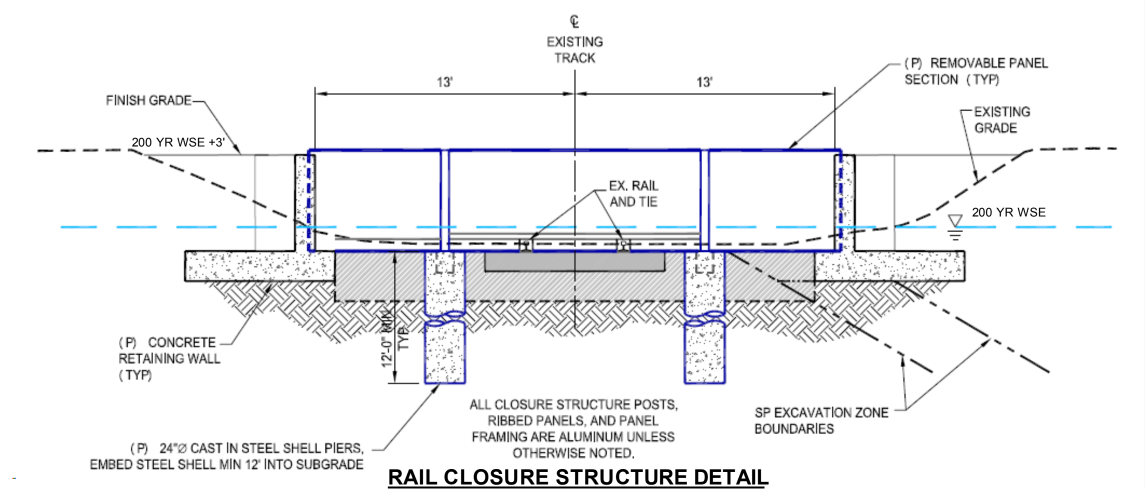
TYPICAL LEVEE WITH BERM SECTION (REACH P, Q, R & S)

PRELIMINARY

FIGURE 4

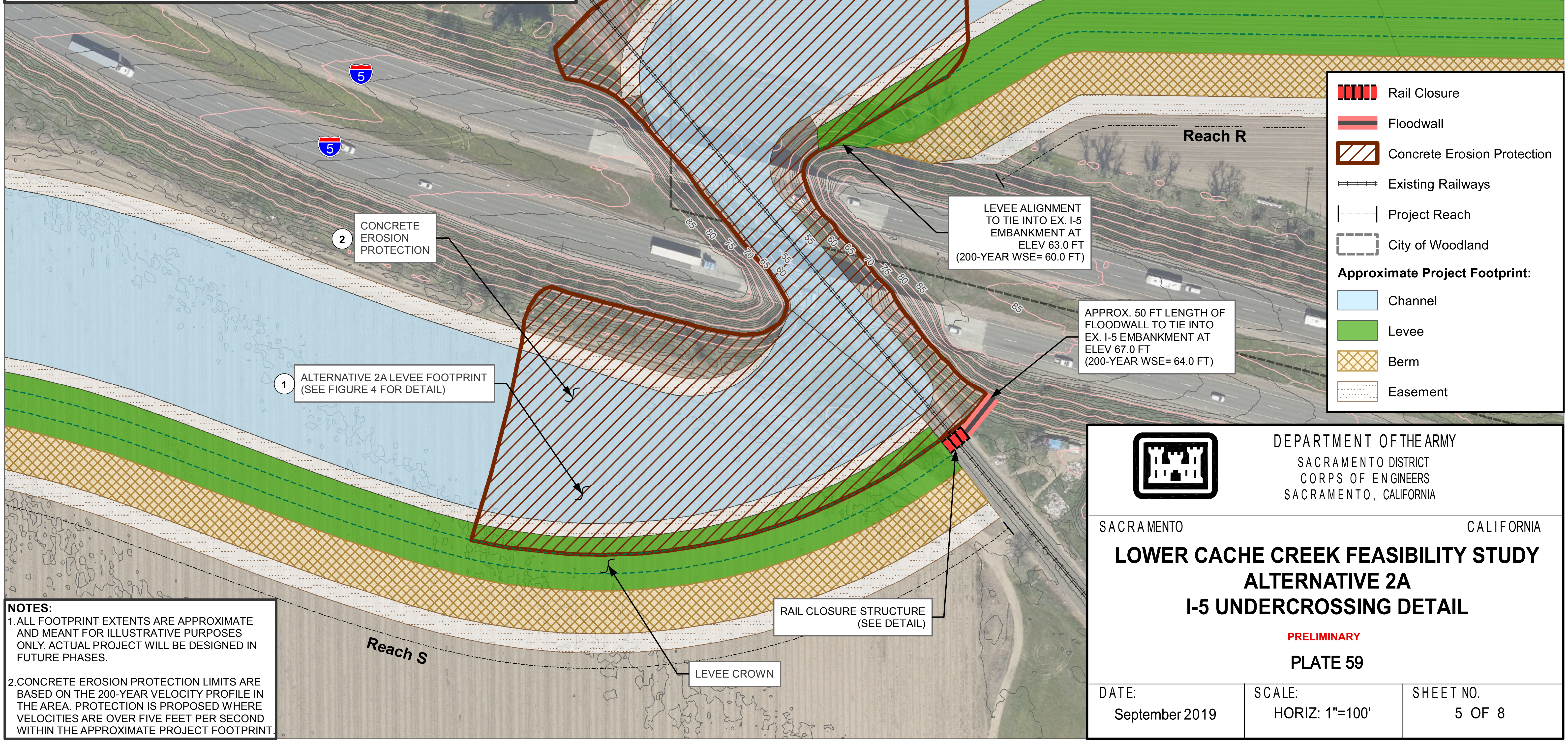
DATE:	SCALE:	SHEET NO.
AUGUST 2019	NOT TO SCALE	4 OF 8

PLOT BY: JPRIEST – Aug 15, 2019 – 6:05:26pm
DRAWING: J:\Jobs\8303\8303.032 LCCFS_Alts_2A_2B_2C\Civil\Exhibits\20190726_Project_Description_Exhibits\FIG_02-06_XSEC_DETAILS.dwg



RAIL CLOSURE STRUCTURE DETAIL

NTS



- 🟥 Rail Closure
- 🟥 Floodwall
- ▨ Concrete Erosion Protection
- ┼┼┼ Existing Railways
- ├·-·┤ Project Reach
- ⬚ City of Woodland

Approximate Project Footprint:

- 🟦 Channel
- 🟩 Levee
- ▨ Berm
- ░ Easement

NOTES:

1. ALL FOOTPRINT EXTENTS ARE APPROXIMATE AND MEANT FOR ILLUSTRATIVE PURPOSES ONLY. ACTUAL PROJECT WILL BE DESIGNED IN FUTURE PHASES.

2. CONCRETE EROSION PROTECTION LIMITS ARE BASED ON THE 200-YEAR VELOCITY PROFILE IN THE AREA. PROTECTION IS PROPOSED WHERE VELOCITIES ARE OVER FIVE FEET PER SECOND WITHIN THE APPROXIMATE PROJECT FOOTPRINT.

DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

SACRAMENTO CALIFORNIA

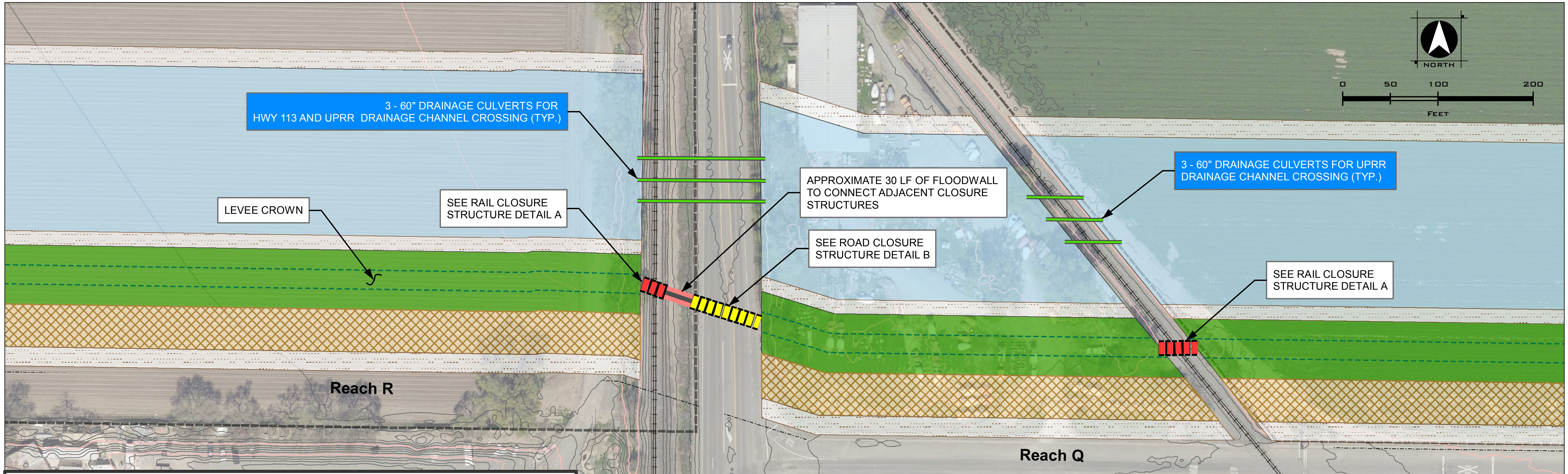
LOWER CACHE CREEK FEASIBILITY STUDY
ALTERNATIVE 2A
I-5 UNDERCROSSING DETAIL

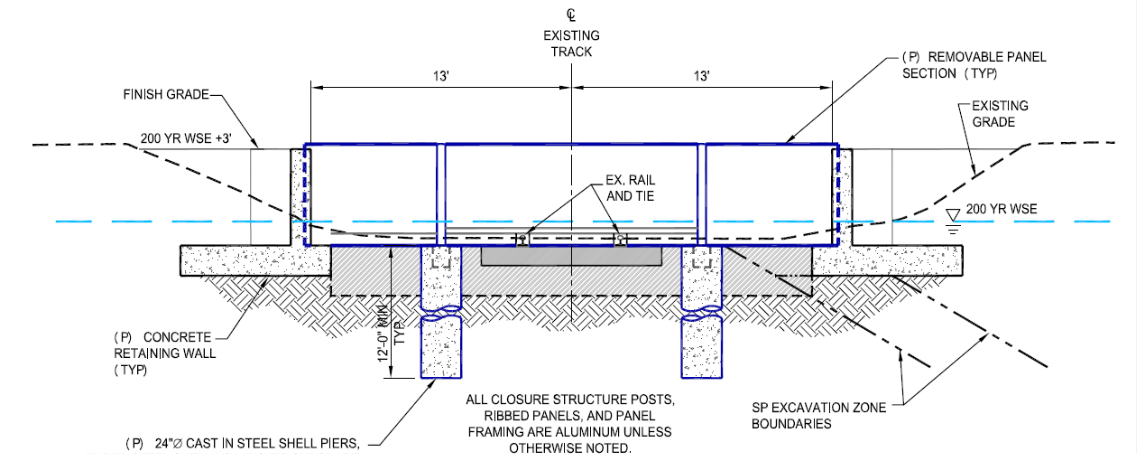
PRELIMINARY

PLATE 59

DATE:	SCALE:	SHEET NO.
September 2019	HORIZ: 1"=100'	5 OF 8

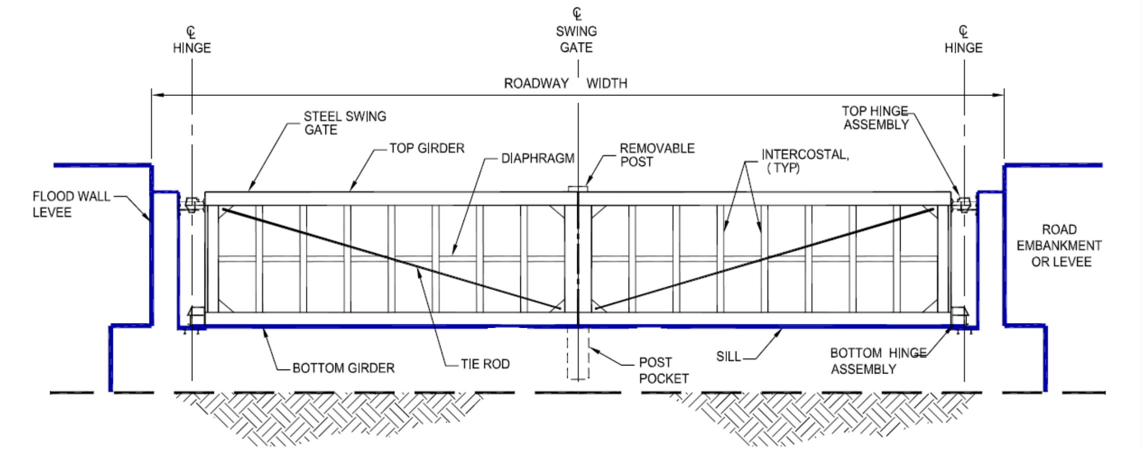
J:\Jobs\8303\8303.032 LCCFS_Alts_2A_2B_2C\GIS\Tasks\20190725_Project_Description_Exhibits\FIG_05_Rail_Closure_20190813.mxd 8/14/2019 3:02:47 PM jpriest





ALL CLOSURE STRUCTURE POSTS, RIBBED PANELS, AND PANEL FRAMING ARE ALUMINUM UNLESS OTHERWISE NOTED.

RAIL CLOSURE STRUCTURE DETAIL A
NTS



ROAD CLOSURE STRUCTURE DETAIL B
NTS

🟥 Rail Closure
🟥 Floodwall
🟨 Road Closure
┼┼┼ Existing Railways
├┈┤ Project Reach
▭ City of Woodland

Levee Footprint Design:
🟦 Channel
🟩 Levee
▨ Berm
▭ Easement
🟩 Proposed Culvert

DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

SACRAMENTO CALIFORNIA

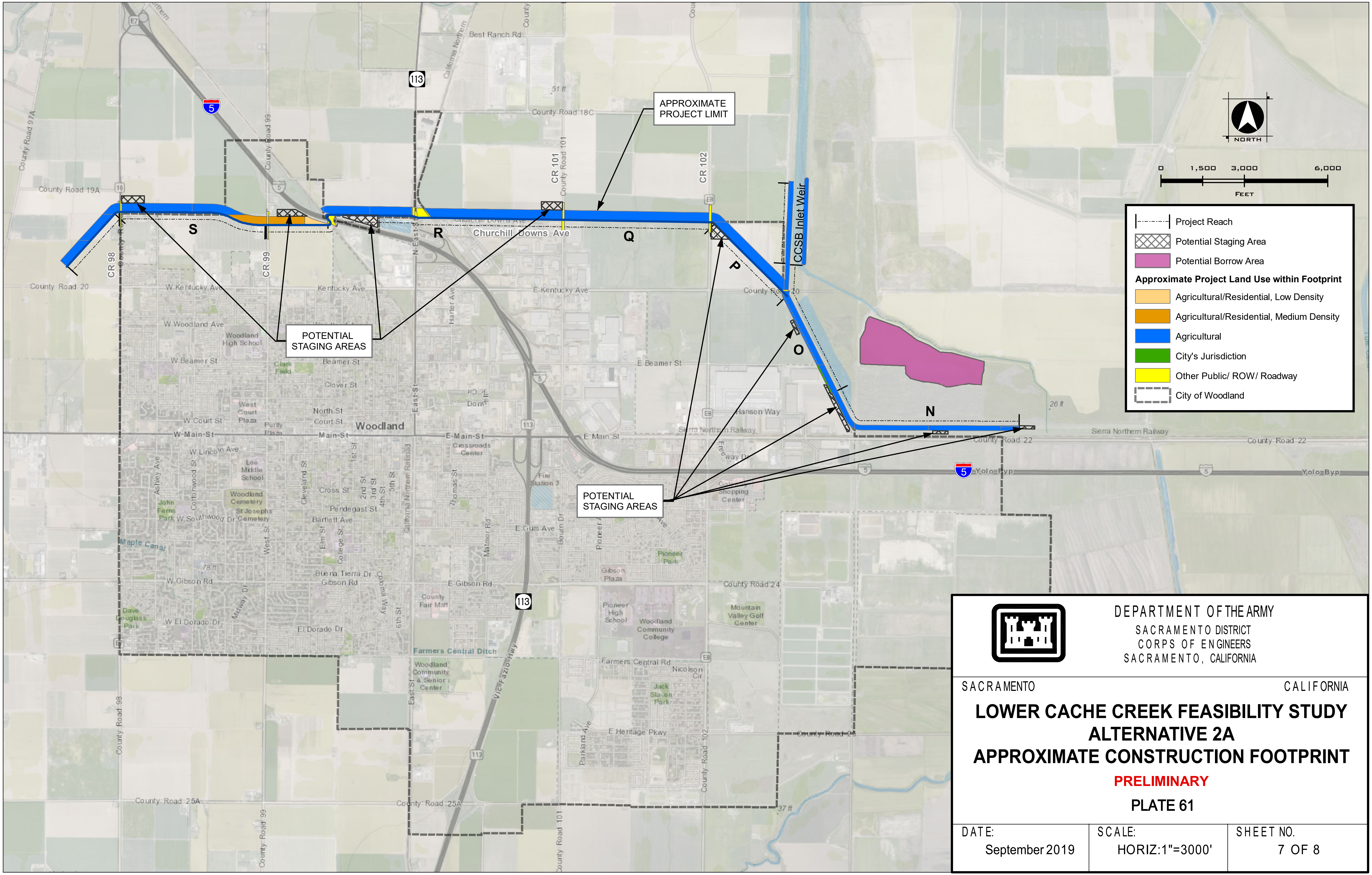
LOWER CACHE CREEK FEASIBILITY STUDY
ALTERNATIVE 2A
HWY 113 AND UPRR CROSSINGS DETAIL

PRELIMINARY

PLATE 60

DATE:	SCALE:	SHEET NO.
September 2019	HORIZ: 1"=100'	6 OF 8

J:\Jobs\8303\8303.032 LCCFS_Alts_2A_2B_2C\GIS\Tasks\20190725_Project_Description_Exhibits\FIG_06_Rail_Closure-2_20190814.mxd 8/15/2019 6:12:27 PM jpriest



DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

SACRAMENTO CALIFORNIA

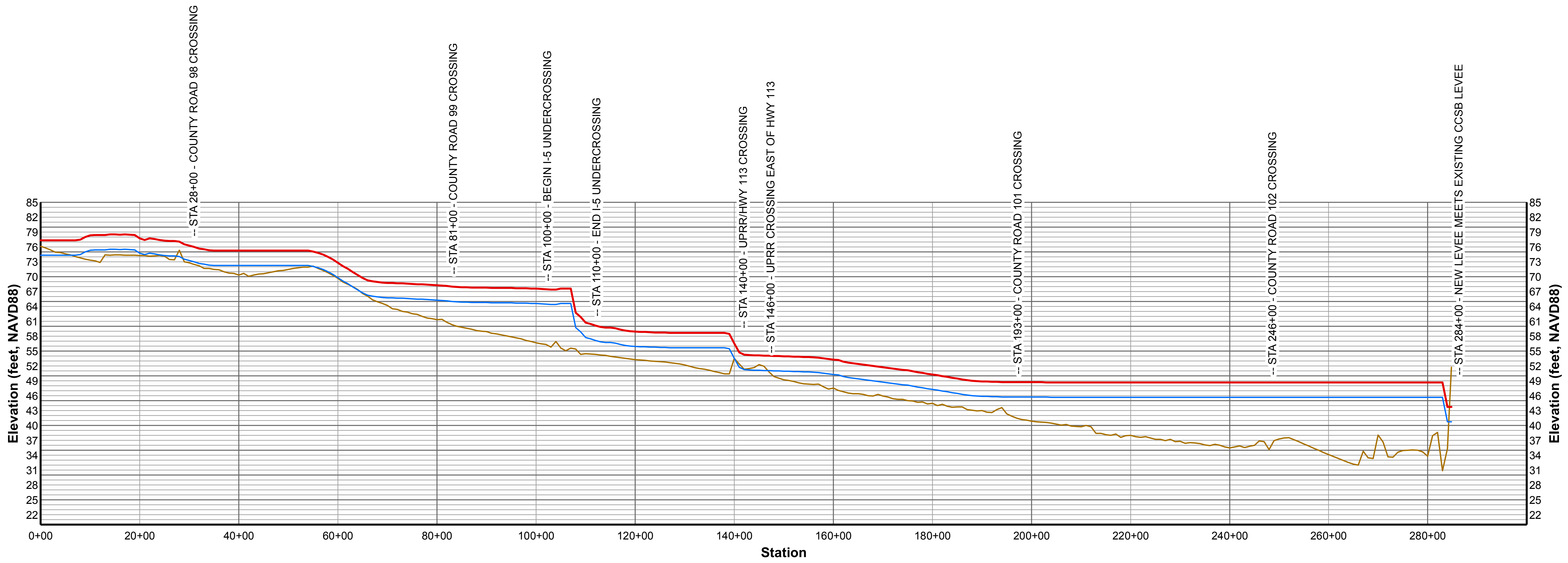
LOWER CACHE CREEK FEASIBILITY STUDY
ALTERNATIVE 2A
APPROXIMATE CONSTRUCTION FOOTPRINT

PRELIMINARY

PLATE 61

DATE:	SCALE:	SHEET NO.
September 2019	HORIZ:1"=3000'	7 OF 8

\\woodrodgers.loc\ProductionData\Jobs\Jobs\8303\8303.032 LCCFS_Alts_2A_2B_2C\GIS\Tasks\20190725_Project_Description_Exhibits\FIG_07_Const_Footprint_20190814.mxd 8/23/2019 3:11:00 PM chilliard



Legend

🟥	Top of Levee
🟦	200 year Water Surface
🟫	Existing Ground

NOTES:

1. SEE FIGURE 1 FOR PLAN VIEW OF ALIGNMENT SHOWN IN THIS PROFILE

0 1,000 2,000 4,000
Feet

DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

SACRAMENTO CALIFORNIA

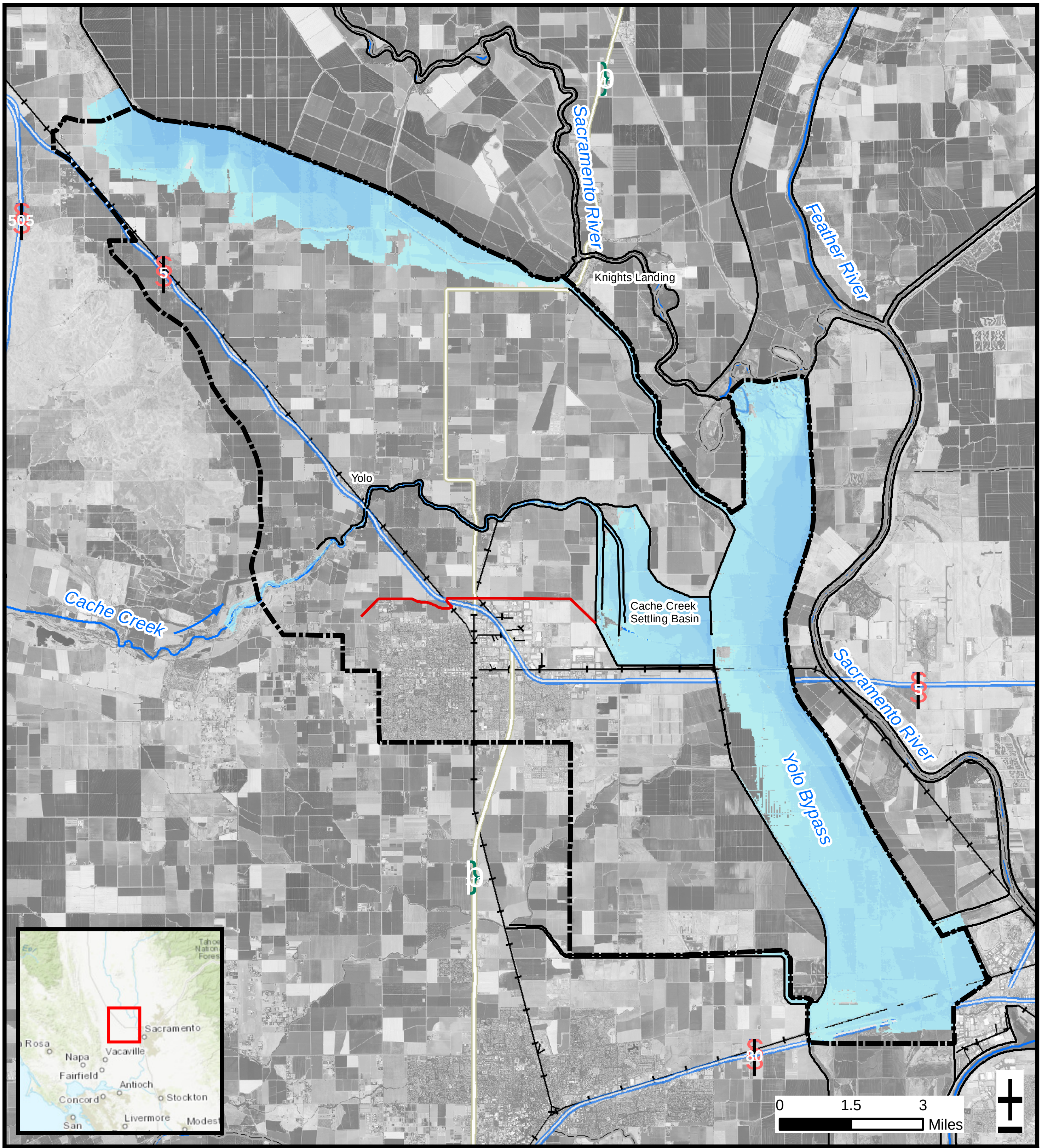
LOWER CACHE CREEK FEASIBILITY STUDY
ALTERNATIVE 2A
LEVEE PROFILE

PRELIMINARY

PLATE 62

DATE:	SCALE:	SHEET NO.
SEPTEMBER 2019	Vertical: 1"=20' Horizontal: 1"=2000'	8 OF 8

J:\Jobs\8303\8303.032 LCCFS_Alts_2A_2B_2C\GIS\Tasks\20190725_Project_Description_Exhibits\Fig_08_Profile_Map_20190814.mxd 8/15/2019 6:20:17 PM jpriest



Legend

- Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

Max Depth (feet)

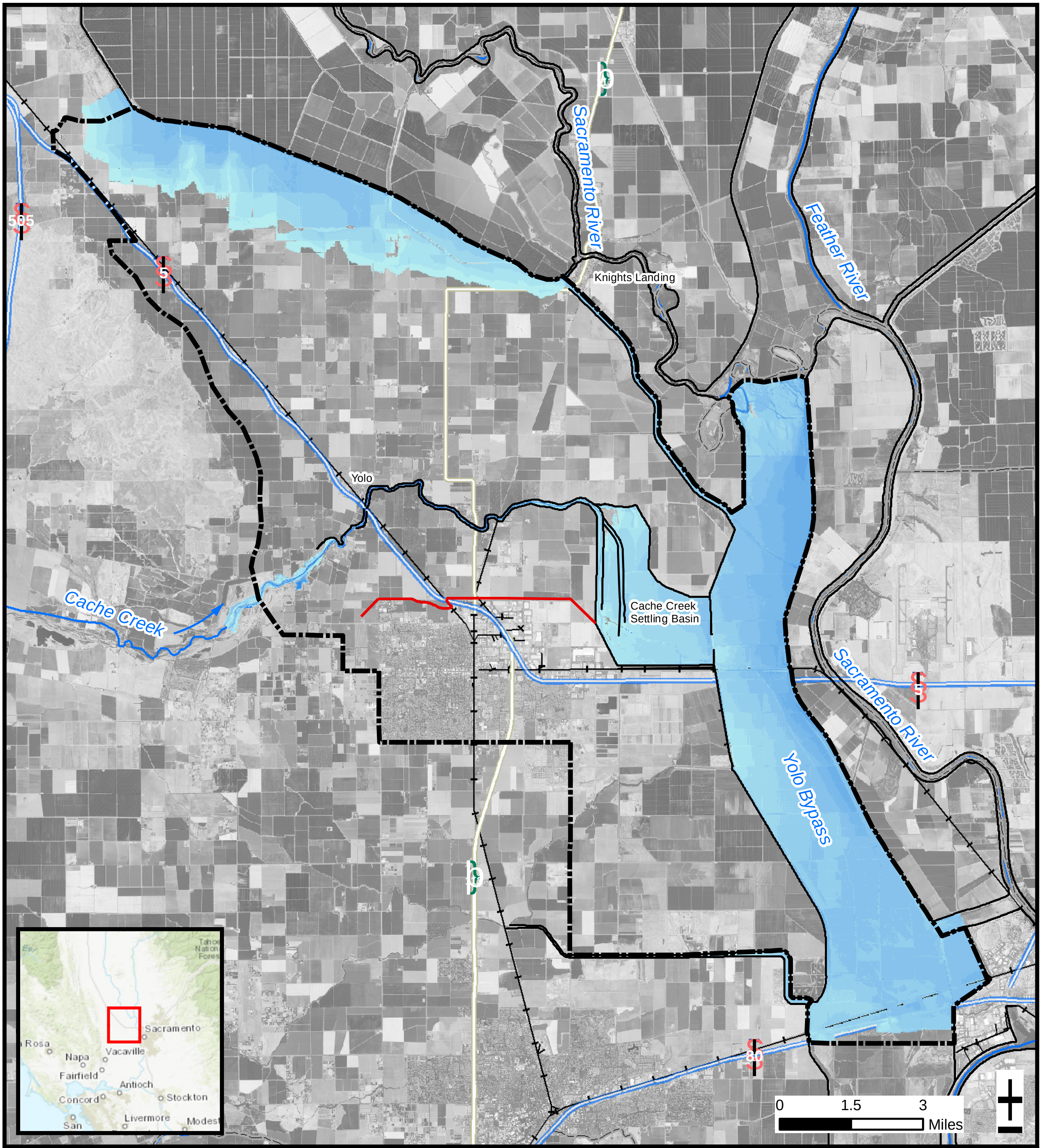
- 0 to 2
- 2 to 4
- 4 to 6
- 6 to 8
- 8 to 10
- 10 to 12
- 12 to 14
- 14 to 16
- 16 to 18
- 18 to 20
- 20 to 22
- 22 to 24
- 24 to 26
- 26 to 28
- 28 to 30
- 30 to 32
- 32 to 34
- 34 to 36
- 36 to 38
- 38 to 40
- 40 to 42
- 42 to 44
- 44 to 46

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE SOUTH BYPASS 2A 50% (1/2) ACE FLOODPLAIN OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

Proposed Levee
Project Boundary
Existing Federal Levees
Interstate
Highway
Railroad
County Boundary
River/Creek

Max Depth (feet)

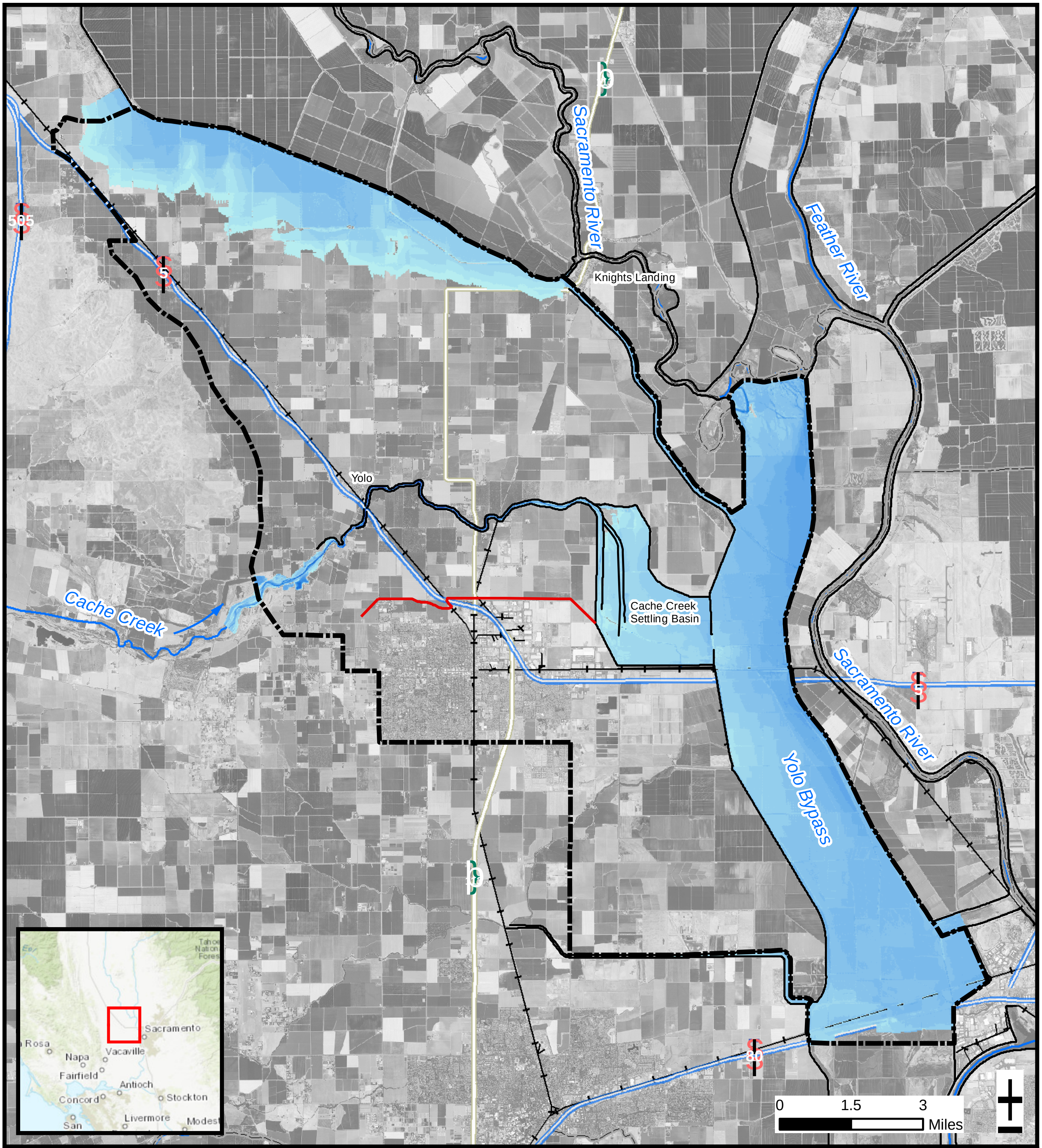
0 to 2
2 to 4
4 to 6
6 to 8
8 to 10
10 to 12
12 to 14
14 to 16
16 to 18
18 to 20
20 to 22
22 to 24
24 to 26
26 to 28
28 to 30
30 to 32
32 to 34
34 to 36
36 to 38
38 to 40
40 to 42
42 to 44
44 to 46

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE SOUTH BYPASS 2A 20% (1/5) ACE FLOODPLAIN OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

Proposed Levee

Project Boundary

Existing Federal Levees

Interstate

Highway

Railroad

County Boundary

River/Creek

Max Depth (feet)

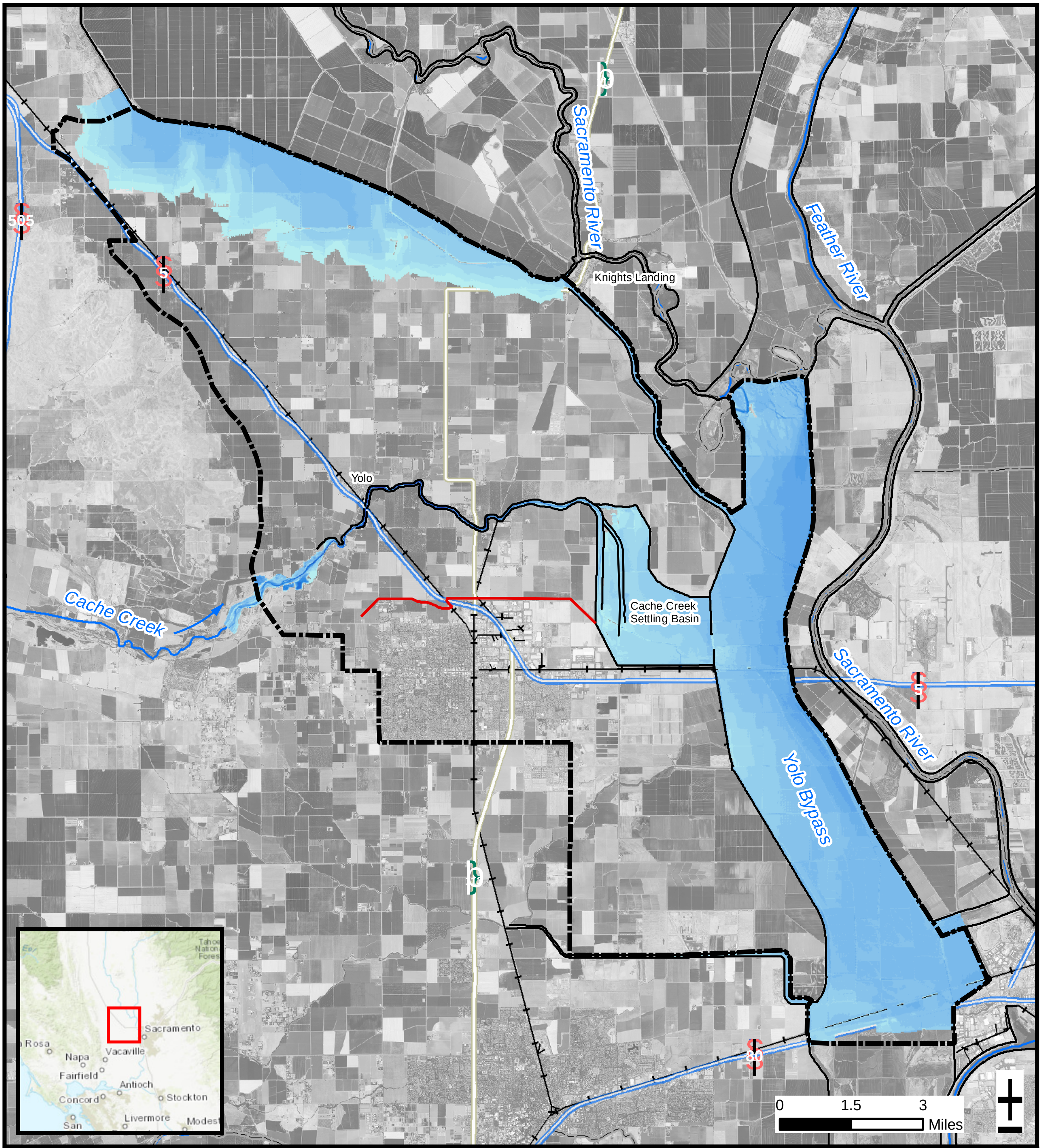
0 to 2
2 to 4
4 to 6
6 to 8
8 to 10
10 to 12
12 to 14
14 to 16
16 to 18
18 to 20
20 to 22
22 to 24
24 to 26
26 to 28
28 to 30
30 to 32
32 to 34
34 to 36
36 to 38
38 to 40
40 to 42
42 to 44
44 to 46

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE SOUTH BYPASS 2A 10% (1/10) ACE FLOODPLAIN OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

Proposed Levee
Project Boundary
Existing Federal Levees
Interstate
Highway
Railroad
County Boundary
River/Creek

Max Depth (feet)

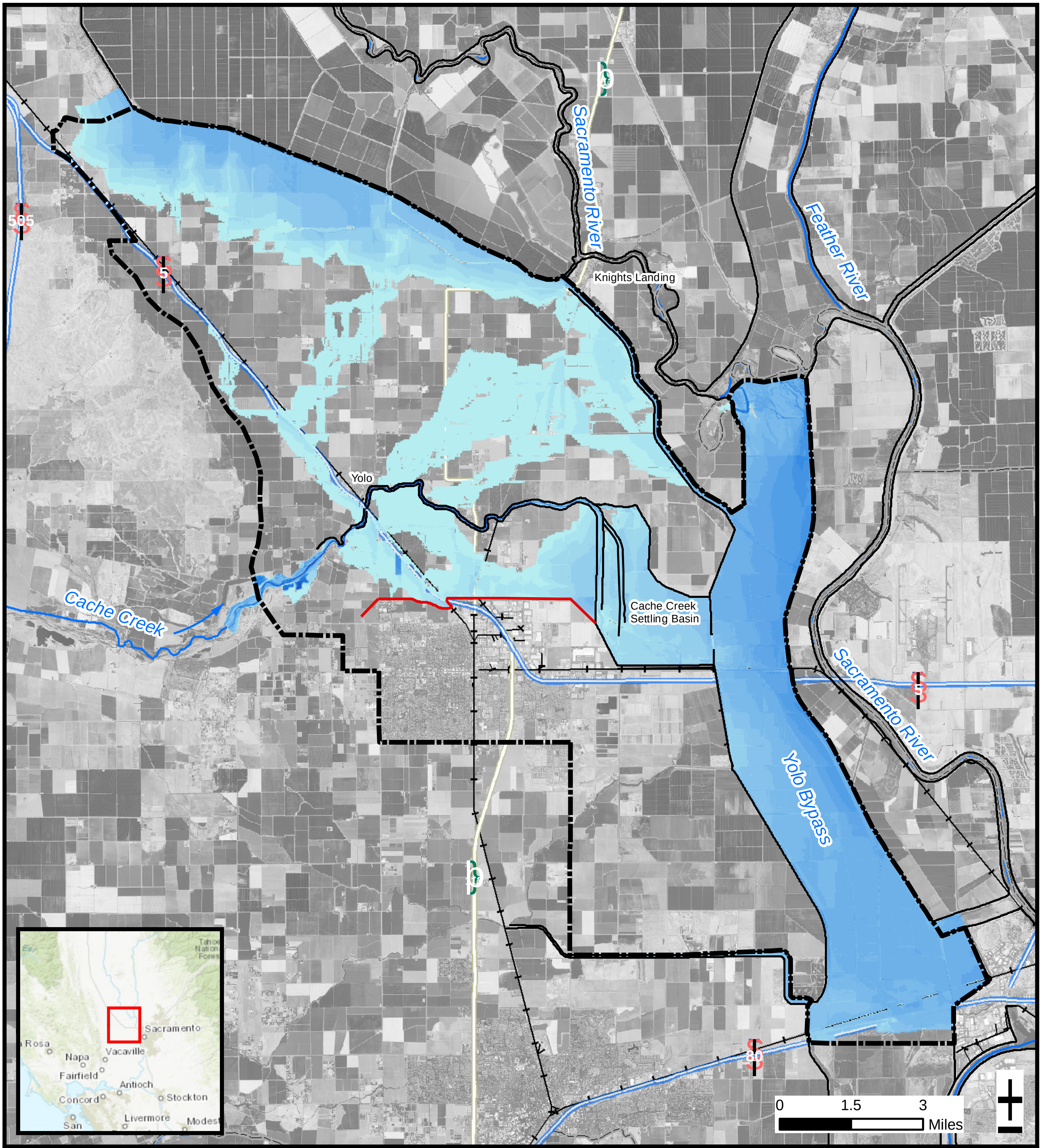
0 to 2
2 to 4
4 to 6
6 to 8
8 to 10
10 to 12
12 to 14
14 to 16
16 to 18
18 to 20
20 to 22
22 to 24
24 to 26
26 to 28
28 to 30
30 to 32
32 to 34
34 to 36
36 to 38
38 to 40
40 to 42
42 to 44
44 to 46

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE SOUTH BYPASS 2A 5% (1/20) ACE FLOODPLAIN OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

- Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

Max Depth (feet)

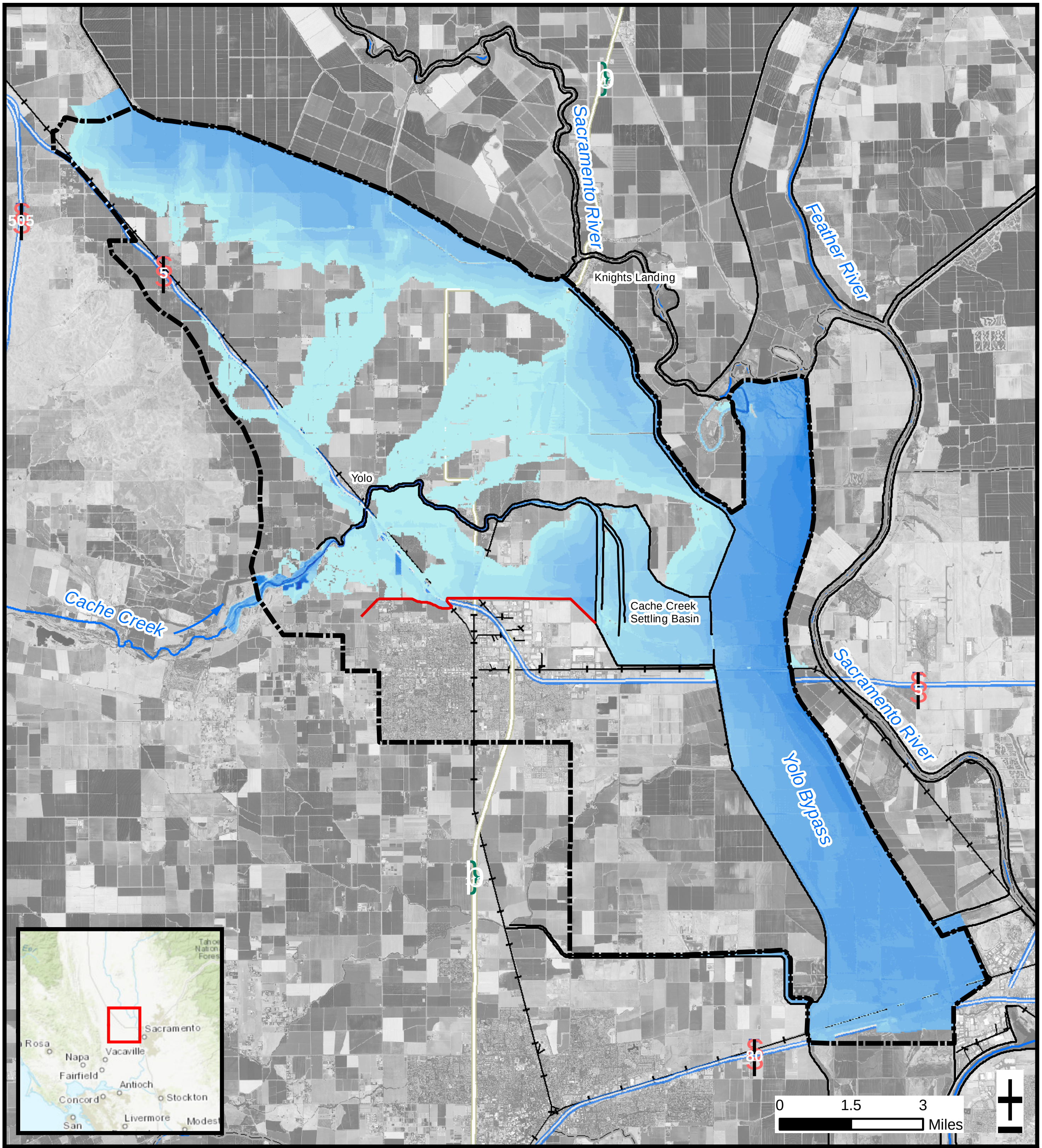
- 0 to 2
- 2 to 4
- 4 to 6
- 6 to 8
- 8 to 10
- 10 to 12
- 12 to 14
- 14 to 16
- 16 to 18
- 18 to 20
- 20 to 22
- 22 to 24
- 24 to 26
- 26 to 28
- 28 to 30
- 30 to 32
- 32 to 34
- 34 to 36
- 36 to 38
- 38 to 40
- 40 to 42
- 42 to 44
- 44 to 46

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE SOUTH BYPASS 2A 2% (1/50) ACE FLOODPLAIN OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

- 🟥 Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

Max Depth (feet)

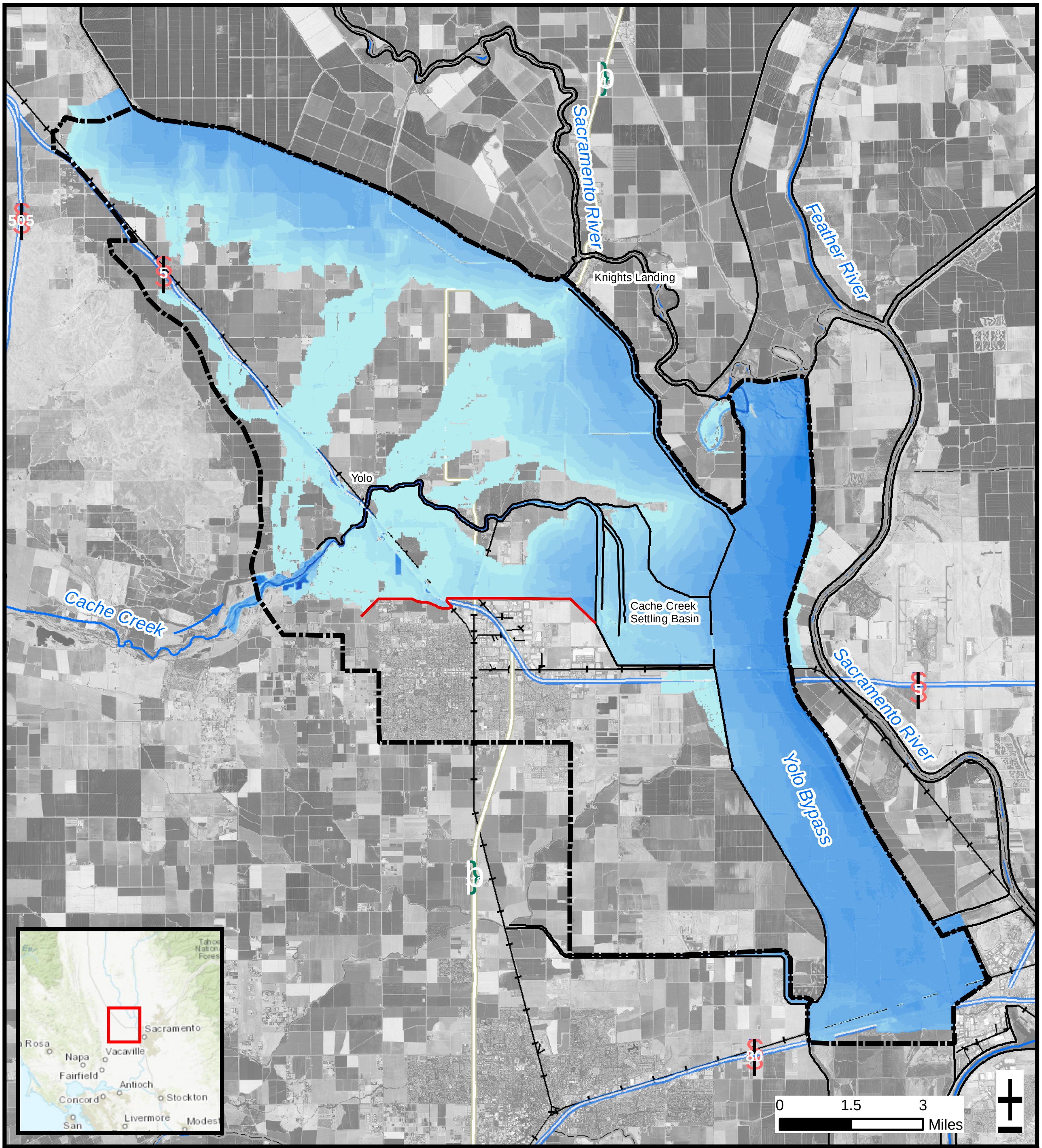
- 0 to 2
- 2 to 4
- 4 to 6
- 6 to 8
- 8 to 10
- 10 to 12
- 12 to 14
- 14 to 16
- 16 to 18
- 18 to 20
- 20 to 22
- 22 to 24
- 24 to 26
- 26 to 28
- 28 to 30
- 30 to 32
- 32 to 34
- 34 to 36
- 36 to 38
- 38 to 40
- 40 to 42
- 42 to 44
- 44 to 46

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE SOUTH BYPASS 2A 1% (1/100) ACE FLOODPLAIN OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

Proposed Levee

Project Boundary

Existing Federal Levees

Interstate

Highway

Railroad

County Boundary

River/Creek

Max Depth (feet)

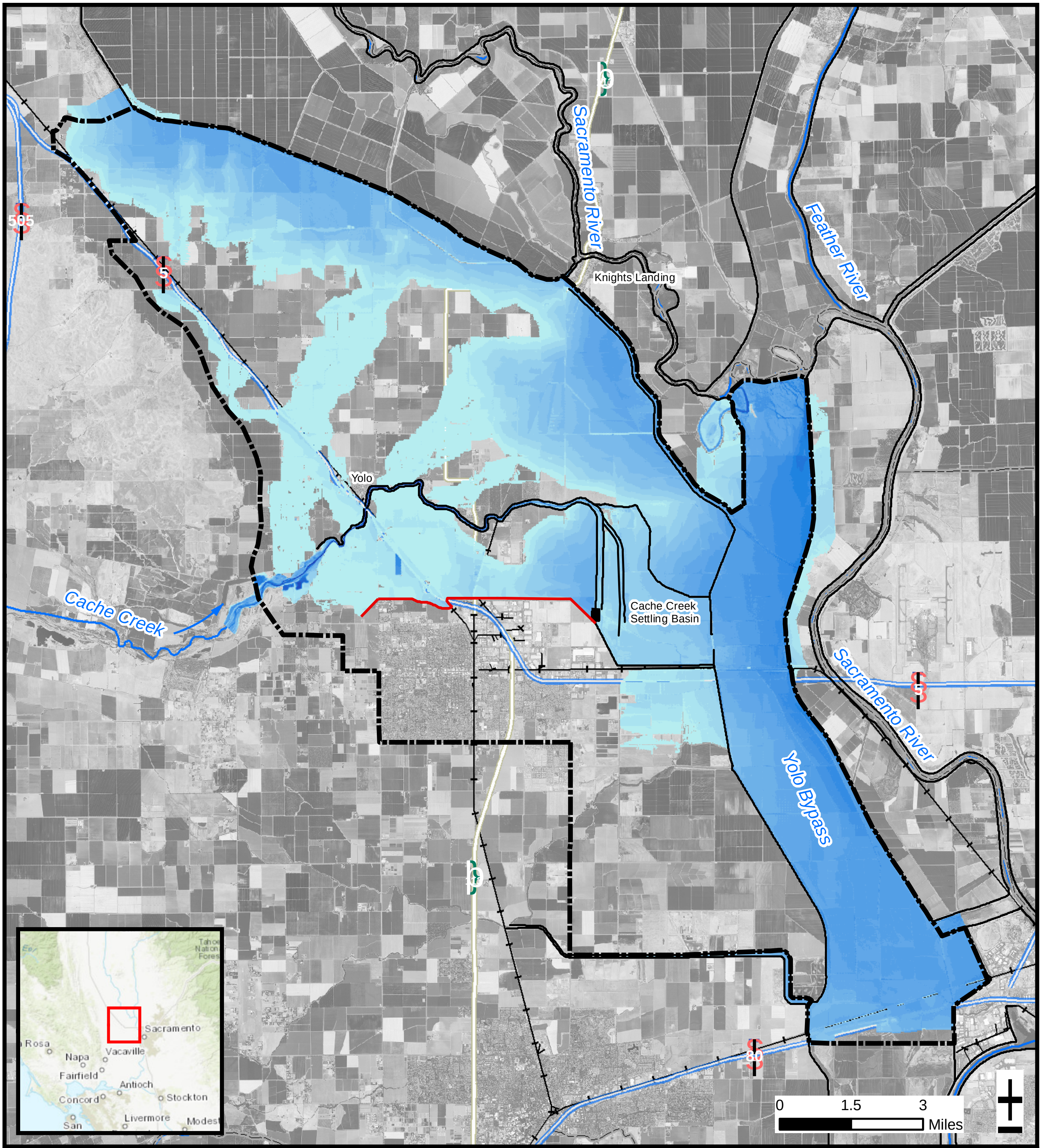
- 0 to 2
- 2 to 4
- 4 to 6
- 6 to 8
- 8 to 10
- 10 to 12
- 12 to 14
- 14 to 16
- 16 to 18
- 18 to 20
- 20 to 22
- 22 to 24
- 24 to 26
- 26 to 28
- 28 to 30
- 30 to 32
- 32 to 34
- 34 to 36
- 36 to 38
- 38 to 40
- 40 to 42
- 42 to 44
- 44 to 46

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE SOUTH BYPASS 2A 0.5% (1/200) ACE FLOODPLAIN OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

- 🟥 Proposed Levee
- ▭ Project Boundary
- — Existing Federal Levees
- ═ Interstate
- ═ Highway
- ┼ Railroad
- ▭ County Boundary
- — River/Creek

Max Depth (feet)

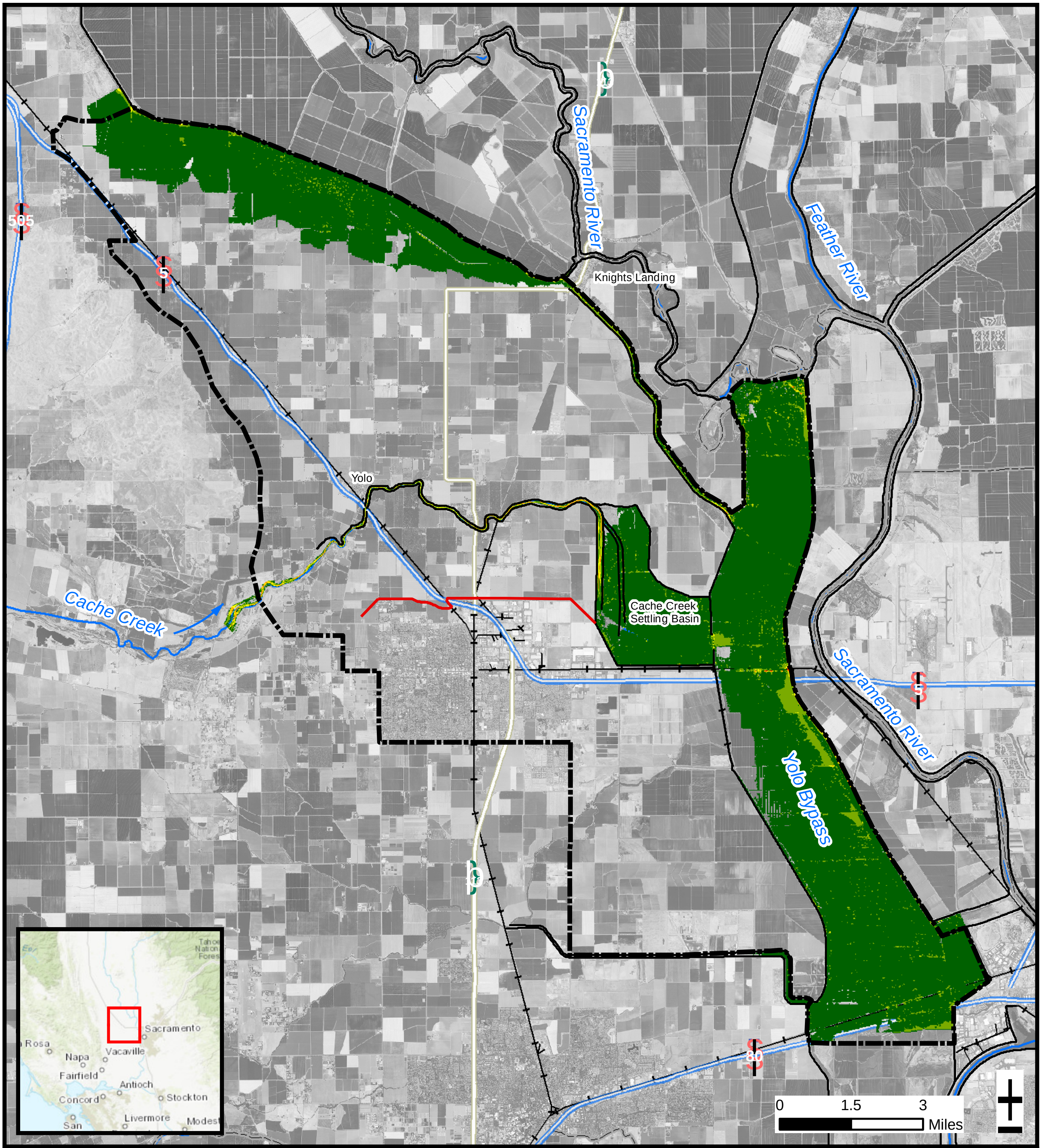
- 0 to 2
- 2 to 4
- 4 to 6
- 6 to 8
- 8 to 10
- 10 to 12
- 12 to 14
- 14 to 16
- 16 to 18
- 18 to 20
- 20 to 22
- 22 to 24
- 24 to 26
- 26 to 28
- 28 to 30
- 30 to 32
- 32 to 34
- 34 to 36
- 36 to 38
- 38 to 40
- 40 to 42
- 42 to 44
- 44 to 46

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE
SOUTH BYPASS 2A
0.2% (1/500) ACE FLOODPLAIN
OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

- Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

Velocity (fps)

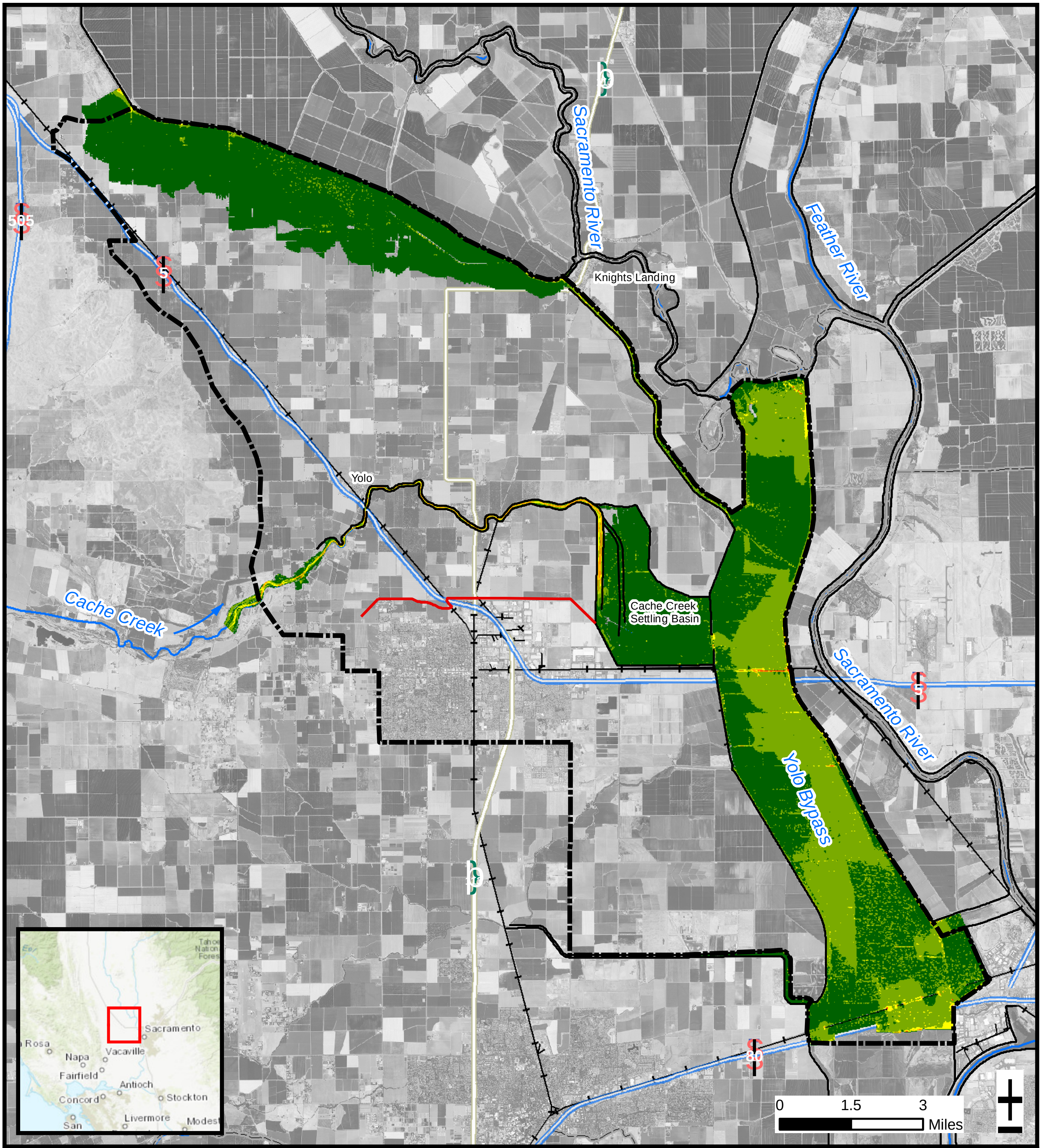
- 🟩 0 - 2
- 🟩 3 - 4
- 🟨 5 - 6
- 🟧 7 - 8
- 🟥 8+

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE
SOUTH BYPASS 2A
50% (1/2) ACE OVERTOPPING
NO FAILURE MAX VELOCITY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

- Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

Velocity (fps)

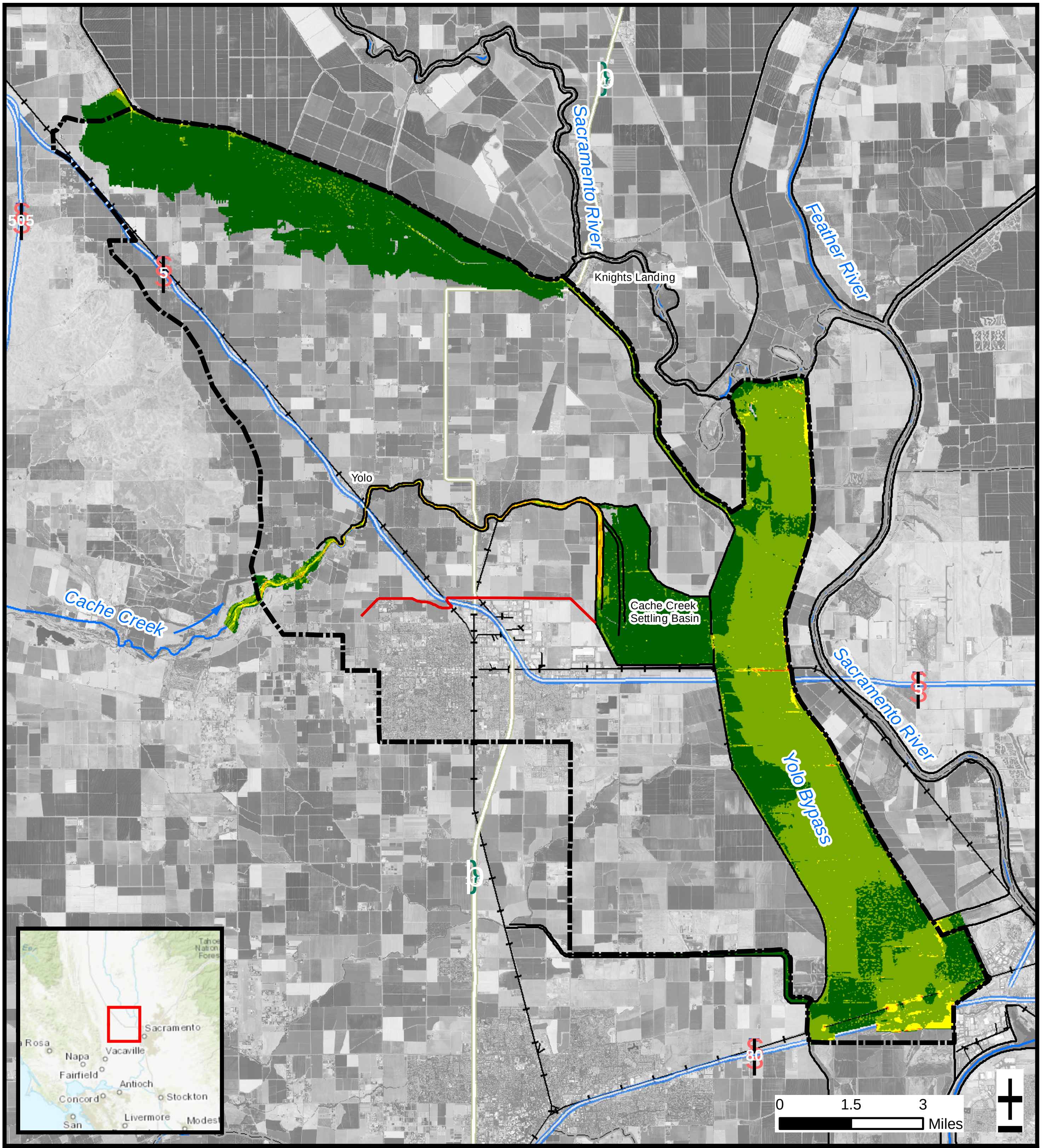
- 🟩 0 - 2
- 🟩 3 - 4
- 🟨 5 - 6
- 🟧 7 - 8
- 🟥 8+

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE
SOUTH BYPASS 2A
20% (1/5) ACE OVERTOPPING
NO FAILURE MAX VELOCITY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

- Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

Velocity (fps)

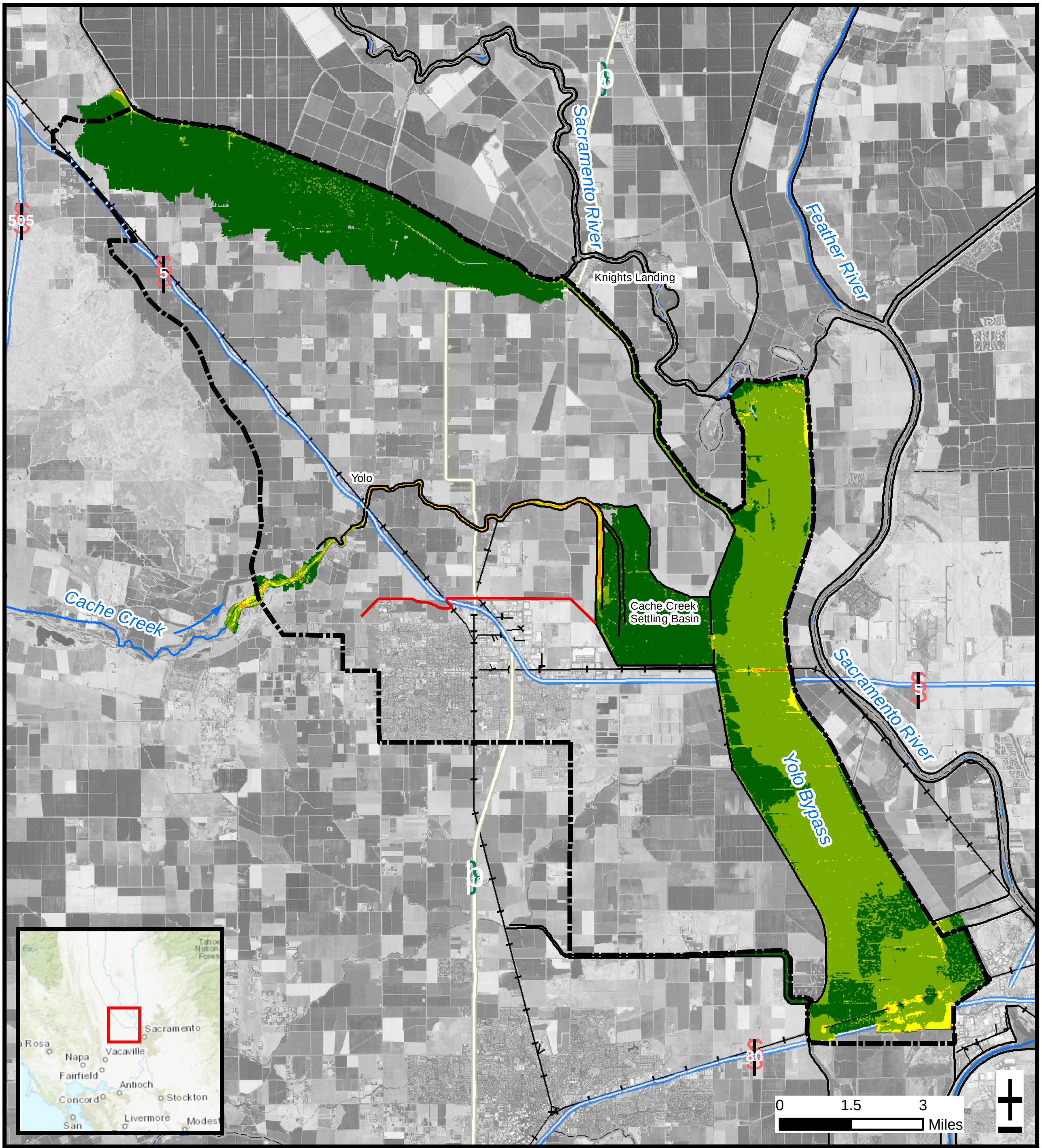
- 🟩 0 - 2
- 🟩 3 - 4
- 🟨 5 - 6
- 🟧 7 - 8
- 🟥 8+

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE SOUTH BYPASS 2A 10% (1/10) ACE OVERTOPPING NO FAILURE MAX VELOCITY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

- Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

Velocity (fps)

- 🟩 0 - 2
- 🟩 3 - 4
- 🟨 5 - 6
- 🟧 7 - 8
- 🟥 8+

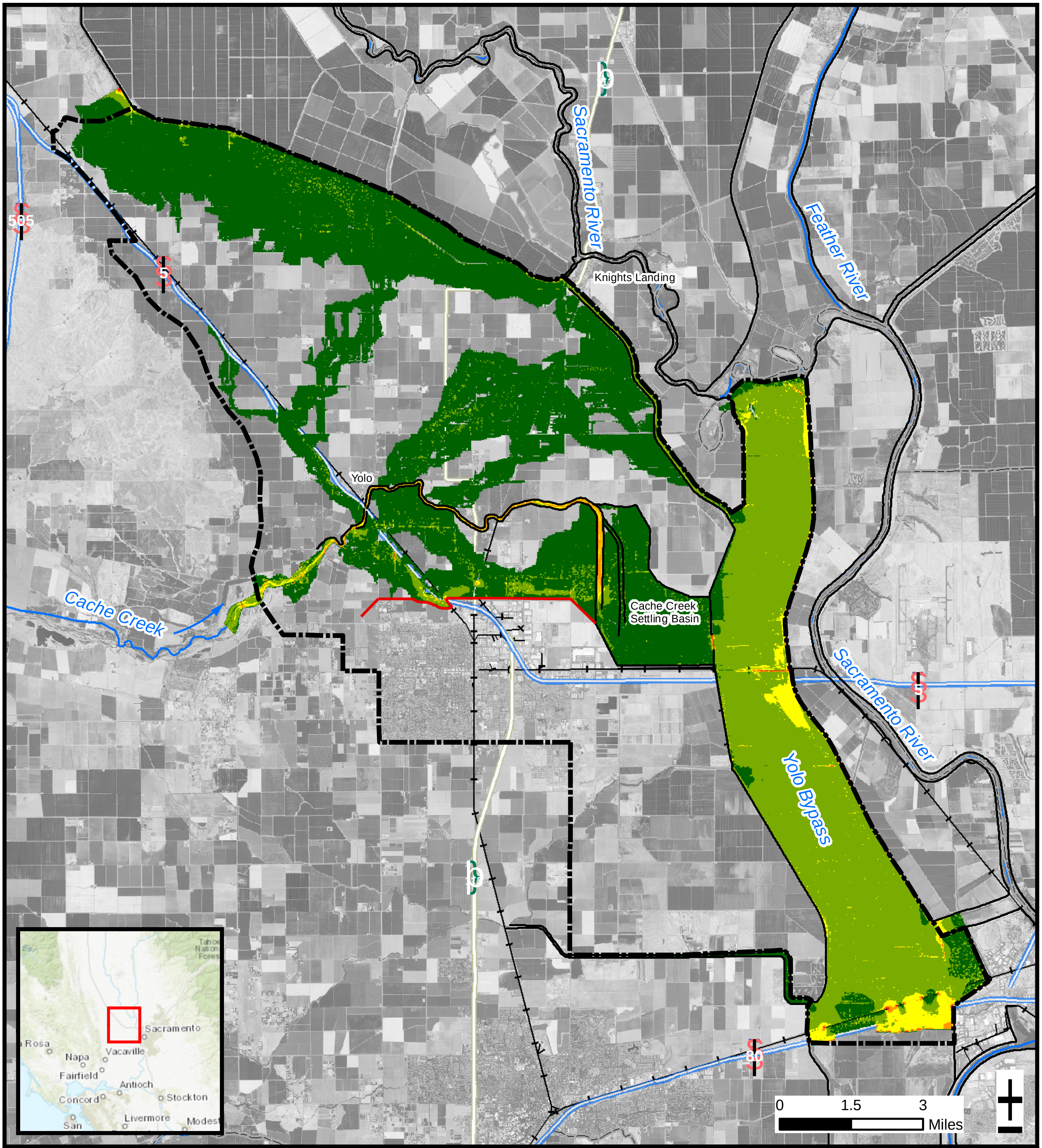
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE
SOUTH BYPASS 2A
5% (1/20) ACE OVERTOPPING
NO FAILURE MAX VELOCITY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019

PLATE 74



Legend

Proposed Levee
Project Boundary
Existing Federal Levees
Interstate
Highway
Railroad
County Boundary
River/Creek

Velocity (fps)

🟩 0 - 2
🟩 3 - 4
🟨 5 - 6
🟧 7 - 8
🟥 8+

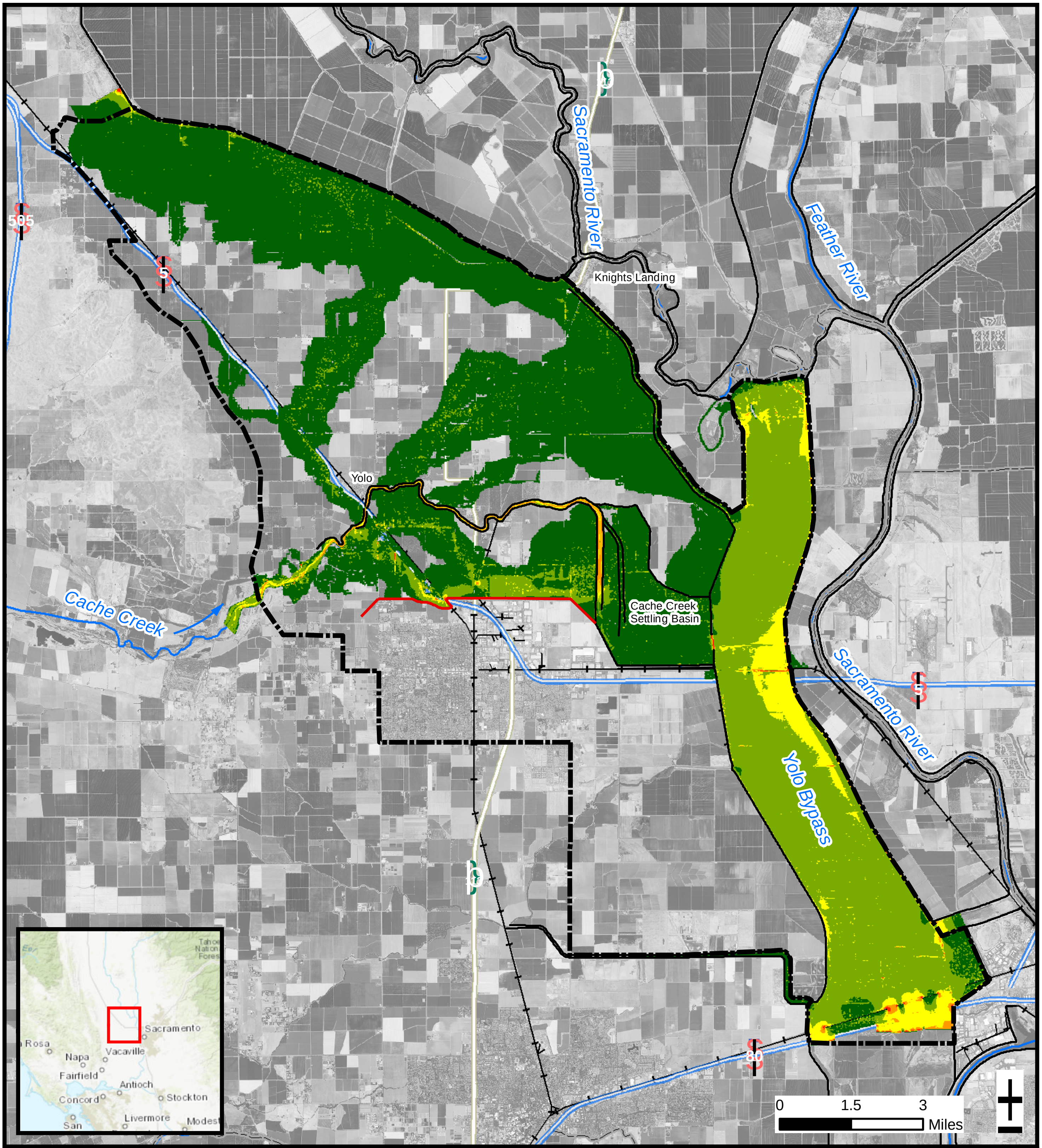
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE
SOUTH BYPASS 2A
2% (1/50) ACE OVERTOPPING
NO FAILURE MAX VELOCITY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019

PLATE XXX



Legend

- Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

Velocity (fps)

