CENTRAL VALLEY
FLOOD MANAGEMENT
PLANNING PROGRAM

FloodSAFE CALIFORNIA

Public Draft

2012 Central Valley Flood Protection Plan

Attachment 8C: Riverine Channel Evaluations

January 2012

STATE OF CALIFORNIA
THE NATURAL RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

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1.0 Introduction

This section states the purpose of this attachment, gives background information (including a description of planning areas, goals, and approaches), overviews the Sacramento and San Joaquin river basins, Stockton area, and the San Joaquin Area Flood Control Agency (SJAFCA) Flood Protection Restoration Project, and provides an overview of the report organization.

1.1 Purpose of this Attachment

As part of development of the 2012 Central Valley Flood Protection Plan (CVFPP), hydraulic modeling was performed for the Sacramento and San Joaquin river basins, Stockton area, and Sacramento-San Joaquin River Delta (Delta) to support flood management system evaluations. The analysis in the Sacramento and San Joaquin river basins was performed using hydrology and hydraulic models initially developed as part of the *Sacramento and San Joaquin River Basins Comprehensive Study* (Comprehensive Study) (USACE, 2002a).

The Comprehensive Study did not develop impact areas or models on the Calaveras River (including Mormon Slough and the Stockton Diverting Canal) and Bear Creek in Stockton, even though the streams include State Plan of Flood Control (SPFC) levees. Therefore, this attachment also documents the development and use of hydrology and hydraulic models for those two streams in the Stockton area. Note that hydraulic modeling for the Delta is documented in Attachment 8D: Estuary Channel Evaluation.

Results from the modeling were used to describe the hydraulic performance of the existing flood management system (No Project condition) and to simulate management actions for various approaches for improving the system. Modeling results were also used as input to flood damage evaluation models to estimate economic values of flood damages. All modeling was done at a reconnaissance level for use in comparing approaches on a systemwide basis, and should not be used for any other purpose.

This attachment documents riverine channel hydraulic modeling methodology and results for the Sacramento and San Joaquin river basins and Stockton area for the No Project condition and each of the following CVFPP approaches:

- Achieve SPFC Design Flow Capacity Preliminary Approach
- Protect High Risk Communities Preliminary Approach
- Enhance Flood System Capacity Preliminary Approach
- State Systemwide Investment Approach

The riverine channel hydraulic modeling of the No Project condition was done to provide a baseline for comparison with the four approaches. While the No Project condition is meant to describe the existing conditions of flood management systems in the Central Valley, it also includes projects that have been authorized and have funding, or that have started construction or implementation. The No Project condition includes the following:

- Levee improvements in south Yuba County implemented by the Three Rivers Levee Improvement Authority (TRLIA) since 2004 (TRLIA, 2011)
- Natomas Levee Improvement Program by the Sacramento Area Flood Control Agency (SAFCA) (SAFCA, 2011)
- Folsom Dam Joint Federal Project to improve the ability of Folsom Dam to manage major floods by allowing more water to be safely released earlier in a storm event, leaving more storage capacity for capturing peak inflow (Reclamation, 2009)
- Levee improvements along the American River to safely pass a flow of 160,000 cubic feet per second (cfs) as part of the American River Common Features Project (SAFCA, 2011)
- Marysville levee improvements (USACE, 2009b)

Riverine channel hydraulic modeling developed flow rates (discharge in cubic feet per second (cfs)) and water surface elevations (stage in feet above the National Geodetic Vertical Datum of 1929 (NGVD29)) for various theoretical floods in the Sacramento and San Joaquin river basins for each CVFPP approach. Elevations are in NGVD29 instead of the more commonly used North American Vertical Datum of 1988 (NAVD88) for consistency with the Comprehensive Study.

This attachment documents the following modeling results:

- The discharge-frequency (Q-F) relationship for in-river locations in the Sacramento and San Joaquin river basins and Stockton area. Discharge is in cfs and storm event frequency, or annual exceedence probability

(AEP), is expressed in percentage (i.e., 1 percent AEP, or a storm with a 100-year return period).

- The stage-frequency (S-F) relationship for in-river locations inside the Sacramento and San Joaquin river basins and Stockton area. Stage is in feet above the NGVD29 and frequency (AEP) is expressed in percentage.

- Out-of-system volume from river reaches in the Sacramento and San Joaquin river basins and Stockton area. This represents the total volume of water that leaves a section of channel and enters the adjacent floodplain, typically through a breach in a levee. Out-of-system volume is expressed in thousand acre-feet (TAF).

These modeling results were used to assess the hydraulic performance at a systemwide scale under the No Project condition and each of the four approaches. After completion of the 2012 CVFPP, new riverine and floodplain models developed by DWR's Central Valley Floodplain Evaluation and Delineation Program (CVFED) will be become available for use in the 2017 CVFPP.

1.2 Background

As authorized by Senate Bill 5, also known as the Central Valley Flood Protection Act of 2008, the California Department of Water Resources (DWR) has prepared a sustainable, integrated flood management plan called the CVFPP, for adoption by the Central Valley Flood Protection Board (Board). The 2012 CVFPP provides a systemwide approach to protecting lands currently protected from flooding by existing facilities of the SPFC, and will be updated every 5 years.

As part of development of the 2012 CVFPP, a series of technical analyses were conducted to evaluate hydrologic, hydraulic, geotechnical, economic, ecosystem, and related conditions within the flood management system and to support formulation of system improvements. These analyses were conducted in the Sacramento River Basin, San Joaquin River Basin, and Delta.

1.3 CVFPP Planning Areas

For planning and analysis purposes, and consistent with legislative direction, two geographical planning areas were important for CVFPP development (Figure 1-1):

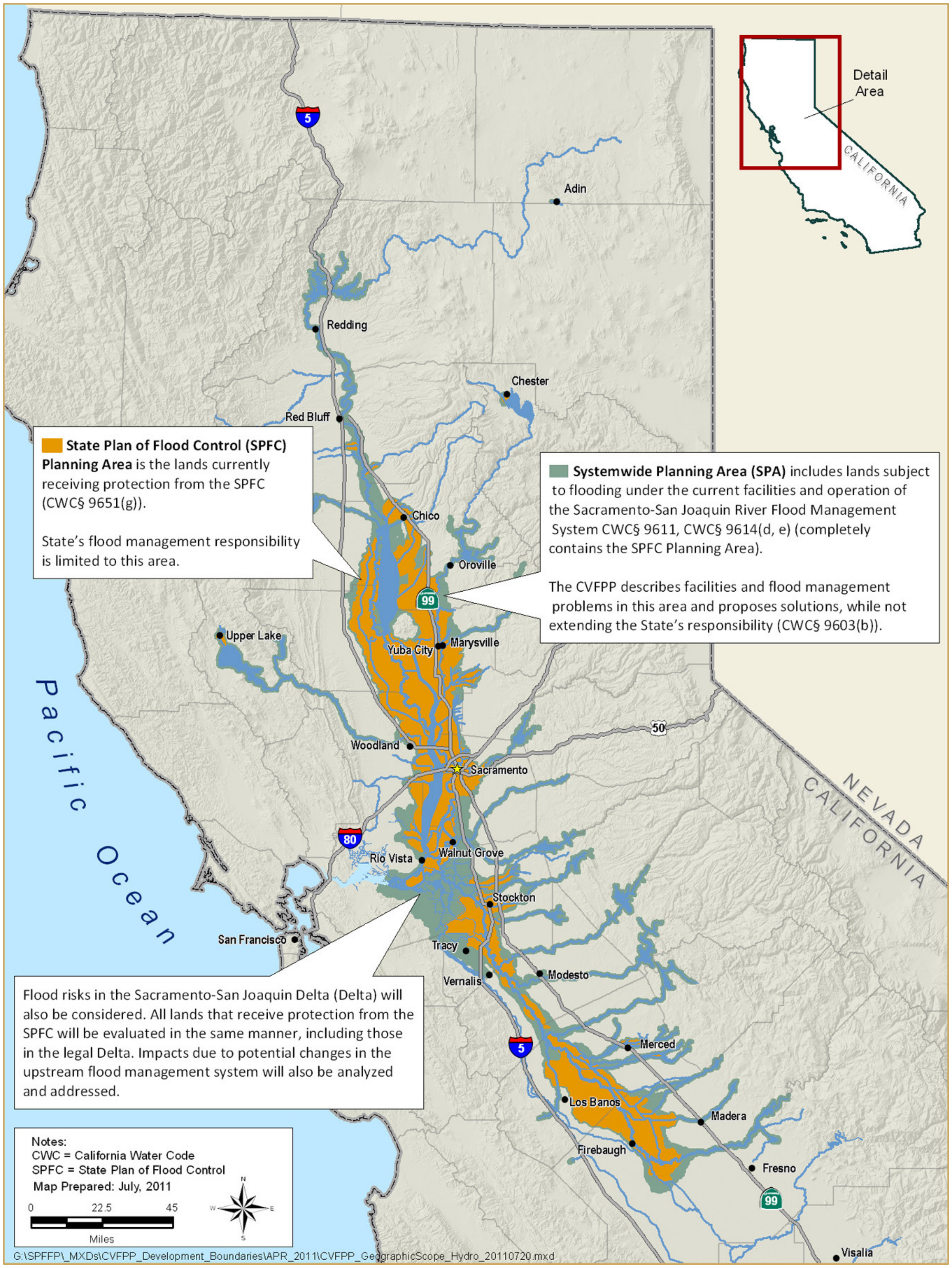

Figure 1-1. Central Valley Flood Protection Plan Planning Areas

- **SPFC Planning Area –** This area is defined by the lands currently receiving flood protection from facilities of the SPFC (see *State Plan of Flood Control Descriptive Document* (DWR, 2010)). The State of California's (State) flood management responsibility is limited to this area.

- **Systemwide Planning Area** – This area includes the lands that are subject to flooding under the current facilities and operation of the Sacramento-San Joaquin River Flood Management System (California Water Code Section 9611). The SPFC Planning Area is completely contained within the Systemwide Planning Area which includes the Sacramento River Basin, San Joaquin River Basin, and Delta regions.

Planning and development for the CVFPP occurs differently in these planning areas. The CVFPP focused on SPFC facilities; therefore, evaluations and analyses were conducted at a greater level of detail within the SPFC Planning Area than in the Systemwide Planning Area.

Hydraulic modeling was performed for major waterways and river channels within the SPFC Planning Area and Delta. This attachment describes the riverine modeling in the Sacramento River Basin, which comprises the entire northern part of the SPFC Planning Area, and the riverine modeling for the San Joaquin River Basin, which includes almost the entire portion of the southern part of the SPFC Planning Area. Hydraulic modeling of the Stockton area in the San Joaquin River Basin was also conducted and covers portions of the City of Stockton and vicinity on reaches of the Calaveras River, Mormon Slough, Stockton Diverting Canal, and Bear Creek that are protected by SPFC levees and facilities. Modeling results from the Sacramento and San Joaquin river basins provided the upstream boundary conditions for Delta hydraulic modeling that is described in Attachment 8D – Estuary Channel Evaluations.

1.4 2012 CVFPP Planning Goals

To help direct CVFPP development to meet legislative requirements and address identified flood-management-related problems and opportunities, a primary and four supporting goals were developed:

- **Primary Goal –** Improve Flood Risk Management

- **Supporting Goals**:

  - Improve Operations and Maintenance

- Promote Ecosystem Functions
- Improve Institutional Support
- Promote Multi-Benefit Projects

Modeling results in this attachment demonstrate how each of the approaches (described below) meets the primary goal.

1.5 2012 CVFPP Planning Approaches

In addition to the **No Project** condition, three fundamentally different approaches to flood management were initially compared to explore potential improvements in the Central Valley. These preliminary approaches are not alternatives; rather, they bracket a range of potential actions and help explore trade-offs in costs, benefits, and other factors important in decision making. The preliminary approaches are as follows:

- **Achieve SPFC Design Flow Capacity** – Address capacity inadequacies and other adverse conditions associated with existing SPFC facilities, without making major changes to the footprint or operation of those facilities.
- **Protect High Risk Communities** – Focus on protecting life safety for populations at highest risk, including urban areas and small communities.
- **Enhance Flood System Capacity** – Seek various opportunities to achieve multiple benefits through enhancing flood system storage and conveyance capacity.

Comparing these preliminary approaches helped identify the advantages and disadvantages of different combinations of management actions, and demonstrated opportunities to address the CVFPP goals to different degrees.

Based on this evaluation, a **State Systemwide Investment Approach** was developed that encompasses aspects of each of the preliminary approaches to balance achievement of the goals from a systemwide perspective, and includes integrated conservation elements. Figure 1-2 illustrates this plan formulation process.

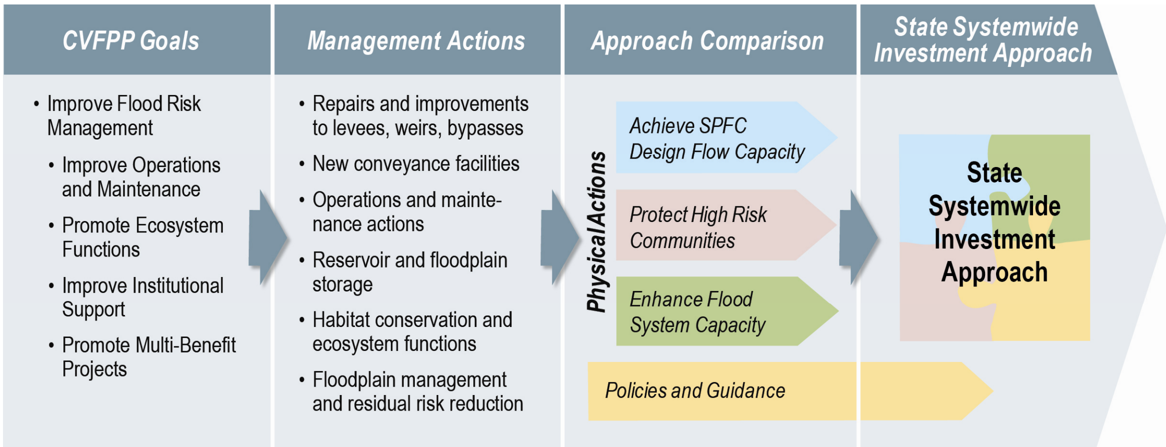

Figure 1-2. Formulation Process for State Systemwide Investment Approach

1.6 Sacramento River Basin

The flood management system in the Sacramento River Basin manages flows from approximately 27,000 square miles in the Sierra Nevada, Central Valley, and Coast Ranges in Northern California. Major tributaries to the Sacramento River include the Feather, Yuba, Bear, and American rivers, which discharge to the Sacramento River from the east. Additional tributaries, such as Cottonwood Creek, enter the mainstem of the Sacramento from the west and can provide significant flood flows. Flood management facilities in the Sacramento Valley include the following:

- Six dams and reservoirs that contribute to flood management (Shasta, Black Butte, Folsom, Oroville, New Bullards Bar, and Indian Valley dams)
- Levees along the Sacramento River and major tributaries
- Four leveed bypasses (Sutter, Tisdale, Sacramento, and Yolo bypasses)
- Five weirs (Moulton, Colusa, Tisdale, Fremont, and Sacramento weirs)
- Two sets of outfall gates (Butte Slough, Knights Landing)
- Six major drainage pumping plants (Sutter Bypass 1, 2, and 3, American River 1 and 2, and Magpie Creek)

1.7 San Joaquin River Basin

The flood management system in the San Joaquin River Basin manages flows from approximately 16,700 square miles in the Sierra Nevada, Central Valley, and Coast Ranges in Central California. Major tributaries to the San Joaquin River include the Mokelumne, Calaveras, Stanislaus, Tuolumne, Merced, and Fresno rivers, and Littlejohns Creek, which discharge to the San Joaquin River from the east. Streams on the west side of the basin, including Los Banos, Orestimba, and Del Puerto creeks, are intermittent, and their flows rarely reach the San Joaquin River except during large floods. In addition, floodflows from Kings River are diverted north into the San Joaquin River during periods of high flow in the Tulare Lake Basin. Flood management facilities in the San Joaquin Valley include the following:

- Levees along the San Joaquin River and major tributaries
- Three leveed bypasses (Eastside, Chowchilla, and Mariposa bypasses)
- Six in-stream control structures (Chowchilla Canal Bypass, San Joaquin River, Mariposa Bypass, Eastside Bypass, Sand Slough, and San Joaquin River Structure)
- Sixteen dams and reservoirs that contribute to flood management (Friant, New Exchequer, New Don Pedro, Hidden, Buchanan, New Melones, Los Banos Detention, Pardee, Camanche, New Hogan, Little Panoche Detention, Mariposa, Owens, Burns, Castle, and Bear dams)
- Five major pumping plants (Lower San Joaquin River, Mormon Slough 1 to 3, and Weatherbee Lake)

1.8 Stockton Area

The Stockton area as defined for this analysis includes portions of the City of Stockton and vicinity, as well as Lower Roberts Island, as shown on Figure 1-3. These hydraulic modeling extents were selected based on available data and the location of existing SPFC facilities.

This region is inside the SPFC planning area but no study was conducted there for the Comprehensive Study. Because of its location in the Delta, hydraulic modeling for Lower Roberts Island (STK01 on Figure 1-3) was conducted using the RMA Delta Model (see Attachment 8D: Estuary Channel Evaluations for details). This technical attachment focuses on areas labeled STK06 through STK10 on Figure 1-3.

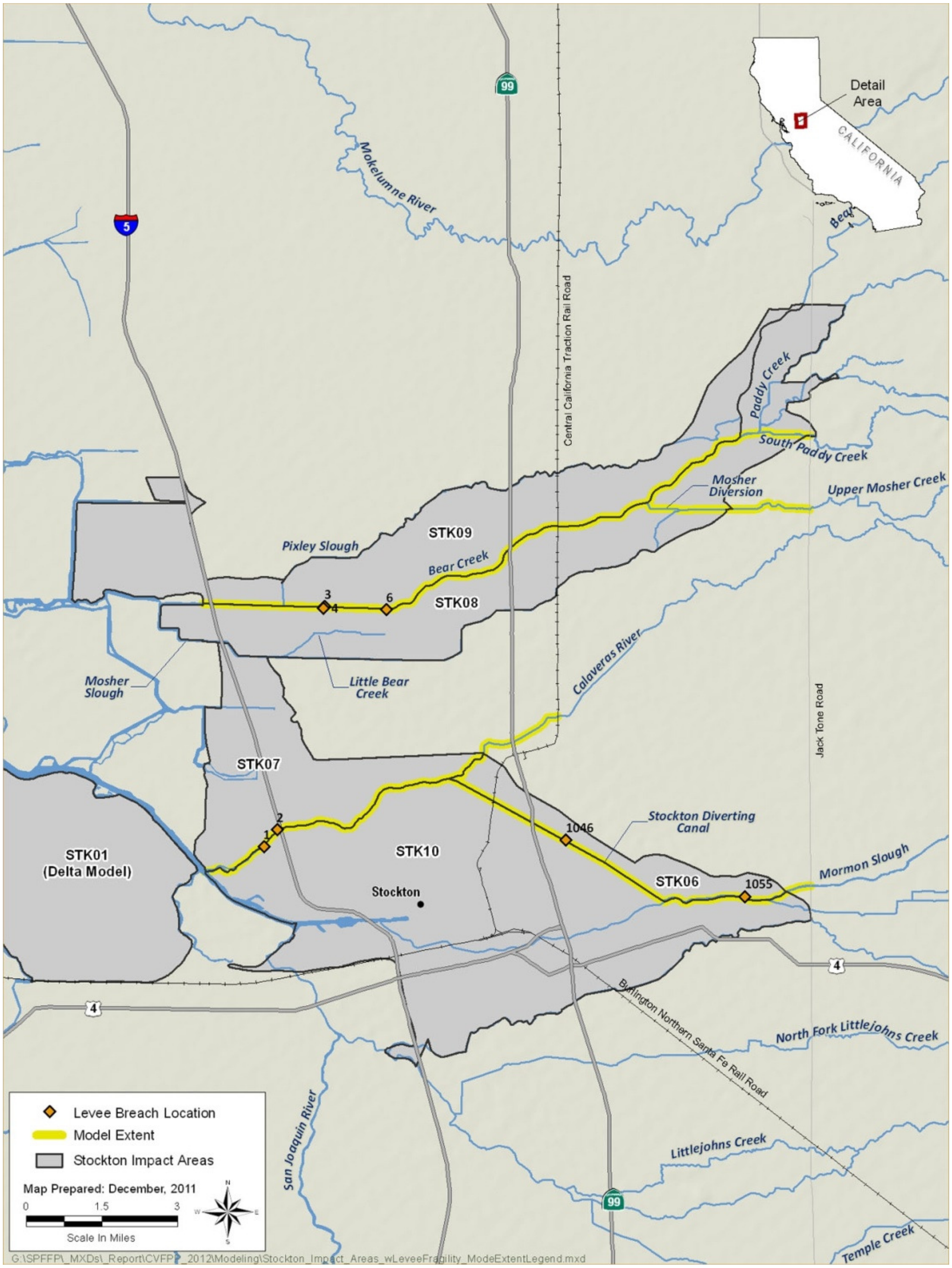

Figure 1-3. Model Extents for Stockton Area Analysis

The Stockton area streams include Bear Creek, Paddy Creek, Calaveras River, Mormon Slough/Stockton Diverting Canal, and Mosher Slough. Along the Bear Creek, SPFC levees extend from South Paddy Creek at Jack Tone Road to Bear Creek's crossing with Interstate 5 on the northwest side of the City of Stockton. The SPFC levees along Mormon Slough extend from Jack Tone Road to where it enters the Stockton Diverting Canal. The levees continue along the Stockton Diverting Canal to where it ends at the Calaveras River and then to the Calaveras River's crossing with Interstate 5 on the west side of the City of Stockton. The SPFC facilities also include three pumping plants on the Stockton Diverting Canal.

In 1998, the San Joaquin Area Flood Control Agency (SJAFCA) completed both hydrologic and hydraulic analyses for streams near the City of Stockton as part of its Flood Protection Restoration Project. The objective of this analysis was to identify solutions to resolve the finding that four streams (Bear Creek, Calaveras River, Mormon Slough/Diverting Canal, and Mosher Slough) were deficient in containing the 100-year flood flows in accordance with Federal Emergency Management Agency (FEMA) requirements. To accomplish this, SJAFCA reviewed the hydrology used by FEMA to make its deficiency finding. Additional information regarding the assumptions made in verifying and developing the hydrology and hydraulics can be found in the Flood Protection Restoration Project's *Final Technical Memorandum No. 1 – Hydrology* (SJAFCA, 1998a) and *Final Technical Memorandum No. 2 – Hydraulics* (SJAFCA, 1998b).

Models developed from the SJAFCA Flood Protection Restoration Project fit the purpose of this analysis and were used to assess the performance of the streams in the Stockton area.

1.9 Report Organization

Organization of this document is as follows:

- Section 1 describes the purpose of this attachment, and provides an overview of the CVFPP and the Sacramento and San Joaquin river basins.
- Section 2 summarizes results and findings for CVFPP riverine hydraulic modeling in the Sacramento and San Joaquin river basins.
- Section 3 describes the overall CVFPP modeling methodology, the CVFPP hydraulic model, and the model selection process for the Sacramento and San Joaquin river basins.
- Section 4 provides complete results for the riverine hydraulic analysis by CVFPP approach for the Sacramento and San Joaquin river basins.
- Section 5 provides methodology and results for the Stockton area analysis.
- Section 6 contains references for the sources cited in this document.
- Section 7 lists acronyms and abbreviations used in this document.

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2.0 Results Summary and Findings

Results from hydraulic modeling of the Sacramento and San Joaquin rivers and their major tributaries are summarized in Figures 2-1 through 2-12, which map the changes in stage between the No Project condition and the four CVFPP approaches throughout the system. Methodology and results for the Stockton area are contained in Section 5.

Maps are only included for AEPs of 2 percent, 1 percent, and 0.5 percent (50-, 100-, and 200-year return period) because the flood management system doesn't exhibit significant differences between the No Project and four approaches for the 10 percent and 4 percent (10- and 25-year return period), and similarly the 0.2 percent AEP flood (500-year return period) overwhelms the flood management system in all cases.

2.1 Achieve SPFC Design Flow Capacity Approach

Figures 2-1 through 2-3 indicate the changes in stage that would result from repairing or improving all SPFC levees to meet their design flows (Section 3.6, Tables 3-1 and 3-2) as specified by the 55/57 design profiles. Overall, for all of the AEPs there would be fewer upstream levee breaks, resulting in increased flows and higher water surface elevations in downstream reaches for both the Sacramento and San Joaquin rivers. In the San Joaquin River, higher stages (more than three feet) would be seen in the bypass system because of the reduction in levee breaks in the bypass. This would carry over into the San Joaquin River downstream from the Merced River as these increased flows leave the bypass system and enter the San Joaquin River.

2.2 Protect High Risk Communities Approach

Figures 2-4 through 2-6 indicate the changes in stage that would result from repairing or improving all urban levees to meet the 0.5 percent AEP (200-year) design criteria (Section 3.7, Tables 3-1 and 3-2), and providing increased protection to selected small communities. Since this approach would improve only urban and small community levees, other levees would be untouched and function as in the No Project condition. Stage increases of a foot or less would be seen on the lower Sacramento River as a result of increased protection for upstream urban areas. Little change would be seen along the San Joaquin River with maximum changes of much less than a foot near the Tuolumne River confluence.

2.3 Enhance Flood System Capacity Approach

Figures 2-7 through 2-9 indicate the changes in stage that would result from modifying the flood management system as described in Section 3.8 and shown in Tables 3-1 and 3-2. Key components of the approach are added upstream reservoir storage, improving SPFC levees to their design flow capacity, improving urban levees to pass the 0.5 AEP flood, widened and new bypasses, levee setbacks, and floodplain storage. Added upstream storage would result in lower stages in the upper Feather, San Joaquin, Merced, and Tuolumne rivers. Floodplain storage and levee setbacks would result in lower stages in the Sutter Bypass and lower Feather River, as well as the Sacramento River downstream from the Tisdale Weir. These lower stages would continue downstream in the Yolo Bypass and lower Sacramento River. In the San Joaquin River, a reduction in levee breaks in the Chowchilla and Eastside bypasses because of fixes to SPFC levees would result in higher stages (more than three feet higher) because of the increased the volume of water remaining in the bypasses all the way from the San Joaquin River to the Merced River. This would carry over into the San Joaquin River downstream from the Merced River as these increased flows leave the bypass system and enter the San Joaquin River. Stages downstream from the Tuolumne River to Stockton would be lowered as a result of floodplain storage and levee setbacks.

2.4 State Systemwide Investment Approach

Figures 2-10 through 2-12 indicate the changes in stage resulting from repairing or improving all urban levees to meet the 0.5 percent AEP (200-year) design criteria and other improvements in the State Systemwide Investment Approach (Section 3.9, Tables 3-1 and 3-2). Because this approach would improve only urban levees, other levees would be untouched and function as in the No Project condition. Stage decreases would be seen in the upper Feather River as a result of the new bypass from the Feather River to the Butte Basin (Biggs Bypass), which would also result in a slight increase in stage in the upper end of the Sutter Bypass. Stages would be lower in the Sutter Bypass and the Sacramento River downstream from the Tisdale Weir as a result of the levee setbacks in the Sutter Bypass and lengthening of the Fremont Weir. Stages would also be lower in portions of the Yolo Bypass as a result of levee setbacks. Slight stage increases (one foot or less) would be seen on the lower Sacramento River as a result of the increased protection for upstream urban areas.

