July 2014

West Sacramento General Reevaluation Report

US Army Corps of Engineers®
Sacramento District

WSAFCA
West Sacramento Area Flood Control Agency

Draft Report Documentation

Hydraulic Appendix

Cover Photo: Sacramento River, West Sacramento, and Yolo Bypass, March 2011
Photo courtesy of Chris Austin.

WEST SACRAMENTO PROJECT, CALIFORNIA
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TABLE OF CONTENTS

1 - STUDY DESCRIPTION 1-1
1.2 INTRODUCTION 1-1
1.2 LOCATION 1-1
1.3 TOPOGRAPHIC DATA 1-2
1.4 STUDY APPROACH 1-2
1.5 BASIS OF DESIGN 1-4
2 - PROJECT DESCRIPTION 2-1
2.1 PROJECT AREA LIMITS 2-1
2.2 WITH AND WITHOUT PROJECT CONDITIONS 2-2
3 - CHANNEL HYDRAULICS 3-1
3.1 BACKGROUND 3-1
3.2 HYDROLOGY 3-1
3.3 MODEL CALIBRATION 3-1
3.4 WATER SURFACE PROFILES 3-2
3.5 LEVEE BREACH ASSUMPTIONS 3-2
4 - ALTERNATIVE DEVELOPMENT 4-1
4.1 EVALUATION OF MEASURES 4-1
4.2 ALTERNATIVE 1: IMPROVE LEVEES IN PLACE 4-2
4.3 ALTERNATIVE 2: IMPROVE LEVEES IN PLACE AND WIDEN SACRAMENTO BYPASS 4-3
4.4 ALTERNATIVE 3: IMPROVE LEVEES IN PLACE AND DWSC CLOSURE STRUCTURE 4-4
4.5 ALTERNATIVE 4: IMPROVE LEVEES IN PLACE WITH WIDEN SACRAMENTO BYPASS AND DWSC CLOSURE STRUCTURE 4-4
4.6 ALTERNATIVE 5: IMPROVE LEVEES IN PLACE WITH SACRAMENTO RIVER SETBACK LEVEE 4-5
5 - FLOODPLAIN HYDRAULICS AND FLOODPLAIN DELINEATION 5-1
5.1 FLO-2D MODEL DEVELOPMENT 5-1
5.2 LEVEE BREACH HYDROGRAPH SENSITIVITY 5-2
5.3 WITH-PROJECT FLOODPLAINS 5-3
6 - RISK ANALYSIS 6-1
6.1 INDEX POINTS 6-1
6.2 STAGE-DISCHARGE FREQUENCY CURVES 6-2
6.3 UNCERTAINTY 6-2
6.4 FLOOD DAMAGE MODELING 6-2
6.5 PERFORMANCE EVALUATION 6-3

6.6 CONSIDERATIONS AND ASSUMPTIONS 6-4
6.7 FEMA CERTIFICATION/ACCREDITATION 6-4
6.8 SYSTEMS RISK AND UNCERTAINTY 6-5
7 - RESIDUAL RISK 7-1
7.1 SUPERIORITY 7-1
7.2 CLIMATE CHANGE – HYDROLOGY 7-1
7.3 SEA LEVEL RISE 7-3
7.4 INTERIOR DRAINAGE 7-6
7.5 LIFE SAFETY 7-6
8 - EROSION 8-1
8.1 OVERVIEW AND ASSUMPTIONS 8-1
8.2 EXISTING BANK EROSION CONDITIONS 8-1
8.3 SEDIMENT TRANSPORT 8-2
8.4 WIND-WAVE 8-2
8.5 BOAT WAVE EROSION 8-3
8.6 VEGETATION ANALYSIS (TREE SCOUR) 8-3
8.7 BRIDGE SCOUR 8-3
9 - REFERENCES 9-1

LIST OF TABLES

TABLE 1-1: WEST SACRAMENTO HYDRAULIC ANALYSES AND KEY ASSUMPTIONS 1-3
TABLE 4-1: LEVEE HEIGHT DEFICIENCY IN PROJECT AREA 4-3
TABLE 6-1: INDEX POINTS 6-1
TABLE 6-2: PERFORMANCE AT EACH INDEX POINT 6-4
TABLE 7-1: CLIMATE CHANGE DIFFERENCES FOR NORTHERN SIERRA NEVADA, WY 2049 7-2
TABLE 7-2: CHANGE IN FREQUENCY OF FLOWS WITH CLIMATE CHANGE AT AMERICAN RIVER FAIR OAKS 7-2
TABLE 7-3: CHANGE IN FREQUENCY OF FLOWS WITH CLIMATE CHANGE AT SACRAMENTO RIVER VERONA 7-3
TABLE 7-4: SUMMARY OF CALCULATED SEA LEVEL RISE VALUES AT SAN FRANCISCO GAGE 94114290 7-5
TABLE 7-5: SEA LEVEL RISE VALUES SEEN IN LITERATURE 7-5
TABLE 7-6: LIFE SAFETY AND LIFE LOSS INFORMATION FROM USACE'S LEVEE SCREENING TOOL 7-7
TABLE 8-2: NHC & URS COMBINED EROSION LOCATIONS 8-1

LIST OF FIGURES

Table 7-1: Climate Change Differences For Northern Sierra Nevada, WY 2049 2

LIST OF PLATES

Plate 1 Sacramento River Watershed

Plate 2 General Topographic Map

Plate 3 Sacramento River Flood Control System

Plate 4 Project Area Map

Plate 5 Index Points

Plate 6 Sacramento River (U/S of the American River) – Right Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition

Plate 7 Sacramento River (D/S of the American River) – Right Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition

Plate 8 Sacramento Bypass – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition

Plate 9 Yolo Bypass – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition

Plate 10 Sacramento DWSC – Left and Right Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition

Plate 11 Sacramento River (U/S of the American River) – Right Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives

Plate 12 Sacramento River (D/S of the American River) – Right Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives

Plate 13 Sacramento Bypass – Left Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives

Plate 14 Yolo Bypass – Right Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives

Plate 15 Sacramento DWSC – Left and Right Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives

Plate 16 Sacramento River (U/S of the American River) – Right Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives

Plate 17 Sacramento River (D/S of the American River) – Right Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives

Plate 18 Sacramento Bypass – Left Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives

Plate 19 Yolo Bypass – Right Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives

Plate 20 Sacramento DWSC – Left and Right Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives

Plate 21 Alternative 1

Plate 22 Alternative 2

Plate 23 Alternative 3

Plate 24 Alternative 4

Plate 25 Alternative 5

Plate 26 Floodplains – Index Point 1

Plate 27 Floodplains – Index Point 2

Plate 28 Floodplains – Index Point 3

Plate 29 Floodplains – Index Point 4

Plate 30 Floodplains – Index Point 5

Plate 31 Floodplains – Index Point 6

Plate 32 Floodplains – Index Point 7

Plate 33 Floodplains – Index Point 8

Plate 34 Risk Analysis Inputs – Index Point 1

Plate 35 Risk Analysis Inputs – Index Point 2

Plate 36 Risk Analysis Inputs – Index Point 3

Plate 37 Risk Analysis Inputs – Index Point 4

Plate 38 Risk Analysis Inputs – Index Point 5

Plate 39 Risk Analysis Inputs – Index Point 6

Plate 40 Risk Analysis Inputs – Index Point 7

Plate 41 Risk Analysis Inputs – Index Point 8

Plate 42 Locations of Wind Wave Risks

Technical Memorandums Supporting this Executive Summary Report

Memorandums are referred to in the text by the numbers shown below but are not included in this report. Copies are available on request.

1. Sacramento Basin HEC-RAS Phase I Model Development
2. Sacramento Basin HEC-RAS Phase II Model Development
3. Sutter Basin HEC-RAS Model Conversion
4. Datum Conversion of Hydraulic Models to NAVD88 Values
5. Downstream Boundary Conditions
6. Gages
7. Hydrologic Inputs (DSS files)
8. High-Water Marks
9. Hydraulic Uncertainty
10. Levee Breach Sensitivity
11. Climate Change Memo
12. Systems Risk and Uncertainty
13. Upstream Alternative Analysis
14. Calibration

1 - STUDY DESCRIPTION

1.1 INTRODUCTION

This executive report summarizes hydraulic analysis performed to support the West Sacramento GRR and has been prepared to meet the intention of the new USACE SMART Planning process – Specific, Measurable, Attainable, Risk-informed and Timely. This document references a collection of technical memorandums prepared for the American River Common Features (ARCF) GRR hydraulic analysis. Much of the hydraulic analysis for West Sacramento and ARCF studies is the same; the two projects are on adjacent sides of the Sacramento River and much of the analysis for both projects is based on the same hydraulic model. A complete list of the memorandums cited in this document follows the Table of Contents and are also located in the References section. To support streamlined documentation as part of SMART Planning, the memorandums are referenced but not included with this report. They can be provided on request.

Several significant factors justify a reevaluation of the West Sacramento Project at this time:

1. Since the last authorization of the West Sacramento Project, the scope and cost of levee improvements have increased.
2. New hydraulic modeling and geotechnical studies suggest potential issues with the levees along the Sacramento River, Yolo Bypass, Sacramento Bypass and Sacramento Deep Water Ship Channel. Specifically, the levees have shown evidence of through-seepage and underseepage that could lead to a failure. Such a failure could cause major flooding in the city of West Sacramento.

1.2 LOCATION

The West Sacramento GRR study area is located in eastern Yolo County in the north central region of California's Central Valley (see Plates 1 & 2 for watershed and topographic maps). The study area approximately corresponds with the city limit for the City of West Sacramento comprising 13,000 acres of mixed-use land and an estimated population of 44,000 residents. The City of West Sacramento is located directly across the Sacramento River from the City of Sacramento, the State's Capitol.

The study area is almost completely bound by floodways and levees (Plate 3). The study area is bound by the Yolo Bypass to the west, the Sacramento Bypass to the north, the Sacramento River to the east and a non-project levee called the South Cross Levee serves as a southern border. Further, the City of West Sacramento is divided by the Sacramento River Deep Water Ship Channel (DWSC) and Barge Canal. The associated levee system currently protecting the study area includes nearly 50 miles of levees in Reclamation District (RD) 900, RD 537, Maintenance Area 4, and along the DWSC and Barge Canal.

Flood control channels and other features in the West Sacramento area are part of a much larger flood control system known as the Sacramento River Flood Control Project (SRFCP). The SRFCP in the Sacramento Valley consists of a series of levees and bypasses, placed to protect urban and agricultural areas and take advantage of several natural overflow basins. See Plate 4 for a graphic depiction of the system layout. The SRFCP system includes levees along the Sacramento River south of Ord Ferry; levees along the lower portion of the Feather, Bear, and Yuba Rivers; and levees along the American River. The system benefits from three natural basins – Butte, Sutter, and Yolo. These basins run parallel to the

Sacramento River and receive excess flows from the Sacramento, Feather, and American rivers via natural overflow channels and constructed weirs. During floods, the three basins form one continuous waterway.

1.3 TOPOGRAPHIC DATA

Existing topography and bathymetry were used for most of the study's hydraulic modeling efforts. The topography for the HEC-RAS model was previously collected for the Sacramento River Bank Protection Project and the Sacramento San Joaquin Comprehensive Study (Comp Study) UNET model. More detailed descriptions of the hydrographic and topographic surveys completed are in documentation provided by Ayres Associates in support of the Comp Study (Ayres, 1998 & 2003).

The City of West Sacramento provided light detection and ranging (LiDAR) topographic data for the entire West Sacramento basin. The City of West Sacramento obtained the LiDAR from the Sacramento Area Council of Governments where:

> *"Merrick and Company flew a mapping mission from February 18, 2006 to April 19, 2006 to capture LIDAR surface data and aerial photography over 1052 square miles of SACOG project area. The topo area is approximately 89 square miles of 2 foot interval raw topo created from a 2 foot grid (DEM) with a gaussian smoothing filter of 30. The final output .tif files are 0.5 foot pixel resolution."*

All topographic data references the North American Vertical Datum of 1988 (NAVD88) and the North American Datum of 1983 (NAD83), projected in California State Plane Zone 2. The units are in feet. Several of the topographic datasets were created in different vertical datums and significant effort has been made to convert the topographic datasets and hydraulic models into the current standard vertical datum, NAVD88. See both the Technical Memorandum (USACE May2013c) on model datum conversion and the reference on the Comprehensive Study topography conversion (HJW Geospatial, 2010). Further details of the LIDAR survey conducted for this study can be found with the Sacramento Area Council of Governments (SACOG) GIS Department.

1.4 STUDY APPROACH

HEC-RAS (1-dimensional channel model) and FLO-2D (2-dimensional gridded model) hydraulic models were used to produce necessary outputs for the economic evaluation of the future without-project conditions and alternatives. The analysis used the same basic models that were developed and refined for the existing conditions (F3, July 2011). HEC-RAS was used to model the main flood control channels of the system to determine the water surface profiles and flood hydrographs into the floodplain areas. This HEC-RAS model includes much of the Sacramento River Basin. This was done to capture upstream and downstream influences to the project area as well as to eventually determine the potential project impacts to areas outside the project area.

Flood hydrographs generated in HEC-RAS from a levee break were input into FLO-2D for delineation of the floodplain. In order to generate flood damages for economic evaluations, floodplains were delineated for the 2-, 10-, 25-, 50-, 100-, 200-, and 500-year events. The analysis was limited to flooding within the basin from levee breaches and does not include localized flooding from rainfall-runoff.

Floodplain delineations presented in this study are based on a single levee break within a levee reach. The levee break location was determined by the most significant geotechnical concerns along that reach and by any overriding hydraulic concerns, such as low levee elevations or locations where a large amount of water could travel through the levee break and out into the floodplain. The resultant flood depths from FLO-2D and the stage-discharge-frequency curves derived from HEC-RAS outputs were used to perform the risk analysis for the future without-project condition and the alternatives.

This report presents a very specific and detailed analysis of the with- and without-project conditions for West Sacramento. In light of SMART Planning, some analyses typically found in a hydraulic appendix have been reduced to a sensitivity analysis or have been postponed to a later date and will likely be completed during design. The assumptions made to reduce the level of detail or postponed analyses until the design phase are captured in the Risk Register. These efforts are summarized below:

Efforts analyzed using sensitivity:
- Climate change
- Sea level rise

Efforts not expected to be completed at this time or in design:
- FEMA accreditation/certification
- Safe overtopping locations and evacuation plans
- Boat wave erosion

Efforts to be completed in design or during refinement of selected plan:
- Sedimentation engineering, fluvial geomorphology
- Channel stability, channel stabilization, bridge scour
- Bank projection, vegetation analysis (tree scour)
- Operation and maintenance

The key assumptions for each analysis are listed in Table 1-1.

Table 1-1: West Sacramento Hydraulic Analyses and Key Assumptions

ARCF HYDRAULIC DELIVERABLES	KEY ASSUMPTIONS
Evaluation of final alternatives for evaluation (HEC-RAS)	For alternative analysis, large cost measures screened out qualitatively. No locally preferred plan analyzed. Many features reduced and combined into final array of alternatives.
Alternative 5, setback levee	The Sacramento River setback levee is not included in the hydraulic model. It is assumed a setback levee will be hydraulically neutral.
With-project floodplain analysis (Flo-2D)	Used without-project floodplains to represent with-project. Rating curve in FDA input represents hydraulics of with-project conditions.
Hydraulic impacts (HEC-RAS)	The baseline for hydraulic impacts is based on future operation at Folsom Dam with all authorized features added (JFP Spillway, Dam Raise, target release 160k cfs).
Systems risk and uncertainty	HEC methodology used based on Risk Analysis of Modifications to SRFCP (HEC, 2009).
Climate change	Used same methodology as Sutter Feasibility Study, sensitivity analysis only (USACE, 2013b).

ARCF HYDRAULIC DELIVERABLES	KEY ASSUMPTIONS
Sea level rise	Used Information from recent study in the Delta and existing sensitivity analysis (Dynamic Solutions, 2011).
Superiority	No analysis was performed. Instead, ETL 1110-2-299 was used with bypasses serving as the overtopping locations along with using congressional legislation assumptions.
Vegetation variance	Deferred, will be part of erosion scoping, likely a HEC-18 analysis for tree scour.

1.5 BASIS OF DESIGN

The following is a partial list of USACE guidance used in the hydraulic analysis:

ER 1110-2-1150	Engineering and Design for Civil Works Projects
EC 1110-2-281	Requirements of River Hydraulics Studies
ER 1110-2-8153	Sedimentation Investigations
ER 1110-2-1405	Hydraulic Design for Local Flood Protection Projects
EC 1165-2-201	Ecosystem Restoration in the Civil Works Program
EM 1110-2-1416	River Hydraulics
EM 1110-2-1619	Risk-Based Analysis for Flood Damage Reduction Studies
EM 1110-2-4000	Sediment Investigations of Rivers and Reservoirs
EM 1110-2-1205	Environmental Engineering for Local Flood Control Channels
EM 1110-2-1601	Hydraulic Design of Flood Control Channels
ERDC/CHL TR-01-28	Hydraulic Design of Stream Restoration Projects
ETL 1110-2-299	Design of Overtopping of Levee
EC 1110-2-6067	USACE Levee Certification Guidance

2 - PROJECT DESCRIPTION

2.1 PROJECT AREA LIMITS

West Sacramento is divided into two sub-basins and shown in Plate 3. A description of the sub-basins and the levee reaches that comprise each includes the following:

Northern Sub-basin – The northern sub-basin, representing approximately 6,100 acres, is bounded by the DWSC to the south, the Sacramento River West Levee to the north and east, the Sacramento Bypass Levee to the north, and the Yolo Bypass Levee to the west. This area is traversed by the right bank of the Sacramento River from rivermile (RM)[1] 63.0 to RM 57.5.

- ***Sacramento River North Levee*** extends for approximately 5.5 miles along the Sacramento River right bank levee from the Sacramento Bypass south to the confluence of the Barge Canal and the Sacramento River.

- ***Sacramento Bypass Levee*** extends for approximately 1.1 miles along the Sacramento Bypass left bank levee from the Sacramento Weir west to the Yolo Bypass Levee.

- ***Yolo Bypass Levee*** extends for approximately 3.7 miles along the Yolo Bypass levee left bank from the confluence of the Sacramento Bypass and the Yolo Bypass south to the Navigation Levee (DWSC West).

Southern Sub-Basin – The Southern Sub-Basin encompasses approximately 6,900 acres and is bounded by the Port South Levee and the DWSC to the north, the Sacramento River West-South Levee to the east, the South Cross Levee to the south, and the DWSC East Levee to the west. The right bank of the Sacramento River extends from RM 57.5 to RM 51.5.

- ***Port South Levee*** extends for approximately 4 miles along the DWSC left bank levee from the Barge Canal west past the bend in the DWSC.

- ***Deep Water Ship Channel West Levee*** extends for approximately 21.4 miles along the DWSC right bank levee from the bend in the DWSC at the intersection of Port North Levee and Yolo Bypass Levee south to Miners Slough. The DWSC West levee protects West Sacramento from flood flows in the Yolo Bypass.

- ***Deep Water Ship Channel East Levee*** extends for approximately 2.8 miles along the DWSC left bank levee from the end of Port South Levee south to South Cross Levee.

- ***Sacramento River South Levee*** extends approximately 5.9 miles along the Sacramento River right bank levee from the confluence of the Barge Canal and the Sacramento River south to the South Cross Levee.

[1] River Mile (RM) refers to river miles from the Sacramento Basin HEC-RAS model and UNET Comp Study model.

- ***South Cross Levee*** extends along the South Cross levee for approximately 1.2 miles from Jefferson Boulevard to the Sacramento River where it intersects the southern end of Sacramento River West South Levee.

A majority of the levees within the study area are part of the SRFCP. The few exceptions are the Port South Levee, the DWSC West levee and the South Cross Levee. The Port South and DWSC West levees were constructed as part of the Port of Sacramento. The South Cross Levee is a private levee. Although the DWSC West levee was constructed as part of the navigation project supporting the Port of Sacramento, this levee provides significant flood benefits to portions of both the northern and southern sub-basins. During the large flood events, the water surface elevation in the Yolo Bypass can be more than 10-feet higher than the water surface elevation in the DWSC at the northern limit of the DWSC West levee. This difference in water surface elevation is still greater than 10-feet between these two water courses downstream near the South Cross Levee.

2.2 WITH AND WITHOUT PROJECT CONDITIONS

West Sacramento is in close proximity to two other federally authorized projects that will affect the flows and stages at West Sacramento. The American Rivers Common Features GRR includes repairing levees along the American River and the left bank of the Sacramento River adjacent to West Sacramento. The Joint Federal Project (JFP) includes improvements at Folsom Dam: construction of a new spillway, a new water control manual (reoperation of the dam utilizing the new spillway) and a Folsom Dam mini raise.

The future without-project condition includes all previously authorized constructed and unconstructed work on the American River, the new spillway being constructed at Folsom Dam, and the future planned raise of Folsom Dam. Any work beyond the future without-project condition, proposed under the West Sacramento GRR, is considered part of the with-project condition.

As part of the Sacramento Bank Protection Study (Sac Bank) a setback levee on the Sacramento River adjacent to the City of West Sacramento (River Mile 57.2) is currently being constructed. The Sac Bank hydraulic analysis (USACE, 2010e) determined there are no hydraulic impacts with a setback levee at this location. This setback levee is not included in the HEC-RAS future without project condition; however, since the setback levee will not change the hydraulics of the system, it will not affect the modeled results.

The major hydrologic/hydraulic difference between the without-project condition and the future without-project condition is that the peak flow on the American River is higher due to routing changes (for the 200-year event, without-project is 145,000 cfs and future without-project is 160,000 cfs).

3 - CHANNEL HYDRAULICS

3.1 BACKGROUND

This chapter documents continued HEC-RAS model development and calibration for the Sacramento River Basin river system in support of the West Sacramento GRR. HEC-RAS is a 1-D hydraulic model that can be run in steady or unsteady mode. The model for the Sacramento River Basin was generated from a combination of several previous modeling efforts, many of which modeled a portion of the Sacramento Basin.

A basin-wide UNET model was previously developed for the Sacramento Basin as part of the Sacramento and San Joaquin River Basins Comprehensive Study (Comp Study). As part of the F3, the entire model was converted from UNET to HEC-RAS, with the exception of the Butte Basin and the Sacramento River north of Colusa. All modeling is currently being done using HEC-RAS. Handoffs from the UNET model in the form of flow hydrographs were used as upstream boundary conditions for the HEC-RAS model. Details regarding development of the HEC-RAS model are contained in the Sacramento Basin HEC-RAS Phase I Development Technical Memorandum (USACE May 2013j).

The HEC-RAS model was further updated to include refinements of the Turning Basin of the Sacramento Deep Water Ship Channel (DWSC) and the South Cross Levee. The Turning Basin of the DWSC was updated with new bathymetry and LiDAR data (described in DWSC Technical Memorandum). Because of the importance of the Sacramento DWSC to the City of West Sacramento, the latest available topographic data was used to reduced the uncertainty of the hydraulic results. Also, the topography of the South Cross Levee was updated with LiDAR data; this corrected low spots that were a result of topographic error and error in extracting the data from limited points.

3.2 HYDROLOGY

There were no updates made to the existing hydrology used in the F3 analysis. For details regarding all hydrologic inputs, see the hydrology appendix. The executive summary and certification of district quality control (DQC) review for the hydrology analysis is included as Appendix A to this report.

3.3 MODEL CALIBRATION

The accuracy and quality of the hydraulic modeling results are limited by the availability of data used in the calibration. The Comp Study model was largely calibrated using gage data. For this phase of modeling the Sacramento Basin with HEC-RAS, high-water mark data was used more extensively than in the Comp Study modeling efforts. The Calibration Technical Memorandum (USACE, May 2013a) includes additional information on the calibration efforts.

The model was calibrated to the 1997 event. The calibration was complicated by the challenges of accurately representing breach flow through two levee failures during that event; however, the modeled water surface profiles reasonably matched measured highwater marks and gage data. The 1986 and 2006 events were considered for model validation. The 1986 flood could not be used for validation, however, because it lacked a complete set of data. The 2006 event was initially selected for model validation for two reasons: (1) there were no levee failures, even though it produced high stages within the Sacramento Flood Control System, and (2) results of the 2006 event, when compared to high-water mark data and gage data gathered at that time, could be used to test the results of the 1997 calibration. The 2006 was used first to validate the hydraulic model results, then it was also used as a second calibration because there were refinements mostly in terms of weir coefficients. This second calibration effort removes the independence of the model validation and there is not an additional flood event with enough hydrologic information to continue the model validation. However, the 2006 event has been reasonably reproduced and demonstrates the model's ability to reproduce results from multiple events.

Insomuch that calibration was done to both the 1997 and 2006 flood events, two separate model geometries had to be created to account for geometric changes to the system that could impact the hydraulics. The first geometry represents the state of the system leading up to the 1997 flood event. The second geometry represents the state of the system leading up to the 2006 flood event. The 2006 geometry is different because it includes the following physical features that were constructed after the 1997 flood event:

1) *Pump Station at the Natomas East Main Drain Canal (NEMDC) / Dry Creek Confluence*
2) *Setback levee at Shanghai Bend on the Feather River*
3) *Setback levee on the Bear River as it meets the Feather River*

Model result hydrographs were compared to gage records and peak stage data, where available, for the 1997 and 2006 flood events. The HEC-RAS model parameters for Manning's *n*, weir coefficients, and levee breaches were then adjusted as needed in an iterative procedure to modify the model results to more closely match the calibration data. The final modeled water surface profiles matched highwater marks, hydrograph peak stages and flows, and hydrograph shapes at numerous gages throughout the system reasonably well.

3.4 WATER SURFACE PROFILES

The HEC-RAS model was used to develop water surface profiles for all reaches surrounding the West Sacramento basin. A suite of seven *n*-year frequency profiles (2-, 10-, 25-, 50-, 100-, 200-, 500-year) is shown in Plates 6-10 for the future without-project condition (FWOP). The FWOP will serve as the baseline for alternative comparison.

The levees along the Sacramento River (upstream of American River), Sacramento Bypass and Yolo Bypass are high enough to contain the 200-year event (within the project area). As shown in Plate 7, the levee along the Sacramento River (downstream of the American River confluence) is high enough to contain the 100-year event flows but overtops the levee at two locations during a 200-year event.

There is a unique feature in the water surface profile on Plate 6. During large flood events, water from the American River flows upstream on the Sacramento River to the Sacramento Weir, where it discharges into the Sacramento Bypass (which connects to the Yolo Bypass). This creates a flat or decreasing water surface profile downstream of the Sacramento Weir (RM 64).

3.5 LEVEE BREACH ASSUMPTIONS

Levee breach model results are needed for input into the 2D floodplain routing model (FLO-2D) to delineate the corresponding floodplains. Several key levee breach assumptions are listed below:

- A levee breach width of 500 feet was used consistently in the models that support the West Sacramento GRR. Historical precedent shows that 1,000 feet (which the Corps has used on other studies in the Sacramento Basin) is an achievable breach width, but it is on the high end of all known widths. The 500-foot width was chosen as a more reasonable or average value.

- For each model run with a levee break, the trigger elevation for a levee break was set to 0.5 feet below the max water surface at the failure location.

- If the maximum water surface did not reach the toe of levee, it was assumed that the levee did not fail.

- The time for the breach to develop was set at 1 hour.

Several of these assumptions were evaluated with a sensitivity analysis and confirmed to not significantly impact the hydraulic results. The sensitivity analysis is discussed further in section 5.2 and the Levee Breach Sensitivity Technical Memorandum (USACE, May 2013h).

4 - ALTERNATIVE DEVELOPMENT

4.1 EVALUATION OF MEASURES

A wide range of features were evaluated to reduce flood risk in the project area. There are two main strategies to reduce this risk:

- Reduce the consequences of flooding by moving communities to higher ground out of the floodplain, floodproofing, land use changes, and/or other non-structural alternatives.

- Reduce the probability of inundation of structures. This is generally done in one of two ways:
  - Reduce the amount of flood water getting to and through the project area
  - Fortify and improve the current flood defense system

Reducing the consequences of flooding is addressed in the main feasibility report and the economic appendix. Reducing the probability of inundation is addressed starting here in Chapter 4, with additional information found in Chapters 5-7. Measures to reduce the probability of inundation by fortifying the existing flood defense system are described below, with additional information found in the geotechnical and civil design appendices.

From a hydraulic perspective, measures to reduce the probability of inundation generally fall into four categories: levee improvements, upstream transitory storage, diversions, and combinations of these features. Of these features, it was determined that the first increment would be some amount of levee improvement and this is the base for combining additional measures to become the alternatives. Based on preliminary analyses, the other measures did not show significant reductions in stage or flow, had the potential to create hydraulic impacts, or had very large real estate requirements. For purposes of the current study, the following measures were therefore removed from further consideration:

- Upstream storage on the American River
- Transitory storage on the Sacramento River
- Reoperation of upstream reservoirs
- Yolo Bypass improvements
- I Street diversion structure

Below is a list of alternatives developed by combining measures that were carried forward; these are described in greater detail in the following sections (4.2 - 4.6). These five alternatives are compared to the FWOP condition to determine the Tentatively Selected Plan (TSP).

- Alt 1: Improve levees in place
- Alt 2: Improve levees in place with the Sacramento Bypass widening
- Alt 3: Improve levees in place with DWSC closure structure
- Alt 4: Improve levees in place with Sacramento Bypass widening and DWSC closure structure
- Alt 5: Improve levees in place with South Sacramento River Setback

Plates 11-20 show the water surface elevations for alternatives 1-4 and the future without-project condition for both the 10-year and the 200-year events respectively. Profiles for all frequencies are available at request. To reduce the number of plates (for a shorter concise document to support SMART planning), the 10-year and 200-year are considered representative events for high and low frequencies. As shown in Plates 11-20, the water surface elevation profiles for alternatives 2 & 4 are the same and the water surface elevation profiles for alternatives 1 & 3 are the same (besides in the DWSC). Overall, the alternatives that include the Sacramento Bypass widening (Alternative 2 & 4) have lower stages in the Sacramento River and higher in the Yolo Bypass compared to alternatives that do not include the widening (Alternative 1 & 3).

