Appendix Q – Draft Hydrologic and Hydraulic System Analysis – Lookout Slough Tidal Habitat Restoration and Flood Improvement Project, Environmental Science Associates, September 2019.

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DRAFT HYDROLOGIC AND HYDRAULIC SYSTEM ANALYSIS

LOOKOUT SLOUGH TIDAL HABITAT RESTORATION AND FLOOD IMPROVEMENT PROJECT

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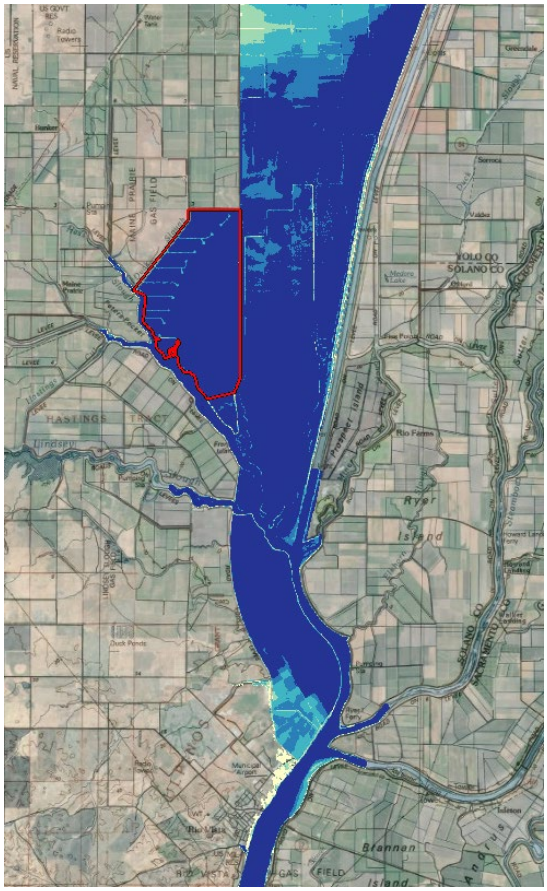
Date: September 2019



Ecosystem Investment Partners

ESA

DRAFT HYDROLOGIC AND HYDRAULIC SYSTEM ANALYSIS

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September 2019

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LOOKOUT SLOUGH TIDAL HABITAT RESTORATION AND FLOOD IMPROVEMENT PROJECT

Draft Hydrologic and Hydraulic System Analysis

Executive Summary

The Lookout Slough Tidal Habitat Restoration and Flood Improvement Project (Project), if approved, will create approximately 3,000 acres of natural freshwater tidal marsh in the Cache Slough Complex in the northern Sacramento-San Joaquin Delta (**Figure ES-1**) and increase the regional flood conveyance capacity of the Yolo Bypass. The Project is being funded by the California Department of Water Resources (DWR) to meet multiple objectives:

- To meet goals outlined in the State of California's Bay Delta Conservation Plan (BDCP) as well as the U.S. Fish and Wildlife Service's (FWS) Biological Opinion (BiOp) issued as part of the Long-Term Operational Criteria and Plan (OCAP) for coordination of the Central Valley Project and State Water Project. The Project is within the priority habitat restoration areas delineated in the 2008 FWS BiOp Delta Smelt Crediting Decision Model, and will create creditable acres for Delta Smelt that will satisfy DWR's obligations under the Delta Smelt BiOp and salmonids under the Salmonid BiOp.

- To meet regional flood management objectives to increase the conveyance capacity of the Yolo Bypass in a manner that is consistent with the 2017 DWR Sacramento Basin-Wide Feasibility Study (BWFS). By setting back the existing State-Federal levee along the west side of the Yolo Bypass, the Project will provide flood storage and reduce upstream flood stages in the Yolo Bypass.

This report documents the methods, data, and assumptions used to establish the design water surface elevation and identify potential impacts associated with the Project. The Project has been determined to create no adverse increases to stage or channel velocity, while providing localized reductions in stage within the Yolo Bypass.

The existing system and future hydraulic performance of the project and its alterations have been described in this report. The analysis establishes that the 1957 authorized design water surface profile shall be used as the basis for design for the Project's setback levee. The design top of levee shall include six feet of freeboard, plus one additional foot of freeboard for climate resiliency. Analysis of the Future Cumulative Condition also indicates that the Project will achieve superior hydraulic performance relative to the preferred concept plan (Yolo Bypass Option 3) identified in the BWFS.

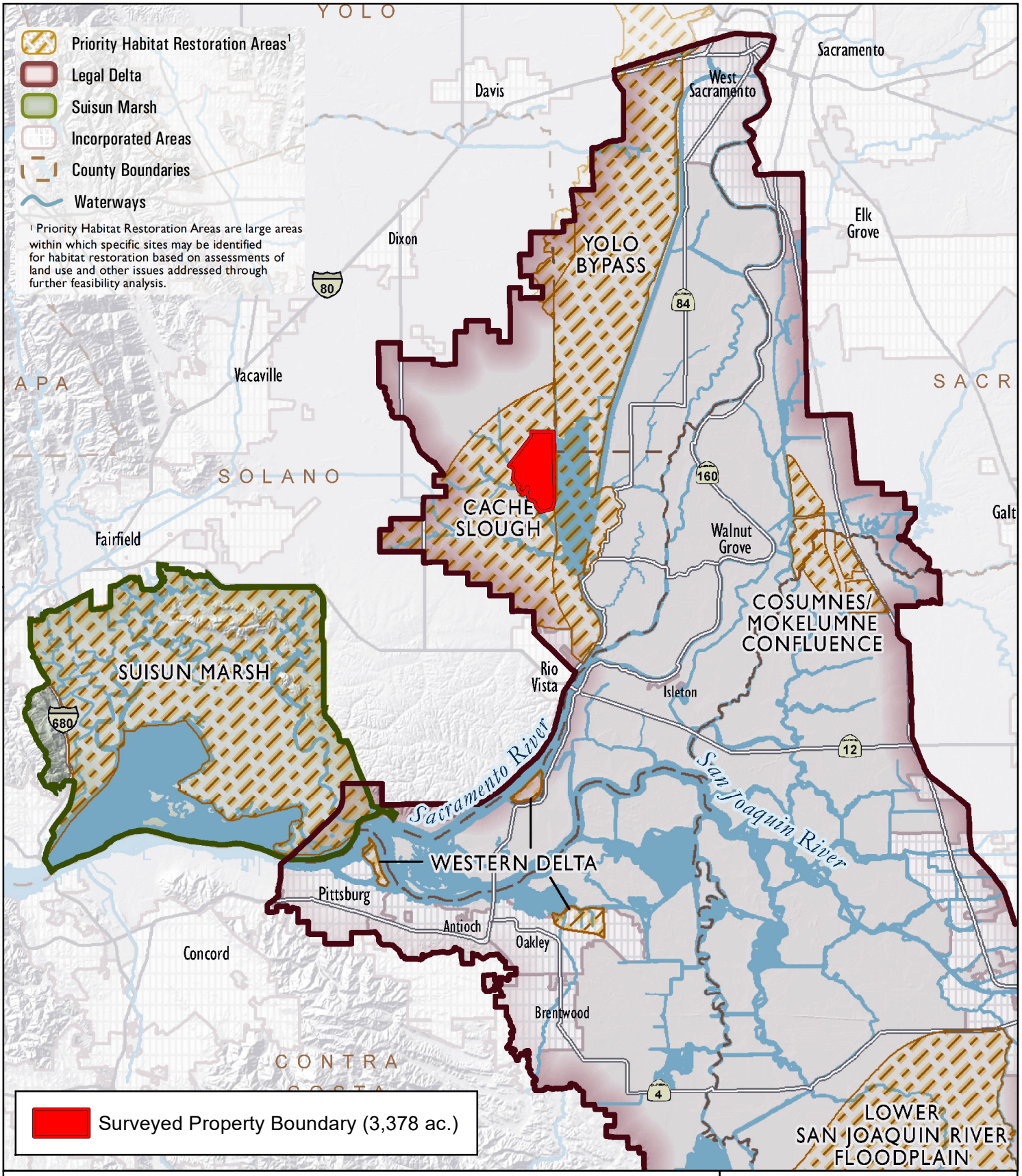

Figure ES-1
Location Map

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

0 3 6 12
Miles

Ecosystem Investment Partners

Prepared by: ESA

Map Prepared Date: 4/8/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):
Delta Stewardship Council, 2013

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The Project alterations would result in no adverse impacts to flood stages within the system for the range of hydrologic loadings analyzed. The region-wide system models have also been reviewed to verify that no significant change in the flow distribution at Fremont Weir or the Sacramento Weir would occur as a result of the Project. As the hydraulic impacts of the Project are localized, and generally result in stage decreases for the design events under consideration (including the 1957 authorized design flow), the Project's potential to transfer risk from one part of the system to another is considered to be negligible. Consequently, a detailed system performance calculation using HEC-FDA is not considered to be warranted. The deterministic analysis conducted for the Project is considered sufficient for describing the overall system performance for the without- and with-Project conditions and verifies that the reduction in assurance posed by the Project is negligible.

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LOOKOUT SLOUGH TIDAL HABITAT RESTORATION AND FLOOD IMPROVEMENT PROJECT

Hydrologic and Hydraulic System Analysis

Introduction

The Lookout Slough Tidal Habitat Restoration and Flood Improvement Project (Project) will create approximately 3,000 acres of natural freshwater tidal marsh in the Cache Slough Complex in the northern Sacramento-San Joaquin Delta (**Figure 1**), and increase the regional flood conveyance capacity of the Yolo Bypass. The Project is being funded by the California Department of Water Resources (DWR) to meet multiple objectives:

- To meet goals outlined in the State of California's Bay Delta Conservation Plan (BDCP) as well as the U.S. Fish and Wildlife Service's (FWS) Biological Opinion (BiOp) issued as part of the Long-Term Operational Criteria and Plan (OCAP) for coordination of the Central Valley Project and State Water Project. The Project is within the priority habitat restoration areas delineated in the 2008 FWS BiOp Delta Smelt Crediting Decision Model, and will create creditable acres for Delta Smelt that will satisfy DWR's obligations under the Delta Smelt BiOp and salmonids under the Salmonid BiOp.

- To meet regional flood management objectives to increase the conveyance capacity of the Yolo Bypass in a manner that is consistent with the 2017 DWR Sacramento Basin-Wide Feasibility Study (BWFS). By setting back the existing State-Federal levee along the west side of the Yolo Bypass, the Project will provide flood storage and reduce upstream flood stages in the Yolo Bypass.

DWR contracted EIP III Credit Co., LLC (EIP) to develop and, if approved, implement the Project as a multi-benefit project targeting both habitat restoration and flood risk reduction. Environmental Science Associates (ESA) is a subconsultant to EIP responsible for hydraulic analyses on the Project. This report provides the hydrologic and hydraulic basis of design for the flood management features of the Project, and documents changes in hydrology and hydraulic performance that would result from implementation of the Project. Hydrologic and hydraulic analysis of the habitat restoration components of the Project are documented in a separate report (ESA, 2019).

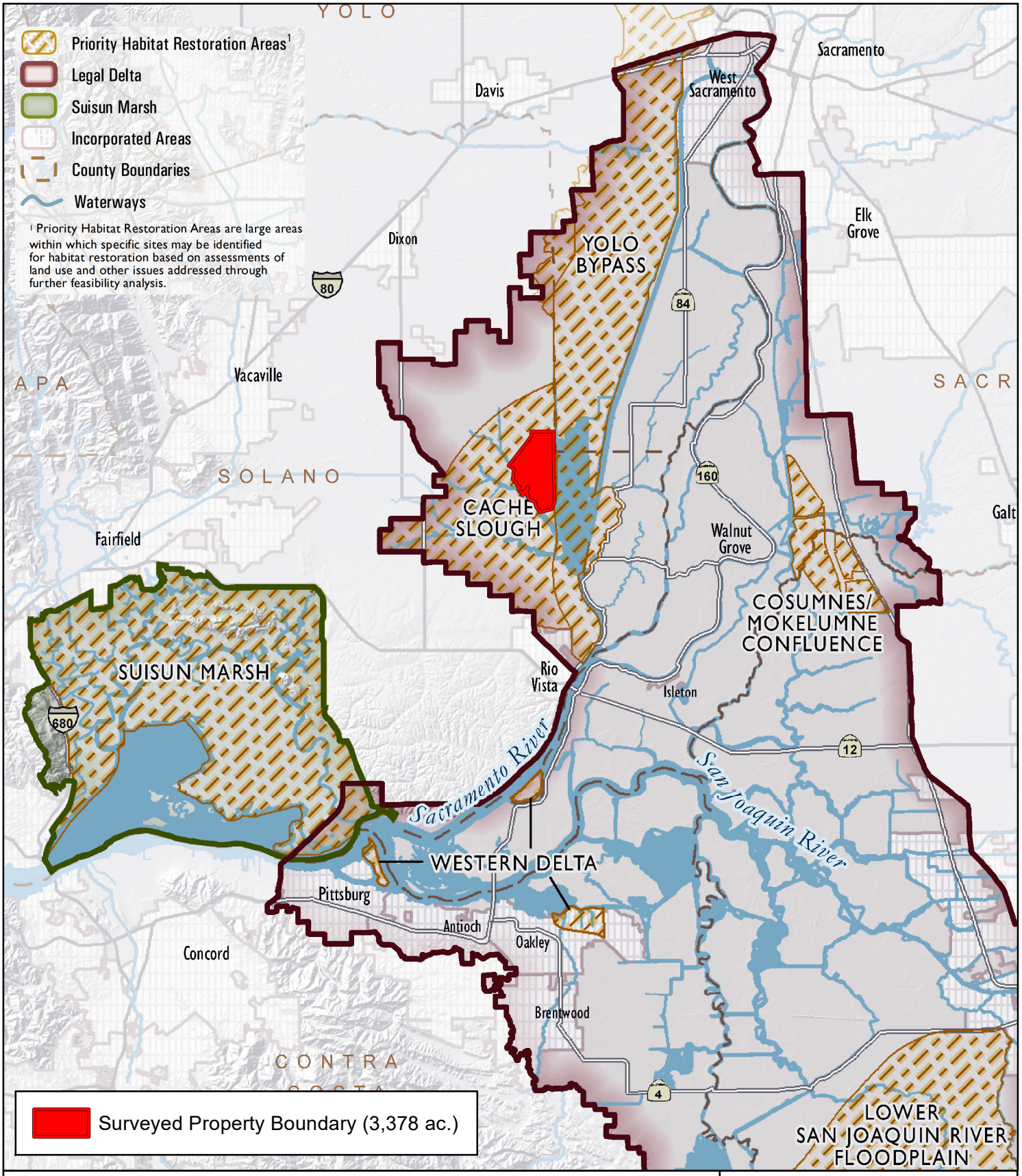

Figure 1
Location Map

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

0 3 6 12
Miles

Ecosystem Investment Partners

Prepared by: ESA

Map Prepared Date: 4/8/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):
Delta Stewardship Council, 2013

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Background

The Project is located within the Cache Slough Complex, in the northwest corner of the Sacramento-San Joaquin Delta in Solano and Yolo Counties. The Cache Slough Complex is considered ideal for tidal restoration by federal and state wildlife agencies as a result of its "connectivity to the Yolo Bypass floodplain, suitable elevations, high turbidity, high primary and secondary productivity, and use by Delta smelt, Chinook salmon, and other native fishes" (CDFW, 2017).

The Project is bounded to the north by Liberty Island Road, to the east by the Yolo Bypass, to the south by Cache Slough, and to the west by Duck Slough. With the exception of the levee system, land on the Project site ranges between El. -2.0 feet (NAVD 88) and El. 9.0 feet (NAVD 88), and generally slopes from west to east. Precipitation at the site is derived from frontal storms originating from the Pacific Ocean during the primary wet season between the months of October and April. The site receives a mean annual rainfall of approximately 17 inches (Solano County, 1999) and is characterized by poorly drained clay soils, with high runoff potential (USDA, 2018).

Historic Landscape

Up to the early 20th century, the majority of the site was part of the historic tidal tule marsh complex (**Figure 2**) that formed the low-lying southern portion of the Yolo Basin. The upper portions of the Yolo Basin were formed by Holocene basin deposits laid down by the Sacramento River and the two major west side tributaries, Cache Creek and Putah Creek (**Figure 3**). These deposits grade basin-ward into the plains of the north Delta, which is characterized by peat-rich muds (Helley and Harwood, 1983). Flood-basin deposits in this region are typically firm to stiff silty clay, clayey silt, and silt (Atwater, 1982).

The Yolo Basin was largely cutoff from the Sacramento River, except in times when the natural levees along the banks of the river overtopped, similar to flows cresting Fremont Weir today (Opperman et al., 2017). The Yolo Basin received seasonal runoff from the west side tributaries, including Cache Creek and Putah Creek, as well as groundwater seepage from the Sacramento River. These sources combined with freshwater tidal inundation, fed the historic freshwater tidal marsh and channels where the Project is located (PWA, 2008).

The Project is located in what is understood to have been part of the historic tidally-inundated marsh above Cache Slough. Vegetation on the majority of the Project site was tules (*Scirpus acutus,* also known as Hardstem Bulrush), a dense perennial wetland plant species which historically dominated the marshplains of the region. The density of tules and willows in the region are considered to be one of the reasons that these areas were not carefully surveyed prior to reclamation (Atwater, 1982). The site would have been relatively level, gradually draining southward into Cache Slough, with the marshplain edge dictated by elevation of the highest tides (PWA, 2008). As shown on Figure 2, a network of blind tidal channels formed along the banks of Cache Slough.

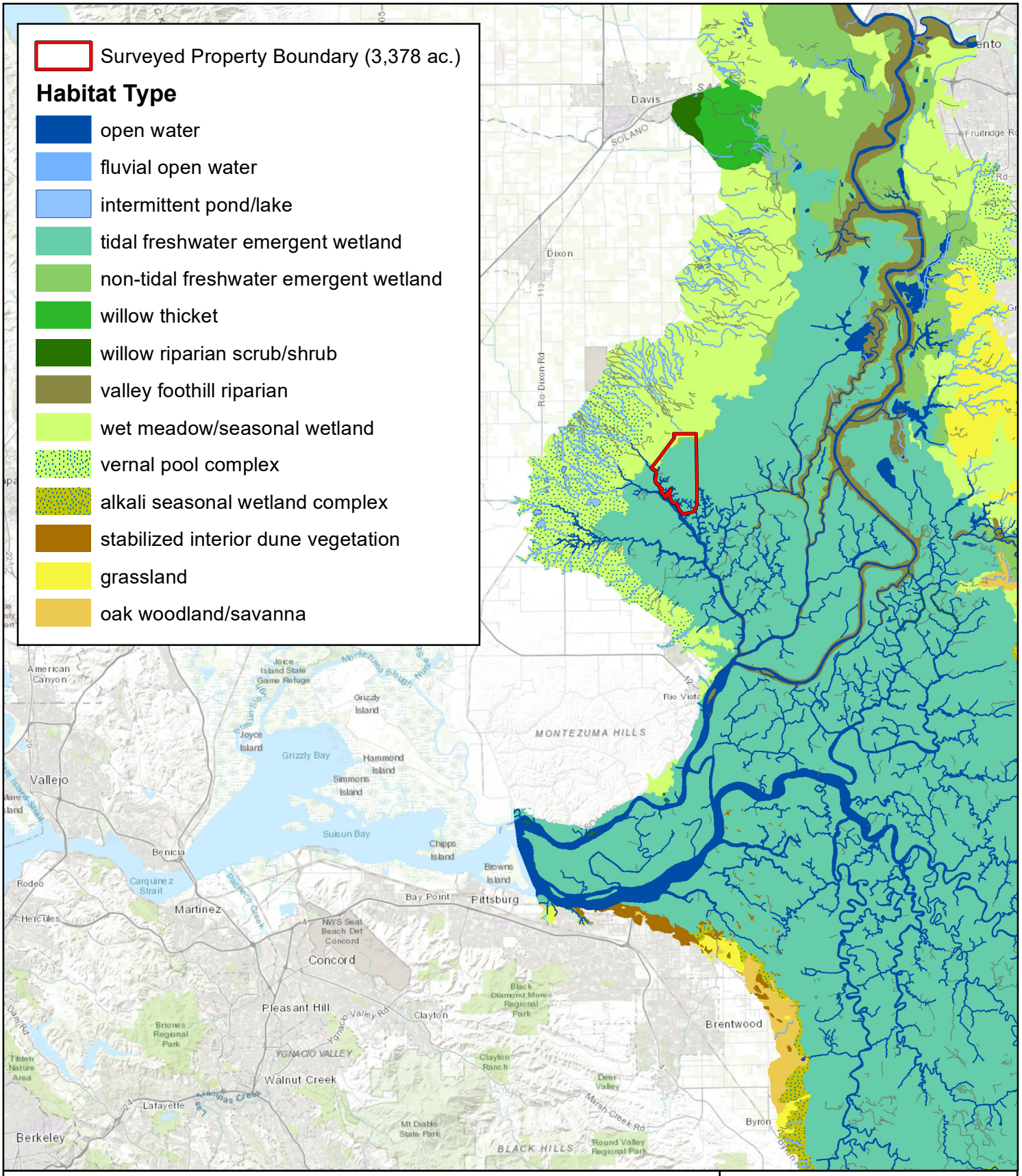

Figure 2
Historical Ecology

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

N
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Miles

Ecosystem Investment Partners

Map Prepared Date: 4/8/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):
SFEI, 2012

Prepared by: ESA

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Figure 3
Geologic Map of Sacramento-San Joaquin Delta, California

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

0 0.5 1 2
Miles

Ecosystem Investment Partners

Prepared by: ESA

Map Prepared Date: 4/8/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):
Atwater, 1982

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Existing Conditions

Beginning in the 1930's and continuing through the 1960's, a series of levee improvements were constructed along the east side of Cache Slough and the west side Yolo Bypass as part of the Sacramento River Flood Control Project (SRFCP) to develop and protect approximately 13,000 acres of agricultural land and associated structures and roads (U.S. Army Corps of Engineers [USACE], 1962). Following repairs in 1962, the southern portion of the original levee system experienced significant subsidence, and in 1986 a plan for a cross levee was finalized and then constructed by the USACE (URS, 2011 and USACE, 1986). The remnant levee system south of the cross levee was subsequently abandoned and breached in May 1992 by the USACE to create the Cache Slough mitigation area south of the Project (Stevens & Rejmankova, 1995). The existing levee system bounding the Project (**Figure 4**) is currently maintained and operated by Reclamation District (RD) No. 2098.

Until recently, the Project site was managed separately by three primary land owners (**Figure 5**):

- The Vogel Island portion of the project was originally purchased for use as a duck club. Historically, the island drained by gravity through a gated outfall structure into Cache Slough. During winter flood season the berms forming the perimeter of Vogel Island often overtop, flooding the property. These same berms prevent flood waters from draining once the island is inundated, creating a condition where water and potentially fish are trapped inside a temporary lake.

- The Bowlsbey Ranch property north and west of Lookout Slough has been operated and managed as irrigated pasture for livestock. The land is irrigated using water pumped from Hass Slough and drains generally from west to east through a network of agricultural ditches to a toe drain that runs parallel to western and northern sides of Lookout Slough, which collects in the southeast corner of the site before ultimately being pumped back to Hass Slough.

- The Liberty Farms property was used for agricultural production for many years before being converted to a duck club circa 2005. Although the northern portion of the property continues to be used for agricultural production, the majority of the site is seasonally flooded and drained through a series of artificial channels to manage vegetation on the duck club. The property is seasonally flooded using water sourced from Cache Slough and is drained via pumping to Shag Slough.

The State-Federal levee system ensures that the Project land is currently inaccessible to fishes, including Delta smelt, green sturgeon, Central Valley Spring Run Chinook salmon, Sacramento River Winter-run Chinook salmon, Central Valley steelhead, and longfin smelt, except during winter runoff events which periodically flood the Vogel Island tract.

The Project will establish tidal hydraulic connectivity to all three pieces of land by breaching the berms at Vogel Island, the west (right) levee of the Yolo Bypass along Shag Slough. The existing pumping and irrigation channel network will be decommissioned and replaced with a network of tidal channels which will allow the site to flood and drain by gravity with the tides. In doing so, the Project will have a continuous supply of fresh water and suspended sediment which will promote establishment of a mosaic of subtidal, intertidal, and uplands habitat types.

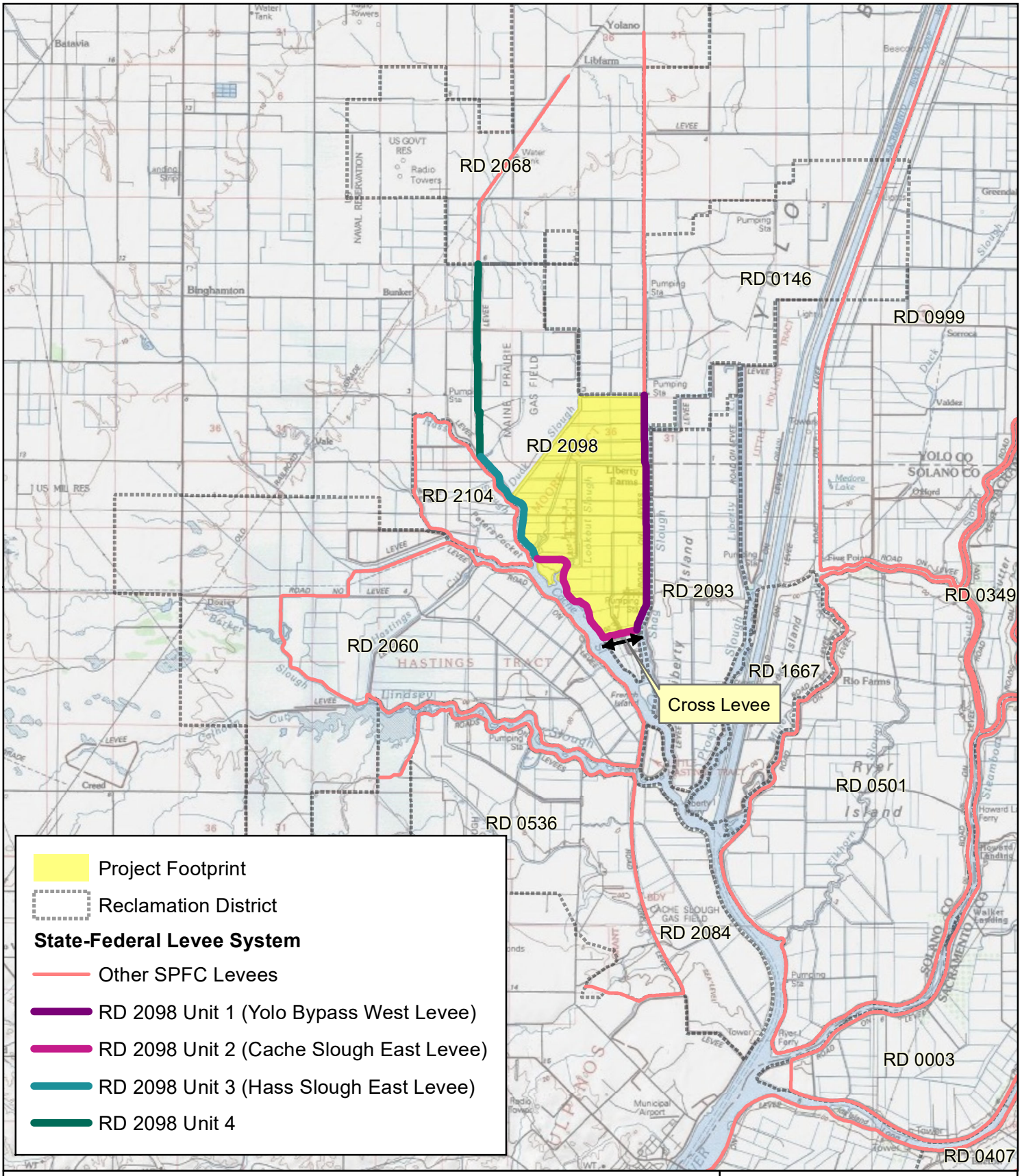

Figure 4
Existing Levee System

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

0 1 2
Miles

Ecosystem Investment Partners

Map Prepared Date: 8/25/2019
Map Prepared By: Brent Davis
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):
CA Levee Database, CBI, DWR
ESRI Surface Layers

Prepared by: ESA

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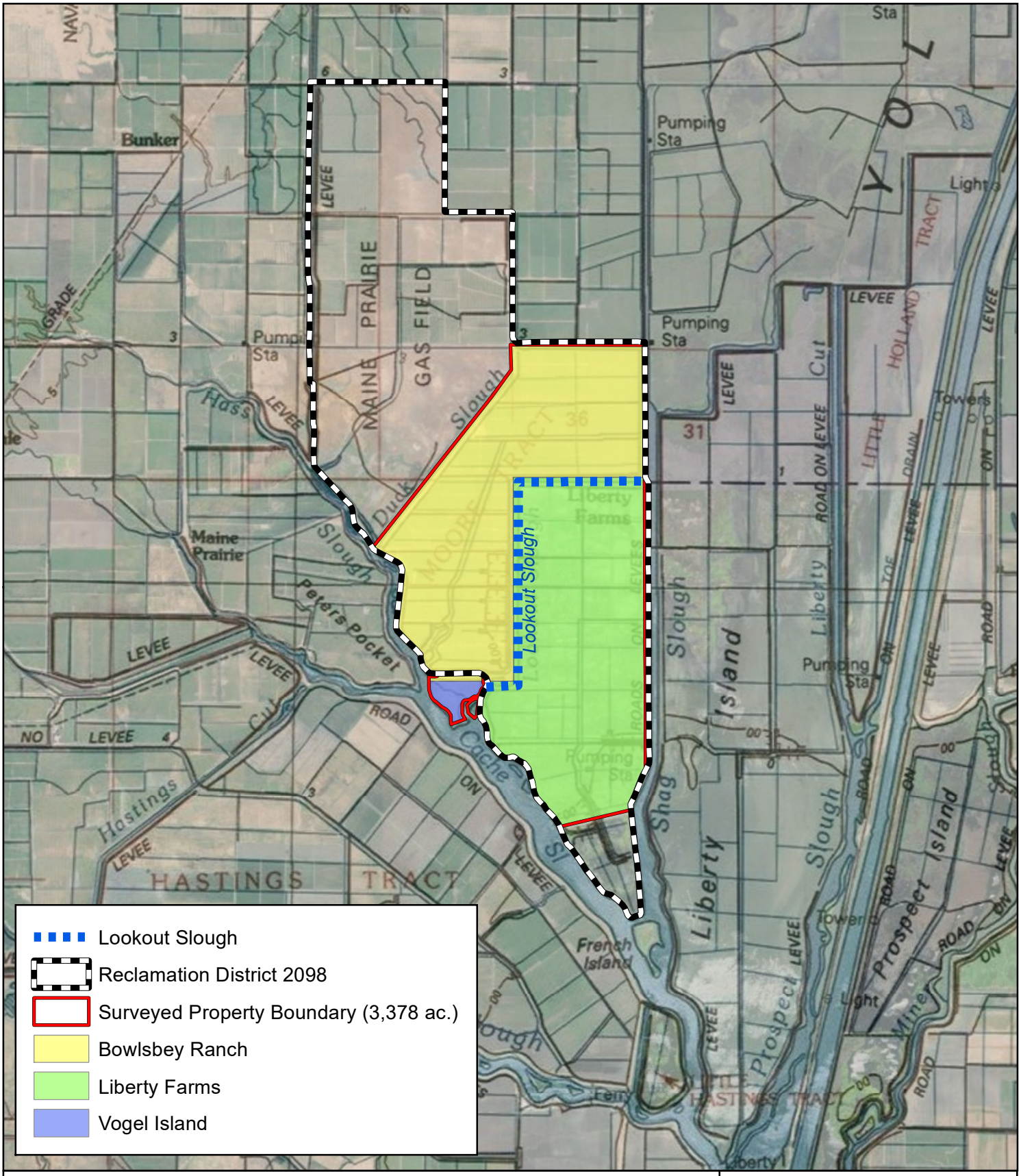


Figure 5
Land Ownership

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

Ecosystem Investment Partners

Prepared by: ESA

Map Prepared Date: 4/28/2019
Map Prepared By: JPritchard
Base Source: Wood Rogers
Base Date: 10/24/2017
Data Source(s):

Path: U:\GIS\GIS\Projects\18xxxx\D181197_00_Lookout_Slough_Restoration_1\03_MXDs_Projects\02_Flood_Task_System_HandH\F05_Property_Boundaries.mxd

Construction of the habitat restoration components of the Project necessitates alteration of the State-Federal levee system. To maintain the existing level of flood protection for lands north of the Project (RD 2068) and lands west of the Project (RD 2098), a new setback levee will be constructed along the northern and western boundaries of the project. The Project will also increase the conveyance capacity in this part of the Yolo Bypass, consistent with DWR's regional planning objectives (DWR, 2016).

Engineering Circular 1165-2-220 (USACE, 2018) states that any project proposing to alter a federal project in any way "*must not be injurious to the public interest or affect the USACE project's ability to meet its authorized purpose*." If that can be shown, then the Project can receive a Section 408 Permit before construction begins.

Two of the alterations to be made as part of the Project classify the Project as falling under jurisdiction of Section 408:

1. Breaching and degrading the existing west (right) levee of the Yolo Bypass between Liberty Island Road and the southern end of Liberty Farms.

2. Improvements to the existing north (left) levee of Cache Slough and Hass Slough on the western side of the Project.

Project Datums

All data for the project is referenced to the North American Datum of 1983 (NAD 83) and the California State Plane II (feet) coordinate system. All vertical elevations described in this report are referenced to the North American Vertical Datum of 1988 (NAVD 88) and are reported in units of feet.

Hydraulic Design Criteria

The project design concept was developed iteratively through engagement between EIP's project delivery team, DWR staff, and members of the Lower Sacramento River/Delta North Regional Flood Management Plan Workgroup including the Sacramento Area Flood Control Agency (SAFCA), Solano County, the Solano County Water Agency (SCWA), RD 2060, RD 2068, and RD 2098. A summary of the criteria used for designing and modifying the Project flood management features follows below.

Existing State-Federal Project Levee System

The existing State-Federal levee system bounding the Project includes the West Levee of the Yolo Bypass (RD 2098 Unit 1) bordering Shag Slough, the cross levee and East Levee of Cache Slough (both of which compose RD 2098 Unit 2), and the East Levee of Hass Slough (RD 2098 Unit 3). With the exception of the cross levee (USACE, 1986), the existing system was designed and constructed in 1961 by the USACE as part of the Sacramento River Flood Control Project (SRFCP [USACE, 1962]). The West Levee of the Yolo Bypass was originally designed and constructed with a crest six feet above the 1957 design water surface profile (1957 Profile), and the levees along Cache Slough and Hass Slough were constructed with a crest at least three feet

above the 1957 design water surface profile (USACE, 1962). The 1957 Profile is based on specified design discharges (not tied to a recurrence frequency) and adopted concurrent conditions at confluences of study streams (USACE, 1993). The 1957 Profile reflects revisions made up to and during design of the SRFCP, as agreed upon by the Reclamation Board (now the Central Valley Flood Protection Board), the State of California, and the USACE, as published in "Levee and Channel Profiles, Sacramento River Flood Control Project," dated March 15, 1957. In this portion of the Yolo Bypass, the 1957 profile was scaled from the 1907 and 1909 floods (DWR, 2016), based upon the authorized design flow of 490,000 cfs.

The six-foot freeboard criterion along the West Levee of the Yolo Bypass provides a factor of safety for both flood stage and run-up from wind-generated waves in the Yolo Bypass. Historically, wind waves can grow to four feet or more during large storm events due to the combination of long fetch lengths in the Yolo Bypass and strong sustained winds (DWR, 2016).

Levee Design Height

The Project design will conform to the latest Central Valley Flood Protection Board (CVFPB), USACE, and Federal Emergency Management Agency (FEMA) standards, methods, procedures, and policies for levee design including the following:

- *California Code of Regulations, Title 23, § 120 – Levees*
- *USACE Engineering Manual No. 1110-2-1913 – Engineering and Design – Design and Construction of Levees*
- *USACE, Design Guidance for Levee Under-Seepage, ETL 1110-2-569, May 1, 2005*
- *Code of Federal Regulations, Title 44. § 65.10 – Mapping of Areas Protected by Levee Systems*

In 2007, the California Legislature passed several bills adding to and amending State flood management and land use laws. As part of this legislation, cities and counties within the Sacramento-San Joaquin Valley are required to make a Finding related either to an urban level of flood protection (defined as a 1-in-200 chance event) or to the FEMA standard of flood protection before: 1) entering into a development agreement within a flood hazard zone; 2) approving a discretionary permit or entitlement of any property development or use that is located in a flood hazard zone; or 3) approving a tentative map/parcel map for a subdivision that is located in a flood hazard zone (California Government Code Sections 65865.5, 65962, and 66474.5). These requirements apply to protecting "urban or urbanizing" areas as defined by California Government Code Section 65007 paragraphs (j) and (k). "Urban" and "urbanizing" areas are defined as those areas with a population greater than 10,000, or that will have a population greater than 10,000 within 10 years, respectively (DWR, 2012). Since the alterations proposed by the Project will not affect any urban or urbanizing areas, this criterion does not apply. Outside of urban or urbanizing areas within the Central Valley, the 1% ACE (100-year) water surface elevation is generally used as the basis for design. The Project will use the 1% ACE (100-year) water surface elevation or the authorized 1957 design profile, whichever is higher.

Adjustments are typically made to the design water surface elevation in order to provide factors of safety to account for uncertainty, climate change and sea-level rise, as well as to provide system resiliency.

Design Water Surface Profile

Wood Rodgers, Inc. (Wood Rodgers) is preparing the civil design of the Project and has reviewed criteria being used by DWR for the design of the Lower Elkhorn Basin Levee Setback (LEBLS) Project, a similar non-urban setback levee proposed along the east levee of the Yolo Bypass north of the confluence with the Sacramento Bypass. The design water surface used in the LEBLS project is based on a 100-year design water surface computed using Central Valley Hydrology Study (CVHS) hydrology (1997 storm pattern with 95% scaling) developed during the Basin-Wide Feasibility Study (BWFS) for the Sacramento River Basin recently prepared by DWR as part of the 2017 Central Valley Flood Protection Plan (CVFPP). For the LEBLS Project, DWR has also provided six feet of freeboard, consistent with the levee design in the Sutter and Yolo Bypasses. As part of the LEBLS design, DWR added an additional one foot of freeboard for resiliency to address future effects of climate change, for a total of seven feet of freeboard above the design water surface elevation. For purposes of the current Project, the 1957 authorized design or the 1% ACE (100-year) water surface will be used as the basis for design, whichever is higher. In addition to the minimum required six feet of freeboard, an additional 1 foot of freeboard will be included for climate resiliency. Although this is a more conservative approach than required by the CVFPB and the USACE, it is consistent with DWR flood planning objectives for the region.

16% ACE (6-year) Design Water Surface Elevation

Once approved and constructed, the project would restore full tidal range to as much of the site as possible. This would be accomplished by breaching the existing levee system at nine locations to establish connectivity to the diurnal tidal signal. It is anticipated that this connection to the adjacent floodplain would result in some attenuation during higher frequency storm events. To further improve floodplain connectivity during larger events and increase capacity in the Yolo Bypass, portions of the west (right) bank levee of the Yolo Bypass along Shag Slough would be degraded to the elevation of the 16% ACE (6-year) design event. This partial degrade of the existing levee would improve connectivity between the Yolo Bypass and Project floodplain, without requiring excessive earthwork to degrade the levee to the landside floodplain elevation. The locations and dimensions of these degraded sections are described in subsequent sections of this report.

Authorized Design Flow (1957 Profile)

The 1957 authorized design capacity of this portion of the Yolo Bypass is 490,000 cfs (USACE, 1957). The resultant design water surface profile establishes the minimum design height of the Project levee system. At the northeastern corner of the Project, the design water surface of the 1957 Profile at the west (right) bank levee of the Yolo Bypass is approximately El. 20.6 feet (NAVD 88) (USACE, 1957 and Atkins, 2013). At the southeastern corner of the project, the

design water surface at the west (right) bank of the Yolo Bypass is approximately El. 18.6 feet (USACE, 1957 and Atkins, 2013).

1% ACE (100-year) Design Water Surface Elevation

To establish the design height of the levee, the Project performance for the 1% ACE (100-year) design flow was evaluated. The resultant water surface elevation was compared with the authorized design (1957 Profile), and the higher of the two was used to establish the design height for the Project flood management features. This approach is conservative and ensures consistency with DWR's planning objectives for rural and non-urban areas (DWR, 2017a).

0.5% ACE (200-year) Design Water Surface Elevation

Although not used for setting the design height of any of the Project features, analysis of the 0.5% ACE (200-year) design flow was performed. The 0.5% ACE (200-year) design flow is of interest to DWR as it relates to informing long term planning activities within the Yolo Bypass.

Channel Stability and Erosion

The Project alterations will result in localized changes in velocity and bed shear stress. To ensure that these changes do not adversely impact the performance of the State-Federal levee system, modeling results from the 1% ACE (100-year) design storm will be used as the basis for assessing bank stability and formulating recommendations for selection of lining materials if necessary. For purposes of the Project, stability threshold values shown in **Table 1** will be used as reference.

TABLE 1
PERMISSIBLE SHEAR AND VELOCITY FOR SELECTED LINING MATERIALS

Boundary Category	Boundary Type	Permissible Shear Stress (psf)	Permissible Velocity (fps)
Soils	Fine colloidal sand	0.02 – 0.03	1.5
	Sandy loam (noncolloidal)	0.03 – 0.04	1.75
	Alluvial silt (noncolloidal)	0.045 – 0.05	2
	Silty loam (noncolloidal)	0.045 – 0.05	1.75 – 2.25
	Firm loam	0.075	2.5
	Fine gravels	0.075	2.5
	Stiff clay	0.26	3 -4.5
	Alluvial silt (colloidal)	0.26	3.75
	Graded loam to cobbles	0.38	3.75
	Graded silts to cobbles	0.43	4
	Shales and hardpan	0.67	6
Gravel/Cobble	1-in.	0.33	2.5 – 5
	2-in.	0.67	3 – 6
	6-in.	2.0	4 – 7.5
	12-in.	4.0	5.5 – 12

TABLE 1
PERMISSIBLE SHEAR AND VELOCITY FOR SELECTED LINING MATERIALS

Boundary Category	Boundary Type	Permissible Shear Stress (psf)	Permissible Velocity (fps)
Vegetation	Class A turf	3.7	6 – 8
	Class B turf	2.1	4 – 7
	Class C turf	1.0	3.5
	Long native grasses	1.2 – 1.7	4 – 6
	Short native and bunch grasses	0.70 -0.95	3 – 4
	Reed plantings	0.10 – 0.60	N/A
	Hardwood tree plantings	0.41 – 2.50	N/A
Temporary Degradable RECPs	Jute net	0.45	1 – 2.5
	Straw with net	1.50 – 1.65	1 – 3
	Coconut fiber with net	2.25	3 – 4
	Fiberglass roving	2.0	2.5 – 7
Non-Degradable RECPs	Unvegetated	3.0	5 – 7
	Partially established	4.0 - 6.0	7.5 – 15
	Fully vegetated	8.0	8 – 21
Riprap	6-in. d50	2.5	5 – 10
	9-in. d50	3.8	7 – 11
	12-in. d50	5.1	10 – 13
	18-in. d50	7.6	12 – 16
	24-in. d50	10.1	14 – 18
Soil Bioengineering	Wattles	0.2 – 1.0	3
	Reed fascine	0.6 - 1.25	5
	Coir roll	3 – 5	8
	Vegetated coir mat	4 - 8	9.5
	Live brush mattress (initial)	0.4 – 4.1	4
	Live brush mattress (grown)	3.9 – 8.2	12
	Brush layering (initial/grown)	0.40 – 6.25	12
	Live fascine	1.25 – 3.10	6 – 8
	Live willow stakes	2.10 – 3.10	3 – 10
Hard surfacing	Gabions	10.0	14 – 19
	Concrete	12.5	> 18

SOURCE: Fischenich, 2001

Wind Setup and Wave Run Up

The effects of potential wind setup and wave run up related to the Project have been analyzed by Wood Rodgers and have been documented in a separate stand-alone appendix to the Project's overall basis of design report.