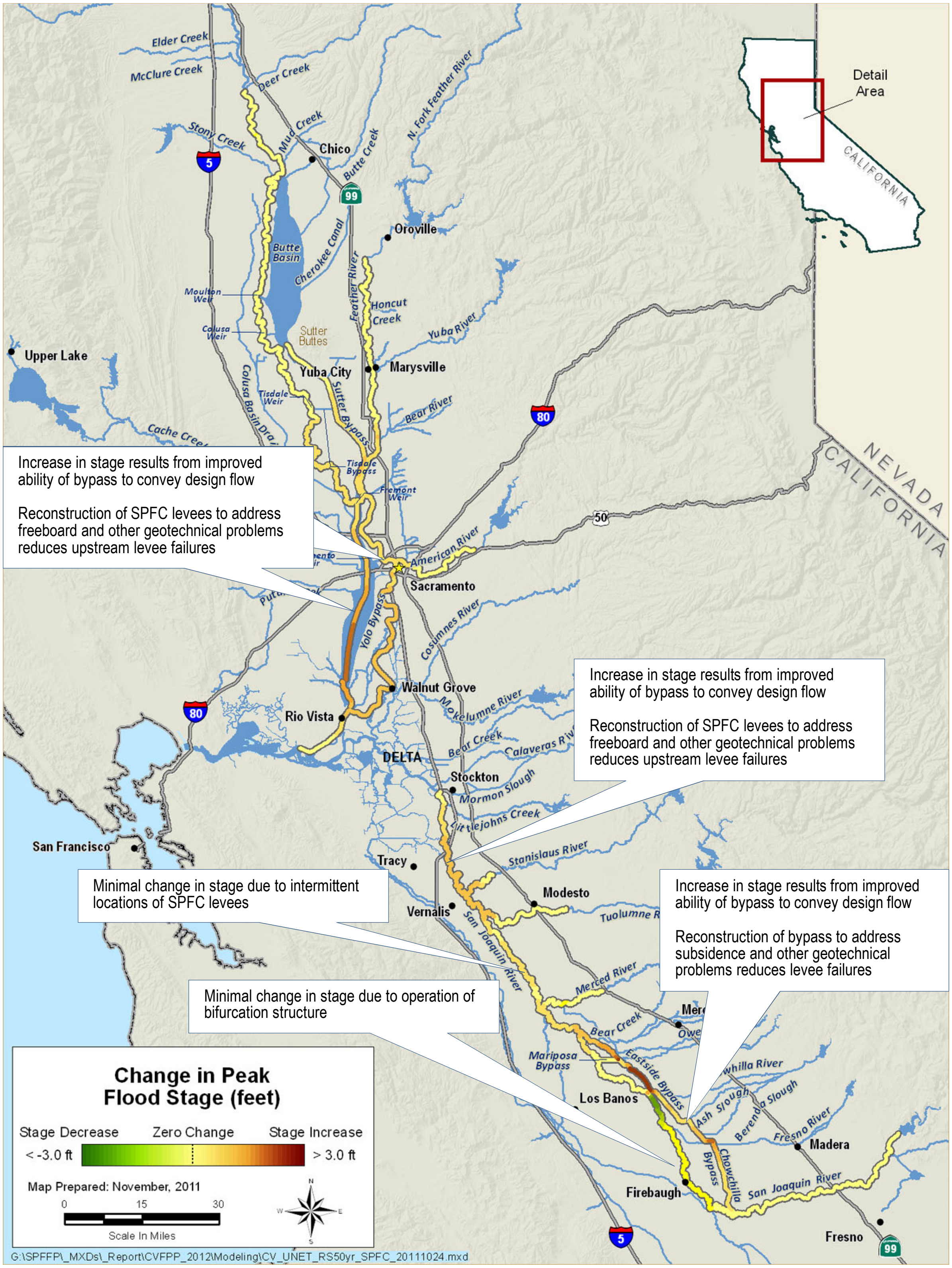

Figure 2-1. Stage Changes from No Project Condition to Achieve SPFC Design Flow Capacity Approach – 2 Percent AEP (50-Year)

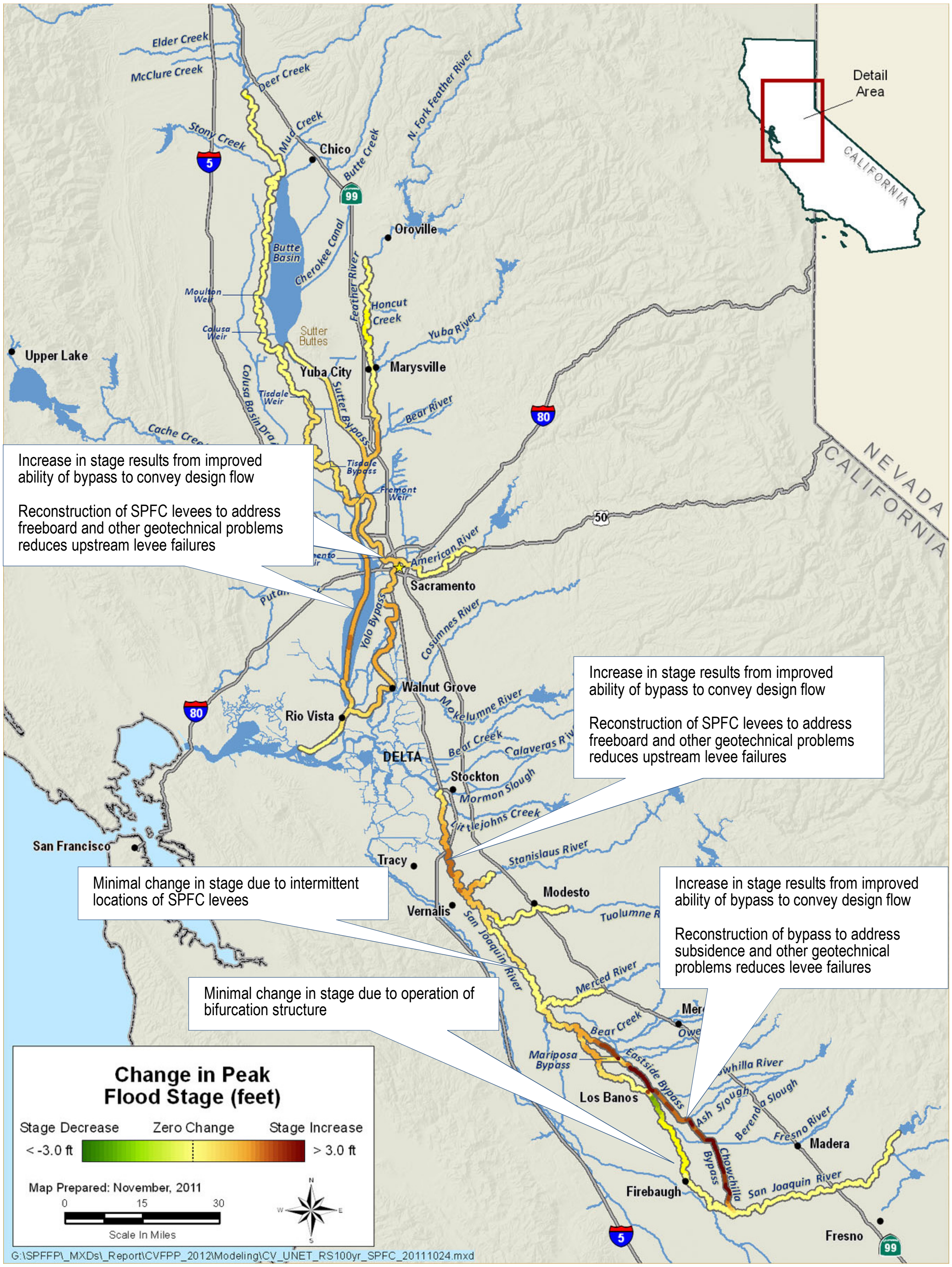

Figure 2-2. Stage Changes from No Project Condition to Achieve SPFC Design Flow Capacity Approach – 1 Percent AEP (100-Year)

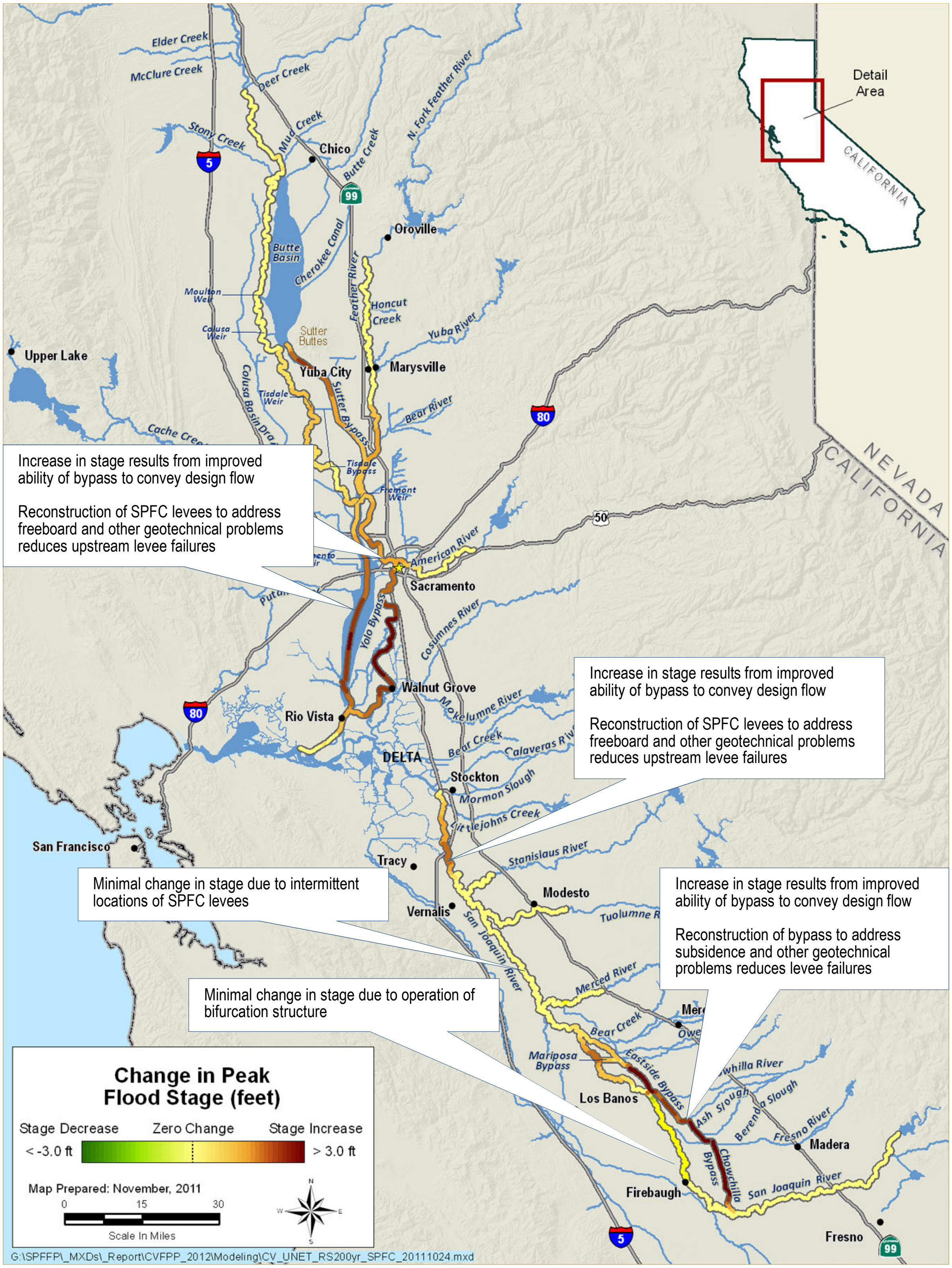

Figure 2-3. Stage Changes from No Project Condition to Achieve SPFC Design Flow Capacity Approach – 0.5 Percent AEP (200-Year)

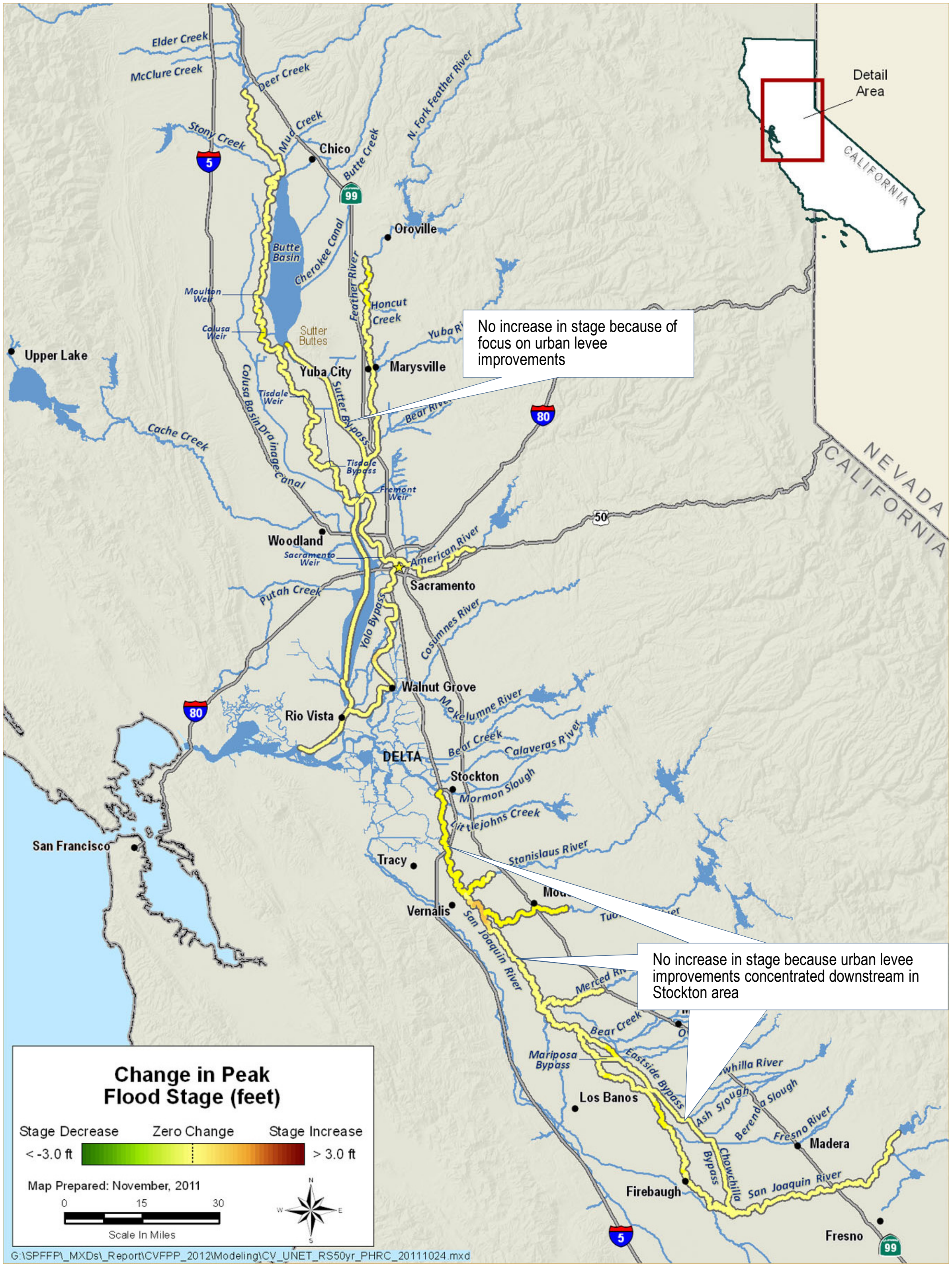

Figure 2-4. Stage Changes from No Project Condition to Protect High Risk Communities Approach – 2 Percent AEP (50-Year)

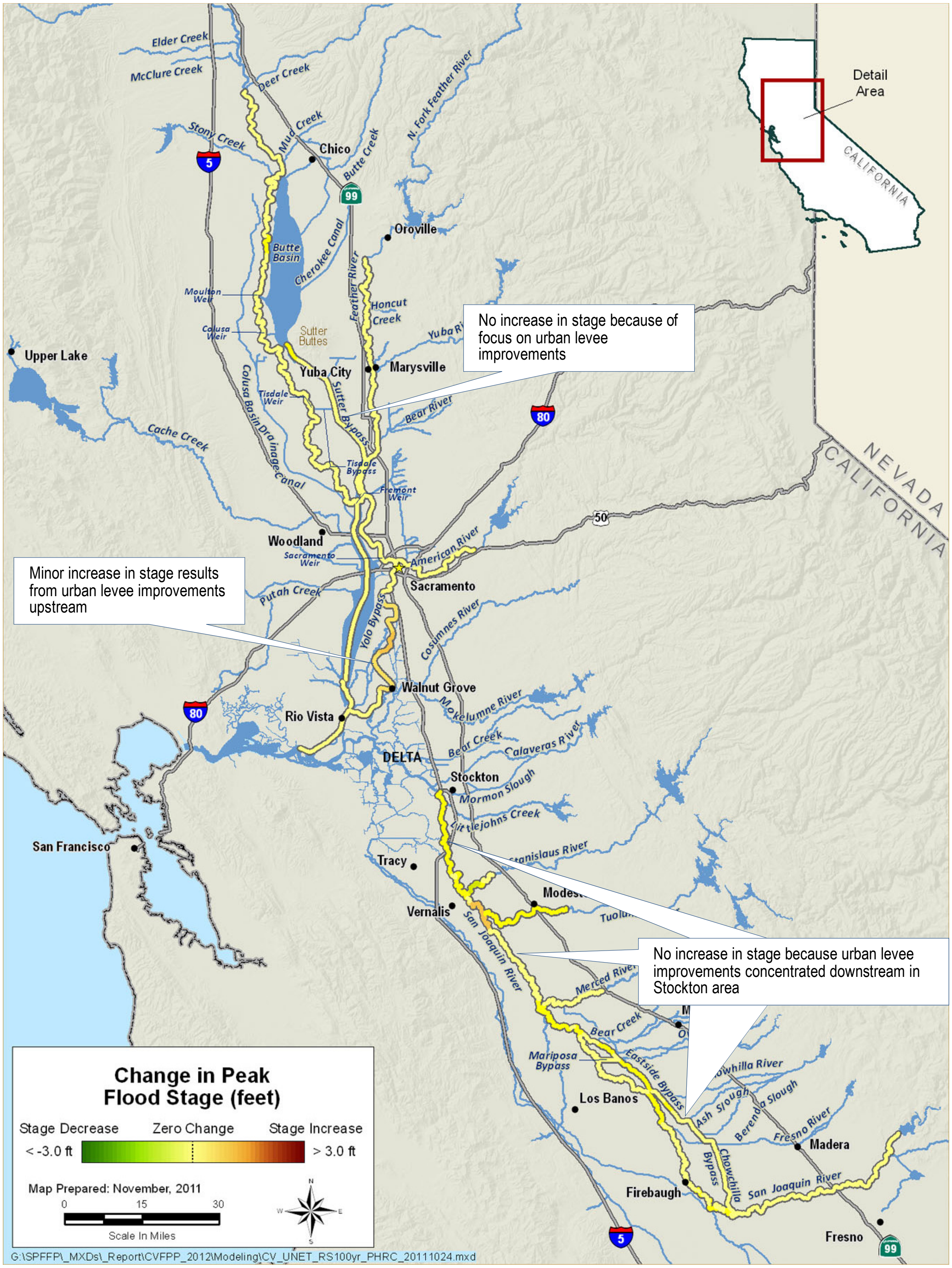

Figure 2-5. Stage Changes from No Project Condition to Protect High Risk Communities Approach – 1 Percent AEP (100-Year)

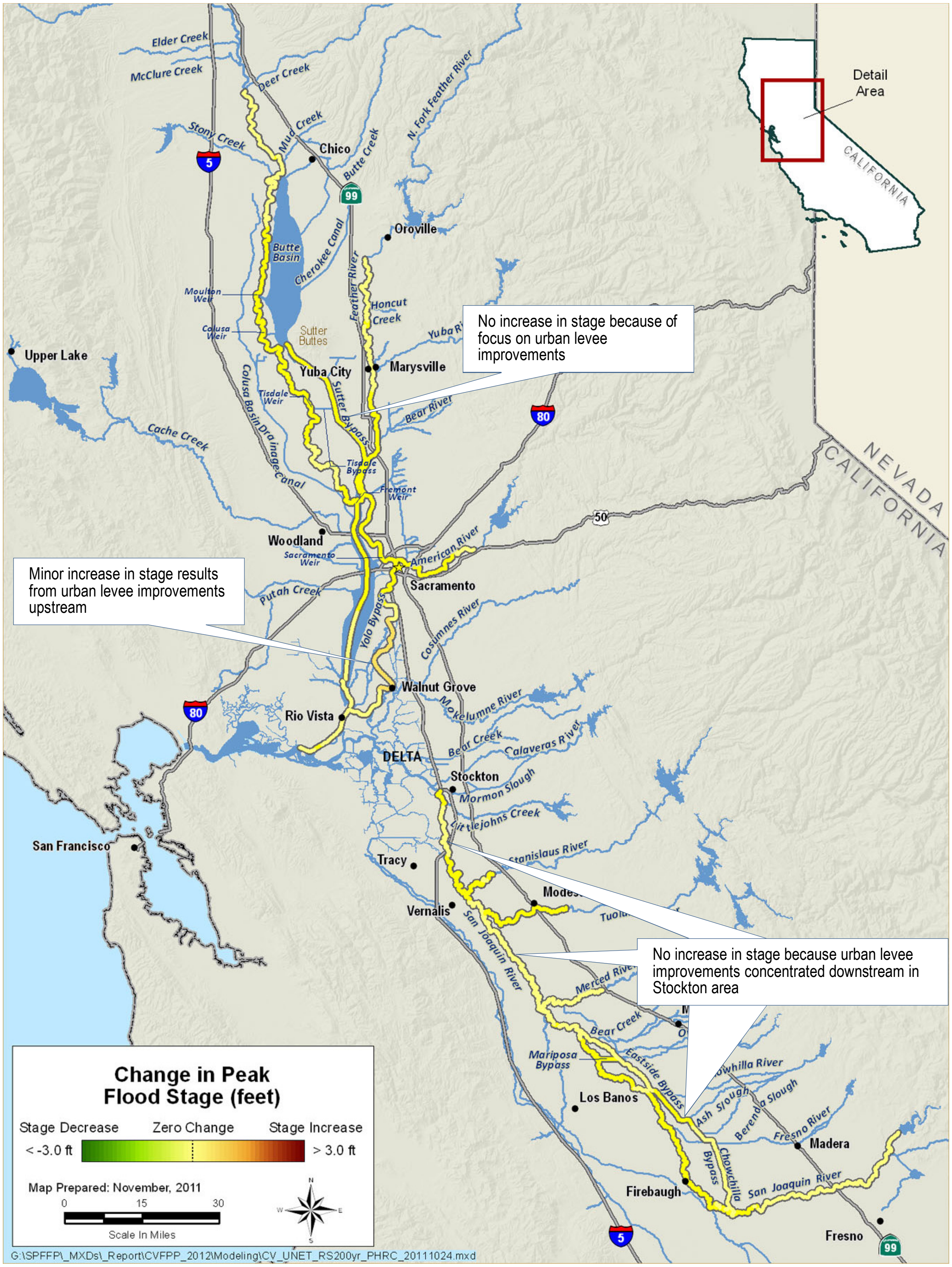

Figure 2-6. Stage Changes from No Project Condition to Protect High Risk Communities Approach – 0.5 Percent AEP (200-Year)

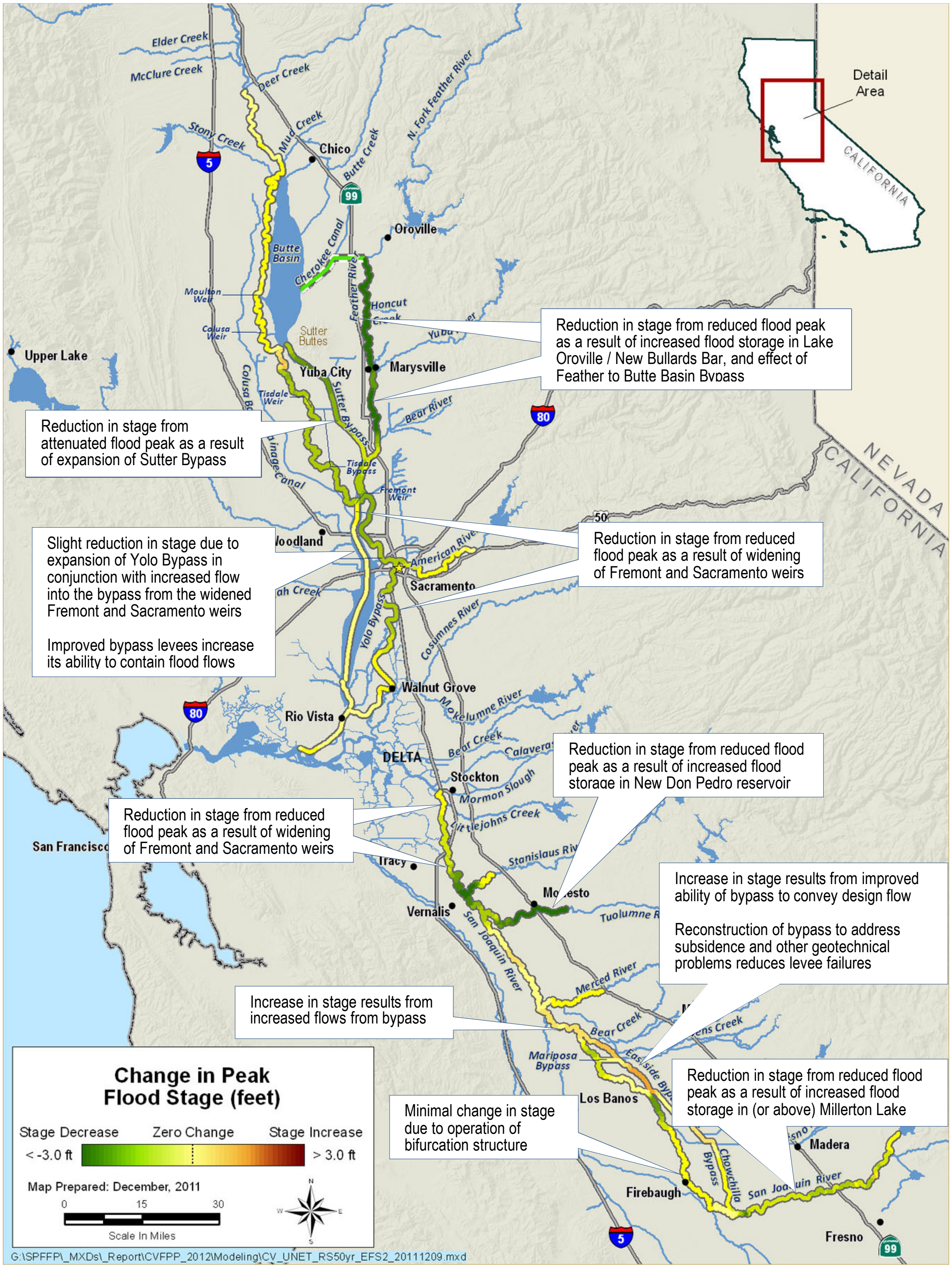

Figure 2-7. Stage Changes from No Project Condition to Enhance Flood System Capacity Approach – 2 percent AEP (50-year)

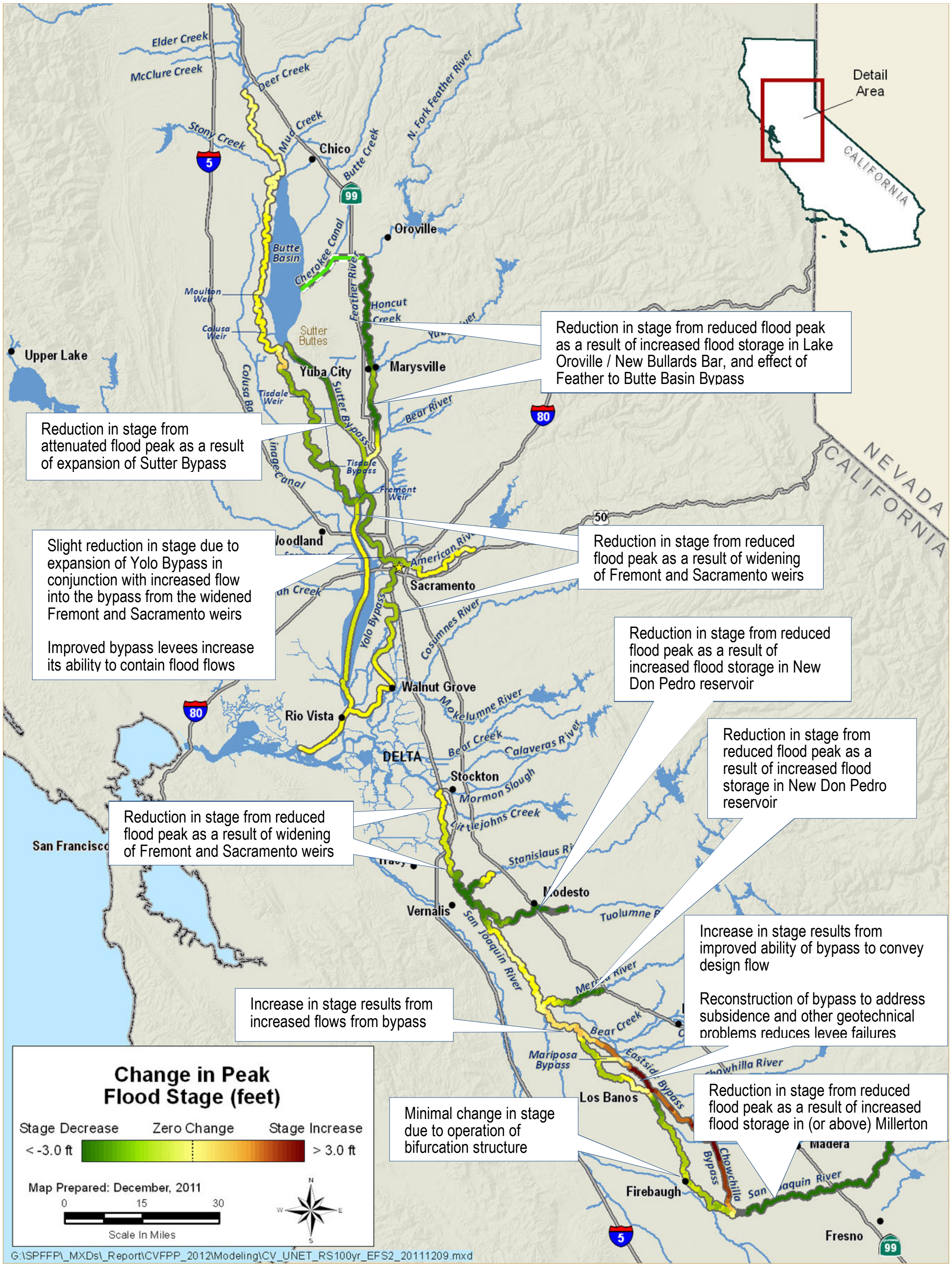

Figure 2-8. Stage Changes from No Project Condition to Enhance Flood System Capacity Approach – 1 Percent AEP (100-Year)