After the hydraulic analysis was completed for alternatives 1-4, the PDT further screened out alternatives that included the Sacramento Bypass widening (alternatives 2 & 4). Since this decision was made after the analysis was complete, all alternatives are reported in this appendix.

4.2 ALTERNATIVE 1: IMPROVE LEVEES IN PLACE

Alternative 1 is to improve the existing levees that protect West Sacramento in place. This involves the construction of levee remediation measures to address deficiencies such as seepage, slope instability, overtopping, and erosion along the Sacramento River; the Sacramento Bypass; Yolo Bypass; the Sacramento DWSC; and the South Cross Levee. Plate 21 shows locations of levee deficiencies. This alternative combines construction of improvement measures while maintaining the present levee alignment in its existing location (fix in place). The stated purpose of this alternative would be to improve the flood damage reduction system to safely convey flows up to a level that maximizes net benefits.

The work in Alternative 1 primarily calls for fixes to levees that do not change in-channel geometry or characteristics; therefore, the hydraulics of the system does not change. As shown in Plates 16-20, the water surface elevation between the FWOP and Alternative 1 are the same for the 200-year event.

A crest elevation of the future without-project 200-year plus 3 feet was compared to the current top of levee. This assumption is based on both the local sponsor’s Urban Levee Design Criteria (DWR 2012) and the intent of the Folsom JFP to control releases up to a 200-Yr event. Levee raising was identified when the current top of levee fell below this profile. The typical amount of height needed is 1 to 2 feet. Table 4-1 shows the extent (length) of levee raising needed per reach. Levee raises will be evaluated as an increment and this assumption will likely need to be confirmed by the economic analysis during refinement of the Tentatively Selected Plan.

Table 4-1: Levee Height Deficiency in Project Area

HEIGHT DEFICIENCY TABLE			
RIVER	200-YEAR W.S. + 3'		
	UPSTREAM RM	DOWNSTREAM RM	LENGTH (FT)
Sacramento River	62.45	62.26	1003
Sacramento River	62.19	62.09	528
Sacramento River	60.63	60.35	1478
Sacramento River	60.02	59.96	317
Sacramento River	59.69	59.62	370
Sacramento River	59.25	58.77	2534
Sacramento River	58.64	58.56	422
Sacramento River	58.46	58.19	1426
Sacramento River	51.88	51.81	370
Sacramento River	51.67	51.5	898
Sacramento River	51.25	51.2	264
Sacramento River	51.14	50.29	4488
Sacramento River	50.07	50.03	211
Yolo Bypass	40.95	38.9	10824
Yolo Bypass	38.14	37.13	5333
Yolo Bypass	36.93	34.49	12883
South Cross Levee	0.98	0	5174
Port South Levee	44.5	43.99	2693
Port North	44.5	42.95	8184

4.3 ALTERNATIVE 2: IMPROVE LEVEES IN PLACE AND WIDEN SACRAMENTO BYPASS

Alternative 2 starts with Alternative 1 (improve levees in place) as a base and adds the widening of the Sacramento Bypass/Weir, as shown in Plate 22. The purpose of this alternative is to redirect more water from the Sacramento River to the Yolo Bypass and thereby reduce the extent of levee repairs required along the Sacramento River downstream of the American River confluence. Currently, the Sacramento Weir is 1,920 feet wide with 48 wooden gates that are manually removed when the water surface elevation on the Sacramento River at the I Street gage reaches 30.0 feet (NAVD 88). If the Sacramento Bypass were widened, it would allow more water to flow into it and, therefore, into the Yolo Bypass. This would lower the water surface elevation on the Sacramento River downstream of the confluence with the American River and subsequently reduce the need for levee raising along the Sacramento River.

The widening of the Sacramento Bypass and Weir was analyzed using the HEC-RAS model and expanding the weir width in increments from 500 feet to 3,000 feet to the north. Each width variation included adding gates (identical to the ones already in place) to the new portion of the weir and widening the bypass to the north. Widening the bypass/weir by 1,500 feet was found to be optimal. With this alternative the stages at the downstream portion of West Sacramento (near the Pocket) would be reduced by a foot (compared to the FWOP condition).

4.4 ALTERNATIVE 3: IMPROVE LEVEES IN PLACE AND DWSC CLOSURE STRUCTURE

Alternative 3 starts with Alternative 1 (improve levees in place) as a base and adds construction of a closure structure in the DWSC (Plate 23). The purpose of this alternative is to reduce the stage in the DWSC (upstream of the closure structure) and within the Port of West Sacramento. The closure structure prevents flood flows from reaching the upper portion of the DWSC and eliminates the need for levee raising along the north and south Port levees. Also, a closure structure reduces the need to improve the DWSC east levee (downstream of the closure structure) and the DWSC west levee (upstream of the closure structure).

The operation of the closure structure and the resultant change in stages in the DWSC has not been analyzed with a hydraulic model. However, since the DWSC does not convey flood flows and is connected to the Yolo Bypass 15 miles downstream of the project area, it is assumed the water surface elevations in the project area (Sacramento River, Sacramento Bypass and Yolo Bypass) will not change with the addition of a closure structure on DWSC.

The gate operation of the closure structure could be dependent on a number of conditions within the study area. The timing of when the gates of the closure structure start to close may be based on one of the following:

- Stages in the Yolo Bypass at the Lisbon Gage. Once a target stage (not yet determined) is reached at the Lisbon gage (located in the Yolo Bypass approximately 2 miles south of the South Cross Levee), the gates of the closure structure would begin to close.
- Operation of the Sacramento Weir. The gates of the closure structure would begin to close based on conditions at the Sacramento Weir (when Sacramento Weir is opened and/or how many gates are opened).
- Stages at the Port of Sacramento. When the stage at the Port of Sacramento reaches 15 feet (NAVD 88), the gates would begin to close. It is assumed by the time the gates are closed, the water surface elevation in the DWSC (upstream of the closure structure) will remain at 16 feet (NAVD88). This is assumed to be a non-damaging stage; it is the same elevation as the landside levee toe at the Port of Sacramento.

The operation of the DWSC closure structure will be further refined with the selection of the TSP. For the purposes of this analysis, operation of the closure structure was assumed to be dependent on the stage at the Port of Sacramento. Based on this assumption, the gates are closed between the 10 year and 25 year events and the stage in the DWSC (upstream of the closure structure) is held constant at 16 feet (NAVD 88).

4.5 ALTERNATIVE 4: IMPROVE LEVEES IN PLACE WITH WIDEN SACRAMENTO BYPASS AND DWSC CLOSURE STRUCTURE

Alternative 4 includes improving the levees protecting West Sacramento (described in Alternative 1); widening the Sacramento Bypass by 1500 feet to allow more flood flows to enter the Yolo Bypass and reduce flows in Sacramento River downstream of the American River confluence (described in Alternative 2); and constructing a closure structure along the DWSC to reduce flood flows in the Port of West Sacramento and reduce levee improvements along the DWSC and the port levees (described in Alternative 3). Alternative 4 is shown in Plate 24.

4.6 ALTERNATIVE 5: IMPROVE LEVEES IN PLACE WITH SACRAMENTO RIVER SETBACK LEVEE

Alternative 5 includes improving levees in place plus a setback levee along the Sacramento River, shown in Plate 25. The setback levee is based on the local sponsor's design submitted as part of the 408 application. The proposed setback levee starts at river mile 56.75 and extends 4.25 miles south with a typical offset distance of approximately 400 feet between the setback levee from the existing levee.

The applicant has completed a hydraulic analysis with the setback levee as part of the 408 submittal. Based on this analysis, there is a slight increase in stage downstream of the setback at the Pocket (0.13 foot and 0.17 foot rise for the 100-year and 200-year, respectively). These results can be used for an initial determination of hydraulic impacts.

Due to time constraints, a setback levee has not been included in the hydraulic model used for the feasibility study and no stage information is available for direct comparisons of alternatives. If the setback levee is selected as the TSP, the design will be further refined to ensure that the hydraulic impacts are considered to be below an acceptable threshold.

For purposes of SMART planning, the 408 hydraulic analysis is considered appropriate to use for evaluation of this alternative. A slight change in stage is not expected to impact the economic analysis because it is assumed the Expected Annual Damages (EAD) is not sensitive to small stage increases for less frequent events.

5 - FLOODPLAIN HYDRAULICS AND FLOODPLAIN DELINEATION

5.1 FLO-2D MODEL DEVELOPMENT

Floodplain mapping was delineated using FLO-2D, a 2-dimensional, finite-difference flood routing model that used breach hydrographs generated from HEC-RAS model runs simulating failures at the Sacramento Bypass, Sacramento River, Yolo Bypass and Sacramento DWSC. An existing calibrated HEC-RAS model of the Sacramento and American River system (described in Chapter 3) was used to develop breach hydrographs at all seven frequencies (2-, 10-, 25-, 50-, 100-, 200-, 500-year) at each breach location. The F3 Hydraulic Technical Documentation (USACE, 2011a) provides detailed information on the FLO-2D model development. Plates 26-33 show the resulting without project floodplains for all eight index locations.

For West Sacramento, the basin acts much like a bathtub. As a breach occurs, floodwaters are contained by the surrounding levees and the area fills up. The West Sacramento Basin is generally not impacted by roadways and other obstructions in modeling large flood events such as a levee breach. Rainfall and interior flooding are also considered insignificant compared to the volume that would be achieved with a levee breach, and therefore were not considered in the development of the with- and without-project floodplains used in the economic analysis.

The following key assumptions were used in the development of the West Sacramento floodplain FLO-2D model:

- **Grid element size: 400 feet.** The goal was to optimize the grid size to ensure reasonable run times while retaining the ability to adequately define floodplain features.

- **Study origin (top left) point: X = 6,676,317 and Y = 1,984,490.** Using a common study origin point allows for different grid systems to be based on the same grid spacing. Models can be merged and enlarged as needed.

- **Grid element elevation based on the FLO-2D Grid Developer System (GDS) interpolation routine with the high and low outlier elevations determined based on the standard deviation difference filtering scheme.** Due to the large amount of point data available from the LiDAR data, the filtering scheme ensures that any low or high outlier points do not unduly influence the final grid elevation.

- **No streets modeled.** Streets are typically used for modeling interior drainage and are not used for riverine flood delineation, especially given the significant volume of water that would overwhelm the streets in the study area.

- **No rainfall on the floodplain modeled.** No information was available to determine the concurrent rainfall events that would occur for the flood events modeled; therefore, a clear sky was assumed at the time of the levee breakouts.

- **Soundwalls along freeways are not modeled.** Soundwalls are not built to the same structural integrity as an engineered floodwall, and it is assumed that the soundwalls would not hold more than 2 to 3 feet of water at a maximum. In most areas having soundwalls, the road embankments are 2 to 3 feet, eliminating the need to separately model the soundwalls.

- **Infiltration was not modeled in the FLO-2D models.** This was due to a number of factors including (1) the short duration of the of the initial breakout flow hydrographs, (2) the urban nature of the primary floodplain with limited potential infiltration area, and (3) the probable saturation of the ground from the storm event and preceding storm events, creating a very low to no initial infiltration potential. While any infiltration that does occur will have a noticeable effect on the final floodplain extent and depth (as accounted for in the dewatering analysis), it would not noticeably affect the maximum extent and floodplain depths, which are the focus of this analysis.

- **Existing interior pump stations and discharge points to the DWSC are assumed to be inoperable.** This is partially based on lessons learned from New Orleans during Hurricane Katrina, including such causes as high stages in the respective rivers, direct and backup power failures, submerged equipment damage, etc. that occur when pump stations are overwhelmed and flooded.

5.2 LEVEE BREACH HYDROGRAPH SENSITIVITY

Levee breach conditions in the HEC-RAS model are dependent on many parameters. A sensitivity analysis was performed for the Common Features GRR to determine how a breach hydrograph is impacted by selection of levee breach elevation, timing of breach, breach formation duration and breach width. A point on the American River South Basin (American RM 4) was used for this analysis, which is documented in the Levee Breach Sensitivity Technical Memorandum (USACE, May 2013h).

The changes in peak river stage, peak river flow and breach hydrograph volume were used to evaluate the sensitivity of the selected breach parameters at both the 25-year and 200-year events. Of the three variables, volume is seen as having the greatest impact for floodplain extents and depths. The same levee breach assumptions described in Section 3.5 were used for each levee break scenario (at each index point for each the seven frequencies.)

General trends were observed and are noted below, though caution must be used in drawing specific conclusions from the results found in Levee Breach Sensitivity Technical Memorandum.

- Floodplains are not sensitive to changes in levee breach elevations, but are sensitive to the timing of the hydrograph of the flood event.

- Floodplains are not sensitive to breach formation duration, based on testing done for the Sutter County Feasibility Study.

- Floodplains are sensitive to breach width during frequent flood events (25-yr) but not infrequent flood events (200-yr). However, many Sacramento Corps feasibility studies generally use infrequent flood events (such as the 100-yr event) based on historical levee breach information.

It is also important to have consistent breach widths (500 ft) for the full sweep of frequency flood events, so the same breach width was used for frequent and infrequent flood events.

- Floodplains are sensitive to the timing of the breach, particularly when the levee breaches after the peak flow during a flood event (on the receding limb of the river hydrograph). When the breach occurs at the end of a flood event, a smaller floodplain occurs because the amount of water conveyed into the floodplain decreases. The sensitivity to the breach timing is independent of the flood frequency because much of the volume of water in the flood event has already passed by the levee breach location. Thus, even though this parameter affects the floodplain volume, assuming a breach on the receding limb of the hydrograph results in a smaller floodplain extent, and is not considered the most likely condition. Breach formation was therefore assumed to occur on the rising limb of the hydrograph to reflect the most likely flooding condition in each damage area.

The conclusion from this sensitivity analysis is that, for the purposes of the feasibility study, the assumptions used for the levee breaches are appropriate for use in the economic analysis.

5.3 WITH-PROJECT FLOODPLAINS

The hydraulics of the West Sacramento Basin does not significantly change with the proposed alternatives; instead, the with project levee repairs (a component to all alternatives) reduces the chance of levee failure (or breaching). Therefore, the same floodplains are used for with and without project conditions and the chance of failure is represented in the levee fragility curves.
For alternatives 1 & 3, there are no proposed changes to the footprint of the existing channel system; the breach hydrographs and floodplains at each of the index points will be the same as the without project condition.

For alternative 2 & 4, the hydraulics of the system will change as more water is conveyed down the Sacramento and Yolo Bypasses and less water flows down the Sacramento River (downstream of the American River confluence). The difference in water surface elevation between the future without project condition and alternatives 2 & 4 on the Sacramento River and Yolo Bypass is approximately 1 and 0.2 feet, respectively.

Using SMART planning, it is assumed appropriate to use without project floodplains for alternative 2 & 4 for the following reasons:

- The rating curves in FDA do represent the hydraulics for alternatives 2 & 4.
- The levees in the project area will be improved and the chance of failure is significantly reduced. For all index points, the with-project fragility curves show a 1-7% chance of failure at the 50 year event. Therefore FDA will rarely utilize floodplains for the 2-50 year events.
- West Sacramento is a closed basin; when a levee breach occurs, the basin fills like a bathtub. Flood waters can be significantly deep as portions of the basin are below sea level. After the basin is filled with 4-5 feet of flooding (as represented by the 50 year floodplain), the damages calculated in FDA do not significantly change with additional depth of flooding.
- This is a conservative approach in calculating with project damages.

6 - RISK ANALYSIS

Inputs were generated for risk analysis from the hydraulic modeling. The Hydrologic Engineering Center's Flood Damage Assessment modeling software (HEC-FDA) is the principal tool used by the Corps to calculate flood damage risks. The HEC-FDA model performs Monte Carlo random sampling of the discharge-frequency, stage-discharge, stage-probability of failure, and damage-stage relationships and their respective uncertainty distributions. The primary outputs of HEC-FDA are expected annual damage (EAD) and project performance statistics. Project performance statistics include the annual exceedance probability (AEP, or the expected annual probability of flooding in any given year), the long-term risk of flooding over a 10-, 25-, or 50-year period, and the conditional non-exceedance probability (CNP) for specific events (the probability of passing specific flood events).

Recent guidance has come out that provides a means for more explicitly performing a risk analysis in a system setting such as the Sacramento River (HEC, 2009). Some processes derived from this new guidance were implemented in generating inputs for the HEC-FDA analyses. The guidance was based upon a demonstration project using the Sacramento River system and an earlier version of the HEC-RAS Common Features model. The work was done by West Consultants, Inc., for the Hydrologic Engineering Center (HEC). Some values derived from the study are therefore directly applicable to this study. A similar assessment was conducted by MBK Engineers and David Ford Consulting Engineers (MBK Engineers, 2009 and David Ford, 2009) for the Sacramento Area Flood Control Agency (SAFCA). Information derived from these reports was considered and used in developing the inputs for the West Sacramento GRR study.

6.1 INDEX POINTS

Hydraulic results are available at each cross section in the HEC-RAS model. For economic purposes, a single point is needed to represent each reach and is often referred to as an index point. The levees surrounding West Sacramento, already separated by a waterway, are further divided into reaches represented by similar geotechnical conditions, as described in the geotechnical appendix. Each reach is represented by a single index point located at the same position as the geotechnical fragility curve. The index points are shown on Plate 5. They are also listed in Table 6-1.

TABLE 6-1: INDEX POINTS

INDEX POINT	SUB-BASIN	PROJECT REACH	RIVER MILE
1	North	Sacramento River	61.5
2	North	Sacramento River	60
3	North	Yolo Bypass	42.62
4	North	Sacramento Bypass	1.49
5	South	Sacramento River	56.75
6	South	Sacramento River	52.75
7	South	Yolo Bypass	40.95
8	South	Sacramento DWSC	43.75

6.2 STAGE-DISCHARGE FREQUENCY CURVES

Peak stage data for all index points was derived for the 10-year through the 500-year events in the same manner for both with- and without-project conditions. Results were taken directly from the HEC-RAS model runs. However, 1-year and 2-year event stage data was derived via a different process using gage data, and is further discussed in the Risk Analysis Technical Memorandum (USACE, May 2013i). The use of flow-frequency and stage-discharge relationships in HEC-FDA is preferable; however, currently HEC-FDA requires an increasing flow value for an increasing stage value (in this case a stage-frequency relationship must be used). For index points 2-7, flow-frequency and stage-discharge relationships were generated for the HEC-FDA analysis (see Plate 5 for location of index points). A stage-stage relationship similar to a stage frequency relationship was used for Index Points 1 and 8 due to reverse flows and backwater effects, respectively.

6.3 UNCERTAINTY

6.3.1 Hydraulic Uncertainty

Previous studies by HEC and SAFCA were used to determine the hydraulic uncertainty. Both studies covered hydraulic uncertainty through a system approach as described previously. These values were checked against the minimum value recommended in Engineer Manual EM 1110-2-1619, "Risk-Based Analysis for Flood Damage Reduction Studies." If less than the minimum value, then the minimum value was used. For all index points a total stage uncertainty of 0.7 feet (within one standard deviation) was used. In further refinement a more detailed analysis will be completed.

6.3.2 Hydrologic Uncertainty

For index points 2-7, the flow frequency analysis is based on a graphical method. Index points 1 & 8 are based on stage frequency; the DWSC does not convey flows (index point 8) and water changes direction of flow (American River water flows upstream to the Sacramento Weir) at index point 1. The period of record (equivalent years of record) for all index points are between 71-73 years. The period of record was chosen based upon the HEC report for the systems risk and uncertainty analysis (HEC, 2009). Results from locations closest to index points were used.

6.4 FLOOD DAMAGE MODELING

In addition to the no-levee-failure model runs, flood damage assessment was done by simulating the flow of water from a levee failure into the West Sacramento Basin. Levee failures were simulated for each reach using seven frequencies (2-, 10-, 25-, 50-, 100-, 200-, 500-year) to generate a stage-damage relationship for each reach for the economic analysis. As described in Section 5.3, levee failure runs were made only using the without-project condition. Plates 34 through 41 contain the water surface elevations at the project index points for the full suite of frequencies and the following conditions and alternatives:

- Future Without-project condition
- Alternative 1: Improve levees in place
- Alternative 2: Improve levees in place with Sacramento Bypass widening
- Alternative 3: Improve levees in place with DWSC Closure Structure

- Alternative 4: Improve levees in place with Sacramento Bypass widening and DWSC Closure Structure

A summary of the key results are described below:

- For index points 1-7, there are no significant changes in stage or flow (from the future without project condition) when levees are fixed in place or when the DWSC closure structure is in place (Alternatives 1 & 3)
- As expected, there are reductions in stage and flow on the Sacramento River Reach below the confluence with the American River (at Index Points 2, 5 & 6) when Alternatives 2 & 4 are compared to the without-project condition.
- The results for the Yolo Bypass (Index Points 3 & 7) are similar for all conditions.

6.4.1 Upstream Levee Performance

As part of the Common Features GRR F3 analysis, upstream levee performance was considered in a sensitivity analysis (USACE, 2009e). A single index point at Verona (just downstream of the Natomas Cross Canal and Sacramento River confluence) was tested using historical data. The analysis showed that there was no significant influence on the stage and resulting expected annual damages from upstream levee performance. Based on this information, a decision was made to proceed with analyses assuming no upstream levee failures. All work under the West Sacramento GRR assumes no upstream levee failures.

6.5 PERFORMANCE EVALUATION

Future without-project annual exceedance probability (AEP) was computed on a reach/index point-specific basis using the HEC-FDA model. The HEC-FDA model integrates the hydrologic, hydraulic, geotechnical and economic relationships with uncertainty to create exceedance probability-damage functions with uncertainty.

The annual exceedance probability (AEP) represents the percent chance of a target stage being exceeded in any given year, thereby causing flooding and subsequent significant property damage. The annual exceedance probability results for each damage area are computed by HEC-FDA based on specific engineering data: frequency-stage curve, equivalent record length, and top-of-bank stage.

The AEP results were used to establish the future without-project expected annual damages (EAD) to determine economic benefits and evaluate performance of the alternatives. Table 6-5 shows the results of the levee performance evaluation for each index point in the project area. The future without project condition is included in Table 6-5 because it is the basis of comparison for the alternatives; this is discussed in greater detail in Section 2.2. More information about the economic benefits and expected annual damages can be found in the economic appendix.

Table 6-2: Performance at Each Index Point

FWOP	Annual Exceedence Probability (AEP)	0.0554	0.0084	0.089	0	0.0236	0.0411	0.1295	0.0124
	1/AEP	1 in 18	1 in 119	1 in 11	N/A	1 in 42	1 in 24	1 in 8	1 in 80
	1% Assurance	75%	88%	23%	100%	85%	90%	12%	70%
	0.4% Assurance	49%	65%	13%	100%	72%	89%	9%	47%
Alt. 1	Annual Exceedence Probability (AEP)	0.0148	0.003	0.0091	0	0.0012	0.0034	0.0117	0.0074
	1/AEP	1 in 68	1 in 333	1 in 110	N/A	1 in 833	1 in 294	1 in 85	1 in 135
	1% Assurance	96%	97%	93%	100%	98%	98%	92%	79%
	0.4% Assurance	79%	90%	92%	100%	98%	98%	91%	54%
Alt. 2	Annual Exceedence Probability (AEP)	0.0071	0.0014	0.0096	0	0.0007	0.002	0.0124	0.0076
	1/AEP	1 in 142	1 in 714	1 in 104	N/A	1 in 1428	1 in 500	1 in 81	1 in 132
	1% Assurance	97%	98%	93%	100%	99%	98%	92%	79%
	0.4% Assurance	94%	95%	92%	100%	98%	98%	91%	53%
Alt. 3	Annual Exceedence Probability (AEP)	0.0148	0.003	0.0091	0	0.0012	0.0034	0.0117	0
	1/AEP	1 in 68	1 in 333	1 in 110	N/A	1 in 833	1 in 294	1 in 85	N/A
	1% Assurance	96%	97%	93%	100%	98%	98%	92%	100%
	0.4% Assurance	83%	90%	92%	100%	98%	98%	91%	100%
Alt. 4	Annual Exceedence Probability (AEP)	0.0071	0.0014	0.0096	0	0.0007	0.002	0.0124	0
	1/AEP	1 in 142	1 in 714	1 in 104	N/A	1 in 1428	1 in 500	1 in 81	N/A
	1% Assurance	97%	98%	93%	100%	99%	98%	91%	100%
	0.4% Assurance	94%	95%	92%	100%	98%	98%	90%	100%

6.6 CONSIDERATIONS AND ASSUMPTIONS

The results of the risk analysis are affected by technical considerations and assumptions regarding the input to HEC-FDA. For example, geotechnical studies developed relationships that characterize the reliability of the levees. These were utilized to trigger levee failures in the hydraulic models that in turn affected the stage-frequency curves used in the risk analysis. Perhaps the most significant assumption is the levee failure methodology, which can significantly influence simulated breach hydrographs. These assumptions are described in Section 3.5 and were also evaluated in a sensitivity analysis in the Levee Breach Sensitivity Technical Memorandum (USACE May 2013h). The methodology chosen provides a conservative and consistent simulation of the potential flooding extent for system-wide hydraulic and economic evaluations. It does not necessarily represent conditions during an actual flood event, when flood fighting and other emergency actions are likely to take place.

6.7 FEMA CERTIFICATION/ACCREDITATION

FEMA certification was not determined at this time. The local sponsor has an interest in having the repaired levees brought up to the minimum requirements needed for FEMA accreditation. If determined to be needed, this additional analysis will most likely be conducted during refinement of the selected alternatives (including a possible locally preferred plan) or during the design phase.

6.8 SYSTEMS RISK AND UNCERTAINTY

Each of the final alternatives included setting the top of levee profile at the 200-year plus 3 feet benchmark, and a systems risk analysis was conducted to determine if there are hydraulic impacts from this levee raising. A process for evaluating system-wide hydraulic impacts of proposed modifications to the levees of the Sacramento River Flood Control Project (SRFCP) has been developed by the Hydrologic Engineering Center (HEC) and further information can be found in their "Documentation and Demonstration of a Process for Risk Analysis of Proposed Modifications to the SRFCP Levees" report. The process utilized risk analysis methods that followed USACE policy as outlined in ER 1105-2-101. The Systems Risk Technical Memorandum (USACE, May 2013l) further details the application of this ER and HEC guidance to this study. The system wide risk analysis method defined by HEC was considered applicable to the West Sacramento GRR study.

A key assumption of the system-wide risk analysis is that risk of a levee failure is associated with overtopping only. Levee fragility curves are not used in this analysis and levees are assumed to convey water to the top of levee throughout the system. This assumption is based on USACE Letter on Guidance on System Risk for modifications to Corps of Engineer Projects (USACE, July 2008).

The purpose of this evaluation was to determine if potential system-wide impacts can be identified based on the increase in annual exceedance probability (AEP) or a decrease in conditional non-exceedance probability (CNP, also referred to as 'assurance') within the FDA model. Using the model HEC created for the Sacramento River Flood Control Project (SRFCP) levees, new plans were created for each of the following three scenarios:

- Future without-project baseline condition
- Alternative 1: Fix in place
- Alternative 2: Fix in place with Sacramento Bypass widening

Alternatives 3, 4 & 5 were not analyzed. Both alternatives include a portion of alternative 1 & 2 plus a closure structure along the DWSC. A DWSC closure structure will not impact the water surface elevations within the SRFCP.

Potential impacts are identified when an increase in the AEP and a reduction in CNP occur at locations throughout the system when compared to the hydraulic baseline condition. The median AEP is computed directly from the inflow discharge-exceedance probability, the inflow-outflow and stage-discharge relationships that are defined at each index location. The expected AEP incorporates uncertainty in these relationships. Typically, an increase in water surface elevation without a change in the levee height will result in an increase in AEP and a reduction in CNP, which indicates an increase in the level of risk.

The following changes in AEP and CNP were identified based on comparison of the two alternatives and the future without project baseline condition:

- There was no significant change in median AEP
- There was no significant change in expected AEP (rounded at three significant figures)
- There are small changes in the CNP/assurance, mostly in the thousandths place.

7 - RESIDUAL RISK

Several methods and types of analysis are used to describe the hydraulic impacts and residual risk of the proposed alternatives. They are described below.

7.1 SUPERIORITY

Superiority is the levee design approach that identifies an initial overtopping location in the least hazardous location of a levee reach. This can be achieved by specifically setting the top of levee lower in the chosen overtopping location.

According to ETL 1110-2-299, "Overtopping of Flood Control Levees and Floodwalls," two design types can be used to control initial overtopping. The first is the use of different levee heights relative to the design water surface from reach to reach to force overtopping in a desired location. The second design uses notches, openings, or weirs in the structure. The inverts for these features are at or above a design water surface elevation but below the neighboring top of levee. Examples are railroad or road crossings of levees and rock weirs.

For this study, the second option (the use of the weirs as described in ETL 1110-2-299) was mostly applied. There is one weir on the Sacramento River in the project area that diverts high flows away from Sacramento into the Yolo Bypass. The Sacramento Weir is a designed flood relief structures in the system. The levees in the project area have not been designed for overtopping, but there are incidental low areas that will likely overtop first.

7.2 CLIMATE CHANGE – HYDROLOGY

A sensitivity analysis was conducted to assess the impact of climate change for the American River Common Features GRR and is applicable to the West Sacramento GRR. Studies have shown that increasing temperatures associated with climate change are causing a shift in the runoff patterns of Pacific slope watersheds with a large snowmelt component. The runoff shifts for those watersheds include increased runoff in winter, less snowmelt in summer, and earlier runoff in the spring (USACE, 2011b).