Hydraulic Impact Considerations

If approved, alteration of the State-Federal levee system would change hydrologic and hydraulic conditions in the Yolo Bypass and Cache Slough Complex. Recognizing this, the analysis includes considerations to ensure that any increases to water surface elevation, velocity, wind-wave, or other hydraulic effects are negligible. Areas identified as sensitive to the Project performance during flood conditions are identified below.

Impacts to the Yolo Bypass

The Project seeks to reduce flood stages in the Yolo Bypass by setting back the existing west (right) bank levee of the Yolo Bypass between Liberty Island Road and the southern boundary of the Project, thereby increasing the overall conveyance corridor width and floodplain storage during large flood events. The Project seeks to maximize resultant stage reductions in this part of the Yolo Bypass without adversely impacting other parts of the system.

Impacts to Cache Slough and Hass Slough

The adjacent levee systems along the west banks of Cache Slough and Hass Slough lack freeboard and suffer from deferred maintenance. This makes them particularly vulnerable to increases in water level, erosion, or wind-wave run-up. One important component of the habitat enhancement objectives of the Project includes establishing hydraulic connectivity between the restored marsh habitat and the Yolo Bypass. The Project seeks to avoid raising water levels in Cache Slough and Hass Slough more than 0.01 feet.

Impacts to Downstream Areas, including Rio Vista

The city of Rio Vista is vulnerable to flooding from the Sacramento River and the Yolo Bypass. The City receives modest flood protection from an existing floodwall that extends from the dock at the end of Montezuma Street to just north of Main Street. This floodwall was overtopped in 1986 and was subsequently raised. Since the raising, the floodwall has not been overtopped by a flood event. However, downtown Rio Vista regularly experiences flooding from minor storm events and high tides (Flood Protect, 2014).

Elevated water stages resulting from a 6-year flood event in the Sacramento River also overtop the west bank of the Sacramento River upstream of State Highway 12 and flow through the highway underpass, thereby effectively flanking the existing floodwall and flooding downtown Rio Vista. During these high water events, businesses upstream of State Highway 12 are forced to close until floodwaters recede, since flooding along State Highway 84 makes the businesses inaccessible.

The project will alter the hydraulics of the Cache Slough Complex during a large flood. Although these changes are assumed to be beneficial due to attenuation of the flood wave in the overbank areas of the Project site, care must be taken to keep water levels from increasing in the vicinity of Rio Vista.

Alteration of State-Federal Project – Concept Plan

The conceptual site design (**Figure 6**) was developed by Wood Rodgers, WRA, Inc. (WRA) and Beaver Creek Hydrology, LLC (Beaver Creek Hydrology) to restore the full tidal range to as much of the site as is practical, and to connect the site hydraulically to the Yolo Bypass during high water events. The project concept seeks to meet flood management objectives using the criteria outlined above, while also supporting habitat function. In addition to alterations to the levee system, a number of functional design components, such as a training levee and refugia areas, have been incorporated into the design. Many of these features are intended to address DWR's obligations in the respective Biological Opinions, and offer dual benefits in the form of enhanced flood risk reduction. The major project features and their intended functions are described below (WRA, 2019a).

Duck Slough Setback Levee Improvements

A new setback levee is proposed on the northwestern and northern sides of the Project site. If approved, this levee would become part of the State-Federal levee system, protecting lands within RD 2098, north and west of the Project. The proposed levee would begin near the confluence of Hass Slough and Duck Slough; run parallel to Duck Slough on the northwestern side of the project; and upon reaching the northwestern corner of the Project, turn east and run parallel to the south side of Liberty Island Road; eventually tying into the West Levee of the Yolo Bypass system at the northeast corner of the Project site. The segment of levee running parallel to Duck Slough would be offset from the property line to provide a refugia habitat buffer on the land side for the endangered Giant Garter Snake (*Thamnophis gigas*).

Alteration of Cache Slough and Yolo Bypass Levees

Prior to being developed for agriculture, the majority of the Bowlsbey Ranch and Liberty Farms parcels were covered in tidal freshwater emergent wetlands, which drained to Cache Sough (Whipple et al., 2012). Today, the existing State-Federal levee system currently prevents the site from flooding and draining with normal tides. Breaching the levee system is necessary to restore tidal exchange on the Project site.

Alteration of the State-Federal levees requires careful consideration to ensure that risk is not transferred from one part of the system to another, and constrains what modifications can be made to re-establish tidal processes on the site. Tidal marsh considerations have been analyzed in parallel with the flood management design, and have been documented in a separate report (ESA, 2019). A brief description of the proposed modifications of the East Levee of Cache Slough and West Levee of the Yolo Bypass follows below.

West Levee of Yolo Bypass Alteration

The Project proposes to breach the west (right bank) levee of the Yolo Bypass along Shag Slough at nine locations to provide hydraulic connectivity between the site and Shag Slough and the Yolo Bypass. This alteration would restore regular tidal exchange to the majority of the site and create habitat connectivity to Shag Slough. Two 1,500-foot long segments of the remainder of the

existing levee would be degraded to match the elevation of the 16% ACE (6-year) design storm. The first of these would be located near the northern end of the Project, and act as an inlet spillway during high flow events to divert additional water onto the site. This inlet section would be degraded to approximately elevation El. 14.7 feet (NAVD 88). The second segment would be located near the southern end of the Project, and act as an outflow spillway during high flow events, and would be degraded to approximately El. 11.8 feet (NAVD 88).

East Levee of Cache Slough Alteration

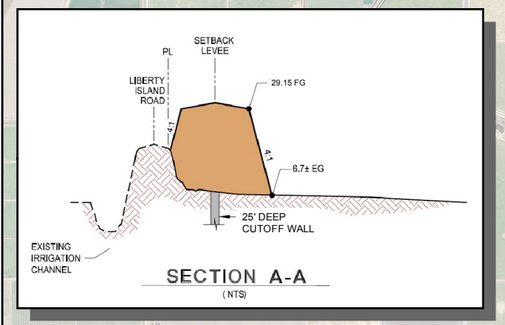
Proposed modifications to the West Levee of the Yolo Bypass would hydraulically connect the Project site to the Yolo Bypass. During less frequent, high flow flood events this will create a condition where the water levels on the Project site will be slightly higher than those inside of Cache Slough. Significant increases to flood levels in Cache Slough and Hass Slough are considered to be unacceptable to RD 2060, RD 2068, and RD 2098 as portions of the levee systems maintained by these entities do not currently meet minimum freeboard requirements and suffer from years of deferred maintenance. Recognizing this, the Project seeks to avoid increasing stage in Cache and Hass Slough.

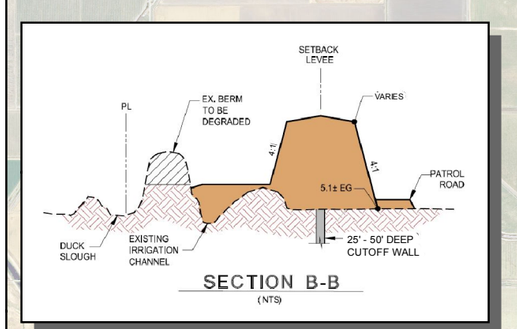
Historically, wind waves can grow to four feet or more during large storm events due to the combination of long fetch lengths in the Yolo Bypass and strong sustained winds (DWR, 2016). The Project proposes to connect the site to the Yolo Bypass floodplain during high flow events, which will increase fetch lengths against the remnant Cache Slough levee. The remnant embankment along Cache Slough would act as a wind-wave buffer providing an additional layer of safety for levees on the opposite sides of Hass Slough and Cache Slough. Wind-wave assessment analysis of the Project and its potential impacts are summarized by Wood Rodgers in a separate appendix to the Project's overall Basis of Design Report.

Following approval and construction of the Project, the remnant Cache Slough levee embankment would have water on both sides and would continue to serve as both a hydraulic barrier and wind-wave buffer between Cache Slough and the Yolo Bypass, taking on the function of a training levee. For purposes of this report, the with-Project remnant embankment will be referred to as the Cache/Hass Slough Training Levee.

Breach of Vogel Island Levees

The Project proposes to breach the uncertified agricultural levees that form the perimeter of Vogel Island at two locations to provide hydraulic connectivity to Cache Slough. This alteration would restore normal tidal exchange to the island and habitat connectivity to Cache Slough. In large flood events, the remnant levee segments would continue to overtop as they do today.





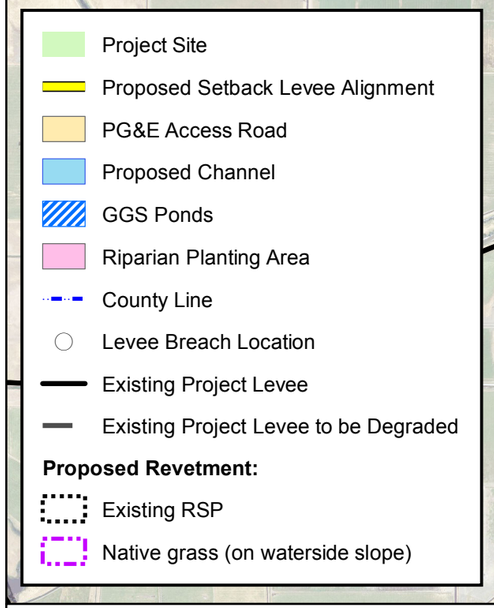


Figure 6
Conceptual Site Design

Lookout Slough Tidal Habitat
Restoration and Flood Improvement Project

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W E
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Ecosystem Investment Partners

Map Prepared Date: 8/6/2019
Map Prepared By: cmilligan
Base Source: Wood Rogers
Base Date: 10/24/17
Data Source(s):

Prepared by:
WOOD RODGERS

Path: J:\3000-s\3487_Ecosystem_Invest_Partners\3487003 Lookout Slough Preliminary Design\GIS\Tasks\WRA_TEMPLATES\Overall_Project_Exhibit_Landscape_20190806.mxd

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Tidal Channel Network

Tidal channel networks provide important low resistance pathways for distributing material and energy between the marsh habitat and adjacent bodies of water (Mitsch & Gosselink, 2015). In general, width and depth of the channel decrease between the channel inlets at Cache Slough and Shag Slough and the back of the site. Constructed channel top widths will range from 60 feet to 250 feet, with channel invert elevations ranging between 1.0 and -1.0 feet (NAVD 88) to limit growth of emergent vegetation. Constructed channel side slopes would vary, but be set to a maximum of 3:1. Additional site grading will be performed to remove man-made berms and existing drainage canals (including the previously realigned Lookout Slough) throughout the site to prevent short-circuiting of the new channel network. The proposed network has been laid out to take advantage of the existing topography which drains primarily from west to east towards Shag Slough, with additional provisions to provide connectivity to Cache Slough. The performance of the Project channel network and marsh plain grading plan was tested and further refined by WRA and Beaver Creek Hydrology (WRA and Beaver Creek Hydrology, 2019) using results from the tidal restoration hydrodynamic modeling analysis (ESA, 2019).

As the proposed tidal channel network has only been sized for daily tidal exchange, the hydraulic capacity of the channels is not anticipated to have a significant effect on flood routing during high water events in the Yolo Bypass. The overbanks and adjacent floodplains of the tidal channel network are anticipated to be covered with tule marsh vegetation. Although dense stands of tules provide significant hydraulic resistance during normal tidal conditions, their influence will be reduced significantly during high water conditions in the Yolo Bypass where depths of flooding on the site will exceed 10 feet or more.

Analysis

The USACE Sacramento District is responsible for determining whether a hydrologic and hydraulic system analysis is needed and, if so, also determining the appropriate scope of analysis based on the complexity of the proposed alteration. Based on pre-coordination meeting with the USACE Sacramento District on January 15, 2019, it was determined that if deterministic analysis of without- and with-Project conditions was conducted for a range of hydrologic loading scenarios (16% ACE, 1% ACE, and 0.5% ACE), and the Project implementation was demonstrated to have only localized effects, and would not result in increased water levels of more than 0.1 feet at key index points within the system, then more detailed performance computations at the index points would not be required.

System Performance Assumptions

The proposed project alterations are being evaluated relative to the Baseline Condition, as well as the Future Cumulative Condition Baseline scenarios described below. Per USACE EC 1165-2-220, Appendix F, Section F-3.f (USACE, 2018) all project features are assumed to be stable and functional to the top of containment (USACE, 2018) in this analysis. Levees are not assumed to breach or otherwise malfunction in the analysis of pre- and post-project conditions. Levees are allowed to overtop and spill water to storage areas adjacent to levees, without failing. The Project

also is assumed to be stabilized to the authorized condition, and based on this assumption, fragility curves are not required.

Levees of the SPFC that do not meet the minimum project standard have been modeled as meeting the minimum authorized height (i.e., the 1957 design profile). Where existing top of levee heights exceed the authorized height, they are modeled as such (DWR, 2017c). These assumptions reflect the ability of upstream projects to engage in maintenance and provide a conservative estimate of flow delivery in the area of interest. This approach is consistent with the assumptions used for LEBLS and similar projects in the region.

Baseline Condition

The Baseline Condition modeling assumes the following Early Implementation Projects (DWR, 2017c):

- American River Common Features Project WRDA 96/99 sites
- Folsom Dam Joint Federal Project (JFP) – including water control manual updated considering forecast-based operations as of August 19, 2016
- Marysville Ring Levee
- Sutter Basin Project – Feather River West Levee Project
- Three Rivers Levee Improvement Project (TRLIA)
- Natomas Levee Improvement Project (NLIP)
- West Sacramento 2016 sites (Southport Levee Improvement Project)
- Hamilton City – Phase 1
- Star Bend (SBFCA)
- Bear River

Future Cumulative Condition

The Future Cumulative Condition scenario builds upon the assumptions in the Baseline Condition, and reflects full build-out of the elements of the recommended Yolo Bypass expansion option (Yolo Bypass Option 3) described in the BWFS (DWR, 2016) and reproduced on **Figure 7**. This includes implementation of the following features:

- **Upper Elkhorn and Fremont Weir Expansion** – a one-mile expansion of the Upper Elkhorn Basin with a corresponding expansion of Fremont Weir
- **Lower Elkhorn Expansion** – a 3,500-feet levee setback along the Lower Elkhorn Basin
- **Sacramento Weir and Bypass Expansion** – a 1,500-feet expansion of the Sacramento Weir and Bypass

- **Cache Creek Settling Basin** – measures to extend useful life of the Cache Creek Settling Basin and address concerns regarding mercury in its sediment
- **Levee Setback Near Willow Slough Bypass** – a 4,000-feet levee setback on the west side of the bypass north of Willow Slough and south of I-80
- **Levee Setback Near Putah Creek** – a 5,000-feet levee setback on the west side of the Yolo Bypass north of Putah Creek
- **Tie-in to Sacramento River Deep Water Ship Channel** – a gated weir to tie into the Sacramento River Deep Water Ship Channel and a closure structure to prevent high stages from reaching West Sacramento
- **Degradation of Step Levees and Lower Egbert Track Levees** – degrading remaining levee segments in the lower Yolo Bypass at the north end of Little Holland Tract and Liberty Island and degrading portions of the Lower Egbert Track (RD 2084) levees.
- **Lower Yolo Bypass Setback** – levee setback south of RD 2068 to Rio Vista, including removal of cross levee at southern boundary of RD 2098)
- **Build Weirs on Prospect Island Levee** – build weirs along portions of the Prospect Island west levee
- **Improved Flood Protection for Rio Vista and Highway 84** – flood protection improvements for the city of Rio Vista to address potential hydraulic impacts of Yolo Bypass capacity improvements
- **Fix-in-place Levee Improvements** – provide six feet of freeboard over the estimated 200-year flood flows (represented by the 110-percent scaling of the 1997 storm pattern)
- **Geotechnical Levee Improvements** – fix any remaining geotechnical inadequacies for urban areas unaddressed in the future baseline condition and fix known critical geotechnical deficiencies for rural and small communities.

Index Points

A total of eleven index points were selected as locations to review the hydraulic impacts of the Project in both a Baseline and Future Cumulative Conditions scenarios. Shown on **Figure 8**, the following locations were identified during preliminary hydraulic analysis in close coordination with DWR and local interests:

1. West (left) bank of Yolo Bypass at County Road 155
2. Hass Slough at western boundary of RD 2098
3. Cache Slough near Hastings Cut
4. West (left) bank of Yolo Bypass at northern boundary of the Project
5. West (left) bank of Yolo Bypass at Yolo County/Solano County Line
6. Cache Slough at Confluence with Yolo Bypass
7. Lindsey Slough approximately 1 mile upstream of Hastings Island Road Bridge

8. Cache Slough at northern end of Little Egbert Tract
9. Cache Slough at Ryer Island
10. Cache Slough at southern end of Little Egbert Tract
11. Sacramento River at Rio Vista

Hydrology

Hydrologic input data for the hydraulic modeling was developed using data previously prepared by the USACE and DWR for regional planning studies. This includes historic flow record data used for calibration and validation of the hydraulic model parameters, as well as design storm hydrology suitable for analyzing the 16% ACE (6-year), 1% ACE (100-year), and 0.5% ACE (200-year) storm events. The sources of hydrology data used for these analyses are described in the following sections.

Calibration and Validation Hydrology

The objective of the model calibration effort is to test and refine the hydraulic model's simplified geometric elements and empirical parameters so that the model will as faithfully as reasonably possible reproduce the behavior of the system during an observed event. The quality of the calibration can be significantly influenced by the quality of its data inputs and observations, particularly with respect to the hydrology which drives the model boundary conditions.

The Baseline Condition hydraulic model has been calibrated using records from the January 1997 flood event and validated using the records from the January 2006 flood event. The calibration and validation time series flow data and high water mark survey data used in this study was compiled by USACE Sacramento District (USACE, 2013). All calibration data prepared by the USACE has been subject to quality control review and is reported in the NAVD 88 vertical datum, consistent with the Project datum. This dataset has been used extensively for calibrating other regional hydraulic models, including those used by DWR in the BWFS and LEBLS projects. For purposes of this project, outputs extracted from DWR's calibration and validation analysis (Wood Rodgers, 2015) were used to define boundary conditions for the Project's baseline two-dimensional hydraulic model calibration analysis and validation analysis.
A summary of the flow inputs used in the calibration and validation analysis is provided in the subsequent hydraulic model boundary conditions discussion.

CVHS Historic Patterns and Design Storm Scalings

Input time series data for evaluating the 16% ACE (6-year), 1% ACE (100-year), and 0.5% (200-year) design storms for existing conditions and future cumulative conditions were developed using information previously prepared by DWR for the LEBLS project (DWR, 2017c) and BWFS (DWR, 2016), respectively. These hydrology datasets were prepared using data and tools originally developed for the Central Valley Hydrology Study (CVHS) completed by the USACE and DWR in 2013. The CVHS-based hydrology uses historic storm patterns, scaled to correspond to statistically-determined return period flows. As part of the BWFS, DWR analyzed 120 scaled event simulations, and identified the 1997 storm pattern as being the dominant pattern in this part

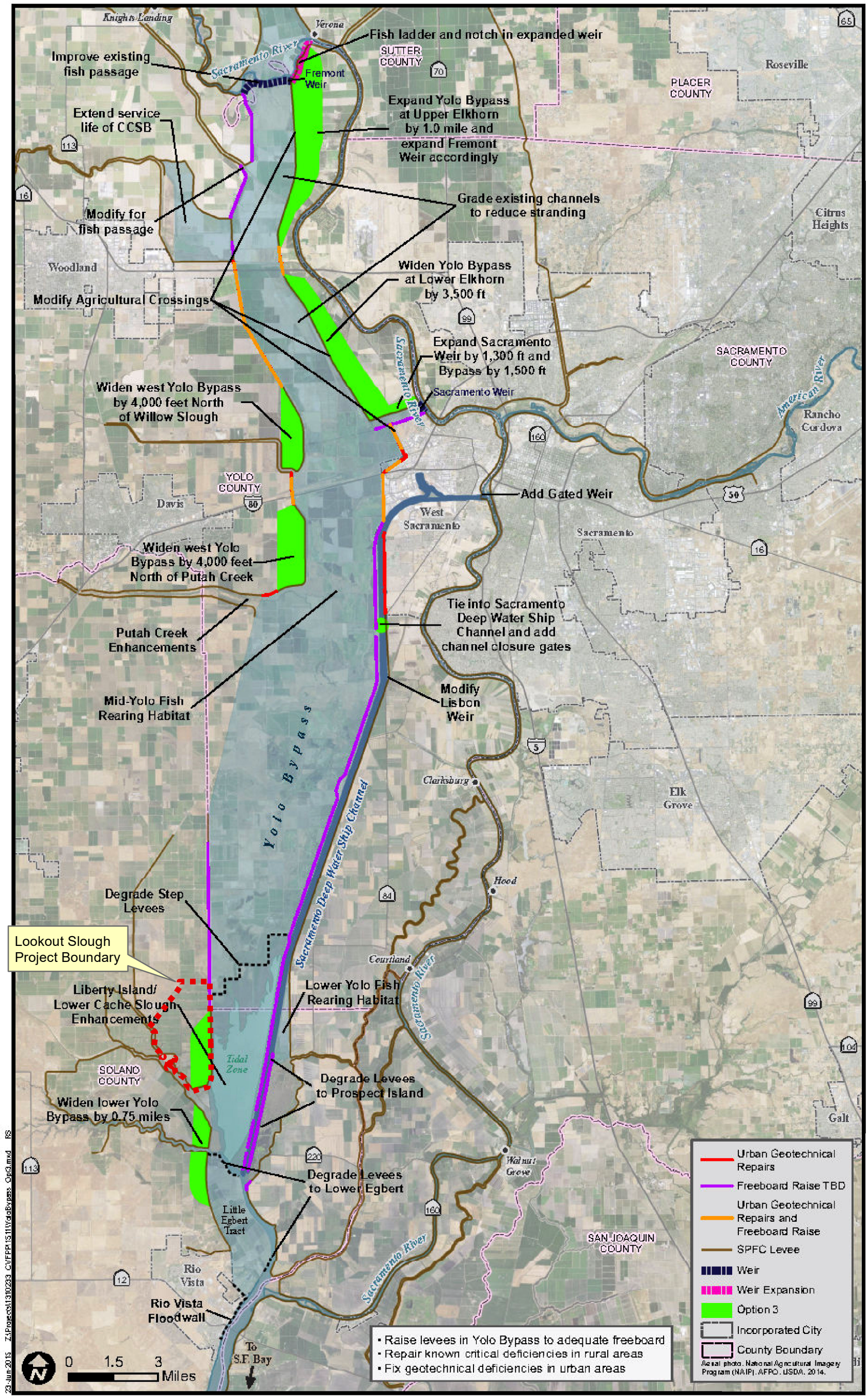

Figure 7
Future Cumulative Condition (BWFS Yolo Bypass Option 3)

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

Ecosystem Investment Partners

Prepared by:
ESA

Map Prepared Date: 8/25/2019
Map Prepared By: JPritchard
Base Source: Wood Rogers
Base Date: 10/24/17
Data Source(s): DWR, 2016

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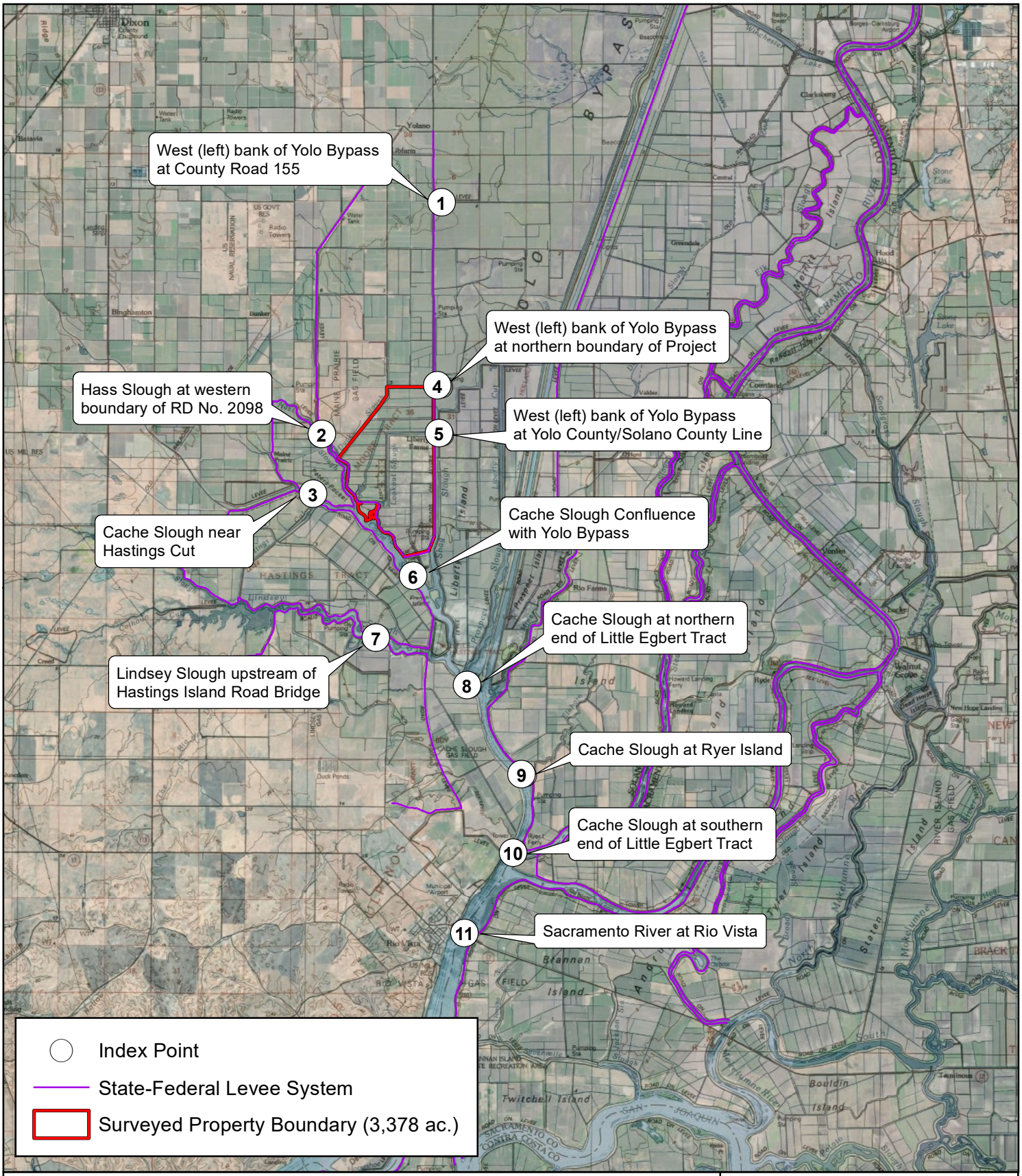

Figure 8
Index Points

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

0 7,500 15,000
Feet

Ecosystem Investment Partners

Prepared by: ESA

Map Prepared Date: 4/8/2019
Map Prepared By: JPritchard
Base Source: Wood Rogers
Base Date: 10/24/2017
Data Source(s):

Path: U:\GIS\GIS\Projects\18xxxx\D181197_00_Lookout_Slough_Restoration_1\03_MXDs_Projects\02_Flood_Task_System_HandH\F08_Index_Points.mxd

of the system. That effort was also used to identify the appropriate event scalings for the 16% ACE (6-year), 1% ACE (100-year), and 0.5% (200-year) design storms for application to the Yolo Bypass (**Table 2**).

TABLE 2
CVHS SCALED EVENTS USED FOR ANALYSIS (DWR, 2016 AND DWR, 2017B)

	ACE	Frequency	SAC 15 Yolo Bypass Downstream of Knights Landing Ridge Cut	SAC 35 Yolo Bypass Upstream of Sacramento Bypass	SAC 17A Yolo Bypass Downstream of I-80 Bridge
Combined Regulated Frequency Curve Peak Flows (cfs)	16%	6-year	176,034	186,957	208,737
	1%	100-year	389,277	407,333	501,046
	0.5%	200-year	426,163	446,532	549,582
CVHS Scale Factor (1997 Event Pattern)	16%	6-year	0.40	0.40	0.40
	1%	100-year	0.95	0.95	0.95
	0.5%	200-year	1.10	1.10	1.10
Event Based Peak Flows (cfs)	16%	6-year	176,032	178,600	209,286
	1%	100-year	390,720	406,613	505,024
	0.5%	200-year	431,324	446,800	561,626

A summary of the flow inputs used in the hydraulic design analysis is provided in the subsequent hydraulic model boundary conditions discussion.

Hydraulic Analysis

To address the complex interaction between Yolo Bypass flood flows and the tidal influences of the north Sacramento-San Joaquin Delta, a two-dimensional hydraulic model is necessary for supporting design of the Project. A description of the modeling approach, tools, supporting data, and system impacts assessment are provided in the following sections.

Parent-Child Model Nesting Concept

One cost-effective and computationally efficient technique that has been deployed successfully in numerical modeling applications is splitting computations between coarse, large scale region-wide models (parent models) and localized high-resolution subdomain areas (child models). It can often be useful to deploy this technique in series, whereby results from the parent model are used to define boundary conditions for the child model, particularly when the child model domain is defined appropriately so as to avoid erroneous biasing at the boundary conditions.

This report documents the development and analysis performed using a child model prepared specifically for design of the Project. Documentation associated with development and deployment of the parent model for establishing boundary conditions in the child model have been referenced where applicable.

Parent Hydraulic Model

One-dimensional HEC-RAS system models prepared previously by DWR were utilized as the parent models for this study. Data from the BWFS, incorporating downstream tidal dynamics was used for representing the Baseline Condition (DWR, 2016). Data from the BWFS recommended alternative for expanding the Yolo Bypass (Yolo Bypass Option 3) was utilized to represent the Future Cumulative Condition (DWR, 2016). The Baseline Conditions modeling of the Sacramento River system extends from Hamilton City to Collinsville, and includes the major tributary systems (Feather River and American River). The future cumulative conditions model is truncated above the Sutter Bypass and Tisdale Bypass systems, but otherwise covers the same geographic area as the existing conditions system model. The geographic coverage and quality of calibration make these models well suited as a source for establishing boundary conditions for a localized site-specific model.

Child Hydraulic Model

For on-site design, a high resolution two-dimensional child model was developed using the TUFLOW commercial software package. The child model builds upon and expands the calibrated two-dimensional model previously developed for analyzing and supporting design of the Project's tidal restoration components. This approach was reviewed during pre-coordination with the Hydraulics Section of the USACE Sacramento District, and is considered appropriate for advancing the Project through the USACE Section 408 Permit process. TUFLOW was approved for use and added to the USACE Hydrology, Hydraulics, and Coastal Software List in 2012, and both DWR and the USACE Sacramento District have expert staff trained in use and review of the software. For this project, the TUFLOW HPC (Heavily Parallelized Compute) finite volume solver has been used, allowing the software to run in simulation on NVidia GPU hardware. All modeling prepared for the Project utilizes the latest software version of TUFLOW (Build: 2018-03-AD-iSP-w64).

The relative extents of the parent and child models are shown on **Figure 9** and **Figure 10**. The child model boundaries are located at appropriate handoff points correlating with cross-sections in the respective one-dimensional HEC-RAS parent models. Boundary locations in the child model were selected to minimize distortions in the area of interest, and at locations where flow and stage could be discretized appropriately to avoid misrepresenting data received from the parent model. Upstream flows routed through the respective parent models are compiled at each of these locations and used as inputs to the TUFLOW model. Likewise, the modeled stage time series data output from the HEC-RAS system is used to define the downstream stage boundary of the TUFLOW model.

Hydraulic Model Development

The following section describes the model extents, general construction of the TUFLOW hydraulic model and input data sources, calibration and validation of the model to observed data, and application of the model for evaluating the project design.

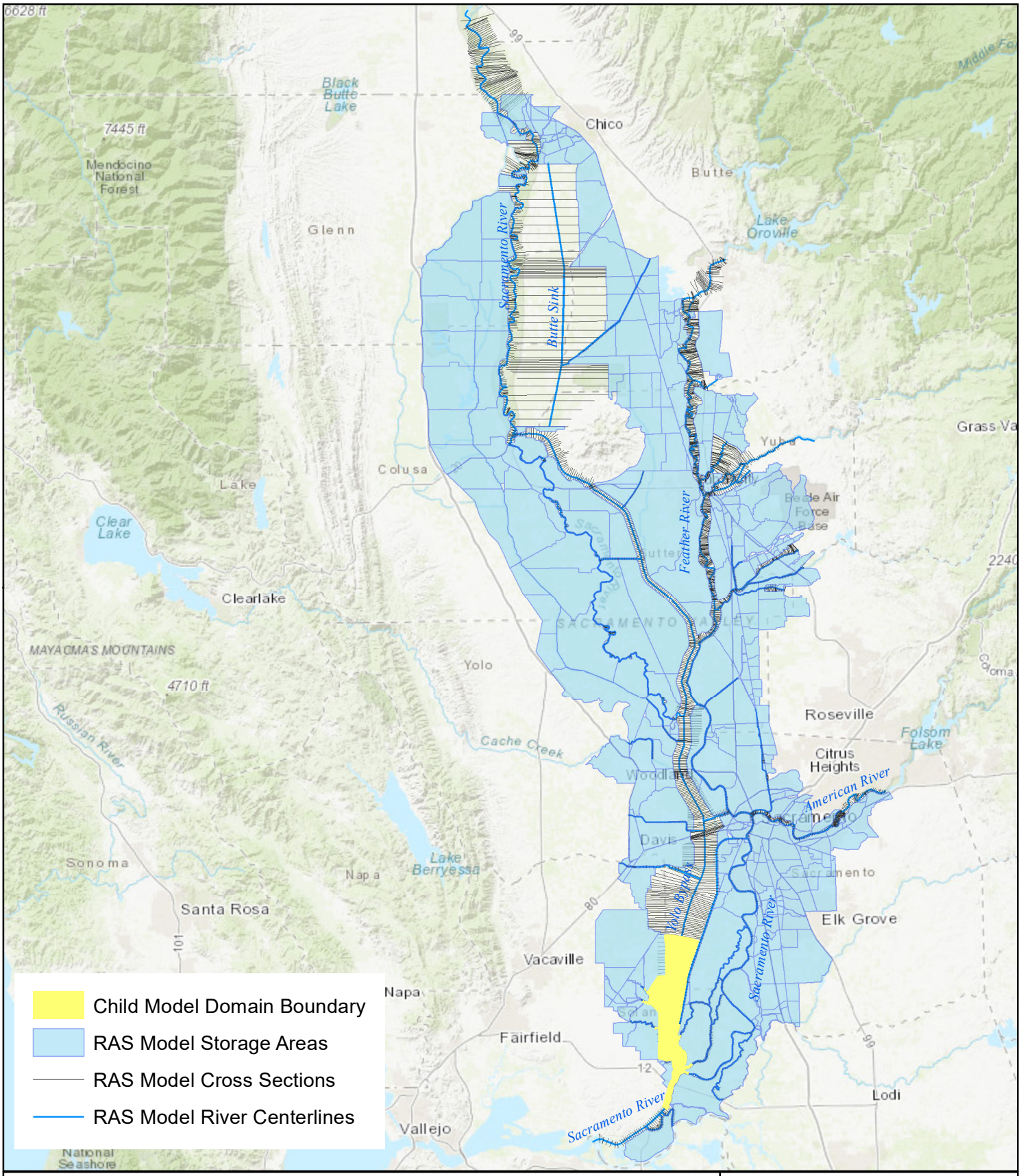

Figure 9
Parent-Child Model Schematic (Baseline Condition)

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

0 7.5 15
Miles

Ecosystem Investment Partners

Map Prepared Date: 4/8/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):
DWR
ESRI Service Layers

Prepared by: ESA

Path: U:\GIS\GIS\Projects\18xxxx\D181197_00_Lookout_Slough_Restoration_1\03_MXDs_Projects\02_Flood_Task_System_HandH\F09_Parent_Child_Schematic_Baseline.mxd

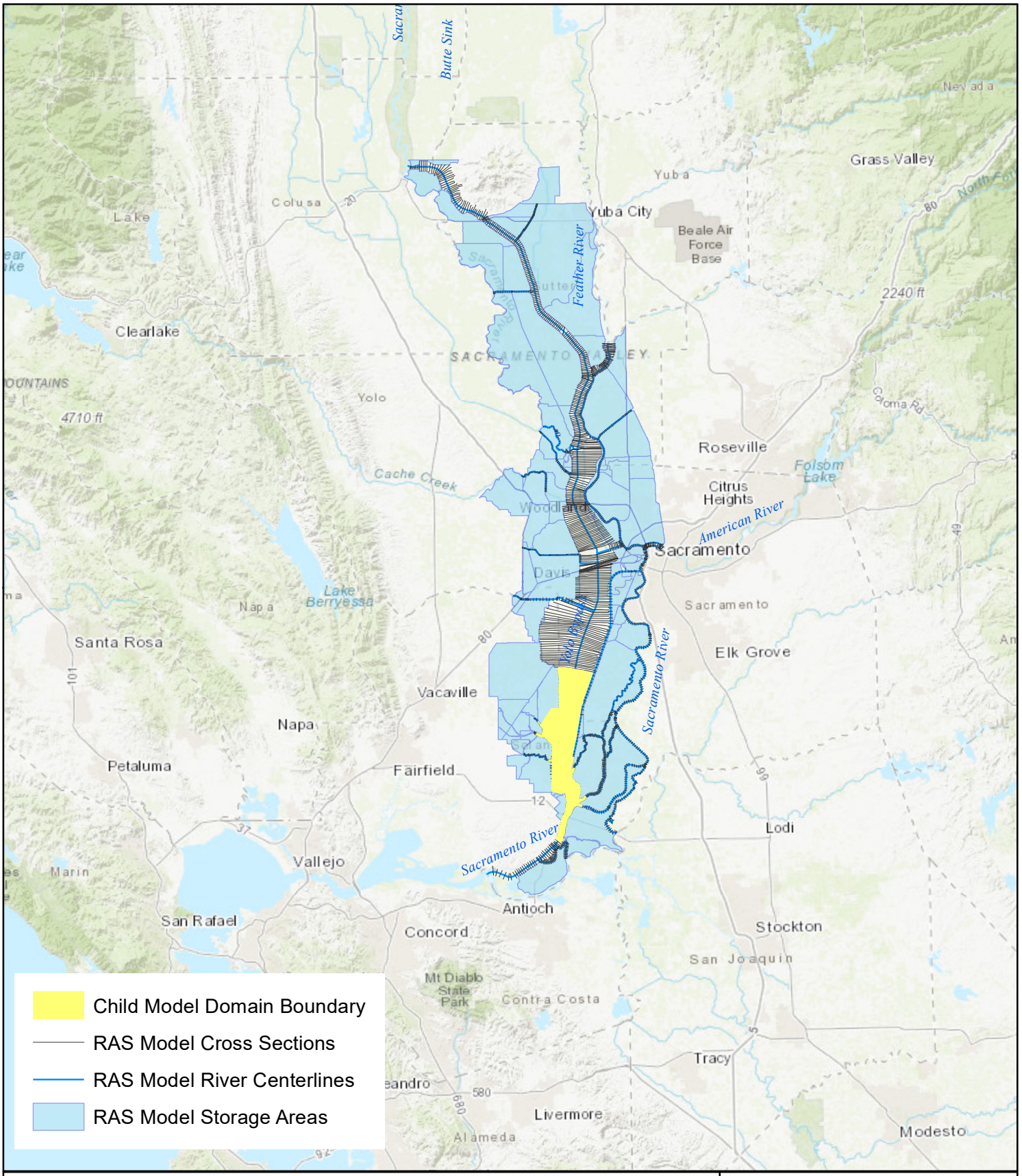

Figure 10
Parent-Child Model Schematic (Future Cumulative Condition)

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

0 7.5 15
Miles

Ecosystem Investment Partners

Map Prepared Date: 4/8/2019
Map Prepared By: Brent Davis
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):
DWR
ESRI Service Layers

Prepared by: ESA

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The TUFLOW hydraulic model utilizes a grid resolution of 60 feet, which was selected based on sensitivity and solution-convergence testing. The grid resolution has been optimized to balance output requirements with computational efficiency and model stability. Quality assurance checks have been conducted to ensure that the model performs within recommended tolerances for numerical stability and mass balance for all simulations.

Geographic Extents

The TUFLOW model domain boundary is shown in **Figure 11**. The northern boundary of the model domain is located on the Yolo Bypass, approximately 5 miles north of Liberty Island Road (the northern boundary of the Project). The eastern edge of the model domain is bounded by the east levee of the Yolo Bypass, and wraps around to include the lower end of the Sacramento River Deep Water Ship Channel, and tracks southward to intercept the confluences with Miner Slough, Steamboat Slough, and the Sacramento River near Rio Vista. The western edge of the model domain covers the Project boundary up to Duck Slough; lower Hass Slough and Cache Slough above where these streams form a confluence at the southeastern tip of the Peters Pocket track; and also includes the lower portion of Lindsey Slough beginning approximately 1 mile above Hastings Island Bridge. The southern (downstream) boundary is located upstream of the Sacramento River's confluence with Three Mile Slough.

The model domain extents have been defined sufficiently far from the area of interest to avoid the influence of numerical artifacts at the model domain boundaries. Care has been taken to avoid setting the model domain boundary beyond the extents of regional parent models and to avoid excessively complicating the model boundary set up by reaching further than necessary into the overall system.

Boundary Conditions

Figure 12 shows the locations of the TUFLOW model boundary conditions. The model boundaries can be generally summarized as follows:

- Tidal boundary at the Sacramento River above Three Mile Slough
- Flow at Yolo Bypass near Yolano
- Flow at Sacramento River Deep Water Ship Channel
- Flow at Hass Slough
- Flow at Cache Slough
- Flow at Miner Slough
- Flow at Lindsey Slough
- Flow at Steamboat Slough
- Flow at Sacramento River

All flow time-series data at the boundary conditions locations was sourced from the respective HEC-RAS parent model output (provided by DWR in *.dss database format).