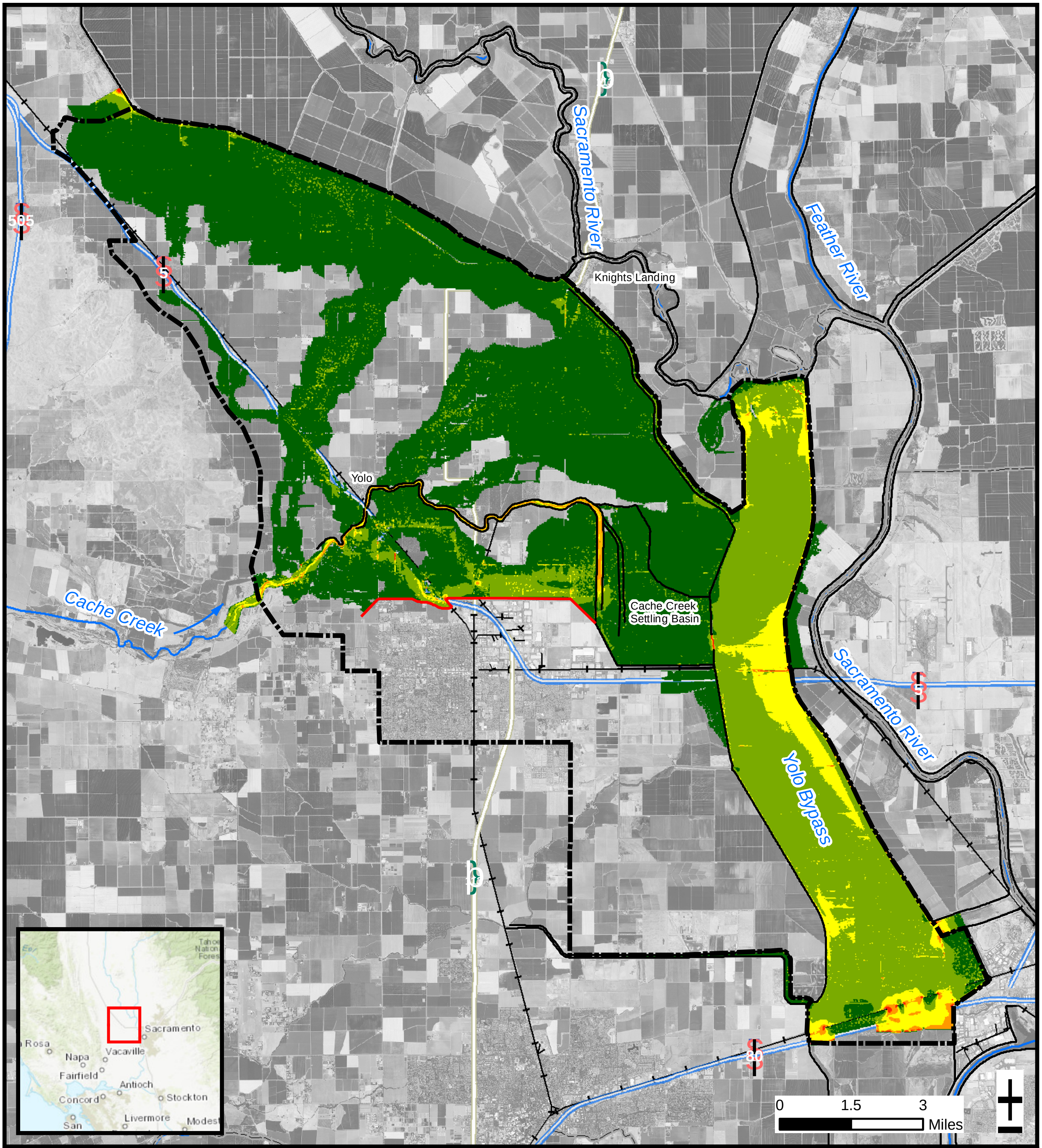
- 🟩 0 - 2
- 🟩 3 - 4
- 🟨 5 - 6
- 🟧 7 - 8
- 🟥 8+

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE
SOUTH BYPASS 2A
1% (1/100) ACE OVERTOPPING
NO FAILURE MAX VELOCITY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

- Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

Velocity (fps)

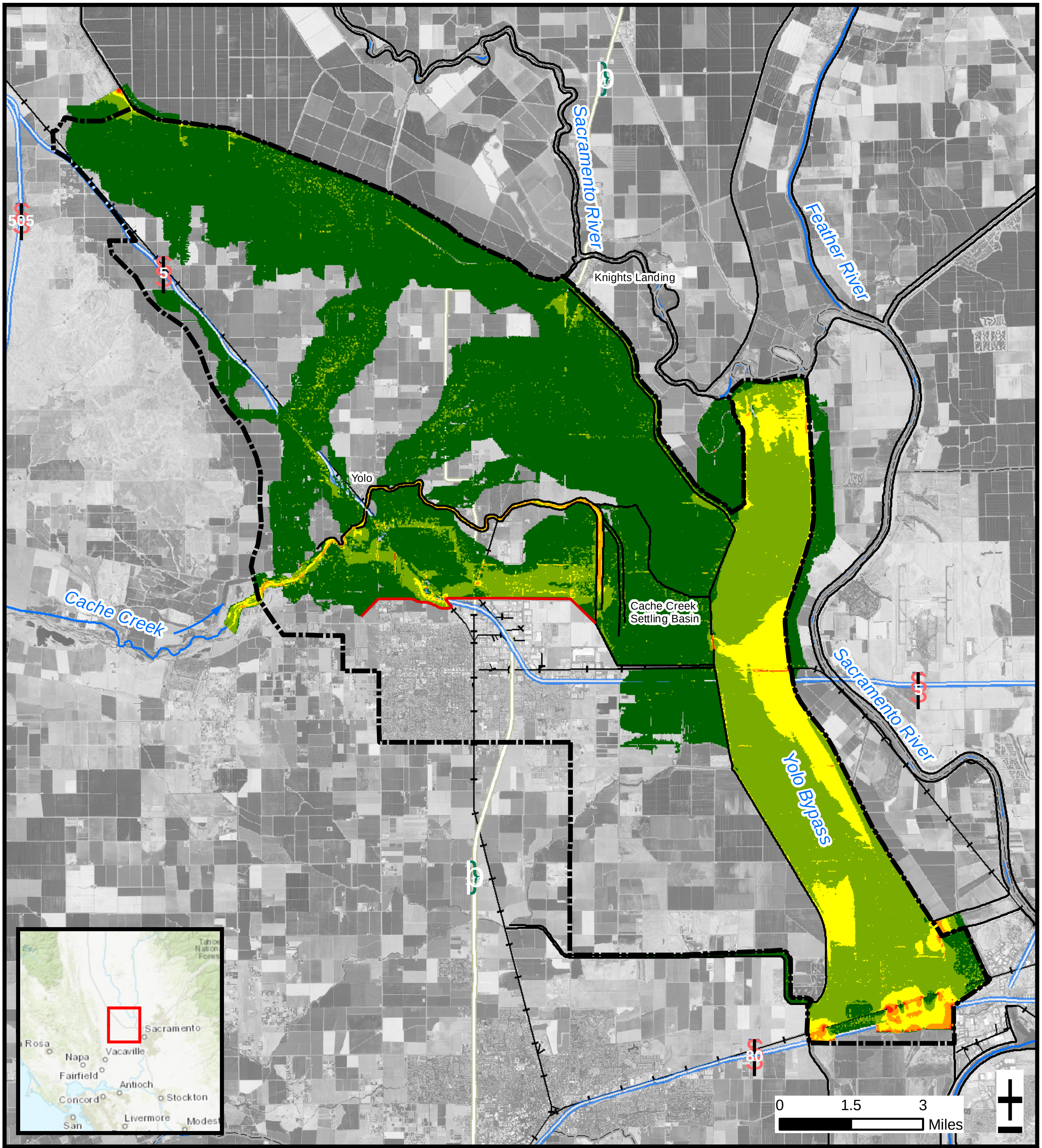
- 🟩 0 - 2
- 🟩 3 - 4
- 🟨 5 - 6
- 🟧 7 - 8
- 🟥 8+

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE
SOUTH BYPASS 2A
0.5% (1/200) ACE OVERTOPPING
NO FAILURE MAX VELOCITY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

- Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

Velocity (fps)

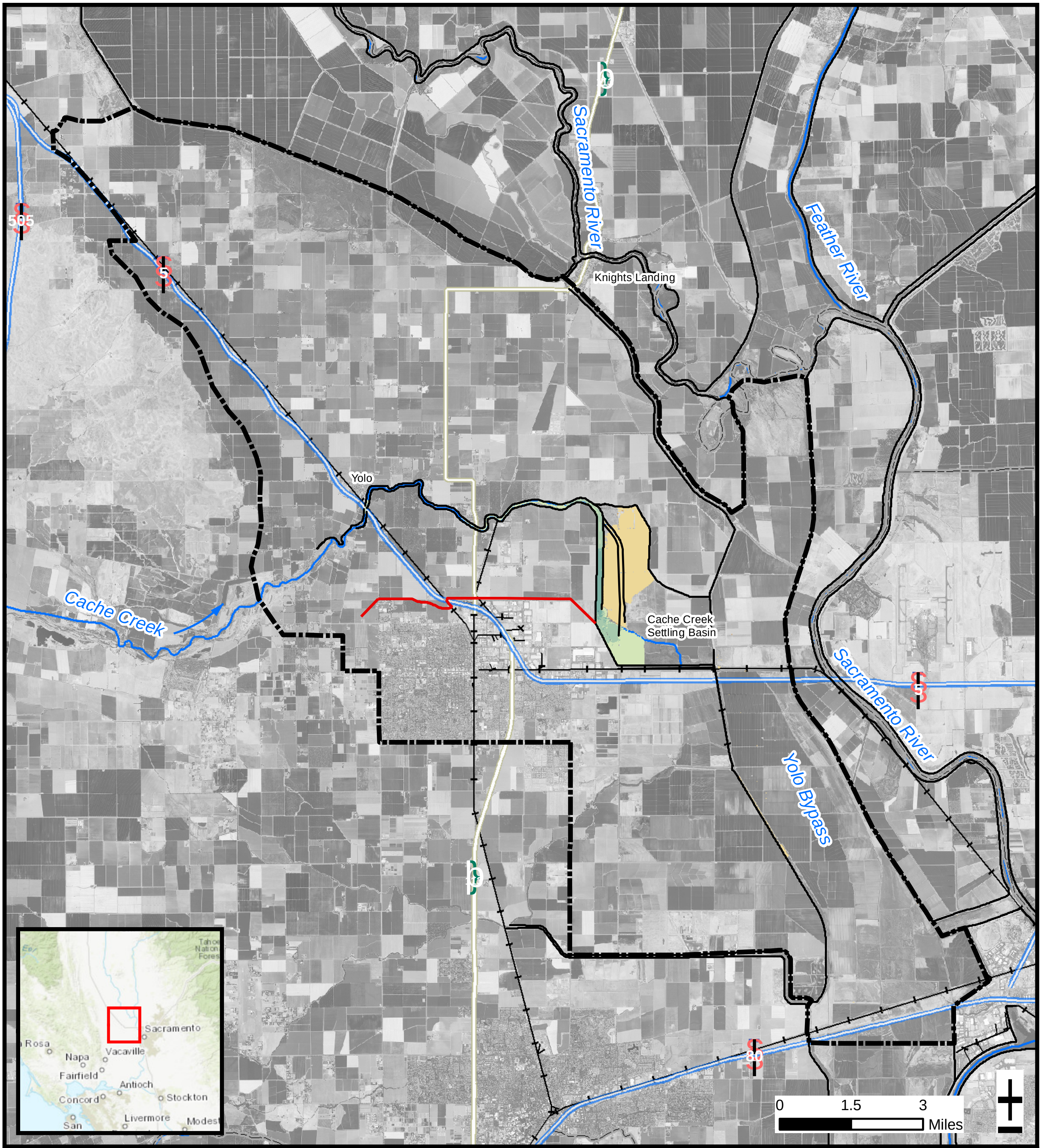
- 🟩 0 - 2
- 🟩 3 - 4
- 🟨 5 - 6
- 🟧 7 - 8
- 🟥 8+

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE SOUTH BYPASS 2A 0.2% (1/500) ACE OVERTOPPING NO FAILURE MAX VELOCITY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

- Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

Avg Change (feet)

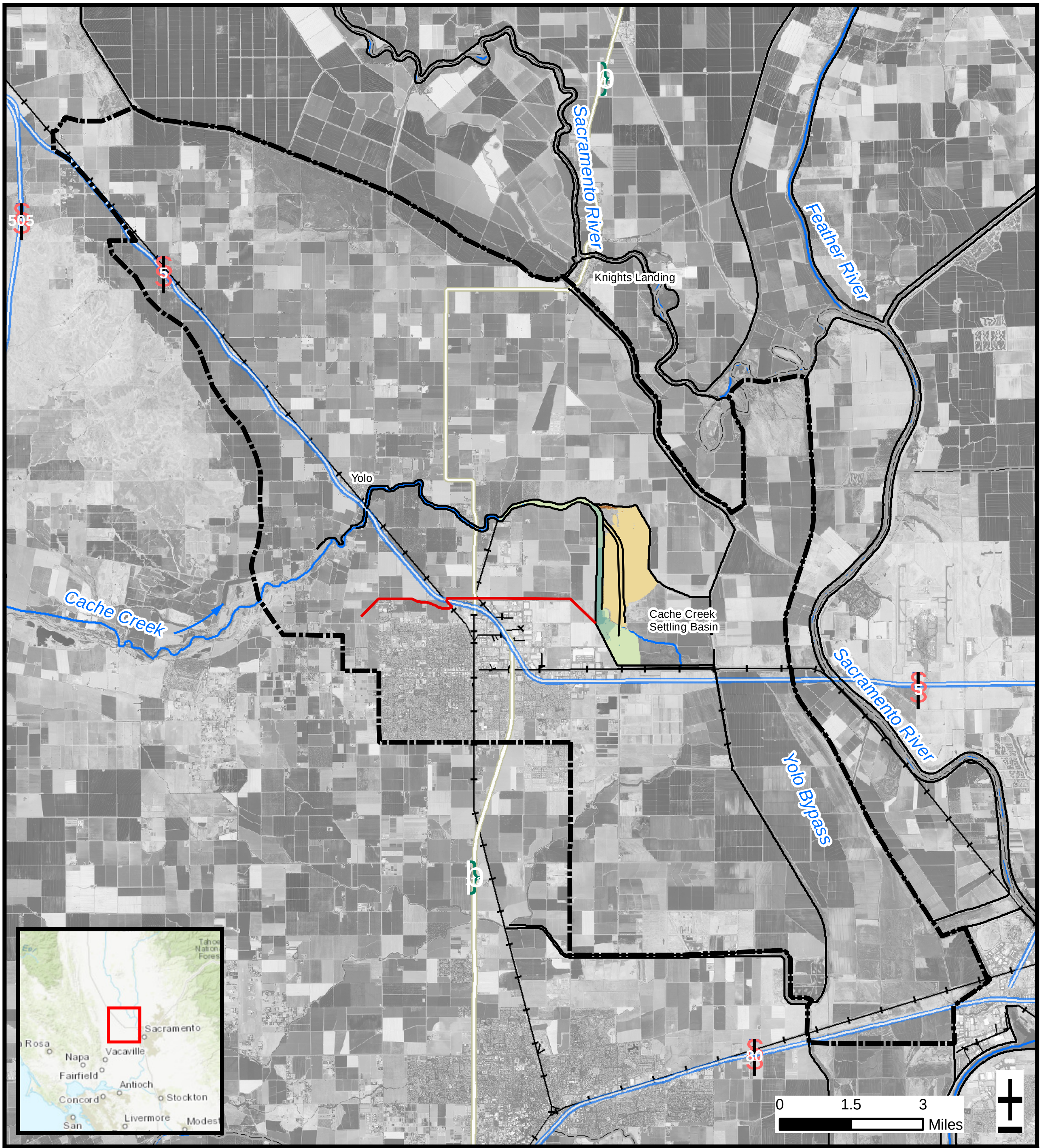
- 🟦 < -6.0
- 🟦 -6.0 - -4.0
- 🟩 -4.0 - -2.0
- 🟩 -2.0 - -1.0
- 🟩 -1.0 - -0.1
- ☐ No Change
- 🟨 0.1 - 1.0
- 🟫 1.0 - 2.0
- 🟫 2.0 - 4.0
- 🟫 4.0 - 6.0
- 🟫 > 6.0

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE
SOUTH BYPASS 2A
AVERAGE CHANGE IN FLOOD DEPTH
50% (1/2) ACE FLOOD EVENT

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

- Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

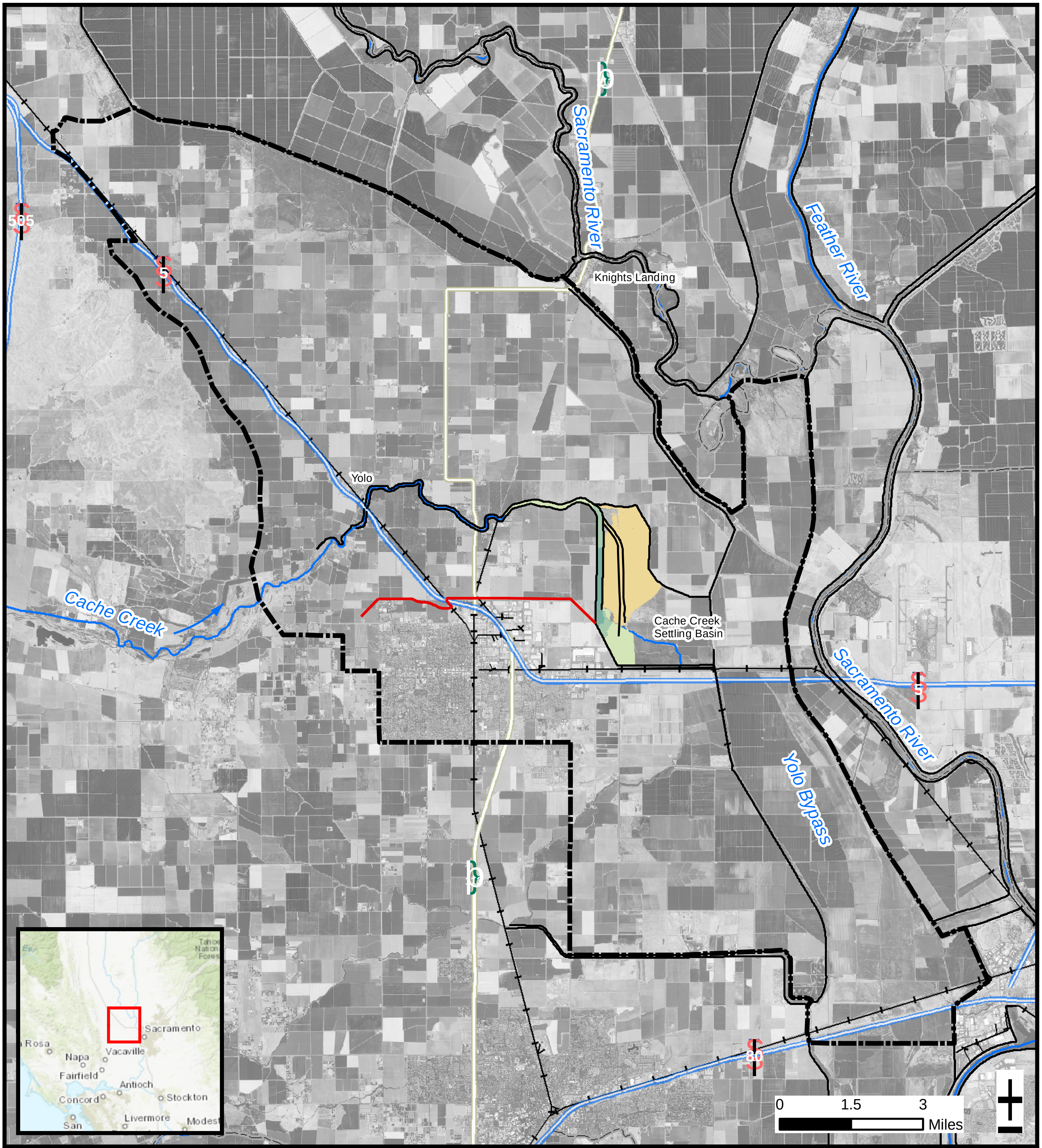
Avg Change (feet)

- < -6.0
- -6.0 - -4.0
- -4.0 - -2.0
- -2.0 - -1.0
- -1.0 - -0.1
- No Change
- 0.1 - 1.0
- 1.0 - 2.0
- 2.0 - 4.0
- 4.0 - 6.0
- > 6.0

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE
SOUTH BYPASS 2A
AVERAGE CHANGE IN FLOOD DEPTH
20% (1/5) ACE FLOOD EVENT

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



Legend

- Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

Avg Change (feet)

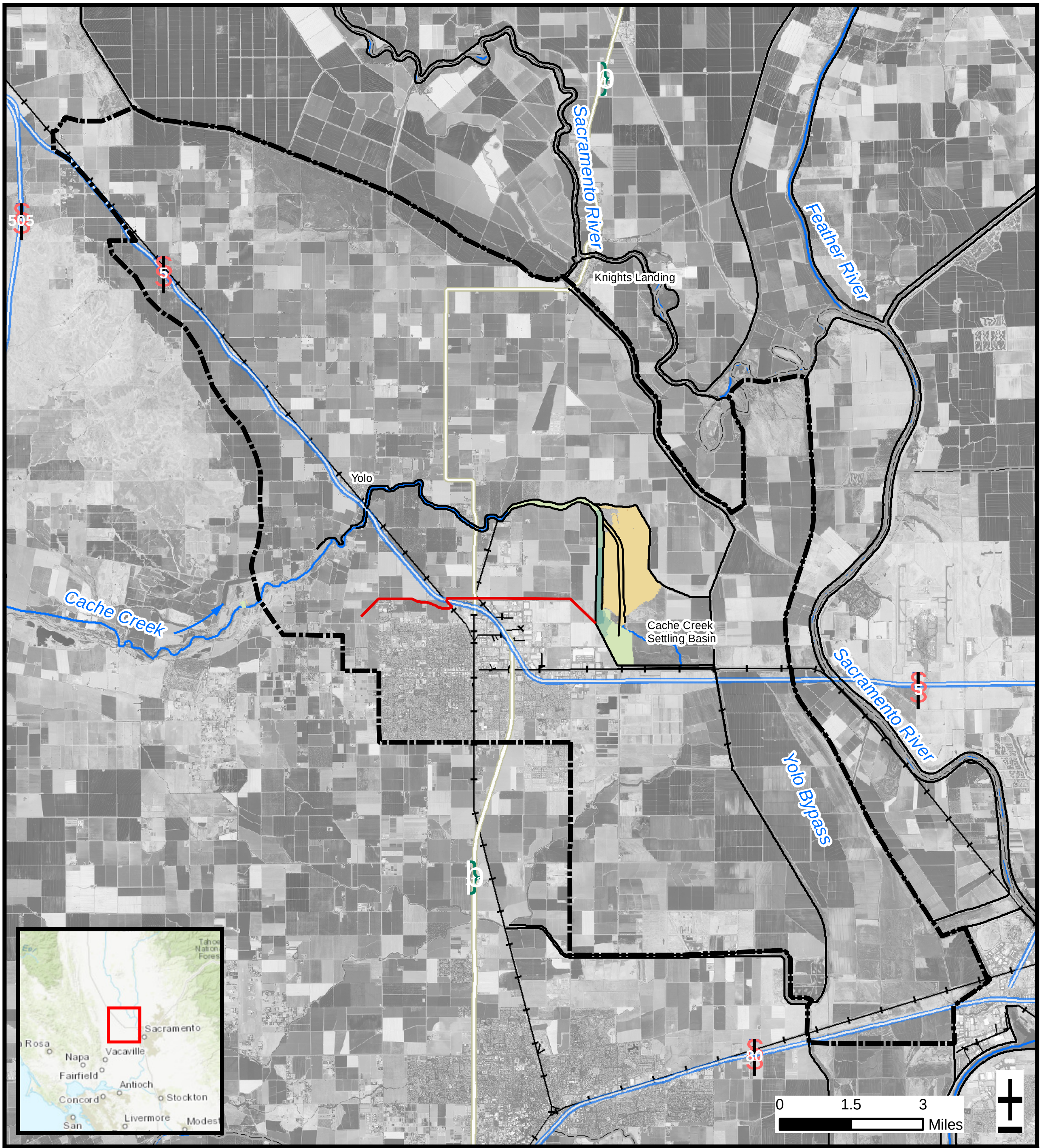
- < -6.0
- -6.0 - -4.0
- -4.0 - -2.0
- -2.0 - -1.0
- -1.0 - -0.1
- No Change
- 0.1 - 1.0
- 1.0 - 2.0
- 2.0 - 4.0
- 4.0 - 6.0
- > 6.0

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE
SOUTH BYPASS 2A
AVERAGE CHANGE IN FLOOD DEPTH
10% (1/10) ACE FLOOD EVENT

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

— Proposed Levee

▭ Project Boundary

— Existing Federal Levees

═ Interstate

═ Highway

┼ Railroad

▭ County Boundary

— River/Creek

Avg Change (feet)

■ < -6.0

■ -6.0 - -4.0

■ -4.0 - -2.0

■ -2.0 - -1.0

■ -1.0 - -0.1

□ No Change

■ 0.1 - 1.0

■ 1.0 - 2.0

■ 2.0 - 4.0

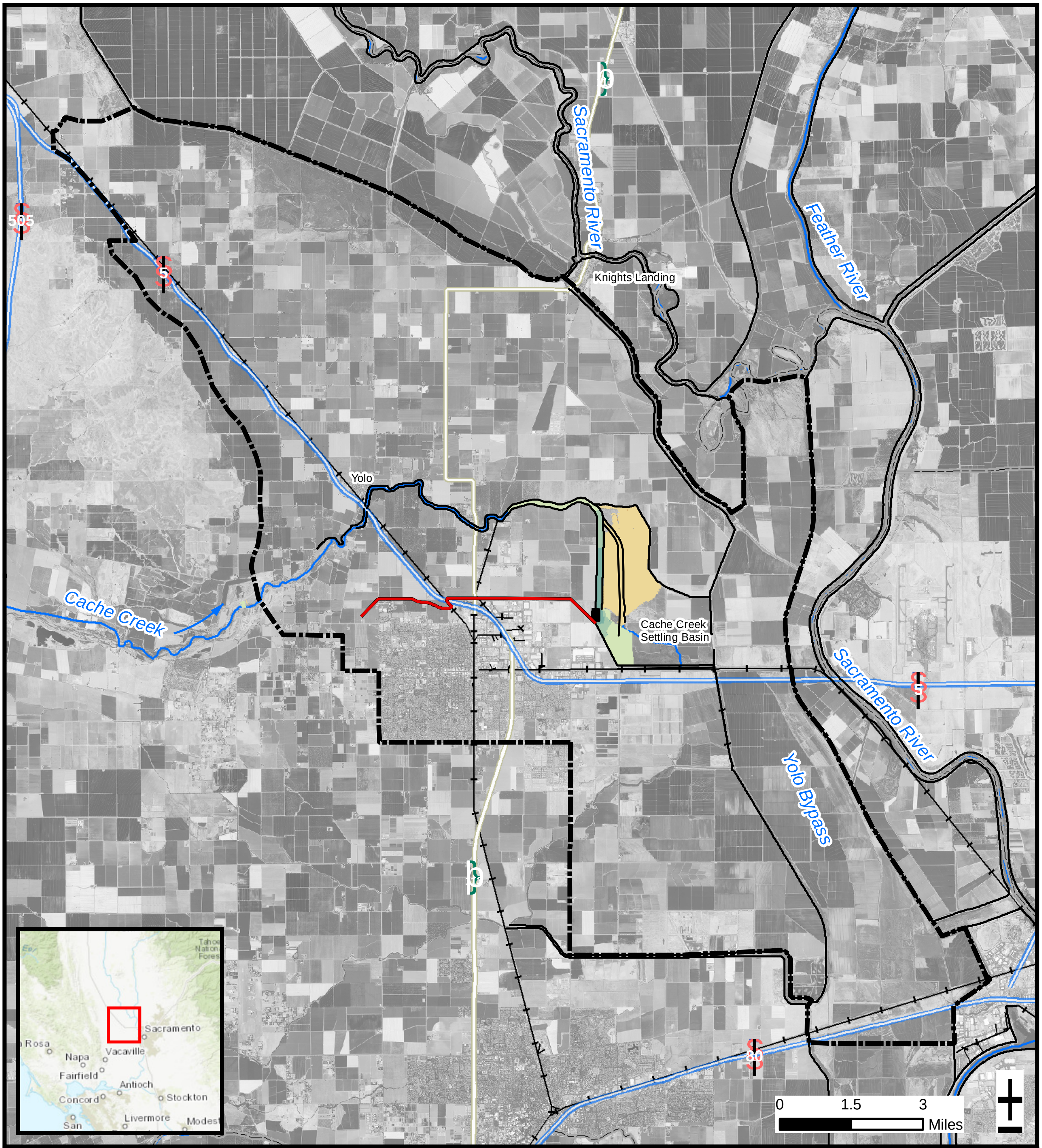
■ 4.0 - 6.0

■ > 6.0

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE SOUTH BYPASS 2A AVERAGE CHANGE IN FLOOD DEPTH 5% (1/20) ACE FLOOD EVENT

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



Legend

- Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

Avg Change (feet)

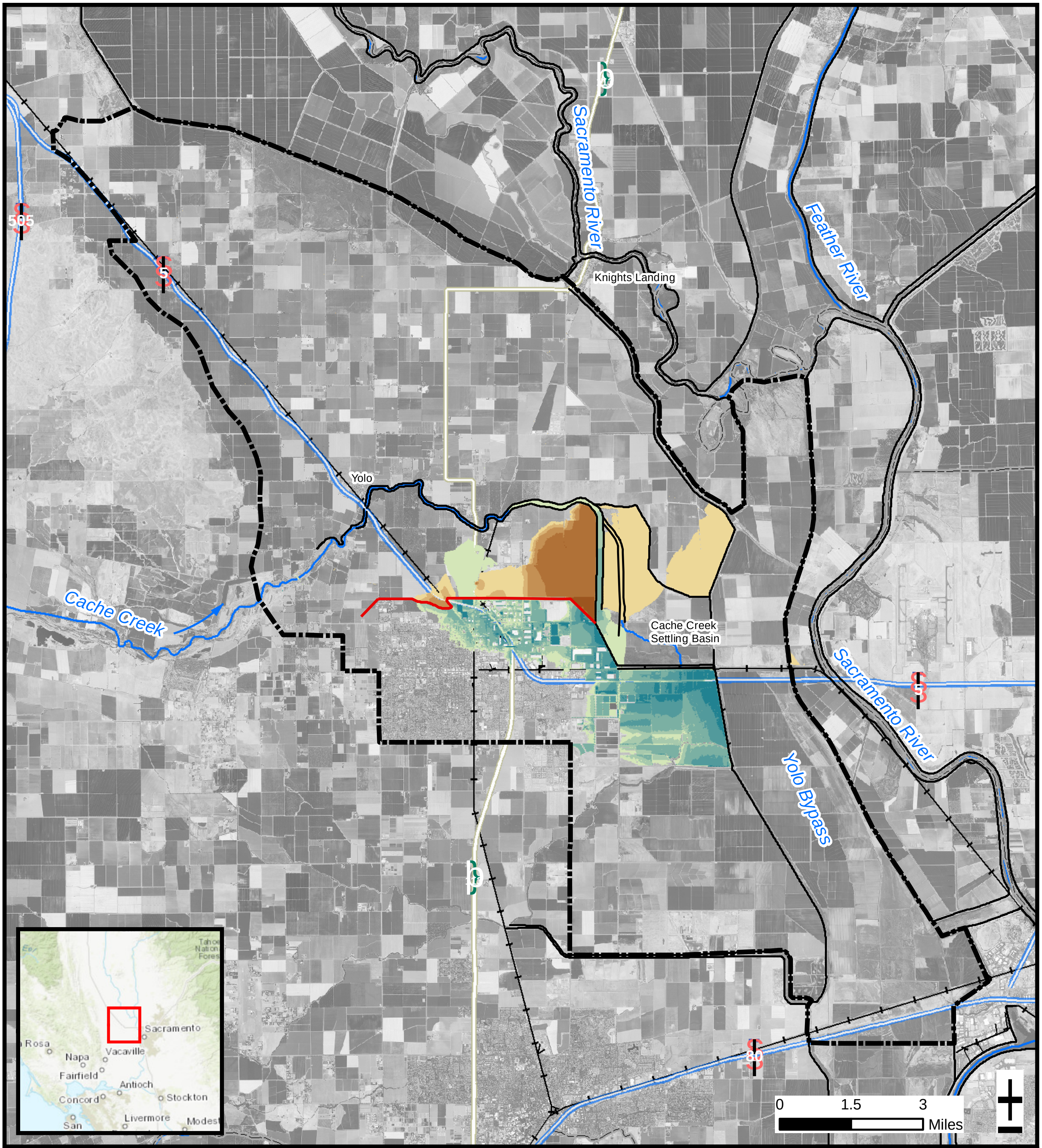
- < -6.0
- -6.0 - -4.0
- -4.0 - -2.0
- -2.0 - -1.0
- -1.0 - -0.1
- No Change
- 0.1 - 1.0
- 1.0 - 2.0
- 2.0 - 4.0
- 4.0 - 6.0
- > 6.0

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE
SOUTH BYPASS 2A
AVERAGE CHANGE IN FLOOD DEPTH
2% (1/50) ACE FLOOD EVENT

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

- Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

Avg Change (feet)

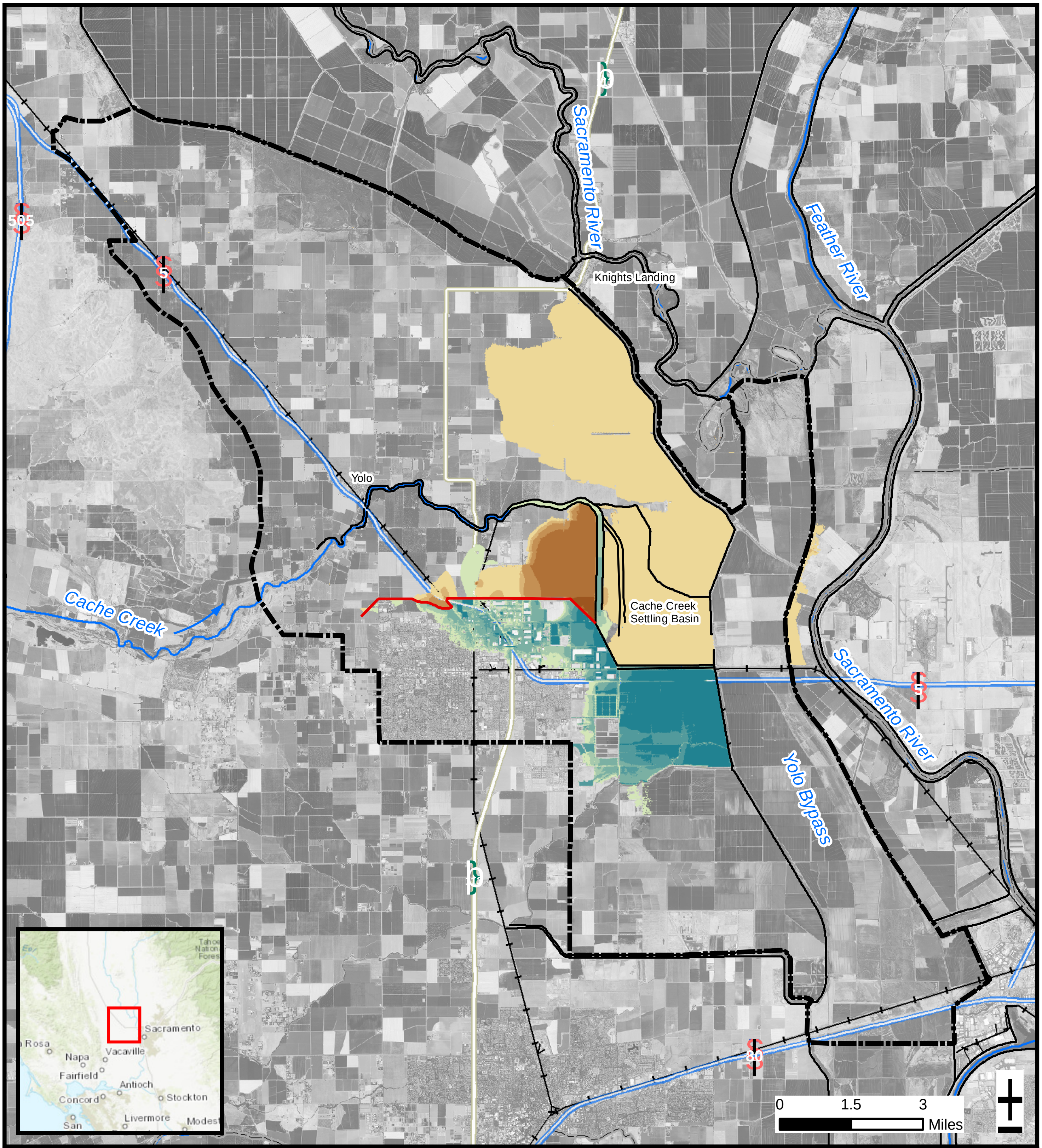
- < -6.0
- -6.0 - -4.0
- -4.0 - -2.0
- -2.0 - -1.0
- -1.0 - -0.1
- No Change
- 0.1 - 1.0
- 1.0 - 2.0
- 2.0 - 4.0
- 4.0 - 6.0
- > 6.0

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE SOUTH BYPASS 2A AVERAGE CHANGE IN FLOOD DEPTH 1% (1/100) ACE FLOOD EVENT

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

Proposed Levee

Project Boundary

Existing Federal Levees

Interstate

Highway

Railroad

County Boundary

River/Creek

Avg Change (feet)

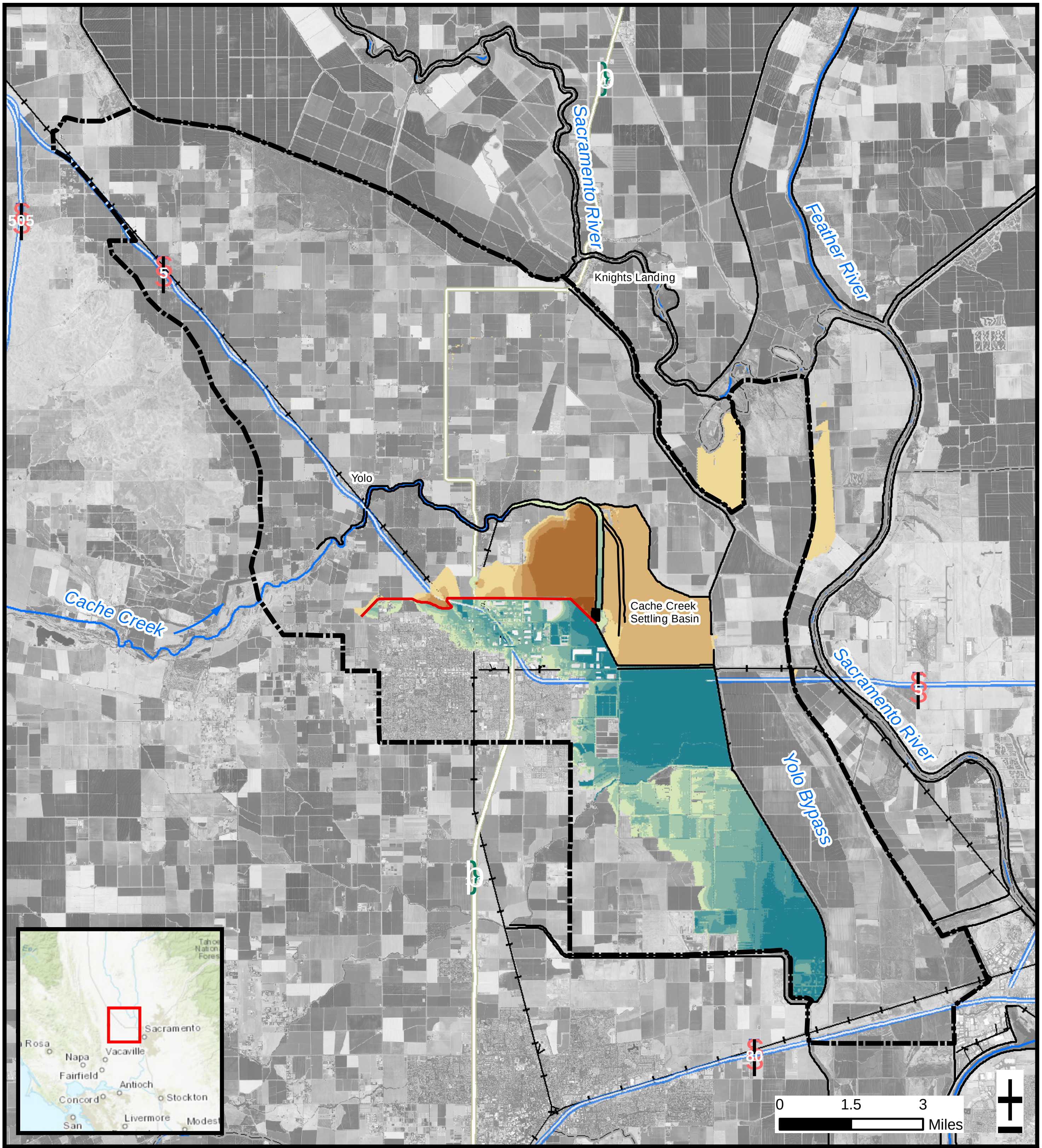
- < -6.0
- -6.0 - -4.0
- -4.0 - -2.0
- -2.0 - -1.0
- -1.0 - -0.1
- No Change
- 0.1 - 1.0
- 1.0 - 2.0
- 2.0 - 4.0
- 4.0 - 6.0
- > 6.0

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE
SOUTH BYPASS 2A
AVERAGE CHANGE IN FLOOD DEPTH
0.5% (1/200) ACE FLOOD EVENT

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

- Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

Avg Change (feet)

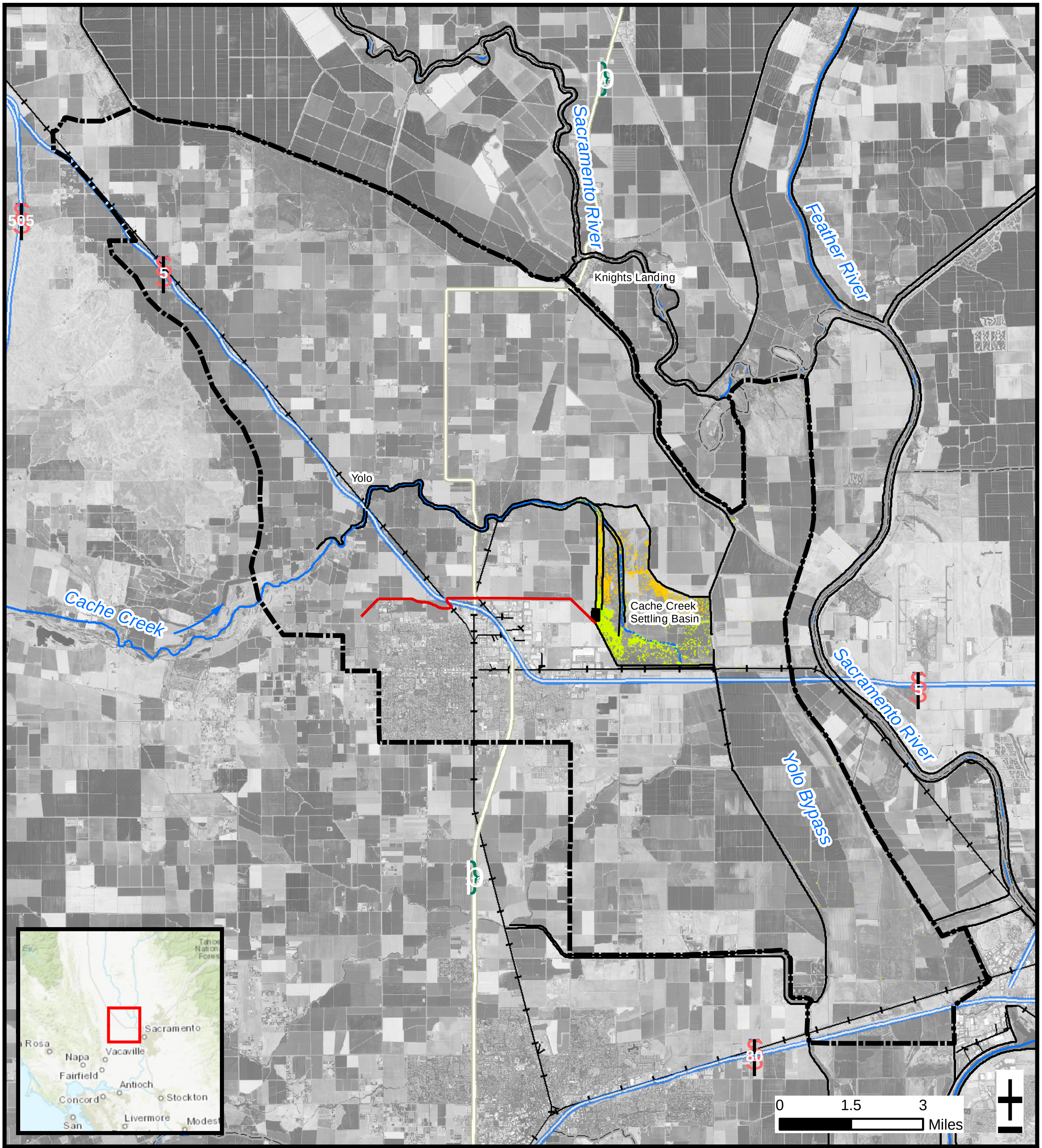
- ■ < -6.0
- ■ -6.0 - -4.0
- ■ -4.0 - -2.0
- ■ -2.0 - -1.0
- ■ -1.0 - -0.1
- □ No Change
- ■ 0.1 - 1.0
- ■ 1.0 - 2.0
- ■ 2.0 - 4.0
- ■ 4.0 - 6.0
- ■ > 6.0

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE
SOUTH BYPASS 2A
AVERAGE CHANGE IN FLOOD DEPTH
0.2% (1/500) ACE FLOOD EVENT

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

Proposed Levee
Project Boundary
Existing Federal Levees
Interstate
Highway
Railroad
County Boundary
River/Creek

Avg Change Velocity (fps)

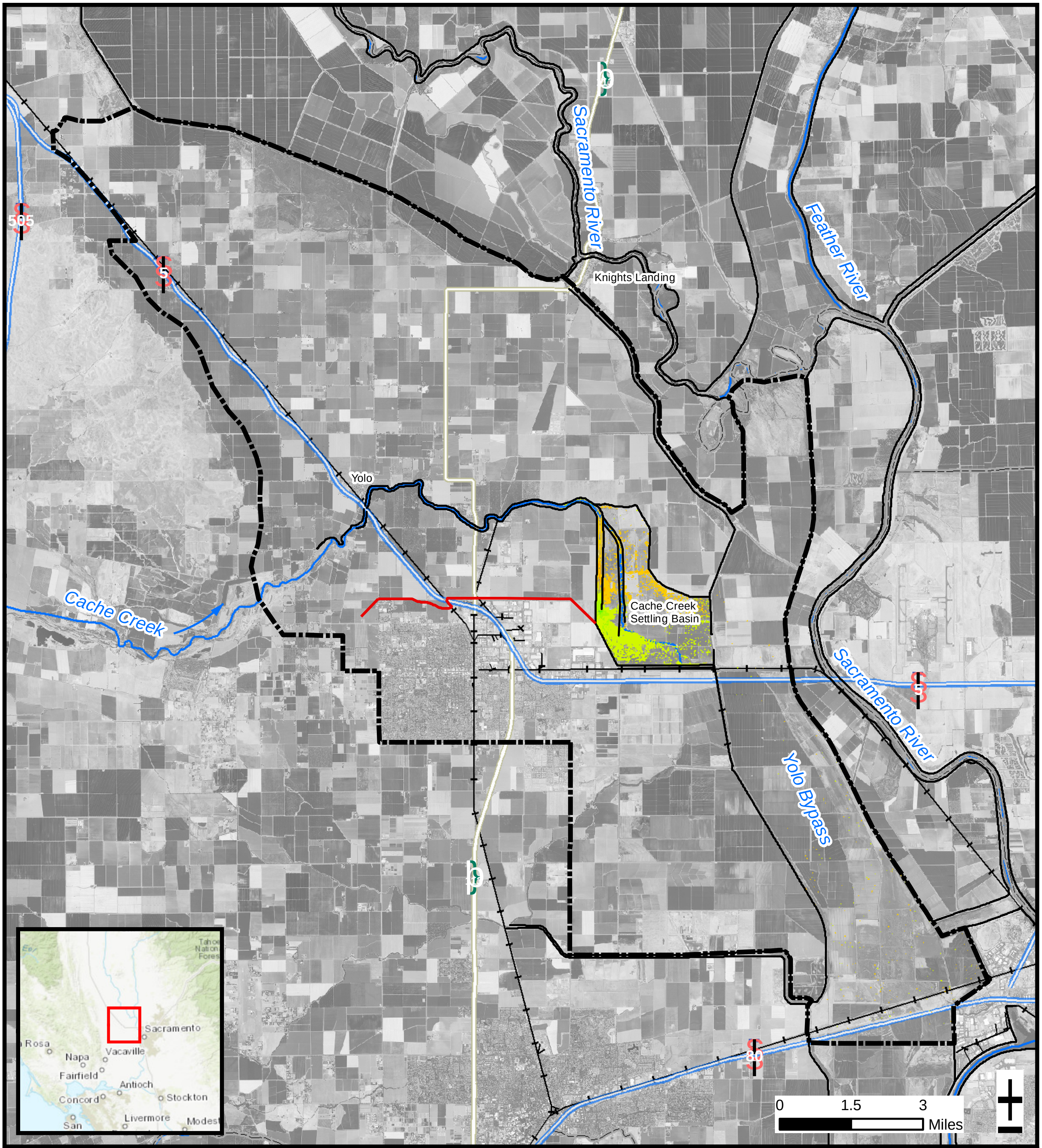
🟩 < -8
🟩 -8 - -6
🟩 -6 - -4
🟩 -4 - -2
🟨 -2 - -0.5
⬜ -0.5 - 0.5
🟨 0.5 - 2
🟧 2 - 4
🟧 4 - 6
🟥 6 - 8
🟥 > 8

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE SOUTH BYPASS 2A AVERAGE CHANGE IN VELOCITY 50% (1/2) ACE FLOOD EVENT

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

- Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

Avg Change Velocity (fps)

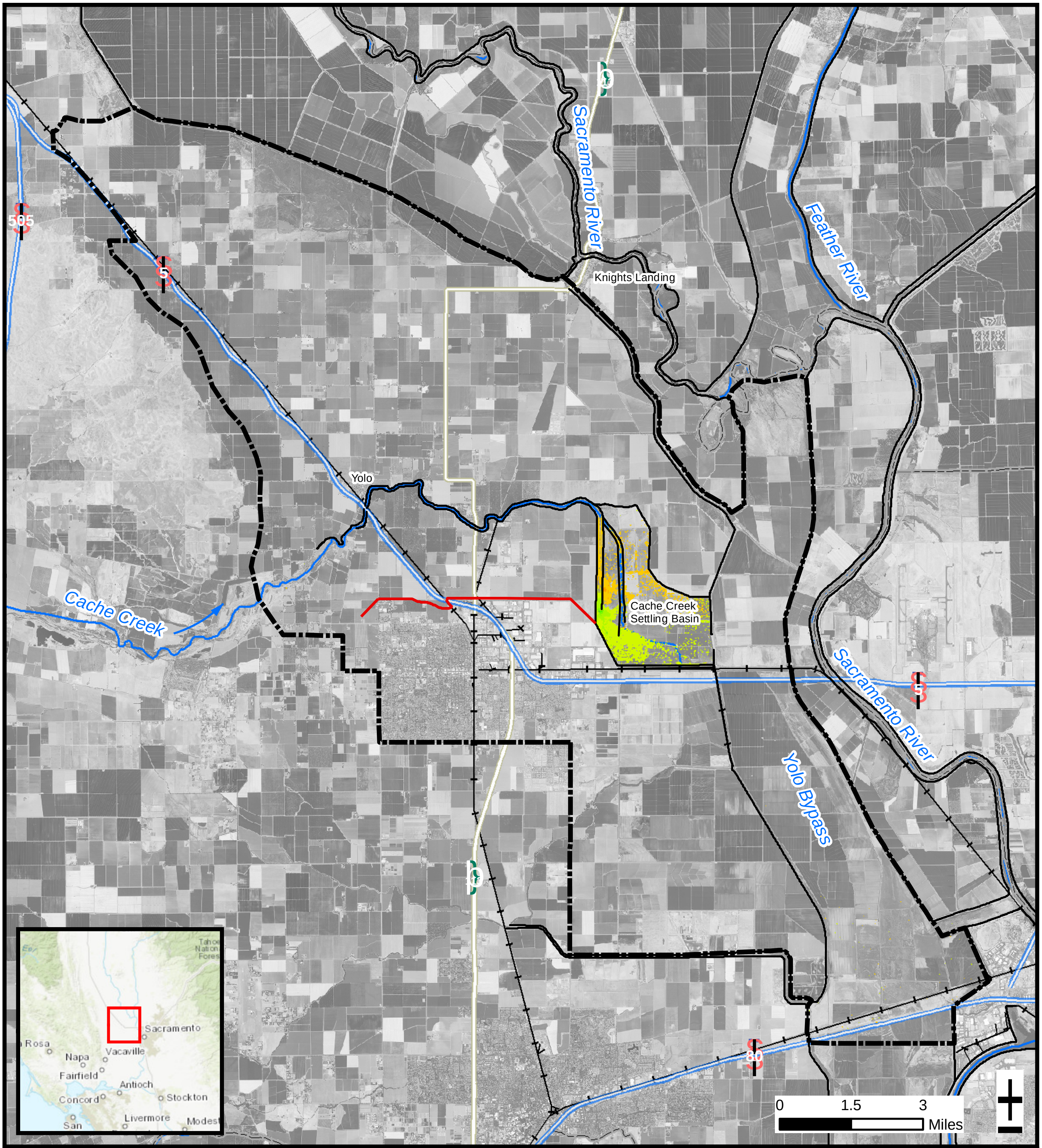
🟩	< -8
🟩	-8 - -6
🟩	-6 - -4
🟩	-4 - -2
🟨	-2 - -0.5
⬜	-0.5 - 0.5
🟨	0.5 - 2
🟧	2 - 4
🟧	4 - 6
🟥	6 - 8
🟥	> 8

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE SOUTH BYPASS 2A AVERAGE CHANGE IN VELOCITY 20% (1/5) ACE FLOOD EVENT

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

- Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

Avg Change Velocity (fps)

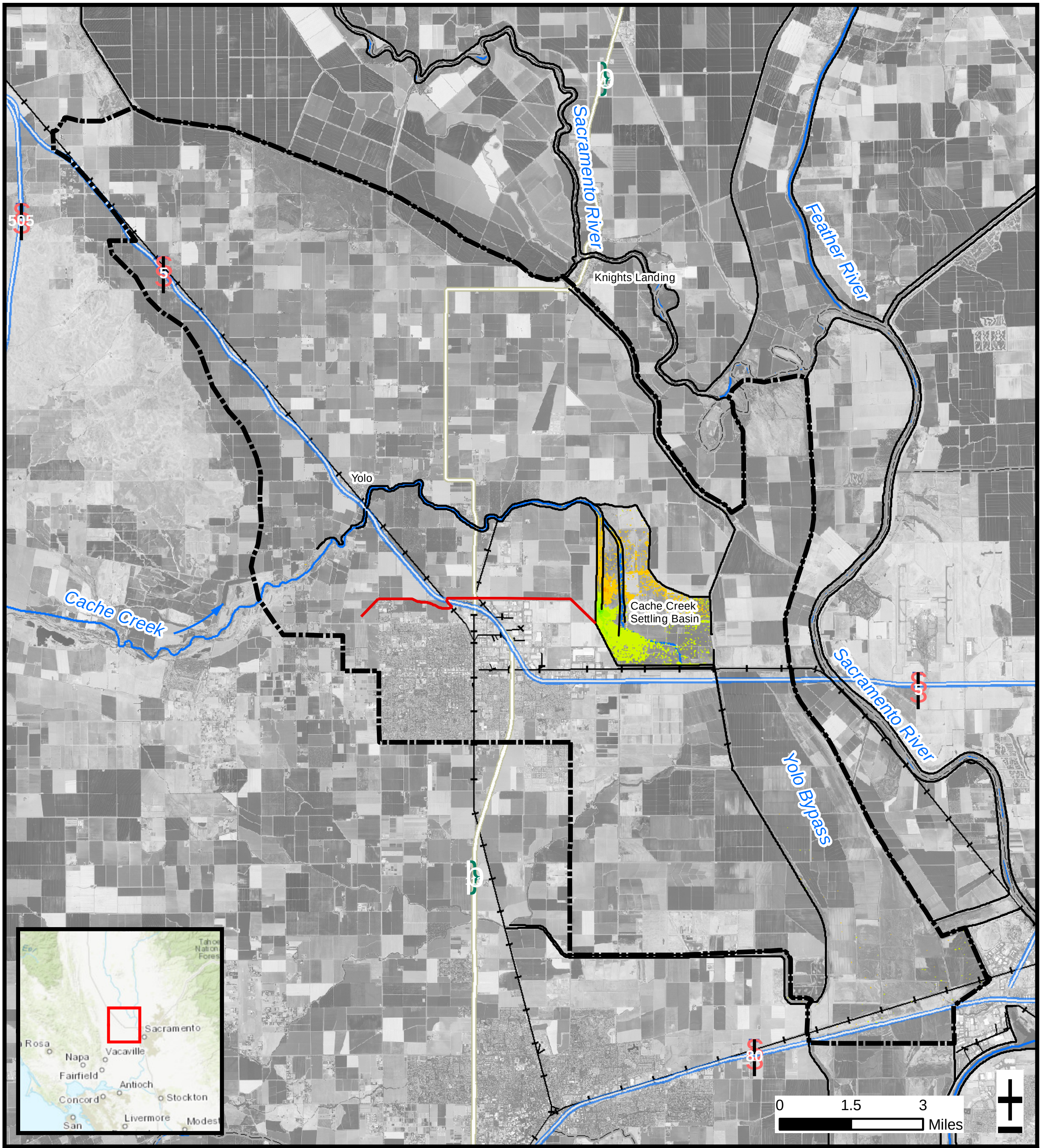
- 🟩 < -8
- 🟩 -8 - -6
- 🟩 -6 - -4
- 🟩 -4 - -2
- 🟨 -2 - -0.5
- ⬜ -0.5 - 0.5
- 🟨 0.5 - 2
- 🟧 2 - 4
- 🟧 4 - 6
- 🟥 6 - 8
- 🟥 > 8

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE
SOUTH BYPASS 2A
AVERAGE CHANGE IN VELOCITY
10% (1/10) ACE FLOOD EVENT

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

- Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

Avg Change Velocity (fps)

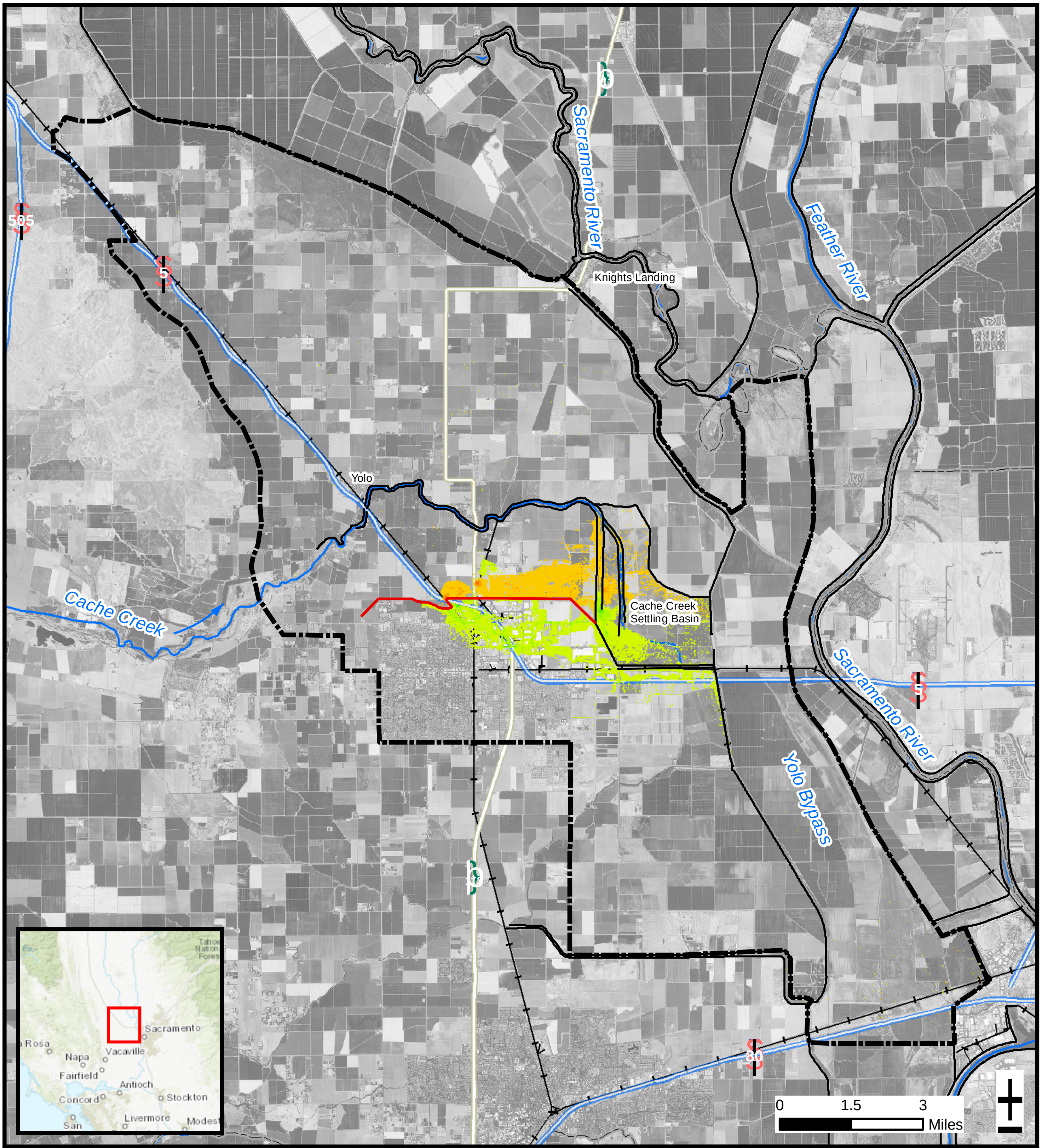
- 🟩 < -8
- 🟩 -8 - -6
- 🟩 -6 - -4
- 🟩 -4 - -2
- 🟨 -2 - -0.5
- ⬜ -0.5 - 0.5
- 🟨 0.5 - 2
- 🟧 2 - 4
- 🟧 4 - 6
- 🟥 6 - 8
- 🟥 > 8

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE
SOUTH BYPASS 2A
AVERAGE CHANGE IN VELOCITY
5% (1/20) ACE FLOOD EVENT

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

- Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

Avg Change Velocity (fps)

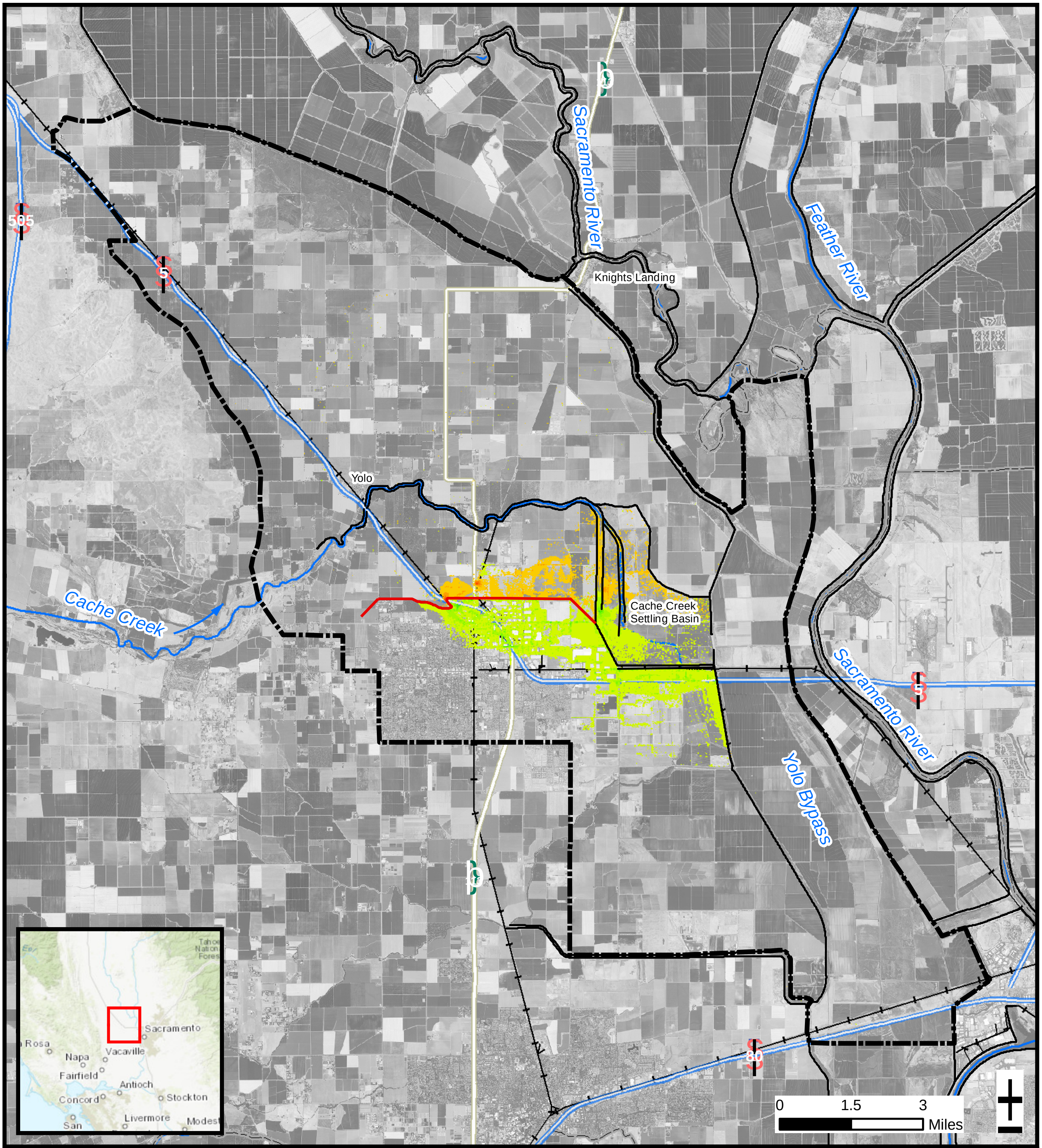
🟩 < -8
🟩 -8 - -6
🟩 -6 - -4
🟩 -4 - -2
🟨 -2 - -0.5
⬜ -0.5 - 0.5
🟨 0.5 - 2
🟧 2 - 4
🟧 4 - 6
🟥 6 - 8
🟥 > 8

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE SOUTH BYPASS 2A AVERAGE CHANGE IN VELOCITY 2% (1/50) ACE FLOOD EVENT

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

Proposed Levee
Project Boundary
Existing Federal Levees
Interstate
Highway
Railroad
County Boundary
River/Creek

Avg Change Velocity (fps)

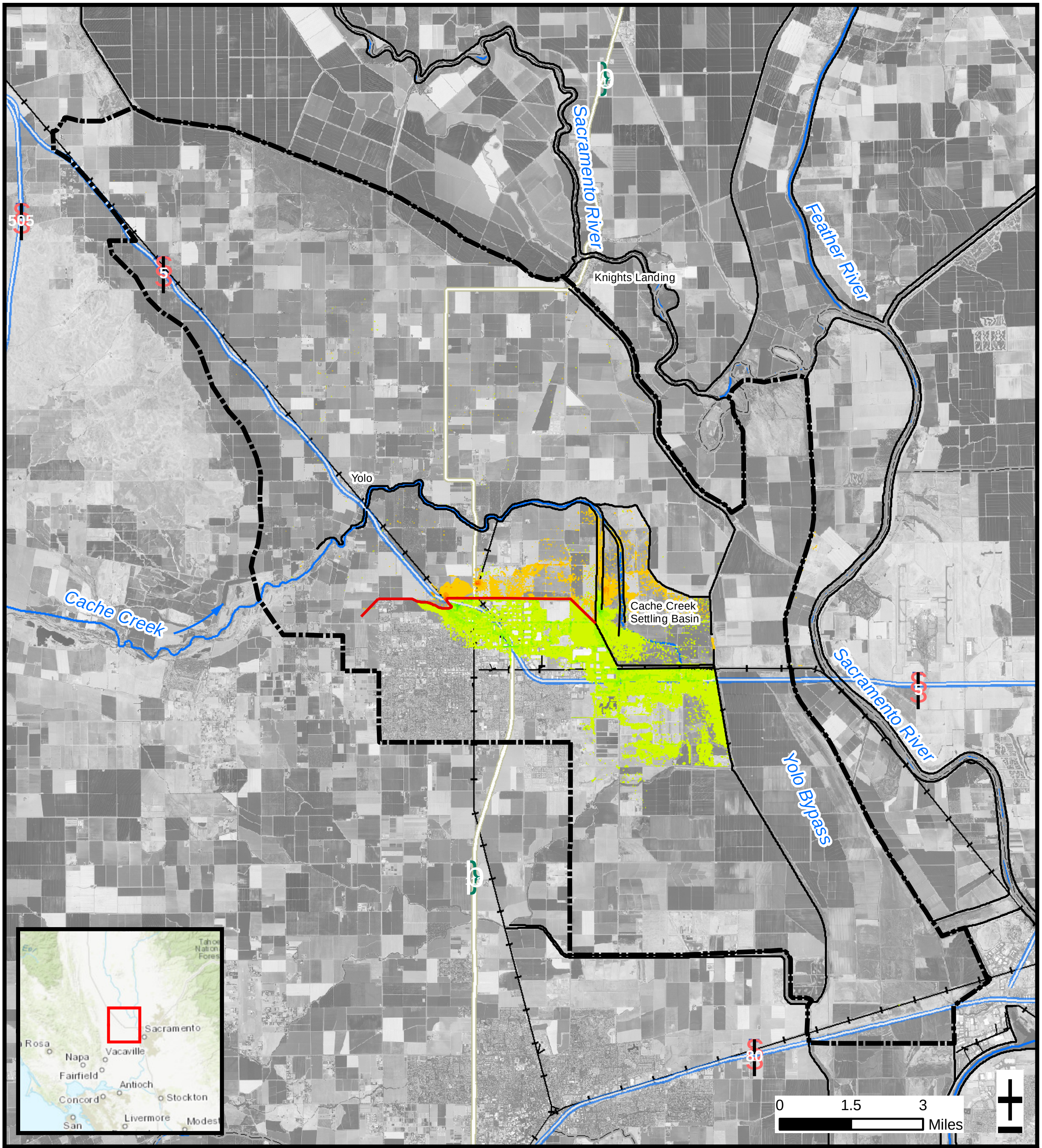
🟩 < -8
🟩 -8 - -6
🟩 -6 - -4
🟩 -4 - -2
🟨 -2 - -0.5
⬜ -0.5 - 0.5
🟨 0.5 - 2
🟧 2 - 4
🟧 4 - 6
🟥 6 - 8
🟥 > 8

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE SOUTH BYPASS 2A AVERAGE CHANGE IN VELOCITY 1% (1/100) ACE FLOOD EVENT

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

- Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

Avg Change Velocity (fps)

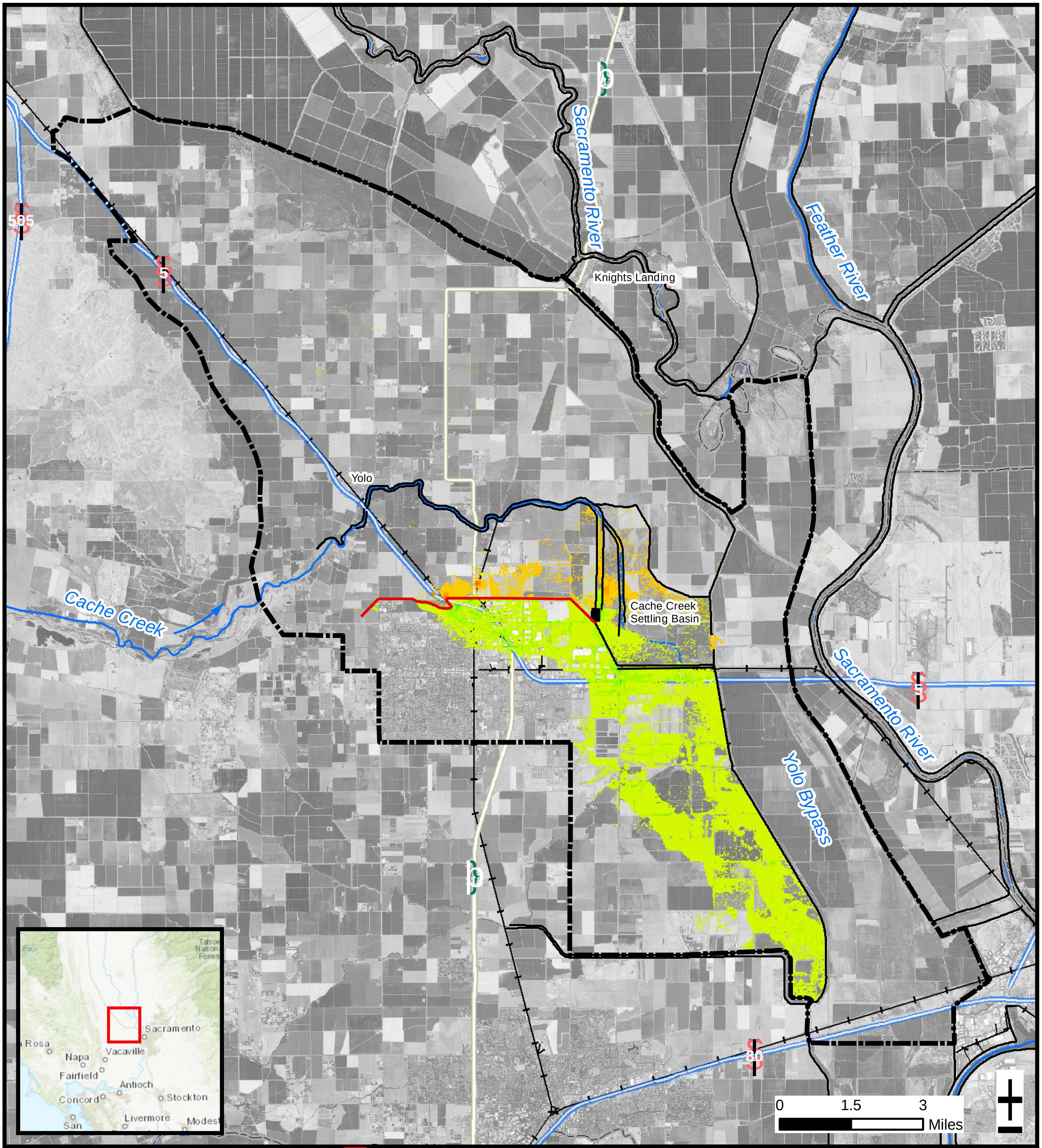
🟩 < -8
🟩 -8 - -6
🟩 -6 - -4
🟩 -4 - -2
🟩 -2 - -0.5
⬜ -0.5 - 0.5
🟨 0.5 - 2
🟧 2 - 4
🟧 4 - 6
🟥 6 - 8
🟥 > 8

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE SOUTH BYPASS 2A AVERAGE CHANGE IN VELOCITY 0.5% (1/200) ACE FLOOD EVENT

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

- Proposed Levee
- Project Boundary
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- River/Creek

Avg Change Velocity (fps)

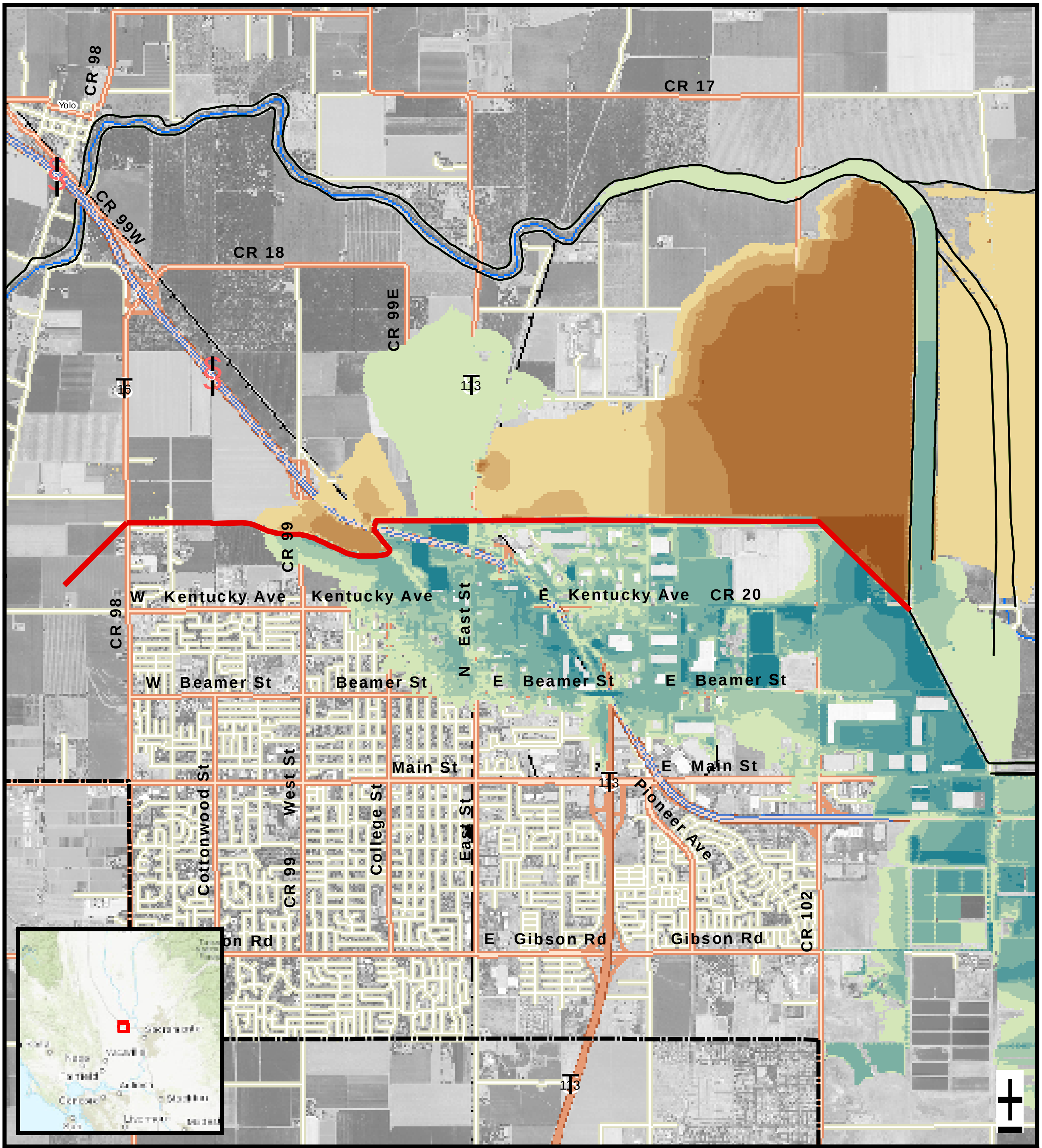
- 🟩 < -8
- 🟩 -8 - -6
- 🟩 -6 - -4
- 🟩 -4 - -2
- 🟨 -2 - -0.5
- ⬜ -0.5 - 0.5
- 🟨 0.5 - 2
- 🟧 2 - 4
- 🟧 4 - 6
- 🟥 6 - 8
- 🟥 > 8

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE SOUTH BYPASS 2A AVERAGE CHANGE IN VELOCITY 0.2% (1/500) ACE FLOOD EVENT

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

26 SEP 2019



Legend

- 🟥 Proposed Levee
- Project Boundary
- Existing Federal Levees
- Existing Non Federal Levees
- Interstate
- Major Highways
- Major Roads
- Streets
- Ramps
- Railroad
- Main rail line
- County Boundary
- River/Creek

Avg Change (feet)

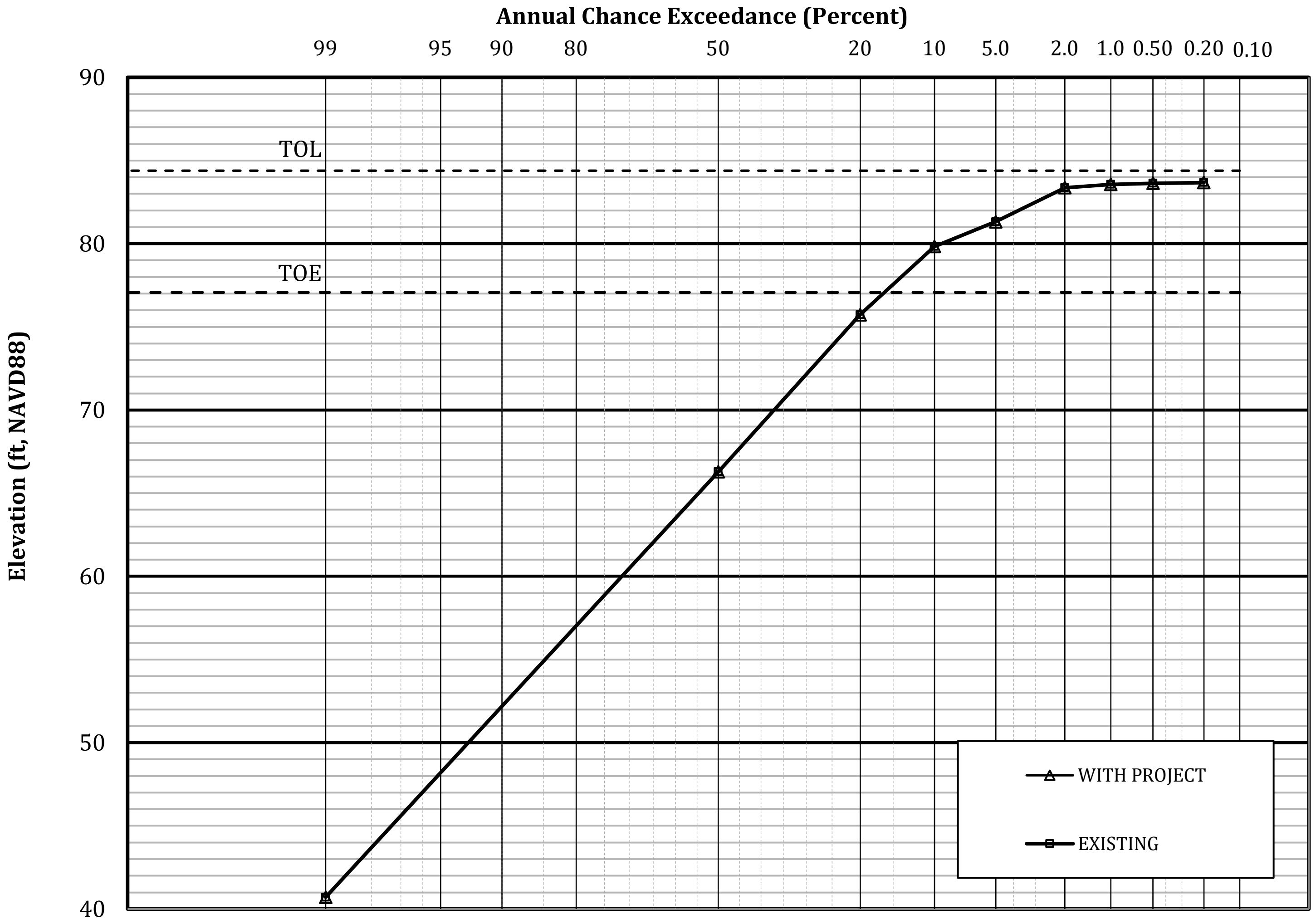
- < -6.0
- -6.0 - -4.0
- -4.0 - -2.0
- -2.0 - -1.0
- -1.0 - -0.1
- No Change
- 0.1 - 1.0
- 1.0 - 2.0
- 2.0 - 4.0
- 4.0 - 6.0
- > 6.0

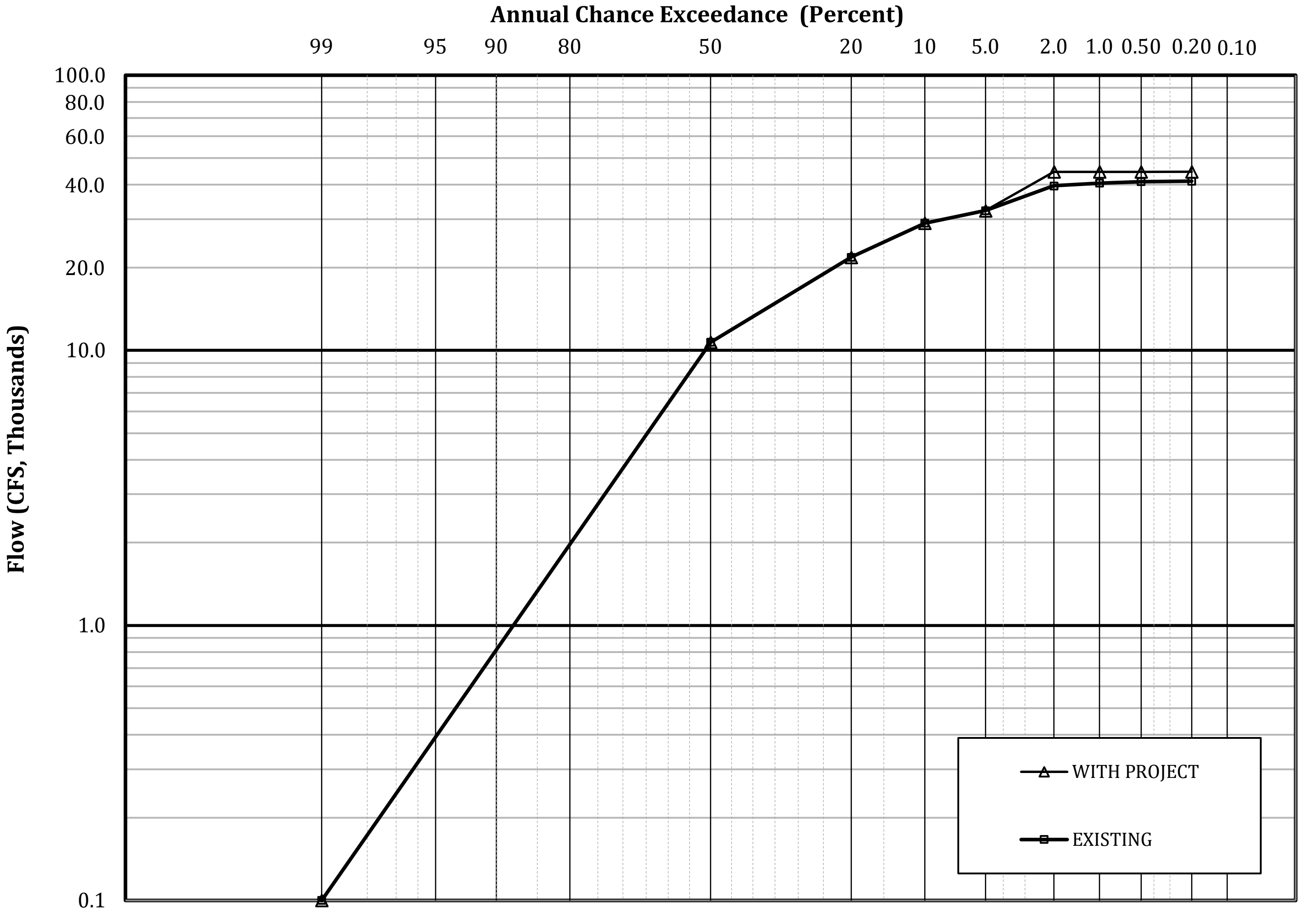
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

UPDATED ALTERNATIVE SOUTH BYPASS 2A AVERAGE CHANGE IN FLOOD DEPTH 1% (1/100) ACE FLOOD EVENT

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

30 SEP 2019





NOTES:

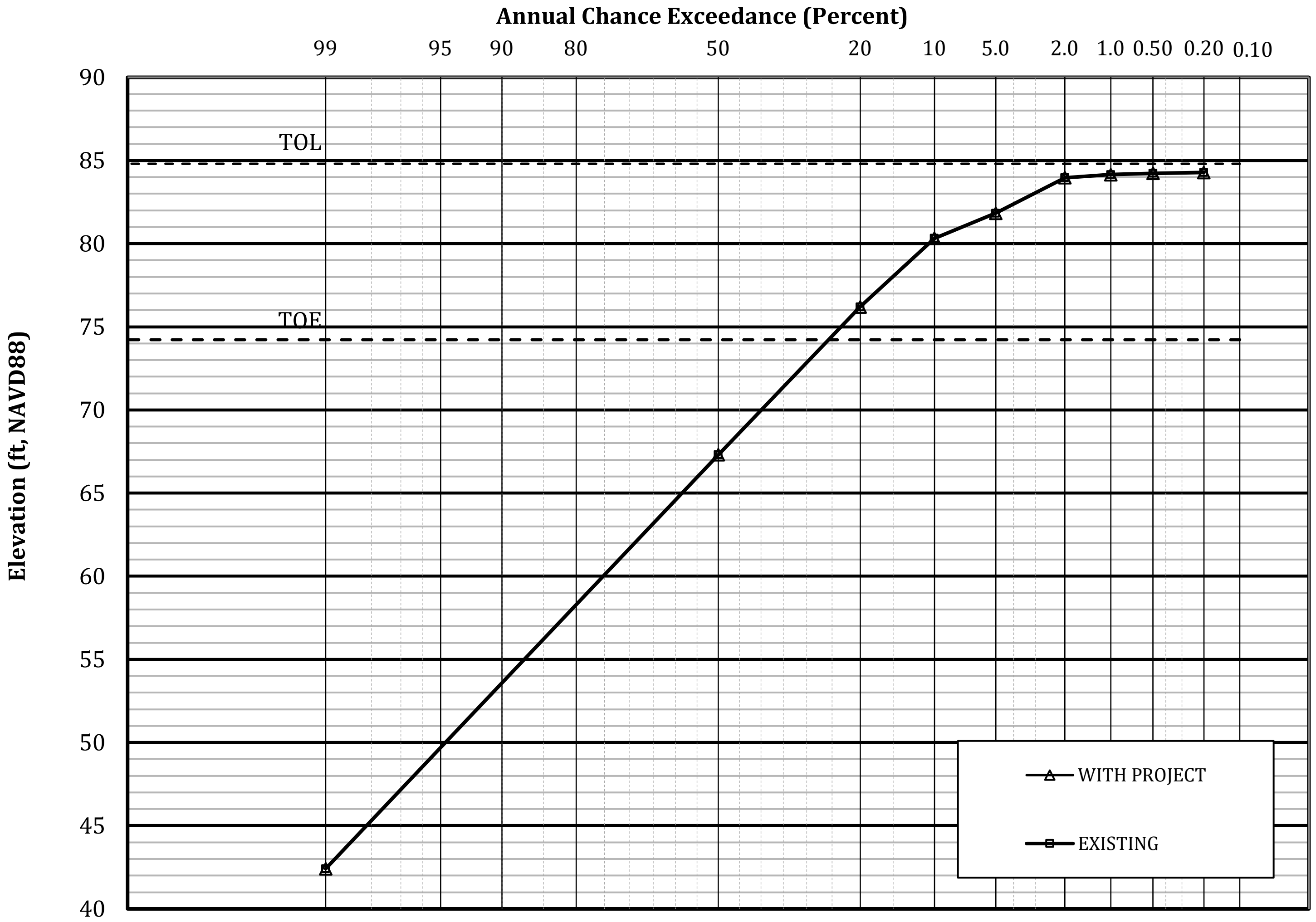
Curves Based on Without and With Project Tuflow simulations.
Stages and Flows for Index Point 4 were obtained from Tuflow (b/w RAS XSECS RM 11.225 and RM 11.068).

