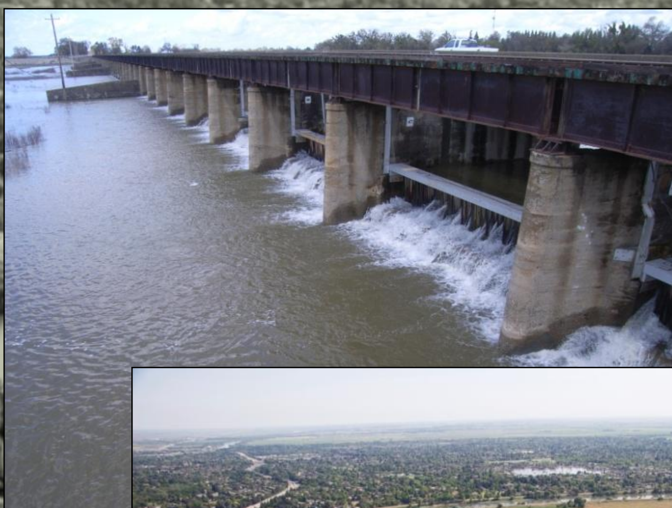
APPENDIX C
ATTACHMENT B

HYDRAULIC APPENDIX EXECUTIVE REPORT

THIS PAGE INTENTIONALLY LEFT BLANK

American River Watershed

Common Features
General Reevaluation Report



Attachment B
Draft Hydraulic
Executive Report

February 2015

SAFCA
Sacramento
Area Flood
Control
Agency

US Army Corps
of Engineers ®
Sacramento District

Cover Photos courtesy of the Sacramento District:

Sacramento Weir during operation

Sacramento River facing south near the Pocket and Little Pocket neighborhoods

High flows on the American River at the Highway 160 overcrossing

Folsom Dam releasing high flows

AMERICAN RIVER, CALIFORNIA
COMMON FEATURES PROJECT
GENERAL REEVALUATION REPORT

Draft Hydraulic Appendix for Public Review

U.S. Army Corps of Engineers
Sacramento District

February 2015

This page intentionally left blank.

AMERICAN RIVER, CALIFORNIA
COMMON FEATURES PROJECT
GENERAL REEVALUATION REPORT

TABLE OF CONTENTS

1 STUDY DESCRIPTION ... 7
1.1 Introduction ... 7
1.2 Location ... 7
1.3 Topographic Data ... 8
1.4 Study Approach ... 8
1.5 Basis of Design ... 10
2 PROJECT DESCRIPTION ... 11
2.1 Project Area Limits ... 11
2.2 Future Without-Project Condition ... 12
3 CHANNEL HYDRAULICS ... 12
3.1 Background ... 13
3.2 Hydrology ... 13
3.3 Model Calibration ... 14
3.4 Water Surface Profiles ... 14
3.5 Levee Breach Assumptions ... 15
4 ALTERNATIVE DEVELOPMENT ... 15
4.1 Evaluation of Measures ... 15
4.2 Alternative 1: Fix Levees in Place ... 16
4.3 Alternative 2: Alternative 1 plus Sacramento Bypass Widening ... 17
5 FLOODPLAIN HYDRAULICS AND FLOODPLAIN DELINEATION ... 20
5.1 FLO-2D Model Development ... 20
5.2 Levee Breach Hydrograph Sensitivity ... 21
5.3 With-Project Floodplains ... 22
6 RISK ANALYSIS ... 23
6.1 Index Points ... 24
6.2 Stage-Discharge Frequency Curves ... 24
6.3 Uncertainty ... 24
6.3.1 Hydraulic Uncertainty ... 24
6.3.2 Hydrologic Uncertainty ... 25
6.3.3 Inflow-Outflow Uncertainty ... 26
6.4 Flood Damage Modeling ... 26
6.4.1 Upstream Levee Performance ... 26
6.5 Performance Evaluation ... 27
6.6 Hydraulic Baseline ... 28
6.1 Potential Hydraulic Impacts to the Yolo Bypass ... 30
6.1.1 Real Estate Considerations ... 31
6.1.2 1957 Profile ... 31
6.2 Considerations and Assumptions ... 32
6.3 FEMA Certification/Accreditation ... 32
6.4 Urban Levee Design Criteria (ULDC) ... 33
6.5 Systems Risk and Uncertainty ... 33

7 RESIDUAL RISK 34
7.1 Residual Risk 34
7.2 Superiority 35
7.3 Climate Change – Hydrology 35
7.4 Sea Level Rise 37
7.4.1 Low Sea Level Rise 38
7.4.2 Intermediate Sea Level Rise 38
7.4.3 High Sea Level Rise 39
7.4.4 Summary of Sea Level Rise Values 39
7.4.5 Sensitivity of Hydraulic Model Results 40
7.5 Interior Drainage 40
7.6 Life Safety 40
8 EROSION 42
8.1 Overview and Assumptions 42
8.2 Existing Bank Erosion Conditions 42
8.3 Sediment Transport 46
8.4 American River Channel Stability 46
8.5 Wind-wave 47
8.6 Boat Wave Erosion 48
8.7 Vegetation Analysis (Tree Scour) 48
8.8 With-Project Erosion Features 48
8.9 Bridge Scour 49
9 REFERENCES 50

TABLES

Table 1-1 ARCF Hydraulic Analyses and Key Assumptions
Table 4-1 Length of Levee Raising
Table 5-1 FWOP Floodplain Use for Alternatives
Table 6-1 Index Points
Table 6-2 Stage Uncertainty at each Index Point
Table 6-3 American River at Fair Oaks (1905-2004) Adopted Unregulated Inflow Statistics
Table 6-4 Performance at Each Index Point
Table 6-5 Comparison of Existing and Future JFP Releases
Table 6-6 Water Surface Elevation for the Yolo Bypass at the Woodland Gage (RM 50.9)
Table 6-7 Water Surface Elevation for the Yolo Bypass at the Lisbon Gage (RM 35.7)
Table 7-1 Climate Change Differences for Northern Sierra Nevada WY 2049
Table 7-2 Change in Frequency of Flows with Climate Change at American River at Fair Oaks
Table 7-3 Change in Frequency of Flows with Climate Change at Sacramento River at Verona
Table 7-4 Summary of Calculated Sea Level Rise Values
Table 7-5 Sea Level Rise Values Seen In Literature
Table 7-6 Life Safety and Life Loss Information

FIGURES

Figure 6-1 Comparison of Existing and Future Conditions with the JFP
Figure 7-1 Sea Level Trend at San Francisco
Figure 7-2 Sacramento River Longitudinal Water Surface Profiles
Figure 8-2 Typical View of the Middle Reach of the Sacramento River
Figure 8-3 Typical View of the Sacramento River – Delta Section
Figure 8-4 Typical View of the American River
Figure 8-5 Typical View of the Dry (Linda) Creek
Figure 8-6 Typical View of the Natomas Cross Canal

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 ARN Project Area Map
Plate 6 ARS Project Area Map
Plate 7 NAT Project Area Map
Plate 8 Index Points
Plate 9 Levee Deficiency Map, American River (Height, Erosion)
Plate 10 Levee Deficiency Map, Sacramento River (Height, Erosion)
Plate 11 Levee Deficiency Map, Natomas Basin (Height, Erosion)
Plate 12 Sacramento River (U/S of the American River) – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition
Plate 13 Sacramento River (D/S of the American River) – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition
Plate 14 Natomas Cross Canal – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition

Plate 15 Pleasant Grove Creek Canal – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition
Plate 16 Magpie Creek – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition
Plate 17 Dry/Robla Creek – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition
Plate 18 Dry/Robla Creek – Right Bank Levee N-Yr Water Surface Profiles, Future Without-Project Condition
Plate 19 Natomas East Main Drain Canal - Right Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition
Plate 20 Natomas East Main Drain Canal – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition
Plate 21 Arcade Creek – Right Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition
Plate 22 Arcade Creek – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition
Plate 23 American River - Right Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition
Plate 24 American River – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition
Plate 25 Flo-2D Model Extents
Plate 26 Reach ARN A Floodplains
Plate 27 Reach ARN E Floodplains
Plate 28 Reach ARS B Floodplains
Plate 29 Reach ARS E Floodplains
Plate 30 Reach NAT D Floodplains
Plate 31 Sacramento River (U/S of the American River) – Left Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives
Plate 32 Sacramento River (D/S of the American River) – Left Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives
Plate 33 Natomas Cross Canal – Left Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives
Plate 34 Pleasant Grove Creek Canal – Left Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives
Plate 35 Magpie Creek – Left Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives
Plate 36 Dry/Robla Creek – Left Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives
Plate 37 Dry/Robla Creek – Right Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives
Plate 38 Natomas East Main Drain Canal – Right Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives
Plate 39 Natomas East Main Drain Canal – Left Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives
Plate 40 Arcade Creek – Right Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives
Plate 41 Arcade Creek – Left Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives
Plate 42 American River – Right Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives
Plate 43 American River – Left Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives
Plate 44 Sacramento River (U/S of the American River) – Left Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives

Plate 45 Sacramento River (D/S of the American River) – Left Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives
Plate 46 Natomas Cross Canal – Left Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives
Plate 47 Pleasant Grove Creek Canal – Left Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives
Plate 48 Magpie Creek – Left Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives
Plate 49 Dry/Robla Creek – Left Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives
Plate 50 Dry/Robla Creek – Right Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives
Plate 51 Natomas East Main Drain Canal – Right Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives
Plate 52 Natomas East Main Drain Canal – Left Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives
Plate 53 Arcade Creek – Right Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives
Plate 54 Arcade Creek – Left Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives
Plate 55 American River – Right Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives
Plate 56 American River – Left Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives
Plate 57 Boundary Condition Locations
Plate 58 Interior Drainage Study Area Map
Plate 59 American River North, Interior Floodplain
Plate 60 American River South, Interior Floodplain
Plate 61 Natomas Interior Floodplain
Plate 62 American River North, Residual Flooding
Plate 63 American River South, Residual Flooding
Plate 64 Natomas Sankey Gap, Residual Flooding
Plate 65 Risk Analysis Inputs ARS Index Pt. B
Plate 66 Risk Analysis Inputs ARS Index Pt. E
Plate 67 Risk Analysis Inputs ARN Index Pt. A
Plate 68 Risk Analysis Inputs ARN Index Pt. E
Plate 69 Risk Analysis Inputs NAT Index Pt. D
Plate 70 200-Yr Existing Conditions and With Project Flows

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. FLO-2D Floodplain Mapping Documentation
11. Levee Breach Sensitivity
12. Climate Change Memo
13. Systems Risk and Uncertainty
14. Interior Drainage
15. Upstream Alternative Analysis
16. Calibration

1 STUDY DESCRIPTION

1.1 Introduction

This executive report summarizes a collection of technical memorandums documenting the hydraulic analysis performed to support the ARCF GRR and has been prepared to meet the intention of the new USACE SMART Planning process – Specific, Measurable, Attainable, Risk-informed and Timely. 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 American River Common Features Project at this time:

1. Since the last authorization of the American River Common Features Project, the scope and cost of levee improvements for the Natomas Basin have increased.
2. New hydraulic modeling and geotechnical studies suggest potential issues with the Sacramento River east levee downstream of the American River. 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 Sacramento.
3. There are also additional erosion issues on the American River that will need to be addressed to ensure that the American River can pass 160,000 cubic feet per second (cfs) with some degree of certainty.

Based on these factors, the city of Sacramento may continue to have a high risk of flooding, even with the completion of all authorized improvements in the Natomas Basin, along the Lower American River, and at Folsom Dam.

Previous study efforts of the Natomas Basin under the Natomas GRR were folded into a more broadly scoped American River Common Features General Reevaluation Report. That report considered all the aforementioned issues from a system approach in order to reduce the flood risk in the entire city of Sacramento.

1.2 Location

The project area is divided into three basins – Natomas, American River North, and American River South – and has an upstream boundary at Verona and a downstream boundary at Freeport on the Sacramento River (see Plate 4 for the location of these basins). It also includes the leveed portions of the American River, the Natomas Cross Canal, the Natomas East Main Drain Canal (NEMDC), the Pleasant Grove Creek Canal, Magpie Creek, and the leveed portions of Dry and Arcade creeks. The study area for the ARCF GRR includes the above project area and extends beyond it both upstream and downstream. See Plates 1 and 2 for a watershed and a general topographic map, respectively.

Flood control channels and other features in the 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 3 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. There were several areas with updates, including the Natomas east side tributaries area for the HEC-RAS model where new surveyed cross sections were developed.

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 Comprehensive Study (References 31, 32).

The geospatial survey data used in the development of the FLO-2D models were obtained from both Sacramento County and the United States Geological Survey (USGS). The Sacramento County information included LiDAR data for the urban area of the county and is dated 2004. The USGS information included publicly available 30-meter USGS Digital Elevation Models (DEMs) which were obtained from http://www.GISdatadepot.com.

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).

1.4 Study Approach

The three basins that are the focus of this GRR – American River North, American River South and Natomas (described in more detail in Chapter 3) – were divided into more than 25 river reaches according to the geotechnical similarity of their levees. Guided by the requirements of SMART Planning, the number was reduced to five representative reaches.

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 ARCF GRR used the same basic models that were developed and refined for the existing conditions (F3, March 2009) analyses and the Natomas Post Authorization Change Document (NPAC, 2010). 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 each basin. In order to generate flood damages for economic evaluations, floodplains were delineated for the 50% (1/2), 10% (1/10), 4% (1/25), 2% (1/50), 1% (1/100), 0.5% (1/200-Yr) and 0.2% (1/500) events. The analysis was limited to flooding within the basin from levee breaches and does not include localized flooding from rainfall-runoff and smaller streams and drainages.

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 without-project condition and the alternatives.

This report presents a very specific and detailed analysis of the with- and without-project conditions for the general Sacramento metropolitan area. In light of SMART Planning, some analyses typically found in a hydraulic appendix have been reduced to a sensitivity analysis, have not been done, or have been postponed to a later date and will likely be completed during design. These efforts are summarized below:

Efforts analyzed using sensitivity:

- Climate change
- Sea level rise
- Interior flooding

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. ARCF Hydraulic Analyses and Key Assumptions

ARCF Hydraulic Deliverables	Key Assumptions
Future without-project condition analysis (HEC-RAS, Flo-2D)	The project area is adequately represented by index points at 5 key locations, reduced from over 25.
Evaluation of final alternatives for evaluation (HEC-RAS)	For alternative analysis, large cost measures screened out qualitatively. Many features reduced and combined into final array of alternatives.
With-project floodplain analysis (Flo-2D)	Used without-project floodplains and adjusted frequency of floodplain based on peak stage and volume.
Potential Hydraulic impacts (HEC-RAS)	The baseline for potential hydraulic impacts at Folsom is one of two conditions: the operation prior to any features being added (JFP Spillway, Dam Raise, circa 1986) and without any interim operation or the future without project condition with the Folsom features described in place.
Residual risk (HEC-RAS, Flo-2D)	Overtopping of American River upstream of leveed reach and Sankey Gap will not be fixed.
Interior drainage	Existing FEMA interior floodplains used in place of full interior drainage analysis.
Systems risk and uncertainty	HEC methodology used based on Reference 5.
Climate change	Sutter methodology used, sensitivity analysis only.
Sea level rise	Used Information from recent study in the Delta and existing sensitivity analysis.
Coincident flow frequency	Based on direction from Hydrology Section Chief, using peak on peak until design, then refinement likely needed.
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 specifically for the American River.
Erosion (including riverine/bank, wind-wave, and channel stability)	Limited analysis conducted, coordinating with ongoing design efforts that are not yet complete. Erosion repair for the American River is identical to all alternatives.
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

The project limits for the floodplain north of the American River cover approximately 124 square miles of Sacramento County (see Plate 5). The American River North basin includes the area north of the American River and east of the Natomas East Main Drain Canal (NEMDC). It is separated from the Natomas Basin by the NEMDC. The American River North Basin is bounded on two sides by levees and high ground on the remainder as follows:

- Southern boundary: American River levees from Hazel Avenue to the NEMDC
- Western boundary: NEMDC levees
- Northern boundary: High ground and Elverta Road
- Eastern boundary: High ground

The American River South basin includes the area south of the American River and east of the Sacramento River (see Plate 6). For this effort, it does not include the Morrison Creek Stream Group. The study limits for the floodplain south of the American River cover approximately 254 square miles of Sacramento County and are defined as follows:

- Southern boundary: Morrison Creek Stream Group levees
- Western boundary: Sacramento River levees
- Northern boundary: American River levees from Hazel Avenue to confluence with Sacramento River
- Eastern boundary: High ground

The Natomas Basin is almost completely enclosed by levees and has significant interior drainage works (see Plate 7). The Natomas basin includes the reach of the Sacramento River from the Natomas Cross Canal to the American River, the Pleasant Grove Creek Canal (PGCC), and the NEMDC. The Natomas basin is bounded as follows:

- Southern boundary: American River levees from the NEMDC to the confluence of the American and Sacramento Rivers
- Western boundary: Sacramento River levees from the Natomas Cross Canal to the confluence of the American and Sacramento Rivers
- Northern boundary: Cross Canal levees

- Eastern boundary: The NEMDC levees to the southern two-thirds of the eastern boundary and levees for a drainage canal connecting to the Cross Canal for the northern one-third of the eastern boundary

There is one location that is not leveed in the Natomas Basin, where the NEMDC and the drainage canal on the eastern boundary meet. This opening is less than a quarter mile in length near Sankey Road, and is commonly referred to as the Sankey Gap.

2.2 Future Without-Project Condition

For hydraulic modeling purposes, the Sacramento River system configuration as it generally exists now (generally between years 2006 and 2014) was used for the future without-project condition with the exception of changes on the American River.

As part of the March 2009 Existing Conditions Conference (F3), multiple scenarios were proposed and analyzed for the without-project and future without-project conditions for the American River. Much of the Sacramento River system was expected to be the same under the future without-project condition with the exception of the following:

- Changing operations at Folsom Dam because of the Joint Federal Project Spillway (JFP),
- Levee repairs as described in the “Natomas Post Authorization Change Report”
- Levee repairs as described in the “Authorized American River WRDA 96/99 Sites”

The Project Delivery Team (PDT) decided to analyze conditions needed to justify only the current work proposed by the ARCF GRR document. This decision considered the significant effort already expended and additional effort still needed to answer the question of incrementally justifying projects on the American River. It also considered the SMART Planning requirement to complete feasibility studies in less time and at reduced cost. Based on this information as well as profile comparisons, it was determined that it is not necessary to consider the multiple without-project conditions as previously studied.

For the ARCF GRR document, only a single without-project condition was analyzed. This condition was known as the NA3 condition in the CF GRR F3 documentation. Because previous nomenclature used was confusing, a new naming system was developed. The NA3 condition is now known as the Authorized Common Features + Joint Federal Plan + Dam Mini-Raise (ACF + JFP + Dam Mini-Raise). This plan 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.

The Natomas Post Authorization Change Report (PACR) proposed levee improvements for the Natomas Basin and the ARCF GRR study assumes that the work identified in the PACR will be completed as stated and proposes that height deficiencies are all that remain to be evaluated in the Natomas Basin.

All this is considered to be part of the without-project condition. Any work beyond the without-project condition, proposed under the ARCF, is considered part of the with-project condition.

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 ARCF 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. Previous modeling was supplemented with new modeling for some reaches.

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 2013i).

Modeling of the basin was done in different phases in order to avoid delays to the major milestones of the ARCF GRR schedule. Phase 1(USACE May 2013i) of the model development was completed previously and supported the Natomas Post Authorization Change Document (Natomas PAC) in 2010 (the Natomas PAC is a portion of the overall ARCF GRR study). Phase 1 is documents the generation of the main geometry files with pertinent features, including representation of major flood control levees in the system. During this phase of model development, the model was calibrated to the 1997 flood event. The model developed under Phase 1 was used to run *n*-year synthetic events (2-, 10-, 25-, 50-, 100-, 200- and 500-year) for without-project conditions to determine economic damages and to screen alternatives for the Natomas PAC study. This model was based on the NGVD1929 vertical datum.

For Phase 2 of model development, the model was converted to the NAVD1988 vertical datum (USACE, May 2013c). Additional reaches were added to the model, in particular the Natomas east side tributaries (WEST July 2010). Though the model does cover a large portion of the Sacramento Basin, its main purpose is not to provide detailed hydraulics for all reaches in the system, but rather to support the ARCF GRR, which is for flood damage reduction efforts in and around Sacramento. Other Corps studies within the Sacramento Basin system, in particular the Sutter County Feasibility Study and the West Sacramento GRR studies, also use the same “base” Phase 2 model, but include changes pertinent to their particular study reaches. More information on Phase 2 development can be found in the Draft Sacramento Basin HEC-RAS Phase II Development Technical Memorandum (USACE, May2013j) .

3.2 Hydrology

Minor updates were made to the existing hydrology used in the Natomas Post Authorization Change Report. This includes greater detail and refinement of the tributary streams on the east side of the Natomas Basin and an update on timing of the American River outflows. For details regarding all hydrologic inputs, see the hydrology appendix. For a revised map showing locations of boundary conditions, see Plate 57. Inflow hydrographs were generated for use at several frequencies, including the 2-year through 500-year events.

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 and 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 three basins. A suite of seven *n*-year frequency profiles (2-, 10-, 25-, 50-, 100-, 200-, 500-year) is shown in Plates 12–24 for the future without-project condition (FWOP). The FWOP will serve as the baseline for alternative comparison. This suite of model runs included raising the levees along the project reaches high enough to contain all of the flow through that reach. This approach supported an economic analysis of levee raises at multiple heights above the existing top of levee. The baseline to determine if a levee needs to be raised was set at the median 200-year event plus 3 feet. 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 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.

There are two unique features on the water surface profiles on Plates 12-24. First, on the NEMDC right bank levee (Plate 19), there is a pump station at RM 6.3 that also acts as a barrier to rising American River backwater flowing up the channel. This is shown by a lower water surface profile upstream of the NEMDC Pump station than on the downstream side. Secondly, 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 increasing water surface profile downstream of the Sacramento Weir, which can be seen in the profile plates noted above.

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 ARCF 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 engineering appendix its geotechnical attachment.

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 (USACE, May 2013m). Even with some of these additional measures, the stages and flows were not reduced enough to eliminate the need for levee improvements. For purposes of the current study, the following measures were therefore removed from further consideration:

- Upstream transitory storage at various locations
- Wicket gates at several location along the Sacramento River upstream of the American River confluence
- Pocket bypass
- Yolo Bypass widening
- I Street Diversion Structure
- Adjacent levee – seen as a design refinement to use where possible

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 - 4.3).

- Fix levees in place
- Fix levees in place with the Sacramento Bypass widening

The alternative including upstream storage on the American River was carried forward for planning purposes but was not analyzed in this study. At this time, no locally preferred plan has been analyzed. Should the sponsor offer a local plan in the future, a decision will be made at that time as to the level of analysis needed to include that alternative in the feasibility study.

4.2 Alternative 1: Fix Levees in Place

Due to the urban nature and proximity of existing development to the levees within the American River North and South basins, Alternative 1 proposes fix-in-place levee remediation. The stated purpose of this alternative is to improve the flood damage reduction system to safely convey flows up to a level that maximizes net benefits.

Alternative 1 primarily calls for landside fixes of levees that do not change in-channel geometry or characteristics. These levee fixes involve the construction of levee remediation measures to address deficiencies such as seepage, slope instability, insufficient height, erosion, lack of vegetation compliance, and lack of O&M access along the following streams: the American and Sacramento Rivers; the Natomas East Main Drainage Canal (NEMDC); Arcade, Dry, and Robla Creeks; Magpie Creek; the Pleasant Grove Creek Canal (PGCC); and the Natomas Cross Canal (NCC). This alternative combines construction of levee improvement measures while maintaining the present levee alignment in its existing location (aka, fix levees in place).

The Natomas Post Authorization Change Report (PACR) proposed levee improvements for the Natomas Basin that consisted of a combination of fix in place, adjacent levee, seepage cutoff walls, and seepage berms. The ARCF GRR study assumes that the work identified in the PACR will be completed as stated and proposes that height deficiencies are all that remain to be evaluated in the Natomas Basin. The height deficiency remediation is expected to be constructed within the existing or now expanded levee footprint. There may need to be some additional real estate considerations along the Natomas East Main Drain Canal downstream of the Pump Station (~RM 6.5). The levee would potentially expand on the landside to minimize any hydraulic impacts. See the Engineering Appendix for more information on the footprints of the alternatives.

A crest elevation of the future without-project 200-year plus 3 feet was compared the current top of levee. Levee raising (except for the Sankey Gap) was identified when the current top of levee fell below this profile. The typical amount of height needed is 1 to 2 feet. Plates 31-56 show the water surface elevations for the alternatives, the future without-project condition and the baseline for both the 10-year and the 200-year events respectively. Plates 9–11 show the locations of levee raising along with erosion repair (Erosion is discussed in Section 8). Table 4-1 shows the extent (length) of levee raising needed per reach.

One reach in the American River North Basin, Magpie Creek, will require more than just fix levees in place to reduce the risk of inundation. Additional features for Magpie Creek may include a detention basin, a new reach of levee, and bridge improvements and are called out in Corps' Section 205 Continuing Authorities Program Basis of Design Report (MWH/CH2M Hill, 1999), and refined by the Draft Supplemental Report to the Section 205 Final Detailed Project Report and Environmental Assessment on Magpie Creek (USACE May 2003). These features will be refined during the Design Phase, with some refinement possibly coming as part of the Tentatively Selected Plan.

After the analysis was complete and in response to the increasing concerns about USACE projects encouraging development in floodplains (EO 11988), all proposed levee improvements proposed as part of this report for the Natomas Basin have been removed from all of the final alternatives. See the main report for more information.

4.3 Alternative 2: Alternative 1 plus Sacramento Bypass Widening

Alternative 2 starts with Alternative 1 (fix levees in place) as a base and adds the widening of the Sacramento Bypass/Weir. The purpose of this alternative is to redirect more from the Sacramento River to the Yolo Bypass and thereby reduce the extent of levee repairs required in the project area. 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. 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 in the Pocket area. Table 4-1 shows the extent (length) of levee raising needed per reach for Alternatives 1 and 2.

The widening of the Sacramento Bypass and Weir was analyzed by expanding the 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; however a limited amount of levee raising along the Sacramento River downstream of the confluence is still needed.
For the purposes of this analysis the operation of the expanded Sac Weir was originally set to same condition as the rest of Sac Weir by maintaining a water surface elevation at the I-street Gage on the Sacramento River.

In an attempt to minimize additional flows into the Yolo Bypass for frequent events and in coordination with the sponsor, the new portion of the Sacramento Weir is proposed to be activated based on Folsom Releases. The new portion of Sacramento Weir will only operate when flows from Folsom into the American River exceed 115,000 cfs. This currently happens beyond a 1% (1/100-Yr) event release yet before a 0.5% (1/200-Yr) event release.

This operation will be further refined in possibly feasibility level design and will receive significant analysis in Preconstruction, Engineering and Design (PED).

Table 4-1:Length of Levee Raising Per Reach (miles)							
River	Basin	Bank	Reach Length (miles)	Alt 1		Alt. 2	
				Length of Raise (mi)	Average Height (ft)	Length of Raise (mi)	Average Height (ft)
American River	ARN	Right	13.8	E	-	E	-
Arcade Creek	ARN	Right	2.1	2	1.0	2	1.0
Arcade Creek	ARN	Left	2.1	2	1.0	2	1.0
Dry/Robla Creek	ARN	Left	2.0	0.4	1.0	0.4	1.0
Dry/Robla Creek	ARN	Right	1.5	-	-	-	-
Magpie Creek	ARN	Left	0.3	0.3	4	0.3	4
Natomas East Main Drain Canal	ARN	Left	3.6	3.6	0.5	0.5	0.5
American River	ARS	Left	11.5	E	-	E	-
Sacramento River	ARS	Left	14.9	8.1	1.0	1.0	1.0
Natomas Cross Canal	NAT	Left	5.0	R	-	R	-
Natomas East Main Drain Canal	NAT	Right	12.4	R	-	R	-
Pleasant Grove Creek Canal	NAT	Left	3.8	R	-	R	-
Sacramento River	NAT	Left	18.2	R	-	R	-
		Totals	91.2	16.4		6.2	

R - Removed per EO11988 considerations

E - American River Levees Height set to slightly different profile, raises assumed not to be necessary.

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 various reaches within the Natomas, the American River North and American River South areas. An existing calibrated HEC-RAS model of the Sacramento and American River system (described in Chapter 3) was used to develop the needed breach hydrographs at all seven frequencies (2-, 10-, 25-, 50-, 100-, 200-, 500-year) at each breach location. These breach hydrographs were then used as inflows for the FLO2D model. The FLO-2D Documentation Technical Memorandum (Tetratech, December 2008) provides detailed information on model development. Much of this information was also provided as part of the F3 Hydraulic Technical Documentation. Plate 25 shows the model extents; the resulting floodplains are shown in Plates 26–30.

For Natomas in particular, the basin acts much like a bathtub. As a breach occurs, floodwaters are contained by the surrounding levees and the area fills up (Plate 7). The Natomas 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 project area is represented with two separate FLO-2D models, one for the floodplain north of the American River and one for the floodplain south of the American River. The study area was split into two floodplains primarily because the north and south floodplains have significantly different topographic characteristics. The north floodplain consists of two basins, the Natomas Basin and North Basin, created by surrounding levees and high ground. The south floodplain slopes away from the American River to the south and west, such that breakout flows from the American River flow across and down valley until diverted or confined by the levees along the Sacramento River and other levees. The American River South model and the American River North model (consisting of the North Basin only) were originally developed for the American River Economic Evaluation Report (ERR) study. For the ARCF GRR study, the Natomas Basin has been added to the American River North model.

The following key assumptions were used in the development of the American River North (Including Natomas) and American River South floodplain FLO-2D models:

- **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 = 6,670,800 and Y = 1,998,800.** 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 American or Sacramento rivers 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 to determine how a breach hydrograph is impacted by selection of levee breach elevation, timing of breach, breach formation duration and breach width. Index point B 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 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 suite 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

For the with-project floodplains, the without-project condition floodplains were used with adjustments made to the frequency of the floodplains.

To approximate each with-project floodplain, the with-project breach hydrographs were compared to the corresponding without-project breach hydrographs. Peak flow and volume were the variables used to compare the two levee breach hydrographs. For each alternative and at each index point, the following comparison was made for each of the seven frequencies:

- If the change between without- and with-project breach hydrograph volumes were within 10%, then the without-project levee breach hydrograph and corresponding floodplain could be substituted for use as the with-project levee breach hydrograph and corresponding floodplain.

- If the change in volume was greater than 10%, then the without-project levee breach hydrograph and corresponding floodplain from the next largest flood event were evaluated based on the same threshold. If that comparison failed, the process was repeated with increasingly large flood events until a substitute event was found that met the threshold. For example, the 10-yr with-project levee breach hydrograph was compared to the 10-yr without-project levee breach hydrograph at each index point and if the volume differed by greater than 10%, the 10-yr with-project levee breach hydrograph was then compared to the 25-yr without-project levee breach hydrograph. If the volume again differed by greater than 10% for that comparison, the 10-yr with-project levee breach hydrograph was then compared to the 50-yr event and so on until the threshold was met.

Table 5-1 shows the specific changes in frequency used to adjust the floodplains from the without-project condition to with-project conditions. The shaded areas in the table represent where a without-project floodplain from a different frequency was used for the with-project floodplain for each alternative.

Table 5-1 Alternative Floodplain Key								
Future Without Project / Alt. 1: Fix in Place								
Basin	**Index Point**	**2-yr**	**10-yr**	**25-yr**	**50-yr**	**100-yr**	**200-yr**	**500-yr**
ARN	A	-	-	25-yr	50-yr	100-yr	200-yr	500-yr
ARN	E	-	10-yr	25-yr	50-yr	100-yr	200-yr	500-yr
ARS	A	-	-	25-yr	50-yr	100-yr	200-yr	500-yr
ARS	F	2-yr	10-yr	25-yr	50-yr	100-yr	200-yr	500-yr
NAT	D	2-yr	10-yr	25-yr	50-yr	100-yr	200-yr	500-yr
Alt. 2: Alt. 1 +Sacramento Bypass Widening								
Basin	**Index Point**	**2-yr**	**10-yr**	**25-yr**	**50-yr**	**100-yr**	**200-yr**	**500-yr**
ARN	A	-	-	25-yr	50-yr	100-yr	200-yr	500-yr
ARN	E	-	10-yr	25-yr	50-yr	100-yr	200-yr	500-yr
ARS	A	-	-	25-Yr	25-Yr	100-Yr	200-Yr	500-Yr
ARS	F	2-yr	10-yr	10-Yr	10-Yr	10-Yr	100-Yr	500-Yr
NAT	D	2-yr	10-yr	25-yr	50-yr	100-yr	200-yr	500-yr

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 ARCF 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 Sacramento, already separated by a waterway, are further divided into reaches represented by similar geotechnical conditions, as described in the geotechnical appendix. Each reach was originally represented by a single index point located at the same position as the geotechnical fragility curve. In an effort to support SMART Planning, the project area was determined to be adequately represented by index points at five key locations, reduced from over 25. The five index points represent the three basins and are shown on Plate 8. They are also listed in Table 6-1.

Table 6-1. Index Points

Index Point	Basin	Index Point	Project Reach	River Mile
American River North Levee	ARN	A	American River	7.8
Arcade Creek North Levee	ARN	E	Arcade Creek	0.9
American River South Levee	ARS	A	American River	8.9
Sacramento River South	ARS	F	Sacramento River	50.3
Natomas Cross Canal South Levee	NAT	D	Natomas Cross Canal	2.7

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 ARN A, ARS B, and ARS E, flow-frequency and stage-discharge relationships were generated for the HEC-FDA analysis (see Plate 8 for location of index points). A stage-stage relationship similar to a stage frequency relationship was used for ARN E and NAT D due to backwater effects.

6.3 Uncertainty

6.3.1 Hydraulic Uncertainty

Following guidance in Engineer Manual EM 1110-2-1619, "Risk-Based Analysis for Flood Damage Reduction Studies," the performance and reliability of the project features were assessed with an uncertainty-based analysis. The stage uncertainty parameter in HEC-FDA is used to account for uncertainties in the calculated water surface elevations. These uncertainties can be attributed to accuracy and precision of the topographic data, hydraulic computational assumptions (roughness coefficients and bridge debris loading), sedimentation and operations (gates/pumps) and other potential factors. The total uncertainty from these attributes is a combination of the following factors from EM 1110-2-1619: natural variations, model uncertainty, sedimentation, and operations factors. Table 6-2 has the total stage uncertainty for each index point for the suite of frequencies. See the Risk Analysis Technical Memorandum (USACE, May 2013i).

Table 6-2: Total Stage Uncertainty (One Standard Deviation), Feet

River		American	Arcade	American	Sacramento	Natomas Cross Canal
Index Point		A	E	A	F	D
RS		7.83	0.95	8.90	50.25	2.71
Basin		ARN	ARN	ARS	ARS	NAT
Percent Annual Chance Exceedance	50%	0.97	0.85	1.00	0.75	0.85
	10%	1.23	0.90	1.29	0.77	0.92
	4%	1.38	0.93	1.45	0.76	1.03
	2%	1.38	0.95	1.45	0.76	1.04
	1%	1.36	0.93	1.43	0.76	0.98
	0.50%	1.53	0.86	1.59	0.75	0.84
	0.20%	0.76	0.75	0.75	0.78	0.75

6.3.2 Hydrologic Uncertainty

For index points along the Sacramento River (ARS E), Natomas Cross Canal (NAT D) and Arcade Creek (ARN E), the flow frequency analysis is based on a graphical method. The period of record (equivalent years of record) for index points NAT D and ARN E is 71 years and period of record for index point ARS E is 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. Values for Arcade Creek were taken from the SAFCA 408 Request (MBK, June 2009), which is based on EM 1110-2-1619.

The index points along the American River (ARN A & ARS B) are based on analytical flow frequency analysis. The input statistics for FDA analysis are shown in Table 6-2.

Table 6-3: American River at Fair Oaks (1905-2004)
Adopted Unregulated Inflow Statistics

Log Mean	4.581
Log Std Dev	0.43
Log Skew	-0.077
Equivalent Record Length (yrs)	100

6.3.3 Inflow-Outflow Uncertainty

The purpose of the inflow-outflow curves is to translate unregulated flow-frequency curves and uncertainty to the regulated condition. It also provides an additional means of accounting for hydrologic uncertainty within the system, recognizing that flow entered into the upstream ends of the system attenuates. How much it attenuates depends in large part upon the capacity of the river or levee system. Inflows correspond to the analytical and graphical inflow frequency curves in FDA (Reference f). The outflows were taken from standard HEC-RAS output tables at each index point. Inflow-outflow curves were generated for both with-project and without-project conditions assuming no upstream levee failures. Uncertainty for the inflow-outflow curve was based on work done in the Natomas Post Authorization Change Hydraulics and Hydrology Appendices.

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 each 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 5.2, levee failure runs were made only using the without-project condition. Plates 65 through 69 contain the water surface elevations at the project index points for the full suite of frequencies and the following conditions and alternatives:

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

A summary of the key results are described below:

- For all index points, there are no significant changes in stage or flow between the future without-project condition and the Fix Levees in Place Alternative 1.
- As expected, there are reductions in stage and flow on the Sacramento River Reach below the confluence with the American River (at ARS E) when Alternative 2 is compared to the future without-project condition.
- The results for Natomas Index Point D, located on the Natomas Cross Canal, are similar for all conditions.
- There are increases in stage and flow from the without-project condition to the future-without project condition along the American River and the Sacramento River downstream of the confluence with the American River. This reflects assumptions about Folsom Operations; see Section 2.2 for further information.

6.4.1 Upstream Levee Performance

As part of the CF 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 American River Common Features 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 6-3 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 6-3 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 6-8: Performance at each Index Point

	Basin	ARN	ARN	ARS	ARS	NAT
	Index Point	A	E	A	F	D
	River	American	Arcade	American	Sacramento	NCC
	River Station	7.8	0.9	8.9	50.3	2.7
FWOP	Annual Exceedence Probability (AEP)	0.010	0.017	0.011	0.031	0.009
	1/AEP	96	61	93	32	108
	1% Assurance	75%	54%	76%	69%	84%
	0.5% Assurance	47%	29%	45%	55%	58%
Alt. 1	Annual Exceedence Probability (AEP)	0.006	0.005	0.005	0.007	0.006
	1/AEP	182	200	185	135	159
	1% Assurance	90%	94%	91%	95%	84%
	0.5% Assurance	59%	69%	64%	93%	56%
Alt. 2	Annual Exceedence Probability (AEP)	0.006	0.004	0.005	0.007	0.006
	1/AEP	172	256	192	147	164
	1% Assurance	89%	95%	91%	95%	85%
	0.5% Assurance	57%	80%	60%	94%	57%

6.6 Hydraulic Baseline

Given the geographic connection of the current ARCF project and several ongoing American River projects (JFP Spillway, Natomas PAC, WRDA 96/99 Sites), there was a rationale to evaluate the individual projects together as a single project to evaluate hydraulic effects or impacts. Many of the projects are tied to the larger single American River Watershed Investigation study that occurred in the early 1990s.

As described in the Enclosure 1 of the ARCF Planning Guidance Memo (USACE 2009d), this project proposes to have a hydraulic baseline that is different than the economic baseline. The hydraulic baseline is a historic without-project condition that will be used to assess the overall impacts of the combined Common Features and Folsom Dam improvements (spillway and raise). The economic baseline for alternative comparison is the future without-project condition.

The historic baseline conditions quickly described below are the operational considerations and physical features in place or not considered in place for this baseline condition:

- Folsom has a fixed storage of 400,000 acre feet (no variable storage)
- The temporary agreement for reoperation at Folsom Dam entered into between the USBR and SAFCA in 1994 is not included;
- The construction and operation of the Folsom Dam Joint Federal Project is not included, which was approved for construction in 2007, and operations of anticipated to be approved in 2017;
- The construction and operation the Folsom Dam Raise Project is not included which was approved for construction in 2007, and the operations of anticipated to be approved in 2022.

There are a range of assumptions used to estimate or create the flows that existed at Folsom.
To be able to evaluate the hydraulic effects, reservoir models being used to develop the Joint Federal Project Spillway were reconfigured to replicate historical conditions. Reservoir operations can be significantly difficult to calibrate to past operations because of the human intervention needed.

From the Folsom PAC (2007), thru the Natomas PAC (2010) and in this current ARCF GRR, a series of models results from several in-progress reservoir routing models were provided over time to give estimates of this the flow releases. Even with the development of the Folsom Water Control Manual Update, these historical model runs are still being re-evaluated. There is not yet any n-year reservoir routings available for release from the Folsom Water Control Manual. At the time of the hydraulic modeling, the reservoir routing models described in the Natomas PAC have the best available and were used in this effort.

Both the Sacramento and American River Storm Centerings were modeled for this analysis. The Sacramento Centering is displayed here and was used because this centering contained larger flows on the Yolo Bypass.

Even using the best case approach, flows and stages for the 100-Yr and 200-Yr events are being reduced by the JFP as reflected in the Future Without Project Condition and Alts. 1 and 2. This has then led to a range of releases provided in Table 6-5.

Table 6-5: Comparison of Existing and Future with JFP flow releases from Folsom Dam.

Frequency, Years	Existing Releases, cfs	Future with JFP, cfs
2	25,000	26,000
10	27,000	72,000
25	84,000	115,000
50	115,000	115,000
100	175,000	115,000
200	430,000	160,000
500	530,000	530,000

The condition used to route the Folsom releases assumes a peak release of 430,000 cfs for the .05% (1/200-year) event. This scenario reflects no improvements to Folsom Dam. Much of the water over 200,000 cfs will leave the channel before it gets to the leveed system.

Figure 6-1 compares the flow releases from Folsom Dam for the existing and future condition with the JFP. The graph shows the flow releases will be higher with the JFP in place for frequent events as compared to the existing conditions. However, flow releases will be lower for the less frequent events with the JFP in place as compared to the existing condition. The benefits of the JFP are that the dam operators will have more flexibility to release more water from Folsom Dam in advance of storms.