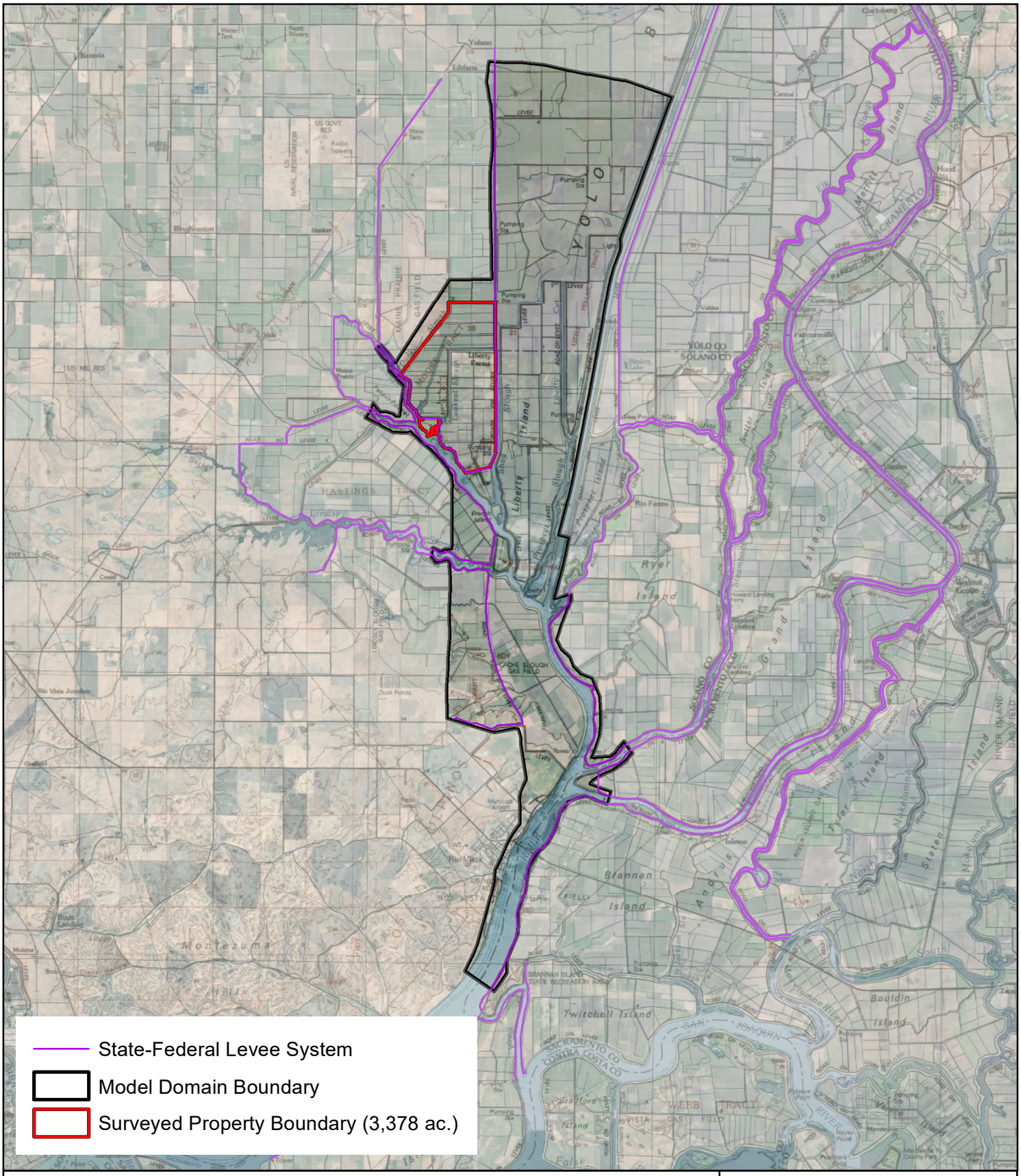

Figure 11
TUFLOW Model Boundary Extents

N
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Ecosystem Investment Partners

Prepared by:
ESA

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

0 7,500 15,000
Feet

Map Prepared Date: 4/8/2019
Map Prepared By: JPritchard
Base Source: Wood Rogers
Base Date: 10/24/2017
Data Source(s):

Path: U:\GIS\GIS\Projects\18xxxx\D181197_00_Lookout_Slough_Restoration_1\03_MXDs_Projects\02_Flood_Task_System_HandH\F11_TUFLOW_Boundary.mxd

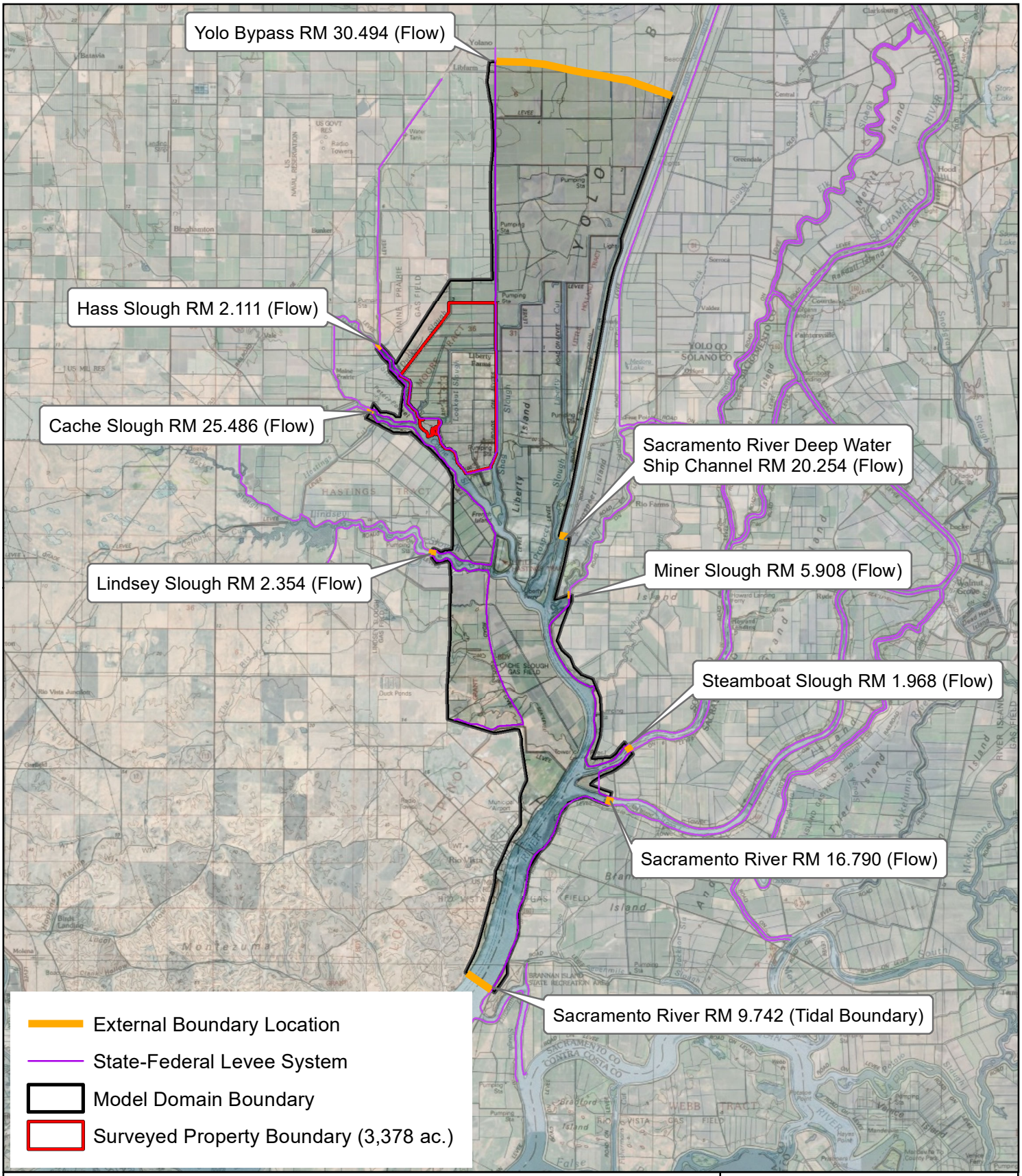

Figure 12
TUFLOW Model Boundary Conditions

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

0 7,500 15,000
Feet

Ecosystem Investment Partners

Prepared by: ESA

Map Prepared Date: 4/8/2019
Map Prepared By: JPritchard
Base Source: Wood Rogers
Base Date: 10/24/2017
Data Source(s):

Path: U:\GIS\GIS\Projects\18xxxx\D181197_00_Lookout_Slough_Restoration_1\03_MXDs_Projects\02_Flood_Task_System_HandH\F12_TUFLOW_BC_Locations.mxd

For modeling downstream tidal boundary conditions in the calibration and validation simulations, historic records from the 1997 and 2006 storm periods were used to define dynamic stage time series at the extremities of the HEC-RAS parent model.

For the design storm events, two approaches were utilized for representing the tidal boundary conditions at the downstream end of the system. The 1% ACE (100-year) and 0.5% ACE (200-year) events were modeled using a dynamic tidal time series derived from routing the CVHS hydrology through the RMA Delta model (DWR, 2016). For the 16% ACE (6-year) simulations, a dynamic stage boundary was not provided, and a fixed water surface was used at each of the tidal boundaries instead. The simulated 16% ACE stage was derived from stage-frequency analysis of the respective gages at the Sacramento River at Collinsville, Georgiana Slough at Mokelumne River, and Three Mile Slough at San Joaquin River (**Appendix A**). For ease of interpretation, the 10% (10-year) downstream stage was used as the basis for analyzing the 16% ACE (6-year) storm event. Although this assumption is somewhat conservative, it only results in differences of approximately 0.5 feet at the downstream boundaries, and is not anticipated to have a significant effect on the results in the vicinity of the Project. The peak stages in the dynamic time series for the 1% ACE (100-year) and 0.5% ACE (200-year) were also reviewed and found to be in close agreement with the corresponding stage-frequency relationships computed at each of the downstream boundary locations.

Modeling of the 1957 authorized design condition in the TUFLOW child model did not require use of the parent model for boundary conditions. To establish a downstream boundary for the authorized design condition, a static water surface was interpolated from the authorized 1957 design profile on the Sacramento River downstream of Rio Vista.

Table 3 summarizes the peak flow or stage values at each boundary location for the respective hydrology scenarios.

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TABLE 3
BOUNDARY CONDITION SUMMARY (PEAK FLOW AND STAGE SUMMARY)

Source	HEC-RAS Cross-Section Handoff Designation	1957 Authorized Design Flow and Profile	Calibration and Validation		Baseline Condition			Future Cumulative Condition		
			1997 Historic Storm Calibration Simulation	2006 Historic Storm Validation Simulation	1997 Pattern 40% Scaling 16% ACE (6-year)	1997 Pattern 95% Scaling 1% ACE (100-year)	1997 Pattern 110% Scaling 0.5% ACE (200-year)	1997 Pattern 40% Scaling 16% ACE (6-year)	1997 Pattern 95% Scaling 1% ACE (100-year)	1997 Pattern 110% Scaling 0.5% ACE (200-year)
Yolo Bypass	YOL R03 RM 30.494	490,000 cfs	458,781 cfs	272,026 cfs	206,944 cfs	489,525 cfs	544,481 cfs	242,064 cfs	472,014 cfs	521,124 cfs
Sacramento River Deep Water Ship Channel	SAD R01 RM 20.254	N/A	15,219 cfs	16,881 cfs	1,063 cfs	14,984 cfs	12,420 cfs	1,935 cfs	18,255 cfs	19,257 cfs
Hass Slough	HAS R01 RM 2.111	N/A	2,524 cfs	840 cfs	169 cfs	1,965 cfs	2,057 cfs	177 cfs	2,546 cfs	1,896 cfs
Cache Slough	CAS R04 RM 25.486	N/A	2,363 cfs	522 cfs	118 cfs	2,535 cfs	2,545 cfs	129 cfs	993 cfs	1,952 cfs
Miner Slough	MIN R01 RM 5.908	10,000 cfs	18,681 cfs	14,422 cfs	10,687 cfs	18,125 cfs	19,119 cfs	10,627 cfs	12,559 cfs	12,879 cfs
Lindsey Slough	LIN R01 RM 2.354	N/A	3,691 cfs	4,292 cfs	541 cfs	2,826 cfs	2,799 cfs	569 cfs	4,713 cfs	3,226 cfs
Steamboat Slough	STM R01 RM 1.968	43,500 cfs	34,002 cfs	27,216 cfs	25,657 cfs	35,508 cfs	37,400 cfs	25,801 cfs	30,970 cfs	32,645 cfs
Sacramento River (Inflow)	SAC R05 RM 16.790	35,900 cfs	46,101 cfs	42,430 cfs	40,444 cfs	47,130 cfs	48,655 cfs	40,596 cfs	41,490 cfs	42,504 cfs
Sacramento River (Downstream Stage, NAVD 88)	SAC R04 RM 9.742	11.51 feet	9.82 feet	9.39 feet	9.13 feet	10.11 feet	10.43 feet	8.94 feet	10.24 feet	10.60 feet

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Topographic and Bathymetric Survey Data

Terrain data for this project is based on the following data sources, which are layered in the hydraulic model input to build a composite bathymetric and terrain surface:

- The primary terrain data source representing existing terrain for the southern portion of the model domain is based on the DWR *San Francisco Bay and Sacramento-San Joaquin Delta DEM* (Wang & Ateljevich, 2012) which aggregates a number of data sources. In the vicinity of the Project, coverage consists primarily of Delta Risk Management Strategy (DRMS) LiDAR data (Dudas, 2010) and the Liberty Island single beam bathymetric surveys prepared by cbec/EDS in 2006, 2009, and 2010. Elevation data was prepared by DWR in 10m DEM format (Esri Grid) in units of centimeters, referenced to NAVD 88. For purposes of preparing the model input, the elevation data was converted to units of feet and re-projected to California State Plane II FIPS 0402 (US Feet) for consistency with the Project datum, and clipped to a smaller extent to reduce the overall data footprint and terrain processing overhead.

- The DRMS LiDAR dataset (Dudas, 2010) was used to fill in gaps in some of the low confidence marsh areas on Liberty Island. Wood Rodgers utilized DRMS tiles which were post-processed as part of DWR's CVFED Program to create "patch" areas to improve the terrain representation in these areas. The CVFED post-processed tiles incorporate breaklines to enforce edges of water bodies and avoid undesired interpolation across large flat areas.

- The DRMS and CVFED LiDAR datasets were also used to provide a continuous surface inside the Yolo Bypass north of Liberty Island and west of the Toe Drain.

- USGS conducted bathymetric surveys of the Little Holland Tract area in 2015 (Snyder et al., 2016). Data was provided in NAD 83 UTM Zone 10 coordinates in units of meters. Elevations were provided in units of meters referenced to NAVD 88. Wood Rodgers re-projected the data to California State Plane II FIPS 0402 (US Feet) using ArcGIS. Elevation values were converted using the ArcGIS Spatial Analyst extension (vertical metric conversion to feet using ArcGIS Times function: 1m = 3.28084 feet).

- DWR's North Central Regional Office (NCRO) provided bathymetric survey data collected in 2015 along the northern "steps" of Liberty Island. This data was provided in NAD83, California State Plane II FIPS 0402 (US Feet) coordinates and referenced to NAVD 88 in units of feet. No additional processing was required.

- To correct for isolated issues identified in the *San Francisco Bay and Sacramento-San Joaquin Delta DEM* surface, some locations were replaced with data from the DWR Bay-Delta Office Cross Section Development Program (CSDP).

- At the project site, new topographic surveys flown by Wood Rodgers were used to define without-Project conditions. This data was collected and mapped in NAD 83, California State Plane II FIPS 0402 (US Feet) and referenced to NAVD 88 in units of feet, consistent with the Project datums. Field surveys were also performed to rectify aerial survey data in marsh areas within the Liberty Farms tract.

The TUFLOW topographic layering hierarchy was input as follows (layers listed in order from the "top" of the stack, to "bottom"):

1. San Francisco Bay and Sacramento-San Joaquin Delta DEM (Wang & Ateljevich, 2012)
2. DRMS LiDAR DEM (Dudas, 2010)
3. Little Holland Tract DEM (Snyder et al., 2016).
4. Liberty Cut bathymetry survey DEM (DWR NCRO, 2015)
5. CSDP Bathymetry for localized bathymetry corrections (DWR Bay-Delta Office, 2001)
6. On-site topography (aerial and bathymetry) collected in Fall 2017 by Wood Rodgers. For the with-Project scenarios, a preliminary grading surface reflecting the proposed marsh grading plan and tidal channel network replaces the onsite topography.

The geographic distribution of the respective terrain layer datasets is shown on **Figure 13**.

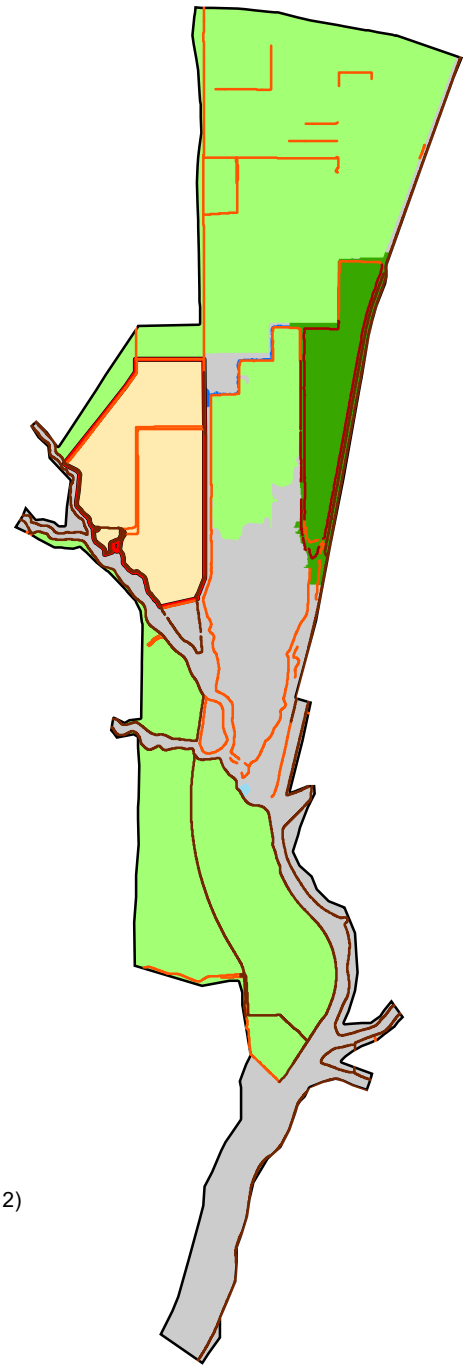
Terrain Enforcement

The DWR Delta DEM surface exhibits areas with erroneous elevations or missing data. These areas are filled/cleaned using TUFLOW's topographic layering tools to generate TIN surfaces which eliminate gaps and clean up erroneous data values in the terrain.

Using the 3D breaklines prepared previously as part of DWR's CVFED LiDAR surveying efforts and data contained in the DWR California Levee Database (DWR, 2010) as a base, a comprehensive breakline dataset was developed to enforce the tops of levees and embankments within the domain area. In some cases, manual edits were made to better align the line work with tops of embankments considered hydraulically significant. The California Levee Database line work was then densified to intervals of 30 feet (roughly half the cell size of the computational grid) and converted to points using ArcGIS, which were then assigned elevations using the SF Bay SJ Delta DEM surface. The CVFED 3D breaklines already contained elevation values and were converted to points accordingly. The respective breakline datasets used to enforce terrain in the model are shown on Figure 12. The resultant composite terrain and bathymetry surface utilized in the respective model scenarios is shown on **Figure 14** through **Figure 17**.

Bed Roughness

Land use classifications derived from mapping prepared by the California Department of Fish and Game (now Fish and Wildlife, CDFW) in 2007 were aggregated into general land cover (materials) types for input into the baseline hydraulic model: subtidal, mudflats, low and middle marsh, upland, cropland, and riparian plantings proposed as part of the Project (WRA, 2019b). With the exception of cropland, these are generally associated with vegetation densities and depths that will be associated with different portions of the tidal prism (**Figure 18**), which are expected to be representative of conditions in the north Delta and lower Yolo Bypass. The crosswalk between CDFW vegetation and the model material type reclassification scheme used is summarized in **Table 4**.



- Supplemental Breaklines
- CVFED Breaklines
- CA Levee Database Breaklines
- Surveyed Property Boundary (3,378 ac.)
- Model Domain Boundary
- SF Bay and Sacramento-San Joaquin DEM V3 (DWR, 2012)
- Post-Processed DRMS LiDAR (DWR, 2013)
- Little Holland Tract Bathymetry (USGS, 2015)
- Liberty Cut Bathymetry (DWR, 2015)
- CSDP Bathymetry (DWR, 2003)
- Site Design Surface (Wood Rodgers, 2018)

Figure 13
Topographic and Bathymetric Data Sources and Coverage

N
W E
S

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

0 7,500 15,000
Feet

Ecosystem Investment Partners

Map Prepared Date: 4/8/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):
Esri Service Layers (2018)

Prepared by: ESA

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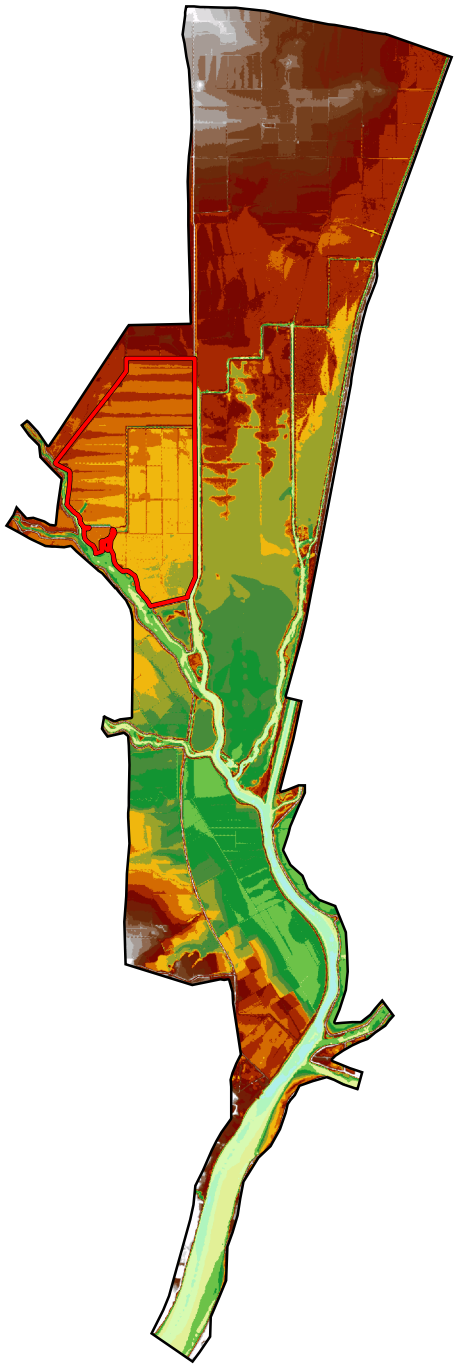

Surveyed Property Boundary (3,378 ac.)

Model Domain Boundary

Elevation (feet, NAVD 88)

- -55 - -40
- -40 - -30
- -30 - -20
- -20 - -10
- -10 - -5
- -5 - -2
- -2 - 0
- 0 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- 10 - 12
- 12 - 14
- 14 - 16
- 16 - 18
- 18 - 20
- 20 - 22
- 22 - 24
- 24 - 26

Figure 14
TUFLOW Composite Digital Elevation Model
Baseline Condition Without-Project

N
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Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

0 7,500 15,000
Feet

Ecosystem Investment Partners

Map Prepared Date: 4/8/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):
USGS, DWR, Wood Rodgers

Prepared by: ESA

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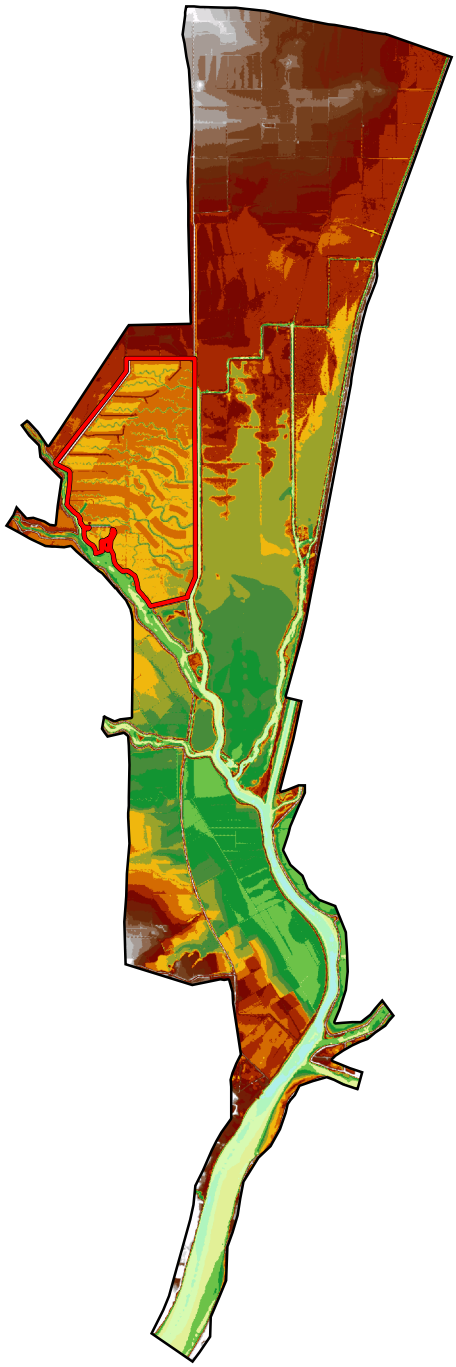

Surveyed Property Boundary (3,378 ac.)

Model Domain Boundary

Elevation (feet, NAVD 88)

- -55 - -40
- -40 - -30
- -30 - -20
- -20 - -10
- -10 - -5
- -5 - -2
- -2 - 0
- 0 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- 10 - 12
- 12 - 14
- 14 - 16
- 16 - 18
- 18 - 20
- 20 - 22
- 22 - 24
- 24 - 26

Figure 15
TUFLOW Composite Digital Elevation Model
Baseline Condition With-Project

N
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Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

0 7,500 15,000
Feet

Ecosystem Investment Partners

Map Prepared Date: 8/25/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):
USGS, DWR, Wood Rodgers

Prepared by: ESA

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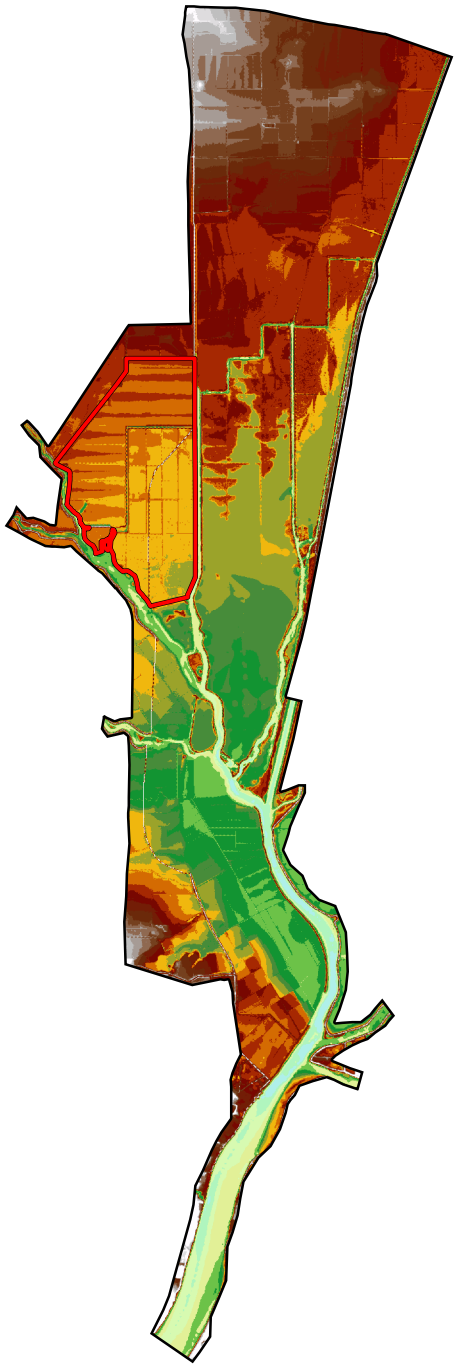

Surveyed Property Boundary (3,378 ac.)

Model Domain Boundary

Elevation (feet, NAVD 88)

- -55 - -40
- -40 - -30
- -30 - -20
- -20 - -10
- -10 - -5
- -5 - -2
- -2 - 0
- 0 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- 10 - 12
- 12 - 14
- 14 - 16
- 16 - 18
- 18 - 20
- 20 - 22
- 22 - 24
- 24 - 26

Figure 16
TUFLOW Composite Digital Elevation Model
Future Cumulative Condition Without-Project

N
W E
S

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

0 7,500 15,000
Feet

Ecosystem Investment Partners

Prepared by: ESA

Map Prepared Date: 4/8/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):
USGS, DWR, Wood Rodgers

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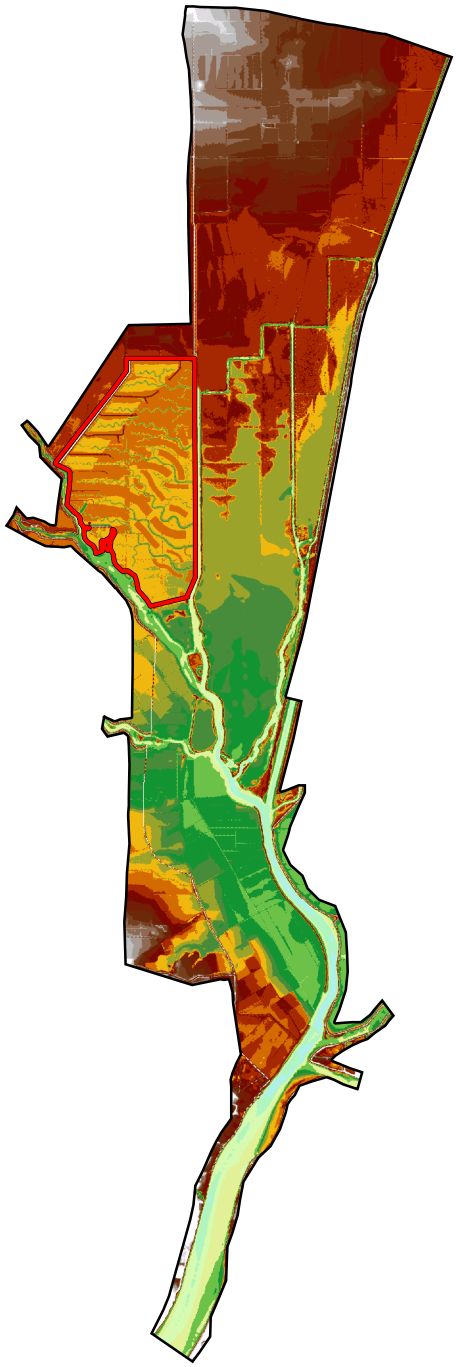

Surveyed Property Boundary (3,378 ac.)

Model Domain Boundary

Elevation (feet, NAVD 88)

- -55 - -40
- -40 - -30
- -30 - -20
- -20 - -10
- -10 - -5
- -5 - -2
- -2 - 0
- 0 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- 10 - 12
- 12 - 14
- 14 - 16
- 16 - 18
- 18 - 20
- 20 - 22
- 22 - 24
- 24 - 26

Figure 17
TUFLOW Composite Digital Elevation Model
Future Cumulative Condition With-Project

N
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Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

0 7,500 15,000
Feet

Ecosystem Investment Partners

Prepared by: ESA

Map Prepared Date: 4/8/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):
USGS, DWR, Wood Rodgers

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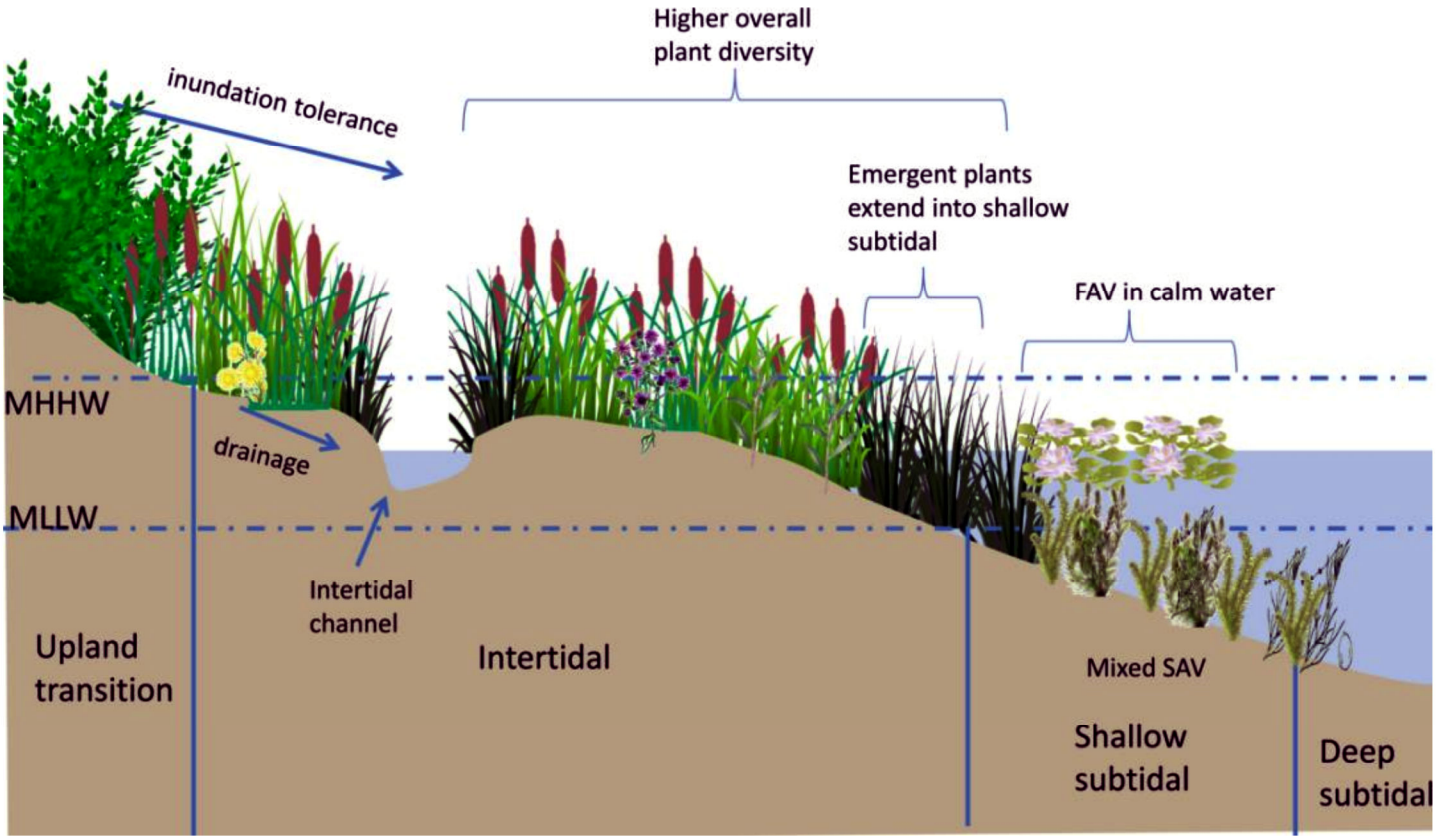


Note: FAV denotes floating aquatic vegetation, SAV denotes submerged aquatic vegetation.

Figure 18
General Factors Controlling Vegetation Zonation
in Freshwater Marshes (Sherman et al, 2017)

Lookout Slough Tidal Habitat Restoration
and Flood Improvement Project

Ecosystem Investment Partners

Map Prepared Date: 4/8/2019
Map Prepared By: JPritchard
Data Source(s):
Sherman et al (2017)

Prepared by: ESA

Path: U:\GIS\GIS\Projects\18xxxx\D181197_00_Lookout_Slough_Restoration_1\03_MXDs_Projects\02_Flood_Task_System_HandH\F18_MarshProfile.mxd

TABLE 4
MODEL MATERIAL CLASSIFICATION KEY

California Wildlife Habitat Relationship[1]	TUFLOW Model Material Type
Unclassified	Upland
Annual Grassland	Mudflat/Grassland
Barren	Mudflat/Grassland
Coastal Oak Woodland	Upland
Coastal Scrub	Low and Middle Marsh
Cropland	Cropland
Deciduous Orchard	Cropland
Eucalyptus	Upland
Fresh Emergent Wetland	Low and Middle Marsh
Riverine	Riverine
Saline Emergent Wetland	Low and Middle Marsh
Urban	Upland
Valley Foothill Riparian	Upland
Vineyard	Cropland

1 SOURCE: CDFW, 2007.

In the hydraulic model, the default material assignment to the 2D domain is Open Water, representing a roughness coefficient of 0.023 to 0.027 (consistent with the HEC-RAS parent model, and refined during model calibration). Roughness coefficient values for the Mudflat and Grassland, Low and Middle Marsh, Upland, Cropland, and Riparian materials types were estimated using the procedure for floodplains described in USGS Water Supply Paper No. 2339 (USGS, 1989). **Table 5** summarizes the respective material classification scheme and associated roughness coefficient estimates.

TABLE 5
MANNING'S ROUGHNESS CLASSIFICATIONS

Vegetation Complex Type	Typical Vegetation	Manning's Roughness[1]	Elevation Range (feet, NAVD 88)
Open Water	Negligible (primarily open water)	0.023 – 0.027	< 2.0 (MLLW)
Mudflat and Grassland	Minor	0.035	2.0 – 3.5 (MTL)
Low and Middle Marsh	Perennial vegetation, dense stands of bulrushes (tules and cattails)	0.045 (*assumes marsh vegetation lies down during flood conditions*)	3.5 – 7.0 (MHHW)
Upland	Riparian vegetation	0.060	> 7.0 (Maximum Tide)
Cropland	Rice, field crops	0.030	> 7.0
Riparian Planting	Riparian trees and scrub	0.140	7.0 – 9.0

NOTES:
1 Manning's roughness coefficients estimated using USGS, 1989 and base values computed previously by RMA, 2013.

The resultant materials input file representing the Baseline without-Project condition is shown on **Figure 19**. This dataset is also used for the 2006 event validation analysis.

Prior to the January 1997 storm, land use on Liberty Island was primarily agriculture cover. For the 1997 event calibration analysis, the base land use classification input was modified to reflect this historic land cover condition, as shown on **Figure 20**.

For the with-Project condition, the Lookout Slough Restoration site will be converted from agricultural use to a mix of tule marsh and subtidal habitat. For the with-Project analysis, the base land use classification input was modified to reflect the proposed land cover condition, as shown on **Figure 21**.

Bridge Hydraulics

The only major bridge crossing included explicitly in the model is the State Route 12 bridge crossing the Sacramento River at Rio Vista. Results from the parent model indicate that losses through the bridge are generally minor (0.2 feet or less), and that the bridge will not go under pressure or overtop for the range of flows being evaluated. For purposes of this analysis, the standard TUFLOW layered bridge approach (BMT WBM, n.d.) was applied to reflect form losses at the bridge piers. Form losses for bridge piers were estimated based on pier shape and blockage area using standard bridge pier backwater computation procedures (FHWA, 1978). During model testing, head losses through the bridge were compared with results from the parent model and found to be similar for each of the studied design storm return frequencies.

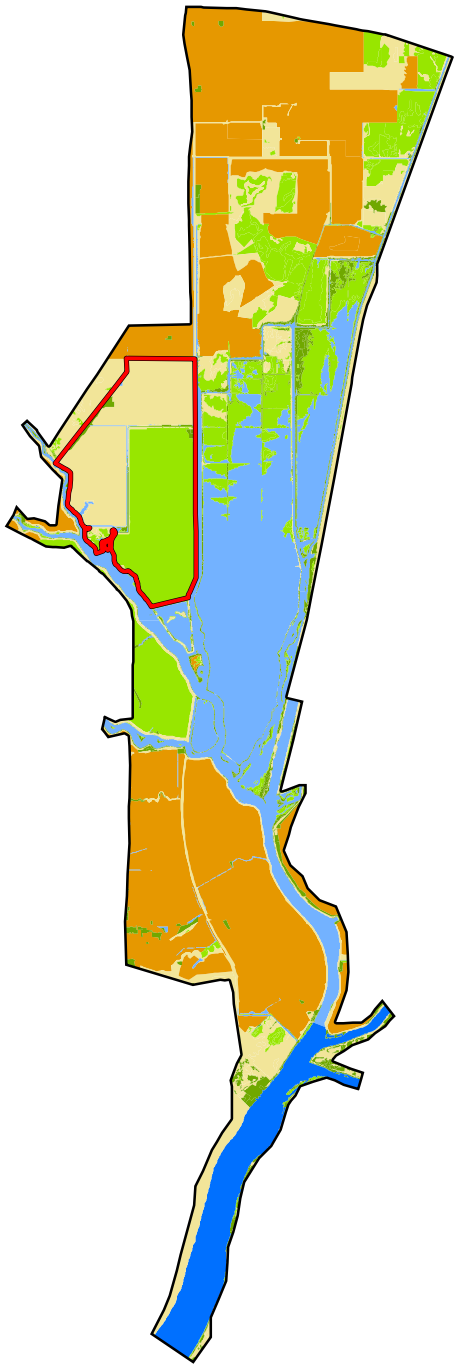
The Liberty Island Road bridge crossing near the project site is also within the model domain, however it has been omitted from the modeling for purposes of this study. Although in the area of interest, the bridge occupies a very small portion of the floodplain (less than 4% of the total width of the Yolo Bypass), and is not considered hydraulically significant with respect to analyzing flood impacts of the project.

The Hastings Island Road bridge crossing Lindsey Slough is also located within the model domain. This bridge is located on a backwater reach and is not considered to be hydraulically significant with respect to analyzing the flood impacts of the project.

The bridge pier form loss coefficients used in this study are summarized in **Appendix B**.

Model Calibration and Validation

The hydraulic model was calibrated to record data from the January 1997 storm and validated using record data from the January 2006 storm, consistent with work done by DWR for the Sacramento River system (Wood Rodgers, 2015). In general, more data is available for the 1997 event in the form of high water mark observations. However, levee failures that occurred at Little Egbert Tract and on Liberty Island during the January 1997 storm introduce significant uncertainties in timing and routing of flows in the Cache Slough Complex.



Surveyed Property Boundary (3,378 ac.)