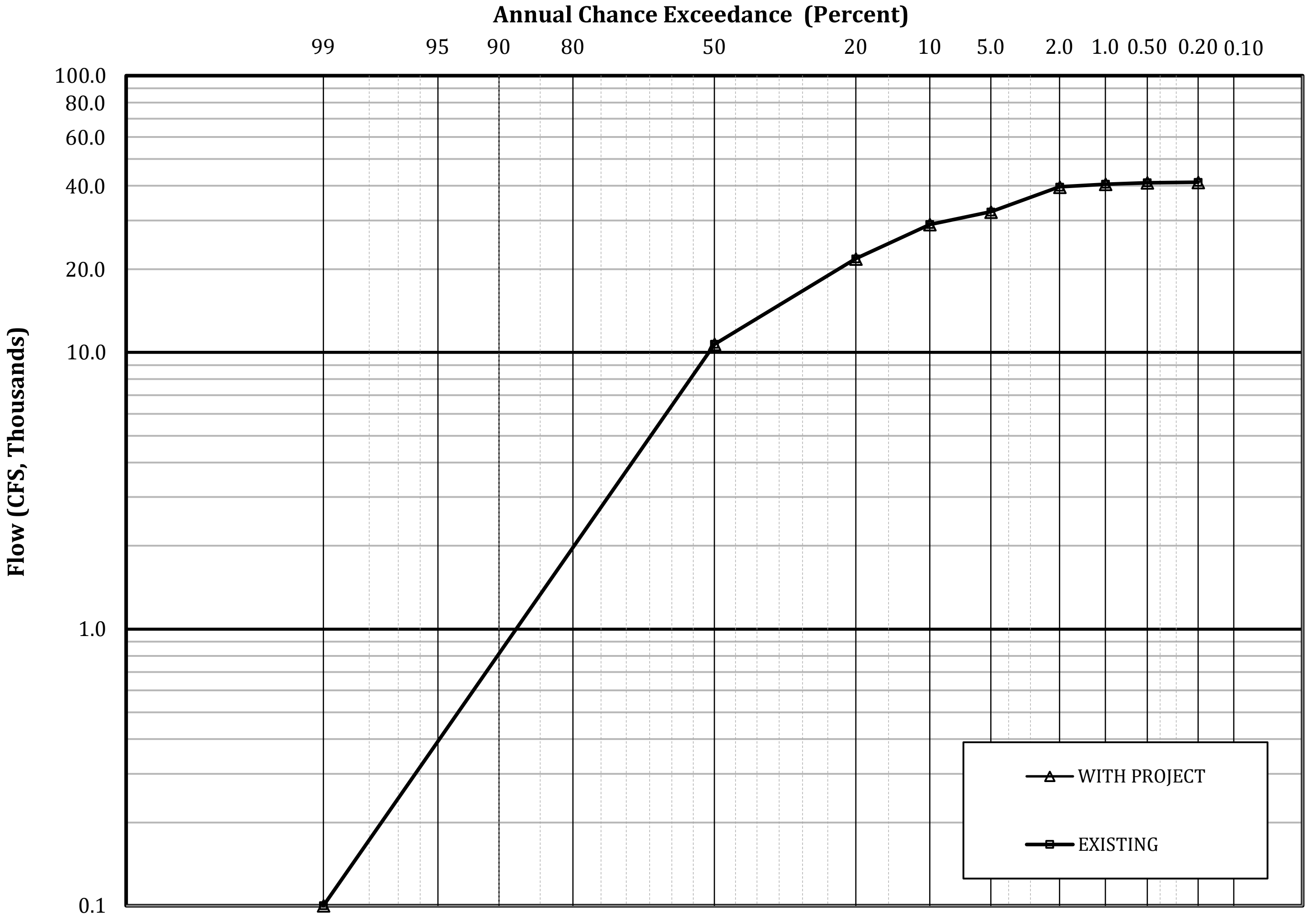
TOL - Top of Levee
TOE - Approximate elevation of natural floodplain adjacent to levee

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

STAGE AND DISCHARGE FREQUENCY CURVES INDEX POINT P4

U.S. ARMY CORSP OF ENGINEERS
SACRAMENTO DISTRICT





NOTES:

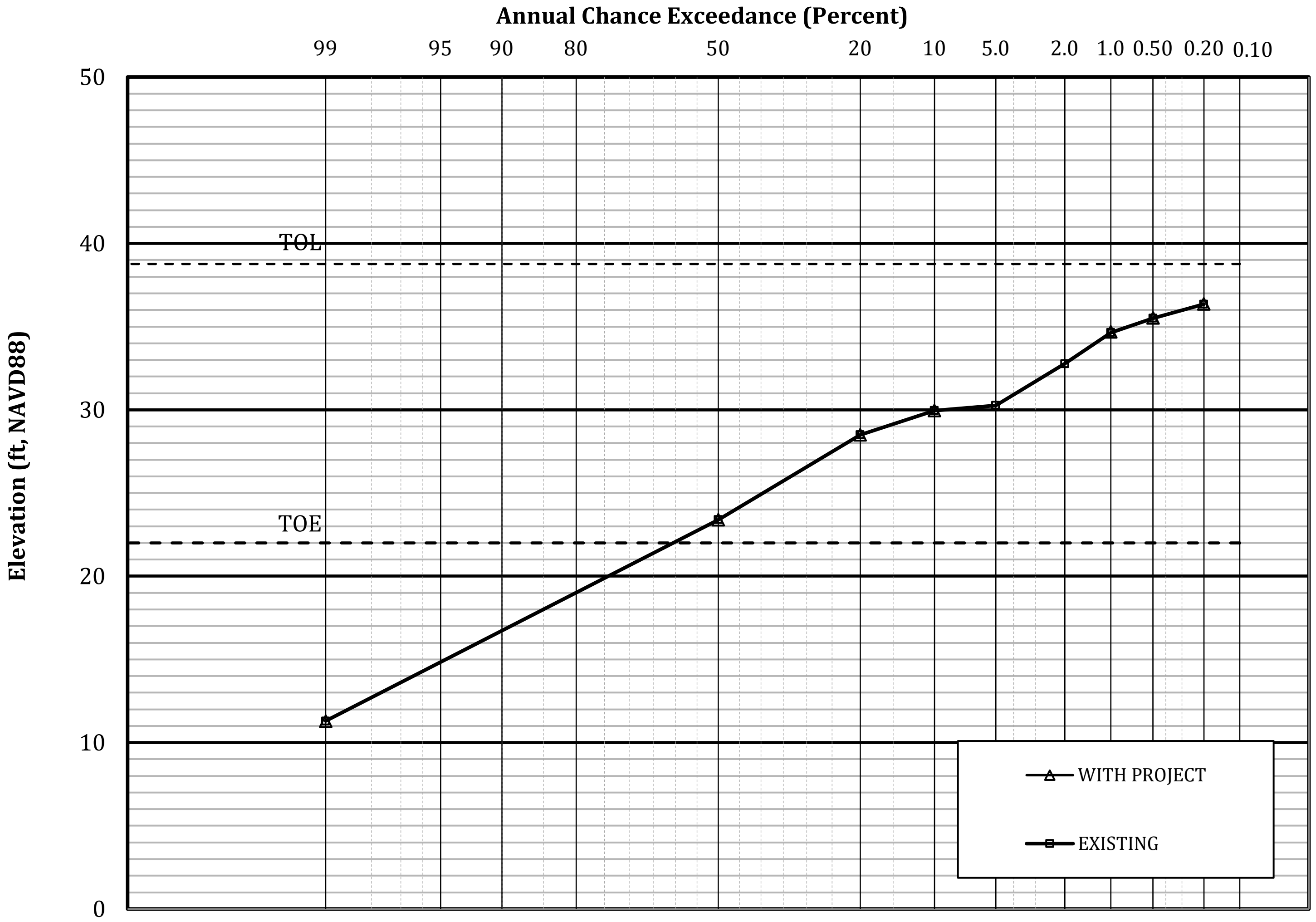
Curves Based on Without and With Project Tuflow simulations.
Stages and Flows for Index Point 5 were obtained from Tuflow (b/w RAS XSECS RM 11.336 and RM 11.225).

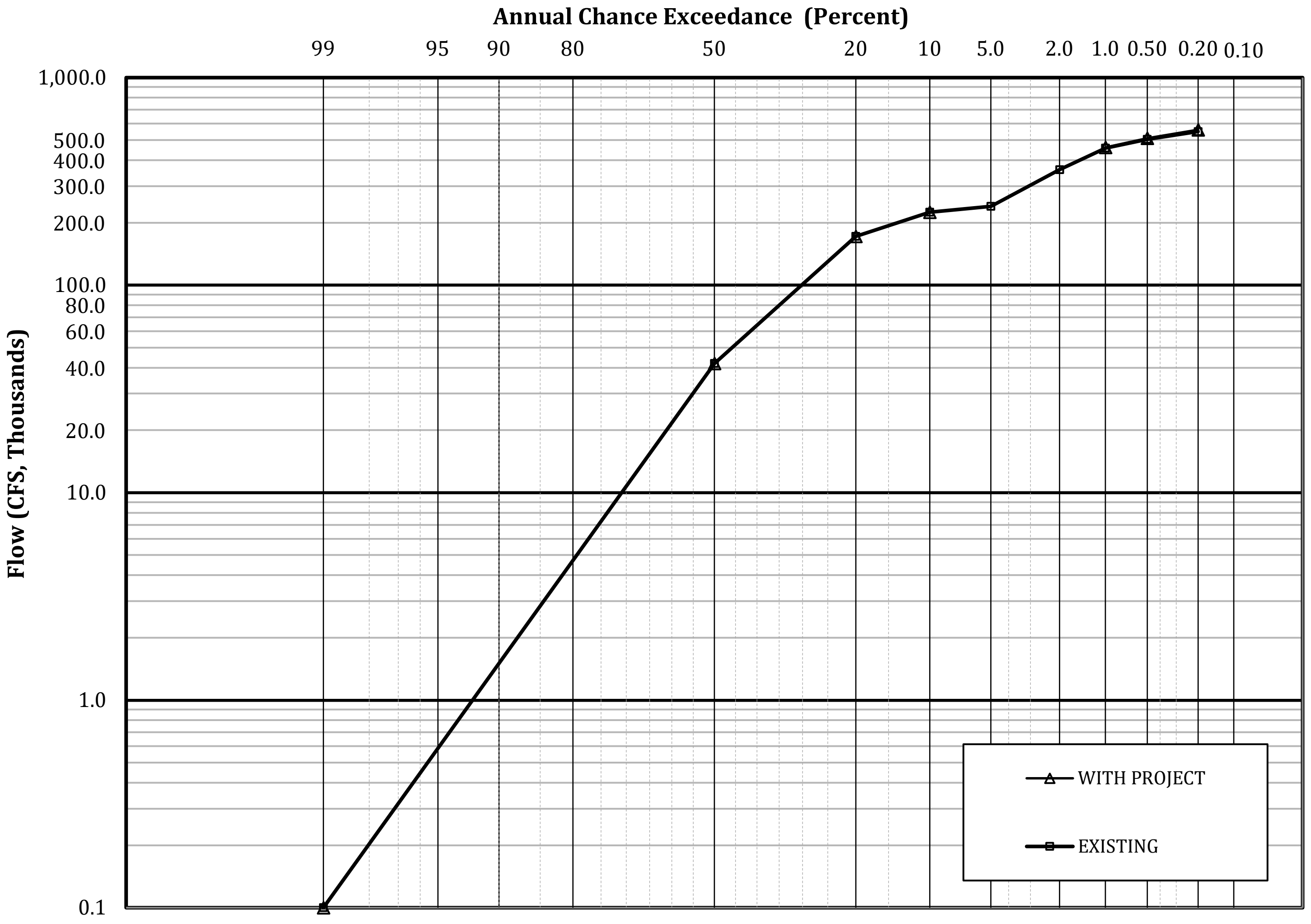
TOL - Top of Levee
TOE - Approximate elevation of natural floodplain adjacent to levee

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

STAGE AND DISCHARGE FREQUENCY CURVES INDEX POINT P5

U.S. ARMY CORSP OF ENGINEERS
SACRAMENTO DISTRICT





NOTES:

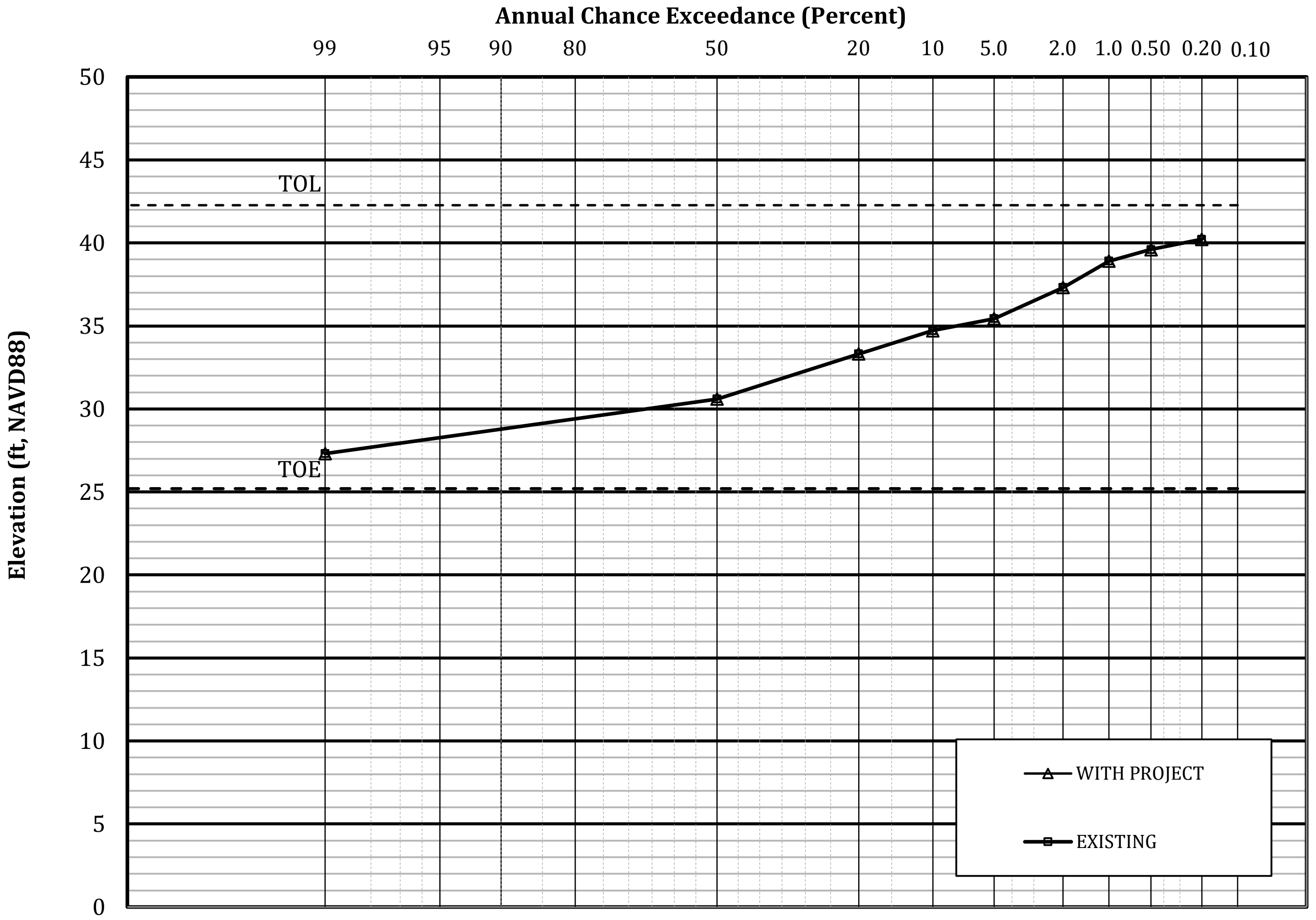
Curves Based on Without and With Project Tuflow simulations.
Stages and Flows for Index Point 6 were obtained from Tuflow.

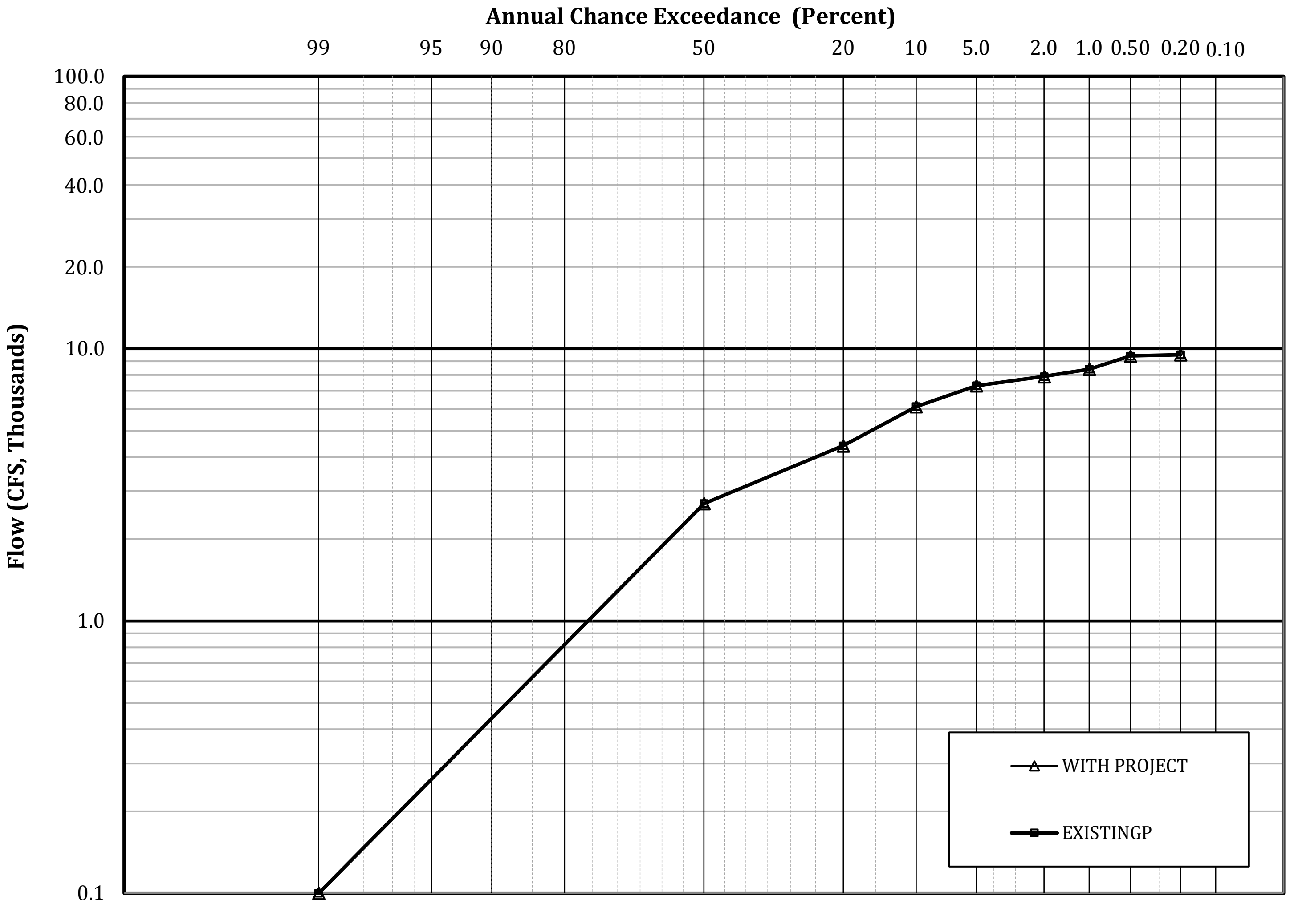
TOL - Top of Levee
TOE - Approximate elevation of natural floodplain adjacent to levee

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

STAGE AND DISCHARGE FREQUENCY CURVES INDEX POINT P6

U.S. ARMY CORSP OF ENGINEERS
SACRAMENTO DISTRICT





NOTES:

Curves Based on Without and With Project Tuflow simulations.
Stages and Flows for Index Point 7 were obtained from Tuflow.

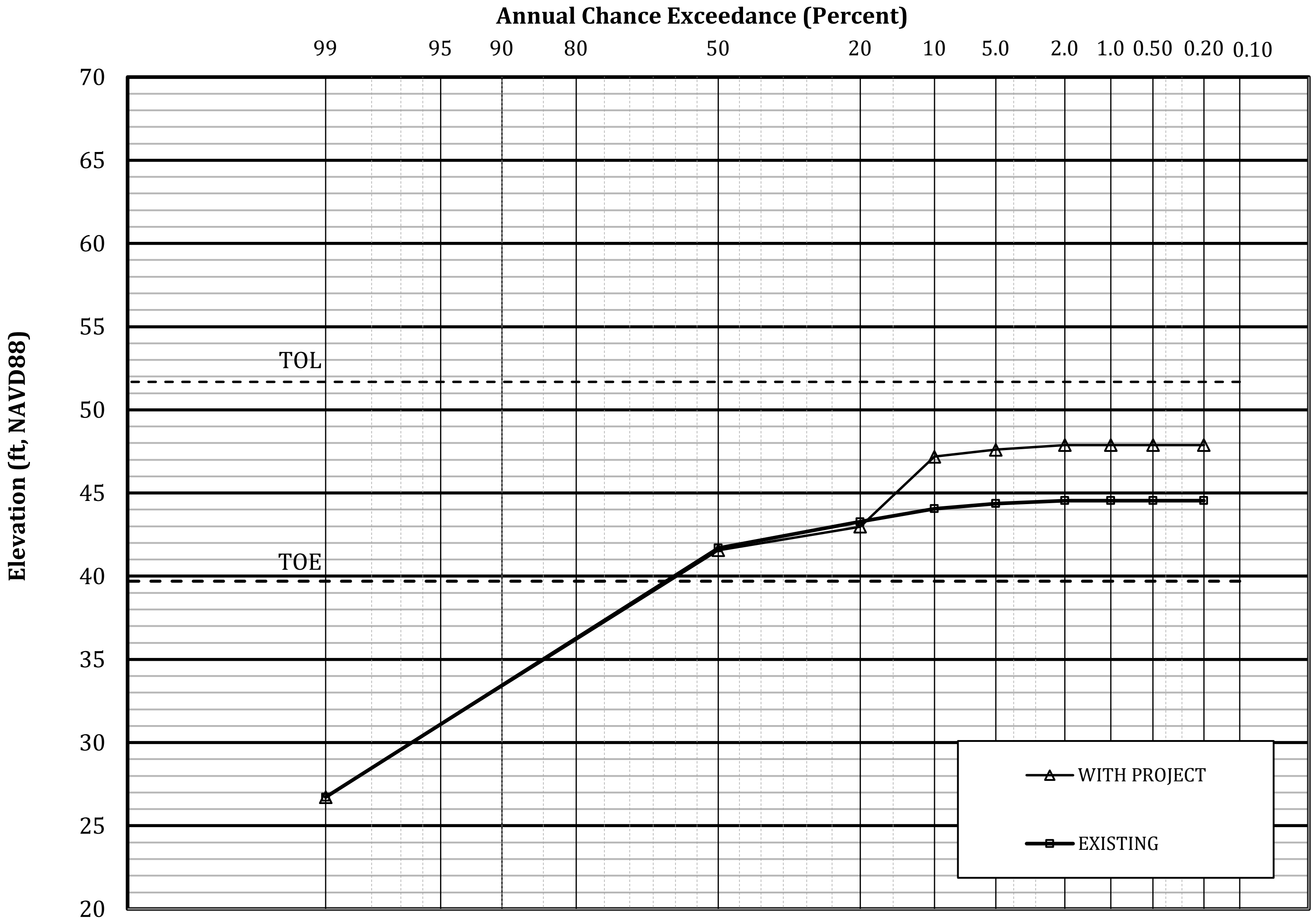
TOL - Top of Levee
TOE - Approximate elevation of natural floodplain adjacent to levee

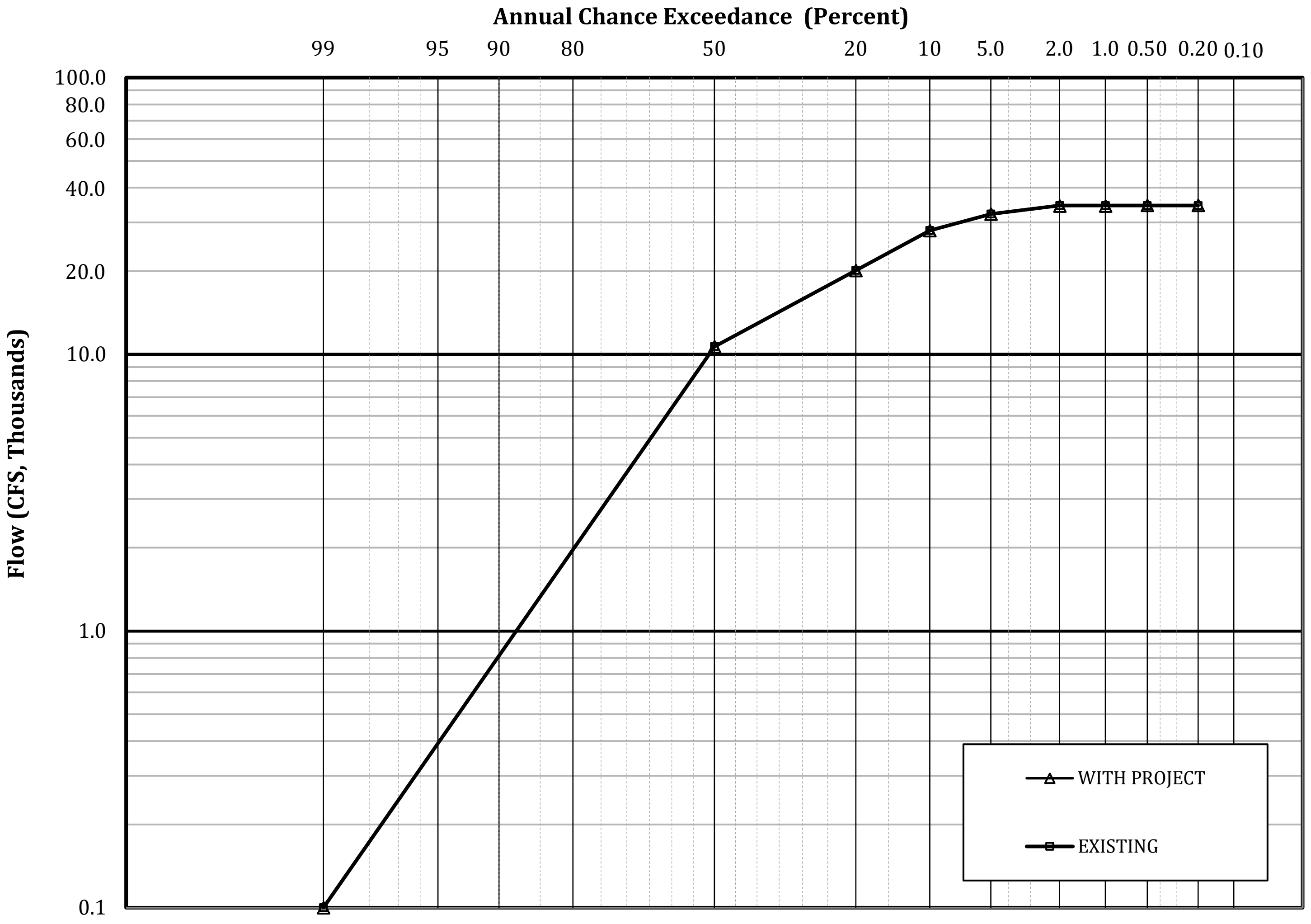
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

STAGE AND DISCHARGE FREQUENCY CURVES INDEX POINT P7

U.S. ARMY CORSP OF ENGINEERS
SACRAMENTO DISTRICT

September 2019





NOTES:

Curves Based on Without and With Project Tuflow simulations.
Stages and Flows for Index Point 8 were obtained from Tuflow.

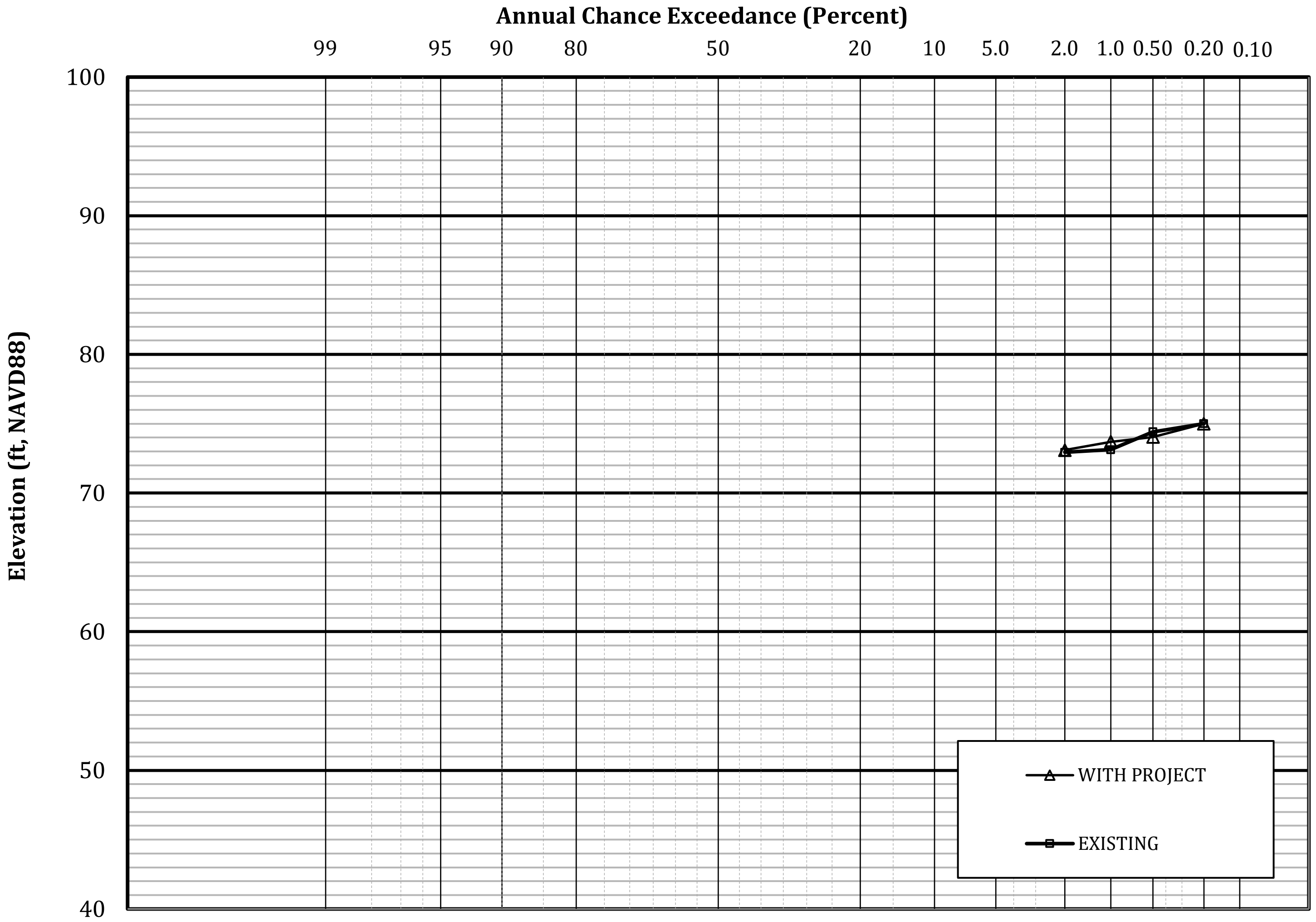
TOL - Top of Levee
TOE - Approximate elevation of natural floodplain adjacent to levee

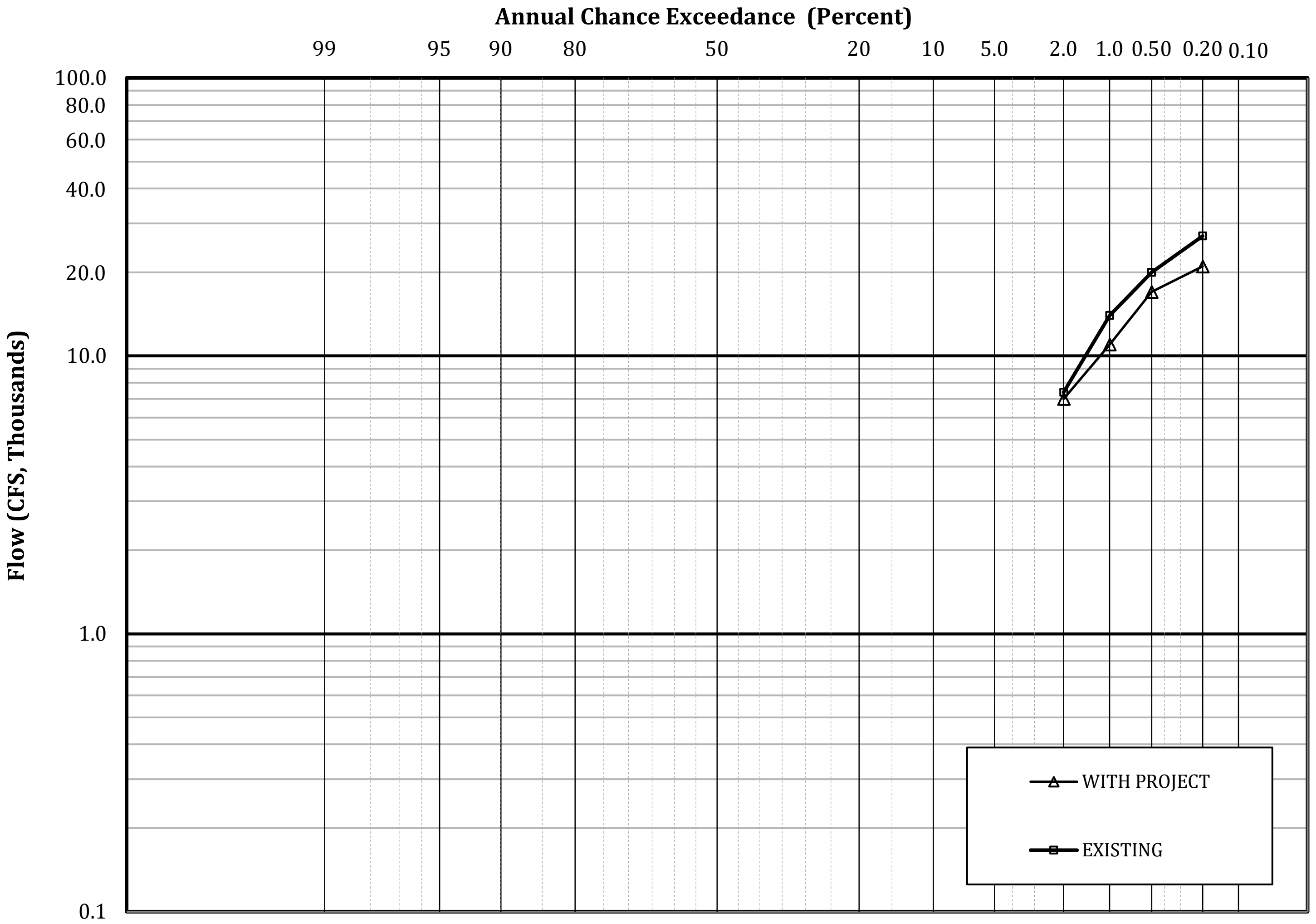
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

STAGE AND DISCHARGE FREQUENCY CURVES INDEX POINT P8

U.S. ARMY CORSP OF ENGINEERS
SACRAMENTO DISTRICT

September 2019





NOTES:

Curves Based on Without and With Project Tuflow simulations.

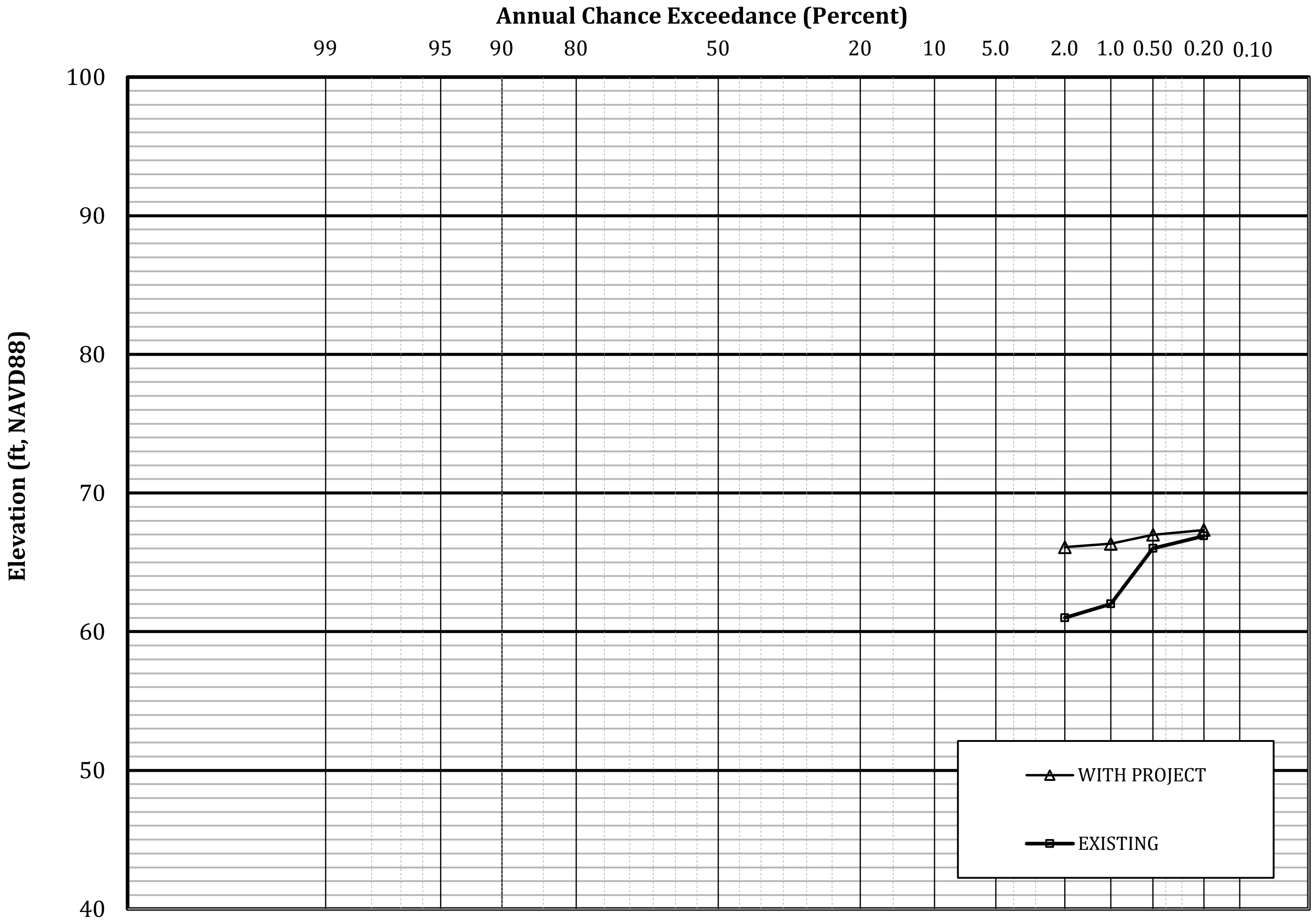
TOB - Top of Bank
TOE - Approximate elevation of natural floodplain adjacent to levee

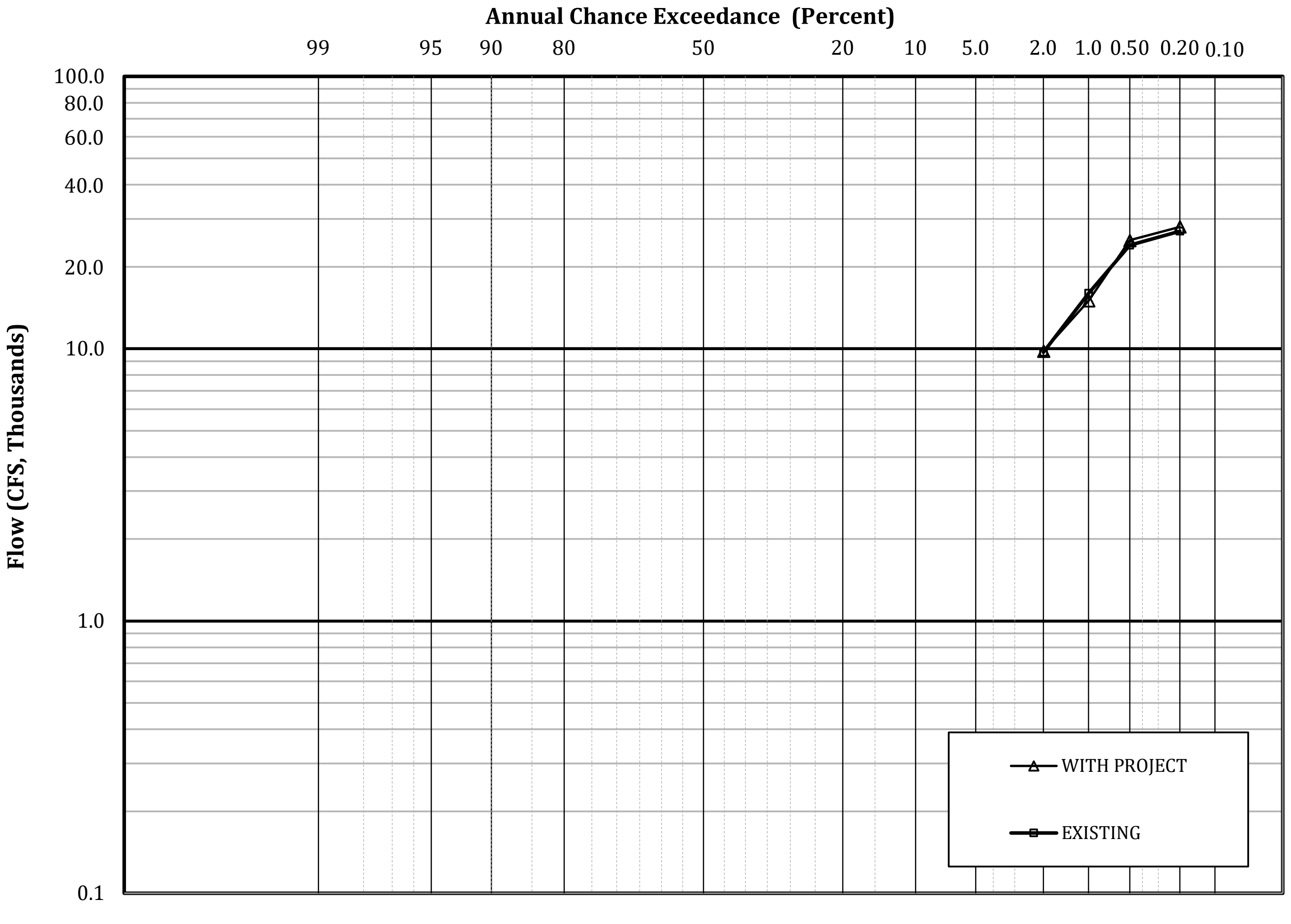
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

STAGE AND DISCHARGE FREQUENCY CURVES INDEX POINT Road 98

U.S. ARMY CORSP OF ENGINEERS
SACRAMENTO DISTRICT

September 2019





NOTES:

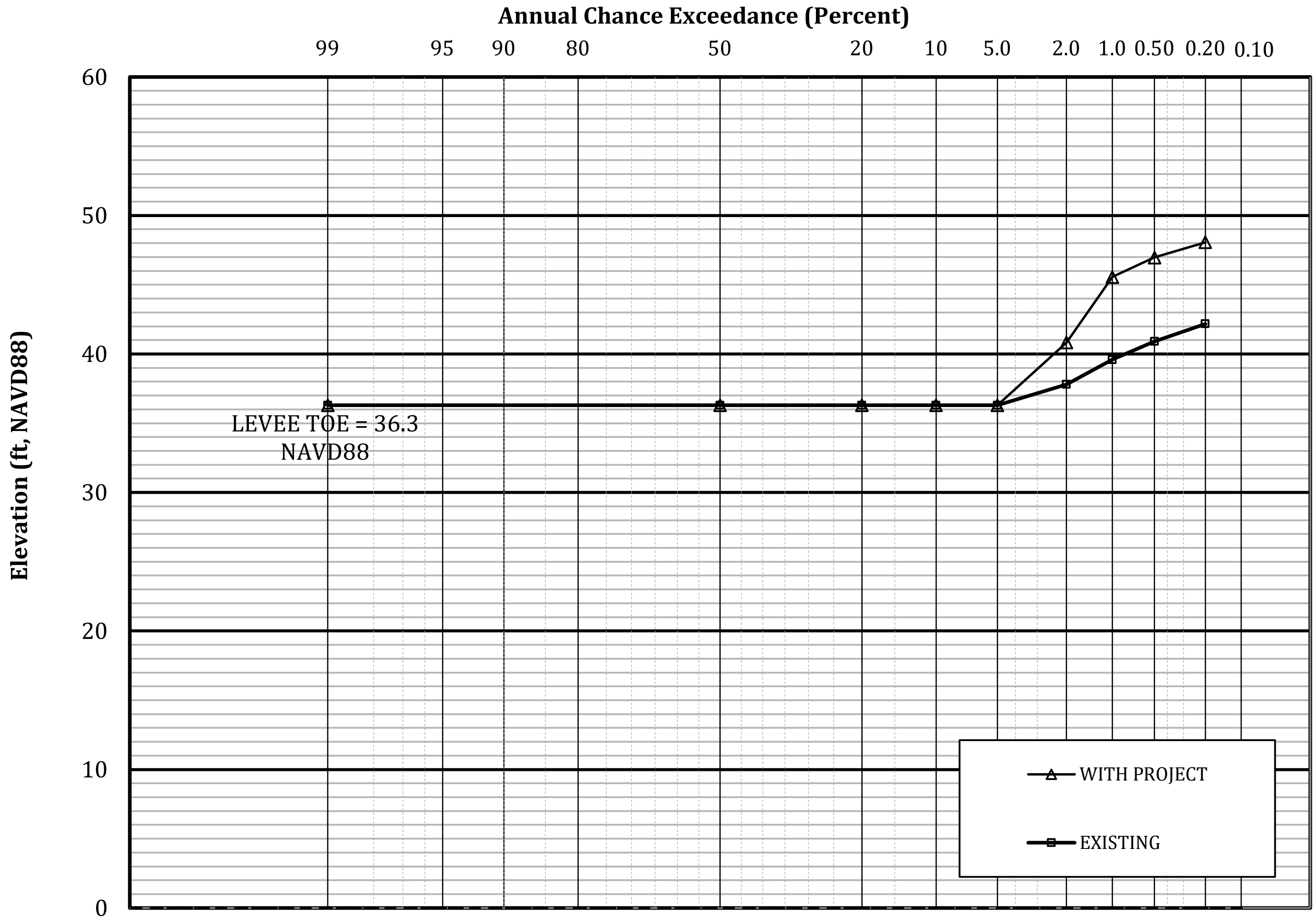
Curves Based on Without and With Project Tuflow simulations.

.

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

STAGE AND DISCHARGE FREQUENCY CURVES INDEX POINT ROAD 99

U.S. ARMY CORSP OF ENGINEERS
SACRAMENTO DISTRICT



NOTES:

Curves Based on Without and With Project Tuflow simulations.
.

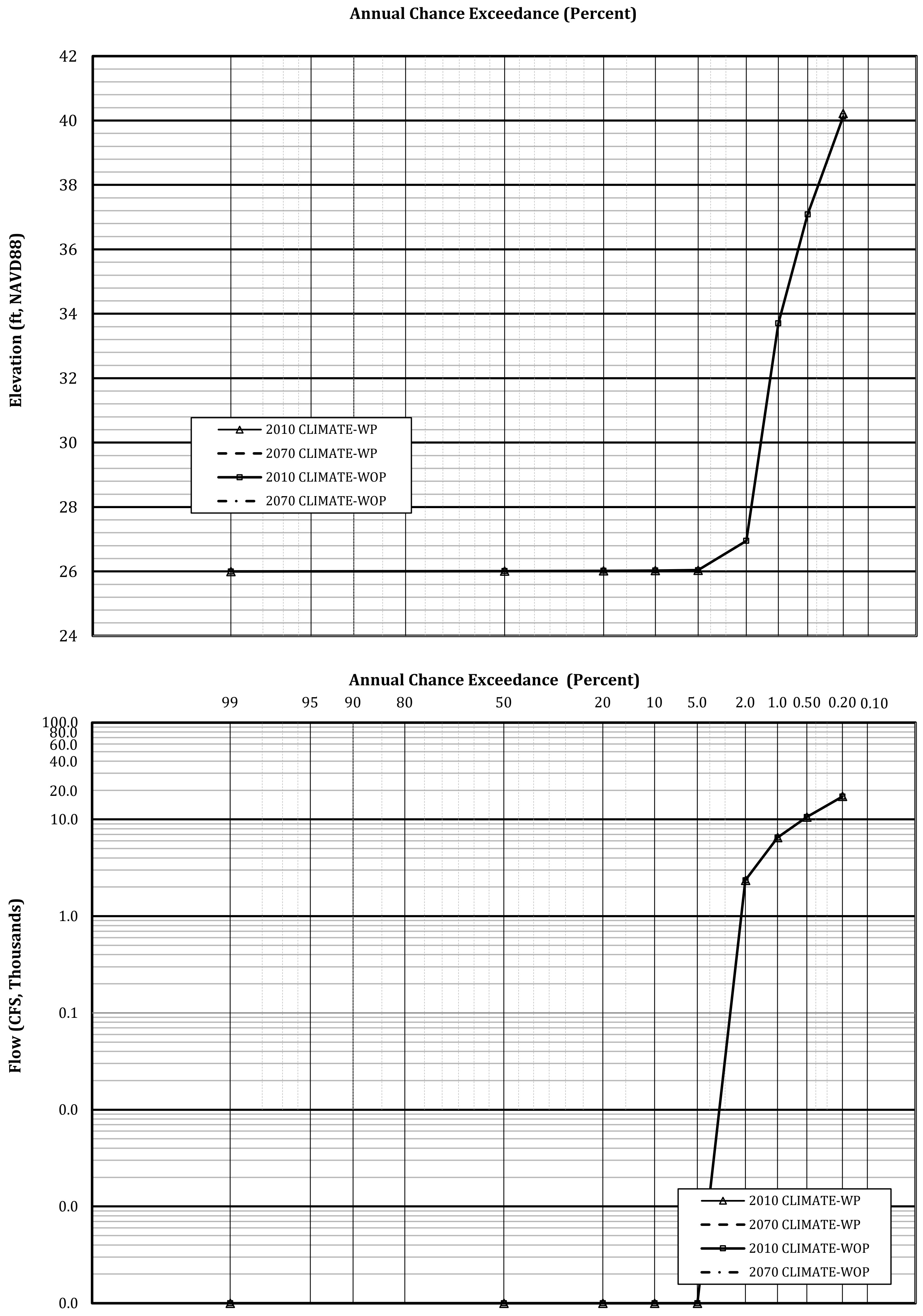
TOB - Top of Bank
TOE - Approximate elevation of natural floodplain adjacent to levee

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

STAGE FREQUENCY CURVES
County Road 102

U.S. ARMY CORSP OF ENGINEERS
SACRAMENTO DISTRICT

September 2019



NOTES:

Curves Based on Without and With Project Tuflow simulations.
Stages and Flows for Index Point 8 were obtained from Tuflow.

TOL - Top of Levee
TOE - Approximate elevation of natural floodplain adjacent to levee

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

STAGE AND DISCHARGE FREQUENCY CURVES KNIGHTS LANDING RIGHT OVERBANK (2013280E, 14073200N)

U.S. ARMY CORSP OF ENGINEERS
SACRAMENTO DISTRICT

September 2019

GEOTECHNICAL INVESTIGATION AND EVALUATION

APPENDIX C

LOWER CACHE CREEK FEASIBILITY STUDY

YOLO COUNTY, CALIFORNIA

December 2019

United States Army Corps of Engineers
Sacramento District

TABLE OF CONTENTS

Report Text

Tables

Figures

Plates

Attachment A

Attachment B

1. INTRODUCTION

1.1. Project Purpose, Description and Background

The purpose of the Lower Cache Creek Feasibility Study is to identify a project that addresses flooding from the right bank of Cache Creek north of the city of Woodland. Flooding from Cache Creek is anticipated to occur on a once-in-twenty-year to once-in-thirty-year recurrence interval due to the limited capacity of Lower Cache Creek. The study area is located about 15 miles northwest of Sacramento, California. Cache Creek flows southeast out of Clear Lake, through the Capay Valley and the eastern foothills of the Coast Range Mountains through the Cache Creek Settling Basin (CCSB) and western levees of the Yolo Bypass. Flooding in the Cache Creek basin is principally caused by runoff of high-intensity rainstorms during the winter and spring. The flood threat in the area is exacerbated by the raised bed of Interstate 5 (I-5) (and, potentially, the existing railroad) which diverts flood flows into Woodland. Lower Cache Creek has not experienced a 1% (1/100) AEP flood since the city was built. It is possible that a 1% (1/100) AEP flood may not occur within a hundred-year period. Statistically there is only a 63% chance that a flood of this magnitude will occur in any given century. Based on current analyses presented in the Hydraulic and Civil Design Appendix (Appendix B), the existing levee profile would pass a 10% (1/10) AEP event (30,000 cfs) with 90% assurance, if the levee is assumed to not fail prior to overtopping. However, including the probability of geotechnical failure prior to overtopping, the existing levee project would pass a 50% AEP (1/2) event (10,800 cfs) with 90% assurance.

USACE studied several alternative plans to identify a project that best addresses the solution to flooding. Alternative 2A, the Tentatively Selected Plan (TSP), involves constructing a partial ring levee north of the city of Woodland, California. This alternative is similar to the National Economic Development (NED) plan in the March 2003 feasibility study. The following is a brief description summarizing the project features proposed under Alternate 2A:

- New Levee: The proposed plan includes construction of a new levee north of the urban area of Woodland. The levee would be approximately 6 miles in length, originating near the intersection of County Road 19B and County Road 96B and extend easterly to the CCSB. The alignment of the levee would generally follow the northern City limit line west of Highway 113 and Churchill Downs Avenue east of Highway 113. The height of the levee would vary from 2 feet near CR 96B to 18 feet at its intersection with the existing west levee of the CCSB. The levee crown width is 12 feet and the waterside and landside slopes are each 1V:3H. The south side of the new levee would include a 30-foot wide by 5 foot high landside seepage berm along its length; however, depending on the outcome of future design studies during PED, a cutoff wall may be required in some reaches where a seepage berm is not feasible.
- Improved Section of Levee: Alternative 2A would tentatively rehabilitate the southwest levee of the CCSB by constructing a 2.5-foot wide 45-foot deep cutoff wall through the levee and a portion of the southern levee of the CCSB would be rehabilitated with a 60-foot deep cutoff wall. A soil bentonite cutoff wall would be constructed along the center of the levee to address seepage design criteria. Considered remediation alternatives for Reach E/Alternative 2A (Reach N) and Reach F/Alternative 2A (Reach O) are presented in paragraphs 5.3 and 6.5 respectively and should be further explored during PED).

- Drainage Canal: Expanding the proposed 350 cfs drainage canal along the waterside (north side) toe of the proposed levee would provide a source of levee embankment material. The drainage canal would also avoid impacts to local drainage facilities severed by the proposed levee. In addition, the canal would also provide drainage of floodwaters from low areas along the levee after a flood. The drainage canal would be located a minimum of 15 feet away from the levee toe to reduce potential for under-seepage related failure of the proposed levee. The maximum allowable depth of canal excavation will be determined during PED but should not exceed 5 feet. The new levee would require raising of CR98, CR99, CR101 and CR102. Culverts would be installed at each of these crossings, and culverts would be installed under Highway 113. The proposed levee will be aligned upstream (west) of Highway 113 in order to utilize an existing I-5 overpass above an existing railroad to convey flood waters across I-5. This will require a closure structure across the railroad and coordination with the railroad to get this concept approved if the railroad line is not abandoned in this area.
- Detention Basin: A detention basin would be located at the downstream end of the proposed drainage canal. The detention basin would include an east outlet and south outlet which are intended to optimize the drainage of ponded floodwaters on the west side of the proposed CCSB inlet weir. The east outlet would provide for gravity drainage to the CCSB and consist of a bank of three 60 inch diameter culverts fitted with flap gates. This would allow gravity flow into the CCSB after stages in the CCSB had fallen below the inlet weir crest. Reverse flow from the CCSB into the detention basin would be prevented by the flap gates. The south outlet would consist of a set of three 60 inch diameter culverts fitted with sluice gates. The gated culverts would discharge to a ditch that terminates at a pump station owned and operated by the city of Woodland. The sluice gate outlet, in combination with the detention basin, would allow for temporary detention of drainage until the pump station had available capacity to discharge the floodwaters to the Yolo Bypass.
- Inlet Weir to CCSB: A section of the west levee of the setting basin would be removed and replaced with a 3,000 foot long concrete weir. The weir would be located north of the point at which the new levee intersects the existing levee of the CCSB. The height of the inlet weir would be set at elevation 43 feet NAVD88 to prevent backflow from the settling basin during smaller flood events. Due to stage uncertainty in the CCSB the weir would be designed to resist erosion if weir flow were to occur in either direction. However, flow from the CCSB to the west is not expected.
- Outlet Weir from CCSB: The existing CCSB outlet weir has a crest elevation of 35.0 feet (NAVD88). No modifications will be made to the outlet weir. Hydraulic models of the existing weir configuration demonstrated that the existing weir has sufficient capacity to convey the additional flows that would be introduced to the CCSB through the proposed inlet weir.
- Bank Protection: Rock slope protection to address wind wave erosion during periods of ponding would be placed on the proposed new levee between CR 101 and the CCSB inlet weir. Rock slope protection would also be placed along 17,000 feet of the east and south faces of the existing CCSB and Cache Creek levee from Station 0+00 to Station 10+00 and Station 40+00 to Station 210+00 to address wind wave erosion during periods of ponding.
- Road Crossings: Closure structures were specified at the UPRR line near I-5, Highway 113, railroad spur line on the west side of Highway 113 and the local railroad spur line on the east side of Highway 113. All other road crossings would include roadway grade modifications to go over the

top of the levee. All road crossings would include operating provisions requiring the installation of temporary barriers during flood conditions.

2. PLAN FORMULATION

2.1 General

The initial and final array of plans were selected through a risk informed plan formulation process involving multi-disciplinary analysis using an appropriate level of detail for decision making. At each level of screening and analysis the level of detail was improved and the relative uncertainty was assessed. A measure or alternative was carried forward if the level of detail was insufficient to screen it out. Throughout this process the concept of absolute accuracy versus relative accuracy was considered in alternative comparisons. Although it would appear that every plan should be compared to the most accurate assessment of existing conditions, this was not necessary because the relative accuracy between plans is sufficient to select the most optimal plans to move forward.

2.2 Formulation and Evaluation Approach for Focused Array

A focused array of alternatives was formulated from an initial array of alternatives described in the feasibility study report. The focused alternatives were evaluated using qualitative and quantitative engineering analyses. Analyses included floodplain hydraulic modeling, geotechnical evaluations, cost estimating, and economic benefit estimations. The level of detail was limited to that required to decide which plans to carry forward. Results were evaluated at a combined Value Engineering (VE) study and planning charette attended by the project sponsors and subject matter experts. At the conclusion of the VE study and planning charette, refinements to the focused array of alternatives were identified for further, more detailed analysis.

2.3 Focused Array of Alternatives

Based on the screening process of the initial array described above, the no action and four action alternatives were carried forward to the focused array: Alternative 1: North Bypass, Alternative 2: South Bypass, Alternative 6: Levee Fix in Place, and Alternative 7: Partial Setback Levees. The PDT developed and evaluated several configurations of each alternative in the focused array based on a qualitative assessment of inflection points in the costs and/or benefits of alternatives, as described below. Letters following the alternative number (i.e., 1A, 1B, 1C) represent various performance options of each alternative. A value engineering (VE) study conducted on the focused array further informed the screening of alternatives and lead to the inclusion of alternatives 1D, 7A, and 7B. The following provides a description of the focused array of alternatives.

2.3.1 Alternative 1A: North Bypass A

This alternative includes strengthening the right bank of the existing levees from downstream of I-5 to the CCSB, as well as the left bank near the town of Yolo. In addition, this alternative includes a grade control structure and a right bank levee extension upstream of I-5, to accommodate excess flows. These features would increase the stage upstream of I-5, resulting in floodwaters overtopping the left bank and flowing north towards the Colusa Basin Drain. This alternative would include seepage mitigation and rock bank protection along most of its length. A map of this alternative is shown in Figure 3-4 in the draft Feasibility Report

The geotechnical basis of design for Alternative 1A is as follows:

Reach E – Cutoff Wall: levee crown width: 12 feet; waterside slope: 1V:3.5H; landside slope: 1V:2.5H; height of levee: 19 feet; length of soil bentonite wall: 7,808 feet; depth of wall: 60 feet; height of levee degrade: 9.5 feet.

Reach F – Cutoff Wall: levee crown width: 12 feet; waterside slope: 1V:3.5H; landside slope: 1V:2.5H; height of levee: 19 feet, length of soil bentonite wall: 5,535 feet; depth of wall: 45 feet; height of levee degrade: 9.5 feet.

Reach H – Cutoff Wall: levee crown width: 12 feet; waterside slope: 1V:3.5H; landside slope: 1V:2.5H; height of levee: 15 feet; length of soil bentonite wall: 4,554 feet; depth of wall: 18 feet; height of levee degrade: 7.5 feet.

Reach I.1 – RB Seepage Berm: levee crown width: 12+ feet; waterside slope: 1V:_H; landside slope: 1V:3H; height of levee: 10 feet. The landside of the levee would include a 60' wide x 5' high seepage berm along this reach segment.

R wateach I.2.1 – RB Seepage Berm: levee crown width: 12+ feet; waterside slope: 1V:_H; landside slope: 1V:3H; height of levee: 5 feet. The landside of the levee would include a 60' wide x 5' high seepage berm along this reach segment.

Reach I.2.2 – RB Seepage Berm: levee crown width: 12+ feet; waterside slope: 1V:_H; landside slope: 1V:3H; height of levee: 5 feet. The landside of the levee would include a 60' wide x 5' high seepage berm along this reach segment.

Reach I.2.3 – RB Seepage Berm: levee crown width: 12+ feet; waterside slope: 1V:_H; landside slope: 1V:3H; height of levee: 5 feet. The landside of the levee would include a 60' wide x 5' high seepage berm along this reach segment.

Reach I.3.1 – RB Seepage Berm: levee crown width: 12+ feet; waterside slope: 1V:_H; landside slope: 1V:3H; height of levee: 5 feet. The landside of the levee would include a 60' wide x 5' high seepage berm along this reach segment.

Reach I.3.2 - RB Seepage Berm: levee crown width: 12+ feet; waterside slope: 1V:_H; landside slope: 1V:3H; height of levee: 5 feet. The landside of the levee would include a 60' wide x 5' high seepage berm along this reach segment.

Reach I.3.3 - RB Seepage Berm: levee crown width: 12+ feet; waterside slope: 1V:_H; landside slope: 1V:3H; height of levee: 5 feet. The landside of the levee would include a 60' wide x 5' high seepage berm along this reach segment.

Reach I.4 – LB Cutoff Wall: levee crown width: 15 feet; waterside slope: 1V:3.5H; landside slope: 1V:2.5H; height of levee: 5 feet; length of soil bentonite wall: entire reach segment; depth of wall: 16 feet; height of levee degrade: 2.5 feet.

Reach I.4 – RB Seepage Berm: levee crown width: 12+ feet; waterside slope: 1V:_H; landside slope: 1V:3H; height of levee: 15 feet. The landside of the levee would include a 60’ wide x 5’ high seepage berm along this reach segment.

Reach 1.5 – LB Seepage Berm: levee crown width: 12+ feet; waterside slope: 1V:_H; landside slope: 1V:3H; height of levee: 3 feet. The landside of the levee would include a 60’ wide x 3’ high seepage berm along this reach.

Reach 1.5 – RB Seepage Berm: levee crown width: 12+ feet; waterside slope: 1V:_H; landside slope: 1V:3H; height of levee: 5 feet. The landside of the levee would include a 60’ wide x 5’ high seepage berm along this reach segment.

Reach J – New RB Levee with Seepage Berm: levee crown width: 15 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 9.5 feet. The landside of the levee would include a 30’ wide x 5’ high seepage berm along this reach segment.

Reach J.1 – New LB Levee with Seepage Berm: levee crown with: 15 feet; waterside slope: 1V:3H; landside slope: 1V:3H, height of levee: 9 feet. The landside of the levee would include a 30’ wide x 5’ high seepage berm along this reach segment.

2.3.2 Alternative 1B: North Bypass B

This alternative consists of the same structural features as Alternative 1A, though it adds the purchase of flowage easements on the land that would convey floodwaters to the Colusa Basin Drain. This alternative would include seepage mitigation and rock bank protection along most of its length. A map of this alternative is shown in Figure 3-5 in the draft Feasibility Report.

The geotechnical basis of design elements are essentially the same as for Alternative 1A

2.3.3 Alternative 1C: North Bypass C

This alternative includes strengthening the right bank of the existing levees from downstream of I-5 to the CCSB, similar to the structural features in Alternatives 1A and 1B. However, it includes the construction of bypass levees to ensure the floodwaters are conveyed to the Colusa Basin Drain. This alternative would include seepage mitigation and rock bank protection along most of its length. A map of this alternative is shown in Figure 3-6 in the draft Feasibility Report.

The geotechnical basis of design elements are essentially the same as for Alternative 1A

2.3.4 Alternative 1D: North Bypass D

This alternative is similar to Alternative 1A. However, it replaces the grade control structure and a right bank levee extension upstream of I-5 with a smaller extension of the right bank, a degrading of the left bank levee upstream of I-5, a new levee segment adjacent to I-5, and no strengthening of levees on the right bank of Cache Creek downstream of I-5. A map of this alternative is shown in Figure 3-7 in the draft Feasibility Report.

The geotechnical basis of design elements are essentially the same as for Alternative 1A

2.3.5 Alternative 2A: South Bypass A

This alternative would consist of a levee that would direct floodwaters that would otherwise enter the urban area of the City of Woodland east towards the Cache Creek Settling basin. The floodwaters would then pass into CCSB through a new inlet weir. The new inlet weir in the western levee of the CCSB would allow the floodwater to enter the CCSB while reducing the probability that Cache Creek floodwaters would escape the CCSB during smaller flood events. The inlet weir reduces stages west of the CCSB and is less costly than flowage easements that would have been required due to frequent flooding in the absence of the inlet weir. A portion of the floodwaters overtopping the south bank of Cache Creek would be conveyed by a channel created by the borrow area adjacent to the proposed levee. The channel would divert flows to the CCSB or to the City of Woodland pumping plant which would then discharge to the Yolo Bypass. The alternative also includes removal of a portion of a sediment training levee inside the CCSB so it does not obstruct the inlet weir. A map of this alternative is shown in Figure 3-8 in the draft Feasibility Report.

The geotechnical basis of design for Alternative 2A is as follows:

Segment S - New Levee & Seepage Berm: levee crown width: 12 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 6 feet. The south side of the new levee would include a 30’ wide x 5’ high seepage berm along its length.

Segment R - New Levee & Seepage Berm: levee crown width: 12 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 7 feet. The south side of the new levee would include a 30’ wide x 5’ high seepage berm along its length.

Segment Q - New Levee & Seepage Berm: levee crown width: 12 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 11 feet. The south side of the new levee would include a 30’ wide x 5’ high seepage berm along its length.

Segment P - New Levee & Seepage Berm: levee crown width: 12 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 14 feet. The south side of the new levee would include a 30’ wide x 5’ high seepage berm along its length.

Segment O - Cutoff Wall: levee crown width: 12 feet; waterside slope: 1V:3.5H; landside slope: 1V:2.5H; height of levee degrade: 9.5 feet; depth of soil bentonite wall: 45 feet.

Segment N - Cutoff Wall: levee crown width: 12 feet; waterside slope: 1V:3.5H; landside slope: 1V:2.5H; height of levee degrade: 9.5 feet; depth of soil bentonite wall: 60 feet.

2.3.6 Alternative 2B: South Bypass B

This alternative would consist of a levee that would direct floodwaters that would otherwise enter the urban area of the City of Woodland east towards the Cache Creek Settling basin, similar to Alternative 2A. However, rather than constructing an inlet weir to convey the water into the CCSB, a channel would convey floodwaters to the south of the CCSB and into the Yolo Bypass. Based on additional qualitative analysis, including of real estate requirements in an industrial complex adjacent to the CCSB, this alternative was screened out of the focused array. Alternative 2C incorporates some of the proposed features of Alternative 2B. A map of this alternative is shown in Figure 3-9 in the draft Feasibility Report.

The geotechnical basis of design for Alternative 2B is as follows:

The proposed plan includes construction of a new levee north of the urban area of Woodland. The levee would be approximately 6 miles in length, originate near the intersection of County Road 19B and County Road 96B and extend easterly to the Cache Creek Settling Basin. Dimensions of the new levee are as follows: levee crown width: 12 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: varies from 2 feet near CR 96B to 18 feet at its intersection with the existing west levee of the CCSB. The south side of the new levee would include a 30' wide x 5' high seepage berm along its length. Along the north side of the new levee, an open trapezoidal drainage ditch is planned to include rock slope protection. Deep cutoff wall depths are as follows: Reach O: 45 feet; Reach N: 60 feet. Cutoff walls may be required in some reaches where a seepage berm is not feasible. Depending on further analysis and design during PED, a cutoff wall may be required in some reaches where a seepage berm is not feasible. The levee design height for the new levee was considered to be based on providing 0.5% (1/200) AEP flood protection with 3 feet freeboard.

2.3.7 Alternative 2C: South Bypass C

This alternative would consist of a levee that would direct floodwaters that would otherwise enter the urban area of the City of Woodland east toward the CCSB, similar to Alternative 2A and 2B land east towards the Cache Creek Settling basin, similar to Alternative 2A and 2B, but rather than constructing an inlet weir to accommodate excess flows to the west of the CCSB, a channel would convey floodwaters to the south of the CCSB and into the Yolo Bypass. This channel would involve moving a portion of the CCSB west levee further to the east to avoid a large industrial complex. The railroad line along the south side of the CCSB would also require extensive modifications to allow for the flood control channel. A map of this alternative is shown in Figure 3-10 in the draft Feasibility Report.

The geotechnical basis of design for Alternative 2C is as follows:

Segment U - New Levee with Cutoff Wall: levee crown width: 12 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 19 feet; length of soil bentonite wall: 9,540 feet; depth of wall: 60 feet.

Segment T - New Levee with Cutoff Wall: levee crown width: 12 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 12 feet; length of soil bentonite wall: 8,206 feet; depth of wall: 60 feet.

Segment S - New Levee & Seepage Berm: levee crown width: 12 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 6 feet; overall length: 12,479 feet. The south side of the new levee would include a 30' wide x 5' high seepage berm along its length.

Segment R - New Levee & Seepage Berm: levee crown width: 12 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 7 feet; overall length: 4,628 feet. The south side of the new levee would include a 30' wide x 5' high seepage berm along its length.

Segment Q - New Levee & Seepage Berm: levee crown width: 12 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 8 feet; overall length: 11,657 feet. The south side of the new levee would include a 30' wide x 5' high seepage berm along its length.

Segment P - New Levee & Seepage Berm: levee crown width: 12 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 11 feet; overall length: 3,904 feet. The south side of the new levee would include a 30' wide x 5' high seepage berm along its length.

Segment O - Cutoff Wall: levee crown width: 12 feet; waterside slope: 1V:3.5H; landside slope: 1V:2.5H; height of levee: 9.5 feet; length of soil bentonite wall: 6,741 feet; depth of wall: 45 feet.

Segment N - Cutoff Wall: levee crown width: 12 feet; waterside slope: 1V:3.5H; landside slope: 1V:2.5H; height of levee: 9.5 feet; length of soil bentonite wall: 8,801 feet; depth of wall: 60 feet.

2.3.8 Alternative 2D: South Bypass D

This alternative would consist of a levee that would direct floodwaters that would otherwise enter the urban area of the City of Woodland east towards the Cache Creek Settling basin, similar to Alternative 2C. However, it would also include strengthening the right bank levee of Cache Creek to reduce flooding north of the City of Woodland and strengthen the left bank levee of Cache Creek adjacent to the town of Yolo. This alternative includes seepage mitigation and rock bank protection along most of right bank of Cache Creek. A map of this alternative is shown in Figure 3-11 in the draft Feasibility Report.

The geotechnical basis of design for Alternative 2D is as follows:

Segment U - New Levee with Cutoff Wall: levee crown width: 12 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of the levee: 19 feet; length of soil bentonite wall: 9,540 feet; depth of wall: 60 feet.

Segment T - New Levee with Cutoff Wall: levee crown width: 12 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 12 feet; length of soil bentonite wall: 8,206 feet; depth of wall: 60 feet.

Segment S - New Levee & Seepage Berm: levee crown width: 12 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 6 feet; overall length: 10,196 feet. The south side of the new levee would include a 30’ wide x 5’ high seepage berm along its length.

Segment R - New Levee & Seepage Berm: levee crown width: 12 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 7 feet; overall length: 3,333 feet. The south side of the new levee would include a 30’ wide x 5’ high seepage berm along its length.

Segment Q - New Levee & Seepage Berm: levee crown width: 12 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 8 feet; overall length: 10,587 feet. The south side of the new levee would include a 30’ wide x 5’ high seepage berm along its length.

Segment P - New Levee & Seepage Berm: levee crown width: 12 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 11 feet; overall length: 3,904 feet. The south side of the new levee would include a 30’ wide x 5’ high seepage berm along its length.

Segment O - Cutoff Wall: levee crown width: 12 feet; waterside slope: 1V:3.5H; landside slope: 1V:2.5H; height of levee degrade: 9.5 feet; length of soil bentonite wall: 5,096 feet; depth of wall: 65 feet.

Segment N - Cutoff Wall: levee crown width: 12 feet; waterside slope: 1V:3.5H; landside slope: 1V:2.5H; height of levee degrade: 9.5 feet; length of soil bentonite wall: 10,602 feet; depth of wall: 65 feet.

Reach I.4 - LB Cutoff Wall: levee crown width: 15 feet; waterside slope: 1V:3.5H; landside slope: 1V:2.5H; height of levee degrade: 2.5 feet; length of soil bentonite wall: 2,534 feet; depth of wall: 16 feet. (documentation for 16 foot depth not available)

Reach I.4 - RB Seepage Berm: The south side of the existing levee would include a 60’ wide x 5’ high seepage berm along its overall length of 2,255 feet.

Reach I.5 - RB Seepage Berm: The south side of the existing levee would include a 60’ wide x 5’ high seepage berm along its overall length of 2,555 feet.