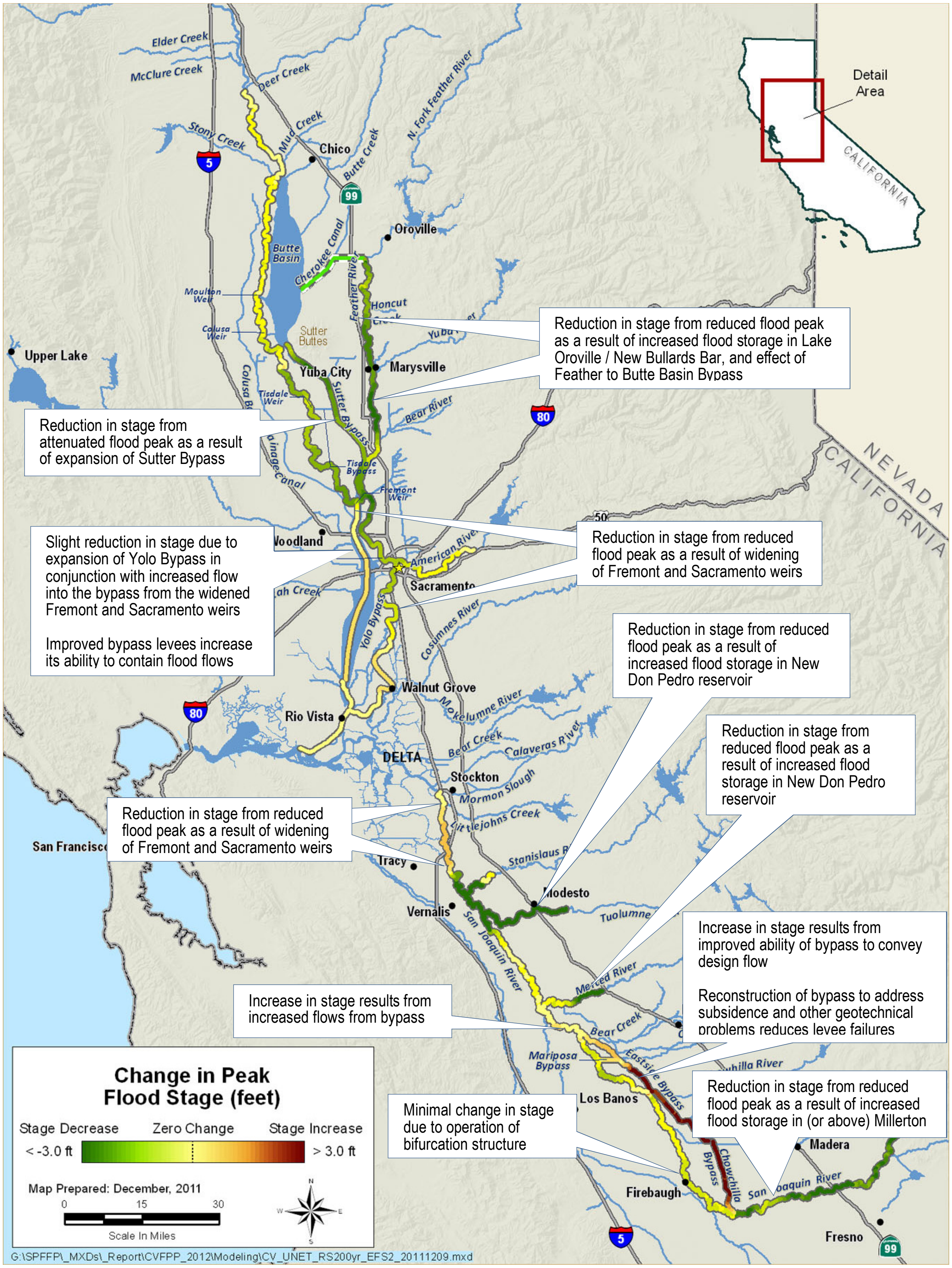

Figure 2-9. Stage Changes from No Project Condition to Enhance Flood System Capacity Approach – 0.5 Percent AEP (200-Year)

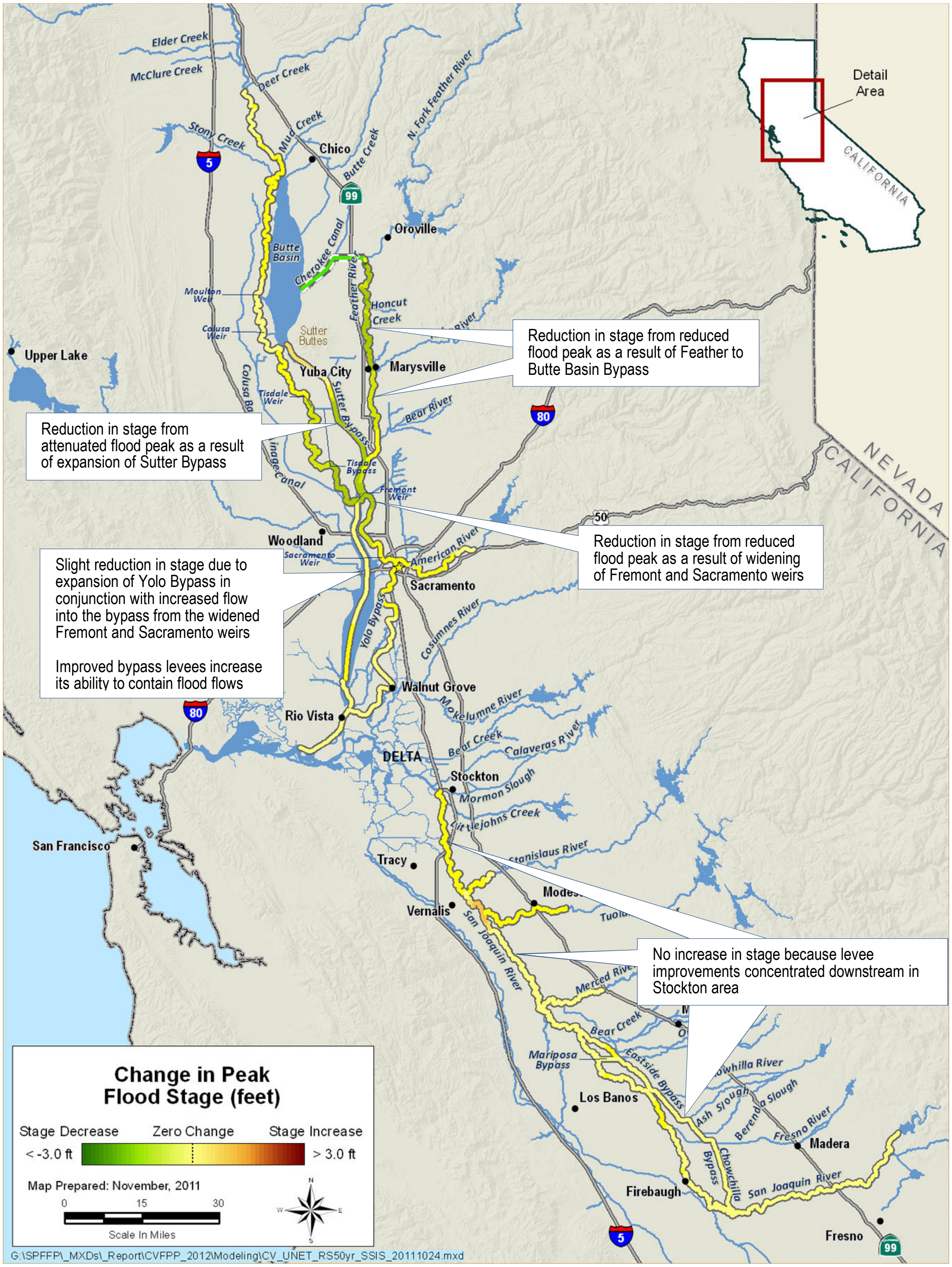

Figure 2-10. Stage Changes from No Project Condition to State Systemwide Investment Approach – 2 Percent AEP (50-Year)

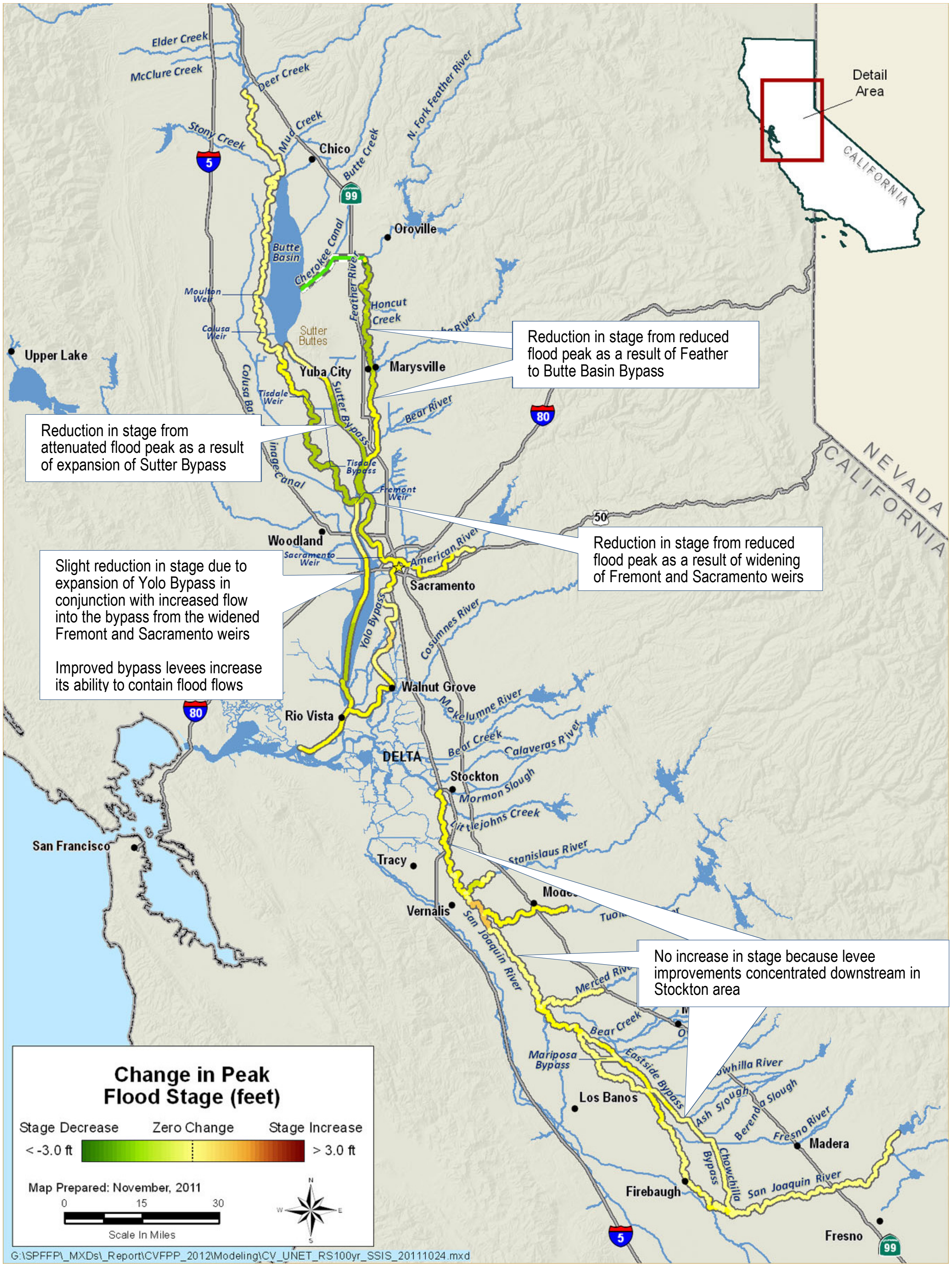

Figure 2-11. Stage Changes from No Project Condition to State Systemwide Investment Approach – 1 Percent AEP (100-Year)

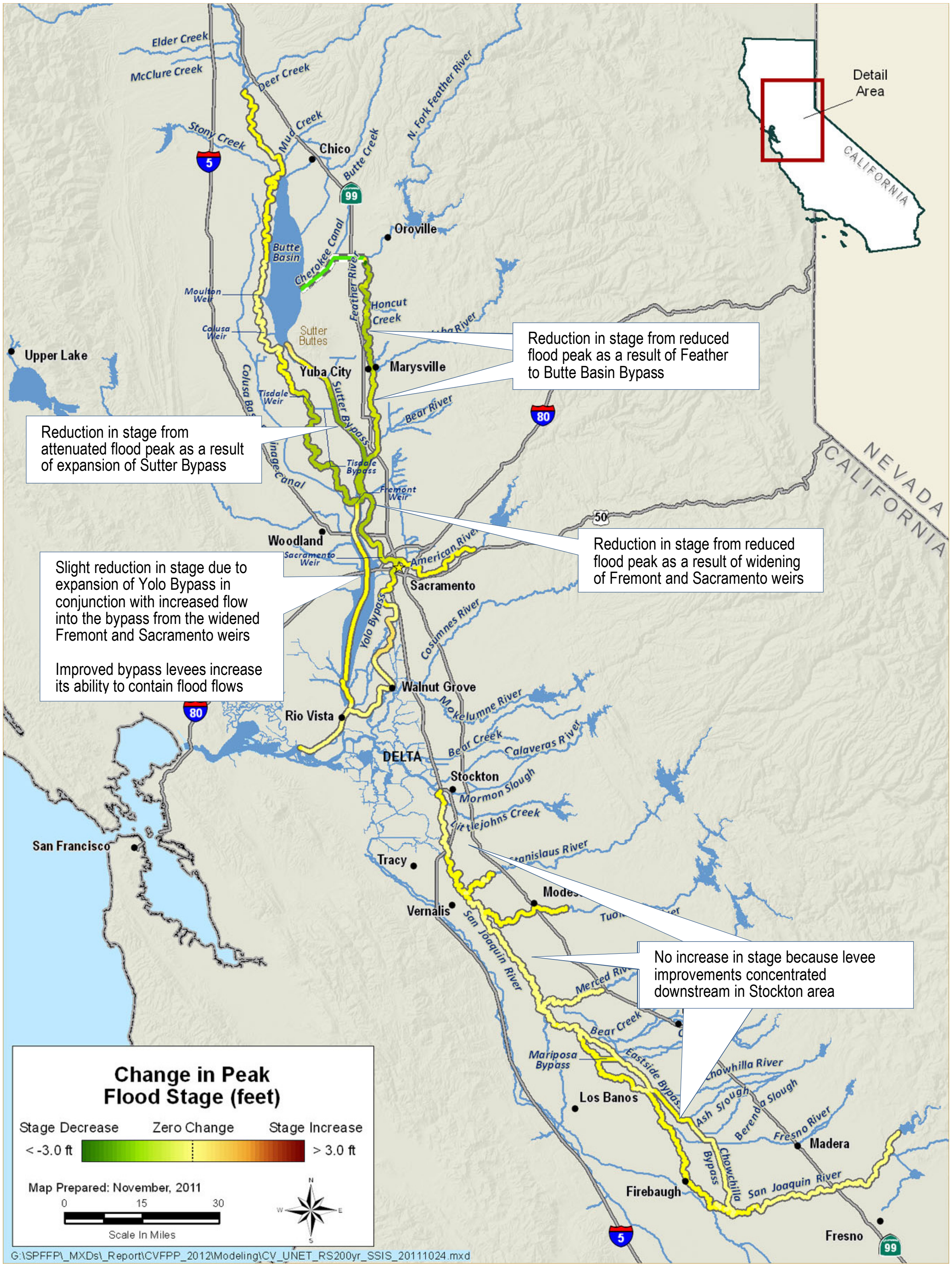

Figure 2-12. Stage Changes from No Project Condition to State Systemwide Investment Approach – 0.5 Percent AEP (200-Year)

3.0 Methodology

This section provides an overview of the 2012 CVFPP riverine modeling framework for the Sacramento and San Joaquin river basins, and discusses model selection, the UNET hydraulic models, levee performance curves, assumptions for the riverine channel evaluation, and modeling assumptions for the No Project condition and each CVFPP approach. Methodology and results for the Stockton area are contained in Section 5.

It is important to note that the hydraulic modeling described below was performed only to support development of the 2012 CVFPP. The modeling is a deterministic process that simulates levee breaches based on data provided regarding levee stability, but it cannot and does not predict the location of actual levee breaches.

3.1 2012 CVFPP Riverine Modeling Overview

Figure 3-1 shows the overall riverine hydraulic modeling schematic for the CVFPP. With defined boundary conditions (including upstream hydrographs to represent storm events, downstream tailwater stage, levee breach scenarios, etc.), riverine hydraulic conditions were simulated to generate hydrographs that would be the upstream boundary conditions for the Delta hydraulic model. The simulated riverine water stages were also used to evaluate flood damage (Attachment 8F: Flood Damage Analysis).

3.2 Model Selection

DWR is developing new riverine hydraulic models through the CVFED Program, but these models were not completed in time to be used for the 2012 CVFPP. Therefore, it was necessary for DWR to use readily available models and data for the CVFPP riverine hydraulic evaluation. Two sets of existing models were considered for the CVFPP riverine hydraulic evaluation: UNET models from the Comprehensive Study[1]

[1] In response to extensive flooding and damage experienced in California in1997, the United States Congress authorized the Sacramento District of the U.S. Army Corps of Engineers (USACE) to provide a comprehensive analysis of the Sacramento and San Joaquin river basin flood management systems and to partner with the State of California to develop master plans for flood management and integrate ecosystem restoration in the Sacramento and San Joaquin river basins (USACE, 2002a).

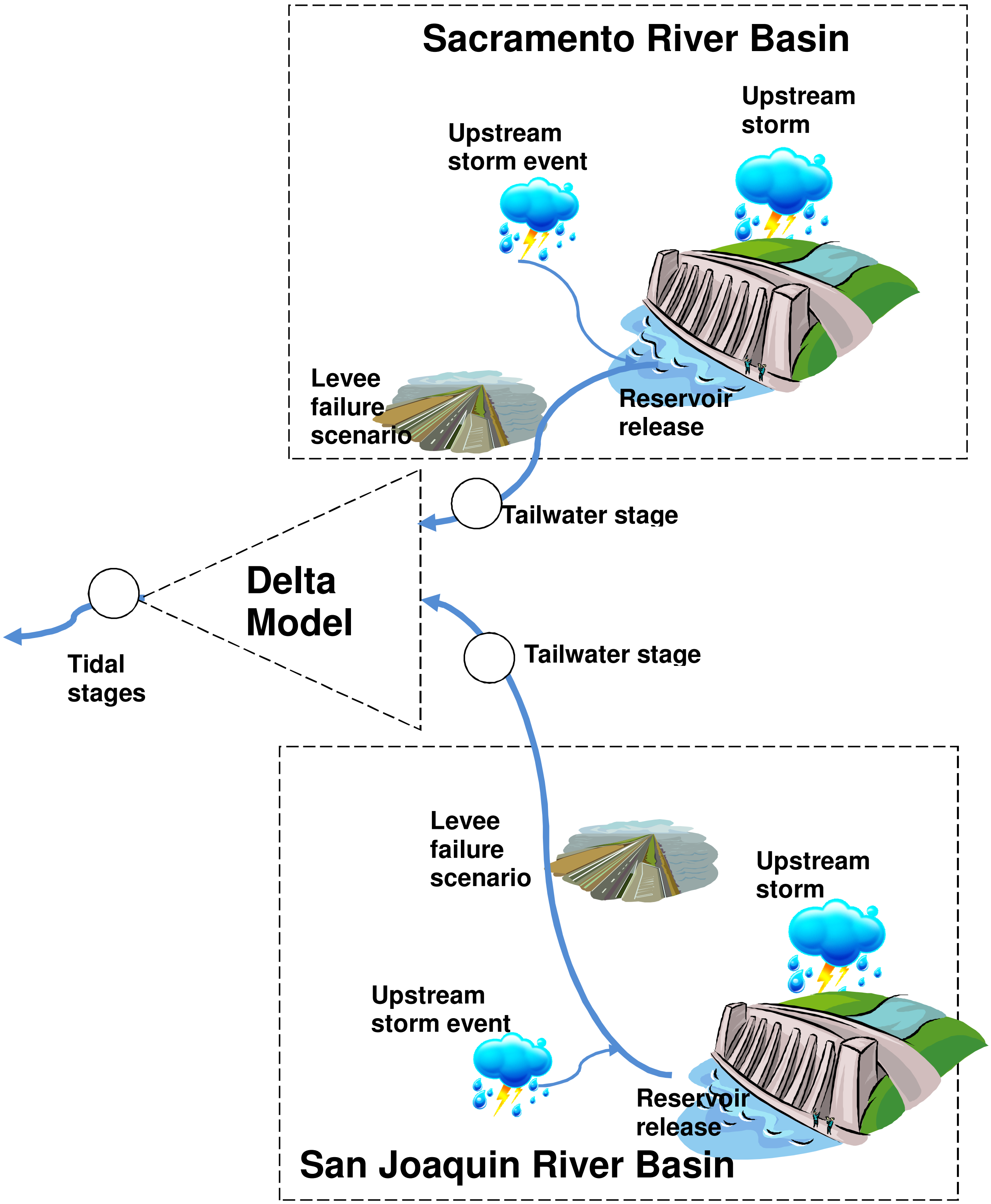

Figure 3-1. Schematic of Central Valley Flood Protection Plan Hydraulic Modeling

(USACE 2002a) and models based on the Hydrologic Engineering Center River Analysis System (HEC-RAS).

3.2.1 Comprehensive Study UNET Models

UNET is a computer model designed to simulate one-dimensional (1-D), fully unsteady flow through a full network of open channels, weirs, bypasses, and storage areas. It is a fixed-bed analysis and does not account for sediment movement, scour, or deposition. UNET assumes no exchange with groundwater and is capable of simulating levee breaks and breaches (USACE, 1997; 2002c).

The authorization for the Comprehensive Study directed the U.S. Army Corps of Engineers (USACE) to develop a UNET application for the Sacramento and San Joaquin river basins to simulate the Sacramento and San Joaquin River Flood Management System and allow basin-wide, systematic evaluation. The August 1998 UNET Version 4.0, with additional modifications made in April 2000, was used for the Comprehensive Study. Separate UNET model data sets were developed for the Sacramento River system and the San Joaquin River system. The Comprehensive Study UNET models incorporated synthetic hydrology floodflows, reservoir operations, and flows in the river systems and major tributaries to evaluate the hydraulic performance of the flood management systems of the two rivers. For a given inflow hydrology, the riverine hydraulic models were used to determine river flow, stage, velocity, and depth, as well as levee breaches and breakout and return flows from overbank areas, allowing the modeler to assess the systemwide performance of a range of flood management modifications under various hydrologic conditions.

3.2.2 HEC-RAS Model

The HEC-RAS software can perform hydraulic calculations for a full network of natural and constructed channels in steady or unsteady mode. The 1-D river analysis components include steady flow, unsteady flow, sediment transport/mobile bed computations, and water quality. (UNET is the predecessor of the unsteady module used in HEC-RAS (USACE, 2010)). Unlike UNET, HEC-RAS has a graphical user interface and advanced capabilities for data input and output.

HEC-RAS has been applied in the Sacramento River Basin through multiple individual evaluations focusing on localized projects, instead of basin-wide effects. The USACE Sacramento District has converted the Comprehensive Study UNET model for the Sacramento River Basin into the HEC-RAS platform (USACE, 2009). The two models (UNET and HEC-RAS) have almost the same study area, except that the HEC-RAS model has no coverage in the Butte Basin, the Sacramento River north of Colusa, Colusa Basin Drain, Natomas Cross and Natomas East Main Drainage canals and tributaries (USACE, 2008).

For the San Joaquin River Basin, the conversion from the Comprehensive Study UNET model into the HEC-RAS platform was completed in February 2010 (DWR, 2009). Results from the San Joaquin HEC-RAS model using Comprehensive Study hydrology, however, were different from the results of the accepted Comprehensive Study UNET model.

3.2.3 Model Selection for 2012 CVFPP

The HEC-RAS and UNET models for the Sacramento and San Joaquin river basins use the same Central Valley hydrology. As previously described, HEC-RAS has more user-friendly functions, such as a graphical user interface, and multiple input and output options that are not available in UNET. However, coverage for the Sacramento River Basin in the existing UNET model is more extensive than in the available HEC-RAS model. Because this more extensive modeling coverage is important to the systemwide planning effort, the Comprehensive Study UNET model for the Sacramento River Basin was selected as the base riverine hydraulic model for 2012 CVFPP hydraulic model development. To be consistent with the Sacramento River Basin, the Comprehensive Study UNET model for the San Joaquin River Basin was also selected to be the base riverine model for 2012 CVFPP development.

3.3 CVFPP UNET Model Overview

The two Comprehensive Study UNET models, one for the Sacramento River Basin and one for the San Joaquin River Basin, provided a means for understanding and representing channel hydraulics in the two river systems for development of the 2012 CVFPP. Modifications were made for the CVFPP application, and these two modified models for the CVFPP are referred to in this attachment as the Sacramento UNET Model and San Joaquin UNET Model.

As described previously, the Sacramento and San Joaquin UNET models were used to determine river stage, velocity, depth, and levee breaches, as well as breakout and return flows from overbank areas for each CVFPP approach. Extensive topographic data were collected and assembled to develop digital river alignments and cross sections by USACE as part of the Comprehensive Study effort. UNET modeling coverage and output data locations for the Sacramento River Basin and the San Joaquin River Basin are shown in Figures 3-2 and 3-3, respectively. Assumptions for all CVFPP approaches are described in detail in the following sections.