Model Domain Boundary

Material Classification

Riverine (n = .023)

Riverine (n = 0.027)

Mudflat / Grassland (n = 0.035)

Low and Middle Marsh (n = 0.045)

Upland Vegetation (n = 0.06)

Cropland (n= 0.03)

Figure 19
TUFLOW Without-Project Materials File

N
W E
S

Ecosystem Investment Partners

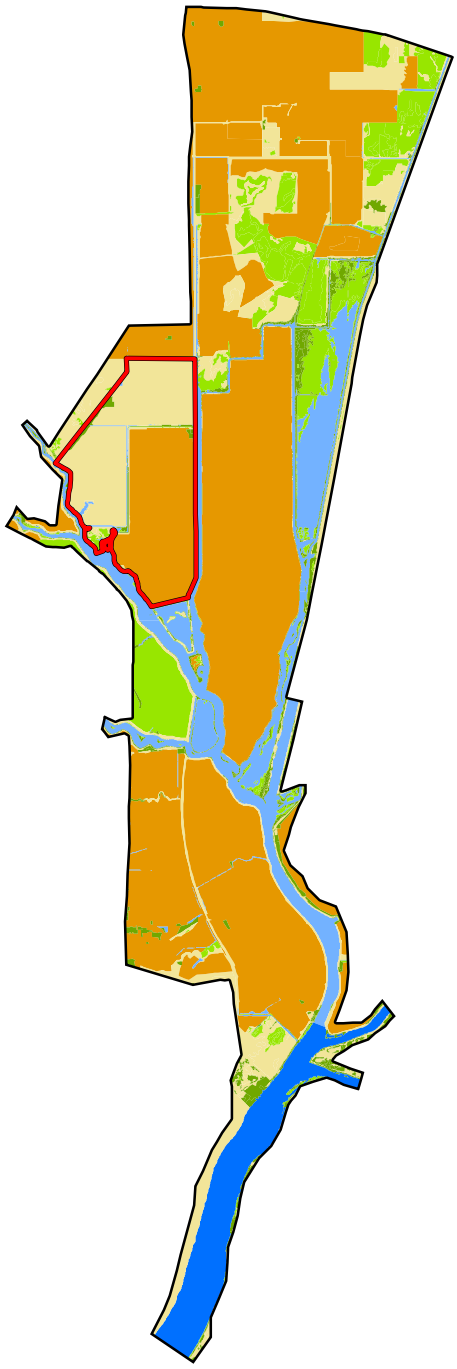
Prepared by: ESA

Map Prepared Date: 9/1/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):
USGS, DWR, Wood Rodgers

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

0 7,500 15,000
Feet

Path: U:\GIS\GIS\Projects\18xxxx\D181197_00_Lookout_Slough_Restoration_1\03_MXDs_Projects\02_Flood_Task_System_HandH\F19_TUFLOW_Materials_wo_Project.mxd



Surveyed Property Boundary (3,378 ac.)

Model Domain Boundary

Material Classification

Riverine (n = .023)

Riverine (n = 0.027)

Mudflat / Grassland (n = 0.035)

Low and Middle Marsh (n = 0.045)

Upland Vegetation (n = 0.06)

Cropland (n= 0.03)

Figure 20
TUFLOW 1997 Historic Conditions Materials File

N
W E
S

Ecosystem Investment Partners

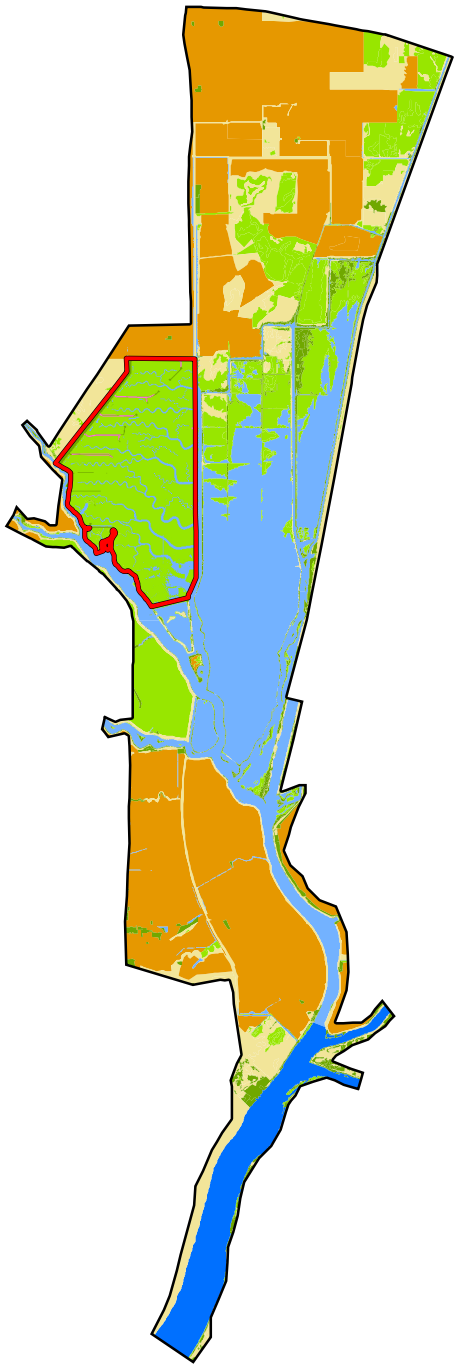
Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

0 7,500 15,000
Feet

Map Prepared Date: 9/1/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):
USGS, DWR, Wood Rodgers

Prepared by: ESA

Path: U:\GIS\GIS\Projects\18xxxx\D181197_00_Lookout_Slough_Restoration_1\03_MXDs_Projects\02_Flood_Task_System_HandH\F20_TUFLOW_Materials_1997_Historic.mxd



Surveyed Property Boundary (3,378 ac.)

Model Domain Boundary

Riparian Planting (n = 0.140)

Material Classification

Riverine (n = .023)

Riverine (n = 0.027)

Mudflat / Grassland (n = 0.035)

Low and Middle Marsh (n = 0.045)

Upland Vegetation (n = 0.06)

Cropland (n= 0.03)

Figure 21
TUFLOW With-Project Materials File

N
W E
S

Ecosystem Investment Partners

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

0 7,500 15,000
Feet

Map Prepared Date: 9/1/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):
USGS, DWR, Wood Rodgers

Prepared by: ESA

Path: U:\GIS\GIS\Projects\18xxxx\D181197_00_Lookout_Slough_Restoration_1\03_MXDs_Projects\02_Flood_Task_System_HandH\F21_TUFLOW_Materials_w_Project.mxd

Geometry Modifications for Calibration Analysis (1997 Storm)

Prior to the January 1997 flood, Liberty Island was a productive agriculture tract protected by levees. Despite attempts to protect the tract, Liberty Island flooded 27 times in the years between 1918 and 1973 (Liberty Farms Company, n.d.). Following the levee failures during the 1997 storm, the area was eventually sold to the Trust for Public Land (TPL) in 1999 and natural processes took over, returning the farm land to a naturalized state. To properly reflect conditions during the 1997 calibration simulation, the following modifications were made to the model geometry and material parameters:

- During the 1997 storm, ten breaches occurred along the west Cache Slough Levee protecting RD 2084 (Little Egbert Tract), ranging from 100 to 850 feet in length. These have been included in the calibration analysis using information provided by MBK in a memo addressed to the Reclamation Board and dated February 10, 1997 (**Figure 22**). Although the timing and sequence of the levee failures during the 1997 event is uncertain, it is likely that the majority occurred prior or during the peak of the flood.

  For purposes of this analysis, two scenarios were evaluated to understand the sensitivity of the model results to the breaches on Little Egbert Tract. The first scenario assumed that all of the known 1997 failures were fully formed prior to the beginning of the simulation. Although a simplification of the actual beach formation and timing, this is considered to represent the maximum conveyance that might have been possible in the Cache Slough Complex during the peak of the storm. The second scenario assumed that none of the breaches on Little Egbert Tract formed. Although the second scenario is not representative of what actually occurred, it is consistent with the assumptions used to calibrate the parent HEC-RAS system model and will provide a useful comparison with the parent model results.

- In the time since Liberty Island was sold to the TPL, natural processes have been acting to passively restore the site to its current state. To reflect the historic condition in the calibration analysis, the land cover (materials) file was modified to reflect Liberty Island as agricultural land use (whereas today it is predominantly open water and tidal marsh, as depicted in Figure 19).

Model Calibration and Validation Approach

The following data hierarchy was used to assess the quality of the calibration and validation results:

1. Stream gage records, including:
   - Yolo Bypass near Liberty Island (LIY)
   - Cache Slough at Ryer Island (RYI)
   - Sacramento River at Rio Vista (SRV)
2. High water marks
3. Comparison with the HEC-RAS parent model results

Locations of stream gages and high water mark observations are shown on **Figure 23**. The primary approach for calibrating the model was refinement of breakline definitions and bathymetry, particularly in the vicinity of Liberty Island where the step levees act as a hydraulic control which significantly influences the flow distribution in the vicinity of the LIY stream gage.

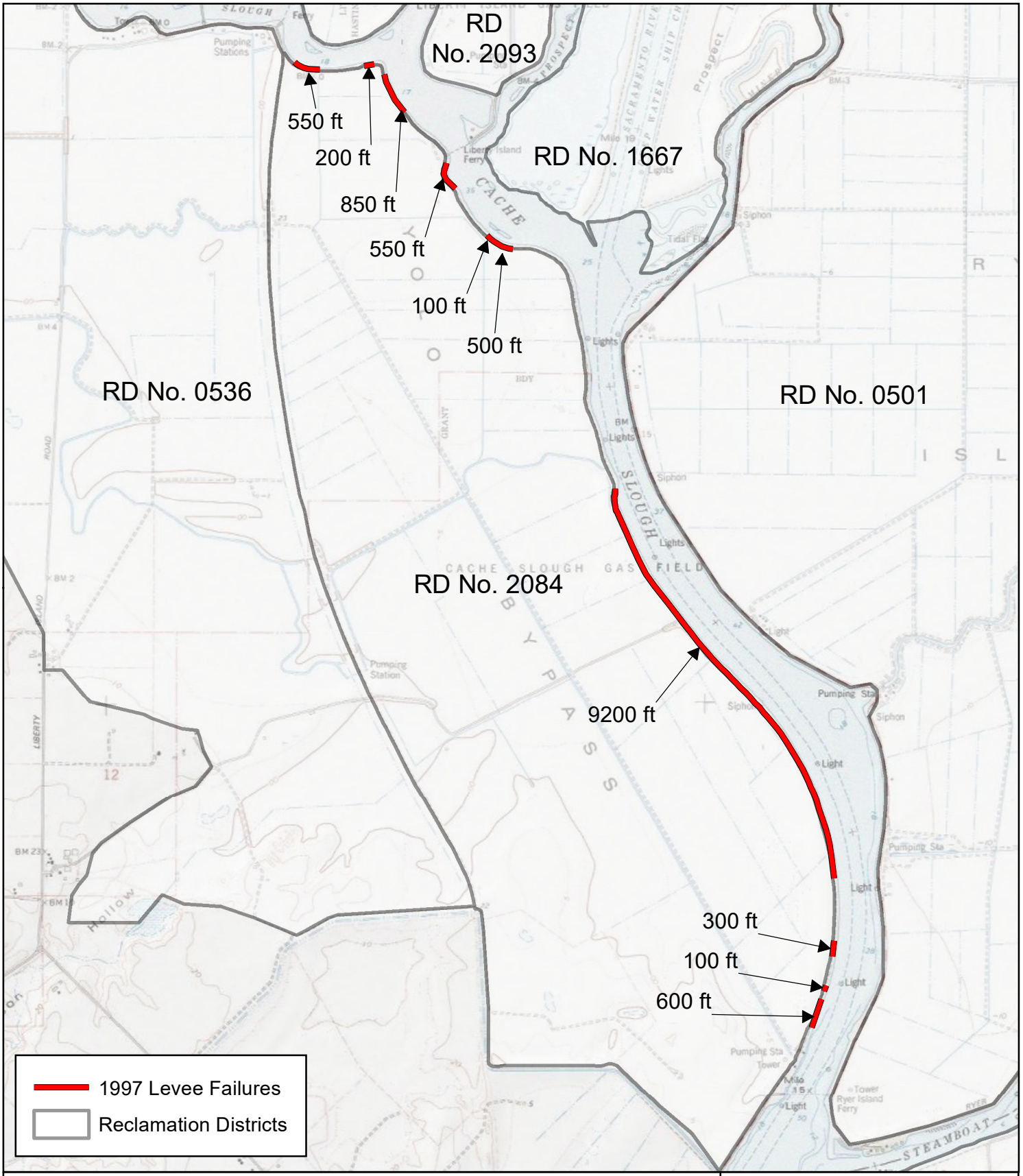


Figure 22
1997 Levee Failures along Cache Slough into Little Egbert Tract

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

0 0.25 0.5
Miles

Ecosystem Investment Partners

Map Prepared Date: 3/6/2019
Map Prepared By: Brent Davis
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):
DWR, ESRI Service Layers, MBK (1997)

Prepared by: ESA

Path: U:\GIS\GIS\Projects\18xxxx\D181197_00_Lookout_Slough_Restoration_1\03_MXDs_Projects\02_Flood_Task_System_HandH\F22_1997_Levee_Failures.mxd

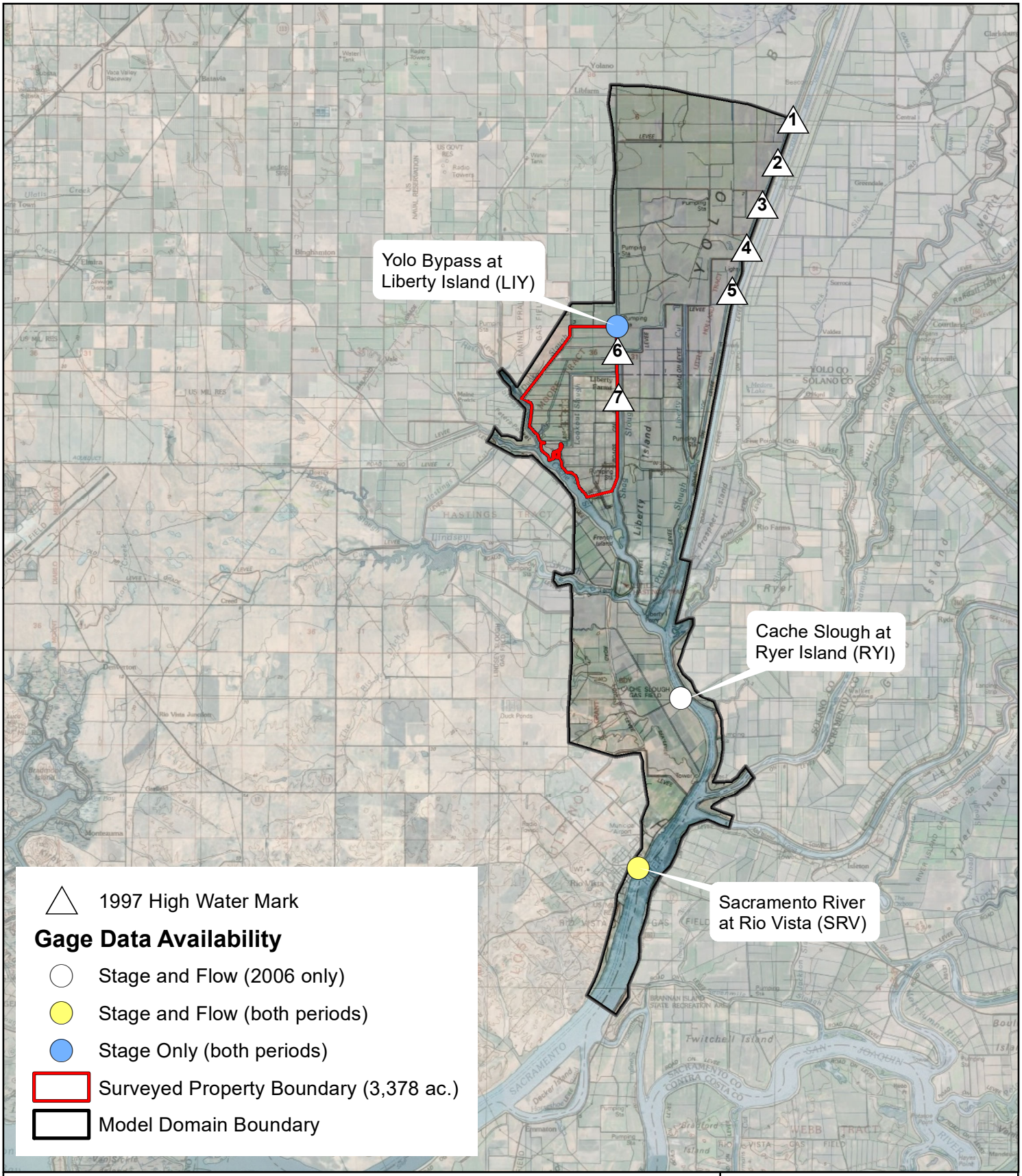


Figure 23
Calibration and Validation Data Observation Locations

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

0 7,500 15,000
Feet

Ecosystem Investment Partners

Prepared by: ESA

Map Prepared Date: 4/8/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):
DWR, ESA PWA, MWD, SCWA

Path: U:\GIS\GIS\Projects\18xxxx\D181197_00_Lookout_Slough_Restoration_1\03_MXDs_Projects\02_Flood_Task_System_HandH\F23_Calibration_Data.mxd

Model Calibration Results (1997 Storm)

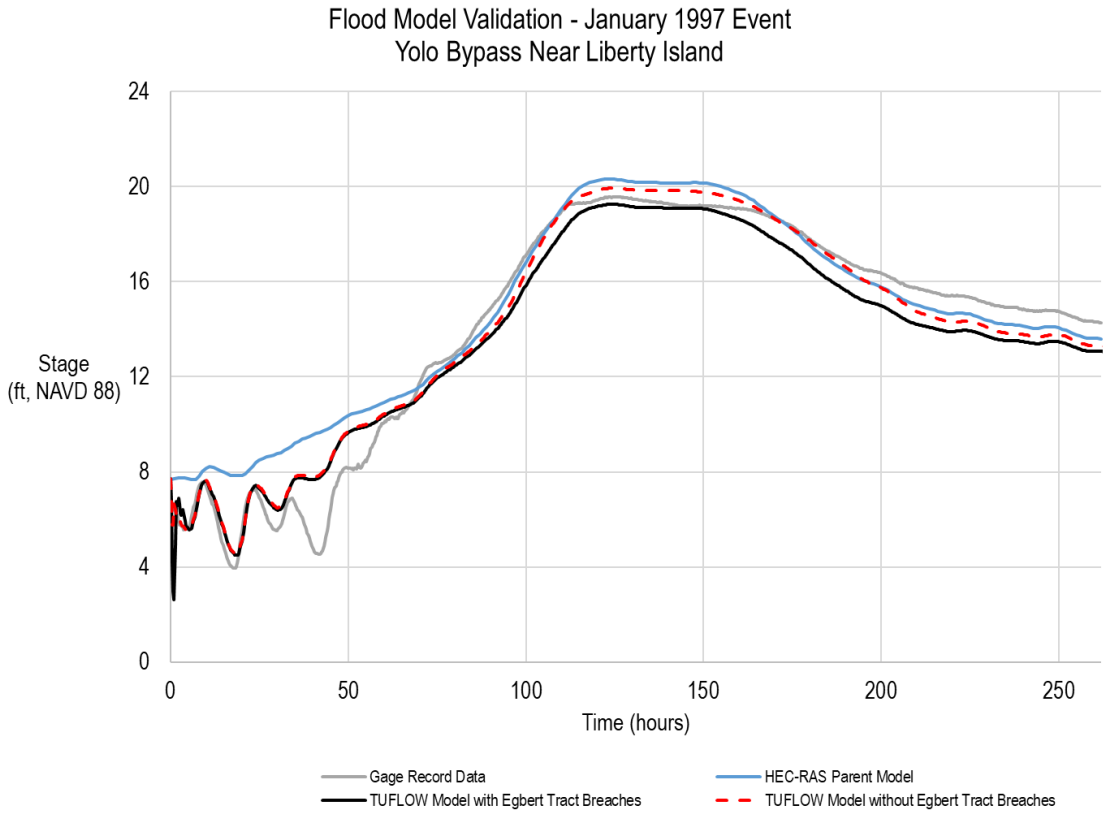
The model provides reasonable results for the validation simulation event, and is generally consistent with the results of the parent HEC-RAS model (**Figure 24** through **Figure 26**). At the LIY gage, the validation model results align much closer with the observed data for the 1997 event than in the parent HEC-RAS model. This is likely due to the incorporation of the levee breaches at Little Egbert Tract, which were omitted in the parent model calibration analysis. **Table 6** summarizes comparisons of the validation analysis with high water mark observations during the 1997 event.

TABLE 6
COMPARISON OF 1997 CALIBRATION SIMULATION WITH OBSERVED HIGH WATER MARKS

Location ID	River Mile Station	Observed High Water Elevation (feet, NAVD 88)	Computed High Water Elevation (feet, NAVD 88)	Difference (feet)
1	30.494	24.8	23.8	-1.0
2[a]	29.709	26.2	23.1	-3.1
3[a]	28.423	23.6	22.0	-1.6
4	27.421	21.2	21.2	0.0
5[a]	26.655	18.7	20.1	+1.4
6	25.211	19.7	18.7	-1.0
7	24.090	19.3	18.1	-1.2

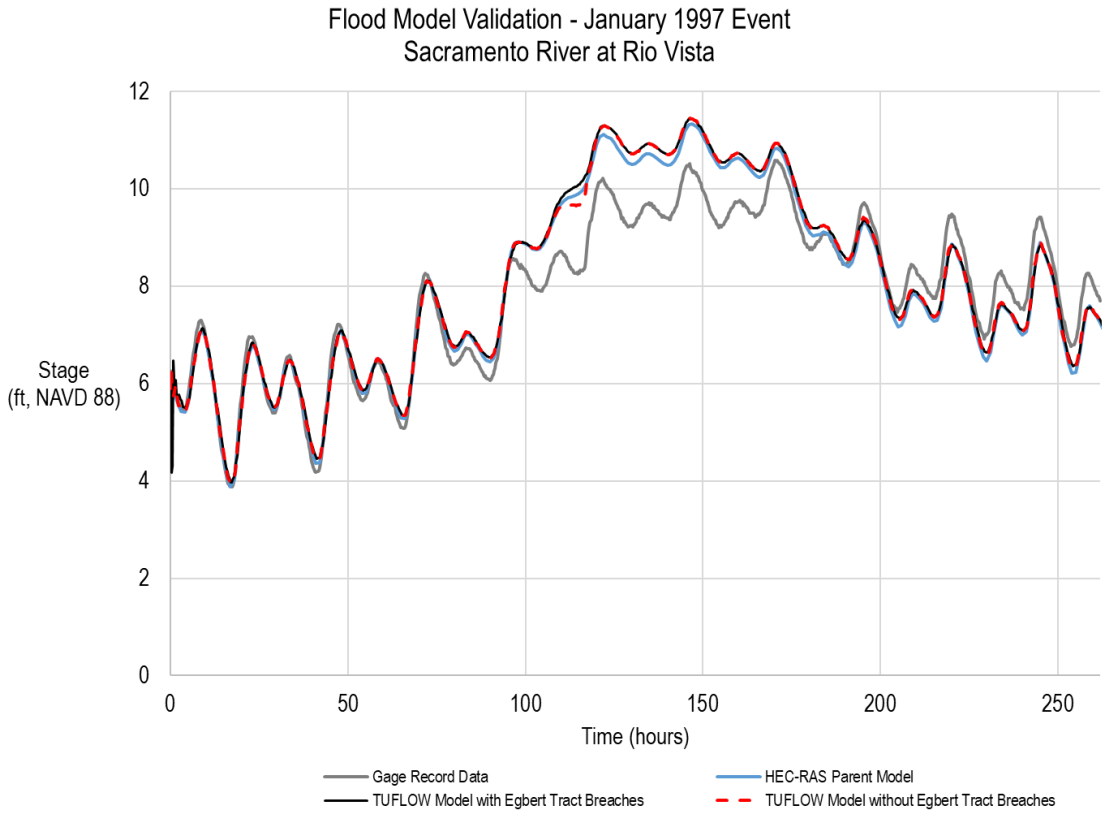
NOTES:
a The 1997 observed high water marks are not monotonically increasing from downstream to upstream, possibly a result of wind-wave action influencing the disposition of the debris line. In many cases this results in an observation that is higher than the actual water surface. The specific high water marks noted here have been flagged by DWR has excessively deviating from the trend and are not considered reliable. They are presented for documentation purposes only, and are presented in a lighter font for de-emphasis.
b Results are shown reflect levee failures simulated at Little Egbert Tract

Figure 24 Calibration Results, Liberty Island at Yolo Bypass Gage (Stage)



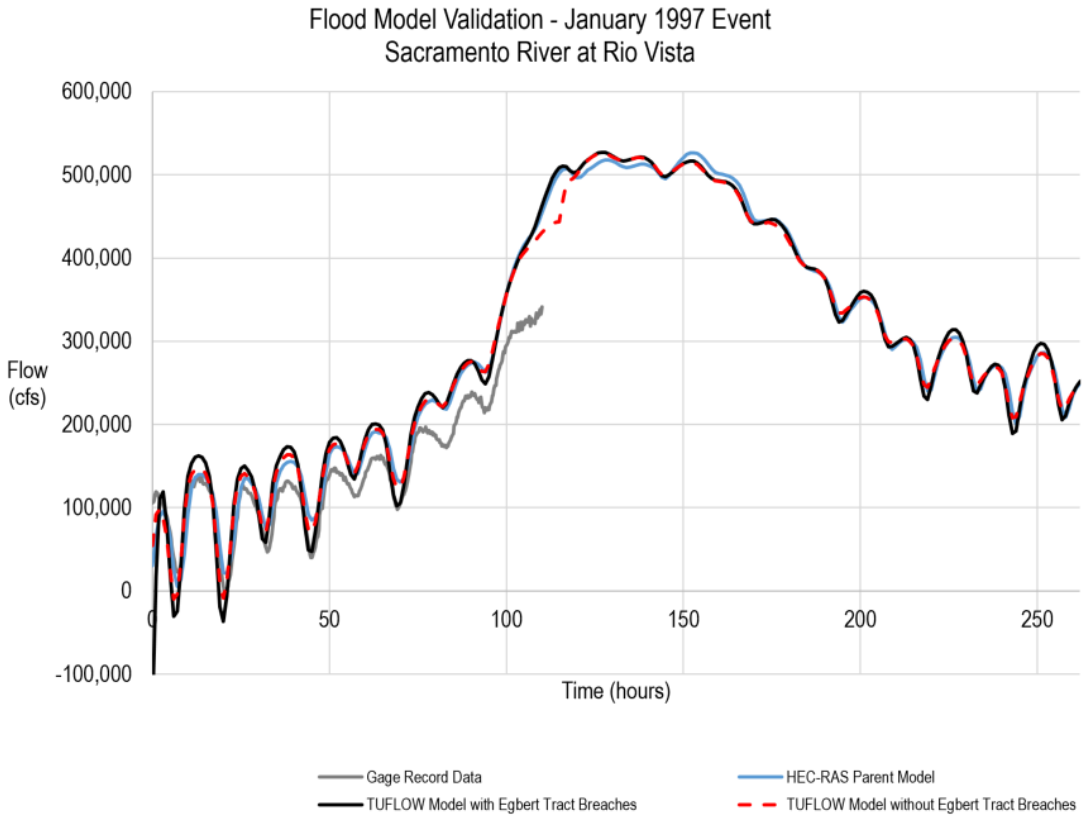
TUFLOW two-dimensional model results correlate well with observed peak data when the historic downstream levee failures at Little Egbert Tract are included. The HEC-RAS parent model appears to over-predict maximum water levels at the peak, likely due to the omission of levee failures at Little Egbert Track and changes on Liberty Island.

Figure 25 Calibration Results, Sacramento River at Rio Vista Gage (Stage)



Both the parent and child models are in close agreement with one another, but appear to over-predict flood stages during the peak, possibly a result of uncertainties in the 1997 event simulation datasets. The model results at this location do not appear to be sensitive to the breach hydraulics at Little Egbert Tract except for a short period on the rising limb of the flood wave (beginning around Hour 110 and ending around Hour 118 in the simulation).

Figure 26 Calibration Results, Sacramento River at Rio Vista Gage (Flow)



The stream flow instrumentation failed at approximately Hour 110. Both the parent and child models are in close agreement with one another, but appear to over-predict stages compared to the measured data during the rising limb, possibly a result of uncertainties in the 1997 event simulation datasets. The model results at this location do not appear to be sensitive to the breach hydraulics at Little Egbert Tract except for a short period on the rising limb of the flood wave (beginning around Hour 110 and ending around Hour 118 in the simulation).

Model Validation Results (2006 Storm)

In general, the calibration model produces peak water level results that are consistent with the observed data and the parent model (**Figure 27** through **Figure 31**). One location where the model produces water levels that are noticeably higher than the regional HEC-RAS model is in the lower reach of Cache Slough as it approaches its confluences with Steamboat Slough and the Sacramento River. In this location the 1D model appears to underestimate the hydraulic grade line. This is considered a product of the limitations in the one-dimensional model schematization at this location, as momentum is not transferred through the storage areas used to represent the junctions at Steamboat Slough and the Sacramento River. The child model in this case is considered to provide a more reasonable estimation of water levels at this location.

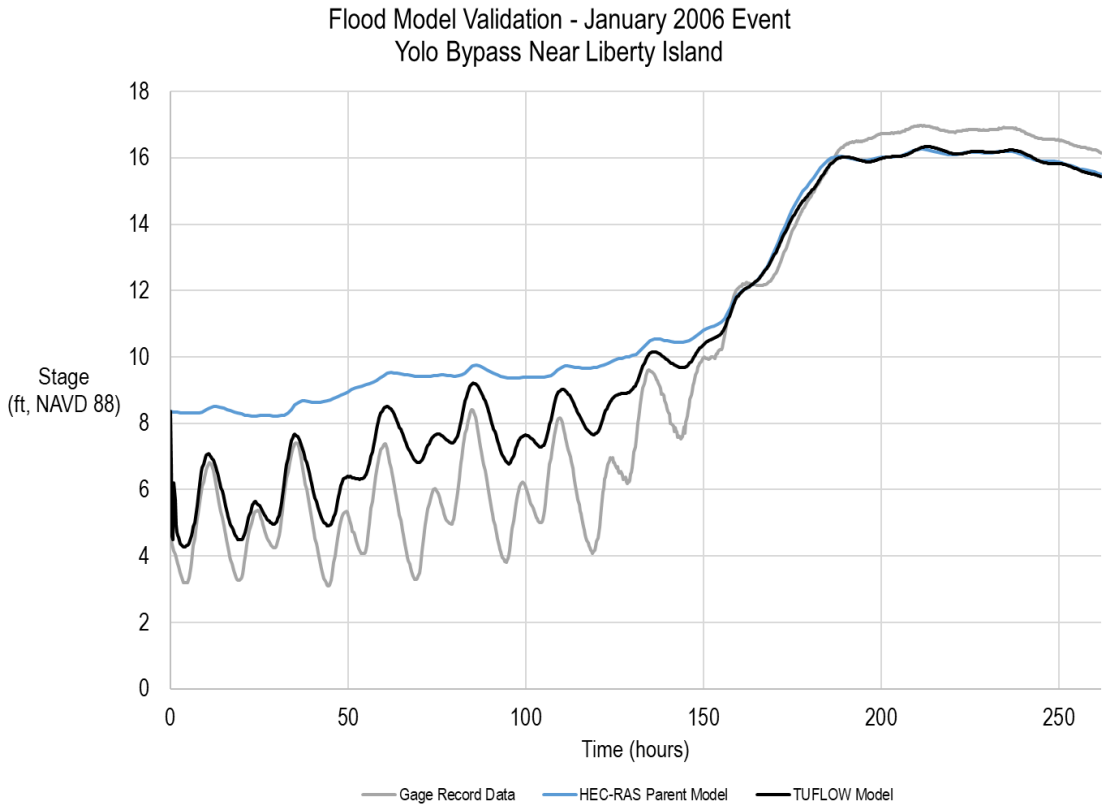
In the vicinity of the Project, the model provides good correlation with the results at the LIY stream gage, coming within 0.6 feet of the observed peak stage. This correlates well with the results shown in the parent model.

Calibration and Validation Summary

In general, the calibration and validation results appear to be within accepted tolerances. Although some deviation occurs between the modeled and measured data, comparisons between the TUFLOW HPC child model and HEC-RAS parent model indicate that both models are performing similarly within the region of interest, and that the flood peak is well represented in both models, particularly when historic levee breaches are taken into consideration.

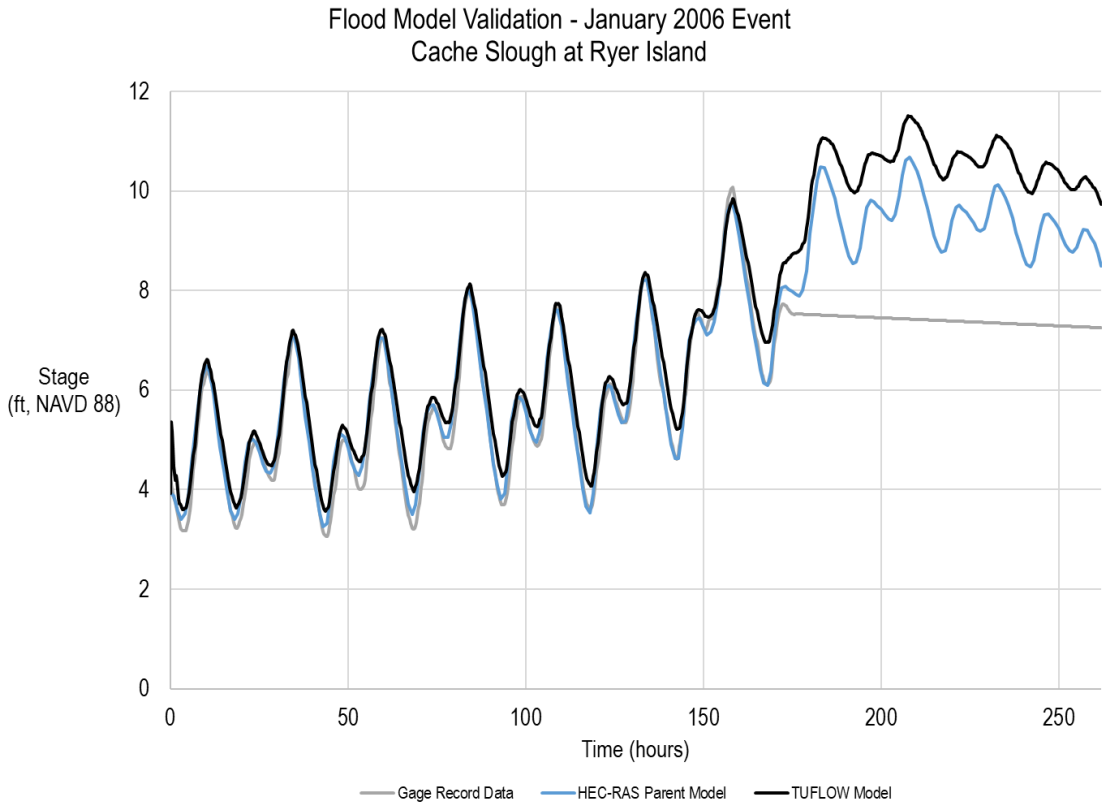
In general, the modeling predicts water surfaces that are generally lower than high water marks surveys collected after the 1997 storm. Given the general uncertainty in the high water mark survey dataset as a whole, these deviations are not considered to reflect poor model performance and may simply reflect the effects of wind-wave run-up in the Yolo Bypass that are not captured explicitly in the model simulation.

Figure 37 Validation Results, Liberty Island at Yolo Bypass Gage (Stage)



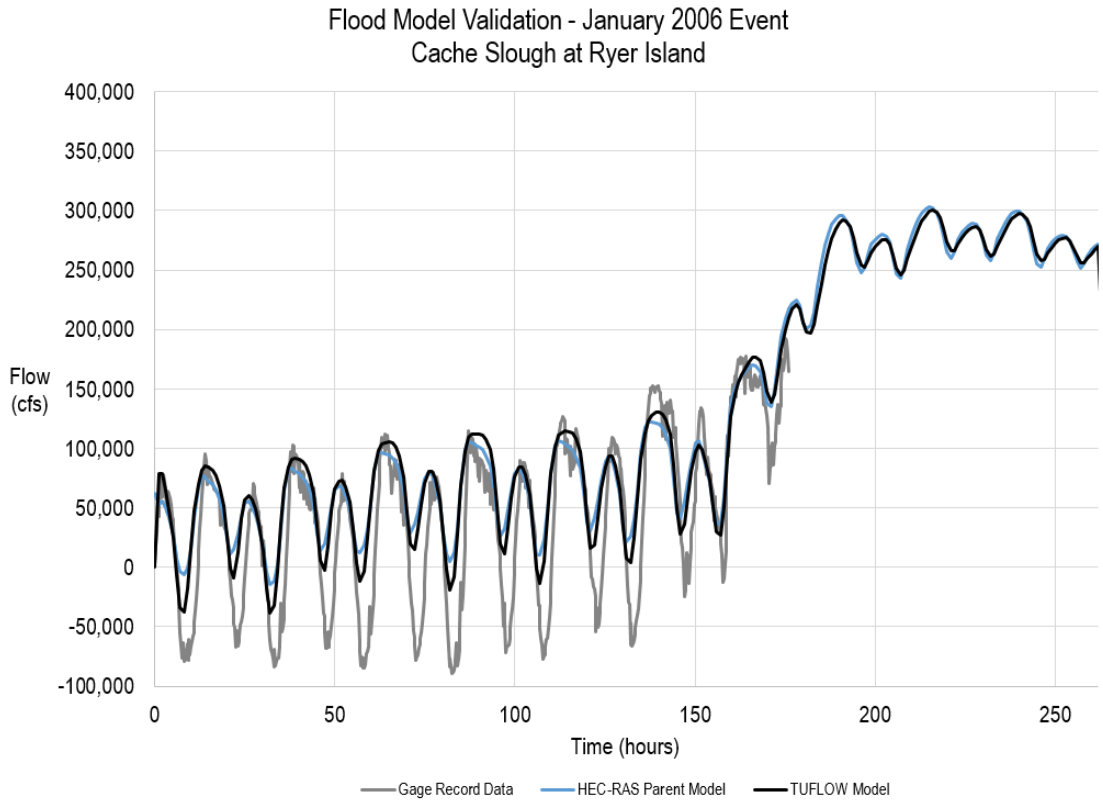
Although the TUFLOW two-dimensional model results are slightly lower than peak stage recorded at the gage (approximately 0.6 feet), they are consistent with the calibrated and validated one-dimensional HEC-RAS parent model during the peak of the storm event. Differences between the models in the initial run up of the simulation (hours 0 to 150) are likely due to limitations of the parent model's one-dimensional representation of the Cache Slough Complex.

Figure 28 Validation Results, Cache Slough at Ryer Island Gage (Stage)



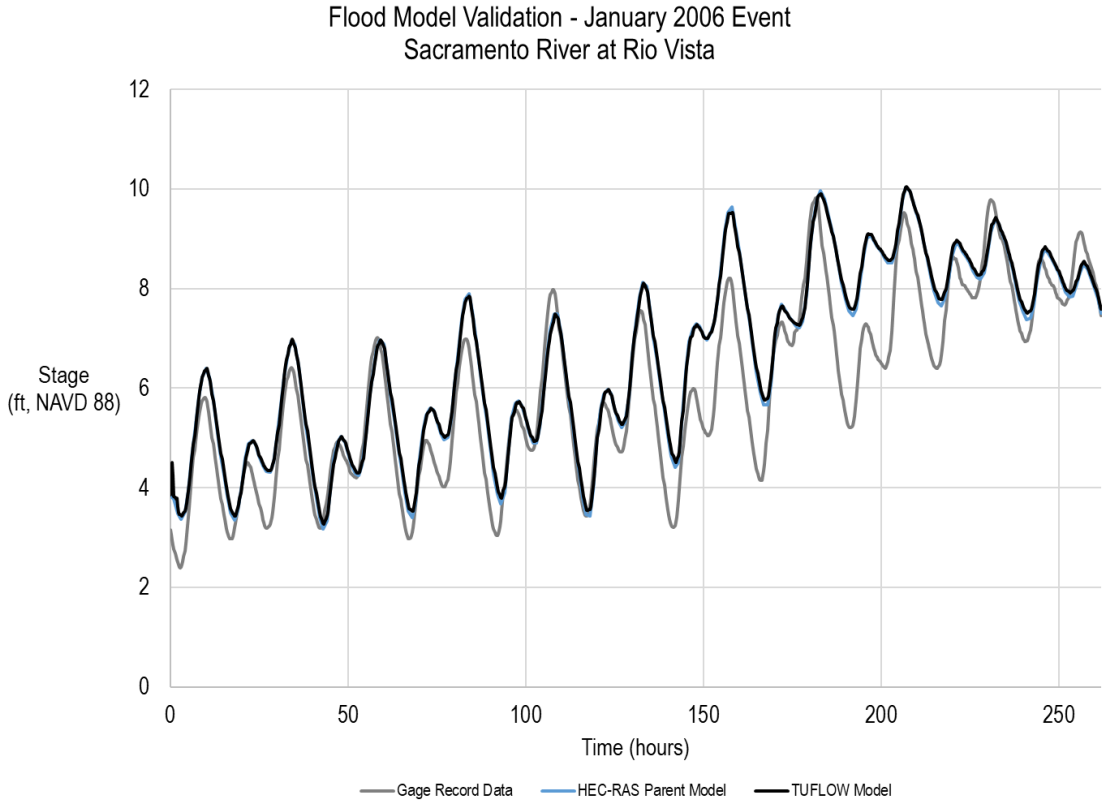
The gage records appear to be erroneous beginning around hour 170, suggesting instrument failure occurred on the rising limb of the flood hydrograph (this is corroborated by flow records shown on Figure 29). Both the one-dimensional and two-dimensional models appear to provide good correlation with the measured data up to that point that it is available. Differences between the models at the peak appear linked to the manner in which the one-dimensional model is defined at the series of junctions between Cache Slough, Steamboat Slough, and the Sacramento River near Rio Vista. At these locations, the one-dimensional hydraulic model computes a relatively flat hydraulic grade line through a series of junctions, likely under-predicting the stage during periods of higher flow.