Reach I.3.3 - RB Seepage Berm: The south side of the existing levee would include a 60’ wide x 5’ high seepage berm along its overall length of 4,506 feet.

Reach I.3.2 - RB Seepage Berm: The south side of the existing levee would include a 60’ wide x 5’ high seepage berm along its overall length of 1,793 feet.

Reach I.3.1 - RB Seepage Berm: The south side of the existing levee would include a 60’ wide x 5’ high seepage berm along its overall length of 6,720 feet.

Reach I.2.3 - RB Seepage Berm: The south side of the existing levee would include a 60’ wide x 5’ high seepage berm along its overall length of 2,248 feet.

Reach I.2.2 - RB Seepage Berm: The south side of the existing levee would include a 60’ wide x 5’ foot high seepage berm along its overall length of 3,076 feet.

Reach I.2.1 - RB Seepage Berm: The south side of the existing levee would include a 60’ wide x 5’ high seepage berm along its overall length of 2,009 feet.

Reach I.1 - RB Seepage Berm: The south side of the existing levee would include a 60’ wide x 5’ high seepage berm along its overall length of 9,023 feet.

Reach H - Cutoff Wall: levee crown width 12 feet; waterside slope: 1V:3H; landside slope: 1V:2H; height of levee degrade: 7.5 feet; length of soil bentonite wall: 4,233 feet; depth wall: 18 feet. (documentation for 18 foot depth not available)

Reach I.3.3 - LB Seepage Berm: The north side of the existing levee would include a 60’ wide x 5’ high seepage berm along its overall length of 4,506 feet.

Reach I.3.2 ‘ LB Seepage Berm: The north side of the existing levee would include a 60’ wide x 5’ foot high seepage berm along its overall length of 1,793 feet.

Reach I.3.1 - LB Seepage Berm: The north side of the existing levee would include a 60’ wide x 5’ high seepage berm along its overall length of 6,720 feet.

Reach I.2.3 - LB Seepage Berm: The north side of the existing levee would include a 60’ wide x 5’ high seepage berm along its overall length of 2,248 feet.

Reach I.2.2 - LB Seepage Berm: The north side of the existing levee would include a 60’ wide x 5’ high seepage berm along its overall length of 3,076 feet.

Reach I.2.1 - LB Seepage Berm: The north side of the existing levee would include a 60’ wide x 5’ high seepage berm along its overall length of 2,009 feet.

Reach I.1 - LB Seepage Berm: The north side of the existing levee would include a 60’ wide x 5’ high seepage berm along its overall length of 9,023 feet.

2.3.9 Alternative 6A: Strengthen in Place A

This alternative would involve strengthening the right bank levee of Cache Creek. The alternative would also include strengthening the left bank of Cache Creek along the town of Yolo. This alternative reduces the risk of flooding associated with geotechnical related failures (e.g. through- and under-seepage). However, the hydraulic capacity (overtopping) related failure probability would remain the same. This alternative includes seepage mitigation and rock bank protection along most of its length. A map of this alternative is shown in Figure 3-12 in the draft Feasibility Report.

The geotechnical basis of design for Alternative 6A is a follows:

- Setback Levees: For the setback levee alternative for the Lower Cache Creek Left Bank (LCCL)/Lower Cache Creek Right Bank (LCCR) include a new embankment and based on geologic information, assume similar subsurface conditions exist, therefore requiring the same mitigation measures as the fix in place alternative.
- Fix in Place Levees: Preliminary recommendations are as follows:

Reach E (CCSB) – Type of Mitigation Required: Under-seepage; Mitigation Measure: Soil-bentonite Cutoff Wall; Mitigation Depth: 60 feet; Working Platform Elevation: 43 feet (NAVD 88); Mitigation Invert Elevation: -17 feet (NAVD 88); Length of Cutoff Wall: 7,808 feet.

Reach F (CCSB) – Type of Mitigation Required: Under-seepage and embankment stability; Mitigation Measure: Soil-bentonite Cutoff Wall; Mitigation Depth: 45 feet; Working Platform Elevation: 43 feet (NAVD 88); Mitigation Invert Elevation: -2 feet (NAVD 88); Length of Cutoff Wall: 5,535 feet.

Reach H (CCSB) – Type of Mitigation Required: Under-seepage; Mitigation Measure: Soil-bentonite Cutoff Wall; Mitigation Depth: 18 feet; Working Platform Elevation: 43 feet (NAVD 88), Mitigation Invert Elevation: 18 feet (NAVD 88); Length of Cutoff Wall: 4,554 feet.

Reach I (LCCL) – Type of Mitigation Required: Through-levee seepage and under-seepage; Mitigation Measure: Seepage Berm with filtered exit; Recommended Measure: Construct a seepage berm on the landside toe of levee to a height of 5 feet and a width of 60 feet for entire length of reach, 34,700 feet.

Reach I (LCCR) – Type of Mitigation Required: Through-levee seepage and under-seepage; Mitigation Measure: Seepage berm with filtered exit; Recommended Measure: Construct a seepage berm on the landside toe of levee to a height of 5 feet and a width of 60 feet for entire length of reach, 34,700 feet.

2.3.10 Alternative 6B: Strengthen/Raise in Place B

This alternative strengthens and increases the height of the right bank levee and the left bank levee near Yolo. Floodwaters would flow overland to the Colusa Basin and Knights Landing Ridge Cut before draining into the Yolo Bypass. This alternative includes seepage mitigation and rock bank protection along most of its length. A map of this alternative is shown in Figure 3-13 in the draft Feasibility Report.

2.3.11 Alternative 6C: Strengthen/Raise in Place C

This alternative includes strengthening or increasing the height of existing left and right bank levees to contain flow in the existing levee alignment. The left bank levee upstream of I-5 would be removed and a new levee would be constructed adjacent to I-5, to force the floodwaters to the north where they would be conveyed across I-5 through a bank of culverts. This alternative would include seepage mitigation and rock bank protection along most of its length. A map of this alternative is shown in Figure 3-14 in the draft Feasibility Report.

2.3.12 Alternative 7A: Partial Setback Levee A

This alternative would involve building levees set back from Cache Creek on the right bank to contain flow within an expanded levee system, reducing the probability of flooding in the City of Woodland. The channel dimensions for the setback levee configuration would be designed to maintain the same water surface profile as existing condition but with additional flow. The additional flow would be based on maintaining the same left bank overflow upstream of I-5 as the no-action plan. At bridges, culverts would be included in the overbank area to eliminate constrictions. The alternative would modify the existing CCSB outlet weir into the Yolo Bypass to accommodate the increase flow. A map of this alternative is shown in Figure 3-15 in the draft Feasibility Report.

The geotechnical basis of design for Alternative 7A is as follows:

Dimensions of Partial Setback Levee Upstream of I-5 (New Levee and Seepage Berm): levee crown width: 15 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 11 feet; overall length: 2,000 feet. The north side of the new levee would include a 30’ wide x 5’ high seepage berm along its length.

Dimensions of Partial Setback Levee (New J Levee and Seepage Berm): levee crown width: 15 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 9 feet; overall length: 13,000 feet. The south side of the new levee would include a 30’ wide x 5’ high seepage berm along its length.

Dimensions of Partial Setback Levee Downstream of I-5 (New Levee and Seepage Berm): levee crown width: 15 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 14 feet; overall length: 38,000 feet. The south side of the new levee would include a 30’ wide x 5’ high seepage berm along its length.

Dimensions of Reach I.4 - LB Cutoff Wall: levee crown width: 12 feet; waterside slope: 1V:3H; landside slope: 1V:2H; height of levee degrade: 4.5 feet; length of soil bentonite wall: 2,534 feet; depth of wall: 16 feet.

Dimensions of Reach O Cutoff Wall: levee crown width: 12 feet; waterside slope: 1V:3.5H; landside slope: 1V:2.5H; height of levee degrade: 9.5 feet; length of soil bentonite wall: 5,528 feet; depth of wall: 45 feet.

Dimensions of Reach N Cutoff Wall: levee crown width: 12 feet; waterside slope: 1V:3.5H; landside slope: 1V:2.5H; height of levee degrade: 9.5 feet; length of soil bentonite wall: 7,840 feet; depth of wall: 60 feet.

Degrade of Existing Right Bank Levee: levee crown width: 15 feet; waterside slope: 1V:3H; landside slope: 1V:2H; height of levee degrade: 5 feet; length of degrade: 34,700 feet.

2.3.13 Alternative 7B: Partial Setback Levee B

This alternative would involve building levees set back from Cache Creek on the right bank as well as culverts under I-5, UPRR and other utilities, similar to Alternative 7A. However, it also includes a bypass channel to the north of the CCSB. Measures include excavation of material to accommodate flow through the North Channel, flowage easements on inundated lands, and a new inlet weir north of the CCSB to allow flows to enter the Yolo Bypass. A map of this alternative is shown in Figure 3-16 in the draft Feasibility Report.

The geotechnical basis of design for Alternative 7B is as follows:

Dimensions of Partial Setback Levee Upstream of I-5 (New Levee and Seepage Berm): levee crown width: 15 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 11 feet; overall length: 2,000 feet. The north side of the new levee would include a 30’ wide x 5’ high seepage berm along its length.

Dimensions of Partial Setback Levee (New J Levee and Seepage Berm): levee crown width: 15 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 9 feet; overall length: 13,000 feet. The south side of the new levee would include a 30’ wide x 5’ high seepage berm along its length.

Dimensions of Partial Setback Levee Downstream of I-5 (New Levee and Seepage Berm): levee crown width: 15 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 14 feet; overall length: 38,000 feet. The north side of the new levee would include a 30’ wide x 5’ high seepage berm along its length.

Dimensions of Reach I.4 - LB Cutoff Wall: levee crown width: 12 feet; waterside slope: 1V:3H; landside slope: 1V:2H; height of levee degrade: 4.5 feet; length of soil bentonite wall: 2,534 feet; depth of wall: 16 feet.

Dimensions of Easternmost Partial Setback Levee (New Levee and Seepage Berm): levee crown width: 15 feet; waterside slope: 1V:3H; landside slope: 1V:3H; height of levee: 14 feet; overall length: 7,600 feet. The north side of the new levee would include a 30’ wide x 5’ high seepage berm along its length.

Degrade of Existing Right Bank Levee: levee crown width: 15 feet; waterside slope: 1V:3H: landside slope: 1V:3H; height of levee degrade: 5 feet; length of degrade: is 34,700 feet.

3. GEOLOGIC AND GEOMORPHIC SETTING

The Woodland study area lies within part of the alluvial valley between the California Coast Range and the Sacramento River (**Figure 1**). In the Woodland area, this broad alluvial valley is traversed by Cache Creek, which originates from and drains portions of the Coast Range Mountains. The geology of the lower portion of the Cache Creek Basin consists of Quaternary-aged continentally-derived deposits of clay, silt, sand and gravel. Underlying the sedimentary fill is the massive Great Valley Sequence of early-Cretaceous to mid-Tertiary-aged marine shales, sandstones and conglomerates up to 40,000 feet thick in some locations in California. The surficial deposits at the project area are alluvium and flood plains and generally not as coarse as the continentally-derived sedimentary fill. This material forms significant aquifers that underlie the Great Valley portion of the basin at the study area. The size and extent of the aquifers are not known.

Within the project area, Lower Cache Creek flows on alluvial fan and flood plain deposits ranging from clay and silt to coarse sand and gravel (Wahler Associates, 1982). Borehole data show clay deposits to be common at depths in excess of 20 to 25 feet from ground surface, whereas more recently deposited silt and sand characterize sediments above the 20- to 25-foot depth (USACE, 1958).

Several faults are located in the vicinity of the project area. The Dunnigan Hills Fault is less than 5 miles northwest of the project area and is considered active due to recent activity during the Holocene epoch (the last 10,000 years) (Toppozada, T., D. Branum, M. Petersen, C. Hallstrom, C. Cramer, and M. Reichle, 2000). Other faults in the region include the Zamora and Capay Faults, both of which are considered to be inactive. Lower Cache Creek has experienced a small amount of land subsidence due to groundwater withdrawal. From 1942 to 1987, the city of Woodland had an estimated maximum cumulative land subsidence of 2.25 feet.

In the vicinity of the Woodland study area, the geomorphic setting can be subdivided into two domains: the alluvial-fan domain, which is characterized by alluvial fans and low alluvial plains, and the flood basin domain, which is characterized by distal alluvial fan deposition and fluvial basin sedimentation.

The alluvial-fan domain consists of alluvial fans and low alluvial plains on the western side of the Sacramento Valley, between the uplands of the Coast Range and the flood basins of the Sacramento River. The alluvial fan sediments are composed of relatively fine grained, weathered materials eroded from weak shales, sandstones, and low-grade metamorphic rocks of the eastern Coast Ranges (Wagner et al., 1981; Wagner and Bortugno, 1982). The alluvial fan deposits in the Woodland study area include a complex arrangement of Pleistocene and Holocene alluvial deposits. The Cache Creek alluvial fan is generally coarser-grained upslope (i.e., gravels and sands) and finer-grained downslope (i.e., silts and clays).

The flood basin domain occupies the low lands on the west side of the Sacramento River in broad and topographically low-relief areas between the river’s natural levees and adjacent Coast Range fans. Deposition in the Yolo basin is from slow moving or standing water as opposed to channelized flow, so sediments are primarily silt and clay. Flood basin deposits are unconsolidated and late Holocene in age (Helley and Harwood, 1985). Because of the relatively low-energy environment of deposition, the subsurface stratigraphy should, at most places, have low variability and relatively laterally-extensive deposits (URS, 2011).

4. REGIONAL SUBSIDENCE

Land subsidence caused by groundwater extraction has occurred historically and continues to occur in portions of the Sacramento Valley (DWR, 2018). A 2017 high precision GPS study by the California Department of Water Resources (DWR) concluded that portions of the study area have undergone regional ground subsidence since the 2008 topographic surveys were conducted. A map of the findings is presented in Figure ES-1 of the report. The study indicates that subsidence rates from 2008 to 2017 were greatest on the west side of the Lower Cache Creek feasibility study area (-1.1 feet) and lowest on the east side of the study area (-0.1 feet). During the time of the 2017 survey, groundwater levels in the Sacramento Valley were recovering from the severe drought of 2012-16 (DWR, 2018). During the drought, groundwater levels hit historic lows in most wells in the Sacramento Valley with maximum decreases in Glenn and Colusa Counties of 58 ft. and 43 ft., respectively, compared to 2011 pre-drought conditions. During the survey field work in 2017, groundwater levels had recovered about 7 ft. on average since 2015 (DWR, 2018). Therefore, it is possible the observed rate does not reflect an average future rate.

5. FIELD INVESTIGATIONS

5.1 Woodland Study Area Urban Levee Investigation

URS investigated a 10 mile reach of levee as part of the Woodland Study Area Phase 1 and supplemental investigation programs (URS, 2014). This study was performed under the auspices of the California Department of Water Resources (DWR), Division of Flood Management. The area studied is located along the Yolo Bypass West Levee, the right bank of the CCSB and the right bank of Cache Creek as shown in **Figure ES-2**. The project team obtained historical geotechnical data from geotechnical studies performed near the Woodland Study Area and is summarized in Appendix A of the Phase I Geotechnical Data Report (P1GDR) (URS, 2009). .

The Phase 1 subsurface exploration program took place from April 2008 to May 2008. Additional explorations were performed for the ULE special testing program between May 2009 and September 2009. Supplemental subsurface explorations took place between September 2011 and November 2011. The ULE special testing program and the supplemental subsurface exploration results are presented in the Supplemental Geotechnical Data Report (SGDR) (URS, 2013). Explorations from these previous geotechnical studies are shown on **Plates 1** through **11** and presented in **Table 1**.

5.2 Preliminary Borrow Site Investigation

(AECOM, 2016) performed a preliminary borrow site investigation for the Lower Cache Creek feasibility study. The purpose of this preliminary borrow site investigation was to obtain information regarding shallow subsurface soils located in the proposed channel alignment excavation. Two phases of investigation were performed. Phase 1 was performed in October 2015 and included six test pits (WLCCDB_01TP through WLCCDB_06TP). Phase 1 of the borrow site investigation was performed on the western portion of the proposed channel along Churchill Downs Avenue. Phase 2 of the borrow site investigation was performed in the proposed channel south of the CCSB. Six test pits (WLCCB_10TP through WLCCB_12TP) were performed on May 4, 2016. The locations of the test pits are shown in **Figure 2**. Test pit logs from Phase 1 and Phase 2 are presented in **Attachment A**. Sandy lean clay and lean clay (CL), plastic silt (ML) and fat clay (CH) were encountered in the test pits. Within the proposed depth of the channel excavation (approx. 5 feet) the predominant soil types encountered were lean and fat clay. Laboratory test results indicate these soils have liquid limits above 45 and would be subject to surficial desiccation cracking that can be problematic from a maintenance standpoint. The suitability of these materials was evaluated by the City of Woodland during the early phases of this project. The City's evaluation indicates that, although the subsurface soils contain high-plasticity (fat) clays that do not meet USACE EM 1110-2-1913 criteria for liquid limit, approximately 95% of the material excavated could be used as levee embankment fill with proper design details and construction processing. This includes creating a zoned embankment where the more high-plasticity material is placed within the levee prism to prevent surface desiccation. Other nearby sources of borrow should also be considered. Surficial silt and clay soil deposits in undeveloped land that could potentially be used for borrow within a 5 mile range of the project area. Aggregate base and asphalt materials will be obtained from local sources.

Estimated earthwork quantities for Alternative 2A (Wood Rodgers, 2019) indicate the project earthwork is closely balanced with a total estimated fill requirement of approximately 1,189,000 CY (fill quantities include an additional 20% to account for shrinkage of levee and berm fill material during compaction), and suitable material from excavations estimated to be about 1,183,000 CY leaving approximately 6,000 CY of import. Fill material for the embankment and seepage berm will be obtained from the excavation of the trapezoidal drainage ditch north of the levee toe (intentionally sized at 150 feet wide to balance fill needs), the detention basin excavation, as well as the inspection trench excavation

5.3 New Levee Exploration

Exploration of subsurface conditions along the new levee alignment will be required to support PED design level work. New explorations should be located to supplement any existing subsurface data. CESPK-ED-G Memorandum *Geotechnical Levee Practice,* dated 7 Dec 2010, provides policy guidance for setting up exploration programs. The final report of the 2003 CESPK Levee Task Force, provides the following guidelines for establishing field investigations

- ✓ Explorations should generally be located 1000 to 2000 feet horizontal spacing along the proposed levee alignment.
- ✓ The exploration program should include a geomorphological review of landforms using aerial photography.
- ✓ Judgment should be exercised to adequately capture foundation variability, and to study more critical and unique locations, such as sumps and pump stations.
- ✓ Exploration depths should be sufficient to characterize subsurface conditions. To evaluate seepage conditions, extend the primary explorations to the bottom of the deeper pervious layers, and extend waterside and landside explorations below the waterside and landside impervious blanket layer.
- ✓ Explorations should extend to a depth of at least three times the levee height into the levee foundation and a minimum of one exploration per mile should extend to the bottom of the aquifer.
- ✓ To evaluate stability and settlement extend explorations to competent material. Exploration depths in the range of 40 to 100 feet are generally common.
- ✓ Continuous SPT sampling or CPTs are useful in exploring the top stratum where there is a gradational change from clay to silt to fine sand to assist in determining the top stratum thickness.
- ✓ To correlate CPT data, locate some CPT holes adjacent to SPT holes. Material descriptions from the SPT holes should be verified with an appropriate level of laboratory soil classification test data, there should be at least 1 SPT hole drilled and sampled for every 5 to 10 CPT holes.

6. REACH SELECTION AND METHODOLOGY

6.1 General

The Woodland Study Area was subdivided into 8 reaches for analysis and evaluation as shown in **Figure ES-2**. Reaches were selected based on areas of the levee having similar geometry, performance and/or subsurface conditions. Land use and past levee improvements were also considered in reach selection. The methodologies used in the subsurface investigations, laboratory testing and engineering analyses were developed for the purposes of ULE and are considered screening-level evaluations intended to identify potential levee deficiencies; however, the nature of this screening-level evaluation may not detect all deficiencies that may exist. Analysis results show that six reaches in the Woodland Study Area did not meet ULE criteria and will require further analysis to assess remedial alternatives. **Table 2** provides a brief summary of evaluation findings (URS, 2014).

The investigations and analyses of Reaches E and F are noteworthy since these two reaches encompass the southeastern portion of USACE's Lower Cache Creek Feasibility Study selected alternative (Alternative 2A). The following sections of this report focus on these two reaches. **Table 3** provides an analysis cross section selection summary for Reaches E and F.

6.2 Index Points

Index locations reflect the performance of a channel reach. Engineering inputs for index locations include discharge frequency estimates, stage-discharge relationships and levee performance curves (fragility curves). The index points are shown on Plate 24 in the Hydraulic and Civil Design Appendix (Appendix B). Levee performance curves for the existing project conditions are located in **Attachment B.**

6.3 California State Urban Levee Design Criteria

Although the California State Urban Levee Design Criteria (ULDC) is not a federal objective of the study, it is a local sponsor objective. Two options are offered in the ULDC requirements for determining if a levee meets the urban and urbanizing area levee system design. The freeboard option (option 1) requires 3 feet of freeboard above the mean 0.5% (1/200) AEP flood event. The risk and uncertainty option (option 2) allows for a lesser amount of freeboard (2 feet) if a high level of assurance (95%) can be demonstrated. For Lower Cache Creek, option 1 was adopted.

7. REACH ANALYSES (REACH E: STA. 1287+51 TO 1365+59 / ALTERNATIVE "2A" REACH SEGMENT "N" STA. 45+00 TO 120+00)

Geomorphic information indicates this reach is predominately underlain by Holocene alluvial fan deposits, consisting of silt, clay and poorly sorted-sand deposited by distributary channels on the alluvial fan. These deposits are finer toward the southeastern portion of the reach. Within this reach there is an approximately 19- to 32-foot thick continuous sand and gravel aquifer present about 10 to 14 feet below the blanket layer at the landside toe of levee. To the immediate north in Reach F the aquifer layer is not continuous and is thinner, and to the east in Reach D no aquifer is present. While this reach has no past history of distress related to seepage, Reach F has a past history of seepage. The blanket thickness of this reach and Reach F are similar. Details about approximate levee geometry and design water surface elevation (WSE) data are provided below.

Levee height (from landside toe)	19 to 21 feet
Crown width	10 to 15 feet
Landside slope	Typically 2H:1V but ranges from 1.5H:1V to 2.5H:1V
Waterside slope	Typically 3H:1V but ranges from 3H:1V to 3.5H:1V
200 year WSE (NAVD88)	41.9 feet
Estimated 1997 flood WSE (NAVD88)	38.9 feet

Table 3 summarizes reach details and describes the rationale for reach selection.

7.1 Summary of Studies Completed

Four borings, six CPTs and one vane shear test were performed by URS, AMEC Geomatrix and others for various projects between 2007 and 2012. Two borings, all of the CPTs, and the vane shear test were performed along the crown of the levee. Two of the borings were performed along the landside toe as identified on **Plates 6** through **8**. Geotechnical laboratory tests were performed on selected samples obtained from these explorations. The geotechnical laboratory tests included constant-rate-strain consolidation tests on undisturbed samples collected from Borings WSCCSB-011B and WSCCSB-012B. Geotechnical evaluation results under existing conditions are shown in **Table 4**.

The analysis cross section for this reach at Station 1355+00 (Station 67+49, Alternative 2A stationing) was selected where the landside blanket layer is the thinnest. The cross section was developed using crown Boring WSCCSB-013B and crown CPTs WSCCSB-008C and WSCCSB-009C and was divided into four stratigraphic layers as shown on **Figure B-E-1**. Subsurface information and material properties for each layer are shown in **Table 5.**

7.2 Seepage Analyses

As indicated in **Table 4** this reach of levee did not meet ULE criteria for underseepage. Seepage analyses were performed using the computer program SEEP/W for the following WSEs.

- 200-year plus 3 feet: Elevation 44.9 feet (NAVD88)
- HTOL (500-year): Elevation 42.2 feet (NAVD88)
- 200-year: Elevation 41.9 feet (NAVD88)
- 1955/57 design: Elevation 36.0 feet (NAVD88)

Analyses performed using the 1955/57 design, 200-year and HTOL WSEs resulted in average exit gradients at the landside toe of less than 0.5 for all analyzed WSEs. The average exit gradient at the bottom of the landside ditch about 25 feet from the levee toe was less than 0.5 for the 1955/57 design WSE while gradients at the bottom of the landside ditch were greater than the allowable gradient criteria of 0.55 for the 200-year WSE and 0.65 for the HTOL WSE.

No history of past seepage distress has been recorded for this reach of levee. To further understand conditions and compare the analyses results with observed past performance a sensitivity analysis was performed. The sensitivity analysis consisted of modeling the landside ditch as full of water. The calculated underseepage gradients at the landside toe increased slightly, but were still less than 0.5 for all WSEs. The gradients at the bottom of the ditch were reduced to less than 0.5 for all WSEs.

Figure B-E-2 shows the SEEP/W analysis output at the 200-year WSE. **Table 6** presents the steady-state seepage average gradient results versus WSE. Based on the analyses performed this reach does not meet ULE criteria for underseepage due to gradients at the bottom of the landside ditch. The calculated gradients are based on the assumption of an empty landside ditch condition, as required by ULE protocols. If the landside ditch is modeled as full of water, the resulting underseepage gradient would be somewhat reduced.

7.3 Considered Remediation Alternatives (Reach E/Alternative "2A" Reach "N")

Two corrective remedial alternatives were considered, one involving a ditch backfill and the other involving a Soil-Bentonite (SB) seepage cutoff wall (URS, 2015).

7.3.1 Remedial Alternative 1

Alternative 1 is a ditch backfill to address underseepage. The ditch backfill should be as permeable or more permeable than the natural ground material; however, gravel and rock fill should not be used as the backfill material. The geologic cross section with proposed remedial alternative is shown in **Figure B-E-1**. Steady-state seepage and stability analyses indicate that underseepage, through seepage and landside slope stability criteria are met for the ditch backfill alternative. The steady-state seepage and slope stability results at the 200-year WSE are shown on **Figures B-E-2** and **B-E-3.** Steady-state seepage and landside slope stability analyses results are summarized in **Table 7**.

7.3.2 Remedial Alternative 2

Alternative 2 is an SB seepage cutoff wall intended to address underseepage by penetrating the clay aquiclude layer (layer 4) at a depth of approximately 59 feet below the one-half levee degrade elevation. The geologic cross section with proposed remedial alternative is shown in **Figure B-E-4.** Steady-state seepage and stability analyses indicate that underseepage, through seepage and landside slope stability are met. The steady-state seepage and slope stability results for the SB alternative at the 200-year WSE are shown in **Figures B-E-5** and **B-E-6**. Steady-state seepage and landside slope stability analyses results are summarized in **Table 8.**

8. REACH ANALYSES (REACH F: STA. 1365+59 TO 1420+94 / ALTERNATIVE "2A" REACH SEGMENT "O" STA. 120+00 TO 165+00)

Geomorphic information for this reach indicates the study area is predominately underlain by Holocene alluvial fan deposits, consisting of silt, clay and poorly-sorted sand deposited by distributary channels on the alluvial fan. Within this reach there is a discontinuous 13- to 15-foot thick sand layer approximately 7 feet below a blanket layer at the levee toe. To the south in Reach E there is a continuous thick sand and gravel aquifer and to the north in Reach G there is a more continuous aquifer but it is located deeper than in this reach. While reaches to the north and south have no past history of distress related to seepage this reach (Reach F) has a past history of seepage. Details about approximate levee geometry and design water surface elevation (WSE) data are provided below.

Levee height (from landside toe)	17 to 20 feet
Crown width	9 to 11 feet
Landside slope	Typically 2.0H:1V but ranges from 1.8H:1V to 2H:1V
Waterside slope	Typically 3.0H:1V but ranges from 2H:1V to 3.5H:1V
200 year WSE (NAVD88)	41.9 feet
Estimate 1997 flood WSE (NAVD88)	38.0 feet

Table 3 summarizes reach details and described the rationale for each selection.

8.1 Summary of Studies Completed

Three borings, six CPTs and one vane shear test were performed by URS, AMEC Geomatrix and others for various projects between 2007 and 2012. Two borings, all of the CPTs and the vane shear test were performed along the crown of the levee. One boring was performed along the landside toe as identified on **Plates 8** and **9**. Geotechnical laboratory tests were performed on selected samples obtained from these explorations. The geotechnical laboratory tests included constant-rate-of-strain consolidation tests and a flexible wall permeability test on undisturbed samples collected from Boring WSCCSB-014B and WSCCSB-015B. Geotechnical evaluation results under existing conditions are shown in **Table 9**.

The analysis cross section for this reach was developed at Station 1408+00 (Station 162+41, Alternative 2A stationing) at a location where a Recent channel deposit is mapped crossing below the levee. The cross section was developed using crown Boring WSCCSB-003B, crown CPT WSCCSB-014C and landside Boring WSCCSB-015B. Based on the exploration information, the levee embankment consists of fat clay. An approximately 14-foot thick lean clay blanket is present, which is reduced to about 10 feet thick at the bottom of an unlined landside ditch located about 34 feet from the toe. The blanket is underlain by a 5-foot thick clayey sand layer and a 10-foot thick poorly-graded sand with clay layer. A 32-foot thick clay layer is present below this. The blanket is assumed about 14 feet thick on the waterside. The analysis cross section was divided into eight stratigraphic layers as shown on **Figure B-F-1**. Subsurface information and material properties for each layer are shown in **Table 10**.

8.2 Past Performance

Multiple events of waterside erosion were observed in past flood events. In addition, seepage has been documented within the reach. In 2013, from Station 1378+00 to 1392+00 (Station 132+41 to 146+41, Alternative 2A stationing) clear seepage at the landside toe was observed during a USACE field inspection. The water level in the CCSB was estimated to be 2 feet above the landside toe during the USACE inspection. It is unknown whether the seepage was related to underseepage or through seepage. DWR maintenance personnel indicate that seepage had been observed in the same area in the past, but no boils or seepage carrying materials were observed or documented.

8.3 Seepage Analysis

Seepage analyses were performed using the computer program SEEP/W for the following WSEs.

- 200-year plus 3 feet: Elevation 44.9 feet (NAVD88)
- HTOL (500-year): Elevation 42.2 feet (NAVD88)
- 200-year: Elevation 41.9 feet (NAVD88)
- 1955/57 design: Elevation 36.0 feet (NAVD88)

Analyses performed using the 1955/57 design, 200-year and HTOL WSEs resulted in average exit gradients at the landside toe of less than 0.5; however, the gradients at the bottom of the landside ditch 34 feet from the toe were greater than the allowable gradient of 0.57 for the 1955/57 design and the 200-year WSEs. **Figure B-F-2** shows the SEEP/W analysis output at the 200-year WSE. **Table 11** presents the steady-state seepage average gradient results versus WSE. Based on the analysis performed, this reach does not meet ULE criteria for underseepage due to gradients at the bottom of the landside ditch. Seepage was observed during a USACE field inspection in 2013 but no boil activity was observed. The calculated gradients indicate there is potential for boils to develop at the bottom of the landside ditch. The WSE was estimated at 36.0 feet during the field inspection in 2013 and the WSE for the most recent significant flood in 1997 was reported to be 38.0 feet. Based on interpolation of the seepage analysis results in **Table 11**, the average vertical gradients for both the 2013 WSE and the 1997 flood WSE are estimated to be less than 0.5 at the levee toe and at the bottom of the landside ditch. The analysis results are consistent with the absence of past performance distress related to boil development. The observed seepage may be an indication that water pressure is being relieved by seepage through a more permeable layer.

8.4 Stability Analysis (Landside Steady-State Seepage Condition)

Landside slope stability analyses were performed using the computer program SLOPE/W. **Figure B-F-4** presents the SLOPE/W analysis output showing the failure with the lowest calculated factor of safety. Analyses performed using the 1955/57 design, 200-year and HTOL WSEs resulted in minimum factor of safety of 1.2 and lower. Therefore, this reach does not meet landside stability criteria. **Table 12** presents a summary of the steady-state seepage slope stability results versus WSE

No past performance distresses related to landside stability have been documented. To further understand conditions and compare the analyses results with the observed past performance, a sensitivity analysis was performed increasing the effective cohesion of the embankment fat clay and blanket lean clay layers. Effective cohesion of the embankment (layer 1) was increased from c’=0 psf to c’=50 psf and blanket (layer 2) was increased from c’=50 psf to c’=100 psf. The minimum factor of safety increased for this sensitivity analysis, but still did not meet ULE landside stability criteria. However, landside stability criteria were met if effective cohesion of the embankment (layer 1) was increased from c’=0 psf to c’=100 psf and keeping the same effective cohesion (c’=100) psf for blanket layer (layer 2).

8.5 Considered Remediation Alternatives (Reach F/Alternative “2A” Reach “O”)

Two corrective remedial alternatives were considered, one involving a ditch backfill and partial levee replacement with a chimney drain, and the other involving an SB seepage cutoff wall with landside slope flatting (URS, 2015).

8.5.1 Remedial Alternative 1

Alternative 1 is a ditch backfill and partial levee replacement with a confined chimney drain intended to address underseepage and landside stability. Select ditch backfill should be as permeable or more permeable than the natural ground material; however, gravel and rock fill should not be used as the backfill material. The geologic cross section with proposed remedial alternative is indicated in **Figure B-F-1.** Steady-state seepage and stability analyses indicate underseepage, through seepage a d landside slope stability criteria are met. The steady-state seepage and slope stability results for this alternative at the 200-year WSE are shown on **Figures B-F-2** and **B-F-3**. Steady-state seepage and landside slope stability analyses results are summarized in **Table 13.**

8.5.2 Remedial Alternative 2

Alternative 2 is an SB seepage cutoff wall and landside slope flattening intended to address underseepage and landside slope stability by penetrating into the clay aquiclude layer (layer 5) at a depth of approximately 43 feet below the landside levee toe. The geologic cross section with proposed remedial alternative is shown in **Figure B-F-4**. Steady-state seepage and stability analyses indicate that underseepage, through seepage and landside slope stability criteria are met. The depth of the cutoff wall, assuming a one-half levee degrade, is approximately 43 feet. The steady-state seepage and slope stability results for the SB cutoff wal alternative at the 200-year WSE are shown on **Figures B-F-5** and **B-F-6**. Steady-state seepage and landside slope stability analyses results are summarized in **Table 14**.

9. REFERENCES

AECOM, 2016. *Preliminary Borrow Site Investigation Data Report, Lower Cache Creek Feasibility Study*. 21 June 2016.

California Department of Water Resources (DWR), 2018. *2017 GPS Survey of the Sacramento Valley Subsidence Network.*

Toppozada, T., D. Branum, M. Petersen, C. Hallstrom, C. Cramer, and M. Reichle, 2000. *Yolo Bypass to High Ground Levee Construction.*

United States Army Corps of Engineers, 1958. *Design Memorandum No. 10, Cache Creek, Yolo Bypass to High Ground Levee Construction.*

URS Corporation, 2009. *Geotechnical Data Report (P1GDR), Woodland Study Area.*

URS Corporation. 2011. *Final Geomorphology Technical Memoranda and Maps, North NULE Area Geomorphic Assessments.* January 2011.

URS Corporation 2013. *Supplemental Geotechnical Data Report (SGDR), Woodland Study Area.*

URS Corporation, 2014. *Geotechnical Evaluation Report, Volume 1, Existing Conditions, Woodland Study Area.*

URS Corporation, 2015, *Geotechnical Evaluation Report, Volume 2, Remedial Alternatives, Woodland Study Area.*

Wagner, D., Jennings, C., et al. 1981. *Geologic Map of the Sacramento Quadrangle., California 1:250,000: California Division of Mines and Geology, Regional Geologic Map 1A.* Four sheets.

Wagner, D., Bortugno, E. 1982. *Geologic Map of the Santa Rosa Quadrangle, California, 1:250,000: California Division of Mines and Geology, Regional Geologic Map 2A.* Five sheets.

Wahler Associates, 1982. *Geologic Report, Cache Creek Aggregate Resources, Yolo County, California. For: Aggregate Resources Advisory Committee, County of Yolo, Community Development Agency.*

Wood Rodgers, 2016. *City of Woodlan*d, *Lower Cache Creek Feasibility Study, Alternatives Analysis Report*

Wood Rodger, 2019. *City of Woodland, Lower Cache Creek Feasibility Study, Draft LCCFS Project Description*

TABLES

Table 1 – Subsurface Exploration Summary

Exploration No.	Reference Report	Station	Type	Location	Ground Elevation	Date Completed	Depth (ft)
WR2035-001B	P1GDR	1010+91	BORING	CROWN	37.0	4/29/2008	96.5
WR2035-001C	P1GDR	1000+02	CPT	CROWN	36.8	4/14/2008	85.1
WR2035-002B	P1GDR	1034+06	BORING	CROWN	35.7	4/30/2008	81.5
WR2035-002C	P1GDR	1010+84	CPT	CROWN	37.1	4/14/2008	104
WR2035-003B	P1GDR	1090+97	BORING	CROWN	37.5	5/1/2008	95
WR2035-003C	P1GDR	1022+06	CPT	CROWN	36.7	4/14/2008	102.9
WR2035-004B	P1GDR	1152+65	BORING	CROWN	39.4	4/28/2008	67
WR2035-004C	P1GDR	1028+72	CPT	CROWN	36.0	4/15/2008	119.4
WR2035-004V	SGDR	1063+09	VANE SHEER	CROWN	37.2	9/23/2009	40
WR2035-005B	P1GDR	1201+63B	BORING	CROWN	38.9	5/2/2008	56.5
WR2035-005C	P1GDR	1041+67	CPT	CROWN	36.2	4/15/2008	74.6
WR2035-005V	SGDR	1090+97	VANE SHEER	CROWN	37.5	9/23/2009	37
WR2035-006B	P1GDR	1201+60	BORING	CROWN	38.8	5/5/2008	72
WR2035-006C	P1GDR	1052+97	CPT	CROWN	37.0	4/15/2008	100.1
WR2035-006V	SGDR	1152+69	VANE SHEER	CROWN	39.5	9/28/2011	40
WR2035-007B	Special	1025+24	BORING	CROWN	36.8	5/29/2009	34
WR2035-007C	P1GDR	1068+99	CPT	CROWN	37.0	4/16/2008	65.1
WR2035-008C	P1GDR	1076+89	CPT	CROWN	37.1	4/16/2008	72
WR2035-009C	P1GDR	1101+51	CPT	CROWN	38.0	4/16/2008	72
WR2035-010C	P1GDR	1113+58	CPT	CROWN	38.0	4/16/2008	66.1
WR2035-011C	P1GDR	1124+91	CPT	CROWN	37.8	4/17/2008	64.1
WR2035-012C	P1GDR	1138+72	CPT	CROWN	37.2	4/17/2008	50.2
WR2035-013C	P1GDR	1146+08	CPT	CROWN	40.1	4/17/2008	50
WR2035-014C	P1GDR	1152+77	CPT	CROWN	39.4	4/17/2008	56.1
WR2035-015C	P1GDR	1170+55	CPT	CROWN	38.3	4/18/2008	64.1
WR2035-016C	P1GDR	1180+67	CPT	CROWN	38.4	4/18/2008	58.1
WR2035-017C	P1GDR	1190+92	CPT	CROWN	38.4	4/18/2008	50.2
WR2035-018C	P1GDR	1201+53	CPT	CROWN	38.8	4/18/2008	64
WR2035-019C	P1GDR	1211+91	CPT	CROWN	38.8	4/18/2008	68.1
WR2035-020C	P1GDR	1219+99	CPT	CROWN	38.7	4/21/2008	56.1
WR2035-021C	P1GDR	1234+61	CPT	CROWN	39.2	4/21/2008	68.1
WR2035-026B	SGDR	1010+87	BORING	LANDSIDE	19.0	11/22/2011	40.5
WR2035-027B	SGDR	1027+83	BORING	LANDSIDE	19.9	11/22/2011	40.5
WR2035-028B	SGDR	1063+14	BORING	CROWN	37.1	9/30/2011	59.5
WR2035-029B	SGDR	1091+00	BORING	LANDSIDE	22.1	11/18/2011	31.5
WR2035-030B	SGDR	1125+90	BORING	CROWN	38.0	10/4/2011	59.5
WR2035-031B	SGDR	1152+53	BORING	LANDSIDE	26.7	11/3/2011	40.5
WR2035-032B	SGDR	1201+92	BORING	LANDSIDE	23.7	11/17/2011	40
WR2035-033B	SGDR	1234+68	BORING	CROWN	39.3	10/5/2011	59.5
WR2035-034B	Special	1132+08	BORING	CROWN	37.7	5/28/2009	35
WR2035-035B	Special	1132+08	BORING	CROWN	37.7	5/28/2009	33
WSCCSB-001B	P1GDR	1271+62	BORING	CROWN	50.3	5/6/2008	72

Table 1 – Subsurface Exploration Summary

Exploration No.	Reference Report	Station	Type	Location	Ground Elevation	Date Completed	Depth (ft)
WSCCSB-001C	P1GDR	1244+15	CPT	CROWN	50.8	4/14/2008	100.1
WSCCSB-001V	Special	1273+74	VANE SHEER	CROWN	50.4	9/23/2009	31
WSCCSB-002B	P1GDR	1336+62	BORING	CROWN	50.7	5/7/2008	95
WSCCSB-002C	P1GDR	1257+38	CPT	CROWN	50.3	4/14/2008	84.3
WSCCSB-002V	SGDR	1336+57	VANE SHEER	CROWN	50.7	11/14/2011	36.5
WSCCSB-003B	P1GDR	1407+85	BORING	CROWN	51.5	5/8/2008	92
WSCCSB-003C	P1GDR	1271+70	CPT	CROWN	50.5	4/14/2008	85.1
WSCCSB-003V	SGDR	1407+87	VANE SHEER	CROWN	51.5	11/16/2011	38
WSCCSB-004B	P1GDR	1474+26	BORING	CROWN	53.0	5/9/2008	86.5
WSCCSB-004C	P1GDR	1287+51	CPT	CROWN	50.5	4/15/2008	85.1
WSCCSB-004V	SGDR	1516+09	VANE SHEER	CROWN	53.6	11/15/2011	41
WSCCSB-005B	P1GDR	1530+28	LBORING	CROWN	53.1	5/12/2008	66.5
WSCCSB-005C	P1GDR	1303+07	CPT	CROWN	50.5	4/15/2008	89.2
WSCCSB-005V	SGDR	1285+05	VANE SHEER	CROWN	50.2	9/27/2011	40
WSCCSB-006C	P1GDR	1319+55	CPT	CROWN	50.7	4/15/2008	84.8
WSCCSB-007C	P1GDR	1336+73	CPT	CROWN	50.6	4/16/2008	100.1
WSCCSB-008B	Special	1271+63	BORING	CROWN	50.4	9/16/2009	38.8
WSCCSB-008C	P1GDR	1347+25	CPT	CROWN	51.0	4/16/2008	80.2
WSCCSB-009B	Special	1272+66	BORING	CROWN	50.4	9/17/2009	38.2
WSCCSB-009C	P1GDR	1355+22	CPT	CROWN	50.4	4/16/2008	88.3
WSCCSB-010B	SGDR	1284+99	BORING	CROWN	50.5	10/7/2011	59.5
WSCCSB-010C	P1GDR	1365+60	CPT	CROWN	51.0	4/17/2008	78.6
WSCCSB-011B	SGDR	1319+22	BORING	LANDSIDE	30.1	10/20/2011	39
WSCCSB-011C	P1GDR	1379+05	BORING	CROWN	50.8	4/17/2008	84.2
WSCCSB-012B	SGDR	1336+69	BORING	LANDSIDE	29.9	10/19/2011	35.5
WSCCSB-012C	P1GDR	1389+36	CPT	CROWN	51.3	4/17/2008	86.1
WSCCSB-013B	SGDR	1355+00	BORING	CROWN	50.5	10/10/2011	46.5
WSCCSB-013C	P1GDR	1399+44	CPT	CROWN	51.3	4/18/2008	90.1
WSCCSB-014B	SGDR	1379+05	BORING	CROWN	50.9	10/11/2011	61.5
WSCCSB-014C	P1GDR	1407+97	CPT	CROWN	51.4	4/18/2008	78.2
WSCCSB-015B	SGDR	1407+84	BORING	LANDSIDE	32.1	10/18/2011	41.5
WSCCSB-015C	P1GDR	1416+29	CPT	CROWN	51.5	4/18/2008	75.3
WSCCSB-016B	SGDR	1459+99	BORING	CROWN	52.6	10/12/2011	61.5
WSCCSB-016C	P1GDR	1420+94	CPT	CROWN	51.5	4/18/2008	72
WSCCSB-017C	P1GDR	1430+90	CPT	CROWN	51.6	4/21/2008	74.1
WSCCSB-018B	SGDR	1516+13	BORING	LANDSIDE	37.6	10/17/2011	32.5
WSCCSB-018C	P1GDR	1446+33	CPT	CROWN	52.4	4/21/2008	68.2
WSCCSB-019B	SGDR	1516+20	BORING	CROWN	53.9	10/13/2011	61.5
WSCCSB-019C	P1GDR	1450+42	CPT	CROWN	52.5	4/21/2008	68.1
WSCCSB-020B	SGDR	1529+93	BORING	LANDSIDE	38.5	10/14/2011	41.5
WSCCSB-020C	P1GDR	1467+49	CPT	CROWN	52.4	4/21/2008	68.1
WSCCSB-021C	P1GDR	1474+49	CPT	CROWN	52.7	4/22/2008	74.1

Table 1 – Subsurface Exploration Summary

Exploration No.	Reference Report	Station	Type	Location	Ground Elevation	Date Completed	Depth (ft)
WSCCSB-022C	P1GDR	1489+47	CPT	CROWN	52.8	4/22/2008	76.1
WSCCSB-023C	P1GDR	1498+15	CPT	CROWN	53.2	4/22/2008	72
WSCCSB-024C	P1GDR	1507+61	CPT	CROWN	53.7	4/22/2008	99.6
WSCCSB-025C	P1GDR	1516+22	CPT	CROWN	53.9	4/22/2008	67.9
WSCCSB-026C	P1GDR	1524+59	CPT	CROWN	53.6	4/21/2008	64
WSCCSB-027C	P1GDR	1530+57	CPT	CROWN	53.0	4/21/2008	56.1

Table 2 – Summary of Evaluation Findings[1]

Reach	Erosion Risk[2]	Through Seepage	Underseepage	Landside Slope Stability[3]	Waterside Slope Stability
A	Low	Meets Criteria	Does Not Meet Criteria	Meets Criteria	Meets Criteria
B	Low	Meets Criteria	Meets Criteria	Does Not Meet Criteria	Meets Criteria
C	Low	Meets Criteria	Does not Meet Criteria	Meets Criteria	Meets Criteria
D	Low	Meets Criteria	Meets Criteria	Meets Criteria	Meets Criteria
E	Low	Meets Criteria	Does Not Meet Criteria	Meets Criteria	Meets Criteria
F[4]	Low	Meets Criteria	Does Not Meet Criteria	Does Not Meet Criteria	Meets Criteria
G	Low	Meets Criteria	Meets Criteria	Meets Criteria	Meets Criteria
H	Low	Meets Criteria	Does not Meet Criteria[3]	Meets Criteria	Meets Criteria

[1] For 200 year water surface elevation

[2] Erosion typically of limited length within given reach. Sites with low to medium erosion risk are considered to meet criteria.

[3] Reach does not meet underseepage criteria due to unconfined leaking layer condition

[4] Reaches E and F fall within the southeast footprint of Alternative A alignment

Table 3 – Analysis Cross Section Selection Summary

Levee Segment	Reach ID	DWR Sta. Limits (Alternative A Sta. Limits)	Length of Reach	Cross Section Station Location	Reach Details	Rationale for Reach Selection	Rationale for Cross Section Selection	Rational for Inclusion of Exploration in Cross Sections
Cache Creek Settling Basin – Right Bank	E	1287+51 to 1365+59	7,808	1355+00	Levee Height: 19 to 21 feet Crown Width: 10 to 15 feet Landside Slope: 1.5H:1V to 2.5H:1V Waterside Slope: 3.1H:1V to 3.5H:1v Approximate Design WSE: 41.9 (200 year) Past Performance: Waterside erosion on southern CCSB levee (1244+00 – 1357+00) Improvement History: Waterside erosion repair, partial height rip-rap on CCSB levee Embankment Materials: Very stiff to lean clay Foundation Materials: Reach is underlain primarily by Holocene alluvial fan deposits with finer deposits located in the southeastern portion of the reach. Generally 13-16 feet of lean to fat clay foundation soils underlain by a sandy aquifer with a clay aquitard below.	* Clay levee underlain by thick clay blanket over thick sandy aquifer *Waterside erosion reported *Unlined ditch on landside	Thin clay blanket with shallow drainage layer. High permeability in aquifer	WSCCSB-013B WSCCSB-008C WSCCSB-009C
Cache Creek Settling Basin – Right Bank	F	1365+59 to 1420+94	5,535	1408+00	Levee Height: 17 to 20 feet Crown Width: 9.5 to 10.5 feet Landside Slope: 1.8H:1V to 2.2H:1V Waterside Slope: 2H:1V to 3.5H:1V Approximate Design WSE: 41.9 to 42.4 (200 year) Past Performance: Seepage (1378+00-1392+00), crown erosion (1382+59-1424+72), waterside erosion (1395+00-1428+00), area of concern with no further documentation (1367+75-1372+00), and a waterside area of concern (1417+00) Improvement History: Partial height rip-rap (1395+00 to 1420+94) Embankment Materials: Very stiff fat clay Foundation Materials: Reach is underlain by Holocene fan deposits with Holocene and recent channel deposits throughout . Recent overbank deposits are located near the southern portion of the reach. Lean to fat clay foundation with a blanket thickness as low as about 15 feet. Some isolated silty sand to sand layer located at varying Depths	*Clay levee underlain by clay *Shallow sand layer located near channel deposit at northern end of reach *Waterside erosion reported Channel deposits prominent in this reach *Unlined ditch near the landside toe *Past history of distress related to seepage documented	Thin clay blanket with shallow drainage layer	WSCCSB-003B WSCCSB-014C WSCCSB-015B* *Denotes landside toe

Table 4 – Geotechnical Evaluation Results Summary (Reach E)

Analysis	**Analysis Cases**		
	HTOL WSE	**200-Year WSE**	**1955/57 Design WSE**
Erosion[1]	Not Performed	Low Risk	Not Performed
Through Seepage	Meets	Meets	Meets
Underseepage	Does not meet	Does not meet	Meets
Landside Stability Steady State	Meets	Meets	Meets
Waterside Stability (Rapid Drawdown)[2]	Not Performed	Meets	Not Performed

[1] Erosion is evaluated at the 200-year WSE and typically effects a limited length of reach

[2] Rapd drawdown evaluated form the 200year WSE

Table 5 - Material Properties for Seepage and Stability Analysis (Reach E)

Material Description (Layer Number)	Zone	Soil Layer Details					Field Test Data			Laboratory Test Data										Strength Related Interpretations					Values Considered in Selection of Strength			Selected Strength Parameters for Slope Stability Analysis					Selected Hydraulic Conductivity Values for Seepage Analysis				
							SPT		Strength Index	Index Tests							Consolidation Tests			SPT	CPT																
		Depth to Top of Layer (feet)	Depth to Bottom of Layer (feet)	Elevation of Top of Layer (NAVD88)	Elevation of Bottom of Layer (NAVD88)	Layer Thickness (feet)	N_{60}	$(N_1)_{60}$ 1,2	Pocket Penetrometer (tsf)	Water Content (%)	Total Unit Weight (pcf)	Dry Unit Weight (pcf)	Liquid Limit	Plasticity Index	LI	Percent Passing #200 Sieve	Maximum Past Pressure (ksf)	Effective Overburden Pressure (ksf)	OCR	Effective Angle of Friction from N (deg)[3]	Effective Angle of Friction from CTP	Max Past Pressure from CPT (ksf)[5]	OCR from CPT[5]	Undrained Sheer Strength from CPT	OCR	Maximum Past Pressure (ksf)	Undrained Sheer Strength (ksf)	Drained Cohesion (psf)	Drained Friction Angle (deg)	Undrained Cohesion (psf)	Undrained Friction Angle (deg)	Total Unit Weight (pcf)	Horizontal, K_h (cm/sec)	K_v/K_h	Vertical, K_v (cm/sec)	Horizontal, K_h (ft/day)	Vertical, K_v (ft/day)
CL (1)	Emb	0	20.5	50.5	30.0	20.5	12-13	16-22	2.5-4.5	24	121-128	98-104	48-52	26-29	0.02-0.03	84-94					38 (37-42)	8 (2.7-10+)	10+ (5.5-10+)	2.7 (0.5-5.9)	10+	8	2.7	50	29	360	4	125	4.0E-06	0.25	1.0E-06	1.1E-02	2.8E-03
CL (2)	Fdn	20.5	34	30.0	16.5	13.5	15 (7-22)	16 (7-28)	2.25-4.5	22 (20-23)	128	106	34-48	16-31	0.1-0.31	85 (82-88)	9.1-11.4	0.6-2.0	4.6-16.1		30 (26-33)	3.8 (0.1-10+)	1.3 (0.1-4.5)	1.2 (0.1-3.4)	5.0	9.0	1.2	100	29	700	4	125	4.0E-06	0.25	1.0E-06	1.1E-02	2.8E-03
GW-GM (3)	Fdn	34	64.4	16.5	-13.9	30.4	18-26	13-18		11	143	128				21				34-37	42 (40-46)							0	35			125	5.0E-03	1.00	5.0E-03	1.4E+01	1.4E+01
CL (4)	Fdn	64.4	88.4	-13.9	-37.9	24.0															30 (26-36)	5 (5-10+)	2.5 (2-3.4)	3 (2.0-5.9)	2.5	5	2.0	50	30	360	4	125	4.0E-06	0.25	1.0E-06	1.1E-02	2.8E-03

Table 6 – Seepage Analysis Results Summary (Reach E)

Flood Level	WSE (ft)	Average Vertical Gradient		Maximum Acceptable Gradient at Toe for 200-yr WSE	Maximum Acceptable Gradient at Toe for HTOL
		Toe of Levee	Low Point (25 feet from toe)		
1955/57	36.0	NA[1]	0.41	0.50	0.60
200-yr	41.9	0.10	0.64		
HTOL	42.2	0.10	0.66		
200-yr + 3	44.9	0.17	0.74		

[1] Resulting phreatic surface is below the landside toe

Table 7 - Steady-State Seepage and Landside Slope Stability Results Summary for Alternative 1, Ditch Backfill (Reach E)

Analysis	Analysis Cases		
	200-year WSE	HTOL (500-year WSE)	Comment
Through Seepage	Phreatic surface breakout 3.4 feet above landside toe in clay material	Phreatic surface breakout 3.5 feet above landside toe in clay material	Meets criteria considering breakout in non-erodible fine-grained soils (clay)
Undereseepage	Average vertical exit gradient at landside toe = 0.36	Average vertical exit gradient at landside toe = 0.36	Meet criteria
Landside stability (steady-state)	Factor of safety = 1.47	Factor of safety = 1.46	Meets criteria

Table 8 - Steady-State Seepage and Landside Slope Stability Results Summary for Alternative 2, SB Seepage Cutoff Wall (Reach E)

Analysis	Analysis Cases		
	200-year WSE	HTOL (500-year WSE)	Comment
Through Seepage	Phreatic surface breakout 1.0 feet above landside toe in clay material	Phreatic surface breakout 1.0 feet above landside toe in clay material	Meets criteria considering breakout in non-erodible fine-grained soils (clay)
Undereseepage	Average vertical exit gradient at landside toe = 0.05 Average vertical exit gradient = 0.14 at the base of the ditch (26 feet from the landside toe)	Average vertical exit gradient at landside toe = 0.36 Average vertical exit gradient = 0.14 at the base of the ditch (25 feet from the landside toe)	Meets criteria
Landside stability (steady-state)	Factor of safety = 1.47	Factor of safety = 1.46	Meets criteria

Table 9 – Geotechnical Evaluation Results Summary (Reach F)

Analysis		Analysis Cases		
		HTOL WSE	200-Year WSE	1955/57 Design WSE
Erosion[1]		Not Performed	Low Risk	Not Performed
Through Seepage		Meets	Meets	Meets
Underseepage		Does not meet	Does not meet	Does not meet
Landside Stability Steady State		Does not meet	Does not meet	Does not meet
Waterside Stability (Rapid Drawdown)[2]		Not Performed	Meets	Not Performed

[1] Erosion is evaluated at the 200-year WSE and typically effects a limited length of reach

[2] Rapd drawdown evaluated form the 200year WSE

Table 10 – Material Properties for Seepage and Stability Analysis (Reach F)

		Soil Layer Details					Field Test Data			Laboratory Test Data										Strength Related Interpretations					Values Considered in Selection of Strength			Selected Strength Parameters for Slope Stability Analysis					Selected Hydraulic Conductivity Values for Seepage Analysis				
							SPT		Strength Index	Index Tests							Consolidation Tests			SPT	CPT																
Material Description (Layer Number)	Zone	Depth to Top of Layer (feet)	Depth to Bottom of Layer (feet)	Elevation of Top of Layer (NAVD88)	Elevation of Bottom of Layer (NAVD88)	Layer Thickness (feet)	N_{60}	$(N_1)_{60}$ 1,2	Pocket Penetrometer (tsf)	Water Content (%)	Total Unit Weight (pcf)	Dry Unit Weight (pcf)	Liquid Limit	Plasticity Index	LI	Percent Passing #200 Sieve	Maximum Past Pressure (ksf)	Effective Overburden Pressure (ksf)	OCR	Effective Angle of Friction from N (deg)^3	Effective Angle of Friction from CTP	Max Past Pressure from CPT (ksf)^5	OCR from CPT^5	Undrained Sheer Strength from CPT	OCR	Maximum Past Pressure (ksf)	Undrained Sheer Strength (ksf)	Drained Cohesion (psf)	Drained Friction Angle (deg)	Undrained Cohesion (psf)	Undrained Friction Angle (deg)	Total Unit Weight (pcf)	Horizontal, K_h (cm/sec)	K_v/K_h	Vertical, K_v (cm/sec)	Horizontal, K_h (ft/day)	Vertical, K_v (ft/day)
CH (1)	Emb	0	17.6	51.3	33.7	17.6	25 (22-29)	31 (29-33)		23			53	28	-0.07	92						10+	10+ (8.5-10+)	3.4 (1.4-4.5)	9.0	10	2.2	0	27	360	4	125	4.0E-06	0.25	1.0E-06	1.1E-02	2.8E-03
CL/CH (2)	Fdn	17.6	30.3	33.7	21.0	12.7	26 (19-39)	24(17-34)	0.25-2.5	26 (22-29)			36-58	20-35	0.14-0.65	79	11.4	2.7	4..3			5.9 (2.2-10+)	4.7 (3.7-7.2)	1.2 (0.4-2.7)	4.5	11.4	1.8	50	27	360	4	125	4.0E-06	0.25	1.0E-06	1.1E-02	2.8E-03
SC (3)	Fdn	30.3	34	21.0	17.3	3.7	12	11		15-19						24-31				33-37	31 (30-34)							0	31			125	2.0E-04	0.25	5.0E-05	5.7E-01	1.4E-01
SP-SC (4)	Fdn	34	46.3	17.3	5.0	12.3	47 (32-62)	37 (26-48)								8				45 (40-47)	42 (40-46)							0	35			130	4.8E-04	0.25	1.2E-04	1.4E+00	3.4E-01

Table 10 – Material Properties for Seepage and Stability Analysis (Reach F)

Material Description (Layer Number)	Zone	Soil Layer Details					Field Test Data			Laboratory Test Data										Strength Related Interpretations					Values Considered in Selection of Strength			Selected Strength Parameters for Slope Stability Analysis					Selected Hydraulic Conductivity Values for Seepage Analysis				
							SPT		Strength Index	Index Tests							Consolidation Tests			SPT	CPT																
		Depth to Top of Layer (feet)	Depth to Bottom of Layer (feet)	Elevation of Top of Layer (NAVD88)	Elevation of Bottom of Layer (NAVD88)	Layer Thickness (feet)	N_{60}	$(N_1)_{60}$ 1,2	Pocket Penetrometer (tsf)	Water Content (%)	Total Unit Weight (pcf)	Dry Unit Weight (pcf)	Liquid Limit	Plasticity Index	LI	Percent Passing #200 Sieve	Maximum Past Pressure (ksf)	Effective Overburden Pressure (ksf)	OCR	Effective Angle of Friction from N (deg)[3]	Effective Angle of Friction from CTP	Max Past Pressure from CPT (ksf)[5]	OCR from CPT[5]	Undrained Sheer Strength from CPT	OCR	Maximum Past Pressure (ksf)	Undrained Sheer Strength (ksf)	Drained Cohesion (psf)	Drained Friction Angle (deg)	Undrained Cohesion (psf)	Undrained Friction Angle (deg)	Total Unit Weight (pcf)	Horizontal, K_v (cm/sec)	K_v/K_h	Vertical, K_v (cm/sec)	Horizontal, K_h (ft/day)	Vertical, K_v (ft/day)
CL/CH (5)	Fdn	46.3	86.8	5.0	-35.5	40.5	32 (28-42)	23 (19-31)	1.25-3.0	28 (23-32)			36-53	13-28	0.46 - -0.07	91 (89-92)						10+ (7.7-10+)	2.2 (1.8-4.0)		2.5	10+	2.7	100	30	700	4	125	4.0E-06	0.25	1.0E-06	1.1E-02	2.8E-03
CL/ML (6)	Fdn	86.8	78	-35.5	-26.7	8.8	49 (36-62)	29 (22-37)		16-31			44	17	0.24	88						10+ (6.7-10+)	2.3 (1.4-5.2)		2.5	10+	2.6	100	30	700	4	125	1.0E-05	0.25	2.8E-06	2.8E-02	7.0E-03
SM (7)	Fdn	78	86	-26.7	-34.7	8.0	81	47		20						14				47	30 (28-36)							0	35			130	2.4E-03	1.00	2.4E-03	6.8E+00	6.8E+00
CL (8)	Fdn	86	91.8	-34.7	-40.5	5.8	81	34															2.5		2.0	10+	2.9	100	30	700	4	125	4.0E-06	0.25	1.0E-06	1.1E-02	2.8E=03

Table 5 and 10 Footnotes

Reference Sources:

[1]Youd, T. L. et al. 2001,"Liquefaction Resistance of Soils Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils". Journal of Geotechnical and Geoenvironmental Engineering

[2]Burmister, D. M., 1948, The importance and practical use of relative density in soil mechanics: Proceeding ASTM

[3]Federal Highway Administration. 2002, *"Evaluation of Soil and Rock Properties."* Geotechnical Engineering Circular No. 5, FHWA-1F-02-034

[4]Mayne, P. 2007. Cone Penetration Testing State-of-Practice. NCHRP. Project 20-05

[5]Lunne, T. et al. 1997. Cone Penetration Testing in Geotechnical Practice

Table 11 – Seepage Analysis Results Summary (Reach F)

Flood Level	WSE (ft)	Average Vertical Gradient		Maximum Acceptable Gradient at Toe for 200-yr WSE	Maximum Acceptable Gradient at Toe for HTOL
		Toe of Levee	Low Point (34 feet from toe)		
1955/57	40.3	0.14	0.60	0.50	0.60
200-yr	41.9	0.20	0.68		
HTOL	42.2	0.22	0.69		
200-yr + 3	44.9	0.31	0.82		

[1]Resulting phreatic surface is below the landside toe

Table 12 – Stability Analysis Results Summary (Reach F)
(Landside Steady-State Seepage Condition)

Flood Level	WSE (ft)	Minimum Critical Failure Surface Factor of Safety	Minimum Acceptable Factor of Safety for 200-year WSE
1955/57	40.3	1.20	1.4
200-year	41.9	1.15	
HTOL	42.2	1.14	
200 year + 3	44.9	1.04	

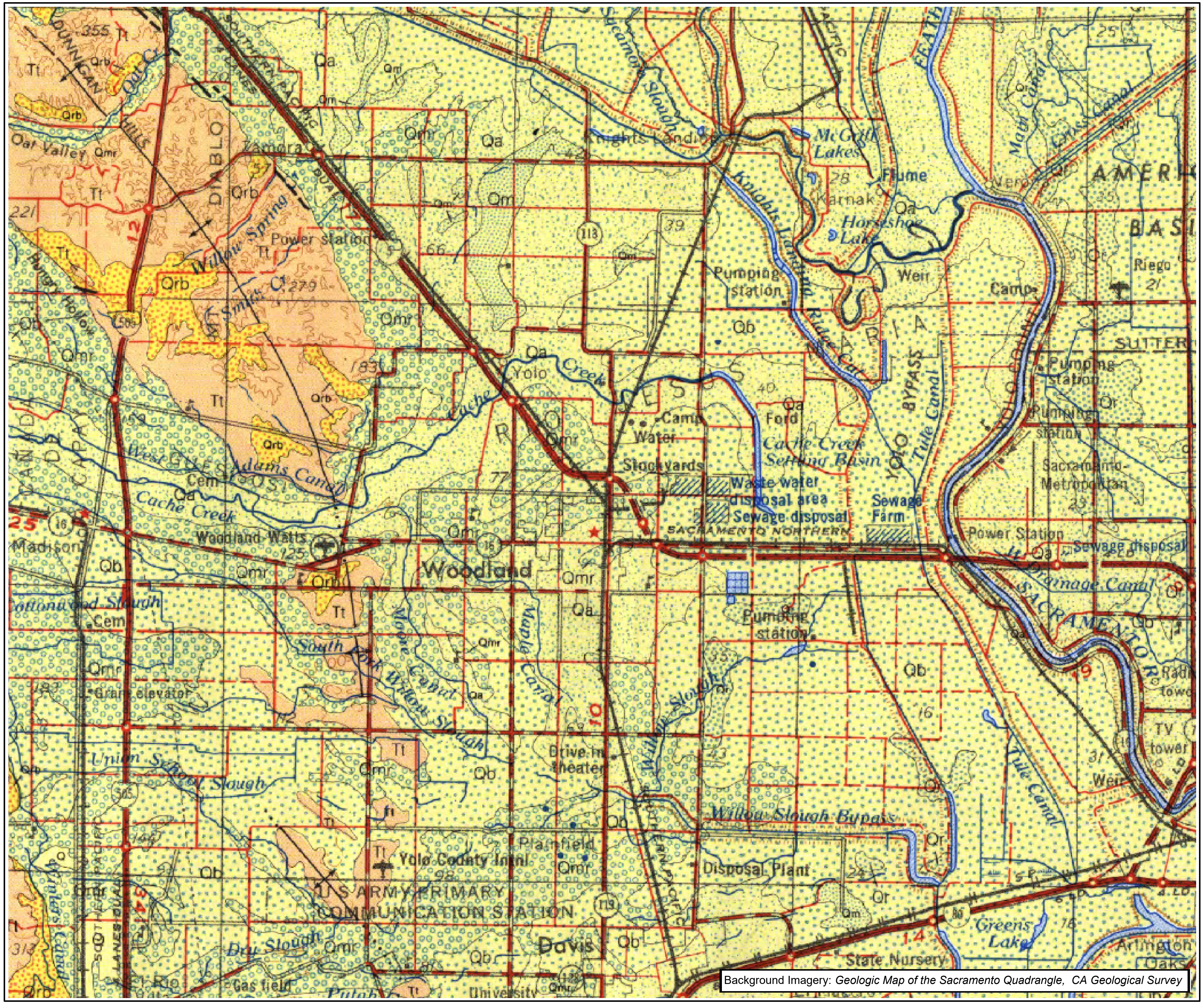
Table 13 - Steady-State Seepage and Landside Slope Stability Results Summary for Alternative 1, Ditch Backfill and Partial Levee Replacement with a Confined Chimney Drain (Reach F)

Analysis	Analysis Cases		
	200-year WSE	**HTOL (500-year WSE)**	**Comment**
Through Seepage	Phreatic surface breakout is at the landside toe	Phreatic surface breakout is at the landside toe	Meets criteria considering breakout is at the landside toe
Undereseepage	Average vertical exit gradient at landside toe = 0.22 Average vertical exit gradient = 0.37 at the low point (101 feet from the landside toe)	Average vertical exit gradient at landside toe = 0.23 Average vertical exit gradient = 0.38 at the low point (101 feet from the landside toe)	Meets criteria
Landside stability (steady-state)	Factor of safety = 1.52	Factor of safety = 1.52	Meets criteria

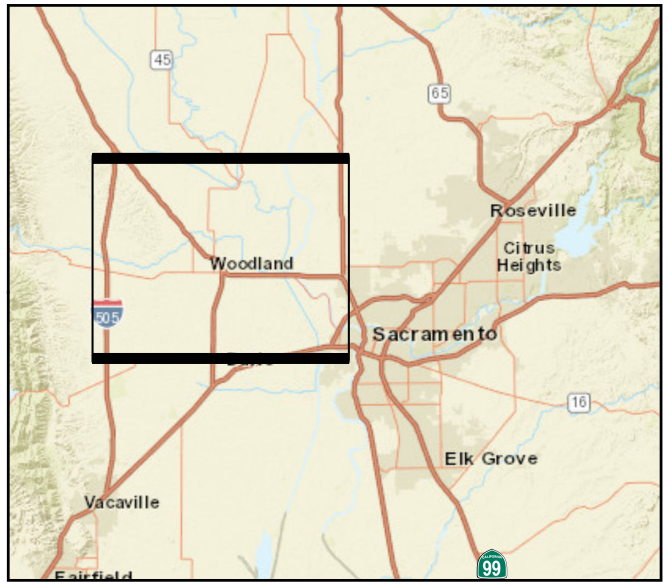
Table 14 - Steady-State Seepage and Landside Slope Stability Results Summary for Alternative 2, SB Seepage Cutoff Wall and Landside Slope Flattening (Reach F)

Analysis	Analysis Cases		
	200-year WSE	**HTOL (500-year WSE)**	**Comment**
Through Seepage	Phreatic surface breakout is 0.6 feet above the landside toe	Phreatic surface breakout is 1.2 feet above the landside toe	Meets criteria considering breakout is in non-erodible fine-grained soil (clay)
Undereseepage	Average vertical exit gradient at landside toe = 0.17 Average vertical exit gradient = 0.28 at the low point (30 feet from the landside toe)	Average vertical exit gradient at landside toe = 0.18 Average vertical exit gradient = 0.29 at the low point (30 feet from the landside toe)	Meets criteria
Landside stability (steady-state)	Factor of safety = 1.47	Factor of safety = 1.46	Meets criteria

FIGURES



Background Imagery: *Geologic Map of the Sacramento Quadrangle, CA Geological Survey*



Map Legend

CENOZOIC	QUATERNARY	Q	Alluvium
		Qa	Levee and channel deposits
		Qb	Basin deposits *(Alluvium)*
		Qm	Modesto Formation *(Alluvium)*
		Qr	Riverbank Formation *(Alluvium)*
		Qmr	Modesto-Riverbank Formations *(Arkosic alluvium)*
		Qrb	Red Bluff Formation *(Gravel in reddish, silty or sandy matrix)*
	TERTIARY	Tt	Tehama Formation *(Sand, silt, and volcaniclastic rocks)*

0 5 miles

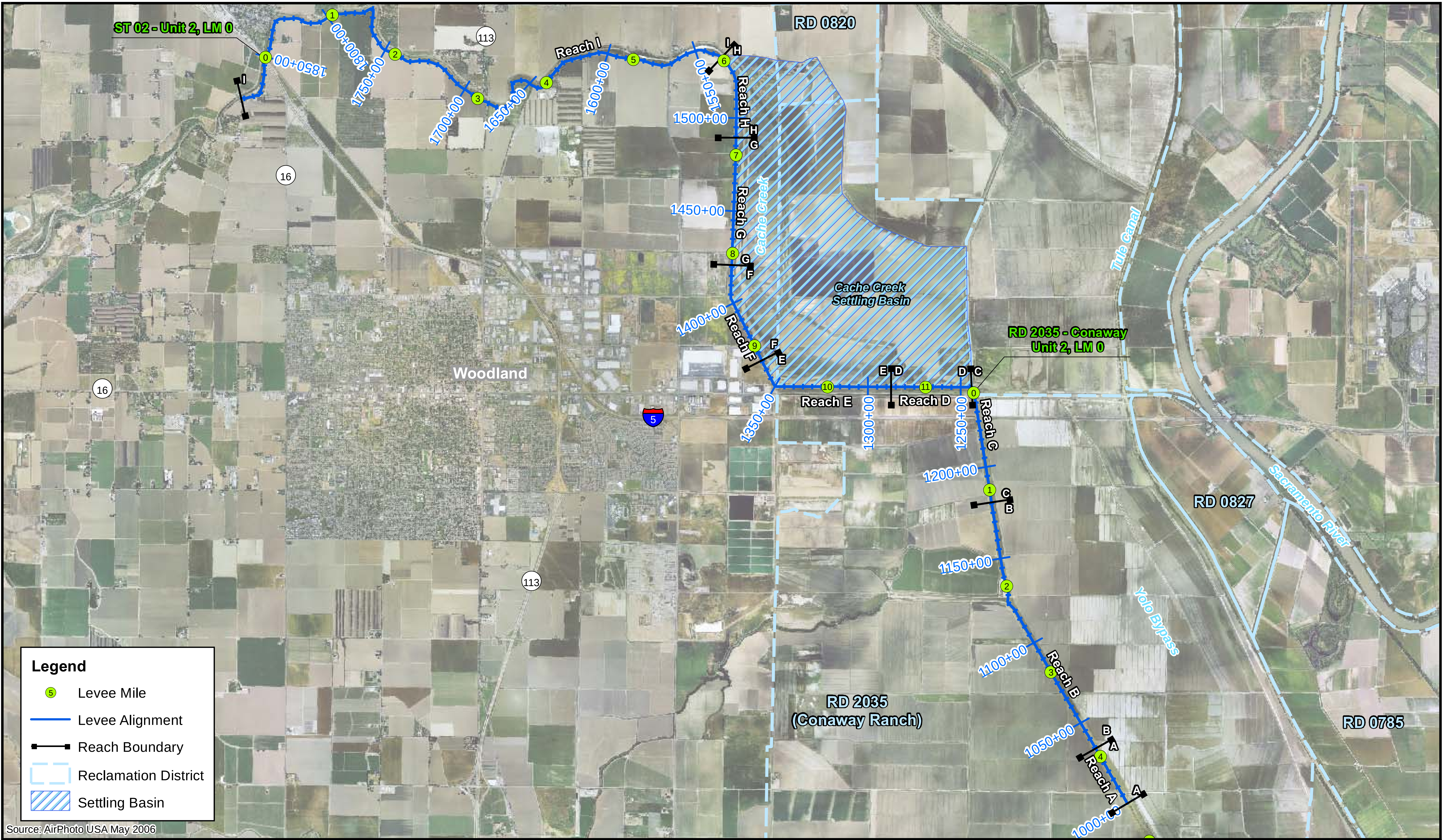
N

GEOLOGIC MAP

Lower Cache Creek Basin
Woodland, Yolo County,
California

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Map Prepared by Christy Cox



N

0 2,500 5,000

Feet

Note: Refer to Table 4-1 for latitude and longitude information.