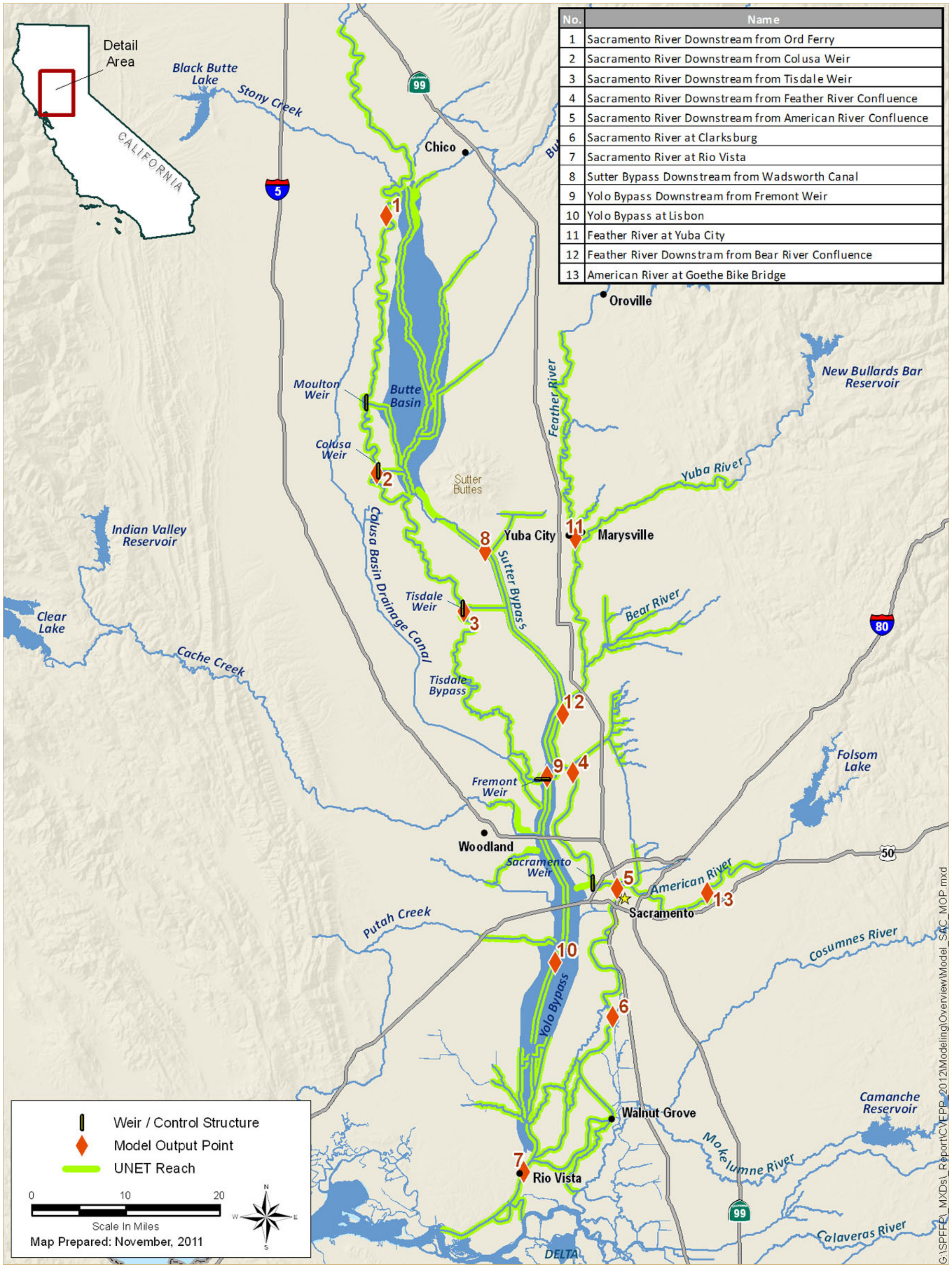

Figure 3-2. UNET Coverage in Sacramento River Basin

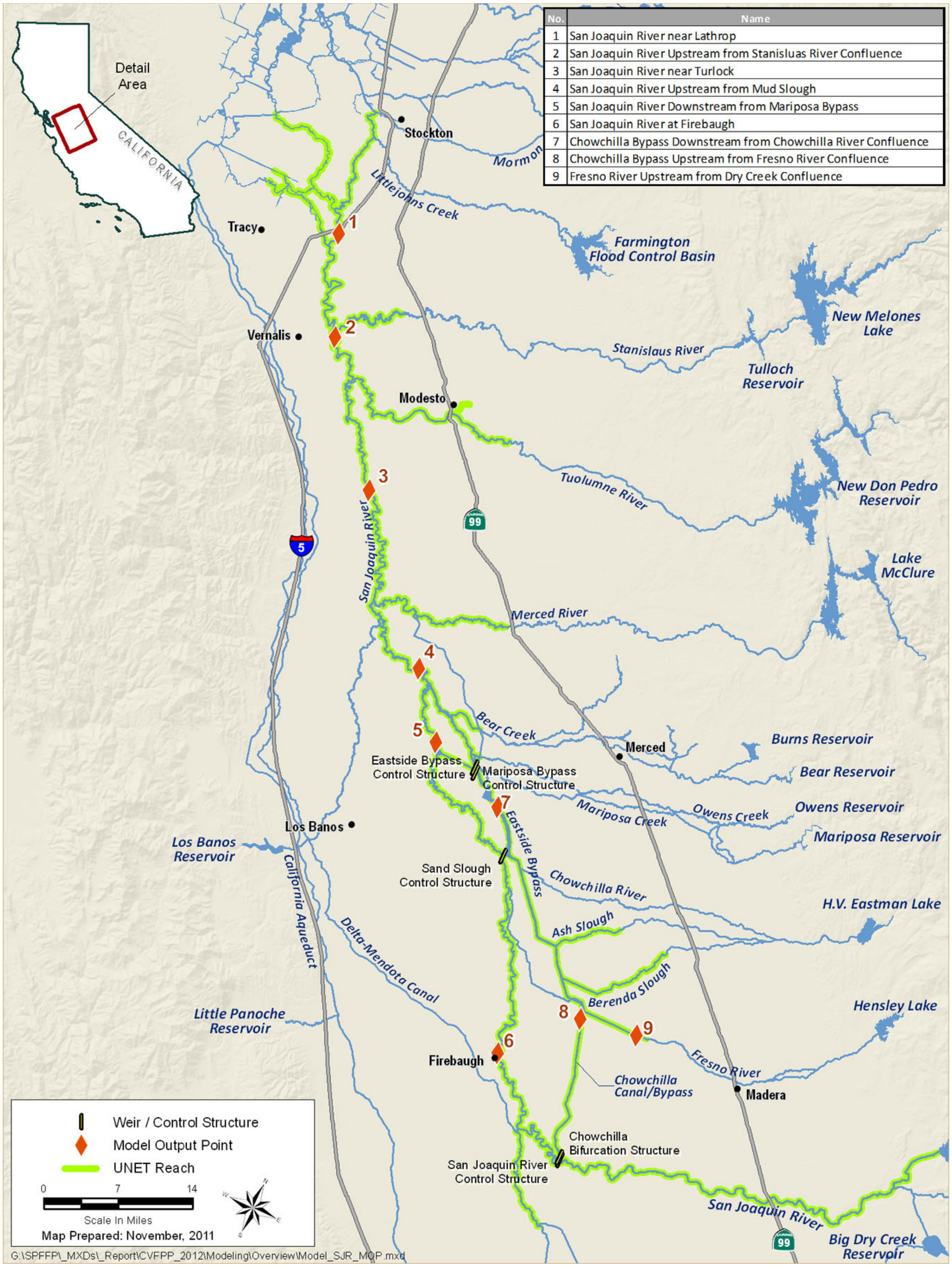

Figure 3-3. UNET Coverage in San Joaquin River Basin

3.4 Levee Performance Curves for CVFPP

The Urban Levee Evaluations (ULE) Project and the Non-Urban Levee Evaluations (NULE) Project under the DWR Levee Evaluations Program developed performance curves for levees in the Sacramento River and San Joaquin River basins. Levee performance curves provide geotechnical relationships between river stage and the probability that a levee segment will breach (water from the water side of the levee flows in an uncontrolled manner to the landside of the levee) at that stage. Details on levee performance curve development are contained in Attachment 8E: System/Levee Performance.

Levee performance curves from ULE and NULE were used to identify two water surface elevations of interest for the hydraulic analyses. These water surface elevations, and the corresponding probability of levee failure at a particular levee location are as follows:

- **Probable failure point (PFP)** – 85 percent probability of failure
- **Top of levee (TOL)** – 100 percent probability of failure

These two water surface elevations were incorporated into UNET models to simulate conditional levee failure, meaning that once the simulated river stage at a specific levee location reaches the specified breach elevation (PFP or TOL depending on the CVFPP approach being modeled), a levee breach would begin to develop in UNET. Water from the river would then enter into the adjacent floodplain through the levee breach, and the downstream river stage and flow would be reduced. Because the PFP is always lower than the top of the levee, the breach would begin to form at below the TOL. On the other hand, if a TOL breach elevation is used in the simulation, the water surface elevation and flow would be higher than with the PFP before the levee breach, because the TOL is always higher than the PFP.

The water surface elevations of interest described above are not intended to represent or predict how levees would fail under an actual flood event. For example, under the PFP scenario, all levees assigned a PFP would fail in a simulated flood event once the water surface was equal to or higher than the PFP elevation. In reality, many of these levees would not fail even when the stage exceeds the PFP elevations, while others might fail before the stage reaches the PFP elevations. Further, floodfighting and other emergency actions (conditions that are not simulated in the hydraulic models) could result in very different levee failure probabilities.

In addition to simulating the PFP and TOL scenarios, model simulations were also conducted that considered very tall levees along the river channels. These "infinite levee" simulations helped determine the maximum possible floodflows at various locations in the Sacramento and San Joaquin river flood management system.

3.5 Model Assumptions: No Project

Tables 3-1 and 3-2 show modeling assumptions for the Sacramento and San Joaquin river basins, respectively, for the No Project condition and each of the CVFPP approaches. The following sections describe assumptions for the Sacramento and San Joaquin UNET models for the No Project condition.

3.5.1 Sacramento UNET Model

Simulation Period

The simulation period for the Sacramento UNET model is from 9:00 a.m., January 6, to 9:00 a.m., January 29. Peak flows for all flood events occur in the simulation between January 18 and 20.

Upstream Boundary Conditions

Upstream boundary conditions for the Sacramento River UNET model are flow hydrographs (i.e., discharge in cfs over time) for each particular flood at the upstream boundary of all reaches that are not connected to another reach at their upstream end.

Each set of hydrographs represents either unregulated flows (no reservoir upstream) or regulated flows (reservoir releases simulated by reservoir models) under different storm centerings. A centering is a set of synthetic floods for a range of AEP that would result in peak flows at a given location (see Attachment 8A: Hydrology for details). The CVFPP followed the composite floodplain methodology used in the Comprehensive Study (USACE, 2002b) to define the maximum extent of inundation at all locations for a flood of any given AEP. As described in Attachment 8A: Hydrology, five storm centerings were used for the Sacramento River Basin: three mainstem centerings (Ord Ferry, Sacramento, and Shasta) and two tributary centerings (Yuba River, and American River). Each storm center had six flood events, with AEPs of 10, 4, 2, 1, 0.5, and 0.2 percent, corresponding to 10-, 25-, 50-, 100-, 200-, and 500-year return periods.

Table 3-1. Summary of Sacramento River Basin Modeling Assumptions

Element	Description	No Project (NPRJ)	Achieve SPFC Design Flow Capacity (SPFC)	Protect High Risk Communities (PHRC)	Enhance Flood System Capacity (EFSC)	State Systemwide Investment (SSIA)
Levee Setback	Sacramento River RM 199.5 to 197				√	
	Sacramento River RM 169.5 to 111.25				√	
	Feather River RM 24.5 to 0				√	
Levee Improvement	Restore 1955/1957 design levee: Assume levee breach at top of levee in hydraulic model		√		√	
	Fix urban area levee: Assume levee breach at top of levee in hydraulic model			√	√	√
	TRLIA levee improvement	√	√	√	√	√
	Marysville levee improvement	√	√	√	√	√
	Natomas levee improvement	√	√	√	√	√
Bypass	Widen Yolo Bypass[1] & lengthen Fremont Weir				√	√
	Widen Sacramento Bypass and Gates				√	
	Widen Sutter Bypass				√	√
	Feather to Butte Basin (Biggs) Bypass				√	√
Reservoir Storage and Operations	Folsom Dam Joint Federal Project	√	√	√	√	√
	Lake Oroville: Modify Lake Oroville release schedule				√	
	New Bullards Bar and Lake Oroville: Implement coordinated operation of the Feather-Yuba River Basin	√	√	√	√	√
Floodplain Storage	Sutter Butte Basin				√	
	Feather River Basin				√	
	Elkhorn				√	
	Merritt Island				√	

Notes:
55/57 levee design profile was the design standard for the State Plan of Flood Control.
[1] Use off-stream storage to model levee setback.

Key:
EFSC = Enhance Flood System Capacity Approach
NPRJ = No project
PHRC = Protect High Risk Communities Approach
RM = River Mile
SPFC = State Plan of Flood Control
SSIA = State Systemwide Investment Approach
TRLIA = Three Rivers Levee Improvement Authority

Table 3-2. Summary of San Joaquin River Basin Modeling Assumptions

Element	Description	No Project (NPRJ)	Achieve SPFC Design Flow Capacity (SPFC)	Protect High Risk Communities (PHRC)	Enhance Flood System Capacity (EFSC)	State Systemwide Investment (SSIA)
Levee Setback	SJR RM115 to 99				√	
	SJR RM 81.5 to 72.5				√	
Levee Improvement	Restore 55/57 levee design profile: Assume levees breach at top of levee in hydraulic model		√		√	
	Fix urban area levees: Assume levees breach at top of levee in hydraulic model			√	√	√
	Restore bypass levees: Assume levees breach at top of levee in hydraulic model		√		√	
Bypass	Widen Paradise Cut				√	√
Reservoir Storage and Operations	New Don Pedro Reservoir: Increase flood storage allocation by 230,000 acre-feet				√	
	Friant Dam and Millerton Lake: Increase flood storage allocation by 60,000 acre-feet				√	
	New Exchequer Dam and Lake: Increase flood storage allocation by 100,000 acre-feet				√	
Floodplain Storage	Roberts Island				√	
	San Joaquin River: between Merced and Tuolumne rivers				√	
	San Joaquin River: between Tuolumne River and Stanislaus River				√	

Note:
55/57 levee design profile was the design standard for the State Plan of Flood Control

Key:
EFSC = Enhance Flood System Capacity Approach
NPRJ = No project
PHRC = Protect High Risk Communities Approach
RM = river mile
SJR = San Joaquin River
SPFC = State Plan of Flood Control
SSIA = State Systemwide Investment Approach
TRLIA = Three Rivers Levee Improvement Authority

Frequent flows, with an AEP of greater than 10 percent (e.g., return period less than 10-year), were not modeled because the Sacramento River flood management systems can handle at a minimum floods that have AEPs of 4 percent or greater (25-year or less return period). Therefore, it is anticipated that storms with greater than a 10 percent AEP would not cause serious economic impacts.

Interior Boundary Conditions

Interior boundary conditions define the connections between stream reaches, as well as between stream reaches and other parts of the model. The UNET model uses flow and stage continuity to control normal reach connections. Extensive topographic data were collected and incorporated during Comprehensive Study model development to represent river channel alignment, cross sections, and bridge geometries in the UNET model (USACE, 2002c). During the model development process for the 2012 CVFPP, updates were made to cross sections in the Tisdale and Yolo bypasses to reflect excavation work completed on those two areas after the Comprehensive Study (DWR, 2006a and 2006b).

Downstream Boundary Conditions

To function properly, a hydraulic model of a river system must define the water surface elevation at the downstream end of all model reaches not connected to another reach or river. Downstream boundary conditions are usually in the form of tailwater stage hydrographs that describe the variation of the downstream water surface elevation over time.

The downstream boundaries for the Sacramento River hydraulic model are in the Delta, and, as a result, represent tailwater conditions under tidal and estuary influences. Tailwater hydrographs for the Sacramento River hydraulic model include the Sacramento River at Collinsville and the downstream ends of Three-Mile and Georgiana sloughs. The tailwater hydrographs were developed from information gathered at tide gages during the 1997 flood, which represents conservative or high tailwater conditions.

Internal Boundary Conditions

As mentioned, interior boundary conditions define the connections between stream reaches, and between stream reaches and other parts of the model. Internal boundary conditions, however, are placed in the model to represent levee failure scenarios or storage interactions, spillways or weir overflow/diversion structures, bridge or culvert hydraulics, or pumped diversions.

Operation rules for weirs are embedded in the model. For example, the Colusa Weir was modeled as an uncontrolled lateral spillway 1,736 feet long that begins spilling at a river elevation of 58.89 feet. As another example, the Sacramento Weir was modeled as a controlled lateral spillway. All 48 gates on the weir were modeled in groups of 8. Each group of eight gates is 300 feet wide and was explicitly named so that it can be referenced in the boundary conditions for a time series of gate openings.

Levee Breach Modeling

The Sacramento UNET model, for the No Project condition, simulates levee breaches using the simple levee failure option; once the water surface elevation at a levee breach location reaches the PFP elevation, the levee breaches and allows water to flow from the channel to the attached storage (floodplain) area, consequently reducing the stage at the breach and the flow downstream in the channel. Levee breach locations and elevations were from levee performance curves developed from data from the ULE and NULE projects.

The simple levee failure option used in the Sacramento UNET model applies a simple storage connection concept in which the flow through a breach is computed by multiplying the volume of available storage by a coefficient. Because information on the size and evolution of breaches in levee systems is limited, and detailed levee breach information is often not available, modeling of embankment failures is not practical. The UNET simple linear storage algorithm acknowledges this lack of data and applies a simple concept for filling a storage area behind a levee. Flow into the storage area behind the levee is assumed to be proportional to the available storage (i.e., flow through a breach is greatest at the start of the levee breach and decreases as the leveed area fills). This procedure also has a computational advantage in that it is stable and would function with larger time steps.

3.5.2 San Joaquin UNET Model

Simulation Period

The simulation period of the San Joaquin River Basin UNET model is from 10:00 a.m., January 15, through 12 a.m., February 3. Peak flows for all flood events occur in the simulation between January 18 and 20.

Upstream Boundary Conditions

Upstream boundary conditions for the San Joaquin River UNET model are flow hydrographs (i.e., discharge in cfs over time) for each particular flood at the upstream boundary of all reaches that are not connected to another reach at their upstream end.

The use of regulated and unregulated hydrographs in the San Joaquin River UNET model are the same as described for the Sacramento River UNET model in Section 3.5.1. As described in Attachment 8A: Hydrology, upstream boundary conditions for the San Joaquin River Basin are hydrographs from five storm centerings: three mainstem centerings (El Nido, Newman, and Vernalis) and two tributary centerings (Friant Dam and Merced River). Each storm centering had six flood events, with AEPs of 10, 4, 2, 1, 0.5, and 0.2 percent, corresponding to 10-, 25-, 50-, 100-, 200-, and 500-year return periods.

Frequent flows with an AEP of greater than 10 percent (e.g., return period less than 10-year) were not modeled because the San Joaquin River flood management system can handle at a minimum flood events that have AEPs of 10 percent or greater (10-year or less return period). Therefore, it is anticipated that storms with greater than a 10 percent AEP (e.g., return period of less than 10-years) would not cause serious economic impacts.

Interior Boundary Conditions

Interior boundary conditions define the connections between stream reaches, as well as between stream reaches and other parts of the model. The UNET model uses flow and stage continuity to control normal reach connections. Extensive topographic data were collected and incorporated during Comprehensive Study model development to represent river channel alignment, cross sections, and bridge geometries in the UNET Model (USACE, 2002c).

Downstream Boundary Conditions

The downstream boundaries for the San Joaquin River hydraulic model are in the Delta, and, as a result, represent tailwater conditions under tidal and estuary influences. The four tailwater hydrographs for the San Joaquin River are (1) Grant Line Canal at Tracy Boulevard, (2) Middle River at Highway 4, (3) Old River at Tracy Boulevard, and (4) the San Joaquin River at the Stockton Deep Water Ship channel. The tailwater hydrographs were developed from information gathered at tide gages during the 1997 flood, which represents conservative or high tailwater conditions.

Internal Boundary Conditions

Operation rules for weirs are embedded in the model. For example, the bifurcation/diversion structure from the San Joaquin River to the Eastside/Chowchilla Bypass was modeled to control the upstream water surface in the San Joaquin River to an elevation of 172.5 feet NGVD29 using a rating table that divides the flows between the San Joaquin River and the Eastside/Chowchilla Bypass. The model also assumes that 12,500 cfs is the largest flow that would reach the bifurcation structure because higher flows would cause upstream levee breaches. The bifurcation/

diversion structure from the Eastside/Chowchilla Bypass to the Mariposa Bypass and Deep Slough was modeled in the same manner, with the upstream pool elevation held to an elevation of 97 feet NGVD29 and flows divided between the Mariposa Bypass and Deep Slough. Flows in excess of 30,000 cfs were assumed to overtop the control structure and surrounding levees.

Levee Breach Modeling

Similar to the Sacramento River Basin, the San Joaquin River Basin UNET model, for the No Project condition, uses the simple levee failure option to simulate levee breaches when water surface elevation at a specific levee breach location reaches the PFP elevation. Levee breach locations and elevations were from levee performance curves developed from data from the ULE and NULE projects.

3.6 Model Assumptions: Achieve SPFC Design Flow Capacity Approach

This approach focuses on improving existing SPFC facilities so that they can convey their design flows with a high degree of reliability based on current engineering criteria. Levee improvements would be made to SPFC levees regardless of the areas they protect.

Tables 3-1 and 3-2 show modeling assumptions for the Sacramento and San Joaquin river basins, respectively, for the No Project condition and each of the CVFPP approaches. The following sections describe specific assumptions for the Sacramento and San Joaquin UNET models for the Achieve SPFC Design Flow Capacity Approach.

3.6.1 Sacramento UNET Model

Upstream, Downstream, Interior, and Internal Boundary Conditions

Upstream, downstream, interior, and internal boundary conditions were unchanged from the No Project condition.

Levee Breach Modeling

For the Achieve SPFC Design Flow Capacity Approach, the breach elevation at each levee breach point on an SPFC levee was set to be the 55/57 design profile (the design standard for construction of the State Plan of Flood Control) plus freeboard (3 feet), or the existing TOL elevation as determined by the ULE and NULE projects, whichever was greater. This means repairing or reconstructing all SPFC levees to their design TOL, or the existing TOL, whichever is greater. For the purposes of hydraulic modeling on a systemwide scale, a reconstructed levee is assumed to have zero probability of failure until it is overtopped.

3.6.2 San Joaquin UNET Model

Upstream, Downstream, Interior, and Internal Boundary Conditions

Upstream, downstream, interior, and internal boundary conditions were unchanged from the No Project condition.

Levee Breach Modeling

For the Achieve SPFC Design Flow Capacity Approach, the breach elevation at each levee breach point on an SPFC levee was set to be the 55/57 design profile plus freeboard (3 feet), or the existing TOL elevation as determined by the ULE and NULE projects, whichever is greater. This means repairing or reconstructing all SPFC levees to their design TOL, or the existing TOL, whichever is greater. For the purposes of hydraulic modeling on a systemwide scale, a reconstructed levee is assumed to have zero probability of failure until it is overtopped.

3.7 Model Assumptions: Protect High Risk Communities Approach

This approach evaluates improvements to levees to protect life, safety, and property for high risk population centers, including urban and small communities. Levees in rural-agricultural areas would remain in their existing configurations.

Tables 3-1 and 3-2 show modeling assumptions for the Sacramento and San Joaquin river basins, respectively, for the No Project condition and each of the CVFPP approaches. The following sections describe specific assumptions for the Sacramento UNET Model and San Joaquin UNET Model for the Protect High Risk Communities Approach.

3.7.1 Sacramento UNET Model

Upstream, Downstream, Interior, and Internal Boundary Conditions

Upstream, downstream, interior, and internal boundary conditions were unchanged from No Project.

Levee Breach Modeling

For the Protect High Risk Communities Approach, breach elevations for all levees were the same as for the No Project condition, except levees in urban areas, where the elevations of the levees were raised to a design water surface elevation that would pass a flood with a 0.5 percent AEP

(200-year), with 3 feet of freeboard. The breach elevations for all levees that were modified as part of this approach were set to the TOL, meaning that for the purposes of hydraulic modeling on a systemwide scale, the probability of levee failure is zero until the levee is overtopped. If an existing urban levee had a TOL that was already higher than the 0.5 percent AEP design water surface plus freeboard, the TOL was left as existing, and the breach elevation was set to the TOL.

3.7.2 San Joaquin UNET Model

Upstream, Downstream, Interior, and Internal Boundary Conditions

Upstream, downstream, interior, and internal boundary conditions were unchanged from No Project.

Levee Breach Modeling

For the Protect High Risk Communities Approach, breach elevations for all levees were the same as for the No Project condition, except levees in urban areas, where the elevations of the levees were raised to a design water surface elevation that would pass a flood with a 0.5 percent AEP (200-year), with 3 feet of freeboard. The breach elevations for all levees that were modified as part of this approach were set to the TOL, meaning that for the purposes of hydraulic modeling on a systemwide scale, the probability of levee failure is zero until the levee is overtopped. If an existing urban levee had a TOL that was already higher than the 0.5 percent AEP design water surface plus freeboard, the TOL was left as existing, and the breach elevation was set to the TOL.

3.8 Model Assumptions: Enchance Flood System Capacity Approach

This approach evaluates opportunities to achieve multiple benefits through enhanced flood system storage and conveyance capacity, to protect high risk communities, and to fix levees in place in rural-agricultural areas. This approach combines the features of the above two approaches and provides more room within flood conveyance channels to lower flood stages throughout most of the system, with additional features and functions for ecosystem restoration and enhancements.

Tables 3-1 and 3-2 show modeling assumptions for the Sacramento and San Joaquin river basins, respectively, for the No Project condition and each of the CVFPP approaches. The following sections describe specific assumptions for the Sacramento and San Joaquin UNET models for the Enhance Flood System Capacity Approach.

3.8.1 Sacramento UNET Model

Upstream, Downstream, and Interior Boundary Conditions

Upstream boundary conditions were modified to include reservoir operation criteria modifications at Oroville Dam and New Bullards Bar Dam as described in Attachment 8B: Reservoir Analysis. Downstream and interior boundary conditions were unchanged from the No Project condition.

Levee Breach Modeling

For the Enhance Flood System Capacity Approach, the breach elevation at each levee breach point on a nonurban SPFC levee was set to be the 55/57 design profile (the design standard for construction of the State Plan of Flood Control) plus freeboard (3 feet), or the existing TOL elevation as determined by the ULE and NULE projects, whichever was greater. This means repairing or reconstructing all nonurban SPFC levees to their design TOL, or the existing TOL, whichever is greater.

Levee breach elevations of urban levees were raised to a design water surface elevation that would pass a flood with a 0.5 percent AEP (200-year), with 3 feet of freeboard or the 55/57 design profile with 3 feet of freeboard, whichever was greater. The breach elevations for urban levees were set to the TOL, meaning that for the purposes of hydraulic modeling on a systemwide scale, the probability of levee failure is zero until the levee is overtopped. If an existing urban levee had a TOL that was already higher than the 0.5 percent AEP design water surface plus freeboard, the TOL was left as existing, and the breach elevation was set to the TOL.

The breach elevations for levees on both sides of the channel in reaches where levees were setback were set to the TOL, representing the new setback levees and modifications to the existing levees. A reconstructed levee is assumed to have zero probability of failure until it is overtopped.

Internal Boundary Conditions

Internal boundary conditions were modified to include floodplain storage on easements, as described in Table 3-1. Storage areas were also used in the Yolo Bypass to represent widening of the bypass. Two sets of eight gates were added to the Sacramento Bypass structure. The length of the Fremont Weir was increased by 1 mile. A 25,000 cfs bypass was added between the Feather River near Biggs and the Butte Basin.

Cross Section Modifications

Cross sections were modified in specified reaches (Table 3-1) of the Sacramento and Feather rivers to represent levee setbacks. Cross sections were also modified in the Sutter, Yolo, and Sacramento bypasses to represent widening of the bypasses. Cross sections were added to represent the bypass between the Feather River and the Butte Basin.

3.8.2 San Joaquin UNET Model

Upstream, Downstream, and Interior Boundary Conditions
Upstream boundary conditions were modified to include reservoir operation criteria modifications to Friant, New Exchequer, and New Don Pedro dams as described in Attachment 8B: Reservoir Analysis. Downstream and interior boundary conditions were unchanged from the No Project condition.

Levee Breach Modeling
For the Enhance Flood System Capacity Approach, the breach elevation at each levee breach point on a nonurban SPFC levee was set to be the 55/57 design profile plus freeboard (3 feet), or the existing TOL elevation as determined by the ULE and NULE projects, whichever is greater. This means repairing or reconstructing all nonurban SPFC levees to their design TOL, or the existing TOL, whichever is greater.

Levee breach elevations of urban levees were raised to a design water surface elevation that would pass a flood with a 0.5 percent AEP (200-year), with 3 feet of freeboard or the 55/57 design profile with 3 feet of freeboard, whichever was greater. The breach elevations for all levees that were modified as part of this approach were set to the TOL, meaning that for the purposes of hydraulic modeling on a systemwide scale, the probability of levee failure is zero until the levee is overtopped. If an existing urban levee had a TOL that was already higher than the 0.5 percent AEP design water surface plus freeboard, the TOL was left as existing, and the breach elevation was set to the TOL.

The breach elevations for levees on both sides of the channel in reaches where levees were setback were set to the TOL, representing the new setback levees and modifications to the existing levees. A reconstructed levee is assumed to have zero probability of failure until it is overtopped.

Internal Boundary Conditions
Internal boundary conditions were modified to include storage on floodplain easements, as outlined in Table 3-2.

Cross Section Modifications
Cross sections were modified to represent levee setbacks along the mainstem San Joaquin River at locations between the Merced and Stanislaus rivers, as described in Table 3-2.

3.9 Model Assumptions: State Systemwide Investment Approach

The State Systemwide Investment Approach (SSIA) reflects the State's strategy to address current challenges and affordably meet the 2012 CVFPP Goals. The preliminary approaches, described previously, suggested a broad range of physical and institutional flood damage reduction actions to improve public safety and achieve economic, environmental, and social sustainability. The SSIA is an assembly of the most promising, affordable, and timely elements of the three preliminary approaches.

Tables 3-1 and 3-2 show modeling assumptions for the Sacramento and San Joaquin river basins, respectively, for the No Project condition and each of the CVFPP approaches. The following sections describe specific assumptions for the Sacramento and San Joaquin UNET models for the State Systemwide Investment Approach.

3.9.1 Sacramento UNET Model

Upstream, Downstream, and Interior Boundary Conditions

Upstream, downstream, and interior boundary conditions were unchanged from the No Project condition.

Internal Boundary Conditions

Storage areas were used in the Yolo Bypass to represent widening of the bypass. The length of the Fremont Weir was increased by 1 mile. A bypass was added between the Feather River near Biggs and the Butte Basin.

Cross Section Modifications

Cross sections were modified in the Sutter and Yolo bypasses to represent widening of the bypasses. Cross sections were added to represent the 25,000 cfs Biggs Bypass from the Feather River to the Butte Basin.

Levee Breach Modeling

Levee breach elevations were the same as in the Protect High Risk Communities Approach, except that new levees resulting from widening the Yolo and Sutter bypasses were assumed to fail only on overtopping.

3.9.2 San Joaquin UNET Model

Upstream, Downstream, Interior, and Internal Boundary Conditions

Upstream, downstream, interior, and internal boundary conditions were unchanged from the No Project condition.

Levee Breach Modeling

Levee breach elevations were the same as the Protect High Risk Communities Approach.

3.10 Model Limitations

It is important to note some of the basic capabilities, assumptions, and limitations inherent with the UNET models. UNET is used to simulate one-dimensional, fully unsteady flow. It is a fixed-bed analysis and does not account for sediment movement, scour, or deposition. The models assume no exchange with groundwater. The model is intended to adequately reproduce levee breaks and breaches and simulate channel hydraulics. The spacing of cross sections in the UNET models (1,000 to 1,500 feet) is appropriate for large systemwide analyses; however, it also limits the application of these models to analysis requiring more detail.