Figure 29 Validation Results, Cache Slough at Ryer Island Gage (Flow)



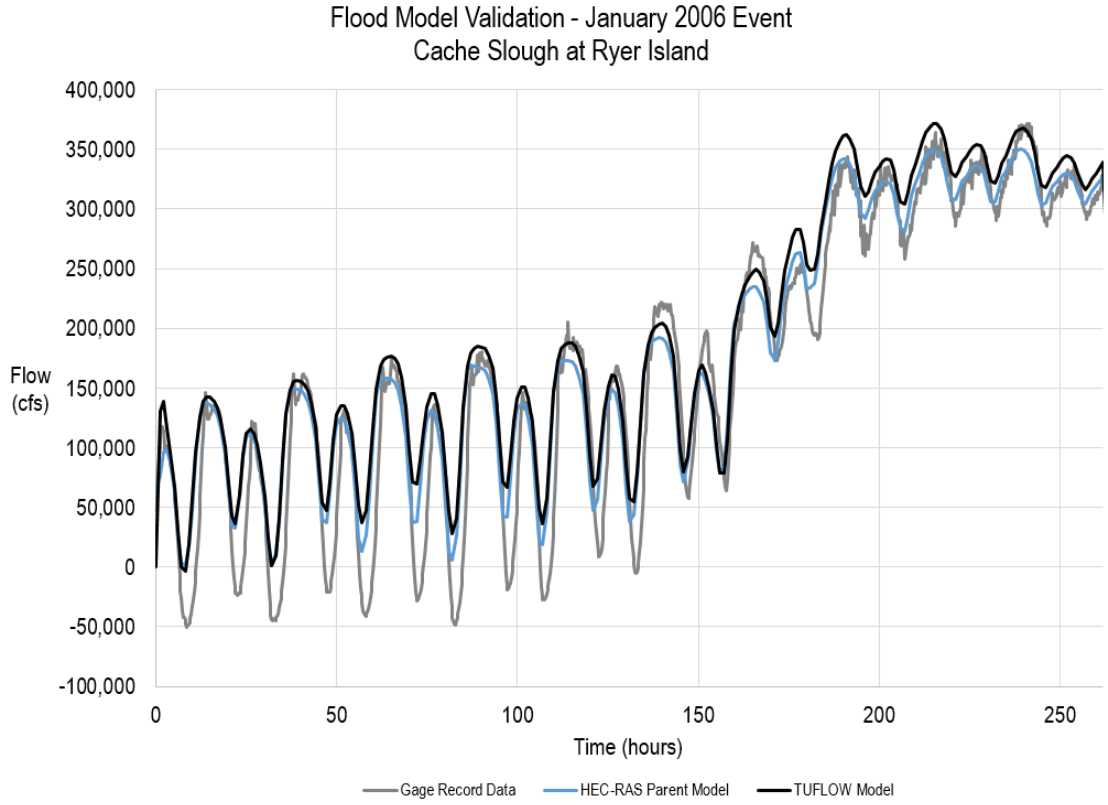
Gage records terminate around hour 170, suggesting instrument failure on the rising limb of the flood hydrograph. Both the one-dimensional and two-dimensional models appear to provide good correlation with the measured data up on the high tide portions of the tidal signal. The ebb tide correlation is much poorer, likely due to limitations of the one-dimensional parent model's ability to represent the tidal exchange through this part of the system. This appears to also be supported by the more pronounced muting of the tidal signal in the one-dimensional model results at this location.

Figure 30 Validation Results, Sacramento River at Rio Vista Gage (Stage)



Both models appear to provide reasonable results at this location. Both models provide relatively similar results due to the proximity of this location to the downstream stage boundary handoff from the parent HEC-RAS model to the TUFLOW child model.

Figure 31 Validation Results, Sacramento River at Rio Vista Gage (Flow)



Both models provide similar results that appear to be reasonable at this location. Both models provide relatively similar results due to the proximity of this location to the downstream stage boundary handoff from the parent HEC-RAS model to the TUFLOW child model; however, the child model appears to provide results which more closely follow the peaks in the observed data. Performance within the tidal range could probably be further improved by deriving the downstream boundary from observed data or another hydrodynamic model of the Delta (i.e., RMA Delta model).

Uncertainty in Stages for Computed Water Surface Profiles

Uncertainty is the result of imperfect knowledge concerning the present or future state of a system, event, situation, or (sub) population under consideration (USACE, 2017). Known sources of uncertainty relevant to the current analysis include (USACE, 1996):

- Uncertainty about future hydrologic events, including climate change. Recognizing this, the Project has incorporated an additional 1 foot of freeboard in the levee design.

- Uncertainty related to structural and geotechnical performance of water-control measures when these are subjected to rare stresses and loads caused by floods. For purposes of assessing the Project performance, the system is assumed to be stable up to the top of containment (no breaching) in accordance with USACE Section 408 guidance (USACE, 2018). This is anticipated to provide the most conservative estimate of flow deliveries and flood stages within the area of interest.

- Uncertainty arising from the use of simplified models to describe complex phenomena. Although the hydraulic models used to support this study have been calibrated and validated using historic flood records, residual uncertainty in parameters such as Manning's roughness coefficients is inevitable.

For purposes of assessing stage uncertainty in the current study, a sensitivity analysis was performed to assess the upper and lower bounds of Manning's roughness for the given design discharges (16%, 1%, and 0.5% ACE). Per discussion with the USACE Sacramento District, Manning's roughness coefficients were adjusted globally by +/-20% relative to the calibrated values. This resultant range of stages is assumed reflect 95% of the error range in the Manning's roughness parameter, or two standard deviations above and below the mean. The standard deviation is assumed to be the total range of these values divided by four (USACE, 1996).

Figure 32 through **Figure 35** depict the spatial distribution of the standard deviation in stage based on adjusting the Manning's roughness coefficient +/-20% for the respective without- and with-Project conditions assessments for the Baseline and Future Cumulative Conditions. The Manning's roughness value reliability was assessed based on the ranges recommended by the USACE for cross-sections based on field surveys or aerial spot elevation (USACE, 1996) as summarized in **Table 7** below.

TABLE 7
MINIMUM STANDARD DEVIATION OF ERROR IN STAGE

Manning's n Value Reliability	Standard Deviation (in feet) for Cross Section Based on Field Survey or Aerial Spot Elevation
Good	0.3
Fair	0.7
Poor	1.3

SOURCE: USACE, 1996

Review of the standard deviation maps for the respective geometry conditions and design flow rates indicates that the reliability of the model's Manning's roughness coefficients can be characterized as good to fair in all cases. All of the maps exhibit a small standard deviation in the downstream portion of model domain inside of the Sacramento River and Cache Slough corridors. This effect is most prominent in the lower flow events (i.e., 16% ACE), and is likely due to the influence the tidal boundary exerts on these zones. In tidal zones, the inertia terms are more influential than the friction terms, reducing the model sensitivity to the bed roughness coefficient in these locations.

In the 16% ACE comparisons, a small portion in the northwestern portion of the model domain exhibits a standard deviation in excess of 1.3 feet (shown in orange on Figure 11 through Figure 14). This area is located west of a small agricultural berm within the Yolo Bypass which overtops in the 16% ACE event only as higher roughness coefficients are applied. During higher flow events this area is completely inundated and the model is less sensitive to changes in roughness, resulting in a lower standard deviation for the 1% ACE and 0.5% ACE events. The increased uncertainty in this localized portion of the model domain during the 16% ACE event is not considered to have a significant impact on the overall quality of the model results as it relates to describing the performance of the system without- and with-Project.

Impacts of Proposed Project Alteration

As described in the preceding section on model calibration and validation, the simulation modeling conducted for the analysis of conditions without the project reasonably reproduces the drivers of flood risk within the child model domain, peak flow and peak stage. While the simulation results may imperfectly reflect measured conditions, the analysis of impacts will focus on the *differences* between the with- and without-project conditions. The differences in predicted peak stage and peak flow due to project-induced changes are typically more accurate than the absolute results of the models may be. Thus, it is entirely reasonable to rely on the differences in modeled results to evaluate the impact of the project.

The hydraulic performance analysis consisted of analyzing the Baseline Condition and Future Cumulative Condition both without- and with-Project using a range of hydraulic loadings (16%, 1%, and 0.5% ACE) in unsteady state. In addition to this, Baseline Condition was analyzed for without- and with-Project conditions to verify that the Project would not adversely impact the performance of the system using the authorized 1957 design flow. For purposes of this Project, increases in water surface elevation are reflected as a reduction in assurance (conditional non-exceedance probability [CNP]).

16% ACE (6-year) Event

1% ACE (100-year) Event

0.5% ACE (200-year) Event

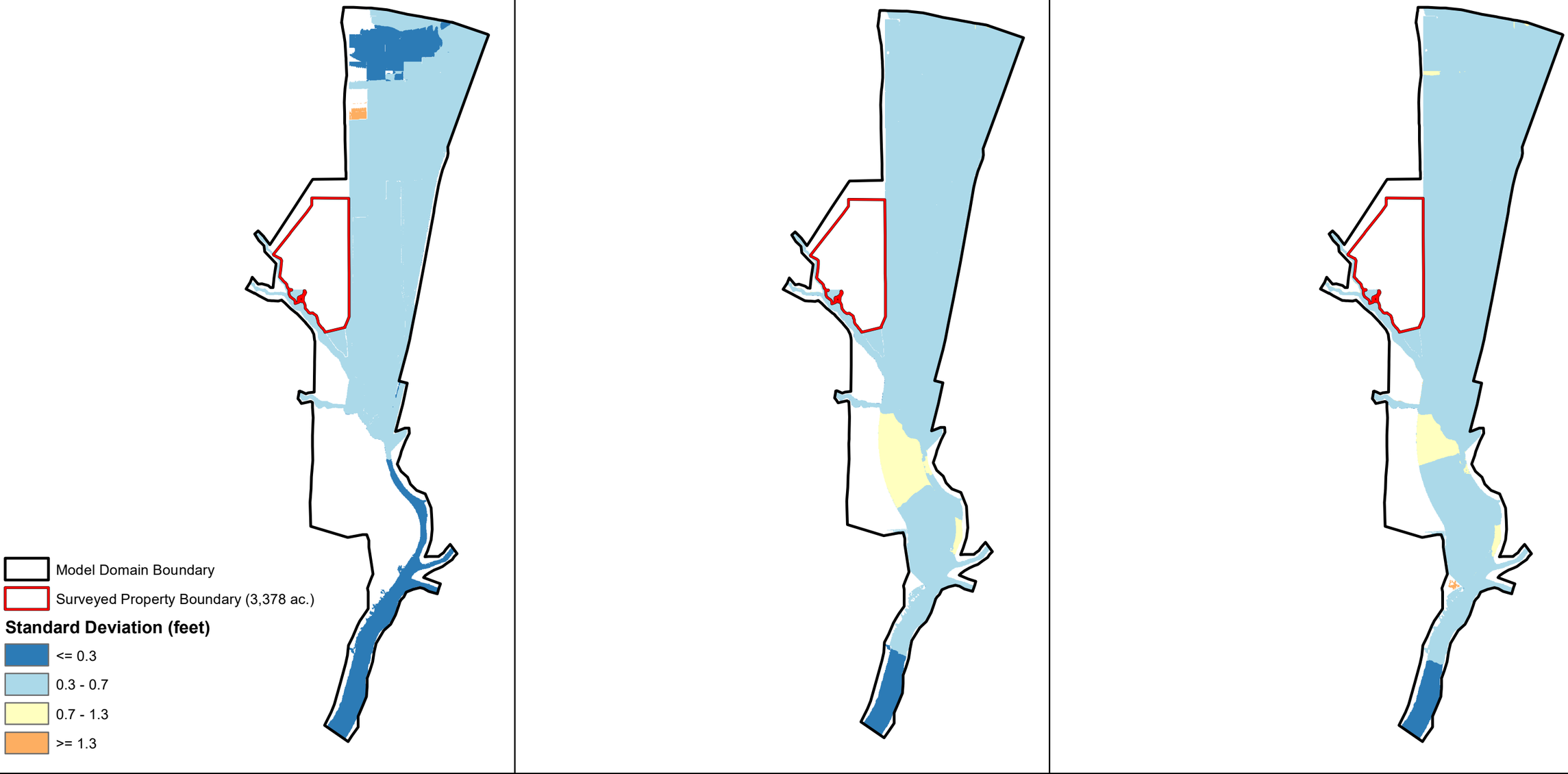


Figure 32
Stage Computation Uncertainty - Baseline Condition without-Project

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

0 15,000 30,000
Feet

Ecosystem Investment Partners

Map Prepared Date: 9/1/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):

Prepared by: ESA

Path: U:\GIS\GIS\Projects\18xxxx\D181197_00_Lookout_Slough_Restoration_1103_MXDs_Projects\02_Flood_Task_System_HandHF32_Uncertainty_Baseline_wo_Project.mxd JPritchard 9/1/2019

16% ACE (6-year) Event

1% ACE (100-year) Event

0.5% ACE (200-year) Event

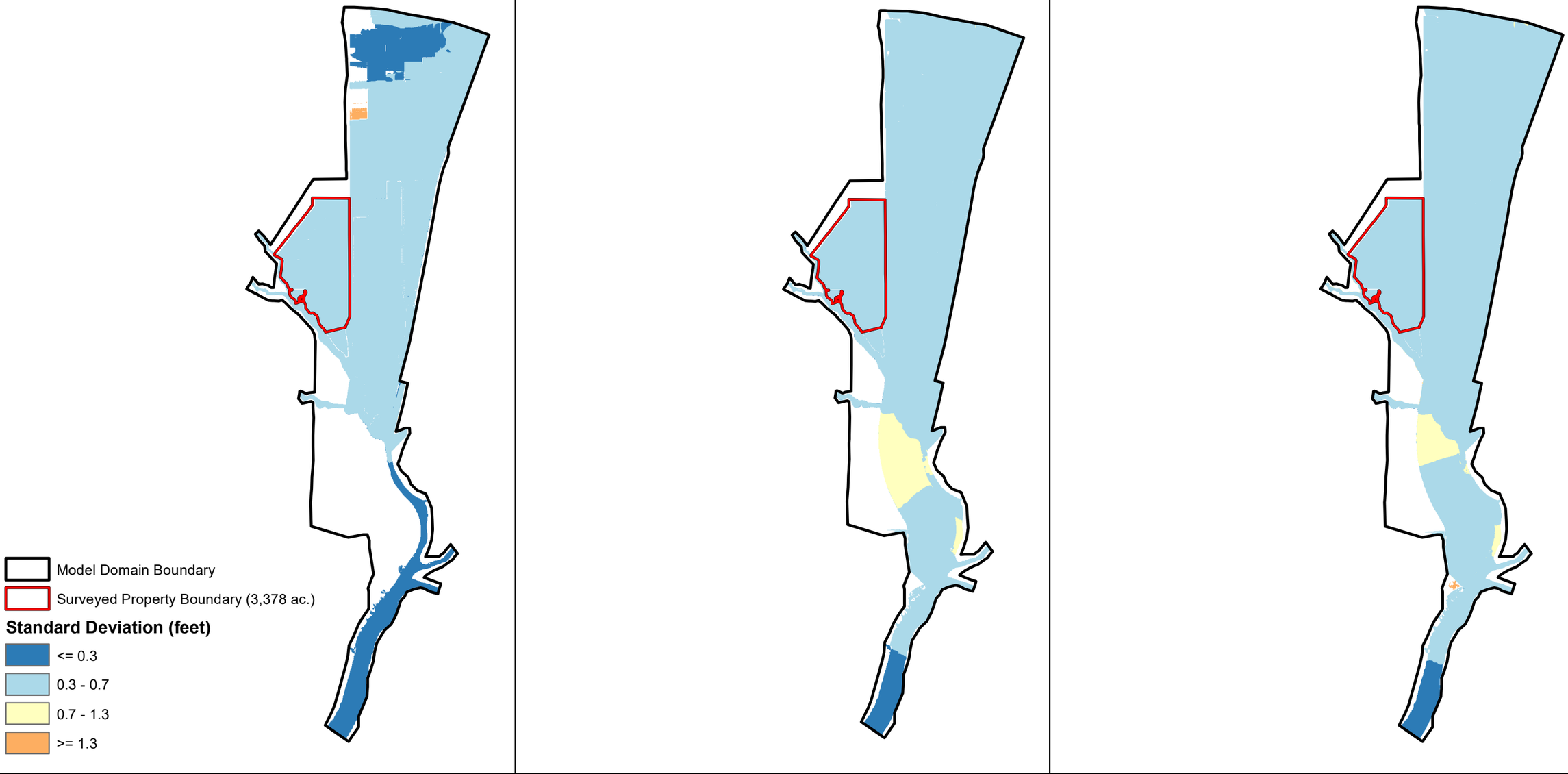


Figure 33
Stage Computation Uncertainty - Baseline Condition with-Project

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

0 15,000 30,000
Feet

Ecosystem Investment Partners

Map Prepared Date: 9/1/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):

Prepared by: ESA

Path: U:\GIS\GIS\Projects\18xxxx\D181197_00_Lookout_Slough_Restoration_1103_MXDs_Projects\02_Flood_Task_System_Hand\HF33_Uncertainty_Baseline_w_Project.mxd JPritchard 9/1/2019

16% ACE (6-year) Event

1% ACE (100-year) Event

0.5% ACE (200-year) Event

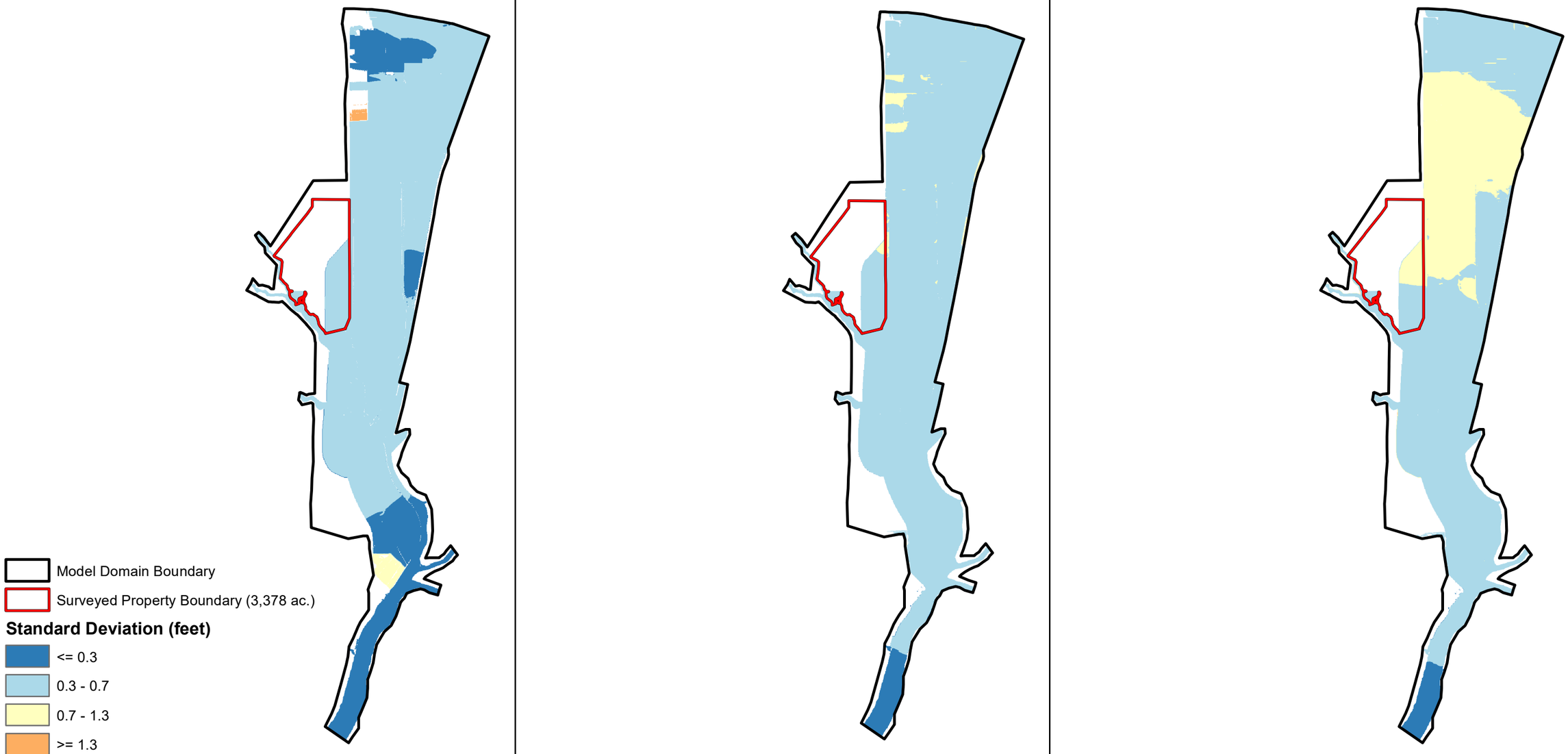


Figure 34
Stage Computation Uncertainty - Future Cumulative Condition without-Project

0 15,000 30,000
Feet

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

Ecosystem Investment Partners

Map Prepared Date: 9/1/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):

Prepared by: ESA

Path: U:\GIS\GIS\Projects\18xxxx\D181197_00_Lookout_Slough_Restoration_1103_MXDs_Projects\02_Flood_Task_System_HandHF34_Uncertainty_FCC_wo_Project.mxd JPritchard 9/1/2019

16% ACE (6-year) Event

1% ACE (100-year) Event

0.5% ACE (200-year) Event

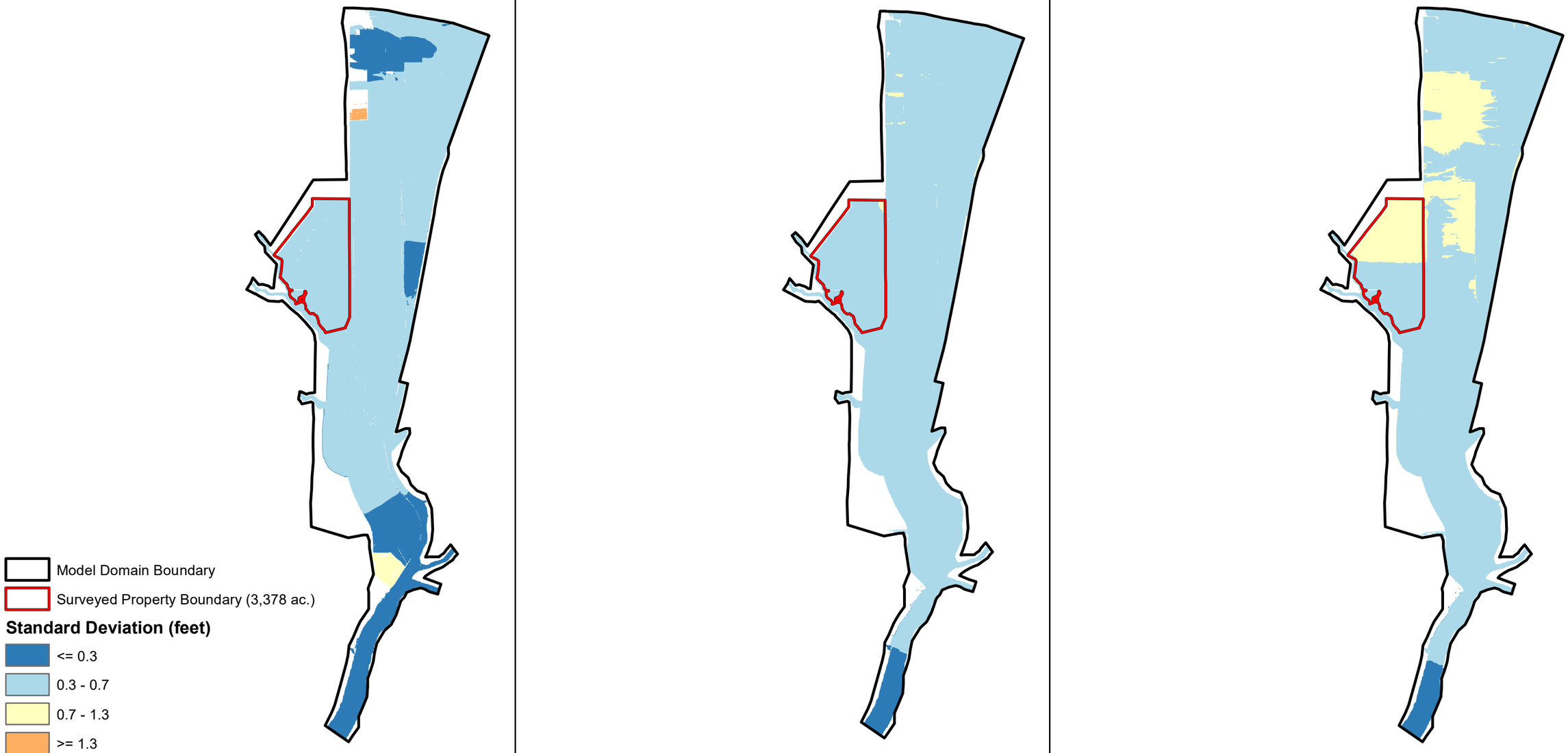


Figure 35
Stage Computation Uncertainty - Future Cumulative Condition with-Project

N
W E
S

0 15,000 30,000
Feet

Ecosystem Investment Partners

Map Prepared Date: 9/1/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):

Prepared by: ESA

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

Path: U:\GIS\GIS\Projects\18xxxx\D181197_00_Lookout_Slough_Restoration_1103_MXDs_Projects\02_Flood_Task_System_HandHF35_Uncertainty_FCC_w_Project.mxd_JPritchard_9/1/2019

As shown on **Figure 36** and **Table 8**, the proposed Project alterations result in no adverse impacts to assurance (expressed as flood stage) at the identified index locations for the range of hydrologic loadings analyzed. The parent HEC-RAS system models have also been reviewed to verify that no significant change in the flow distribution at Fremont Weir or the Sacramento Weir occurs as a result of the Project (**Table 9**). As the hydraulic impacts of the Project are localized, and generally result in stage decreases for the design events under consideration (including the 1957 authorized design flow), the Project's potential to transfer risk from one part of the system to another is considered to be negligible. These changes are not considered significant enough to warrant a detailed system performance calculation using HEC-FDA. The deterministic analysis conducted for the Project is considered sufficient for describing the overall system performance for the without- and with-Project conditions and verifies that the reduction in assurance is negligible.

Authorized Design Flow Performance Assessment

The Project proposes to alter the west (right) levee of the Yolo Bypass and the east (left) levee of Cache Slough, both of which are part of the SRFCP. The Project is also in close proximity to other SRFCP levees along the Yolo Bypass, Cache Slough, Hass Slough, Miner Slough, Lindsey Slough, Steamboat Slough, and the Sacramento River. The design capacities of the majority of these facilities are documented in the individual project O&M Manuals, and on the 1957 Levee and Channel profile exhibits (USACE, 1957). There are no published design flows for Hass Slough, Cache Slough, and Lindsey Slough. This is perhaps because the flooding in these reaches is governed by backwater within the Cache Slough Complex, which is driven by a combination of Yolo Bypass flood flows and interaction with the tides. The authorized design flows for the reaches within the model domain and stage at the downstream boundary of the model are summarized in Table 3.

To analyze the effects of the Project for the authorized design flow condition, a quasi-steady state simulation was developed using the authorized design flows for this part of the system. The relative changes in stage and velocity without- and with-Project are described below.

Stage Impacts

The Baseline Condition was simulated for without- and with-Project conditions using the authorized design flows. The resultant change in water surface at the respective index point locations is summarized in **Table 10**. The resultant floodplain extents, depth, and computed maximum water surface for the without- and with-Project simulations are shown on **Figure 37**. Figure 37 also depicts the change in maximum stage between the without- and with-Project conditions.

In general, the Project results in localized stage reductions in the Yolo Bypass. That the geographic extent of these increases appear to be slightly less than what is shown in the analysis of the ACE storms (with comparable flow rates) is most likely attributable to the quasi-steady state nature of the analysis, where the transient effects (timing and volume) of the flood wave are not accounted for. The higher downstream stage boundary defined by the 1957 authorized design profile may also be contributing to these differences.

TABLE 8
SUMMARY OF CHANGE IN ASSURANCE AT RESPECTIVE INDEX POINTS

Index Point	1957 Design WSEL (ft, NAVD 88)	Design Freeboard (feet)	Existing Top of Levee Elevation (ft, NAVD 88)	Condition	CNP	% ACE	WSEL (ft, NAVD 88) Without-Project	With-Project	Change
1	22.83	6	28.65	Baseline	0.160	16%	19.74	19.72	-0.02
					0.010	1%	23.85	23.74	-0.11
					0.005	0.5%	24.63	24.49	-0.14
				Future Cumulative	0.160	16%	20.16	20.15	-0.01
					0.010	1%	23.26	23.20	-0.06
					0.005	0.5%	23.92	23.83	-0.09
2	17.88	3	20.86	Baseline	0.160	16%	13.01	13.00	-0.01
					0.010	1%	18.65	18.63	-0.02
					0.005	0.5%	19.58	19.53	-0.05
				Future Cumulative	0.160	16%	11.98	11.97	-0.01
					0.010	1%	17.02	16.99	-0.03
					0.005	0.5%	18.12	18.11	-0.01
3	17.88	3	20.86	Baseline	0.160	16%	13.01	13.00	-0.01
					0.010	1%	18.65	18.63	-0.02
					0.005	0.5%	19.56	19.51	-0.05
				Future Cumulative	0.160	16%	11.98	11.97	-0.01
					0.010	1%	17.00	16.97	-0.03
					0.005	0.5%	18.12	18.11	-0.01
4	20.46	6	24.88	Baseline	0.160	16%	14.81	14.36	-0.45
					0.010	1%	20.80	20.28	-0.52
					0.005	0.5%	21.77	21.22	-0.55
				Future Cumulative	0.160	16%	14.28	13.92	-0.36
					0.010	1%	19.24	18.74	-0.50
					0.005	0.5%	20.22	19.73	-0.49
5	19.71	6	25.34	Baseline	0.160	16%	13.68	13.57	-0.11
					0.010	1%	19.86	19.59	-0.27
					0.005	0.5%	20.84	20.55	-0.29
				Future Cumulative	0.160	16%	13.12	12.95	-0.17
					0.010	1%	18.09	17.90	-0.19
					0.005	0.5%	19.10	18.95	-0.15
6	17.86	3	20.59	Baseline	0.160	16%	13.01	13.00	-0.01
					0.010	1%	18.65	18.63	-0.02
					0.005	0.5%	19.54	19.52	-0.02
				Future Cumulative	0.160	16%	11.94	11.94	0.00
					0.010	1%	16.98	16.96	-0.02
					0.005	0.5%	18.07	18.06	-0.01

TABLE 8
SUMMARY OF CHANGE IN ASSURANCE AT RESPECTIVE INDEX POINTS

Index Point	1957 Design WSEL (ft, NAVD 88)	Design Freeboard (feet)	Existing Top of Levee Elevation (ft, NAVD 88)	Condition	CNP	% ACE	WSEL (ft, NAVD 88)		
							Without-Project	With-Project	Change
7	17.85	3	19.57	Baseline	0.160	16%	12.83	12.81	-0.02
					0.010	1%	18.22	18.22	0.00
					0.005	0.5%	19.07	19.06	-0.01
				Future Cumulative	0.160	16%	11.60	11.59	-0.01
					0.010	1%	16.47	16.44	-0.03
					0.005	0.5%	17.56	17.55	-0.01
8	17.82	3	20.82	Baseline	0.160	16%	12.19	12.15	-0.04
					0.010	1%	17.66	17.63	-0.03
					0.005	0.5%	18.59	18.56	-0.03
				Future Cumulative	0.160	16%	11.42	11.40	-0.02
					0.010	1%	16.28	16.23	-0.05
					0.005	0.5%	17.38	17.36	-0.02
9	15.08	3	21.71	Baseline	0.160	16%	11.40	11.28	-0.12
					0.010	1%	16.09	16.09	0.00
					0.005	0.5%	17.21	17.21	0.00
				Future Cumulative	0.160	16%	10.96	10.96	0.00
					0.010	1%	15.61	15.57	-0.04
					0.005	0.5%	16.69	16.68	-0.01
10	12.42	3	11.85 (Restricted Height Levee El.)	Baseline	0.160	16%	11.41	11.36	-0.05
					0.010	1%	13.98	13.98	0.00
					0.005	0.5%	14.94	14.94	0.00
				Future Cumulative	0.160	16%	10.26	10.25	-0.01
					0.010	1%	13.85	13.85	0.00
					0.005	0.5%	14.80	14.80	0.00
11	12.01	3	22.99	Baseline	0.160	16%	10.54	10.54	0.00
					0.010	1%	11.88	11.88	0.00
					0.005	0.5%	12.43	12.43	0.00
				Future Cumulative	0.160	16%	9.63	9.63	0.00
					0.010	1%	11.96	11.96	0.00
					0.005	0.5%	12.52	12.52	0.00

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TABLE 9
SUMMARY OF CHANGE IN FLOWS DOWNSTREAM OF FREMONT WEIR AND SACRAMENTO WEIR

Location	Design Flow (cfs)	Condition	CNP	% ACE	Peak Flow (cfs)			Volume (acre-feet)		
					Without-Project	With-Project	% Change	Without-Project	With-Project	% Change
Yolo Bypass Downstream of Fremont Weir	343,000	Baseline	0.160	16%	177,900	177,900	0.00%	4,037,500	4,037,500	0.00%
			0.010	1%	380,500	380,500	0.00%	5,787,100	5,787,000	0.00%
			0.005	0.5%	419,300	419,300	0.00%	6,785,400	6,785,200	0.00%
		Future Cumulative	0.160	16%	206,000	206,000	0.00%	3,926,800	3,926,800	0.00%
			0.010	1%	390,500	390,500	0.00%	4,437,000	4,436,800	0.00%
			0.005	0.5%	430,200	430,200	0.00%	5,111,900	5,111,700	0.00%
Sacramento Bypass Downstream of Sacramento Weir	112,000	Baseline	0.160	16%	31,800	31,800	0.00%	224,000	224,000	0.00%
			0.010	1%	109,300	109,300	0.00%	1,363,400	1,363,500	0.01%
			0.005	0.5%	122,600	122,600	0.00%	1,643,900	1,644,200	0.02%
		Future Cumulative	0.160	16%	39,800	39,800	0.00%	247,300	247,300	0.00%
			0.010	1%	114,500	114,500	0.00%	1,160,500	1,161,000	0.04%
			0.005	0.5%	128,800	128,900	0.08%	1,392,100	1,392,800	0.05%

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West (left) bank of Yolo Bypass at County Road 155					
Model Geometry	Conditional Non-Exceedance Probability (CNP)	Flood Frequency (ACE)	Without Project Peak Stage (ft, NAVD 88)	With Project Peak Stage (ft, NAVD 88)	Difference Between With and Without Project Peak Stage (ft, NAVD 88)
Baseline Condition	0.160	16.0%	19.74	19.72	-0.02
Baseline Condition	0.010	1.0%	23.85	23.74	-0.11
Baseline Condition	0.005	0.5%	24.63	24.49	-0.14
Future Cumulative Condition	0.160	16.0%	20.16	20.15	-0.01
Future Cumulative Condition	0.010	1.0%	23.26	23.20	-0.06
Future Cumulative Condition	0.005	0.5%	23.92	23.83	-0.09

Haas Slough at western boundary of RD No. 2098					
Model Geometry	Conditional Non-Exceedance Probability (CNP)	Flood Frequency (ACE)	Without Project Peak Stage (ft, NAVD 88)	With Project Peak Stage (ft, NAVD 88)	Difference Between With and Without Project Peak Stage (ft, NAVD 88)
Baseline Condition	0.160	16.0%	13.01	13.00	-0.01
Baseline Condition	0.010	1.0%	18.65	18.63	-0.02
Baseline Condition	0.005	0.5%	19.58	19.53	-0.5
Future Cumulative Condition	0.160	16.0%	11.98	11.97	-0.01
Future Cumulative Condition	0.010	1.0%	17.02	16.99	-0.03
Future Cumulative Condition	0.005	0.5%	18.12	18.11	-0.01

Cache Slough near Hastings Cut					
Model Geometry	Conditional Non-Exceedance Probability (CNP)	Flood Frequency (ACE)	Without Project Peak Stage (ft, NAVD 88)	With Project Peak Stage (ft, NAVD 88)	Difference Between With and Without Project Peak Stage (ft, NAVD 88)
Baseline Condition	0.160	16.0%	13.01	13.00	-0.01
Baseline Condition	0.010	1.0%	18.65	18.63	-0.02
Baseline Condition	0.005	0.5%	19.56	19.51	-0.5
Future Cumulative Condition	0.160	16.0%	11.98	11.97	-0.01
Future Cumulative Condition	0.010	1.0%	17.00	16.97	-0.03
Future Cumulative Condition	0.005	0.5%	18.12	18.11	-0.01

Lindsey Slough upstream of Hastings Island Road Bridge					
Model Geometry	Conditional Non-Exceedance Probability (CNP)	Flood Frequency (ACE)	Without Project Peak Stage (ft, NAVD 88)	With Project Peak Stage (ft, NAVD 88)	Difference Between With and Without Project Peak Stage (ft, NAVD 88)
Baseline Condition	0.160	16.0%	12.83	12.81	-0.02
Baseline Condition	0.010	1.0%	18.22	18.22	0.00
Baseline Condition	0.005	0.5%	19.07	19.06	-0.01
Future Cumulative Condition	0.160	16.0%	11.60	11.59	-0.01
Future Cumulative Condition	0.010	1.0%	16.47	16.44	-0.03
Future Cumulative Condition	0.005	0.5%	17.56	17.55	-0.01

Cache Slough at southern end of Little Egbert Tract					
Model Geometry	Conditional Non-Exceedance Probability (CNP)	Flood Frequency (ACE)	Without Project Peak Stage (ft, NAVD 88)	With Project Peak Stage (ft, NAVD 88)	Difference Between With and Without Project Peak Stage (ft, NAVD 88)
Baseline Condition	0.160	16.0%	11.41	11.36	-0.05
Baseline Condition	0.010	1.0%	13.98	13.98	0.00
Baseline Condition	0.005	0.5%	14.94	14.94	0.00
Future Cumulative Condition	0.160	16.0%	10.26	10.25	-0.01
Future Cumulative Condition	0.010	1.0%	13.85	13.85	0.00
Future Cumulative Condition	0.005	0.5%	14.80	14.80	0.00

Sacramento River at Rio Vista					
Model Geometry	Conditional Non-Exceedance Probability (CNP)	Flood Frequency (ACE)	Without Project Peak Stage (ft, NAVD 88)	With Project Peak Stage (ft, NAVD 88)	Difference Between With and Without Project Peak Stage (ft, NAVD 88)
Baseline Condition	0.160	16.0%	10.54	10.54	0.00
Baseline Condition	0.010	1.0%	11.88	11.88	0.00
Baseline Condition	0.005	0.5%	12.43	12.43	0.00
Future Cumulative Condition	0.160	16.0%	9.63	9.63	0.00
Future Cumulative Condition	0.010	1.0%	11.96	11.96	0.00
Future Cumulative Condition	0.005	0.5%	12.52	12.52	0.00

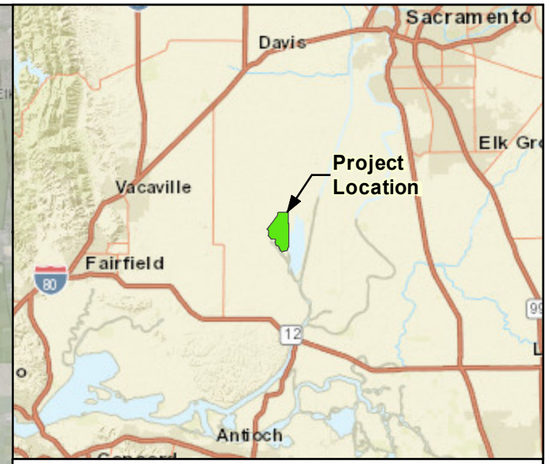
West (left) bank of Yolo Bypass at northern boundary of the Project					
Model Geometry	Conditional Non-Exceedance Probability (CNP)	Flood Frequency (ACE)	Without Project Peak Stage (ft, NAVD 88)	With Project Peak Stage (ft, NAVD 88)	Difference Between With and Without Project Peak Stage (ft, NAVD 88)
Baseline Condition	0.160	16.0%	14.81	14.36	-0.45
Baseline Condition	0.010	1.0%	20.80	20.28	-0.52
Baseline Condition	0.005	0.5%	21.77	21.22	-0.55
Future Cumulative Condition	0.160	16.0%	14.28	13.92	-0.36
Future Cumulative Condition	0.010	1.0%	19.24	18.74	-0.50
Future Cumulative Condition	0.005	0.5%	20.22	19.73	-0.49

West (left) bank of Yolo Bypass at Yolo County/Solano County Line					
Model Geometry	Conditional Non-Exceedance Probability (CNP)	Flood Frequency (ACE)	Without Project Peak Stage (ft, NAVD 88)	With Project Peak Stage (ft, NAVD 88)	Difference Between With and Without Project Peak Stage (ft, NAVD 88)
Baseline Condition	0.160	16.0%	13.68	13.57	-0.11
Baseline Condition	0.010	1.0%	19.86	19.59	-0.27
Baseline Condition	0.005	0.5%	20.84	20.55	-0.29
Future Cumulative Condition	0.160	16.0%	13.12	12.95	-0.17
Future Cumulative Condition	0.010	1.0%	18.09	17.90	-0.19
Future Cumulative Condition	0.005	0.5%	19.10	18.95	-0.15

Cache Slough at Confluence with Yolo Bypass					
Model Geometry	Conditional Non-Exceedance Probability (CNP)	Flood Frequency (ACE)	Without Project Peak Stage (ft, NAVD 88)	With Project Peak Stage (ft, NAVD 88)	Difference Between With and Without Project Peak Stage (ft, NAVD 88)
Baseline Condition	0.160	16.0%	13.01	13.00	-0.01
Baseline Condition	0.010	1.0%	18.65	18.63	-0.02
Baseline Condition	0.005	0.5%	19.54	19.52	-0.02
Future Cumulative Condition	0.160	16.0%	11.94	11.94	0.00
Future Cumulative Condition	0.010	1.0%	16.98	16.96	-0.02
Future Cumulative Condition	0.005	0.5%	18.07	18.06	-0.01

Cache Slough at Ryer Island					
Model Geometry	Conditional Non-Exceedance Probability (CNP)	Flood Frequency (ACE)	Without Project Peak Stage (ft, NAVD 88)	With Project Peak Stage (ft, NAVD 88)	Difference Between With and Without Project Peak Stage (ft, NAVD 88)
Baseline Condition	0.160	16.0%	11.40	11.28	-0.12
Baseline Condition	0.010	1.0%	16.09	16.09	0.00
Baseline Condition	0.005	0.5%	17.21	17.21	0.00
Future Cumulative Condition	0.160	16.0%	10.96	10.96	0.00
Future Cumulative Condition	0.010	1.0%	15.61	15.57	-0.04
Future Cumulative Condition	0.005	0.5%	16.69	16.68	-0.01

Cache Slough at northern end of Little Egbert Tract					
Model Geometry	Conditional Non-Exceedance Probability (CNP)	Flood Frequency (ACE)	Without Project Peak Stage (ft, NAVD 88)	With Project Peak Stage (ft, NAVD 88)	Difference Between With and Without Project Peak Stage (ft, NAVD 88)
Baseline Condition	0.160	16.0%	12.19	12.15	-0.04
Baseline Condition	0.010	1.0%	17.66	17.63	-0.03
Baseline Condition	0.005	0.5%	18.59	18.56	-0.03
Future Cumulative Condition	0.160	16.0%	11.42	11.40	-0.02
Future Cumulative Condition	0.010	1.0%	16.28	16.23	-0.05
Future Cumulative Condition	0.005	0.5%	17.38	17.36	-0.02



LOOKOUT SLOUGH TIDAL HABITAT RESTORATION AND FLOOD IMPROVEMENT PROJECT

PROJECT IMPACTS AT INDEX POINTS

SOLANO COUNTY, CALIFORNIA
AUGUST, 2019

NORTH

0 6,000 12,000 24,000

FEET

Project Location

RD 2060 and RD 2068 Levees

① Index Point

Sources: Esri Service Layers 2018 (World Imagery, World Topographic Map, World Street Map).