Department of Water Resources
Division of Flood Management

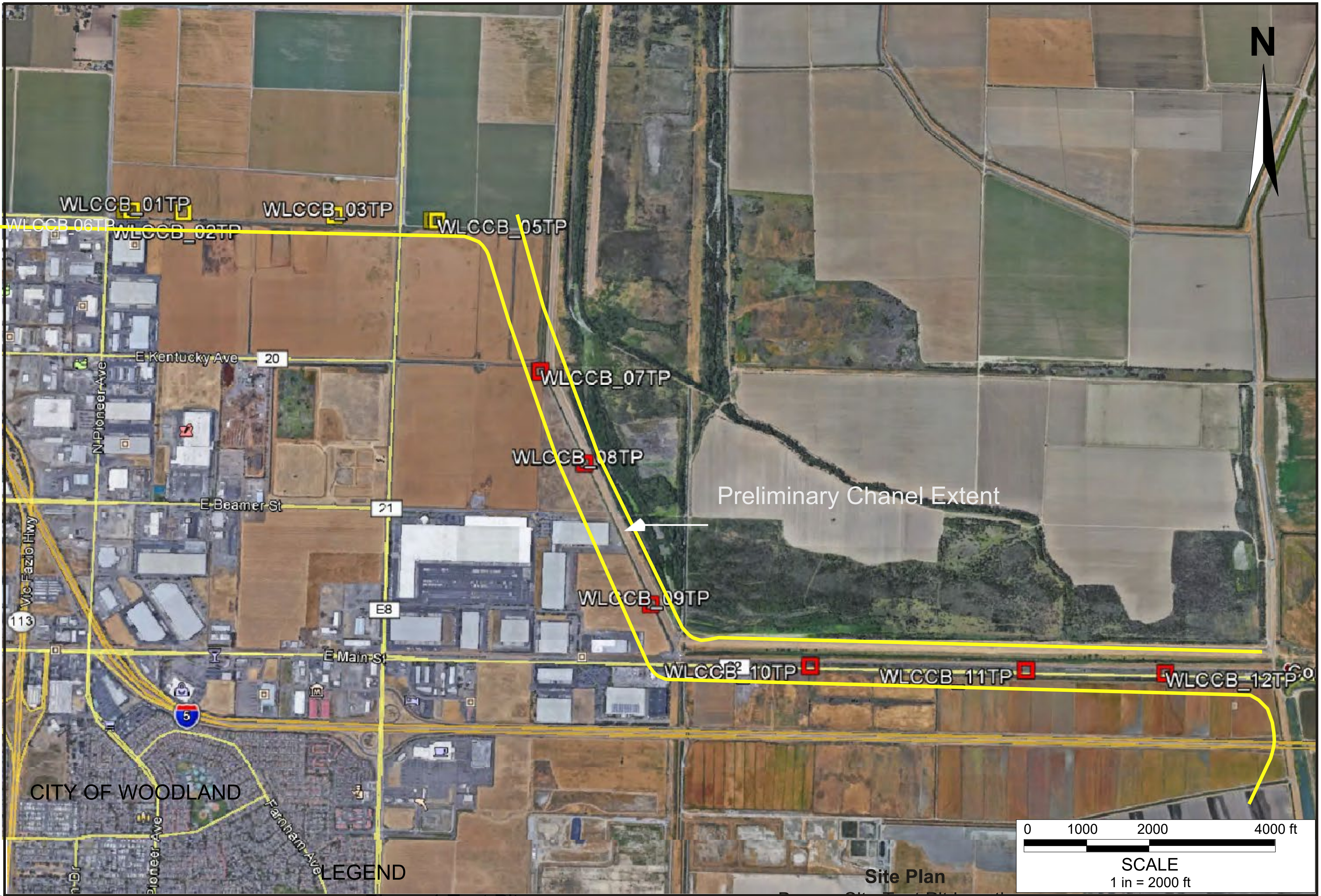
URS

Reach Boundaries
Woodland

URBAN LEVEE EVALUATIONS

Figure ES-2

\GIS\Data\Deliverable\WDLD_GER1_V1\TOC_WDLD_GER1_V1\ExecutiveSummary\MXD\WDLDGER1V1ES2REACH.mxd 09.30.2014 SAC



LEGEND

🟨 Phase 1 Test Pit

🟥 Phase 2 Test Pit

City of Woodland

AECOM

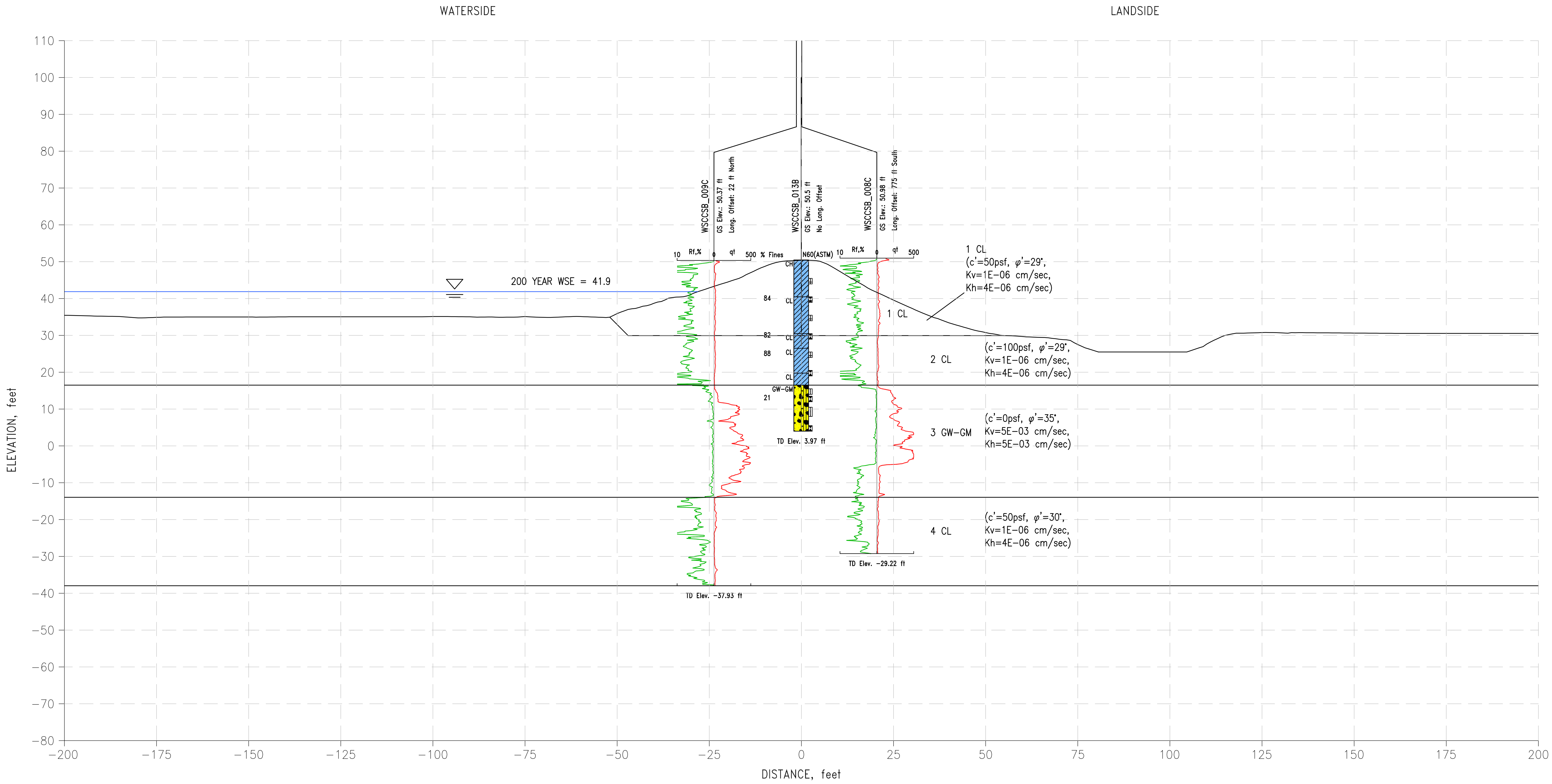
Site Plan

Borrow Site Test Pit Locations

LOWER CACHE CREEK FEASIBILITY STUDY

Figure 2

S:\Renata\Figure1_SitePlan.indd 11.04.2015



PLOT BY: GORDON_FONG – Apr 15, 2014 – 5:10:42pm
DRAWING: G:\DWR-7418\WorkZone\woodland ger\01_reaches\02_CADD\Drawings\01 Transverse X-sec\Station 1355+00.dwg

Department of Water Resources
Division of Flood Management

URS

CONTRACT NUMBER
17326650

TASK ORDER
U32

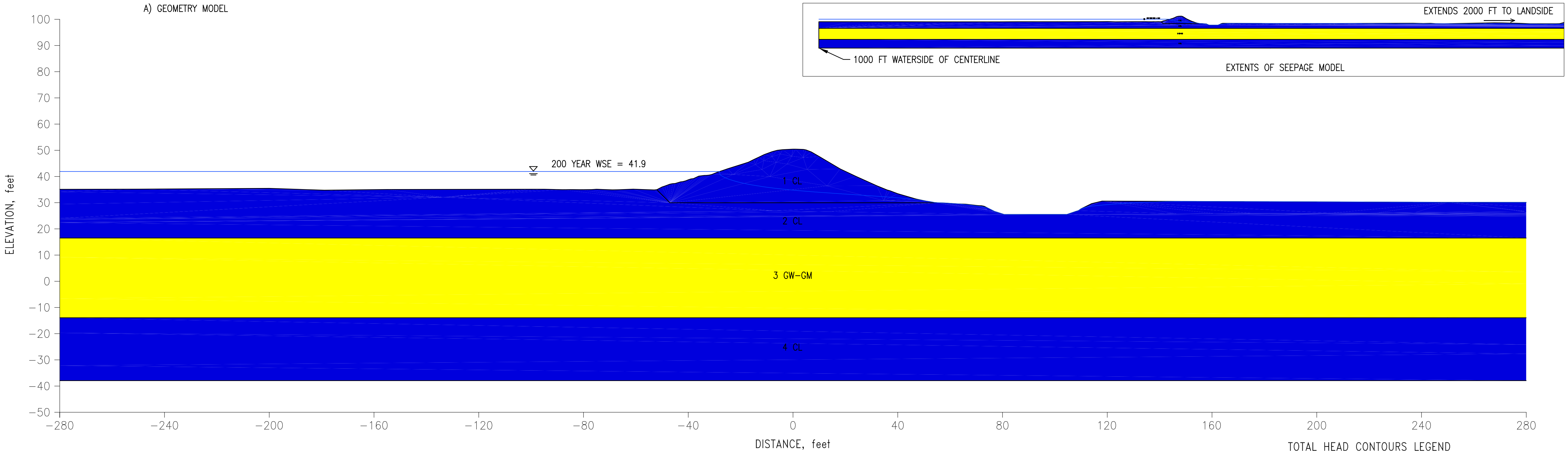
PREPARED BY
G. SCHAERTL

CHECKED BY
M. CHOWDHURY

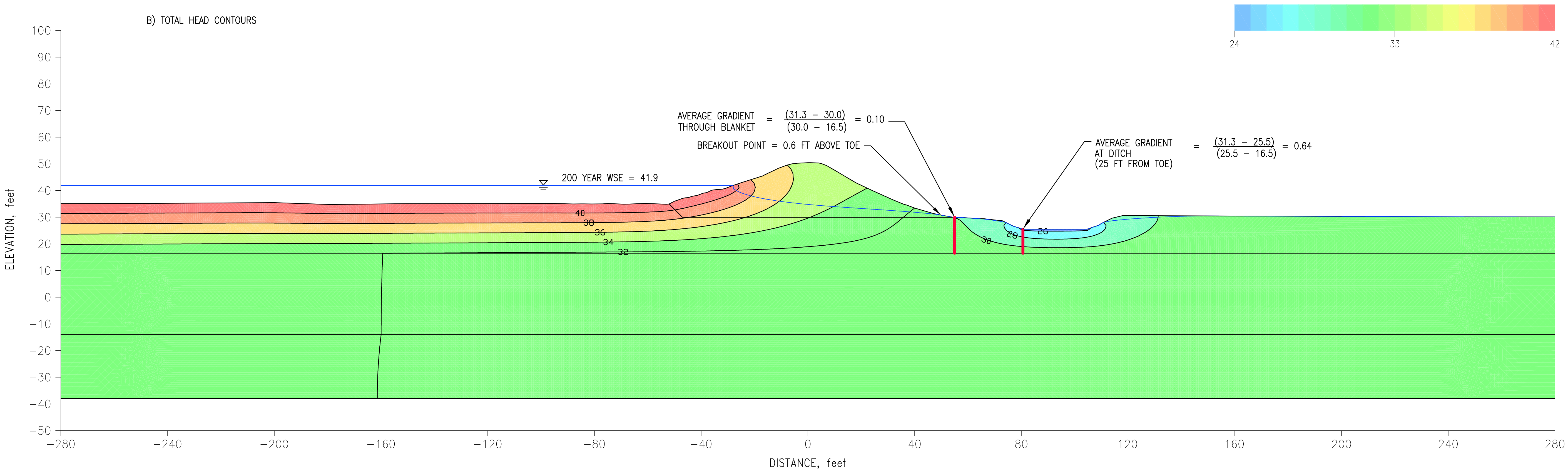
WOODLAND STUDY AREA
URBAN LEVEE EVALUATIONS

TRANSVERSE CROSS SECTION
REACH E
STATION 1355+00
ST 02 UNIT 2, LM 9.36

FIGURE
B-E-1



A) GEOMETRY MODEL



B) TOTAL HEAD CONTOURS

PLOT BY: MYNUL_CHOWDHURY – Apr 16, 2014 – 2:17:51pm
DRAWING: G:\DWR-7418\WorkZone\woodland ger\03_existcond\02_CADD\Drawings\02 Seepage Figures\E-2 Station 1355+00.dwg

Department of Water Resources
Division of Flood Management

URS

CONTRACT NUMBER
17326650

PREPARED BY
M. ERMAKOVICH

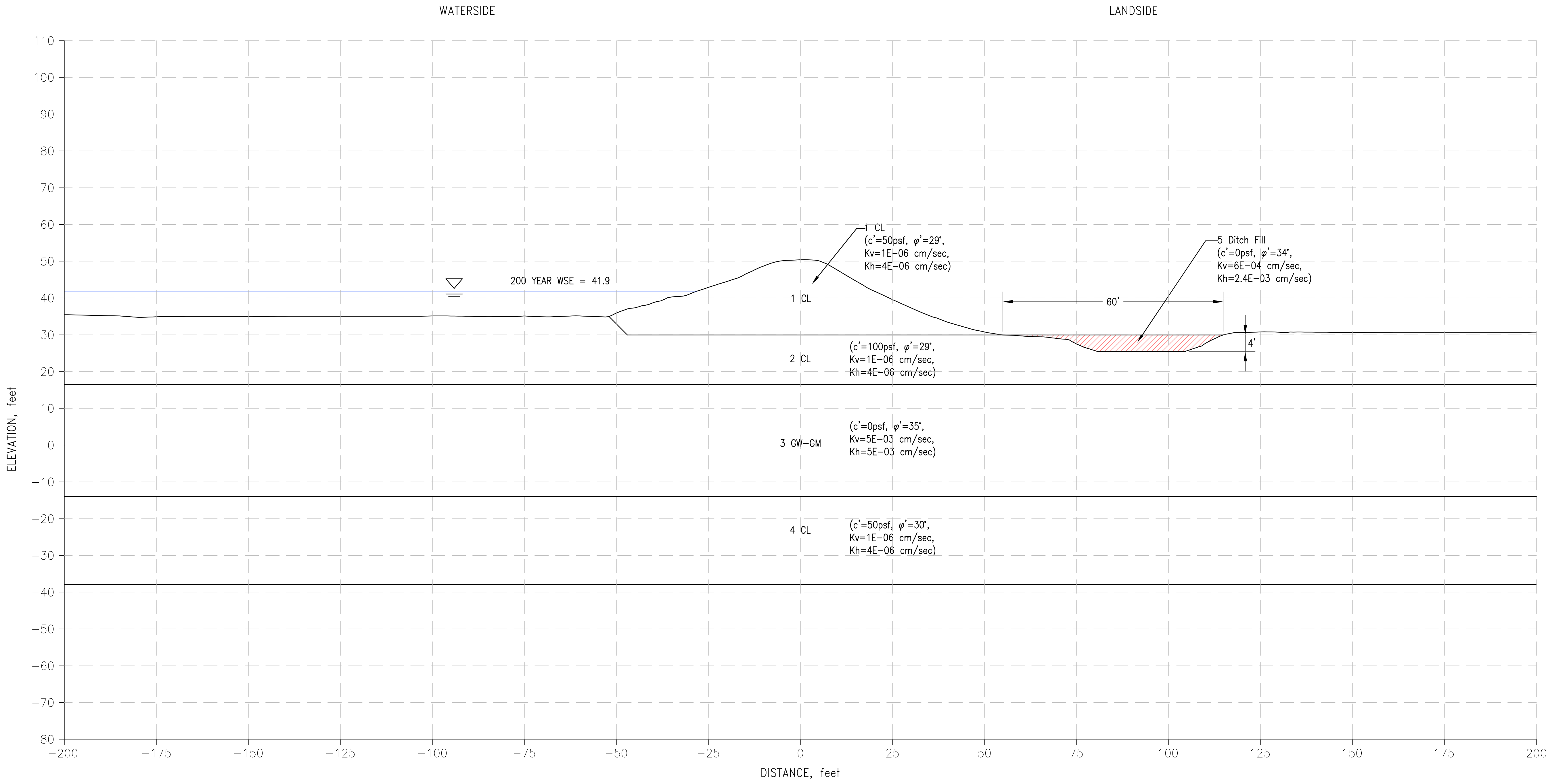
TASK ORDER
U32

CHECKED BY
M. CHOWDHURY

WOODLAND STUDY AREA
URBAN LEVEE EVALUATIONS

STEADY STATE SEEPAGE ANALYSIS
REACH E
STATION 1355+00
ST 02 UNIT 2, LM 9.36

FIGURE
B-E-2



PLOT BY: MIKHAIL_ERMAKOVICH – Mar 26, 2015 – 11:14:50am
DRAWING: G:\DWR-7418\WorkZone\woodland ger\05_remediatedcond\02_CADD\Drawings\01 Transverse X-sec\B-E-1 Station 1355+00 – Ditch Fill.dwg

Department of Water Resources
Division of Flood Management

URS

CONTRACT NUMBER
4600008101

PREPARED BY
G. Schaertl

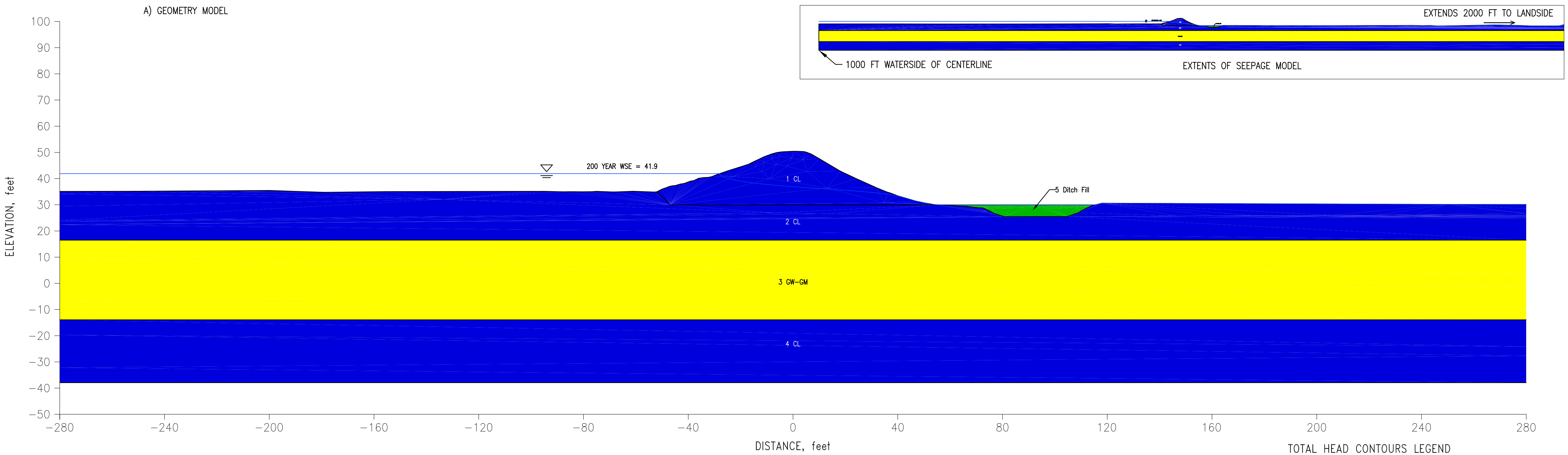
TASK ORDER
U32

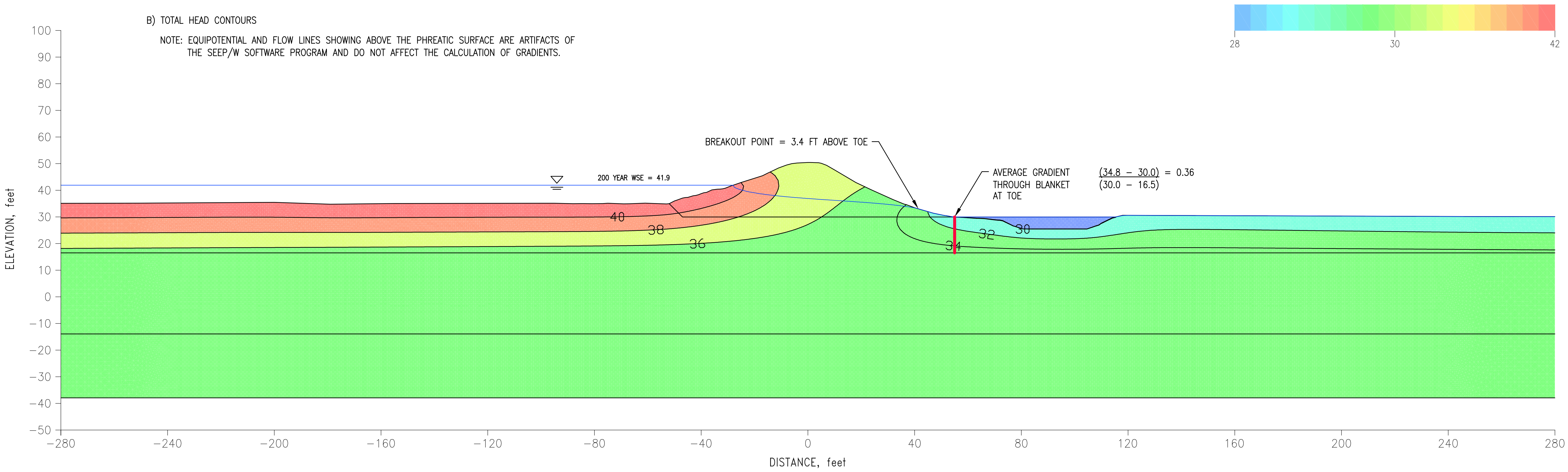
CHECKED BY
M. Chowdhury

WOODLAND STUDY AREA
URBAN LEVEE EVALUATIONS

TRANSVERSE CROSS SECTION
REACH E – STATION 1355+00
DITCH BACKFILL
ST 02 UNIT 2, LM 9.36

FIGURE
B-E-1





PLOT BY: MIKHAIL_ERMAKOVICH - Apr 13, 2015 - 10:47:35am
DRAWING: G:\DWR-7418\WorkZone\woodland ger\05_remediatedcond\02_CADD\Drawings\02 Seepage Figures\B-E-2 Station 1355+00 - Ditch Fill.dwg

Department of Water Resources
Division of Flood Management

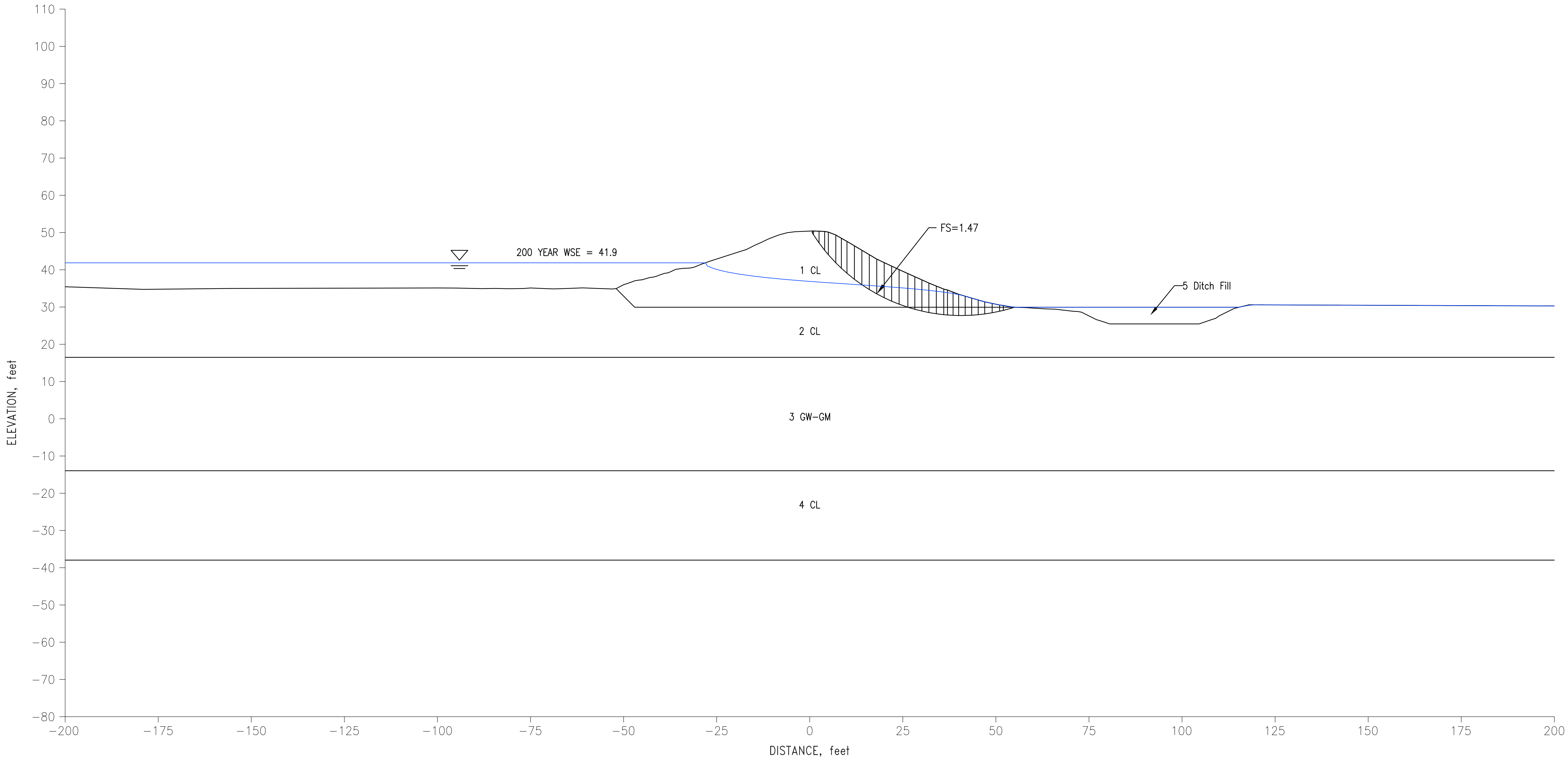
URS

CONTRACT NUMBER 4600008101	PREPARED BY G. Schaertl
TASK ORDER U32	CHECKED BY M. Chowdhury

WOODLAND STUDY AREA
URBAN LEVEE EVALUATIONS

STEADY STATE SEEPAGE ANALYSIS
REACH E - STATION 1355+00
DITCH BACKFILL
ST 02 UNIT 2, LM 9.36

FIGURE
B-E-2



PLOT BY: MIKHAIL_ERMAKOVICH – Apr 13, 2015 – 10:56:47am
DRAWING: G:\DWR-7418\WorkZone\woodland ger\05_remediatedcond\02_CADD\Drawings\03 Stability Figures\B-E-3 Station 1355+00 – Ditch Fill.dwg

Department of Water Resources
Division of Flood Management

URS

CONTRACT NUMBER
4600008101

PREPARED BY
G. Schaertl

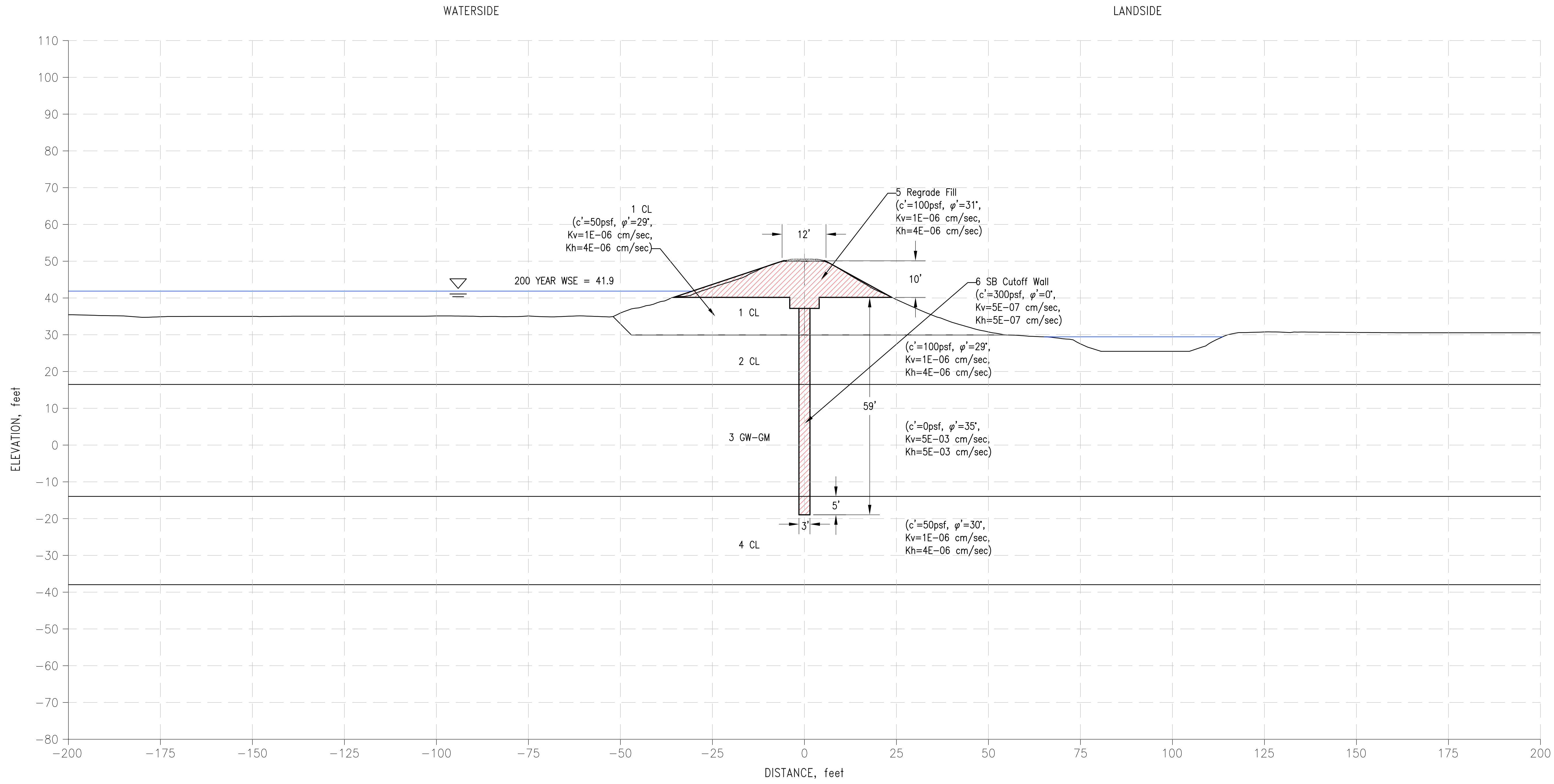
TASK ORDER
U32

CHECKED BY
M. Chowdhury

WOODLAND STUDY AREA
URBAN LEVEE EVALUATIONS

STEADY STATE SLOPE STABILITY ANALYSIS
REACH E – STATION 1355+00
DITCH BACKFILL
ST 02 UNIT 2, LM 9.36

FIGURE
B-E-3



PLOT BY: MIKHAIL_ERMAKOVICH – Apr 13, 2015 – 10:11:46am
DRAWING: G:\DWR-7418\WorkZone\woodland ger\05_remediatedcond\02_CADD\Drawings\01 Transverse X-sec\B-E-4 Station 1355+00 – Cutoff Wall.dwg

Department of Water Resources
Division of Flood Management

URS

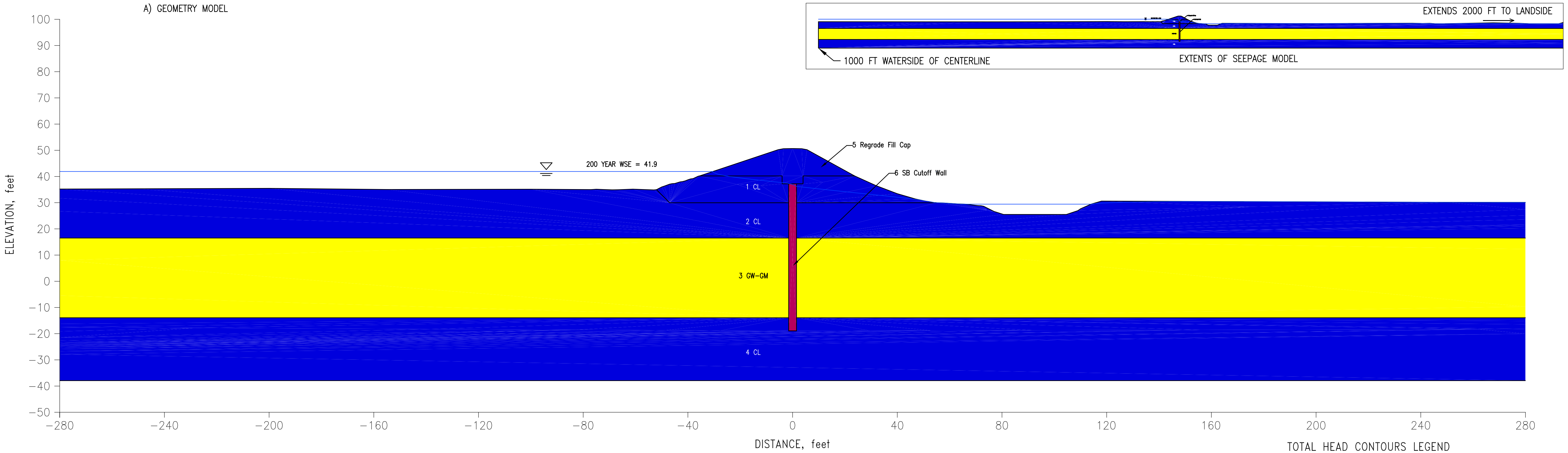
CONTRACT NUMBER 4600008101	PREPARED BY G. Schaertl
TASK ORDER U32	CHECKED BY M. Chowdhury

WOODLAND STUDY AREA
URBAN LEVEE EVALUATIONS

TRANSVERSE CROSS SECTION
REACH E – STATION 1355+00
SB CUTOFF WALL
ST 02 UNIT 2, LM 9.36

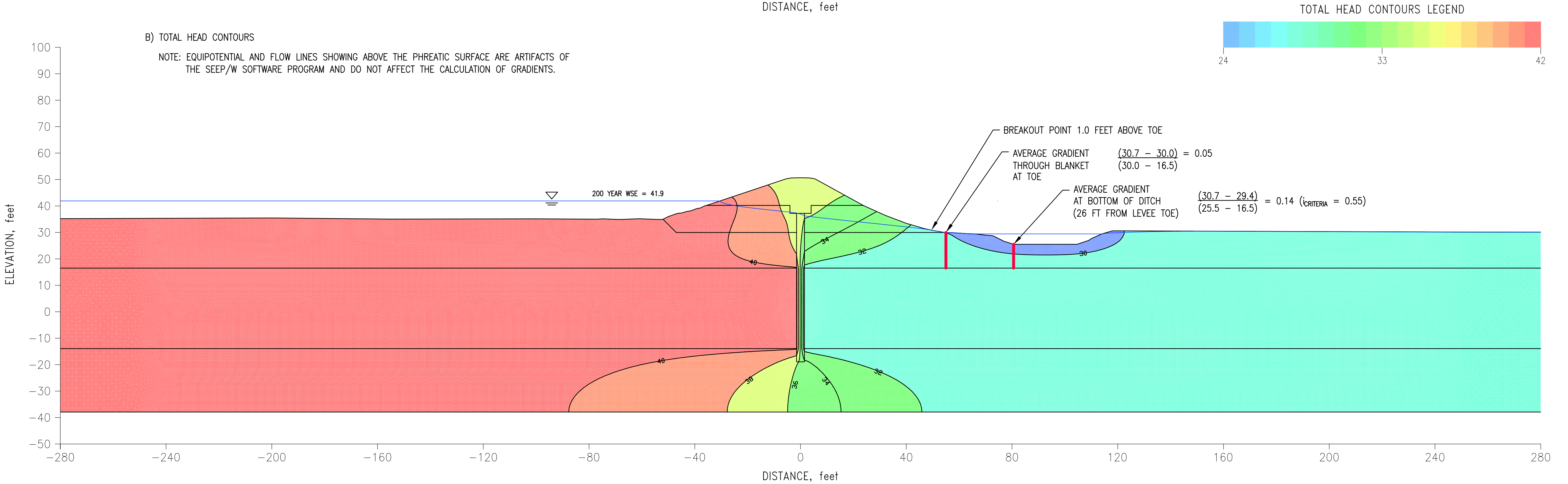
FIGURE
B-E-4

A) GEOMETRY MODEL



B) TOTAL HEAD CONTOURS

NOTE: EQUIPOTENTIAL AND FLOW LINES SHOWING ABOVE THE PHREATIC SURFACE ARE ARTIFACTS OF THE SEEP/W SOFTWARE PROGRAM AND DO NOT AFFECT THE CALCULATION OF GRADIENTS.



BREAKOUT POINT 1.0 FEET ABOVE TOE

AVERAGE GRADIENT THROUGH BLANKET AT TOE $\frac{(30.7 - 30.0)}{(30.0 - 16.5)} = 0.05$

AVERAGE GRADIENT AT BOTTOM OF DITCH (26 FT FROM LEVEE TOE) $\frac{(30.7 - 29.4)}{(25.5 - 16.5)} = 0.14$ ($i_{CRITERIA} = 0.55$)

Department of Water Resources
Division of Flood Management

URS

CONTRACT NUMBER
4600008101

PREPARED BY
G. Schaertl

TASK ORDER
U32

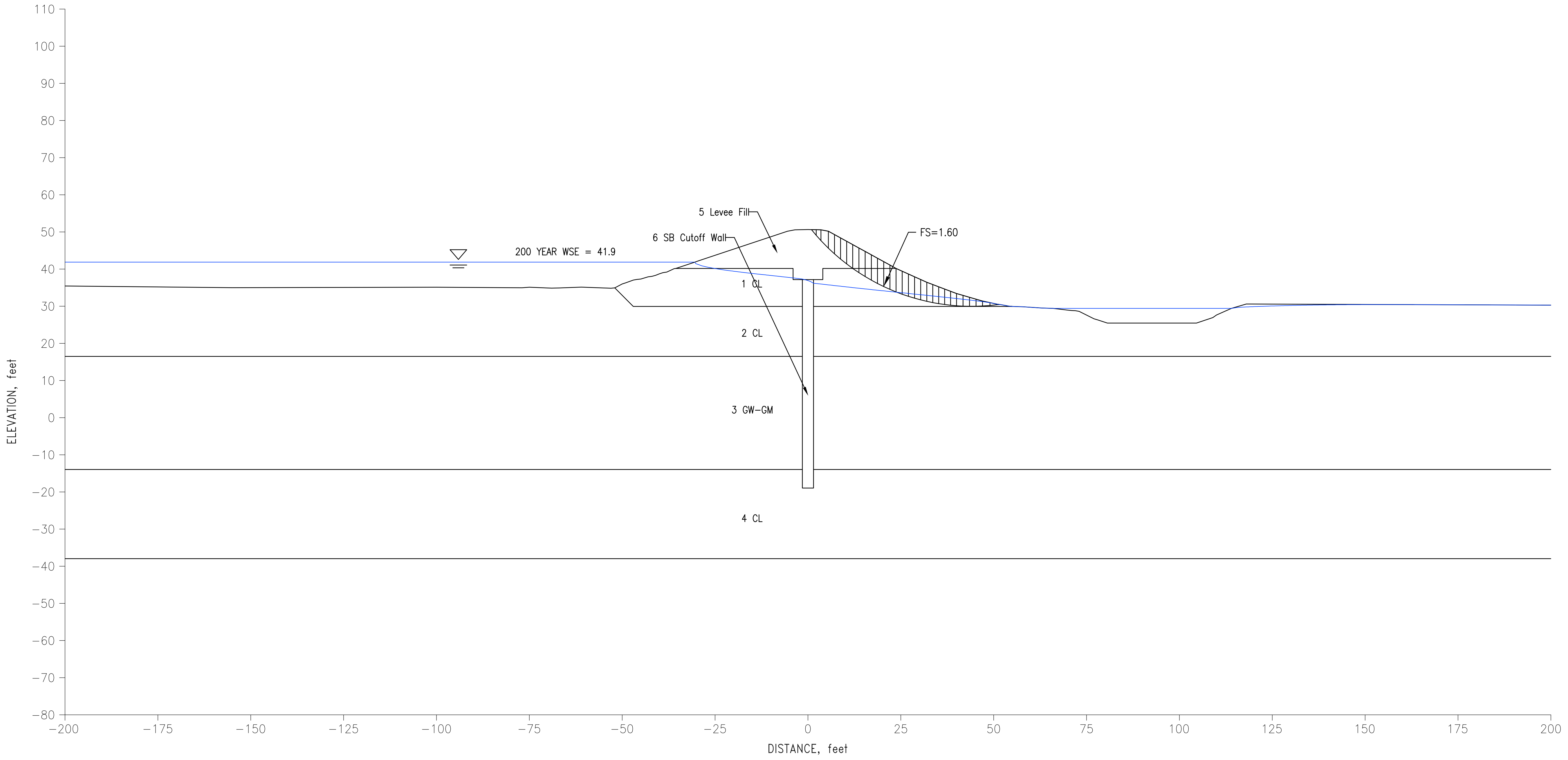
CHECKED BY
M. Chowdhury

WOODLAND STUDY AREA
URBAN LEVEE EVALUATIONS

STEADY STATE SEEPAGE ANALYSIS
REACH E – STATION 1355+00
SB CUTOFF WALL
ST 02 UNIT 2, LM 9.36

FIGURE
B-E-5

PLOT BY: MIKHAIL_ERMAKOVICH – Apr 13, 2015 – 10:48:33am
DRAWING: G:\DWR-7418\WorkZone\woodland ger\05_remediatedcond\02_CADD\Drawings\02 Seepage Figures\B-E-5 Station 1355+00 – Cutoff Wall.dwg



PLOT BY: MIKHAIL_ERMAKOVICH – Apr 13, 2015 – 10:57:30am
DRAWING: G:\DWR-7418\WorkZone\woodland ger\05_remediatedcond\02_CADD\Drawings\03 Stability Figures\B-E-6 Station 1355+00 – Cutoff Wall.dwg

Department of Water Resources
Division of Flood Management

URS

CONTRACT NUMBER
4600008101

TASK ORDER
U32

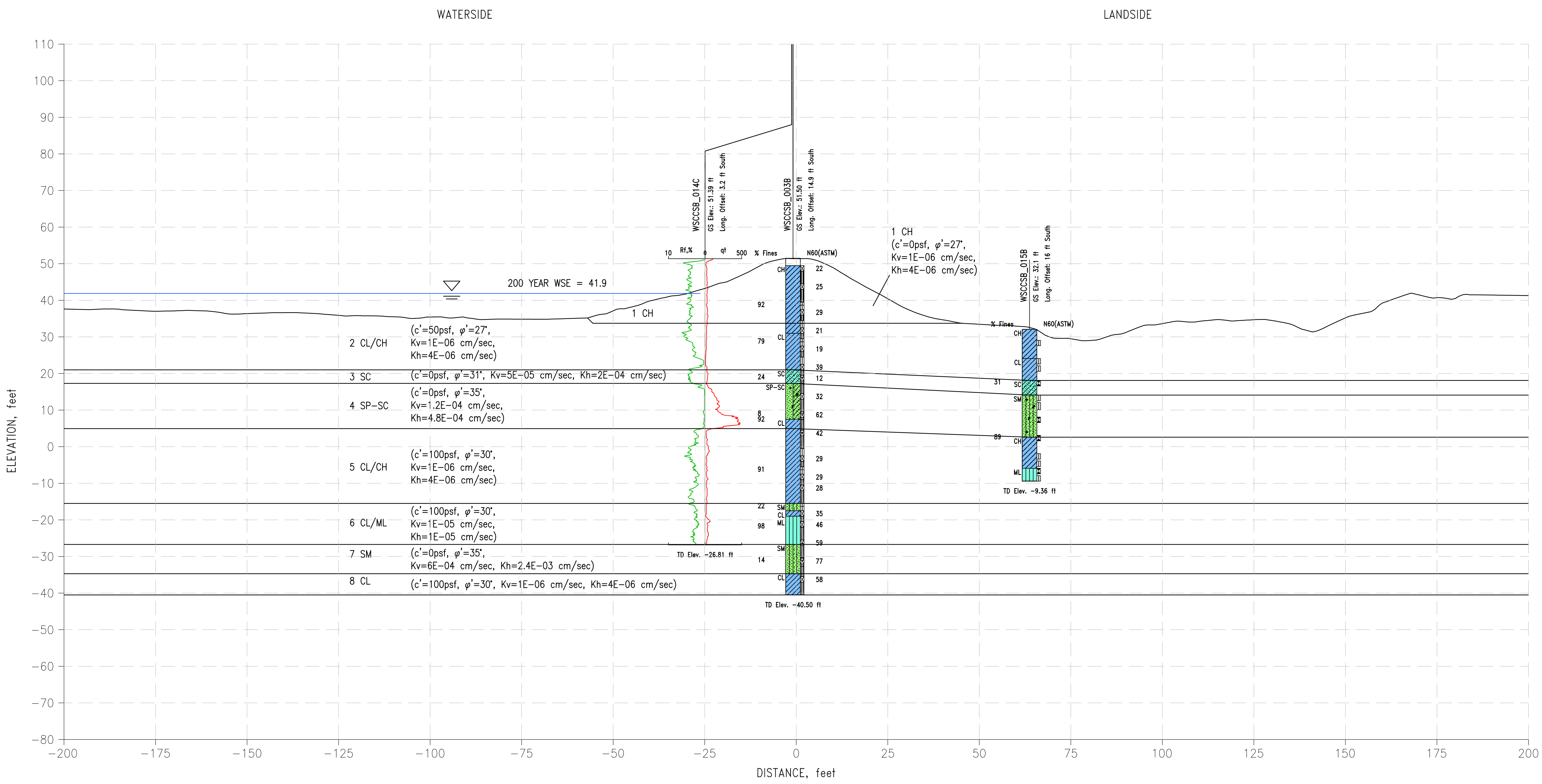
PREPARED BY
G. Schaertl

CHECKED BY
M. Chowdhury

WOODLAND STUDY AREA
URBAN LEVEE EVALUATIONS

STEADY STATE SLOPE STABILITY ANALYSIS
REACH E – STATION 1355+00
SB CUTOFF WALL
ST 02 UNIT 2, LM 9.36

FIGURE
B-E-6



Department of Water Resources
Division of Flood Management

URS

CONTRACT NUMBER
17326650

PREPARED BY
G. SCHAERTL

TASK ORDER
U32

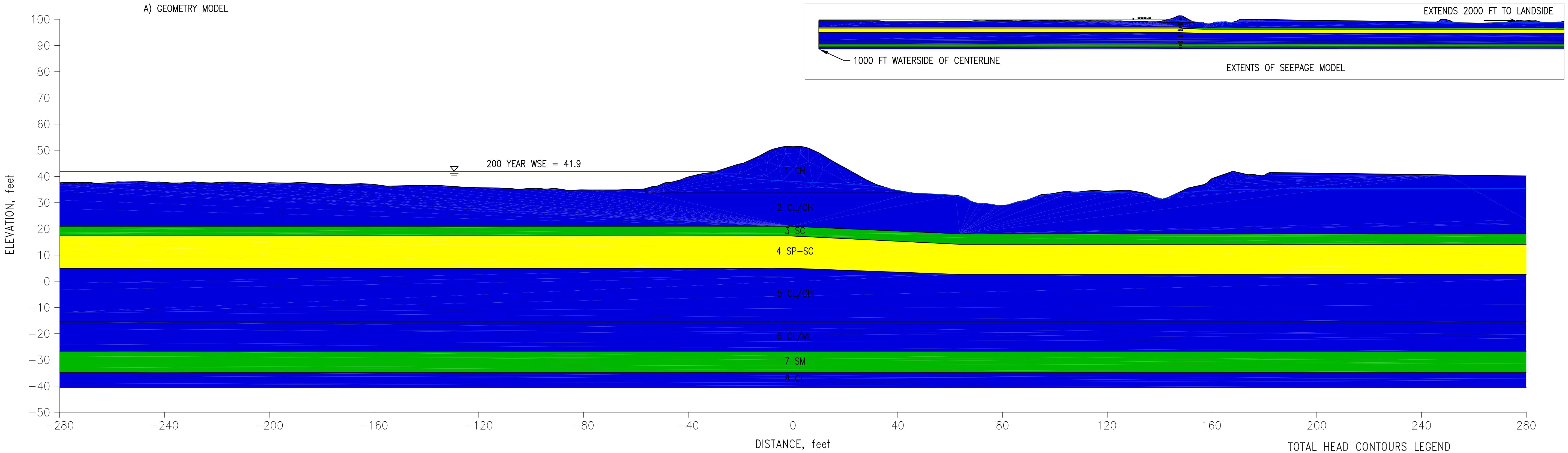
CHECKED BY
M. CHOWDHURY

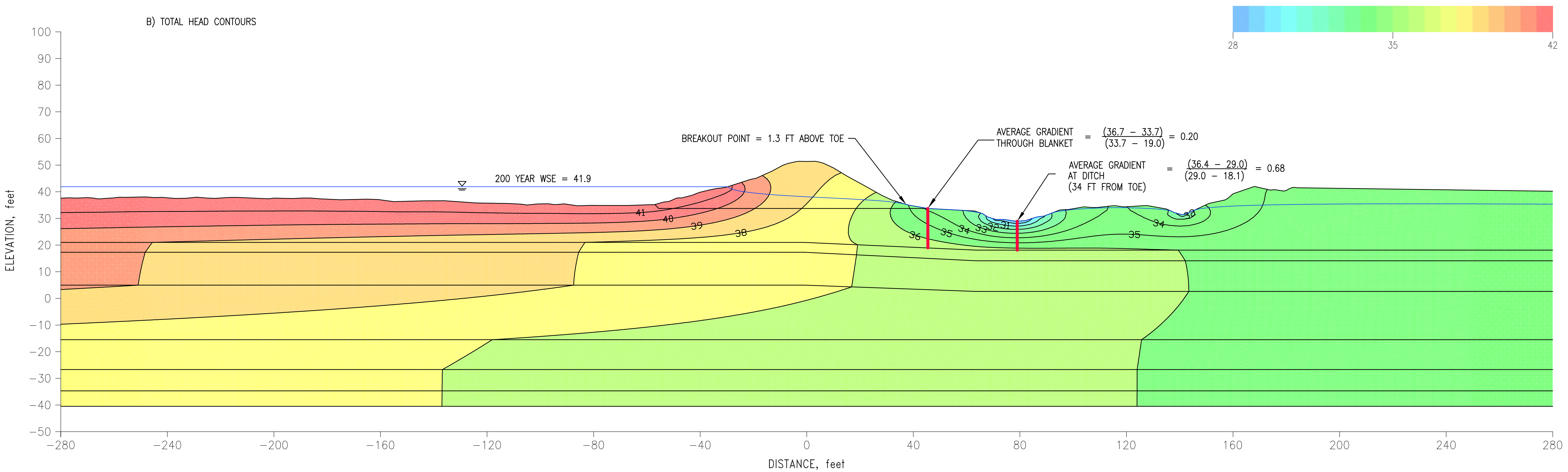
WOODLAND STUDY AREA
URBAN LEVEE EVALUATIONS

TRANSVERSE CROSS SECTION
REACH F
STATION 1408+00
ST 02 UNIT 2, LM 8.39

FIGURE
B-F-1

PLOT BY: GORDON_FONG – Apr 15, 2014 – 5:10:47pm
DRAWING: G:\DWR-7418\WorkZone\woodland ger\01_reaches\02_CADD\Drawings\01 Transverse X-sec\Station 1408+00.dwg


A) GEOMETRY MODEL


B) TOTAL HEAD CONTOURS

PLOT BY: MYNUL_CHOWDHURY – Apr 16, 2014 – 2:18:02pm
DRAWING: G:\DWR-7418\WorkZone\woodland ger\03_existcond\02_CADD\Drawings\02 Seepage Figures\F-2 Station 1408+00.dwg

Department of Water Resources
Division of Flood Management

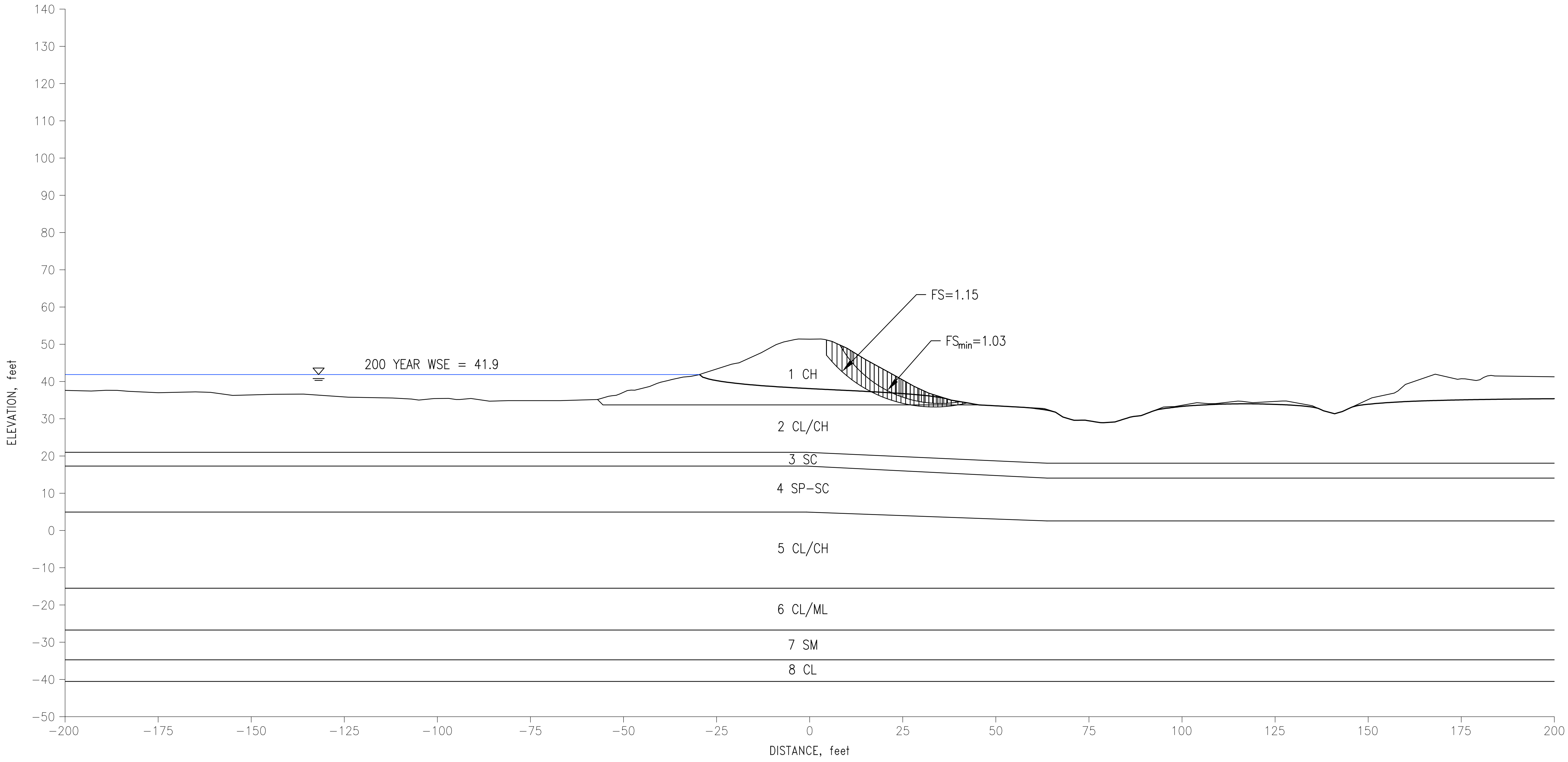
URS

CONTRACT NUMBER 17326650	PREPARED BY M. ERMAKOVICH
TASK ORDER U32	CHECKED BY M. CHOWDHURY

WOODLAND STUDY AREA
URBAN LEVEE EVALUATIONS

STEADY STATE SEEPAGE ANALYSIS
REACH F
STATION 1408+00
ST 02 UNIT 2, LM 8.39

FIGURE
B-F-2



PLOT BY: GORDON_FONG – Apr 15, 2014 – 5:02:07pm
DRAWING: G:\DWR-7418\WorkZone\woodland_ger\03_existcond\02_CADD\Drawings\03 Stability Figures\F-3 Station 1408+00.dwg

Department of Water Resources
Division of Flood Management

URS

CONTRACT NUMBER
17326650

PREPARED BY
M. ERMAKOVICH

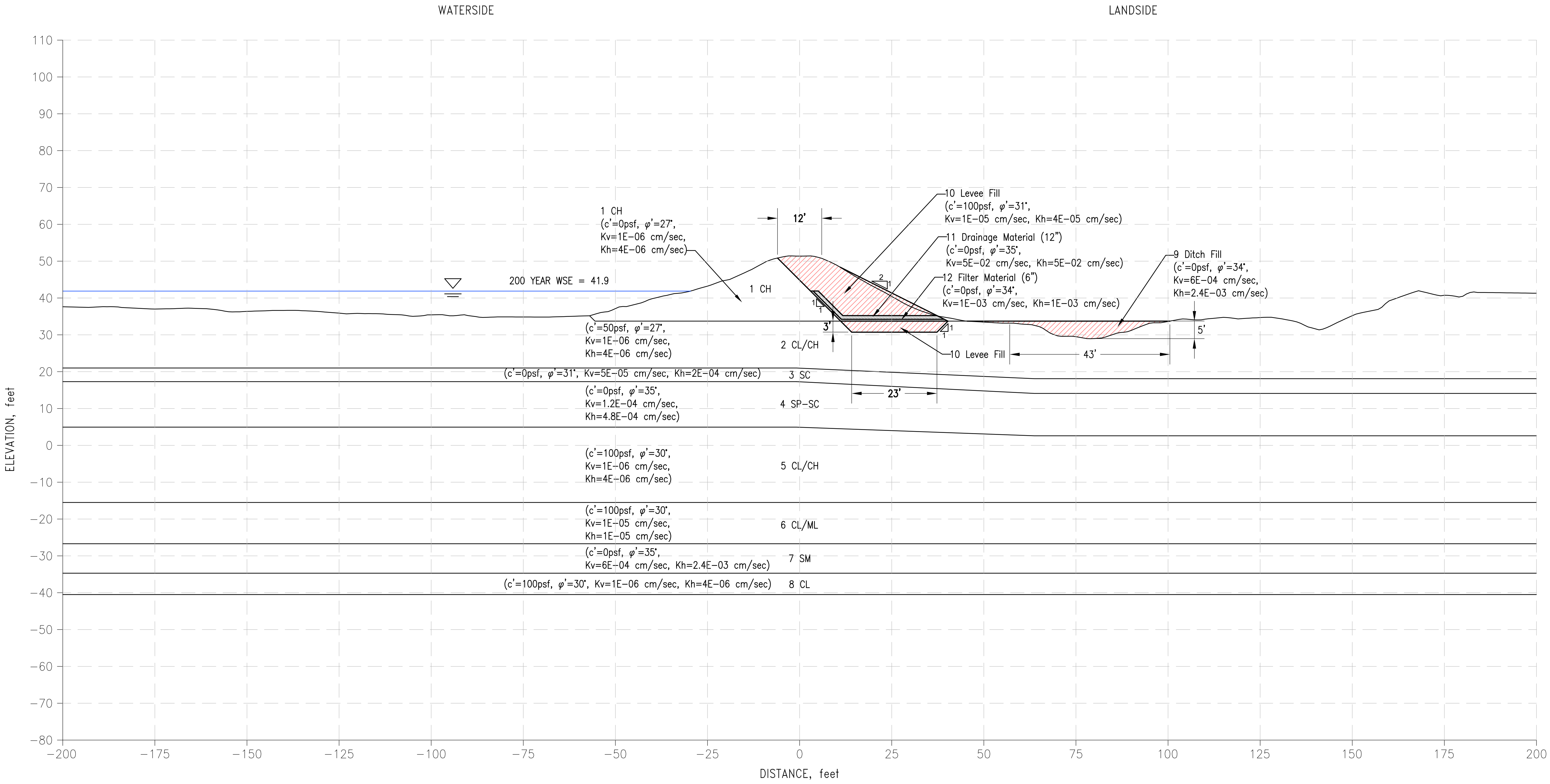
TASK ORDER
U32

CHECKED BY
M. CHOWDHURY

WOODLAND STUDY AREA
URBAN LEVEE EVALUATIONS

STEADY STATE SLOPE STABILITY ANALYSIS
REACH F
STATION 1408+00
ST 02 UNIT 2, LM 8.39

FIGURE
B-F-4



PLOT BY: MIKHAIL_ERMAKOVICH – Mar 26, 2015 – 11:16:21am
DRAWING: G:\DWR-7418\WorkZone\woodland ger\05_remediatedcond\02_CADD\Drawings\01 Transverse X-sec\B-F-1 Station 1408+00 – Partial Replacement with Chimney Drain.dwg

Department of Water Resources
Division of Flood Management

URS

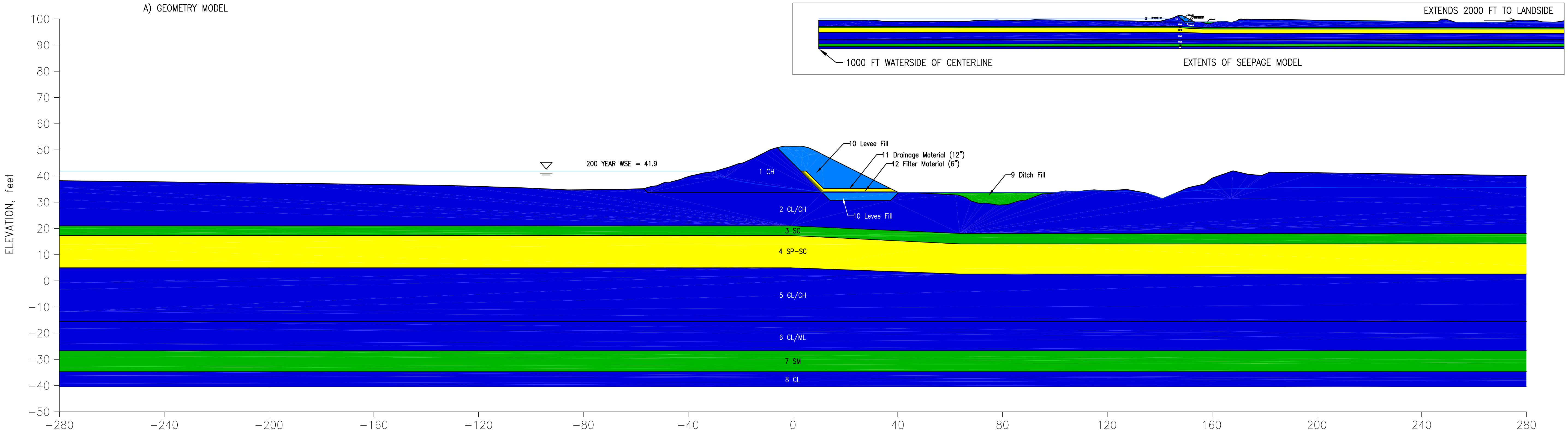
CONTRACT NUMBER 4600008101	PREPARED BY G. Schaertl
TASK ORDER U32	CHECKED BY M. Chowdhury

WOODLAND STUDY AREA
URBAN LEVEE EVALUATIONS

TRANSVERSE CROSS SECTION
REACH F – STATION 1408+00
PARTIAL LEVEE REPLACEMENT WITH CHIMNEY DRAIN
ST 02 UNIT 2, LM 8.39

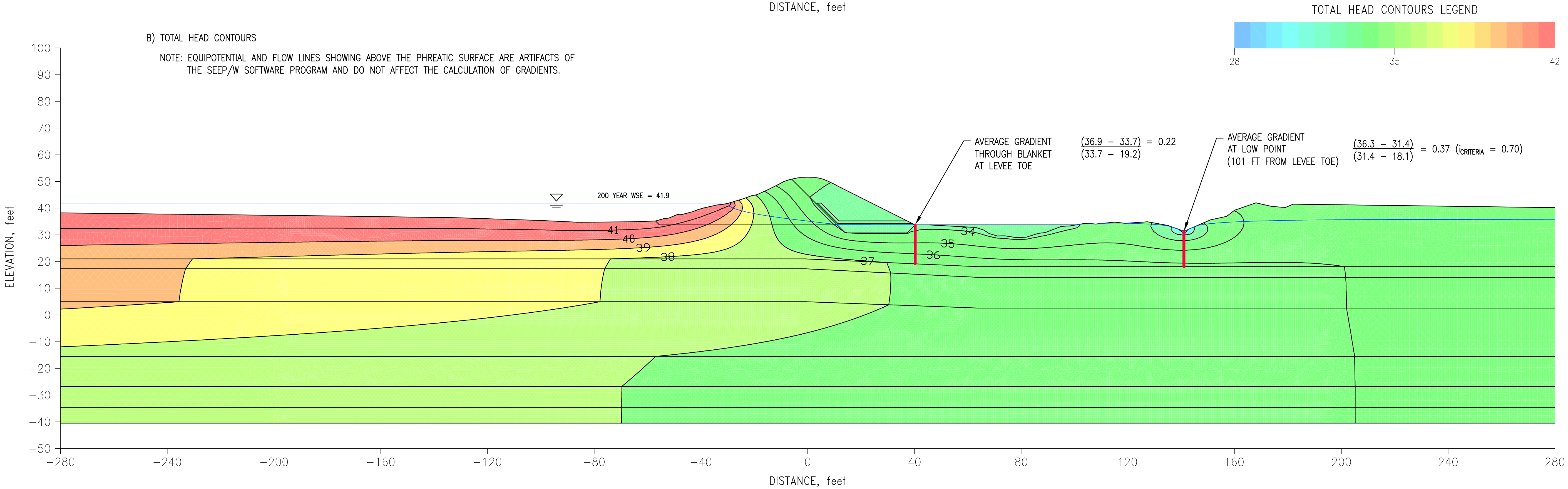
FIGURE
B-F-1

A) GEOMETRY MODEL



B) TOTAL HEAD CONTOURS

NOTE: EQUIPOTENTIAL AND FLOW LINES SHOWING ABOVE THE PHREATIC SURFACE ARE ARTIFACTS OF THE SEEP/W SOFTWARE PROGRAM AND DO NOT AFFECT THE CALCULATION OF GRADIENTS.



AVERAGE GRADIENT THROUGH BLANKET AT LEVEE TOE $\frac{(36.9 - 33.7)}{(33.7 - 19.2)} = 0.22$

AVERAGE GRADIENT AT LOW POINT (101 FT FROM LEVEE TOE) $\frac{(36.3 - 31.4)}{(31.4 - 18.1)} = 0.37$ ($i_{CRITERIA} = 0.70$)

Department of Water Resources
Division of Flood Management

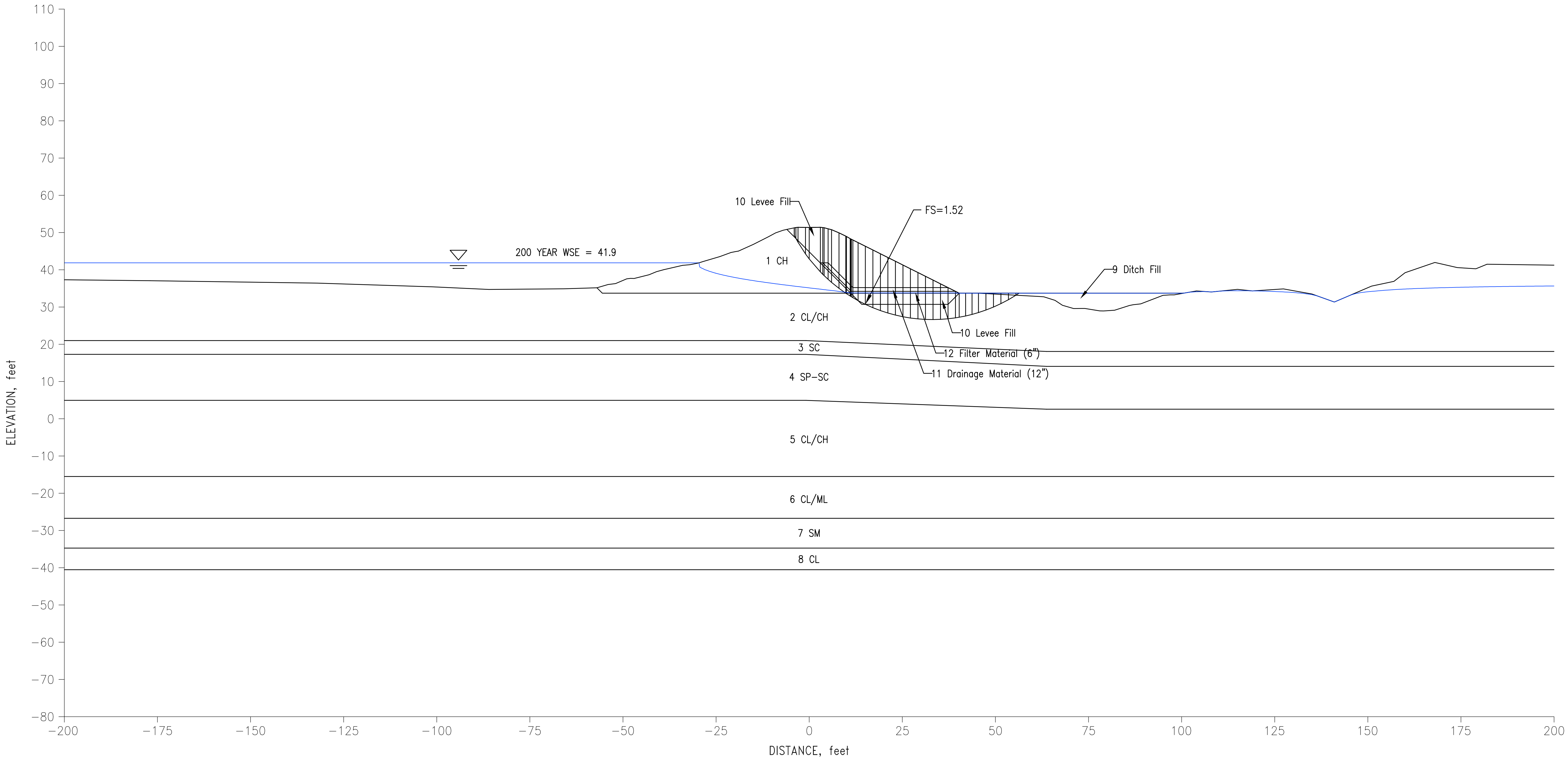
URS

CONTRACT NUMBER 4600008101	PREPARED BY G. Schaertl
TASK ORDER U32	CHECKED BY M. Chowdhury

WOODLAND STUDY AREA
URBAN LEVEE EVALUATIONS

STEADY STATE SEEPAGE ANALYSIS
REACH F – STATION 1408+00
PARTIAL LEVEE REPLACEMENT WITH CHIMNEY DRAIN
ST 02 UNIT 2, LM 8.39

FIGURE
B-F-2



PLOT BY: MIKHAIL_ERMAKOVICH – Apr 13, 2015 – 10:58:13am
DRAWING: G:\DWR-7418\WorkZone\woodland ger\05_remediatedcond\02_CADD\Drawings\03 Stability Figures\B-F-3 Station 1408+00 – Partial Replacement with Chimney Drain.dwg

Department of Water Resources
Division of Flood Management

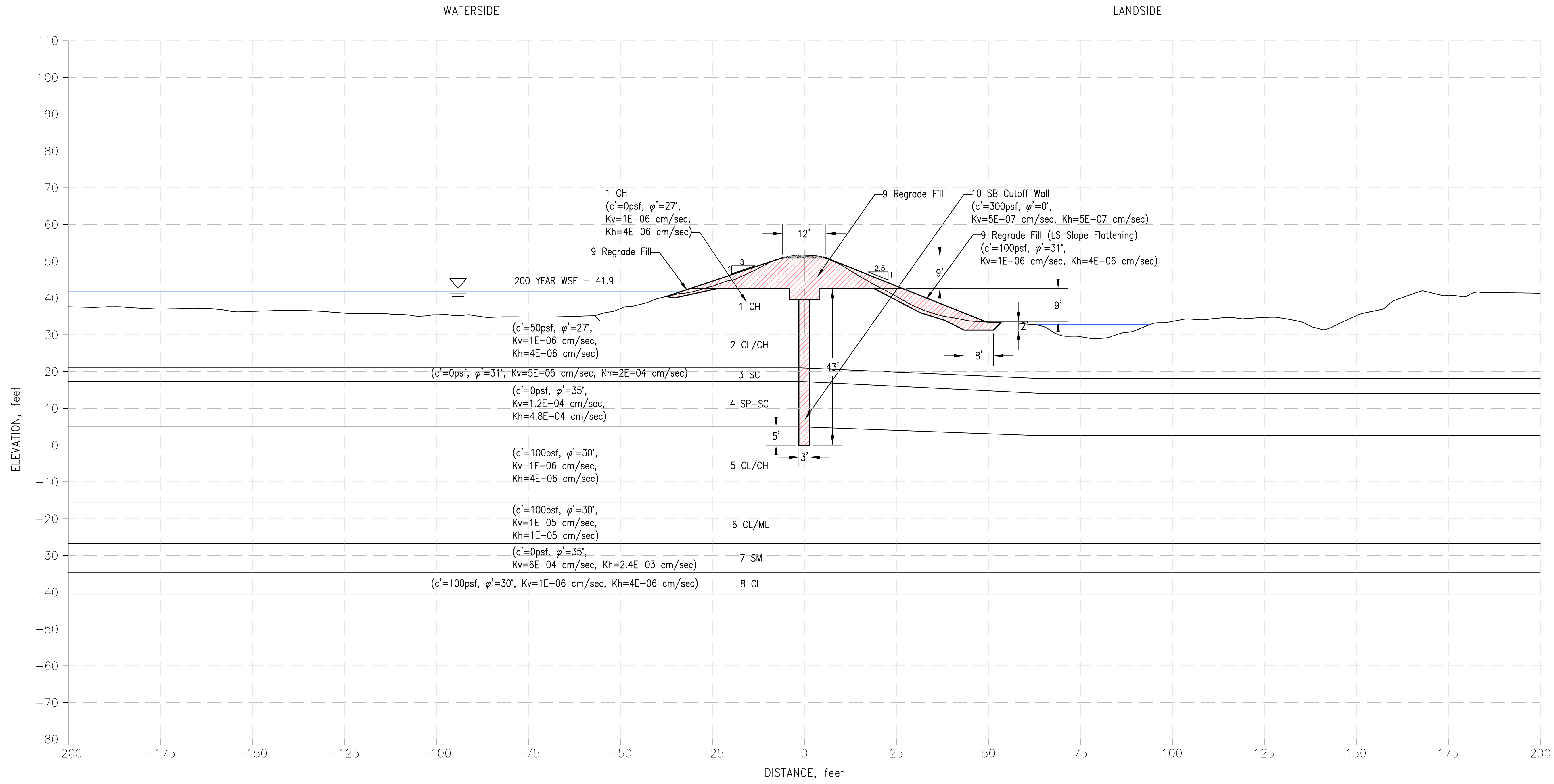
URS

CONTRACT NUMBER 4600008101	PREPARED BY G. Schaertl
TASK ORDER U32	CHECKED BY M. Chowdhury

WOODLAND STUDY AREA
URBAN LEVEE EVALUATIONS

STEADY STATE SLOPE STABILITY ANALYSIS
REACH F – STATION 1408+00
PARTIAL LEVEE REPLACEMENT WITH CHIMNEY DRAIN
ST 02 UNIT 2, LM 8.39

FIGURE
B-F-3



PLOT BY: MIKHAIL_ERMAKOVICH − Apr 13, 2015 − 10:12:42am
DRAWING: G:\DWR−7418\WorkZone\woodland ger\05_remediatedcond\02_CADD\Drawings\01 Transverse X−sec\B−F−4 Station 1408+00 − Cutoff Wall.dwg

Department of Water Resources
Division of Flood Management

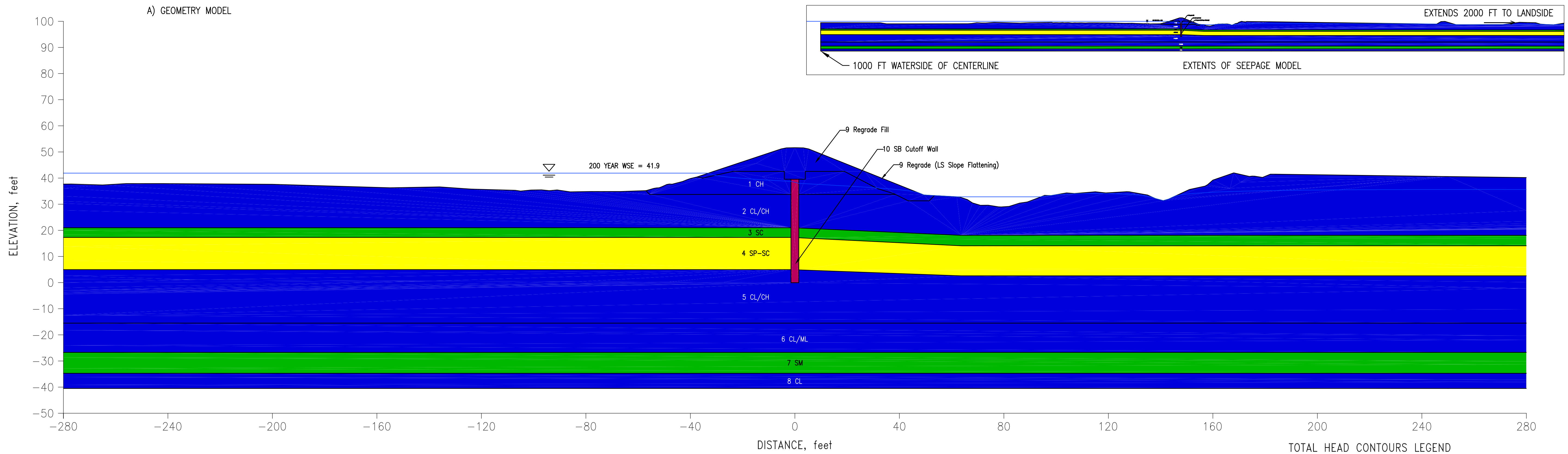
URS

CONTRACT NUMBER 4600008101	PREPARED BY G. Schaertl
TASK ORDER U32	CHECKED BY M. Chowdhury

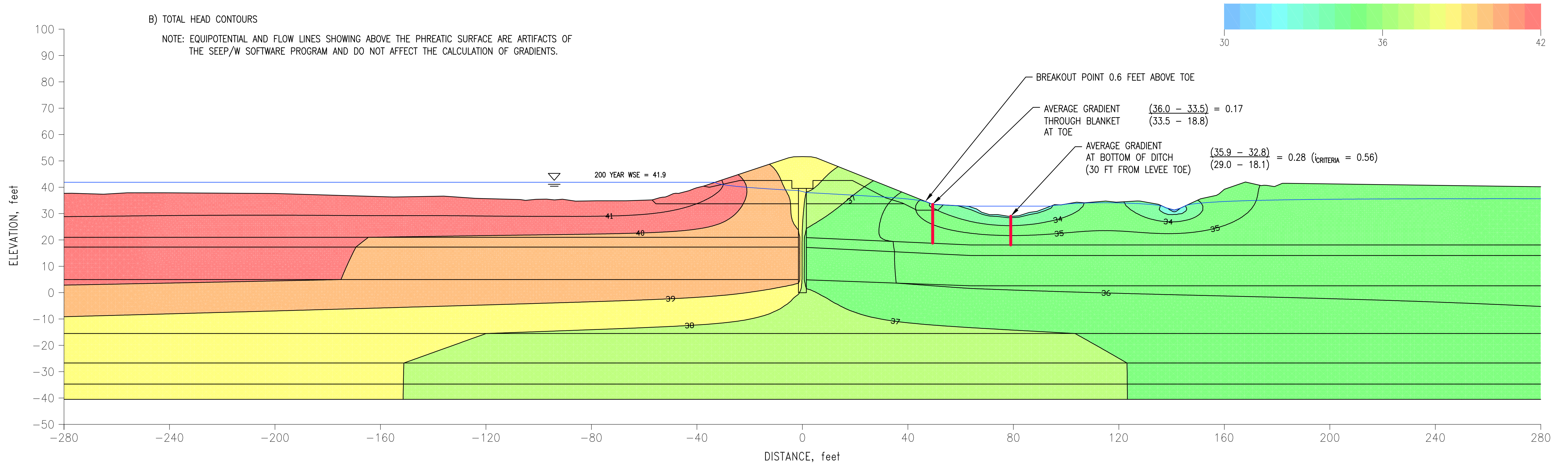
WOODLAND STUDY AREA
URBAN LEVEE EVALUATIONS

TRANSVERSE CROSS SECTION
REACH F − STATION 1408+00
SB CUTOFF WALL AND LANDSIDE SLOPE FLATTENING
ST 02 UNIT 2, LM 8.39

FIGURE
B-F-4



A) GEOMETRY MODEL



B) TOTAL HEAD CONTOURS

NOTE: EQUIPOTENTIAL AND FLOW LINES SHOWING ABOVE THE PHREATIC SURFACE ARE ARTIFACTS OF THE SEEP/W SOFTWARE PROGRAM AND DO NOT AFFECT THE CALCULATION OF GRADIENTS.

BREAKOUT POINT 0.6 FEET ABOVE TOE

AVERAGE GRADIENT THROUGH BLANKET AT TOE $\frac{(36.0 - 33.5)}{(33.5 - 18.8)} = 0.17$

AVERAGE GRADIENT AT BOTTOM OF DITCH (30 FT FROM LEVEE TOE) $\frac{(35.9 - 32.8)}{(29.0 - 18.1)} = 0.28$ ($i_{CRITERIA} = 0.56$)

PLOT BY: MIKHAIL_ERMAKOVICH – Apr 13, 2015 – 10:50:30am
DRAWING: G:\DWR-7418\WorkZone\woodland ger\05_remediatedcond\02_CADD\Drawings\02 Seepage Figures\B-F-5 Station 1408+00 – Cutoff Wall.dwg

Department of Water Resources
Division of Flood Management

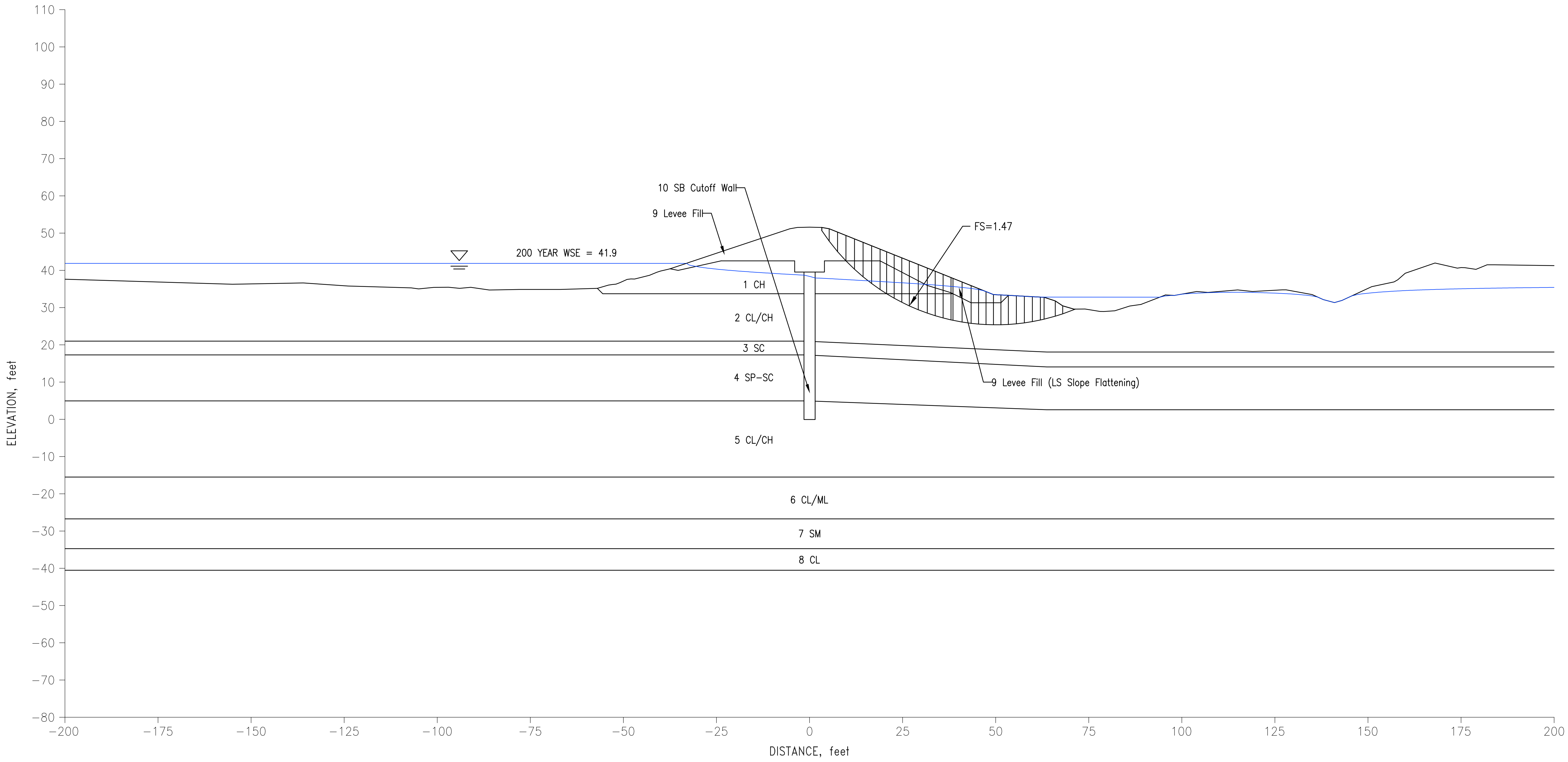
URS

CONTRACT NUMBER 4600008101	PREPARED BY G. Schaertl
TASK ORDER U32	CHECKED BY M. Chowdhury

WOODLAND STUDY AREA
URBAN LEVEE EVALUATIONS

STEADY STATE SEEPAGE ANALYSIS
REACH F – STATION 1408+00
SB CUTOFF WALL AND LANDSIDE SLOPE FLATTENING
ST 02 UNIT 2, LM 8.39

FIGURE
B-F-5



PLOT BY: MIKHAIL_ERMAKOVICH – Apr 13, 2015 – 10:58:59am
DRAWING: G:\DWR-7418\WorkZone\woodland ger\05_remediatedcond\02_CADD\Drawings\03 Stability Figures\B-F-6 Station 1408+00 – Cutoff Wall.dwg

Department of Water Resources
Division of Flood Management

URS

CONTRACT NUMBER
4600008101

TASK ORDER
U32

PREPARED BY
G. Schaertl

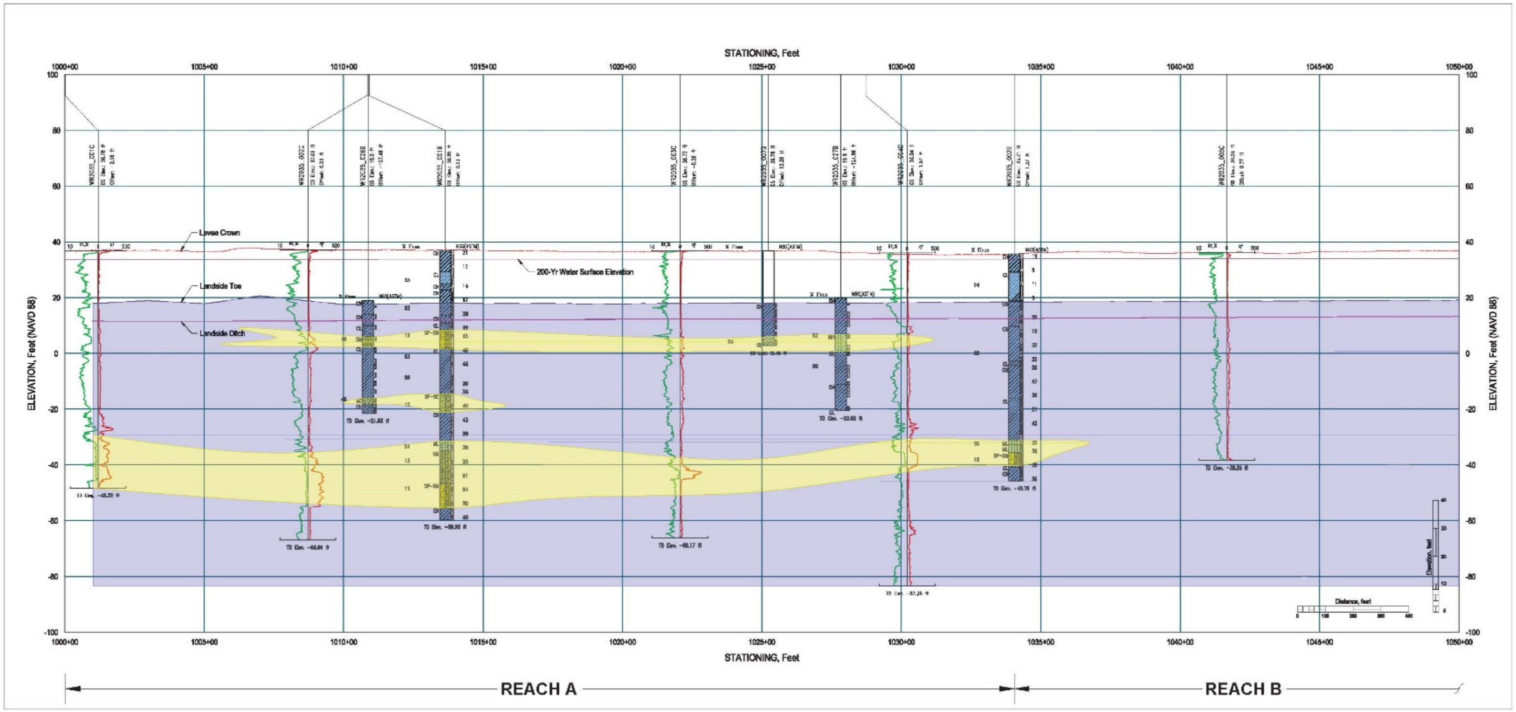
CHECKED BY
M. Chowdhury

WOODLAND STUDY AREA
URBAN LEVEE EVALUATIONS

STEADY STATE SLOPE STABILITY ANALYSIS
REACH F – STATION 1408+00
SB CUTOFF WALL AND LANDSIDE SLOPE FLATTENING
ST 02 UNIT 2, LM 8.39

FIGURE
B-F-6

PLATES



LOWER CACHE CREEK FEASIBILITY STUDY
SUBSURFACE PROFILE

KEY:
TYPE I SOIL–FINE GRAINED IMPERVIOUS SOIL ■
TYPE II SOIL–INTERMEDIATE SOIL OF LOW PERMEABILITY 🟩
TYPE III SOIL–COARSE GRAINED PERVIOUS SOIL ■
CUTOFF WALL —

NOTES:
1. NOT ALL BORINGS SHOWN.
2. BORING LOCATIONS ARE APPROXIMATE.
3. SEE MAP PLATE FOR BORING LOCATION.
4. INTERPRETED PROFILE IS BASED ON BORINGS AND/OR HEM DATA.