3.11 Model Output Formats

As an unsteady flow model, UNET produces extensive results. For purposes of this attachment, the results are displayed as Stage- and Flow-Frequency curves and as Out-of-System Flows, as described below.

3.11.1 Stage- and Flow-Frequency Curves

Outputs from the hydraulic models would be shown in two formats: stage-frequency curves and flow-frequency curves. For a given location and return period, the highest peak stage, generated by any of the storm centerings, was selected to represent the maximum stage for that location and return period. The maximum stages for all return periods were plotted to generate the stage-frequency curve, as illustrated in Figure 3-4 using stages for only two sets of storm centerings to simplify the example. This same approach was used to obtain the flow-frequency curve for each location.

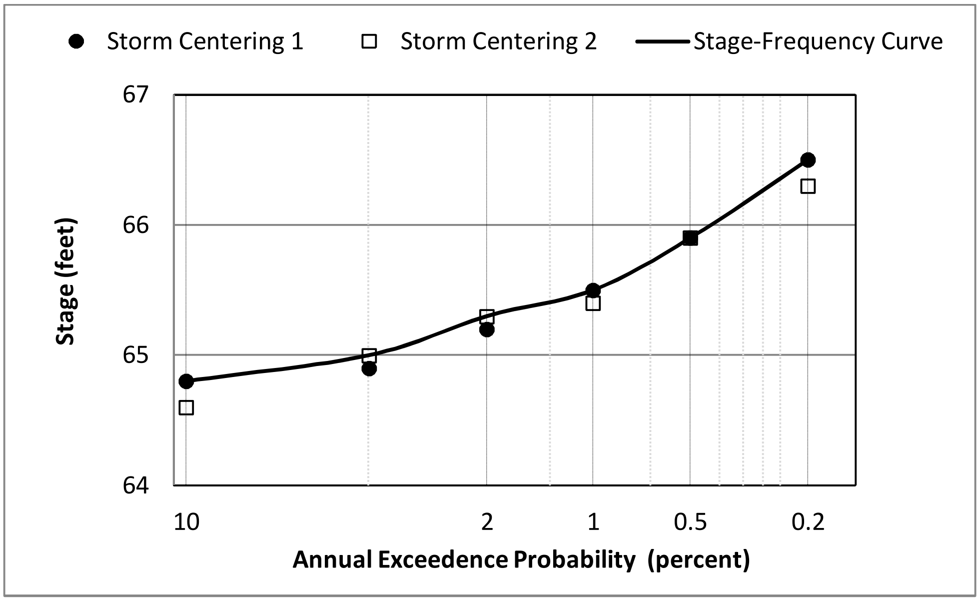

Figure 3-4. Illustration of Stage-Frequency Curve

3.11.2 Out-of-System Flows

To understand the operation of the flood management system, it is also necessary to know how much of a flood has left the river channels and has entered the floodplain. In a leveed reach of a river, this would mean that the levee had breached and water was leaving the river channel and entering the floodplain behind the levee. A levee breach can have a significant effect on stage and flow in the river channel adjacent to or downstream from the breach.

If a flood management system approach improves levees, floodwater that would have previously left the channel through a levee breach would continue downstream, thus increasing stage and flow at downstream locations and potentially causing downstream levee breaches. In addition, stages in the river would increase at the location where the breach previously occurred.

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4.0 Sacramento and San Joaquin River Basins Results

Figures 4-1 and 4-2 indicate the locations in the Sacramento and San Joaquin river basins at which stage- and flow-frequency curves will be plotted to allow comparison of the operations of the flood management systems among the No Project condition and the various approaches. The floodplains of the Sacramento and San Joaquin river basins have been subdivided into flood zones, which are also shown in Figures 4-1 and 4-2. Out-of-system volume in the flood zones was used in conjunction with the flow- and stage-frequency curves to demonstrate how the approaches differ as to in-channel flows, stage, and out-of-channel flow at various locations in each river basin.

It is important to remember that the results shown in this section area based come from a systemwide analysis and while they are indicative of system problems and general results from the various approaches, the results should not be used to design or analyze any specific location. Model results at a given location are often highly dependent on the upstream modeling assumptions.

All graphic and tabular results referenced in this section have been placed at the end of this section for easier access and readability.

4.1 Sacramento River Basin

This section describes UNET model output for the Sacramento River Basin and the simulated peak flow rates and stages for storms of various frequencies for the No Project condition and all approaches.

There are 13 model output locations in the Sacramento River Basin (see Figure 4-1). Seven locations are along the Sacramento River; the remaining six are on the Feather River, American River, Sutter Bypass, and Yolo Bypass.

Abbreviations are used on the flow- and stage-frequency plots to designate the No Project condition and the approaches, as follows:

- No Project = No Project Condition
- SPFC = Achieve SPFC Design Flow Capacity Approach

- PHRC = Protect High Risk Communities Approach
- EFSC = Enhance Flood System Capacity Approach
- SSIA = State Systemwide Investment Approach

4.1.1 Flow- and Stage-Frequency Curves

Figures 4-3 through 4-15 show flow- and stage-frequency curves for all of the approaches for each of the 13 selected output locations in the Sacramento River Basin (Figure 4-1). Because of differences in elevations and flows between the output locations, scales on the flow- and stage-frequency curves are not the same for all the output locations.

A detailed result description is given on the facing page of each of the paired flow- and stage- frequency curves (Figures 4-3 through 4-15).

4.1.2 Out-of-System Volumes

Figure 4-1 shows the geographic extent of designated flood zones in the Sacramento River Basin. The flood zones are groupings of impact areas or floodplains used to tabulate the volume of floodflows leaving the flood management system during a given flood. Table 4-1 contains the out-of-system volume for each of the approaches in each of the flood zones. These out-of-system volumes are instrumental in understanding the function of the system. For example, the stage at a given location may be lower for the 100-year flood than for the 50-year flood. If flood zones upstream from this location are reviewed and a significant increase is observed in out-of-system volume in the upstream flood zones between the 50- and the 100-year floods, it can be concluded that a levee breach upstream from the location likely has reduced the flows to a level less than the 50-year flow.

Another example would be a location where the stage between No Project condition and one of the approaches increases significantly for the same AEP flood. Again, if upstream out-of-system volume is reduced, it can be concluded that additional flow remains in the river because upstream levees may have been reconstructed or raised and no longer breach as they did in the No Project condition.

4.1.3 Flows to Delta

Table 4-2 contains the volume of flow entering the Delta for the No Project condition and each of the approaches for the Sacramento River Basin. Flow volume into the Delta is another important factor to consider when comparing approaches. The model measures flow volume into the Delta as the sum of the volume in the Yolo Bypass that passes Lisbon and the flow volume downstream from the confluence of the Sacramento and American rivers.

4.2 San Joaquin River Basin

This section describes the UNET model output for the San Joaquin River Basin and the simulated peak flow rates and stages for storms of various frequencies for the No Project condition and all approaches.

There are nine model output locations in the San Joaquin River Basin (see Figure 4-2). Six locations are along the San Joaquin River; the remaining three are on the Fresno River, Chowchilla Bypass, and Eastside Bypass.

4.2.1 Flow- and Stage-Frequency Curves

Results of the San Joaquin River Basin UNET model were processed using the same methodology used for the Sacramento River Basin. Figures 4-16 through 4-25 show flow- and stage-frequency curves for all of the approaches, for each of the nine selected output locations in the San Joaquin River Basin (Figure 4-2). Because of differences in elevations and flows between the output locations, scales on the flow- and stage-frequency curves are not the same for all the output locations.

A detailed result description is given on the facing page of each of the paired flow- and stage- frequency curves (Figures 4-16 through 4-25).

4.2.2 Out-of-System Volumes

Figure 4-2 shows the geographic extent of designated flood zones in the San Joaquin River Basin. Table 4-3 contains the out-of-system volume for each of the approaches in each of the flood zones in the San Joaquin River Basin. These out-of-system volumes are instrumental in understanding the function of the system.

4.2.3 Flows to the Delta

Table 4-4 contains the volume of flow entering the Delta for the No Project condition and each of the approaches for the San Joaquin River Basin. The model measures flow volume into the Delta from the San Joaquin River as the volume that passes the gage at Vernalis.

4.3 Summary Findings

This section describes some of the systemwide findings that can be drawn from the data presented in this section.

4.3.1 Achieve SPFC Design Flow Capacity Approach

Restoring all SPFC levees to their original design flow capacity for the Achieve SPFC Design Flow Capacity Approach would significantly reduce the number of levee breaks and therefore keep more flow in the river channels, causing increased stages and flows in both the Sacramento and San Joaquin river basins. With the restored levees, the floodwaters that would have left the system in the No Project condition would continue downstream. As the increased flows and stages continue downstream they cause levee breaks in the lower reaches of both the Sacramento and San Joaquin rivers (Tables 4-1 and 4-3), sometimes in places where the levees did not break in the No Project condition.

Flow volumes entering the Delta increase significantly over the No Project condition for all flood frequencies in both river basins (Tables 4-2 and 4-4).

Protect High Risk Communities Approach

The Protect High Risk Communities Approach modifies urban levees to pass the 200-year (0.5 percent AEP) flood with 3 feet of freeboard. Since only urban levees and a few small communities are modified, flows and stages in both the Sacramento and San Joaquin river basins would remain essentially the same as for No Project condition. The only exceptions would arise if an urban area sustained a levee breach in the No Project condition. In that case, the flows and stages downstream would increase due to the rebuilding of the urban levee so that the levee breach did not occur.

Flow volumes entering the Delta are essentially the same as No Project condition for all floods, except for the 0.2 percent AEP (500-year) flood in which some urban areas that had levee breaches in the No Project condition remain dry, sending additional flow into the Delta.

Enhance Flood System Capacity Approach

The Enhance Flood System Capacity Approach modifies urban levees to pass the 200-year (0.5 percent AEP) flood with 3 feet of freeboard. In addition, the breach elevations for nonurban SPFC levees were set to be the 55/57 design profile (the design standard for construction of the State Plan of Flood Control) plus freeboard (3 feet), or the existing TOL elevation as determined by the ULE and NULE projects, whichever was greater.

Other key components of the approach are added upstream reservoir storage, widened and new bypasses, levee setbacks, and floodplain storage. The added upstream storage would result in lower stages in the upper Feather, San Joaquin, Merced, and Tuolumne rivers. Floodplain storage and levee setbacks would result in lower stages in the Sutter Bypass and lower Feather River, as well as the Sacramento River downstream from the

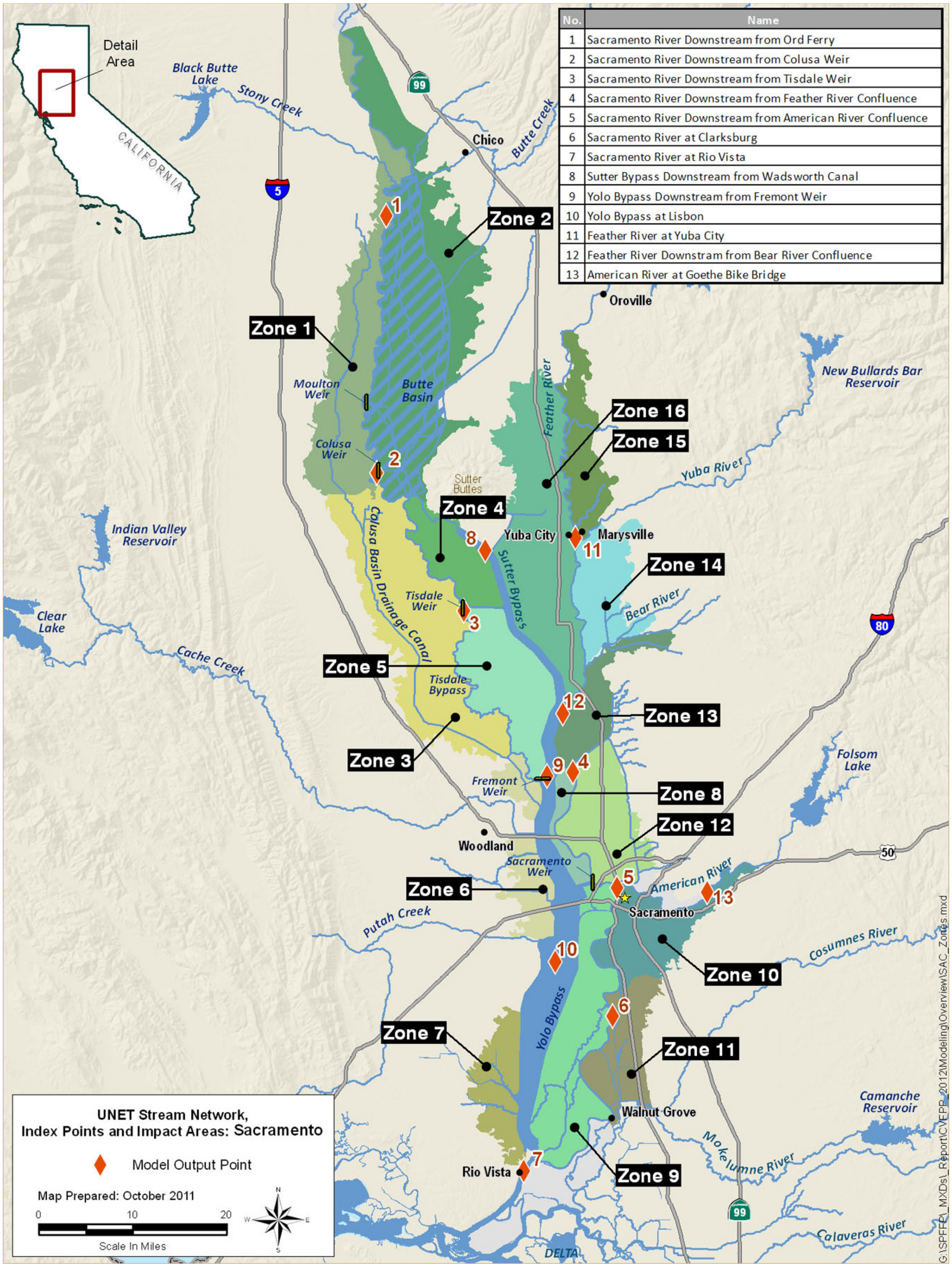
Tisdale Weir. These lower stages would continue downstream in the Yolo Bypass and lower Sacramento River. Higher stages would be seen in the Chowchilla and Eastside bypasses as a result of levee fixes that increase the volume of water remaining in the bypasses all the way from the San Joaquin River to the Merced River. Stages downstream from the Tuolumne River to Stockton would also be lowered as a result of floodplain storage and levee setbacks.

Even though restoring all urban and SPFC levees as described above should result in additional flow volumes entering the Delta, flow volumes entering the Delta are significantly decreased for the 10, 4, 2, and 1 percent (10-, 25, 50-, 100-year) floods as a result of the added upstream reservoir and floodplain storage. For the 0.5 and 0.2 percent AEP (200- and 500-year) floods the reservoir and floodplain storage is not enough to prevent an increase in flow into the Delta.

State Systemwide Investment Approach

The State Systemwide Investment Approach consists of the same improvements to urban levees included in the Protect High Risk Communities Approach. In addition, a new bypass (Biggs) and widening of the Yolo and Sutter bypasses are included in the Sacramento River Basin, and Paradise Cut Bypass is widened in the San Joaquin River Basin. Flows and stages for the State Systemwide Investment Approach are similar to the Protect High Risk Communities Approach, except where changes to the bypasses reduce stages.

Flows entering the Delta from the Sacramento River Basin are marginally increased for less frequent floods because there are fewer levee breaches as a result of the urban levee improvements and the widening of the bypasses. Flows entering the Delta from the San Joaquin River Basin are essentially the same as for the Protect High Risk Communities Approach.



No.	Name
1	Sacramento River Downstream from Ord Ferry
2	Sacramento River Downstream from Colusa Weir
3	Sacramento River Downstream from Tisdale Weir
4	Sacramento River Downstream from Feather River Confluence
5	Sacramento River Downstream from American River Confluence
6	Sacramento River at Clarksburg
7	Sacramento River at Rio Vista
8	Sutter Bypass Downstream from Wadsworth Canal
9	Yolo Bypass Downstream from Fremont Weir
10	Yolo Bypass at Lisbon
11	Feather River at Yuba City
12	Feather River Downstream from Bear River Confluence
13	American River at Goethe Bike Bridge

Figure 4-1. Sacramento River Basin Output Locations and Flood Zones

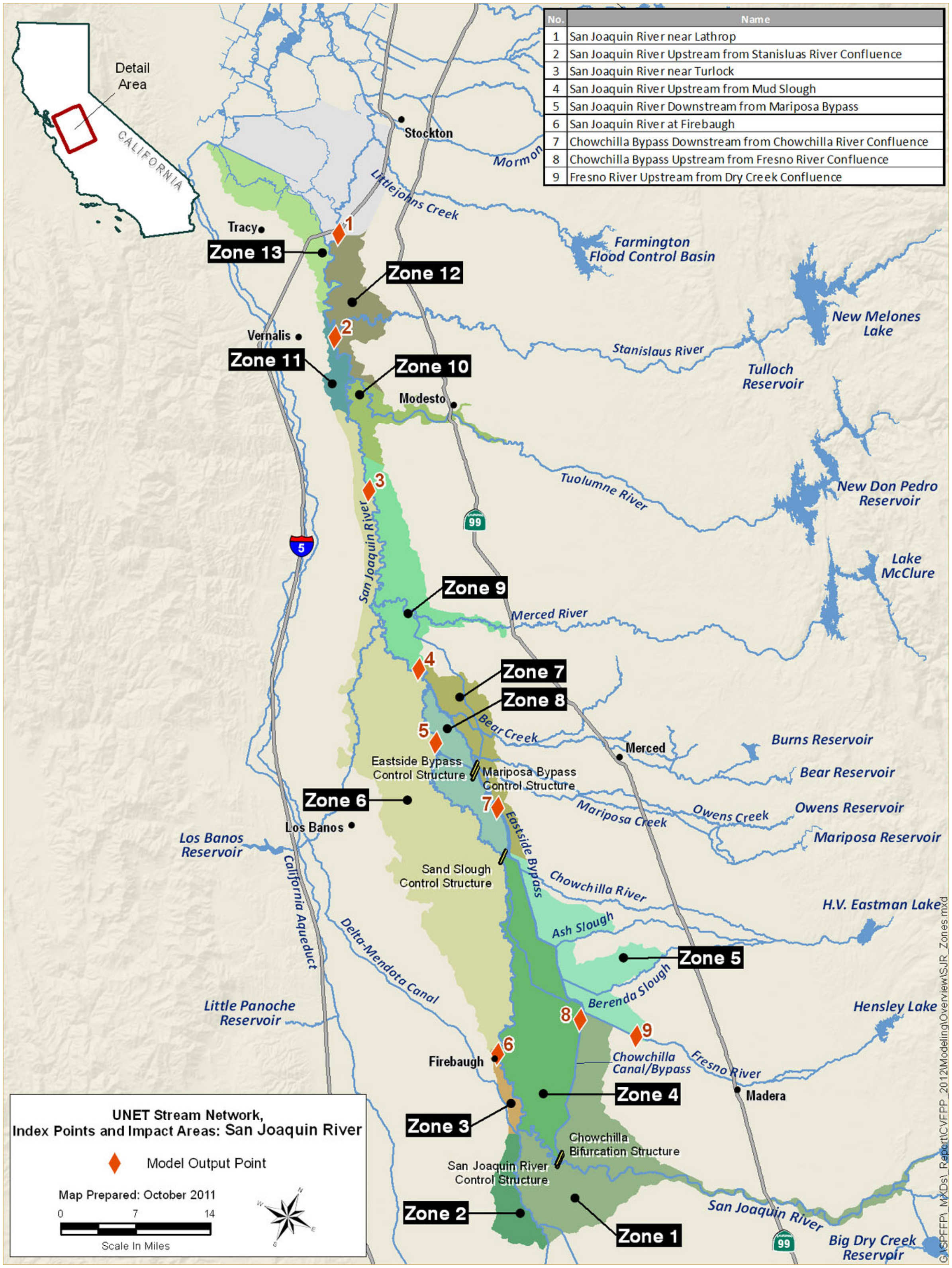


Figure 4-2. San Joaquin River Basin Output Locations and Flood Zones

- **No Project Condition and All Approaches –**No modifications to the existing flood management system upstream from this location or in close proximity downstream, so flows are the same for all cases (flows are largely controlled by boundary inflows). Flows decrease slightly for the 0.5 percent and 0.2 percent floods because higher flows cause more outflow through levee breaks. However, stage continues to rise for larger flood events as a result of increasing backwater effects resulting from increased flows downstream.

- **SPFC Approach –** Restoring SPFC levees (to the 57 design profile) reduces the number of levee breaks downstream from this location, without any improvements to reservoir flood management pools, floodplain storage capacity, bypass conveyance capacity, or channel conveyance capacity, resulting in higher stages downstream from this location than in No Project condition or other approaches. This backwater effect travels upstream to this location, and causes stages to increase slightly.

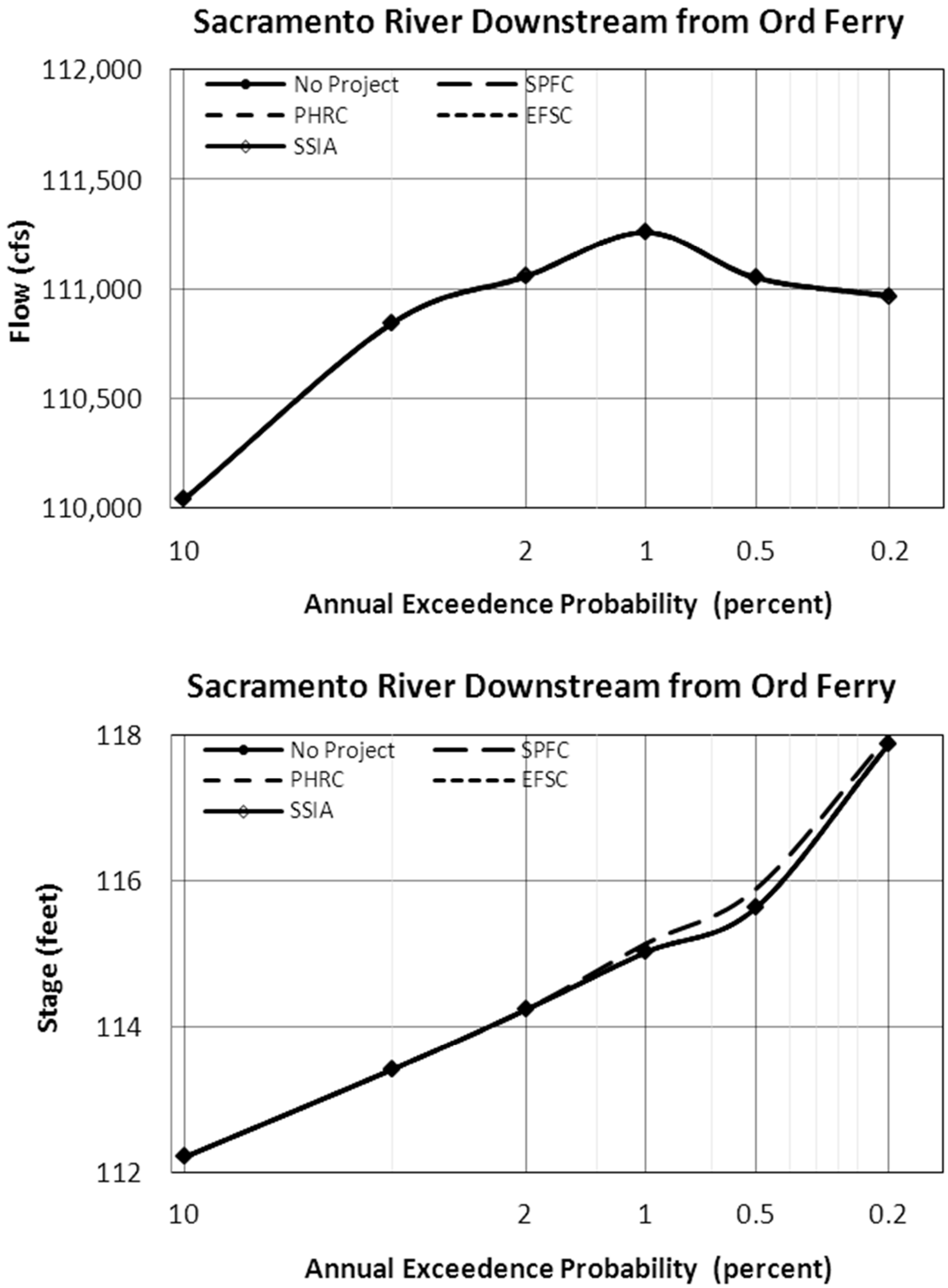


Figure 4-3. Flow- and Stage-Frequency Curves: Sacramento River Downstream from Ord Ferry [1]

- **No Project Condition and All Approaches –**Flow and stage are similar for all events through the 1 percent AEP flood because there are few modifications to the flood management system upstream from this location for any of the approaches.

- **SPFC Approach –** River stage increases slightly at the 0.5 percent and 0.2 percent AEP events compared to the No Project condition due to increased backwater, which results from SPFC levee restoration downstream from this location. However, flow decreases because there is more flow over the Colusa Weir, as a result of the higher stage.

- **EFSC Approach** – Stage decreases at the 0.5 percent and 0.2 percent AEP events as a result of levee setbacks in this reach of the river. Flow also decreases at the 0.2 percent flood as a result of Sutter bypass widening, which results in a lows stage in the Colusa Bypass at Colusa Weir, and allows more flow the enter the bypass.

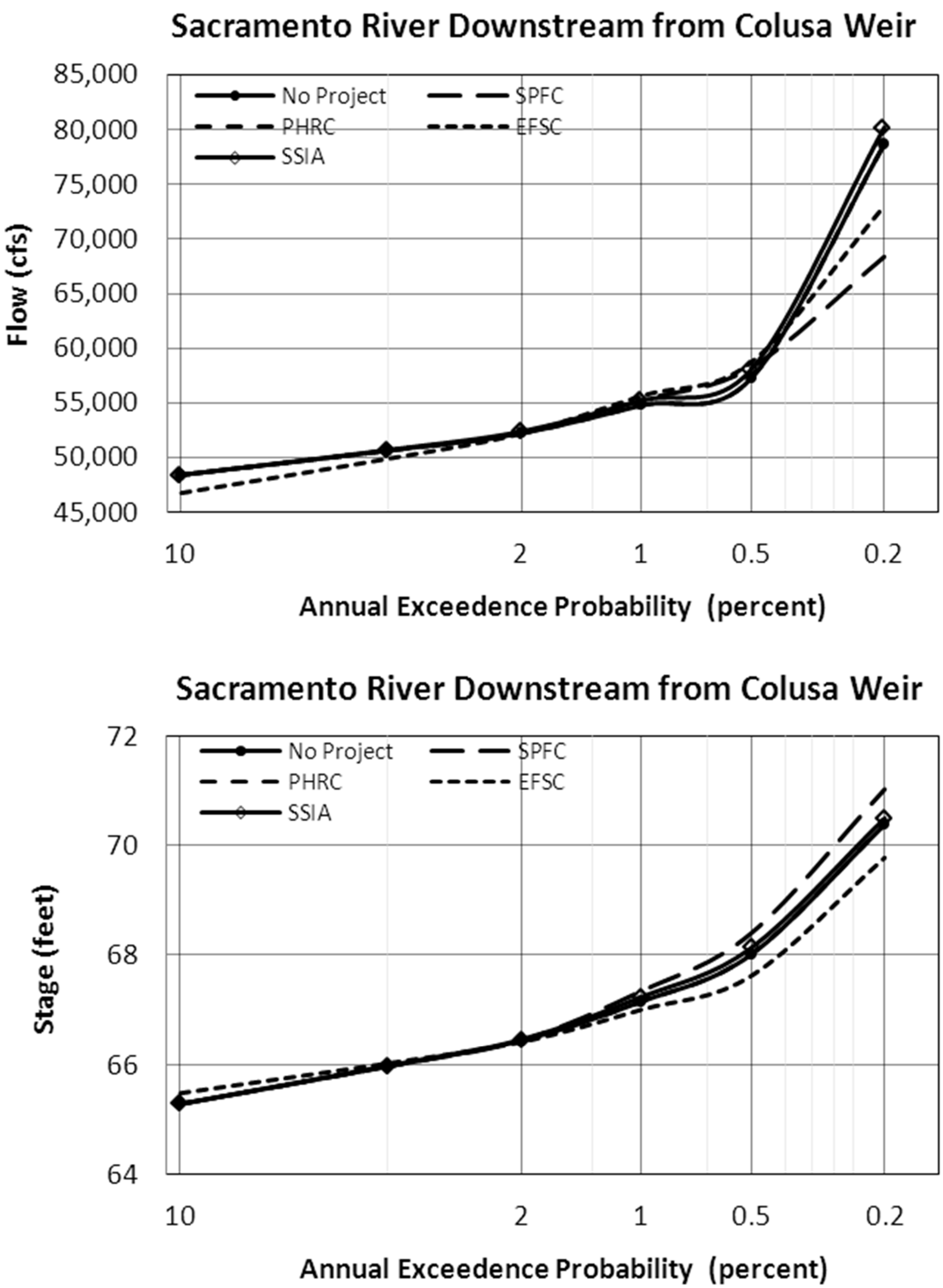


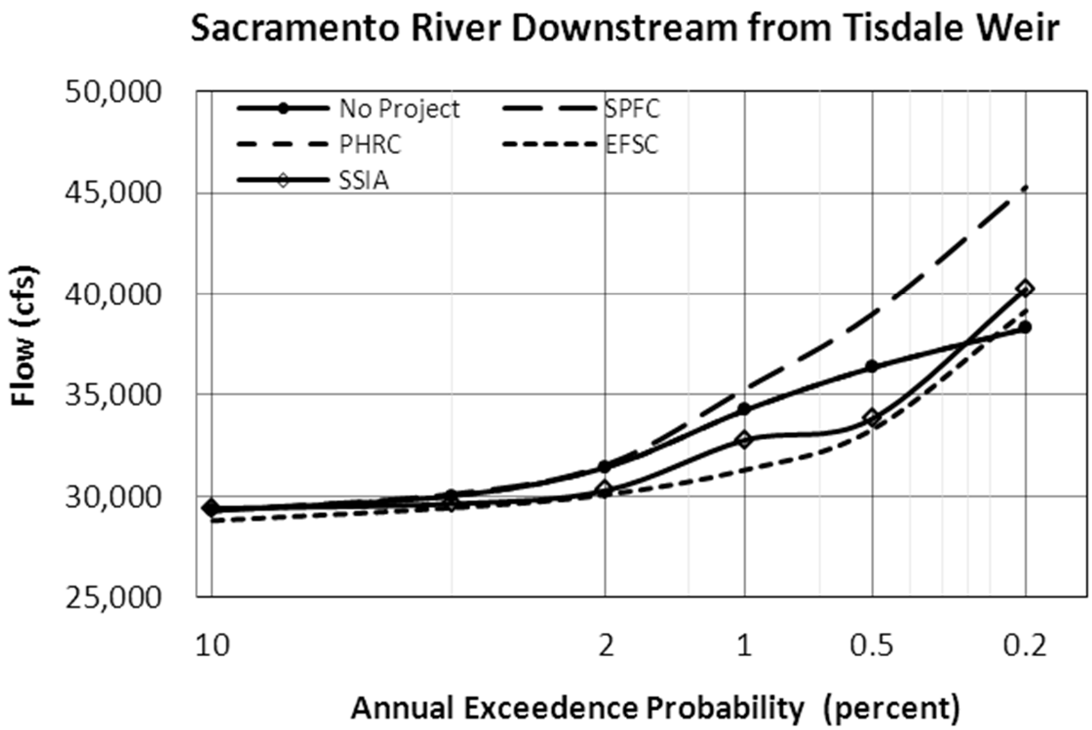
Figure 4-4. Flow- and Stage-Frequency Curves: Sacramento River Downstream from Colusa Weir [2]

- **No Project Condition and PHRC Approach –** Levees break along the Sutter Bypass upstream from the Tisdale Bypass at the 0.5 percent AEP flood event and greater, increasing flow over the Tisdale weir by lowering the backwater from the Sutter Bypass, thus preventing any major increases in flow or stage downstream from the weir.