Notes:

1. Hydrology input data adapted from "Basin-Wide Feasibility Studies - Sacramento River Basin" prepared by California Departmentof Water Resources in 2017. Event hydrology is based on the Central Valley Hydrology Study (USACE, 2015) methodology. 10% ACE uses the 1997 pattern with 0.40 scale factor. 1% ACE uses the 1997 pattern with 0.95 scale factor, and 0.5% ACE uses the 1997 pattern with 1.10 scale factor.

2. Future Cumulative Condition represents full build-out of the Yolo Bypass Option 3 concept presented in "Basin-Wide Feasibility Studies - Sacramento River Basin" prepared by DWR in 2017.

PRELIMINARY

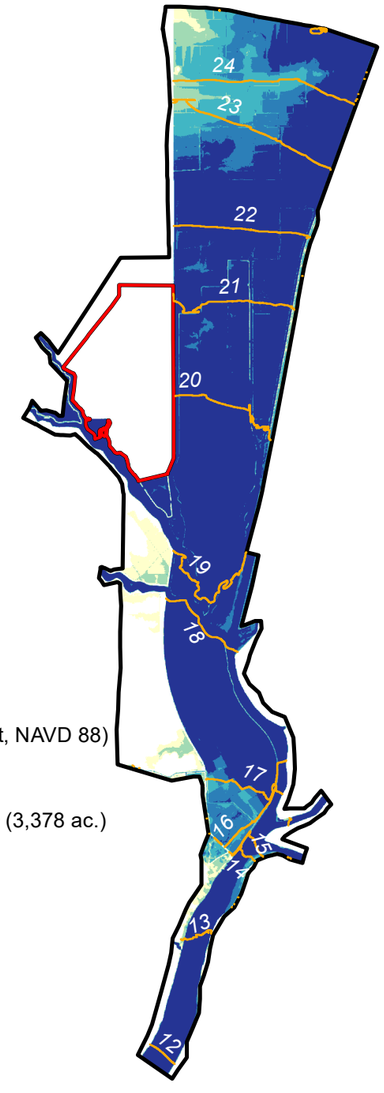
Ecosystem Investment Partners

WOOD RODGERS

J:\3000-s\3487_Ecosystem_Invest_Partners\3487002 Lookout Slough Prelim Hydraulic Analysis\GIS\Tasks\20190807_Comparison_Point_Map\FXX_Overall_Project_Impacts_Map_20190807_V1.mxd 8/7/2019 4:23:25 PM cmilligan

FIGURE 36

Without-Project



Water Surface Elevation (feet, NAVD 88)

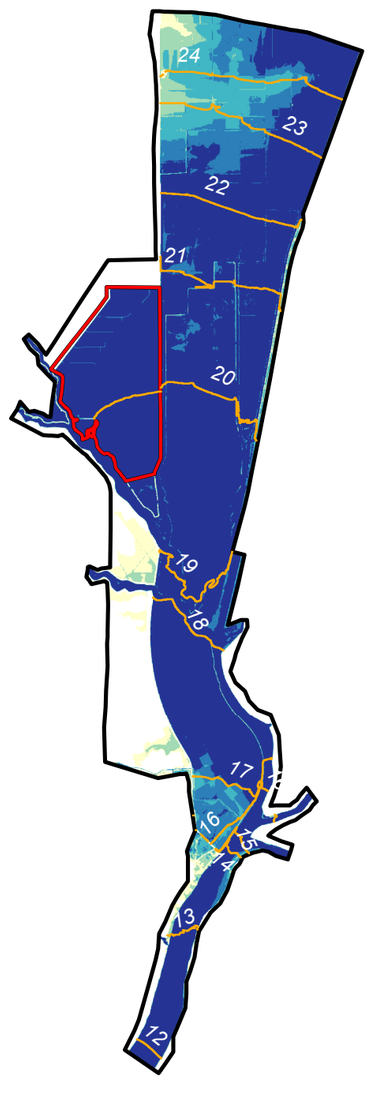
Model Domain Boundary

Surveyed Property Boundary (3,378 ac.)

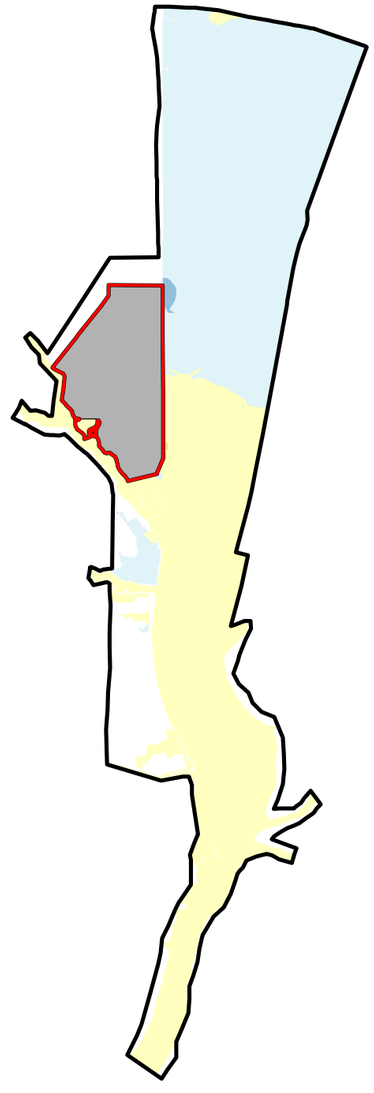
Depth (feet)

- < 3
- 3 - 6
- 6 - 9
- 9 -12
- > 12

With-Project



Project Impacts



Change in WSEL (feet)

- < -1.0
- - 1.0 - -0.5
- -0.5 - -0.1
- -0.1 - 0.1
- 0.1 - 0.5
- 0.5 - 1
- > 1
- Area Added to Floodplain

Figure 37
Authorized Design Flow Performance - Stage

N
W E
S

0 15,000 30,000
Feet

Ecosystem Investment Partners

Map Prepared Date: 9/1/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):

Prepared by: ESA

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

Path: U:\GIS\GIS\Projects\18xxxx\D181197_00_Lookout_Slough_Restoration\103_MXDs_Projects\02_Flood_Task_System_Hand\HF37_1957_Authorized_Design_WS_Impacts.mxd, JPritchard 9/1/2019

TABLE 10
SUMMARY OF AUTHORIZED DESIGN FLOW COMPUTED WATER SURFACE ELEVATIONS (FEET, NAVD 88)
BASELINE CONDITION

Index Point	Location	Without-Project	With-Project	Change
1	West (left) bank of Yolo Bypass at County Road 155	24.05	23.92	-0.13
2	Hass Slough at western boundary of RD 2098	19.36	19.35	-0.01
3	Cache Slough near Hastings Cut	19.36	19.35	-0.01
4	West (left) levee of Yolo Bypass at northern boundary of the Project	21.29	20.76	-0.53
5	West (left) bank of Yolo Bypass at Yolo County/Solano County Line	20.43	20.20	-0.23
6	Cache Slough at Confluence with Yolo Bypass	19.35	19.34	-0.01
7	Lindsey Slough upstream of Hastings Island Road Bridge	18.94	18.94	0.00
8	Cache Slough at northern end of Little Egbert Tract	18.51	18.51	0.00
9	Cache Slough at Ryer Island	17.33	17.33	0.00
10	Cache Slough at southern end of Little Egbert Tract	15.49	15.49	0.00
11	Sacramento River at Rio Vista	13.19	13.19	0.00

Velocity Impacts

The resultant computed maximum velocity for the without- and with-Project simulations are shown on **Figure 38**. Figure 38 also depicts the change in maximum velocity between the without- and with-Project conditions. Although the Project results in localized increases in velocity in some locations, the maximum velocities remain low enough that channel erosion and scour potential along the SRFCP facilities are not considered to be significant.

Baseline Condition Performance Assessment

The Baseline Condition was analyzed without- and with-Project to identify hydraulic changes that would result from the proposed alteration. The assessment included hydraulic analysis of the authorized design flow capacity, and assessment of the respective 16% ACE (6-year), 1% ACE (100-year), and 0.5% ACE (200-year) design storm events. The following section describes the changes in the hydraulic performance of the system created by the Project.

Stage Impacts

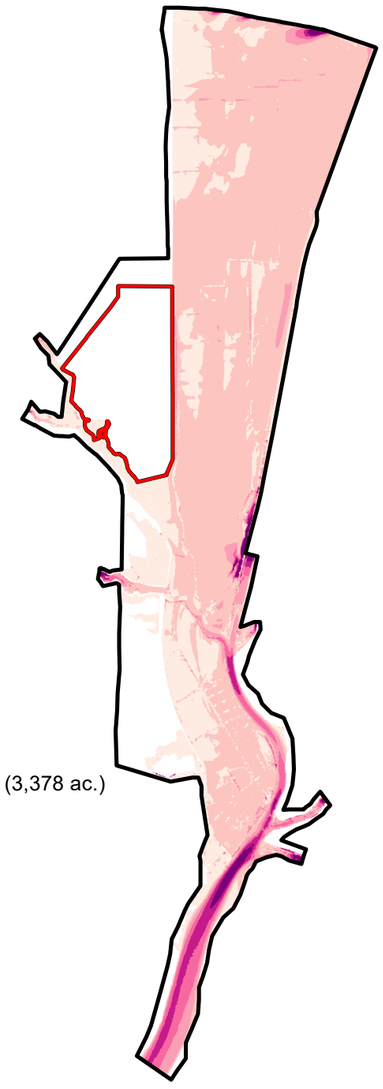
The resultant change in the Baseline Condition water surfaces at the respective index point locations is summarized in on Figure 36 as well as in Table 8. The resultant floodplain extents, depth, and computed maximum water surface for the 16% ACE (6-year), 1% ACE (100-year), and 0.5% ACE (200-year) design flows for the without- and with-Project simulations are shown on **Figure 39** through **Figure 41**, respectively. Figure 39 through Figure 41 also depict the change in maximum stage between the without- and with-Project conditions for the respective design storm events. In general, the Project results in localized stage reductions in the Yolo Bypass and does not increase stages in other parts of the system.

Velocity Impacts

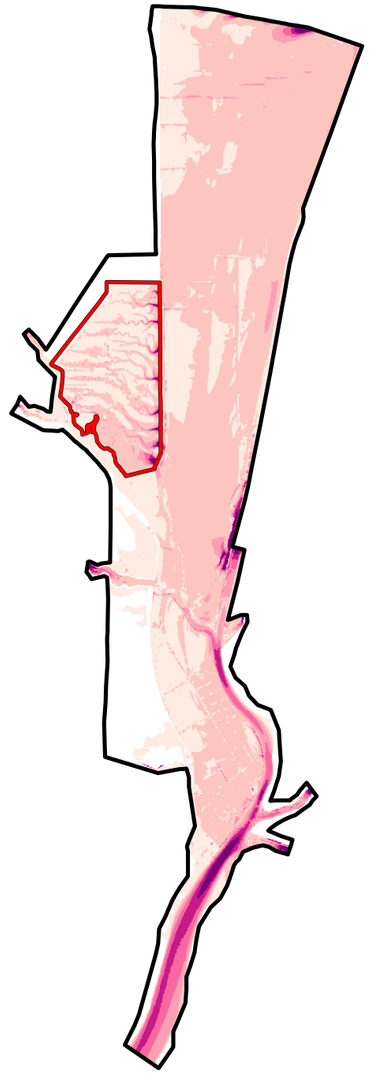
The resultant change in the Baseline Condition velocities for the 16% ACE (6-year), 1% ACE (100-year), and 0.5% ACE (200-year) design flows for the without- and with-Project simulations are shown on **Figure 42** through **Figure 44**, respectively. Figure 42 through Figure 44 also depict the change in the Baseline Condition maximum velocity between the without- and with-Project conditions for the respective design storm events. Although the Project results in localized increases in velocity in some locations, the maximum velocities remain low enough that channel erosion and scour potential along existing and proposed SRFCP facilities are not considered to be significant during the 1% ACE (100-year) storm event.

The Wood Rodgers civil design team has determined that planting native grasses will be adequate for protecting the waterside of the new setback levee. A detailed discussion of the erosion countermeasures design is included in the main body of the overall Basis of Design Report.

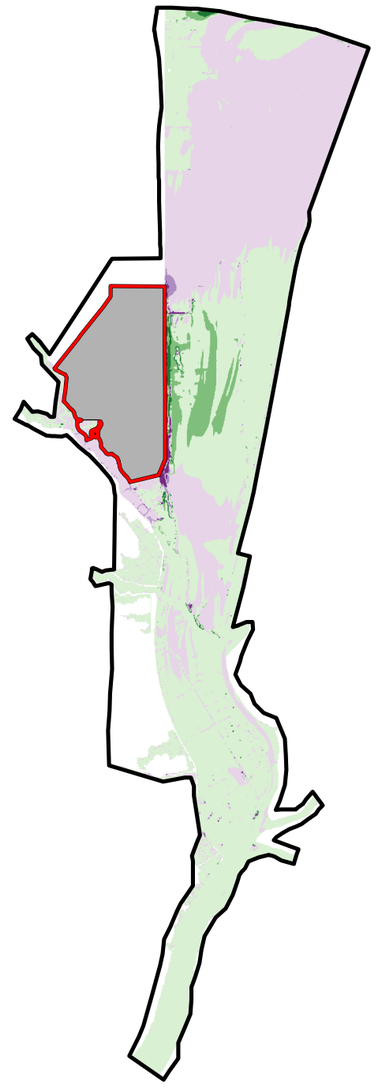
Without-Project



With-Project



Project Impacts



Model Domain Boundary

Surveyed Property Boundary (3,378 ac.)

Velocity (fps)

- < 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- > 10

Change in Velocity (fps)

- < - 1
- - 1 - -0.5
- -0.5 - 0
- 0 - 0.5
- 0.5 - 1
- > 1
- Area Added to Floodplain

Figure 38
Authorized Design Flow Performance - Velocity

N
W E
S

0 15,000 30,000
Feet

Ecosystem Investment Partners

Prepared by: ESA

Map Prepared Date: 9/1/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

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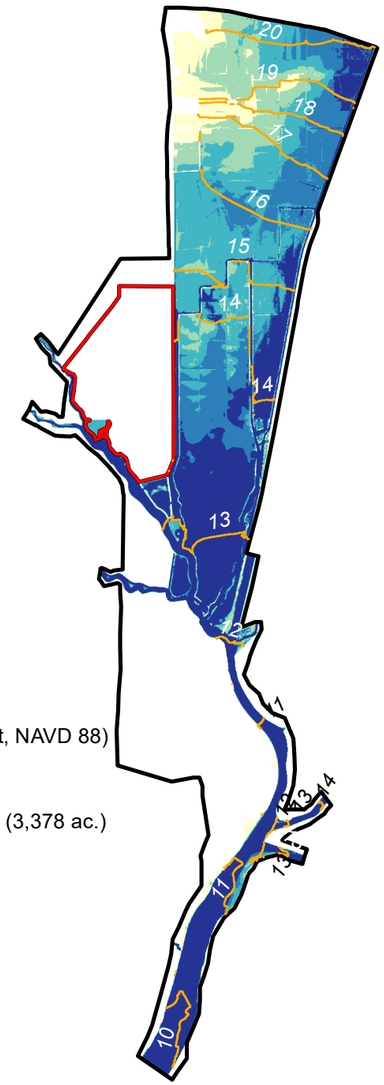
Without-Project



Water Surface Elevation (feet, NAVD 88)

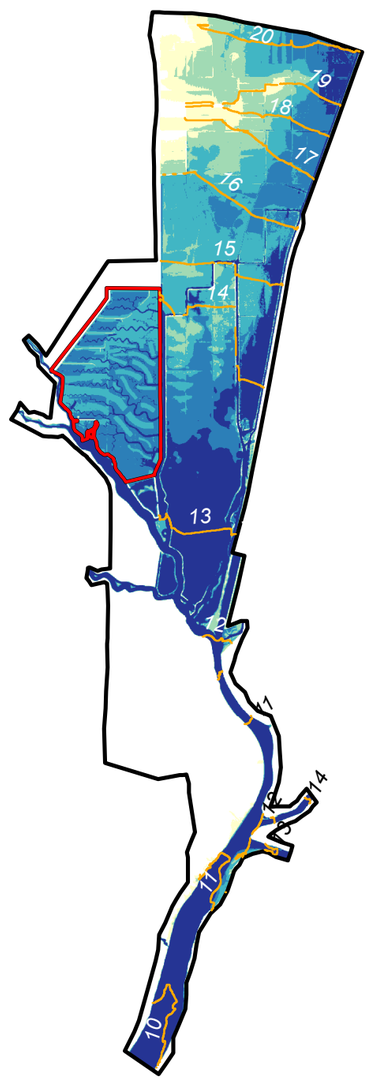
Model Domain Boundary

Surveyed Property Boundary (3,378 ac.)

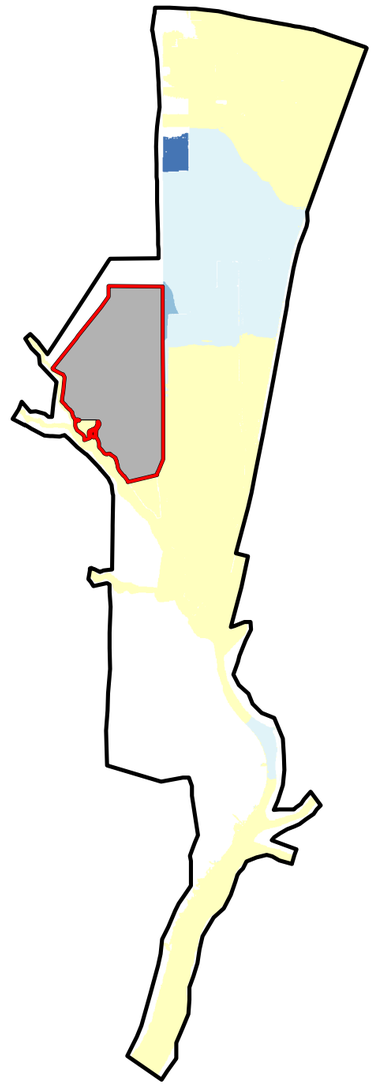
Depth (feet)

- < 3
- 3 - 6
- 6 - 9
- 9 -12
- > 12

With-Project



Project Impacts



Change in WSEL (feet)

- < -1.0
- - 1.0 - -0.5
- -0.5 - -0.1
- -0.1 - 0.1
- 0.1 - 0.5
- 0.5 - 1
- > 1
- Area Added to Floodplain

Figure 39
Baseline Condition Performance 16% ACE (6-year) - Stage

N
W E
S

0 15,000 30,000
Feet

Ecosystem Investment Partners

Map Prepared Date: 9/1/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):

Prepared by: ESA

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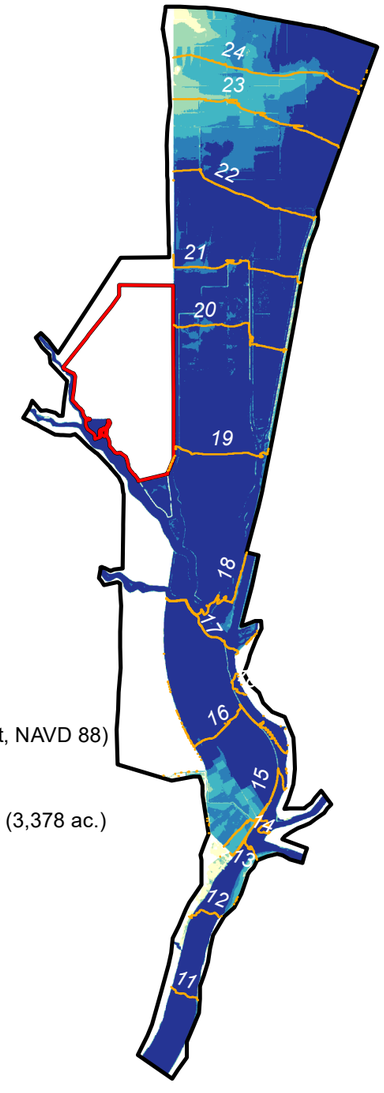
Without-Project



Water Surface Elevation (feet, NAVD 88)

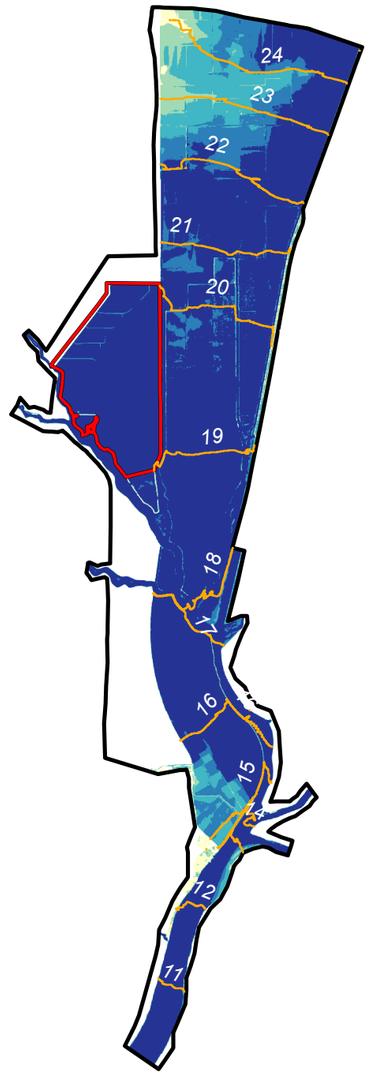
Model Domain Boundary

Surveyed Property Boundary (3,378 ac.)

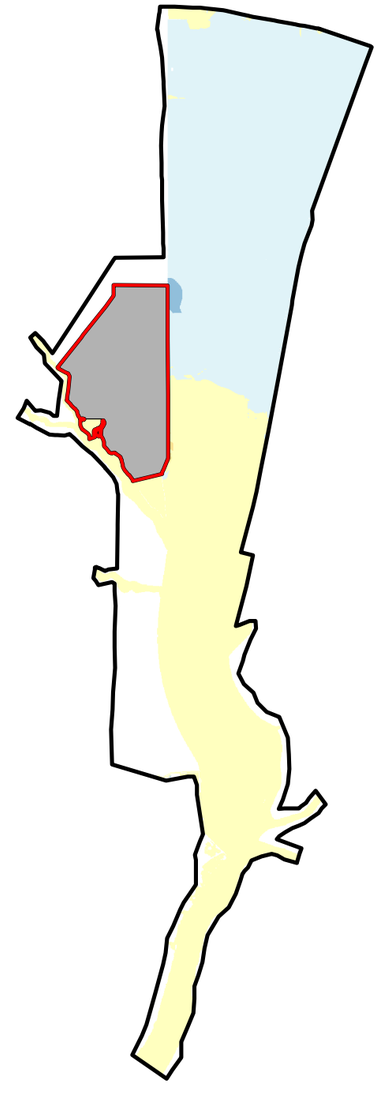
Depth (feet)

- < 3
- 3 - 6
- 6 - 9
- 9 -12
- > 12

With-Project



Project Impacts



Change in WSEL (feet)

- < -1.0
- - 1.0 - -0.5
- -0.5 - -0.1
- -0.1 - 0.1
- 0.1 - 0.5
- 0.5 - 1
- > 1
- Area Added to Floodplain

Figure 40
Baseline Condition Performance 1% ACE (100-year) - Stage

N
W E
S

0 15,000 30,000
Feet

Ecosystem Investment Partners

Prepared by: ESA

Map Prepared Date: 9/1/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):

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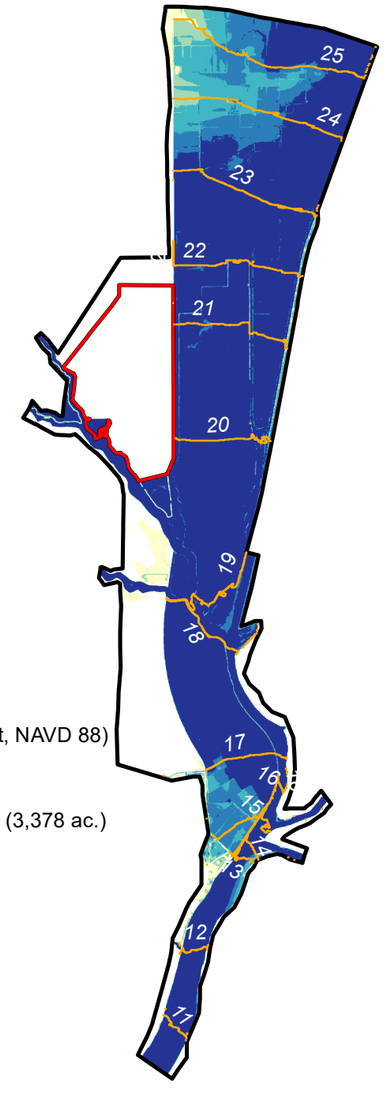
Without-Project



Water Surface Elevation (feet, NAVD 88)

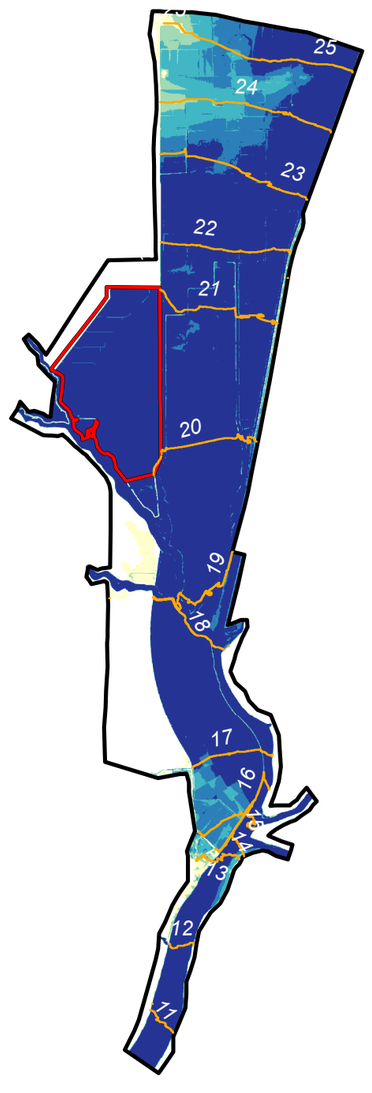
Model Domain Boundary

Surveyed Property Boundary (3,378 ac.)

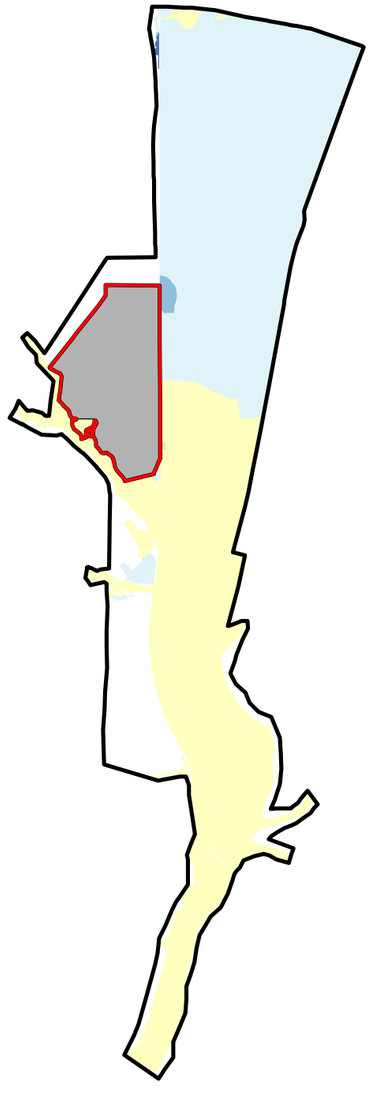
Depth (feet)

- < 3
- 3 - 6
- 6 - 9
- 9 -12
- > 12

With-Project



Project Impacts



Change in WSEL (feet)

- < -1.0
- - 1.0 - -0.5
- -0.5 - -0.1
- -0.1 - 0.1
- 0.1 - 0.5
- 0.5 - 1
- > 1
- Area Added to Floodplain

Figure 41
Baseline Condition Performance 0.5% ACE (200-year) - Stage

N
W E
S

0 15,000 30,000
Feet

Ecosystem Investment Partners

Map Prepared Date: 9/1/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):

Prepared by: ESA

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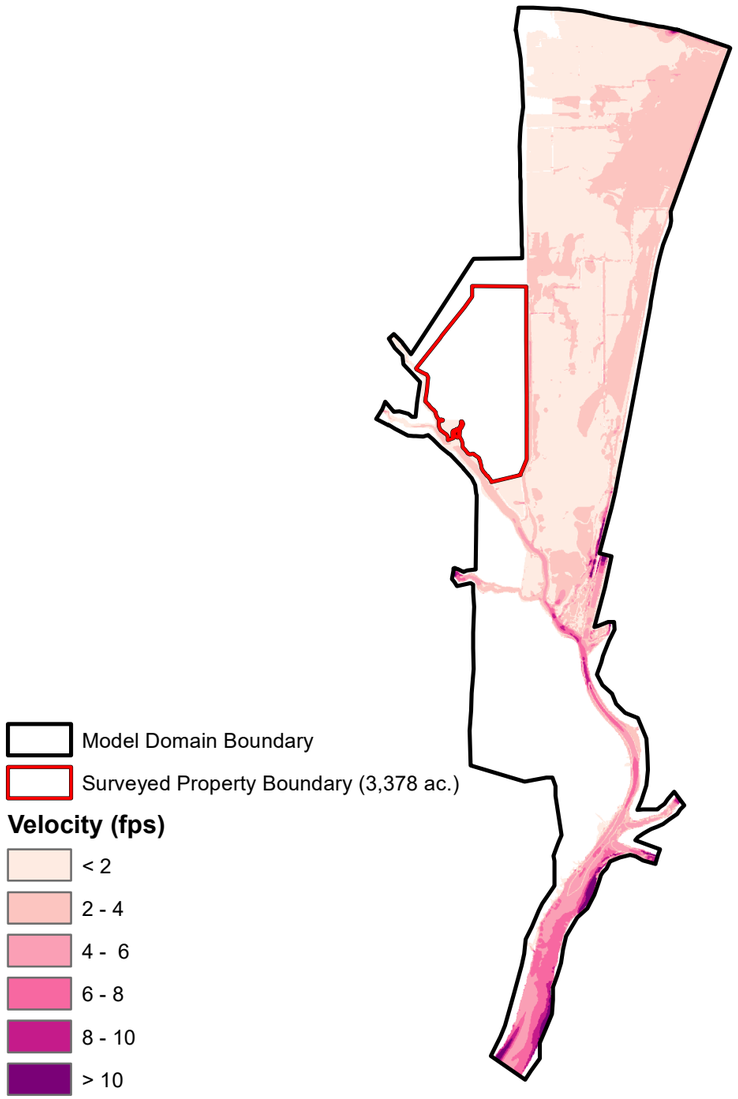
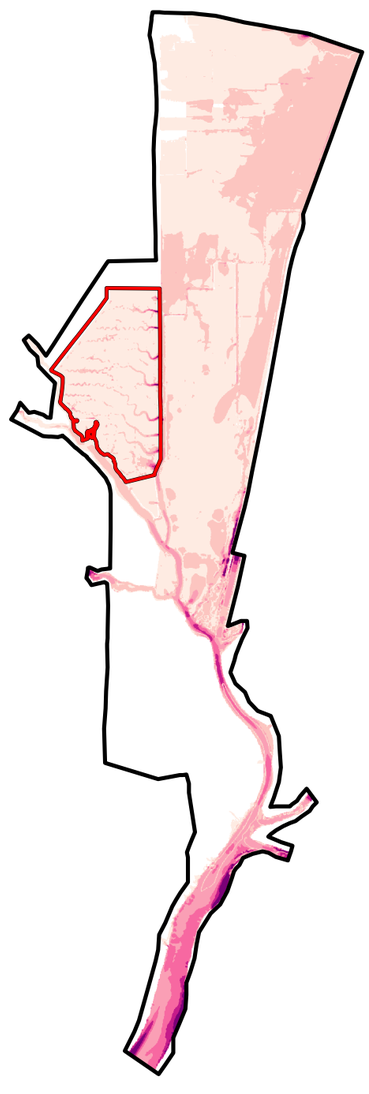
Without-Project



With-Project



Project Impacts

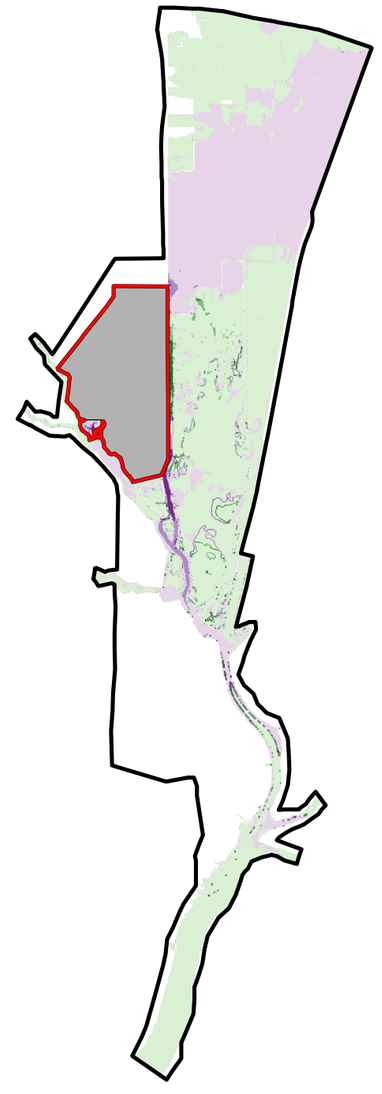


Figure 42
Baseline Condition Performance 16% ACE (6-year) - Velocity

0 15,000 30,000
Feet

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

Ecosystem Investment Partners

Map Prepared Date: 9/1/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):

Prepared by: ESA

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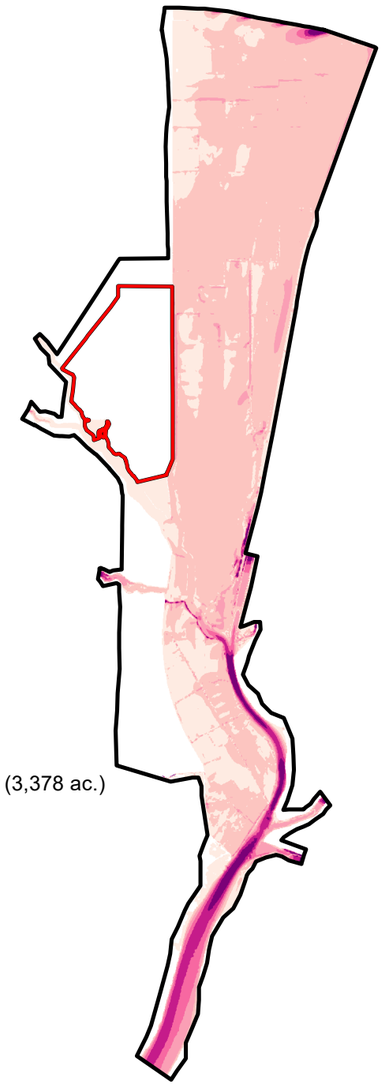
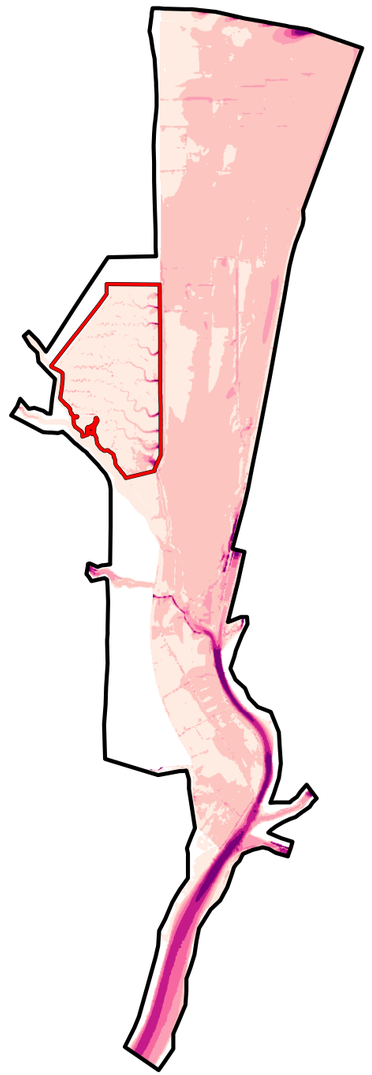
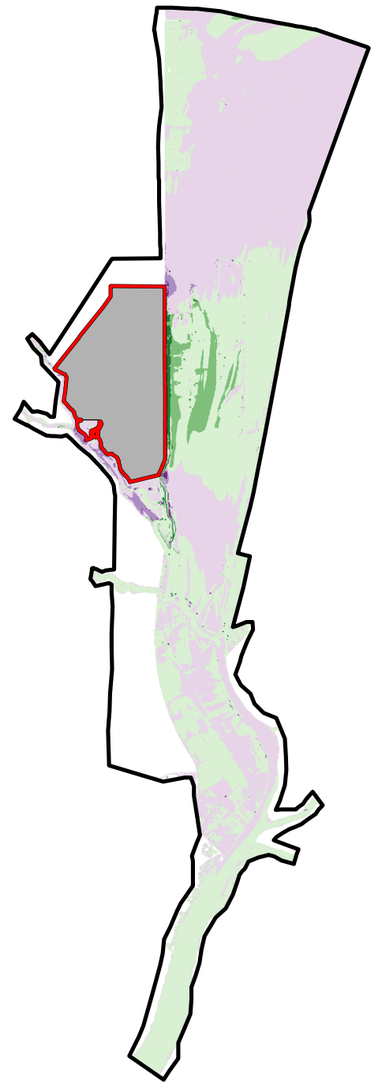
Without-Project



With-Project



Project Impacts



Model Domain Boundary

Surveyed Property Boundary (3,378 ac.)

Velocity (fps)

- < 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- > 10

Change in Velocity (fps)

- < - 1
- - 1 - -0.5
- -0.5 - 0
- 0 - 0.5
- 0.5 - 1
- > 1
- Area Added to Floodplain

Figure 43
Baseline Condition Performance 1% ACE (100-year) - Velocity

N W E S

0 15,000 30,000
Feet

Ecosystem Investment Partners

Prepared by: ESA

Map Prepared Date: 9/1/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):

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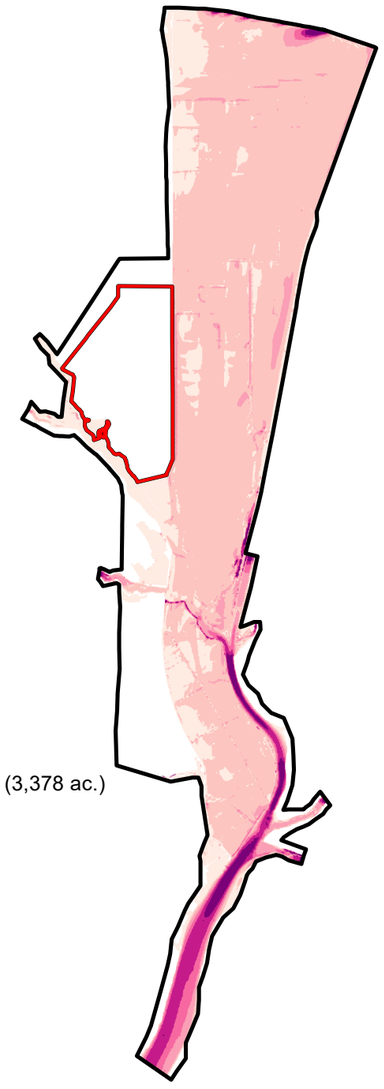
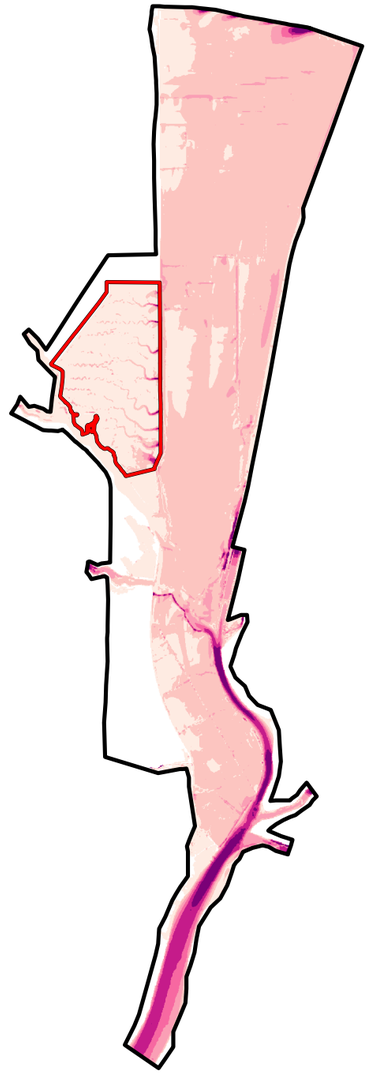
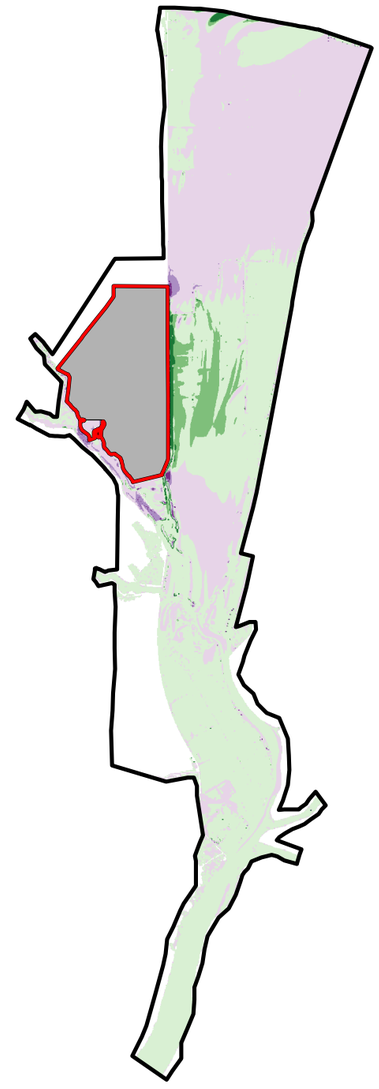
Without-Project



With-Project



Project Impacts



Model Domain Boundary

Surveyed Property Boundary (3,378 ac.)