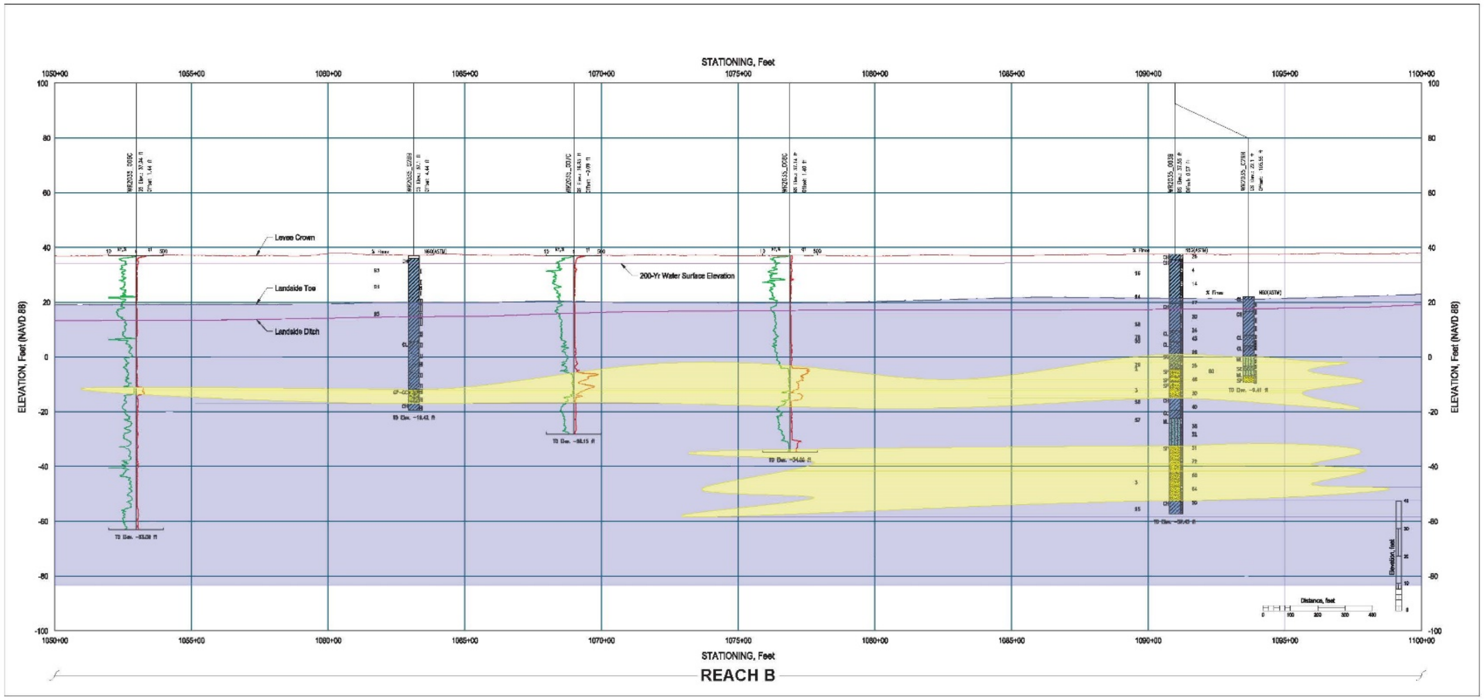
DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

YOLO COUNTY CALIFORNIA

LOWER CACHE CREEK FEASIBILITY STUDY
GEOTECHNICAL APPENDIX

BORING PROFILE
STA 1000+00 TO 1050+00

DATE: 07 APRIL 2015
SCALE: AS SHOWN
PLATE 1



LOWER CACHE CREEK FEASIBILITY STUDY
SUBSURFACE PROFILE

KEY:

TYPE I SOIL–FINE GRAINED IMPERVIOUS SOIL	🟪
TYPE II SOIL–INTERMEDIATE SOIL OF LOW PERMEABILITY	🟩
TYPE III SOIL–COARSE GRAINED PERVIOUS SOIL	🟨
CUTOFF WALL	—

NOTES:
1. NOT ALL BORINGS SHOWN.
2. BORING LOCATIONS ARE APPROXIMATE.
3. SEE MAP PLATE FOR BORING LOCATION.
4. INTERPRETED PROFILE IS BASED ON BORINGS AND/OR HEM DATA.

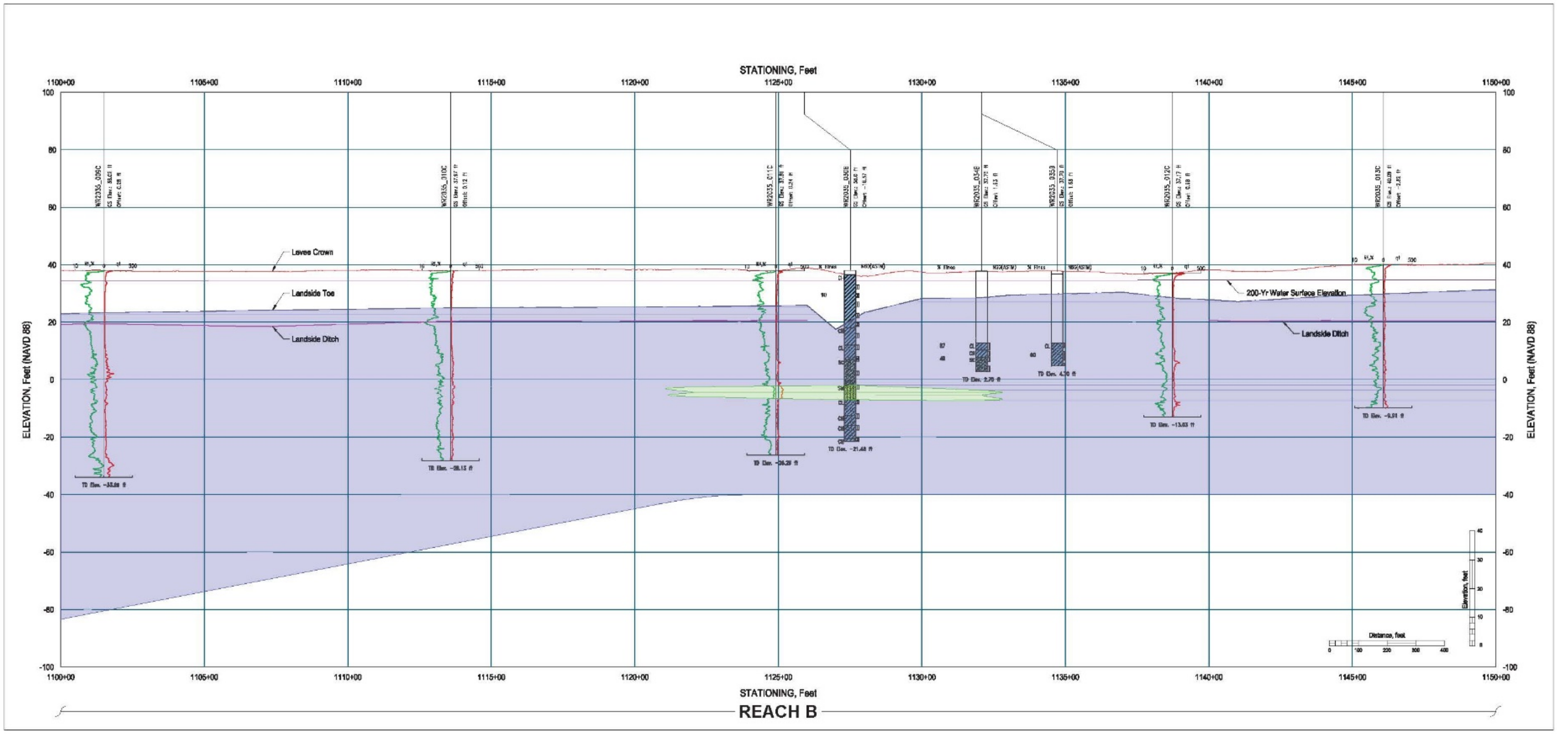
DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

YOLO COUNTY CALIFORNIA

LOWER CACHE CREEK FEASIBILITY STUDY
GEOTECHNICAL APPENDIX

BORING PROFILE
STA 1050+00 TO 1100+00

DATE:	SCALE:	
07 APRIL 2015	AS SHOWN	PLATE 2



LOWER CACHE CREEK FEASIBILITY STUDY
SUBSURFACE PROFILE

KEY:	
TYPE I SOIL–FINE GRAINED IMPERVIOUS SOIL	🟪
TYPE II SOIL–INTERMEDIATE SOIL OF LOW PERMEABILITY	🟩
TYPE III SOIL–COARSE GRAINED PERVIOUS SOIL	🟨
CUTOFF WALL	—

NOTES:
1. NOT ALL BORINGS SHOWN.
2. BORING LOCATIONS ARE APPROXIMATE.
3. SEE MAP PLATE FOR BORING LOCATION.
4. INTERPRETED PROFILE IS BASED ON BORINGS AND/OR HEM DATA.

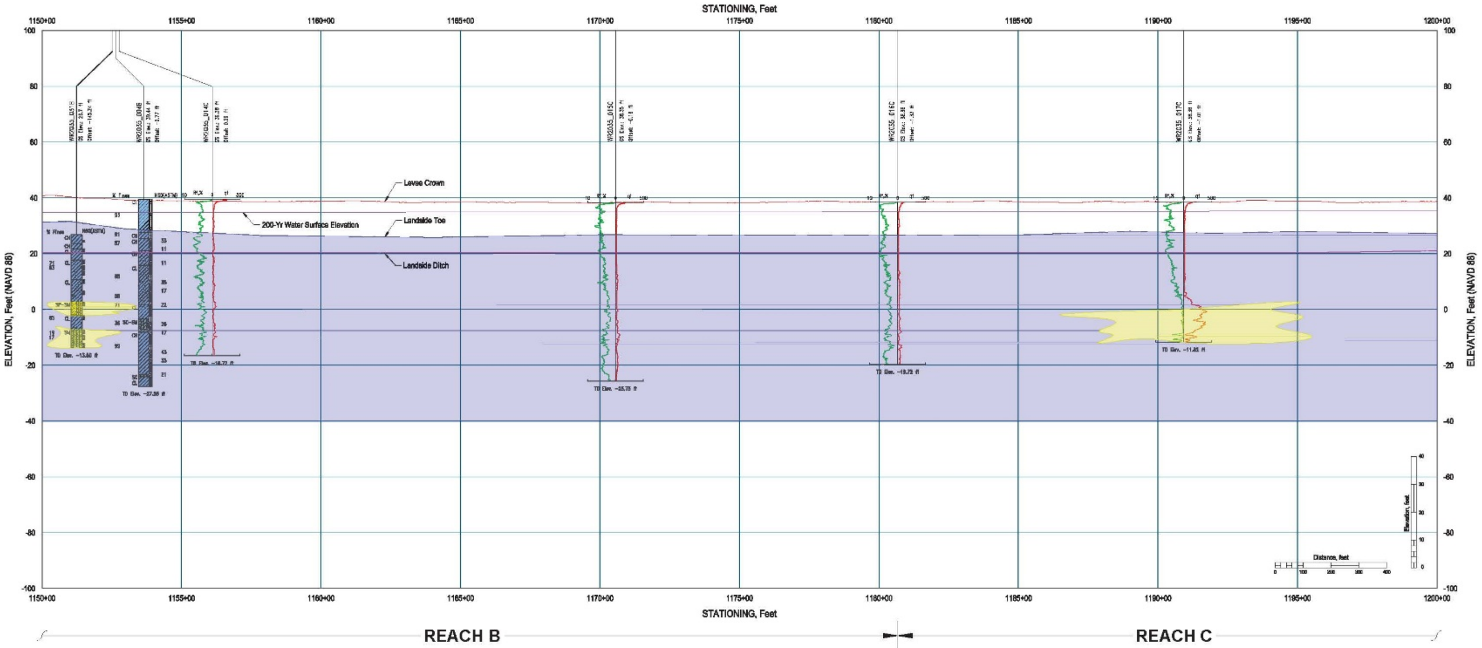
DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

YOLO COUNTY CALIFORNIA

LOWER CACHE CREEK FEASIBILITY STUDY
GEOTECHNICAL APPENDIX

BORING PROFILE
STA 1100+00 TO 1150+00

DATE: 07 APRIL 2015
SCALE: AS SHOWN
PLATE 3



LOWER CACHE CREEK FEASIBILITY STUDY
SUBSURFACE PROFILE

KEY:

TYPE I SOIL–FINE GRAINED IMPERVIOUS SOIL	🟪
TYPE II SOIL–INTERMEDIATE SOIL OF LOW PERMEABILITY	🟩
TYPE III SOIL–COARSE GRAINED PERVIOUS SOIL	🟨
CUTOFF WALL	—

NOTES:
1. NOT ALL BORINGS SHOWN.
2. BORING LOCATIONS ARE APPROXIMATE.
3. SEE MAP PLATE FOR BORING LOCATION.
4. INTERPRETED PROFILE IS BASED ON BORINGS AND/OR HEM DATA.

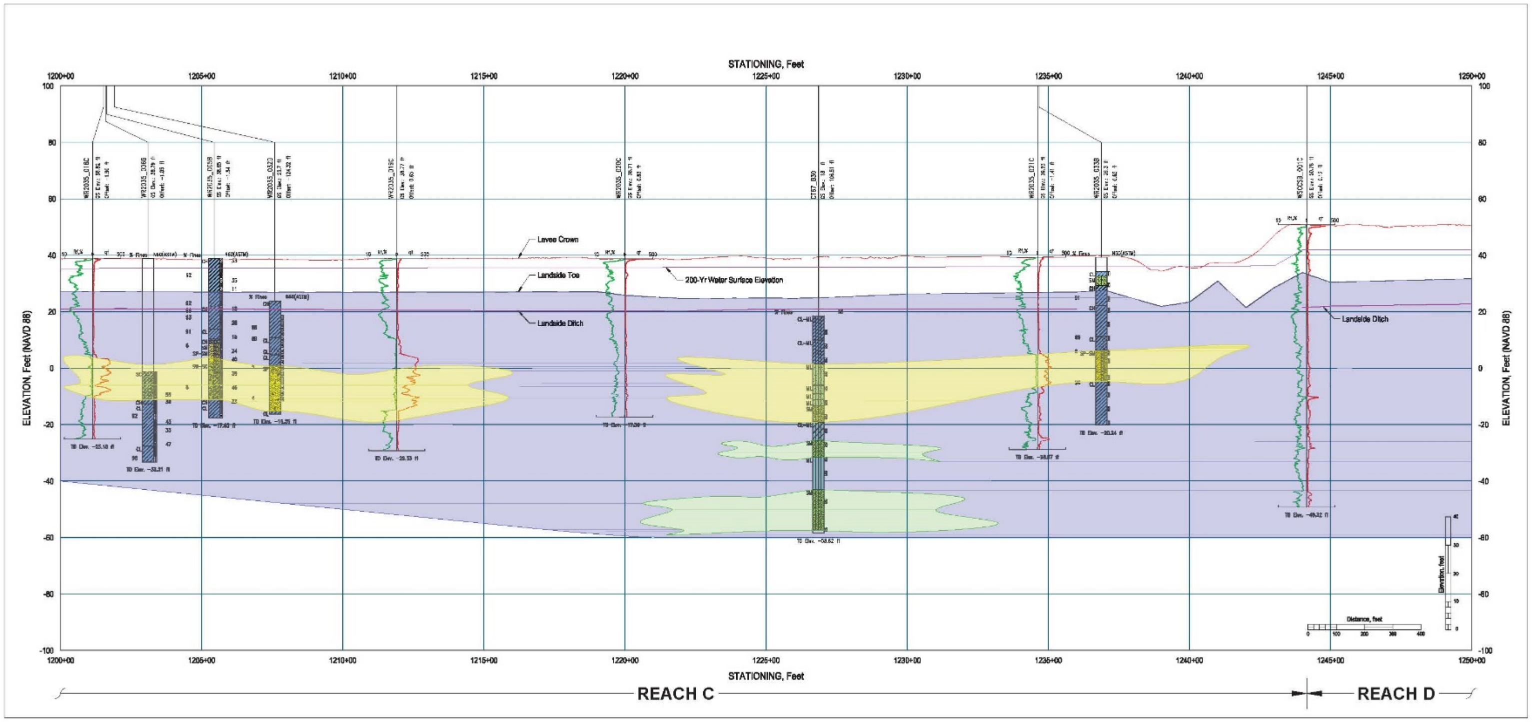
DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

YOLO COUNTY CALIFORNIA

LOWER CACHE CREEK FEASIBILITY STUDY
GEOTECHNICAL APPENDIX

BORING PROFILE
STA 1150+00 TO 1200+00

DATE: 07 APRIL 2015
SCALE: AS SHOWN
PLATE 4



LOWER CACHE CREEK FEASIBILITY STUDY
SUBSURFACE PROFILE

KEY:

TYPE I SOIL–FINE GRAINED IMPERVIOUS SOIL	🟪
TYPE II SOIL–INTERMEDIATE SOIL OF LOW PERMEABILITY	🟩
TYPE III SOIL–COARSE GRAINED PERVIOUS SOIL	🟨
CUTOFF WALL	—

NOTES:
1. NOT ALL BORINGS SHOWN.
2. BORING LOCATIONS ARE APPROXIMATE.
3. SEE MAP PLATE FOR BORING LOCATION.
4. INTERPRETED PROFILE IS BASED ON BORINGS AND/OR HEM DATA.

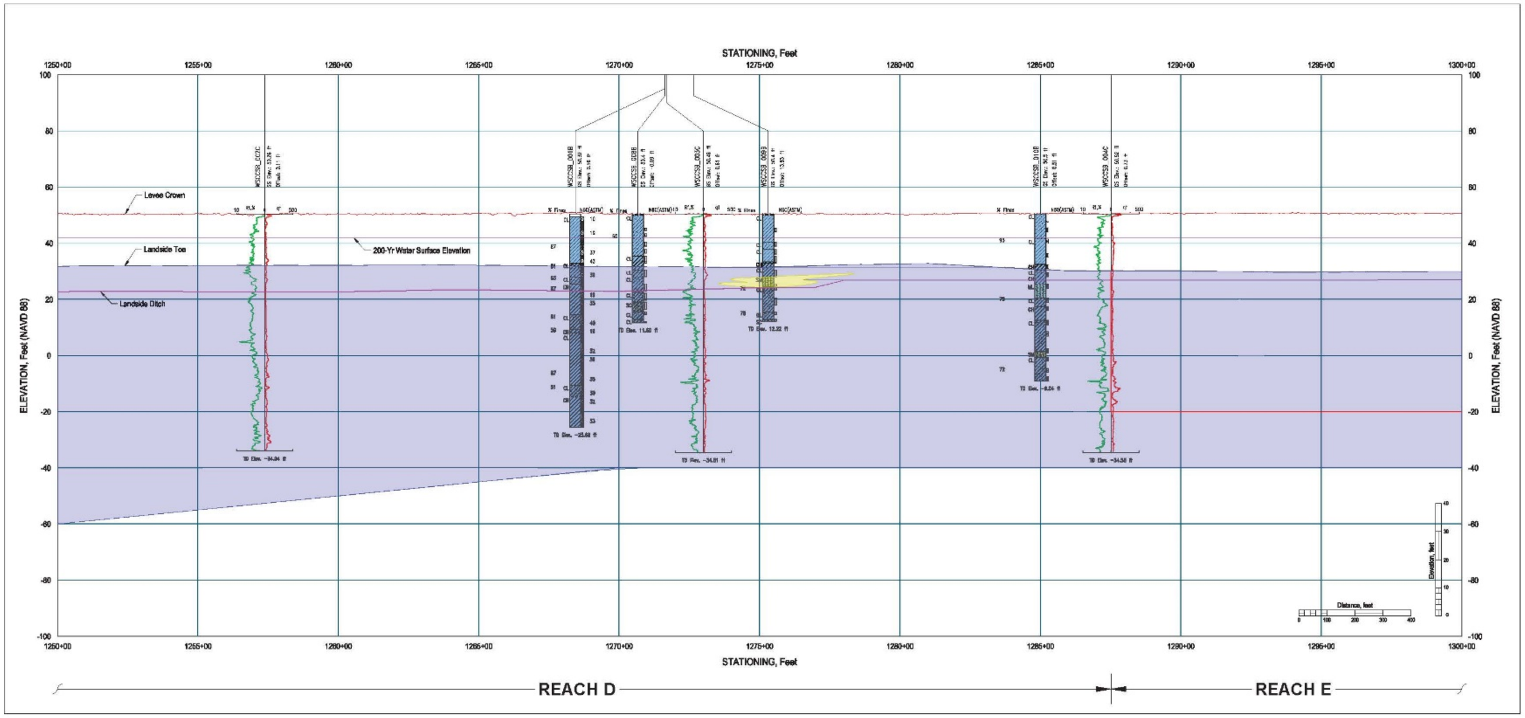
DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

YOLO COUNTY
CALIFORNIA

LOWER CACHE CREEK FEASIBILITY STUDY
GEOTECHNICAL APPENDIX

BORING PROFILE
STA 1200+00 TO 1250+00

DATE: 07 APRIL 2015
SCALE: AS SHOWN
PLATE 5



LOWER CACHE CREEK FEASIBILITY STUDY SUBSURFACE PROFILE

KEY:

TYPE I SOIL–FINE GRAINED IMPERVIOUS SOIL	▨
TYPE II SOIL–INTERMEDIATE SOIL OF LOW PERMEABILITY	🟩
TYPE III SOIL–COARSE GRAINED PERVIOUS SOIL	🟨
CUTOFF WALL	—

NOTES:
1. NOT ALL BORINGS SHOWN.
2. BORING LOCATIONS ARE APPROXIMATE.
3. SEE MAP PLATE FOR BORING LOCATION.
4. INTERPRETED PROFILE IS BASED ON BORINGS AND/OR HEM DATA.

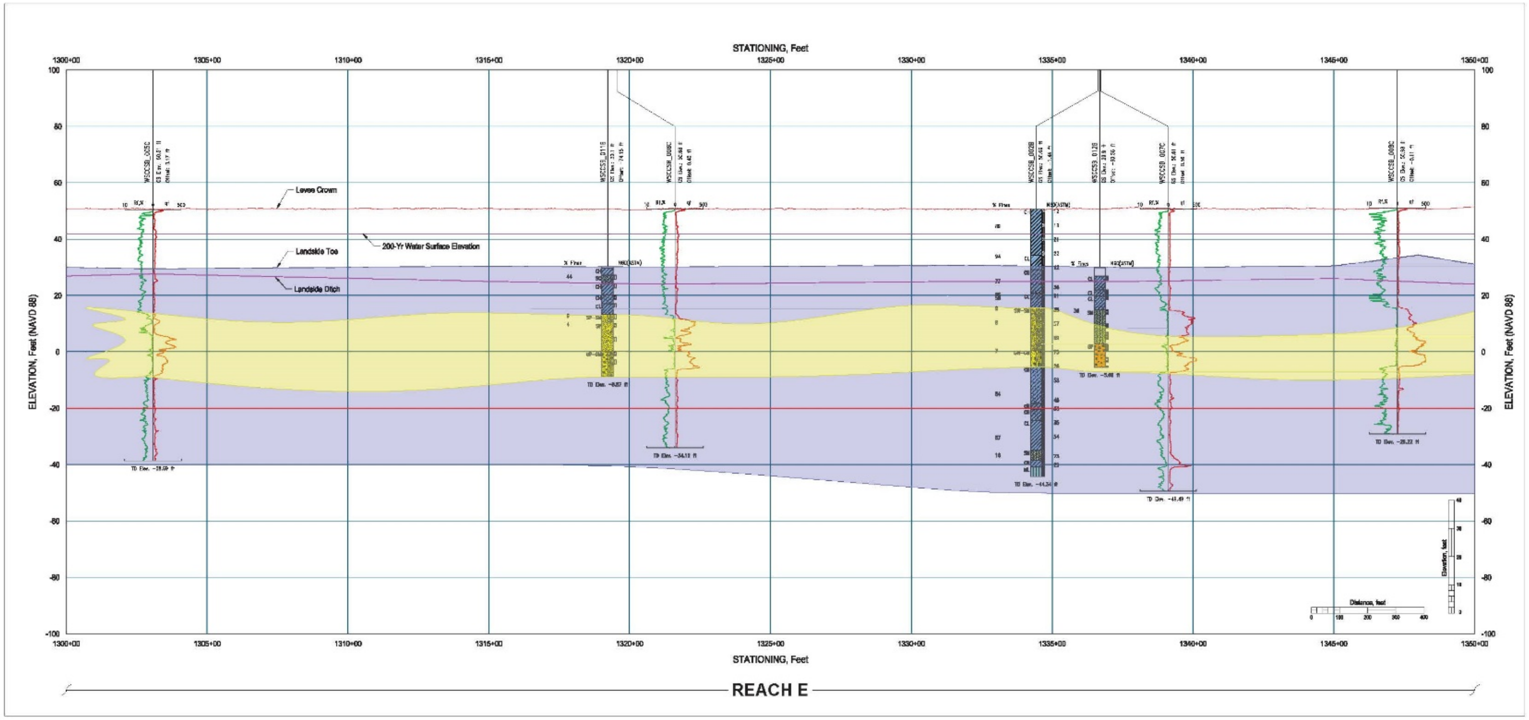
DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

YOLO COUNTY CALIFORNIA

LOWER CACHE CREEK FEASIBILITY STUDY
GEOTECHNICAL APPENDIX

BORING PROFILE
STA 1250+00 TO 1300+00

DATE:	SCALE:	
07 APRIL 2015	AS SHOWN	PLATE 6



LOWER CACHE CREEK FEASIBILITY STUDY
SUBSURFACE PROFILE

KEY:

TYPE I SOIL–FINE GRAINED IMPERVIOUS SOIL	🟪
TYPE II SOIL–INTERMEDIATE SOIL OF LOW PERMEABILITY	🟩
TYPE III SOIL–COARSE GRAINED PERVIOUS SOIL	🟨
CUTOFF WALL	—

NOTES:
1. NOT ALL BORINGS SHOWN.
2. BORING LOCATIONS ARE APPROXIMATE.
3. SEE MAP PLATE FOR BORING LOCATION.
4. INTERPRETED PROFILE IS BASED ON BORINGS AND/OR HEM DATA.

DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

YOLO COUNTY CALIFORNIA

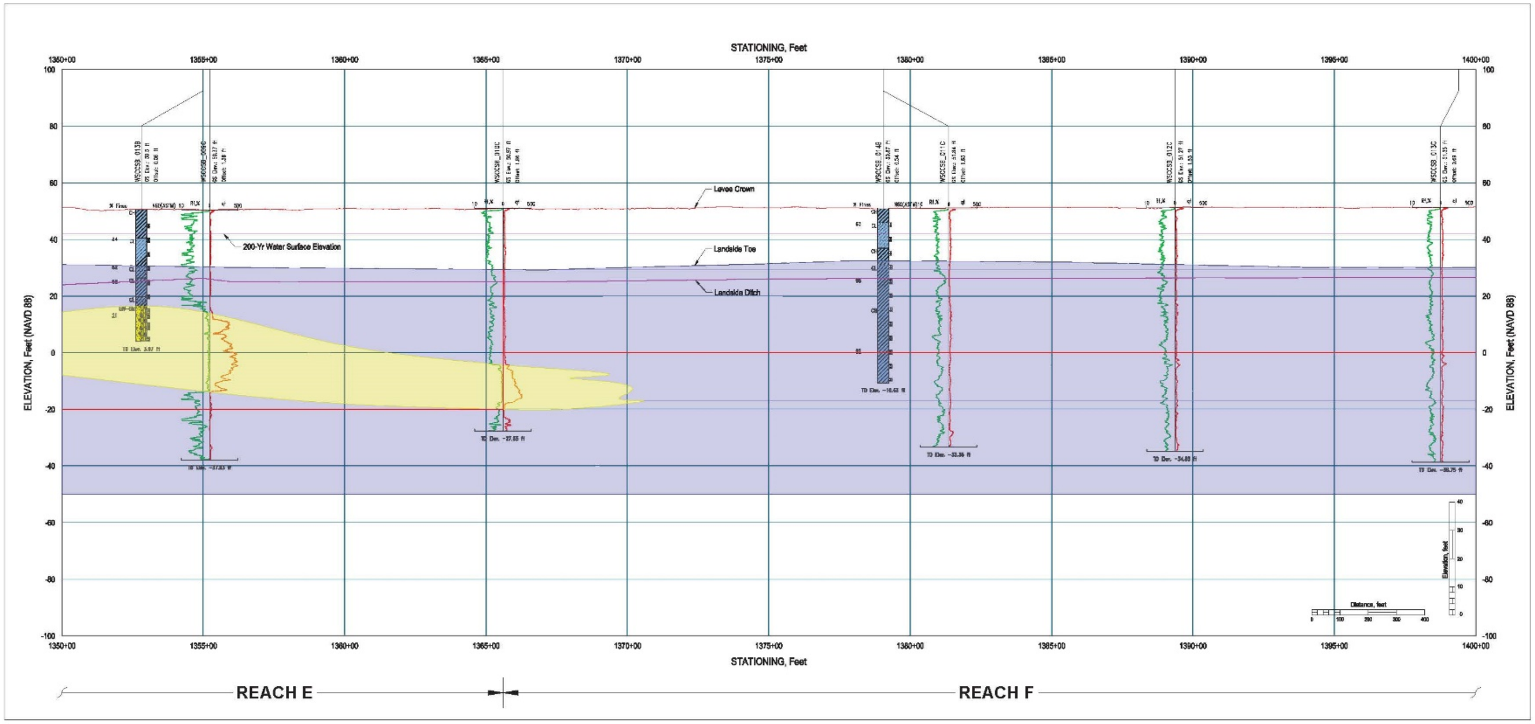
LOWER CACHE CREEK FEASIBILITY STUDY
GEOTECHNICAL APPENDIX

BORING PROFILE
STA 1300+00 TO 1350+00

DATE: 07 APRIL 2015

SCALE: AS SHOWN

PLATE 7



LOWER CACHE CREEK FEASIBILITY STUDY
SUBSURFACE PROFILE

KEY:

TYPE I SOIL–FINE GRAINED IMPERVIOUS SOIL	🟪
TYPE II SOIL–INTERMEDIATE SOIL OF LOW PERMEABILITY	🟩
TYPE III SOIL–COARSE GRAINED PERVIOUS SOIL	🟨
CUTOFF WALL	—

NOTES:
1. NOT ALL BORINGS SHOWN.
2. BORING LOCATIONS ARE APPROXIMATE.
3. SEE MAP PLATE FOR BORING LOCATION.
4. INTERPRETED PROFILE IS BASED ON BORINGS AND/OR HEM DATA.

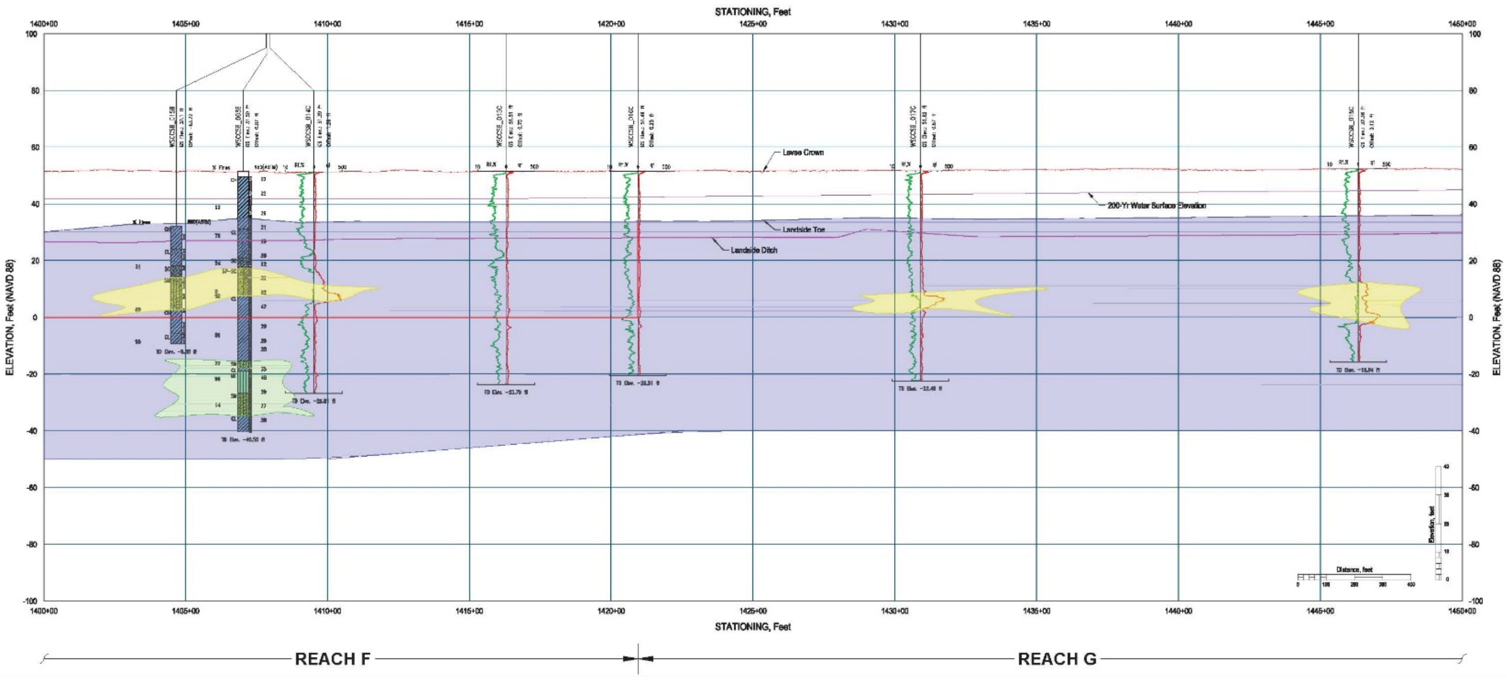
DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

YOLO COUNTY CALIFORNIA

LOWER CACHE CREEK FEASIBILITY STUDY
GEOTECHNICAL APPENDIX

BORING PROFILE
STA 1350+00 TO 1400+00

DATE:	SCALE:	
07 APRIL 2015	AS SHOWN	PLATE 8



LOWER CACHE CREEK FEASIBILITY STUDY
SUBSURFACE PROFILE

KEY:

TYPE I SOIL–FINE GRAINED IMPERVIOUS SOIL	🟪
TYPE II SOIL–INTERMEDIATE SOIL OF LOW PERMEABILITY	🟩
TYPE III SOIL–COARSE GRAINED PERVIOUS SOIL	🟨
CUTOFF WALL	—

NOTES:
1. NOT ALL BORINGS SHOWN.
2. BORING LOCATIONS ARE APPROXIMATE.
3. SEE MAP PLATE FOR BORING LOCATION.
4. INTERPRETED PROFILE IS BASED ON BORINGS AND/OR HEM DATA.

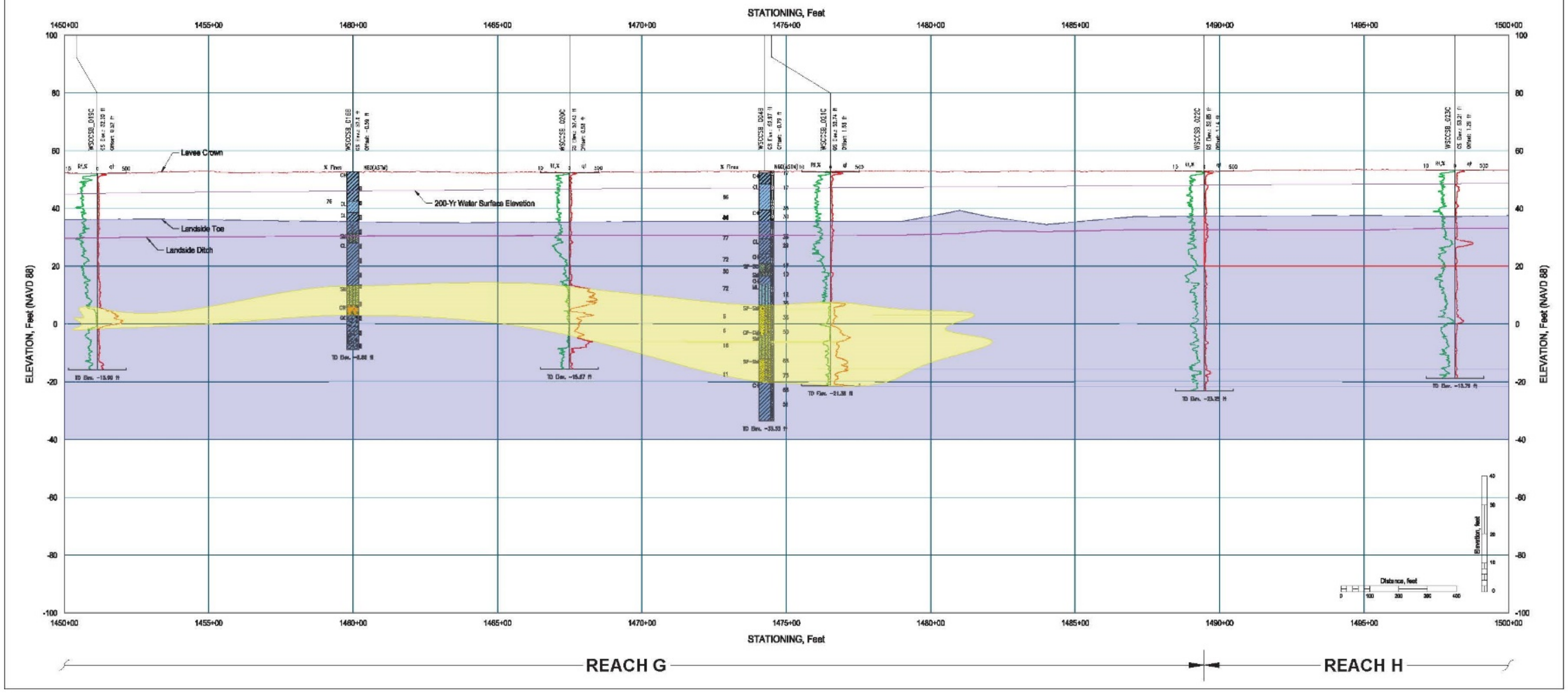
DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

YOLO COUNTY CALIFORNIA

LOWER CACHE CREEK FEASIBILITY STUDY
GEOTECHNICAL APPENDIX

BORING PROFILE
STA 1400+00 TO 1450+00

DATE:	SCALE:	
07 APRIL 2015	AS SHOWN	PLATE 9



LOWER CACHE CREEK FEASIBILITY STUDY
SUBSURFACE PROFILE

KEY:

TYPE I SOIL-FINE GRAINED IMPERVIOUS SOIL	🟪
TYPE II SOIL-INTERMEDIATE SOIL OF LOW PERMEABILITY	🟩
TYPE III SOIL-COARSE GRAINED PERVIOUS SOIL	🟨
CUTOFF WALL	—

NOTES:
1. NOT ALL BORINGS SHOWN.
2. BORING LOCATIONS ARE APPROXIMATE.
3. SEE MAP PLATE FOR BORING LOCATION.
4. INTERPRETED PROFILE IS BASED ON BORINGS AND/OR HEM DATA.

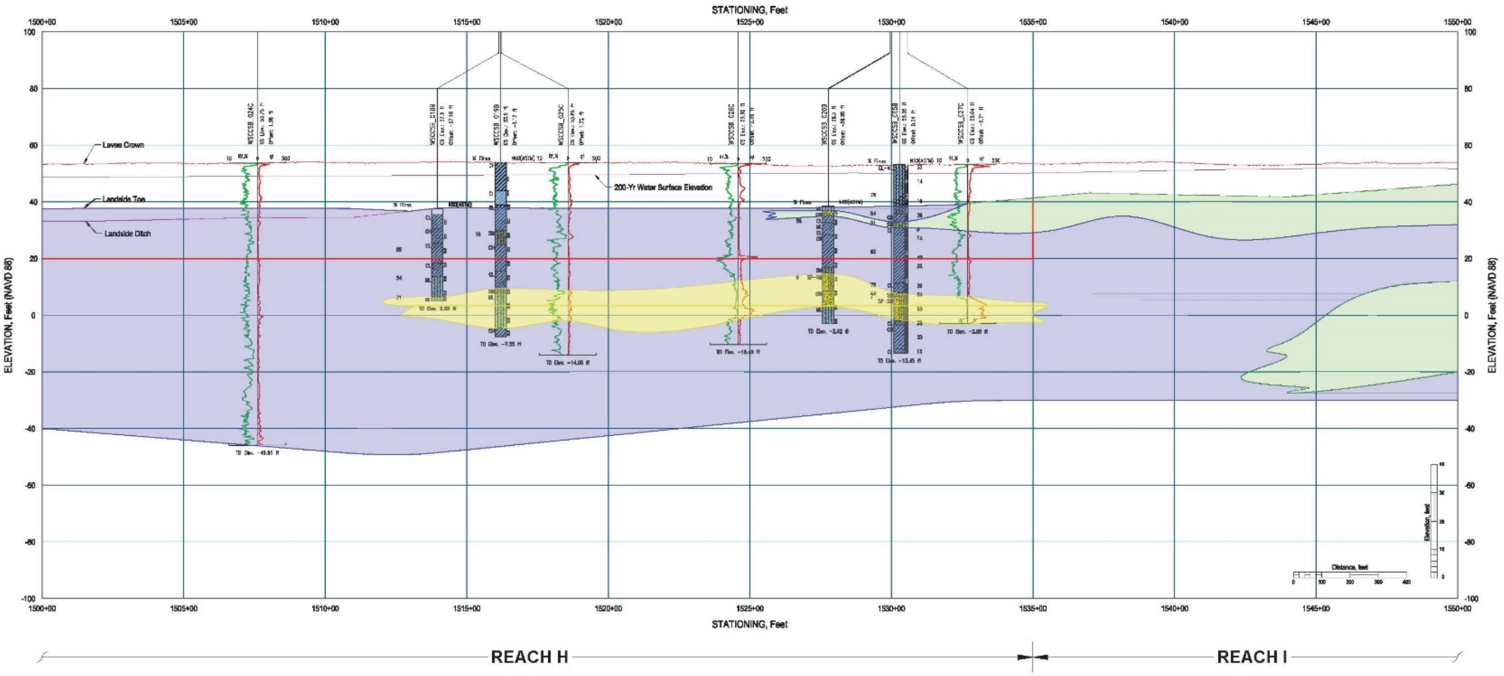
DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

YOLO COUNTY CALIFORNIA

LOWER CACHE CREEK FEASIBILITY STUDY
GEOTECHNICAL APPENDIX

BORING PROFILE
STA 1450+00 TO 1500+00

DATE: 07 APRIL 2015
SCALE: AS SHOWN
PLATE 10



LOWER CACHE CREEK FEASIBILITY STUDY
SUBSURFACE PROFILE

KEY:

TYPE I SOIL–FINE GRAINED IMPERVIOUS SOIL	🟪
TYPE II SOIL–INTERMEDIATE SOIL OF LOW PERMEABILITY	🟩
TYPE III SOIL–COARSE GRAINED PERVIOUS SOIL	🟨
CUTOFF WALL	—

NOTES:
1. NOT ALL BORINGS SHOWN.
2. BORING LOCATIONS ARE APPROXIMATE.
3. SEE MAP PLATE FOR BORING LOCATION.
4. INTERPRETED PROFILE IS BASED ON BORINGS AND/OR HEM DATA.

DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

YOLO COUNTY CALIFORNIA

LOWER CACHE CREEK FEASIBILITY STUDY
GEOTECHNICAL APPENDIX

BORING PROFILE
STA 1500+00 TO 1550+00

DATE:	SCALE:	
07 APRIL 2015	AS SHOWN	PLATE 11

ATTACHMENT A

DATE STARTED 10/15/15 DATE COMPLETED 10/15/15	GROUND ELEVATION 44 ft ELEVATION DATUM NAVD 88	TOTAL DEPTH OF BORING 8.0 ft
DRILLING CONTRACTOR AECOM	DRILLER'S NAME Nelson Madieras HELPER'S NAME	TOTAL DEPTH OF FILL 3 ft
DRILLING METHOD Test Pit	DRILL RIG MAKE AND MODEL Deere 310K	CONSULTANT COMPANY AECOM
DRILL BIT SIZE AND TYPE (HOLE DIAMETER) 3-foot wide bucket	DRILLING ROD TYPE AND DIAMETER N/A	FIELD LOGGER K. Atyam
☒ VERTICAL ☐ INCLINED	CASING TYPE, DIAMETER, INSTALLATION DEPTH N/A	FIELD LOG REVIEWER K. Chowdhury
SAMPLER TYPE(S) Bag	HAMMER TYPE, MAKE/MODEL, WEIGHT/DROP N/A	HAMMER EFFICIENCY N/A%
BOREHOLE BACKFILL OR COMPLETION Compacted Native Soil	GROUNDWATER READING: DURING DRILLING Not encountered during excavation	AFTER DRILLING (DATE-TIME) N/A

Elevation, feet	Depth, feet	Material Graphics	CLASSIFICATION OF MATERIALS (Description)	Sample Location	Sample Number	Recovery, %	Blows per 6 in. [Blows per ft]	N_{60}(ASTM)	PP or TV, tsf	LABORATORY DATA Water Content, %	Liquid Limit	Plasticity Index	Fines, % < #200	Other Lab Tests	REMARKS
FILL	0	▨	LEAN CLAY (CL); medium brown; dry; 86% low plasticity fines; 14% fine sand; some organics.		S01					13	46	23	86		S01_00_01 E
	1	▨	LEAN CLAY with Sand (CL); dark brown; moist; 85% low to medium plasticity fines; 15% fine sand.		S02										S02_01_02 M
	2	▨	LEAN CLAY (CL); dark brown; moist; 90% medium plasticity fines; 10% fine sand.		S03										S03_02_03 M
	3	▨	FAT CLAY (CH); dark brown; moist; 94% high plasticity fines; 6% fine sand; trace organics.		S04					21	57	33	94		S04_03_04 M
40	4	▨	Some reddish mottling.		S05										S05_04_05 M
	5	▨	LEAN CLAY (CL); dark brown; moist; 90% low plasticity fines; 10% fine sand.		S06										S06_05_06 M
	6	▥	SILT (ML); mottled medium brown and grayish brown; moist; 90% low plasticity fines; 10% fine sand; trace organics.		S07										S07_06_07 E
	7	▨	LEAN CLAY (CL); mottled medium brown and grayish brown; moist; 95% low plasticity fines; 5% fine sand.		S08										S08_07_08 E
	8														
35	9														
	10														
	11														
	12														
	13														
30	14														
	15														

Bottom of hole 8 feet (target depth).
Groundwater not observed.

-Field classification of percent fines and percent sand are estimates. See legend for ASTM procedures used for field and lab classification.
-Sample IDs and corresponding depth ranges are noted in the Remarks column.
-(E or M or H) in Remarks column. Represents Easy/Medium/Hard digging.
E - half to full bucket of soil in one pass
M - scraping to half bucket of soil in mulitple passes
H - multiple passes to excavate soil

Final Report Version 10/21/2015

AECOM

Borehole Location: City of Woodland
County: Yolo
Coordinates: Latitude: 38.69900 Longitude: -121.74546
Coordinate System: Survey Method: Estimated From Map

LOG OF TEST PIT
WLCCB_01TP

Sheet 1 of 1

Lower Cache Creek Feasibility Study

DATE STARTED 10/15/15 DATE COMPLETED 10/15/15	GROUND ELEVATION 40 ft ELEVATION DATUM NAVD 88	TOTAL DEPTH OF BORING 8.0 ft
DRILLING CONTRACTOR AECOM	DRILLER'S NAME Nelson Madieras HELPER'S NAME	TOTAL DEPTH OF FILL 1 ft
DRILLING METHOD Test Pit	DRILL RIG MAKE AND MODEL Deere 310K	CONSULTANT COMPANY AECOM
DRILL BIT SIZE AND TYPE (HOLE DIAMETER) 3-foot wide bucket	DRILLING ROD TYPE AND DIAMETER N/A	FIELD LOGGER K. Atyam
☒ VERTICAL ☐ INCLINED	CASING TYPE, DIAMETER, INSTALLATION DEPTH N/A	FIELD LOG REVIEWER K. Chowdhury
SAMPLER TYPE(S) Bag	HAMMER TYPE, MAKE/MODEL, WEIGHT/DROP N/A	HAMMER EFFICIENCY N/A%
BOREHOLE BACKFILL OR COMPLETION Compacted Native Soil	GROUNDWATER READING: DURING DRILLING Not encountered during excavation	AFTER DRILLING (DATE-TIME) N/A

Elevation, feet	Depth, feet	Material Graphics	CLASSIFICATION OF MATERIALS (Description)	Sample Location	Sample Number	Recovery, %	Blows per 6 in. [Blows per ft]	N_{60}(ASTM)	PP or TV, tsf	LABORATORY DATA Water Content, %	Liquid Limit	Plasticity Index	Fines, % < #200	Other Lab Tests	REMARKS
40 FILL	0	▨	LEAN CLAY with Sand (CL); medium brown; dry; 80% low plasticity fines; 20% fine sand; some organics.		S01										S01_00_01 E
	1	▨	FAT CLAY with Sand (CH); dark brown; moist; 84% high plasticity fines; 16% fine sand; trace organics.		S02					20	61	38	84		S02_01_02 M
	2	▨	With some reddish brown mottling.		S03										S03_02_03 M
	3	▨	SANDY LEAN CLAY (CL); mottled grayish brown; moist; 67% medium plasticity fines; 33% fine sand; some organics.		S04					16	42	22	67		S04_03_04 H
	4	▨			S05										S05_04_05 H
35	5	▨	LEAN CLAY with Sand (CL); mottled grayish brown; moist; 83% medium plasticity fines; 17% fine sand; with iron oxide staining.		S06					19	44	22	83		S06_05_06 M
	6	▨	LEAN CLAY (CL); dark brown; moist; 95% medium plasticity fines; 5% fine sand; iron oxide staining and trace organics.		S07										S07_06_07 M
	7	▨	Low to medium plasticity fines.		S08										S08_07_08 M
	8														
	9														
30	10														
	11														
	12														
	13														
	14														
25	15														

Bottom of hole 8 feet (target depth).
Groundwater not observed.

-Field classification of percent fines and percent sand are estimates. See legend for ASTM procedures used for field and lab classification.
-Sample IDs and corresponding depth ranges are noted in the Remarks column.
-(E or M or H) in Remarks column. Represents Easy/Medium/Hard digging.
E - half to full bucket of soil in one pass
M - scraping to half bucket of soil in mulitple passes
H - multiple passes to excavate soil

Final Report Version 10/21/2015

AECOM

Borehole Location: City of Woodland
County: Yolo
Coordinates: Latitude: 38.69891 Longitude: -121.74192
Coordinate System: Survey Method: Estimated From Map

LOG OF TEST PIT
WLCCB_02TP

Sheet 1 of 1

Lower Cache Creek Feasibility Study

AECOM BORING LOG; WOODLAND BORROW TP LOGS.GPJ; URS SAC GINT LIBRARY 04202015.GLB; 10/30/15

DATE STARTED 10/15/15 **DATE COMPLETED** 10/15/15	**GROUND ELEVATION** 37 ft **ELEVATION DATUM** NAVD 88	**TOTAL DEPTH OF BORING** 8.0 ft
DRILLING CONTRACTOR AECOM	**DRILLER'S NAME** Nelson Madieras **HELPER'S NAME**	**TOTAL DEPTH OF FILL** 4 ft
DRILLING METHOD Test Pit	**DRILL RIG MAKE AND MODEL** Deere 310K	**CONSULTANT COMPANY** AECOM
DRILL BIT SIZE AND TYPE (HOLE DIAMETER) 3-foot wide bucket	**DRILLING ROD TYPE AND DIAMETER** N/A	**FIELD LOGGER** K. Atyam
☒ VERTICAL ☐ INCLINED	**CASING TYPE, DIAMETER, INSTALLATION DEPTH** N/A	**FIELD LOG REVIEWER** K. Chowdhury
SAMPLER TYPE(S) Bag and Bucket	**HAMMER TYPE, MAKE/MODEL, WEIGHT/DROP** N/A	**HAMMER EFFICIENCY** N/A%
BOREHOLE BACKFILL OR COMPLETION Compacted Native Soil	**GROUNDWATER READING: DURING DRILLING** Not encountered during excavation	**AFTER DRILLING (DATE-TIME)** N/A

Elevation, feet	Depth, feet	Material Graphics	CLASSIFICATION OF MATERIALS (Description)	Sample Location	Sample Number	Recovery, %	Blows per 6 in. [Blows per ft]	N_{60}(ASTM)	PP or TV, tsf	LABORATORY DATA					REMARKS
										Water Content, %	Liquid Limit	Plasticity Index	Fines, % < #200	Other Lab Tests	
	0	▨	LEAN CLAY with Sand (CL); medium brown; dry; 83% low plasticity fines; 17% fine sand; some organics.		S01					7	38	16	83		S01_00_01 E
	1	▨	LEAN CLAY (CL); mottled dark brown; moist; 94% medium plasticity fines; 6% fine sand; trace organics, some iron oxide stains.		S02										S02_01_02 M
35	2	▨			S03					18	46	24	94		S03_02_03 H
FILL	3	▨	No iron oxide stains, no organics.		S04										S04_03_04 H
	4	▨	FAT CLAY (CH); dark brown; moist; 94% high plasticity fines; 6% fine sand.		S05					29	64	40	94		S05_04_05 E
	5	▨			S06										S06_05_06 E
	6	▨	Mottled grayish brown and reddish brown; trace iron oxide stains.		S07										S07_06_07 E
30	7	▨	LEAN CLAY (CL); mottled dark brown; moist; 90% medium plasticity fines; 10% fine sand; iron oxide stains throughout.		S08										S08_07_08 E
	8														
	9														
	10														
	11														
25	12														
	13														
	14														
	15														

Bottom of hole 8 feet (target depth).
Groundwater not observed.

-One 5-gallon bucket sample collected (consists of soils from 0-5 feet)
-Field classification of percent fines and percent sand are estimates. See legend for ASTM procedures used for field and lab classification.
-Sample IDs and corresponding depth ranges are noted in the Remarks column.
-(E or M or H) in Remarks column. Represents Easy/Medium/Hard digging.
E - half to full bucket of soil in one pass
M - scraping to half bucket of soil in mulitple passes
H - multiple passes to excavate soil

Final Report Version 10/21/2015

AECOM

Borehole Location: City of Woodland
County: Yolo
Coordinates: Latitude: 38.69887 **Longitude:** -121.73231
Coordinate System: ____________ **Survey Method:** Estimated From Map

LOG OF TEST PIT
WLCCB_03TP

Sheet 1 of 1

Lower Cache Creek Feasibility Study

DATE STARTED 10/15/15 **DATE COMPLETED** 10/15/15	**GROUND ELEVATION** 34 ft **ELEVATION DATUM** NAVD 88	**TOTAL DEPTH OF BORING** 8.0 ft
DRILLING CONTRACTOR AECOM	**DRILLER'S NAME** Nelson Madieras **HELPER'S NAME**	**TOTAL DEPTH OF FILL** 1 ft
DRILLING METHOD Test Pit	**DRILL RIG MAKE AND MODEL** Deere 310K	**CONSULTANT COMPANY** AECOM
DRILL BIT SIZE AND TYPE (HOLE DIAMETER) 3-foot wide bucket	**DRILLING ROD TYPE AND DIAMETER** N/A	**FIELD LOGGER** K. Atyam
☒ VERTICAL ☐ INCLINED	**CASING TYPE, DIAMETER, INSTALLATION DEPTH** N/A	**FIELD LOG REVIEWER** K. Chowdhury
SAMPLER TYPE(S) Bag	**HAMMER TYPE, MAKE/MODEL, WEIGHT/DROP** N/A	**HAMMER EFFICIENCY** N/A%
BOREHOLE BACKFILL OR COMPLETION Compacted Native Soil	**GROUNDWATER READING: DURING DRILLING** Not encountered during excavation	**AFTER DRILLING (DATE-TIME)** N/A

Elevation, feet	Depth, feet	Material Graphics	CLASSIFICATION OF MATERIALS (Description)	Sample Location	Sample Number	Recovery, %	Blows per 6 in. [Blows per ft]	N_{60}(ASTM)	PP or TV, tsf	LABORATORY DATA					REMARKS
										Water Content, %	Liquid Limit	Plasticity Index	Fines, % < #200	Other Lab Tests	
FILL	0		SANDY LEAN CLAY (CL); medium brown; moist; 70% low plasticity fines; 30% fine sand; some organics.		S01										S01_00_01 E
	1		FAT CLAY (CH); grayish brown; moist; 97% high plasticity fines; 3% fine sand; trace organics.		S02										S02_01_02 E
	2		Mottled with light grayish brown, some iron oxide stains.		S03					33	50	25	97		S03_02_03 E
	3		FAT CLAY with Sand (CH); dark brown; moist; 73% high plasticity fines; 27% fine sand.		S04										S04_03_04 E
30	4				S05					24	51	33	73		S05_04_05 E
	5		LEAN CLAY with Sand (CL); yellowish brown; moist; 75% low plasticity fines; 25% fine sand; some iron oxide stains.		S06										S06_05_06 E
	6		Mottled grayish brown and reddish brown.		S07										S07_06_07 E
	7				S08										S08_07_08 E
	8														
25	9														
	10														
	11														
	12														
	13														
20	14														
	15														

Bottom of hole 8 feet (target depth).
Groundwater not observed.

- -Top 3 to 4 inches below ground surface contained abundant organics (alf-alfa roots)
- -Field classification of percent fines and percent sand are estimates. See legend for ASTM procedures used for field and lab classification.
- -Sample IDs and corresponding depth ranges are noted in the Remarks column.
- -(E or M or H) in Remarks column. Represents Easy/Medium/Hard digging.
  - E - half to full bucket of soil in one pass
  - M - scraping to half bucket of soil in mulitple passes
  - H - multiple passes to excavate soil

Final Report Version 10/21/2015

AECOM

Borehole Location: City of Woodland
County: Yolo
Coordinates: Latitude: 38.69869 Longitude: -121.72610
Coordinate System: Survey Method: Estimated From Map

LOG OF TEST PIT
WLCCB_04TP

Sheet 1 of 1

Lower Cache Creek Feasibility Study

DATE STARTED 10/15/15 DATE COMPLETED 10/15/15	GROUND ELEVATION 34 ft ELEVATION DATUM NAVD 88	TOTAL DEPTH OF BORING 8.0 ft
DRILLING CONTRACTOR AECOM	DRILLER'S NAME Nelson Madieras HELPER'S NAME	TOTAL DEPTH OF FILL 3 ft
DRILLING METHOD Test Pit	DRILL RIG MAKE AND MODEL Deere 310K	CONSULTANT COMPANY AECOM
DRILL BIT SIZE AND TYPE (HOLE DIAMETER) 3-foot wide bucket	DRILLING ROD TYPE AND DIAMETER N/A	FIELD LOGGER K. Atyam
☒ VERTICAL ☐ INCLINED	CASING TYPE, DIAMETER, INSTALLATION DEPTH N/A	FIELD LOG REVIEWER K. Chowdhury
SAMPLER TYPE(S) Bag	HAMMER TYPE, MAKE/MODEL, WEIGHT/DROP N/A	HAMMER EFFICIENCY N/A%
BOREHOLE BACKFILL OR COMPLETION Compacted Native Soil	GROUNDWATER READING: DURING DRILLING Not encountered during excavation	AFTER DRILLING (DATE-TIME) N/A

Elevation, feet	Depth, feet	Material Graphics	CLASSIFICATION OF MATERIALS (Description)	Sample Location	Sample Number	Recovery, %	Blows per 6 in. [Blows per ft]	N_{60}(ASTM)	PP or TV, tsf	LABORATORY DATA					REMARKS
										Water Content, %	Liquid Limit	Plasticity Index	Fines, % < #200	Other Lab Tests	
	0		LEAN CLAY with Sand (CL); medium brown; moist; 75% low plasticity fines; 25% fine sand; some organics.		S01										S01_00_01 E
	1		Poorly Graded SAND with Silt (SP-SM); medium brown; moist; 94% no plasticity fines; 6% fine to medium sand.		S02					8	NP	NP	6	PA	S02_01_02 E
FILL	2		LEAN CLAY with Sand (CL); mottled medium brown and reddish brown; moist; 85% medium plasticity fines; 15% fine sand; trace organics.		S03										S03_02_03 E
	3		FAT CLAY (CH); dark brown; moist; 93% high plasticity fines; 7% fine sand.		S04										S04_03_04 E
30	4				S05					29	67	44	93		S05_04_05 E
	5		LEAN CLAY (CL); yellowish brown; moist; 90% medium plasticity fines; 10% fine sand.		S06										S06_05_06 E
	6		Mottled yellowish brown and grayish brown.		S07										S07_06_07 E
	7				S08										S08_07_08 E
	8														
25	9														
	10														
	11														
	12														
	13														
20	14														
	15														

Bottom of hole 8 feet (target depth).
Groundwater not observed.

-Top 3 to 4 inches below ground surface contained abundant organics (alf-alfa roots)
-Field classification of percent fines and percent sand are estimates. See legend for ASTM procedures used for field and lab classification.
-Sample IDs and corresponding depth ranges are noted in the Remarks column.
-(E or M or H) in Remarks column. Represents Easy/Medium/Hard digging.
  E - half to full bucket of soil in one pass
  M - scraping to half bucket of soil in mulitple passes
  H - multiple passes to excavate soil

Final Report Version 10/21/2015

AECOM

Borehole Location: City of Woodland
County: Yolo
Coordinates: Latitude: 38.69869 Longitude: -121.72593
Coordinate System: Survey Method: Estimated From Map

LOG OF TEST PIT
WLCCB_05TP

Sheet 1 of 1

Lower Cache Creek Feasibility Study

DATE STARTED 10/15/15	**DATE COMPLETED** 10/15/15	**GROUND ELEVATION** 42 ft **ELEVATION DATUM** NAVD 88	**TOTAL DEPTH OF BORING** 8.0 ft
DRILLING CONTRACTOR AECOM		**DRILLER'S NAME** Nelson Madieras **HELPER'S NAME**	**TOTAL DEPTH OF FILL** 1 ft
DRILLING METHOD Test Pit		**DRILL RIG MAKE AND MODEL** Deere 310K	**CONSULTANT COMPANY** AECOM
DRILL BIT SIZE AND TYPE (HOLE DIAMETER) 3-foot wide bucket		**DRILLING ROD TYPE AND DIAMETER** N/A	**FIELD LOGGER** K. Atyam
☒ VERTICAL ☐ INCLINED		**CASING TYPE, DIAMETER, INSTALLATION DEPTH** N/A	**FIELD LOG REVIEWER** K. Chowdhury
SAMPLER TYPE(S) Bag		**HAMMER TYPE, MAKE/MODEL, WEIGHT/DROP** N/A	**HAMMER EFFICIENCY** N/A%
BOREHOLE BACKFILL OR COMPLETION Compacted Native Soil		**GROUNDWATER READING: DURING DRILLING** Not encountered during excavation	**AFTER DRILLING (DATE-TIME)** N/A

Elevation, feet	Depth, feet	Material Graphics	CLASSIFICATION OF MATERIALS (Description)	Sample Location	Sample Number	Recovery, %	Blows per 6 in. [Blows per ft]	N_{60}(ASTM)	PP or TV, tsf	LABORATORY DATA Water Content, %	Liquid Limit	Plasticity Index	Fines, % < #200	Other Lab Tests	REMARKS
FILL	0	▨	LEAN CLAY with Sand (CL); light brown; dry; 75% low plasticity fines; 25% fine sand; some organics.		S01										S01_00_01 E
	1	▨	FAT CLAY (CH); dark brown; moist; 97% high plasticity fines; 3% fine sand.		S02										S02_01_02 E
40	2	▨	Trace organics.		S03					22	54	32	97		S03_02_03 M
	3	▨	With reddish brown mottling.		S04										S04_03_04 M
	4	▨			S05										S05_04_05 M
	5	▨	LEAN CLAY (CL); mottled light gray and light brown; moist; 90% medium plasticity fines; 10% fine sand.		S06					21	49	25	91		S06_05_06 M
	6	▨	SANDY LEAN CLAY (CL); light brown and gray; moist; 60% low plasticity fines; 40% fine sand; interbedded layers.		S07					15	28	8	60	PA	S07_06_07 E
35	7	▨	Some iron oxide stains.		S08										S08_07_08 E
	8														
	9														
	10														
	11														
30	12														
	13														
	14														
	15														

Bottom of hole 8 feet (target depth).
Groundwater not observed.

-Field classification of percent fines and percent sand are estimates. See legend for ASTM procedures used for field and lab classification.
-Sample IDs and corresponding depth ranges are noted in the Remarks column.
-(E or M or H) in Remarks column. Represents Easy/Medium/Hard digging.
  E - half to full bucket of soil in one pass
  M - scraping to half bucket of soil in mulitple passes
  H - multiple passes to excavate soil

Final Report Version 10/21/2015

AECOM

Borehole Location: City of Woodland
County: Yolo
Coordinates: Latitude: 38.69897 **Longitude:** -121.74561
Coordinate System: **Survey Method:** Estimated From Map

LOG OF TEST PIT
WLCCB_06TP

Sheet 1 of 1

Lower Cache Creek Feasibility Study

DATE STARTED 5/4/16 DATE COMPLETED 5/4/16	GROUND ELEVATION 15 ft ELEVATION DATUM NAVD 88	TOTAL DEPTH OF BORING 10.0 ft
DRILLING CONTRACTOR AECOM	DRILLER'S NAME Nelson Madieras HELPER'S NAME	TOTAL DEPTH OF FILL 2 ft
DRILLING METHOD Test Pit	DRILL RIG MAKE AND MODEL Case 580N	CONSULTANT COMPANY AECOM
DRILL BIT SIZE AND TYPE (HOLE DIAMETER) 3-foot wide bucket	DRILLING ROD TYPE AND DIAMETER N/A	FIELD LOGGER M. Maghsoudlou
☒ VERTICAL ☐ INCLINED	CASING TYPE, DIAMETER, INSTALLATION DEPTH N/A	FIELD LOG REVIEWER GT Hong
SAMPLER TYPE(S) Bag	HAMMER TYPE, MAKE/MODEL, WEIGHT/DROP N/A	HAMMER EFFICIENCY N/A%
BOREHOLE BACKFILL OR COMPLETION Compacted Native Soil	GROUNDWATER READING: DURING DRILLING 9.5 ft	AFTER DRILLING (DATE-TIME)

Elevation, feet	Depth, feet	Material Graphics	CLASSIFICATION OF MATERIALS (Description)	Sample Location	Sample Number	Recovery, %	Blows per 6 in. [Blows per ft]	N_{60}(ASTM)	PP or TV, tsf	LABORATORY DATA Water Content, %	Liquid Limit	Plasticity Index	Fines, % < #200	Other Lab Tests	REMARKS
15	0	▨	Fat CLAY with Sand (CL); dark yellowish brown; moist; 85% high plasticity, no dilatancy fines; 15% fine sand; rootlets, some road gravel on surface.		S01										S01_0.0_1.0B M
FILL	1	▨			S02					17	53	28	82	HD PA	S02_1.0_2.0B M
	2	▨	LEAN CLAY (CL); dark yellowish brown; moist; 90% medium plasticity, no dilatancy fines; 10% fine sand; iron oxide staining.		S03										S03_2.0_3.0B M
	3	▨			S04										S04_3.0_4.0B M
	4	▨			S05										S05_4.0_5.0B M
10	5	▨			S06					23	49	31	86		S06_5.0_6.0B M
	6	▨			S07										S07_6.0_7.0B M
	7	▨			S08										S08_7.0_8.0B E
	8	▨	LEAN CLAY with Sand (CL); reddish brown; moist; 75% medium plasticity, no dilatancy fines; 25% fine sand.		S09					21	22	8	76	HD PA	S09_8.0_9.0B E
∇	9	▨			S10										S10_9.0_10.0B E
5	10														
	11														
	12														
	13														
	14														
0	15														

Total Depth 10 feet

- -Top 3 to 4 inches below ground surface may contain organics
- -Field classification of percent fines and percent sand are estimates. See legend for ASTM procedures used for field and lab classification.
- -Sample IDs and corresponding depth ranges are noted in the Remarks column.
- -(E or M or H) in Remarks column. Represents Easy/Medium/Hard digging.
  - E - half to full bucket of soil in one pass
  - M - scraping to half bucket of soil in mulitple passes
  - H - multiple passes to excavate soil

Draft 3 After All Lab Data Added 5/23/2016

AECOM

Borehole Location: City of Woodland
County: Yolo
Coordinates: Latitude: 38.69127 Longitude: -121.71905
Coordinate System: Survey Method: Estimated From Map

LOG OF BORING
WLCCB_07TP

Sheet 1 of 1

Lower Cache Creek Feasibility Study

DATE STARTED 5/4/16 / DATE COMPLETED 5/4/16	GROUND ELEVATION 15 ft / ELEVATION DATUM NAVD 88	TOTAL DEPTH OF BORING 6.0 ft
DRILLING CONTRACTOR AECOM	DRILLER'S NAME Nelson Madieras / HELPER'S NAME	TOTAL DEPTH OF FILL 2 ft
DRILLING METHOD Test Pit	DRILL RIG MAKE AND MODEL Case 580N	CONSULTANT COMPANY AECOM
DRILL BIT SIZE AND TYPE (HOLE DIAMETER) 3-foot wide bucket	DRILLING ROD TYPE AND DIAMETER N/A	FIELD LOGGER M. Maghsoudlou
☒ VERTICAL ☐ INCLINED	CASING TYPE, DIAMETER, INSTALLATION DEPTH N/A	FIELD LOG REVIEWER GT Hong
SAMPLER TYPE(S) Bag	HAMMER TYPE, MAKE/MODEL, WEIGHT/DROP N/A	HAMMER EFFICIENCY N/A%
BOREHOLE BACKFILL OR COMPLETION Compacted Native Soil	GROUNDWATER READING: DURING DRILLING 5.5 ft	AFTER DRILLING (DATE-TIME)

Elevation, feet	Depth, feet	Material Graphics	CLASSIFICATION OF MATERIALS (Description)	Sample Location	Sample Number	Recovery, %	Blows per 6 in. [Blows per ft]	N_{60}(ASTM)	PP or TV, tsf	LABORATORY DATA Water Content, %	Liquid Limit	Plasticity Index	Fines, % < #200	Other Lab Tests	REMARKS
15	0		LEAN CLAY (CL); dark yellowish brown; moist; 90%medium to high plasticity, no dilatancy fines; 10% fine sand; top soil; rootlets.		S01										S01_0.0_1.0B E
FILL	1				S02					15	48	30	91	HD PA	S02_1.0_2.0B M
	2		FAT CLAY (CH); black; moist; 90% high plasticity, no dilatancy fines; 10% fine sand; rootlets.		S03										S03_2.0_3.0B M
	3		LEAN CLAY with Sand (CL); dark grayish brown; moist; 75% medium plasticity, no to slow dilatancy fines; 25% fine sand.		S04										S04_3.0_4.0B E
	4				S05					25	33	14	77		S05_4.0_5.0B E
10 ▽	5				S06										S06_5.0_6.0B E
	6														

Total Depth 6 feet

-Top 3 to 4 inches below ground surface may contain organics
-Field classification of percent fines and percent sand are estimates. See legend for ASTM procedures used for field and lab classification.
-Sample IDs and corresponding depth ranges are noted in the Remarks column.
-(E or M or H) in Remarks column. Represents Easy/Medium/Hard digging.
E - half to full bucket of soil in one pass
M - scraping to half bucket of soil in mulitple passes
H - multiple passes to excavate soil

Elevation, feet	Depth, feet
	7
	8
	9
5	10
	11
	12
	13
	14
0	15

Draft 3 After All Lab Data Added 5/23/2016

AECOM

Borehole Location: City of Woodland
County: Yolo
Coordinates: Latitude: 38.68675 Longitude: -121.71614
Coordinate System: Survey Method: Estimated From Map

LOG OF BORING
WLCCB_08TP

Sheet 1 of 1

Lower Cache Creek Feasibility Study

DATE STARTED 5/4/16 / DATE COMPLETED 5/4/16	GROUND ELEVATION 15 ft / ELEVATION DATUM NAVD 88	TOTAL DEPTH OF BORING 10.0 ft
DRILLING CONTRACTOR AECOM	DRILLER'S NAME Nelson Madieras / HELPER'S NAME	TOTAL DEPTH OF FILL 2 ft
DRILLING METHOD Test Pit	DRILL RIG MAKE AND MODEL Case 580N	CONSULTANT COMPANY AECOM
DRILL BIT SIZE AND TYPE (HOLE DIAMETER) 3-foot wide bucket	DRILLING ROD TYPE AND DIAMETER N/A	FIELD LOGGER M. Maghsoudlou
☒ VERTICAL ☐ INCLINED	CASING TYPE, DIAMETER, INSTALLATION DEPTH N/A	FIELD LOG REVIEWER GT Hong
SAMPLER TYPE(S) Bag	HAMMER TYPE, MAKE/MODEL, WEIGHT/DROP N/A	HAMMER EFFICIENCY N/A%
BOREHOLE BACKFILL OR COMPLETION Compacted Native Soil	GROUNDWATER READING: DURING DRILLING Not encountered	AFTER DRILLING (DATE-TIME)

Elevation, feet	Depth, feet	Material Graphics	CLASSIFICATION OF MATERIALS (Description)	Sample Location	Sample Number	Recovery, %	Blows per 6 in. [Blows per ft]	N_{60}(ASTM)	PP or TV, tsf	LABORATORY DATA Water Content, %	Liquid Limit	Plasticity Index	Fines, % < #200	Other Lab Tests	REMARKS
15	0	▨	LEAN CLAY (CL); yellowish brown; moist; 90% medium plasticity, no dilatancy fines; 10% fine sand; rootlets; blocky texture.		S01										S01_0.0_1.0B E
FILL	1	▨			S02										S02_1.0_2.0B M
	2	▨	FAT CLAY (CH); dark yellowish brown; moist; 98% high plasticity, no dilatancy fines; 2% fine sand; iron oxide staining.		S03					20	54	31	98		S03_2.0_3.0B M
	3	▨			S04										S04_3.0_4.0B M
	4	▨	LEAN CLAY (CL); yellowish brown; moist; 87% medium plasticity, no dilatancy fines; 13% fine sand; slightly indurated.		S05										S05_4.0_5.0B M
10	5	▨			S06					20	40	21	87	HD PA	S06_5.0_6.0B M
	6	▨			S07										S07_6.0_7.0B M
	7	▨			S08										S08_7.0_8.0B M
	8	▨			S09					21	49	29	90		S09_8.0_9.0B M
	9	▨			S10										S10_9.0_10.0B M
5	10														
	11														
	12														
	13														
	14														
0	15														

Total Depth 10 feet

-Top 3 to 4 inches below ground surface may contain organics
-Field classification of percent fines and percent sand are estimates. See legend for ASTM procedures used for field and lab classification.
-Sample IDs and corresponding depth ranges are noted in the Remarks column.
-(E or M or H) in Remarks column. Represents Easy/Medium/Hard digging.
  E - half to full bucket of soil in one pass
  M - scraping to half bucket of soil in mulitple passes
  H - multiple passes to excavate soil

Draft 3 After All Lab Data Added 5/23/2016

AECOM

Borehole Location: City of Woodland
County: Yolo
Coordinates: Latitude: 38.67989 Longitude: -121.71183
Coordinate System: Survey Method: Estimated From Map

LOG OF BORING
WLCCB_09TP

Sheet 1 of 1

Lower Cache Creek Feasibility Study

DATE STARTED 5/4/16	DATE COMPLETED 5/4/16	GROUND ELEVATION 10 ft	ELEVATION DATUM NAVD 88	TOTAL DEPTH OF BORING 7.0 ft
DRILLING CONTRACTOR AECOM		DRILLER'S NAME Nelson Madieras	HELPER'S NAME	TOTAL DEPTH OF FILL 2 ft
DRILLING METHOD Test Pit		DRILL RIG MAKE AND MODEL Case 580N		CONSULTANT COMPANY AECOM
DRILL BIT SIZE AND TYPE (HOLE DIAMETER) 3-foot wide bucket		DRILLING ROD TYPE AND DIAMETER N/A		FIELD LOGGER M. Maghsoudlou
☒ VERTICAL	☐ INCLINED	CASING TYPE, DIAMETER, INSTALLATION DEPTH N/A		FIELD LOG REVIEWER GT Hong
SAMPLER TYPE(S) Bag		HAMMER TYPE, MAKE/MODEL, WEIGHT/DROP N/A		HAMMER EFFICIENCY N/A%
BOREHOLE BACKFILL OR COMPLETION Compacted Native Soil		GROUNDWATER READING:	DURING DRILLING 7 ft	AFTER DRILLING (DATE-TIME)

Elevation, feet	Depth, feet	Material Graphics	CLASSIFICATION OF MATERIALS (Description)	Sample Location	Sample Number	Recovery, %	Blows per 6 in. [Blows per ft]	N$_{60}$(ASTM)	PP or TV, tsf	LABORATORY DATA Water Content, %	Liquid Limit	Plasticity Index	Fines, % < #200	Other Lab Tests	REMARKS
10	0	▨	LEAN CLAY (CL); black; moist; 90% medium plasticity, no dilatancy fines; 10% fine sand; rootlets; top soil.		S01										S01_0.0_1.0B E
FILL	1	▨			S02										S02_1.0_2.0B E
	2	▨	FAT CLAY (CH); dark grayish brown; moist; 86% high plasticity, no dilatancy fines; 14% fine sand.		S03										S03_2.0_3.0B E
	3	▨			S04					24	51	30	85		S04_3.0_4.0B E
	4	▨			S05										S05_4.0_5.0B E
5	5	▨	LEAN CLAY with Sand (CL); brown; moist; 78% medium plasticity, no dilatancy fines; 22% fine sand.		S06										S06_5.0_6.0B E
	6	▨			S07					22	37	19	78		S07_6.0_7.0B E
▽	7														
	8														
	9														
0	10														
	11														
	12														
	13														
	14														
-5	15														

Total Depth 7 feet

-Top 3 to 4 inches below ground surface may contain organics
-Field classification of percent fines and percent sand are estimates. See legend for ASTM procedures used for field and lab classification.
-Sample IDs and corresponding depth ranges are noted in the Remarks column.
-(E or M or H) in Remarks column. Represents Easy/Medium/Hard digging.
E - half to full bucket of soil in one pass
M - scraping to half bucket of soil in mulitple passes
H - multiple passes to excavate soil

Draft 3 After All Lab Data Added 5/23/2016

AECOM

Borehole Location: City of Woodland
County: Yolo
Coordinates: Latitude: 38.67701 Longitude: -121.70180
Coordinate System: Survey Method: Estimated From Map

LOG OF BORING
WLCCB_10TP

Sheet 1 of 1

Lower Cache Creek Feasibility Study

DATE STARTED 5/4/16 **DATE COMPLETED** 5/4/16	**GROUND ELEVATION** 10 ft **ELEVATION DATUM** NAVD 88	**TOTAL DEPTH OF BORING** 9.0 ft
DRILLING CONTRACTOR AECOM	**DRILLER'S NAME** Nelson Madieras **HELPER'S NAME**	**TOTAL DEPTH OF FILL** 2 ft
DRILLING METHOD Test Pit	**DRILL RIG MAKE AND MODEL** Case 580N	**CONSULTANT COMPANY** AECOM
DRILL BIT SIZE AND TYPE (HOLE DIAMETER) 3-foot wide bucket	**DRILLING ROD TYPE AND DIAMETER** N/A	**FIELD LOGGER** M. Maghsoudlou
☒ VERTICAL ☐ INCLINED	**CASING TYPE, DIAMETER, INSTALLATION DEPTH** N/A	**FIELD LOG REVIEWER** GT Hong
SAMPLER TYPE(S) Bag	**HAMMER TYPE, MAKE/MODEL, WEIGHT/DROP** N/A	**HAMMER EFFICIENCY** N/A%
BOREHOLE BACKFILL OR COMPLETION Compacted Native Soil	**GROUNDWATER READING:** **DURING DRILLING** 8.5 ft	**AFTER DRILLING (DATE-TIME)**

Elevation, feet	Depth, feet	Material Graphics	CLASSIFICATION OF MATERIALS (Description)	Sample Location	Sample Number	Recovery, %	Blows per 6 in. [Blows per ft]	N_{60}(ASTM)	PP or TV, tsf	LABORATORY DATA					REMARKS
										Water Content, %	Liquid Limit	Plasticity Index	Fines, % < #200	Other Lab Tests	
10 FILL	0	▨	LEAN CLAY (CL); yellowish brown; moist; 95% medium plasticity, slow dilatancy fines; 5% finesand; rootlets.		S01					22	40	19	96	HD PA	S01_0.0_1.0B E
	1	▨			S02										S02_1.0_2.0B E
	2	▨	LEAN CLAY (CL); dark yellowish brown; moist; 90% medium plasticity fines; 10% fine sand.		S03										S03_2.0_3.0B E
	3	▨			S04										S04_3.0_4.0B E
	4	▨	LEAN CLAY with Sand (CL); yellowish brown; moist; 80% medium plasticity fines; 20% fine sand; slightly indurated.		S05										S05_4.0_5.0B M
5	5	▨			S06					20	44	27	79		S06_5.0_6.0B M
	6	▨			S07										S07_6.0_7.0B M
	7	▨			S08										S08_7.0_8.0B M
▽	8	▨	At 8 feet, mottled and blocky.		S09										S09_8.0_9.0B M
	9		Total Depth 9 feet												
0	10														
	11														
	12														
	13														
	14														
-5	15														

Total Depth 9 feet

-Top 3 to 4 inches below ground surface may contain organics
-Field classification of percent fines and percent sand are estimates. See legend for ASTM procedures used for field and lab classification.
-Sample IDs and corresponding depth ranges are noted in the Remarks column.
-(E or M or H) in Remarks column. Represents Easy/Medium/Hard digging.
  E - half to full bucket of soil in one pass
  M - scraping to half bucket of soil in mulitple passes
  H - multiple passes to excavate soil

Draft 3 After All Lab Data Added 5/23/2016

AECOM

Borehole Location: City of Woodland
County: Yolo
Coordinates: Latitude: 38.69127 **Longitude:** -121.71905
Coordinate System: **Survey Method:** Estimated From Map

LOG OF BORING
WLCCB_11TP
Sheet 1 of 1

Lower Cache Creek Feasibility Study

DATE STARTED 5/4/16 **DATE COMPLETED** 5/4/16	**GROUND ELEVATION** 10 ft **ELEVATION DATUM** NAVD 88	**TOTAL DEPTH OF BORING** 7.0 ft
DRILLING CONTRACTOR AECOM	**DRILLER'S NAME** Nelson Madieras **HELPER'S NAME**	**TOTAL DEPTH OF FILL** 2 ft
DRILLING METHOD Test Pit	**DRILL RIG MAKE AND MODEL** Case 580N	**CONSULTANT COMPANY** AECOM
DRILL BIT SIZE AND TYPE (HOLE DIAMETER) 3-foot wide bucket	**DRILLING ROD TYPE AND DIAMETER** N/A	**FIELD LOGGER** M. Maghsoudlou
☒ VERTICAL ☐ INCLINED	**CASING TYPE, DIAMETER, INSTALLATION DEPTH** N/A	**FIELD LOG REVIEWER** GT Hong
SAMPLER TYPE(S) Bag	**HAMMER TYPE, MAKE/MODEL, WEIGHT/DROP** N/A	**HAMMER EFFICIENCY** N/A%
BOREHOLE BACKFILL OR COMPLETION Compacted Native Soil	**GROUNDWATER READING: DURING DRILLING** Not encountered	**AFTER DRILLING (DATE-TIME)**

Elevation, feet	Depth, feet	Material Graphics	CLASSIFICATION OF MATERIALS (Description)	Sample Location	Sample Number	Recovery, %	Blows per 6 in. [Blows per ft]	N_{60}(ASTM)	PP or TV, tsf	LABORATORY DATA Water Content, %	Liquid Limit	Plasticity Index	Fines, % < #200	Other Lab Tests	REMARKS
10 (FILL 0–2)	0	▨	LEAN CLAY (CL); yellowish brown; moist; 95% meium plasticity, no to slow dilatancy fines; 5% fine sand.		S01										S01_0.0_1.0B E
	1	▨			S02					29	48	27	95		S02_1.0_2.0B E
	2	▨	LEAN CLAY (CL); yellowish brown; moist; 90% medium plasticity fines; 10% fine sand.		S03										S03_2.0_3.0B E
	3	▨			S04										S04_3.0_4.0B E
	4	▨	FAT CLAY (CH); dark yellowish brown; moist; 90% high plasticity fines; 10% fine sand.		S05										S05_4.0_5.0B E
5	5	▨			S06					25	57	37	90		S06_5.0_6.0B E
	6	▨			S07										S07_6.0_7.0B E
	7														

Total Depth 7 feet

-Top 3 to 4 inches below ground surface may contain organics
-Field classification of percent fines and percent sand are estimates. See legend for ASTM procedures used for field and lab classification.
-Sample IDs and corresponding depth ranges are noted in the Remarks column.
-(E or M or H) in Remarks column. Represents Easy/Medium/Hard digging.
E - half to full bucket of soil in one pass
M - scraping to half bucket of soil in mulitple passes
H - multiple passes to excavate soil

Elevation, feet	Depth, feet
	8
	9
0	10
	11
	12
	13
	14
-5	15

Draft 3 After All Lab Data Added 5/23/2016

AECOM

Borehole Location: City of Woodland
County: Yolo
Coordinates: Latitude: 38.67688 Longitude: -121.67960
Coordinate System: Survey Method: Estimated From Map

LOG OF BORING
WLCCB_12TP

Sheet 1 of 1

Lower Cache Creek Feasibility Study

ATTACHMENT B

Fragility Curve Summary Tables:

FRAGILITY CURVE P3	
Stage Elevation (ft, 88)	P_f
78.5 (landside levee toe)	0.0000
81.5	0.1603
83.0	0.2693
84.63 (Levee crest)	0.4196

FRAGILITY CURVE P4	
Stage Elevation (ft, 88)	P_f
78.0 (landside levee toe)	0.0000
81.0	0.1603
82.5	0.2693
84.39 (Levee crest)	0.4196

FRAGILITY CURVE P5	
Stage Elevation (ft, 88)	P_f
74.2 (landside levee toe)	0.0000
78.1	0.1603
79.6	0.2693
81.1	0.4196
84.8 (Levee crest)	0.9333

FRAGILITY CURVE P6	
Stage Elevation (ft, 88)	P_f
22.0 (landside levee toe)	0.0000
26.0	0.0036
31.1	0.0151
36.1	0.1005
38.77 (Levee crest)	0.7413

FRAGILITY CURVE P7	
Stage Elevation (ft, 88)	P_f
25.2 (landside levee toe)	0.0000
28.2	0.0401
33.8	0.1550
39.3	0.4163
42.27 (Levee crest)	0.7031

FRAGILITY CURVE P8	
Stage Elevation (ft, 88)	P_f
34.2 (landside levee toe)	0.0000
41.2	0.0281
48.2	0.3851
51.68 (Levee crest)	0.6984

Notes:
FRAGILITY CURVE P1- NO LEVEE
FRAGILITY CURVE P2- NO LEVEE

Fragility Curve Summary Tables:

FRAGILITY CURVE P3	
Stage Elevation (ft, 88)	P_f
78.5 (landside levee toe)	0.0000
81.5	0.0862
83.0	0.1476
84.63 (Levee crest)	0.2634

FRAGILITY CURVE P4	
Stage Elevation (ft, 88)	P_f
78.0 (landside levee toe)	0.0000
81.0	0.0862
82.5	0.1476
83.3 (RTOL)	0.1950
84.39 (Levee crest)	0.2634

FRAGILITY CURVE P5	
Stage Elevation (ft, 88)	P_f
74.2 (landside levee toe)	0.0000
78.1	0.0862
79.6	0.1476
81.1	0.2634
83.5 (RTOL)	0.6740
84.8 (Levee crest)	0.8999

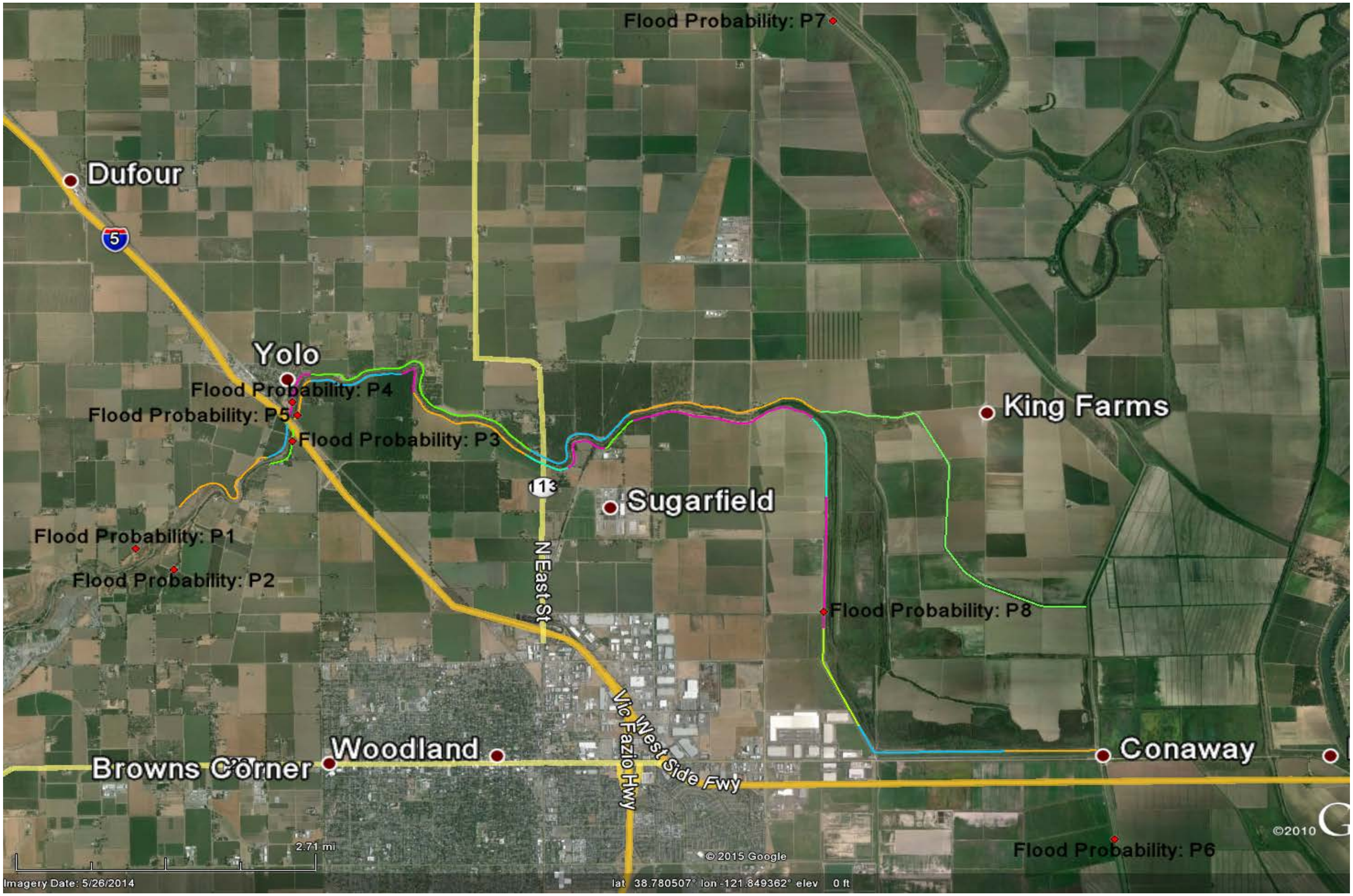
FRAGILITY CURVE P6	
Stage Elevation (ft, 88)	P_f
22.0 (landside levee toe)	0.0000
26.0	0.0036
31.1	0.0151
36.1	0.1005
38.77 (Levee crest)	0.7413

FRAGILITY CURVE P7	
Stage Elevation (ft, 88)	P_f
25.2 (landside levee toe)	0.0000
28.2	0.0401
33.8	0.1550
39.3	0.4163
42.27 (Levee crest)	0.7031

FRAGILITY CURVE P8	
Stage Elevation (ft, 88)	P_f
34.2 (landside levee toe)	0.0000
41.2	0.0281
48.2	0.3851
51.68 (Levee crest)	0.6984

Notes:
FRAGILITY CURVE P1- NO LEVEE
FRAGILITY CURVE P2- NO LEVEE

Fragility Curve Location Map:



COST ENGINEERING REPORT

APPENDIX D

LOWER CACHE CREEK DRAFT FEASIBILITY STUDY

Yolo County, CA

December 2019

United States Army Corps of Engineers
Sacramento District

Table of Contents

1 General

The cost estimates under the study have been prepared under ER 1110-2-1302 Civil Works Cost Engineering which describes levels of detail with respect to cost. The level of detail is based on ASTM E 2516-06, Standard Classification for Cost Estimate Classification System. The Parametric Cost Estimating Tool (PCET) used to parametrically define the focused and final array of alternatives is based on a Class 4 level of detail.