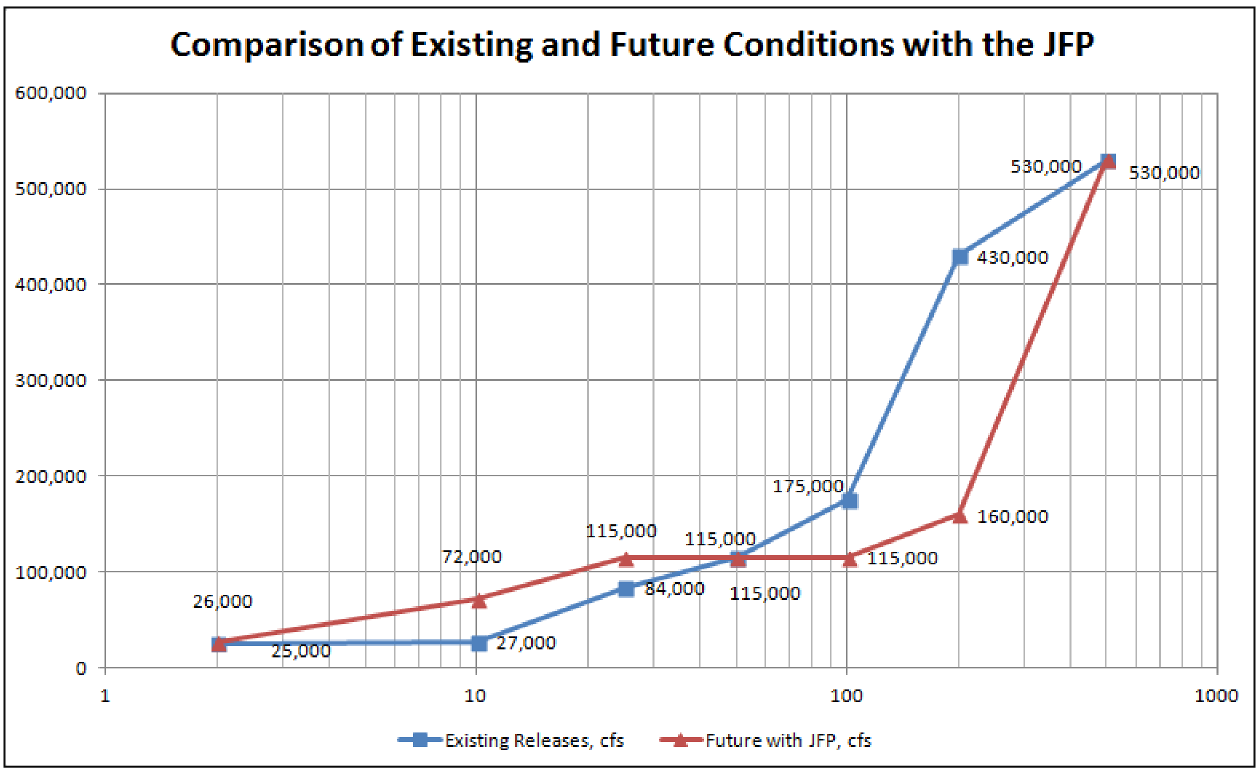


Figure 6-1: Comparison of Existing and Future Conditions with the JFP

6.1 Potential Hydraulic Impacts to the Yolo Bypass

The proposed project features main purpose is to reduce flood risk in the project area. Hydraulic Impacts outside of the project area as result of these features being implemented have to be disclosed and possibly accounted or mitigated for in this study. With the widening of the Sacramento Bypass, there was added attention to how this widening would impact the Yolo Bypass.

From the executive summary HEC's PR-71 document:
"The potential impacts defined from deterministic analysis results are changes in water surface elevation and freeboard that are defined in units of length such as feet. Due to the common use of length units in everyday affairs, the significance of differences expressed in units of length are generally well understood. In contrast, the potential impacts defined from risk analysis results are changes in probabilities. In general, the significance of differences in probabilities, particularly small differences in probabilities, are difficult to conceptualize. Consequently, a need exists for development of guidance or criteria to define the significance of risk analysis results."

For purposes of this analysis, the definition of a potential hydraulic impact was defined as a change in water surface elevation. With the advent of risk and uncertainty, guidance is lacking on what constitutes a significant impact though changes in stage on the order of 0.1 feet to 1.0 feet are often used as a threshold.

The hydraulic baseline can be one of two options already described above and shortly reiterated here:

-Historical Baseline without recent and in-construction Folsom improvements in place.
-Future Without Project Condition - with recent and in construction Folsom improvements (including the JFP) in place.

For with project conditions, the peak releases from Folsom Dam for the 100- and 200-year events are reduced to 115,000 cfs and 160,000 cfs. This amount of flow continues on down the American River to the Sacramento River. Because these flows are significantly less than the baseline condition, the amount of flow that would go downstream on the Sacramento River and upstream on the Sacramento River to the Sacramento Weir and Bypass are also greatly reduced. Flow conditions splits for the 10-yr, 100-Yr, 200-Yr events are depicted on the Sacramento-American River Confluence Plates 70-72.

With Alternative 2 and the widening of the Sacramento Weir and Bypass, some of the American River flow that would have gone downstream on the Sacramento River is instead drawn upstream to the widened Sacramento weir. Baseline and with project condition stages in the Yolo Bypass are shown on Tables 2 and 3 for the 100- and 200-year events, respectively.

To determine if there are potential hydraulic impacts in the Yolo Bypass, stages from the baseline condition and the future without-project condition were compared with the stages from Alternatives 1 and 2. The additional water that would flow through the weir and into the Sacramento Bypass could raise water surface elevations in the Yolo Bypass up to 0.8 feet. This increase is considered less than significant because it would not change land uses, require additional levee remediation, and is not expected to increase flood risk. Tables 6-6 and 6-7 contain water surface elevations for a point upstream and downstream of where the Sacramento Bypass meets the Yolo Bypass.

Table 6-6. Water Surface Elevation Summary for the Yolo Bypass at the Woodland Gage (RM 50.9).

Water Surface Elevation Summary Yolo Bypass at the Woodland Gage(RM 50.9)						
Frequency	Baseline NAVD88	FWOP NAVD88	Alt. 1 Fix in Place NAVD88	Alt. 2 Sac Bypass NAVD88	FWOP - Alt. 2 NAVD88	Baseline - Alt. 2 NAVD88
2-Yr	27.1	27.1	27.1	27.0	0.1	0.1
10-Yr	30.5	30.7	30.7	30.7	0.0	-0.2
25-Yr	33.1	33.5	33.5	33.5	0.0	-0.4
50-Yr	34.3	34.3	34.3	34.3	0.0	0.0
100-Yr	35.5	35.3	35.3	35.3	0.0	0.1
200-Yr	37.1	37.0	37.0	37.0	0.0	0.0
500-Yr	38.2	37.9	38.0	38.0	-0.1	0.2

Table 6-7. Water Surface Elevation Summary for the Yolo Bypass at the Lisbon Gage (RM 35.7).

Water Surface Elevation Summary Yolo Bypass at the Lisbon Gage (RM 35.7)						
Frequency	Baseline NAVD88	FWOP NAVD88	Alt. 1 Fix in Place NAVD88	Alt. 2 Sac Bypass NAVD88	FWOP - Alt. 2 NAVD88	Baseline - Alt. 2 NAVD88
2-Yr	19.7	19.7	19.7	19.9	-0.2	-0.2
10-Yr	23.8	24.5	24.5	24.6	-0.2	-0.8
25-Yr	26.3	26.9	27.0	27.1	-0.2	-0.8
50-Yr	27.7	27.0	27.7	27.9	-0.8	-0.2
100-Yr	28.8	28.0	28.6	28.7	-0.7	0.1
200-Yr	29.7	29.1	29.6	29.7	-0.6	0.0
500-Yr	30.5	30.0	30.7	30.9	-0.9	-0.4

6.1.1 Real Estate Considerations

The hydraulic effects likely do not constitute a real estate take. The water is contained within the Yolo bypass where Real Estate interests already held in the form of flowage easements; Yolo Bypass land-use already based on regular flooding.

6.1.2 1957 Profile

An additional rationale to support this project not having any hydraulic impacts to the System and specifically the Yolo Bypass is by using the 1957 Design Profile

The levees that reduce the flood risk for the city of Sacramento are part of the Sacramento River Flood Control Project, an integrated system of levee protected basins. The design of the Sacramento River Flood Control Project anticipates that agricultural basins will be protected by levees that are at least high enough to contain flood waters comparable to those produced by the floods of 1907 and 1909 and later modified to include floods that occurred in the 1920s and 1930s. The flood water elevations designated for each basin in the system were specified in a Memorandum of Understanding (MOU) between the Corps and the State of California. The MOU was originally developed in 1953 and later amended. The design specified in the MOU calls for agricultural levees to be at least equal in height to the designated water surface elevation (“1957 profile”) plus three to six feet of freeboard to address hydrologic and engineering uncertainty and contain wind-driven waves.

A fundamental assumption for the hydraulic impact analysis is that increasing flow to the advertised capacity of a channel is not an impact. The rationale for this is that the maintaining agency for each reach of levee is obligated to maintain their stretch of levee so that it can convey the advertised capacity with stages up to the design profile. Flood events can happen at any time, so the operators need to and are required to maintain their levees so that they can convey the flow they were intended to convey. They are required to do so in perpetuity.

By widening the Sacramento Weir and Bypass, some amount of additional flow will be pulled from the American River compared to the existing condition. The Sacramento Weir and Bypass widening will accommodate this additional flow and direct it to the Yolo bypass. Because these additional flows are below the 1957 profile for the 10 year event, this rationale would conclude that there is no hydraulic impact for this frequency event.

6.2 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.

6.3 FEMA Certification/Accreditation

The Engineering Circular 1110-2-6067 serves as guidance for USACE to provide the necessary Risk and Uncertainty (R&U) rationale to certify/accredit levees for FEMA. 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. By traditional FEMA methodology (Title 44 CFR Section 65.10) , it is likely that the local sponsor could achieve FEMA Certification in all three basins using this proposed project, recent projects(Natomas PAC) and the locals ongoing efforts under the Natomas Levee Improvement Program(NLIP). 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. At a minimum this would be likely be completed by ensuring that there is 3 three feet of freeboard above the 100-yr event for all the levees in the project area.

6.4 Urban Levee Design Criteria (ULDC)

Urban Levee Design Criteria (ULDC) is a state standard established by the CA Dept of Water Resources where from a hydraulic perspective; urban levees are required to have at least 3' feet of free board above the mean 200-Yr event or a combination of freeboard (2-3) and assurance (90%-95%) to contain the mean 200-Yr event.

The 3 feet of freeboard was set as a target on all reaches except the American River where there was already a design water surface profile. The American River has 3' of freeboard at the index point but this would need to be confirmed for the entire reach for levees on both sides.

6.5 Systems Risk and Uncertainty

Each of the final alternatives included setting the top of levee profile at the 200-year plus 3 feet benchmark (except for Sankey Gap), 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 ARCF 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 four scenarios. The following four scenarios were analyzed:

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

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 two baseline conditions:

- 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 Residual Risk

Residual risk is the risk of being inundated after the selected alternative has been implemented. There are two types of residual risk discussed in this report: residual risk associated with project features, and residual risk from physical conditions not related to project features. The residual risk associated with project features is captured by the with-project fragility curves and floodplains, and is covered in Chapters 4 through 6 of this report. The residual risk floodplains were developed using HEC-RAS and FLO-2D, and provided to the Economics Section to be included as part of the overall net benefit calculation. The residual risk from both project features and physical conditions not related to project features are reflected in the residual floodplains for each of the three basins (Plates 62-64). A description of these two sources of residual risk for each basin is described below.

In the Natomas basin, the Sankey Gap is located in the northeastern corner of the basin between the Pleasant Grove Creek Canal and the Natomas East Main Drain Canal (see Plate 7). The Sankey Gap is a hardened overtopping weir built to handle flow from ponded water that flows into the basin. During a flood event on the Sacramento River, water will pond on the northeastern exterior edge of the Natomas Basin and then back up small creeks along the Pleasant Grove Creek Canal and eventually flow through this hardened weir. The height of the ponded water at the Sankey Gap is tied directly to stages in the Sacramento River, and flow through the Sankey Gap was observed in the 1986 and 1997 flood events. There are no plans to change the operation of this feature to reduce the residual risk.

For the other two basins, American River North and American River South, overtopping occurs from the American River channel upstream of the leveed system. This upstream part of the channel is not part of the project and there are no plans to reduce this residual risk as part of the study. Plates 65–66 only contain the 500-year residual floodplains for the two basins as it is assumed that the channel will be able to hold up to a 200-yr event coming out of Folsom after completion of the Joint Federal Project Auxiliary Spillway and levee improvements along the American River. This assumption is based on the auxiliary spillway's ability to control flows out of Folsom up to the 200-Year event.

For the areas described above, the residual risk associated with project features, and physical conditions not related to project features is assumed to be the same for the final array of alternatives. The levee improvements and possible Sacramento Bypass widening do not significantly change the hydraulic conditions on the American River upstream of the leveed section or the northern part of the Natomas basin.

7.2 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 are two weirs on the Sacramento River in the project area that divert high flows away from Sacramento into the Yolo Bypass. The two weirs are the only 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.

7.3 Climate Change – Hydrology

A sensitivity analysis was conducted to assess the impact of climate change for the American River Common Features 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 in the study 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
½	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 ARCF GRR study.

7.4 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 1165-2-212, 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.

7.4.1 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.

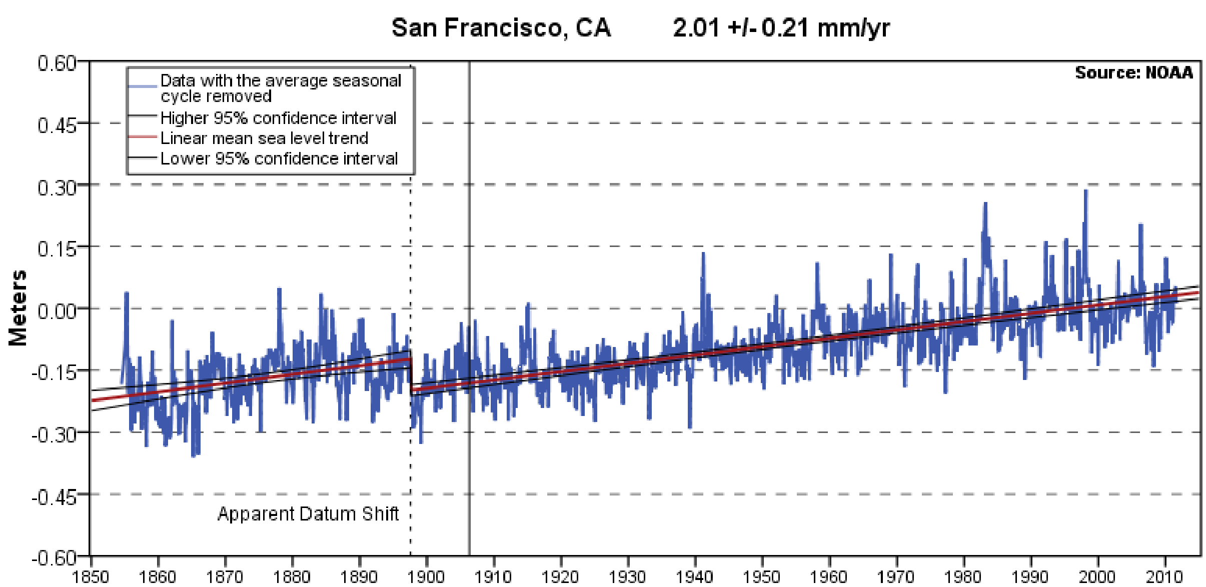


Figure 7-1. Sea Level Trend at San Francisco (NOAA, 2009)

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.

7.4.2 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.

7.4.3 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.

7.4.4 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.

7.4.5 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 American River Common Features 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 American River Common Features project was 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 Verona, 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.

7.5 Interior Drainage

An analysis was done to examine the interior drainage of the smaller, non-leveed streams in the three project basins (USACE November 2012). Measures to reduce the risk for flooding from these small streams are not being considered for alternatives, but the risk of flooding is being accounted for in the economic analysis. The results (flood depths and water surface elevations for the 10-, 25-, 100- and 500-year) will be used to estimate residual damages in the floodplain when doing the larger-scale risk estimation for the ARCF study. Plate 58 shows the project area for the interior drainage study.

Existing FEMA Digital Flood Insurance Rate Maps (DFIRMs) and associated flood insurance studies (FIS) were used to represent the interior flooding within the three basins. This analysis is general and approximate in nature and the level of detail is deemed appropriate in light of applying SMART Planning to this study. More information on the interior drainage analysis and process performed can be found in Interior Drainage Technical Memorandum (USACE November 2012).

Flood depths were determined for each recurrence interval by rasterizing the topographic data, the DFIRM shapefiles (30-foot grid cells), and the FIS data points in GIS and determining the difference between the two. The floodplains were created by interpolating the resultant rasterized flood depths. Plates 59-61 show the floodplains for the three areas.

7.6 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 on the three basins or systems. (USACE, 2011), (USACE, 2012a), (USACE 2012b)

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

American River North		Natomas	
Population at Risk (Day)	58,558	Population at Risk (Day)	76,973
Population at Risk (Night)	51,380	Population at Risk (Night)	65,696
Loss of Life (Day)	170	Loss of Life (Day)	669
Loss of Life (Night)	156	Loss of Life (Night)	553
American River North, Small Streams		**American River South**	
Population at Risk (Day)	15,457	Population at Risk (Day)	350,000
Population at Risk (Night)	23,816	Population at Risk (Night)	439,491
Loss of Life (Day)	77	Loss of Life (Day)	503
Loss of Life (Night)	131	Loss of Life (Night)	978

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 and in the study area, with most of the focus on the American River.

The primary concern about erosion in the project area is on the American River and secondary concern is on the Sacramento River. While there may be erosion occurring on the smaller tributaries in the project area, it is assumed that any repairs would be incorporated into current designs with limited added costs, would not involve large quantities of rock, and would not have specific designs called out.

The plan for erosion is ongoing; more analysis is expected to provide greater insight. Erosion repairs are expected to be part of all three alternatives and refinement efforts will continue beyond the Tentatively Selected Plan (TSP) milestone. Existing erosion conditions in the project area are presented briefly in the following section. A separate multidisciplinary Erosion Protection Report was developed for this study that contains addition information.

8.2 Existing Bank Erosion Conditions

Below is a brief description of the existing bank erosion condition for each of the reaches in the project area. This section is based on existing annual erosion survey reports from the Sacramento River Bank Protection Project that covers the entire Sacramento River Flood Control System. (USACE 2012a) See Plate 3.

Sacramento River – Middle Reach, Colusa to Sacramento (RM 79 to RM 61). The middle reach of the Sacramento River has the levees close to the river and multiple diversion structures to move flow into the bypass system. The Sacramento River was split at the confluence with the American River for the purposes of this discussion because the conditions of the river change at this location. The middle reach was intentionally designed with the levees close to the banks to help move some of the bed load and debris that remained from the days of hydraulic mining. In addition, USACE was responsible for keeping the river navigable up to the city of Colusa. As a result of this design, much of the reach is protected with rock, especially the outsides of bends. The majority of the rock in this reach is cobbles placed prior to the 1960s and some areas with more recent quarry stone. The cobble sites are reaching the end of their design life. Figure 8-2 shows a typical view of the middle reach of the Sacramento River.

Figure 8-1. Typical View of the Middle Reach of the Sacramento River

Sacramento River – Delta Section (RM 61 to RM 45). The Delta reach of the Sacramento River has tight levees and is tidally influenced. The location of the channel has been relatively stable for the past 150 years. A large percentage of this reach has already been armored with riprap. This area has heavy wave action from recreational boats and wind, and the banks are heavily used by the public. Many of the levees are constructed of dredged soils from the bottom of the channel. Figure 8-3 shows a typical view of the Delta section of the Sacramento River. The causes of erosion in this reach are boat wake, wind-wave, mass failure, fluvial processes, and public use.

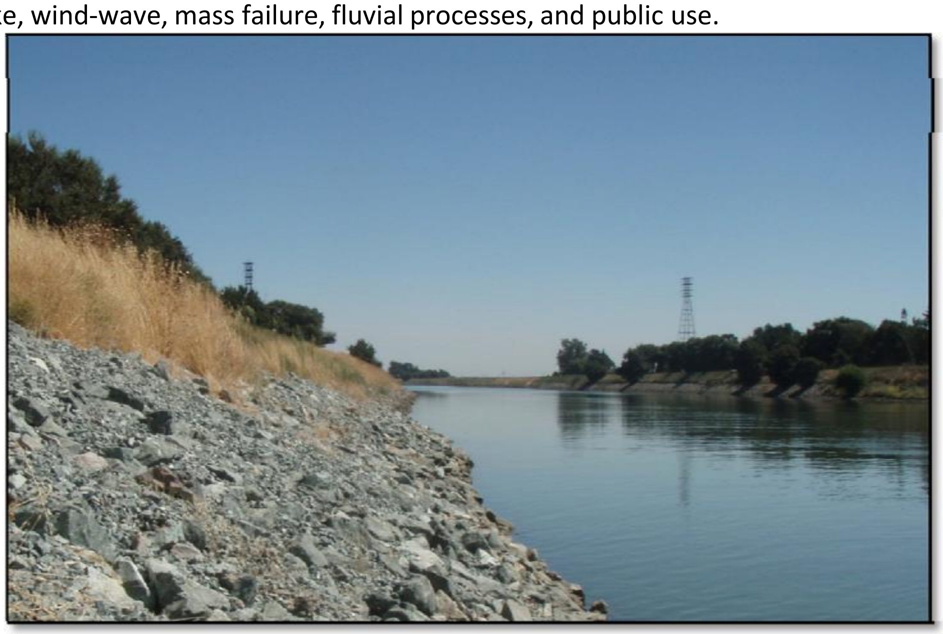


Figure 8-2. Typical View of the Delta Section of the Sacramento River

American River. The American River is fed by Folsom Dam, is therefore generally sediment-starved, and has been eroding and transporting the fine materials from the channel bed. Once the fines have been removed and the bed is armored, the channel is expected to move laterally and erode the banks. The right bank is set back from the channel for the lower 5 miles. Boat wake is not a concern as there is a no wake zone for the entire river. The main causes of erosion are fluvial, tree pop-outs, and public use. This river is generally well maintained and has had many bank repairs in the recent years. Figure 8-4 shows a typical view of the American River.

Figure 8-3. Typical View of the American River

Natomas East Main Drainage Canal, Arcade Creek, and Dry Creek. Arcade Creek and Dry Creek (formerly known as Linda Creek, and now more commonly referred to as Big Dry Creek) drain water from the Rio Linda, Roseville, Antelope, Citrus Heights, and Carmichael areas. Arcade Creek has the levees relatively close to the channel; however, the small amount of floodplain maintains a healthy riparian habitat. Dry Creek has a large floodplain but relatively little riparian habitat, as the floodplains appear to be used for cattle grazing. Figure 8-5 shows a typical view of Dry Creek. The Natomas East Main Drainage Canal (NEMDC) directs the flow from Arcade and Dry creeks and sends it south to the American River. NEMDC is a man-made channel that runs north-south and protects the east side of Natomas.

Erosion is not considered to be a significant problem on these smaller tributaries or on the Natomas Cross Canal, Pleasant Grove Canal, or Coon Creek Interceptor (described below). Any work needed to address erosion will be part of the levee design effort and is not expected to add any cost or change the hydraulics of these reaches.

Figure 8-4. Typical View of Dry (Linda) Creek

Natomas Cross Canal, Pleasant Grove Canal, and Coon Creek Interceptor. Pleasant Grove Canal and Coon Creek Interceptor collect water from the east foothills and communities of Lincoln and Pleasant Grove. These flows are then directed into the Natomas Cross Canal, which moves the water down to the Sacramento River. Pleasant Grove Canal and Coon Creek only have levees on the east side. The levees are steep with some grass and shrub vegetation. The Natomas Cross Canal is man-made and the levee on the south side was recently rebuilt. The south levee is mowed and grazed by sheep in the summer while the north levee has tall grasses with shrubs/trees on the lower bank. Figure 8-6 shows a typical view of the Natomas Cross Canal.

Figure 8-5. Typical View of the Natomas Cross Canal

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 entire study reach of the Sacramento River (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.

On the lower American River, the long-term simulation results indicate that most of the 22-mile long study reach is actively degrading. Upstream sediment supply on the American River is interrupted by Folsom and Nimbus Dams, which results in “sediment-hungry” waters and channel degradation below the dams. Simulated long-term changes in the American River bed profile range from 9-16 ft of degradation to about 3-4 ft of aggradation. Degradation is simulated upstream of RM 12 and downstream of RM 11, while aggradation is simulated in a short reach between RMs 12-11. For the entire study reach of the American River, the average bed degradation is 4.8 ft and 5.8 ft for the 50- and 100-year simulations, respectively.

It should be noted that the channel of the American River is highly irregular at many locations (especially in braided reaches upstream of RM 8). These irregular reaches may not be adequately represented in the 1-d HEC-6T model. Therefore, results obtained for the irregular reaches may be subject to modeling errors and should be treated with caution. In general, however, the degradational trend predicted by the model agrees with stage-discharge records showing ongoing channel degradation of the American River channel.

8.4 American River Channel Stability

Specific to the American River, multiple analyses have been completed and many are still underway to better understand the overall channel stability. These efforts are ongoing and are expected to be incorporated into the design of the tentatively selected plan.

Recognizing that significant efforts have been completed and that current studies are not yet finished, the hydraulic characteristics of the American River channel under with-project conditions were evaluated using existing information [or something like that]. The 2004 Ayres Report, “Lower American River – Erosion Susceptibility Analysis for Infrequent Flood Events” for the American River provided 2-D hydraulic model results of velocity, shear stress and water depth for flows of 115,000 cfs, 130,000 cfs, 145,000 cfs, and 160,000 cfs. The report and model results were provided to the Civil Design and

Geotechnical Sections; additional information on erosion designs can be found in their respective appendices.

The conclusions from the Ayres 2004 report provide further evidence for the need of erosion protection measures to reduce the flood risk on both sides of the American River and are described below:

> *Based upon our modeling efforts, field review and overall experience with the Lower American River system, we offer the following conclusions:*
>
> 1. *Geomorphic principles, the thalweg profile, and the field review all agree that the river system is degradational under present operating conditions.*
>
> 2. *The Lower American River is starved of sediments by Folsom and Nimbus dams. Bedrock has been reached in the channel bottom as far downstream as Guy West Bridge, and this bedrock is slowing further degradation. With the river starved for sediments and without significant bed slope reduction, it will now tend to erode laterally to satisfy the need for sediment.*
>
> 3. *The hydraulic modeling shows areas of riverbank and levees where allowable velocities for vegetative cover and soil materials are exceeded. These sites need to be evaluated in more detail to determine if a levee failure is likely to occur.*
>
> 4. *The field review verified that erosion of the riverbank is occurring (RM 9.0R) even at low flow conditions of 7,000 cfs, which was the peak flow from the 2003 runoff season. Erosion on the American River is continually occurring. This condition is leaving the channel banks scarred and susceptible to further erosion, especially during a high flow event. In addition, this condition is further reducing the amount of berm separating the main channel from the levee. The loss of underlying vegetation is leaving bare soil, which is susceptible to erosion at a lower velocity.*

8.5 Wind-wave

Wind-wave analysis was done to evaluate the risk of failure due to wind-wave erosion for about 85 miles of the American River Common Features levees in Sacramento and Sutter Counties for coincident 200-year water levels and extreme wind events (NHC, 2010). 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 than generalized to nearby sites, which were expected to experience similar wave heights and which had similar geometry and protection. Overall, 46 miles of levee were determined to be at high risk of failure due to wind-wave erosion during coincident extreme wind and water levels, 25 miles were determined to be of moderate risk, and 14 miles were assumed to be low risk. High risk sites are likely to require repair for the levee to be a certifiable flood defense structure. 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, and that conservative assumptions were made in regards to the need for erosion protection due to wind-wave action on the PGCC and the upper NEMDC.

8.6 Boat Wave Erosion

Boat wave erosion has not been accounted for in this analysis because the impact of boat wave erosion in the project area is unlikely to be significant. Only smaller recreational boats operate in the Sacramento and lower American Rivers, and the other project reaches do not have enough consistent depth or width of channel to sustain boat traffic. Any repairs needed from boat waves would likely be addressed as part of standard operation and maintenance of the levees.

8.7 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.

8.8 With-Project Erosion Features

With the levees set back on the American River, there are some additional options available to address erosion. A launchable rock trench at the levee toe is considered a viable measure, along with protecting the bank with a rock layer. All launchable rock trenches would be constructed outside of the natural river channel and designed to deploy once erosion has removed the bank material covering it.

In a flood event where the bank erodes back to the levee, the launchable rock would already be in place to protect the levee slope and nearby bank, halting the erosion. The rock trench can be covered with dirt and vegetation so that the entire fix is not visible. A key assumption for the rock trench is that it would not change the hydraulics, because the design would not affect the cross sectional area of the channel. See the geotechnical appendix for information on the details of this erosion repair measure.

The preliminary locations where bank protection (as opposed to rock trench protection) was proposed suggested a concern about channel capacity. An initial hydraulic model run was made with a revised geometry reflecting the obstruction estimated for the bank protection. This model run showed stage increases approximating 1 foot for the 200-year event (currently set to be 160,000 cfs). Given the significant increase in stage, the option of replacing the bank protection upstream of the narrowest part of the American River (near Guy West Bridge, approximately RM 6.5) with rock trench measures was evaluated with another hydraulic model run. The results indicated that this limited erosion fix option caused very little change in stage for the 200-year event.

Based on this analysis, the proposed measure is to use a rock trench upstream of the Guy West Bridge (approx. RM 6.5) with bank protection or a rock trench downstream of this point. Further refinement in design will likely be necessary to verify this measure.

8.9 Bridge Scour

There are over 15 bridges crossing the channel on multiple reaches in the project area. Bridges along the Sacramento and American rivers 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.

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.

MBK Engineers. 9 August 2005. Design Water Surface Profile for the Sacramento River East and Natomas Cross Canal Levees in Natomas. Prepared by MBK Engineers for SAFCA. Sacramento, CA.

MBK Engineers. 30 June 2009. Natomas Levee Improvement Project, Hydraulic Analysis for Section 408 Hydraulic Impact Risk Analysis. Draft. Prepared by MBK Engineers for SAFCA. Sacramento, CA.

Montgomery Watson and CH2M Hill. (MWH/CH2M Hill). February 1999. Magpie Creek 50% Design Study Basis of Design Report. Prepared by MWH/CH2MHill for the Civil Design Branch, Sacramento District, US Army Corps of Engineers, Sacramento, CA.

Northwest Hydraulics Consultants (NHC). 26 February 2010. Computation of Wave Runup for American River Common Features General Reevaluation Report. Prepared by NHC for Sacramento District, US Army Corps of Engineers. 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 suppor t 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.

Sacramento Area Flood Control Agency (SAFCA). April 2003. SAFCA's North Area Local Project, Project Description. Sacramento, CA

Tetratech (Tetratech) December 2008. FLO-2D Floodplain Mapping Documentation. Prepared for American River Common Features Feasibility Study, Sacramento District, USACE. Rancho Cordova, CA.

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). May 2003. Draft Supplemental Report to the Section 205 Final Detailed Project Report and Environmental Assessment on Magpie Creek. Sacramento District, Sacramento, 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) December 2011. 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

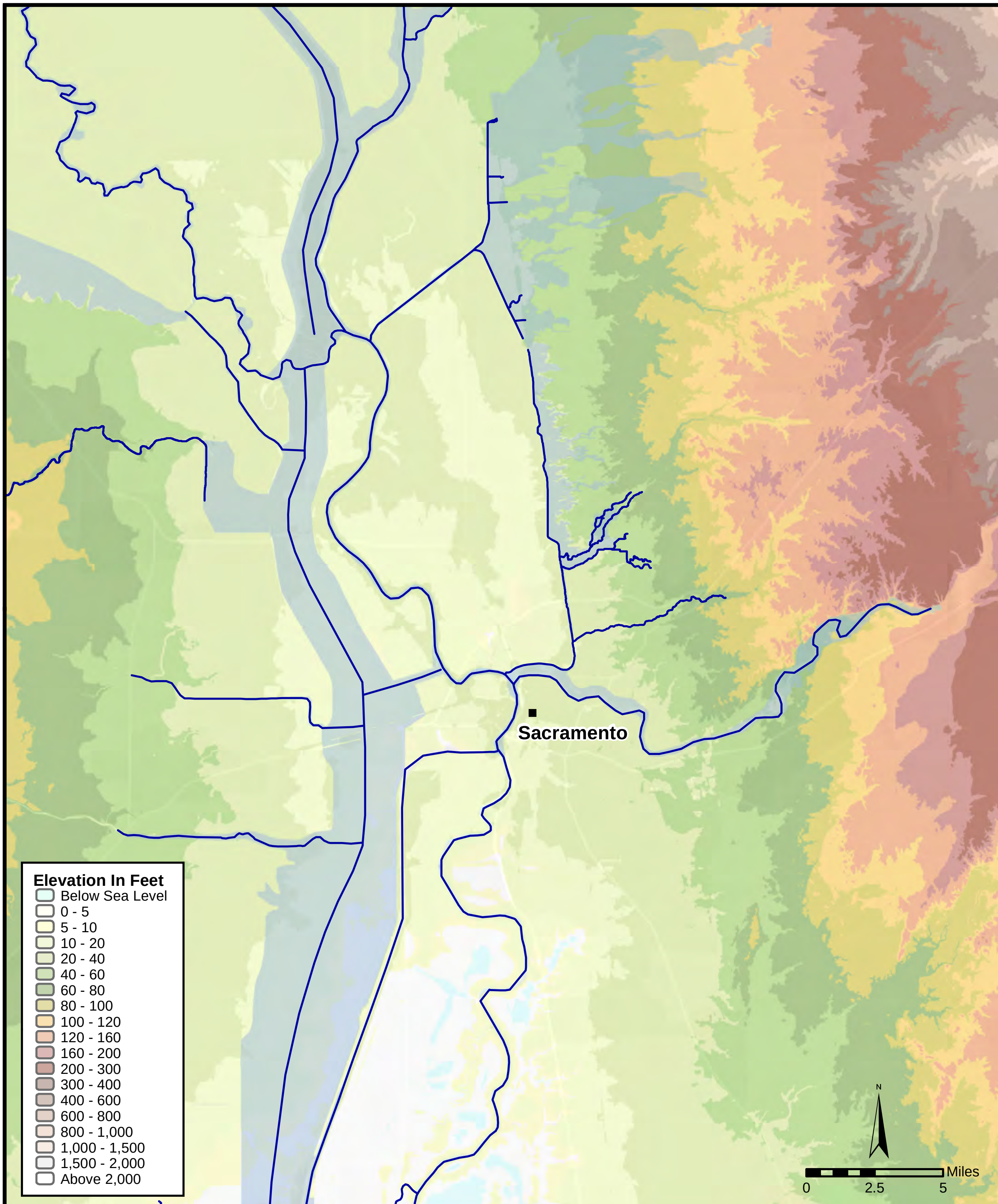
Designated Floodways

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

SACRAMENTO RIVER WATERSHED

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Feb 2013



LEGEND

Rivers

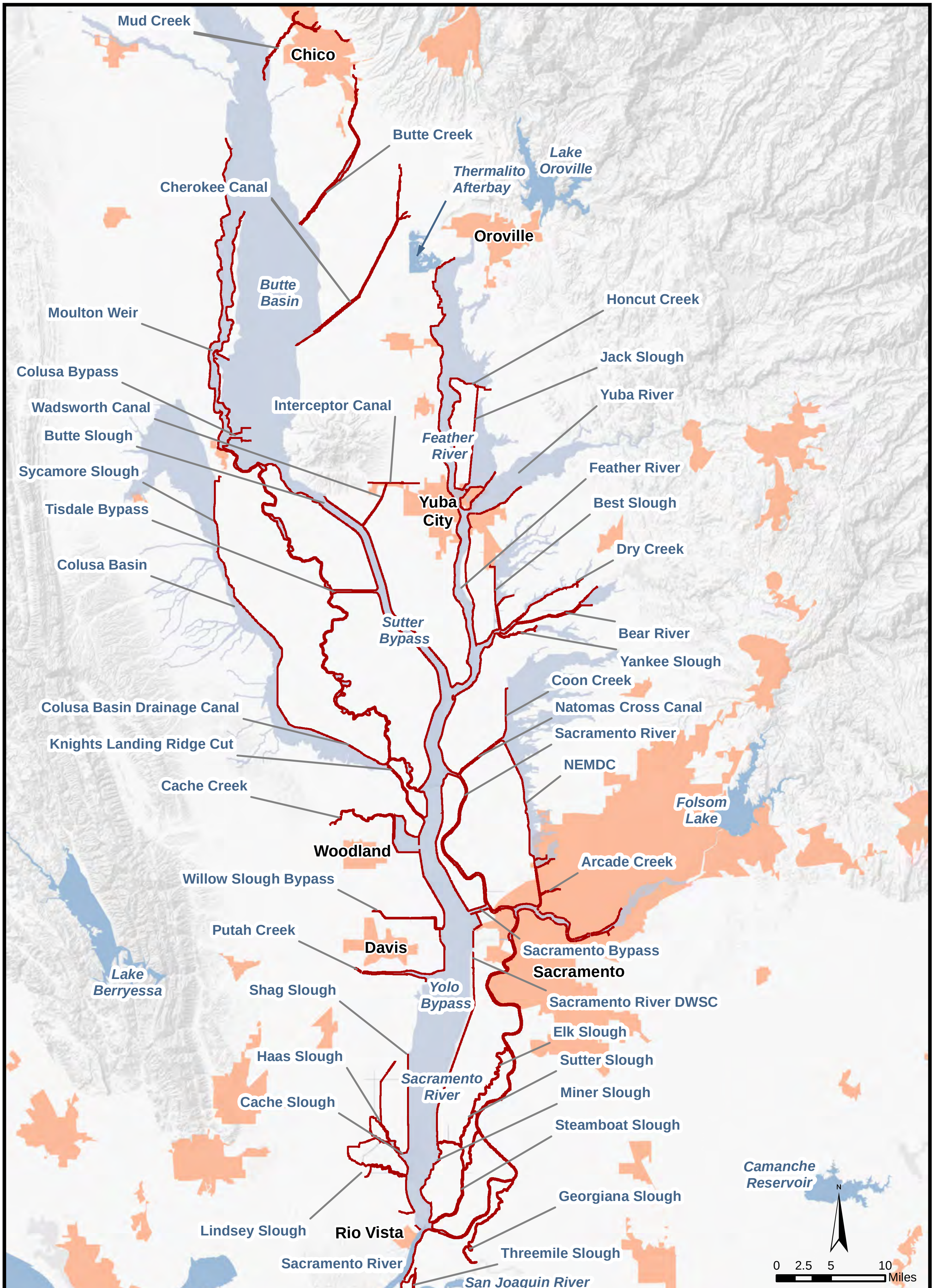
Floodways

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

GENERAL TOPOGRAPHIC MAP

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

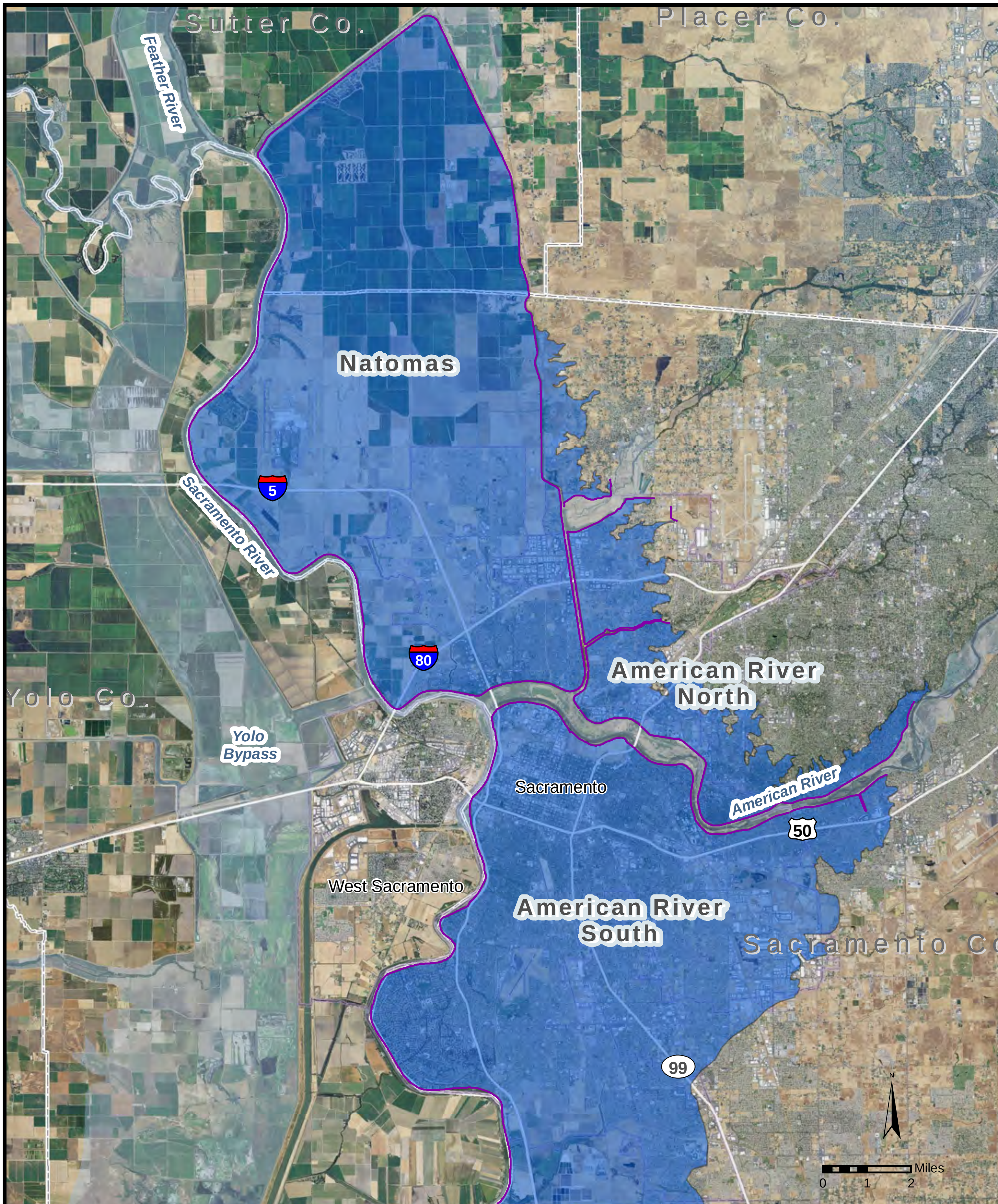
Feb 2013



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

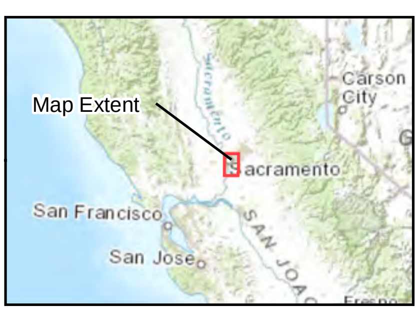
Feb 2013

Plate 3



LEGEND

- ARCF Levees
- ARCF Study Area
- Floodways
- Cities
- County Lines

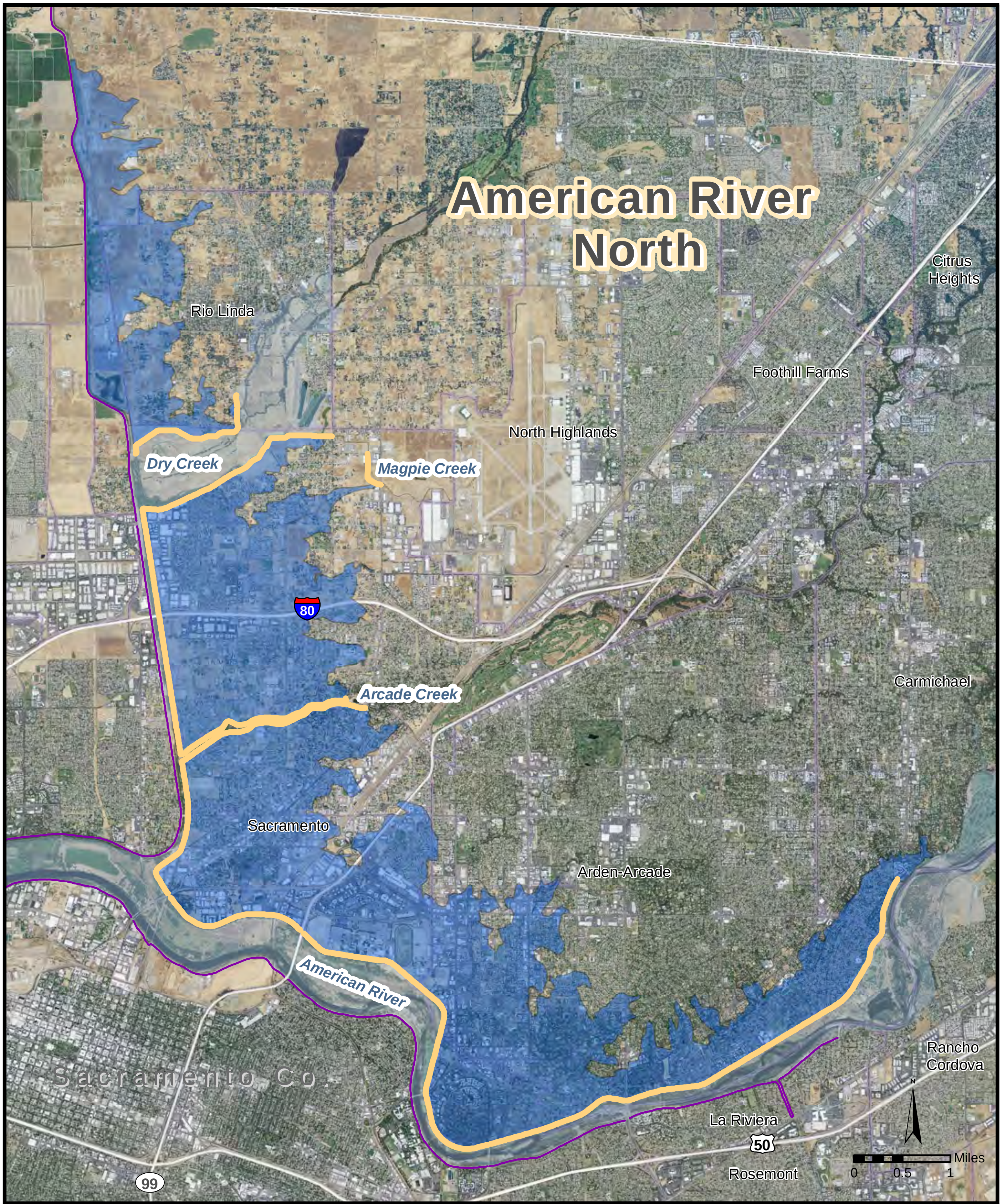


AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

PROJECT AREA MAP

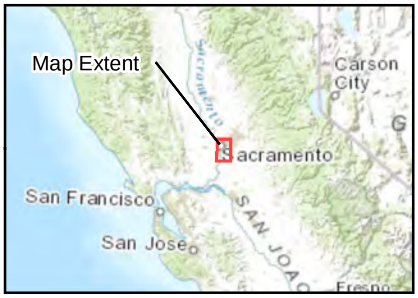
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Feb 2013