The methodology for the climate change sensitivity analysis of runoff peaks and volumes was developed by the Sutter Basin Pilot Study, and this method was applied to the American River Common Features Study. The Sutter team made further refinements to this method, but because the refinements yielded results similar to the first attempt, the ARCF PDT continued to use the results of the first method. The approach is summarized below, and more details on the application of this method can be found in the Climate Change Technical Memorandum (USACE, May 2013b).

The present-condition hydrology in the study was assumed to be representative of 2009 conditions. For future-condition hydrology scenarios, results from a University of California, San Diego study on Sierra Nevada runoff (UCSD, 2011) were interpolated and extrapolated to determine the percent difference of the 25-, 100-, 200- and 500-year events. The return period was plotted as a function of the percent difference, and a logarithmic curve was fit to the graph. The resultant estimated climate change differences from the study presented in Table 7-1 were used to translate the frequency of the water flowing into the various reservoirs in the Sacramento River system.

Table 7-1: Climate Change Differences For Northern Sierra Nevada, WY 2049

FREQUENCY	% DIFFERENCE IN 3-DAY FLOW		
	CNRM CM3	GFDL CM2.1	NCAR PCM1
1/2	12	22	6
1/5	16	23	-4
1/10	21	27	-10
1/20	27	32	-14
1/50	35	40	-19
1/100	35	40	-19
1/200	35	40	-19
1/500	35	40	-19

Global Climate Change Models:
CNRM CM3: French National Centre de Recherches Meteorlogiques Climate Models.
GFDL: Geophysical Fluids Dynamics Laboratory model version 2.1
NCAR PCM 1: National Center for Atmospheric Research Parallel Climate Model

A sensitivity analysis was conducted at two locations near West Sacramento to evaluate the effect of climate change on regulated flows: at the American River Fair Oaks gage and at the Sacramento River Verona gage. The analysis was performed by applying the changes shown in Table 7-1 to the unregulated flow-frequency curves at the two locations. Reservoir operations were assumed to remain the same for future conditions, and therefore inflow-outflow relationships would not change. The translation of regulated flows was made graphically with more information on this process found in the Climate Change Technical Memorandum (USACE, May2013b). Tables 7-2 and 7-3 show the future regulated flows and anticipated annual exceedance probability (AEP) for both index locations.

Table 7-2: Change in Frequency of Flows with Climate Change at American River Fair Oaks

Climate Model		CNRM CM3	GFDL CM2.1	NCAR
Present Regulated Frequency and Flow		Future Regulated Frequency: WY 2049	Future Regulated Frequency: WY 2049	Future Regulated Frequency: WY 2049
AEP	Flow (cfs)	ACE	ACE	ACE
1/2	26,000	1/2	1/2	1/2
1/10	72,000	1/7	1/7	1/13
1/25	115,000	1/17	1/14	1/39
1/50	115,000	1/25	1/25	1/83
1/100	115,000	1/48	1/40	1/167
1/200	160,000	1/83	1/71	1/385
1/500	224,000	1/200	1/167	1/1000

Table 7-3: Change in Frequency of Flows with Climate Change at Sacramento River Verona

Climate Model:		CNRM CM3	GFDL CM2.1	NCAR
Present Regulated Frequency and Flow		Future Regulated Frequency: WY 2049	Future Regulated Frequency: WY 2049	Future Regulated Frequency: WY 2049
AEP	Flow (cfs)	ACE	ACE	ACE
1/2	70,000	1/2	1/2	1/2
1/10	93,000	1/6	1/6	1/14
1/25	110,000	1/13	1/13	1/50
1/50	113,000	1/20	1/20	1/111
1/100	120,000	1/33	1/33	1/250
1/200	130,000	1/56	1/56	1/500
1/500	155,000	1/125	1/111	---

Climate change may also have an effect upon the levees, where a levee raise might be needed to maintain a desired levee performance. The levee crest elevation for future conditions was set at a 200-year event stage plus 3 feet. This new top of levee was compared with present levee crest heights. For the American River Fair Oaks, it appears that no levee raise is needed in response to climate change. However, for the Sacramento River Verona gage, it appears that the left levee crest would need to be raised an average of 3 feet and the right levee crest will need to be raised by 3.5 feet in response to climate change. The current alternatives have an average levee height raise of 1-2 feet, so this average height raise would need to be doubled to account for the estimated effects of climate change along the Sacramento River reach.

The analysis described above should be considered a sensitivity analysis, not a rigorous analysis of climate change using snowmelt hydrology models, reservoir operations models, and river routing models. The State of California is developing a state-wide approach to climate change with a system-wide historical record for unregulated conditions (no reservoirs) along with one regulated condition (with reservoirs). Some of the preliminary data from that state-wide approach was used in this analysis, but the final results are not currently available for use in the West Sacramento GRR study.

7.3 SEA LEVEL RISE

A second aspect of climate change is sea level rise. Rising sea levels have been observed at locations around the world, and the rate is expected to continue at the current level or increase in the future (IPCC, 2007). Increases in sea level can have a variety of impacts on coastal areas, including flooding, changing ecosystems, and declining water quality. Local subsidence can also cause a greater apparent sea level rise. To analyze potential effects on the Sacramento River system from these changes, several sea level rise scenarios were developed for 50 and 100 years. A subsidence rate was also applied to the low and high 100-year sea level rise scenarios.

Three sea level rise scenarios were developed based on the information contained in EC 1165-2-211, Water Resources Policies and Authorities Incorporating Sea-Level Change Considerations in Civil Works Programs (USACE, 2009). Following the method described in EC 1165-2-211, values for low, intermediate, and high sea level rise rates were developed for 50 and 100 years. The information describing the application of EC 1165-2-211 came from an existing report developed for USACE for work on the Sacramento-San Joaquin Delta (Dynamic Solutions, 2011) and a summary of that information is provided below.

7.3.1 Low Sea Level Rise

Following guidance outlined in EC 1165-2-211, the low sea level rise scenario was developed using historically measured data at the San Francisco tide gage. EC 1165-2-211 suggests using a tide gage with a minimum of 40 year period of record. The San Francisco tide gage period of record begins in 1897, which is more than sufficient to see long term patterns. Figure 7-1 shows the tidal signal at San Francisco with the seasonal cycle removed.

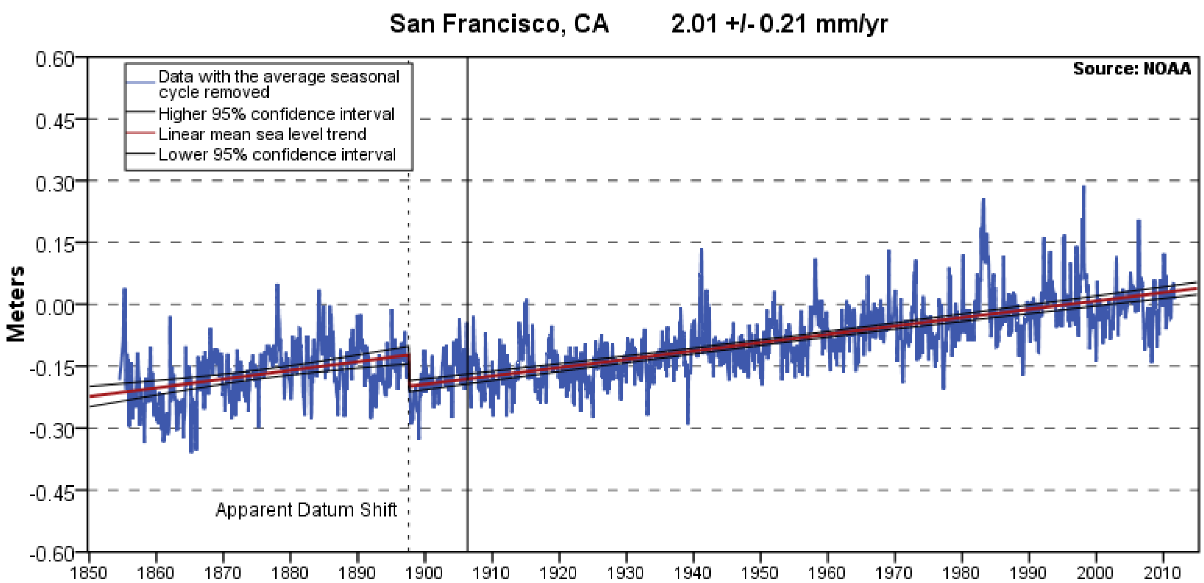


Figure 7- 1. Sea Level Trend at San Francisco (NOAA, 2009)

The red line shows the mean sea level trend of 2.01 mm/yr, and the black lines are the 95 percent confidence intervals. The solid vertical line is the 1906 earthquake, while the dashed vertical line is an apparent datum shift. Based on the historical data observed at San Francisco and following the guidance in EC-1165-2-211 of using the historical trend, a sea level rise of 2.01 mm/yr was chosen for the low case. This sea level rise value resulted in a 50-year increase of 0.10 m and a 100-year increase of 0.20 m at this location.

7.3.2 Intermediate Sea Level Rise

The intermediate sea level rise case was calculated using the modified NRC Curve I, as described in EC 1165-2-211. The equation used was

$$E(t_2) - E(t_1) = 0.0017(t_2 - t_1) + b(t_2{}^2 - t_1{}^2)$$

where t_2 is the time between the projected time and 1986, t_1 is the time between current time and 1986, and b is a constant value of 2.36E-5 for the medium sea level rise. To estimate the sea level rise in 2061, 50 years from 2011, values of 75 and 25 were used for t_2 and t_1, respectively. For the 100 year scenario, values of 125 and 25 were used for t_2 and t_1, respectively.

Using the above equation, sea level rise values of 0.20 m and 0.52 m were calculated for the 50 and 100 year scenarios, respectively.

7.3.3 High Sea Level Rise

The high sea level rise case was calculated using the modified NRC Curve III as described in EC 1165-2-211. The equation is the same as given above, with a b of 1.005E-4. Again, for the 50 year scenario, 75 and 25 were used for t_2 and t_1, respectively, and for the 100 year scenario, 125 and 25 were used for t_2 and t_1, respectively.

Using the above values, a sea level rise of 0.59 m was calculated for 50 years, and 1.7 m for 100 years.

7.3.4 Summary of Sea Level Rise Values

The sea level rise values calculated above were checked against other sources to determine their validity. Table 7-4 presents a summary of the calculated sea level rise values, and Table 7-5 presents a sample of the range of sea level rise values described in the literature.

Table 7-4: Summary of Calculated Sea Level Rise Values at San Francisco Gage 94114290

SEA LEVEL RISE SCENARIO	50-YEAR RISE (M)	100-YEAR RISE (M)
Low	0.10	0.20
Intermediate	0.20	0.52
High	0.59	1.68

Table 7-5: Sea Level Rise Values Seen in Literature

SOURCE	100-YEAR SEA LEVEL RISE RANGE (M)
California Climate Change Center – Projecting Future Sea Level Rise (CCCC, 2006)	0.13–0.89
International Panel on Climate Change – Synthesis Report (IPCC, 2007)	0.18–0.59
Delta Risk Management Strategy (DRMS) – Climate Change (DRMS, 2008)	0.20–1.40

As shown in the above tables, the 100-year range calculated from EC 1165-2-211 of 0.2–1.7 m compares well with the ranges presented in the literature.

The low sea level rise rate was verified with observed data at the San Francisco station. For 2001, the arithmetic mean of the hourly water surface elevations was 2.75 m NAVD88. After applying the 2.01 mm/yr sea level rise, an average of 2.77 m was predicted. This matched well with the observed average in 2010 of 2.78 m.

7.3.5 Sensitivity of Hydraulic Model Results

The estimates in sea level rise described previously were used in a sensitivity analysis to evaluate the impacts of sea level rise on the water surface profiles in the West Sacramento project area. More information can be found in the Downstream Boundary Sensitivity Analysis Memorandum for File (USACE, January 2010b). The analysis focused on the downstream boundary conditions. The sensitivity of the downstream boundaries for the West Sacramento project were tested by varying downstream stage hydrographs at three locations to reflect increases in stage due to sea level rise. Water surface profiles from the original model and the sensitivity runs (with shifted downstream boundary stage hydrographs) were compared along the American River reach and Sacramento River reach.

The effects of shifting the downstream hydrograph to account for changes in stage due to sea level rise resulted in no changes on the Sacramento at Verona and minimal changes on the Sacramento at Freeport. The largest difference in stage was two-tenths of a foot for the 10-Yr event on the Sacramento River at Freeport, and the average difference in stage was one-hundredth of a foot or less for the 100-Yr event along the Sacramento River. There were also minimal variations in surface water elevations in the Yolo Bypass, indicating no significant change in the routing of the flood event through the combined waterways of the Sacramento River and the Yolo Bypass. These minimal changes in water surface elevations indicate that the project water surface profiles are not sensitive to reasonably estimated future sea level rise conditions.

7.4 INTERIOR DRAINAGE

The City of West Sacramento is surrounded on all sides by water so when a rain event happens all the water has to be collected and pumped out of the basin. There is an existing interior drainage system already in place to accomplish this task. An evaluation of that system was conducted by HDR and documented in the Interior Drainage Evaluation Report (HDR, 2010). The report establishes the existing conditions and it will be further used in the refinement of the TSP and requirements for possible FEMA levee accreditation. The general findings and conclusions from Section 6.1.1 in the report are that:

> *"This report provides an internal evaluation of the north and south basins for the City of West Sacramento. This section provides a summary discussion of the findings from the HDR evaluation for both the north and south basins. The internal drainage system is a combination of underground gravity flow pipes, earthen channels and various internal pump stations that appear to be adequate for the City's existing storm water drainage system. Review of the requested frequency storms indicates isolated residual floodplain impacts to the City's north basin. The residual floodplain for the south basin indicated no flooding impacts for the 100-year frequency storms in the existing basins. The 200-year frequency storm volumes showed limited or no freeboard in the basins."*

7.5 LIFE SAFETY

Life safety information was taken from the USACE Levee Screening Tool (LST) for use in this study. The Levee Screening Tool supports the levee screening process by facilitating a preliminary assessment of the general condition and associated risks of levees in support of the USACE Levee Safety Program. (RMC, 2011)

The LST determines a screening risk index that considers routine inspection results and ratings coupled with a review and evaluation of historical performance data, as-built drawings, economic and life loss consequences, historic and current hydraulic and hydrology data, and other data. This helps determine the potential for failure and the consequences of failure. The culmination of the LST process is a screening risk index and risk classification that can be weighed against other screened levee segments in the portfolio.

Life safety can be evaluated using the consequence portion of the Levee Screening Tool (LST). Readily available data and information are used along with limited analysis to assess the potential consequences related to two different flooding scenarios: overtopping of a levee segment (with or without breach) and breach prior to overtopping of a levee segment. Consequence estimates focus on loss of life, but also include population at risk, number of structures, and direct monetary damage estimates to structures. The following is a description of the consequence results:

- **Population at Risk (Day/Night)**. These values represent the computed total number of people that would get wet if they did not evacuate when a levee breach occurred and inundated the entire leveed area up to the maximum profile elevation of the levee segment being screened.
- **Exposure Weighted Life Loss Estimates**. Computed "average" life loss estimates for each scenario that represent the loss of life caused by breach of the levee based on the movement of people in and out of the leveed area throughout the day.

The overall data for life safety and life loss estimates can be found in Table 7-6. This information comes from a series of Levee Screen Tool Presentations by the Sacramento District. It is important to note that these numbers are still preliminary and subject to change after presented to the Levee Safety Oversight Group (LSOG).

Table 7-6: Life Safety and Life Loss Information From USACE's Levee Screening Tool

WEST SACRAMENTO	
Population at Risk (Day)	50,720
Population at Risk (Night)	48,821
Loss of Life (Day)	124
Loss of Life (Night)	90

8 - EROSION

8.1 OVERVIEW AND ASSUMPTIONS

Erosion is the removal of sediment, rocks, cobble, vegetation and general deterioration of a bank or a levee due to the power of water, often measured by shear stress and velocity. There have been many studies on erosion, sediment transport, and channel stability in the study area.

The plan for erosion is ongoing; more analysis (likely in PED) is expected to provide greater insight. Erosion repairs are expected to be part of all alternatives and refinement efforts will continue beyond the Tentatively Selected Plan (TSP) milestone. Existing erosion conditions in the project area are presented in greater detail in the following section.

8.2 EXISTING BANK EROSION CONDITIONS

Two reports by NHC and URS evaluated erosion sites along the project levees. The NHC analysis identified erosion sites by boat and vehicle inspections. URS used an erosion screening process which consisted of a three tier analysis including: (1) a flow velocity and erosion surface adequacy analysis, (2) wind-wave shear and erosion surface adequacy test, and (3) a field evaluation.

Table 8-2 shows the erosion sites from both reports that were combined to create one master table that describes the locations of erosion sites along the levees. If there was an overlap between the two studies, the sites were combined to create one reach. Although URS and NHC used different methods to analyze erosion along the levees, both reports were able to identify where the levees needed repair.

Table 8-2: NHC & URS Combined Erosion Locations

RIVER MILE	SITE LENGTH	STARTING POINT
SACRAMENTO RIVER WEST LEVEE		
62.90	1848	Upstream
62.50	4224	Upstream
61.00	457	Upstream
60.35	528	Upstream
60.00	250	Upstream
59.90	1584	Upstream
58.65	528	Upstream
57.65	1320	Upstream
57.14	2851	Upstream
56.21	6230	Upstream
54.95	2904	Upstream
54.00	1700	Upstream
53.80	528	Upstream
53.60	528	Upstream
SACRAMENTO BYPASS		
1.25	140	Middle

RIVER MILE	SITE LENGTH	STARTING POINT
SACRAMENTO RIVER WEST LEVEE		
1.15	20	Middle
0.75	2006	Middle
0.20	2693	Middle
YOLO BYPASS (BYPASS SIDE)		
37.11	100	Middle
30.41	100	Middle
27.57	100	Middle
YOLO BYPASS (DWSC SIDE)		
25.41	100	Middle
24.76	100	Middle
23.81	100	Middle
23.68	100	Middle
PORT OF SACRAMENTO & DWSC EAST LEVEES		
40.54	100	Middle
38.83	100	Middle

8.3 SEDIMENT TRANSPORT

A sedimentation analysis was not completed for this study. However, a sediment study of the Sacramento River from Colusa to Freeport is near completion under the Sacramento River Bank Protection Project (NHC, 2012). The main objective of this sediment study was to investigate sediment transport processes and geomorphic trends along the lower Sacramento River and its major tributaries and distributaries. A HEC-6T sediment transport model was developed for the study reaches of the Sacramento, Feather, and American Rivers to estimate degradational or aggradational trends over the next 50 and 100 years.

For the Sacramento River reach (RM 79-46), the average bed elevation decreases by 0.02 ft for the 50-year simulation period and decreases by 0.10 ft for the 100-year simulation period. Despite a few significant (on the order of feet) localized vertical adjustments in the channel geometry (mostly associated with infilling of deep pools and scour of elevated riffles), the study reach of the Sacramento River appears to be generally stable, with a slight degradational trend.

8.4 WIND-WAVE

Wind-wave analysis was done to evaluate the risk of failure due to wave erosion for about 22 miles of Federal Project levees surrounding West Sacramento in Yolo County for coincident 200-year water levels and extreme wind events (NHC, 2011). The study approach and methods followed Engineering Circular 1110-2-6067 and other technical publications related to wind-wave analysis. Wind-wave characteristics were calculated from the highest observed winds on record at stations in the Sacramento area. Frequency analysis of the annual maxima at the stations, by direction, suggested that the maximum 1-hour gusts had about a 50-year return period. No studies were performed to determine the coincident probability of the 200-year water level and the maximum wind occurring simultaneously.

Each site was assigned a risk level based on the highest risk assigned for either levee face erosion or overtopping for any wind direction at a given site. The risk at each study site was then generalized to nearby sites, which were expected to experience similar wave heights and which had similar geometry and protection. Overall, 6.5 miles of levee were determined to be at high risk of failure due to wind wave erosion during coincident extreme wind and water levels, 12 miles were determined to be of moderate risk, and 3.5 miles were assumed to be low risk. Plate 42 shows locations of high, medium and low risk. High risk sections are likely to require repair for the levee to meet erosion standards for the 200-year flood. Sections of levee with moderate risk are not expected to require repair and any damage at these locations during a large flood should likely be mitigated with flood fighting. Low risk sites do not require repair and likely will not require any flood fighting for wind wave erosion.

It should be noted that the possibility of levee breach due to wind-wave action is small compared to other issues currently being considered, such as underseepage and stability.

8.5 BOAT WAVE EROSION

Boat wave erosion has not been accounted for in this analysis because there is no boating in the Sacramento Bypass and Yolo Bypass and the impact of boat wave erosion along the Sacramento River is unlikely to be significant. Majority of boats operating on the Sacramento River are smaller recreational boats with few ocean-going yachts. It is assumed that any boat wave erosion that may occur will be addressed by the Sacramento River Bank Protection Project and by standard operation and maintenance of the levees.

Boat wave erosion on the Deep Water Ship Channel will be further analyzed and addressed after the selection of the TSP. The current assumption is that any repairs needed from boat waves would likely be addressed as part of standard operation and maintenance of the DWSC levees.

8.6 VEGETATION ANALYSIS (TREE SCOUR)

The preliminary designs for erosion protection include leaving some of the vegetation in place, an option made possible by a waiver process included in ETL 1110-2-571. A pier scour analysis to represent tree scour (likely using HEC-18) is included in the application for waiver. This effort is considered part of the erosion analysis, and is expected to be done during the refinement of the tentatively selected plan.

8.7 BRIDGE SCOUR

There are over 6 bridges crossing the channel on multiple reaches in the project area. Bridges along the Sacramento River will likely need an analysis during design or refinement of the selected alternative to account for bridge scour protection. This effort is considered part of the erosion analysis and is expected to be done as part of the refinement of the tentatively selected plan.

9 - REFERENCES

Ayres Associates. December 1997. American and Sacramento River, CA Project, Geomorphic, Sediment Engineering, and Channel Stability Analysis. Prepared by Ayres Associates for the Sacramento District, U.S. Army Corps of Engineers. Sacramento, CA

Ayres Associates. March 1998. Draft Hydrographic and Topographic Surveying and Mapping RM 0 to RM 218. Supplement No. 7 to Design Memorandum No. 2. Sacramento River Bank Protection Project, Sacramento River and Tributaries. Prepared by Ayres Associates for the Sacramento District, U.S. Army Corps of Engineers. Sacramento, CA.

Ayres Associates. May 2003. Topographic and Hydrographic Surveys of the Feather River System for the Sacramento and San Joaquin River Basins Comprehensive Study, CA. Prepared by Ayres Associates for the Sacramento District, U.S. Army Corps of Engineers, Sacramento, CA.

DWR, May 2012. Urban Levee Design Criteria. California Department of Water Resources. Sacramento, CA.

David Ford Consulting Engineers. 6 July 2009. Conditional Risk Analysis for Natomas Levee Improvement Project. Prepared by David Ford Consulting Engineers for SAFCA. Draft. Sacramento, CA.

Dynamic Solutions, LLC.(Dynamic Solutions) December 2011. Extended Delta EFDC Hydrodynamic Model Sea Level Rise Analysis. Prepared by Dynamic Solutions for the Sacramento District, U.S. Army Corps of Engineers, Sacramento, CA.

Ensign and Buckley Consulting Engineers. December 1996. Natomas Basin Conditional Letter of Map Revision. Prepared by Ensign and Buckley Consulting Engineers for SAFCA. Sacramento, CA.

HDR. December 2010. Internal Drainage Evaluation Report. Prepared by HDR for the City of West Sacramento and West Sacramento Area Flood Control Agency. Sacramento, CA.

HEC, June 2009. “Documentation and Demonstration of a Process for Risk Analysis of Proposed Modifications to the Sacramento River Flood Control Project (SRFCP) Levees, PR-71.” Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, CA.

HEC, January 2010. “HEC-RAS, River Analysis System, Users Manual,” Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, CA.

HJW GeoSpatial, Inc. 01 July 2010. American River Common Features, Control Survey. Task 5 Report. Prepared by HJW GeoSpatial, Inc. for the Sacramento District, U.S. Army Corps of Engineers. Oakland, CA.

MBK Engineers. August 2001. Cache Creek Hydraulic Analysis Road 94B to Cache Creek Settling Basin. Prepared by MBK Engineers for the Sacramento District, U.S. Army Corps of Engineers. Sacramento, CA.

Northwest Hydraulics Consultants (NHC). 15 February 2011. Wave Runup and Erosion Analysis for West Sacramento Levee System. Prepared by NHC for HDR for West Sacramento Area Flood Control Agency. West Sacramento, CA.

Northwest Hydraulics Consultants (NHC). 12 December 2012. Sacramento River Sediment Study Phase II Sediment Transport Modeling and Channel Shift Analysis, Sacramento River Bank Protection Project. Prepared by NHC for Sacramento District, US Army Corps of Engineers. West Sacramento, CA.

Peterson Brustad, Inc. (PBI) July 2010. Vertical Datum Conversion of the Sutter Bypass-Feather River HECRAS model. Prepared in support of the Sutter Basin Feasibility Study, Sacramento District. Folsom, CA.

PBS & J (Now part of and acquired by Aktins). May 2008. Levee Inventory Project, Volumes 1 & 2. Prepared for the National Levee Database, for U.S. Army Corps of Engineers Sacramento District, Sacramento, CA.

Risk Management Center. (RMC). November 2011. Levee Screening Tool Methodology and Application. Levee Safety Program.

U.S. Army Corps of Engineers (USACE). August 1980. Sacramento River and Tributaries Bank Protection and Erosion Control Investigation, CA Status Report. Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE). November 1990. Study of Vegetation of Revetments, Sacramento River Bank Protection Project, Phase 1. Engineer Research and Development Center (ERDC) Vicksburg, MS.

U.S. Army Corps of Engineers (USACE). February 1992. Sacramento-San Joaquin Delta California, Special Study. Hydrology Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE). April 1992. Sacramento River, Riprap Design Velocity Study and Sustained High Water Study, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE), March 1999. American River Watershed Project, California, Natomas Federal Plan. Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE). September 2001. Tisdale Weir HEC-RAS Model Memorandum for Record (MFR). Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE). December 2002a. San Joaquin Sacramento River Basins Comprehensive Study. Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE). December 2002b. “Technical Studies, Appendix D, Hydraulic Technical Documentation”, Sacramento and San Joaquin River Basins Comprehensive Study. Sacramento District, Sacramento District, CA.

U.S. Army Corps of Engineers (USACE). September 2004. Hydraulic Technical Report (Without-Project Conditions). Sutter County Feasibility Study. Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) 17 February 2005. Lower Feather River Floodplain Mapping Study. Prepared by the Sacramento District, U.S. Army Corps of Engineers for the State of California Department of Water Resources, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) 20 July 2005. Draft F3 Hydraulics Appendix. Yuba River Basin General Reevaluation Report. Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE). August 2005. Yuba River Basin California General Reevaluation Study Feasibility Scoping Meeting (F3). Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE). 16 February 2006. Sacramento River UNET Model Comparison Draft Memorandum For Record (MFR), Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE). May 2007a. American River Common Features American River Levee Raising Top of Levee Profile Design Documentation Report.

U.S. Army Corps of Engineers (USACE) 31 May 2007b. Hydraulic Engineering Appendix, American River Watershed Project Economic Reevaluation Report. Hydraulic Design Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE). May 2008. Upper Feather River Floodplain Mapping Study. Prepared by the Sacramento District for the State of California Department of Water Resources. Sacramento, CA.

U.S. Army Corps of Engineers (USACE). July 2008. Memorandum for Record. Subject: Hamilton City Flood Damage Reduction and Ecosystem Restoration Project – PED Level of Performance. Hydraulic Design Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE). July 2008. Memorandum for See Distribution: Clarification Guidance on the Policy and Procedural Guidance for the Approval of Modifications and Alterations of Corps of Engineers Projects. Headquarters, Washington, D.C.

U.S. Army Corps of Engineers (USACE), January 2009a. American River Watershed Common Features Project, General Reevaluation Report, F3 Pre-Conference Documentation. Hydraulic Design Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) June 2009b. Development of Sacramento River Stage Frequency Curves. American River Common Features, General Reevaluation Report. Hydrology Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE). 28 August 2009c. Memorandum for Record. Subject: Napa River/Napa Creek Flood Protection Project 1% Event Conditional Non-Exceedance Probability Analysis. Hydraulic Design Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE). 28 August 2009d. Memorandum for South Pacific Division, American River Common Features General Re-evaluation Report Feasibility Scoping Meeting Planning Guidance Memo (PGM). Planning Division, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE). 08 October 2009e. Memorandum for File. Analysis of Historic Sacramento River Flood Control Levee Failures to determine stage effects at Verona. Hydraulic Design Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) 17 January 2010a. Memorandum for Chief, Flood Protection & Navigation Section (CESPK-CO-OR). Subject: Natomas Levee Improvement Program, Phase 3 – 33 USC 408 Hydraulic Engineering Review. Hydraulic Design Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) 19 January 2010b. Memorandum for File. Downstream Boundary Sensitivity Analysis. Hydraulic Design Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) April 2010b. Levee Raises and Hydraulic Impacts White Paper for the American River Watershed Common Features Natomas Post Authorization Change Report. Engineering and Planning Divisions, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) May 2010c. Memorandum for Record: Consideration of Transfer of Risk and Hydraulic Impact for the American River Watershed Common Features Natomas Post Authorization Change Report. Hydraulic Design Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) August 2010d. Hydraulic Technical Documentation. Post-Authorization Change Report and Interim General Reevaluation Report. American River Watershed, Common Features Project, Natomas Basin, Sacramento and Sutter Counties, California. Hydraulic Analysis Section, Sacramento District, CA.