The quantities and project cost estimates for the final array of alternatives were prepared by Civil Design and the sponsor's engineering consultants, utilizing unit costs for typical construction items as developed by the Cost Engineering Section.

2 Focused Array

Cost estimates presented are the combination of Construction costs, Real Estate costs, Fish and Wildlife Facilities costs, Cultural Resources costs, and Planning and Design costs. Annualized Operations, Maintenance, Repair, Rehabilitation, and Replacement (OMRR&R) costs are also estimated in the economic analysis.

The cost estimates for the focused array are summarized in the following table:

	Estimated Project based on 47% Contingency ($1,000) Escalated to 4th Quarter FY 2019 Dollars												
	Strengthen In Place			Partial Setback		North Bypass			Non Structural	South Bypass			
	6A	6B	6C	7A	7B	1A	1B	1C	3A	2A	2B	2C	2D
11 & 02 - Const. and Relocation Costs	153,508	203,579	1,614,752	1,354,262	372,029	394,963	394,816	469,746	0	146,180	339,923	384,851	530,784
06 - Environmental Mitigation	44,957	66,163	121,504	104,498	5,424	92,571	92,533	96,062	0	12,048	58,407	79,974	110,527
18 - Cultural Resource Preservation	1,985	2,699	4,980	13,544	3,722	4,877	4,875	5,659	0	1,583	3,985	4,649	6,157
01 - Lands and Damages	5,680	39,414	50,563	77,970	129,651	19,944	208,568	136,292	0	45,582	35,724	36,387	42,068
30 - Plans, Engineering, Design	29,769	40,462	74,675	203,158	55,824	73,131	73,103	84,872	0	23,735	59,751	69,725	92,349
31 - Construction Management	19,847	26,974	49,784	122,211	23,138	48,754	48,736	56,581	0	15,824	39,834	46,483	61,566
TOTAL	255,748	379,291	1,916,258	1,875,643	589,786	634,239	822,630	849,214	0	244,953	537,622	622,069	843,452
	Estimated Increase in Annual OMRR&R Cost ($1,000)												
Increased OMRR&R	0	108	108	360	432	108	108	659	0	180	180	290	290

2.1 Construction Costs.

Construction costs were the sum of parametric costs and special item costs. Costs for levee improvements or new levees were developed using a parametric spreadsheet based on typical cross section dimensions and seepage control measures. A spreadsheet developed by URS Corporation was selected to prepare the parametric level cost estimates for levee improvements and new levees. The parametric spreadsheet utilizes unit costs for typical levee design parameters including, for example, stripping vegetation, earthwork, cutoff walls, etc. The cost of utility relocations was assumed to be 10% of the construction costs and is included in the construction cost line item.

Construction costs for remaining “special item” features were based on historical cost from other studies within the vicinity or assembled from RS Mean’s unit costs. Typical examples of special items included in the construction cost estimates are bridges, culverts, closure structures, bank erosion protection, and avoidance of increasing the discharge of sediments containing mercury out of the Cache Creek Settling Basin (CCSB).

2.2 Fish and Wildlife Facilities

The cost of Fish and Wildlife facilities include the estimated cost of environmental mitigation. Environmental mitigation costs were estimated as a percentage of the construction cost of each project feature except for proposed earthwork in the CCSB. The percentage was based on a qualitative assessment of the environmental impacts of each reach. The costs ranged from 0% to 35% of the construction costs depending on the reach. Mitigation cost for earthwork in the CCSB was based on estimated acres of disturbance and application of a typical $55,000 per acre mitigation cost. The typical mitigation cost was based on similar projects near the study area.

2.3 Cultural Mitigation

Cultural Mitigation was assumed to be 1% of construction cost. This cost is based on other studies within the region.

2.4 Lands and Damages

The cost of lands and damages for each alternative is described in a memorandum for file “Focused Array RE assumptions”. The estimated cost of real estate was based on applying typical costs for land, acquisition, relocation, and improvements. The cost of land was estimated based on delineation in GIS and applying a cost of $15,000/acre for agriculture zoning and $150,000/acre for industrial zoning. Acquisition costs were estimated by delineating the number of parcels in GIS and applying a cost of $85,000 per parcel. Relocation costs were estimated by delineating the number of structures that were impacted and applying $47,000/structure. Improvement costs were extracted from the County Assessor's database as last known sale price on file. These costs are typical costs for use in the level 5 cost estimates to support the evaluation of the focused array of alternatives. It is anticipated that more detailed cost estimates will be developed for the final array.

2.5 Planning, Engineering, and Design

The cost for Planning Engineering and Design costs were assumed to be 15% of construction costs. This cost is based on other studies within the region.

2.6 Construction Management.

The cost for construction management was assumed to be 10% of construction costs. This cost is based on other studies within the region.

2.7 Operations, Maintenance, Repair, Rehabilitation, and Replacement

Operations, Maintenance, Repair, Rehabilitation, and Replacement (OMRR&R) cost was estimated using estimates of historical OMRR&R costs within the region. Data were obtained from a draft report by the State of California's Long Term Operations and Maintenance, Repair, Replacement and Rehabilitation Cost Evaluation, dated February 2015. The OMRR&R costs for each alternative only include the costs for additional features and do not include existing OMRR&R costs. The costs are based on an average annual routine OMRR&R cost of $22,000 per mile for levees and $451 per mile for channels. The costs do not include non-routine costs such as emergency flood fight repairs, bank stabilization, etc. The cost estimate for OMRR&R is documented in the memorandum "O&M cost estimate for new project features".

2.8 Contingencies

Costs are provided at 25%, 50%, 75% and 80% confidence levels (Percent chance the cost would not exceed this value). The contingencies necessary to estimate costs at these confidence levels were based on cost risk analysis conducted for a class 5 cost analysis conducted during the Sutter Feasibility Study. The contingencies to obtain 25%, 50%, 75%, and 80% confidence were estimated to be 20%, 30%, 45%, and 47% respectively.

3 Final Array

This section indicates Cost Engineering results for the final array of alternatives. The final array only consists of Alternative 2A and the no action plan.

Cost estimates presented are the combination of Construction costs, Real Estate costs, Fish and Wildlife Facilities costs, Cultural Resources costs, and Planning and Design costs. Annualized Operations, Maintenance, Repair, Rehabilitation, and Replacement (OMRR&R) costs are also estimated in the economic analysis.

The cost estimate for Alternative 2A is summarized in Table 1, and the TPCS is presented in Appendix A.

Table 1. Alternative 2A Cost Estimates

ACCOUNT	DESCRIPTION	QTY	UOM	SUBTOTAL	CONT. %	CONT. $$	TOTAL COST
01	LANDS AND DAMAGES	1	LS	$14,357,720	41%	$5,270,758	$19,628,478
02	RELOCATIONS	1	LS	$29,363,269	53%	$15,505,905	$44,869,174
06	FISH AND WILDLIFE FACILITIES	1	LS	$3,280,719	36%	$1,178,577	$4,459,296
09	CHANNELS & CANALS	1	LS	$4,574,733	30%	$1,374,010	$5,948,744
11	LEVEES & FLOODWALLS	1	LS	$100,089,809	25%	$25,566,578	$125,656,387
18	CULTURAL RESOURCE PRESERVATION	1	LS	$578,000	0%	$0	$578,000

ACCOUNT	DESCRIPTION	QTY	UOM	SUBTOTAL	CONT. %	CONT. $$	TOTAL COST
30	PLANNING, ENGINEERING AND DESIGN	1	LS	$23,440,710	54%	$12,653,426	$36,094,136
31	CONSTRUCTION MANAGEMENT	1	LS	$11,858,242	30%	$3,516,725	$15,374,966
	Total LOWER CACHE CREEK			$187,543,201		$65,298,489	$252,841,691

3.1 Construction Costs

Construction costs were the sum of parametric costs and special item costs. Costs for levee improvements or new levees were developed using a parametric spreadsheet based on typical cross section dimensions and seepage control measures. The parametric spreadsheet utilizes unit costs for typical levee design parameters including, for example, stripping vegetation, earthwork, cutoff walls, etc. The cost of utility relocations was assumed to be $2.7M per mile based on the average costs used in Sac River GRR and is included in the construction cost line item.

Construction costs for remaining "special item" features were based on historical cost from other studies within the vicinity or assembled from RS Mean's unit costs. Typical examples of special items included in the construction cost estimates are bridges, culverts, closure structures, bank erosion protection, and avoidance of increasing the discharge of sediments containing mercury out of the Cache Creek Settling Basin (CCSB).

3.2 Fish and Wildlife Facilities

The cost of Fish and Wildlife facilities include the estimated cost of environmental mitigation (species and habitat) and air quality. Environmental mitigation costs were provided by Sacramento Environmental Section, and are included in the estimate, and Total Project Cost Summary (TPCS). Fish and Wildlife estimated costs are $3,280,719.20.

3.3 Cultural Mitigation

The cost of Cultural Mitigation include the estimated cost of historical properties treatment plan, data recovery/mitigation field work, laboratory analyses for data recovery fieldwork and data recovery report. Cultural mitigation costs were provided by Sacramento Environmental Section, and are included in the estimate, and Total Project Cost Summary (TPCS). Cultural Mitigation costs are estimated $578,000.

3.4 Lands and Damages

The costs for lands and damages were provided by Sacramento Real Estate division. Estimated costs are $825,000 of Federal costs and $13,532,720 Non-Federal costs. Costs are provided in Table 2, of the Real Estate Plan.

3.5 Planning, Engineering, and Design

A value of 17% of the Construction Costs are used, and are consistent with those used in recent years for feasibility studies performed by the Sacramento District.

3.6 Construction Management

A value of 8.6% of the Construction Costs are used, and are consistent with those used in recent years for feasibility studies performed by the Sacramento District.

3.7 Operations, Maintenance, Repair, Rehabilitation, and Replacement

Operations, Maintenance, Repair, Rehabilitation, and Replacement (OMRR&R) costs were taken from the focused array costs and escalated from 2015 prices to 2019 prices. The costs are based on an average annual routine OMRR&R cost of $24,508 per mile for levees and $502 per mile for channels. The costs do not include non-routine costs such as emergency flood fight repairs, bank stabilization, etc.

3.8 Contingencies

An Abbreviated Risk Analysis (ARA) using the Cost MCX Abbreviated Risk Analysis Template (spreadsheet) was performed for each of the final array of alternatives. The alternative was divided into its main component areas and risks were assessed relative to each area. The summary is provided in Table 2.

Table 2. Contingency Factors

FEATURED ACCOUNT	ELEMENT	CONTINGENCY FACTOR
02	Relocations	52.8%
06	Fish & Wildlife Facilities	35.9%
09	Channels & Canals	30.0%
11	Levees & Floodwalls	25.5%
18	Cultural Resource Preservation	0%
	Total Construction Contingency	**31.4%**
01	Lands & Damages	40.7%
30	Planning, Engineering, and Design	54.0%
31	Construction Management	29.7%

Costs are provided at 50% and 80% confidence levels (Percent chance the cost would not exceed this value). The contingencies necessary to estimate costs at these confidence levels were based on the ARA performed by members of the PDT from USACE, Wood Rogers, The City of Woodland, and MBK on August 28, 2019. The contingency to obtain 80% confidence was estimated to be 35%.

3.9 Total Project Schedule (including Construction)

A formal construction schedule has not been developed. The initial PED portion of the project is assumed to take about 2 years. The original total duration for construction completion for each alternative in the final array is provided in Table 3:

Table 3. Construction Duration Estimations

APPROXIMATE DURATION	
Alternative	**Years**
2A	2

4 Recommended Plan

This section will be filled out after the ADM Milestone.

Appendix A: Total Project Cost Summary (TPCS)

PROJECT: **Lower Cache Creek Feasibility Study**
PROJECT NO:
LOCATION: Lower Cache Creek, CA

DISTRICT: SPK **PREPARED:**
POC: CHIEF, COST ENGINEERING, xxx

This Estimate reflects the scope and schedule in report; LCCFS-Draft_Project_Description

Civil Works Work Breakdown Structure		**ESTIMATED COST**				**PROJECT FIRST COST (Constant Dollar Basis)**						**TOTAL PROJECT COST (FULLY FUNDED)**			
									Program Year (Budget EC): Effective Price Level Date:	2020 1 OCT 19					
WBS NUMBER *A*	Civil Works Feature & Sub-Feature Description *B*	COST ($K) *C*	CNTG ($K) *D*	CNTG (%) *E*	TOTAL ($K) *F*	ESC (%) *G*	COST ($K) *H*	CNTG ($K) *I*	**TOTAL ($K)** *J*	Spent Thru: **1-Oct-18** ($K)	**TOTAL FIRST COST** ($K) *K*	INFLATED (%) *L*	COST ($K) *M*	CNTG ($K) *N*	FULL ($K) *O*
02	RELOCATIONS	$29,363	$15,506	52.8%	$44,869	2.4%	$30,072	$15,880	$45,952	$0	$45,952	1.0%	$30,379	$16,042	$46,422
06	FISH & WILDLIFE FACILITIES	$3,281	$1,179	35.9%	$4,459	2.4%	$3,360	$1,207	$4,567	$0	$4,567	1.0%	$3,394	$1,219	$4,614
09	CHANNELS & CANALS	$4,575	$1,374	30.0%	$5,949	2.4%	$4,685	$1,407	$6,092	$0	$6,092	1.0%	$4,733	$1,422	$6,155
11	LEVEES & FLOODWALLS	$100,090	$25,227	25.2%	$125,317	2.4%	$102,504	$25,836	$128,340	$0	$128,340	1.0%	$103,553	$26,100	$129,654
18	CULTURAL RESOURCE PRESERVATION	$578	$0	0.0%	$578	2.4%	$592	$0	$592	$0	$592	1.0%	$598	$0	$598
08	ROADS, RAILROADS & BRIDGES	$0	$0 -		$0	-	$0	$0	$0	$0	$0	-	$0	$0	$0
09	CHANNELS & CANALS	$0	$0 -		$0	-	$0	$0	$0	$0	$0	-	$0	$0	$0
10	BREAKWATER & SEAWALLS	$0	$0 -		$0	-	$0	$0	$0	$0	$0	-	$0	$0	$0
	CONSTRUCTION ESTIMATE TOTALS:	$137,887	$43,286	31.4%	$181,173	2.4%	$141,213	$44,330	$185,543	$0	$185,543	1.0%	$142,658	$44,784	$187,442
01	LANDS AND DAMAGES	$14,358	$5,842	40.7%	$20,200	2.4%	$14,704	$5,983	$20,687	$0	$20,687	1.0%	$14,855	$6,045	$20,899
30	PLANNING, ENGINEERING & DESIGN	$23,441	$12,653	54.0%	$36,094	3.4%	$24,239	$13,085	$37,324	$0	$37,324	-1.5%	$23,867	$12,884	$36,751
31	CONSTRUCTION MANAGEMENT	$11,858	$3,517	29.7%	$15,375	3.4%	$12,262	$3,637	$15,899	$0	$15,899	0.9%	$12,378	$3,671	$16,049
	PROJECT COST TOTALS:	$187,543	$65,298	34.8%	$252,842		$192,419	$67,035	**$259,453**	$0	**$259,453**	0.7%	$193,758	$67,383	$261,141

DRAFT REAL ESTATE PLAN

APPENDIX E

LOWER CACHE CREEK DRAFT FEASIBILITY STUDY

Yolo County, CA

December 2019

United States Army Corps of Engineers
Sacramento District

TABLE OF CONTENTS

Contents

1. INTRODUCTION

This Real Estate Plan (REP) presents the real estate requirements and costs for an Interim Feasibility Report for the Lower Cache Creek Feasibility Study (LCCFS). The information contained herein is tentative in nature for planning purposes only. At the time the REP was prepared, the Project Delivery Team (PDT) had reached the Tentatively Selected Plan (TSP} milestone, and feasibility-level analysis was just beginning. The TSP selected was alternative 2a. Footprint maps which identify locations of access, staging, borrow, mitigation and other project features were not available at the time of this draft. The information contained within this REP is based on assumptions made by the PDT and estimated acreages of project features. This REP does not fully conform to the requirements of Chapter 2 (ER 405-1-12). This report is for planning purposes only and will be revised for the final plan to conform to Chapter 2.

2. PROJECT AUTHORIZATION

This study was authorized by Section 209 of the Flood Control Act of 1962, Pub. L. 87-874, § 209, 76 Stat. 1196 (1962), which states as follows for the Sacramento River Basin:

> “The Secretary of the Army is hereby authorized and directed to cause surveys for flood control and allied purposes, including channel and major drainage improvements, and floods aggravated by or due to wind or tidal effects, to be made under the direction of the Chief of Engineers, in drainage areas of the United States and its territorial possessions, which include the following named localities: Provided, That after the regular or formal reports made on any survey are submitted to Congress, no supplemental or additional report or estimate shall be made unless authorized by law except that the Secretary of the Army may cause a review of any examination or survey to be made and a report thereon submitted to Congress, if such review is required by the national defense or by changed physical or economic conditions: Provided further, That the Government shall not be deemed to have entered upon any project for the improvement of any waterway or harbor mentioned in this title until the project for the proposed work shall have adopted by law:...
>
> Sacramento River Basin and streams in northern California draining into the Pacific Ocean for the purposes of developing, where feasible, multiple-purpose water resource projects, particularly those which be eligible under the provisions of title III of Public Law 85-500…”

This study will only partially address the Sacramento River Basin authority. Therefore, the LCCFS will be called an “Interim Feasibility Report” to indicate that the study addresses the flood risk issues of a specific area within the authority, rather than the entire authorized area. This report does not rule out additional studies for this, or other areas, within the authorized study area at a future date.

Per Section 1203 of America's Water Infrastructure Act of 2018, Pub. L. 115-270, § 1203, 132 Stat 3803, the “Secretary shall expedite the completion of a feasibility study” for Lower Cache Creek, subject to the availability of funding.

3. Discussion of the Focus Array of Plans

The following is a summary of alternatives that have been evaluated in 2015.

3.1. NORTH NATURAL BYPASS ALTERNATIVE 1

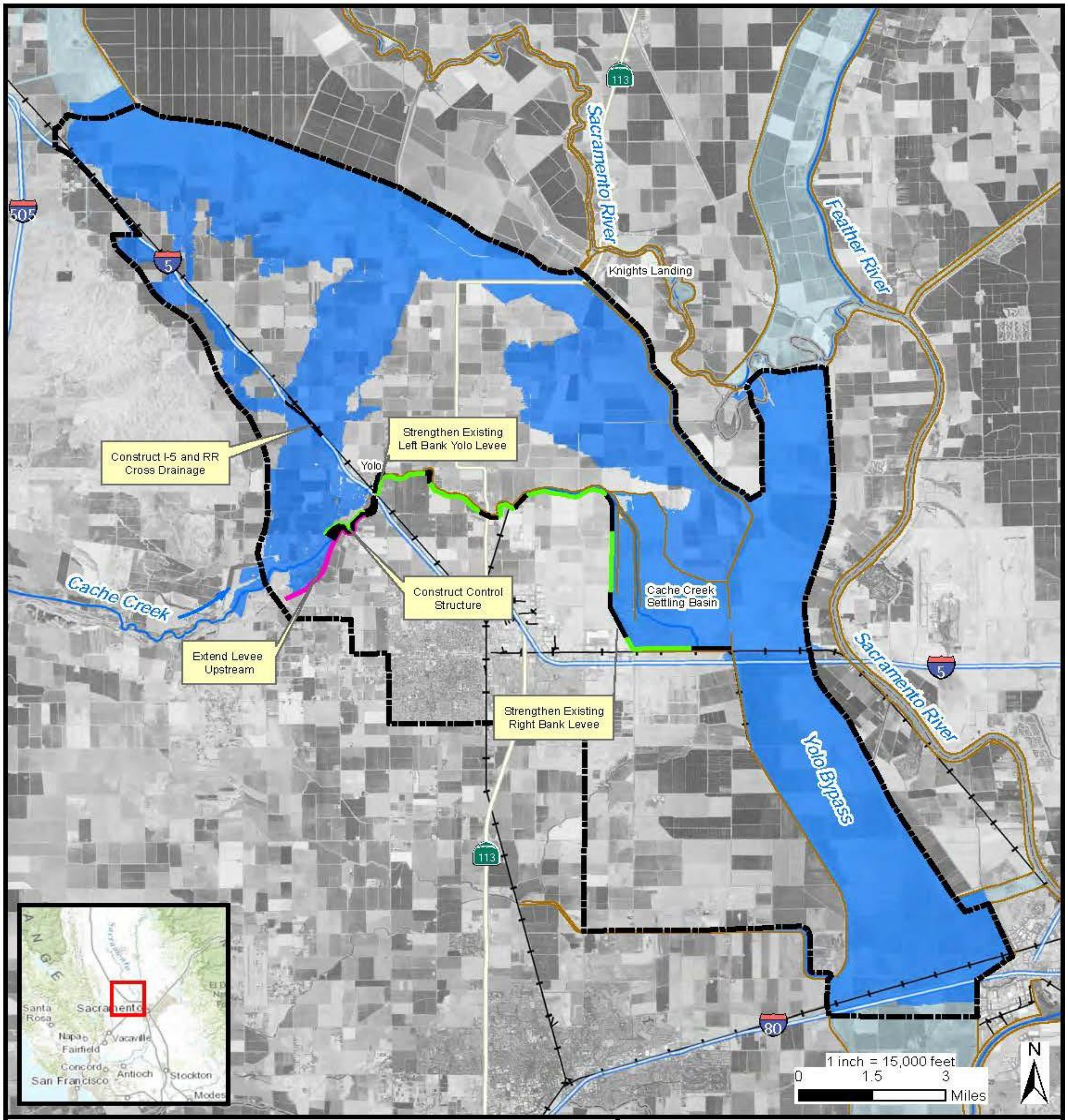
North Natural Bypass A (ALT 1A) –This alternative includes a grade control structure and a right bank levee extension upstream of I-5. A map showing the project features and flood inundation are shown on Plate 1. These features would increase the stage upstream of I-5 resulting in floodwaters overtopping the left bank and flowing north towards the Colusa Basin Drain. Due to the high probability of erosion related failure, this alternative would likely include Rock Bank Protection along most of its length. However, the extent of this is currently being evaluated.

North Natural Bypass B (ALT 1B). This alternative is similar to the Alternative 1A. However, it includes the purchase of flowage easements to insure the floodwaters are conveyed to the Colusa Basin Drain. A map showing the project features and flood inundation are shown on Plate 2. Due to the high probability of erosion related failure, this alternative would likely include Rock Bank Protection along most of its length. However, the extent of this is currently being evaluated.

North Natural Bypass C (ALT 1C). This alternative is similar to Alternative 1A. However, it includes the construction of levees to insure the floodwaters are conveyed to the Colusa Basin Drain. A map showing the project features and flood inundation are shown on Plate 3. As indicated by the map, only the areas removed from the flowage easements shown in the North Bypass B version would benefit from the proposed levees. Due to the high probability of erosion related failure, this alternative would likely include Rock Bank Protection along most of its length. However, the extent of this is currently being evaluated. It is anticipated that this alternative will be screened out using rough order of magnitude costs compared to the benefits.

Table 1. PCET- RE Cost Estimate for Linear Features, F.E. - Flowage Easements

Alternative	Number of Parcels	Land and Damages /Admin Costs 01 Account	Total Land Costs 01 Account with 45% contingency
1A North Bypass 14 Relocations PCET	90 -PCET Closure Structure 2	$12,178,000	$17,658,100
1B North Bypass 14 Relocations PCET 53 relocations F.E.	90 PCET / 195 F.E. parcels	$127,363,000	$184,676,350
1C North Bypass 14 Relocations PCET 39 Relocations Relocation F.E	90 PCET / 129 F.E. parcels	$83,228,000	$120,680,600



Legend

Existing Federal Levees	Designated Floodways
Interstate	Floodplain
Highway	
Railroad	
River/Creek	
Project Boundary	
County Boundary	

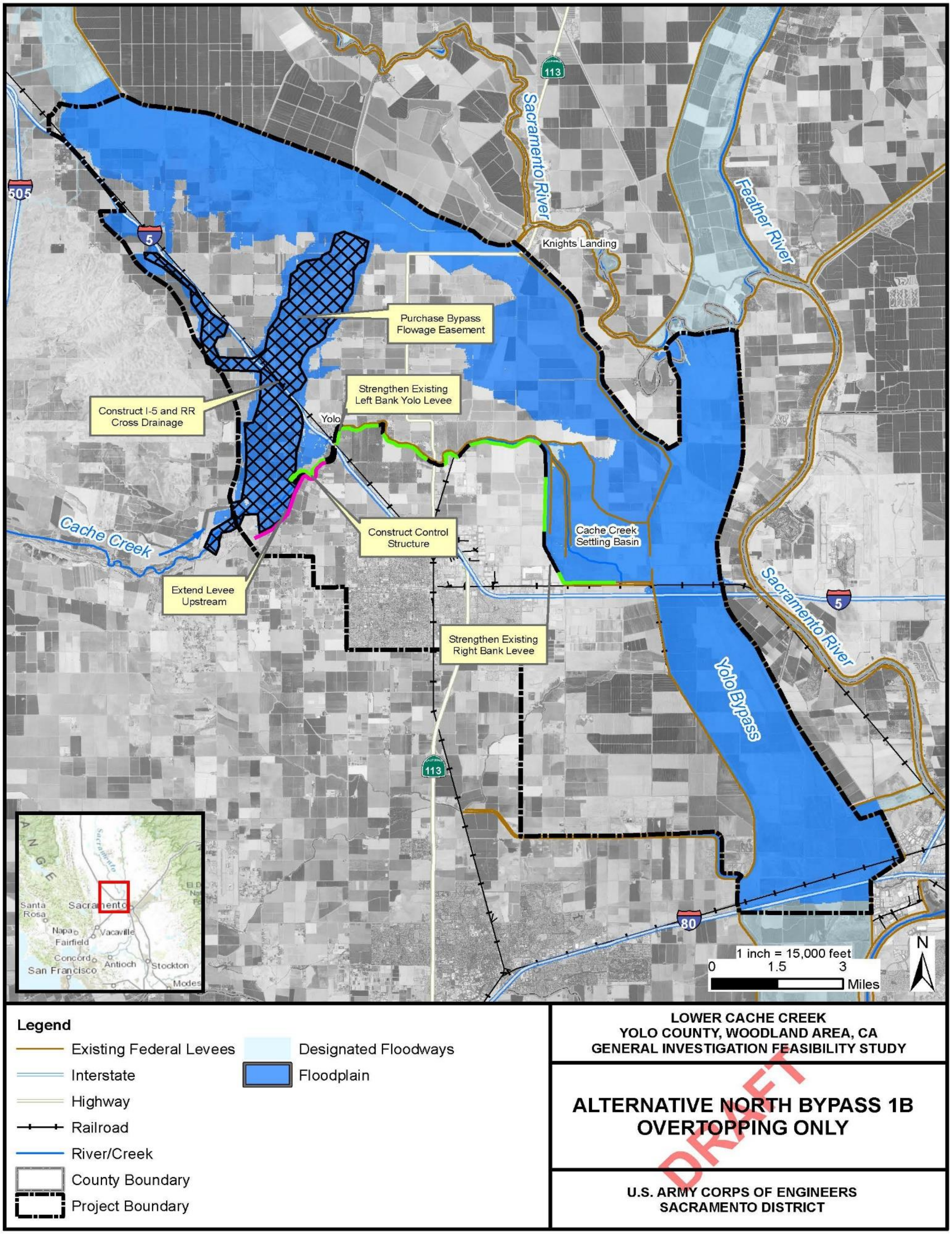
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE NORTH BYPASS 1A
OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

07 MAY 2015 DRAFT

PLATE 1



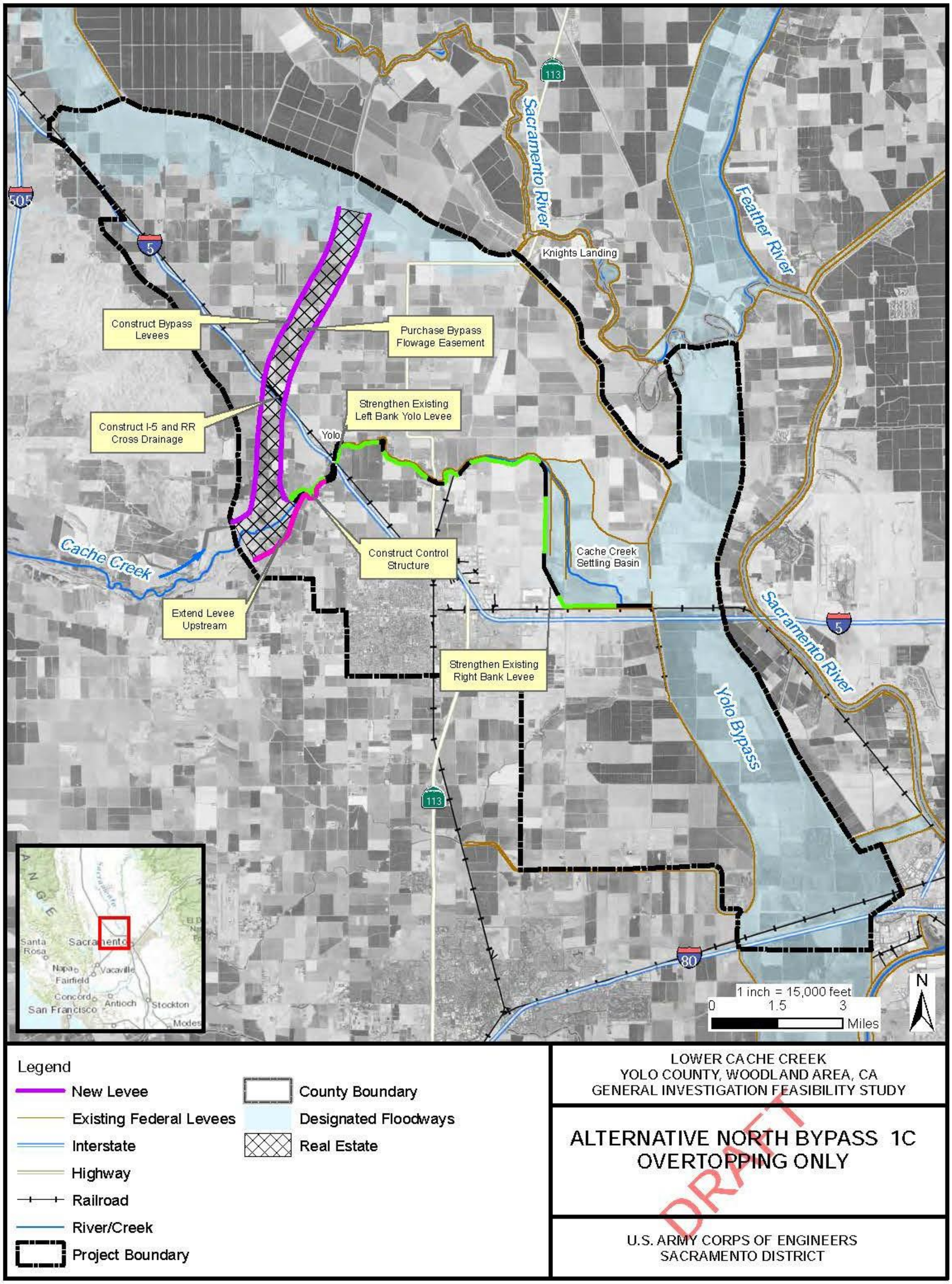
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE NORTH BYPASS 1B OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

06 JUL 2015 DRAFT

PLATE 2



LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE NORTH BYPASS 1C
OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

07 MAY 2015 DRAFT

PLATE 3

3.2. SOUTHBYPASS ALTERNATIVE 2

South Bypass A (Alt 2A). This plan would consist of a levee that would prevent floodwaters from entering the urban area of woodland. A map showing the project features and flood inundation are shown on Plate 4. The floodwaters would pass into the Cache Creek Settling basin (CCSB) through a cut in the levee of the CCSB. Later analysis may determine that a weir could be placed at the cut to reduce the probability that Cache Creek floodwaters would escape the CCSB during smaller flood events.

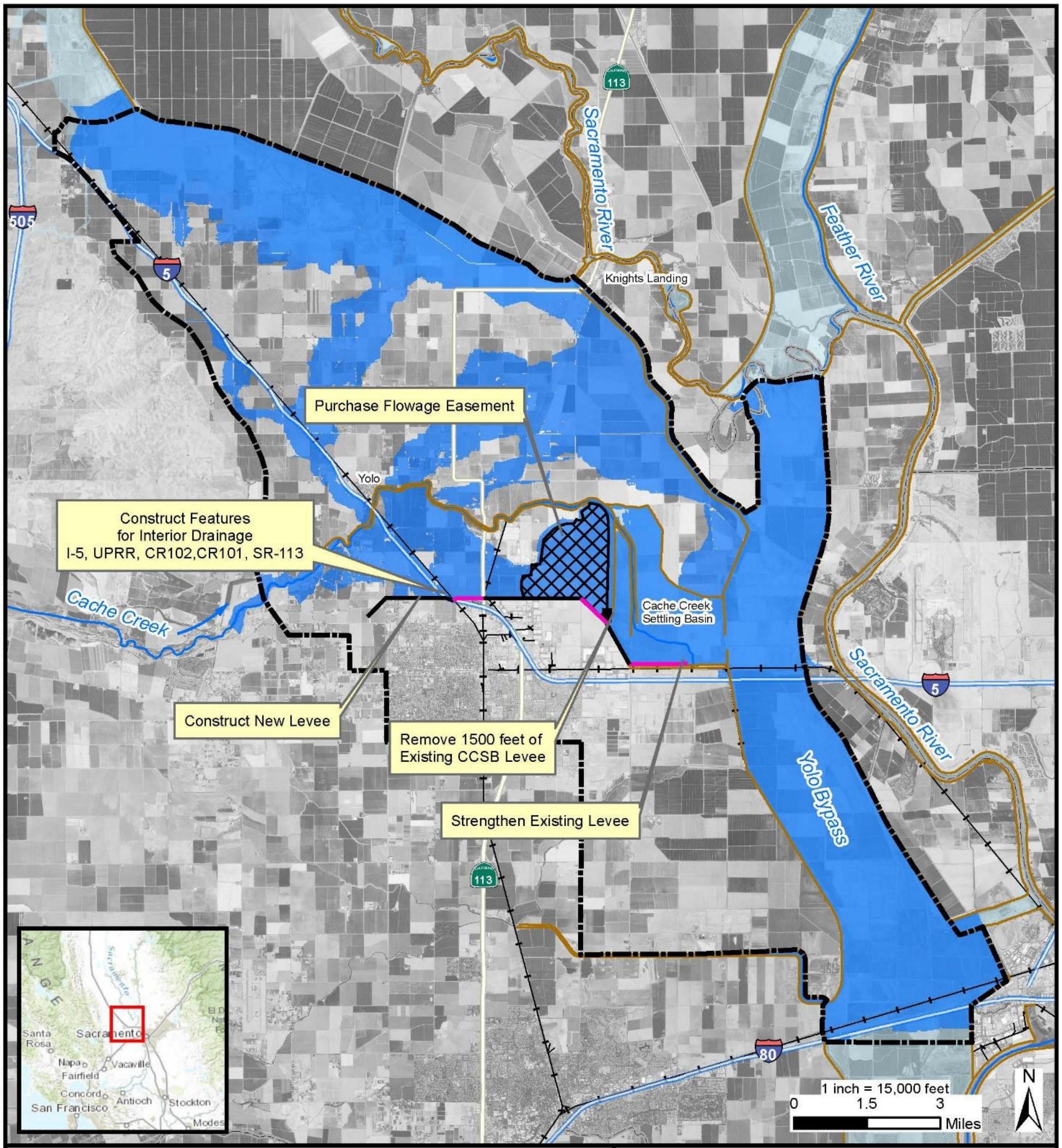
South Bypass B (Alt 2B). (screened out) This alternative is similar to Alternative 2A. However, it includes additional features to address localized induced stages at I-5 and Highway 113. Based on additional qualitative analysis this increment was screened out of the incremental array because there was no significant inflection in the cost and benefits.

South Bypass C (Alt 2C). This alternative is similar to Alternative 2A. However, a channel has been included that would convey floodwaters to the Yolo Bypass has been included. A map showing the project features and flood inundation are shown on Plate 5. This channel would involve moving a portion of the CCSB east levee further to the east to avoid a large industrial complex. The railroad line along the south side of the CCSB would also require extensive modifications to allow for the flood control channel.

South Bypass D (Alt 2D). This alternative would be similar to Alternative 2C. However, it would also include strengthening the left and right bank levees of Cache Creek. A map showing the project features and flood inundation are shown on Plate 6. Due to the high probability of erosion related failure, this alternative would likely include Rock Bank Protection along most of its length. However, the extent of this is currently being evaluated.

Table 2. PCET - RE Cost Estimate for Linear Features, F.E. - Flowage Easements

Alternative	Number of Parcels	Land and Damages /Admin Costs 01 Account	Total Land Costs 01 Account + 45% Contingency
2A South Bypass Induced Flooding	16 – PCET 15 F.E.	$27,835,000	$40,360,750
02 Potential Relocations 2A UPRR Railroad Trestle Hwy 113 Closure Structure I-5 road relocation SB I-5 road relocation NB Hwy 113 road relocation County Road 101 relocation County Road 102 relocation			$21,788,300
2B South Bypass	Screened out		
2C South Bypass	27-PCET Bypass - 35	$36,769,200	$53,315,340
2D South Bypass	61 – PCET Bypass 35	$43,579,250	$63,189,913



Purchase Flowage Easement

Construct Features
for Interior Drainage
I-5, UPRR, CR102,CR101, SR-113

Construct New Levee

Remove 1500 feet of
Existing CCSB Levee

Strengthen Existing Levee

Legend

Existing Federal Levees
Interstate
Highway
Railroad
River/Creek
Project Boundary
County Boundary
Designated Floodways
Floodplain

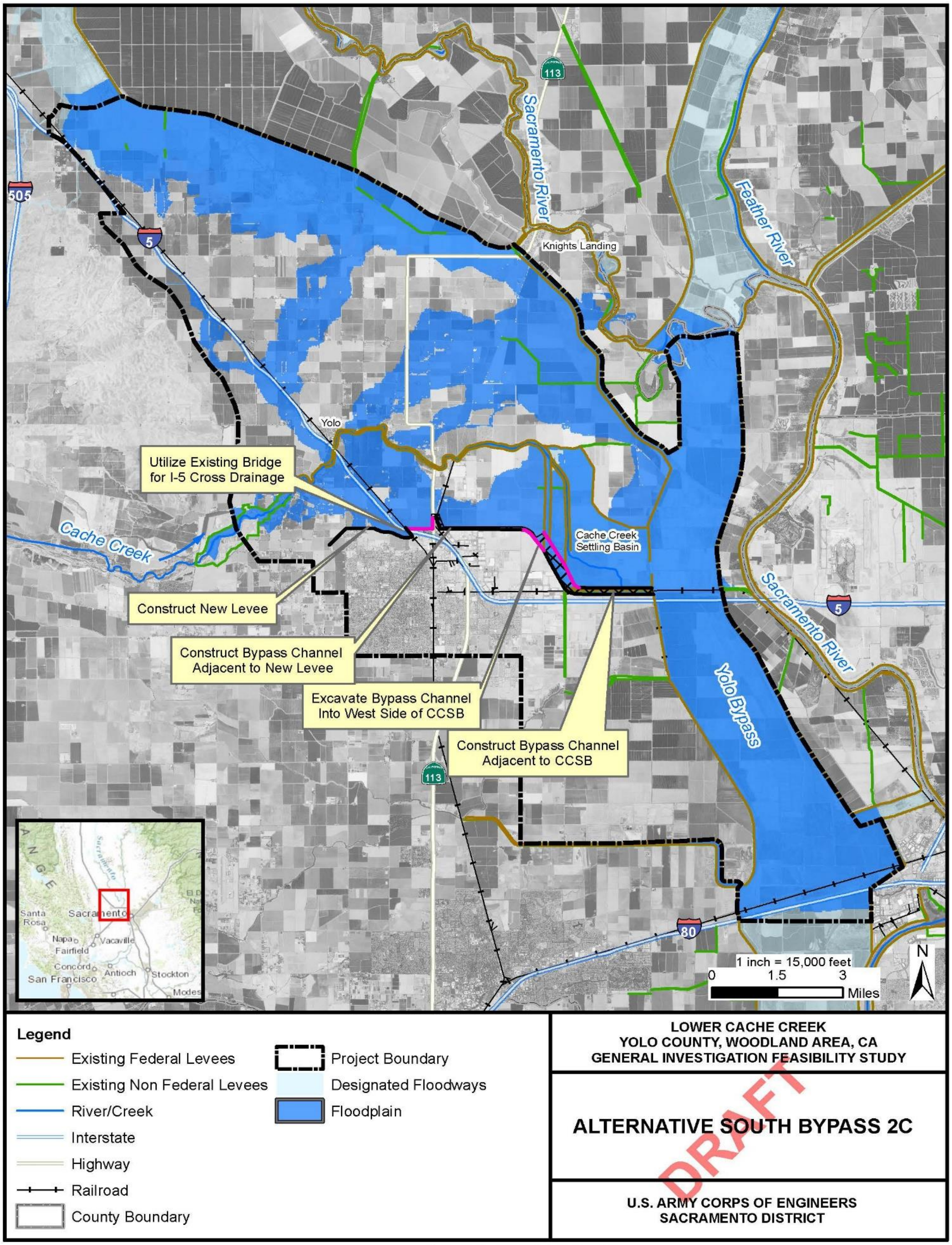
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE SOUTH BYPASS 2A

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

06 JUL 2015 DRAFT

PLATE 4



Utilize Existing Bridge for I-5 Cross Drainage

Construct New Levee

Construct Bypass Channel Adjacent to New Levee

Excavate Bypass Channel Into West Side of CCSB

Construct Bypass Channel Adjacent to CCSB

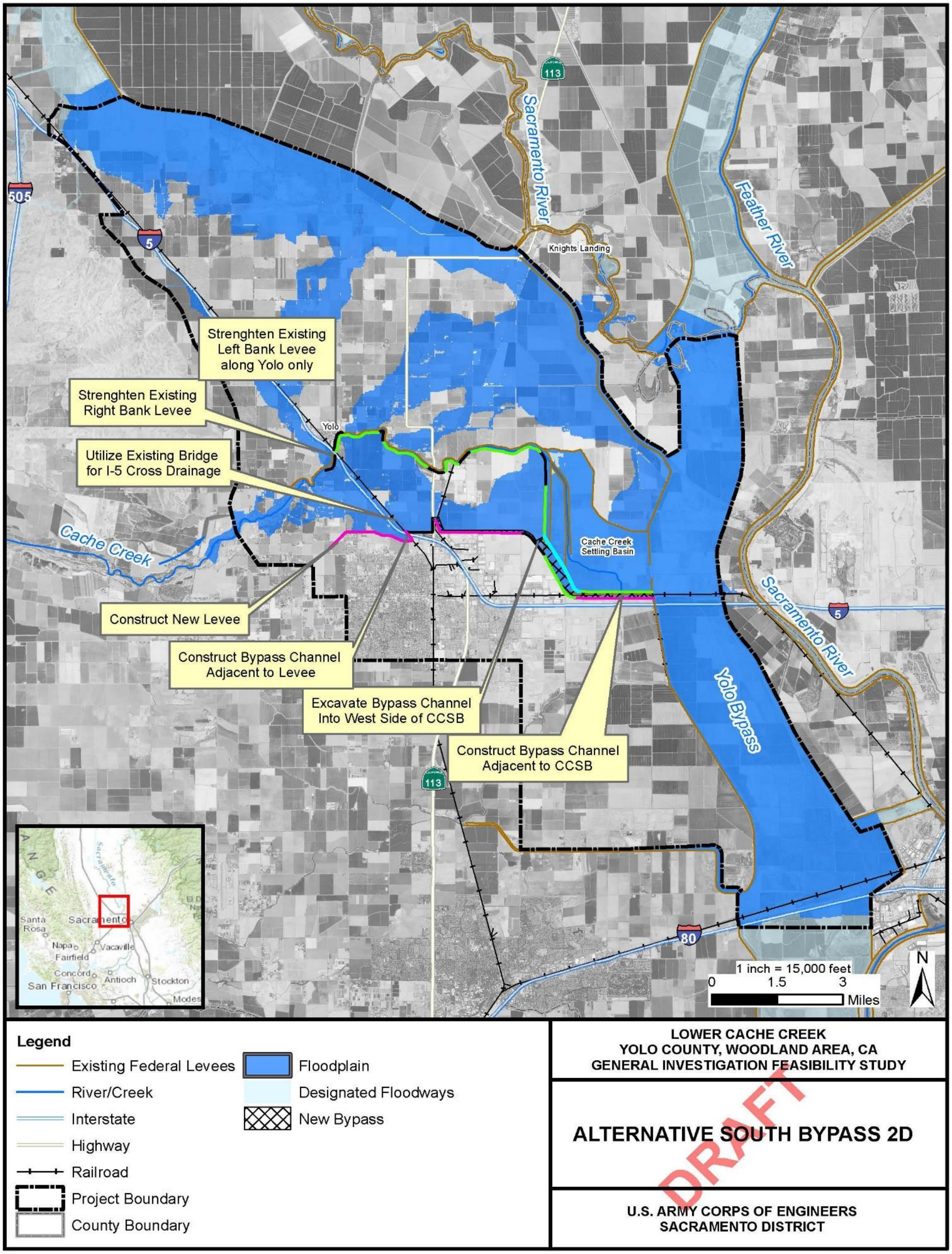
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE SOUTH BYPASS 2C

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

06 JUL 2015 DRAFT

PLATE 5



LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE SOUTH BYPASS 2D

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

06 JUL 2015 DRAFT

PLATE 6

3.3. STRENGTHEN LEVEE IN PLACE

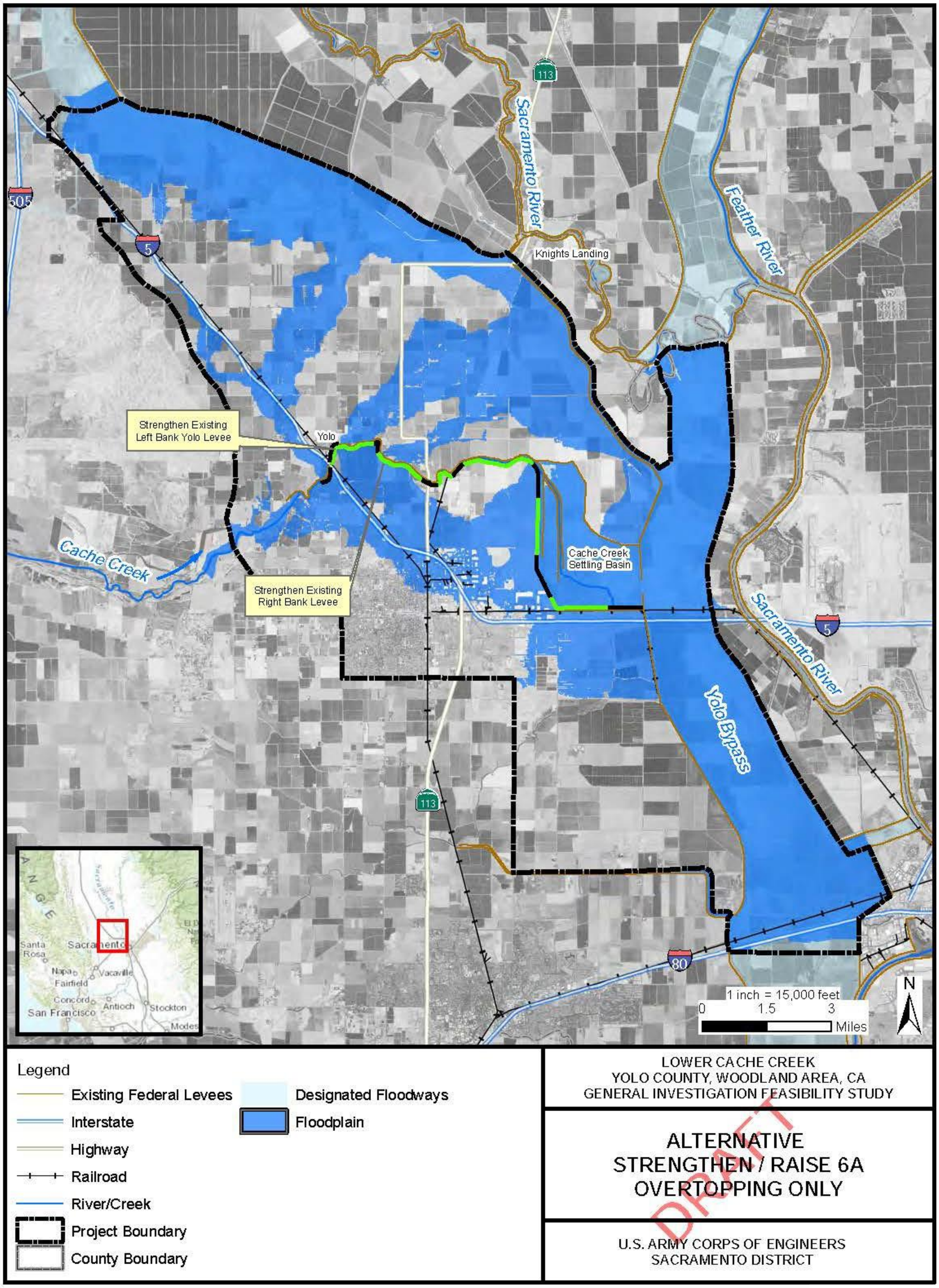
Strengthen Levee In Place A (ALT 6A). This alternative would involve fixing the right bank levee of Cache Creek. A map showing the project features and flood inundation are shown on Plate 7. The alternative would also include fixing the left bank of Cache Creek along the town of Yolo. However, the Yolo segment would have to be incrementally justified. This alternative reduces the risk of flooding associated with geotechnical related failures. However, the hydraulic capacity (overtopping) related failure probability would remain the same. Due to the high probability of erosion related failure, this alternative would likely include Rock Bank Protection along most of its length. However, the extent of this is currently being evaluated.

Strengthen Levee In Place B (ALT 6B). This alternative is similar to Alternative 6A except includes increasing the height of the right bank levee and the left bank levee near Yolo. This would significantly reduce the risk of flooding to the south of Cache Creek. A map showing the project features and flood inundation are shown on Plate 8. Due to the high probability of erosion related failure, this alternative would likely include Rock Bank Protection along most of its length. However, the extent of this is currently being evaluated.

Strengthen Levee In Place C (ALT 6C). This alt is similar to Alternative 6A but includes strengthening or increasing the height of both left and right levees along their entire length. A map showing the project features and flood inundation are shown on Plate 9. The left bank levee upstream of I-5 would be removed and a new levee would be constructed adjacent to I5. This would force the floodwaters to the north where it would be conveyed across I-5 through a bank of culverts. Due to the high probability of erosion related failure, this alternative would likely include Rock Bank Protection along most of its length. However, the extent of this is currently being evaluated.

Table 3. PCET - RE Cost Estimates for Linear Features, F.E. - Flowage Easements

Alternative	Number of Parcels Impacted	Land and Damages /Admin Costs 01 Account	Total Land Costs 01 Account 45% contingency
6A Strengthen Levee in Place 12 Relocations	34 - PCET	$3,468,000	$5,028,600
6B Strengthen Levee in Place includes 10 relocations PCET, 7 relocations F.E.	96 – PCET 67 F.E.	$24,053,000	$34,876,850
6C Strengthen Levee in Place 14 Relocations PCET 7 Relocations F.E	173-PCET 67 F.E.	$30,876,000	$ 44,770,200



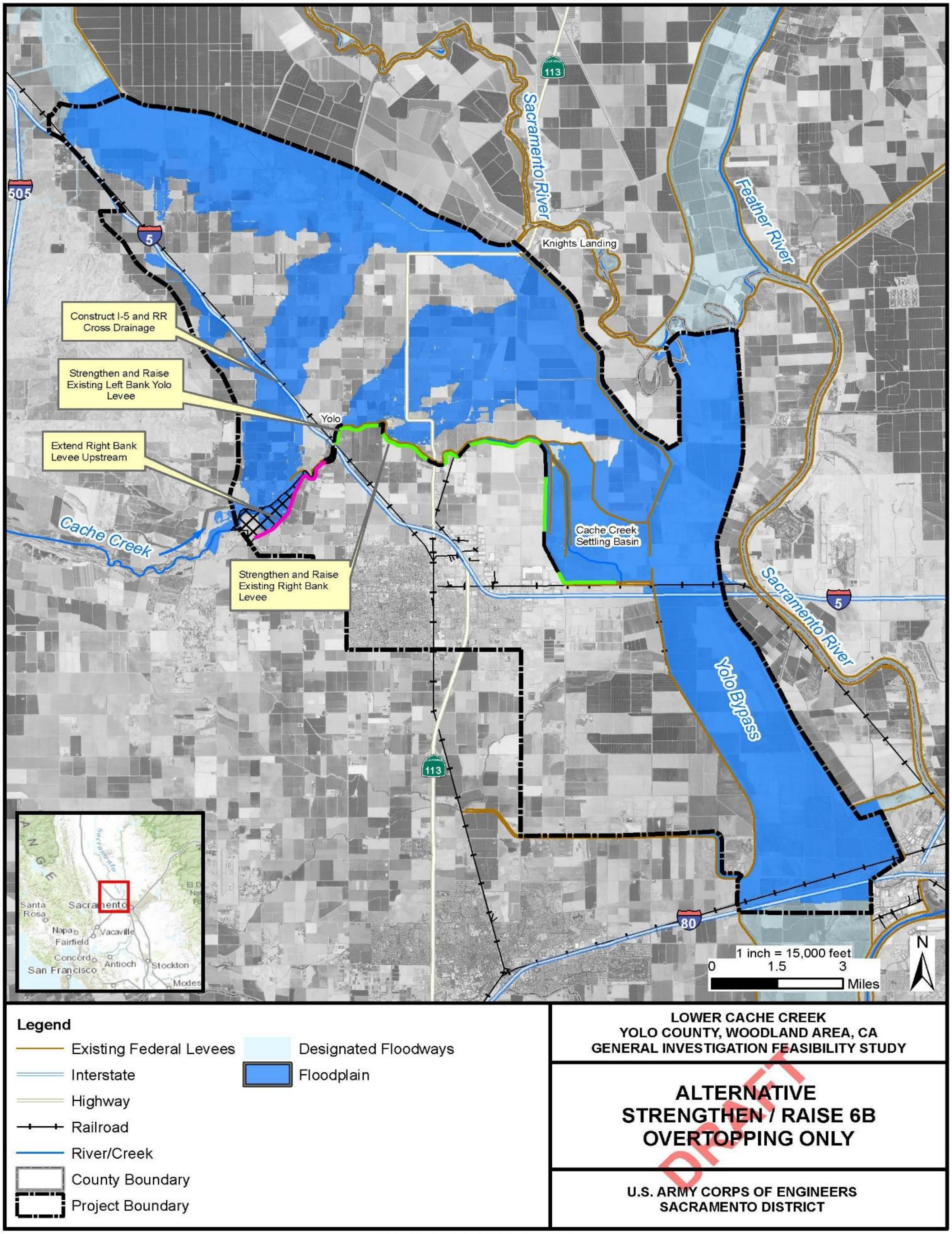
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE
STRENGTHEN / RAISE 6A
OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

07 MAY 2015 DRAFT

PLATE 7



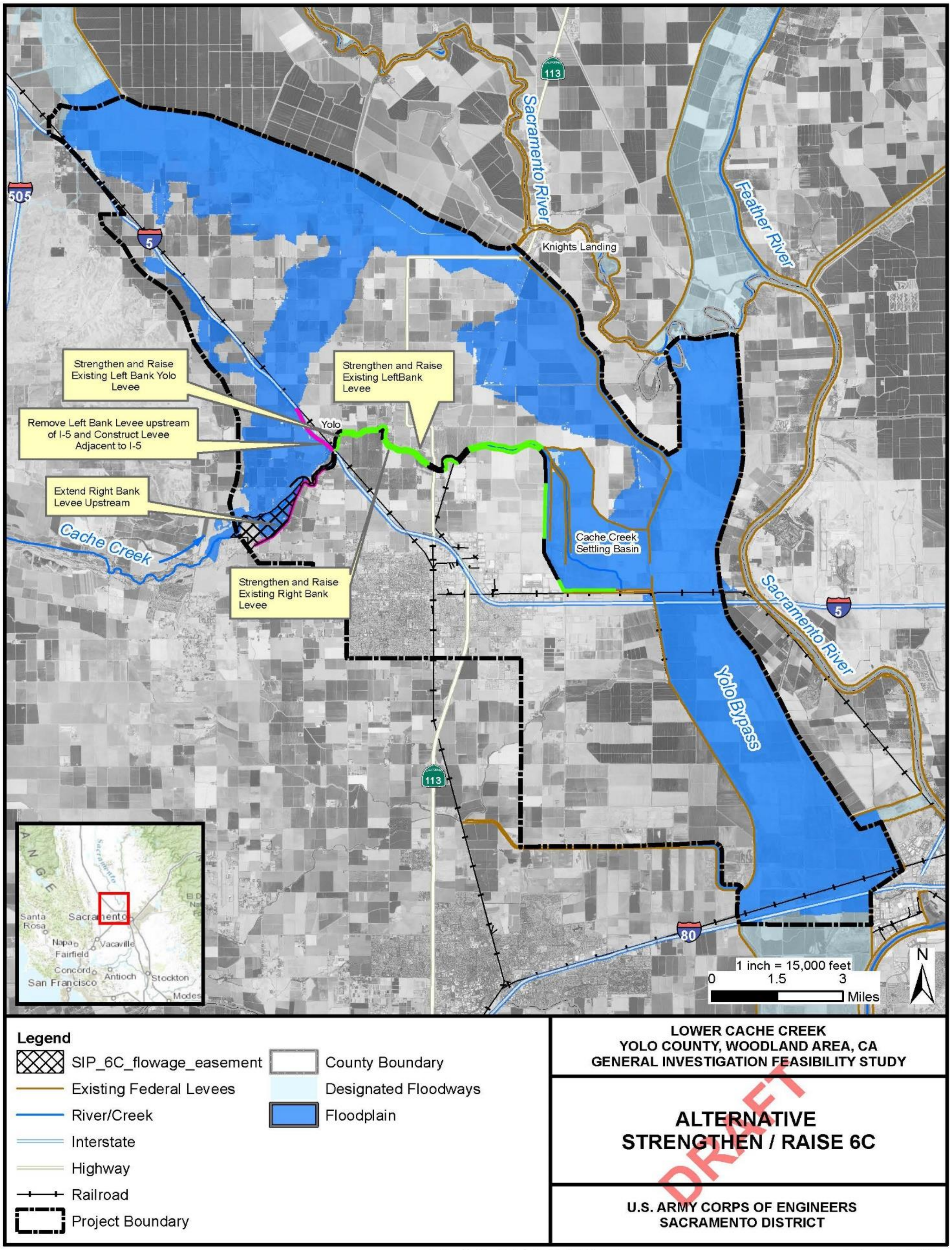
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE
STRENGTHEN / RAISE 6B
OVERTOPPING ONLY

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

06 JUL 2015 DRAFT

PLATE 8



LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE
STRENGTHEN / RAISE 6C

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

06 JUL 2015 DRAFT

PLATE 9

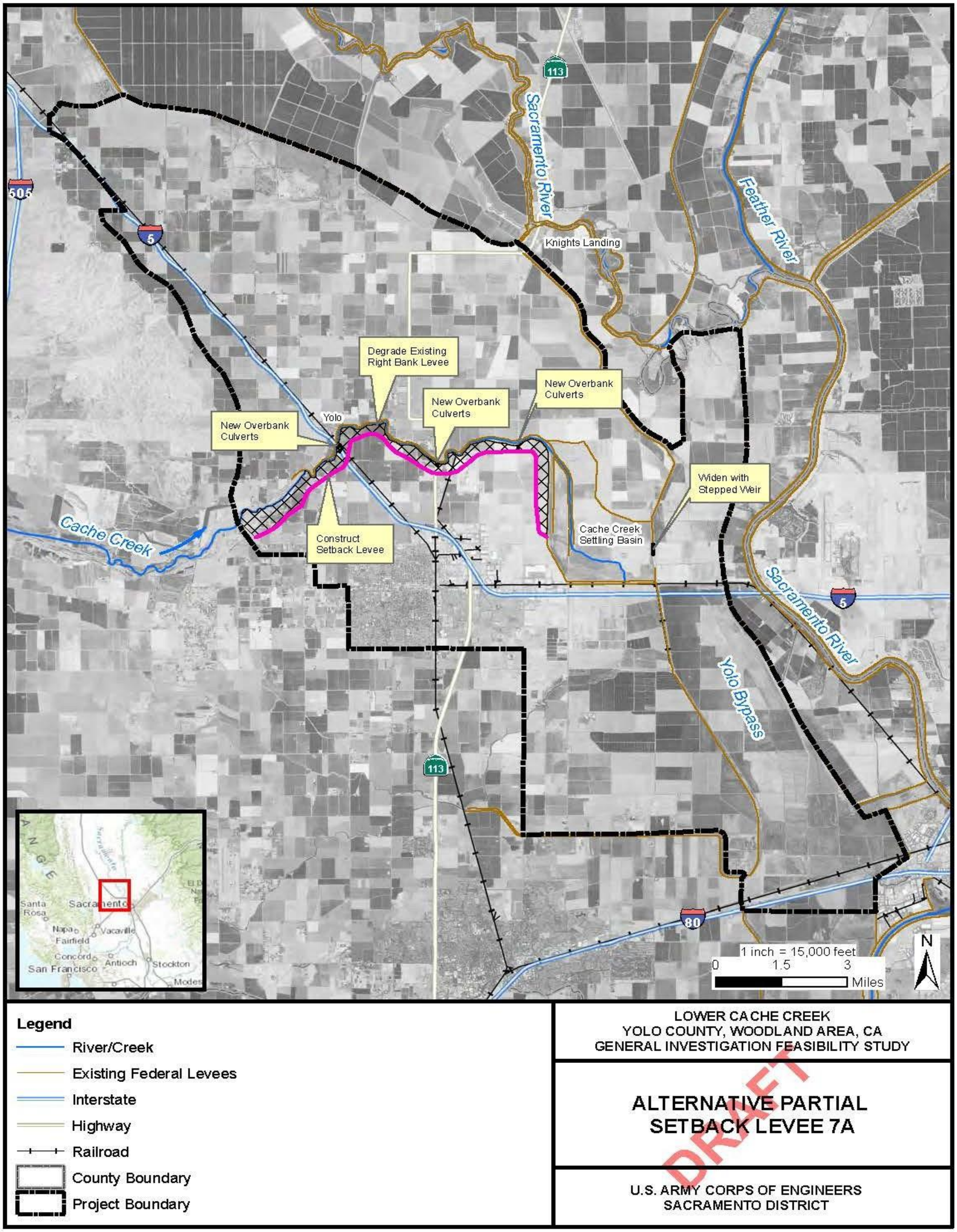
3.4. PARTIAL SETBACK LEVEE ALTERNATIVE 7

Partial Setback Levee (ALT 7A). This alternative would involve building levees set back from Cache Creek on the right bank to contain flow within an expanded levee system, reducing the probability of flooding in Woodland from erosion related levee failure. This alternative also involves new levees upstream of I-5 set back from the right bank, and culverting under I-5, UPRR and other utilities, to accommodate excess flows.

Partial Setback Levee (ALT 7B). This is similar to Alternative 7A but includes a bypass channel to the north of the Cache Creek Settling Basin, some excavation of material from this channel and flowage easements to accommodate flow through the channel.

Table 4. PCET - RE Cost Estimate for Linear Features, F.E. - Flowage Easements

Alternative	Number of Parcels Impacted	Land and Damages /Admin Costs 01 Account	Total Land Costs 01 Account 45% contingency
7A Partial Setback Levee with F.E.	104	$44,212,000	$64,107,400
7B Partial Setback Levee 1 Relocation PCET 30 Relocations F.E.	97 PCET and F.E. 12 Mercury Mitigation	$69,751,000	$101,138,950



Legend

- River/Creek
- Existing Federal Levees
- Interstate
- Highway
- Railroad
- County Boundary
- Project Boundary

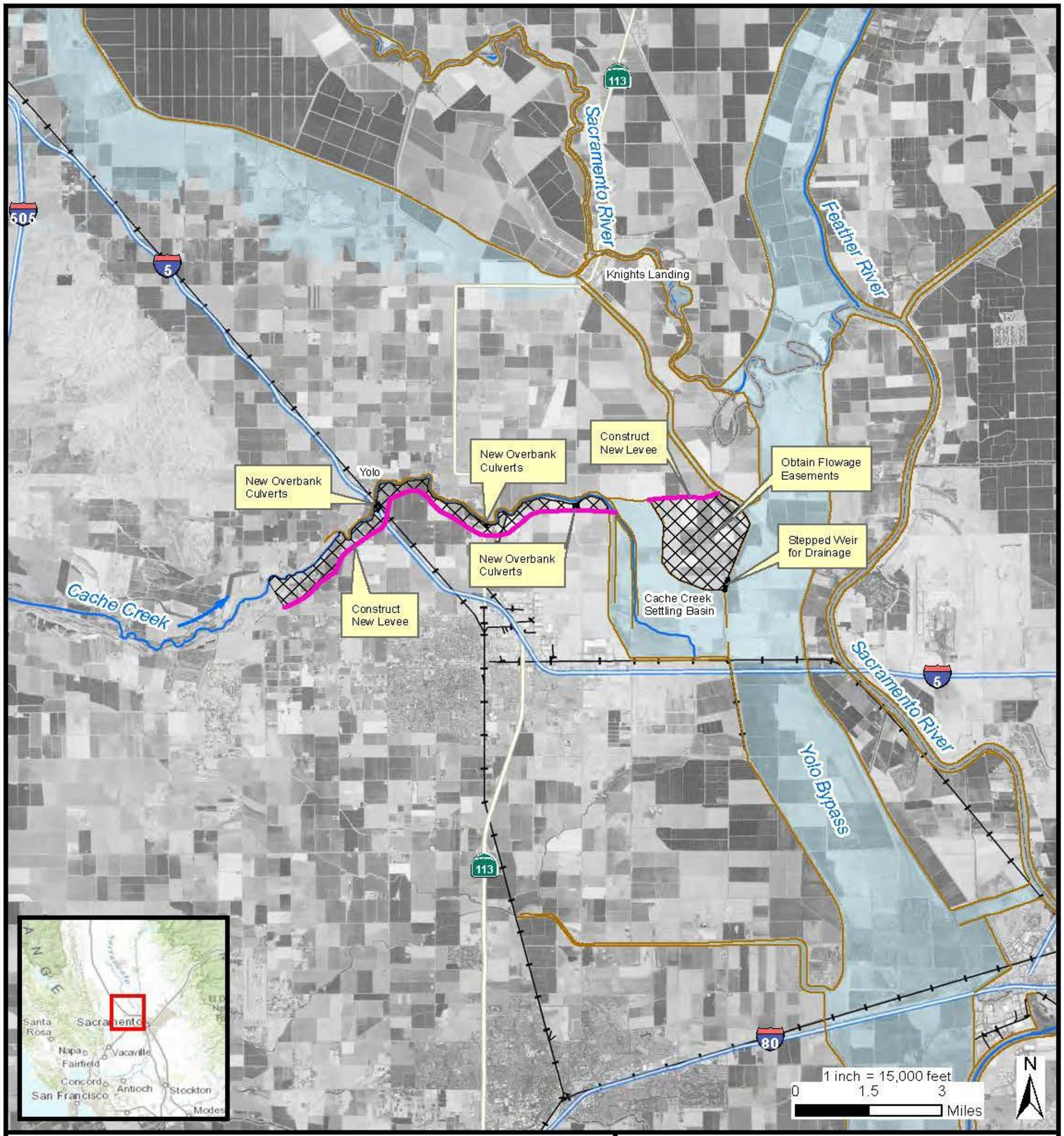
LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE PARTIAL SETBACK LEVEE 7A

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

23 JUN 2015 DRAFT

PLATE 10



Legend

River/Creek
Existing Federal Levees
Interstate
Highway
Railroad
County Boundary
Designated Floodways

LOWER CACHE CREEK
YOLO COUNTY, WOODLAND AREA, CA
GENERAL INVESTIGATION FEASIBILITY STUDY

ALTERNATIVE PARTIAL SETBACK LEVEE 7B

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

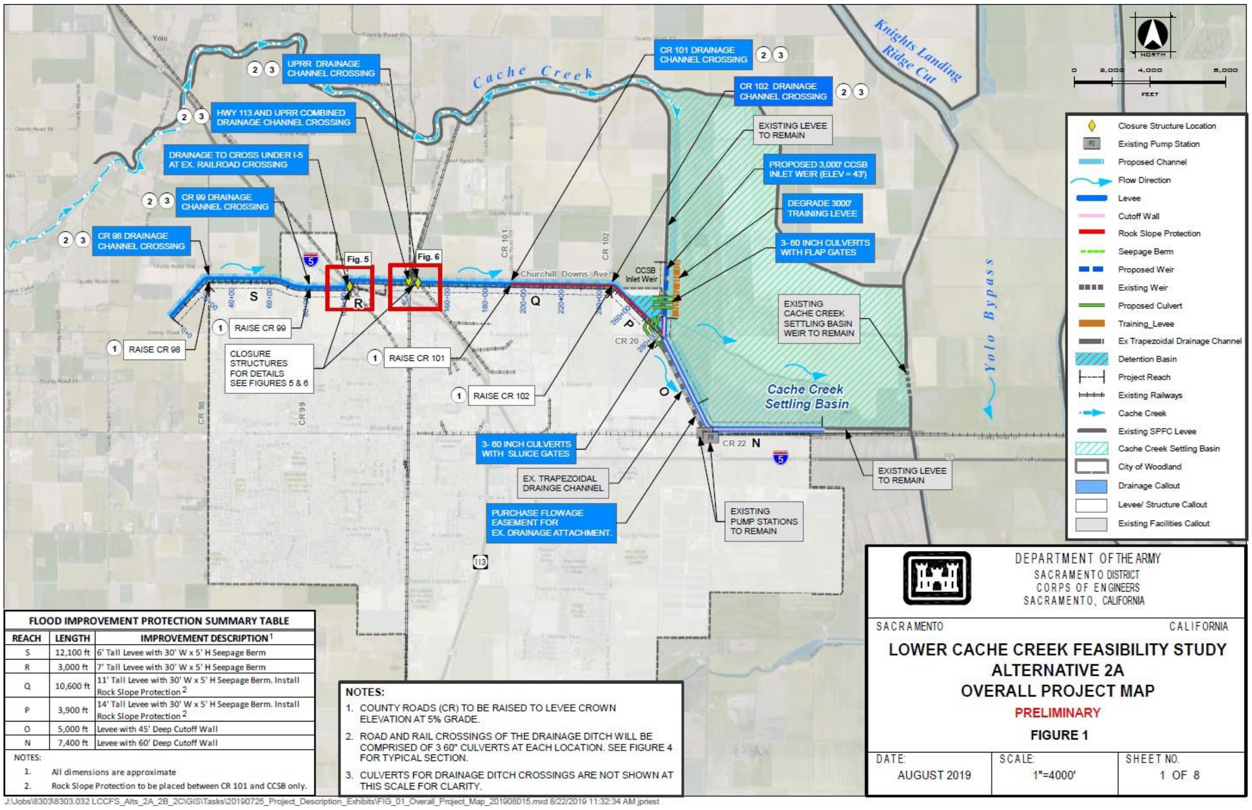
16 JUN 2015 DRAFT

PLATE 11

4. PROJECT DESCRIPTION OF THE TENTATIVELY SELECTED PLAN - Alternative 2A

Alternative 2A consists, overall, of improving existing levees and constructing a new levee north of the city of Woodland (City) in order to protect the City from flooding emanating from Lower Cache Creek. The United States Army Corps of Engineers (USACE) determined the necessary height of the levee embankment north of the City and the capacity of the project features by modeling a range of flood flow magnitudes/return frequencies, and then estimating the cost and benefits for four incremental heights.