Velocity (fps)

- < 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- > 10

Change in Velocity (fps)

- < - 1
- - 1 - -0.5
- -0.5 - 0
- 0 - 0.5
- 0.5 - 1
- > 1
- Area Added to Floodplain

Figure 44
Baseline Condition Performance 0.5% ACE (200-year) - Velocity

N
W E
S

0 15,000 30,000
Feet

Ecosystem Investment Partners

Prepared by: ESA

Map Prepared Date: 9/1/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

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Future Cumulative Condition Performance Assessment

The Future Cumulative Condition was analyzed without- and with-Project to identify hydraulic changes that would result from the proposed alteration relative to the preferred Yolo Bypass expansion concept (Yolo Bypass Option 3) identified in the BWFS. The assessment included hydraulic analysis of the authorized design flow capacity, and assessment of the respective 16% ACE (6-year), 1% ACE (100-year), and 0.5% ACE (200-year) design storm events. The following section describes the changes in the hydraulic performance of the system created by the Project.

Stage Impacts

The resultant change in the Future Cumulative Condition water surfaces at the respective index point locations is summarized on Figure 36 as well as in Table 8. The resultant floodplain extents, depth, and computed maximum water surface for the 16% ACE (6-year), 1% ACE (100-year), and 0.5% ACE (200-year) design flows for the without- and with-Project simulations are shown on **Figure 45** through **Figure 47**, respectively. Figure 45 through Figure 47 also depict the change in maximum stage between the without- and with-Project conditions for the respective design storm events. In general, the Project results in localized stage reductions in the Yolo Bypass and does not increase stages in other parts of the system for any of the frequency intervals analyzed.

Velocity Impacts

The resultant change in the Future Cumulative Condition velocities for the 16% ACE (6-year), 1% ACE (100-year), and 0.5% ACE (200-year) design flows for the without- and with-Project simulations are shown on **Figure 48** through **Figure 50**, respectively. Figure 48 through Figure 50 also depict the change in the Baseline Condition maximum velocity between the without- and with-Project conditions for the respective design storm events. Although the Project results in localized increases in velocity in some locations, the maximum velocities remain low enough that channel erosion and scour potential along existing and proposed SRFCP facilities are not considered to be significant during the 1% ACE (100-year) storm event.

As noted previously, a detailed discussion of the erosion countermeasures design is included in the main body of the overall Basis of Design Report.

Design Water Surface Elevation

Figure 51 shows the With-Project 1% ACE (100-year) design water surface profile along the Project's proposed setback levee alignment plotted relative to the 1957 authorized design profile (projected westward, perpendicular from the existing levee alignment). Although the flow rates in this part of the Yolo Bypass are comparable, the authorized 1957 design water surface profile is generally higher than the computed 1% ACE (100-year) design profile. The differences seen here are considered to be the product of the stage reductions in the Yolo Bypass created by the Project in conjunction with higher downstream stage assumptions in the 1957 authorized design profile (see Table 3).

The 1957 Profile is based on specified design discharges (not tied to a recurrence frequency) and adopted concurrent conditions at confluences of study streams (USACE, 1993). In this portion of the Yolo Bypass, the 1957 profile was based on flow extents and durations from the 1907 and

1909 floods (DWR, 2016, U.S. House, 1917). For the purposes of designing a new setback levee, the 1957 profile will provide a slightly more conservative design water surface elevation and should generally be used as the basis of design except at locations where the 1% ACE (100-year) stage provides a higher elevation.

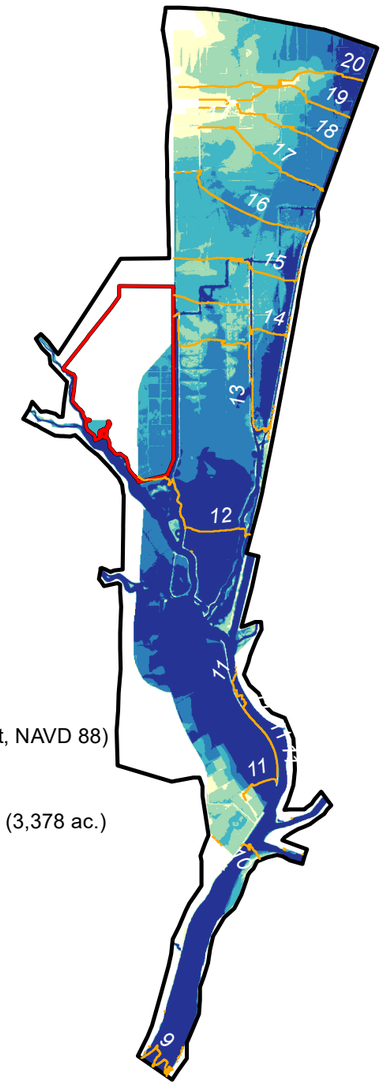
Summary and Conclusion

This report documents the methods, data, and assumptions used to establish the design water surface elevation and potential impacts associated with a multi-benefit project that meets the objectives of habitat restoration while also improving flood conveyance in the Yolo Bypass. The Project as proposed, has been determined to create no adverse impacts to stage or channel velocity, while providing localized reductions in stage within the Yolo Bypass.

The existing system and future hydraulic performance of the project have been described in this report. A fundamental precept of the analysis is that the 1957 authorized design water surface profile shall be used as the basis for design for the Project's setback levee. The design top of levee shall include 6 feet of freeboard, plus 1 additional foot of freeboard for climate resiliency. Analysis of the Future Cumulative Condition also indicates that the Project will achieve superior hydraulic performance relative to the preferred concept plan (Yolo Bypass Option 3) identified in the BWFS.

The analysis described in this report shows that the proposed Project alterations would result in negligible adverse impacts to flood stages in the system. The region-wide system models have also been reviewed to verify that no significant change in the flow distribution at Fremont Weir or the Sacramento Weir would occur as a result of the Project. As the hydraulic impacts of the Project are localized, and generally result in stage decreases for the design events under consideration (including the 1957 authorized design flow), the Project's potential to transfer risk from one part of the system to another is considered to be negligible. The deterministic analysis conducted for the Project is considered sufficient for describing the overall system performance for the without- and with-Project conditions and verifies that the reduction in assurance is negligible.

Without-Project



Water Surface Elevation (feet, NAVD 88)

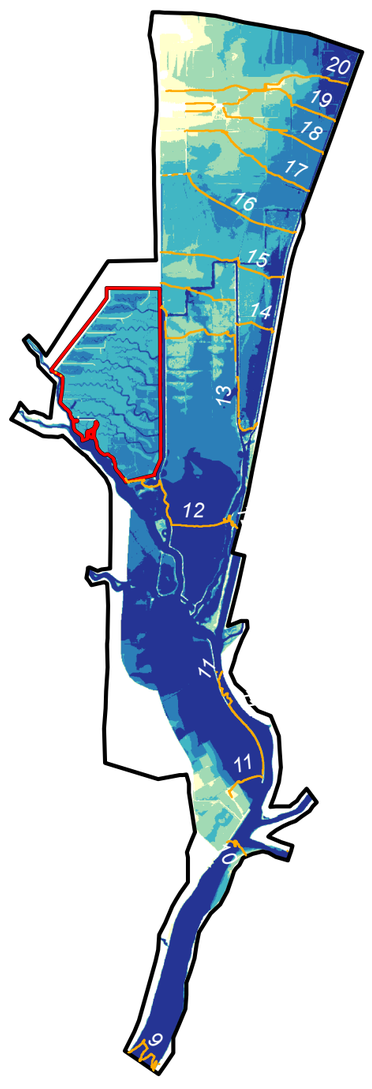
Model Domain Boundary

Surveyed Property Boundary (3,378 ac.)

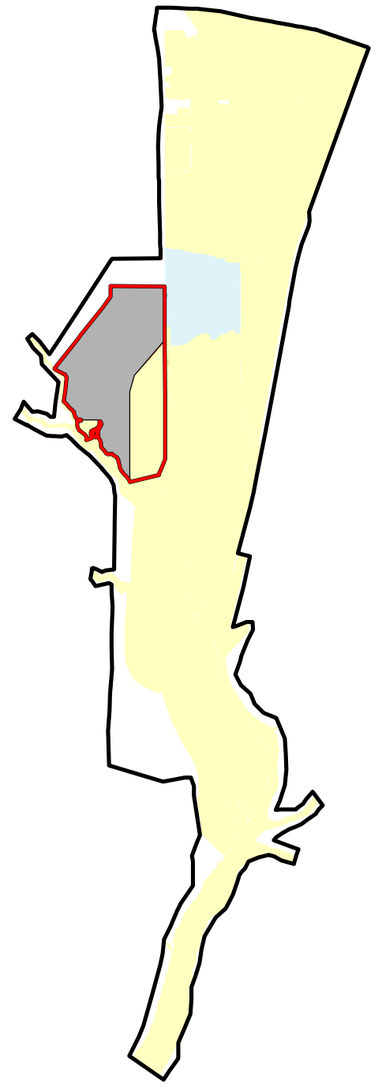
Depth (feet)

- < 3
- 3 - 6
- 6 - 9
- 9 -12
- > 12

With-Project



Project Impacts



Change in WSEL (feet)

- < -1.0
- - 1.0 - -0.5
- -0.5 - -0.1
- -0.1 - 0.1
- 0.1 - 0.5
- 0.5 - 1
- > 1
- Area Added to Floodplain

Figure 45
Future Cumulative Condition Performance 16% ACE (6-year) - Stage

N
W E
S

0 15,000 30,000
Feet

Ecosystem Investment Partners

Map Prepared Date: 9/1/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):

Prepared by: ESA

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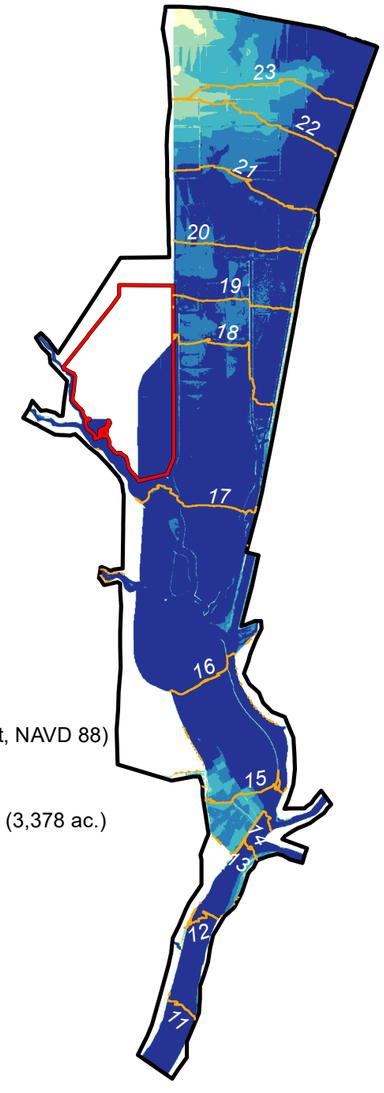
Without-Project



Water Surface Elevation (feet, NAVD 88)

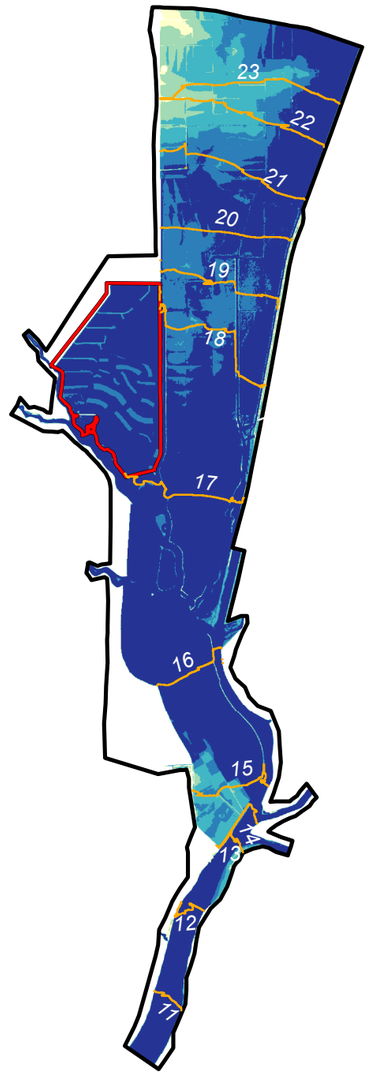
Model Domain Boundary

Surveyed Property Boundary (3,378 ac.)

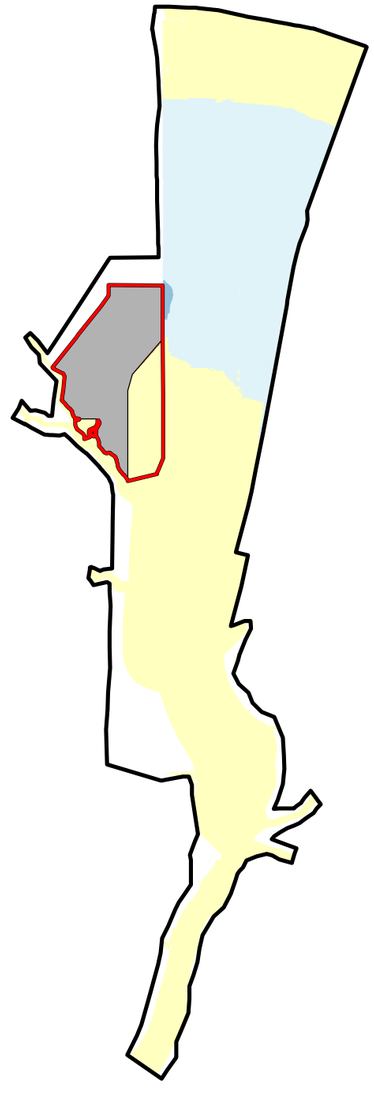
Depth (feet)

- < 3
- 3 - 6
- 6 - 9
- 9 -12
- > 12

With-Project



Project Impacts



Change in WSEL (feet)

- < -1.0
- - 1.0 - -0.5
- -0.5 - -0.1
- -0.1 - 0.1
- 0.1 - 0.5
- 0.5 - 1
- > 1
- Area Added to Floodplain

Figure 46
Future Cumulative Condition Performance 1% ACE (100-year) - Stage

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

N
W E
S

0 15,000 30,000
Feet

Ecosystem Investment Partners

Map Prepared Date: 9/1/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):

Prepared by: ESA

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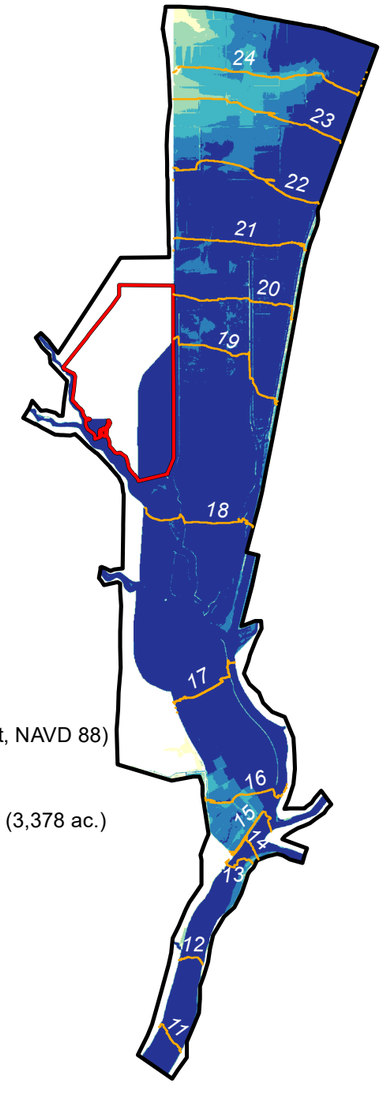
Without-Project



Water Surface Elevation (feet, NAVD 88)

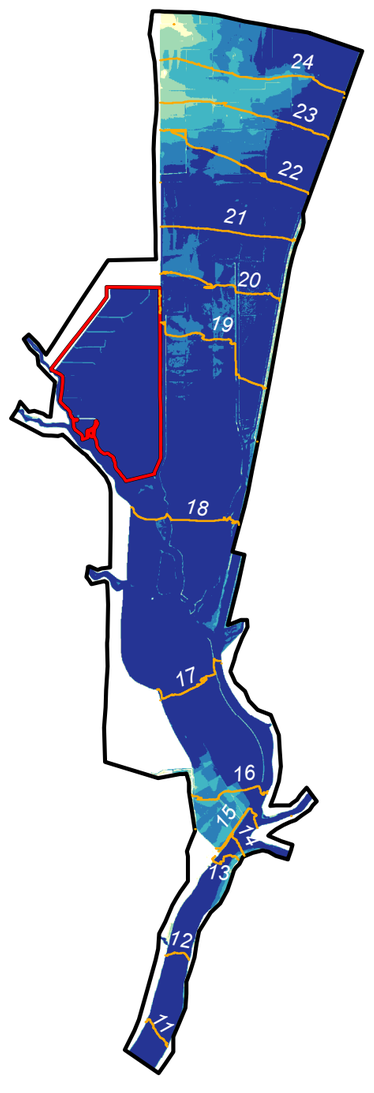
Model Domain Boundary

Surveyed Property Boundary (3,378 ac.)

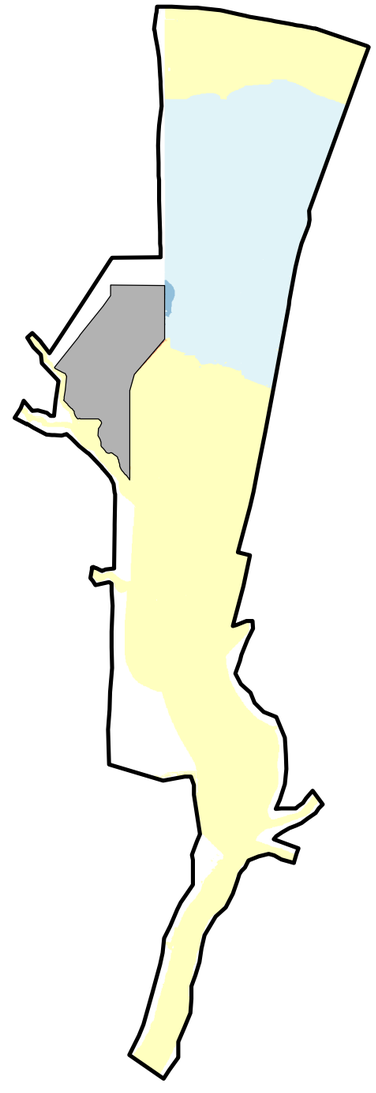
Depth (feet)

- < 3
- 3 - 6
- 6 - 9
- 9 -12
- > 12

With-Project



Project Impacts



Area Added to Floodplain

Change in WSEL (feet)

- < -1.0
- - 1.0 - -0.5
- -0.5 - -0.1
- -0.1 - 0.1
- 0.1 - 0.5
- 0.5 - 1
- > 1

Figure 46
Future Cumulative Condition Performance 0.5% ACE (200-year) - Stage

N
W E
S

0 15,000 30,000
Feet

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

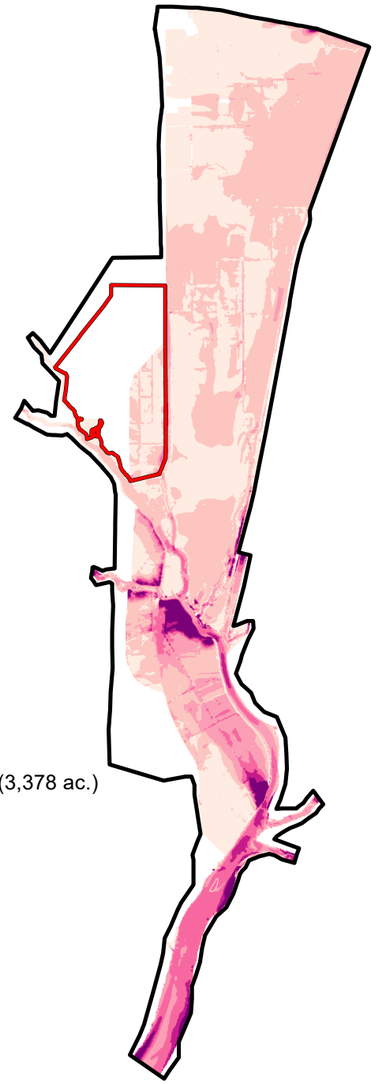
Ecosystem Investment Partners

Map Prepared Date: 9/1/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):

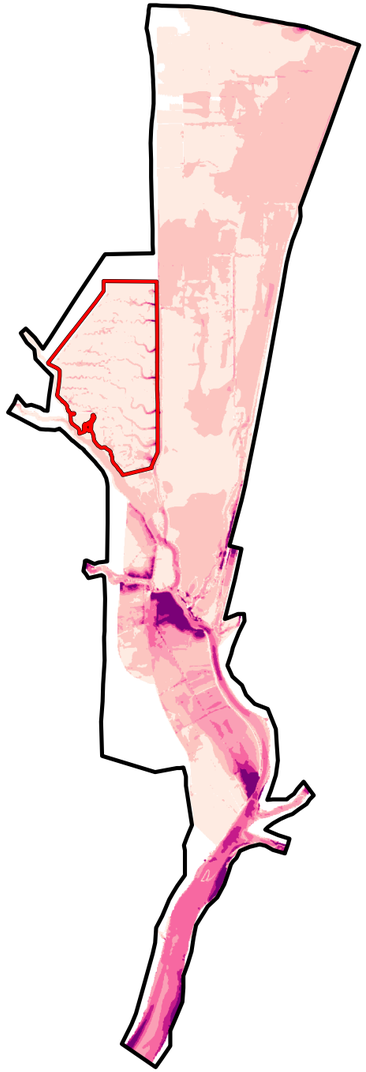
Prepared by: ESA

Path: U:\GIS\GIS\Projects\18xxxx\D181197_00_Lookout_Slough_Restoration_1103_MXDs_Projects\02_Flood_Task_System_Hand\HF47_FCC_Q200_WS_Impacts.mxd_JPritchard_9/1/2019

Without-Project



With-Project



Project Impacts



Model Domain Boundary

Surveyed Property Boundary (3,378 ac.)

Velocity (fps)

- < 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- > 10

Change in Velocity (fps)

- < - 1
- - 1 - -0.5
- -0.5 - 0
- 0 - 0.5
- 0.5 - 1
- > 1
- Area Added to Floodplain

Figure 48
Future Cumulative Condition Performance 16% ACE (6-year) - Velocity

N
W E
S

0 15,000 30,000
Feet

Ecosystem Investment Partners

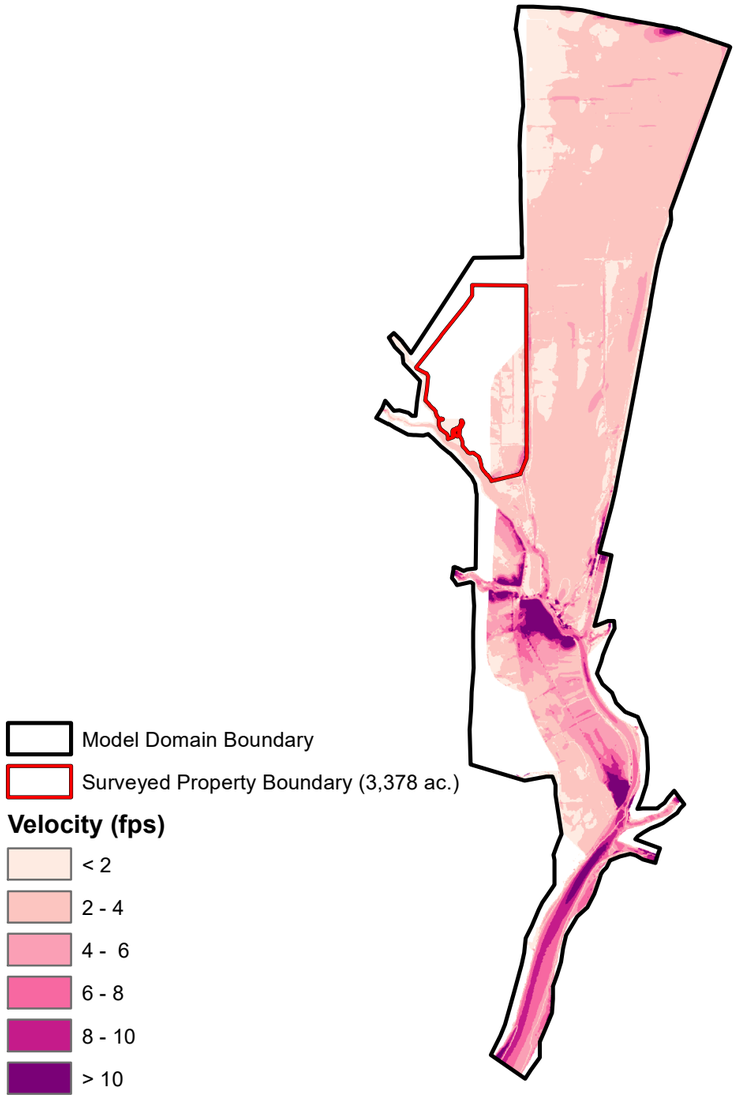
Prepared by: ESA

Map Prepared Date: 9/1/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):

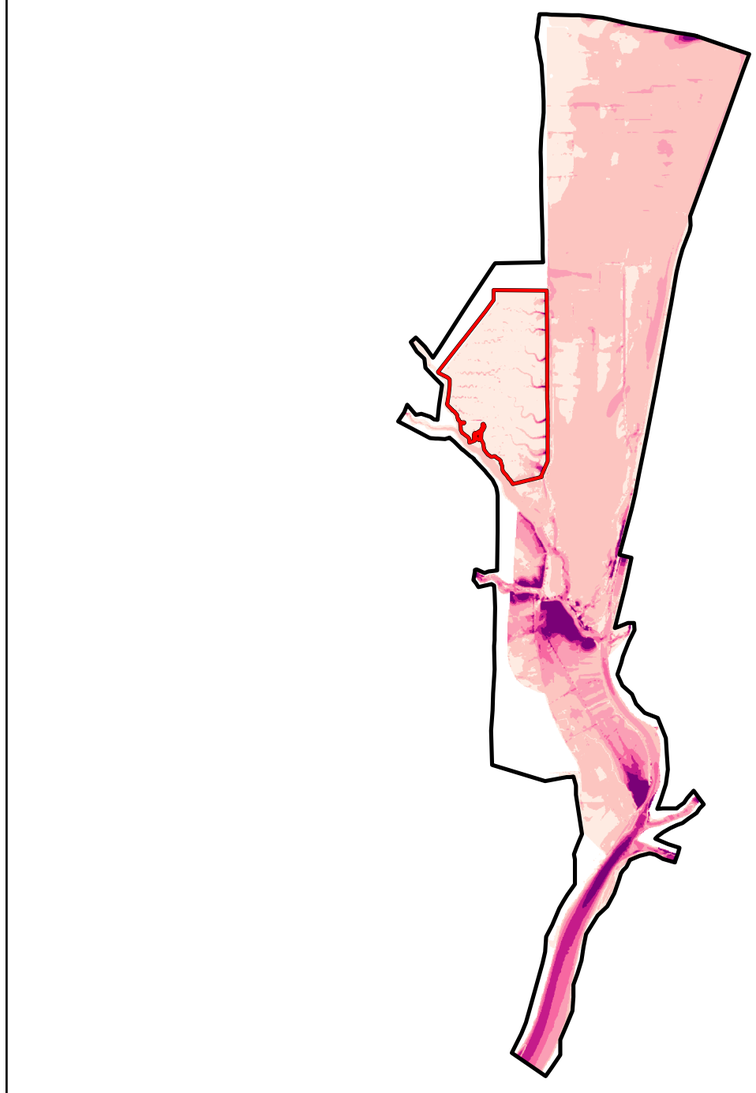
Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

Path: U:\GIS\GIS\Projects\18xxxx\D181197_00_Lookout_Slough_Restoration_1\03_MXDs_Projects\02_Flood_Task_System_Hand\HF48_FCC_Q010_Vel_Impacts.mxd JPritchard 9/12/2019

Without-Project



With-Project



Project Impacts

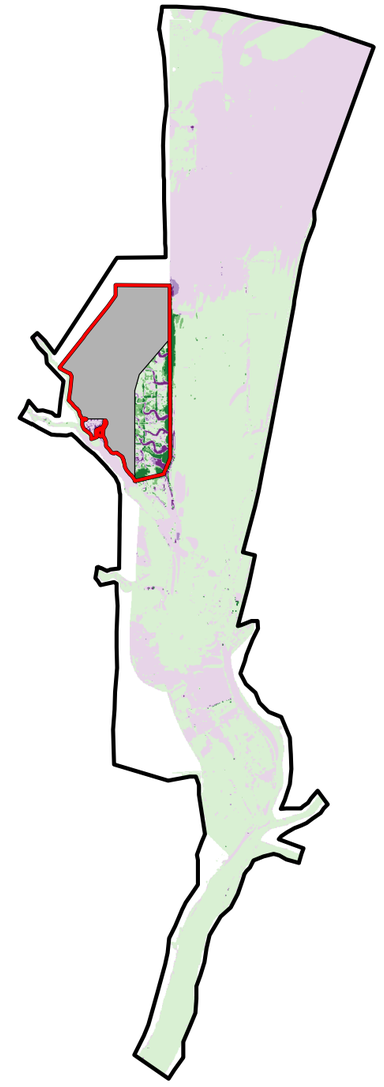


Figure 49
Future Cumulative Condition Performance 1% ACE (100-year) - Velocity

N
W E
S

0 15,000 30,000
Feet

Ecosystem Investment Partners

Prepared by: ESA

Map Prepared Date: 9/1/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

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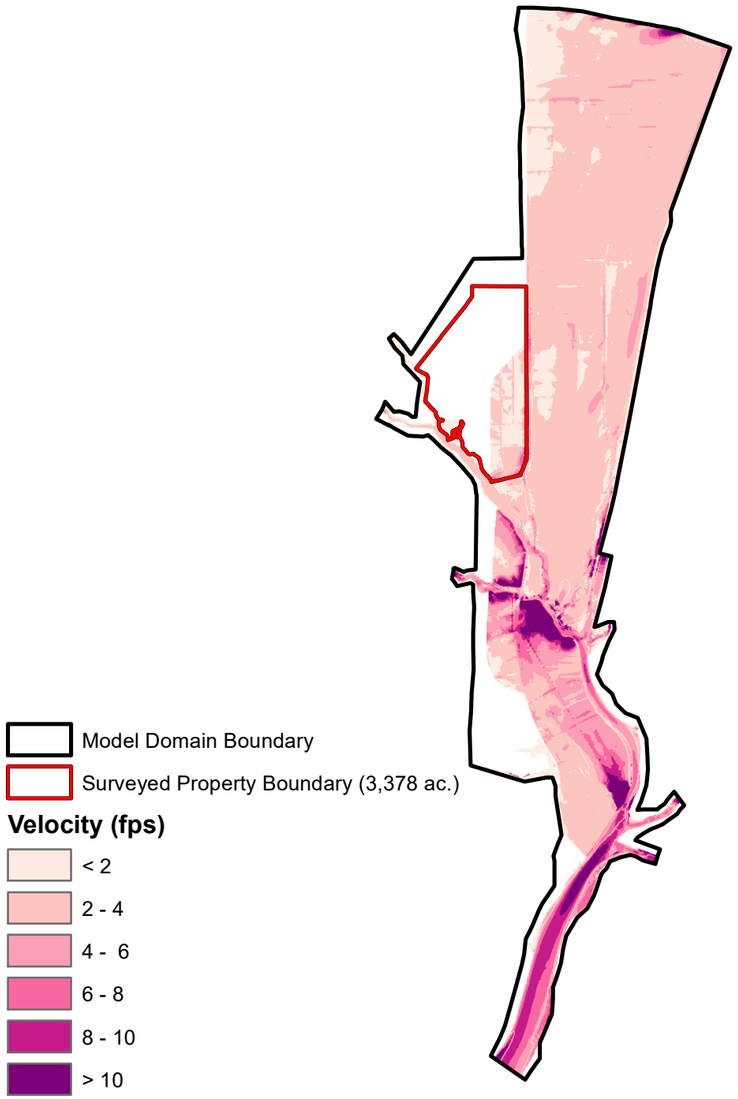

With-Project



Project Impacts

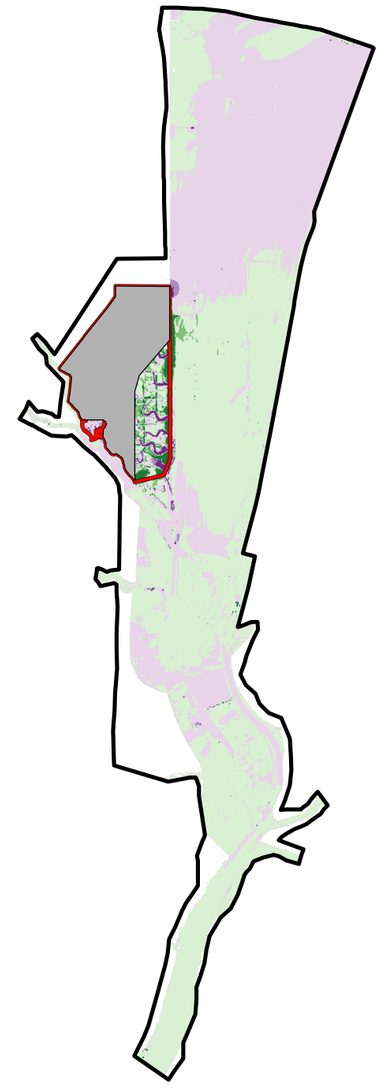

Figure 50
Future Cumulative Condition Performance 0.5% ACE (200-year) - Velocity

N
W E
S

0 15,000 30,000
Feet

Ecosystem Investment Partners

Map Prepared Date: 9/1/2019
Map Prepared By: JPritchard
Base Source: Wood Rodgers
Base Date: 10/24/2017
Data Source(s):

Prepared by: ESA

Lookout Slough Tidal Habitat Restoration and Flood Improvement Project

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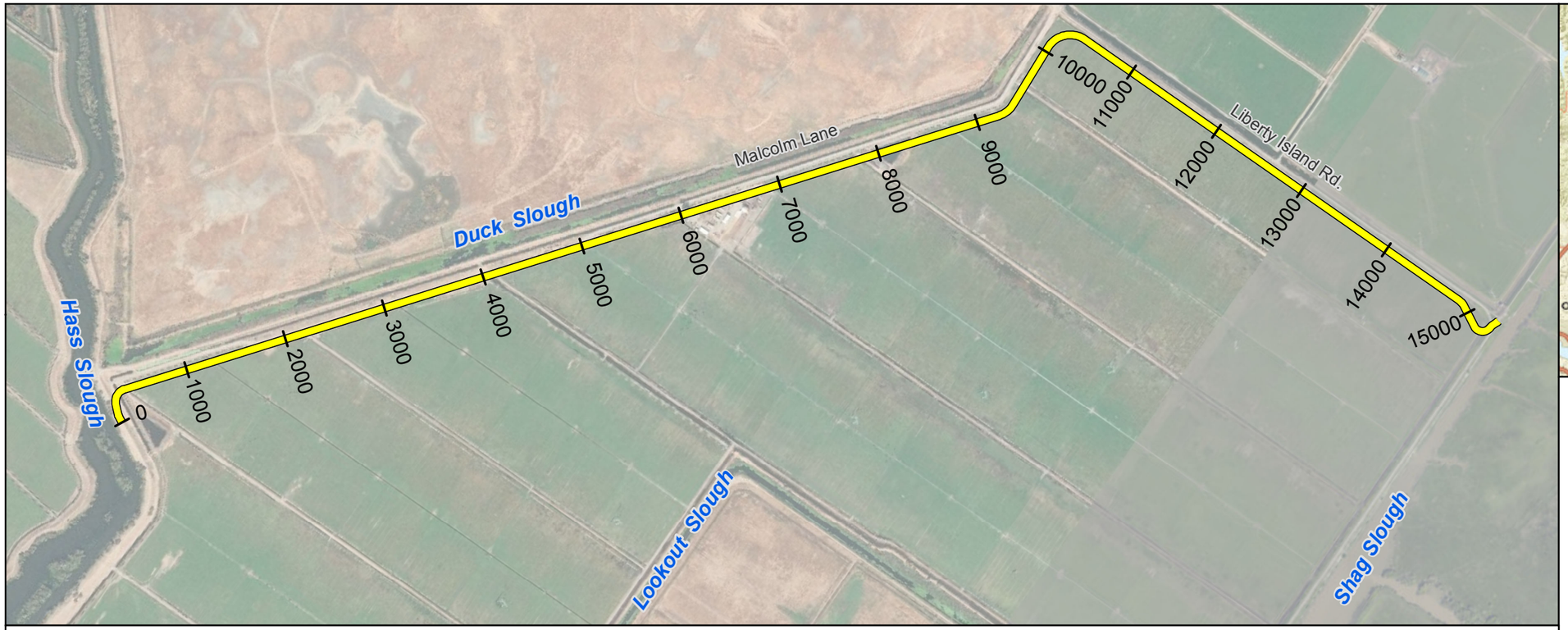

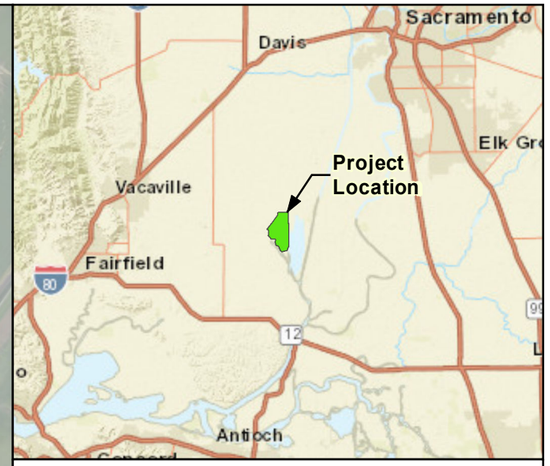

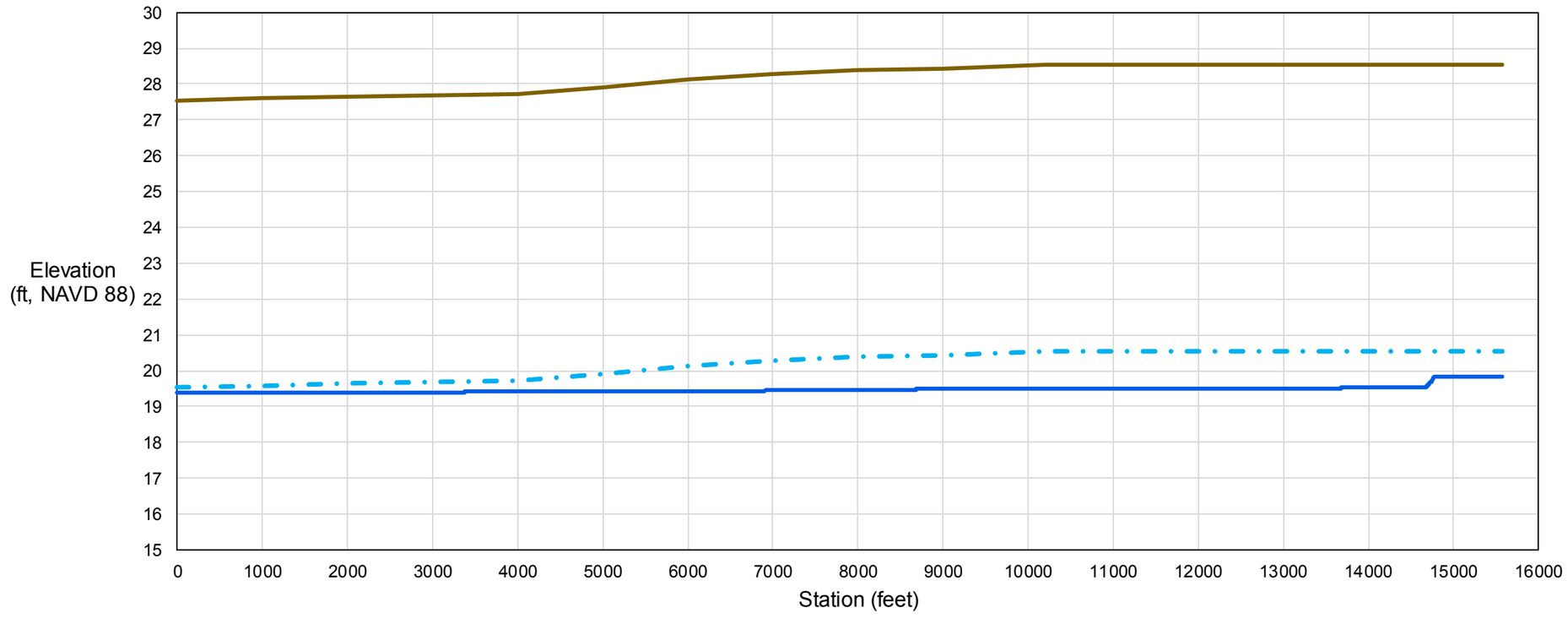

Ecosystem Investment Partners

LOOKOUT SLOUGH SETBACK LEVEE

ALTERNATIVE 17 OVERALL PROJECT EXHIBIT

SOLANO COUNTY, CALIFORNIA

AUGUST, 2019

NORTH

0 600 1,200 2,400

FEET

- Proposed Setback Levee Alignment
- Proposed Top of Levee
- 1% AEP (100-year) Baseline Condition with-Project Water Surface Elevation
- 1957 Authorized Design Water Surface Profile

PRELIMINARY

WOOD RODGERS

J:\3000-s\3487_Ecosystem_Invest_Partners\3487002 Lookout Slough Prelim Hydraulic Analysis\GIS\Tasks\20190807_DWSE_Exhibit\FXX_100YR_Design_WSE_Exhibit_20190807.mxd 8/7/2019 5:05:31 PM cmilligan

FIGURE 51

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Appendix A

Downstream Boundary Conditions Hydrology

TECHNICAL MEMORANDUM

TO: Mr. David Urban, P.E., Ecosystem Investment Partners

FROM: Mr. Mitch Berggren, EIT, Wood Rodgers, Inc.
Mr. Cody L. Milligan, P.E., CFM, Wood Rodgers, Inc.

DATE: February 28, 2019

SUBJECT: Lookout Slough Restoration Project North Delta Boundary Stage-Frequency Analysis

INTRODUCTION

Ecosystem Investment Partners (EIP) and the California Department of Water Resources (DWR) are in the process of creating more than 3,000 acres of habitat for listed and vulnerable native species as part of the Lookout Slough Restoration Project (Project). When completed, the Project will provide upland, tidal, subtidal, and floodplain habitat for Delta Smelt, Longfin Smelt, Steelhead Salmon, Splittail, Giant Garter Snake, and other species. In addition to the habitat created, the Project will create between 40,000 and 50,000 acre-feet of seasonal floodplain storage.