LEGEND

- ARN Study Area
- ARN Levees
- ARCF Levees
- Floodways
- County Lines
- Cities

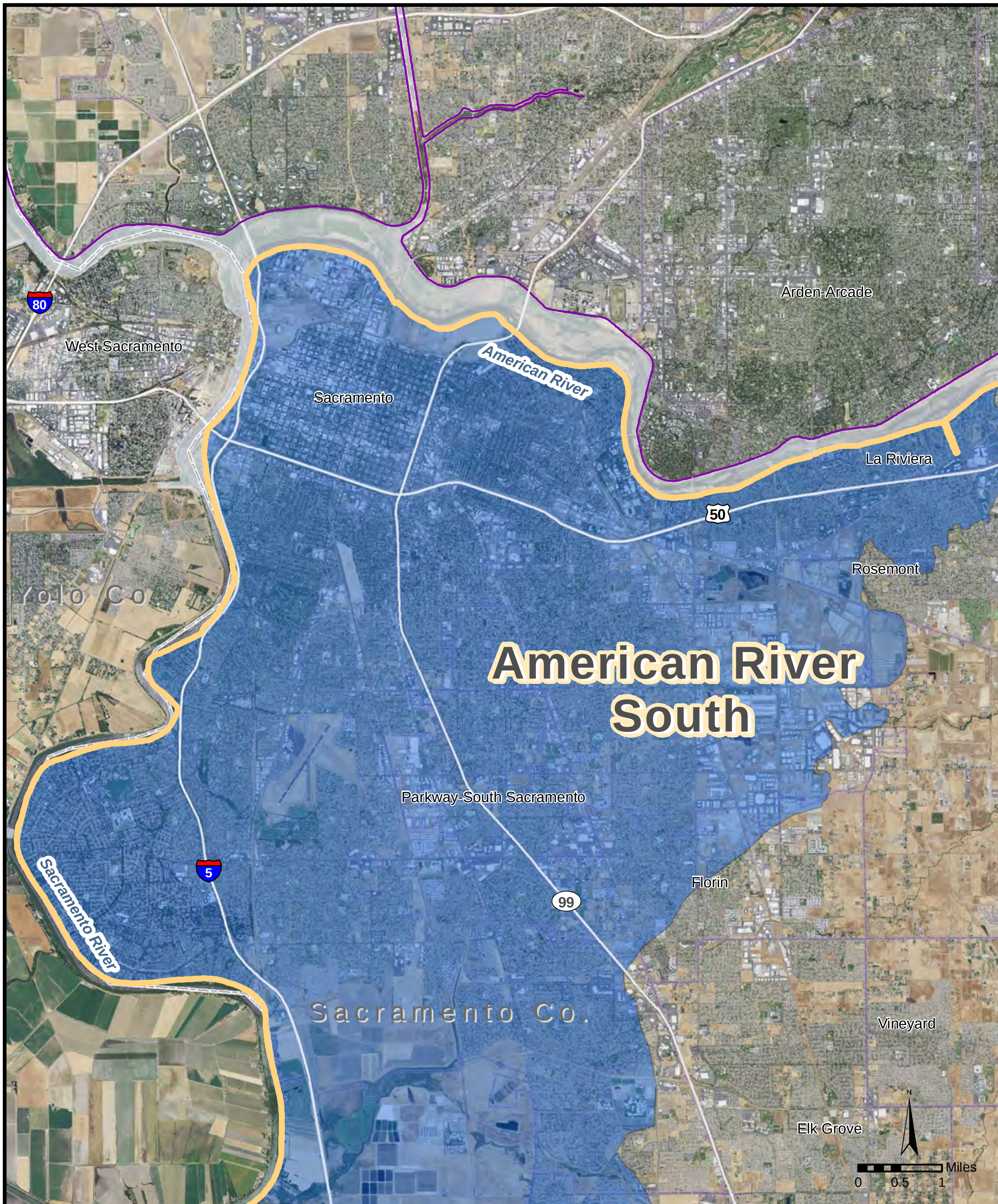


AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

AMERICAN RIVER NORTH PROJECT AREA

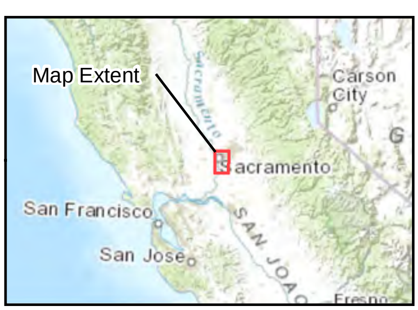
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Feb 2013



LEGEND

- ARCF Levees
- ARS Levees
- County Lines
- Cities

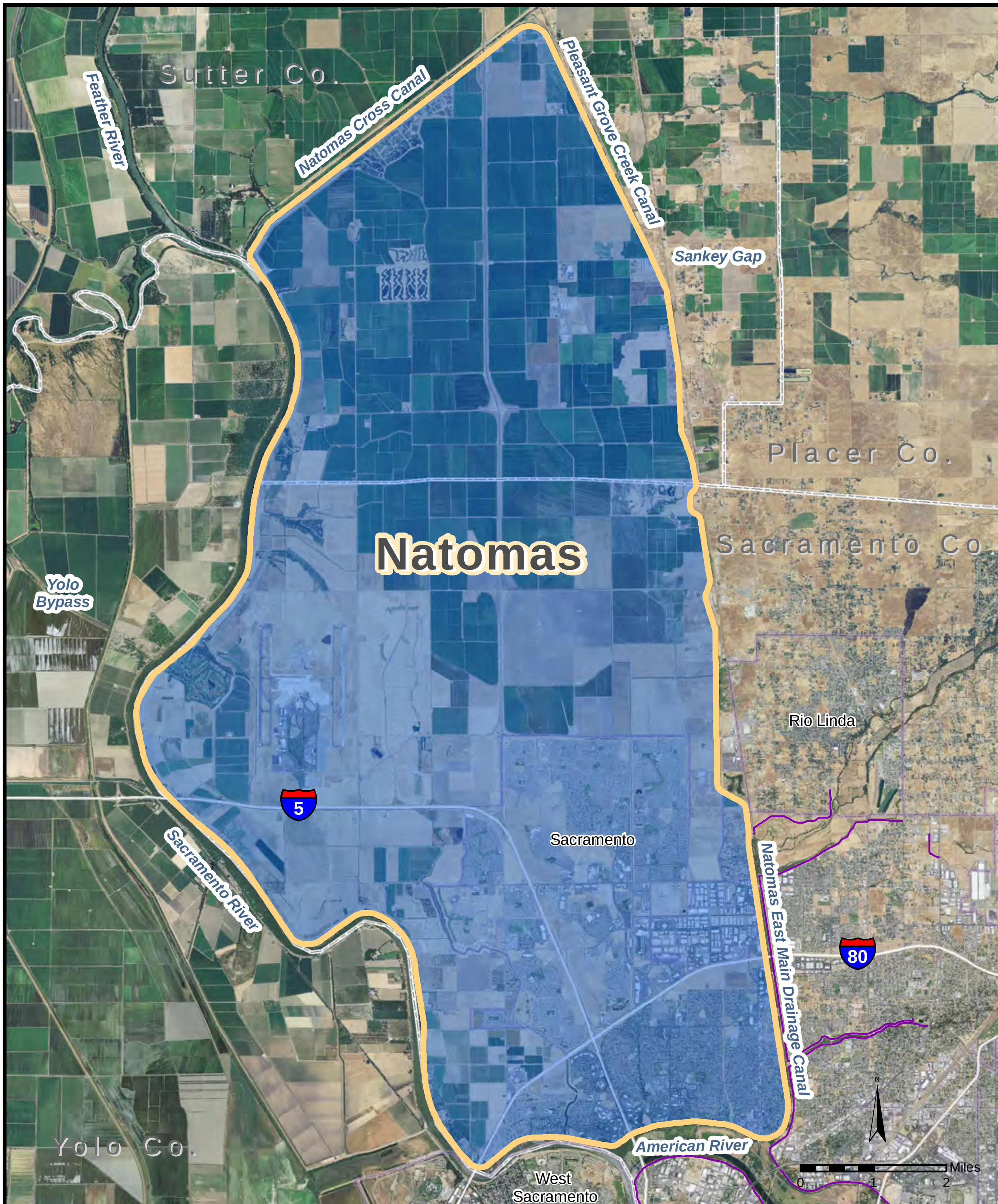


AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

AMERICAN RIVER SOUTH PROJECT AREA

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

June 2014



LEGEND

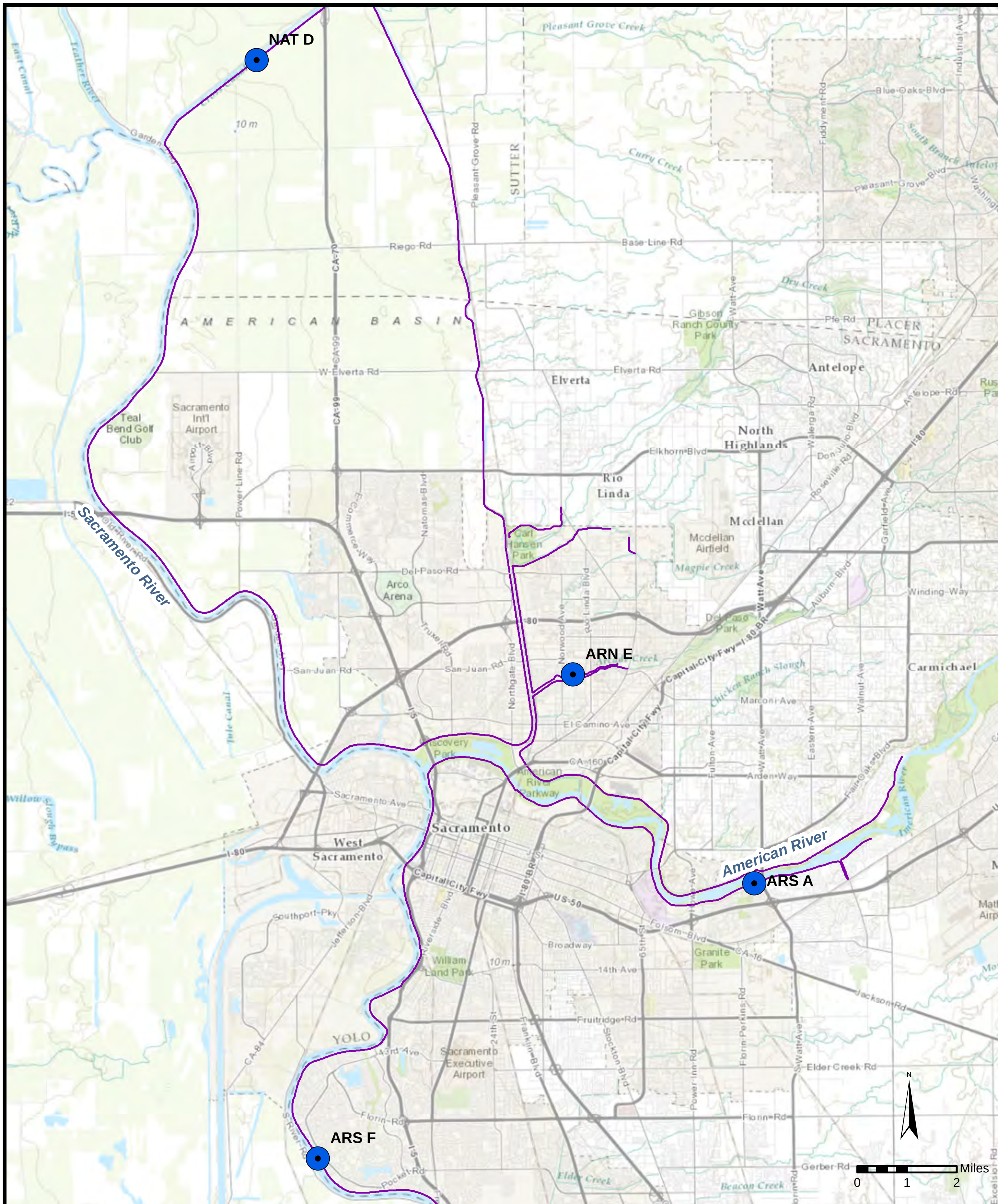
- ARCF Levees
- Natomas Levees
- Cities
- County Lines

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

NATOMAS BASIN PROJECT AREA

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

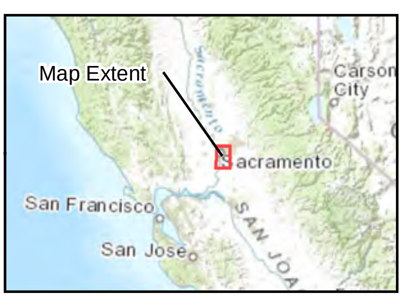
June 2014



LEGEND

ARCF Index Points

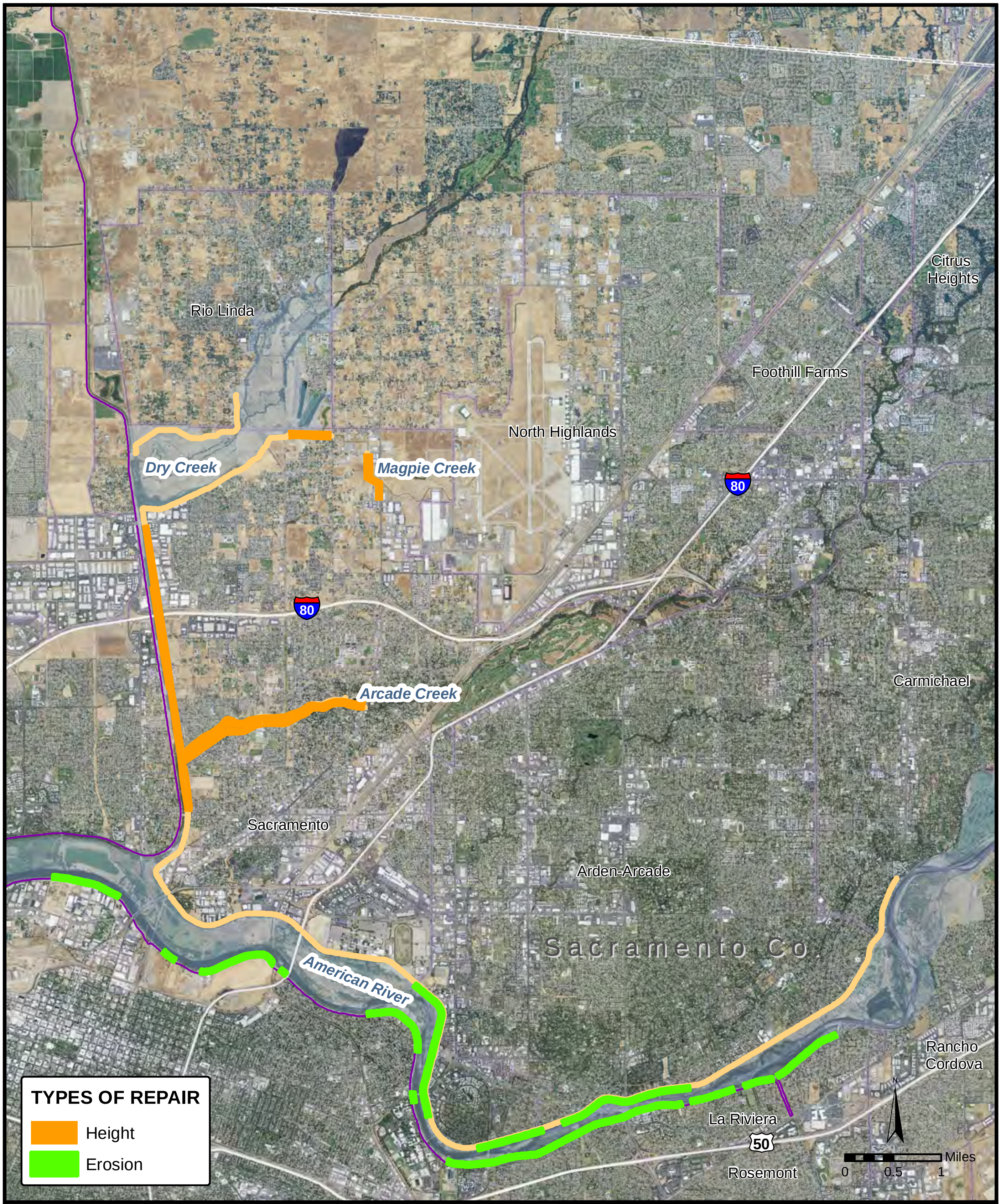
ARCF Levees



AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

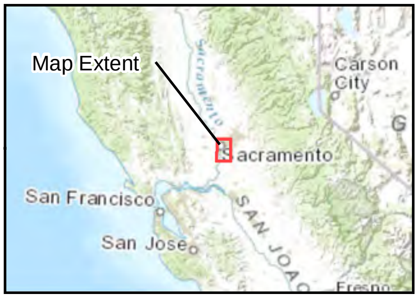
INDEX POINT LOCATION MAP

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



LEGEND

- ARN Levees
- ARCF Levees
- Floodways
- County Lines
- Cities

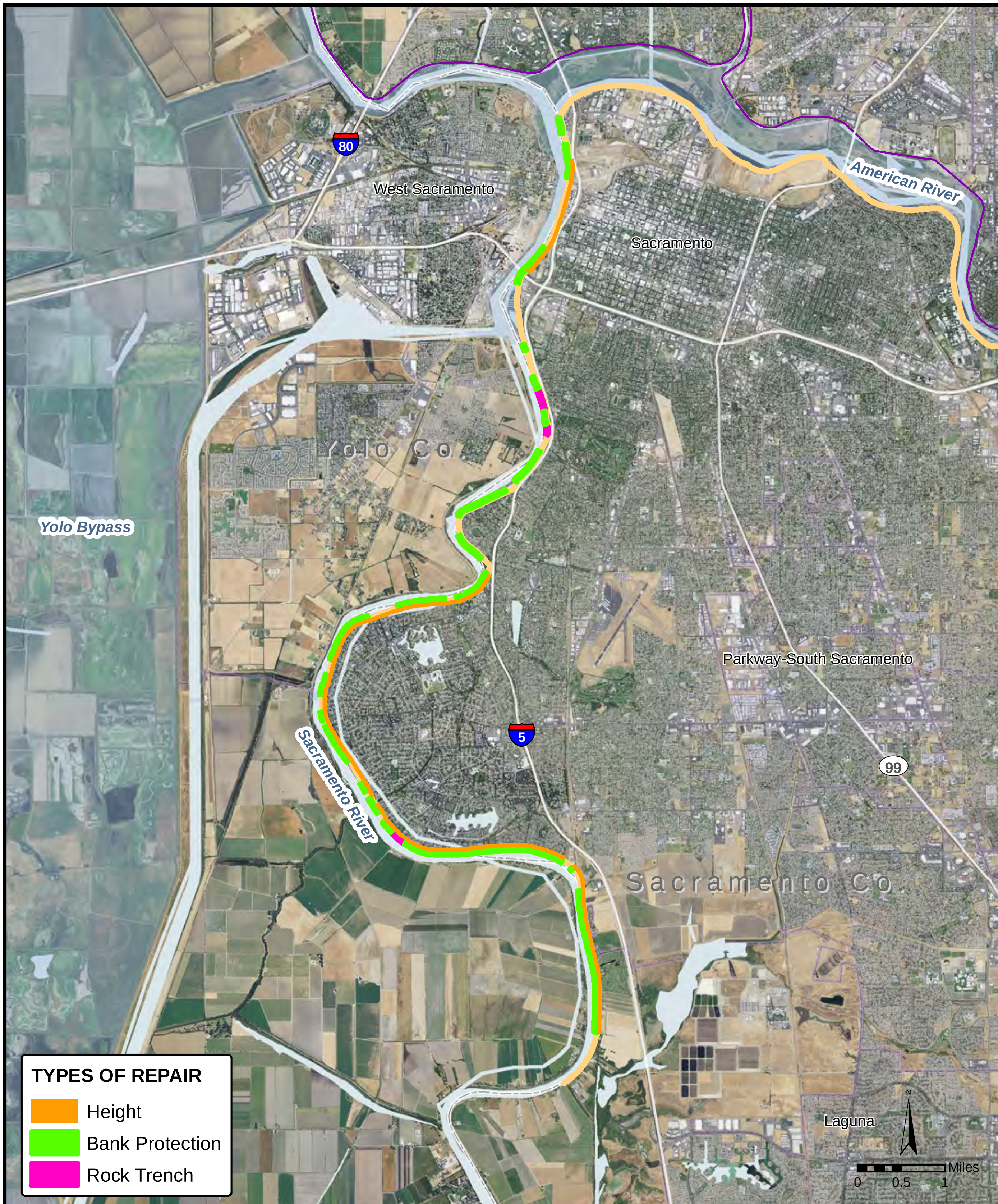


AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

LOCATIONS OF REPAIR FOR HEIGHT AND EROSION ALONG THE AMERICAN RIVER AND EAST SIDE TRIBUTARIES

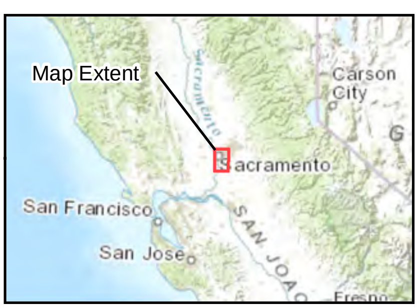
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

June 2014



LEGEND

- ARCF Levees
- ARS Levees
- Floodways
- County Lines
- Cities

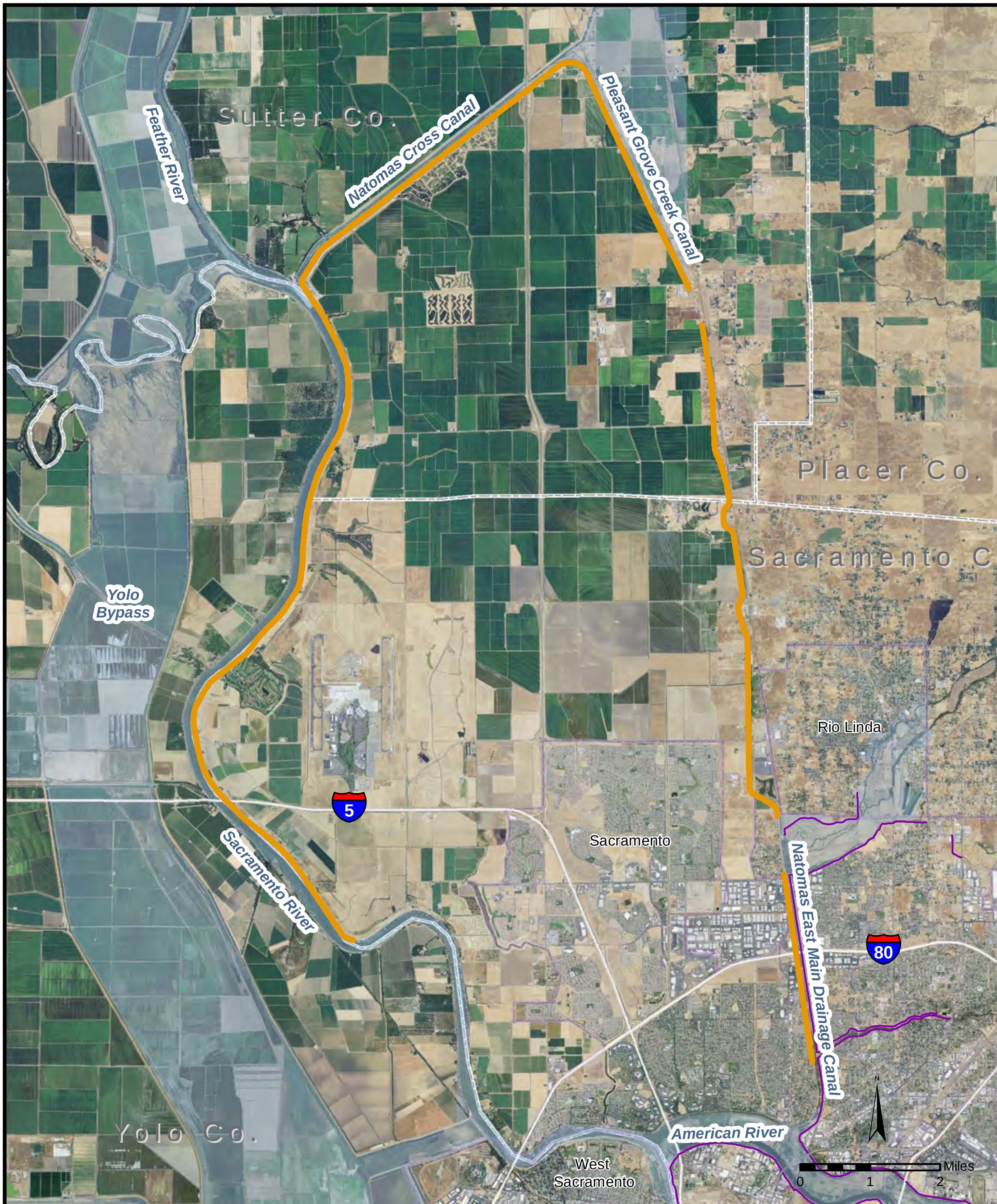


AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

LOCATIONS OF REPAIR FOR HEIGHT AND EROSION ALONG THE SACRAMENTO RIVER

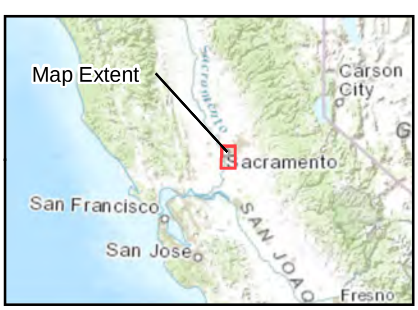
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

June 2014



LEGEND

- Height
- ARCF Levees
- Floodways
- Cities
- County Lines

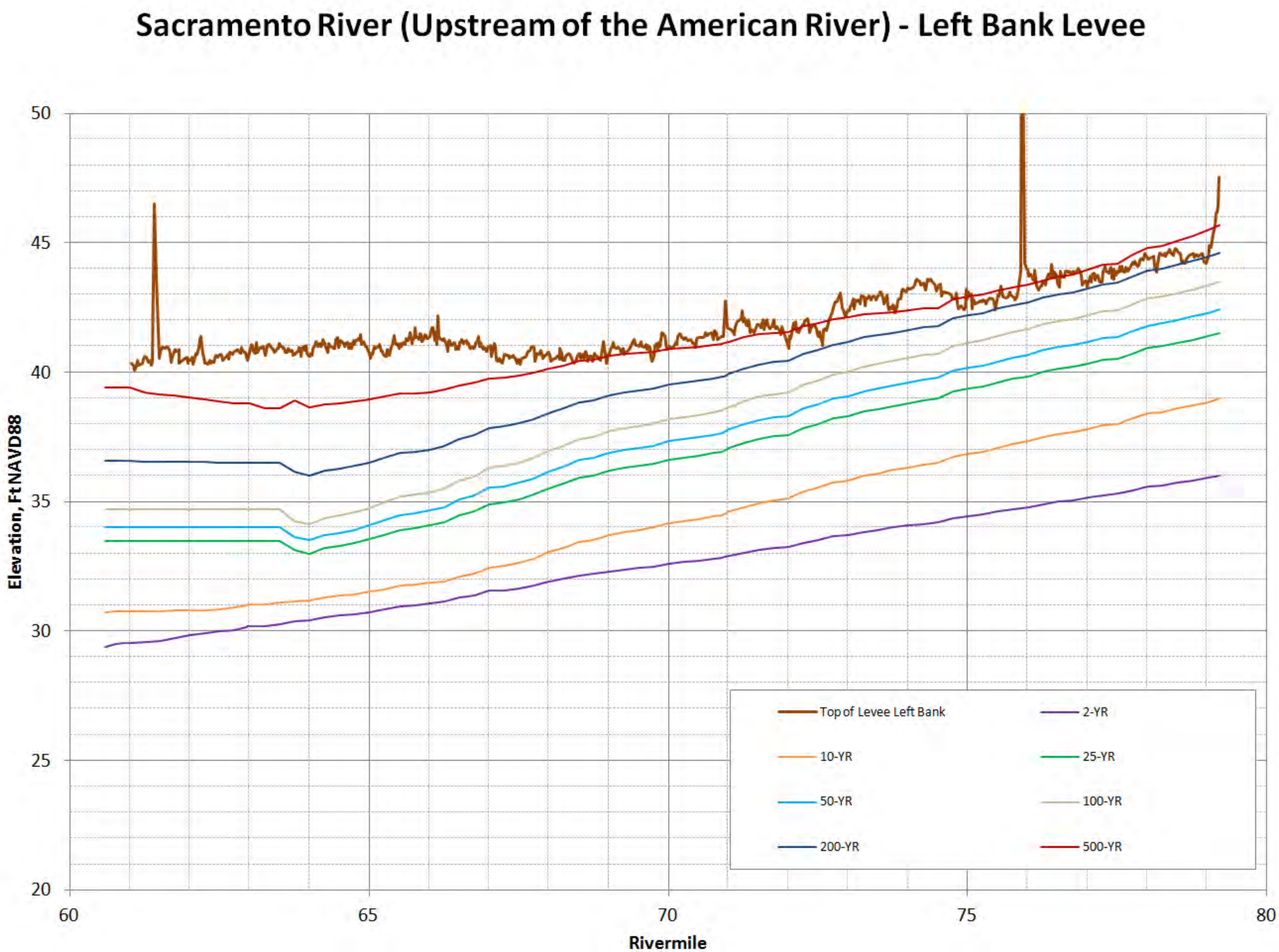


AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

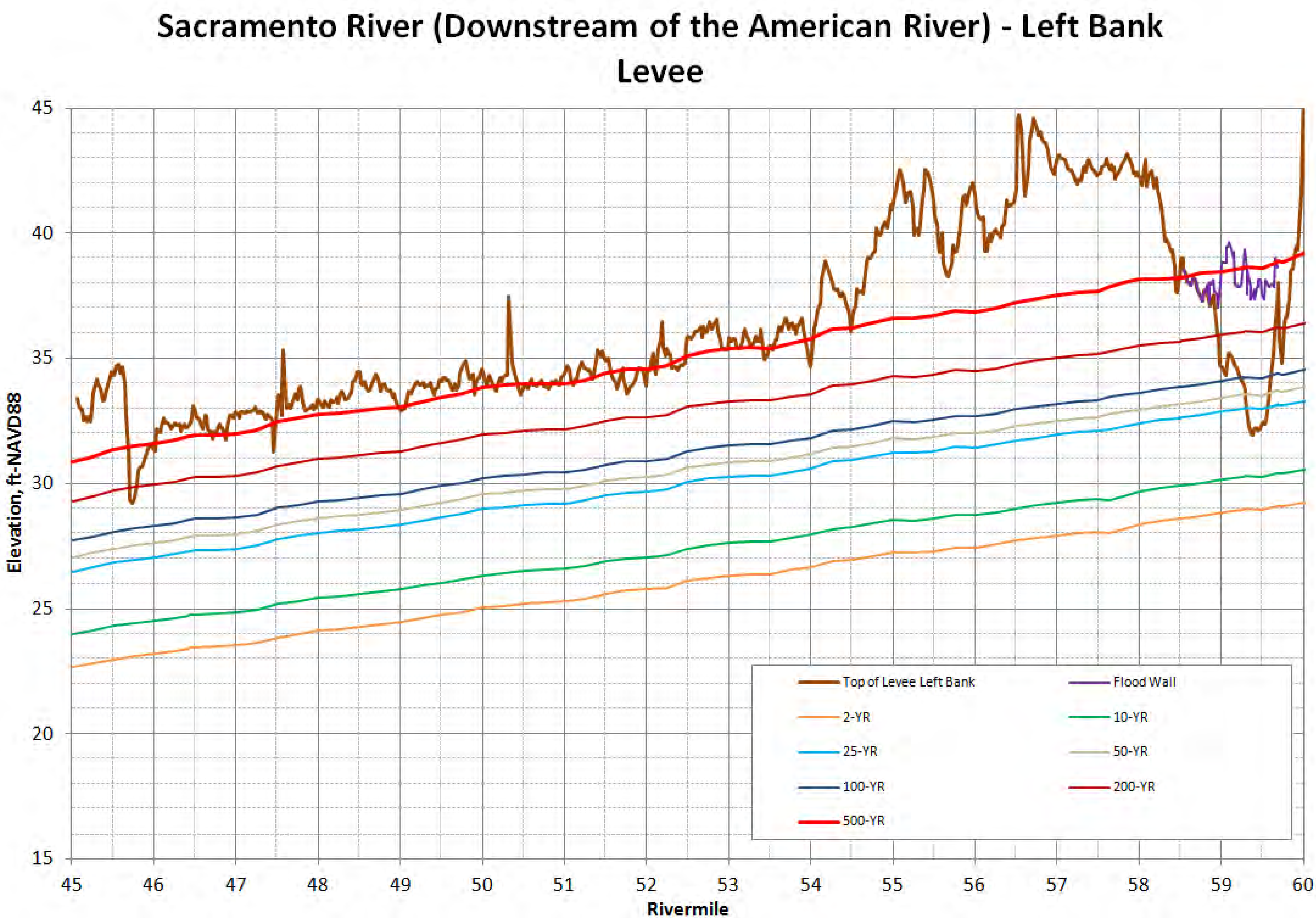
LOCATIONS OF REPAIR FOR HEIGHT ALONG THE NATOMAS BASIN

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

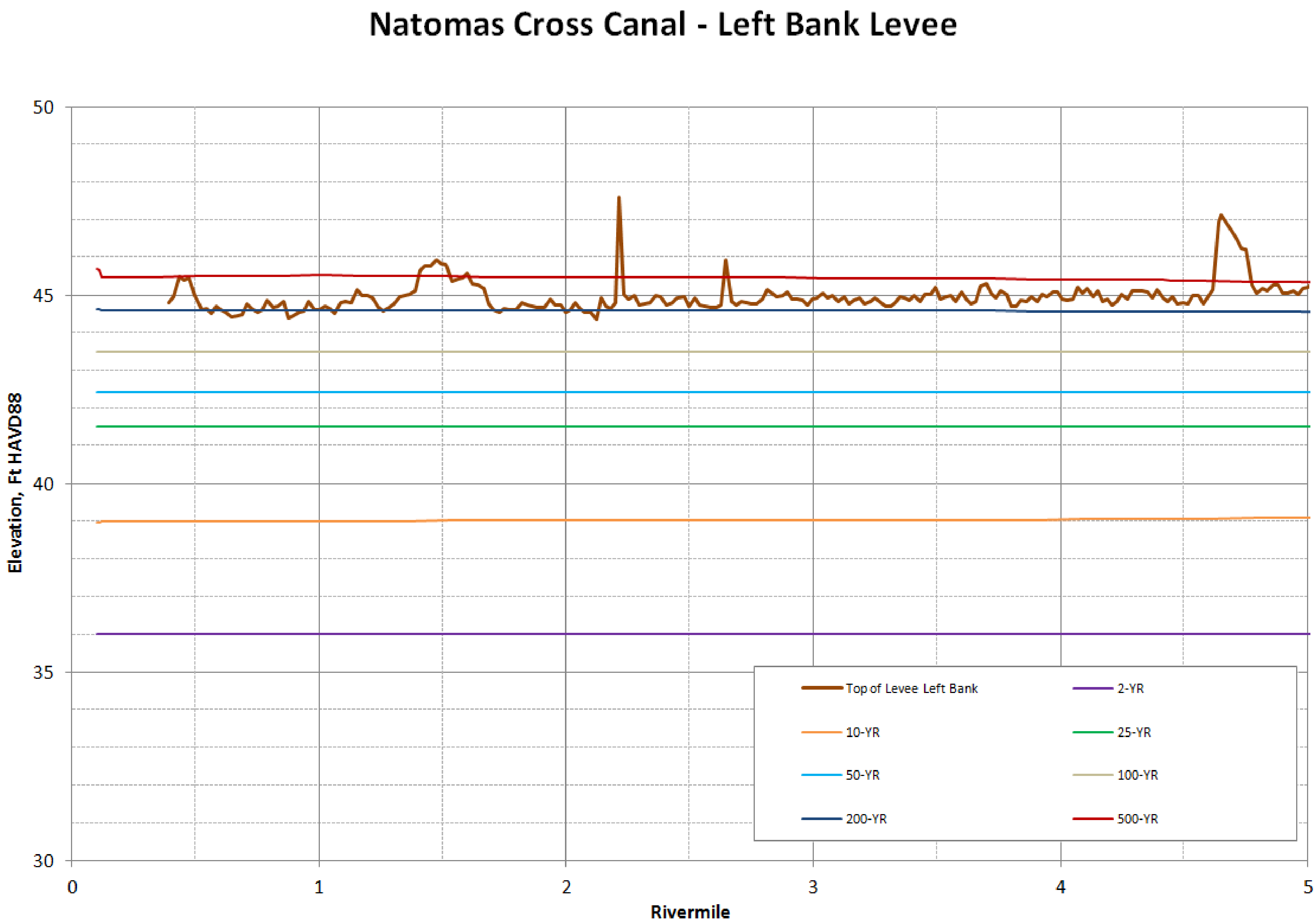
June 2014



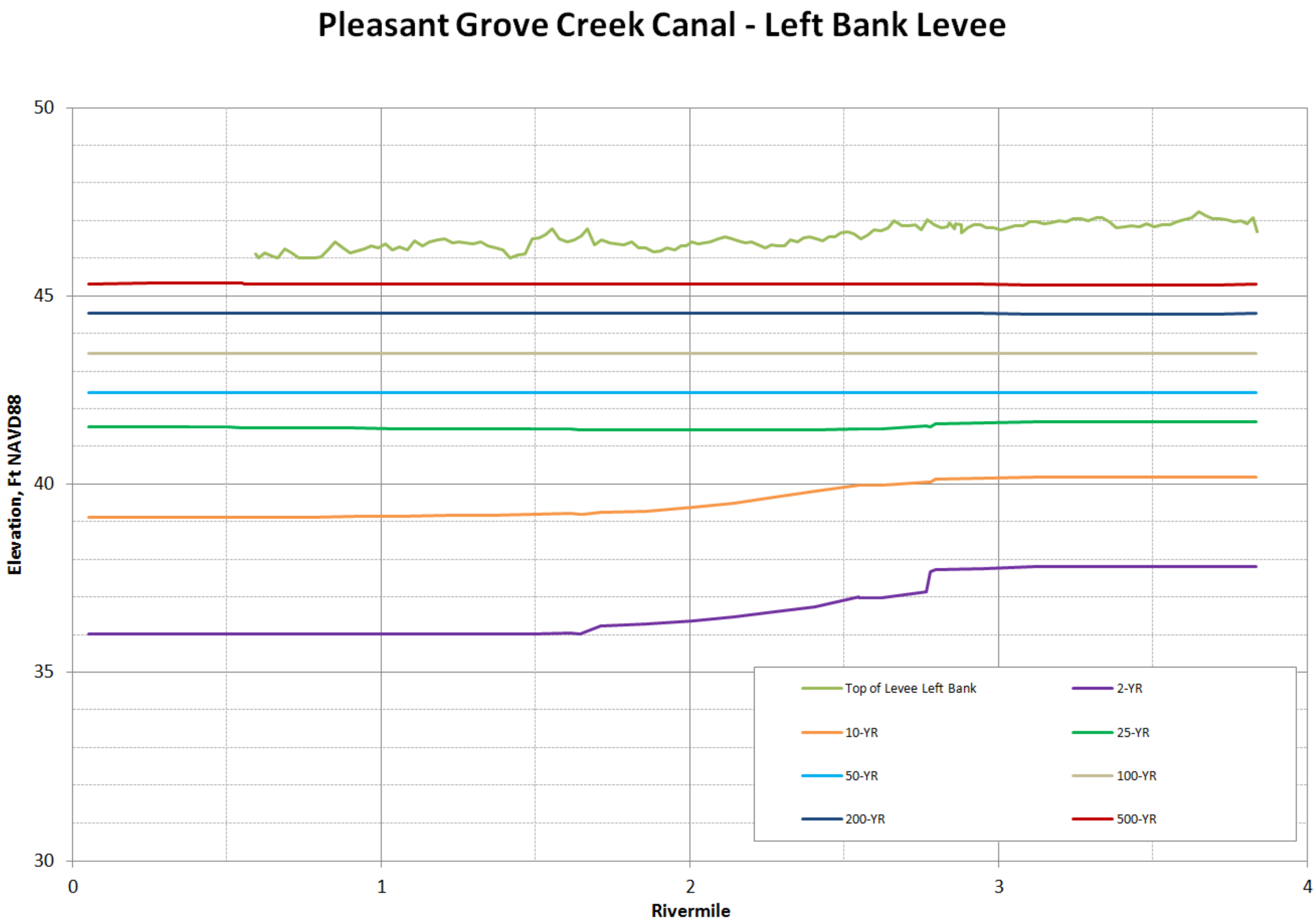
American River Common Features GRR Sacramento, California	Sacramento River (U/S of the American River) – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