The alternative identified as Alternative 2A provided the height and capacity that maximized the net benefits (annual benefits minus annual costs). Alternative 2A is comprised of six distinct project reaches (Reach N through Reach S). A general overview of Alternative 2A is provided in **Figure 1**.



FLOOD IMPROVEMENT PROTECTION SUMMARY TABLE

REACH	LENGTH	IMPROVEMENT DESCRIPTION[1]
S	12,100 ft	6' Tall Levee with 30' W x 5' H Seepage Berm
R	3,000 ft	7' Tall Levee with 30' W x 5' H Seepage Berm
Q	10,600 ft	11' Tall Levee with 30' W x 5' H Seepage Berm. Install Rock Slope Protection[2]
P	3,900 ft	14' Tall Levee with 30' W x 5' H Seepage Berm. Install Rock Slope Protection[2]
O	5,000 ft	Levee with 45' Deep Cutoff Wall
N	7,400 ft	Levee with 60' Deep Cutoff Wall

NOTES:
1. All dimensions are approximate
2. Rock Slope Protection to be placed between CR 101 and CCSB only.

NOTES:
1. COUNTY ROADS (CR) TO BE RAISED TO LEVEE CROWN ELEVATION AT 5% GRADE.
2. ROAD AND RAIL CROSSINGS OF THE DRAINAGE DITCH WILL BE COMPRISED OF 3 60" CULVERTS AT EACH LOCATION. SEE FIGURE 4 FOR TYPICAL SECTION.
3. CULVERTS FOR DRAINAGE DITCH CROSSINGS ARE NOT SHOWN AT THIS SCALE FOR CLARITY.

J:\Jobs\8303\8303.032 LCCFS_Alts_2A_2B_2C\GIS\Tasks\20190725_Project_Description_Exhibits\FIG_01_Overall_Project_Map_201908015.mxd 8/22/2019 11:32:34 AM jpriest

Figure 1 General Project Map

Project features include levee embankment, seepage berms, drainage channel; cutoff walls, weir, and closure structures. A detailed description of Alternative 2A follows below.

Modifications to Existing Levees / Cache Creek Settling Basin

Alternative 2A would rehabilitate a portion of the southern levee (Reach N) of the Cache Creek Settling Basin (CCSB) by constructing a 60-foot-deep cutoff wall through the levee, and the southwest levee (Reach O) of the CCSB by constructing a 45-foot-deep cutoff wall. Along with this cutoff wall installation, a 3,000-foot-long section of the west levee of the settling basin would be degraded to an elevation of 43 feet to accommodate a concrete weir with a height of approximately nine feet above existing adjacent grade. Additionally, the southernmost 3,000-foot portion of the CCSB training levee would be degraded in order to improve the distribution of sediment within the basin before construction begins.

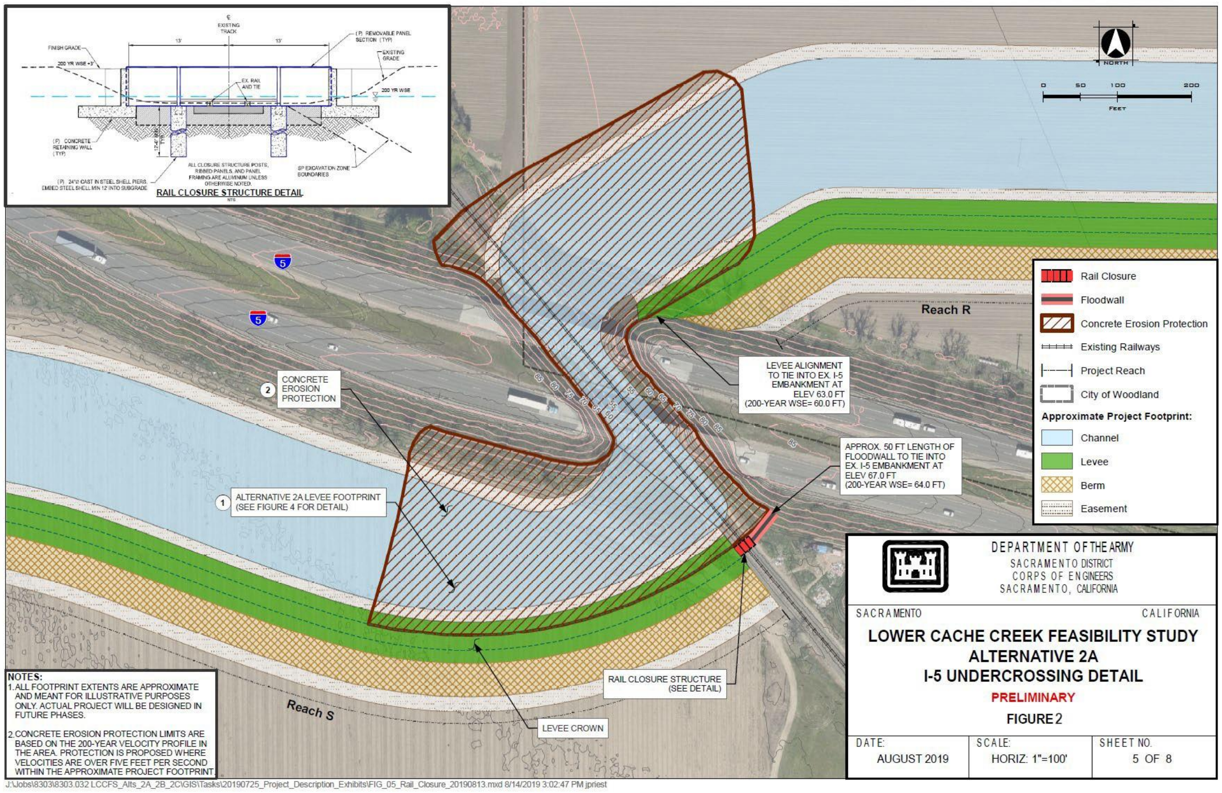
New Levees and Other Proposed Project Features

A new levee with a 20-foot-wide crest and a 30-foot-wide landside seepage berm would begin near the intersection of County Road 20 and County Road 98 and extend east to the CCSB. The height of the new levee would vary from six feet near County Road 98 to 14 feet at its intersection with the existing west levee of the CCSB. Rock slope protection is proposed on the waterside slope of the new levee from County Road 101 east to the southern end of the proposed inlet weir near County Road 20.

A trapezoidal drainage channel with a design capacity of approximately 350 cubic feet per second (cfs) would be constructed north (water ward) of the new levee in Reaches P through S.

A total of four closure structures would be constructed where the embankment crosses the Union Pacific Railroad (UPRR) tracks near Interstate 5 (I-5) (**Figure 2**), the UPRR tracks west of SR 113, (**Figure 3**). Short sections of floodwall would be constructed to connect the closure structure at the I-5 crossing to the existing roadway embankment and to connect the closure structures at the SR 113 crossing and the adjacent UPRR crossing to the west.

Figure 2. Closure Structure I-5



NOTES:
1. ALL FOOTPRINT EXTENTS ARE APPROXIMATE AND MEANT FOR ILLUSTRATIVE PURPOSES ONLY. ACTUAL PROJECT WILL BE DESIGNED IN FUTURE PHASES.

2. CONCRETE EROSION PROTECTION LIMITS ARE BASED ON THE 200-YEAR VELOCITY PROFILE IN THE AREA. PROTECTION IS PROPOSED WHERE VELOCITIES ARE OVER FIVE FEET PER SECOND WITHIN THE APPROXIMATE PROJECT FOOTPRINT.

DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

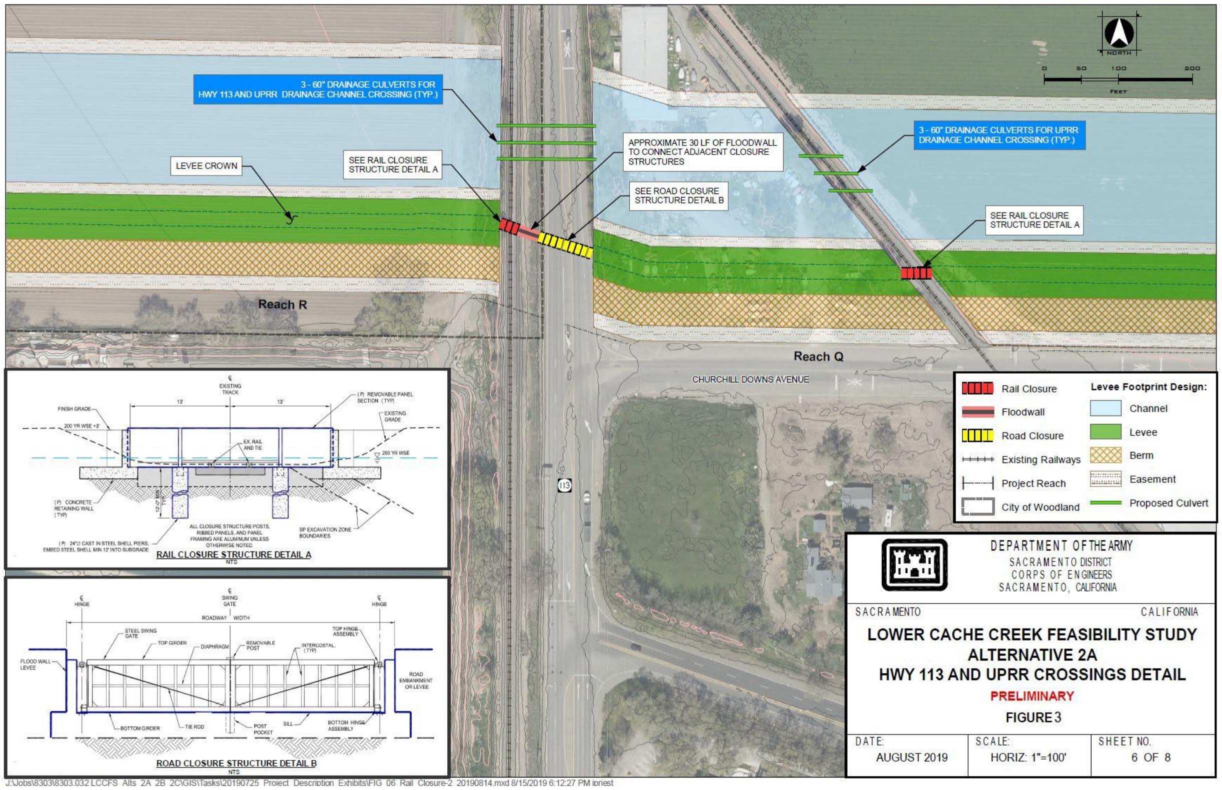
SACRAMENTO CALIFORNIA

LOWER CACHE CREEK FEASIBILITY STUDY
ALTERNATIVE 2A
I-5 UNDERCROSSING DETAIL
PRELIMINARY
FIGURE 2

DATE:	SCALE:	SHEET NO.
AUGUST 2019	HORIZ: 1"=100'	5 OF 8

J:\Jobs\8303\8303.032 LCCFS_Alts_2A_2B_2C\GIS\Tasks\20190725_Project_Description_Exhibits\FIG_05_Rail_Closure_20190813.mxd 8/14/2019 3:02:47 PM jpriest

Figure 3 Highway 113 and UPRR Closure



J:\Jobs\8303\8303.032 LCCFS Alts 2A 2B 2C\GIS\Tasks\20190725 Project Description Exhibits\FIG 06 Rail Closure-2 20190814.mxd 8/15/2019 6:12:27 PM jpriest

Internal Drainage

Water impounded by the proposed levee and the west levee of the CCSB would be drained via proposed culverts into the CCSB and to the City's interior drainage system. A detention basin would be located at the downstream end of the proposed drainage channel along Reach P. The detention basin would include an east outlet and a south outlet. The east outlet would provide for gravity drainage into the CCSB and consist of three 60-inch diameter culverts fitted with flap gates. The south outlet would consist of a set of three 60-inch diameter culverts fitted with sluice gates. The culverts would discharge to an existing ditch that terminates at a pump station owned and operated by the City. The sluice gates would control the discharge flow to the pump station until capacity was available to discharge the flows to the Yolo Bypass. The design and operation of these systems has not been fully developed yet, and will be optimized during later phases of the project.

Roadway Relocations and UPRR Closure Structures

The new levee would require the raising of County Road 98, County Road 99, County Road 101, and County Road 102. Culverts would be installed at each of these raised crossings, as well as under SR 113 and the two UPRR crossings along the alignment. Channel protection would be installed across the entire project footprint area where flood flows velocities exceed the five fps limit.

5. NON FEDERAL SPONSORS

The Central Valley Flood Protection Board (CVFPB, representing the State of California) and the City of Woodland will be required to serve as the Non-Federal Sponsors (NFS) for construction and operation, maintenance, repair, rehabilitation and replacement responsibilities if this project is authorized. Both sponsors have legal authority to acquire and hold title to real property for the project under State of California Water Code Section 8590. The sponsors also have the power of eminent domain and "quick-take" authorities for this project.

6. DESCRIPTION OF LANDS, EASEMENTS, RIGHTS-OF-WAY, RELOCATIONS AND DISPOSAL AREAS (LERRDs)

The real estate cost estimate for the Sacramento District Real Estate Division identified general land use types and their values in the study area. The general land use types and their values were approved by the Sacramento District Real Estate Division in April 2014.

The inventory of lands, easements and rights-of-way required to support the project was created by viewing conceptual designs over real photographs and county parcel maps by Engineering and Real Estate Divisions. These findings will be revised for the final plan to conform to Chapter 2 (ER 405-1-12).

Table 1: TSP Alternative. The following Table 1 provides a summary of acres required and ownerships affected for the TSP Alternative 2A. This information is tentative in nature and will be revised once the recommended plan is selected. The TSP alternative covers approximately 5.6 miles of new levee, 1.7 miles of seepage berm and rock slope protection, 2.3 miles of levee improvement, and 5.6 miles of Drainage canal. Several road/railroad closure structures located on City of Woodland parcels will be needed and as well as weir construction.

Table 5. LERRD Requirements

Ownership	Quantity	Acres
Private Ownerships	24	257.806
Public Ownerships	8	45.84
Railroad	1	0.652
Estates	Quantity	Acres
Permanent Easement Estates	40	314.43
Temporary Work Areas	11	32.61
Fee	0	0
Number of PL-91-646	0	0

A. Access and Temporary Staging

The majority of staging areas for construction of this project will be located within the right- of-way for the levee footprint or existing right-of-way. Specific access and staging areas were not identified. For construction and staging areas planning analysis indicates that sufficient NFS and public-owned properties exist and additional areas will not need to be acquired. These public-owned properties in the form of empty lots, right-of-ways, and easements would be available for the recommended plan. A standard Temporary Work Area Easement will be acquired for the additional right-of-way necessary for access and staging.

B. Borrow

Borrow material will be needed to construct the project. Because the project is in preliminary stages of design, detailed studies of borrow needs have not been completed. For the purposes of NEPA/CEQA a worst case scenario is being evaluated for the volume of borrow material needed. Actual volumes exported from any single borrow site would be adjusted to match for fill.

C. Mitigation

The sponsors will purchase credits from mitigation banks in the project area. The costs and acres needed will be determined by the studies in progress.

7. ESTATES - NON STANDARD ESTATES

Non-standard estates are anticipated for implementation of the TSP Plan. Typically, railroads have difficulty in providing a standard estate due to the interest the railroad has in the land and their requirements to support commerce nationally. At this time the NFS has not approached the railroad to discuss the project. UPRR has worked with other NFS on similar projects. The likelihood of success in reaching an agreement is high. The non- standard estate language will be submitted for approval as an amendment to this plan.

NFS will acquire the minimum necessary interests in real estate to support the construction and subsequent operation and maintenance of the recommended plan and these standard estates are identified as follows:

STANDARD ESTATES

A. PERMENANT ROAD EASEMENT

A (perpetual [exclusive] [non-exclusive] and assignable) (temporary) easement and right- of-way in, on, over and across (the land described in tract register) for the location, construction, operation, maintenance, alternation replacement of (a) road(s) and appurtenances thereto; together with the right to trim. Cut. Fell and remove therefrom all trees, underbrush, obstructions and other vegetation, structures, or obstacles within the limits of the rights-of-way as access to their adjoining land at that locations indicated in the tract register); subject. However, to existing easements for public roads and highways, public utilities, railroads and pipelines.

B. FLOOD PROTECTION LEVEE EASEMENT

A perpetual and assignable right and easement in [the land described in Schedule A] to construct, maintain, repair, operate, patrol and replace a flood protection levee, including all appurtenances thereto; reserving, however, to the owners, their heirs and assigns, all such rights and privileges in the land as may be used without interfering with or abridging the rights and easement hereby acquired; subject, however, to existing easements for public roads and highways, public utilities, railroads and pipelines.

C. TEMPORARY WORK AREA EASEMENT

A temporary easement and right-of-way in, on, over and across [the land described in Schedule A] for a period not to exceed____ beginning with date possession of the land is granted to the NFS, for use by the NFS, its representatives, United States, agents, and contractors as a (borrow area) (work area), including the right to (borrow and/or deposit fill, spoil and waste material thereon) (move, store and remove equipment and supplies, and erect and remove temporary structures on the land and to perform any other work necessary and incident to the construction of the_ Project, together with the right to trim, cut, fell and remove therefrom all trees, underbrush, obstructions, and any other vegetation, structures, or obstacles within the limits of the right-of-way; reserving, however, to the landowners, their heirs and assigns, all such rights and privileges as may be used without interfering with or abridging the rights and easement hereby acquired; subject, however, to existing easements for public roads and highways, public utilities, railroads and pipelines.

D. BORROW EASEMENT

Borrow sites will be identified at the next milestone.

8. EXISTING FEDERAL PROJECTS WITHIN THE STUDY AREA

There are no federal projects in the study area.

9. FEDERALLY OWNED LANDS NEEDED FOR THE PROJECT

There are no known federally owned lands needed for this project.

10. DESCRIPTION OF SPONSOR OWNED LANDS IN THE PROJECT AREA

Portions of the TSP levee footprints lie within easement interests held by the Central Valley Flood Protection Board. The NFS has the legal capability to provide the lands required for the TSP. This information is tentative in nature and will be revised once the recommended plan is selected and sponsor lands can be reviewed for interest owned and sufficiency to support project purposes.

The Non-Federal Sponsors have been notified in writing by letter of the risks of acquiring right-of-way interests before execution of the construction agreement.

11. BASELINE COST ESTIMATE

The baseline cost estimate is the total costs of the lands combined with the cost of support and administrative activities to acquire those lands. The estimated total costs for Real Estate Acquisition for the TSP is shown in **Table 1**. The date of the approved cost estimate prepared by Sacramento District Real Estate Division was April 2014. The costs include land payments as well as administrative costs and incremental costs associated with acquiring the real estate interests to include potential condemnations. Displaced persons and business may be entitled to relocation assistance benefits (P.L. 91-646, Title II as amended). The cost estimate is tentative in nature and will be revised once the recommended plan is selected and appropriate real estate interests are determined.

Table 6. Cost Table for 2019 Real Estate Plan

[This table has been intentionally removed. FOR INTERNAL USE ONLY]

12. UNIFORM RELOCATION ASSISTANCE (PL 91-646, TITLE II AS AMENDED)

Relocation assistance benefits to residents may be applicable, including storage of household goods, moving costs, lodging, incidentals, differential payments, etc. Businesses could be entitled to receive advisory services, reimbursement for actual reasonable moving costs, re- establishment costs which are capped at $10,000, and certain reasonable and necessary incidental costs associated with the relocation. Cost estimates will be revised after completion of feasibility-level design and appropriate real estate interests are determined.

A preliminary estimate of potential PL 91-646 displacements was prepared by the Sacramento District Real Estate and Engineering Divisions. The impacts and estimates relating to potential displacements, and the anticipated need to provide relocation assistance benefits, are provided exclusively for project cost estimating purposes only and are not intended to be relied upon for provision of benefits and/or payment of the estimates referenced herein. Should the project be authorized, a relocation plan will be provided by the NFS.

13. ZONING ORDINANCES

There will be no application or enactment of zoning ordinances in lieu of, or to facilitate, acquisition for structural features of this project. Should plans be developed for non- structural features during feasibility-level design, it is possible that there will be certain building restrictions in areas where elevations or flood proofing measures are proposed, and in areas where there may be buy-out acquisitions.

14. ACQUISITION SCHEDULE

The following acquisition schedule for project features is based on the premise that the project will impact approximately 500 landowners for the levee alignment. It is assumed that the project will be constructed in sections over a 10-15 year period. An acquisition schedule will be prepared when the recommended plan is selected. The schedule below provides the total amount of time to complete the acquisition of real estate rights for mitigation and for the construction of the levee alignment and other project features based on the preliminary information available at this time. This schedule is only for planning purposes and will be updated for the final plan.

Table 7. Real Estate Acquisition Schedule

Project Name: Lower Cache Creek Flood Reduction Project	COE Start	COE Finish	NFS Start	NFS Finish

Receipt of Preliminary Drawings from Engineering/PM	TBA	TBA	TBA	TBA
Receipt of Final Drawings from Engineering/PM	TBA	TBA	TBA	TBA
Formal Transmittal of Final Drawings and Instruction to Acquire LEERDS	TBA			
Conduct Landowner Meetings				6 months
Prepare/Review Mapping & Legal Descriptions				1 year
Obtain/Review Title Evidence				1 year
Obtain/Review Tract Appraisals				1 year
Conduct Negotiations				4 years
Condemnation				6 years
Prepare/Review Condemnations	TBA	TBA		
Perform Condemnations	TBA	TBA		
Obtain Possession	TBA	TBA		
Complete/Review PL 91-646 Benefit Assistance				2 years
Certify All Necessary LERRDS for Construction				TBA
Prepare and Submit Credit Requests				TBA
Review/Approve or Deny Credit Requests	TBA	TBA		
Establish Value for Creditable LERRDS	TBA	TBA		

15. FACILITY/UTILITY RELOCATIONS

Preliminary facility and utility relocation data was collected and detailed by the Sacramento District, Engineering Division. At the time of this report, feasibility-level analysis had yet to be performed.

Real Estate Guidance issued for 3x3x3 studies indicates that if the costs of relocation of facilities and utilities is less than 30% of project costs, a preliminary compensable interest report should not be prepared (refer to Real Estate Policy Guidance Letter Non. 31-Real Estate Support to Civil Works Planning Paradigm (3x3x3) dated January 10, 2013, attached as Exhibit A). Because the estimated cost of relocations does not exceed 30% of total project cost, an Attorney's Preliminary Opinion of Compensable Interest was not prepared for this project. Rather, once the recommended plan is selected and feasibility level of design is complete, a Relocations Report will be prepared and the Real Estate Plan will include a relocations assessment indicating which relocations are covered by the substitute facilities doctrine. A Final Attorney's Opinion of Compensability will be prepared before the project partnership agreement is executed for each utility/facility.

The Non-Federal Sponsor will perform these relocations as a part of its responsibility under the project authority. The Government will make a final determination of the relocations necessary for the construction, operation or maintenance of the project after further analysis, and completion and approval of the Final Attorney's Opinion of Compensability for each of the impacted utilities and facilities.

16. HAZARDOUS, TOXIC AND RADIO ACTIVE WASTE

A Phase I Environmental Site Assessment has not been conducted, but is planned. The information on contaminates on lands within the project area will be revised after database searches are completed and a recommended plan is selected. One area of concern during the assessment will be the Cache Creek Basin.

17. LANDOWNER CONCERNS

The project has received wide-spread support from the community; however, the attitudes of the landowners who will be directly affected by its construction are not known. The Non-Federal Sponsor is confident that they will be able to acquire the right- of-way required for the project.

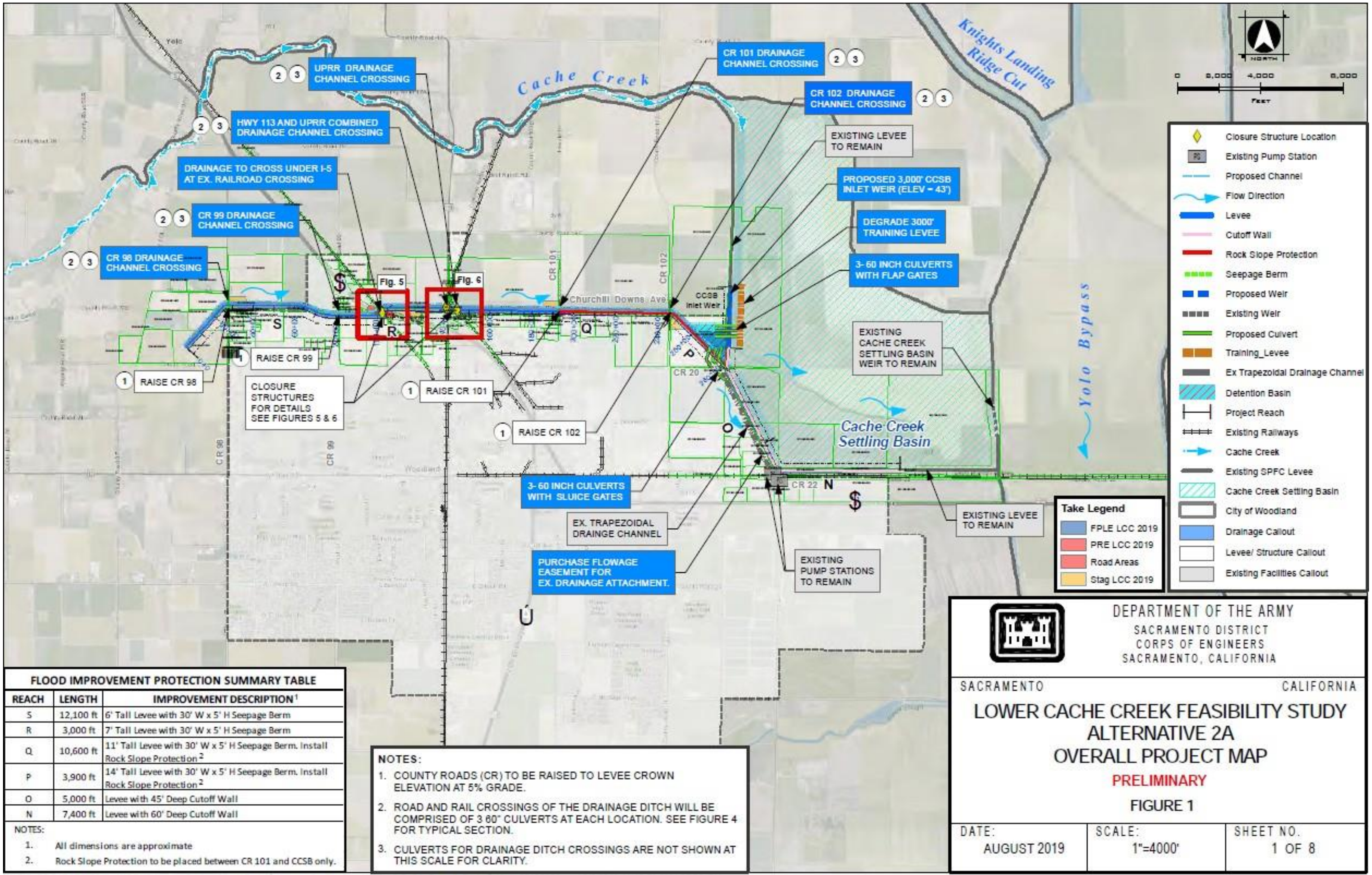
18. PROJECT MAP

Exhibit A indicates the overall project site. Once specific sites are determined, maps will be Register generated and provided to the Non-Federal Sponsor.

19. PHYSICAL TAKINGS ANALYSIS

The Takings Analysis is underway and will be added when completed.

EXHIBIT A PROJECT MAP



FLOOD IMPROVEMENT PROTECTION SUMMARY TABLE

REACH	LENGTH	IMPROVEMENT DESCRIPTION[1]
S	12,100 ft	6' Tall Levee with 30' W x 5' H Seepage Berm
R	3,000 ft	7' Tall Levee with 30' W x 5' H Seepage Berm
Q	10,600 ft	11' Tall Levee with 30' W x 5' H Seepage Berm. Install Rock Slope Protection[2]
P	3,900 ft	14' Tall Levee with 30' W x 5' H Seepage Berm. Install Rock Slope Protection[2]
O	5,000 ft	Levee with 45' Deep Cutoff Wall
N	7,400 ft	Levee with 60' Deep Cutoff Wall

NOTES:

1. All dimensions are approximate
2. Rock Slope Protection to be placed between CR 101 and CCSB only.

NOTES:

1. COUNTY ROADS (CR) TO BE RAISED TO LEVEE CROWN ELEVATION AT 5% GRADE.
2. ROAD AND RAIL CROSSINGS OF THE DRAINAGE DITCH WILL BE COMPRISED OF 3 60" CULVERTS AT EACH LOCATION. SEE FIGURE 4 FOR TYPICAL SECTION.
3. CULVERTS FOR DRAINAGE DITCH CROSSINGS ARE NOT SHOWN AT THIS SCALE FOR CLARITY.

DEPARTMENT OF THE ARMY
SACRAMENTO DISTRICT
CORPS OF ENGINEERS
SACRAMENTO, CALIFORNIA

SACRAMENTO CALIFORNIA

LOWER CACHE CREEK FEASIBILITY STUDY
ALTERNATIVE 2A
OVERALL PROJECT MAP
PRELIMINARY
FIGURE 1

DATE:	SCALE:	SHEET NO.
AUGUST 2019	1"=4000'	1 OF 8

G:\GIS_PROJECTS\CIVIL_WORKS\Lower_Cache_Creek\Projects\Lower_Cache_Creek\MPK\FIG_01_Overall_Project_Map_20190906.mxd 9/5/2019 11:16:51 AM L2RE9JDH

EXHIBIT B - ASSESSMENT OF NON-FEDERAL SPONSOR'S REAL ESTATE ACQUISITION CAPABILITY

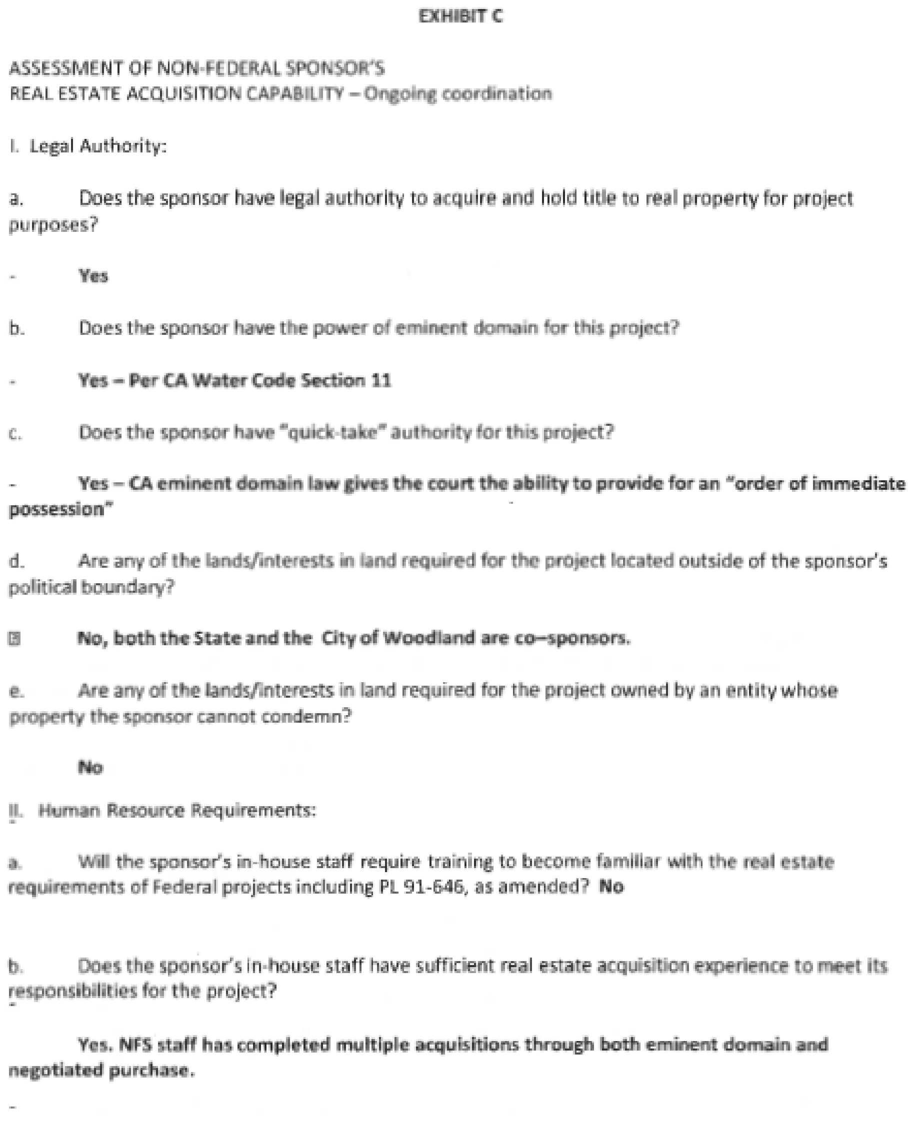


EXHIBIT C

ASSESSMENT OF NON-FEDERAL SPONSOR'S
REAL ESTATE ACQUISITION CAPABILITY – Ongoing coordination

I. Legal Authority:

a. Does the sponsor have legal authority to acquire and hold title to real property for project purposes?

- **Yes**

b. Does the sponsor have the power of eminent domain for this project?

- **Yes – Per CA Water Code Section 11**

c. Does the sponsor have "quick-take" authority for this project?

- **Yes – CA eminent domain law gives the court the ability to provide for an "order of immediate possession"**

d. Are any of the lands/interests in land required for the project located outside of the sponsor's political boundary?

☒ **No, both the State and the City of Woodland are co–sponsors.**

e. Are any of the lands/interests in land required for the project owned by an entity whose property the sponsor cannot condemn?

No

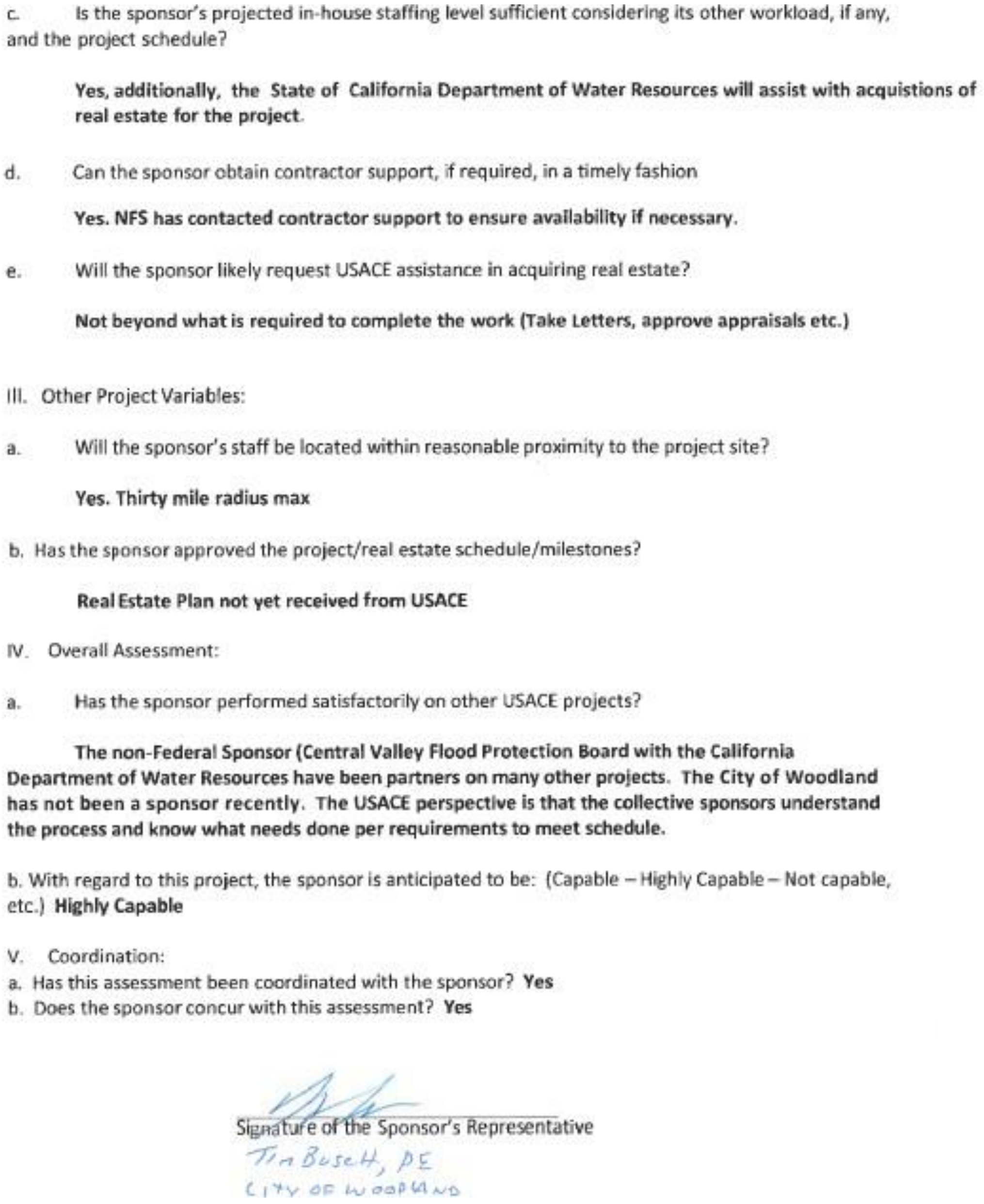
II. Human Resource Requirements:

a. Will the sponsor's in-house staff require training to become familiar with the real estate requirements of Federal projects including PL 91-646, as amended? **No**

b. Does the sponsor's in-house staff have sufficient real estate acquisition experience to meet its responsibilities for the project?

Yes. NFS staff has completed multiple acquisitions through both eminent domain and negotiated purchase.

-



c. Is the sponsor's projected in-house staffing level sufficient considering its other workload, if any, and the project schedule?

Yes, additionally, the State of California Department of Water Resources will assist with acquistions of real estate for the project.

d. Can the sponsor obtain contractor support, if required, in a timely fashion

Yes. NFS has contacted contractor support to ensure availability if necessary.

e. Will the sponsor likely request USACE assistance in acquiring real estate?

Not beyond what is required to complete the work (Take Letters, approve appraisals etc.)

III. Other Project Variables:

a. Will the sponsor's staff be located within reasonable proximity to the project site?

Yes. Thirty mile radius max

b. Has the sponsor approved the project/real estate schedule/milestones?

Real Estate Plan not yet received from USACE

IV. Overall Assessment:

a. Has the sponsor performed satisfactorily on other USACE projects?

The non-Federal Sponsor (Central Valley Flood Protection Board with the California Department of Water Resources have been partners on many other projects. The City of Woodland has not been a sponsor recently. The USACE perspective is that the collective sponsors understand the process and know what needs done per requirements to meet schedule.

b. With regard to this project, the sponsor is anticipated to be: (Capable – Highly Capable – Not capable, etc.) **Highly Capable**

V. Coordination:

a. Has this assessment been coordinated with the sponsor? **Yes**

b. Does the sponsor concur with this assessment? **Yes**

Signature of the Sponsor's Representative

Tim BuscH, PE
CITY OF WOODLAND

Prepared by:

____
Bill Casale
Supervisory Realty Specialist
U.S. Army Engineer District, Sacramento

Date _________________

Reviewed and Approved by:

____
Adam B. Olson
Chief, Real Estate Division
U.S. Army Engineer District, Sacramento

Date ___________________

ECONOMICS REPORT

APPENDIX F

LOWER CACHE CREEK DRAFT FEASIBILITY STUDY

Yolo County, CA

December 2019

United States Army Corps of Engineers
Sacramento District

Page Intentionally Left Blank

TABLE OF CONTENTS

List of Tables

List of Figures

1.0 INTRODUCTION

1.1 Purpose

This appendix describes the assumption, data, methodologies, and techniques used to perform the economic analysis for the Lower Cache Creek Feasibility Study (LCCFS). The results presented in this appendix are based on two project conditions, the without project condition and with-project condition.

1.2 Study Guidance

Pertinent guidance governing economic analysis procedures includes:

- Engineer Regulation (ER) 1105-2-100, Planning Guidance Notebook, 22 April 2000.
- Engineer Regulation (ER) 1105-2-101, Risk Assessment for Flood Risk Management Studies, 17 July 2017.
- Engineer Regulation (ER) 1105-2-100 Appendix D, Economic, Social and Regional Considerations, 1 April 2019.
- Engineer Regulation (ER) 1110-2-1302, Civil Works Cost Engineering, 30 June 2016.
- Economic Guidance Memorandum (EGM) 01-03, Generic Depth-Damage Relationships, 4 December 2000.
- Economic Guidance Memorandum (EGM) 04-01, Generic Depth-Damage Relationships for Residential Structures with Basements, 10 October 2003.
- Economic Guidance Memorandum (EGM) 09-04, Generic Depth-Damage Relationships for Vehicles, 22 June 2009.
- Engineer Manual (EM) 1110-2-1619, Risk-Based Analysis for Flood Damage Reduction Studies, 1 August 1996.
- Institute for Water Resources (IWR) Report 96-R-12, Analysis of Nonresidential Content Value and Depth-Damage Data for Flood Damage Reduction Studies, 1 May 1996.

2.0 STUDY AREA SETTING

2.1 Economic Impact Areas

The study area encompasses the city of Woodland and town of Yolo, California. The main source of flooding to the study area is Lower Cache Creek. To help support the economic analysis and selection of the recommended plan, the study area was divided into ten economic impact areas (EIA), N1, N2, N3, N4, N5, S6, S7, S8, S9, and S10. The "N" and "S" prefixes represent economic impact areas north and south of Lower Cache Creek, respectively. The geographic footprint for each the economic impact areas was developed based on previous flooding characteristics, potential consequence (urban or agricultural areas), and with-project features and how these features may impact future flooding events. See Figure 1.

2.2 Index Points

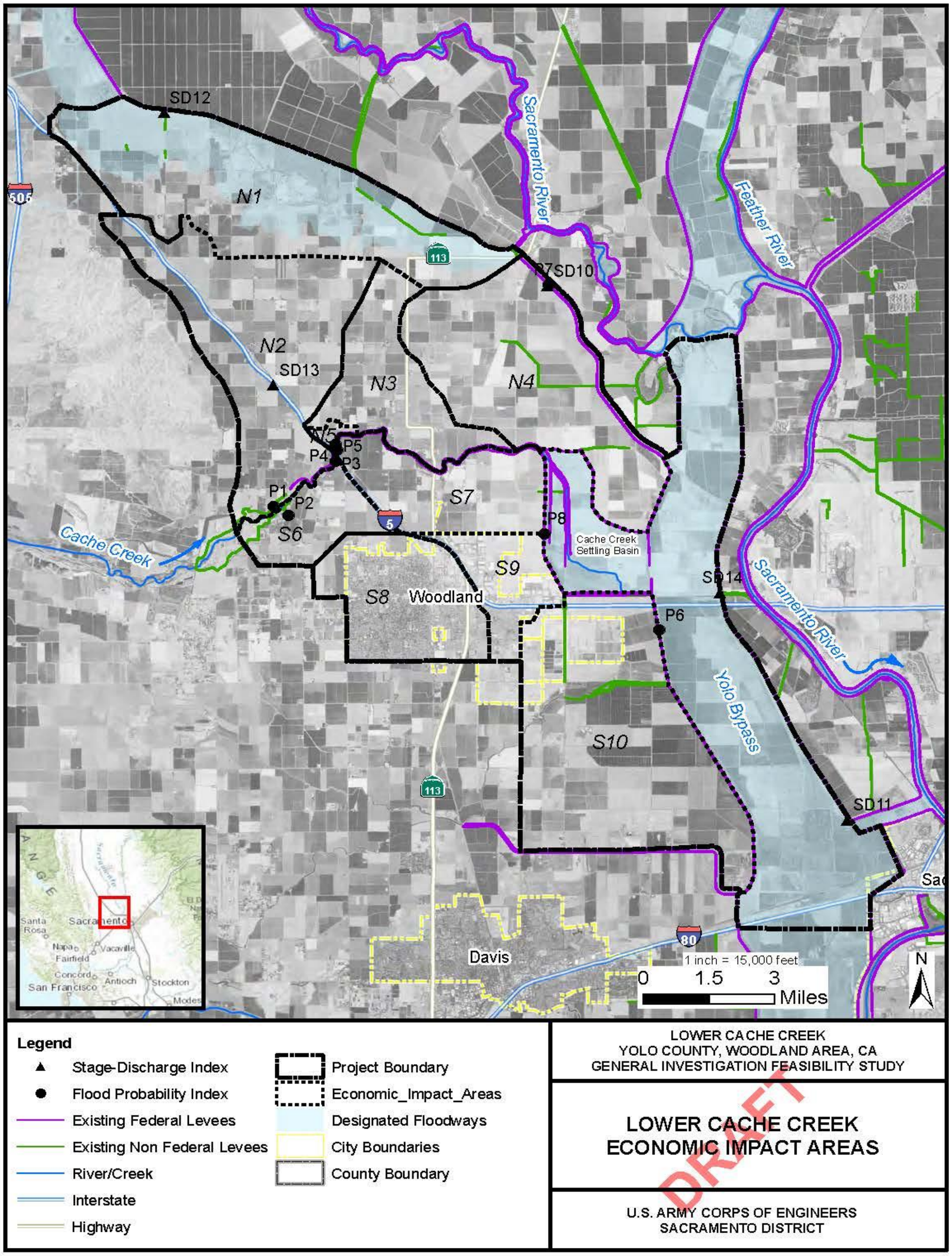
All without project engineering related information developed for this study are specific to eight index points. Index point locations are based on hydrologic, hydraulic, and economic related conditions specific to the economic impact areas. The representative index point's names and general location are listed below and shown in Figure 1.

- P1 Overtopping Right Bank of Lower Cache Creek
- P2 Overtopping Left Bank of Lower Cache Creek
- P3 Lower Cache Creek Right Bank – Upstream of Interstate 5
- P4 Lower Cache Creek Right Bank – Downstream of Interstate 5
- P5 Lower Cache Creek Left Bank – Downstream of Interstate 5
- P6 Yolo Bypass Right Bank
- P7 Knights Landing Ridge Cut
- P8 Cache Creek Settling Basin – Right Bank

2.3 Multiple Source Flooding

Many economic impact areas are susceptible to flooding from multiple index point sources throughout the study area and each source comes with its own unique combination of probabilities and consequences. The simplifying assumption was made that the flood source, or index point, with the highest expected annual damage is representative of both without-project and with project for each economic impact area. In this study, the models do not capture the combined probabilities and consequences of multiple levee breaches within a single economic impact area and may result in the overall economic risk being slightly underestimated. Please see the Hydraulic and Civil Design Appendix (Appendix B) for more information.

Figure 1: Economic Impact Areas and Engineering Index Points



22 MAY 2015 DRAFT PLATE 005

3.0 DATABASE DEVELOPMENT

3.1 Data Development

The economic database, or structure inventory, is from the Yolo County Tax Assessor. Building attribute data were used to determine land use and valuation of structures and contents. However, for most of the non-residential structures, the county database data was supplemented with GIS and Google Earth to estimate building square footages. Several field visits were taken to collect the base inventory data using standard USACE practices. Several factors are taken into consideration when doing the data collection. These factors included number of stories, foundation heights, building use, occupancy types, class, construction rating, and condition. The data collected for the study area produced a structure inventory encompassing the entire study area, an area larger than the current 0.2 percent (1/500) annual exceedance probability (AEP) floodplain. Parcels with structures were categorized by land use and grouped into four main building categories:

a. Residential – Includes all parcels represented by a single unit such as detached single-family homes and parcels with more than one unit such as apartment complexes, condominiums, and multiplex units. Each parcel may have multiple structures. The study area has a total of 12,929 residential structures. There are 588 residential structures potentially subject to flooding from the 0.2 percent AEP event.

b. Commercial – Includes retail, service stations, office buildings, restaurants, and shopping centers. The study area has a total of 793 commercial structures. There are 155 commercial structures potentially subject to flooding in the 0.2 percent AEP event.

c. Industrial – Includes warehouses, light and heavy manufacturing facilities, and food and agricultural processing facilities. The study area has a total of 366 industrial structures. There are 242 industrial structures potentially subject to flooding in the 0.2 percent AEP event floodplain.

d. Public – Includes both public and semi-public uses such as post office, fire department, hospitals, government buildings, schools, and churches. The study area has about total of 25 public structures in the floodplain.

Table 1 shows the number of structures by land use within the 0.2 percent AEP event floodplain.

Table 1. Number of structures by Land Use in 0.2% AEP Floodplain

Land Use	Number of Structures
Residential	588
Commercial	155
Industrial	242
Public	1
Total	**986**

3.2 Damageable Property

Table 2 displays the value of damageable property for all structures, contents, and totals that are contained in the 0.2 percent AEP floodplain. The total value of damageable property, structures and contents, within the 0.2 AEP percent floodplain is approximately $2.3 billion.

Table 2. Damageable Property in 0.2% AEP Floodplain (in $1,000, October 2020 prices)

Land Use Type	Structure Value	Content Value	Total
Commercial	162,528	114,999	277,527
Industrial	662,080	1,045,810	1,707,890
Public	2,116	206	2,322
Residential	167,154	167,154	334,309
Totals	993,879	1,328,169	2,322,048

3.3 Elevations and Stationing

Each property in a flood-risk management economic analysis is assigned a ground elevation at mean sea level, as well as a first-floor elevation and a lowest opening elevation if it is different from the first-floor elevation. Each structure point was overlaid onto the grid-cells of the TuFlow, (Two-dimensional Unsteady FLOW) software, modeling to assign each structure a station that associates with a set of eight water surface elevation grids. TuFlow estimates the probable range of hydraulic characteristics, predicts an area of inundation. The elevations and stations are used in the flood damage analysis model to help determine depths of flooding for each flood event evaluated. The first-floor elevations for each type of structure are assigned an uncertainty factor expressed as a standard deviation around a normally distributed variable.

3.4 Structure Valuation

Corps planning guidance requires property to be valued in terms of depreciated replacement value. Depreciated replacement value of structures were estimated based upon building square footage, estimated cost per square foot (from the October 2018 Marshall & Swift Valuation Handbook), and estimated depreciation. Values per square foot were based on building use, class, and type as outlined in the Marshall and Swift Valuation Handbook. Price levels were updated from October 2018 to October 2020 using July 2019 Marshall-Swift (M-S) Valuations Comparative Cost Multipliers for Sacramento, CA and a simple time trend was used to update from July 2019 to October 2020 price levels.

3.5 Contents Valuation

Residential contents are not valued separately in the damage analysis, since users of standard residential depth-damage functions issued by IWR in 2000 and 2003 are directed to enter 100 percent as the residential content-to-structure value ratio (CSVR). For non-residential structures, a CSVR was based on the specific type of use of the structure. CSVRs developed as part of the American River Economic Reevaluation Report (ERR) completed by Sacramento District were utilized for this study and ranged from 25 percent to 213 percent of the structure value. As a part of the ERR, Sacramento completed an expert elicitation to develop CSVRs and content damage functions that better reflect the land use in the region.

3.6 Automobiles Valuation

The number of cars impacted was based on the number of cars per residential unit (1.93), which in turn was based on the total number of automobiles and trucks registered in the Sacramento Area (source: California Department of Finance) divided by the number of households. The analysis assumed that, based on relatively short evacuation times, about 50% of residential-based vehicles would be removed from the flood area prior to the event and only 20% would be removed from dealerships. This is consistent with EGM 09-04, which recommends a removal rate of 50.6% for areas where the warning time is less than 6 hours.

3.7 Emergency Cost Losses

Depreciated replacement values of structures are used to assess structure and content damages and to gage the cost of replacing damaged portions of structures and contents of similar use and condition. However, there are other costs/damages directly associated with structure and content damages that may result from a flood event but which are not captured in the estimate of structure and content damages. The additional category of emergency costs considered here are clean-up costs.

Clean-Up Costs: Flood waters leave debris, sediment, salts and the dangers of diseases throughout flooded structures, making the cleaning of these structures a necessary post-flood activity. Clean-up costs for the extraction of flood waters, dry-out, and decontamination vary significantly based upon various factors, including depth of flooding. Studies conducted by both Sacramento and New Orleans Districts indicate a maximum value of ten dollars per square foot for such clean-up costs. This maximum per square foot cost covers clean-up costs associated with mold and mildew abatement, which entails having professional firms apply fans, chemicals, and other techniques to eliminate and prevent mold/mildew in inundated areas. The maximum clean-up cost of $10 per square foot was used for this analysis and applied for flood depths equal to and exceeding five feet, with damage percentages scaled down for depths between zero and five feet.

3.8 Depth-Damage Curves

The depth of flooding is the primary factor in determining potential damages to structures, contents, and automobiles. Depth-percent damage functions were used in the HEC-FDA models to estimate the percent of value lost for these categories. Residential depth-damage curves (structures and contents) were taken from Economic Guidance Memorandum (EGM) 01-03, Generic Depth-Damage Relationships, and 04-01, Generic Depth-Damage Relationships for Residential Structure with Basements, for use on both single-family and multi-family residential structures. Structures were identified as 1-story, 2-story, or split-level. Mobile home curves were taken from the May 1997 Final Report, Depth-Damage Relationships in Support of Morganza to the Gulf, Louisiana Feasibility Study. Non-residential structure curves were based on revised FEMA Flood Insurance Administration (FIA) curves.

Depth-percent damage functions for automobiles were based on weighted average from curves developed by the Institute for Water Resources (IWR) and provided in EGM 09-04, Generic Depth-Damage Relationships for Vehicles.

3.9 First Floor Elevations

An important component of structure and content damage estimation within HEC-FDA is first floor elevation (stage). First floor elevation is defined as a structure’s ground elevation (or ground stage) plus structure foundation height. To calculate depth of flooding at each structure, first floor elevations are subtracted from flood elevations within HEC-FDA, this depth is then applied to the appropriate depth damage curve to estimate structure damage.

3.10 Economic Uncertainty

The estimated valuation of residential and non-residential structures and contents along with automobile losses include uncertainty. In the estimation of structure value, three variables were considered to have a possible range of values: 1) value per square foot, 2) building square footage, and 3) percent of estimated depreciation. Using triangular distributions to describe the range of these three variables, a Monte Carlo simulation was run on typical structures by category and the mean and standard deviations were compared to derive coefficients of variation for structure values by category. Content value uncertainties for non-residential structures were based on data from the expert elicitation mentioned previously. The program Best Fit was used to determine what would be a reasonable distribution, and using the model data, it was determined that a normal distribution best described uncertainty in the structure and content valuation. These uncertainty parameters for valuation were imported into the HEC-FDA program.

Several factors contributed to the uncertainty associated with automobile damages. These factors include the average unit value, the number of vehicles per residence, and the evacuation rate. It was assumed that the average number or automobiles per residential unit was two and the evacuation rate was 50%. While uncertainty in these variables was not considered, uncertainty in the percent damage by depth (as reflected in the depth-percent damage curve) was taken into account.

Uncertainty in first floor elevation was also included in the model. During the 2013 and 2015 field inventory, first floor estimates were made by visual inspection and assigned to structures in one half-foot increments. For example, the average SFR built on slab without any fill might be listed as ground elevation + 0.5 foot to 1.0 foot; raised foundations either 1.5, 2 or 2.5 feet. Based on this level of precision, it was assumed that 0.5-foot standard deviation would capture the potential uncertainty in this first-floor elevation adjustment.

The uncertainty associated with the percent damages at specific depths of flooding for automobiles and structures/contents were entered into the HEC-FDA model. Residential structure and content depth-percent damage curves are normally distributed and include standard deviations of percent damages by depth of flooding. Non-residential content depth-percent damage curves are triangularly distributed and include a minimum, most likely, and maximum percent damage by depth of flooding.

4.0 ENGINEERING APPROACH: HYDROLOGIC, HYDRAULIC, AND GEOTECHNICAL DATA

All hydrologic and hydraulic (H&H) data, including all floodplains and water surface elevations, was provided by USACE engineering division. The H&H data was the basis for determining flood damages and engineering performance for the study. Flood inundation was modeled for the following eight AEP events: 0.5, 0.2, 0.1, 0.05, 0.02, 0.01, 0.005, and 0.002 at each index location using TuFlow. Please see Appendix D for more information regarding hydraulic modeling. The following engineering inputs drive the potential for flooding at a given index point:

- Unregulated Flow Probability —the relationship between natural (unregulated) rivers flow and the probability of that flow being exceeded.
- Unregulated to Regulated Flow Transform —the relationship between natural flow and regulated flow resulting from reservoir routing, channel routing, or channel diversion.
- Discharge-Stage Relationship — the relationship between regulated flow and corresponding river depth.
- Geotechnical Performance — the relationship between river depth and the probability of levee overtopping and/or failure at that depth.

5.0 DAMAGE ANALYSIS MODELING

5.1 Basic Modeling

The structure inventory for the study area discussed above, including elevations, structure values, and depth-damage functions, uncertainty factors, and water surface elevations for each AEP event were entered into HEC-FDA to estimate without and with-project damages. Damages in this analysis consist of physical inundation damages to automobiles, commercial, industrial, public, and residential structures. Depth grids produced from the TuFlow model output provide distinct water surface elevations at distinct locations throughout the study area.

5.2 The HEC-FDA Program

The basic assumption underlying use of a risk analysis program is that data in flood-risk studies are based on imperfect knowledge and unpredictable future developments, so that key variables for which median or most likely values are specified could, in reality, take on a range of values above and below the specified values. The Flood Damage Analysis - Hydrologic Engineering Center (HEC-FDA), version 1.4.2, program was used to estimate flood related damages and engineering performance for the LCCRFS.

In HEC-FDA, there are two main types of data required, 1) economic inventory data, which includes: structure values, ground and first-floor elevations, stream stationing, occupancy type (one-story homes, retail businesses, government offices, etc.), content to structure values ratios, depth-damage relationships, and uncertainty factors for all economic variables, and 2) engineering related data, which includes: water surface elevations for each stream station (floodplains), exceedance probability-discharge relationships, stage-discharge relationships, geotechnical related data, and engineering related uncertainty data. All engineering and economic data are entered into the program in terms of mean values and are accompanied by appropriate uncertainty parameters specifying the range of possible values for each variable.

The first step of the risk analysis produces an economic stage-damage function. The program performs numerous iterations, each combining various possible values for each economic input (elevation, value, and depth-damage) by sampling the uncertainty distributions provided for those variables. Estimated flood damages for each foot of flooding are computed based on the level of investment subject to flooding, the beginning damage elevation, and the estimated damage to that investment with various depths of flooding. The HEC-FDA program references each structure’s first floor elevation or beginning damage elevation to the corresponding frequency event elevation at the reach index point. Stage-damage relationships for each structure within each damage category are then aggregated to the reach index location to derive the aggregated stage damage functions.

The second step of the risk analysis integrates the economic aggregate stage-damage function with the engineering data. The HEC-FDA program utilizes a Monte Carlo process to randomly sample multiple probability distribution functions to produce tens of thousands of possible flood events instead of a few discrete scenarios. For each event, the program samples the range of possible values for each variable and determines (a) whether the flood event results in damage, and (b) how much damage occurs. The result is to effectively extend the period of record synthetically to thousands of flood events in a manner that reflects uncertainty in assumptions and the dynamic interaction of variables over long periods of time.

The calculation of annual damages is basically a weighted average where damages corresponding to each AEP event are computed and multiplied by the incremental probability of that event, then all of these products are summed. This total, referred to as expected annual damages (EAD), represents an estimate of the average damages that would be expected in any given year over the long term. The outcome of the Monte Carlo simulations is a single expected value for annual damages that represents an average of the thousands of synthetic events. Even though it is a single value, the expected value integrates many variables, including their uncertainty distributions. Computations are made for expected annual damages under each condition, without-project and with-project.

6.0 WITHOUT-PROJECT CONDITIONS

The section reports the results under the assumption that no project is constructed.

6.1 Without-Project Expected Annual Damages (EAD)

As mentioned above, expected annual damages represents an estimate of the average damages that would be expected in any given year over the long term. It is the primary economic statistic used to describe the flooding problem in the study area; it is also used as the baseline to measure potential benefits from proposed flood risk management projects. Without project expected annual damages by economic impact area for autos, commercial, industrial, public, residential (structures and contents), and emergency clean-up costs for the without and with-project conditions are shown in Table 3.

Table 3. Without-Project Expected Annual Damages by Economic Impact Areas (in $1,000's, October 2020 prices)

Economic Impact Area	Automobiles	Commercial	Industrial	Public	Residential	Emergency Costs	Total
N1	0	20	1	0	10	6	37
N2	0	6	0	0	12	3	21
N3	2	10	0	8	82	5	107
N4	0	18	0	0	9	3	30
N5	23	20	241	26	570	66	945
S6	0	99	0	0	29	8	136
S7	2	10	673	0	53	61	798
S8	83	312	3,500	14	904	514	5,327
S9	0	297	13,385	0	1	1,646	15,330
S10	0	0	0	0	0	0	0
Total	**111**	**792**	**17,800**	**47**	**1,670**	**2,312**	**22,731**

Table 4 shows total EAD by economic impact area percentage of total study wide EAD. Total expected annual damages for the without-project condition are approximately $22.7 million. The economic impact area S9 contains approximately 67 percent of the total EAD for the study area, primarily due to the large amount of commercial/industrial structures in that EIA. EIA S8, which accounts for approximately 23 percent of the without project damages, represents the second highest percentage of total EAD. EIA S8 is primarily residential and commercial structures within the city limits of Woodland.

Table 4. Without-Project Expected Annual Damages and Percentage of EAD by Economic Impact Area (in $1,000's, October 2020 prices)

Economic Impact Area	**EAD**	**Percentage of Without Project EAD**
N1	37	0.2%
N2	21	0.1%
N3	107	0.5%
N4	30	0.1%
N5	945	4.2%
S6	136	0.6%
S7	798	3.5%
S8	5,327	23.4%
S9	15,330	67.4%
S10	0	0.0%
Total	**22,732**	**100.0%**

7.0 WITH-PROJECT CONDTIONS

7.1 Focused Array of Alternatives

This section provide a description of the focused array of alternatives. Many conceptual alternatives were considered during the plan formulation process. See the main report for a detailed description of all alternatives.

7.1.1 Future without-project condition

The No Action Plan is the same as the without project condition.

7.1.2 North Bypass A (Alt 1A)

This alternative is similar to Alternative 6A, however, it also includes a grade control structure and a right bank levee extension upstream of I-5. These features would increase the stage upstream of I-5 resulting in floodwaters overtopping the left bank and flowing north towards the Colusa Basin Drain.

7.1.3 North Bypass B (Alt 1B)

This alternative is similar to the Alternative 1A. However, it includes the purchase of flowage easements to insure the floodwaters are conveyed to the Colusa Basin Drain. This alternative would likely include seepage mitigation and Rock Bank Protection along most of its length.

7.1.4 North Bypass C (Alt 1C)

This alternative is similar to Alternative 1A. However, it includes the construction of levees to insure the floodwaters are conveyed to the Colusa Basin Drain. Only the areas removed from the flowage easements shown in the North Bypass B version would benefit from the proposed levees. This alternative would likely include seepage mitigation and rock bank protection along most of its length.

7.1.5 North Bypass D (Alt 1D)

This alternative is similar to Alternative 1A. However, it replaces the grade control structure and a right bank levee extension upstream of I-5 with a smaller extension of the right bank, a degrading of the left bank levee upstream of I-5, a new levee segment adjacent to I-5, and no strengthening of levees on the right bank of Cache Creek downstream of I-5.

7.1.6 South Bypass A (Alt 2A)

Alternative 2A consists of improving existing levees, especially along the Cache Creek Settling Basin (CCSB), and constructing a new levee north of the City of Woodland (Woodland) to protect Woodland from Lower Cache Creek flooding. The floodwaters would pass into the CCSB through an opening excavated into the western levee of the CCSB. This alternative has been identified as the tentatively selected plan (TSP).

7.1.7 South Bypass B (Alt 2B)

This alternative is similar to Alternative 2A, however, it includes additional features to address localized induced stages at I-5 and Highway 113. Based on additional qualitative analysis this increment was screened out of the incremental array because there was no significant inflection in the cost and benefits relative to the retained alternatives.

7.1.8 South Bypass C (Alt 2C)

This alternative is similar to Alternative 2A. However, a channel has been included that would convey floodwaters to the Yolo Bypass has been included. This channel would involve moving a portion of the CCSB east levee further to the east to avoid a large industrial complex. The railroad line along the south side of the CCSB would also require extensive modifications to allow for the flood control channel.

7.1.9 South Bypass D (Alt 2D)

This alternative would be similar to Alternative 2C. However, it would also include strengthening the right bank levee of Cache Creek and the south bank levee of Cache Creek along the town of Yolo. This alternative would likely include Seepage mitigation and rock bank protection along most of its length.

7.1.10 Strengthen In Place A (Alt 6A)

This alternative would involve fixing the right bank levee of Cache Creek. The alternative would also include fixing the left bank of Cache Creek along the town of Yolo. This alternative reduces the risk of flooding associated with geotechnical related failures. However, the hydraulic capacity (overtopping) related failure probability would remain the same. This alternative would likely include seepage mitigation and rock bank protection along most of its length.

7.1.11 Strengthen In Place B (Alt 6B)

This alternative would involve fixing the right bank levee of Cache Creek. This alternative reduces the risk of flooding associated with geotechnical related failures. This alternative would significantly reduce the risk of flooding to the south of Cache Creek.

7.1.12 Strengthen In Place C (Alt 6C)

This alternative is similar to Alternative 6A but includes strengthening or increasing the height of both left and right levees along their entire length. The left bank levee upstream of I-5 would be removed and a new levee would be constructed adjacent to I-5. This would force the floodwaters to the north where it would be conveyed across I-5 through a bank of culverts. This alternative would likely include seepage mitigation and rock bank protection along most of its length.

7.1.13 Partial Setback Levee A (Alt 7A)

The proposed design would involve setting levees back along the right bank only and extending the right bank levee upstream to prevent right bank floodwaters from overtopping the reach upstream of I-5. The channel dimensions for the setback levee configuration would be designed to maintain the same water surface profile as existing condition but with additional flow. The additional flow would be based on maintaining the same left bank overflow upstream of I-5 as the no-action plan. The alternative would be designed to have no increase in flows to the north. The alternative would increase inflows to the Cache Creek Settling Basin (CCSB). The outlet weir of the CCSB would be modified to a step weir to accommodate these additional flows.

7.1.14 Partial Setback Levee B (Alt 7B)

This proposed design is similar to Alternative 7A. However, instead of increasing the weir capacity of the Cache Creek Settling Basin (CCSB) this alternative would include a levee or channel that would divert overbank flow to the north of CCSB and purchase of flowage easements.

7.1.1 Focused Array Net Benefit and Benefit to Cost Ratio Analysis

This section presents the economic results of the focused array of alternatives. These results will help support the decision regarding the selection of the tentatively selected plan (TSP). Net benefits are the difference between annual benefits and annual costs. Benefit-cost ratios (BCRs) are calculated as annual benefits divided by annual costs. Average annual benefits, average annual costs, net benefits and BCRs for the focused array of alternatives are shown in Table 5. It should be noted that Table 5 is based on FY19 price levels and discount rate, which were the prevailing parameters when this table was developed.

Table 5. Focused Array Annual Benefits, Costs, and BCRs ($1,000 October 2019 price levels, 2.875% discount rate)

Alternative	Annual Benefits	Total Project Costs	Annual Costs	Net Benefits	BCR
6A	$5,108	$226,171	$8,583	-$3,475	0.6
6B	$19,511	$355,428	$13,488	$6,023	1.4
6C	$19,608	$1,694,650	$64,309	-$44,700	0.3
1A	$19,511	$560,892	$21,285	-$1,774	0.9
1B	$19,511	$727,497	$27,607	-$8,096	0.7
1C	$19,638	$751,006	$28,499	-$8,861	0.7
2A	$17,848	$216,625	$8,221	$9,627	2.2
2C	$17,848	$550,129	$20,876	-$3,028	0.9
2D	$19,031	$745,910	$28,306	-$9,275	0.7

7A	$19,511	$1,694,650	$64,309	-$44,798	0.3
7B	$19,511	$521,579	$19,793	-$282	1.0

The alternative that maximizes net benefits is Alternative 2A, with net benefits of approximately $9.6 million. The net benefits for Alternative 2A exceed Alternative 6B, the alternative with the second highest net benefits, by approximately 60 percent. The tentatively selected plan (TSP) for the Lower Cache Creek Feasibility Study is Alternative 2A as this alternative maximizes national economic development (NED) benefits. In addition, since the expected fatality rate is low for the study area, it is the project delivery team's (PDT) belief that life safety is not a significant factor in the selection of the recommended plan.

In terms of economic impact areas protected, the features of Alternative 2A will provide the greatest amount of flood risk management (FRM) protection for EIAs S8 and S9. As Table 4 indicates, these two EIAs contain the highest without project damages in the study area, representing over 90 percent of without project damages. For the remainder of this appendix, a fully constructed and operational Alternative 2A, or the TSP, will be referred to as the with-project condition.

During the period of time since the TSP Milestone Meeting, the HEC-FDA modeling has been updated and emergency clean-up costs have been added to the benefit analysis. As such, the estimates for damages, benefits, and net benefits presented in the following tables will differ from the values presented in

Table 5.

7.2 Smaller Scale Alternatives Benefit to Cost Ratio Analysis

This subsection outlines the notional smaller scale alternatives for the LCCFS. The smaller scale alternatives analysis was requested by vertical team members during the February 2019 Tentatively Selected Plan (TSP) milestone meeting. The following sub-sections describe the two smaller scale alternatives developed by the PDT for further consideration.

7.2.1 Cache Creek Settling Basin Improvements (Alt 20):

This alternative would focus mostly on improving the levees along the CCSB and is intended to target the areas with the highest potential economic damages. It would rehabilitate the southwest levee of the CCSB by constructing a 45-foot-deep cutoff wall through the levee and a portion of the southern levee of the CCSB would be rehabilitated with a 60-foot-deep cutoff wall.

7.2.2 New Levee (Alt 30):

This alternative would construct a new levee north of the City of Woodland to contain overland flows emanating from Cache Creek that threaten the City. A new levee with a 20-foot wide crest and a 30-foot wide landside seepage berm would begin near the intersection of County Road 19B and County Road 98 and extend east to the CCSB. The alignment of the levee would generally follow the northern City limit line west of State Highway 113 (Highway 113) and Churchill Downs Avenue east of Highway 113. This alternative includes an inlet weir in the western levee of the CCSB to allow water trapped by the new levee to enter the CCSB and drain to the Yolo Bypass.

7.2.3 Smaller Scale Net Benefit and Benefit to Cost Ratio Analysis

Table 6 shows net benefit related information for the smaller scale alternatives (Alternatives 20 and 30) along with the TSP, Alternative 2A. The results shown in Table 6 indicate that Alternative 2A maximizes net benefits, with net benefits of approximately $10.6 million. The net benefits for Alternatives 20 and 30 are approximately $2.4 million and -$1.0 million, respectively.

Table 6. Smaller Scale Alternatives Annual Benefits, Costs, and BCRs ($1,000 October 2020 price levels, 2.75% discount rate)

Alternative	Annual Benefits	Annual Costs	Net Benefits	BCR
20	4,561	2,125	2,437	2.1
30	5,334	6,325	(991)	0.8
2A	20,657	10,033	10,624	2.1

7.3 With-Project Damages

With-project damages, also referred to as residual damages, are defined as the estimated annual damages that remain after the proposed project is implemented.

Table 7 shows EAD by EIA for the without and with-project conditions along with damages reduced. It is apparent from Table 7 that residual damages with the TSP in place are substantially lower as the total remaining estimated annual damages are reduced to approximately 9.1 percent. In terms of damages reduced, the TSP reduces annual damages by approximately 90.9 percent.

Table 7. Expected Annual Residual Damages by Economic Impact Areas (in $1,000's October 2020 prices)

EIA	Without Project EAD	With Project EAD	Damages Reduced (Benefits)
N1	37	37	0
N2	21	21	0
N3	107	107	0
N4	30	30	0
N5	945	945	0
S6	136	136	0
S7	798	798	0
S8	5,327	0	5,327
S9	15,330	0	15,330
S10	0	0	0
Total	22,732	2,075	20,657
Percentage of EAD Remaining	100.0%	9.1%	90.9%

8.0 BENEFITS-COSTS ANALYSIS OF TENTATIVELY SELECTED PLAN

8.1 Overview of Evaluation Procedures

Economic costs and benefits resulting from a project are evaluated in terms of their impacts on national wealth, without regard to where in the United States the impacts may occur. NED benefits represent net increases in the economic value of goods and services to the entire nation, not just the local region. For example, if a flood interrupts auto production at a plant in one community, that community suffers a loss. However, if the affected company replaces the interrupted production at another plant in another city, the community's loss does not represent a net loss to the nation and the prevention of such a loss cannot be claimed as a NED benefit.

Table 8 shows EAD by major damage category for each project condition and average annual benefits. Again, average annual benefits are calculated as without project EAD minus with-project EAD. Total without project EAD is approximately $22.7 million and with-project EAD is approximately $2.1 million; average annual benefits for Alternative 2A are approximately $20.7 million.

Table 8. Total Expected Annual Damages by Alternative and Benefit by Damage Category (in $1,000's, October 2020 prices)

Damage Category	Without Project EAD	With Project EAD	Average Annual Benefits
Autos	111	28	83
Commercial	792	182	610
Industrial	17,800	915	16,884
Public	47	34	14
Residential	1,670	764	905
Emergency Costs	2,312	152	2,160
Total	22,732	2,075	20,657

8.2 Cost Estimate

NED costs represent the costs of diverting resources from other uses in implementing the project, as well as the costs of uncompensated economic losses resulting from detrimental effects of the project. Net benefits represent the amount by which the NED benefits exceed NED costs which indicates the alternative's contribution to the nation's economic output.

First cost estimates for the LCCFS were developed by the Sacramento District's Cost Engineering Section. In addition to project first costs, interest during construction (IDC), which is an economic cost, was also factored into the net benefit and BCR analyses. A 50-year economic life and the fiscal year 2020 annual discount rate of 2.75 percent are used to determine the average annual cost and interest during construction (IDC). The construction costs estimates for each of the focused array alternatives, presented in

Table 9, were developed prior to the TSP Milestone Meeting. Cost estimates for Alternative 2A have since been revised and are shown in

Table 9.

Table 9. Construction Costs by Alternative 2A (in $1,000, October 2020 prices, 2.75% discount rate)

Item	**Alt 2A**
First Cost	258,861
Interest During Construction	7,151
Total Project Investment Cost	266,012
Annualized First Cost	9,853
Annual OMRR&R	180
Total Average Annual Cost	10,033

8.3 Net Benefits and Benefit to Cost Analysis for the Tentatively Selected Plan

Average annual benefits, average annual costs, net benefits, and the BCR are shown in Table 10. Annual net benefits for the TSP are approximately $10.6 million and the benefit-cost ratio is 2.1, indicating that each dollar of construction costs generates approximately $2.1 in economic benefits.

Table 10. Annual Benefits, Costs, and BCRs for Alternative 2A ($1,000, October 2020 price levels, 2.75%)

Item	Alt 2A
Average Annual Benefits	20,657
Average Annual Costs	10,033
Net Benefits	10,623
BCR	2.1

An optimization analysis on design features included in the TSP will be conducted after the Agency Decision Milestone (ADM) and presented in the final report. In addition, an Interstate-5 traffic disruption analysis and agricultural analysis will also be included after the ADM.

9.0 PROJECT PERFORMANCE

The HEC-FDA model computes three different statistics that measure engineering performance of each project condition: *annual exceedance probability* (AEP), *long-term risk*, and *assurance*. Annual exceedance probability is a statistic used to describe the chance of flooding in any given year within an economic impact area. Long-term risk describes the chance of flooding over a given time period, such as 30 years, and assurance describes the likelihood of a stream/river being able to safely pass a specific flow event. That is, the stream/river will not overtop its banks or cause damage to structures. The engineering input data needed to calculate these performance statistics include exceedance probability-discharge, transform flows, stage-discharge, and geotechnical data. HEC-FDA models containing a complete structure inventory along with hydrologic, hydraulic, and geotechnical engineering data were developed to measure engineering performance statistics. Tables 12 and 13 show the three performance statistics for each EIA under the without and with-project conditions, respectively. As mentioned above, since the primary economic impact areas for this study are S8 and S9, Table 11 and

Table 12 are highlighted for those areas and the following analysis will focus on these two EIAs.

Table 11. Without-Project Performance

Economic Impact Area	***AEP***	***Long Term Risk (Years)***			***Assurance (AEP)***					
		10	***30***	***50***	***10%***	***4%***	***2%***	***1%***	***0.40%***	***0.20%***
N1	10.9%	68%	97%	100%	82%	75%	69%	63%	59%	58%
N2	10.9%	68%	97%	100%	82%	75%	69%	63%	59%	58%
N2	1.5%	14%	36%	53%	100%	96%	73%	41%	18%	11%
N3	3.4%	29%	64%	82%	91%	70%	51%	38%	29%	27%
N5	3.4%	29%	64%	82%	91%	70%	51%	38%	29%	27%
S6	5.3%	42%	80%	93%	86%	51%	20%	8%	5%	4%
S7	8.2%	58%	92%	99%	67%	37%	19%	11%	8%	7%
S8	5.3%	42%	80%	93%	86%	51%	20%	8%	5%	4%
S9	7.0%	51%	89%	97%	86%	84%	83%	83%	83%	83%
S10	0.7%	7%	20%	30%	99%	98%	95%	89%	80%	75%

Table 12. With-Project Performance

Economic Impact Area	*AEP*	*Long Term Risk (Years)*			*Assurance (AEP)*					
		10	*30*	*50*	*10%*	*4%*	*2%*	*1%*	*0.40%*	*0.20%*
N1	10.9%	68%	97%	100%	82%	75%	69%	63%	59%	58%
N2	10.9%	68%	97%	100%	82%	75%	69%	63%	59%	58%
N2	1.5%	14%	36%	53%	100%	96%	73%	41%	18%	11%
N3	3.4%	29%	64%	82%	91%	70%	51%	38%	29%	27%
N5	3.4%	29%	64%	82%	91%	70%	51%	38%	29%	27%
S6	5.3%	42%	80%	93%	86%	51%	20%	8%	5%	4%
S7	8.2%	58%	92%	99%	67%	37%	19%	11%	8%	7%
S8	0.1%	1%	3%	4%	100%	99%	99%	98%	97%	97%
S9	0.1%	1%	3%	4%	100%	99%	99%	98%	97%	97%
S10	0.7%	7%	20%	30%	99%	98%	95%	89%	80%	75%

Based on the AEP results shown in Table 11, the without project chance of flooding in any given year for EIAs S8 and S9 are approximately 5.3 percent and 7.0 percent, respectively. The results displayed in

Table 12 indicate the with-project condition lowers the overall annual chance of flooding (AEP) for both EIAs S8 and S9 to about 0.1 percent.

The long-term risk, which indicates the percentage chance of flooding over a given period of time, also improves for EIAs S8 and S9 under the with-project condition. In EIA S8, the 10-year, 30-year, and 50-year chance of flooding improves from 42 percent, 80 percent and 93 percent to one percent, three percent, and four percent, respectively. For EIA S9, the 10-year, 30 year, and 50-year chance of flooding improves under the with-project condition from 51 percent, 89 percent and 97 percent to one percent, three percent, and four percent, respectively.

The EIA S8 and S9 assurance values improve under the with-project condition. For example, in EIA S8, the assurance value for the one-percent AEP event is eight percent in the without project condition and improves to 98 percent with-project. This 98 percent assurance value indicates that under the with -project condition, there is a 98 percent chance of safely passing a one percent AEP event in EIA S8. Similarly, in EIA S9, one percent AEP event assurance improves from 83 percent without project to 98 percent with-project.

It is expected that the engineering performance of the project will deteriorate over time, especially 50-100 years beyond construction. There are many reasons for this, such as overall area subsidence, climate change, and other uncertain future hydrologic and hydraulic conditions.

10.0 LIFE SAFETY

10.1 Without-project life safety:

Several factors come into play when evaluating the life risk potential for the without project conditions, including *warning time* and *depths of floodin*g and *population at risk*.

Warning Time: There are two reservoirs upstream and two gauging stations for Lower Cache Creek. On the most upstream gauging station, there is an alerting mechanism that can notify the county Emergency Management Agency (EMA) long before stages begin to rise in the Lower Cache Creek.

Depths: Lower Cache Creek has a history of large sediment deposits and is a very geomorphically active basin. The sedimentation has created topographical features that have created two unique hydraulic characteristics in the area: 1) the channel is elevated above the floodplains and 2) the watershed is gently sloping away from the river, with very few natural features obstructing flow away from the river. These two topographical features work to produce the hydraulic result of relatively shallow sheet flow regardless of the size of the flood event.

Population at Risk: The initial population that could be harmed due to flooding is defined by those that are in the structures that get wet from the flooding associated with the Lower Cache Creek. Due to the nature of the geomorphology of the basin and the location of the populated areas, there is very little likelihood that the high population centers will be flooded in very infrequent events. The population impacted from the 500 year event for the without project condition with levee breaches is approximately 3,000 people. Due to the long warning lead times, this remaining population will be decreased due to evacuation potential. Reasonable expectations of evacuated people would be from 70% to 90% of the population impacted. This would leave a population of approximately 900 people at risk from a 500 year event with breaches. Given shallow depths and a small population at risk the life loss potential for this area is fairly small.

10.2 With-project life safety:

Since the Lower Cache Creek study is a flood risk management study seeking to reduce flood risk along the Lower Cache Creek, the recommended alternative is a structural measure that can potentially induce two types of impacts that may affect life risk: 1) possible increased development that may lead to an increased population subjected to flood risk and 2) transform the current condition of a relatively slow and steady rise of flood risk to a potentially more severe and immediate flood risk with an associated failure under the with-project condition. It is the study team’s determination that the tentatively selected plan will lower the overall life-safety risk for the Lower Cache Creek Study Area as compared to the without project condition. To ensure compliance with the Planning Bulletin, PB 2019-04, and the Engineering and Construction Bulletin (ECB) 2019-15, life safety will be considered further in post-ADM efforts.