The Project is located west of the Yolo Bypass within the north Sacramento-San Joaquin Delta. Once constructed, the Project will be hydraulically connected to the Yolo Bypass and subject to a complex combination of seasonal flood flows and tidal hydrodynamic effects. Decisions related to design of the Project's flood control components are linked to protection levels associated with flood frequency. The Project design flow hydrology is based on information developed by DWR using data and tools developed as part of the Central Valley Hydrology Study (CVHS). Although dynamic tidal boundaries were previously developed by DWR for the 1% ACE (100-year) and 0.5% ACE (200-year) CVHS-based design floods using the RMA Delta Model, similar data was not readily available for the 10% ACE (10-year) design event. A stage-frequency analysis of stream gages located at the downstream boundaries of the regional HEC-RAS hydraulic system models will ensure that a statistically valid design water surface is used for the 10% ACE (10-year) event at the downstream end of the system and used to validate boundary conditions computed for other design frequencies.

PURPOSE

Regional HEC-RAS hydraulic models used to assist in the design of the Project contain three downstream stage boundaries:

1. Georgiana Slough at Mokelumne River
2. Threemile Slough at San Joaquin River
3. Sacramento River at Collinsville

The purpose of this Technical Memorandum is to document the data sources, methods, assumptions, and findings of the stage-frequency analysis conducted for gages at the locations listed above.

ANALYSIS

Modeling Tools

The United States Army Corps of Engineers (USACE) HEC-SSP software (version 2.1.1) was used to conduct the analysis. Annual peak stages for each water year were plotted on a semi-log chart using Weibull plotting positions. The Weibull equation is as follows:

$$P = \frac{M}{N+1}$$

Where:
P = exceedance probability
M = sequence rank
N = number of years in data set

Stage-frequency curves were then computed graphically to fit the data. As curves were extrapolated beyond available data, the peak stages were compared with levee heights at their respective locations to ensure that they did not exceed the height of the adjacent levee crown.

Available Data

The USACE conducted a stage-frequency analysis in 1992 for many gages in the Sacramento-San Joaquin Delta including the gages of interest for this analysis. This study included data between the date each gage was installed up to 1988. For the current analysis, annual maximum gage stages for water years prior to 1988 were taken from the USACE 1992 study. For water years after 1988, annual maximum gage stages were taken from the best available data. This included data from DWR's Water Data Library (WDL) and the California Data Exchange Center (CDEC).

Datum

The datum at all three gages analyzed has changed two or more times of during the period of record. Therefore, for the purposes of this analysis, all values were adjusted to the North American Vertical Datum of 1988 (NAVD 88). The values and methods used varied at each gage location and are discussed below.

Georgiana Slough at Mokelumne River

At this gage location, data from the USACE's 1992 study was available non-continuously for water years 1943 to 1988. Maximum gage stages for this time period were reported using the National Geodetic Vertical Datum of 1929 (NGVD 29). For water years subsequent to 1988, published data from WDL was used. Maximum gage stages for water years 1989 to 2006 were reported using gage datum. Metadata from the USACE's calibrated 1997 HEC-RAS model documents the conversion factors from NGVD 29 to NAVD 88 and from the gage datum to NAVD 88 and these values were used. The reported maximum gage stage was reported in NAVD 88 starting in water year 2007. **Figure 1** shows the results from HEC-SSP and **Table 1** shows the data source, datum, adjustment, and values used in the analysis for this gage.

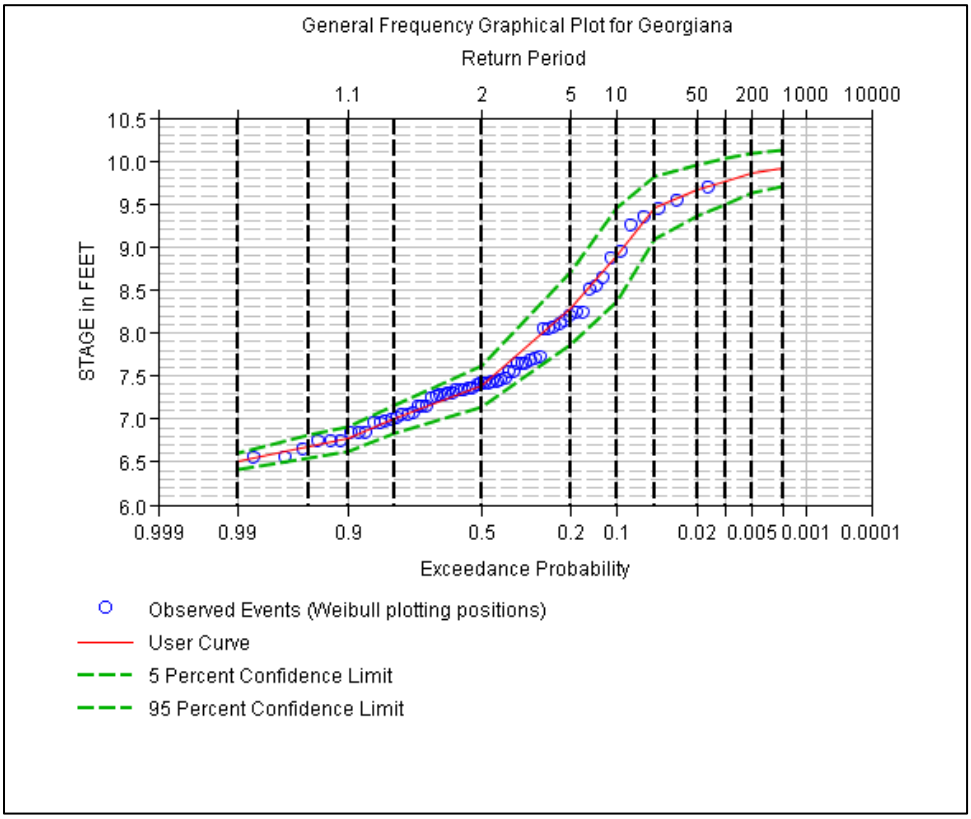

Figure 1 – Frequency plot for Georgiana Slough at Mokelumne River

Table 1 - Georgiana Slough at Mokelumne River Annual Maximum Gage Stages					
Water Year	**Peak Stage (ft)**	**Data Source**	**Datum**	**Correction (ft)**	**Peak Stage (ft, NAVD88)**
1943	4.30	USACE Report	NVGD29	2.54	6.84
1947	4.50	USACE Report	NVGD29	2.54	7.04
1948	4.30	USACE Report	NVGD29	2.54	6.84
1949	4.20	USACE Report	NVGD29	2.54	6.74
1950	4.20	USACE Report	NVGD29	2.54	6.74
1951	6.00	USACE Report	NVGD29	2.54	8.54
1952	5.60	USACE Report	NVGD29	2.54	8.14
1954	4.60	USACE Report	NVGD29	2.54	7.14
1955	4.40	USACE Report	NVGD29	2.54	6.94
1956	6.70	USACE Report	NVGD29	2.54	9.24
1957	4.50	USACE Report	NVGD29	2.54	7.04
1958	6.40	USACE Report	NVGD29	2.54	8.94
1959	4.80	USACE Report	NVGD29	2.54	7.34
1960	4.70	USACE Report	NVGD29	2.54	7.24
1961	4.20	USACE Report	NVGD29	2.54	6.74
1962	4.90	USACE Report	NVGD29	2.54	7.44
1963	5.10	USACE Report	NVGD29	2.54	7.64
1964	4.10	USACE Report	NVGD29	2.54	6.64
1965	5.50	USACE Report	NVGD29	2.54	8.04
1966	4.40	USACE Report	NVGD29	2.54	6.94
1974	5.00	USACE Report	NVGD29	2.54	7.54
1975	4.60	USACE Report	NVGD29	2.54	7.14
1976	4.00	USACE Report	NVGD29	2.54	6.54
1977	4.00	USACE Report	NVGD29	2.54	6.54
1978	5.10	USACE Report	NVGD29	2.54	7.64
1979	4.60	USACE Report	NVGD29	2.54	7.14
1980	6.10	USACE Report	NVGD29	2.54	8.64
1981	4.30	USACE Report	NVGD29	2.54	6.84
1982	5.50	USACE Report	NVGD29	2.54	8.04
1983	6.90	USACE Report	NVGD29	2.54	9.44
1984	5.70	USACE Report	NVGD29	2.54	8.24
1985	4.80	USACE Report	NVGD29	2.54	7.34
1986	7.00	USACE Report	NVGD29	2.54	9.54
1987	5.15	USACE Report	NVGD29	2.54	7.69
1988	5.00	USACE Report	NVGD29	2.54	7.54
1989	7.42	WDL	NVGD29 + 3.0 ft	-0.46	6.96
1990	7.75	WDL	NVGD29 + 3.0 ft	-0.46	7.29
1991	7.44	WDL	NVGD29 + 3.0 ft	-0.46	6.98
1992	7.87	WDL	NVGD29 + 3.0 ft	-0.46	7.41
1993	8.14	WDL	NVGD29 + 3.0 ft	-0.46	7.68
1994	7.74	WDL	NVGD29 + 3.0 ft	-0.46	7.28
1995	8.96	WDL	NVGD29 + 3.0 ft	-0.46	8.50
1996	8.10	WDL	NVGD29 + 3.0 ft	-0.46	7.64
1997	9.80	WDL	NVGD29 + 3.0 ft	-0.46	9.34

Table 1 - Georgiana Slough at Mokelumne River Annual Maximum Gage Stages					
Water Year	**Peak Stage (ft)**	**Data Source**	**Datum**	**Correction (ft)**	**Peak Stage (ft, NAVD88)**
1998	10.15	WDL	NVGD29 + 3.0 ft	-0.46	9.69
1999	7.89	WDL	NVGD29 + 3.0 ft	-0.46	7.43
2000	8.56	WDL	NVGD29 + 3.0 ft	-0.46	8.10
2001	7.47	WDL	NVGD29 + 3.0 ft	-0.46	7.01
2002	7.87	WDL	NVGD29 + 3.0 ft	-0.46	7.41
2003	8.65	WDL	NVGD29 + 3.0 ft	-0.46	8.19
2004	8.18	WDL	NVGD29 + 3.0 ft	-0.46	7.72
2005	8.51	WDL	NVGD29 + 3.0 ft	-0.46	8.05
2006	9.33	WDL	NVGD29 + 3.0 ft	-0.46	8.87
2007	7.25	WDL	NAVD88	0.00	7.25
2008	7.46	WDL	NAVD88	0.00	7.46
2009	7.35	WDL	NAVD88	0.00	7.35
2010	7.42	WDL	NAVD88	0.00	7.42
2011	8.24	WDL	NAVD88	0.00	8.24
2012	7.07	WDL	NAVD88	0.00	7.07
2013	7.38	WDL	NAVD88	0.00	7.38
2014	7.35	WDL	NAVD88	0.00	7.35
2015	7.34	WDL	NAVD88	0.00	7.34
2016	7.30	WDL	NAVD88	0.00	7.30
2017	7.41	WDL	NAVD88	0.00	7.41

Threemile Slough at San Joaquin River

At this gage location, data from the USACE's 1992 study was available non-continuously for water years 1939 to 1988. Maximum gage stages for this time period were reported using NGVD 29. For water years subsequent to 1988, published data from WDL was used. Maximum gage stages for water years 1989 to 2005 were reported using a gage datum. Metadata from the USACE's calibrated 1997 HEC-RAS model documents the conversion factors from NGVD 29 to NAVD 88 and from the gage datum to NAVD 88, and these values were used. The reported maximum gage stage was reported in NAVD 88 starting in water year 2006. **Figure 2** shows the results from HEC-SSP, and **Table 2** shows the data source, datum, adjustment, and values used in the analysis for this gage.

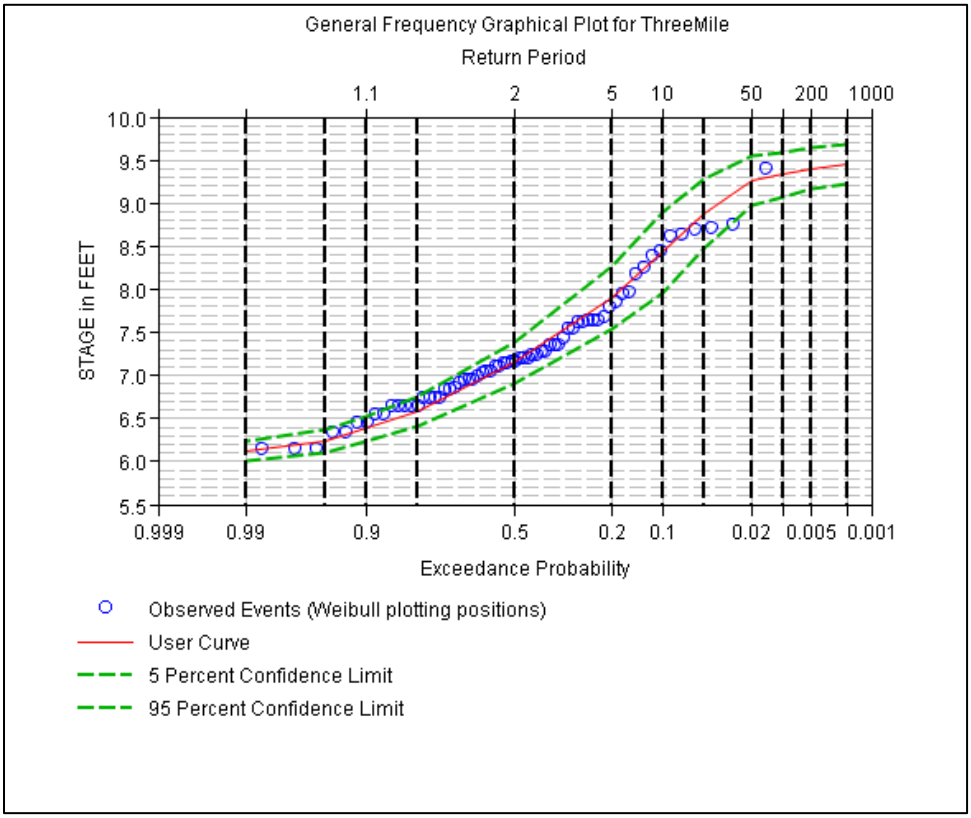

Figure 2 – Frequency plot for Threemile Slough at San Joaquin River

Table 2 - Threemile Slough at San Joaquin River Annual Maximum Gage Stages					
Water Year	**Peak Stage (ft)**	**Data Source**	**Datum**	**Correction (ft)**	**Peak Stage (ft, NAVD88)**
1939	4.30	USACE Report	NVGD29	2.34	6.64
1944	4.60	USACE Report	NVGD29	2.34	6.94
1945	4.40	USACE Report	NVGD29	2.34	6.74
1947	4.40	USACE Report	NVGD29	2.34	6.74
1948	4.40	USACE Report	NVGD29	2.34	6.74
1949	4.30	USACE Report	NVGD29	2.34	6.64
1950	4.90	USACE Report	NVGD29	2.34	7.24
1951	5.60	USACE Report	NVGD29	2.34	7.94
1952	5.30	USACE Report	NVGD29	2.34	7.64
1954	5.90	USACE Report	NVGD29	2.34	8.24
1955	4.30	USACE Report	NVGD29	2.34	6.64
1957	4.10	USACE Report	NVGD29	2.34	6.44
1960	4.50	USACE Report	NVGD29	2.34	6.84
1961	4.00	USACE Report	NVGD29	2.34	6.34
1962	4.60	USACE Report	NVGD29	2.34	6.94
1963	4.60	USACE Report	NVGD29	2.34	6.94
1964	4.10	USACE Report	NVGD29	2.34	6.44

Table 2 - Threemile Slough at San Joaquin River Annual Maximum Gage Stages					
Water Year	**Peak Stage (ft)**	**Data Source**	**Datum**	**Correction (ft)**	**Peak Stage (ft, NAVD88)**
1965	5.00	USACE Report	NVGD29	2.34	7.34
1966	4.30	USACE Report	NVGD29	2.34	6.64
1967	5.20	USACE Report	NVGD29	2.34	7.54
1968	4.20	USACE Report	NVGD29	2.34	6.54
1969	5.30	USACE Report	NVGD29	2.34	7.64
1970	5.00	USACE Report	NVGD29	2.34	7.34
1971	4.40	USACE Report	NVGD29	2.34	6.74
1972	3.80	USACE Report	NVGD29	2.34	6.14
1974	4.70	USACE Report	NVGD29	2.34	7.04
1975	4.30	USACE Report	NVGD29	2.34	6.64
1976	3.80	USACE Report	NVGD29	2.34	6.14
1977	3.80	USACE Report	NVGD29	2.34	6.14
1978	4.90	USACE Report	NVGD29	2.34	7.24
1979	4.20	USACE Report	NVGD29	2.34	6.54
1980	5.50	USACE Report	NVGD29	2.34	7.84
1981	4.00	USACE Report	NVGD29	2.34	6.34
1982	5.00	USACE Report	NVGD29	2.34	7.34
1983	6.30	USACE Report	NVGD29	2.34	8.64
1984	6.10	USACE Report	NVGD29	2.34	8.44
1985	4.50	USACE Report	NVGD29	2.34	6.84
1986	6.40	USACE Report	NVGD29	2.34	8.74
1987	4.70	USACE Report	NVGD29	2.34	7.04
1988	4.80	USACE Report	NVGD29	2.34	7.14
1989	7.85	WDL	NAVD88 + 0.66 ft	-0.66	7.19
1990	7.51	WDL	NAVD88 + 0.66 ft	-0.66	6.85
1991	7.94	WDL	NAVD88 + 0.66 ft	-0.66	7.28
1992	8.20	WDL	NAVD88 + 0.66 ft	-0.66	7.54
1993	7.81	WDL	NAVD88 + 0.66 ft	-0.66	7.15
1994	8.83	WDL	NAVD88 + 0.66 ft	-0.66	8.17
1995	8.09	WDL	NAVD88 + 0.66 ft	-0.66	7.43
1996	9.34	WDL	NAVD88 + 0.66 ft	-0.66	8.68
1997	10.06	WDL	NAVD88 + 0.66 ft	-0.66	9.40
1998	7.82	WDL	NAVD88 + 0.66 ft	-0.66	7.16
1999	9.05	WDL	NAVD88 + 0.66 ft	-0.66	8.39
2000	7.68	WDL	NAVD88 + 0.66 ft	-0.66	7.02
2001	8.33	WDL	NAVD88 + 0.66 ft	-0.66	7.67
2002	8.62	WDL	NAVD88 + 0.66 ft	-0.66	7.96
2003	8.30	WDL	NAVD88 + 0.66 ft	-0.66	7.64
2004	8.27	WDL	NAVD88 + 0.66 ft	-0.66	7.61
2005	9.28	WDL	NAVD88 + 0.66 ft	-0.66	8.62
2006	7.28	WDL	NAVD 88	0.00	7.28
2007	7.62	WDL	NAVD 88	0.00	7.62
2008	7.14	WDL	NAVD 88	0.00	7.14
2009	6.99	WDL	NAVD 88	0.00	6.99

Table 2 - Threemile Slough at San Joaquin River Annual Maximum Gage Stages					
Water Year	**Peak Stage (ft)**	**Data Source**	**Datum**	**Correction (ft)**	**Peak Stage (ft, NAVD88)**
2010	7.79	WDL	NAVD 88	0.00	7.79
2011	6.91	WDL	NAVD 88	0.00	6.91
2012	7.19	WDL	NAVD 88	0.00	7.19
2013	7.10	WDL	NAVD 88	0.00	7.10
2014	7.19	WDL	NAVD 88	0.00	7.19
2015	7.10	WDL	NAVD 88	0.00	7.10
2016	7.10	WDL	NAVD 88	0.00	7.10
2017	8.70	WDL	NAVD 88	0.00	8.70

Sacramento River at Collinsville

At this gage location, data from the USACE's 1992 study was available non-continuously for water years 1945 to 1988. Maximum gage stages for this time period were reported using NGVD 29. Gage data was unavailable for water years from 1989 to 2008. Beginning in water year 2009, gage data was available from CDEC. This data was downloaded and the maximum value was determined for each water year. Data flagged as "erroneous" or that had excessively high values (such as values above the top-of-levee) were excluded from the analysis. All gage data from CDEC was reported in NAVD 88. Metadata from the USACE's calibrated 1997 HEC-RAS model did not contain any information on a conversion factor from NGVD 29 to NAVD 88; thus, the National Oceanic and Atmospheric Administration's (NOAA) VERTCON program was used to convert from NGVD 29 to NAVD 88. **Figure 3** shows the results from HEC-SSP and **Table 3** shows the data source, datum, adjustment, and values used in the analysis for this gage.

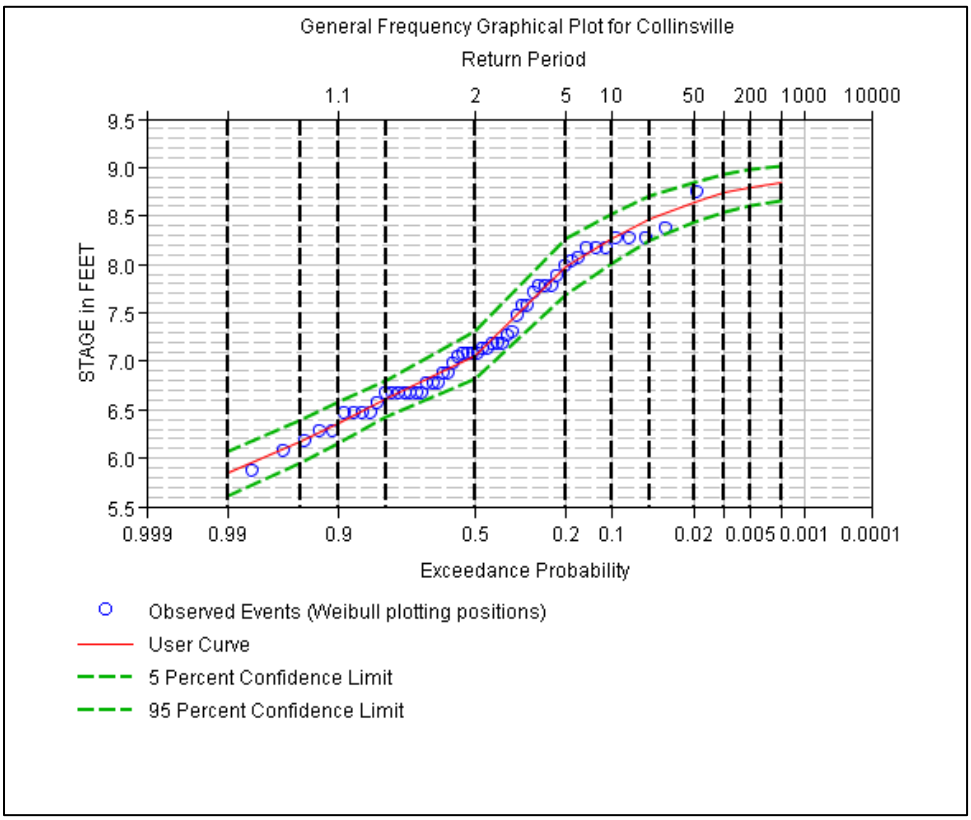

Figure 3 – Frequency Plot for Sacramento River at Collinsville

Table 3 - Collinsville at Sacramento River Annual Maximum Gage Stages					
Water Year	**Peak Stage (ft)**	**Data Source**	**Datum**	**Correction (ft)**	**Peak Stage (ft, NAVD88)**
1945	4.00	USACE Report	NVGD29	2.47	6.47
1946	4.40	USACE Report	NVGD29	2.47	6.87
1947	4.00	USACE Report	NVGD29	2.47	6.47
1948	4.30	USACE Report	NVGD29	2.47	6.77
1949	4.20	USACE Report	NVGD29	2.47	6.67
1950	5.70	USACE Report	NVGD29	2.47	8.17
1951	5.40	USACE Report	NVGD29	2.47	7.87
1952	5.70	USACE Report	NVGD29	2.47	8.17
1953	5.10	USACE Report	NVGD29	2.47	7.57
1954	4.30	USACE Report	NVGD29	2.47	6.77
1955	4.40	USACE Report	NVGD29	2.47	6.87
1956	5.80	USACE Report	NVGD29	2.47	8.27
1957	4.20	USACE Report	NVGD29	2.47	6.67
1958	5.70	USACE Report	NVGD29	2.47	8.17
1959	4.80	USACE Report	NVGD29	2.47	7.27
1960	4.20	USACE Report	NVGD29	2.47	6.67
1961	4.00	USACE Report	NVGD29	2.47	6.47
1962	4.20	USACE Report	NVGD29	2.47	6.67

Table 3 - Collinsville at Sacramento River Annual Maximum Gage Stages					
Water Year	**Peak Stage (ft)**	**Data Source**	**Datum**	**Correction (ft)**	**Peak Stage (ft, NAVD88)**
1963	4.70	USACE Report	NVGD29	2.47	7.17
1964	3.80	USACE Report	NVGD29	2.47	6.27
1965	5.30	USACE Report	NVGD29	2.47	7.77
1966	4.30	USACE Report	NVGD29	2.47	6.77
1967	5.10	USACE Report	NVGD29	2.47	7.57
1968	4.20	USACE Report	NVGD29	2.47	6.67
1969	5.30	USACE Report	NVGD29	2.47	7.77
1970	5.00	USACE Report	NVGD29	2.47	7.47
1971	4.50	USACE Report	NVGD29	2.47	6.97
1972	4.10	USACE Report	NVGD29	2.47	6.57
1973	5.80	USACE Report	NVGD29	2.47	8.27
1974	4.60	USACE Report	NVGD29	2.47	7.07
1975	4.00	USACE Report	NVGD29	2.47	6.47
1976	3.40	USACE Report	NVGD29	2.47	5.87
1977	3.60	USACE Report	NVGD29	2.47	6.07
1978	4.70	USACE Report	NVGD29	2.47	7.17
1979	3.80	USACE Report	NVGD29	2.47	6.27
1980	5.30	USACE Report	NVGD29	2.47	7.77
1981	3.70	USACE Report	NVGD29	2.47	6.17
1982	4.60	USACE Report	NVGD29	2.47	7.07
1983	5.90	USACE Report	NVGD29	2.47	8.37
1984	5.80	USACE Report	NVGD29	2.47	8.27
1985	4.20	USACE Report	NVGD29	2.47	6.67
1986	5.60	USACE Report	NVGD29	2.47	8.07
1987	4.20	USACE Report	NVGD29	2.47	6.67
1988	5.50	USACE Report	NVGD29	2.47	7.97
2009	8.03	CDEC	NAVD88	0.00	8.03
2010	7.07	CDEC	NAVD88	0.00	7.07
2011	7.70	CDEC	NAVD88	0.00	7.70
2012	7.13	CDEC	NAVD88	0.00	7.13
2013	7.18	CDEC	NAVD88	0.00	7.18
2014	7.13	CDEC	NAVD88	0.00	7.13
2015	7.08	CDEC	NAVD88	0.00	7.08
2016	7.04	CDEC	NAVD88	0.00	7.04
2017	8.75	CDEC	NAVD88	0.00	8.75

SUMMARY OF RESULTS

A summary of the results of this analysis for selected storm events are presented in **Table 4**.

Table 4 – Stage-Frequency Analysis Results			
Gage Location	**10% ACE (10-year) Peak Stage (ft, NAVD 88)**	**1% ACE (100-year) Peak Stage (ft, NAVD 88)**	**0.5% ACE (200-year) Peak Stage (ft, NAVD 88)**
Georgiana Slough at Mokelumne River	8.91	9.86	9.92
Threemile Slough at San Joaquin River	8.43	9.34	9.40
Collinsville at Sacramento River	8.27	8.74	8.79

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2. California Department of Water Resources, California Data Exchange Center website accessed from: http://cdec.water.ca.gov/
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5. United States Army Corps of Engineers. (2012). Common Features HEC-RAS Model

Appendix B

Bridge Form Loss Calculation Summary

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technical memorandum

date	September 1, 2019
to	Ecosystem Investment Partners, LLC
cc	
from	John Pritchard, PE, CFM
subject	Lookout Slough Tidal Habitat Restoration and Flood Improvement Project (D181197.00), SR 12 Bridge Crossing at Sacramento River near Rio Vista, TUFLOW modeling input summary

A TUFLOW HPC two-dimensional hydraulic model has been developed to support analysis of flood management alternatives and potential impacts associated with the Lookout Slough Tidal Habitat Restoration and Flood Improvement Project. The purpose of this document is to summarize the modeling approach used to simulate energy losses through the State Route 12 crossing the Sacramento River at Rio Vista (**Figure 1**). As shown on **Figure 2**, the existing structure is a moveable vertical-lift bridge, constructed in 1960 (Smith et al, 1960).

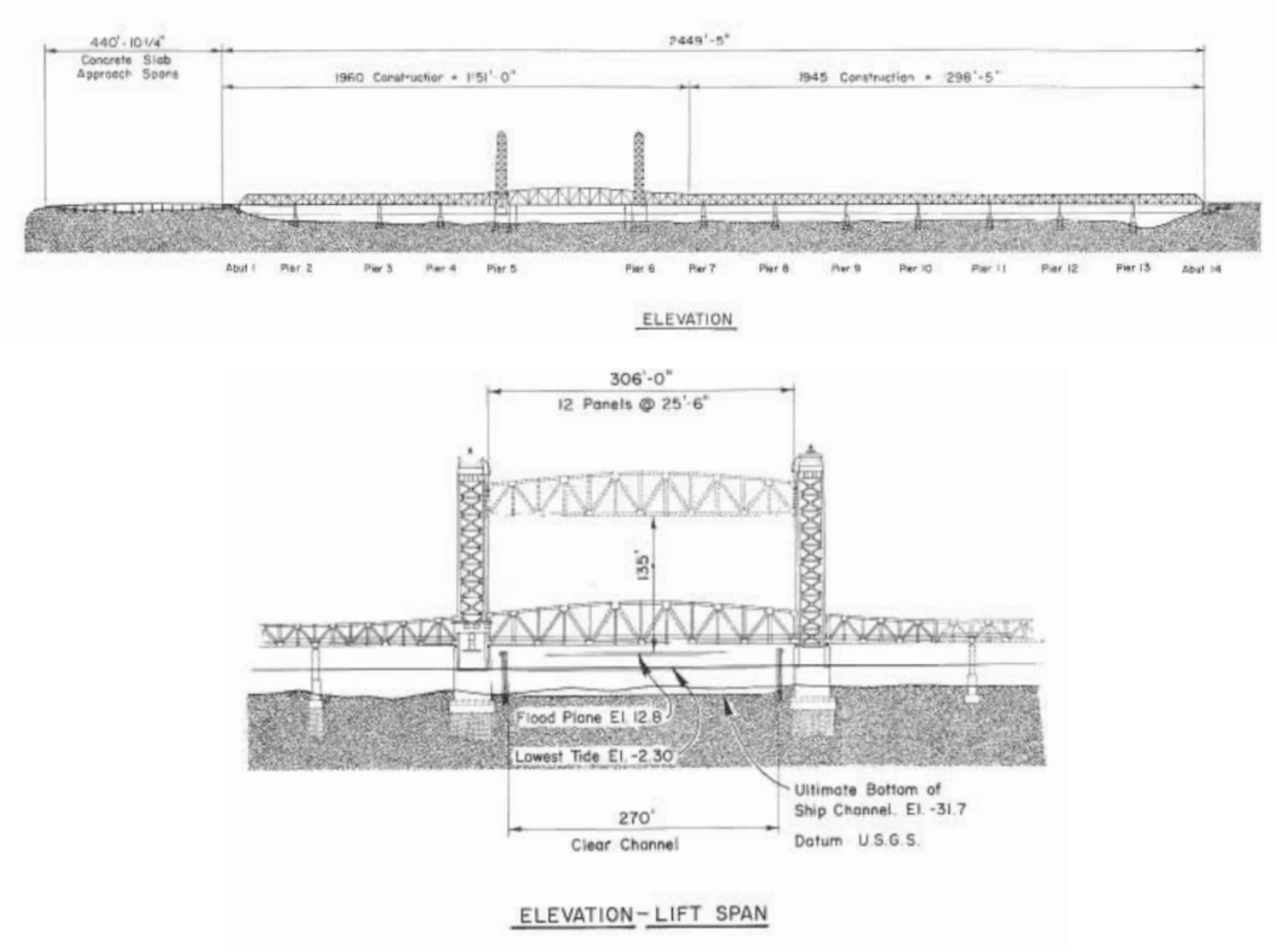
The hydraulic analysis supporting the Lookout Slough Restoration Project is investigating flood performance in the system for events up a 0.5% ACE (200-year) storm frequency. Based on review of existing one-dimensional modeling studies by DWR and the USACE (DWR, 2017 and USACE, 2014), the bridge will not be subject to pressure flow or overtopping during these conditions, and hydraulic analysis through the bridge can therefore be simplified to focus on form losses at the bridge piers and abutments. Drag forces from the piers are also anticipated to create 0.2 feet of head loss or less through the structure for the events being studied.

There are several approaches for modeling form losses at bridge piers in a two-dimensional hydraulic model, including disabling model grid elements, addition of pier drag forces (form losses), and increasing flow resistance (Manning's n) (FHWA, 2012). The authors of the TUFLOW software have examined several approaches, and recommend using the form loss approach in conjunction with procedures outlined in industry standard publications (WBM BMT, n.d.). For purposes of this study, the Federal Highway Administration (FHWA) *Hydraulic Design Series No. 1 – Hydraulics of Bridge Waterways* manual (FHWA, 1978) has been referenced for estimating losses at the bridge piers.



Source: Google Earth, 2019

Figure 1
Location Map



Source: Smith et al, 1960.

Figure 2
Bridge Cross-Sections Facing Downstream

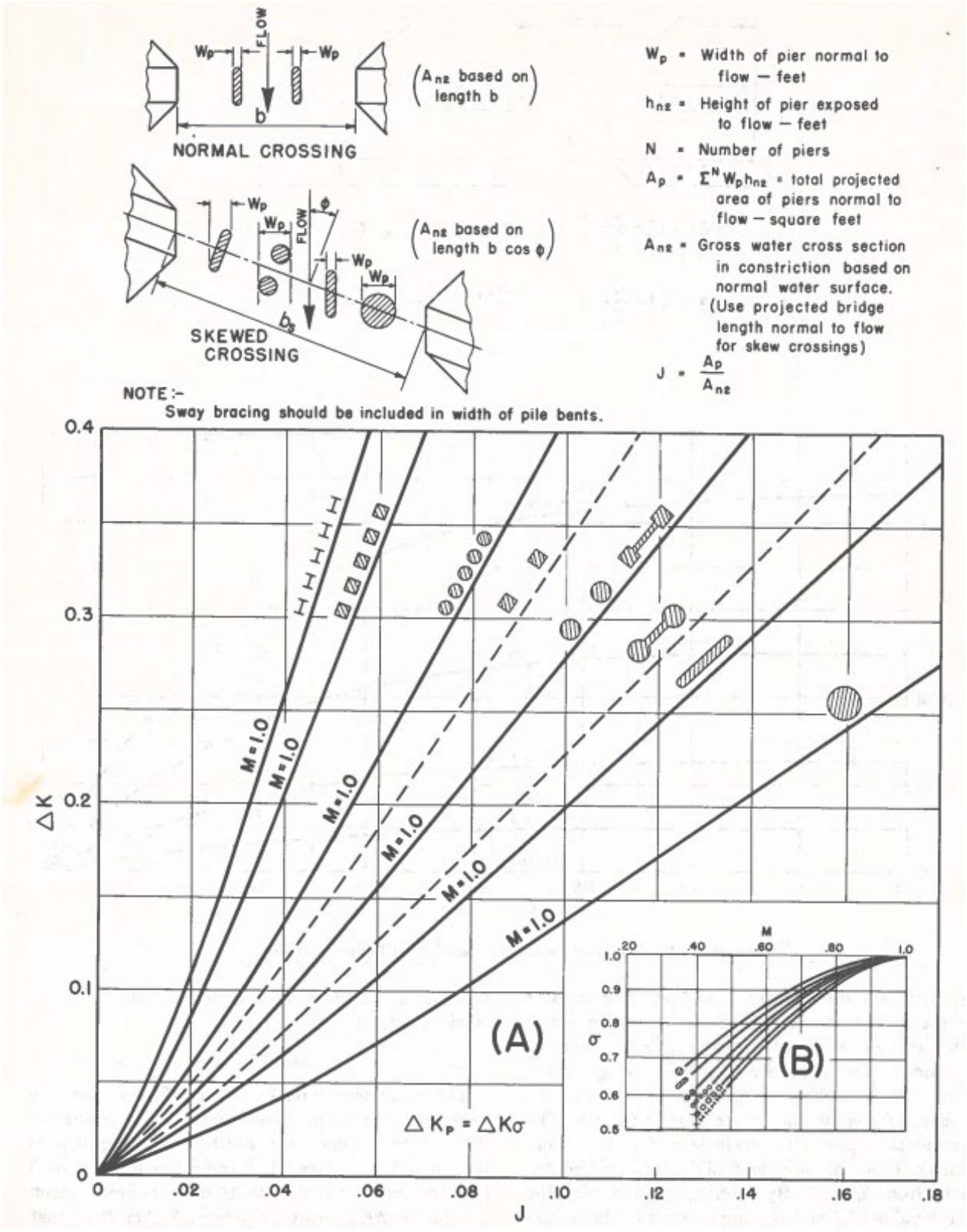
Given that the structure is several miles downstream of the Project, a detailed assessment of the local hydraulics at individual bridge piers is not required. Therefore, the bridge pier losses have been lumped together within a single flow constriction shape across the entire waterway, rather than entered individually at each pier location. This approach simplifies the geometric representation of the bridge and averages losses through the structure across the entire span of the bridge (more akin to a one-dimensional representation). This approach does replicate the anticipated losses through the bridge, and provides results that are consistent with other one-dimensional modeling methods.

Computation of form losses at bridge piers was performed using the incremental backwater approach for computing the effect of piers at normal crossings (FHWA, 1978). This approach computes a backwater coefficient ΔK_p, which is assigned to the form loss shape in the model input. To determine ΔK_p, a ratio of the blockage area of the piers to the gross water cross-section of the channel is computed (*J*). This value is then referenced against nomographs developed by FHWA which account for the pier shape (**Figure 3**) and the ratio (*M*) of the flow which can pass unimpeded through the bridge constriction to the total flow of the river. In this manner, bridge pier form losses can be computed individually, or applied as a weighted average of the blocked area across the entire span of the bridge.

A Microsoft Excel spreadsheet was developed to compute the blocked area of the piers based on regional one-dimensional HEC-RAS modeling geometry (**Figure 4**). The resultant *J* values were then computed and a weighted average ΔK_p value of 0.17 was determined for the entire structure (**Table 1**).

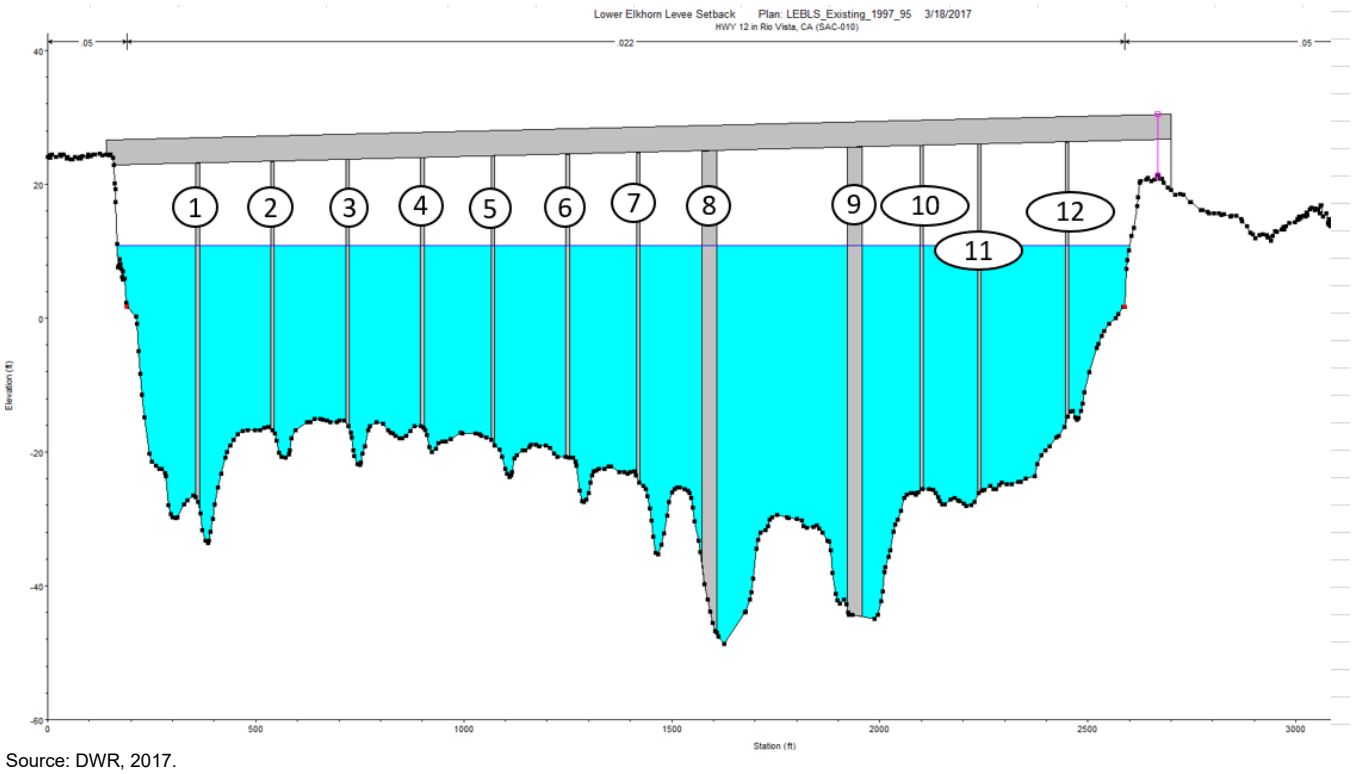
TABLE 1
BRIDGE PIER FORM LOSS CALCULATIONS

Pier Number	Width of Pier (feet)	Area of Pier Blockage, A_p (feet^2)	Gross Water Section, A_{n2} (feet)	J	ΔK_p
1	8.6	327	8,513	0.04	0.08
2	8.6	238	5,197	0.05	0.1
3	8.6	234	4,884	0.05	0.1
4	8.6	233	4,974	0.05	0.1
5	8.6	254	5,299	0.05	0.1
6	8.6	276	5,706	0.05	0.1
7	8.6	299	6,275	0.05	0.1
8	36	1942	12,379	0.16	0.34
9	36	2002	12,403	0.16	0.34
10	8.6	317	5,801	0.05	0.1
11	8.6	322	6,329	0.05	0.1
12	8.6	227	5,800	0.04	0.08



Source: FHWA, 1978.

Figure 3
Incremental Backwater Coefficient for Piers



Source: DWR, 2017.

Figure 4
DWR HEC-RAS Bridge Geometry at State Route 12

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