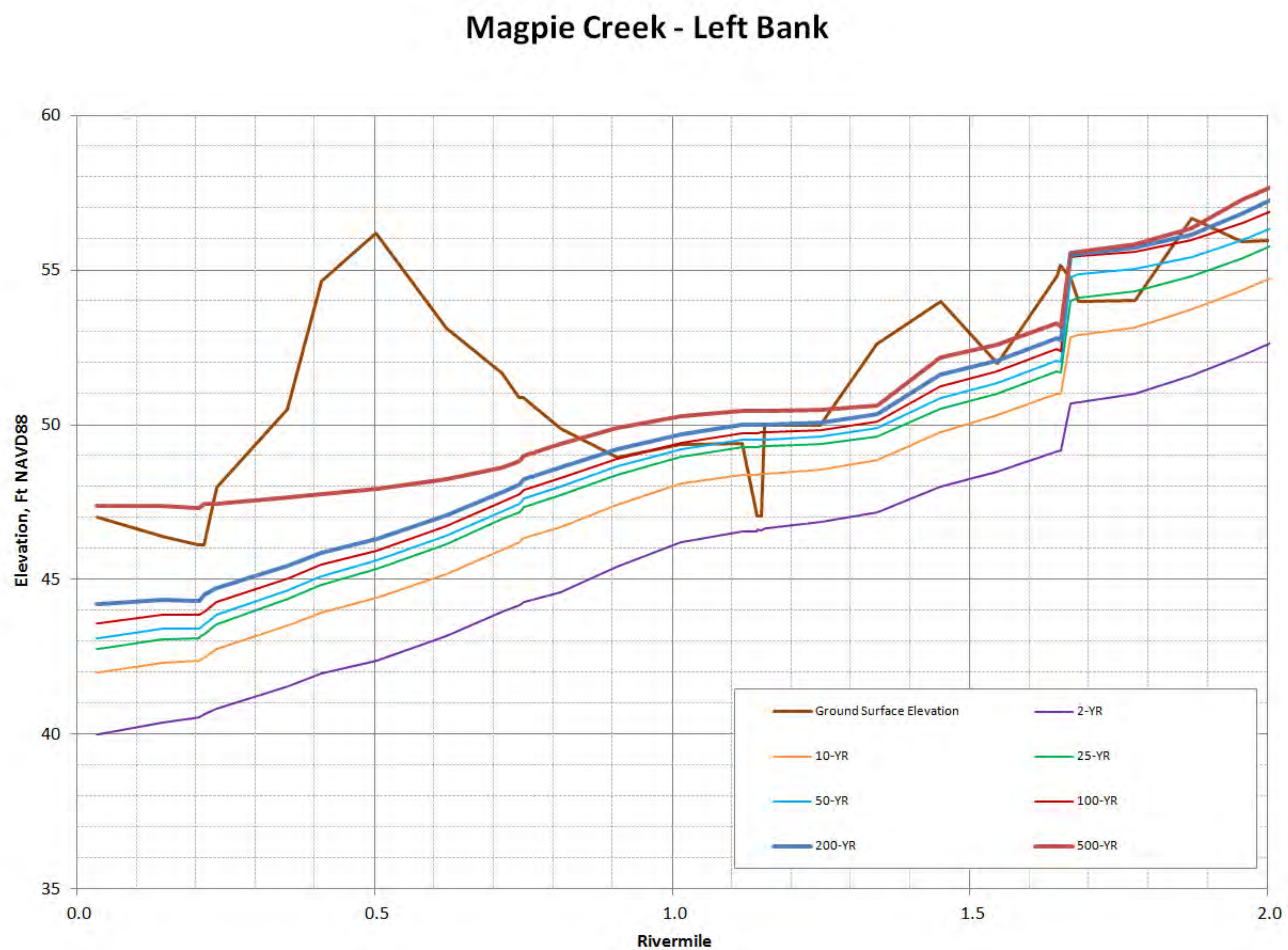
American River Common Features GRR Sacramento, California	Sacramento River (D/S of the American River) – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



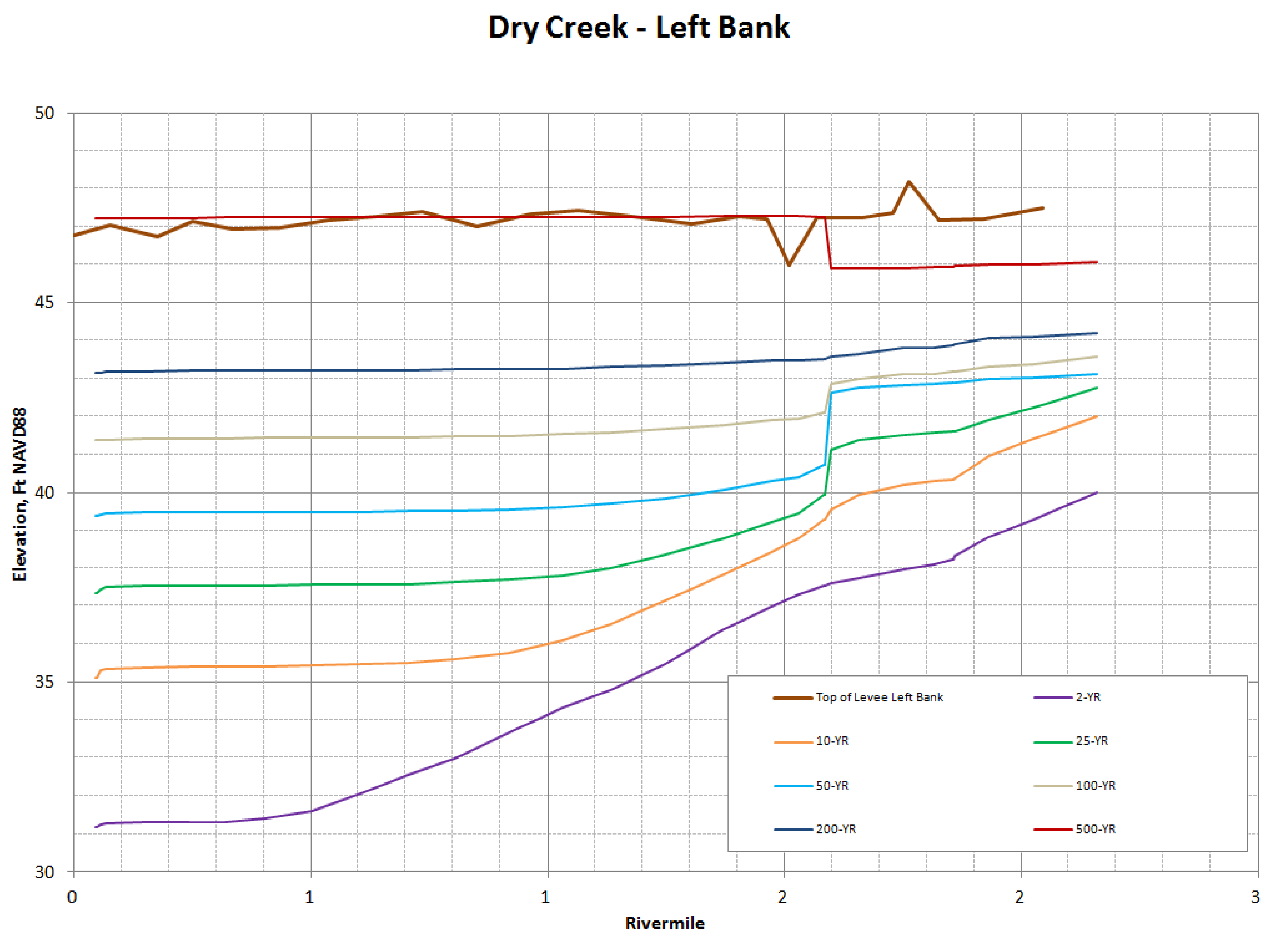
American River Common Features GRR Sacramento, California	Natomas Cross Canal – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



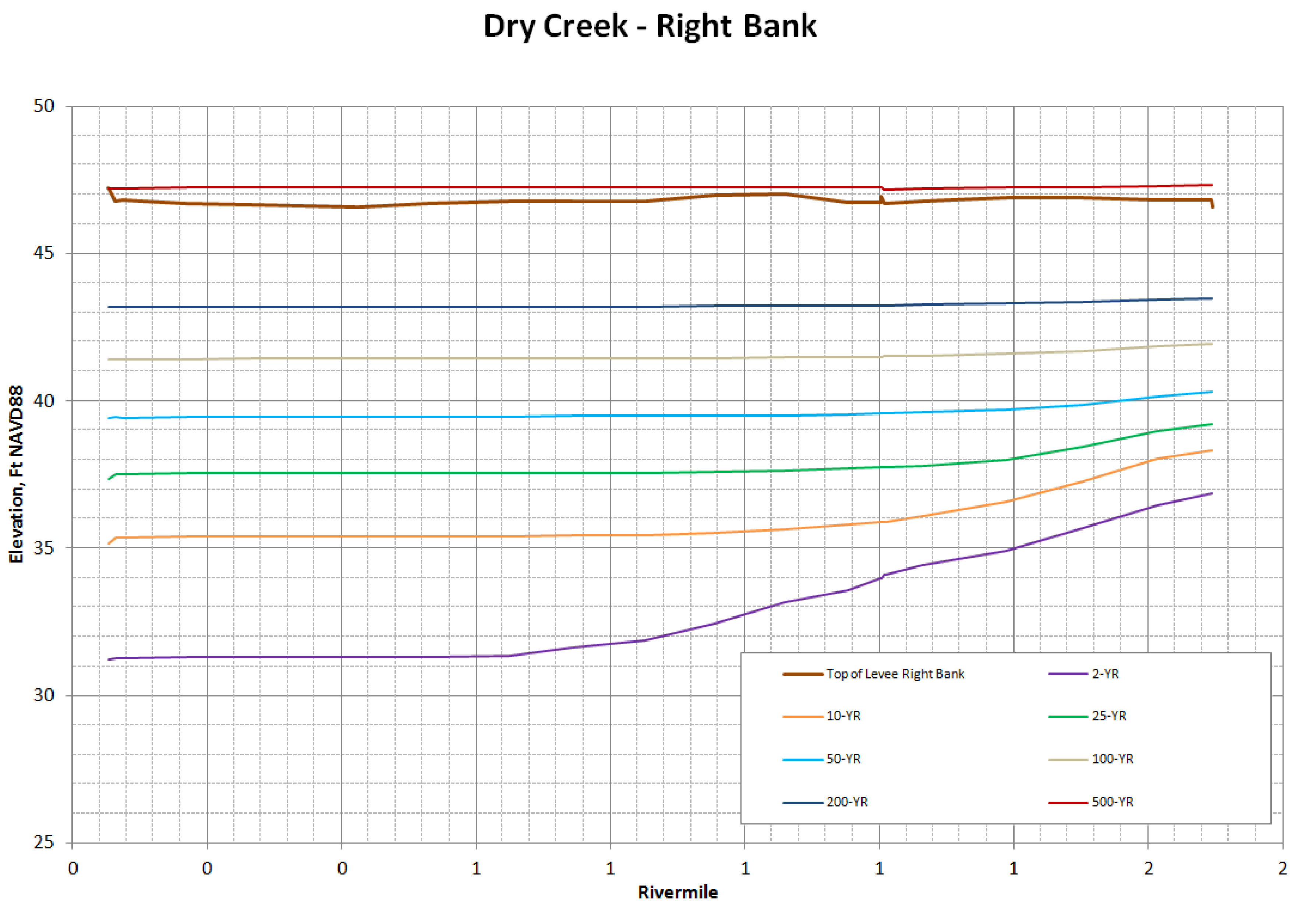
American River Common Features GRR Sacramento, California	Pleasant Grove Creek Canal – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



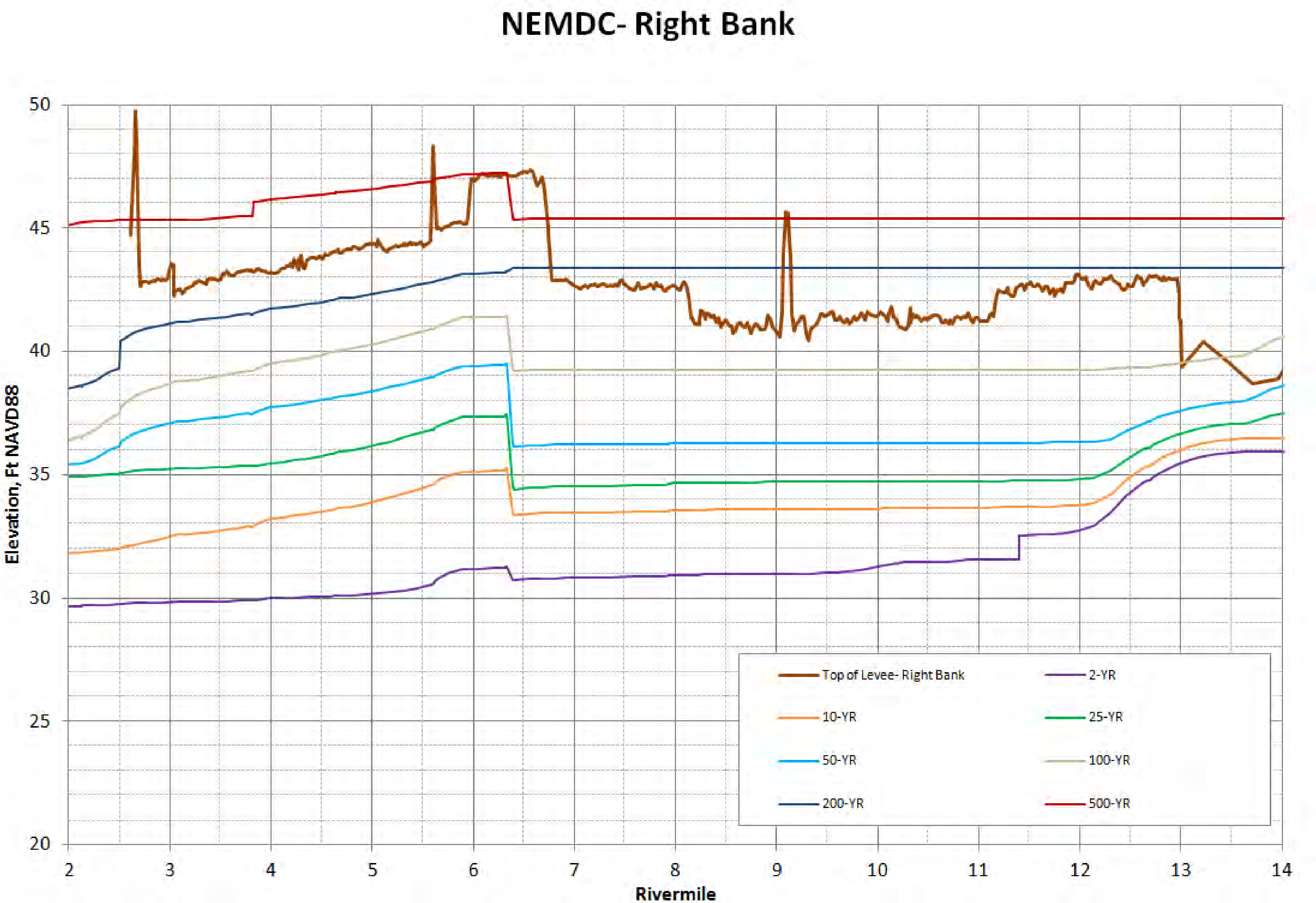
American River Common Features GRR Sacramento, California	Magpie Creek – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



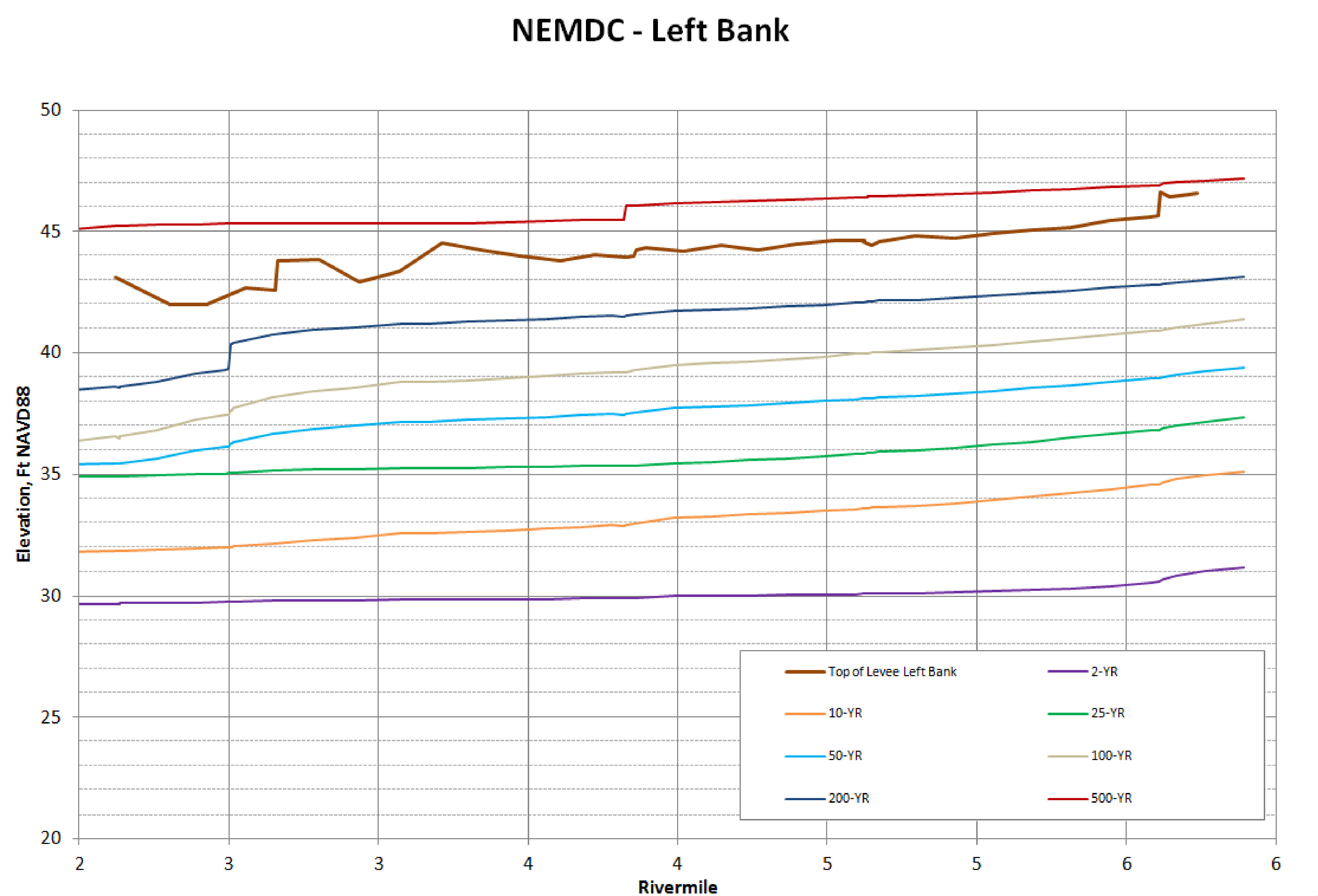
American River Common Features GRR Sacramento, California	Dry Creek – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



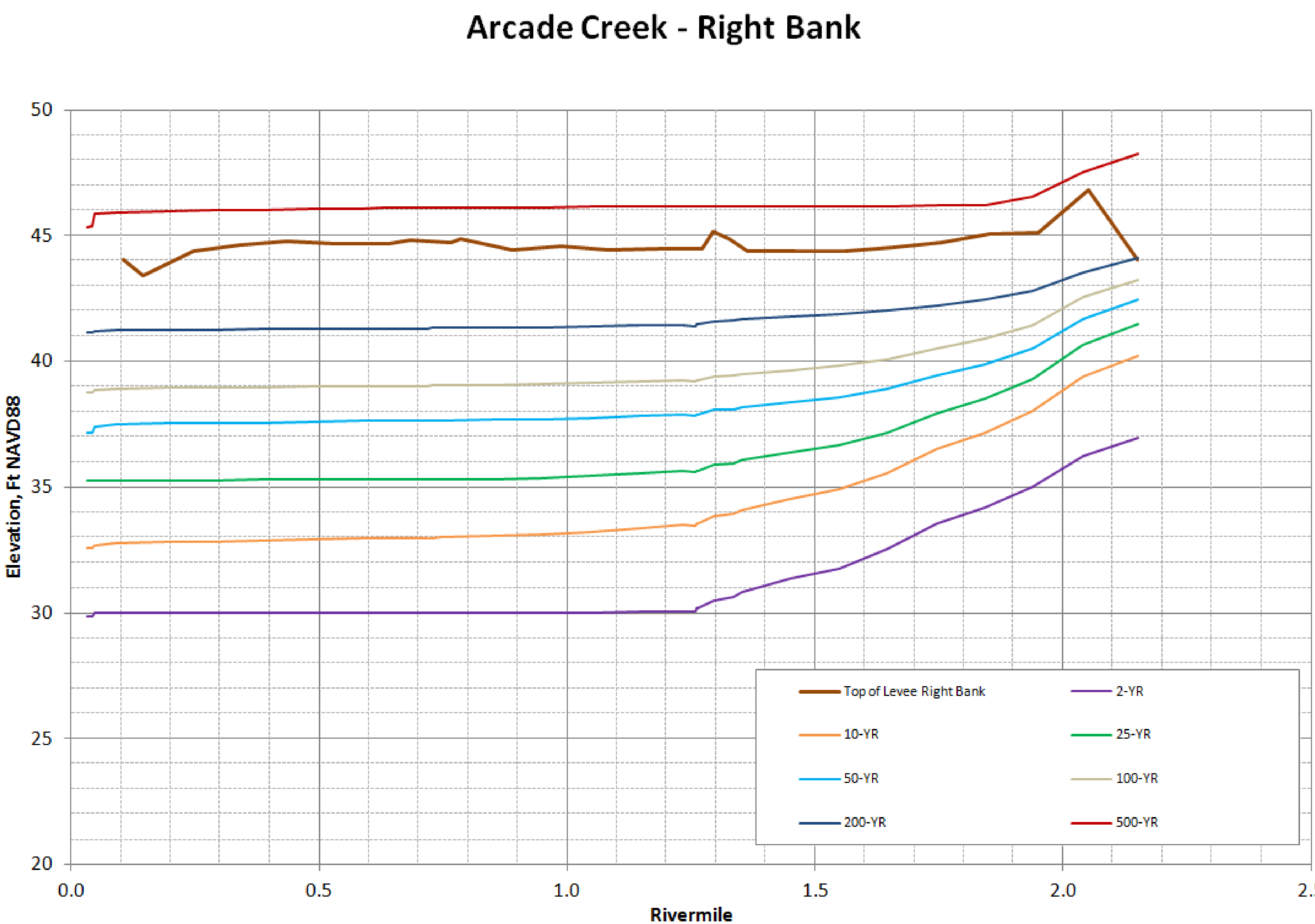
American River Common Features GRR Sacramento, California	Dry Creek – Right Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



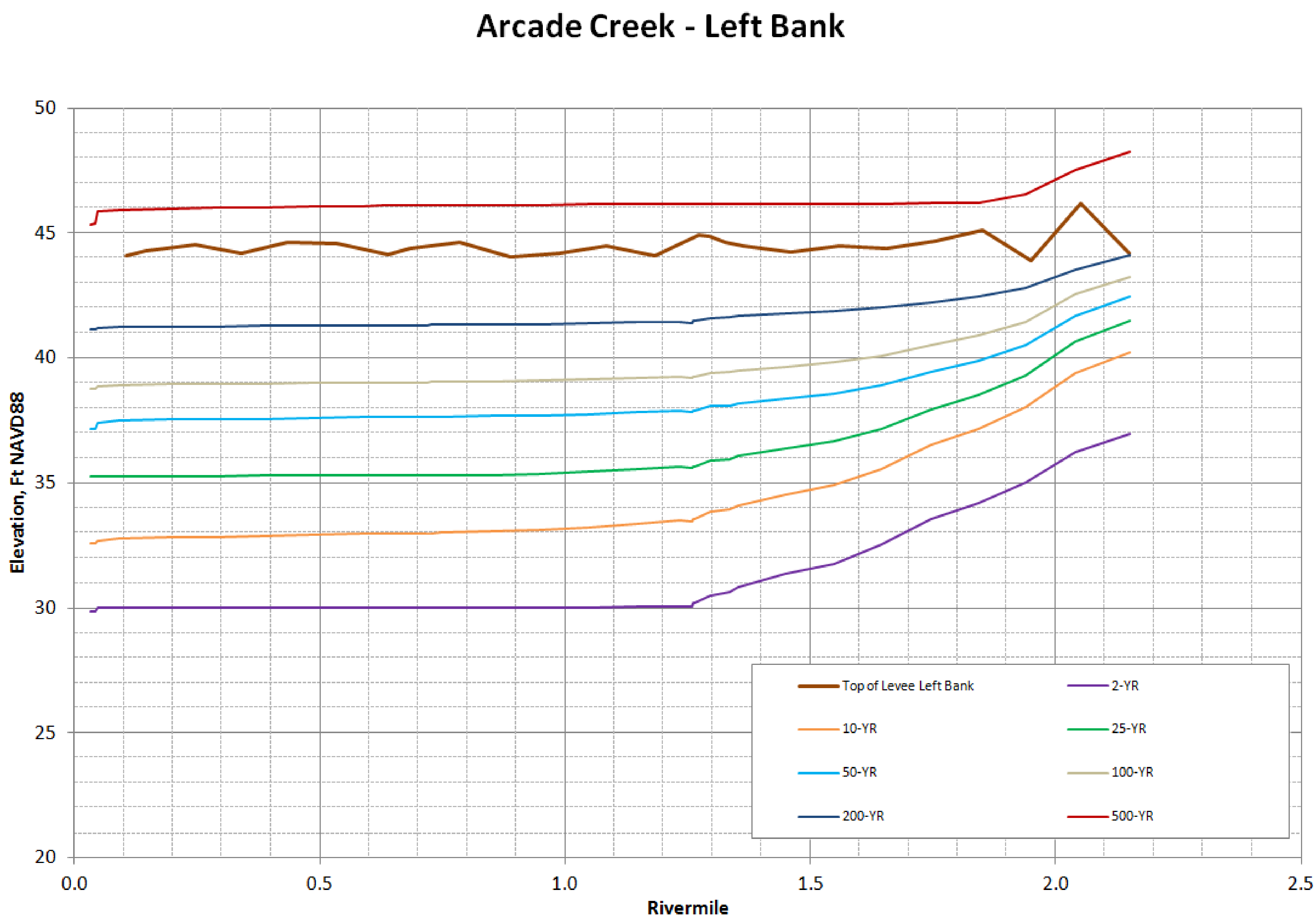
American River Common Features GRR Sacramento, California	NEMDC – Right Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



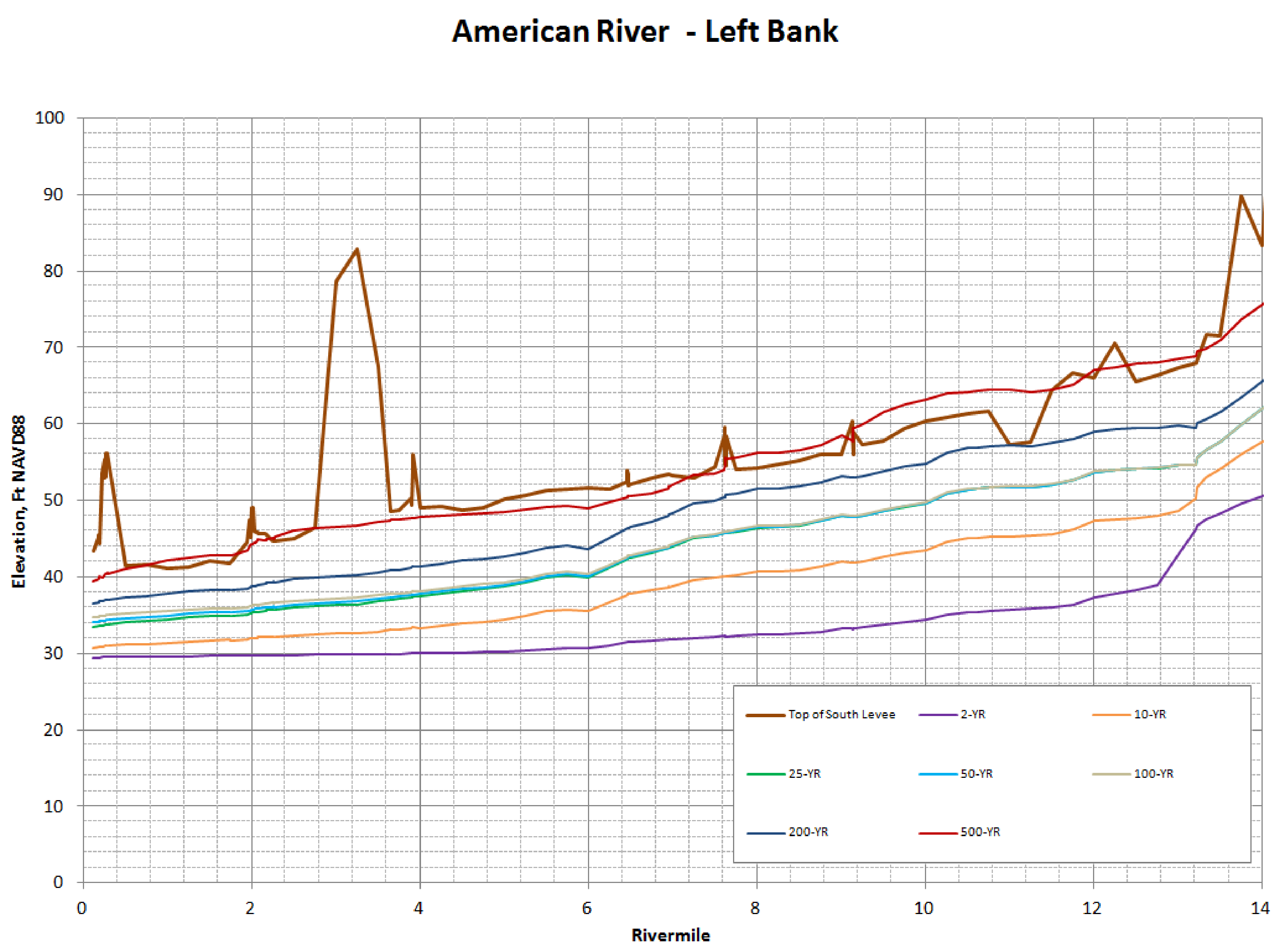
American River Common Features GRR Sacramento, California	NEMDC – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



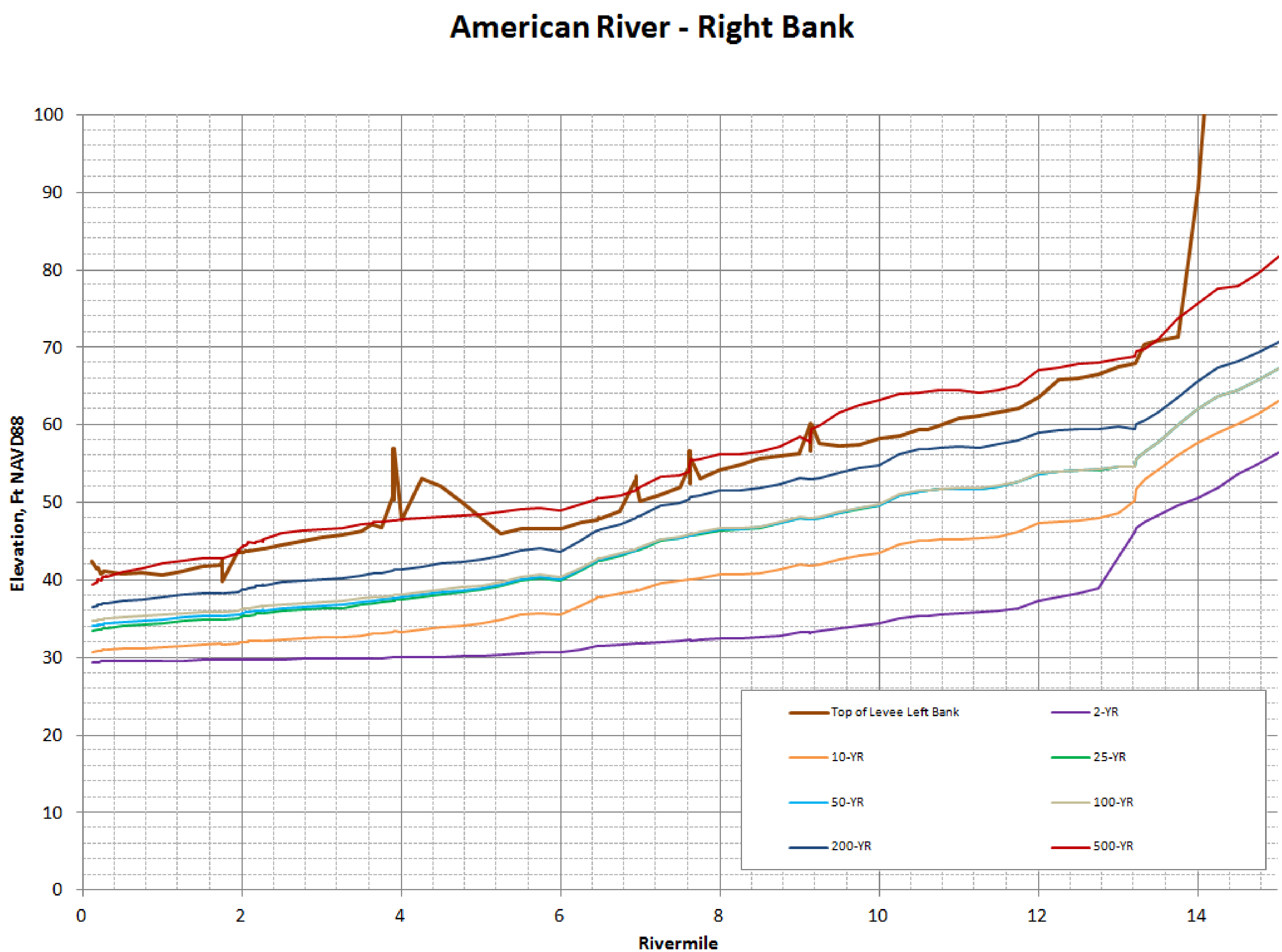
American River Common Features GRR Sacramento, California	Arcade Creek – Right Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



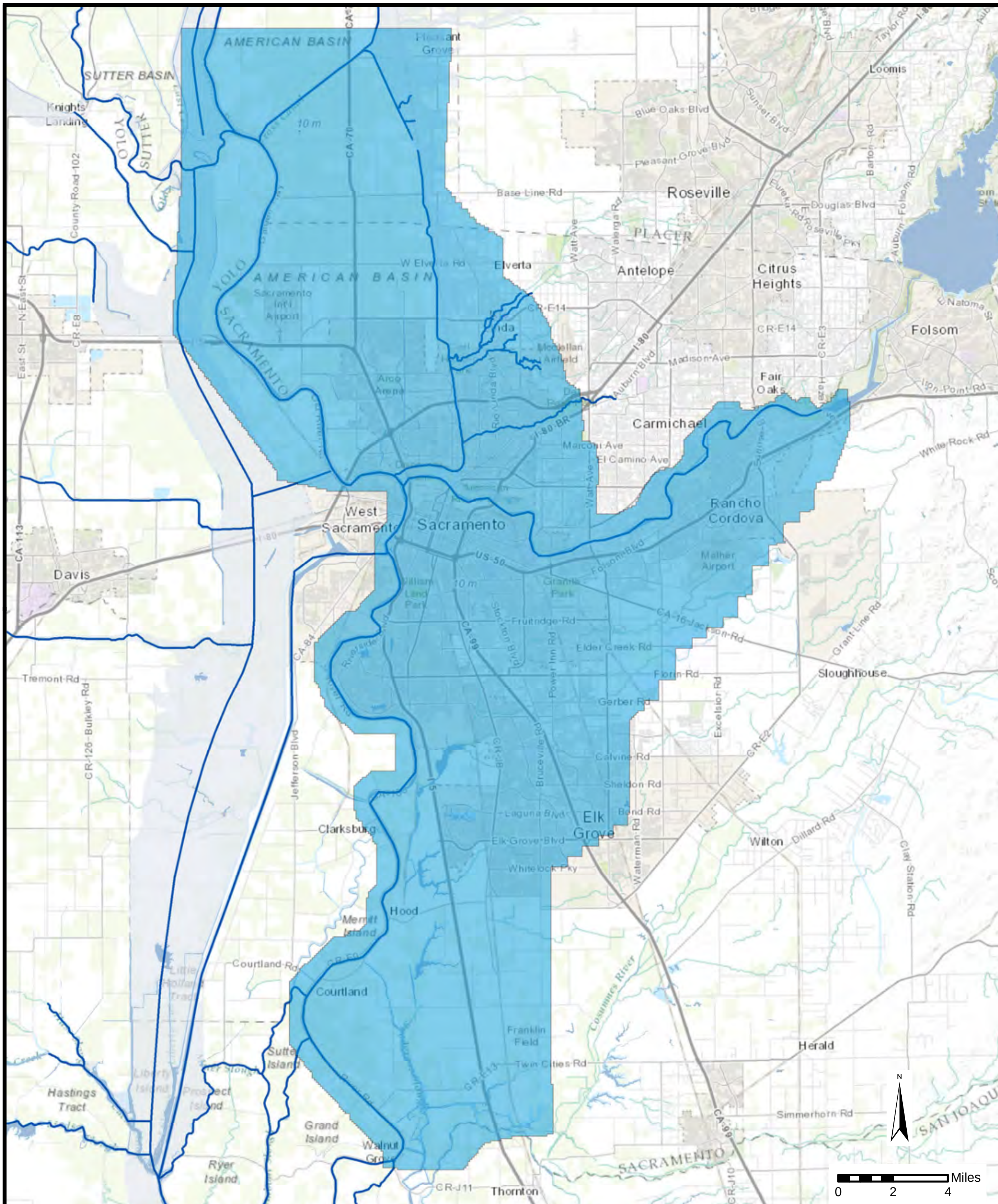
American River Common Features GRR Sacramento, California	Arcade Creek – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



American River Common Features GRR Sacramento, California	American River – Left Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



American River Common Features GRR Sacramento, California	American River – Right Bank Levee N-Yr Water Surface Profiles Future Without-Project Condition	U.S. Army Corps of Engineers Sacramento District



LEGEND

FLO2D Extents

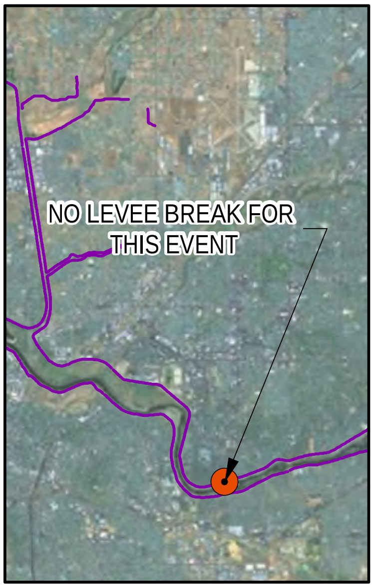
Rivers and Streams

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

FLO2D MODEL EXTENTS

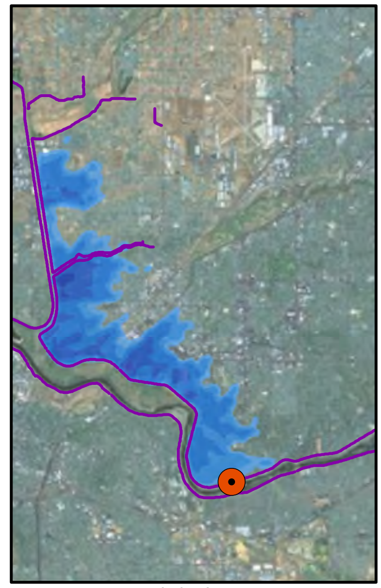
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Jan 2013

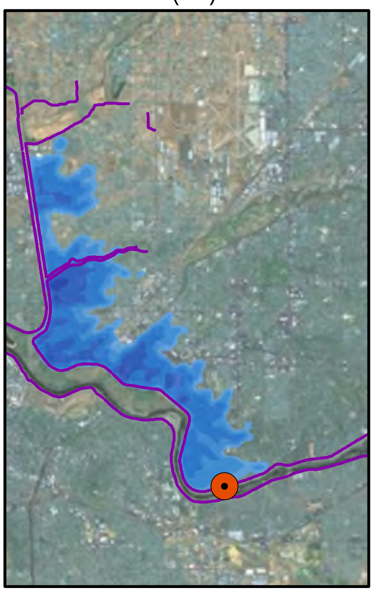


50% (1/2) ACE

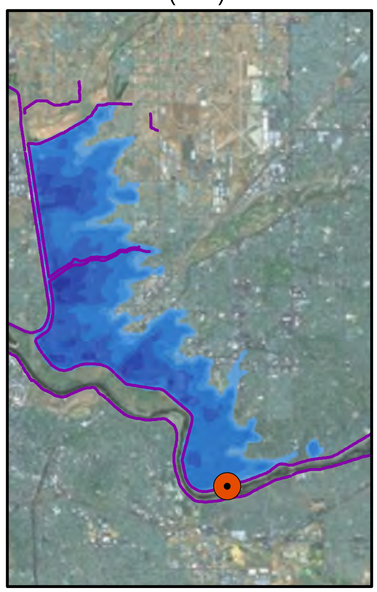
10% (1/10) ACE



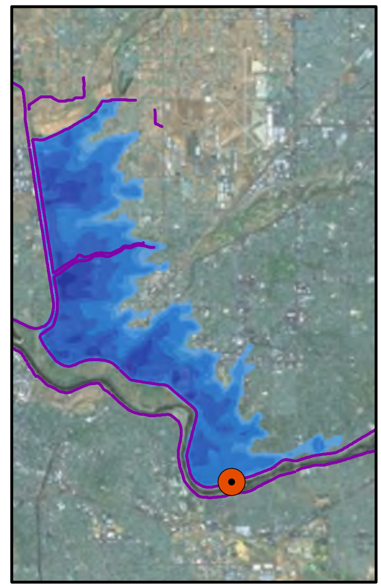
4% (1/25) ACE



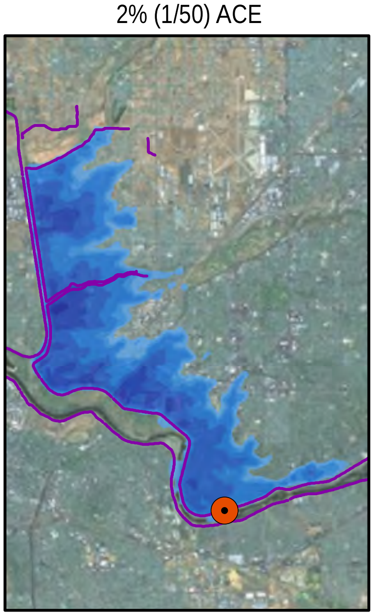
2% (1/50) ACE



1% (1/100) ACE



0.5% (1/200) ACE



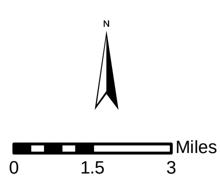
0.2% (1/500) ACE

LEGEND

Depths of Flooding (Feet)

- < 1
- 1.1 - 3
- 3.1 - 5
- 5.1 - 10
- 10.1 - 15
- 15.1 - 20
- 20.1 - 25
- 25.1 +

STUDY AREA EXTENT

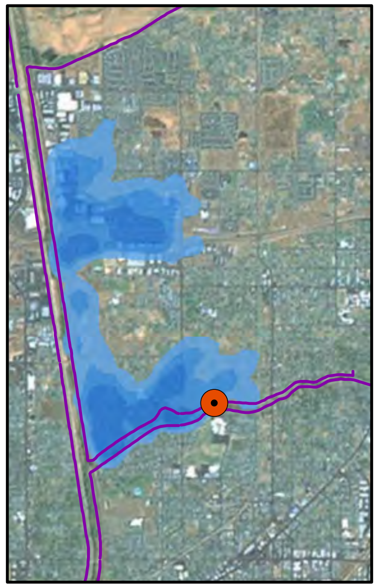


AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

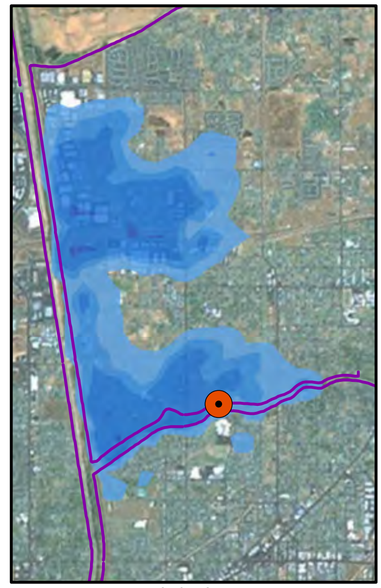
ECONOMIC FLOODPLAINS BASED ON A LEVEE BREACH SIMULATION AMERICAN RIVER NORTH INDEX PT A.