U.S. Army Corps of Engineers (USACE) April 2010e. Hydraulic Technical Documentation. Sacramento River Bank Protection Project. RM 57.2R Setback Levee with Islands Hydraulic Modeling. Hydraulic Analysis Section, Sacramento District, CA.

U.S. Army Corps of Engineers (USACE), July 2011a. West Sacramento General Reevaluation Report, Hydraulic Technical Documentation, Feasibility Scoping Meeting F3 Milestone. Hydraulic Design Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) December 2011b. Levee Screening Tool Presentations of Reaches within Natomas (RD 1000) System, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) February 2012a. 2011 Annual Erosion Reconnaissance Engineering Report for the Sacramento Bank Protection Project, Sacramento River and Tributaries. Sacramento District, Sacramento, CA

U.S. Army Corps of Engineers (USACE) August 2012b. Levee Screening Tool Presentation of Reaches within American River South System, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) September 2012c. Levee Screening Tool Presentation of Reaches within American River North System, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) November 2012. American River Common Features Residual Flood Analysis. Prepared by the Hydrology Section of the Los Angeles District for use as an Interior

Drainage analysis for the American River Common Features Feasibility Study, Sacramento District. Los Angeles District, USACE, Los Angeles, CA.

U.S. Army Corps of Engineers (USACE) May 2013a. Sacramento Basin HEC-RAS Calibration. Technical Memorandum for American River Common Features Feasibility Study Hydraulic Appendix. Hydraulic Analysis Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) May 2013b. Climate Change. Technical Memorandum for American River Common Features Feasibility Study Hydraulic Appendix. Hydraulic Analysis Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) May 2013c. Datum Conversion of Hydraulic Models to NAVD88 Values. Technical Memorandum for American River Common Features Feasibility Study Hydraulic Appendix. Hydraulic Analysis Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) May 2013d. Downstream Boundary Conditions for HECRAS Sacramento River Basin HECRAS Model. Technical Memorandum for American River Common Features Feasibility Study Hydraulic Appendix. Hydraulic Analysis Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) May 2013e. Gages in Sacramento River Basin. Technical Memorandum for American River Common Features Feasibility Study Hydraulic Appendix. Hydraulic Analysis Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) May 2013f. Hydrologic Inputs (DSS files). Technical Memorandum for American River Common Features Feasibility Study Hydraulic Appendix. Hydraulic Analysis Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) May 2013g. High-Water Marks. Technical Memorandum for American River Common Features Feasibility Study Hydraulic Appendix. Hydraulic Analysis Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) May 2013g. Hydraulic Uncertainty. Technical Memorandum for American River Common Features Feasibility Study Hydraulic Appendix. Hydraulic Analysis Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) May 2013h. Levee Breach Sensitivity. Technical Memorandum for American River Common Features Feasibility Study Hydraulic Appendix. Hydraulic Analysis Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) May 2013i. Risk Analysis. Technical Memorandum for American River Common Features Feasibility Study Hydraulic Appendix. Hydraulic Analysis Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) May 2013j. Sacramento Basin HEC-RAS Phase I Model Development. Technical Memorandum for American River Common Features Feasibility Study Hydraulic Appendix. Hydraulic Analysis Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) May 2013k. DRAFT Sacramento Basin HEC-RAS Phase II Model Development. Technical Memorandum for American River Common Features Feasibility Study Hydraulic Appendix. Hydraulic Analysis Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) May 2013l. Systems Risk and Uncertainty. Technical Memorandum for American River Common Features Feasibility Study Hydraulic Appendix. Hydraulic Analysis Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) May 2013m. Upstream Alternative Analysis. Technical Memorandum for American River Common Features Feasibility Study Hydraulic Appendix. Hydraulic Analysis Section, Sacramento District, Sacramento, CA.

U.S. Army Corps of Engineers (USACE) May 2013n. Levee Breach Sensitivity. Technical Memorandum for American River Common Features Feasibility Study Hydraulic Appendix. Hydraulic Analysis Section, Sacramento District, Sacramento, CA.

US Geological Survey. May 2004. Trends in the Sediment Yield of the Sacramento River, California, 1957-2001. Scott A. Wright and David H. Schoellhamer, US Geological Survey. Sacramento, CA.

University of California, San Diego. (UCSD). Authors: Das T, MD Dettinger, DR Cayan, Hugo G Hidalgo. November 2011. Potential increase in floods in California's Sierra Nevada under future climate projections. Springer Science+Business Media B.V. 2011. San Diego, CA.

Schaaf & Wheeler Consulting Civil Engineers. February 1994. Sutter County Flood Control Alternatives, Reconnaissance Level Report. Prepared by Schaaf & Wheeler Consulting Civil Engineers for SAFCA. Sacramento, CA.

Water Engineering and Technology. March 1988. Geomorphic Analysis of Sacramento River, Water Engineering and Technology. Sacramento, CA.

Water Engineering and Technology. July 1990. Geomorphic Analysis and Bank Protection Alternatives for Sacramento R, Feather R, Yuba R, and Bear R, Water Engineering and Technology. Sacramento, CA.

WEST Consultants. July 2010. North Sacramento Stream Survey and Hydraulic Modeling, Sacramento, California. Prepared by WEST Consultants, Inc for the Sacramento District, U.S. Army Corps of Engineers. San Diego, CA.

LEGEND

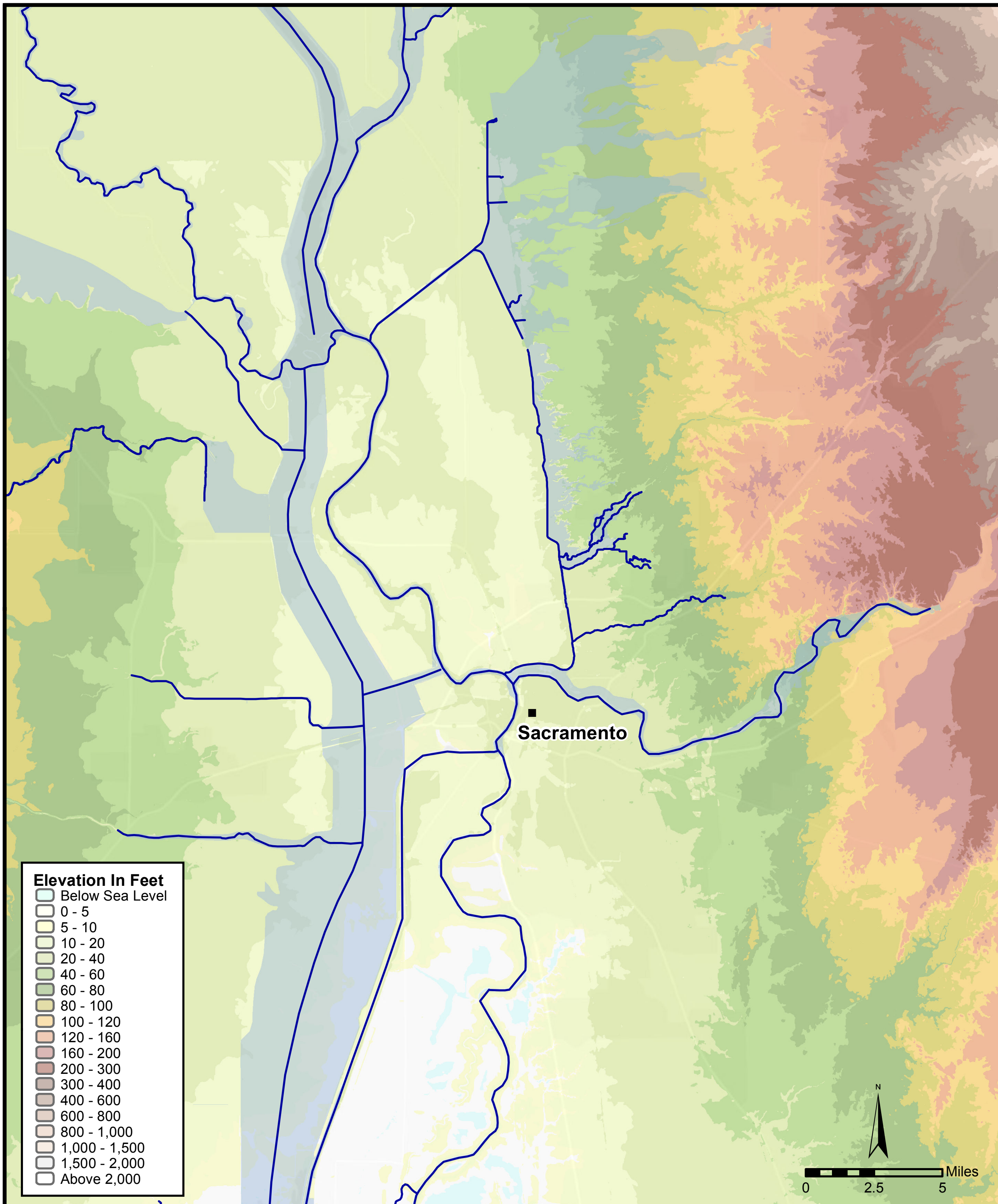
- Rivers
- Sacramento Watershed
- Lakes and Reservoirs
- Designated Floodways

WEST SACRAMENTO GRR
SACRAMENTO, CALIFORNIA

SACRAMENTO RIVER WATERSHED

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Feb 2013



LEGEND

Rivers

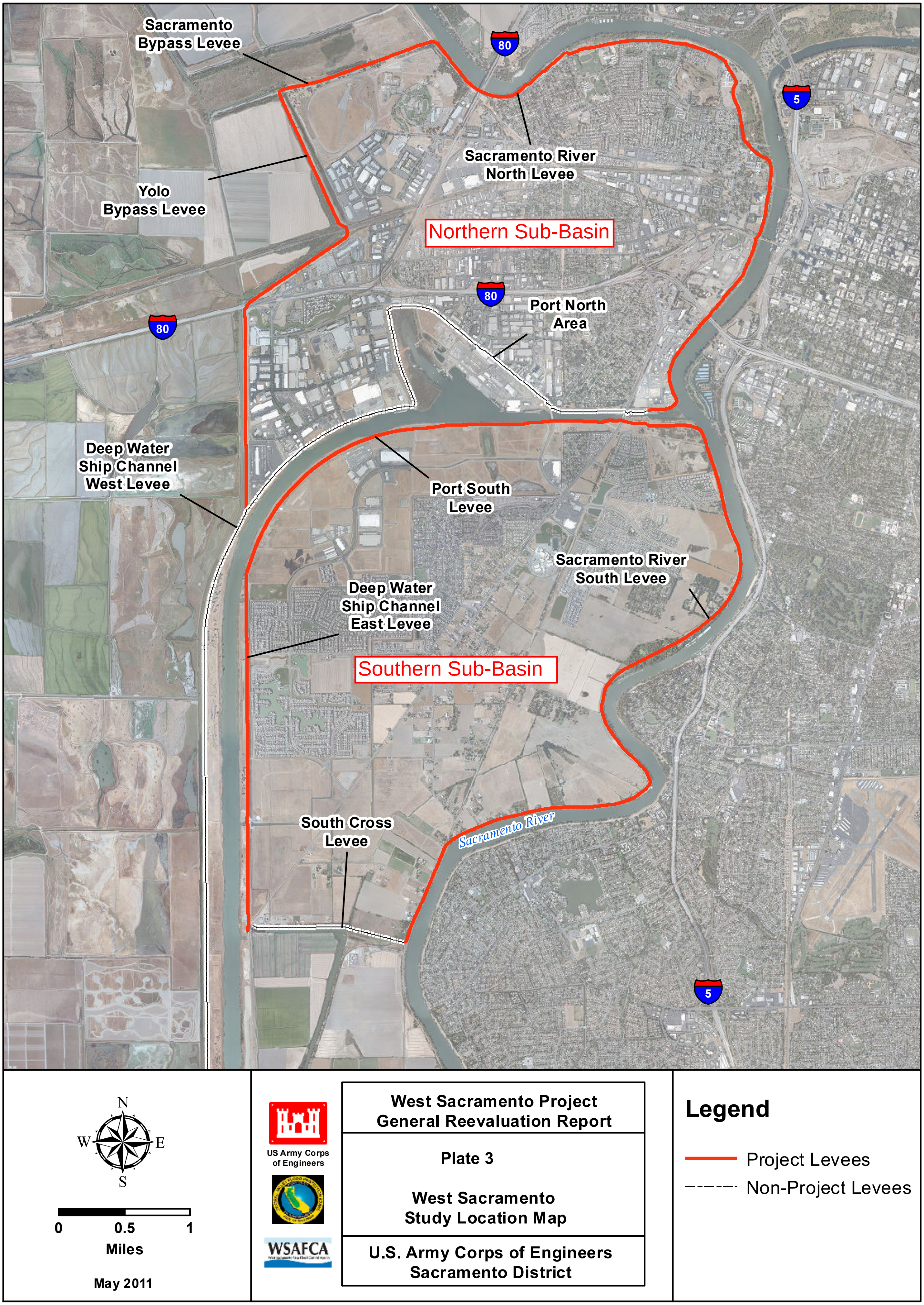
Floodways

WEST SACRAMENTO GRR
SACRAMENTO, CALIFORNIA

GENERAL TOPOGRAPHIC MAP

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Feb 2013

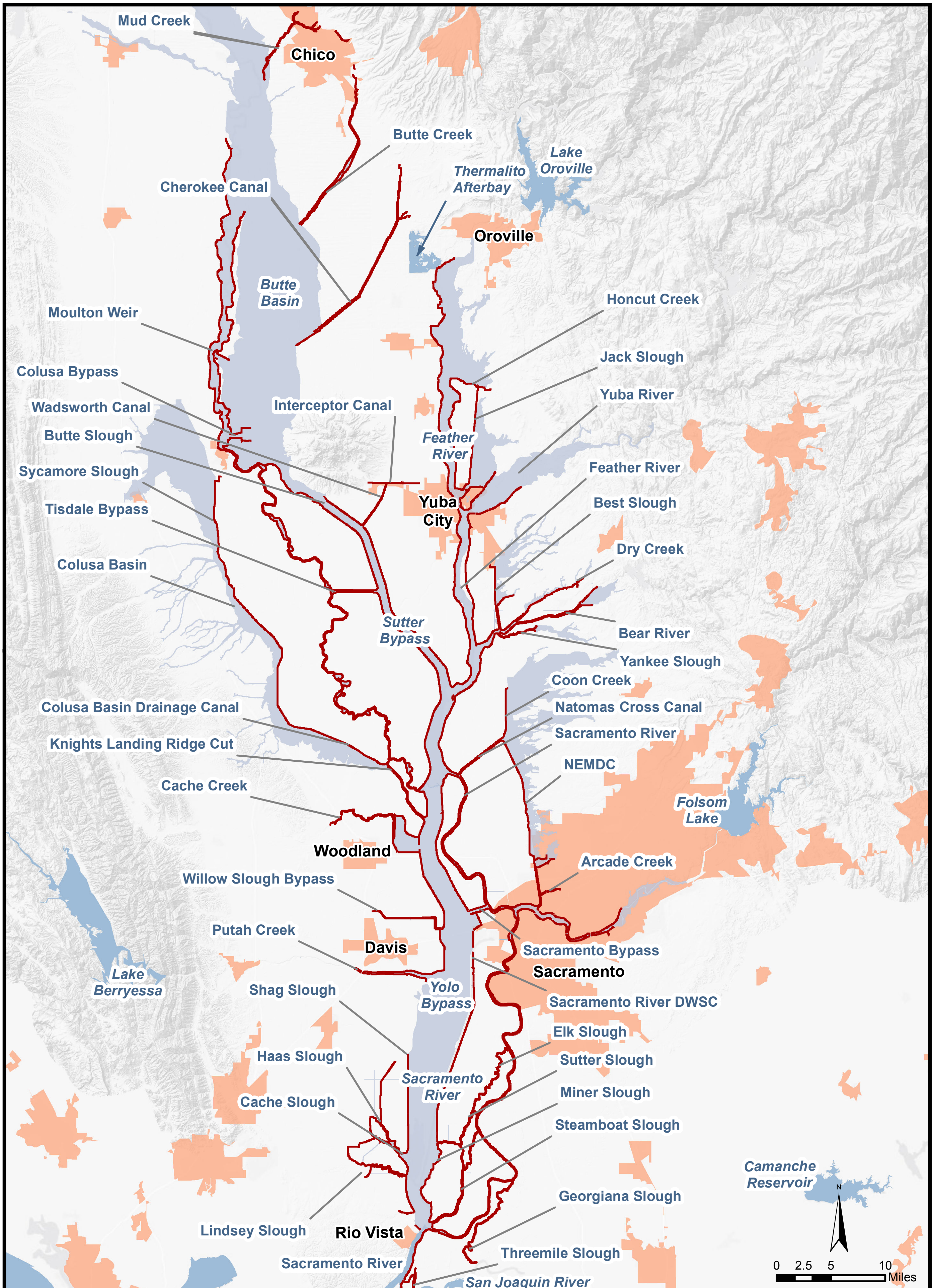


West Sacramento Project
General Reevaluation Report

Plate 3

West Sacramento
Study Location Map

U.S. Army Corps of Engineers
Sacramento District



AMERICAN RIVER COMMON FEATURES GRR SACRAMENTO, CALIFORNIA	**Sacramento River Flood Control System**	U.S. ARMY CORPS OF ENGINEERS SACRAMENTO DISTRICT

Feb 2013

Plate 3

N
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0 0.5 1
Miles

May 2011

US Army Corps of Engineers

WSAFCA

West Sacramento Project
General Reevaluation Report

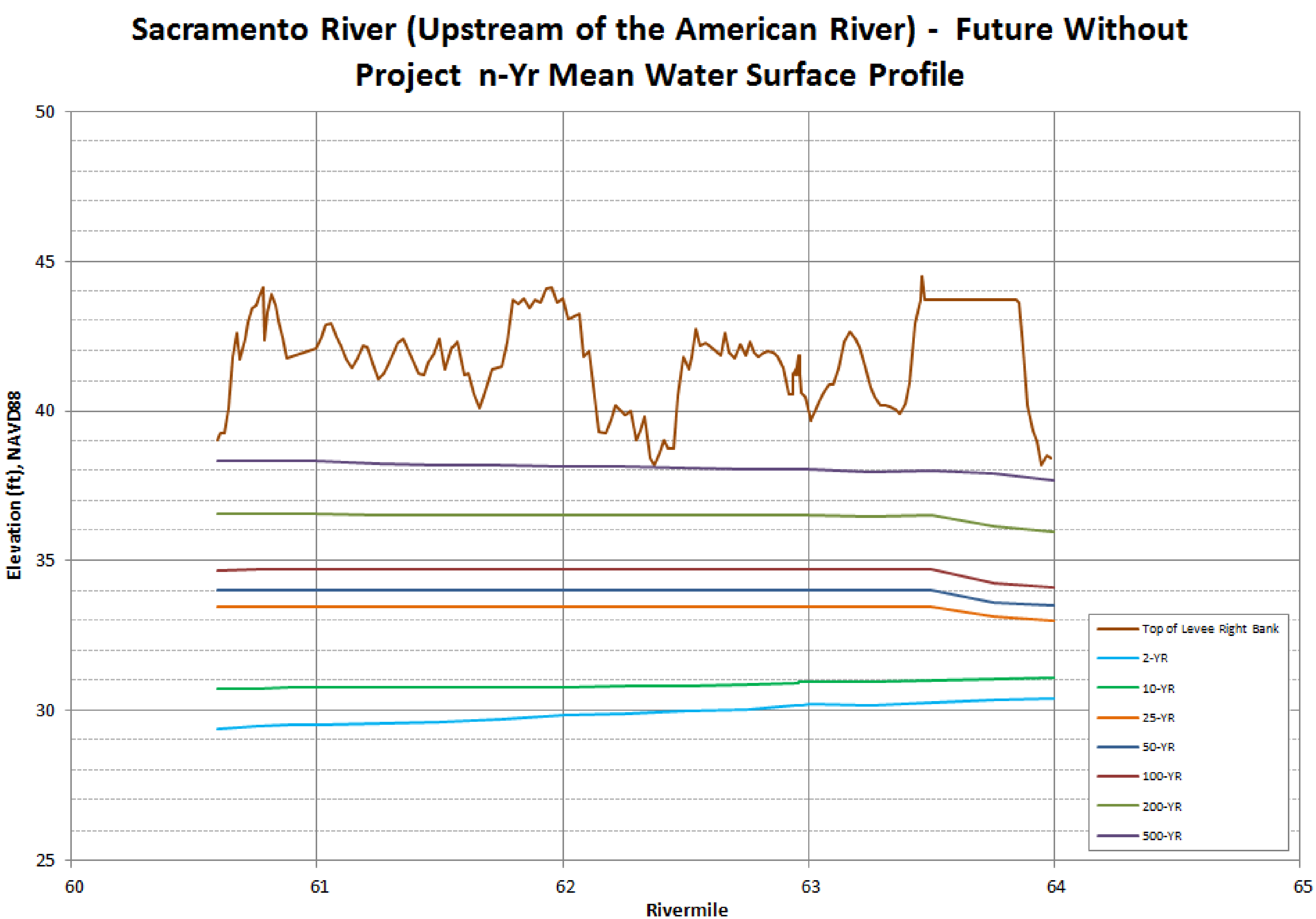
Figure 4 - 1

West Sacramento
Preliminary Index Points

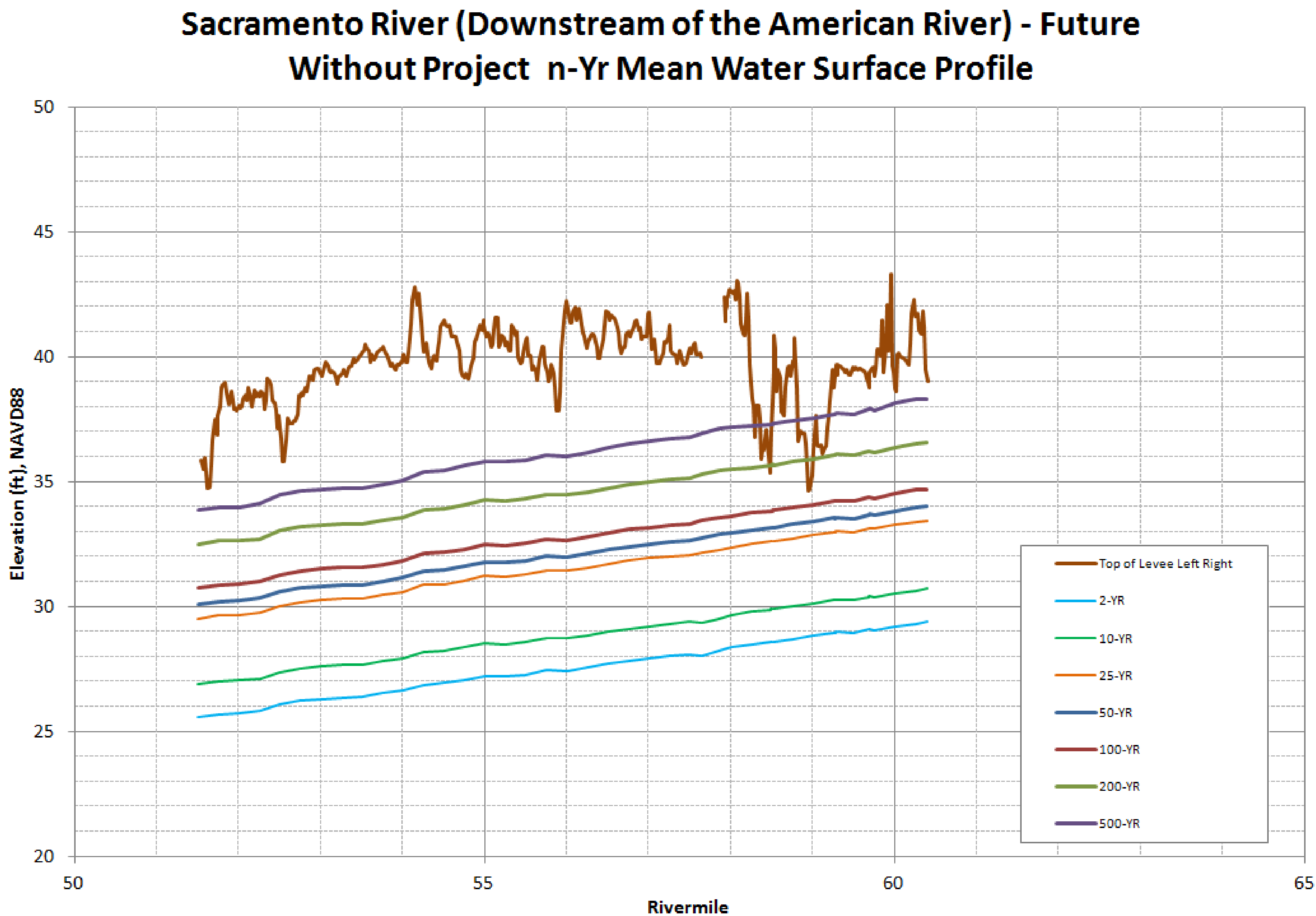
U.S. Army Corps of Engineers
Sacramento District

LEGEND

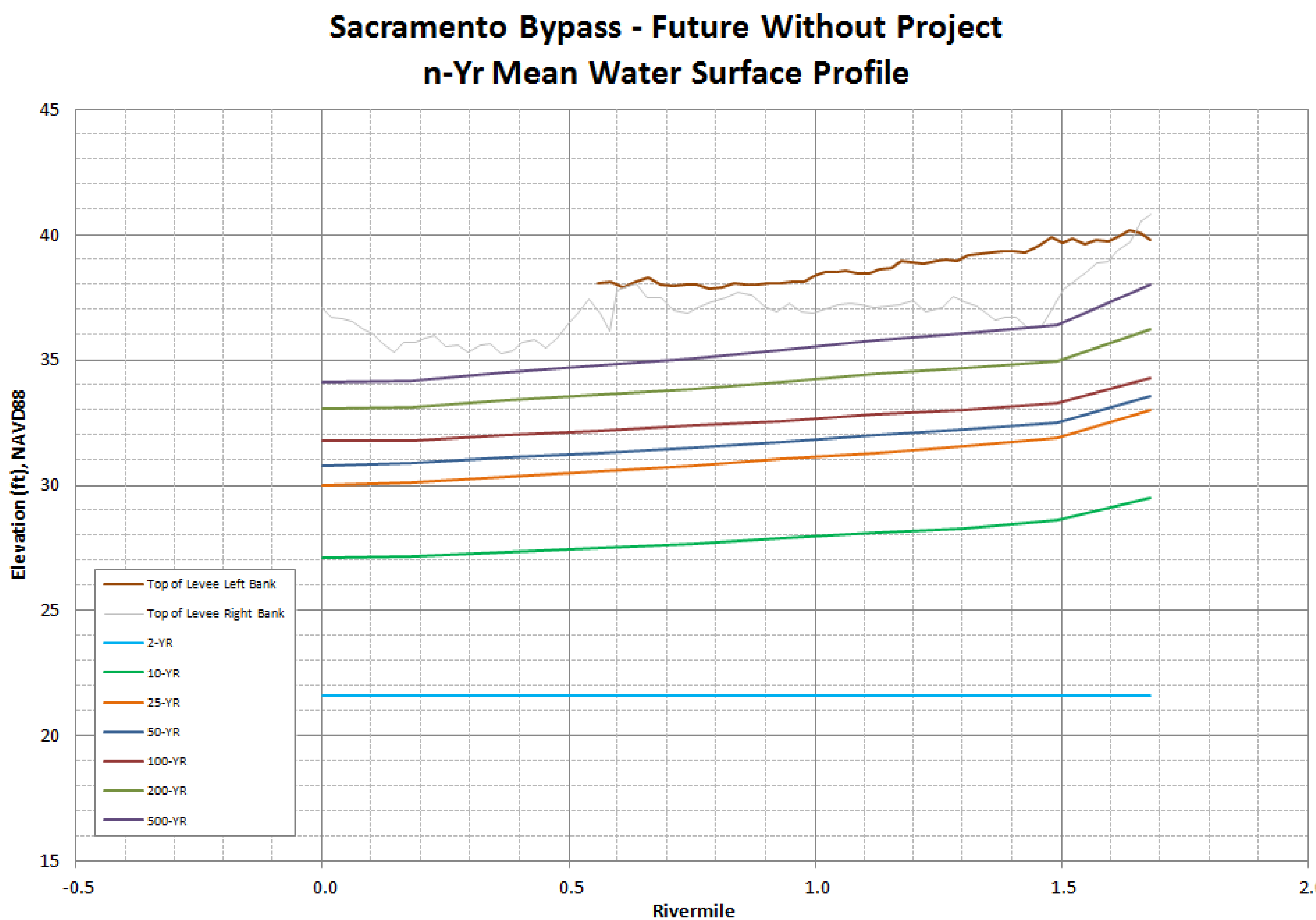
- IndexPoints
- Project Levees
- Non-Project Levees