- **SPFC Approach –** Restoring SPFC levees prevents a number of upstream levee breaks for the 1 percent AEP flood and greater, increasing in-channel flow and river stage upstream from the Tisdale Bypass compared to the No Project condition. However, the flow over the Tisdale Weir into the Tisdale Bypass is generally similar to or less than in the No Project condition, because the stage in the Tisdale and Sutter bypasses is higher (increased stage upstream increases flow over the Moulton and Colusa weirs, so the stage in the Sutter Bypass is higher, resulting in a greater backwater effect on the Tisdale Bypass).

- **EFSC Approach –** The widened Sutter Bypass lowers the stage and allows more flow over the Tisdale weir compared to the No Project condition, as in the SSIA. For the 0.2 percent AEP flood event, the flow in the Sacramento River upstream from the Tisdale Weir increases as a result of levee restoration, but there is also significantly more flow over the Tisdale Bypass as a result of the higher stage in the Sacramento River, so flow and stage are similar to the No Project condition.

- **SSIA –** Stage in the Tisdale Bypass is significantly lower than in the No Project condition through the 0.5 percent AEP flood as a result of widening the Sutter Bypass. The stage in the Sacramento River above the Tisdale Weir is similar for those events, so flow over the Tisdale Weir into the Tisdale bypass is greater. Increasing flow over the Tisdale Weir at the 0.5 percent AEP event prevents any major change in flow or stage downstream on the Sacramento River. For the 0.2 percent AEP event, flow and stage tend to converge with the No Project condition because some of the water in the floodplain enters the Tisdale Bypass, which increases the backwater effect in the bypass to a level similar to the No Project condition (floodplain flows also reenter the bypass in the No Project condition, but at a lower rate, because the stage in the bypass is higher when inflow begins).



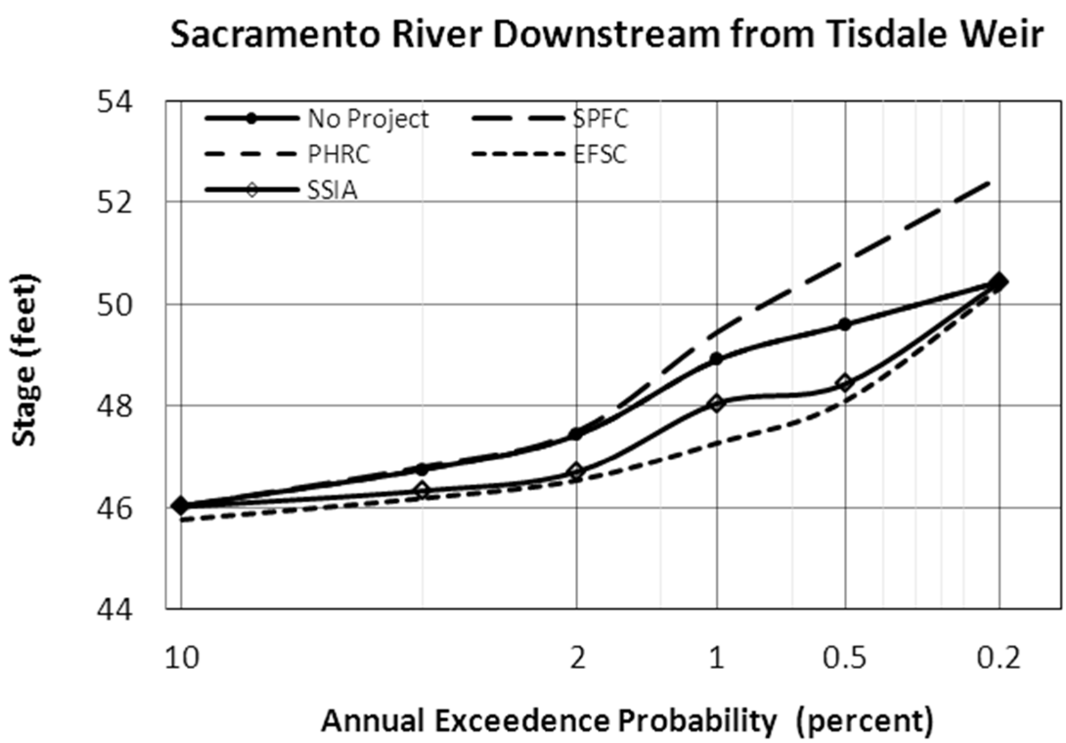


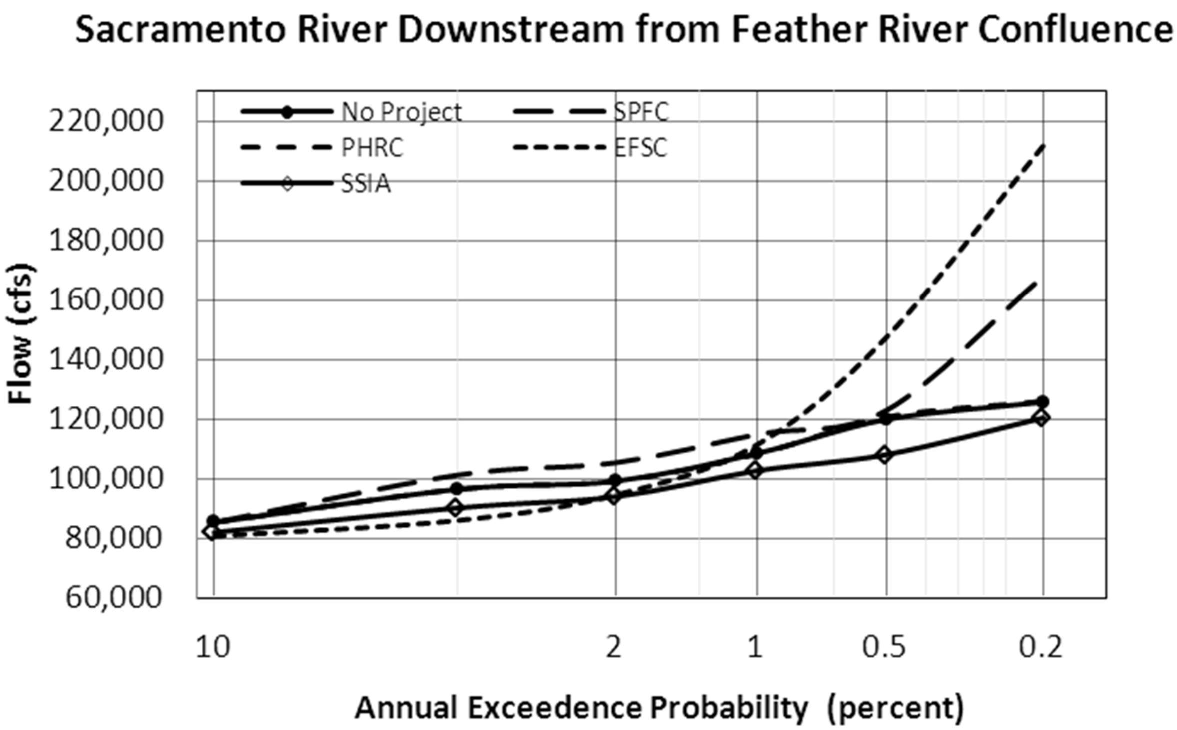
Figure 4-5. Flow- and Stage-Frequency Curves: Sacramento River Downstream from Tisdale Weir [3]

- **SPFC Approach –** Restoring SPFC levees (to the 55/57 design profile) reduces the number of upstream levee breaks, resulting in generally higher in-channel flows. The higher flows are particularly exaggerated for the 0.2 percent AEP. River stages at this point are also higher as a result of the levee reconstruction included in this approach.

- **PHRC Approach –** Produces results similar to the No Project condition at this location because there are few improved upstream urban levees, and effects from downstream changes in river flows resulting from urban levee improvements are negligible.

- **EFSC Approach –** Improvements to the flood management system - including bypass improvements, additional floodplain storage areas, and increased reservoir flood management storage -reduce peak flows for smaller flood events. For larger flood events (0.5 percent AEP and smaller), the relative effect of these improvements on in-channel flows is overwhelmed by the reduced number of upstream levee breaks (resulting from improved urban and restored non-urban levees), which tends to increase in-channel flows. Also, flow into an added floodplain storage area just downstream from this location significantly lowers the river stage adjacent to the storage area. This effectively reduces the backwater effect at the Feather River Confluence, which allows the for a temporarily higher flow rate along with a much lower stage compared to other approaches, especially during very large events.

- **SSIA** – Flows are generally lower than the No Project condition because of bypass improvements, which increase their capacity and reduce river flows at this location. At the 0.2 percent AEP, significant levee breaks occur in the No Project condition, reducing flows and stages to a level closer to the SSIA approach.



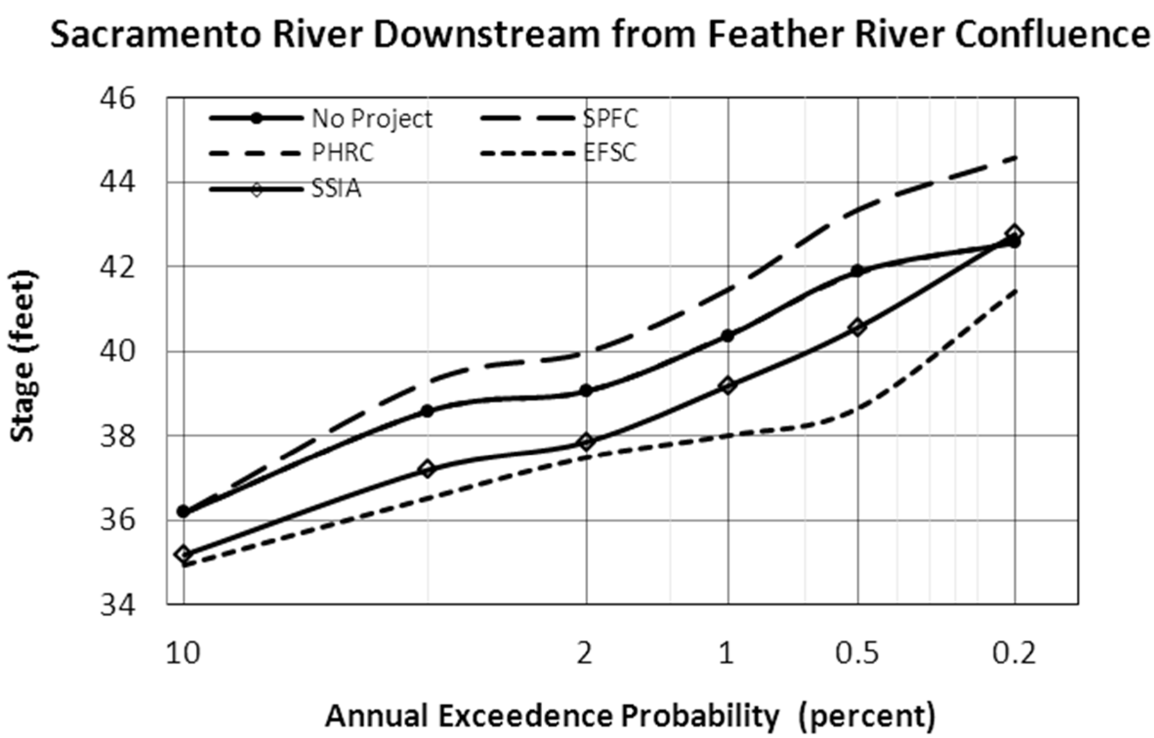
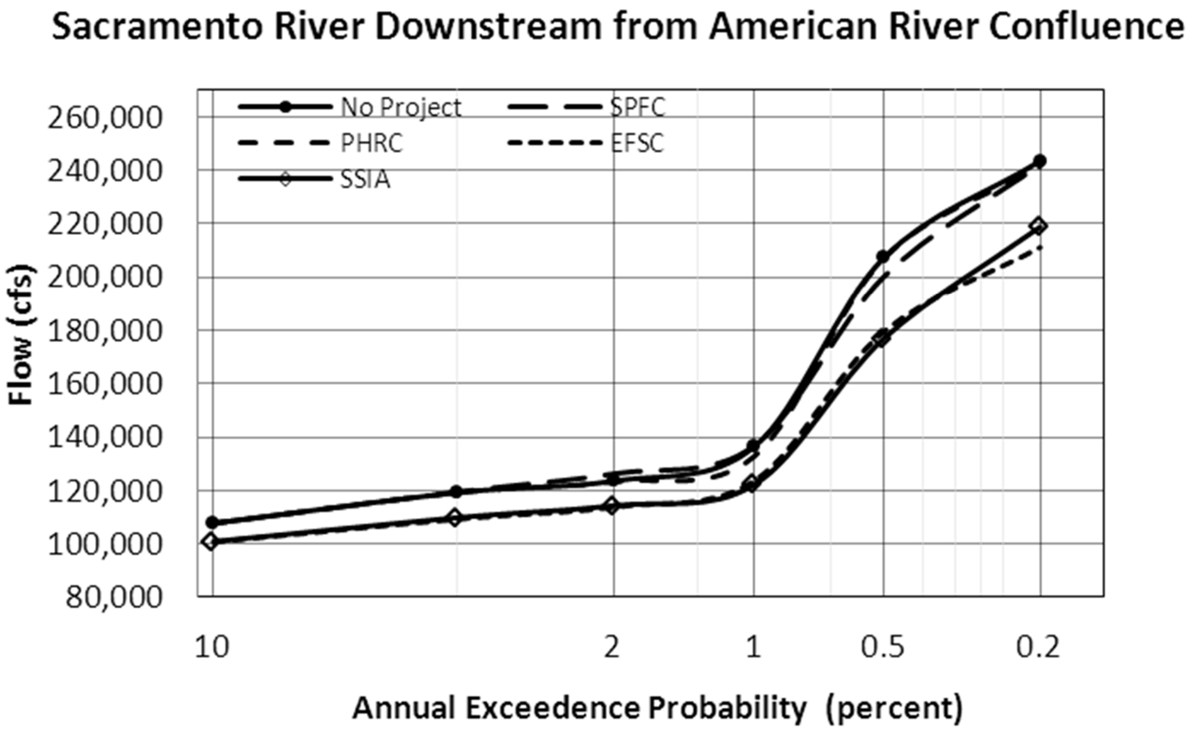


Figure 4-6. Flow- and Stage-Frequency Curves: Sacramento River Downstream from Feather River Confluence [4]

- **No Project Condition, SPFC and PHRC Approaches –** Flows are similar because the Sacramento Bypass diverts a similar portion of flow in each case. For the PHRC and SPFC approaches, stage is generally higher because levee restoration prevents some downstream levee breaks, increasing the backwater effect at this location.

- **EFSC Approach and SSIA** – Flow and stage are lower than the No Project condition because of increased outflows through the widened Sacramento Bypass upstream from this location.



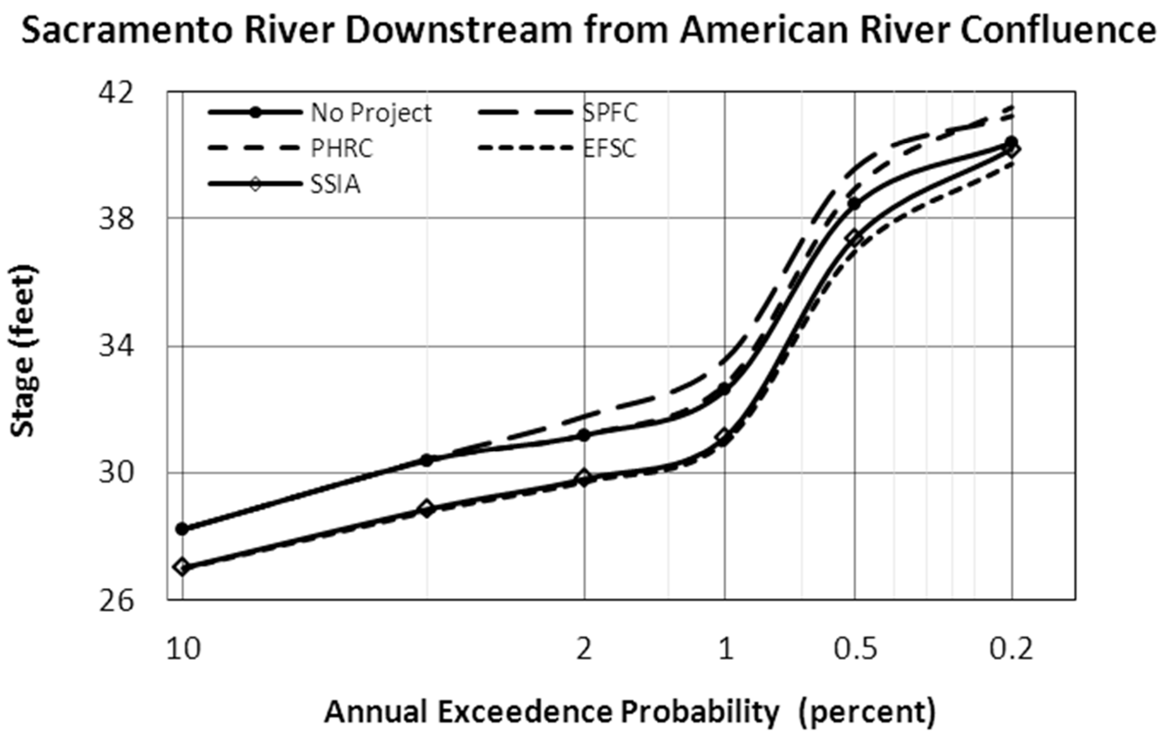


Figure 4-7. Flow- and Stage-Frequency Curves: Sacramento River Downstream from American River Confluence [5]

- **SPFC Approach –** Higher stages at this location than the No Project condition and the other approaches because restoration of all SPFC levees reduces the number of levee breaks both upstream and downstream from this point. However, the increased backwater effect (from increased downstream stages) tends to reduce the velocity of flow, leading to flow rates that are similar to or less than the No Project approach.

- **PHRC Approach** – Leads to higher maximum stages than the No Project condition at this location because improved upstream urban levees would fail at higher flows, resulting in more flow remaining in the system and entering the Yolo Bypass. When that flow re-enters the Sacramento River at Rio Vista, it creates a backwater effect which extends up the Sacramento River to this location. Flows at this location are similar to No Project flows because the levees below Sacramento are unimproved, and tend to break at the same frequency as No Project levees. For large events, the backwater effect is great enough that flow rates are significantly reduced compared to the No Project condition, despite higher water surface elevations.

- **EFSC Approach –** Improvements to the flood management system - including bypass improvements, additional floodplain storage areas, and increase reservoir flood management pools - reduce peak flows for smaller flood events. For larger flood events (200 year and greater), the relative effect of these improvements on in-channel flows is overcome by the reduced number of upstream levee breaches (resulting from improved urban and non-urban levees), which tends to increase in-channel flows. Also, an added floodplain storage area just downstream from this point accepts a large portion of river flow during the peak of each flood event, which significantly lowers the river stage adjacent to the storage area. This effectively reduces the backwater effect at Clarksburg, which allows for a temporarily higher flow rate along with a much lower stage compared to other approaches, especially during very large events.

- **SSIA** – Bypass improvements reduce river flows at this location compared to the No Project condition for all flood events, despite the effect of improved urban levees (which act to increase in-channel flows). Increased flows exiting the Yolo Bypass create a backwater effect on the Sacramento River, which results in higher peak water surface elevations at this location than the No Project condition for the 0.5 and 0.2 percent AEP events.

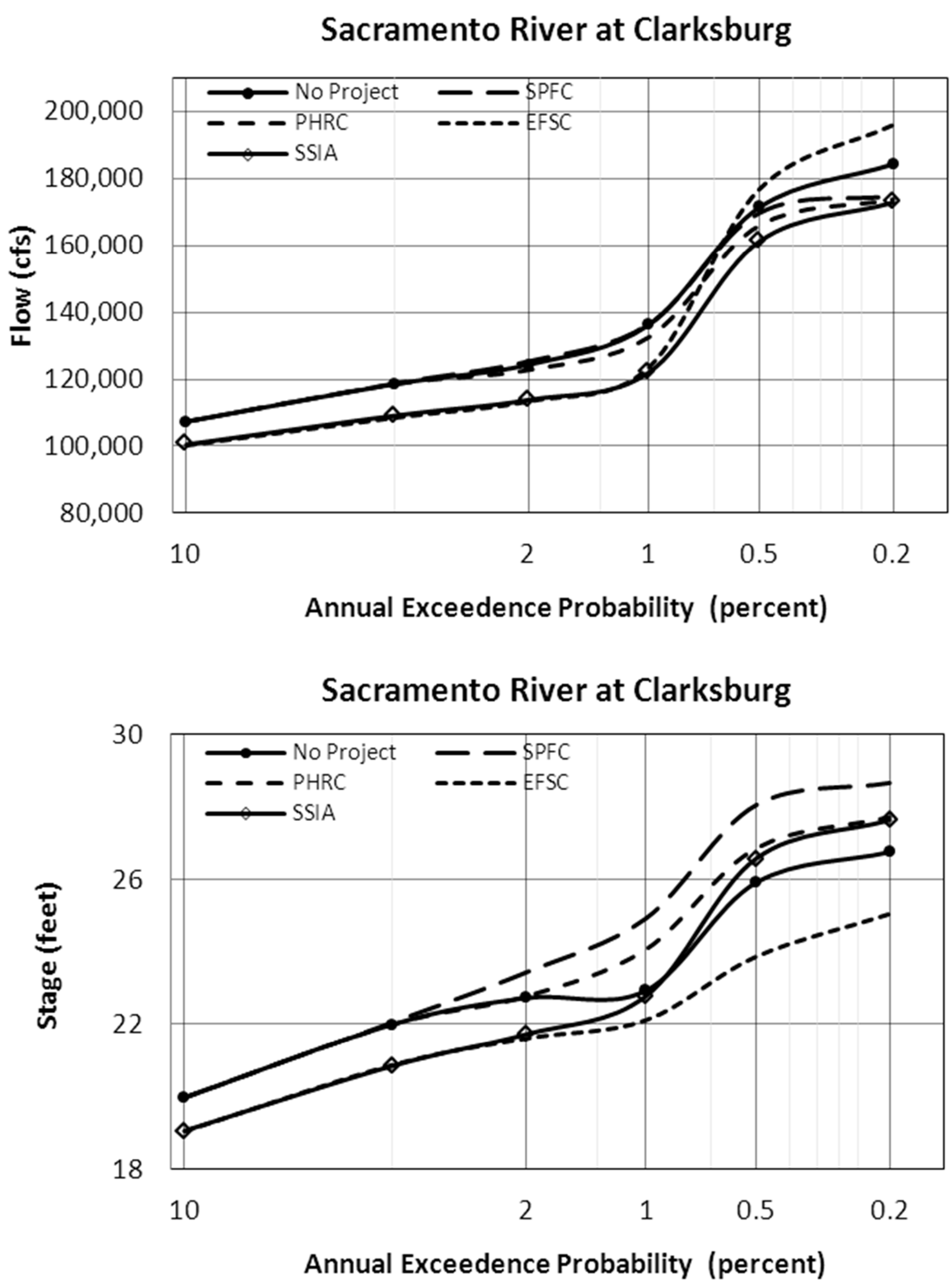


Figure 4-8. Flow- and Stage-Frequency Curves: Sacramento River at Clarksburg [6]

- **No Project Condition and All Approaches –** Flows at this location are largely controlled by the amount of flow reentering the river from the Yolo Bypass through Cache Slough and Steamboat Slough, just upstream from this location.
- **SPFC Approach** – Higher stages than the No Project condition and the other approaches through the 0.5 percent AEP event because restoration of all SPFC levees reduces the number of levee breaks upstream from this location, which increases the amount of inflow to the Yolo Bypass. However, for the 0.2 percent AEP event, levees break along the Yolo bypass as a result of the increased stage.
- **EFSC Approach –** Improvements in the Yolo Bypass as well as rehabilitation of upstream levees result in higher flows from the bypass into the river for the 0.2 percent AEP flood event.
- **SSIA –** inflows to the Yolo Bypass are high, but levee breaks occur in the bypass in the 0.2 percent AEP flood event, resulting in decreased flow and stage at this location.