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

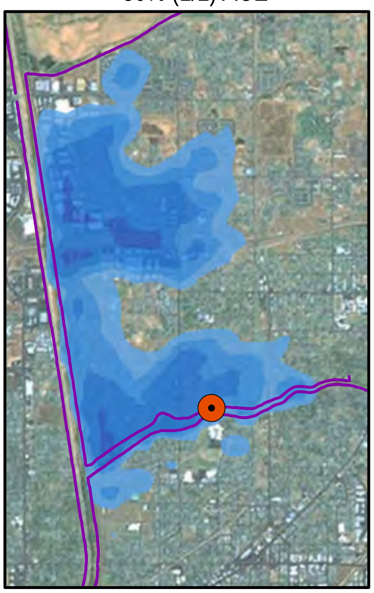
50% (1/2) ACE



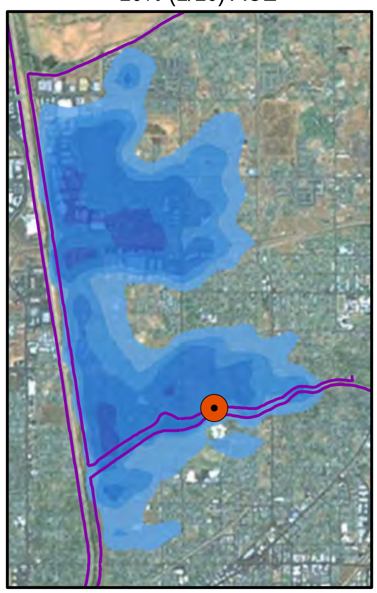
10% (1/10) ACE



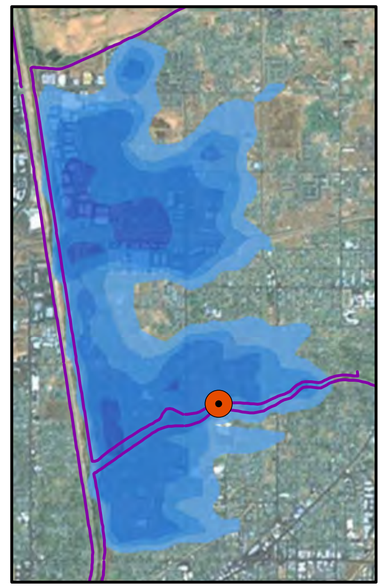
4% (1/25) ACE



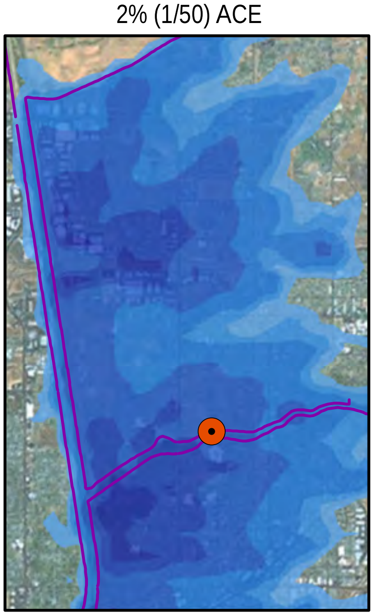
2% (1/50) ACE



1% (1/100) ACE



0.5% (1/200) ACE

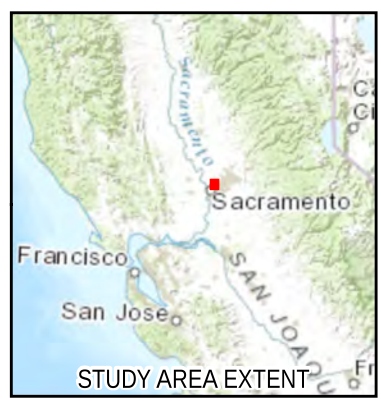


0.2% (1/500) ACE

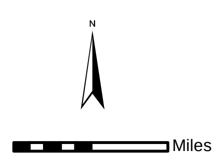
LEGEND

Depths of Flooding (Feet)

- < 1
- 1.1 - 3
- 3.1 - 5
- 5.1 - 10
- 10.1 - 15
- 15.1 - 20
- 20.1 - 25
- 25.1 +



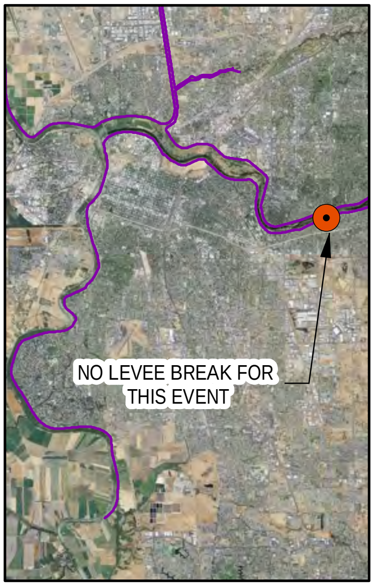
STUDY AREA EXTENT



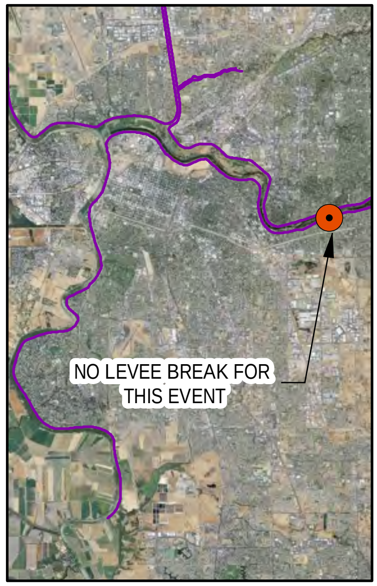
AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

ECONOMIC FLOODPLAINS BASED ON A LEVEE BREACH SIMULATION AMERICAN RIVER NORTH INDEX PT E.

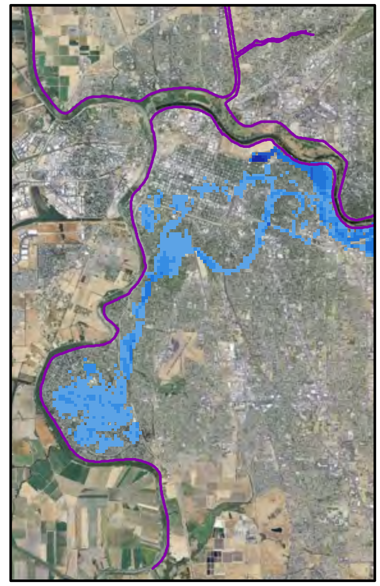
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



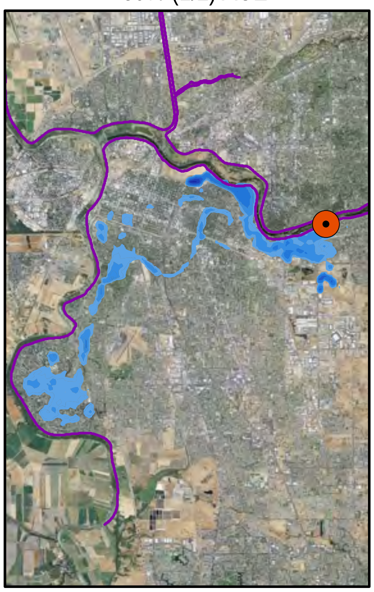
50% (1/2) ACE



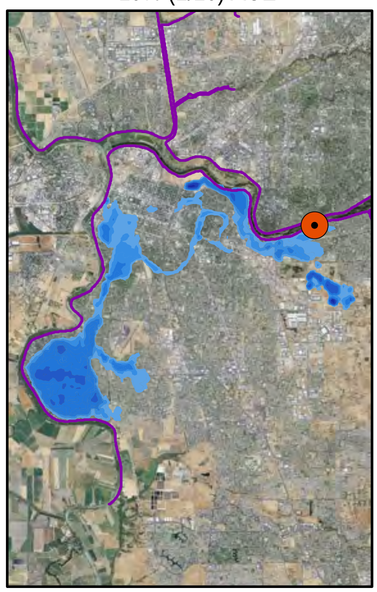
10% (1/10) ACE



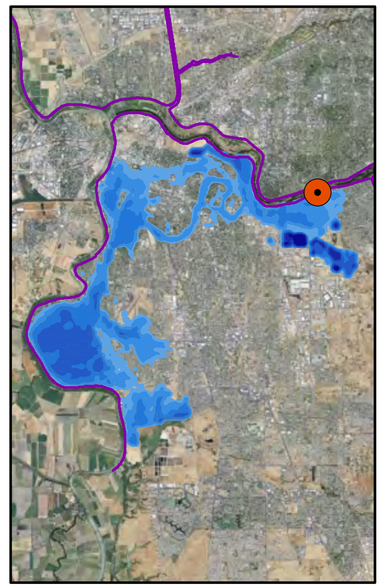
4% (1/25) ACE



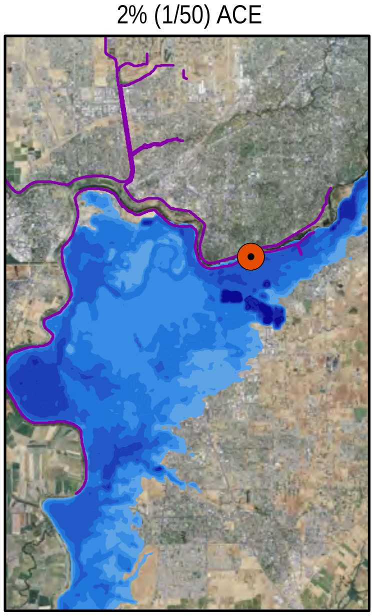
2% (1/50) ACE



1% (1/100) ACE



0.5% (1/200) ACE



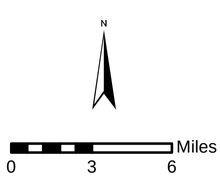
0.2% (1/500) ACE

LEGEND

Depths of Flooding (Feet)

- < 1
- 1.1 - 3
- 3.1 - 5
- 5.1 - 10
- 10.1 - 15
- 15.1 - 20
- 20.1 - 25
- 25.1 +

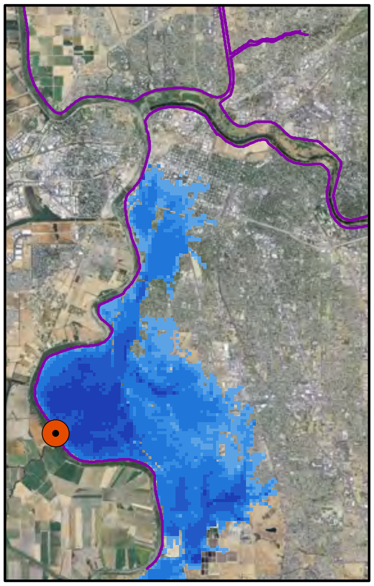
STUDY AREA EXTENT



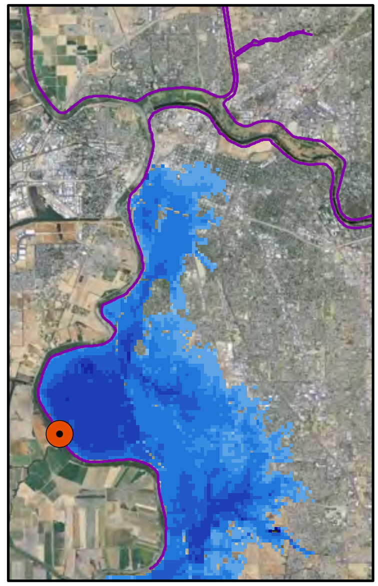
AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

ECONOMIC FLOODPLAINS BASED ON A LEVEE BREACH SIMULATION AMERICAN RIVER SOUTH INDEX PT A.

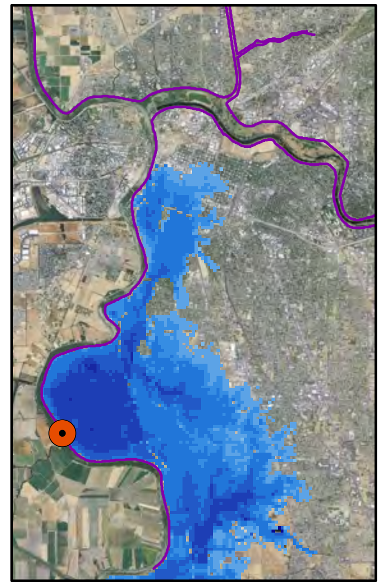
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



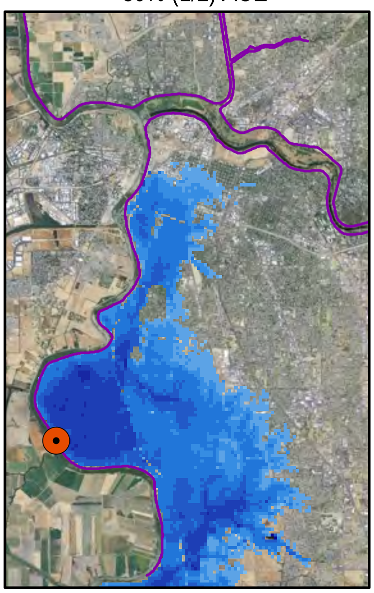
50% (1/2) ACE



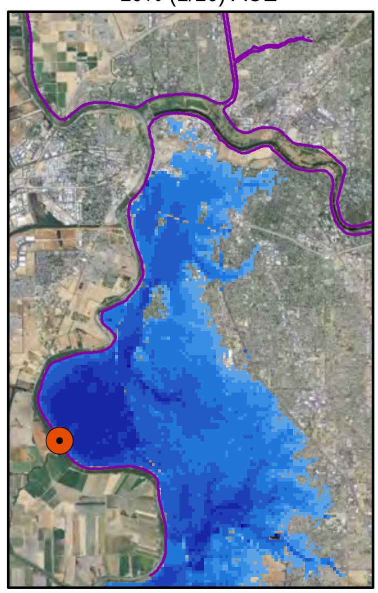
10% (1/10) ACE



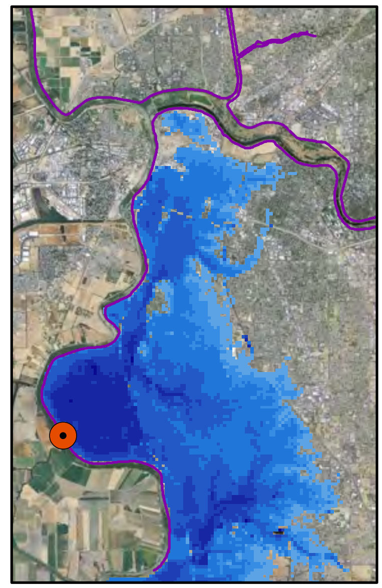
4% (1/25) ACE



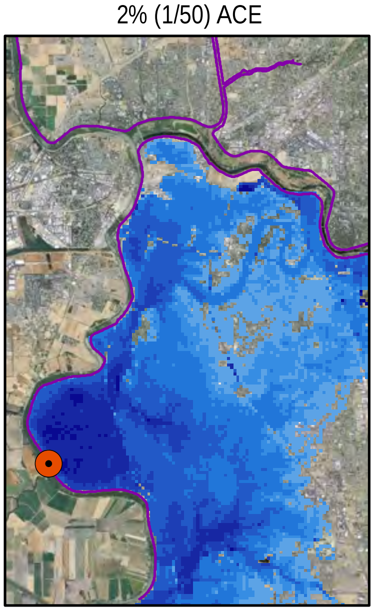
2% (1/50) ACE



1% (1/100) ACE



0.5% (1/200) ACE



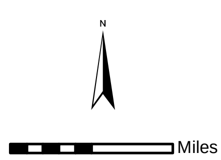
0.2% (1/500) ACE

LEGEND

Depths of Flooding (Feet)

- < 1
- 1.1 - 3
- 3.1 - 5
- 5.1 - 10
- 10.1 - 15
- 15.1 - 20
- 20.1 - 25
- 25.1 +

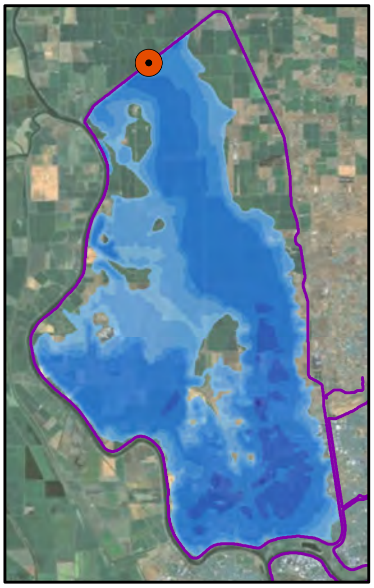
STUDY AREA EXTENT



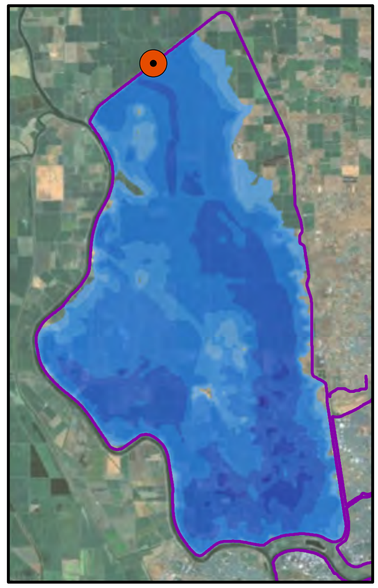
AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

ECONOMIC FLOODPLAINS
BASED ON A LEVEE BREACH SIMULATION
AMERICAN RIVER SOUTH INDEX PT F.

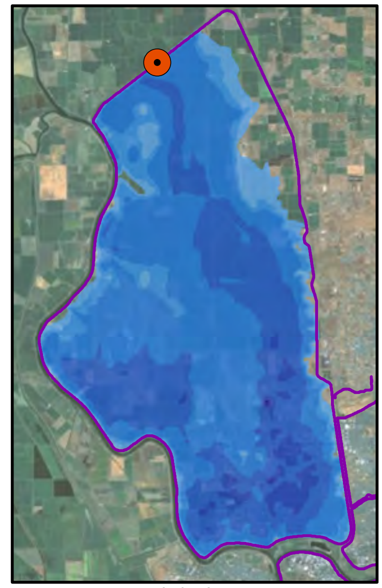
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



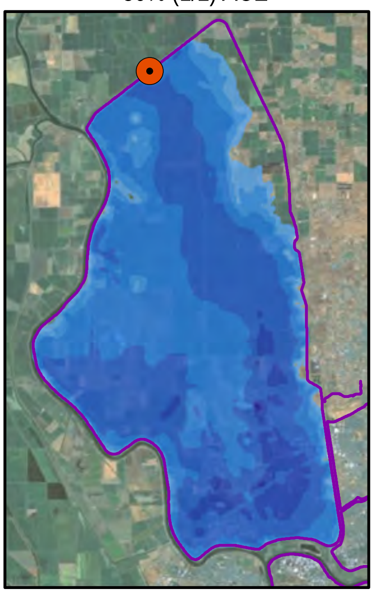
50% (1/2) ACE



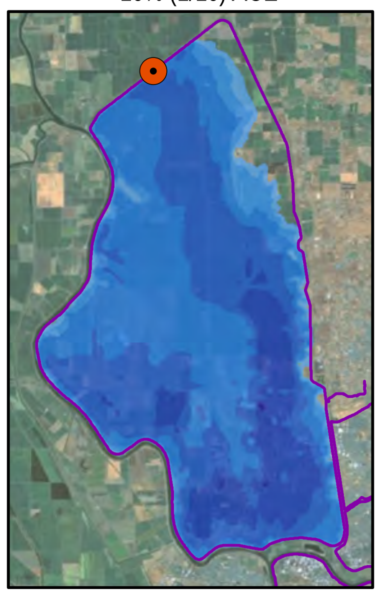
10% (1/10) ACE



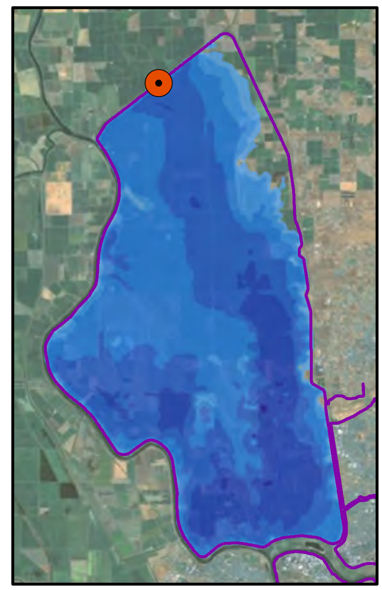
4% (1/25) ACE



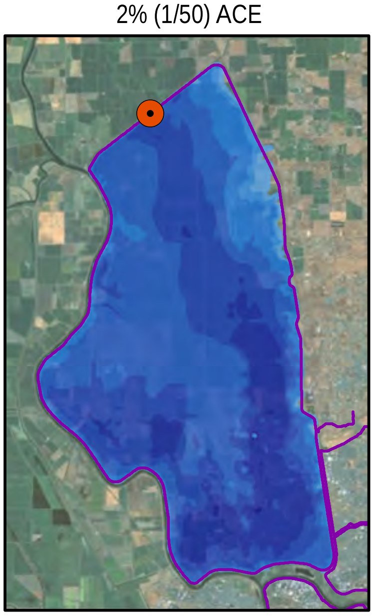
2% (1/50) ACE



1% (1/100) ACE



0.5% (1/200) ACE

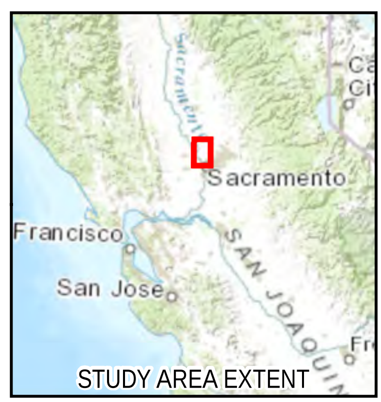


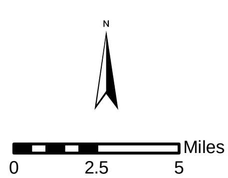
0.2% (1/500) ACE

LEGEND

Depths of Flooding (Feet)

- < 1
- 1.1 - 3
- 3.1 - 5
- 5.1 - 10
- 10.1 - 15
- 15.1 - 20
- 20.1 - 25
- 25.1 +



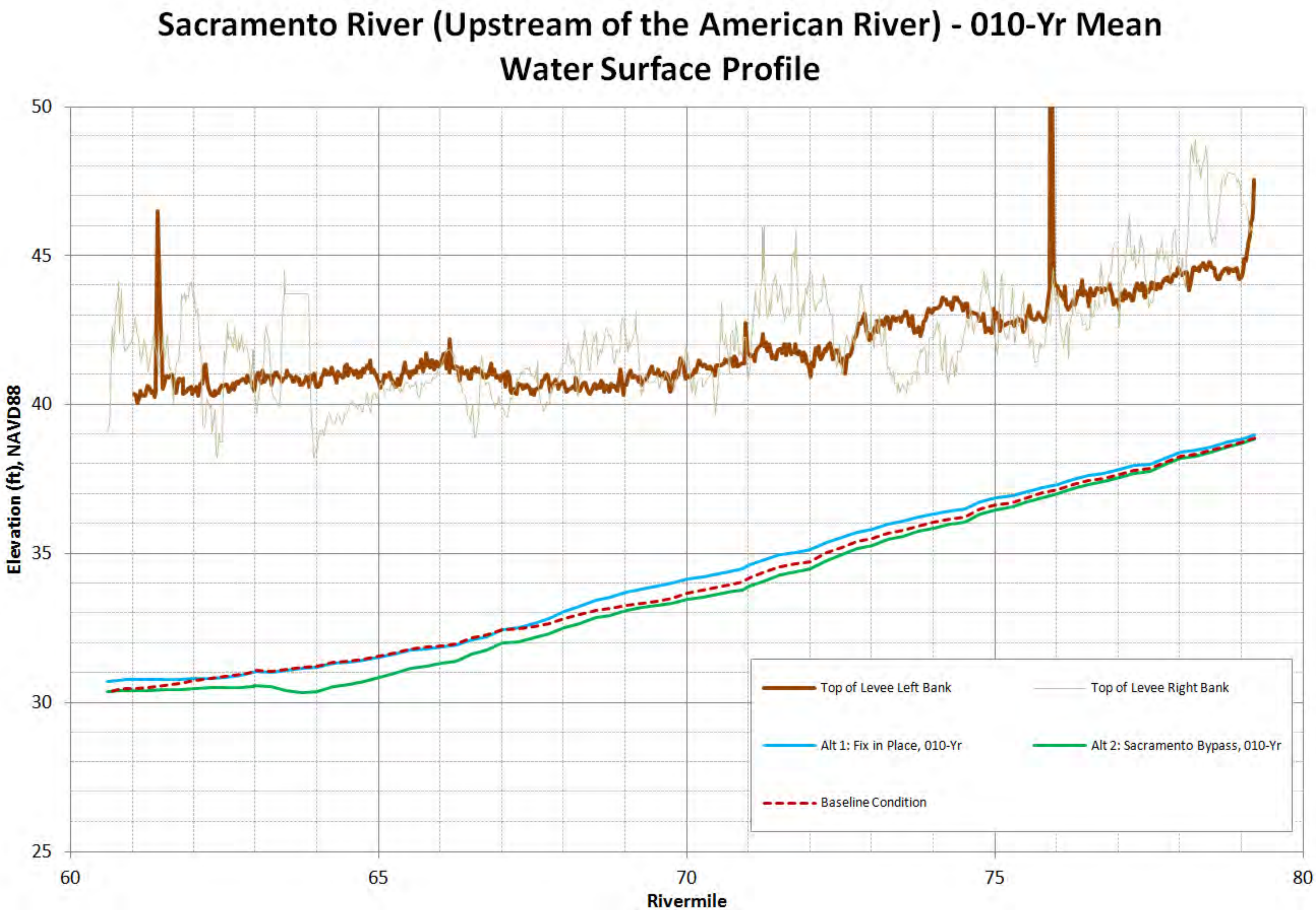


AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

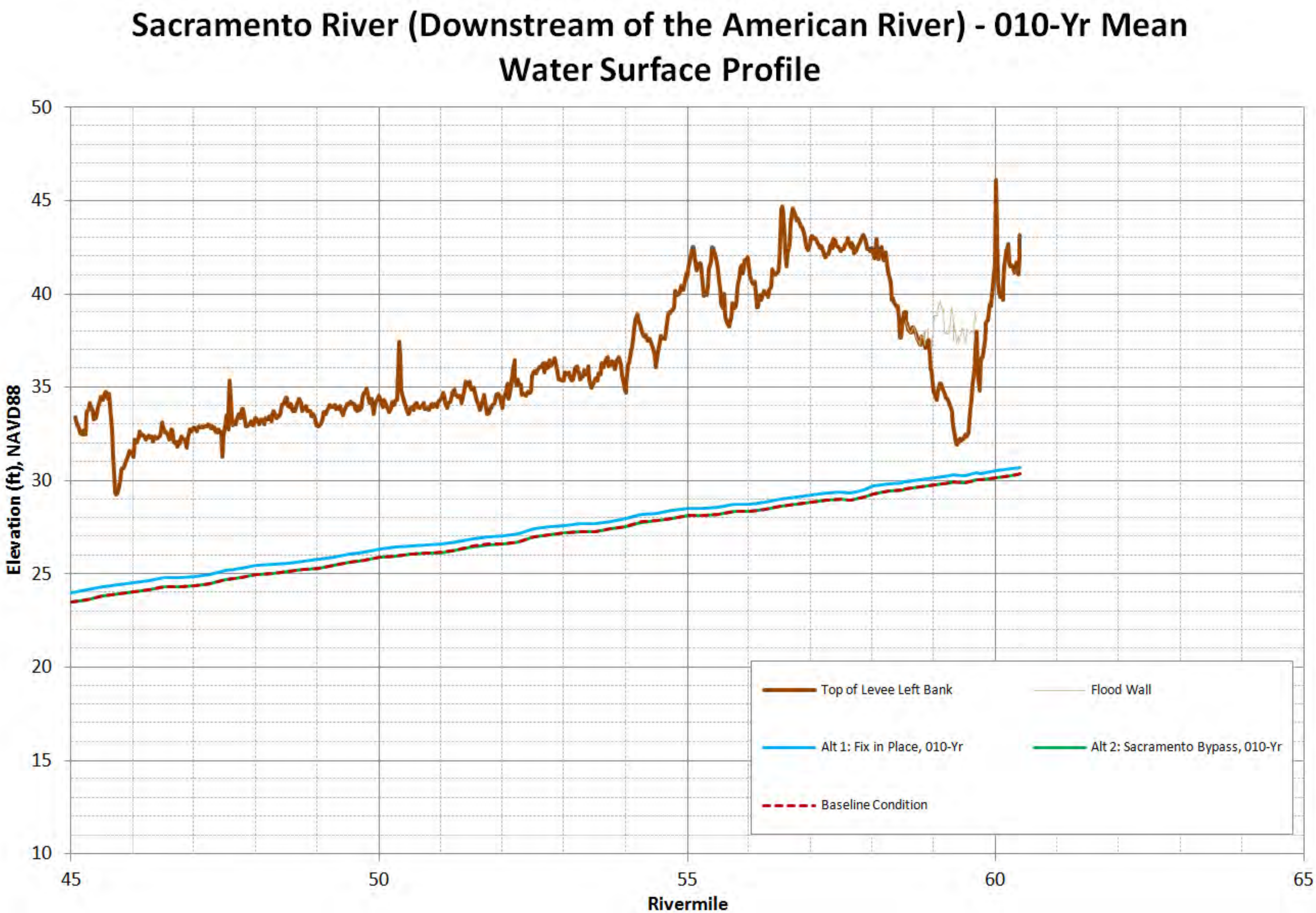
ECONOMIC FLOODPLAINS BASED ON A LEVEE BREACH SIMULATION NATOMAS BASIN INDEX PT D.

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

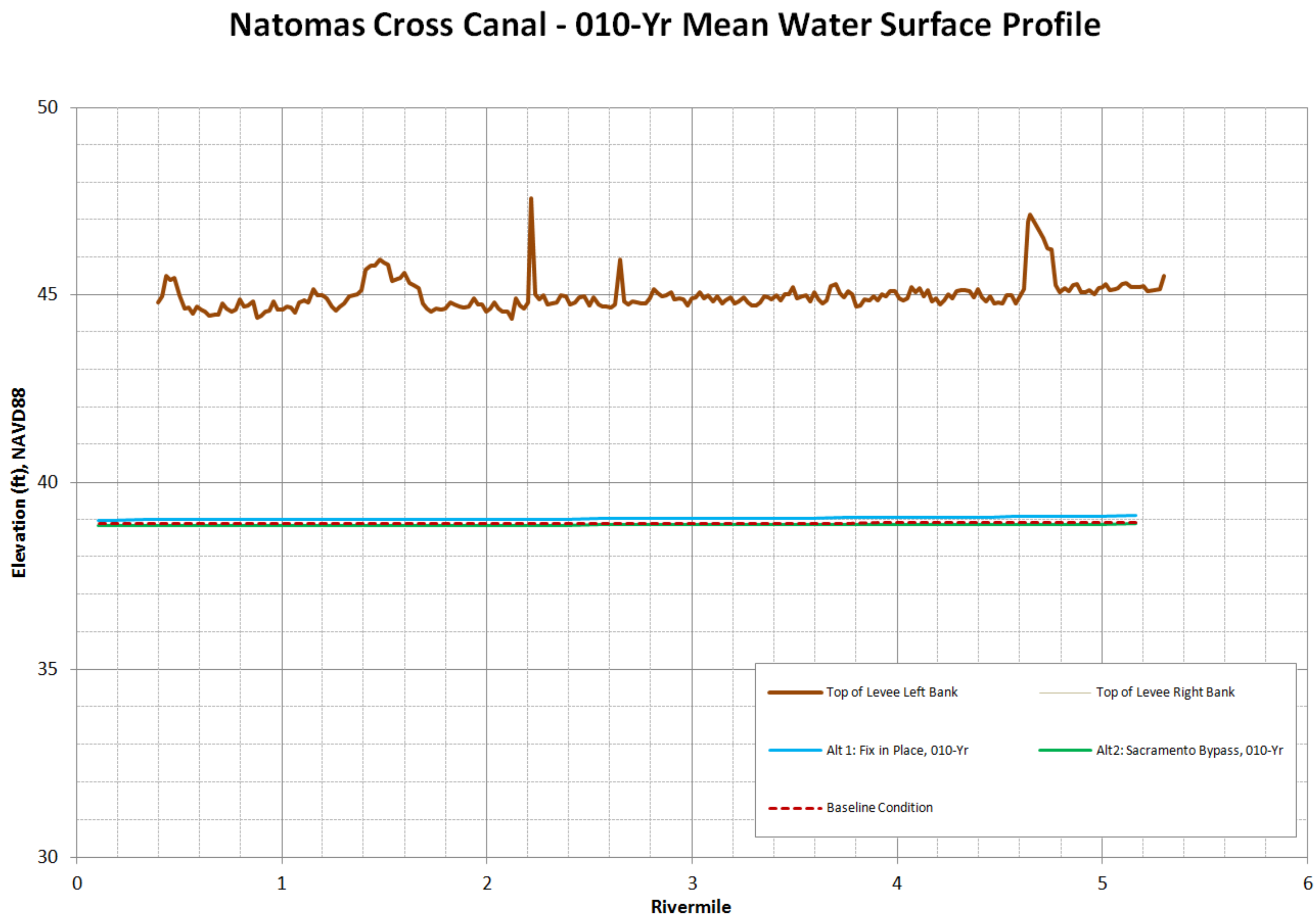
Feb 2013



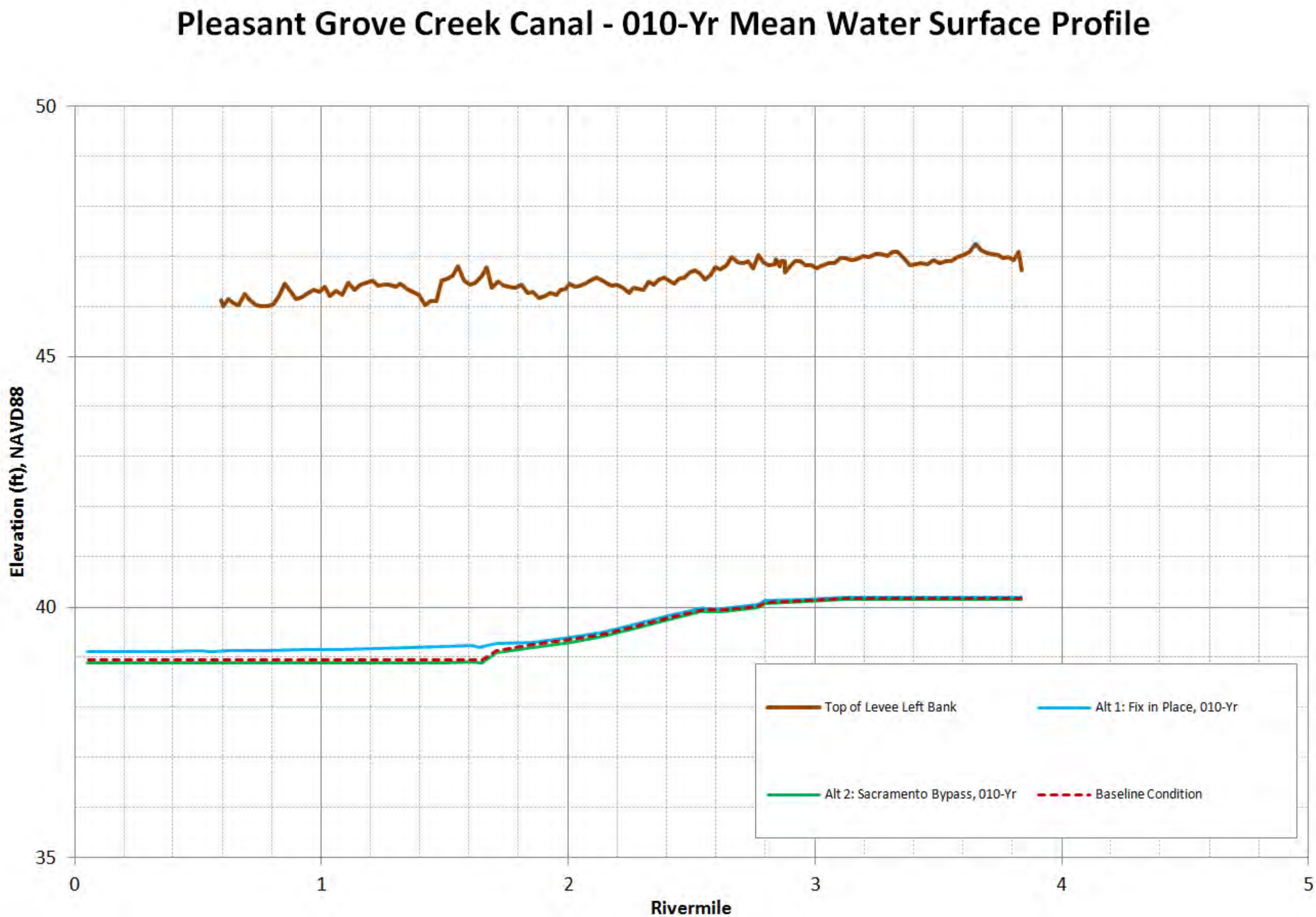
American River Common Features GRR Sacramento, California	Sacramento River (U/S of the American River) – Left Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



American River Common Features GRR Sacramento, California	Sacramento River (D/S of the American River) – Left Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

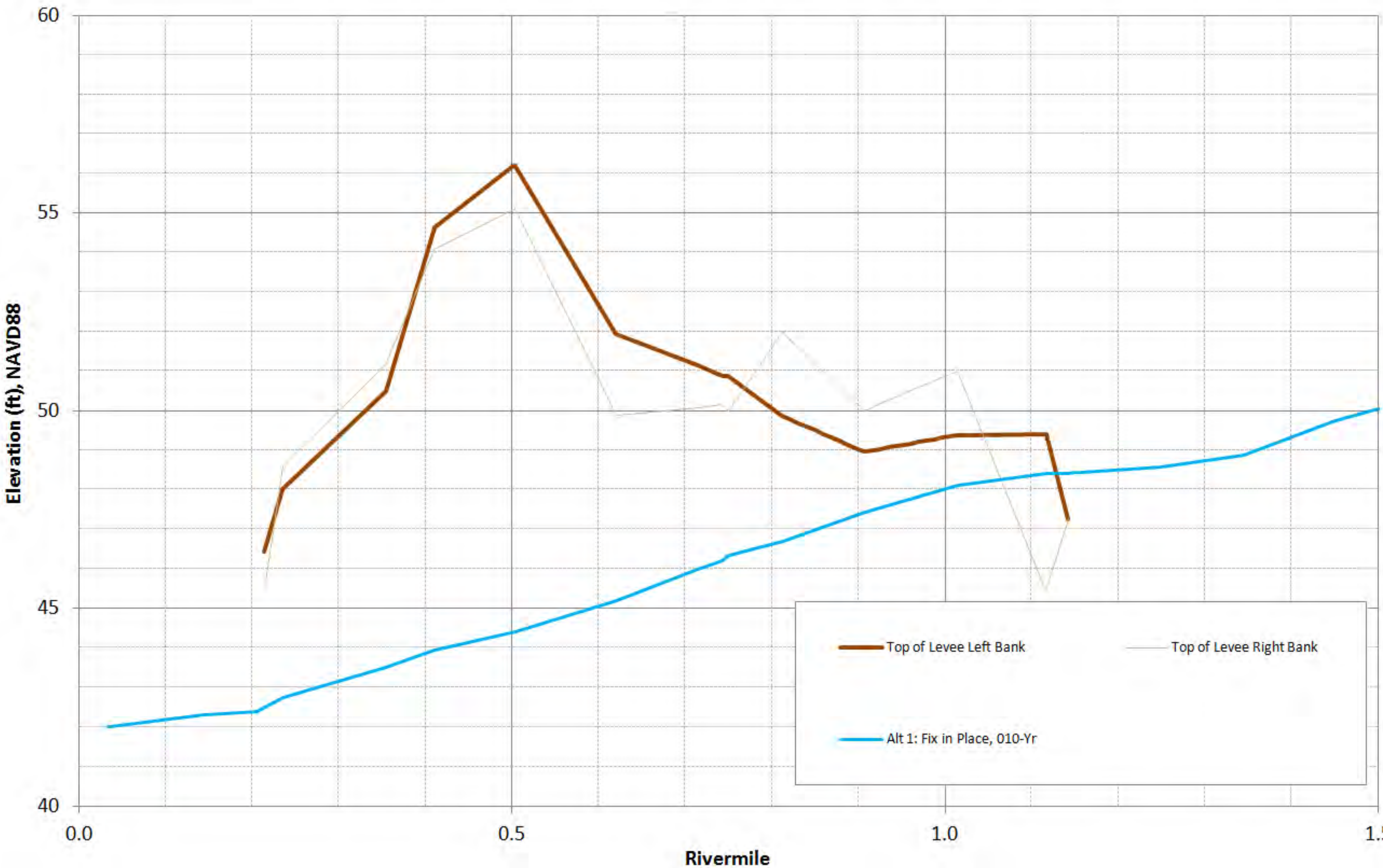


American River Common Features GRR Sacramento, California	Natomas Cross Canal – Left Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