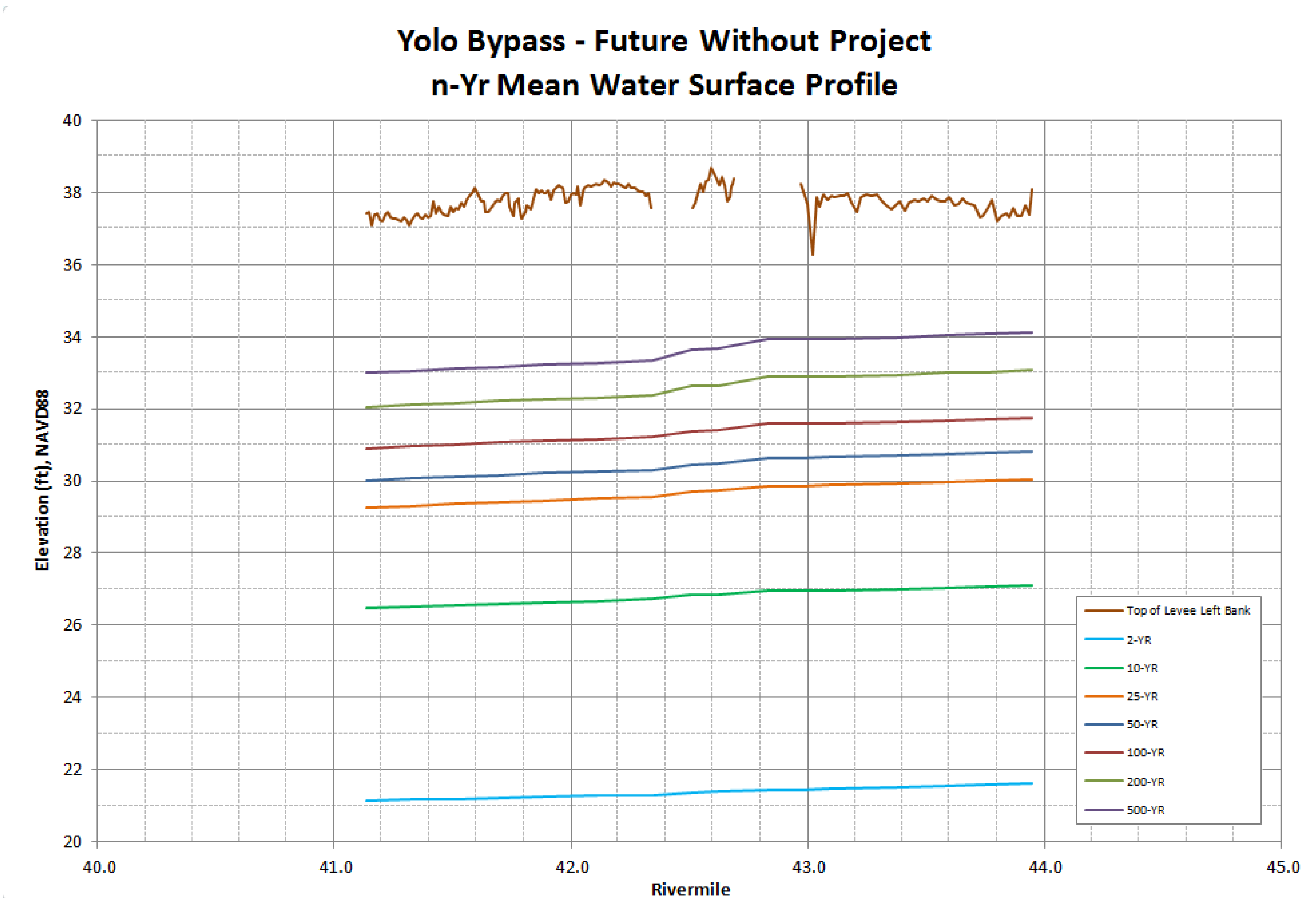
WEST SACRAMENTO GRR FEASBILITY STUDY SACRAMENTO, CALIFORNIA	SACRAMENTO RIVER RIGHT BANK LEVEE UPSTREAM OF AMERICAN RIVER	U.S ARMY CORPS OF ENGINEERS SACRAMENTO DISTRICT



WEST SACRAMENTO GRR FEASBILITY STUDY SACRAMENTO, CALIFORNIA	SACRAMENTO RIVER RIGHT BANK LEVEE DOWNSTREAM OF AMERICAN RIVER	U.S ARMY CORPS OF ENGINEERS SACRAMENTO DISTRICT

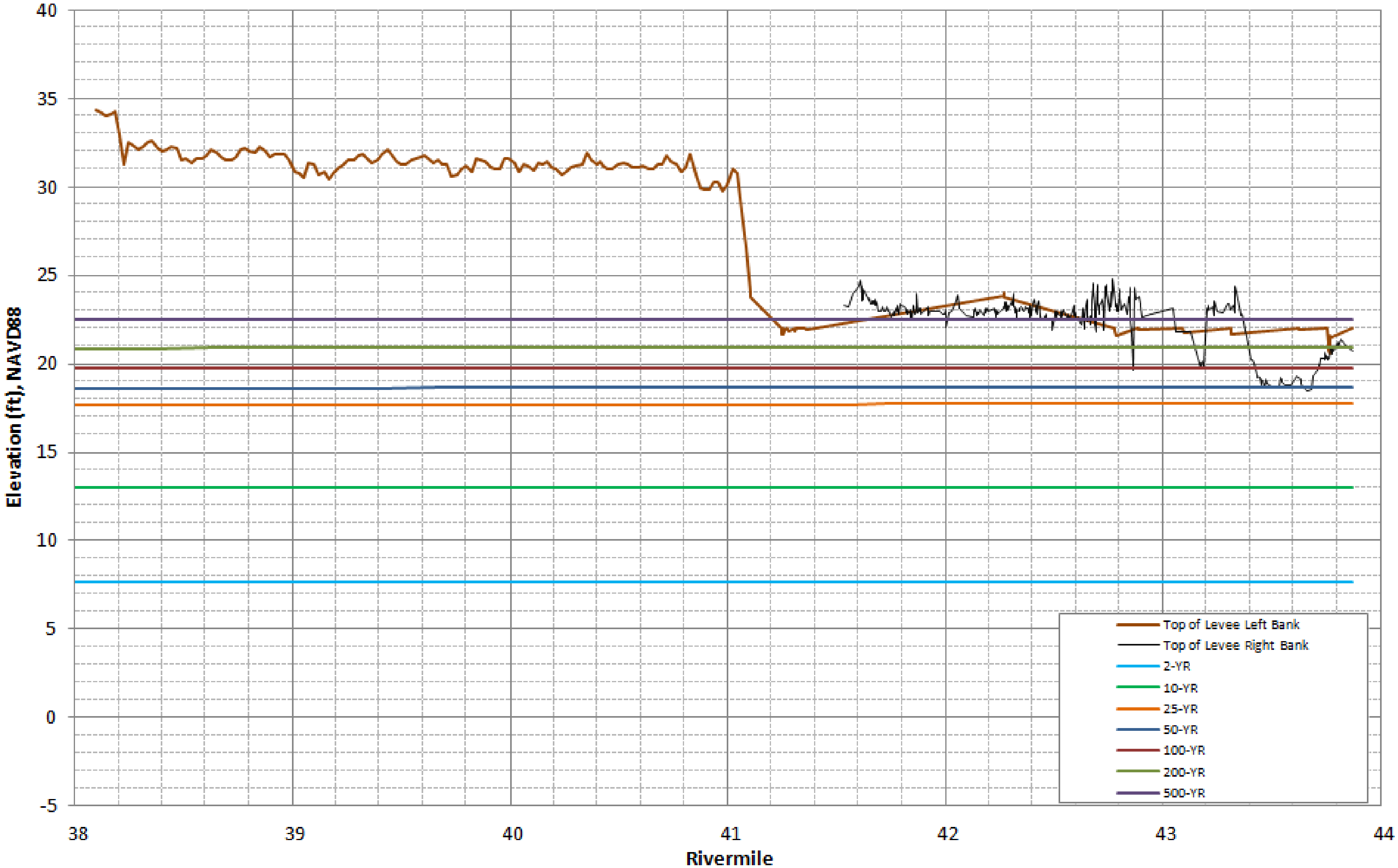


WEST SACRAMENTO GRR FEASBILITY STUDY SACRAMENTO, CALIFORNIA	SACRAMENTO BYPASS	U.S ARMY CORPS OF ENGINEERS SACRAMENTO DISTRICT

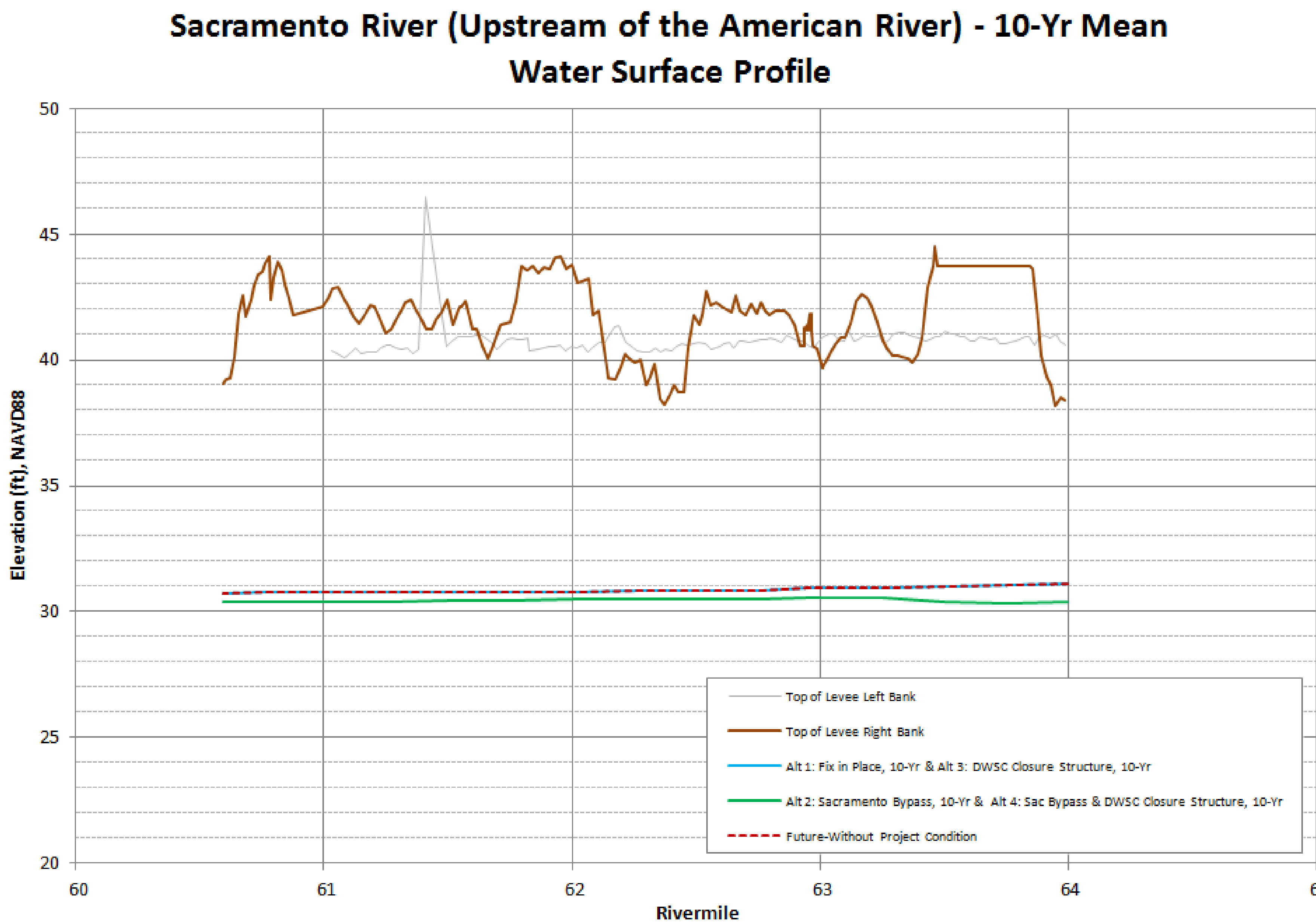


WEST SACRAMENTO GRR FEASBILITY STUDY SACRAMENTO, CALIFORNIA	YOLO BYPASS	U.S ARMY CORPS OF ENGINEERS SACRAMENTO DISTRICT

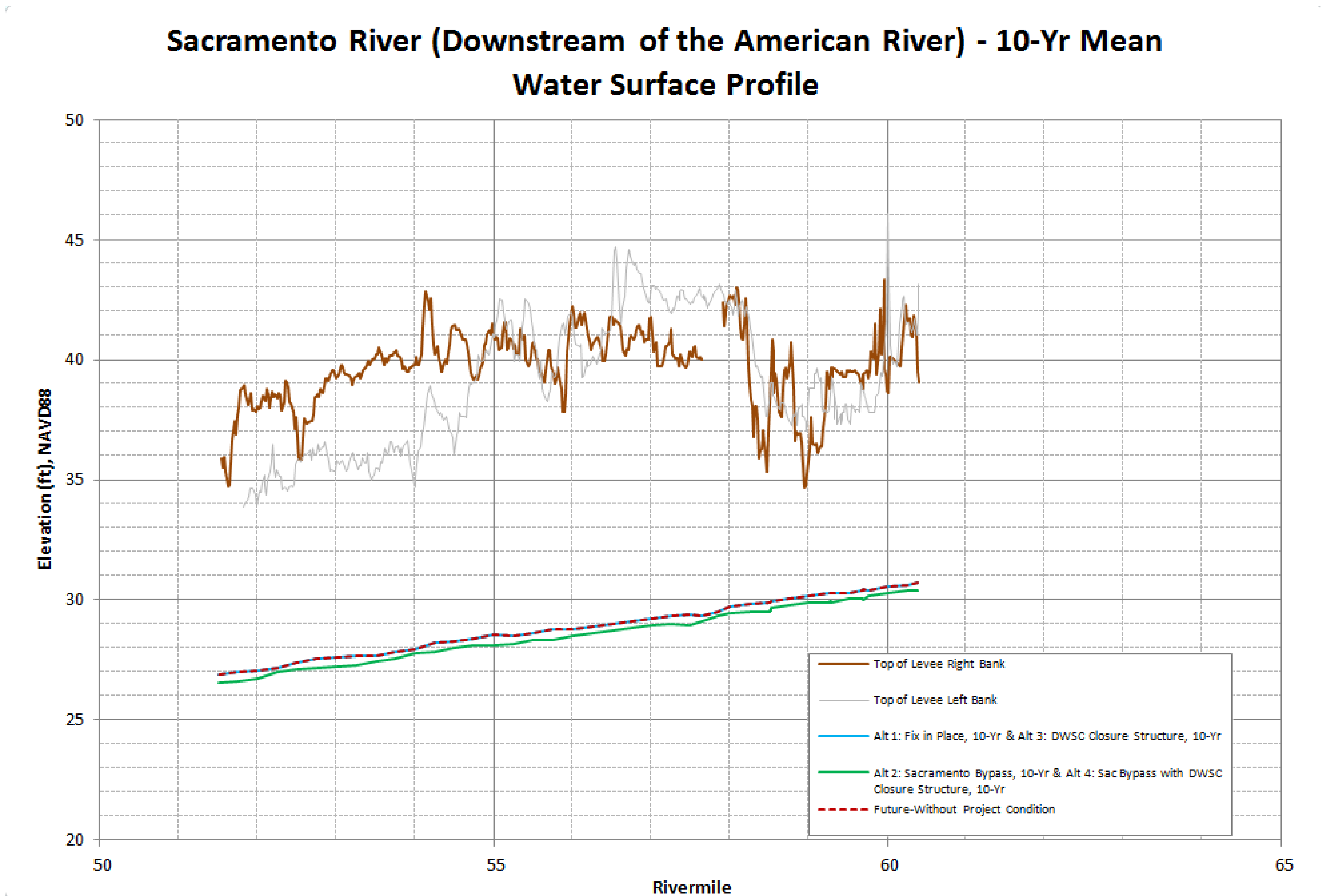
Sacramento Deep Water Ship Channel
Future Without Project n-Yr Mean Water Surface Profile



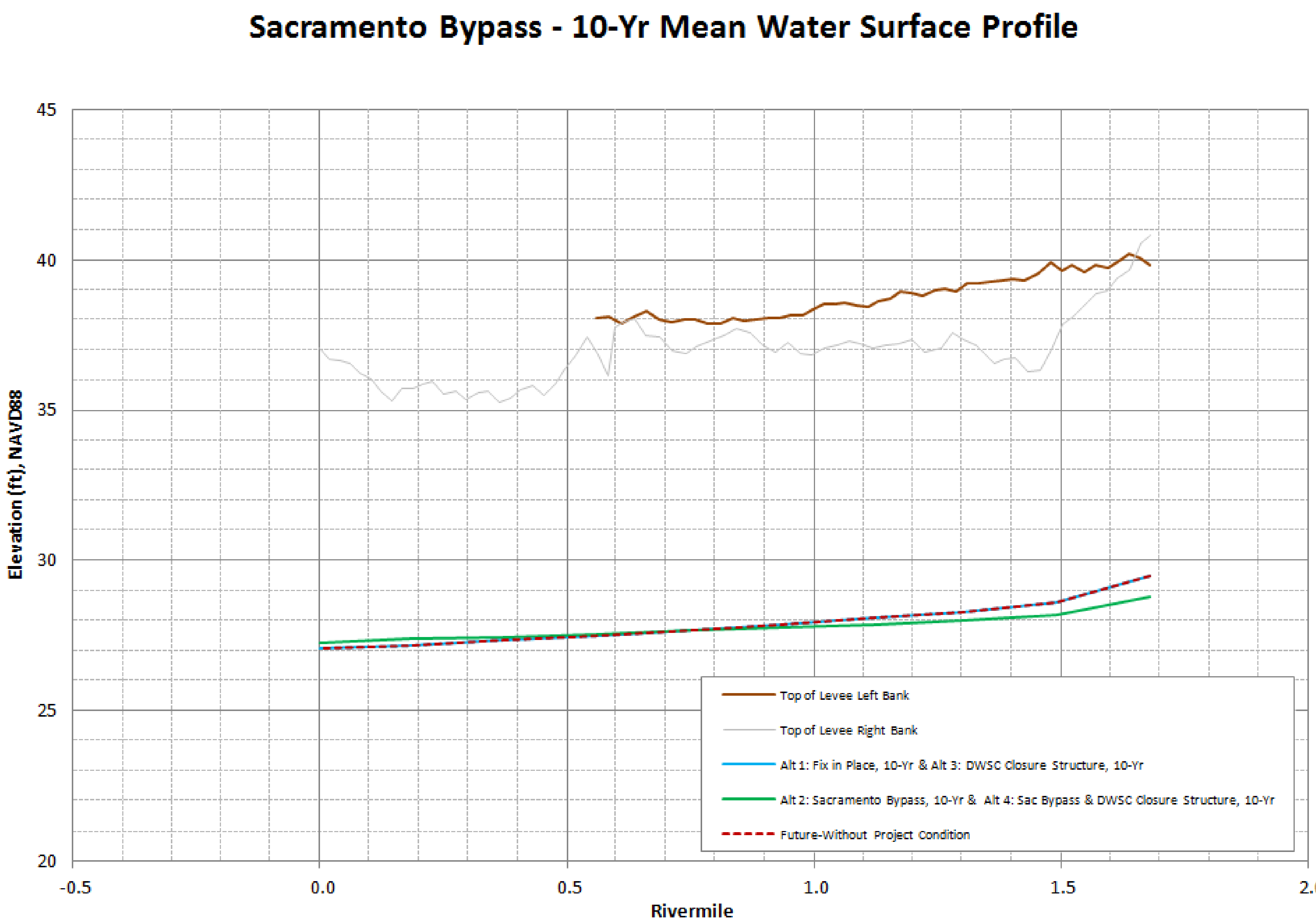
WEST SACRAMENTO GRR FEASBILITY STUDY SACRAMENTO, CALIFORNIA	SACRAMENTO DEEP WATER SHIP CHANNEL	U.S ARMY CORPS OF ENGINEERS SACRAMENTO DISTRICT



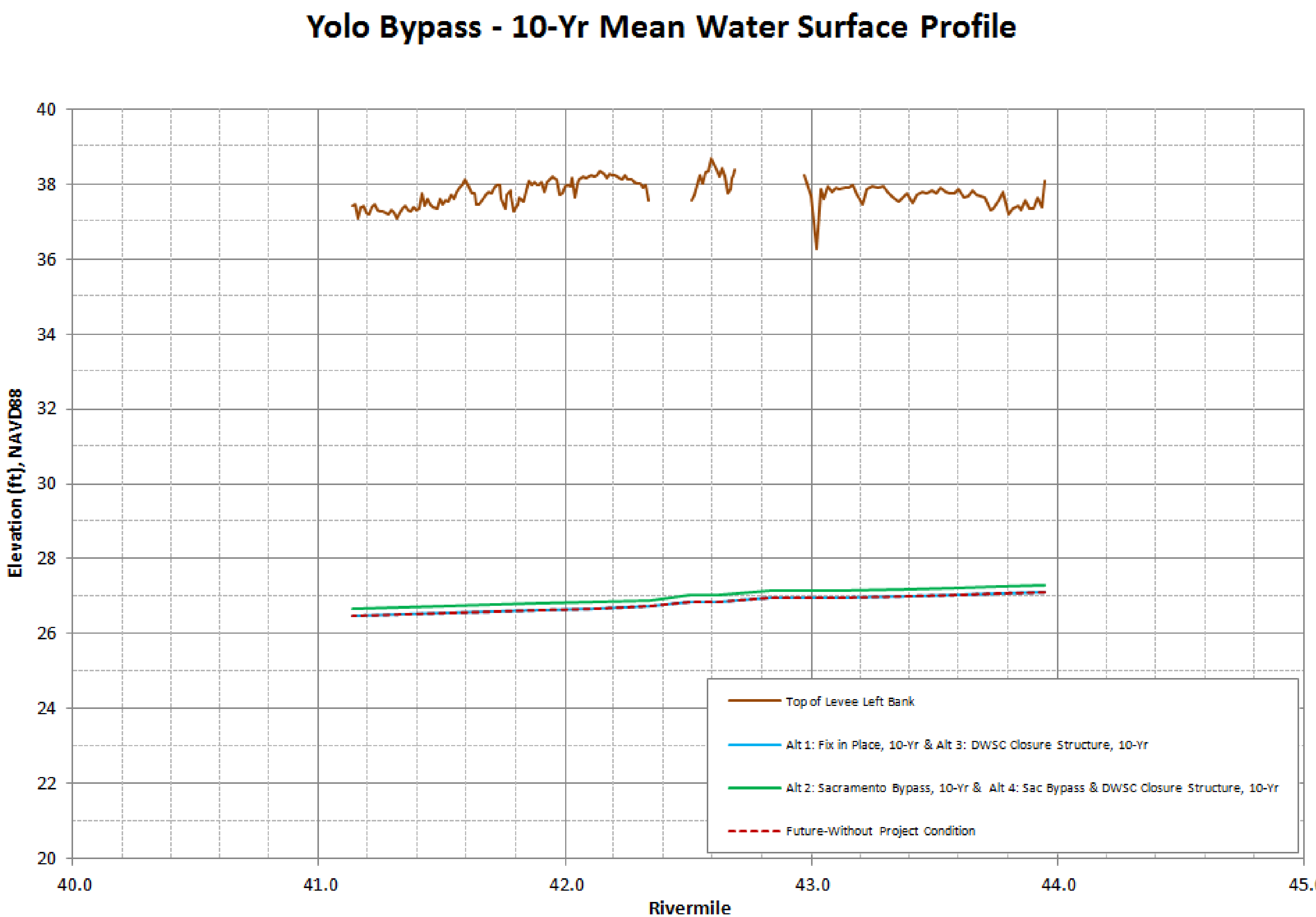
WEST SACRAMENTO GRR FEASBILITY STUDY SACRAMENTO, CALIFORNIA	SACRAMENTO RIVER (U/S OF THE AMERICAN RIVER) – RIGHT BANK LEVEE 10- YR WATER SURFACE PROFILES WITH-PROJECT ALTERNATIVES	U.S ARMY CORPS OF ENGINEERS SACRAMENTO DISTRICT



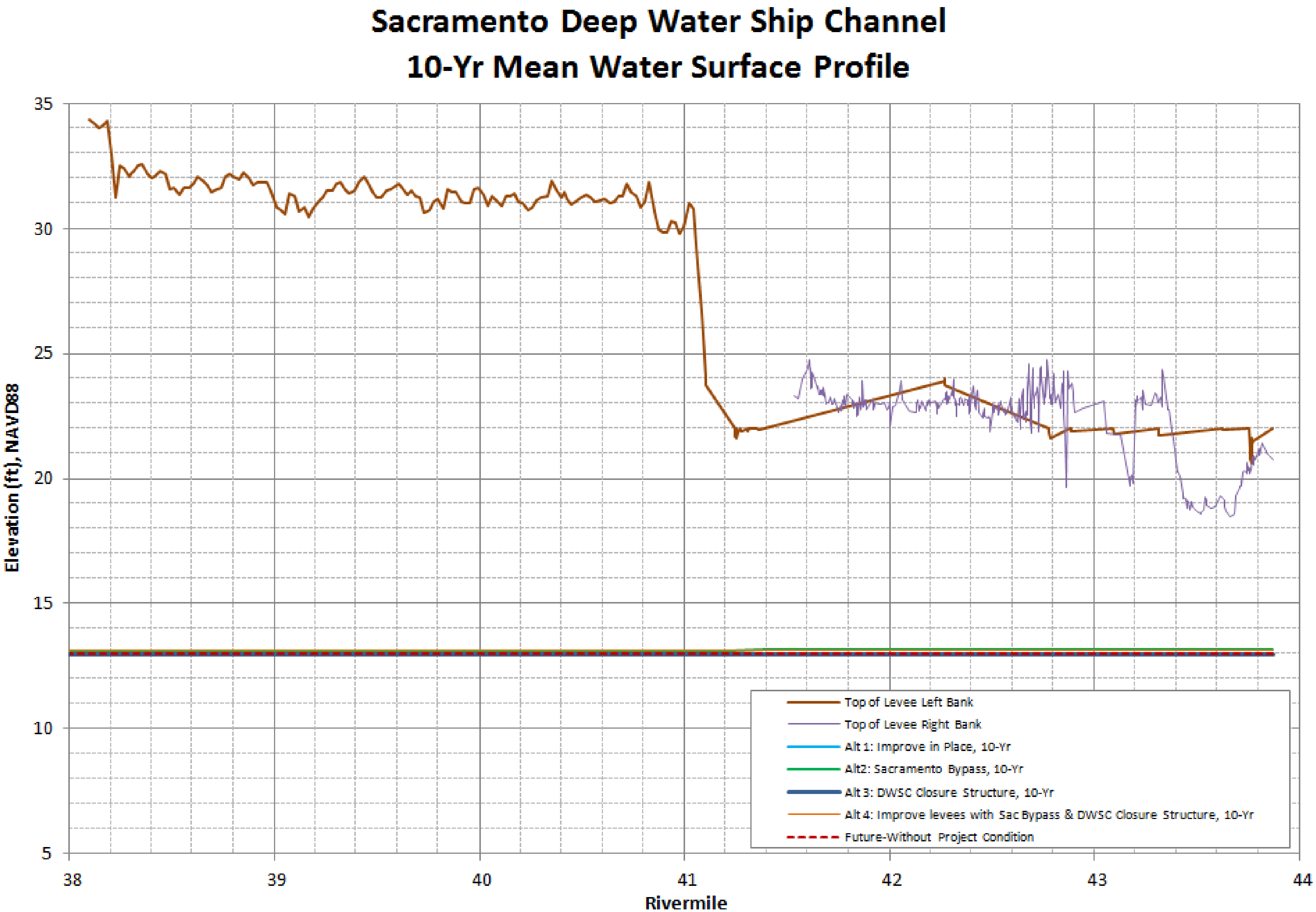
WEST SACRAMENTO GRR FEASBILITY STUDY SACRAMENTO, CALIFORNIA	SACRAMENTO RIVER (D/S OF THE AMERICAN RIVER) – RIGHT BANK LEVEE 10- YR WATER SURFACE PROFILES WITH-PROJECT ALTERNATIVES	U.S ARMY CORPS OF ENGINEERS SACRAMENTO DISTRICT



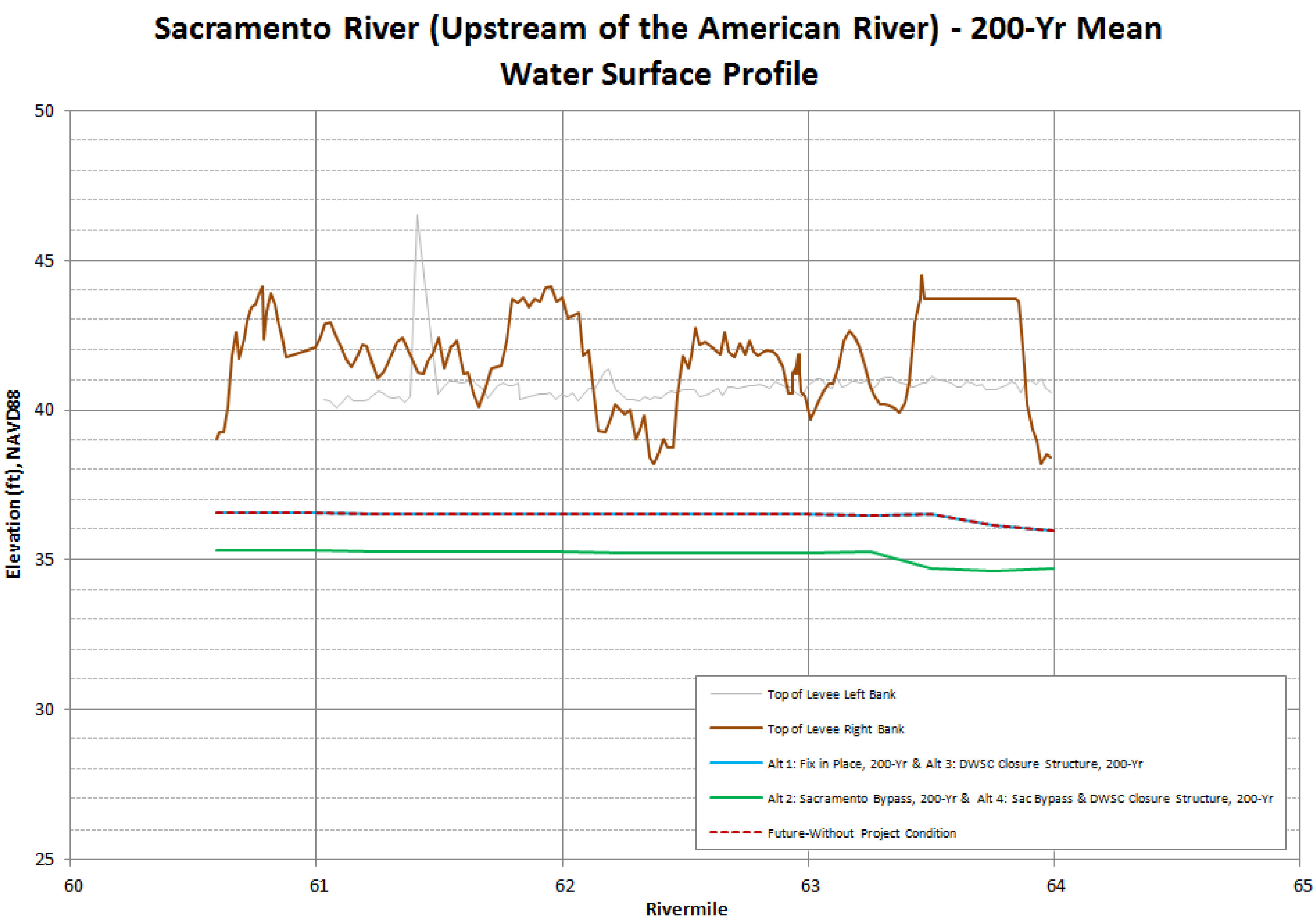
WEST SACRAMENTO GRR FEASBILITY STUDY SACRAMENTO, CALIFORNIA	SACRAMENTO BYPASS – LEFT BANK LEVEE 10- YR WATER SURFACE PROFILES WITH-PROJECT ALTERNATIVES	U.S ARMY CORPS OF ENGINEERS SACRAMENTO DISTRICT