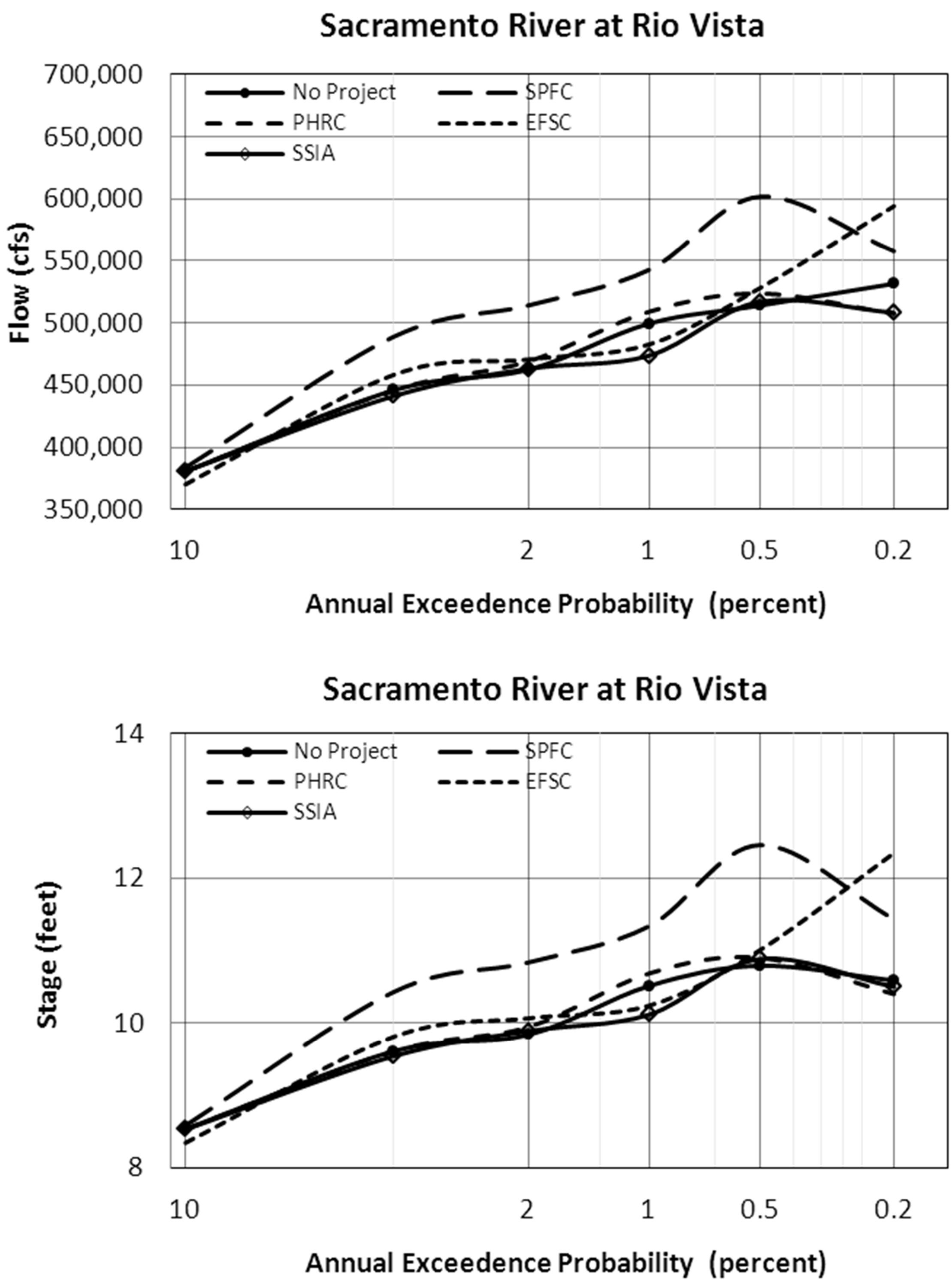
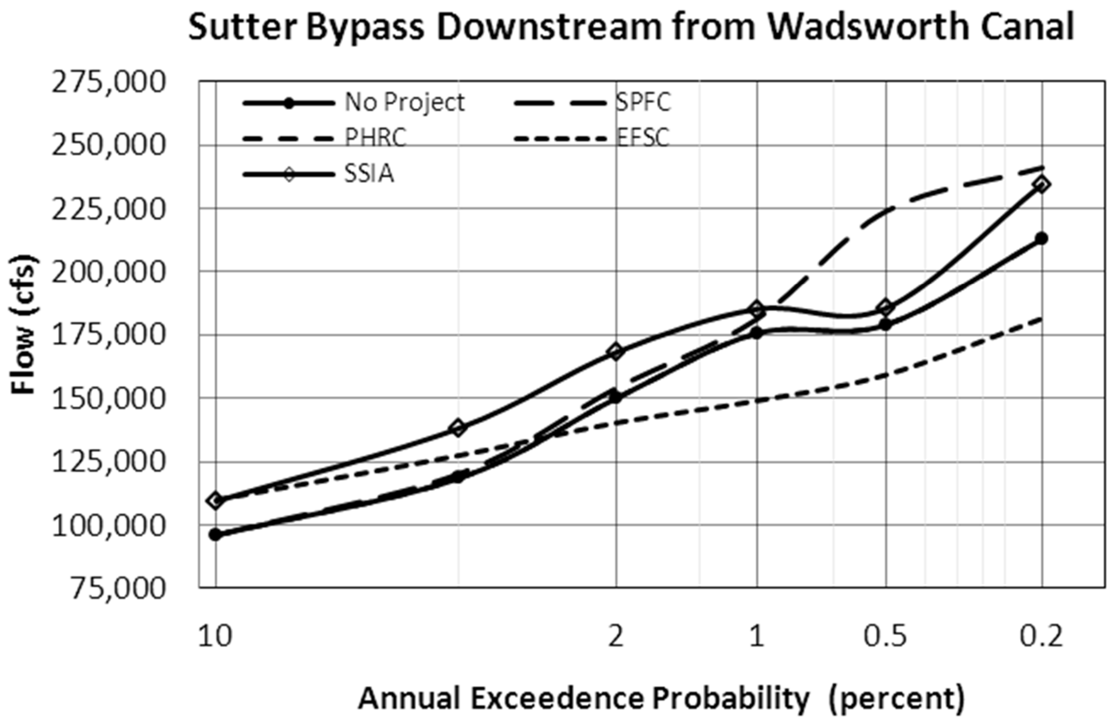


Figure 4-9. Flow- and Stage-Frequency Curves: Sacramento River at Rio Vista [7]

- **No Project Condition and PHRC Approach** – Stage remains relatively constant for the 1 percent AEP event and greater as a result of upstream levee breaks along the Sutter Bypass.
- **SPFC Approach** – Restoring SPFC levees reduces the number of upstream levee breaks in the bypass and along the Sacramento River, so more flow is retained in the channels and stage is increased compared to the No Project condition. For the 0.2 percent AEP event, levees break upstream from this location, so there is relatively little increase in stage and flow.
- **EFSC Approach** – Flow and stage are significantly reduced compared to the No Project condition as a result of the Sutter Butte Basin floodplain storage area, which is immediately upstream from this location and diverts a large portion of the bypass flow, especially for large flood events.
- **SSIA** – Flows are generally higher than in the No Project condition as a result of the addition of the Feather to Butte Basin (Biggs) bypass, which conveys flow to the Sutter Bypass through Cherokee Canal and Butte Creek. However, stages are generally similar to the No Project condition as a result of bypass widening, which increases conveyance capacity for any given stage.



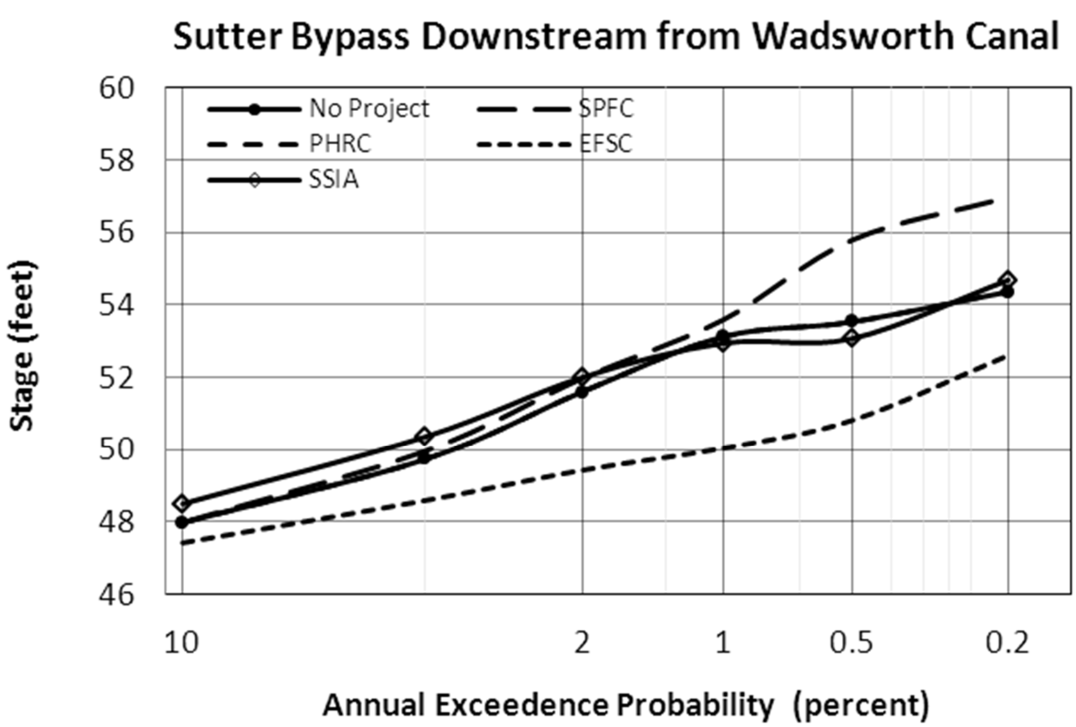


Figure 4-10. Flow- and Stage-Frequency Curves: Sutter Bypass Downstream from Wadsworth Canal [8]

- **No Project Condition and PHRC Approach –** Levee breaks in the Sutter Bypass upstream from the Fremont weir in the 0.2 percent AEP event cause relatively little increase in flow and stage compared to the 0.5 percent AEP event.

- **SPFC Approach** – Restoring SPFC levees reduces the number of upstream levee breaks, resulting in a higher stage at Fremont Weir and a higher flow rate into the Yolo Bypass over the weir compared to the No Project condition for all events.

- **EFSC Approach** – Stage in the Yolo Bypass below the Fremont Weir is generally lower than in the No Project condition as a result of bypass widening. Through the 0.5 percent AEP event, flows in the bypass are decreased by a number of upstream flood management actions, including floodplain storage and modified reservoir operations. However, for the 0.2 percent AEP event, stage is higher than the No Project Condition, while flow is approximately equal, because water stored in the floodplain storage area along the Sacramento River below the Feather River overflows into the Yolo Bypass. These inflows increase the backwater effect at the Fremont Weir, resulting in increased stage and decreased flow over the weir.

- **SSIA –** Widening of the Yolo Bypass results in a lower stage below the Fremont Weir for all events. However, flow is greater than in the No Project condition because the lower stage results in a decreased backwater effect, which allows more flow over the weir, and because there is more inflow to the Sutter Bypass from upstream weirs (also resulting from lower stage in the bypass) and from the addition of the Feather to Butte Basin (Biggs) Bypass.

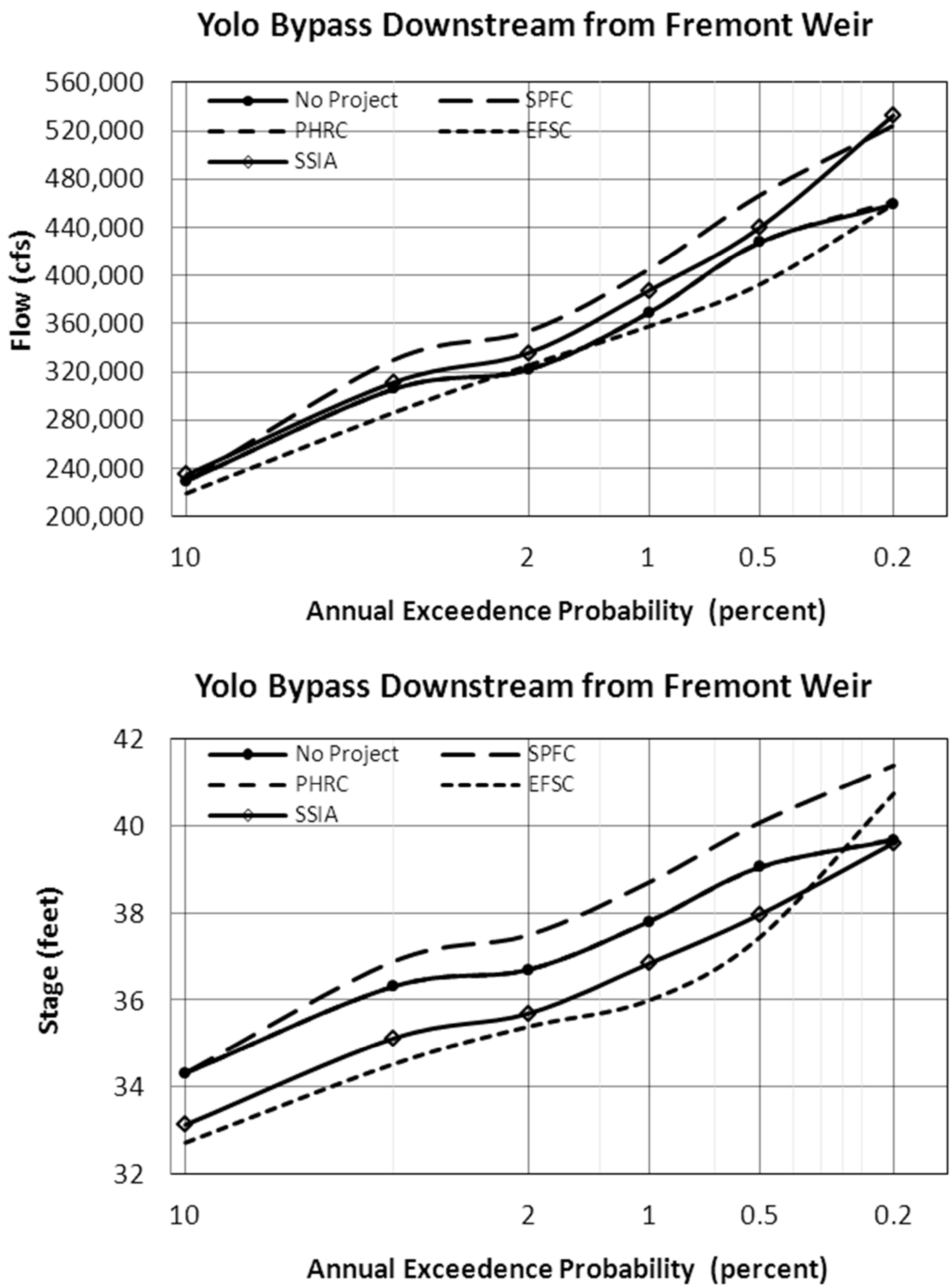


Figure 4-11. Flow- and Stage-Frequency Curves: Yolo Bypass Downstream from Fremont Weir [9]

- **SPFC Approach –** Results in higher stages at this location than the No Project condition and the other approaches through the 0.5 percent AEP event because restoration of all SPFC levees reduces the number of levee breaks upstream on the Sacramento River. This increases river stage, which causes more flow over the both weirs that control inflow to the bypass. However, at the 0.2 percent AEP event, the higher stages in the bypass result in levee breaks in the bypass upstream from this location, lowering the flow compared to the EFSC Approach and SSIA.

- **EFSC Approach** – Maximum flow and stage in the bypass is increased at the 0.2 percent AEP event as a result of upstream levee improvements, which increases the inflow to the bypass, as well as widening of the bypass, which increases its maximum capacity.

- **SSIA –** Flow in the bypass for the 0.2 percent AEP event is greater than in the No Project while stage is similar because widening the bypass increases its conveyance capacity at any given stage. However, levee breaks upstream from this location limit the inflow to the bypass compared to the SPFC and EFSC approaches.

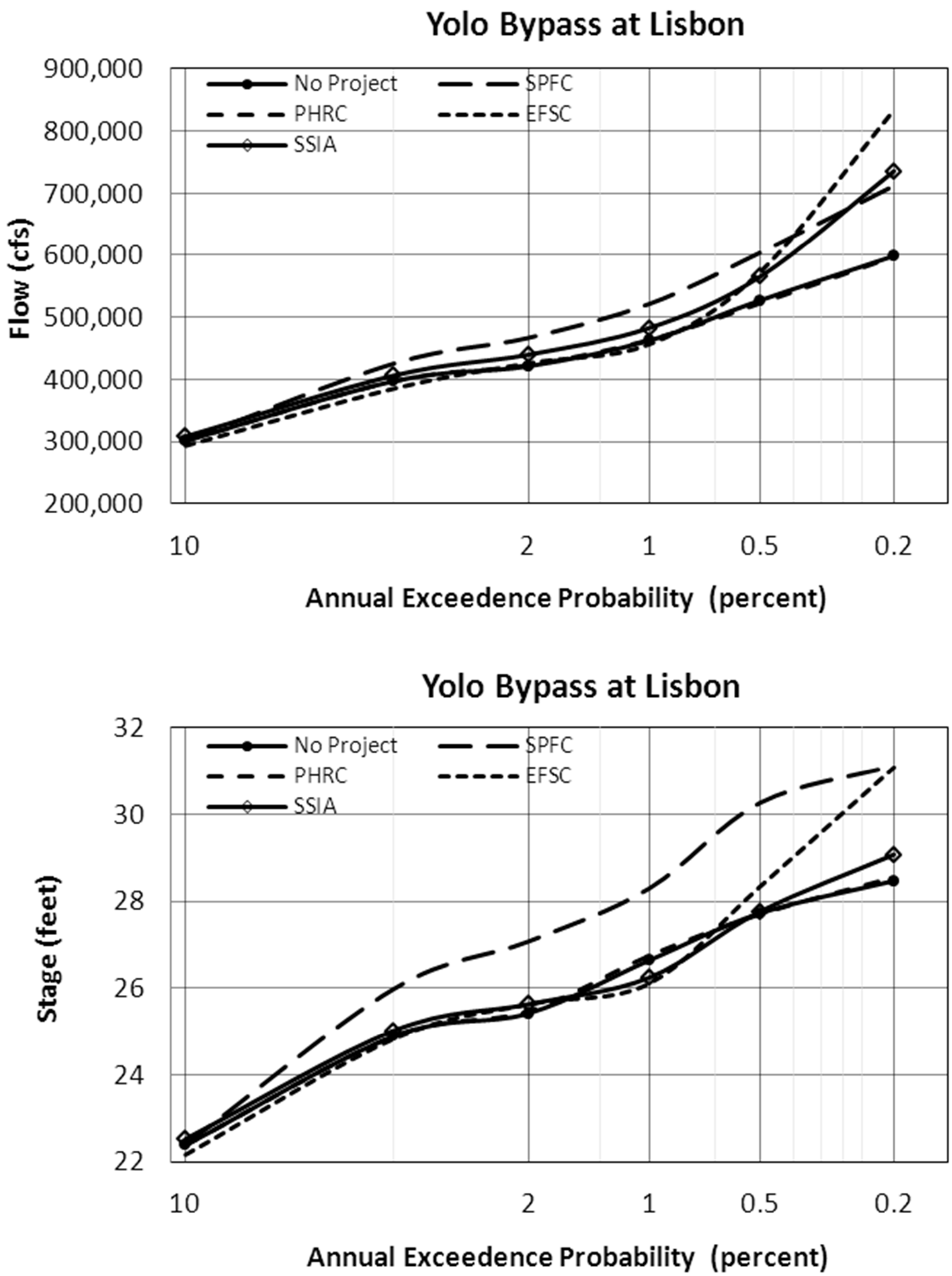


Figure 4-12. Flow- and Stage-Frequency Curves: Yolo Bypass at Lisbon [10]

- **SPFC and PHRC Approaches** – Flow and stage are higher than the No Project condition for the 0.2 percent AEP event because levee rehabilitation decreases the number of upstream levee breaks along the Feather River and more flows remain in the river channel.
- **EFSC Approach –** Increased flood management storage in Lake Oroville and Feather-Sutter Bypass reduce peak stage and flow for all events.
- **SSIA** – The Feather to Butte Basin (Biggs) Bypass diverts flow from the Feather River immediately downstream from Lake Oroville, which reduces flow and stage at this location compared to the No Project condition.

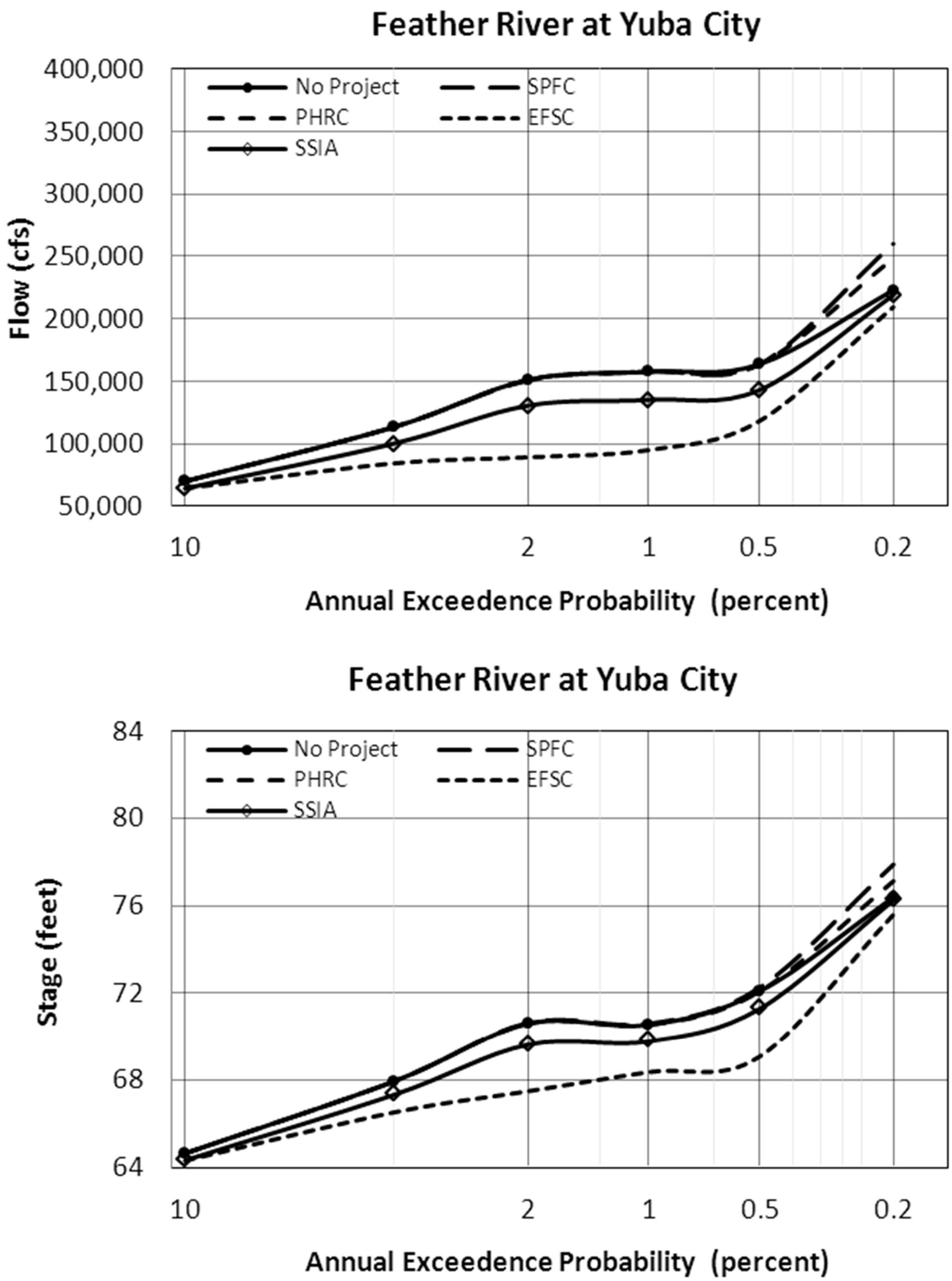


Figure 4-13. Flow- and Stage-Frequency Curves: Feather River at Yuba City [11]

- **No Project Condition and PHRC Approach** – Levee breaks upstream from this location cause the flow and stage to be approximately equal for both cases.

- **SPFC Approach** – Restoring SPFC levees reduces the number of upstream levee breaks along the Feather and Bear Rivers, retaining more in-channel flow compared to the No Project condition and increasing flow and stage.

- **EFSC Approach** – Restoring SPFC levees reduces the number of levee breaks along the Bear River and increases in-channel flow. The increased flow from the Bear is more than offset by the increased flood management storage in Lake Oroville and diversion of flows from the upper Feather River through Feather to Butte Basin (Biggs) Bypass. Peak flows are generally similar to the No Project condition up through the 1 percent AEP event. For larger flood events, the rehabilitated levees prevent significant outflows from levee breaks and greatly increase peak flows compared to the No Project condition.

- **SSIA** – Outflow from the Feather River through the Feather to Butte Basin (Biggs) Bypass causes river flow and stage to be lower than the No Project condition for all flood events

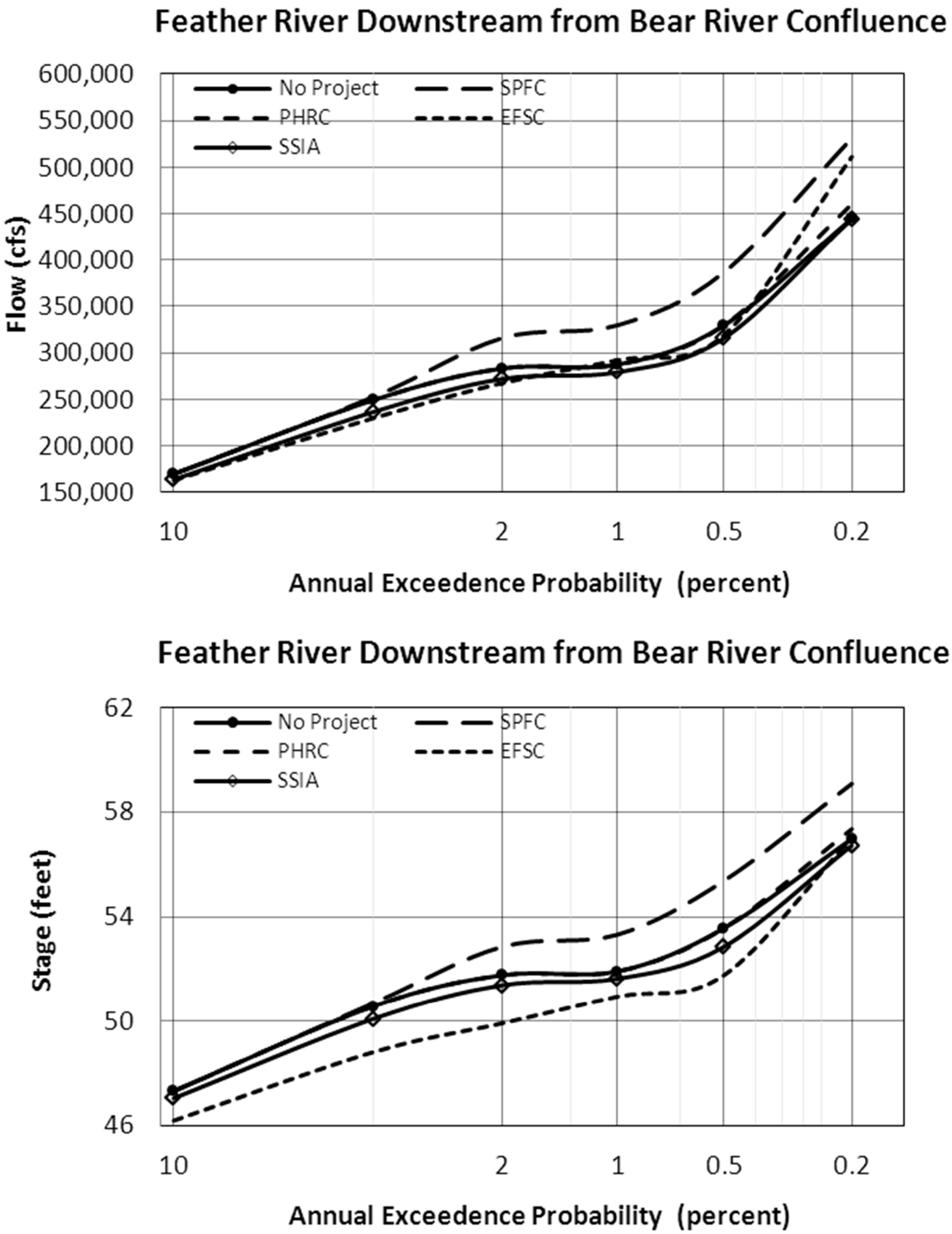


Figure 4-14. Flow- and Stage-Frequency Curves: Feather River Downstream from Bear River Confluence [12]

- **No Project Condition and All Approaches –** No modifications to the flood control system upstream from this location, so flows and stages are similar for the No Project condition and all approaches. Inflows remain relatively constant through the 1 percent AEP event, as a result of upstream reservoir flood management. At the 0.2 percent ARP event and greater, flows cause upstream levee breaks, but some of the flow in the floodplain returns to the channel upstream from this location.