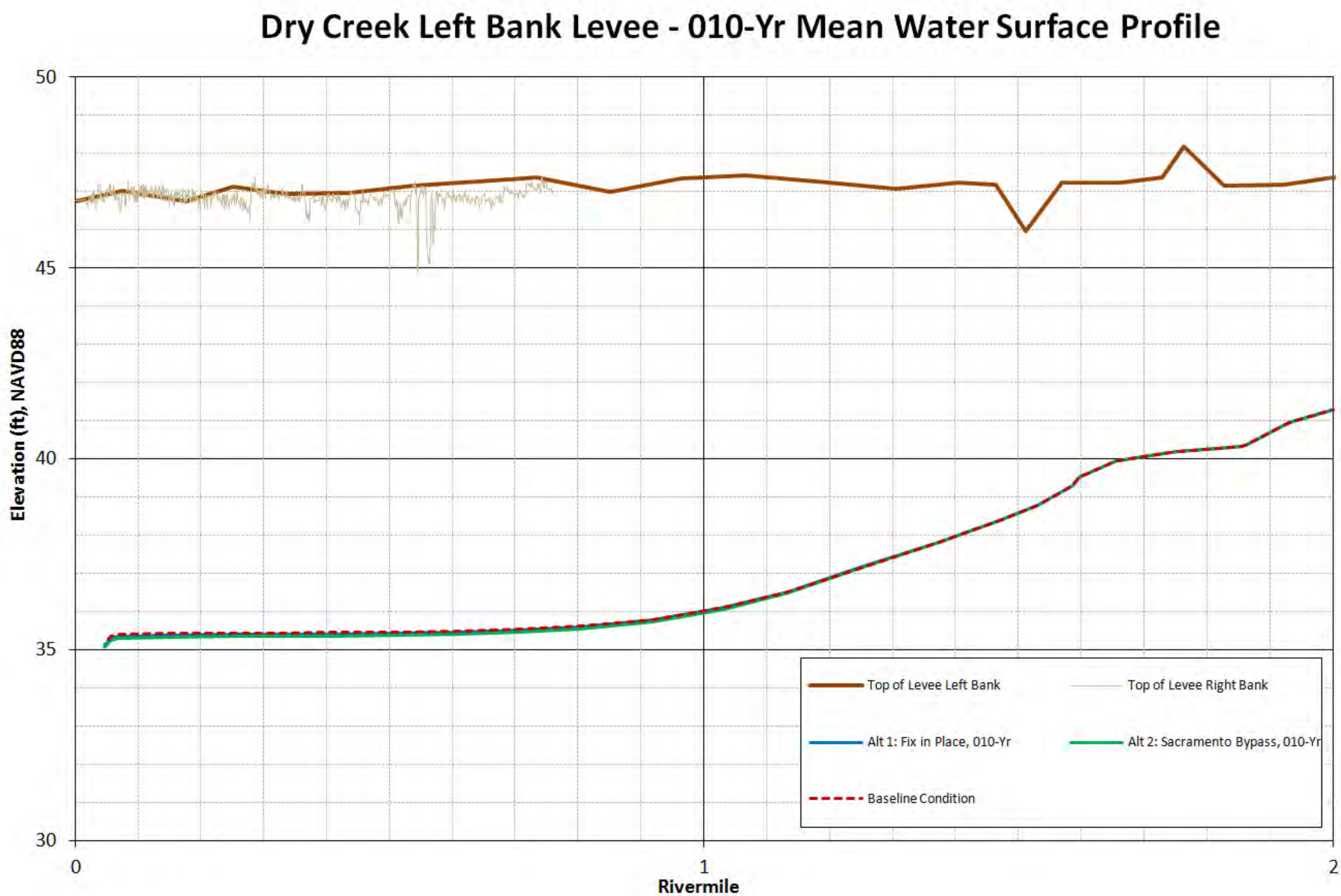


American River Common Features GRR Sacramento, California	Pleasant Grove Creek Canal – Left Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

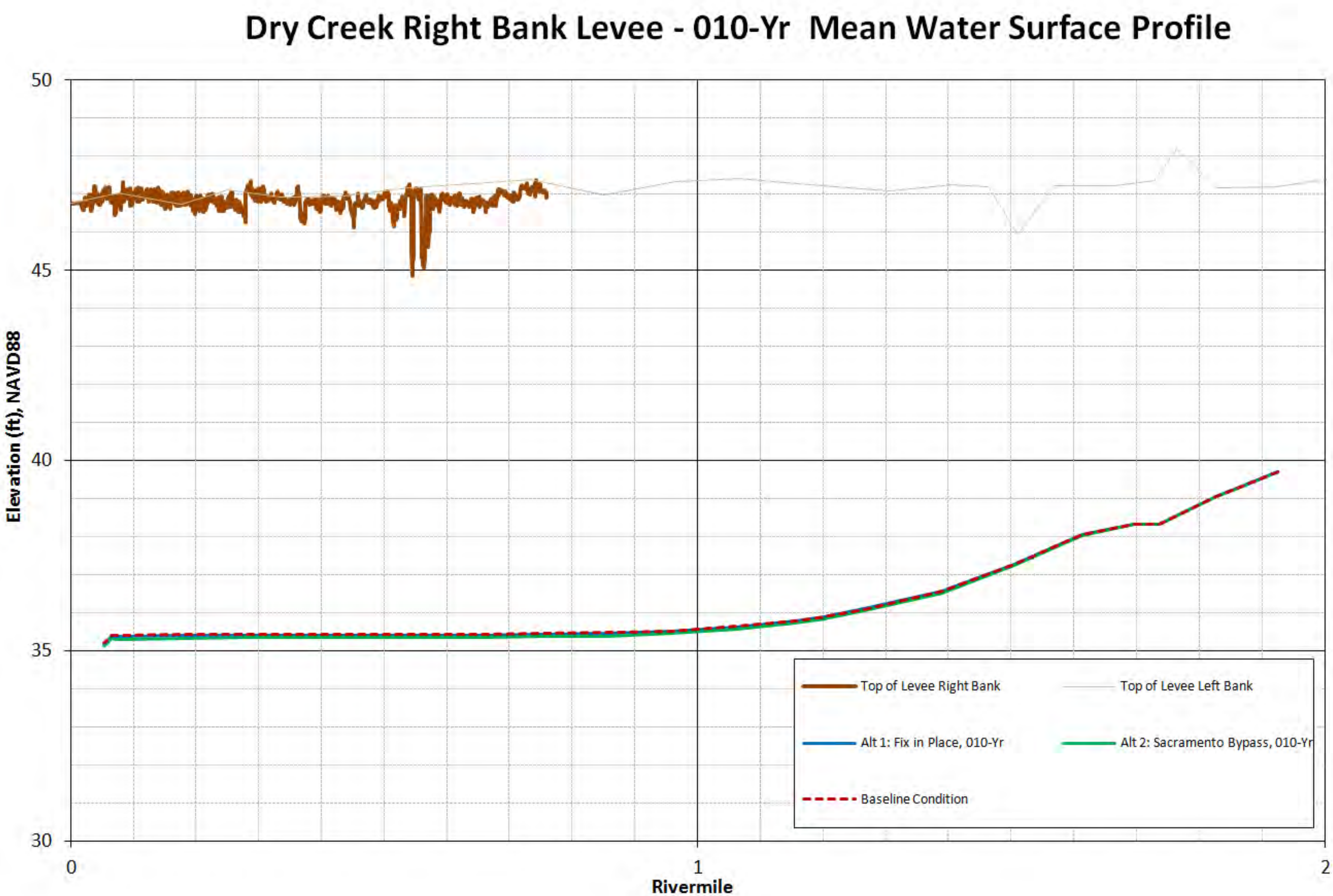
Magpie Creek Left Bank Levee - 010-Yr Mean Water Surface Profile



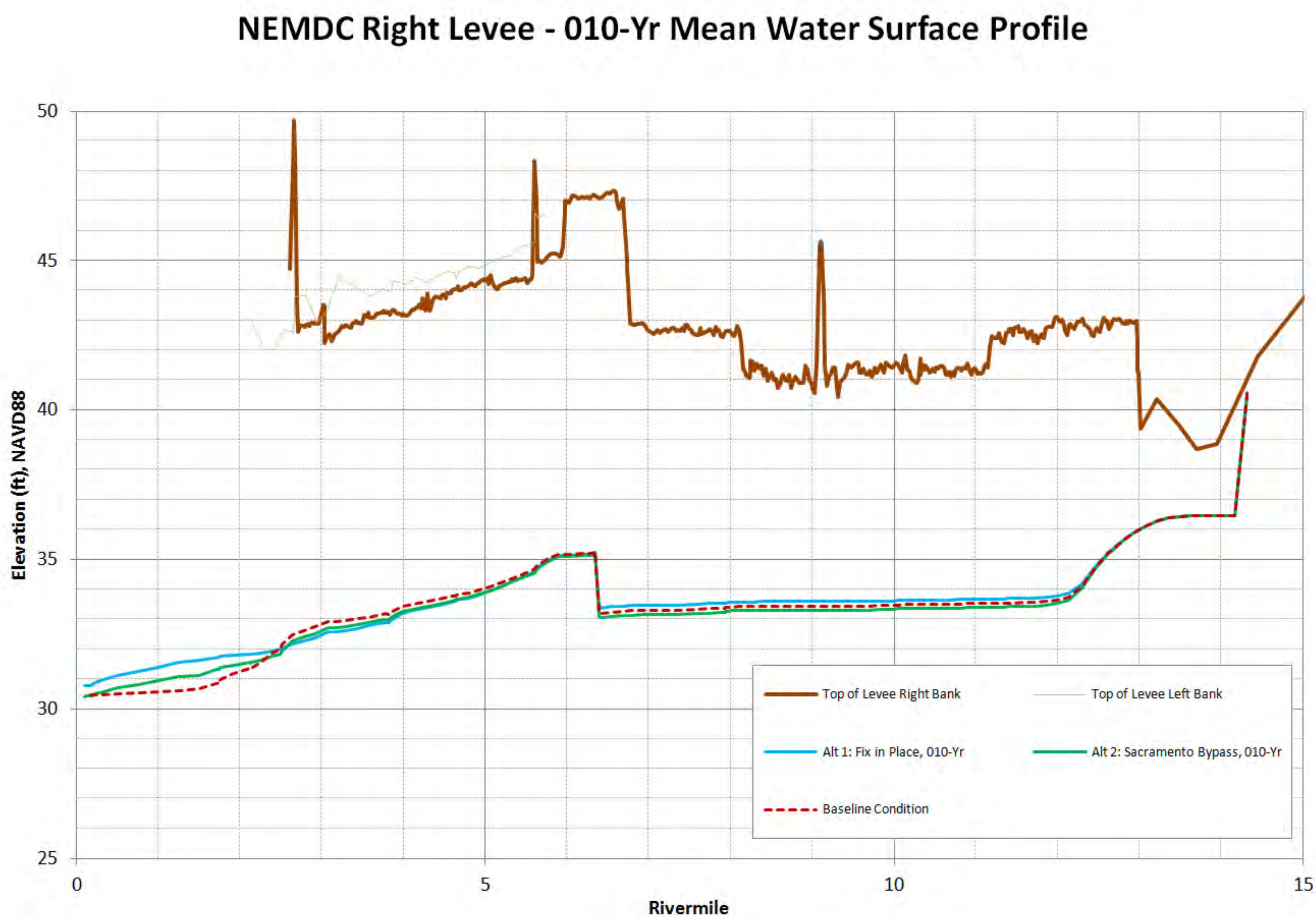
American River Common Features GRR Sacramento, California	Magpie Creek – Left Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



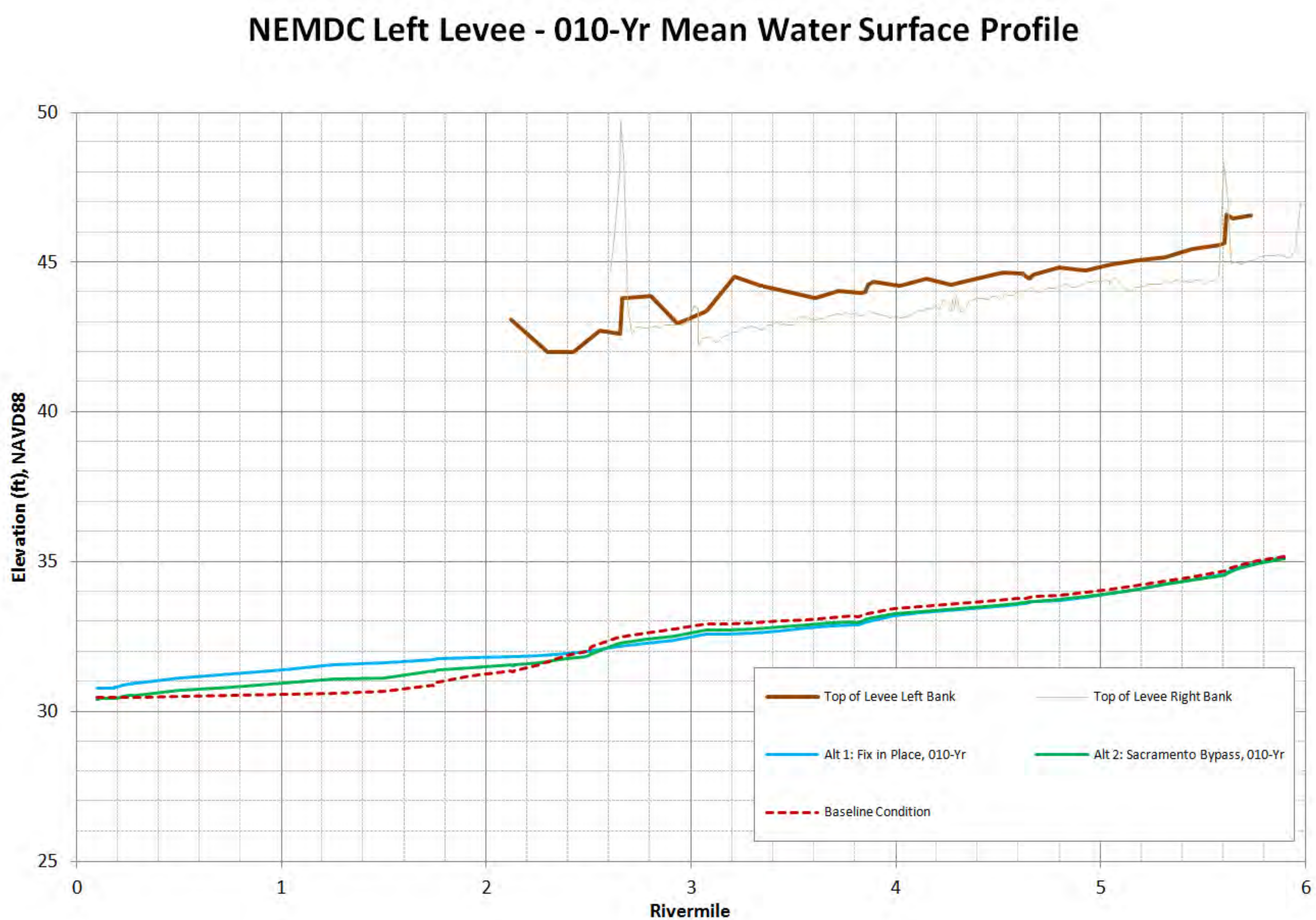
American River Common Features GRR Sacramento, California	Dry Creek – Left Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



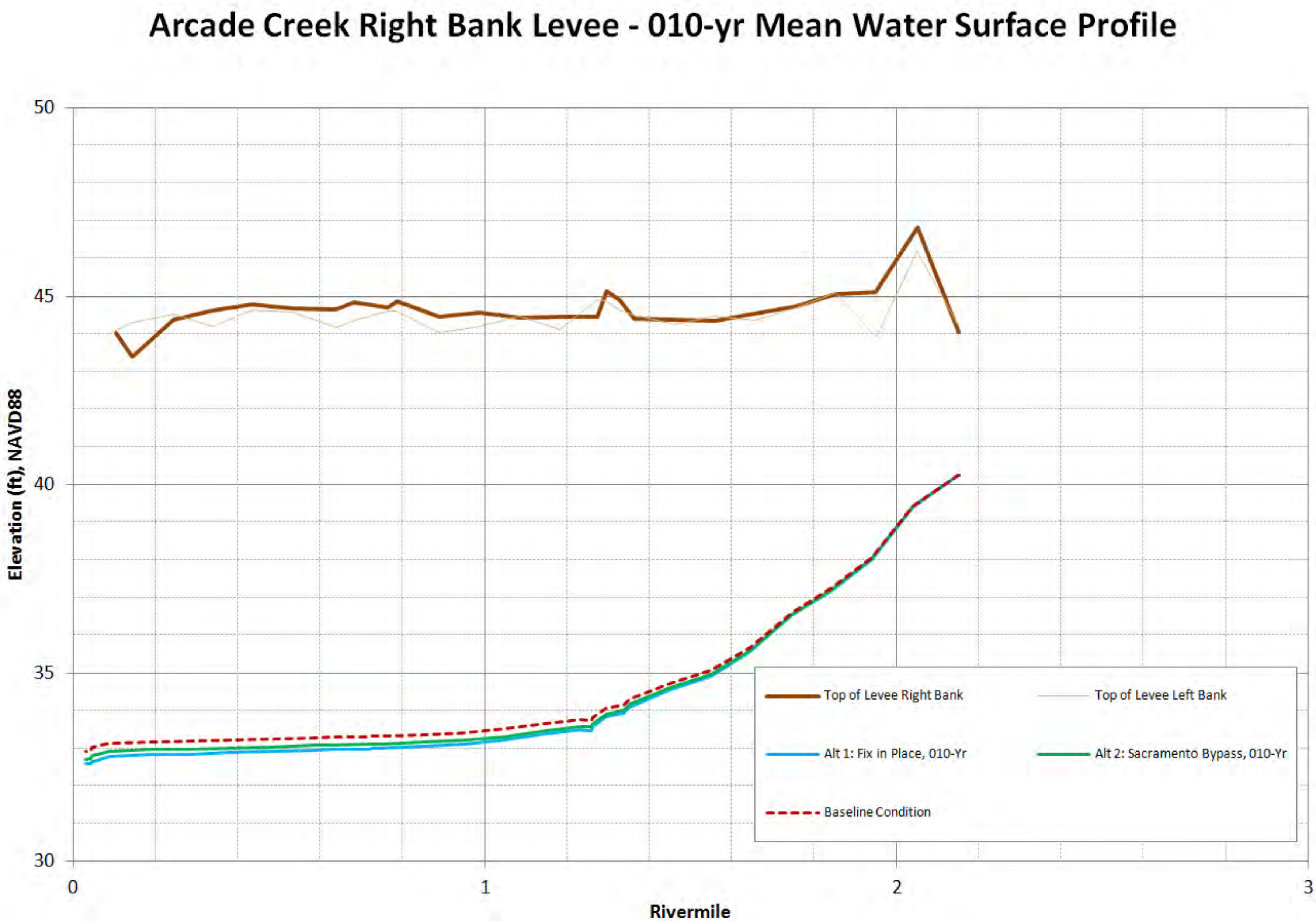
American River Common Features GRR Sacramento, California	Dry Creek – Right Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



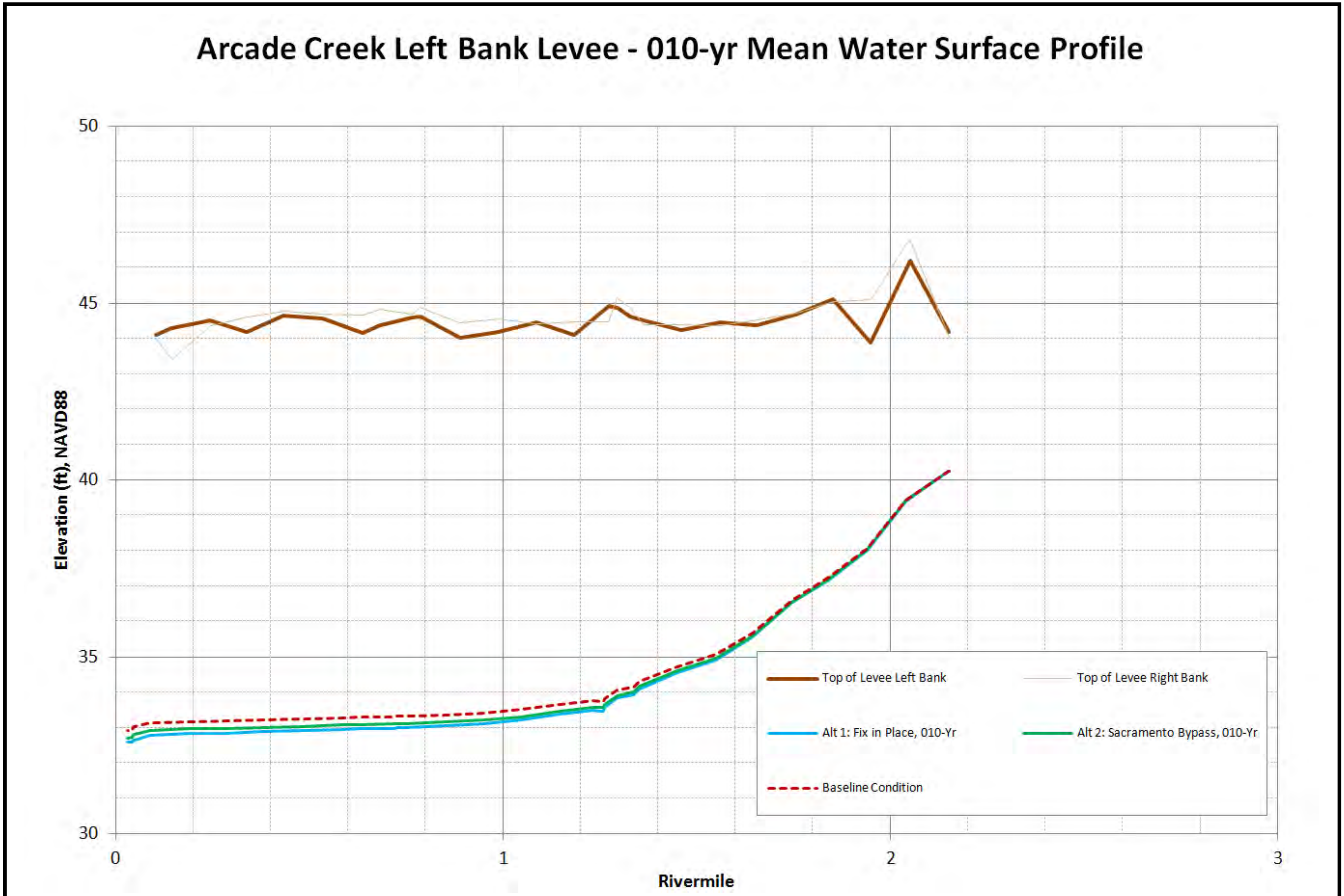
American River Common Features GRR Sacramento, California	NEMDC – Right Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



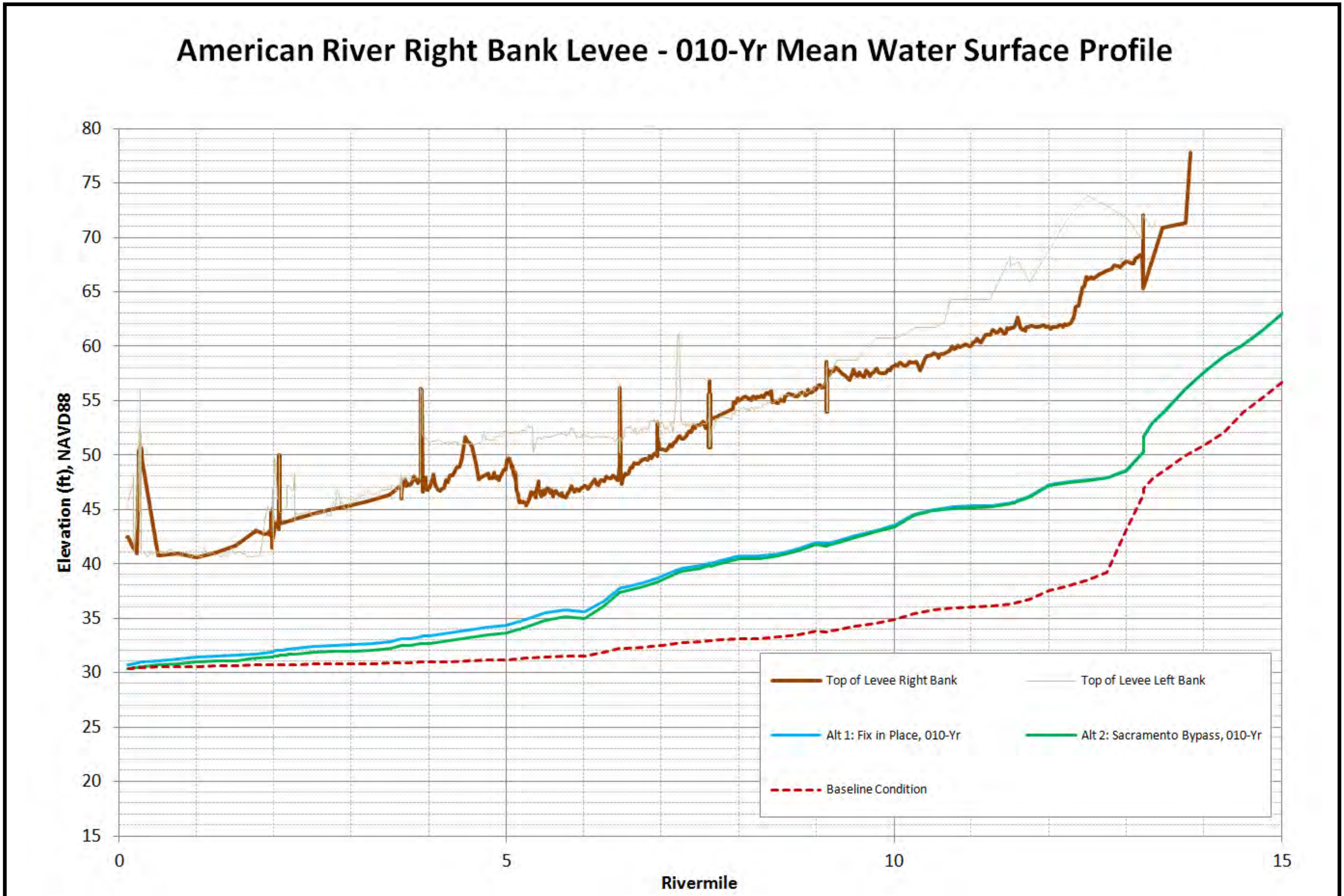
American River Common Features GRR Sacramento, California	NEMDC – Left Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



American River Common Features GRR Sacramento, California	Arcade Creek - Right Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

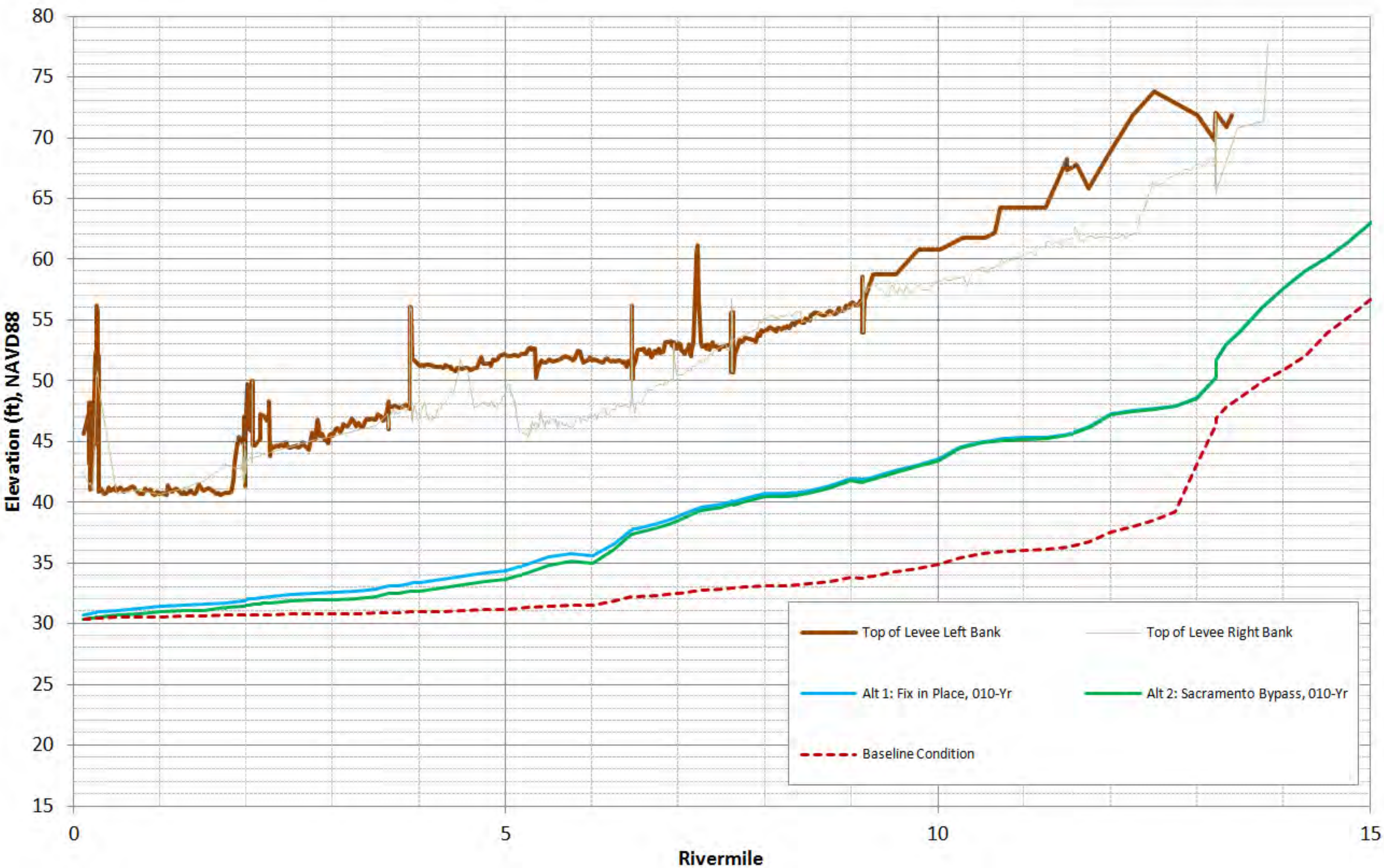


American River Common Features GRR Sacramento, California	Arcade Creek - Left Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



American River Common Features GRR Sacramento, California	American River – Right Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

American River Left Bank Levee - 010-Yr Mean Water Surface Profile

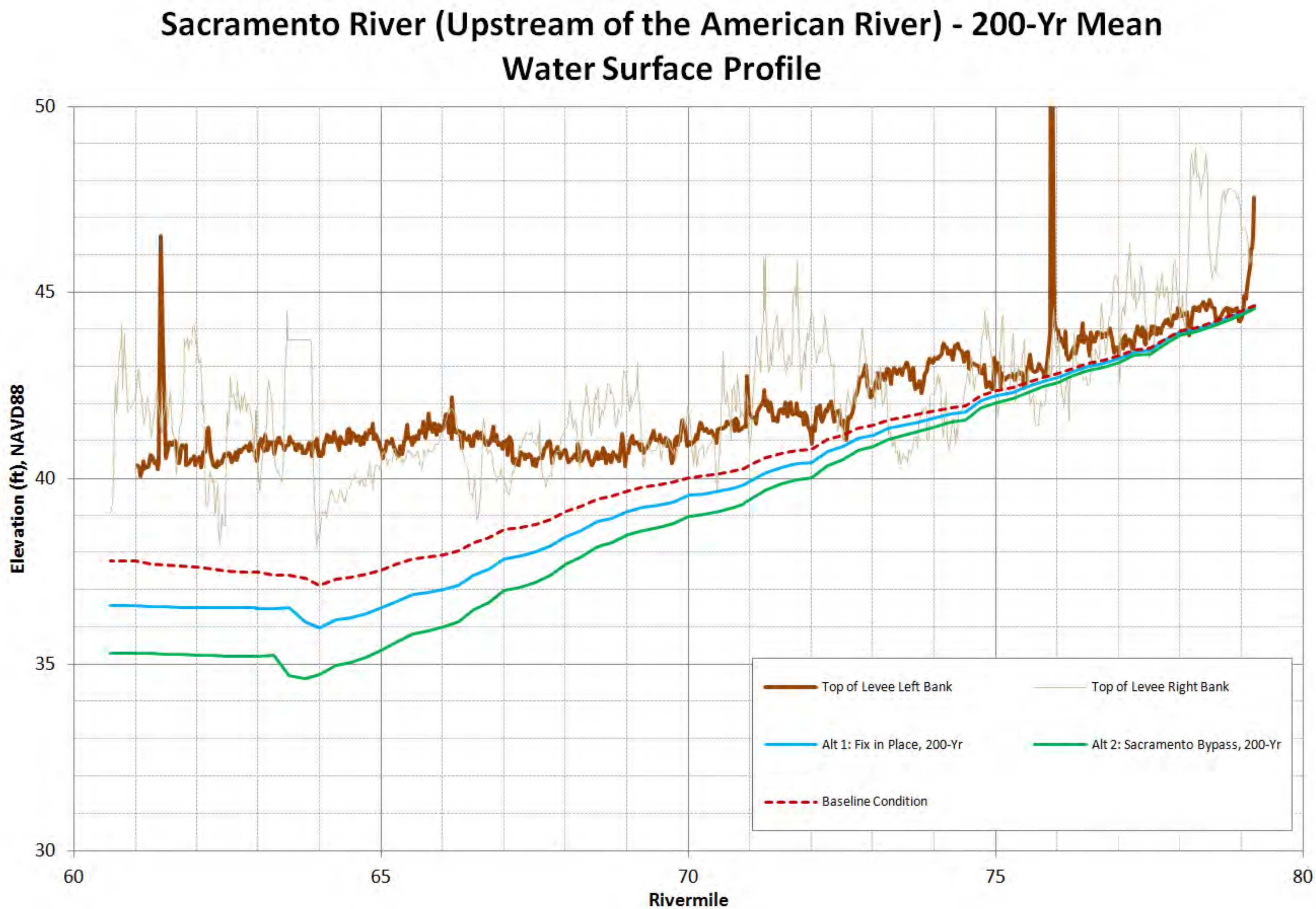


American River Common Features GRR Sacramento, California	American River – Left Bank Levee 10-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

Appendix X

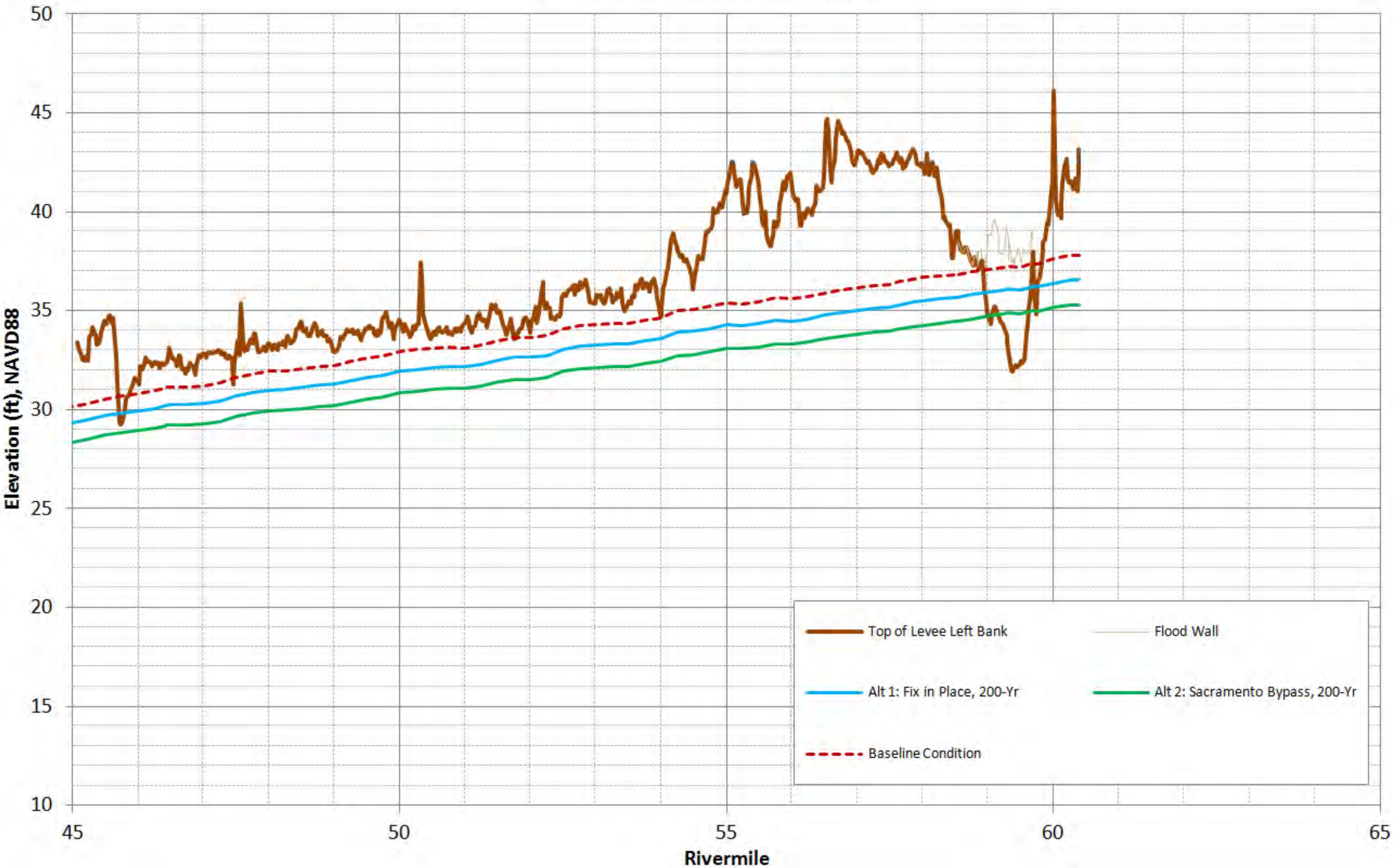
200-Yr Water Surface Profiles

With-Project Alternatives

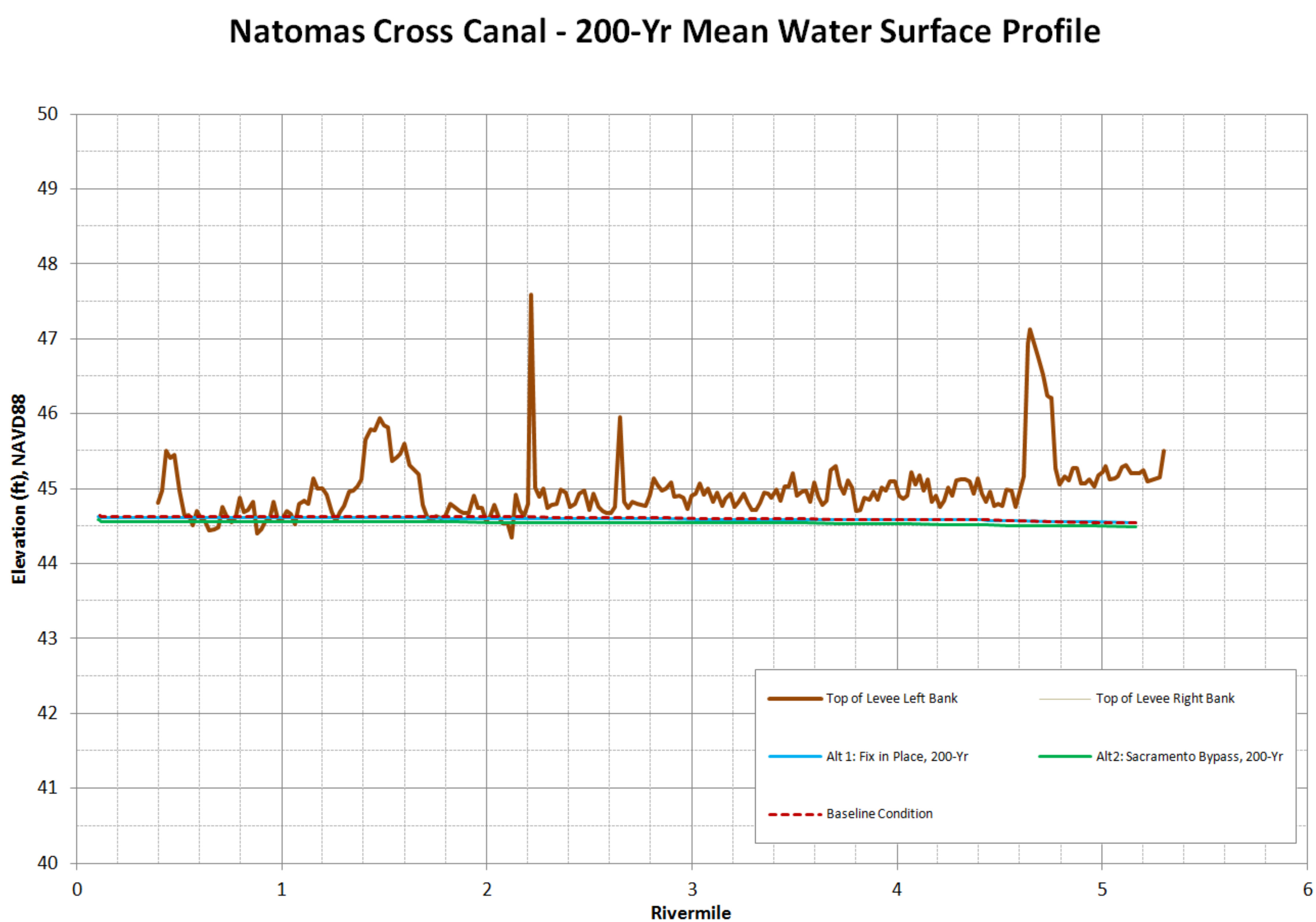


American River Common Features GRR Sacramento, California	Sacramento River (U/S of the American River) – Left Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