WEST SACRAMENTO GRR FEASBILITY STUDY SACRAMENTO, CALIFORNIA	YOLO BYPASS – LEFT BANK LEVEE 10- YR WATER SURFACE PROFILES WITH-PROJECT ALTERNATIVES	U.S ARMY CORPS OF ENGINEERS SACRAMENTO DISTRICT

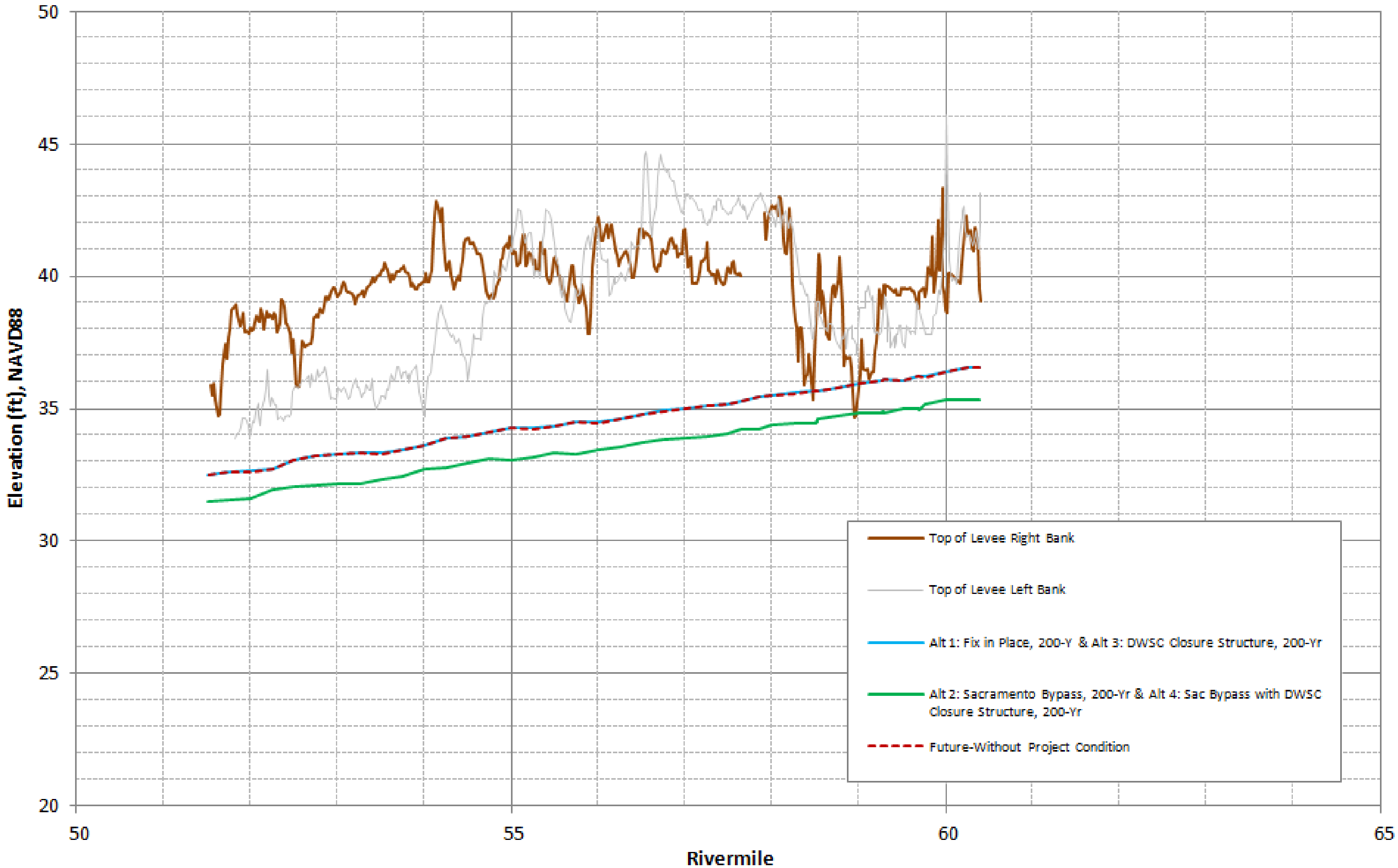


WEST SACRAMENTO GRR FEASBILITY STUDY SACRAMENTO, CALIFORNIA	SACRAMENTO DEEP WATER SHIP CHANNEL – LEFT & RIGHT BANK LEVEE 10- YR WATER SURFACE PROFILES WITH-PROJECT ALTERNATIVES	U.S ARMY CORPS OF ENGINEERS SACRAMENTO DISTRICT

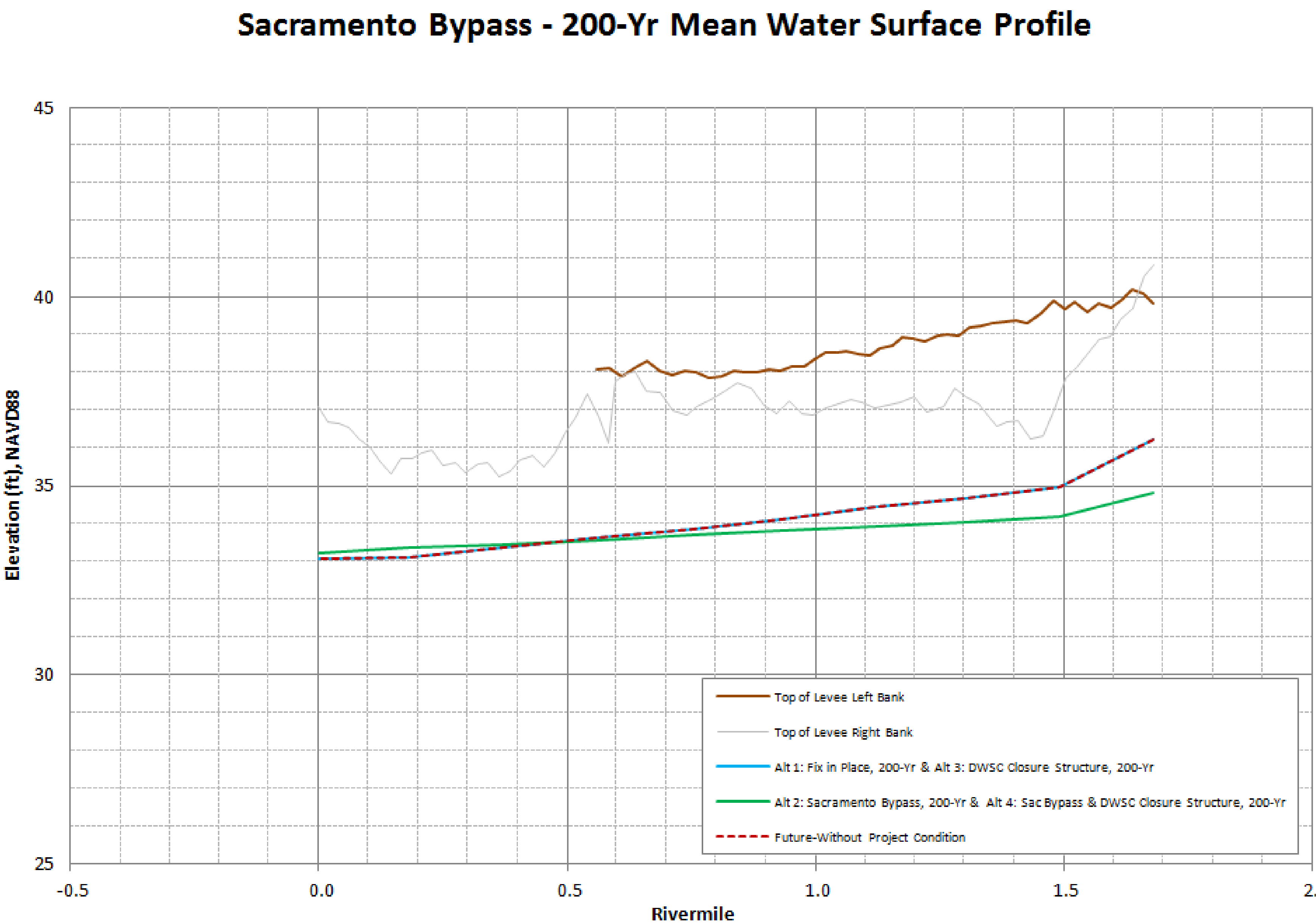


WEST SACRAMENTO GRR FEASBILITY STUDY SACRAMENTO, CALIFORNIA	SACRAMENTO RIVER (U/S OF THE AMERICAN RIVER) – RIGHT BANK LEVEE 200- YR WATER SURFACE PROFILES WITH-PROJECT ALTERNATIVES	U.S ARMY CORPS OF ENGINEERS SACRAMENTO DISTRICT

Sacramento River (Downstream of the American River) - 200-Yr Mean Water Surface Profile

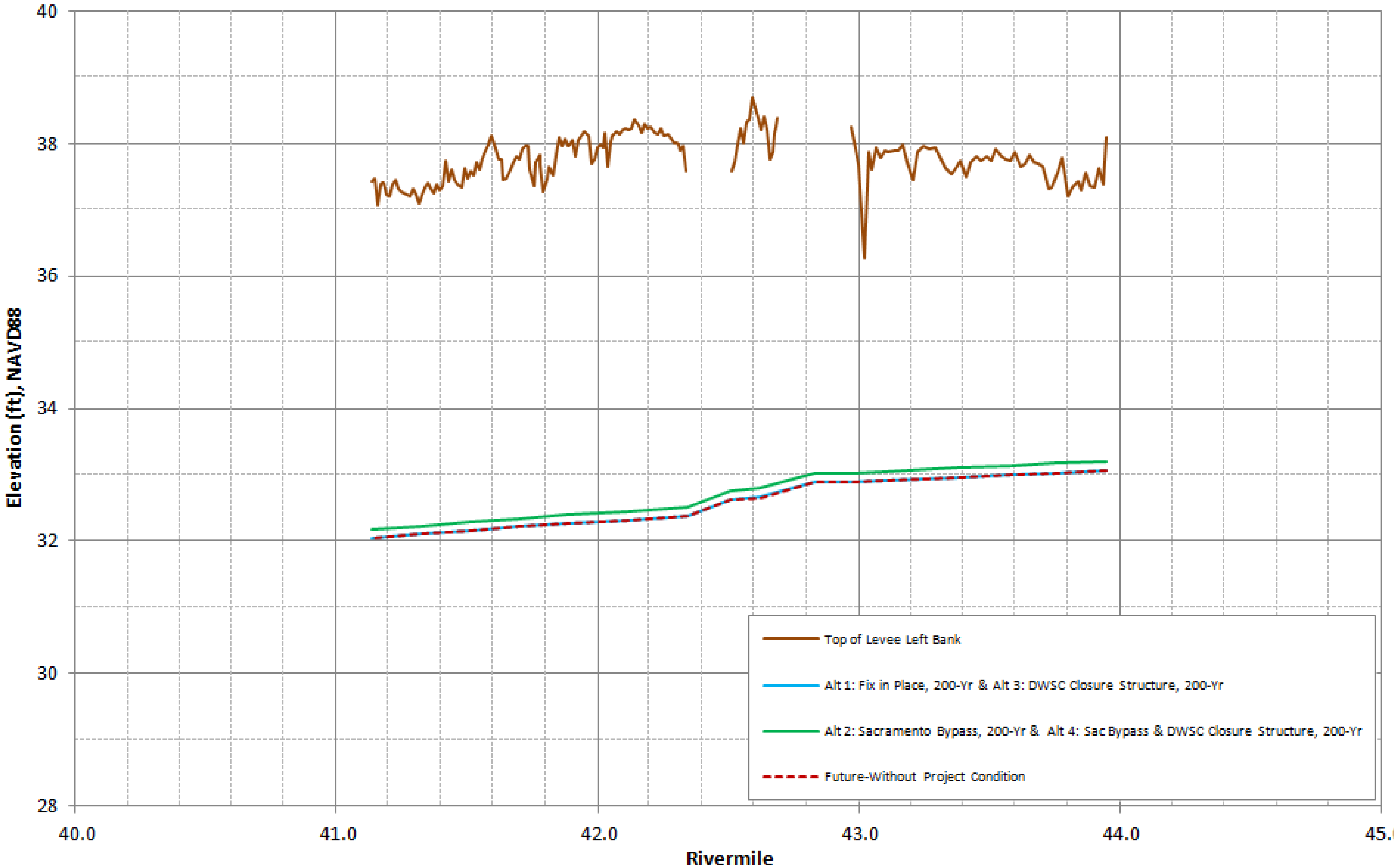


WEST SACRAMENTO GRR FEASBILITY STUDY SACRAMENTO, CALIFORNIA	SACRAMENTO RIVER (D/S OF THE AMERICAN RIVER) – RIGHT BANK LEVEE 200- YR WATER SURFACE PROFILES WITH-PROJECT ALTERNATIVES	U.S ARMY CORPS OF ENGINEERS SACRAMENTO DISTRICT

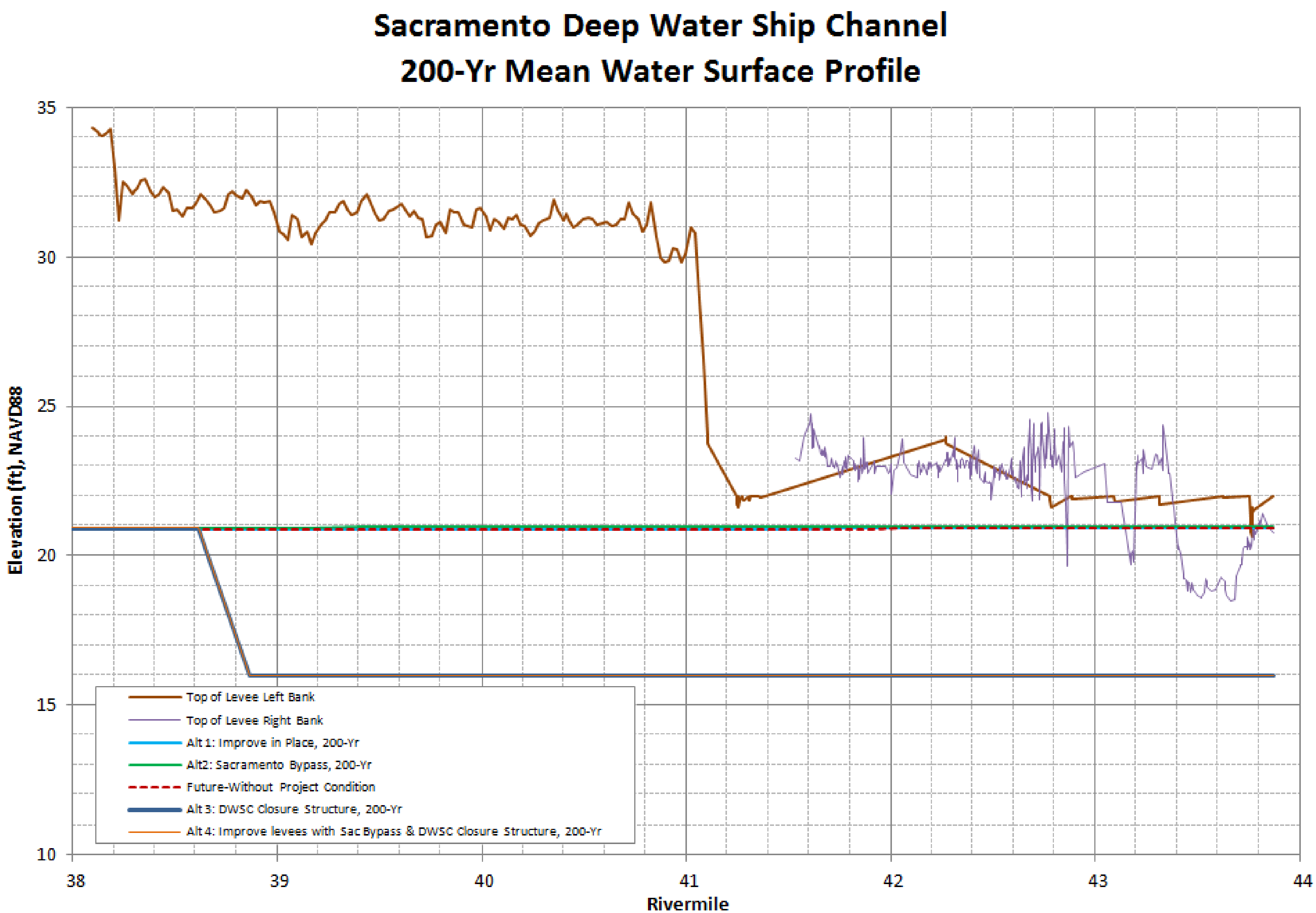


WEST SACRAMENTO GRR FEASBILITY STUDY SACRAMENTO, CALIFORNIA	SACRAMENTO BYPASS – LEFT BANK LEVEE 200- YR WATER SURFACE PROFILES WITH-PROJECT ALTERNATIVES	U.S ARMY CORPS OF ENGINEERS SACRAMENTO DISTRICT

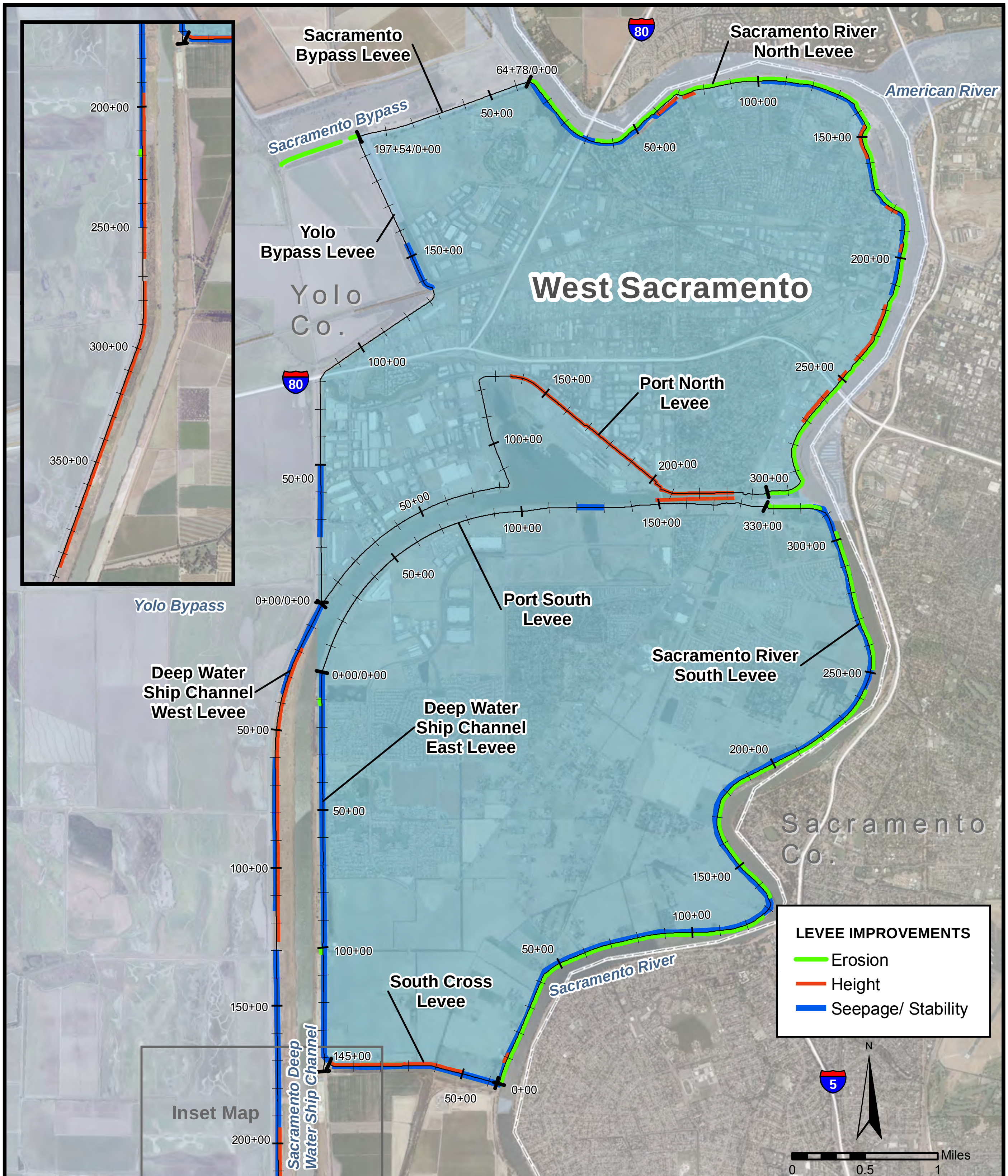
Yolo Bypass - 200-Yr Mean Water Surface Profile



WEST SACRAMENTO GRR FEASBILITY STUDY SACRAMENTO, CALIFORNIA	YOLO BYPASS – LEFT BANK LEVEE 200- YR WATER SURFACE PROFILES WITH-PROJECT ALTERNATIVES	U.S ARMY CORPS OF ENGINEERS SACRAMENTO DISTRICT

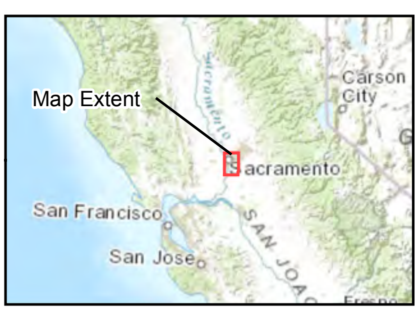


WEST SACRAMENTO GRR FEASBILITY STUDY SACRAMENTO, CALIFORNIA	SACRAMENTO DEEP WATER SHIP CHANNEL – LEFT & RIGHT BANK LEVEE 200- YR WATER SURFACE PROFILES WITH-PROJECT ALTERNATIVES	U.S ARMY CORPS OF ENGINEERS SACRAMENTO DISTRICT