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

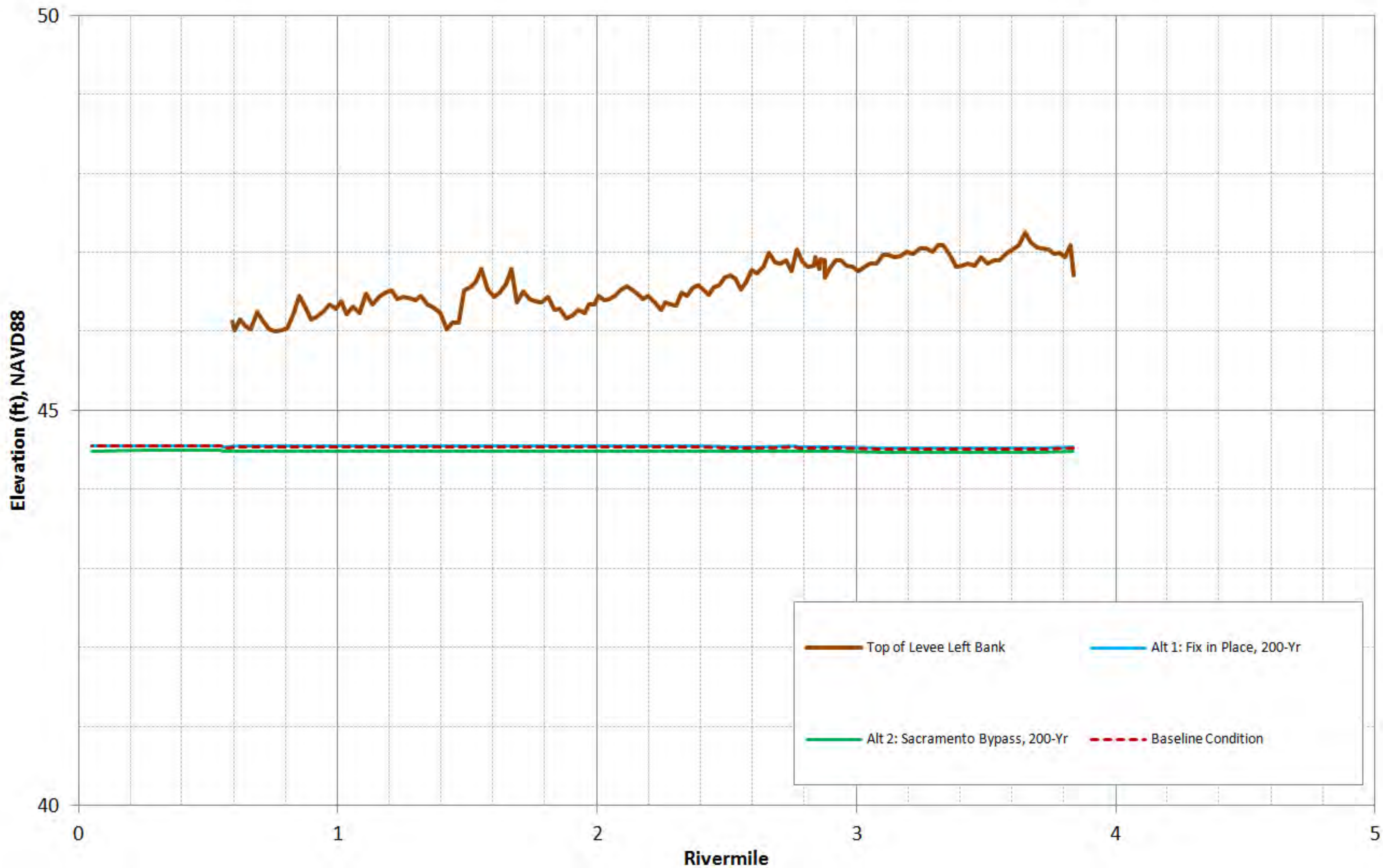


American River Common Features GRR Sacramento, California	Sacramento River (D/S of the American River) – Left Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

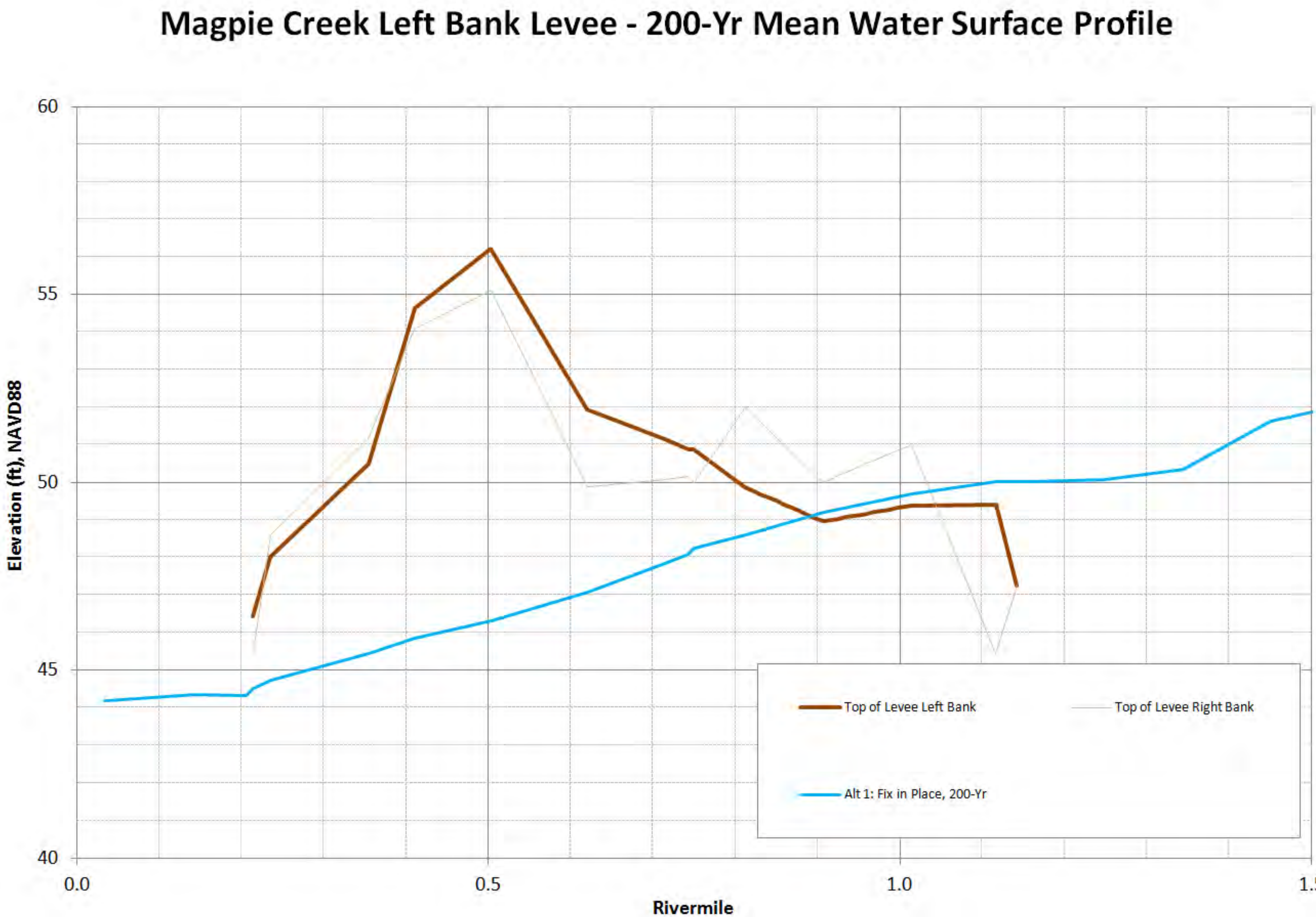


American River Common Features GRR Sacramento, California	Natomas Cross Canal – Left Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

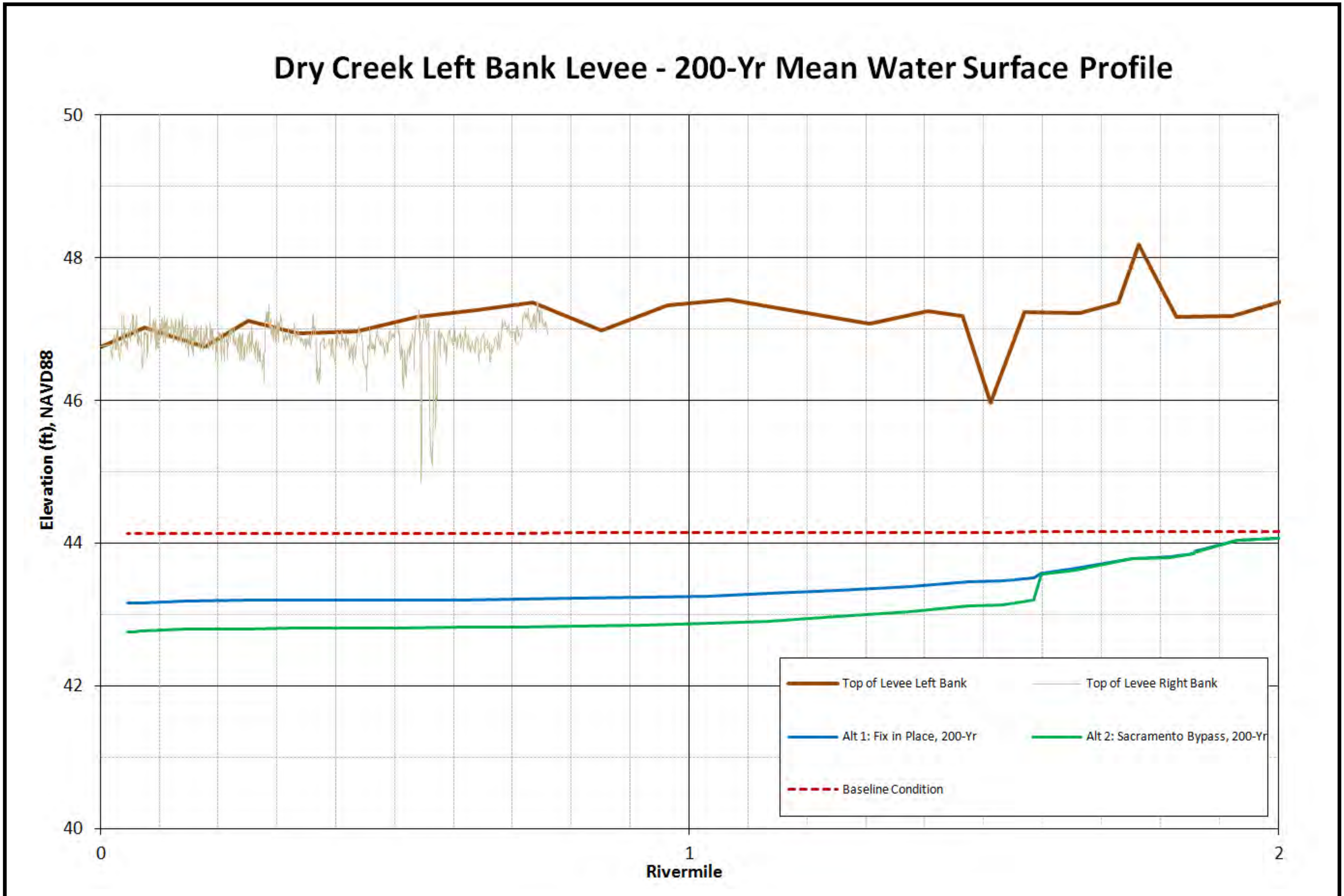
Pleasant Grove Creek Canal - 200-Yr Mean Water Surface Profile



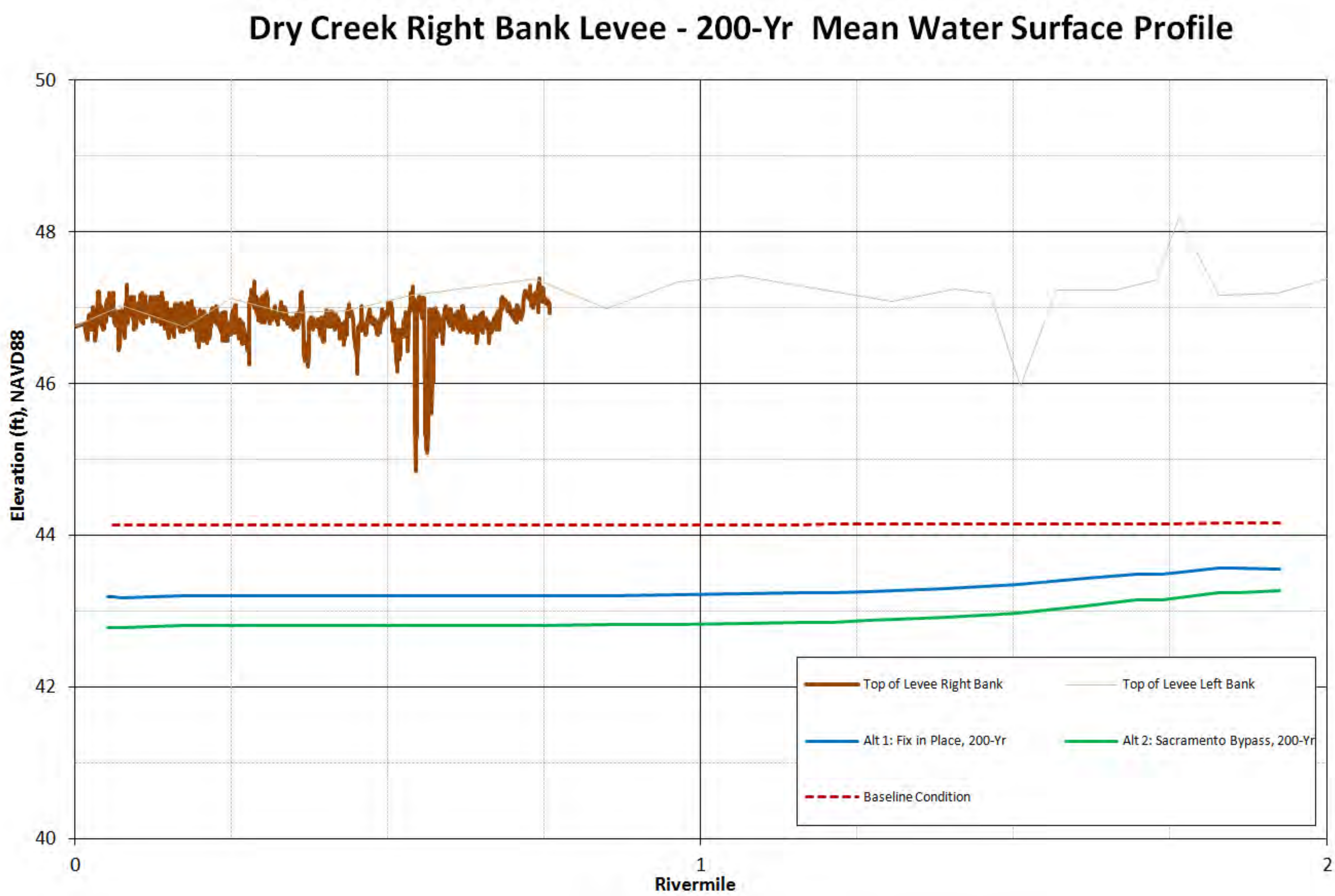
American River Common Features GRR Sacramento, California	Pleasant Grove Creek Canal – Left Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



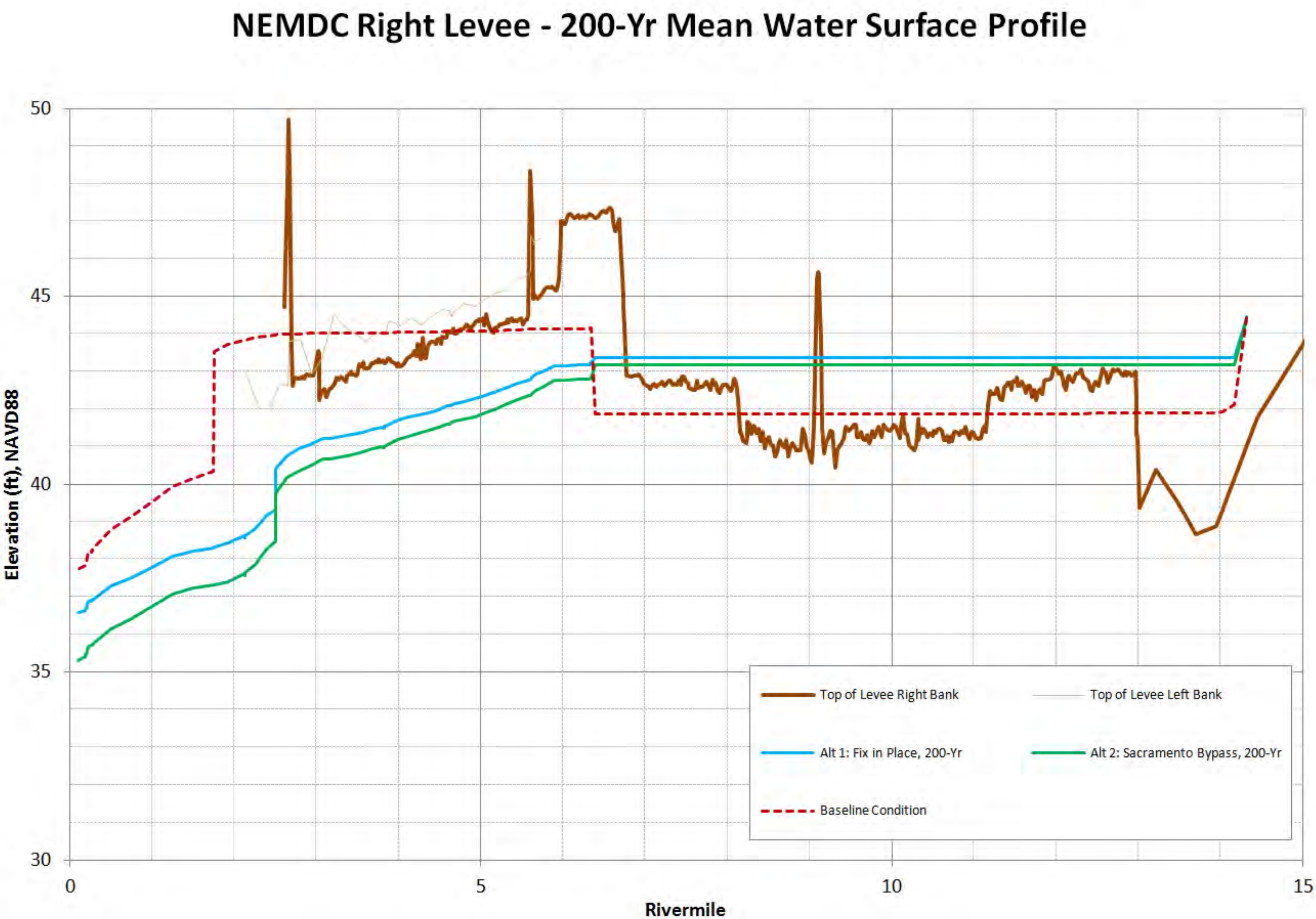
American River Common Features GRR Sacramento, California	Magpie Creek – Left Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



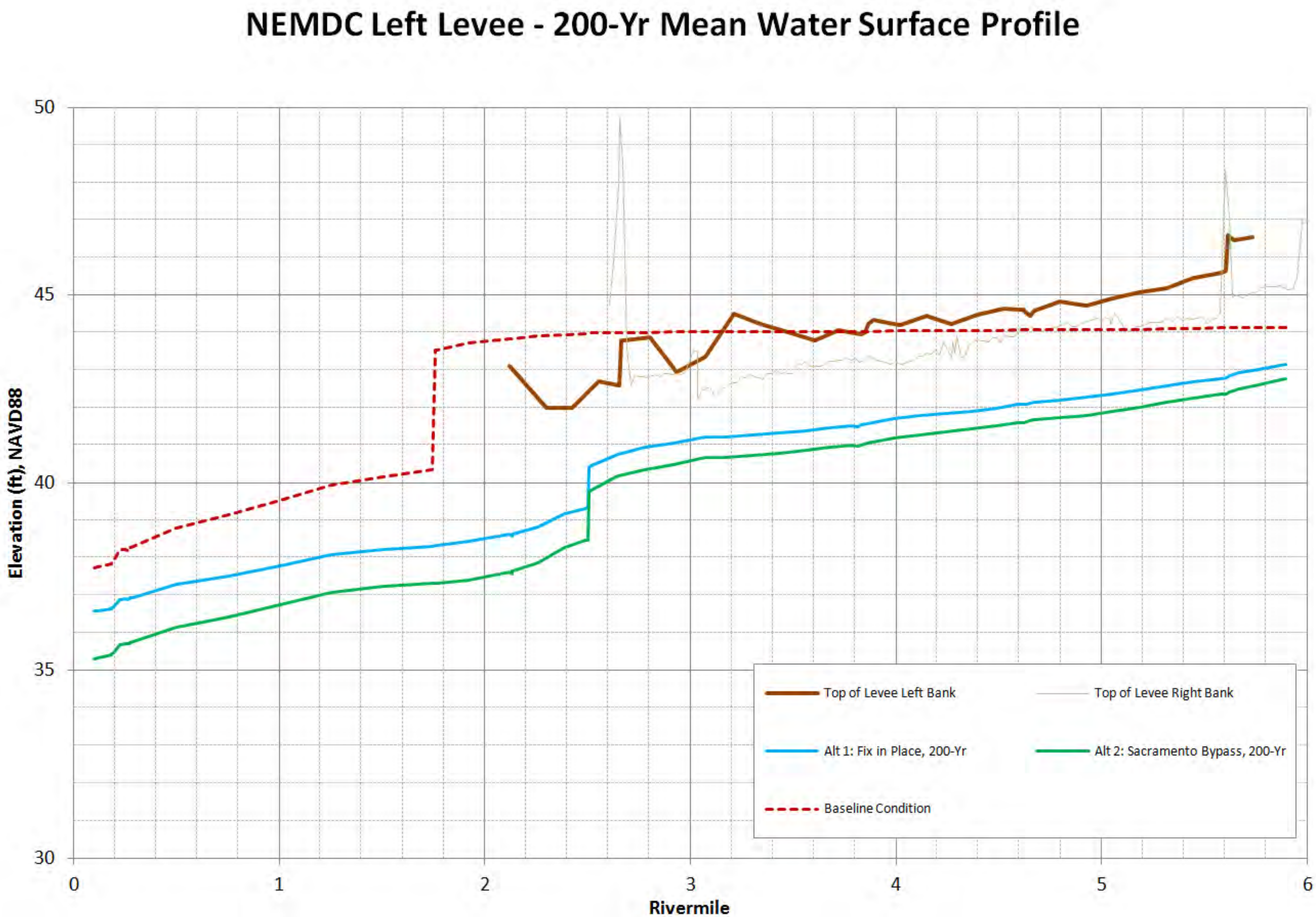
American River Common Features GRR Sacramento, California	Dry Creek – Left Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



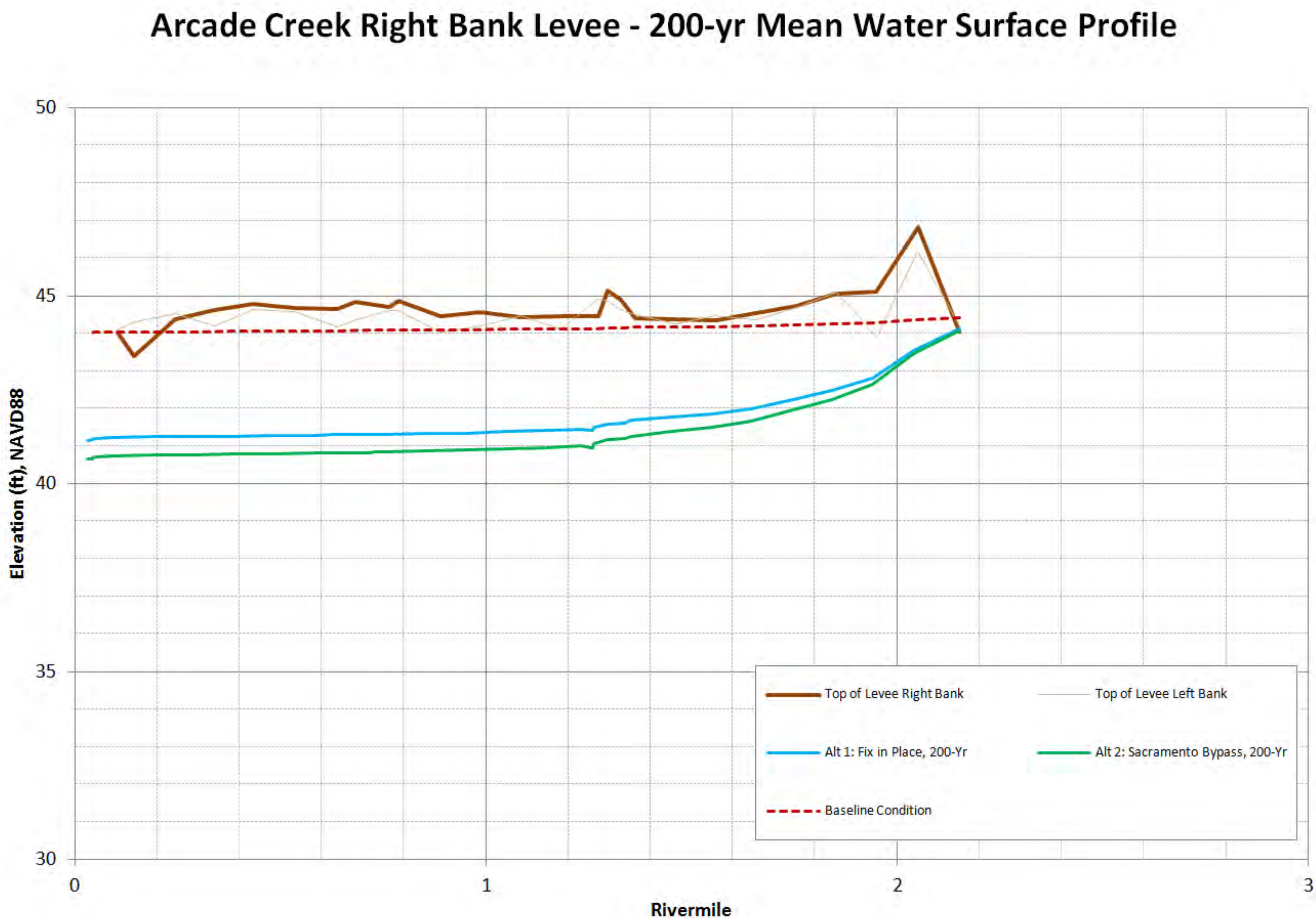
American River Common Features GRR Sacramento, California	Dry Creek – Right Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



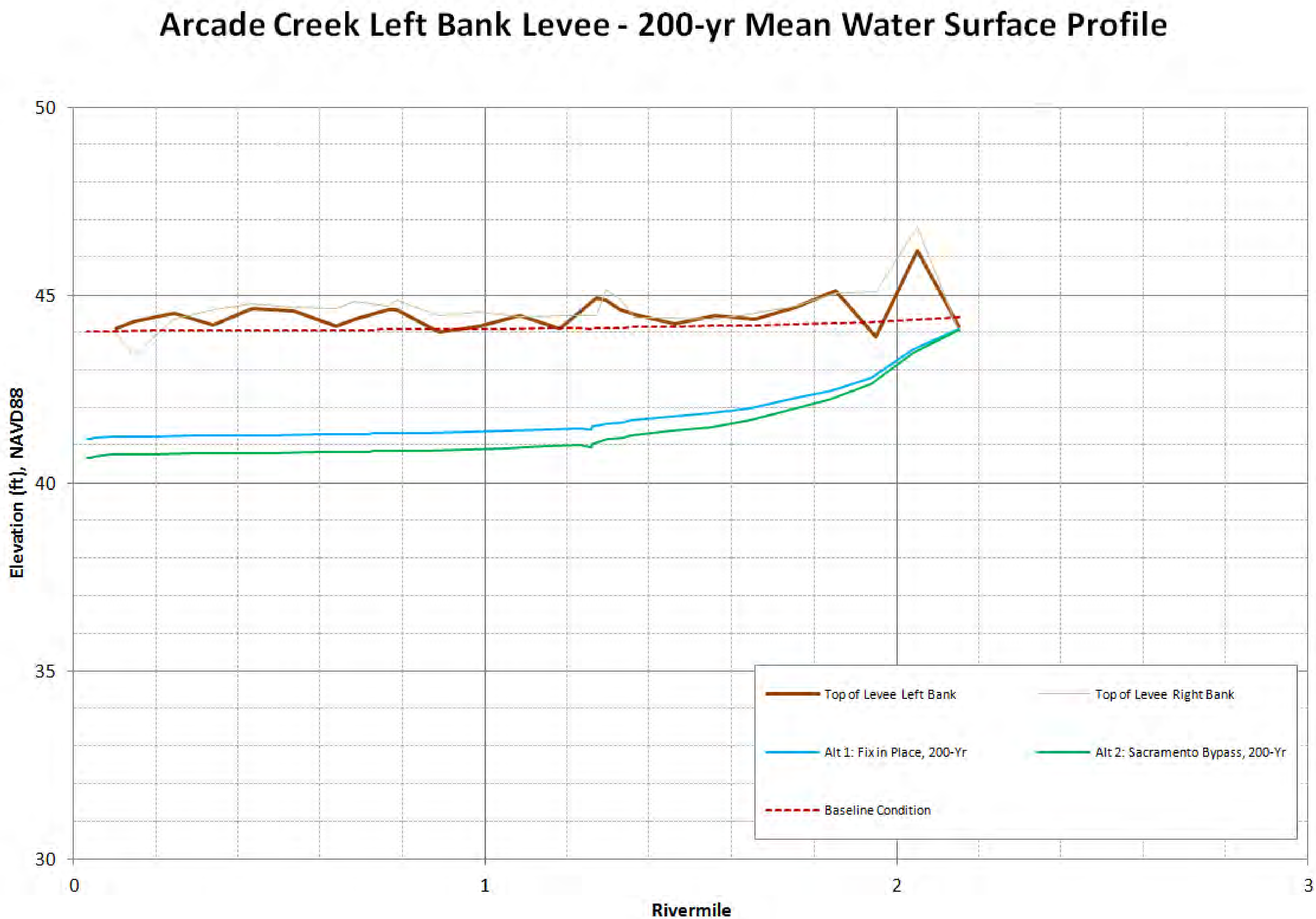
American River Common Features GRR Sacramento, California	NEMDC – Right Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



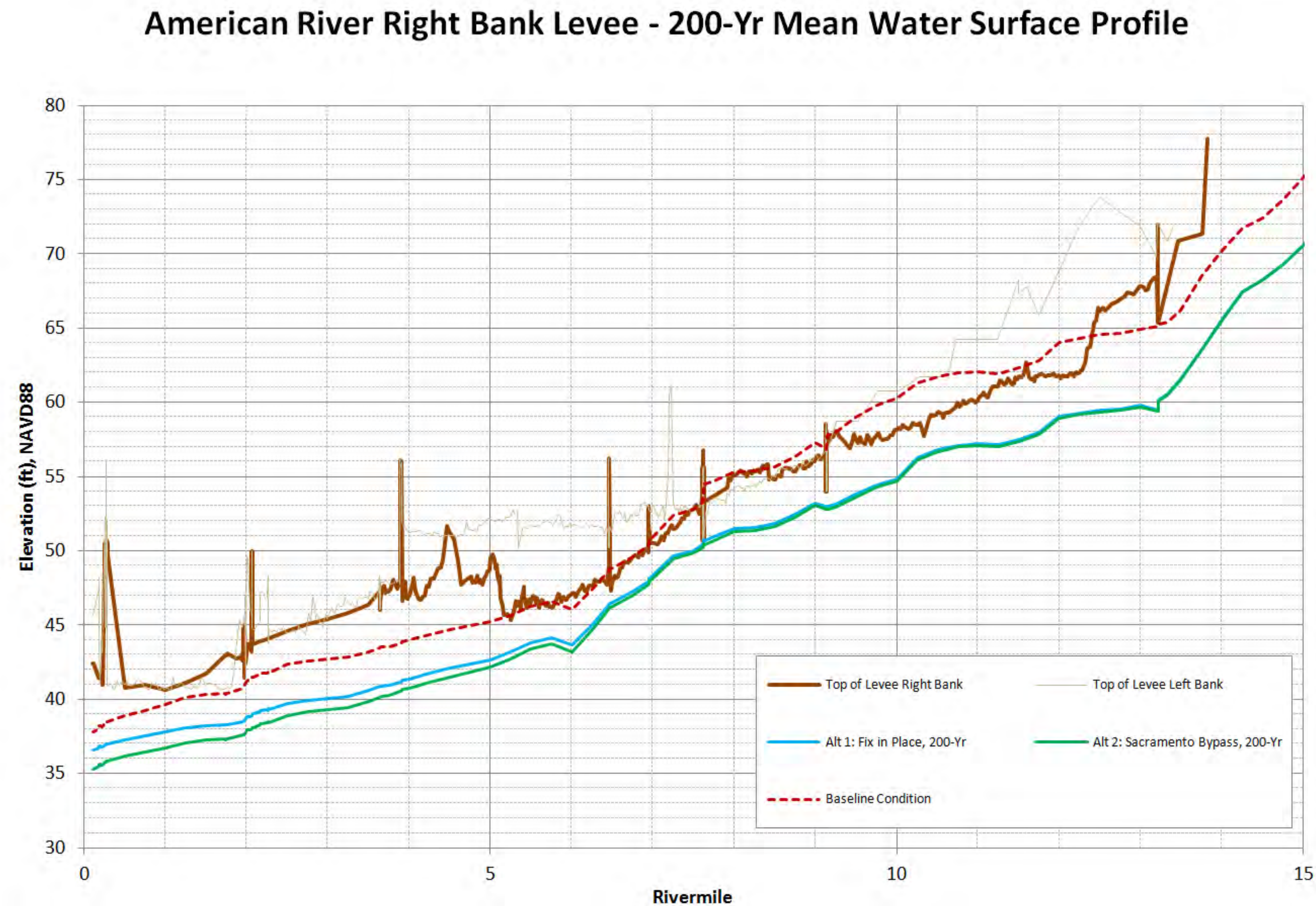
American River Common Features GRR Sacramento, California	NEMDC – Left Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



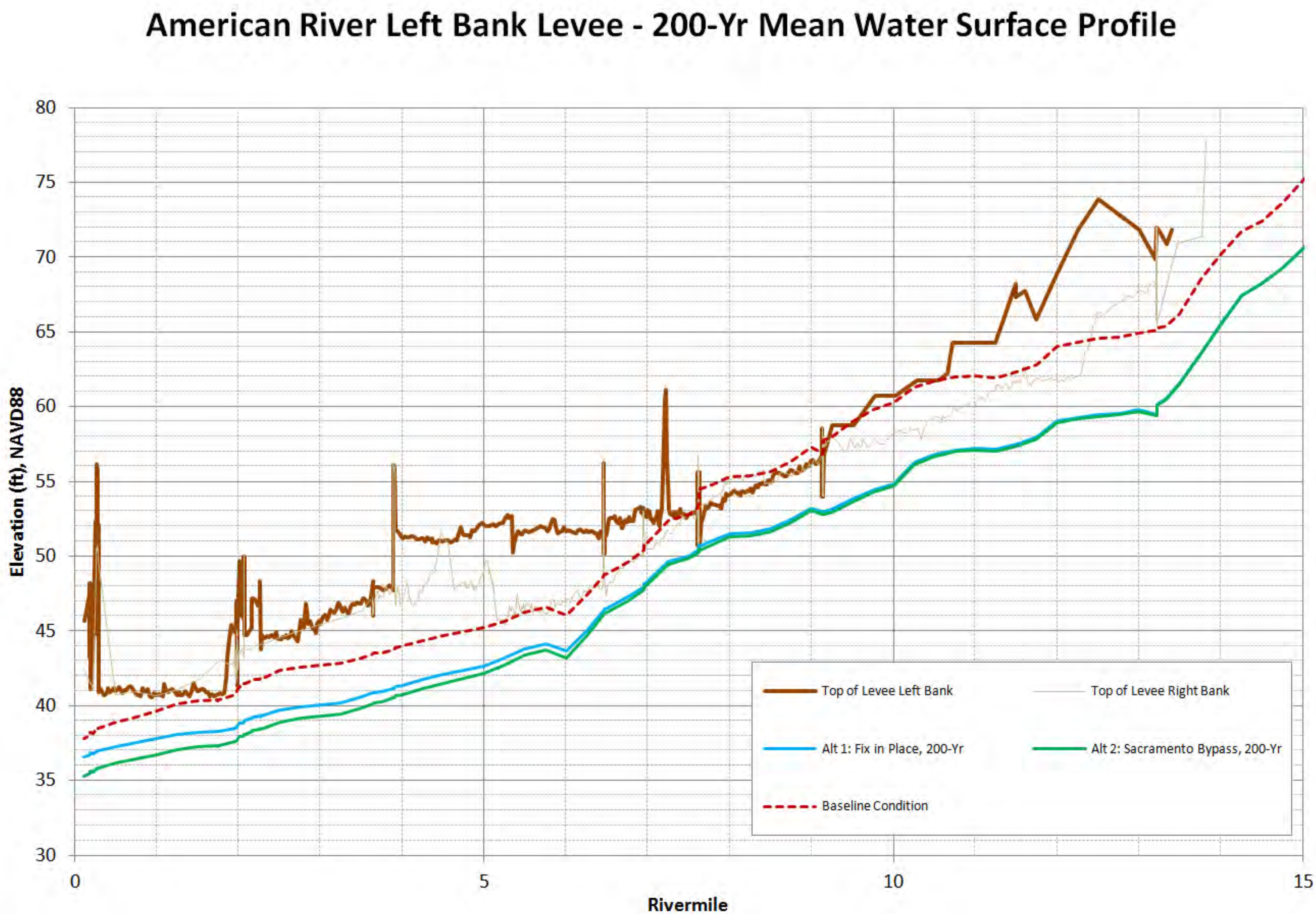
American River Common Features GRR Sacramento, California	Arcade Creek - Right Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



American River Common Features GRR Sacramento, California	Arcade Creek - Left Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



American River Common Features GRR Sacramento, California	American River – Right Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District



American River Common Features GRR Sacramento, California	American River – Left Bank Levee 200-Yr Water Surface Profiles With-Project Alternatives	U.S. Army Corps of Engineers Sacramento District

LEGEND

Hydrologic - Hydraulic Handoff Points

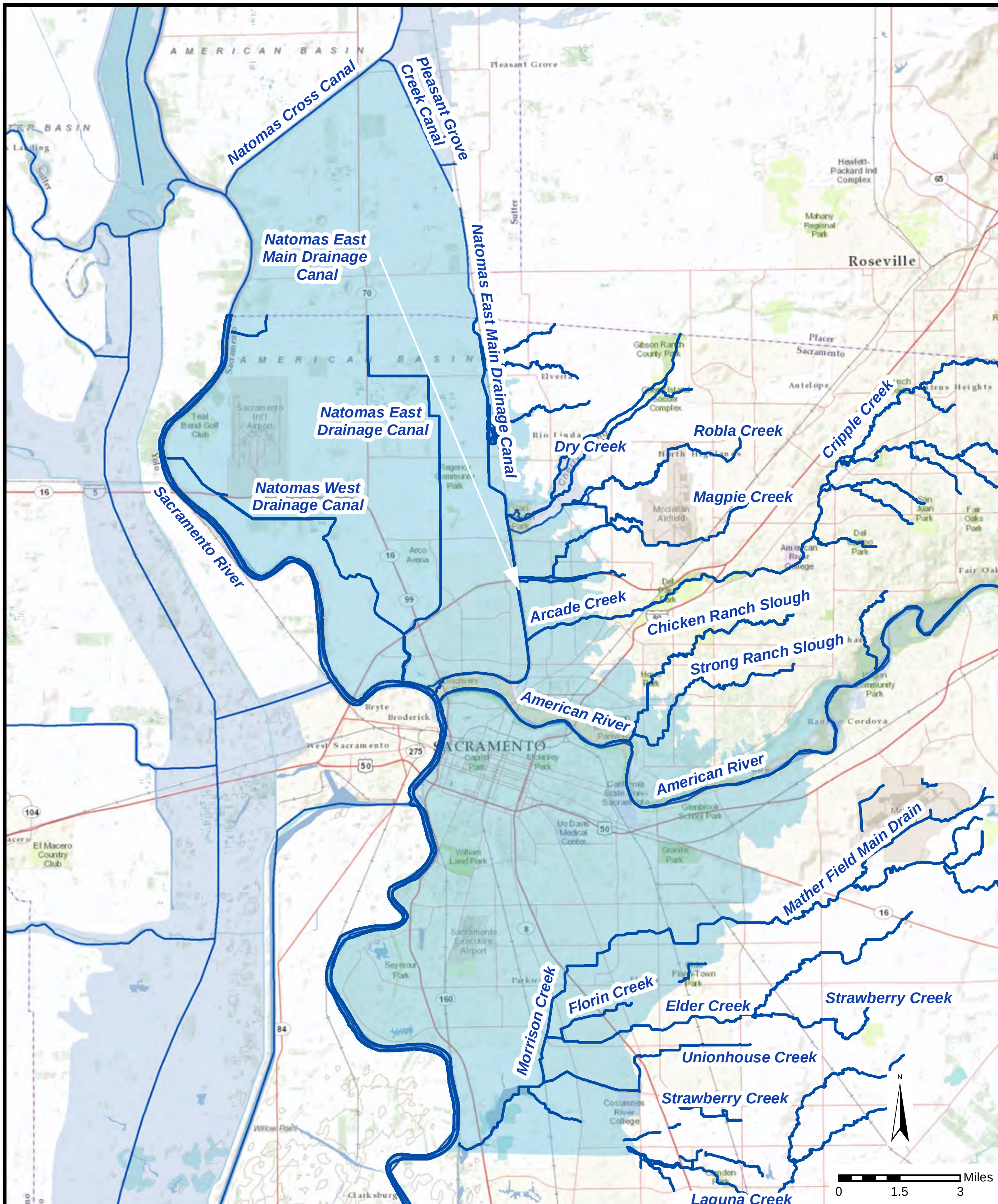
Rivers

Cities

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

BOUNDARY CONDITIONS HYDROLOGIC - HYDRAULIC HANDOFF POINTS

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



LEGEND

Streams

Floodways

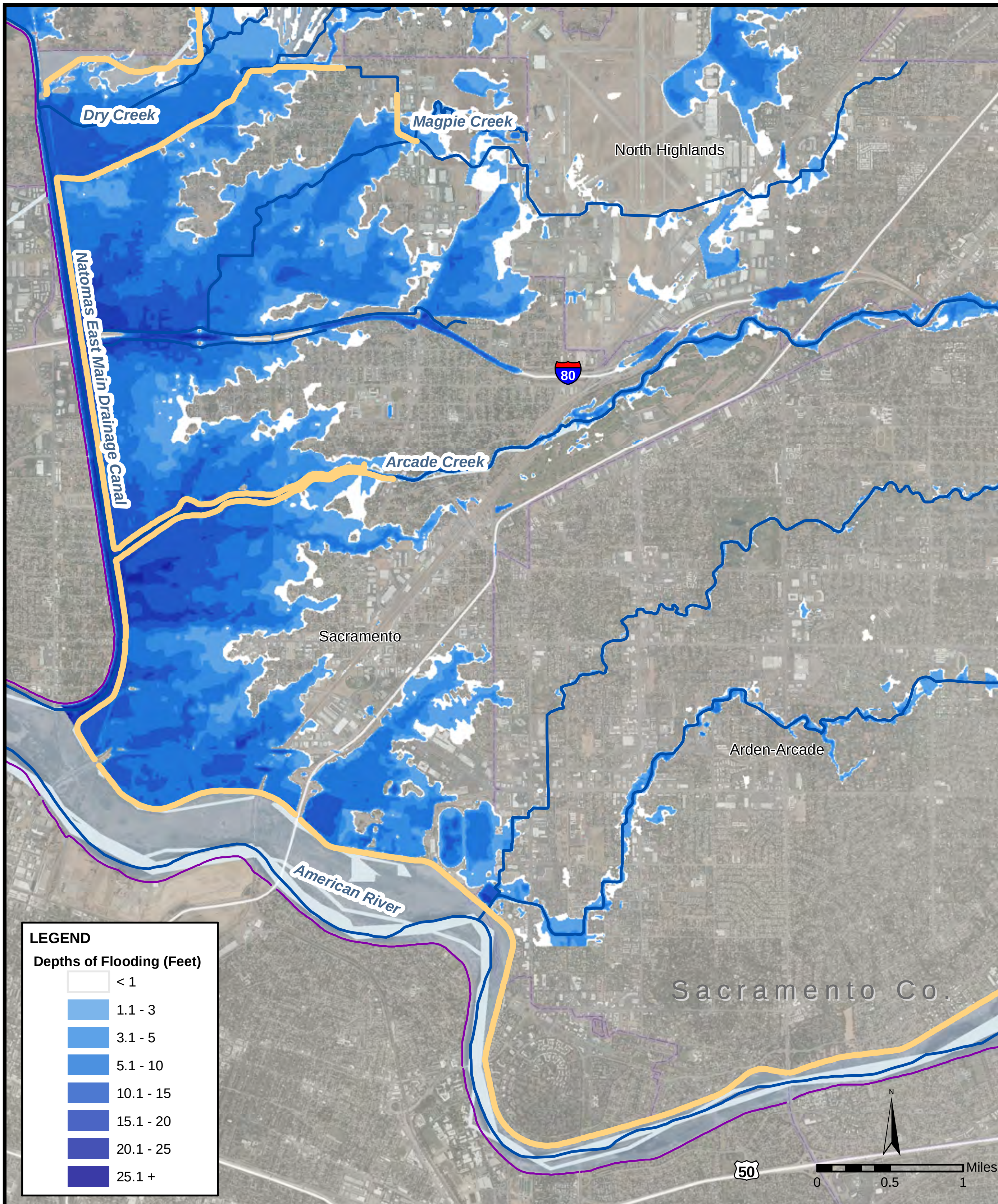
ARCF Study Area

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

INTERIOR DRAINAGE STUDY AREA MAP

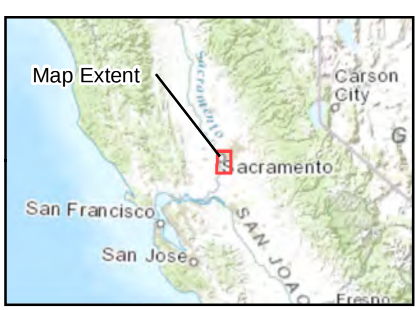
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Feb 2013