Legend

- Levee Centerline
- Floodways
- West Sacramento Project Area
- County Lines

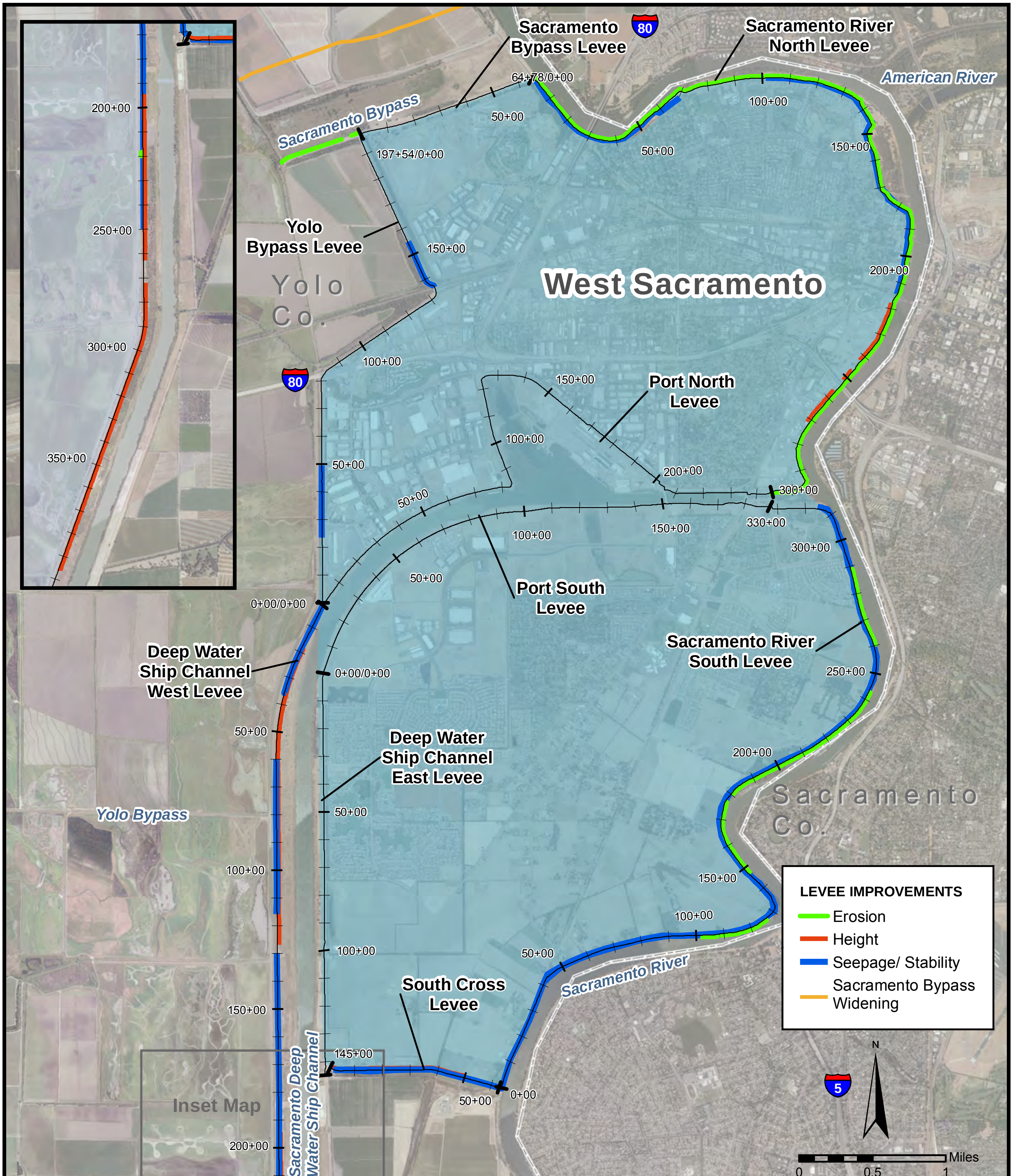


WEST SACRAMENTO GRR
WEST SACRAMENTO, CALIFORNIA

LEVEE IMPROVEMENTS ALTERNATIVE 1

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Plate 21

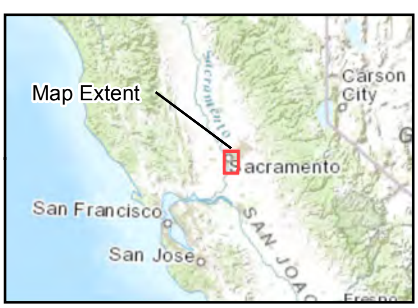


Legend

Levee Centerline

West Sacramento Project Area

County Lines

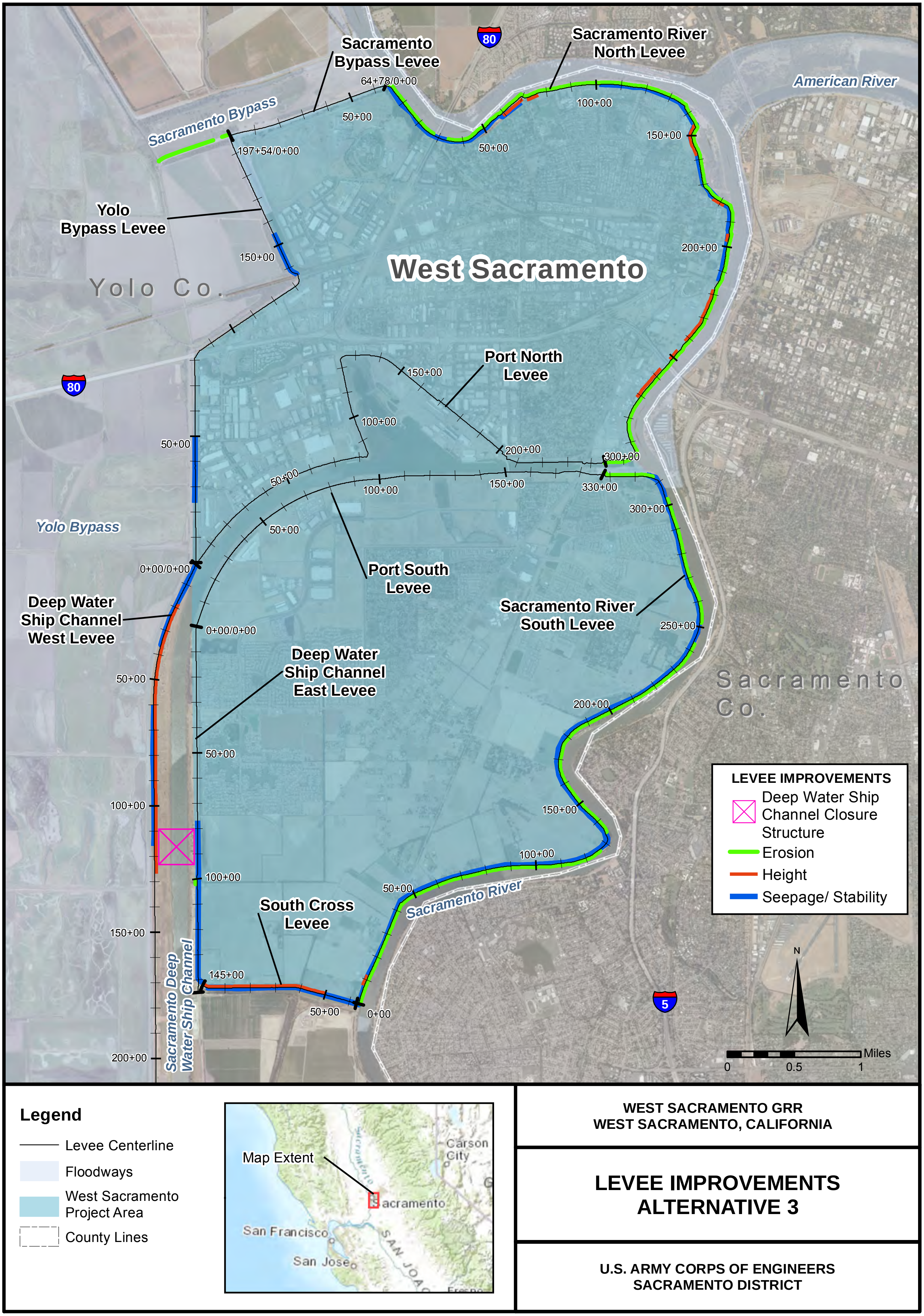


WEST SACRAMENTO GRR
WEST SACRAMENTO, CALIFORNIA

LEVEE IMPROVEMENTS ALTERNATIVE 2

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Plate 22

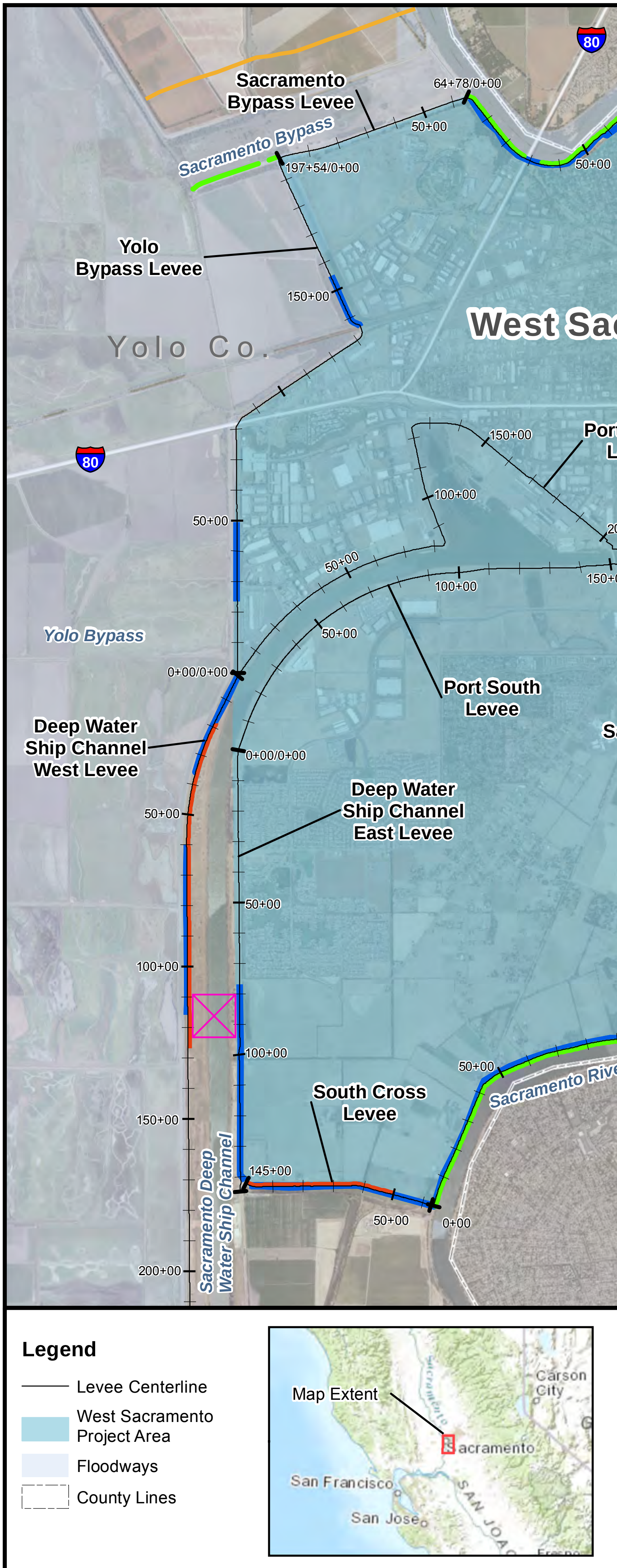


WEST SACRAMENTO GRR
WEST SACRAMENTO, CALIFORNIA

LEVEE IMPROVEMENTS ALTERNATIVE 3

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Plate 23

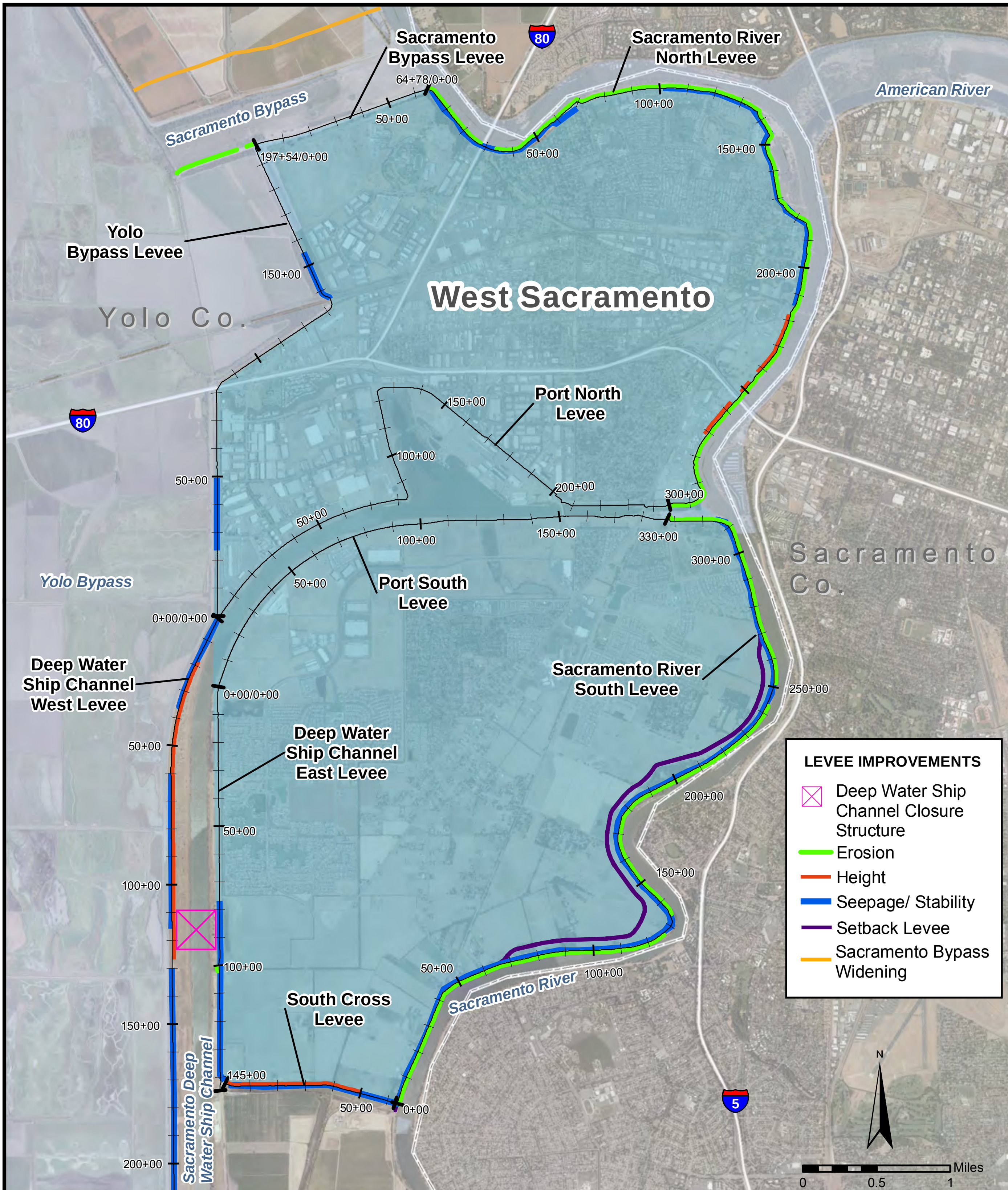


WEST SACRAMENTO GRR
WEST SACRAMENTO, CALIFORNIA

LEVEE IMPROVEMENTS ALTERNATIVE 4

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Plate 24



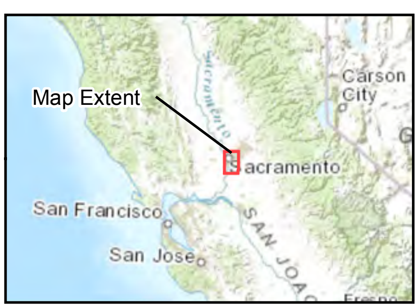
Legend

Levee Centerline

Floodways

West Sacramento Project Area

County Lines

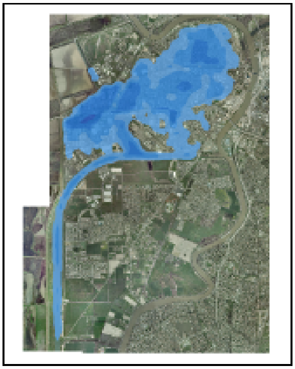


WEST SACRAMENTO GRR
WEST SACRAMENTO, CALIFORNIA

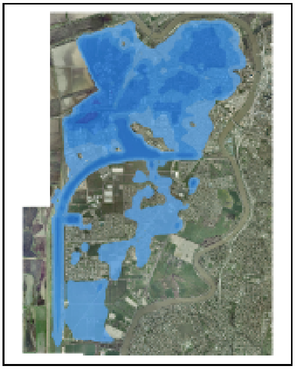
LEVEE IMPROVEMENTS ALTERNATIVE 5

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

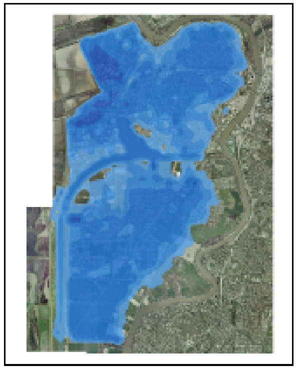
Plate 25



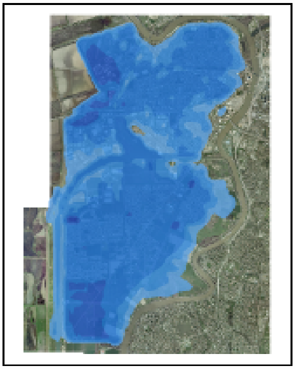
2-yr Inundation Map



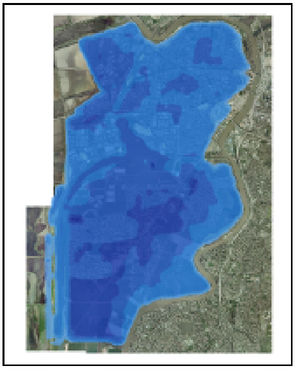
10-yr Inundation Map



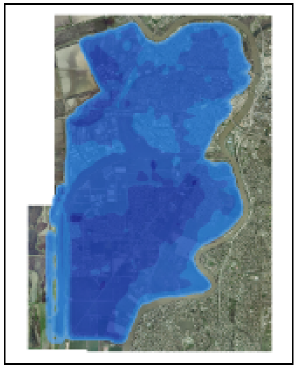
25-yr Inundation Map



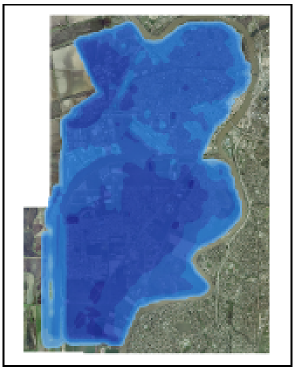
50-yr Inundation Map



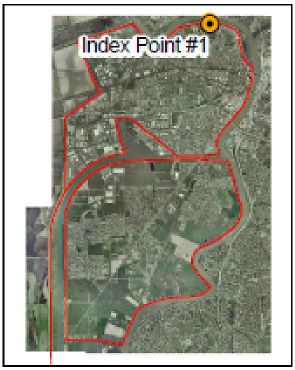
100-yr Inundation Map



200-yr Inundation Map



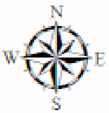
500-yr Inundation Map



Legend

Depths of Flooding (Feet)

- 0.1 - 0.5
- 0.6 - 1
- 1.1 - 3
- 3.1 - 5
- 5.1 - 10
- 10.1 - 15
- 15.1 - 20
- 20.1 - 25
- 25.1 - 30



0 1.5 3

Miles

May 2011

US Army Corps of Engineers

WSAFCA

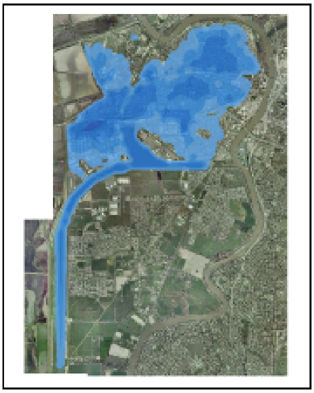
West Sacramento Project
General Reevaluation Report

2-Yr Thru 500-yr Inundation Map
Index Point 1
Sacramento River RM 61

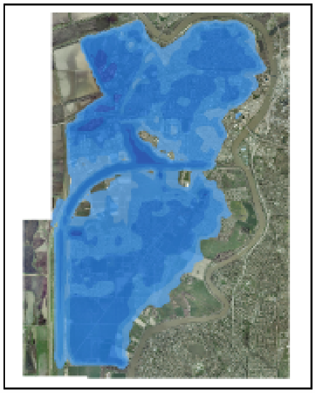
U.S. Army Corps of Engineers
Sacramento District

Without project condition floodplains based on a single levee break into the West Sacramento Basin.

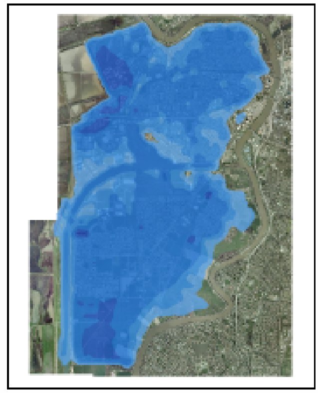
Plate 26 - Sac River Index Point 1



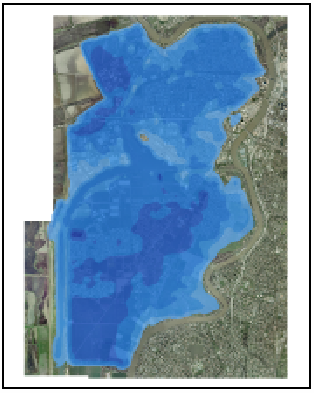
2-yr Inundation Map



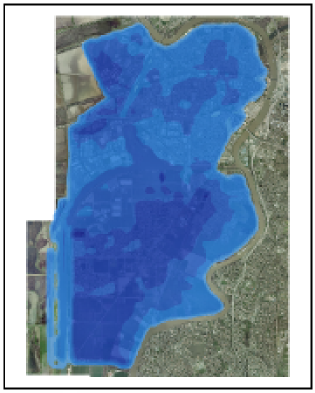
10-yr Inundation Map



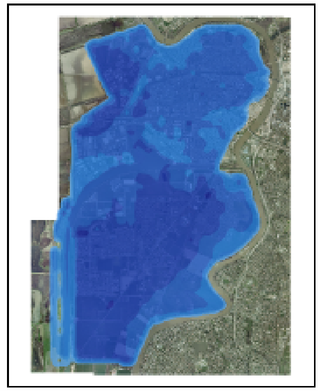
25-yr Inundation Map



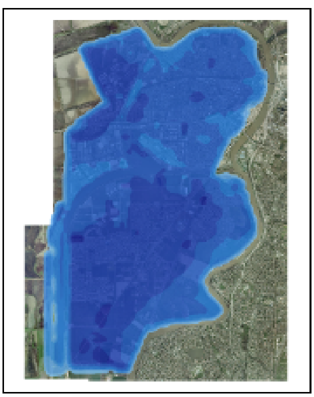
50-yr Inundation Map



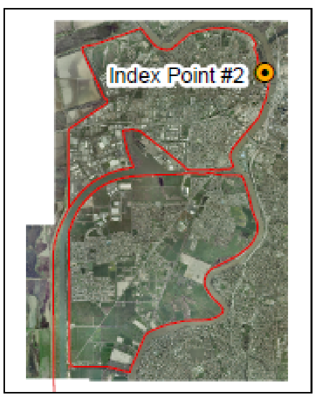
100-yr Inundation Map



200-yr Inundation Map



500-yr Inundation Map

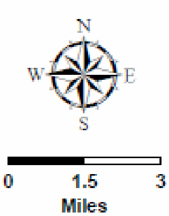


Basemap

Legend

Depths of Flooding (Feet)

- 0.1 - 0.5
- 0.6 - 1
- 1.1 - 3
- 3.1 - 5
- 5.1 - 10
- 10.1 - 15
- 15.1 - 20
- 20.1 - 25
- 25.1 - 30



May 2011

US Army Corps of Engineers

WSAFCA

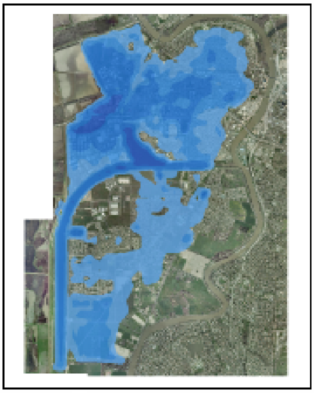
West Sacramento Project
General Reevaluation Report

2-Yr Thru 500-yr Inundation Map
Index Point 2
Sacramento River RM 60

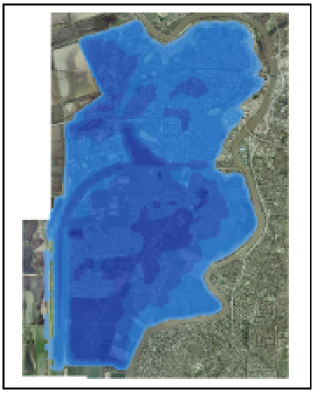
U.S. Army Corps of Engineers
Sacramento District

Without project condition floodplains based on a single levee break into the West Sacramento Basin.

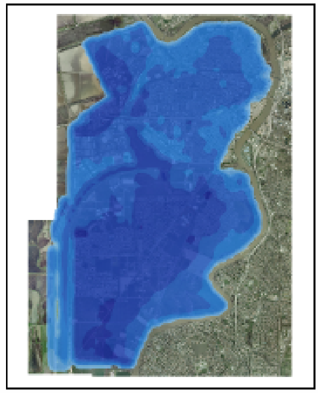
Plate 27 - Sac River Index Point 2



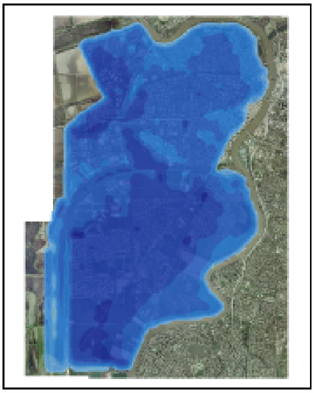
2-yr Inundation Map



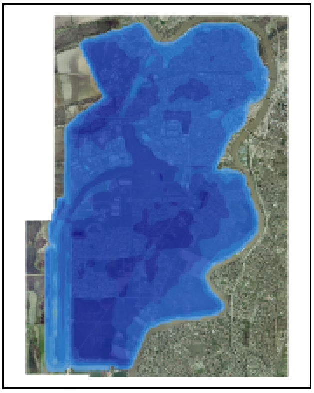
10-yr Inundation Map



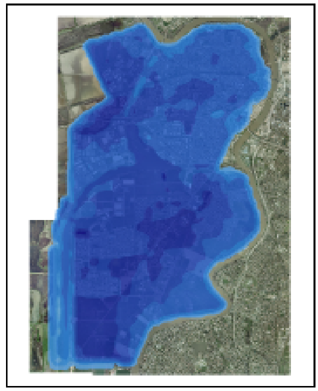
25-yr Inundation Map



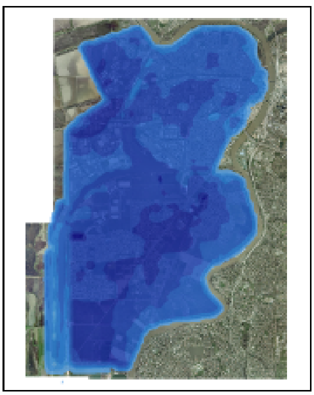
50-yr Inundation Map



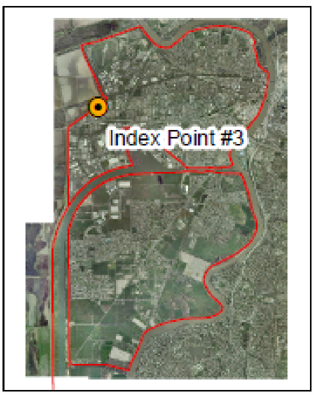
100-yr Inundation Map



200-yr Inundation Map



500-yr Inundation Map

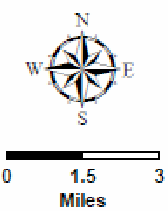


Basemap

Legend

Depths of Flooding (Feet)

- 0.1 - 0.5
- 0.6 - 1
- 1.1 - 3
- 3.1 - 5
- 5.1 - 10
- 10.1 - 15
- 15.1 - 20
- 20.1 - 25
- 25.1 - 30



May 2011

US Army Corps of Engineers

WSAFCA

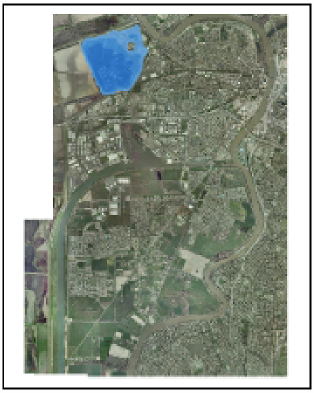
West Sacramento Project
General Reevaluation Report

2-Yr Thru 500-yr Inundation Map
Index Point 3
Yolo Bypass RM 42

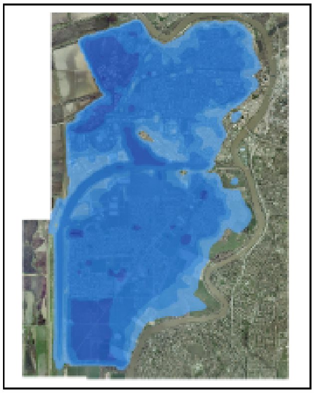
U.S. Army Corps of Engineers
Sacramento District

Without project condition floodplains based on a single levee break into the West Sacramento Basin.

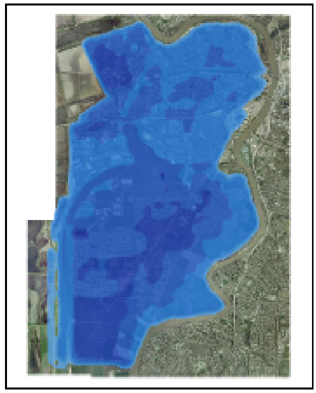
Plate 28 - Yolo Bypass Index Point 3



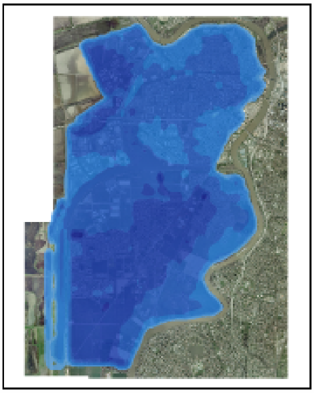
2-yr Inundation Map



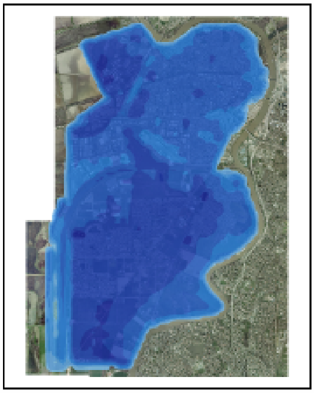
10-yr Inundation Map



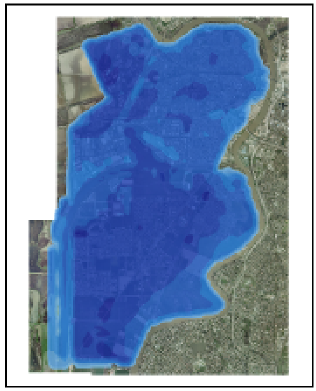
25-yr Inundation Map



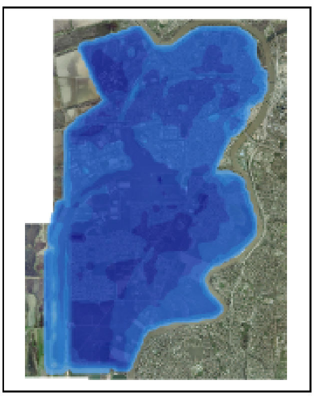
50-yr Inundation Map



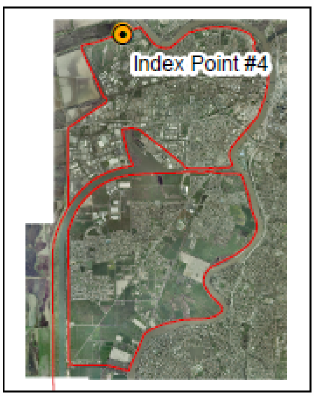
100-yr Inundation Map



200-yr Inundation Map



500-yr Inundation Map

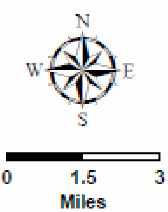


Basemap

Legend

Depths of Flooding (Feet)

- 0.1 - 0.5
- 0.6 - 1
- 1.1 - 3
- 3.1 - 5
- 5.1 - 10
- 10.1 - 15
- 15.1 - 20
- 20.1 - 25
- 25.1 - 30



May 2011

US Army Corps of Engineers

WSAFCA

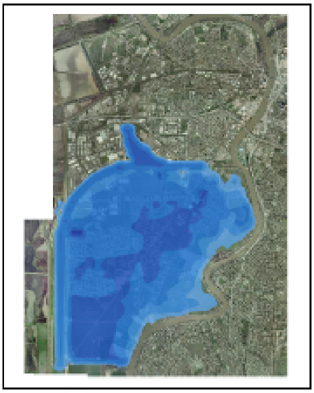
West Sacramento Project
General Reevaluation Report

2-Yr Thru 500-yr Inundation Map
Index Point 4
Sac Bypass RM 1.5

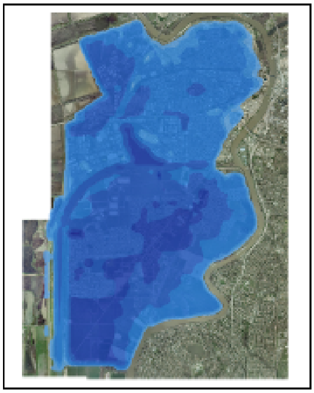
U.S. Army Corps of Engineers
Sacramento District

Without project condition floodplains based on a single levee break into the West Sacramento Basin.