LEGEND

ARCF Levees
ARN Levees
Streams
Floodways
County Lines
Cities

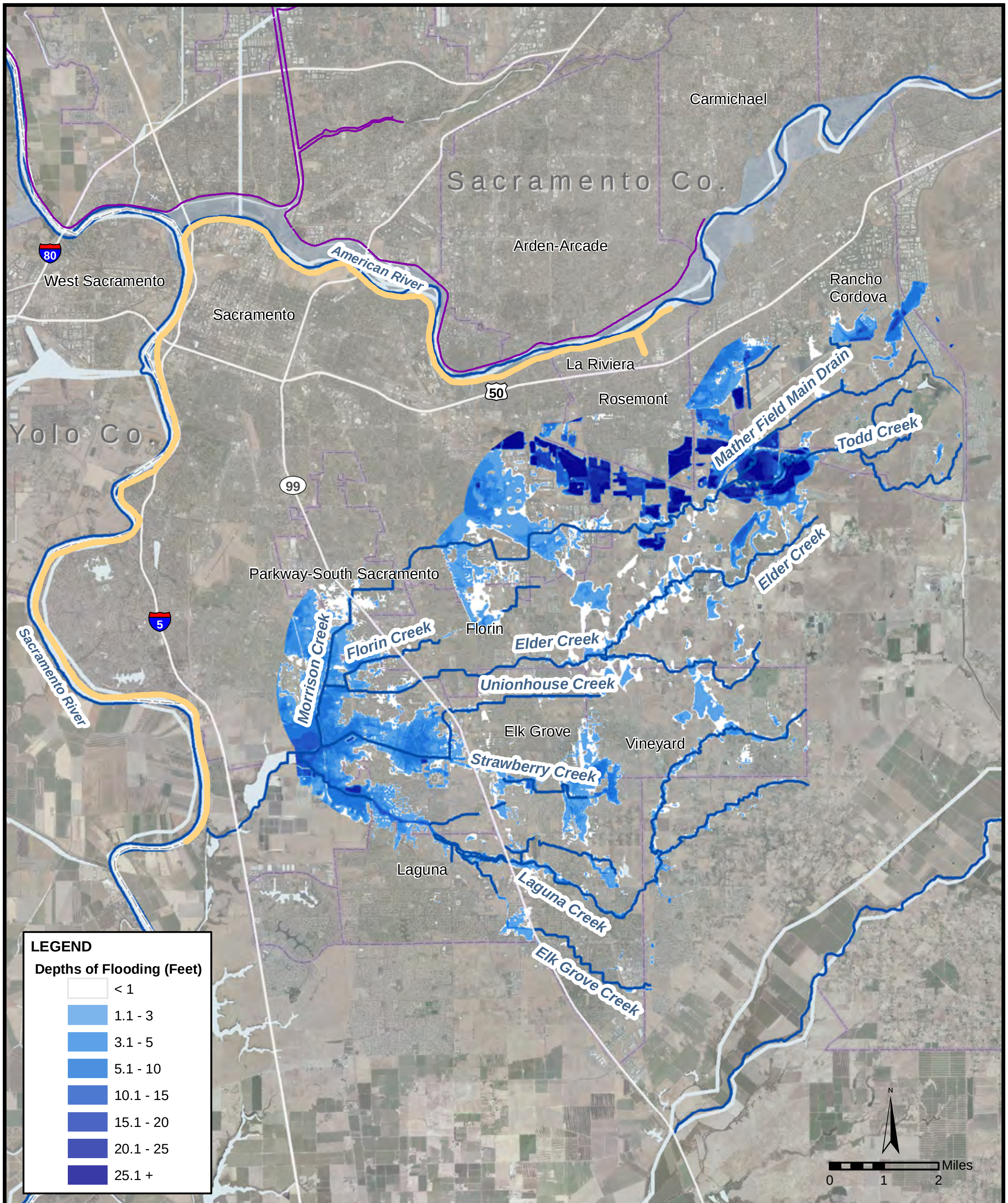


AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

AMERICAN RIVER NORTH 1% ACE (100 YEAR) INTERIOR DRAINAGE FLOODPLAIN

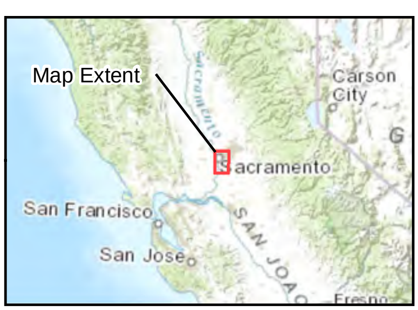
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Feb 2013



LEGEND

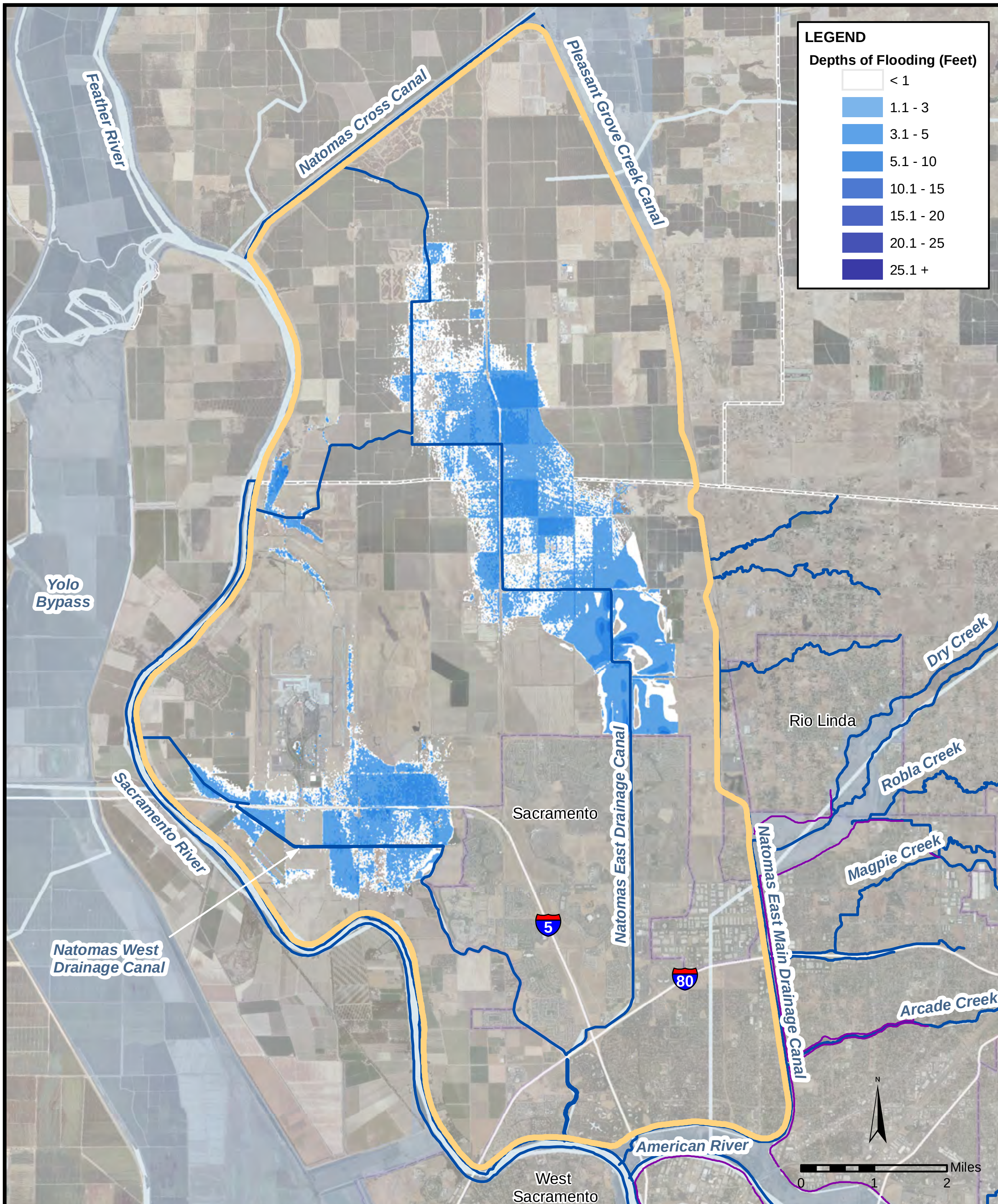
- ARCF Levees
- ARS Levees
- Streams
- Floodways
- County Lines
- Cities



AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

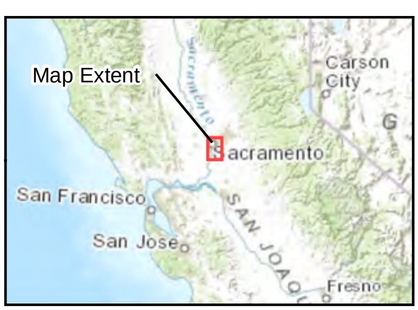
AMERICAN RIVER SOUTH
1% ACE (100 YEAR)
INTERIOR DRAINAGE FLOODPLAIN

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



LEGEND

- ARCF Levees
- Natomas Levees
- Streams
- Floodways
- Cities
- County Lines

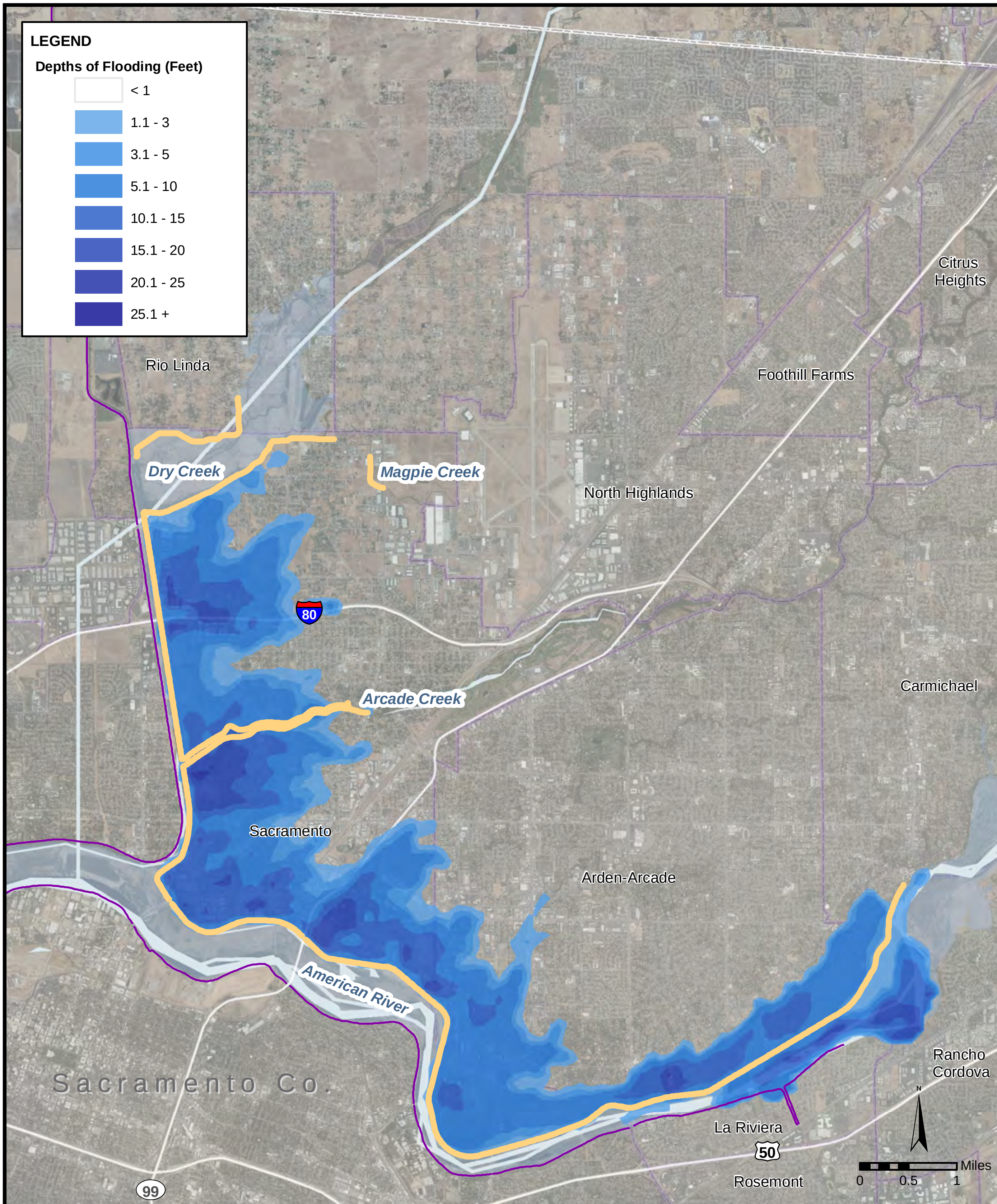


AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

NATOMAS BASIN
1% (1/100) ACE
INTERIOR DRAINAGE FLOODPLAIN

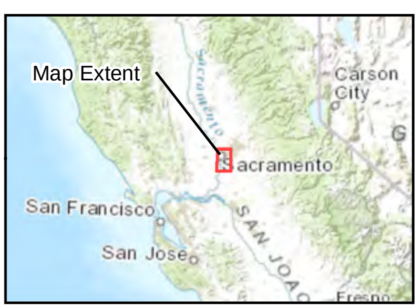
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Jan 2013



LEGEND

- ARN Levees
- ARCF Levees
- Floodways
- County Lines
- Cities

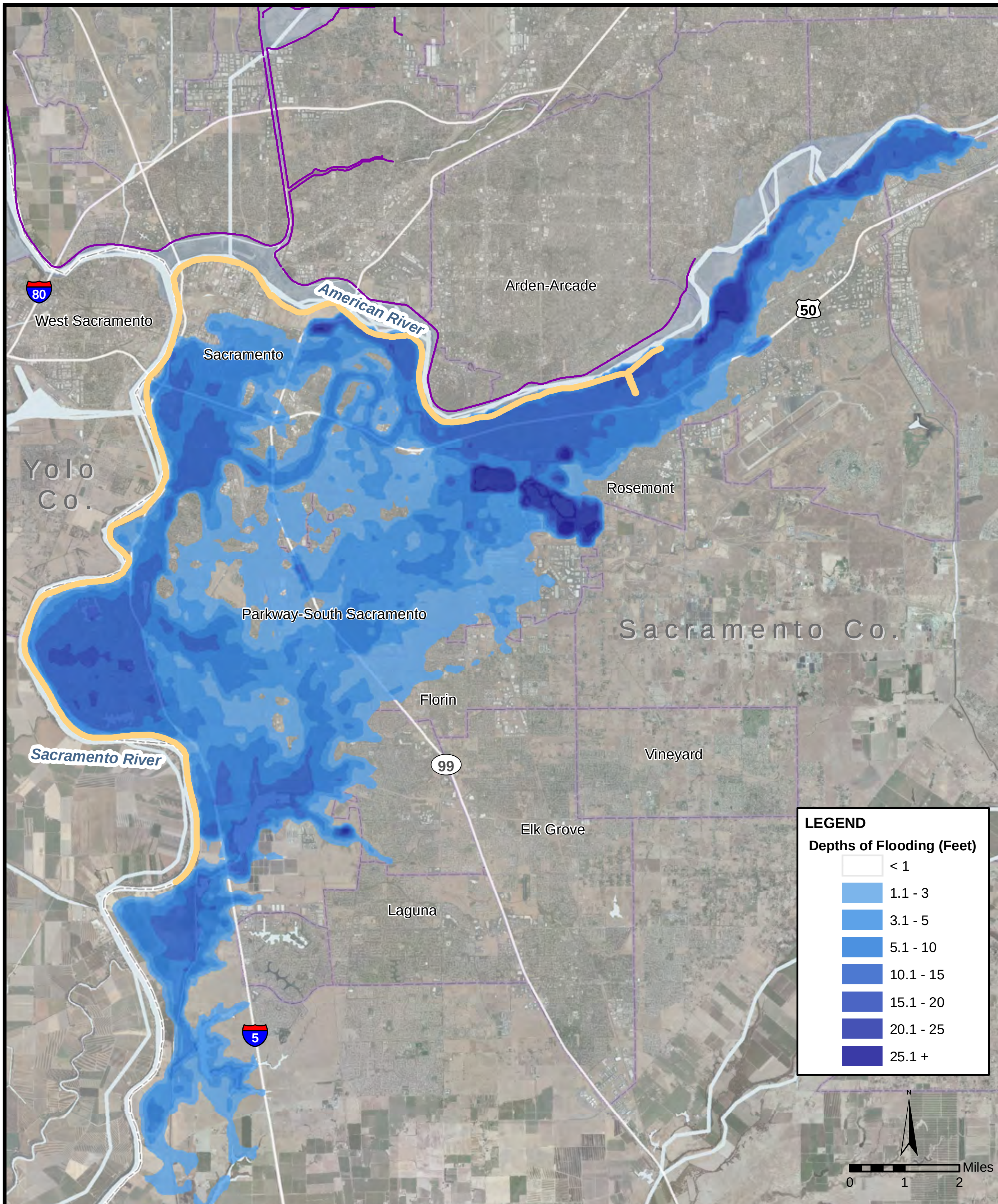


AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

RESIDUAL FLOODING
FROM UPSTREAM CHANNEL OUTFLANKING
INTO THE AMERICAN RIVER BASIN

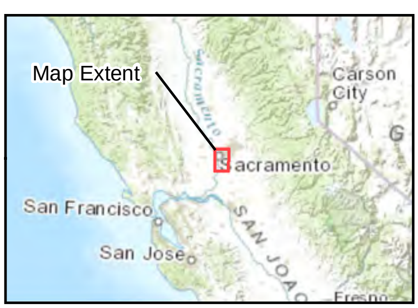
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Feb 2013



LEGEND

- ARCF Levees
- ARS Levees
- County Lines
- Floodways
- Cities

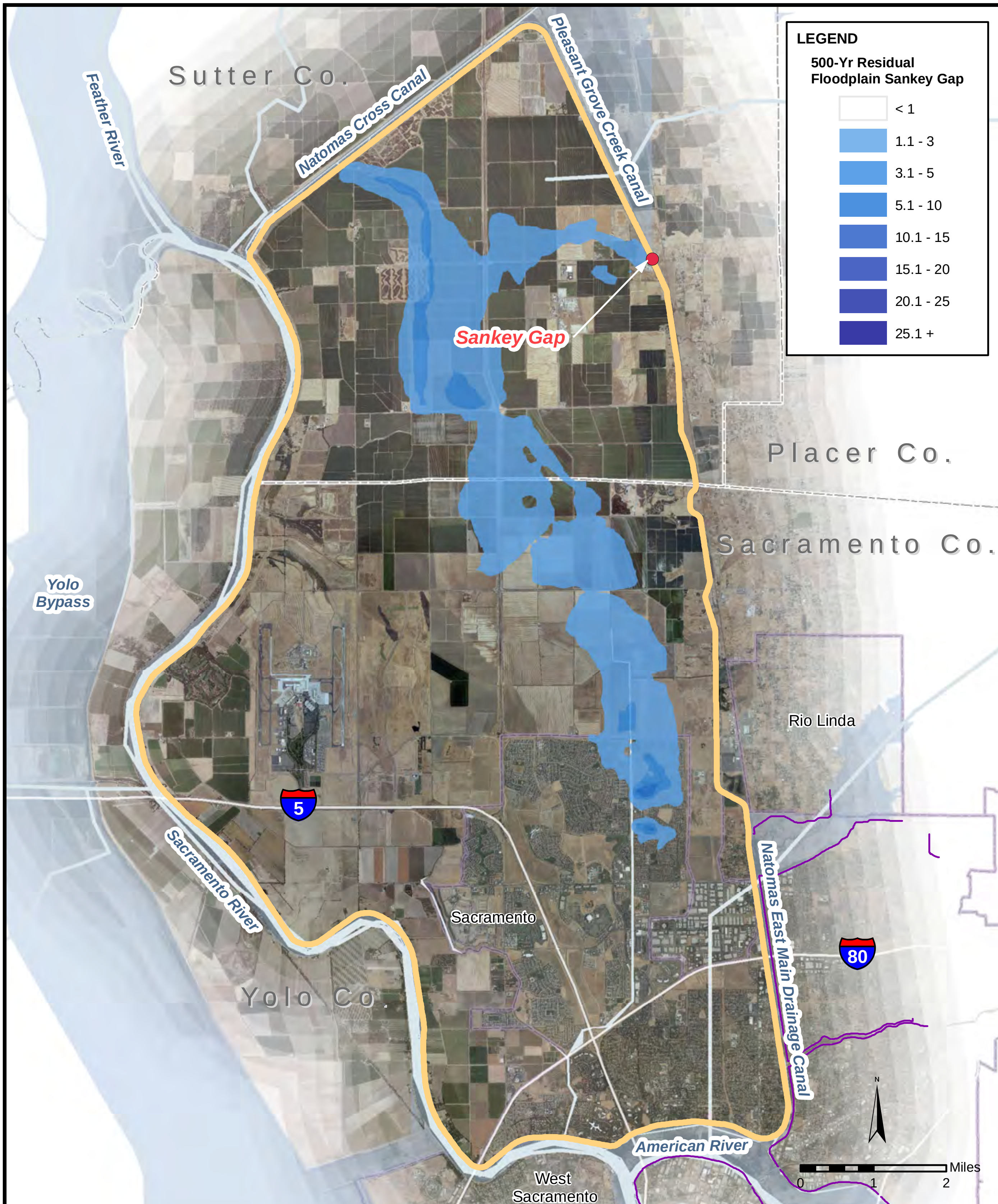


AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

RESIDUAL FLOODING FROM CHANNEL OUTFLANKING INTO THE AMERICAN RIVER SOUTH BASIN

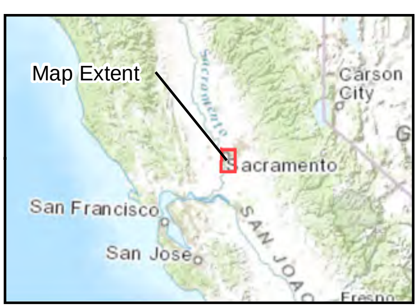
U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Feb 2013



LEGEND

- ARCF Levees
- Natomas Levees
- Floodways
- Cities
- County Lines



AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

RESIDUAL FLOODING FROM SANKEY GAP INTO THE NATOMAS BASIN

U.S. ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

Feb 2013

American River South (ARS) IP A			
American River RM 7.8			
	Future Without Project Condition	**Fix In Place**	**Sacramento Bypass Widening**
Frequency	Stage, NAVD88		
1yr = .999	24.1	24.1	24.1
2yr = .5	31.9	31.9	31.9
10yr = .1	42.0	42.0	41.8
25yr = .04	48.0	48.0	47.9
50yr = .02	48.1	48.1	47.9
100yr = .01	48.2	48.2	48.0
200yr = .005	53.2	53.2	53.0
500yr = .002	58.1	58.1	58.1
Frequency	Flow		
1yr = .999	1423	1423	1439
2yr = .5	25977	25977	25998
10yr = .1	71654	71654	71655
25yr = .04	114993	114993	114990
50yr = .02	115000	115000	114999
100yr = .01	114999	114999	114999
200yr = .005	159995	159995	159982
500yr = .002	254357	254357	254410

Source: Hydraulic Analysis Section, Sacramento District, USACE

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

AMERICAN RIVER SOUTH
INDEX POINT A
RISK ANALYSIS INPUTS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

American River South (ARS) IP F			
Sacramento River RM 50.3			
	Future Without Project Condition	Fix In Place	Sacramento Bypass Widening
Frequency	Stage, NAVD88		
1yr = .999	11.1	11.1	11.1
2yr = .5	20.8	20.8	20.8
10yr = .1	26.4	26.4	26.0
25yr = .04	29.0	29.0	27.9
50yr = .02	29.6	29.6	28.5
100yr = .01	30.3	30.3	29.3
200yr = .005	32.0	32.0	30.9
500yr = .002	33.9	33.9	33.4
Frequency	Flow		
1yr = .999	52823	52823	47842
2yr = .5	94600	94600	87375
10yr = .1	100687	100687	99631
25yr = .04	115395	115395	107204
50yr = .02	118141	118141	110188
100yr = .01	121788	121788	113973
200yr = .005	133200	133200	124750
500yr = .002	152523	152523	144263

Source: Hydraulic Analysis Section, Sacramento District, USACE

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

**AMERICAN RIVER SOUTH
INDEX POINT F
RISK ANALYSIS INPUTS**

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

American River North (ARN) IP A			
American River RM 7.83			
	Future Without Project Condition	Fix In Place	Sacramento Bypass Widening
Frequency	Stage, NAVD88		
1yr = .999	23.3	23.3	22.7
2yr = .5	32.4	32.4	30.5
10yr = .1	40.5	40.5	40.6
25yr = .04	46.2	46.2	46.4
50yr = .02	46.2	46.2	46.5
100yr = .01	46.3	46.3	46.6
200yr = .005	51.2	51.2	51.4
500yr = .002	55.9	55.9	55.7
Frequency	Flow		
1yr = .999	1690	1690	1631
2yr = .5	25969	25969	25996
10yr = .1	71653	71653	71654
25yr = .04	114991	114991	114987
50yr = .02	114999	114999	114999
100yr = .01	115000	115000	114999
200yr = .005	159998	159998	159979
500yr = .002	220684	220684	215253

Source: Hydraulic Analysis Section, Sacramento District, USACE

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

**AMERICAN RIVER NORTH
INDEX POINT A
RISK ANALYSIS INPUTS**

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

American River North (ARN) IP E			
Arcade Creek RM .95			
	Future Without Project Condition	**Fix In Place**	**Sacramento Bypass Widening**
Frequency	Stage, NAVD88		
1yr = .999	27.0	27.0	26.6
2yr = .5	30.0	30.0	29.4
10yr = .1	33.1	33.1	33.2
25yr = .04	35.4	35.4	34.8
50yr = .02	37.7	37.7	36.1
100yr = .01	39.2	39.2	38.6
200yr = .005	41.4	41.4	40.9
500yr = .002	46.1	46.1	45.2
Frequency	Flow		
1yr = .999	-	-	-
2yr = .5	-	-	-
10yr = .1	-	-	-
25yr = .04	-	-	-
50yr = .02	-	-	-
100yr = .01	-	-	-
200yr = .005	-	-	-
500yr = .002	-	-	-

Source: Hydraulic Analysis Section, Sacramento District, USACE

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

AMERICAN RIVER NORTH
INDEX POINT A
RISK ANALYSIS INPUTS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT

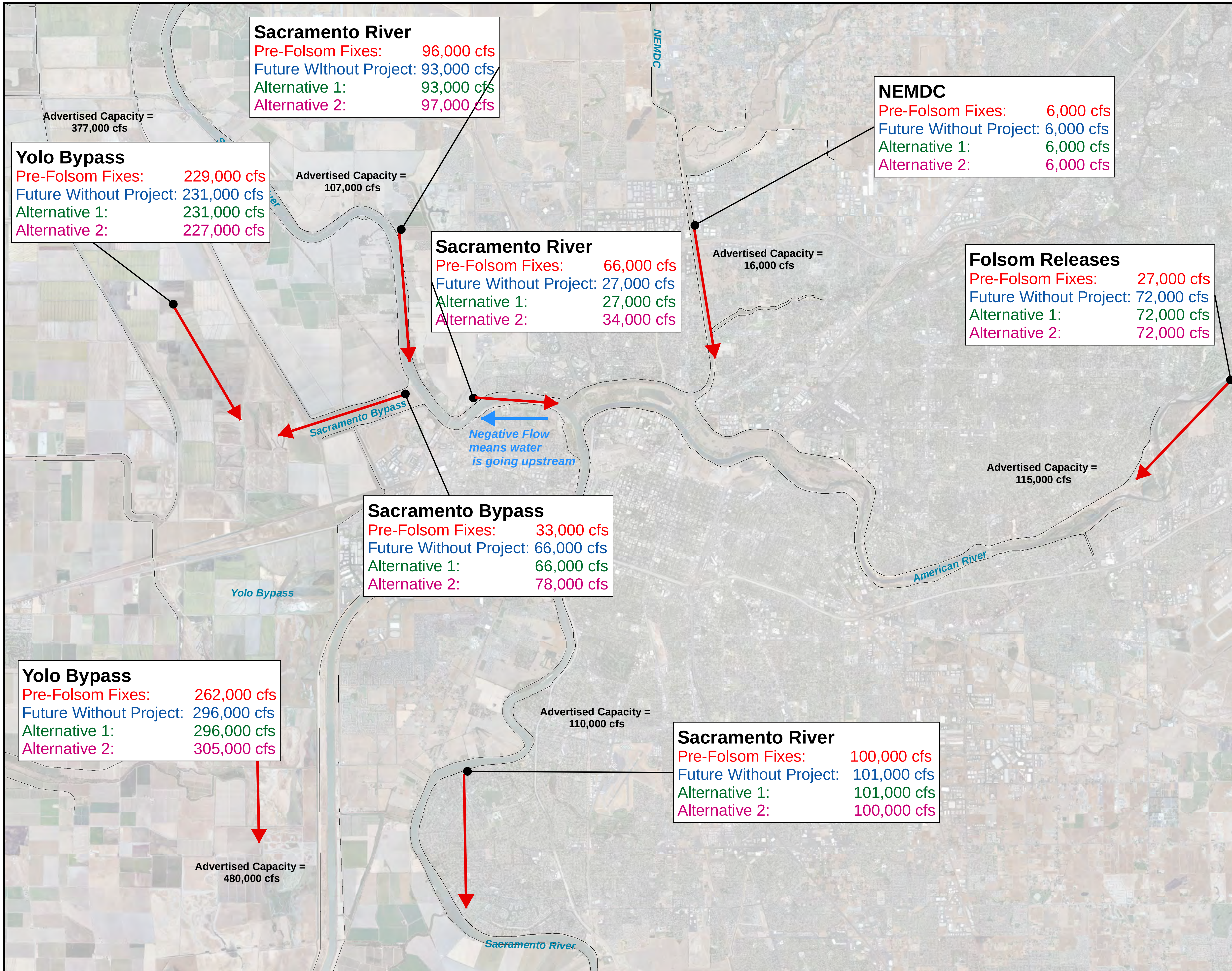
Natomas (NAT) IP D			
Natomas Cross Canal RM 2.71			
	Future Without Project Condition	**Fix In Place**	**Sacramento Bypass Widening**
Frequency	Stage, NAVD88		
1yr = .999	20.6	20.6	20.5
2yr = .5	33.6	33.6	33.5
10yr = .1	39.0	39.0	38.9
25yr = .04	41.5	41.5	41.4
50yr = .02	42.4	42.4	42.3
100yr = .01	43.5	43.5	43.4
200yr = .005	44.6	44.6	44.6
500yr = .002	45.5	45.5	45.5
Frequency	Flow		
1yr = .999	-	-	-
2yr = .5	-	-	-
10yr = .1	-	-	-
25yr = .04	-	-	-
50yr = .02	-	-	-
100yr = .01	-	-	-
200yr = .005	-	-	-
500yr = .002	-	-	-

Source: Hydraulic Analysis Section, Sacramento District, USACE

AMERICAN RIVER COMMON FEATURES GRR
SACRAMENTO, CALIFORNIA

NATOMAS
INDEX POINT D
RISK ANALYSIS INPUTS

U.S ARMY CORPS OF ENGINEERS
SACRAMENTO DISTRICT



LEGEND

SPK_Levees_SegmentType

Levee Reaches (ARCF)

Flow Direction

Backflow

Reach

Pre-Folsom Dam Improvment Flows

Future Without Project Condition Flows

Alternative 1 Flows

Alternative 2 Flows

N

0 0.5 1 2 Miles

1:100,000

US Army Corps of Engineers
Sacramento District

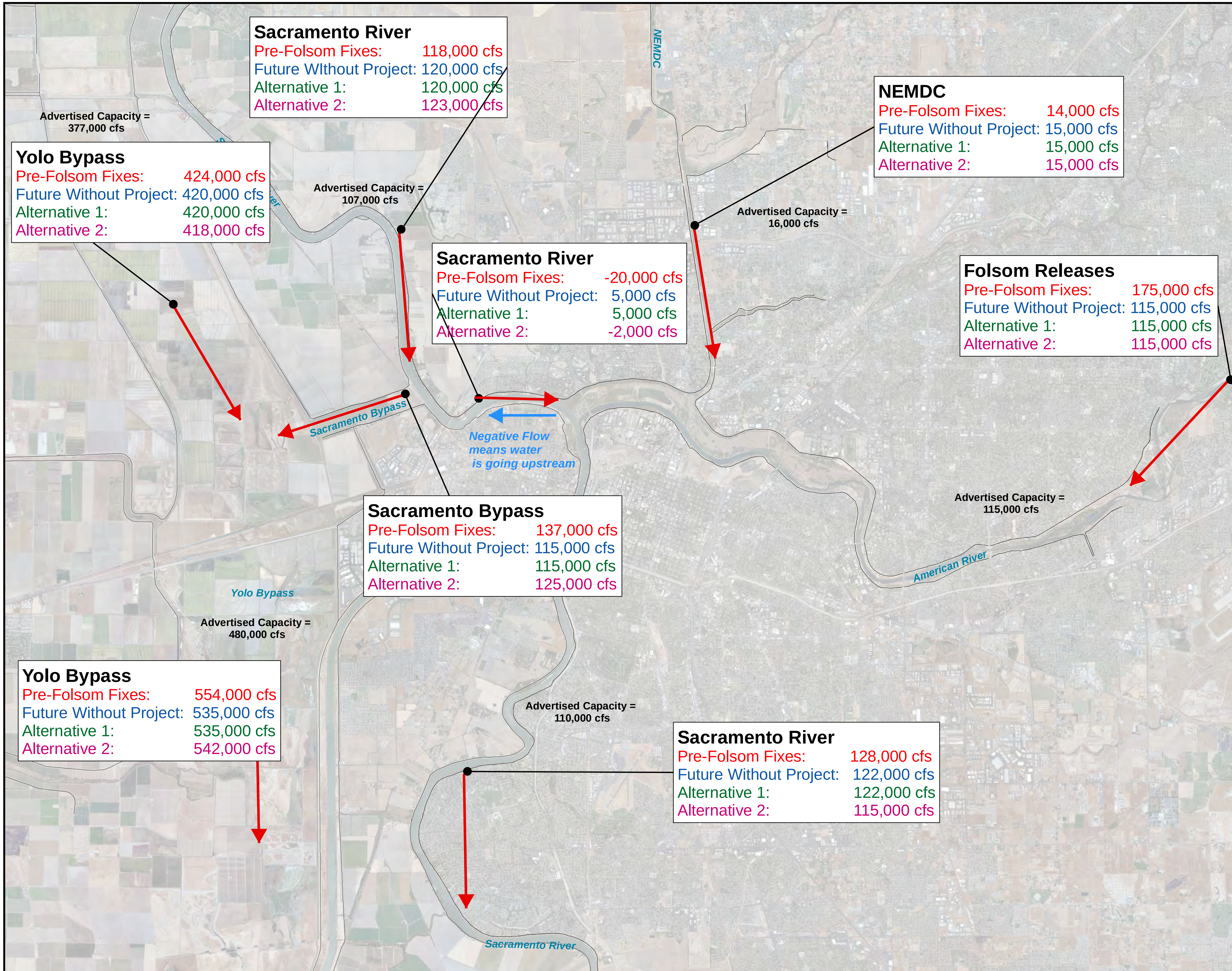
MAXIMUM 10-YR EXISTING CONDITIONS & WITH PROJECT FLOWS

AMERICAN RIVER
COMMON FEATURES GRR

Maxiumum Flows are the greatest flow from either the Sacramento or American Storm Centerings.

Date: 12/8/2014
Path: E:\Projects\GIS\MXD_Graphics\ARCF_Flowsplit_10-Yr_08Dec2014.mxd

Dec 2014



LEGEND

SPK_Levees_SegmentType

Levee Reaches (ARCF)

Flow Direction

Backflow

Reach

Pre-Folsom Dam Improvment Flows

Future Without Project Condition Flows

Alternative 1 Flows

Alternative 2 Flows

N

0 0.5 1 2 Miles

1:100,000

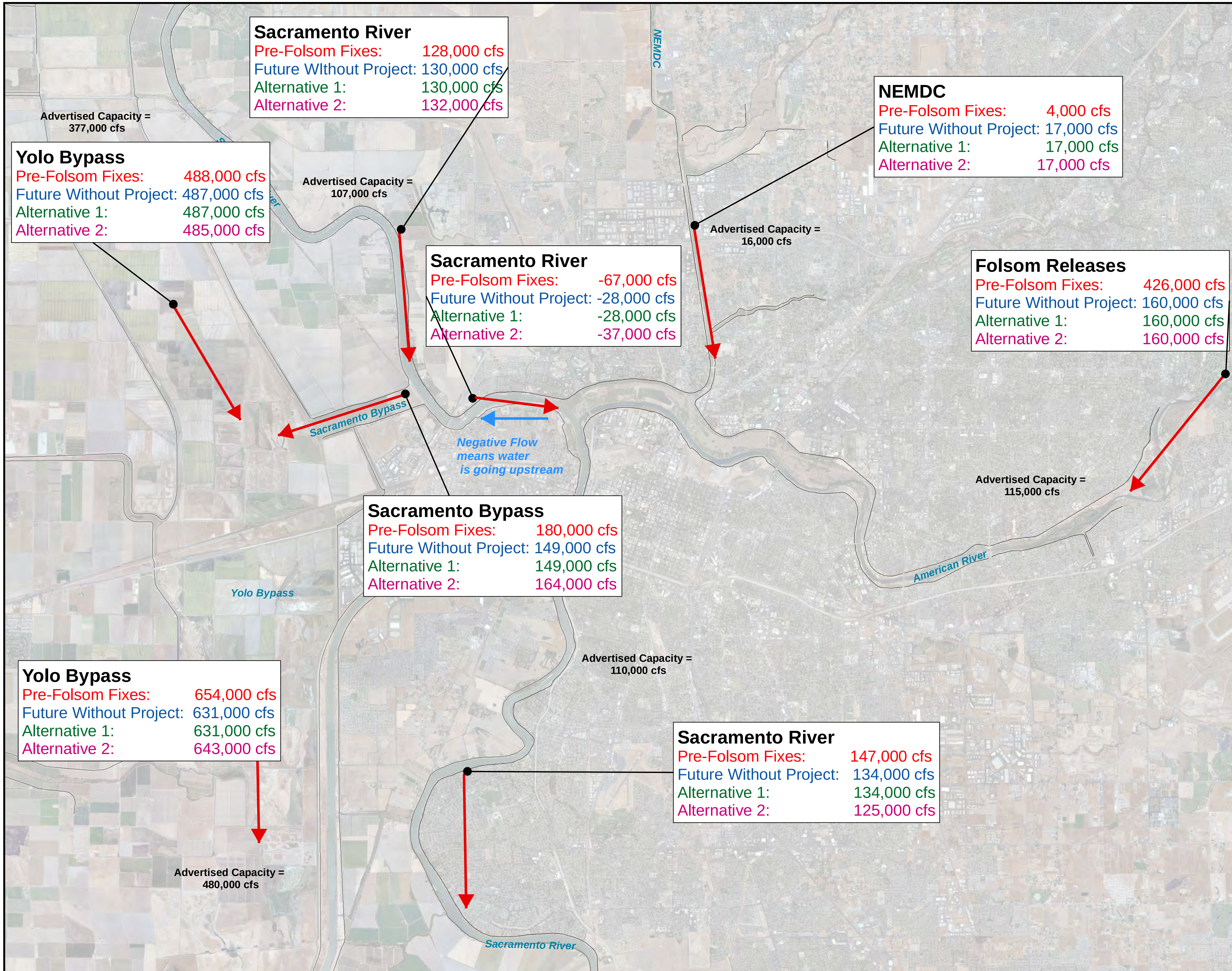
US Army Corps of Engineers Sacramento District

MAXIMUM 100-YR EXISTING CONDITIONS & WITH PROJECT FLOWS

AMERICAN RIVER COMMON FEATURES GRR

Maxiumum Flows are the greatest flow from either the Sacramento or American Storm Centerings.

Date: 12/8/2014
Path: E:\Projects\GIS\MXD_Graphics\ARCF_Flowsplit_100-Yr_08Dec2014.mxd



LEGEND

- Levee Reaches (ARCF)
- Flow Direction
- Backflow

Reach
Pre-Folsom Dam Improvment Flows
Future Without Project Condition Flows
Alternative 1 Flows
Alternative 2 Flows

N

0 0.5 1 2 Miles

1:100,000

US Army Corps of Engineers
Sacramento District

MAXIUMUM 200-YR EXISTING CONDITIONS & WITH PROJECT FLOWS

AMERICAN RIVER COMMON FEATURES GRR

Maxiumum Flows are the greatest flow from either the Sacramento or American Storm Centerings.

Date: 12/8/2014
Path: E:\Projects\GIS\MXD_Graphics\ARCF_Flowsplit_200-Yr_08Dec2014.mxd

Dec 2014