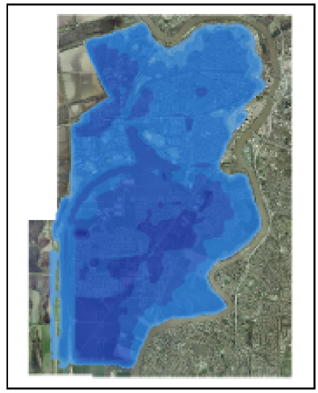
Plate 29 - Yolo Bypass Index Point 4



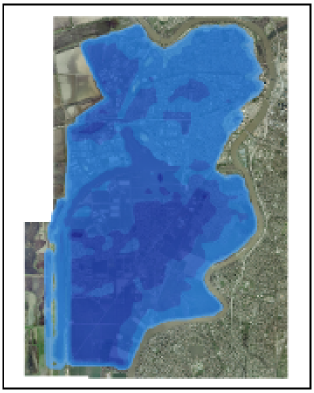
2-yr Inundation Map



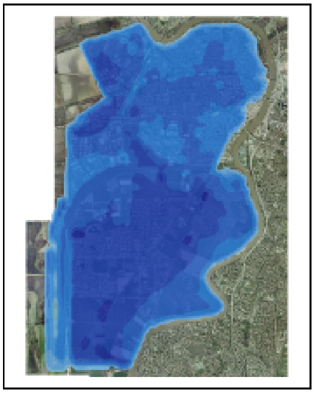
10-yr Inundation Map



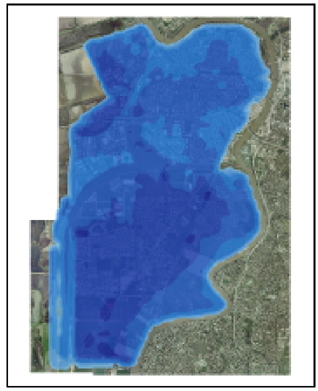
25-yr Inundation Map



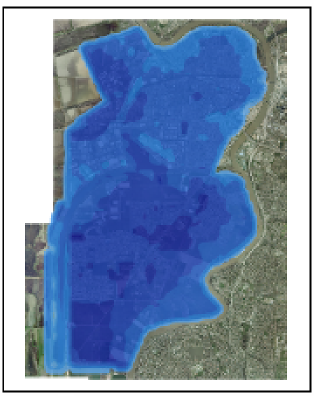
50-yr Inundation Map



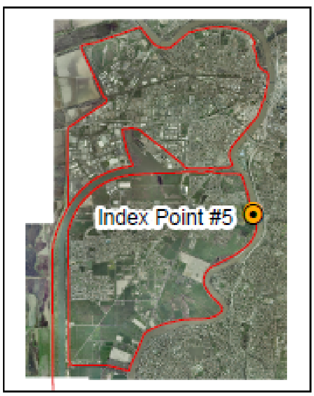
100-yr Inundation Map



200-yr Inundation Map



500-yr Inundation Map

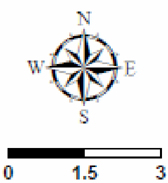


Basemap

Legend

Depths of Flooding (Feet)

- 0.1 - 0.5
- 0.6 - 1
- 1.1 - 3
- 3.1 - 5
- 5.1 - 10
- 10.1 - 15
- 15.1 - 20
- 20.1 - 25
- 25.1 - 30



May 2011

US Army Corps of Engineers

WSAFCA

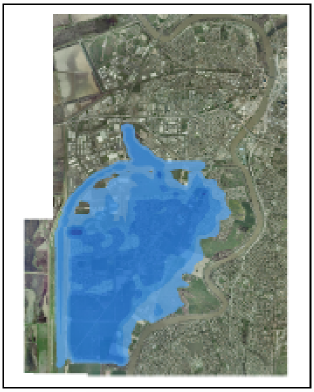
West Sacramento Project
General Reevaluation Report

2-Yr Thru 500-yr Inundation Map
Index Point 5
Sac River RM 57

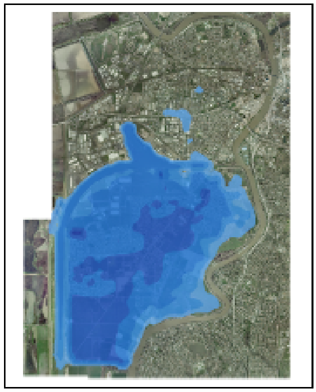
U.S. Army Corps of Engineers
Sacramento District

Without project condition floodplains based on a single levee break into the West Sacramento Basin.

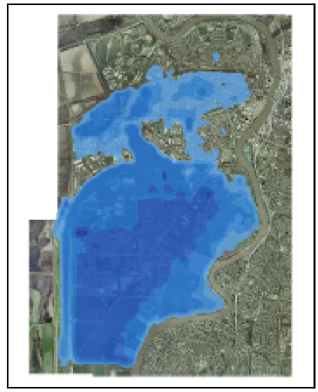
Plate 30 - Yolo Bypass Index Point 5



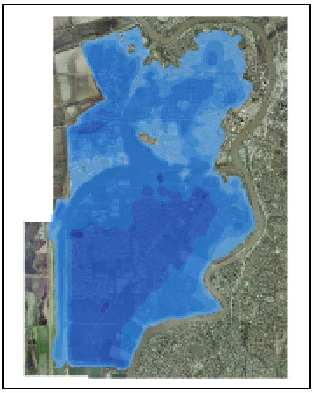
2-yr Inundation Map



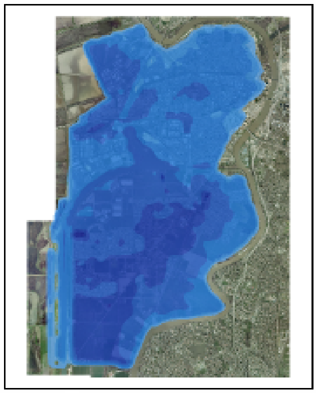
10-yr Inundation Map



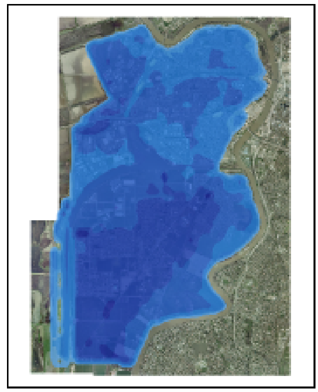
25-yr Inundation Map



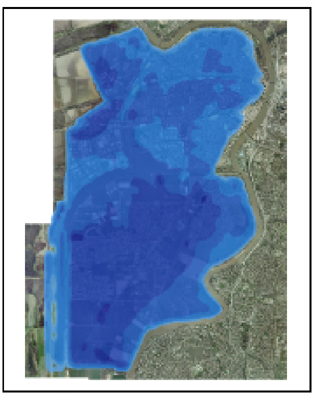
50-yr Inundation Map



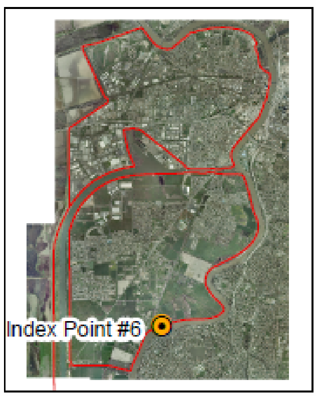
100-yr Inundation Map



200-yr Inundation Map



500-yr Inundation Map

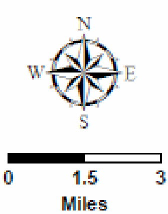


Basemap

Legend

Depths of Flooding (Feet)

- 0.1 - 0.5
- 0.6 - 1
- 1.1 - 3
- 3.1 - 5
- 5.1 - 10
- 10.1 - 15
- 15.1 - 20
- 20.1 - 25
- 25.1 - 30



May 2011

US Army Corps of Engineers

WSAFCA

West Sacramento Project
General Reevaluation Report

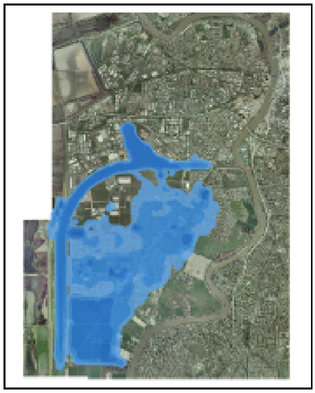
2-Yr Thru 500-yr Inundation Map
Index Point 6
Sac River RM 53

U.S. Army Corps of Engineers
Sacramento District

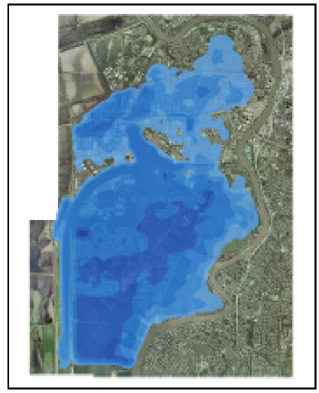
Without project condition floodplains based on a single levee break into the West Sacramento Basin.

Plate 31 - Sacramento River Index Point 6

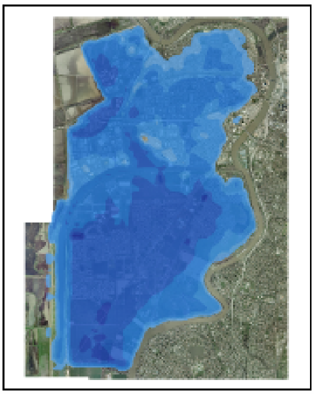
2-yr Inundation Map



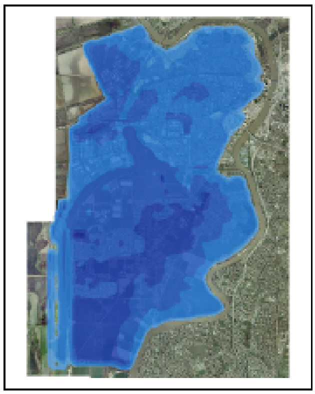
10-yr Inundation Map



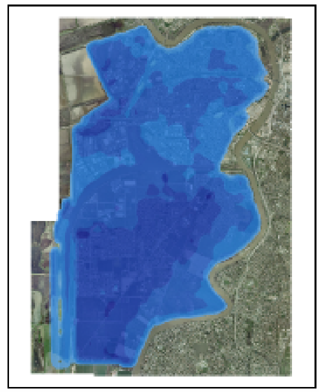
25-yr Inundation Map



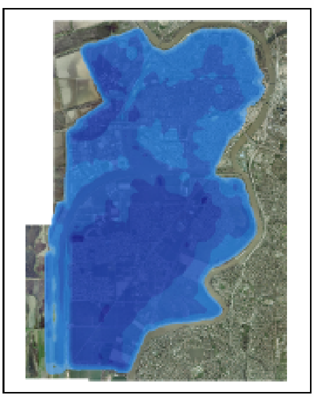
50-yr Inundation Map



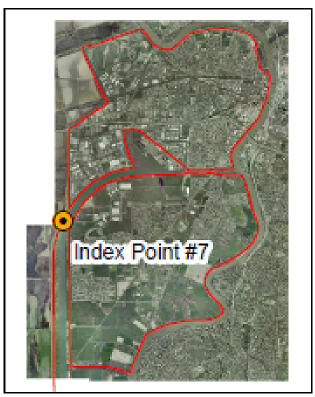
100-yr Inundation Map



200-yr Inundation Map



500-yr Inundation Map

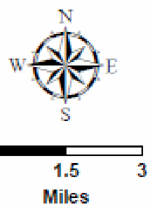


Basemap

Legend

Depths of Flooding (Feet)

- 0.1 - 0.5
- 0.6 - 1
- 1.1 - 3
- 3.1 - 5
- 5.1 - 10
- 10.1 - 15
- 15.1 - 20
- 20.1 - 25
- 25.1 - 30



May 2011

US Army Corps of Engineers

WSAFCA

West Sacramento Project
General Reevaluation Report

2-Yr Thru 500-yr Inundation Map
Index Point 7
Yolo Bypass RM 41

U.S. Army Corps of Engineers
Sacramento District

Without project condition floodplains based on a single levee break into the West Sacramento Basin.

Plate 32 - Yolo Bypass Index Point 7

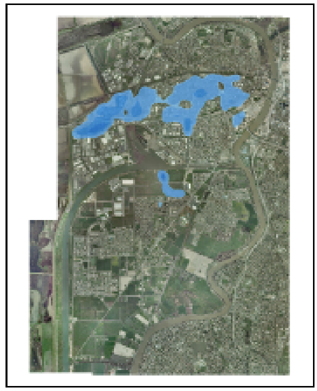
2-yr Inundation Map

10-yr Inundation Map

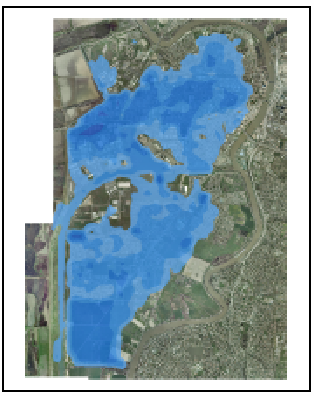
25-yr Inundation Map

50-yr Inundation Map

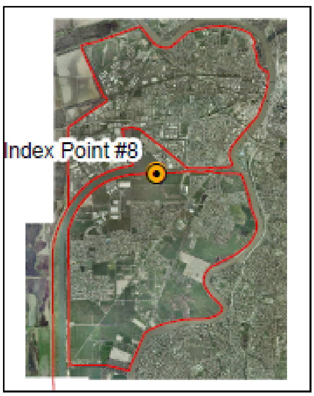
100-yr Inundation Map



200-yr Inundation Map



500-yr Inundation Map



Basemap

Legend

Depths of Flooding (Feet)

- 0.1 - 0.5
- 0.6 - 1
- 1.1 - 3
- 3.1 - 5
- 5.1 - 10
- 10.1 - 15
- 15.1 - 20
- 20.1 - 25
- 25.1 - 30

0 1.5 3

Miles

May 2011

US Army Corps of Engineers

WSAFCA

West Sacramento Project
General Reevaluation Report

2-Yr Thru 500-yr Inundation Map
Index Point 8
Sac DWSC RM 44

U.S. Army Corps of Engineers
Sacramento District

Without project condition floodplains based on a single levee break into the West Sacramento Basin.

Plate 33 - Sac DWSC Index Point 8

Index Point 1					
Sacramento River, RM 61.5					
	Future Without Project Condition	Alternative 1: Improve Levees in Place	Alternative 2: Sacramento Bypass Widening	Alternative 3: DWSC Closure Structure	Alternative 4: Improve Levees with Sacramento Bypass and DWSC Closure Structure
Frequency	**Stage (NAVD 88)**				
1yr = .999	27.0	27.0	27.0	27.0	27.0
2yr = .5	29.6	29.6	28.3	29.6	28.3
10yr = .1	30.8	30.8	30.4	30.8	30.4
25yr = .04	33.5	33.5	32.2	33.5	32.2
50yr = .02	34.0	34.0	32.8	34.0	32.8
100yr = .01	34.7	34.7	33.6	34.7	33.6
200yr = .005	36.5	36.5	35.3	36.5	35.3
500yr = .002	38.2	39.0	37.8	39.0	37.8
Frequency	**Flow (CFS)**				
2yr = .5	66903	66903	59539	66903	59539
10yr = .1	26078	26078	33817	26078	33817
25yr = .04	N/A	N/A	N/A	N/A	N/A
50yr = .02	N/A	N/A	N/A	N/A	N/A
100yr = .01	N/A	N/A	N/A	N/A	N/A
200yr = .005	N/A	N/A	N/A	N/A	N/A
500yr = .002	N/A	N/A	N/A	N/A	N/A

Source: Hydraulic Analysis Section, Sacramento District, USACE

WEST SACRAMENTO GRR
SACRAMENTO, CALIFORNIA

SACRAMENTO RIVER
INDEX POINT 1
RISK ANALYSIS INPUTS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Index Point 2 Sacramento River, RM 60					
	Future Without Project Condition	**Alternative 1: Improve Levees in Place**	**Alternative 2: Sacramento Bypass Widening**	**Alternative 3: DWSC Closure Structure**	**Alternative 4: Improve Levees with Sacramento Bypass and DWSC Closure Structure**
Frequency	**Stage (NAVD 88)**				
1yr = .999	26.4	26.4	26.4	26.4	26.4
2yr = .5	29.2	29.2	27.9	29.2	27.9
10yr = .1	30.6	30.6	30.2	30.6	30.2
25yr = .04	33.3	33.3	32.0	33.3	32.0
50yr = .02	33.9	33.9	32.6	33.9	32.6
100yr = .01	34.5	34.5	33.4	34.5	33.4
200yr = .005	36.4	36.4	35.2	36.4	35.2
500yr = .002	38.1	39.0	38.0	39.0	38.0
Frequency	**Flow (CFS)**				
2yr = .5	94610	94610	87518	94610	87518
10yr = .1	101171	101171	100611	101171	100611
25yr = .04	115657	115657	107696	115657	107696
50yr = .02	118223	118223	110481	118223	110481
100yr = .01	121798	121798	114821	121798	114821
200yr = .005	134255	134255	125027	134255	125027
500yr = .002	158351	179092	155226	179092	155226

Source: Hydraulic Analysis Section, Sacramento District, USACE

WEST SACRAMENTO GRR
SACRAMENTO, CALIFORNIA

SACRAMENTO RIVER
INDEX POINT 2
RISK ANALYSIS INPUTS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Index Point 3
Yolo Bypass, RM 42.62

	Future Without Project Condition	Alternative 1: Improve Levees in Place	Alternative 2: Sacramento Bypass Widening	Alternative 3: DWSC Closure Structure	Alternative 4: Improve Levees with Sacramento Bypass and DWSC Closure Structure
Frequency	**Stage (NAVD 88)**				
1yr = .999	20.7	20.7	20.7	20.7	20.7
2yr = .5	21.4	21.4	21.6	21.4	21.6
10yr = .1	26.9	26.9	27.0	26.9	27.0
25yr = .04	29.7	29.7	29.9	29.7	29.9
50yr = .02	30.5	30.5	30.6	30.5	30.6
100yr = .01	31.4	31.4	31.5	31.4	31.5
200yr = .005	32.7	32.7	32.8	32.7	32.8
500yr = .002	33.7	33.9	34.1	33.9	34.1
Frequency	**Flow (CFS)**				
2yr = .5	106012	106012	110902	106012	110902
10yr = .1	297332	297332	305785	297332	305785
25yr = .04	443711	443711	451721	443711	451721
50yr = .02	483253	483253	490850	483253	490850
100yr = .01	535233	535233	542398	535233	542398
200yr = .005	610692	610692	620024	610692	620024
500yr = .002	674197	688445	703688	688445	703688

Source: Hydraulic Analysis Section, Sacramento District, USACE

WEST SACRAMENTO GRR
SACRAMENTO, CALIFORNIA

YOLO BYPASS
INDEX POINT 3
RISK ANALYSIS INPUTS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Index Point 4 Sacramento Bypass, RM 1.49					
	Future Without Project Condition	**Alternative 1: Improve Levees in Place**	**Alternative 2: Sacramento Bypass Widening**	**Alternative 3: DWSC Closure Structure**	**Alternative 4: Improve Levees with Sacramento Bypass and DWSC Closure Structure**
Frequency	**Stage (NAVD 88)**				
1yr = .999	20.6	20.6	20.6	20.6	20.6
2yr = .5	21.6	21.6	22.0	21.6	22.0
10yr = .1	28.6	28.6	28.2	28.6	28.2
25yr = .04	31.9	31.9	31.1	31.9	31.1
50yr = .02	32.5	32.5	31.8	32.5	31.8
100yr = .01	33.3	33.3	32.6	33.3	32.6
200yr = .005	35.0	35.0	34.2	35.0	34.2
500yr = .002	36.4	37.0	36.2	37.0	36.2
Frequency	**Flow (CFS)**				
2yr = .5	100	100	13922	100	13922
10yr = .1	65843	65843	77979	65843	77979
25yr = .04	107318	107318	118544	107318	118544
50yr = .02	111170	111170	121818	111170	121818
100yr = .01	115016	115016	124798	115016	124798
200yr = .005	148940	148940	163703	148940	163703
500yr = .002	183940	206912	252396	206912	252396

Source: Hydraulic Analysis Section, Sacramento District, USACE

WEST SACRAMENTO GRR
SACRAMENTO, CALIFORNIA

SACRAMENTO BYPASS
INDEX POINT 4
RISK ANALYSIS INPUTS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Index Point 5
Sacramento River, RM 56.75

	Future Without Project Condition	Alternative 1: Improve Levees in Place	Alternative 2: Sacramento Bypass Widening	Alternative 3: DWSC Closure Structure	Alternative 4: Improve Levees with Sacramento Bypass and DWSC Closure Structure
Frequency	**Stage (NAVD 88)**				
1yr = .999	24.5	24.5	24.5	24.5	24.5
2yr = .5	27.8	27.8	26.5	27.8	26.5
10yr = .1	29.1	29.1	28.7	29.1	28.7
25yr = .04	31.8	31.8	30.6	31.8	30.6
50yr = .02	32.4	32.4	31.2	32.4	31.2
100yr = .01	33.1	33.1	32.0	33.1	32.0
200yr = .005	34.9	34.9	33.7	34.9	33.7
500yr = .002	36.5	37.3	36.5	37.3	36.5
Frequency	**Flow (CFS)**				
2yr = .5	94603	94603	87493	94603	87493
10yr = .1	100694	100694	100249	100694	100249
25yr = .04	115596	115596	107593	115596	107593
50yr = .02	118180	118180	110452	118180	110452
100yr = .01	121791	121791	114819	121791	114819
200yr = .005	133454	133374	124912	133374	124912
500yr = .002	148690	159123	146731	159123	146731

Source: Hydraulic Analysis Section, Sacramento District, USACE

WEST SACRAMENTO GRR
SACRAMENTO, CALIFORNIA

SACRAMENTO RIVER
INDEX POINT 5
RISK ANALYSIS INPUTS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Index Point 6 Sacramento River, RM 52.75					
	Future Without Project Condition	**Alternative 1: Improve Levees in Place**	**Alternative 2: Sacramento Bypass Widening**	**Alternative 3: DWSC Closure Structure**	**Alternative 4: Improve Levees with Sacramento Bypass and DWSC Closure Structure**
Frequency	**Stage (NAVD 88)**				
1yr = .999	22.9	22.9	22.9	22.9	22.9
2yr = .5	26.2	26.2	25.0	26.2	25.0
10yr = .1	27.5	27.5	27.1	27.5	27.1
25yr = .04	30.2	30.2	29.0	30.2	29.0
50yr = .02	30.8	30.8	29.6	30.8	29.6
100yr = .01	31.4	31.4	30.4	31.4	30.4
200yr = .005	33.2	33.2	32.1	33.2	32.1
500yr = .002	34.6	35.2	34.6	35.2	34.6
Frequency	**Flow (CFS)**				
2yr = .5	94600	94600	87436	94600	87436
10yr = .1	100688	100688	99871	100688	99871
25yr = .04	115493	115493	107433	115493	107433
50yr = .02	118153	118153	110430	118153	110430
100yr = .01	121789	121789	114818	121789	114818
200yr = .005	133257	133257	124809	133257	124809
500yr = .002	148535	159087	146618	159087	146618

Source: Hydraulic Analysis Section, Sacramento District, USACE

WEST SACRAMENTO GRR
SACRAMENTO, CALIFORNIA

SACRAMENTO RIVER
INDEX POINT 6
RISK ANALYSIS INPUTS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Index Point 7
Yolo Bypass, RM 40.95

	Future Without Project Condition	Alternative 1: Improve Levees in Place	Alternative 2: Sacramento Bypass Widening	Alternative 3: DWSC Closure Structure	Alternative 4: Improve Levees with Sacramento Bypass and DWSC Closure Structure
Frequency	**Stage (NAVD 88)**				
1yr = .999	20.4	20.4	20.4	20.4	20.4
2yr = .5	21.1	21.1	21.3	21.1	21.3
10yr = .1	26.4	26.4	26.6	26.4	26.6
25yr = .04	29.2	29.2	29.4	29.2	29.4
50yr = .02	30.0	30.0	30.1	30.0	30.1
100yr = .01	30.9	30.9	31.0	30.9	31.0
200yr = .005	32.0	32.0	32.1	32.0	32.1
500yr = .002	32.9	33.1	33.3	33.1	33.3
Frequency	**Flow (CFS)**				
2yr = .5	105590	105590	110517	105590	110517
10yr = .1	297134	297134	305595	297134	305595
25yr = .04	442953	442953	450891	442953	450891
50yr = .02	482620	482620	490260	482620	490260
100yr = .01	534852	534852	542033	534852	542033
200yr = .005	610023	610023	619245	610023	619245
500yr = .002	673789	687476	702730	687476	702730

Source: Hydraulic Analysis Section, Sacramento District, USACE

WEST SACRAMENTO GRR
SACRAMENTO, CALIFORNIA

YOLO BYPASS
INDEX POINT 7
RISK ANALYSIS INPUTS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Index Point 8
Sacramento DWSC, RM 43.41

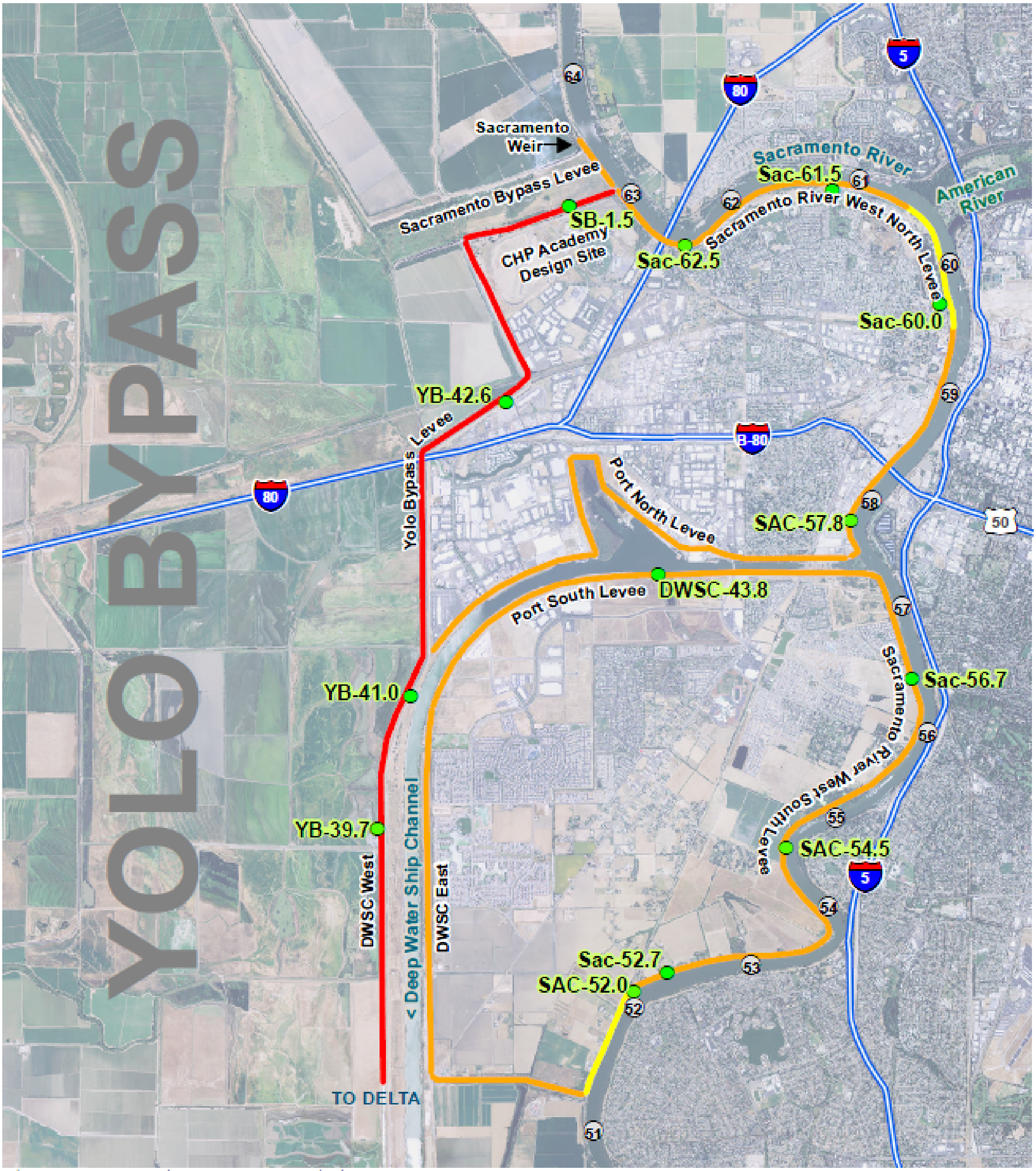
	Future Without Project Condition	Alternative 1: Improve Levees in Place	Alternative 2: Sacramento Bypass Widening	Alternative 3: DWSC Closure Structure	Alternative 4: Improve Levees with Sacramento Bypass and DWSC Closure Structure
Frequency	**Stage (NAVD 88)**				
1yr = .999	7.4	7.4	7.4	7.4	7.4
2yr = .5	7.7	7.7	7.7	7.7	7.7
10yr = .1	13.0	13.0	13.1	13.0	13.1
25yr = .04	17.7	17.7	17.8	16.000	16.000
50yr = .02	18.6	18.6	18.7	16.001	16.001
100yr = .01	19.8	19.8	19.8	16.002	16.002
200yr = .005	20.9	20.9	21.0	16.003	16.003
500yr = .002	22.5	22.7	22.7	16.004	16.004
Frequency	**Flow (CFS)**				
2yr = .5	N/A	N/A	N/A	N/A	N/A
10yr = .1	N/A	N/A	N/A	N/A	N/A
25yr = .04	N/A	N/A	N/A	N/A	N/A
50yr = .02	N/A	N/A	N/A	N/A	N/A
100yr = .01	N/A	N/A	N/A	N/A	N/A
200yr = .005	N/A	N/A	N/A	N/A	N/A
500yr = .002	N/A	N/A	N/A	N/A	N/A

Source: Hydraulic Analysis Section, Sacramento District, USACE

WEST SACRAMENTO GRR
SACRAMENTO, CALIFORNIA

SACRAMENTO DEEP WATER SHIP CHANNEL
INDEX POINT 8
RISK ANALYSIS INPUTS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



Data Source: NAIP Color OrthoImagery, 2009. ESRI StreetMap USA Roads, 2008.

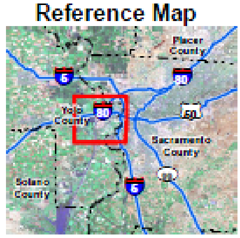
Legend

Roads
- Interstate
- Major Road

- USGS River Miles
- nhc Study Sites

Levee Risk
- High Risk
- Low Risk
- Moderate Risk

Reference Map



West Sacramento GRR Support

Risk from wind-wave by Reach

1 inch = 6,000 feet   Scale - 1:72,000

0 3,000 6,000 12,000 Feet

CA State Plane, Zone II	horz. datum: NAD 83	horz. units: feet
northwest hydraulic consultants	project no. 50618	February 2011

Plate 42