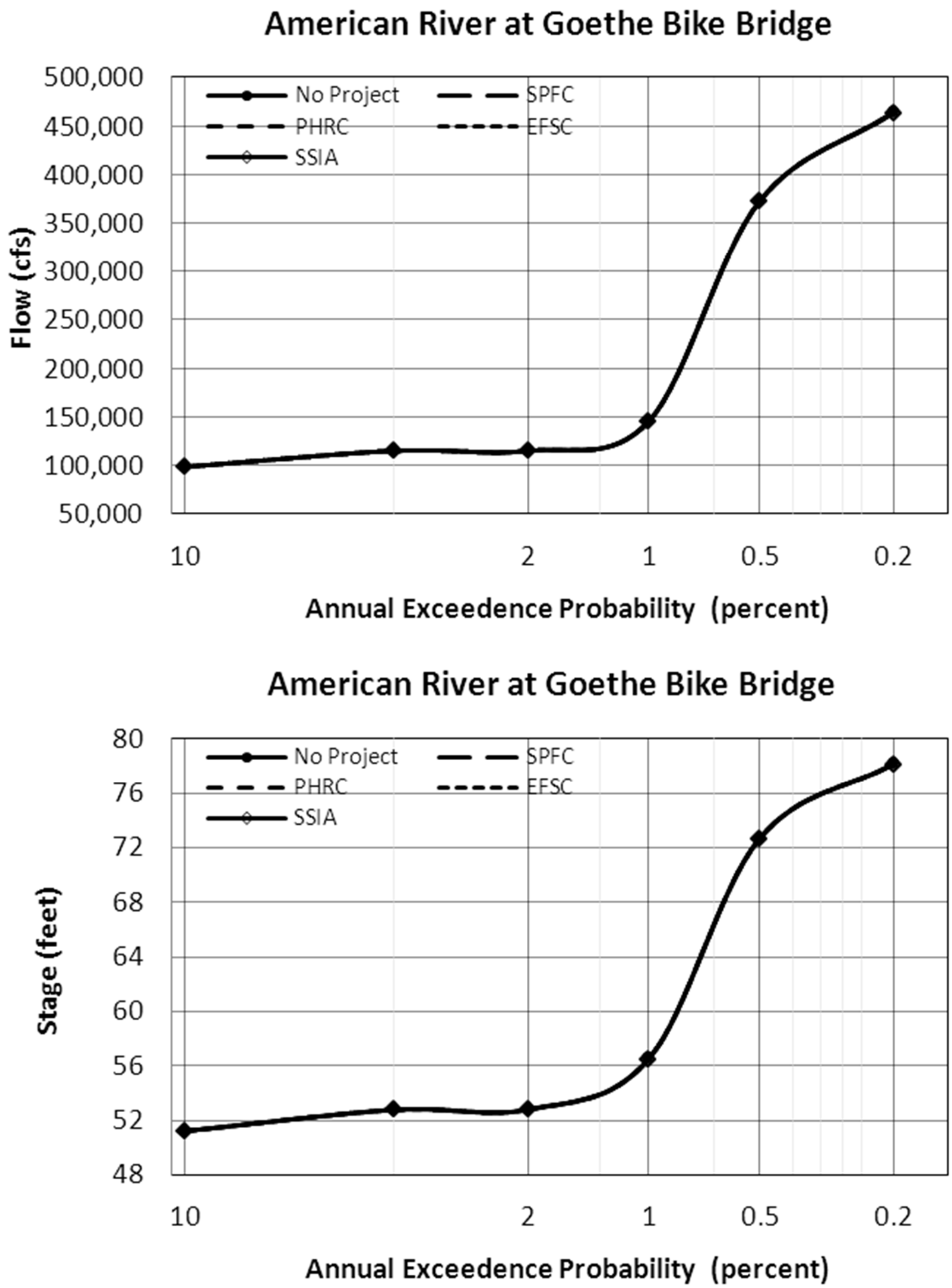


Figure 4-15. Flow- and Stage-Frequency Curves: American River at Goethe Bike Bridge [13]

Table 4-1. Sacramento River Basin Simulated Out-of-System Volumes by Return Period for No Project Condition, and Change in Out-of-System Volumes for CVFPP Approaches

Approach	Return Period (years)	Flood Zones															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
No Project Volume (acre-feet)	10	7	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0
	25	0	0	0	0	0	37	198	0	18	0	0	0	0	13	0	166
	50	24	0	0	0	0	54	264	0	21	0	91	0	0	19	0	287
	100	36	0	0	0	0	65	355	56	24	0	174	0	0	22	0	354
	200	61	0	0	478	0	349	402	100	450	0	244	0	0	25	0	429
	500	89	19	120	893	929	405	407	94	659	181	177	538	182	121	0	787
Achieve SPFC Design Flow Capacity Volume (acre-feet)	10	0	0	0	0	0	0	0	0	-14	0	0	0	0	0	0	0
	25	0	0	0	0	0	-37	-104	0	-18	0	0	0	0	-13	0	-166
	50	-24	0	0	0	0	-54	-78	0	-21	0	-91	0	0	-19	0	-287
	100	-36	0	0	0	0	-65	59	-56	-24	0	-174	0	0	-22	0	-287
	200	-61	0	0	-478	0	-18	92	-31	-425	0	-244	0	0	-25	0	-325
	500	-89	-19	-120	-127	-929	157	86	89	140	34	-90	33	-182	255	0	-423
Protect High Risk Communities Volume (acre-feet)	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	50	0	0	0	0	0	0	4	0	0	0	-91	0	0	0	0	0
	100	0	0	0	0	0	1	9	1	0	0	-174	0	0	0	0	0
	200	0	0	0	0	0	0	3	1	234	0	-244	0	0	0	0	0
	500	0	0	-1	-1	39	10	35	28	208	-167	71	-538	11	141	35	-134
Enhance Flood System Capacity Volume (acre-feet)	10	0	0	0	0	0	0	0	0	-14	0	0	0	0	0	0	0
	25	0	0	0	0	0	-37	-143	0	-18	0	0	0	3	-13	0	-166
	50	0	0	0	0	0	-54	-190	0	-21	0	-91	0	4	-9	0	-287
	100	0	0	0	0	0	-65	-240	-56	-24	0	-174	0	4	-8	0	-354
	200	0	0	0	-478	0	-349	2	-100	-450	0	-244	0	3	-13	0	-371
	500	0	-19	-120	-893	-929	76	84	85	-271	-167	-177	-538	-182	-121	0	-509
State Systemwide Investment Approach Volume (acre-feet)	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	25	0	0	0	0	0	1	2	0	0	0	0	0	2	0	0	-17
	50	0	0	0	0	0	2	4	0	0	0	-91	0	0	0	0	-42
	100	0	0	0	444	0	-6	-52	-4	-1	0	-174	0	0	0	0	-74
	200	0	0	0	26	0	-277	-11	-5	43	0	-244	0	0	0	0	-65
	500	0	1	300	85	-56	-73	31	205	-23	-167	66	-538	-12	44	0	-281

Notes: 10 percent AEP = 10-year return period
2 percent AEP = 50-year return period
0.5 percent AEP = 200-year return period
4 percent AEP = 25-year return period
1 percent AEP = 100-year return period
0.2 percent AEP = 500-year return period

Table 4-2. Sacramento River Basin Simulated Flow Volume into Delta

Approach	Flow Volume Entering Delta (TAF)*											
	10% AEP (10-year)		4% AEP (25-year)		2% AEP (50-year)		1% AEP (100-year)		0.5% AEP (200-year)		0.2% AEP (500-year)	
	Volume	Volume Change**	Volume	Volume Change**	Volume	Volume Change**	Volume	Volume Change**	Volume	Volume Change**	Volume	Volume Change**
No Project Condition	2,602	-	3,385	-	3,785	-	4,167	-	4,557	-	4,780	-
Achieve SPFC Design Flow Capacity Approach	2,602	0	3,506	121	3,979	195	4,436	270	5,015	459	5,513	733
Protect High Risk Communities Approach	2,602	0	3,385	0	3,782	-3	4,161	-5	4,554	-3	4,899	120
Enhance Flood System Capacity Approach	2,507	-95	3,249	-136	3,647	-138	3,974	-193	4,625	69	5,498	718
State Systemwide Investment Approach	2,601	-1	3,388	3	3,813	28	4,113	-54	4,634	78	4,986	206

Notes:
* based on the sum of volume of Sacramento River downstream from American River and Yolo Bypass at Lisbon during 1/18 -1/21
** Volume Change (TAF) is the difference between each approach and the No Project Condition
Key:
AEP = annual exceedence probability
SPFC = State Plan of Flood Control
TAF = Thousand acre-feet

- **No Project Condition, PHRC approach, and SSIA** – Levee breaks occur on Paradise Cut upstream from this location at the 0.5 percent AEP event, allowing a large amount of flow to leave the San Joaquin River, which reduces flow and stage compared to other approaches (for the 0.2 percent AEP event, the same levee breaks occur in other approaches). For the 0.2 percent AEP event, there are also levee breaks just downstream from this location, which result in a higher peak flow rate compared to other approaches, without a significant increase in stage relative to the other approaches.

- **SPFC Approach** – Restoring SPFC levees reduces the number of upstream levee breaks for all events compared to the No Project condition, so peak flows and stages tend to be higher. For the 0.2 percent AEP event, levee restoration also prevents a levee break downstream from this location, so the flow is slightly reduced compared to the No Project condition despite a higher stage.

- **EFSC Approach** – Restoring SPFC levees reduces upstream levee failures similar to the SPFC approach. Flows and stages at this location are generally similar to or lower than the No Project condition and other approaches due to increased upstream reservoir storage and floodplain storage areas, which tend to reduce peak flows and stages. At the 0.5 percent AEP flood, levee restoration reduces the number of levee breaks immediately upstream from this location (both along the San Joaquin River and in Paradise Cut) compared to the No Project condition, so flows and stages are higher. Similar to the SPFC approach, at the 0.2 percent AEP event levee restoration prevents a significant levee break downstream from this location, so the flow is slightly reduced compared to the No Project condition.

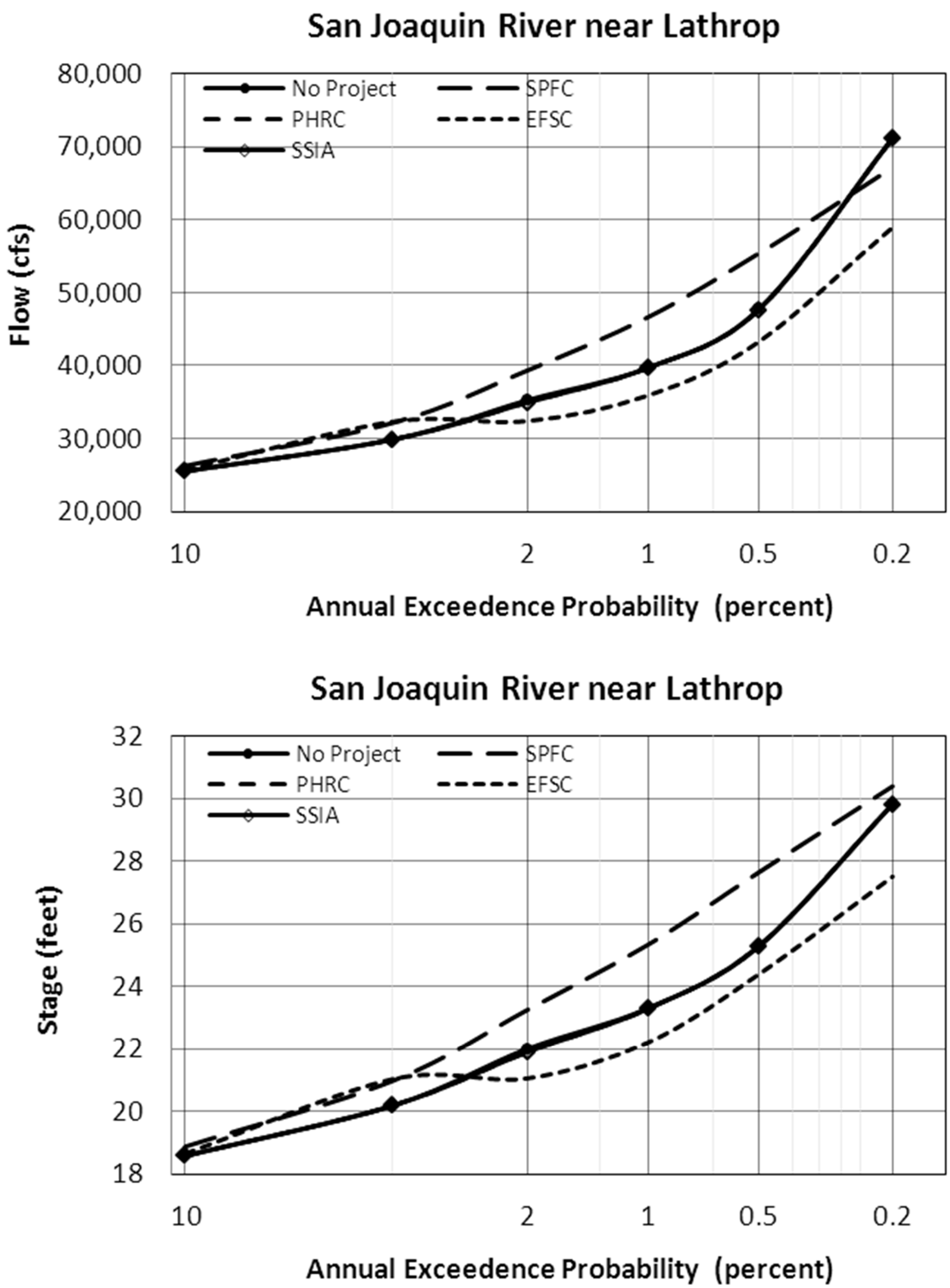


Figure 4-16. Flow- and Stage-Frequency Curves: San Joaquin River Near Lathrop [1]

- **No Project Condition** – Significant levee breaks occur upstream from this location for all floods larger than the 4 percent AEP event. At the 2 percent AEP event, stage continues to rise despite decreasing flows because of the backwater effect from the inflows from the Stanislaus River immediately downstream from this location. For larger events, inflows from the Tuolumne River upstream from this location and the Stanislaus River downstream from this location cause significant increases in flow and stage despite levee breaks along the San Joaquin River.

- **SPFC Approach** – Restoring SPFC levees reduces the number of upstream levee breaches, increasing stage and flow compared to the No Project condition for all events. Levee restoration also prevents a levee break immediately downstream from this location through the 1 percent AEP event, increasing downstream river stage compared to the No Project condition and all other approaches. The resulting backwater effect increases the peak stage for the SPFC approach for these events. At the 0.5 percent AEP event and greater, this levee breaches, so peak stage converges with the No Project condition, but flows continue to increase.

- **PHRC Approach and SSIA** – Levee restoration prevents levee breaches along the Tuolumne River through the 1 percent AEP flood, and as a result, the flow in the San Joaquin River between the Tuolumne and Stanislaus river confluences is greatest for these approaches. However, there is no appreciable difference in stage compared to the No Project condition because levees immediately downstream from this location break in the same location. For the 0.5 percent and 0.2 AEP events, levees along the Tuolumne River fail, so flows tend to converge with the No Project and SPFC approaches.

- **EFSC Approach** – Restoring SPFC levees reduces the number of upstream levee breaks compared to the No Project condition, increasing peak flow through the 1 percent AEP event. However, at the 0.5 percent and 0.2 percent AEP floods, the combined effects of an increased flood management pool in New Don Pedro Reservoir and transitory storage areas along the Tuolumne and San Joaquin Rivers act to keep flows lower than the No Project condition and all other approaches. River stage is lower than the No Project condition for all flood events as a result of levee setbacks along the San Joaquin River, which increase the conveyance capacity at any given stage.

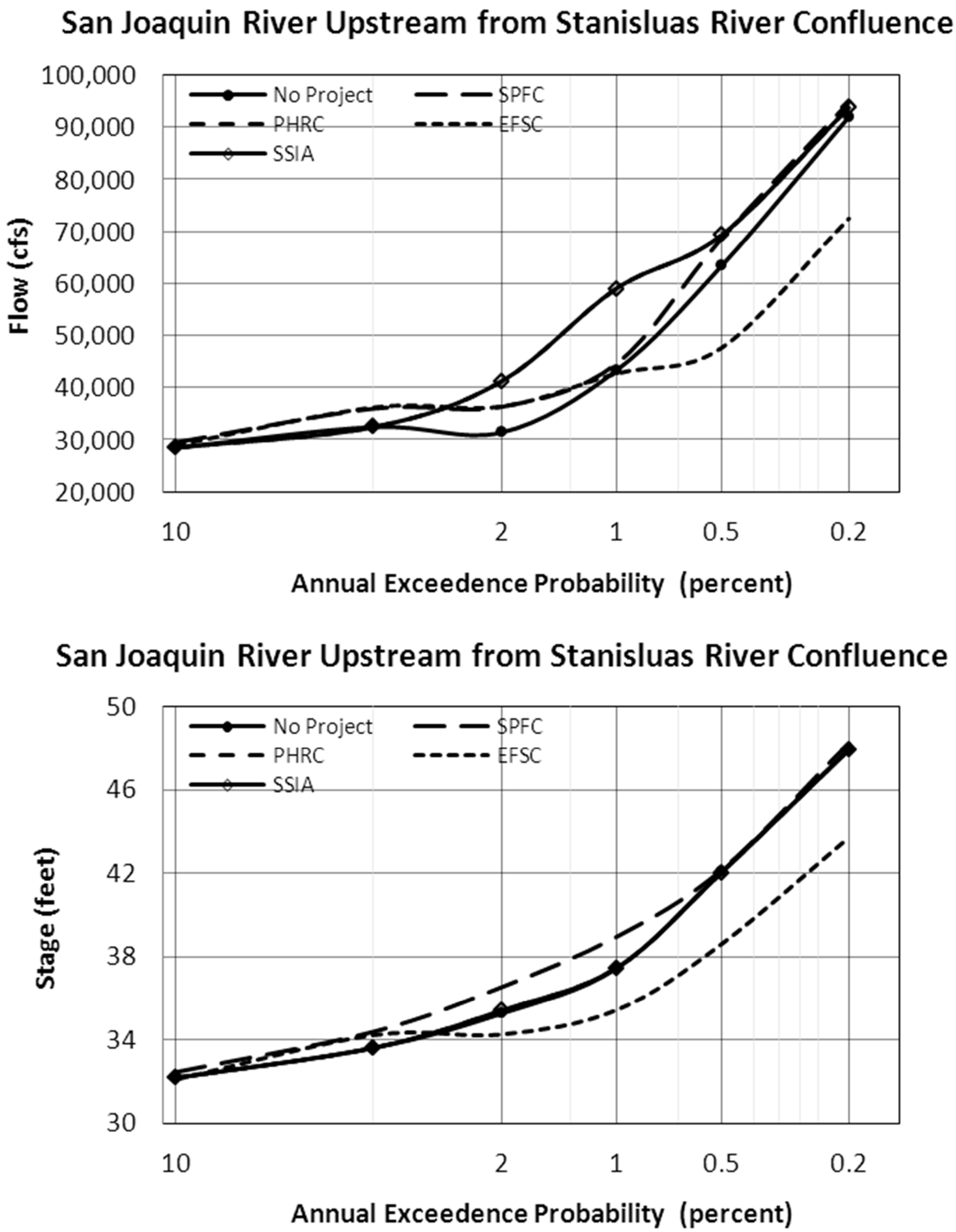


Figure 4-17. Flow- and Stage-Frequency Curves: San Joaquin River Upstream from Stanislaus River Confluence [2]

- **No Project Condition, PHRC Approach, and SSIA** – No modifications to the flood management system upstream from this location, and significant upstream levee breaks occur for all events larger than the 10 percent AEP flood. Levee breaks release flow into adjacent floodplains, so in channel flows and river stages are lower than for approaches with strengthened levees for all flood events. For large flood events (0.1 percent AEP and larger), the magnitude of Merced River inflows (which mostly enter from the surrounding floodplain) is much larger than San Joaquin River flow, and tends to cause flows to increase significantly, converging with SPFC and EFSC flows.

- **SPFC Approach** – Restoring SPFC levees reduces the number of upstream levee breaks through the 1 percent AEP event, increasing in-channel flow and stage compared to the No Project condition. At the 0.5 percent AEP event and greater, inflows from the Merced River (which mostly enter from the surrounding floodplain) tend to cause flows to converge with the No Project condition.

- **EFSC Approach** – Restoring SPFC levees results in higher flows and stages compared to the No Project condition in most cases. In-channel peak flows are higher and stages are lower than in No Project Condition and all other approaches for the 0.2 percent AEP because there is significantly less flow entering the San Joaquin River from the Tuolumne River downstream from this location, as a result of floodplain storage areas along the Tuolumne River and an increased flood management pool at New Don Pedro Reservoir. The lower downstream flow leads to a reduced backwater effect, which travels upstream to this location and tends to reduce river stage while also allowing for faster flows and higher flow rates.

  Peak inflows to the Merced River are reduced in the EFSC approach for all events larger than the 4 percent AEP flood event by the increased flood pool in New Exchequer Dam. However, levee breaks occur along the Merced River for the No Project condition and all approaches except EFSC for the 2 percent AEP flood and greater, releasing significant amounts of flow to the surrounding floodplain, such that flows in the Merced River at the San Joaquin River confluence are approximately equal for all approaches. Much of this flow re-enters the San Joaquin River through levee breaches along the San Joaquin River.

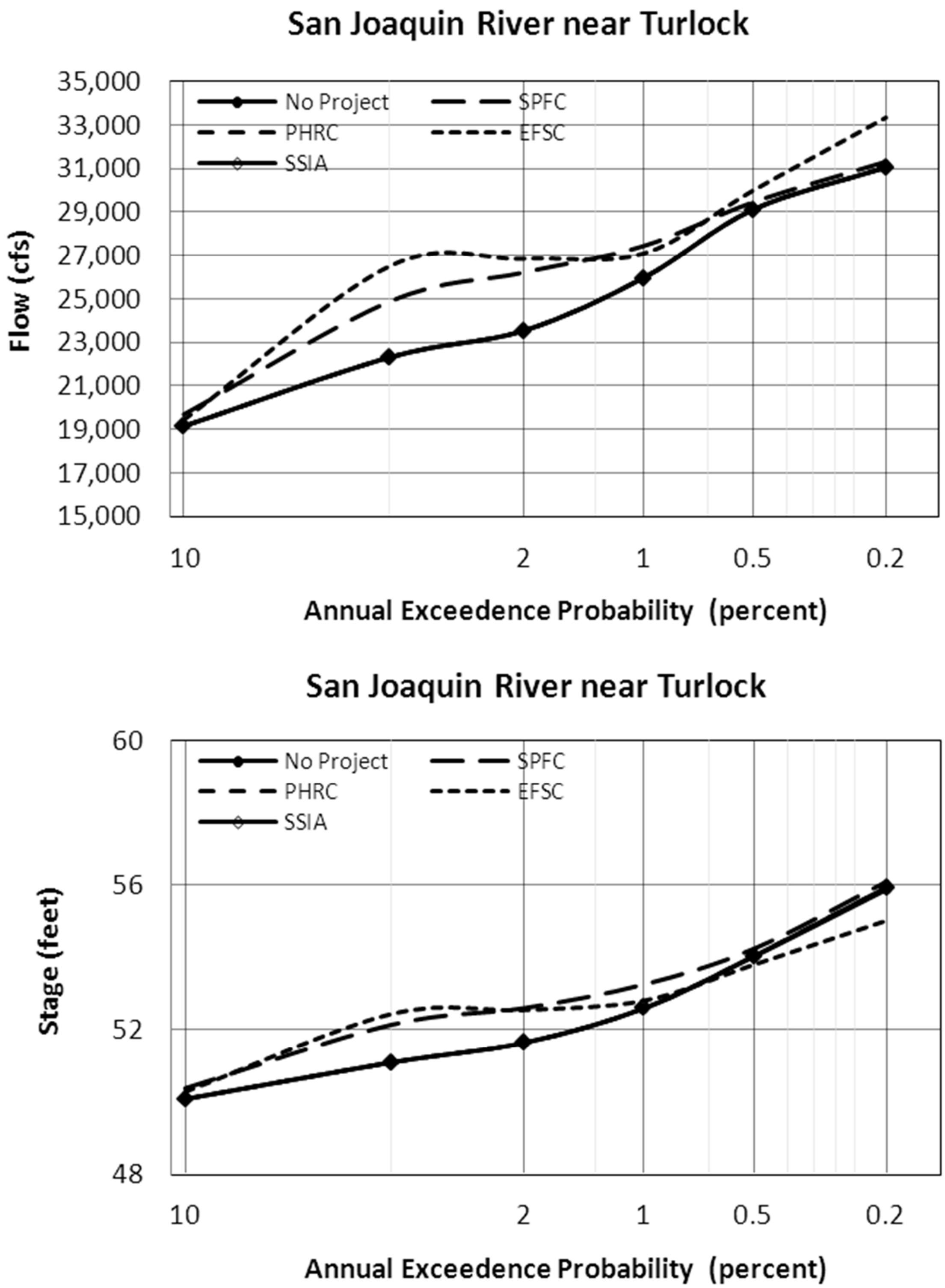


Figure 4-18. Flow- and Stage-Frequency Curves: San Joaquin River near Turlock [3]

- **No Project Condition, PHRC Approach, and SSIA –** No modifications to the flood management system upstream from this location, and significant levee breaks occur for all events larger than the 10 percent AEP flood, both along the San Joaquin River and along the Chowchilla/Eastside Bypass. Levee breaks release flow into adjacent floodplains, so in channel flows and river stages are generally lower than for approaches with strengthened levees. However, for larger flood events (0.5 percent AEP and larger), there are significant inflows to the San Joaquin River from the surrounding floodplain upstream from this location, significantly increasing river flows and stages. The majority of these inflows originate from the Merced River.

- **SPFC Approach** – Restoring SPFC levees reduces the number of upstream levee breaks for all events, increasing in-channel flow and stage compared to the No Project condition. However, for the 0.5 percent AEP event and larger events, overflows from the Merced River enter the San Joaquin River just upstream from this location, as in the No Project condition, so flow and stage tend to converge with those in the No Project condition at the 0.5 percent AEP event.

- **EFSC Approach** – As for the SPFC approach, restoration of SPFC levees results in higher flows and stages compared to the No Project condition in most flood events. For the 0.5 percent AEP flood, flows are lower than in the No Project condition and all other approaches because peak flows along the Merced River are reduced as a result of the increased flood pool at New Exchequer Dam, levee breaks along the Merced River occur later in the storm, which reduces the volume of flows into the floodplain area around the San Joaquin River, thereby, reducing the stage in the floodplain, resulting in reduced outflow from the floodplain to the river. At the 0.2 percent AEP event, flows overwhelm levees along the Merced River, so flow and stage is similar to the No Project condition.

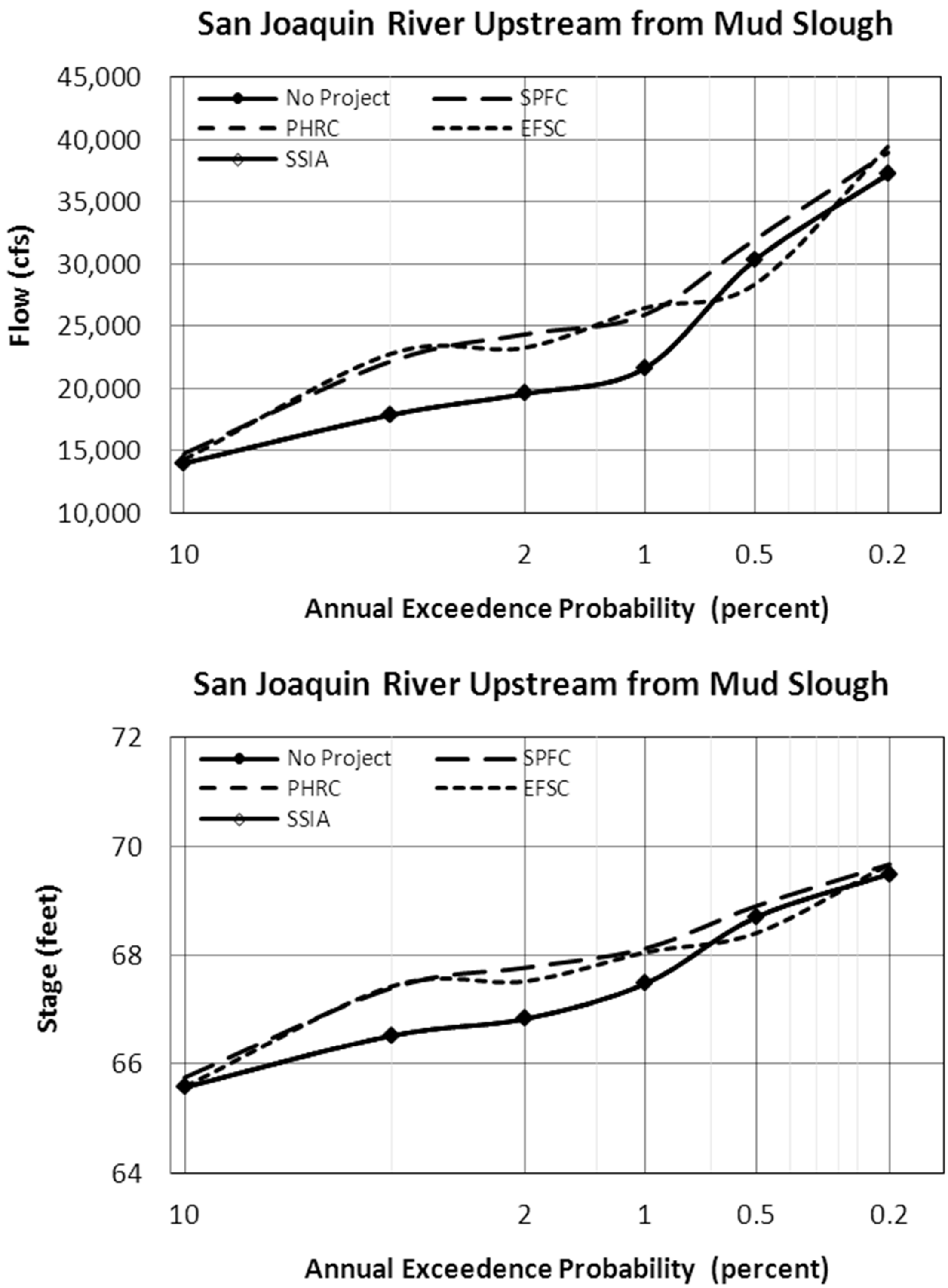


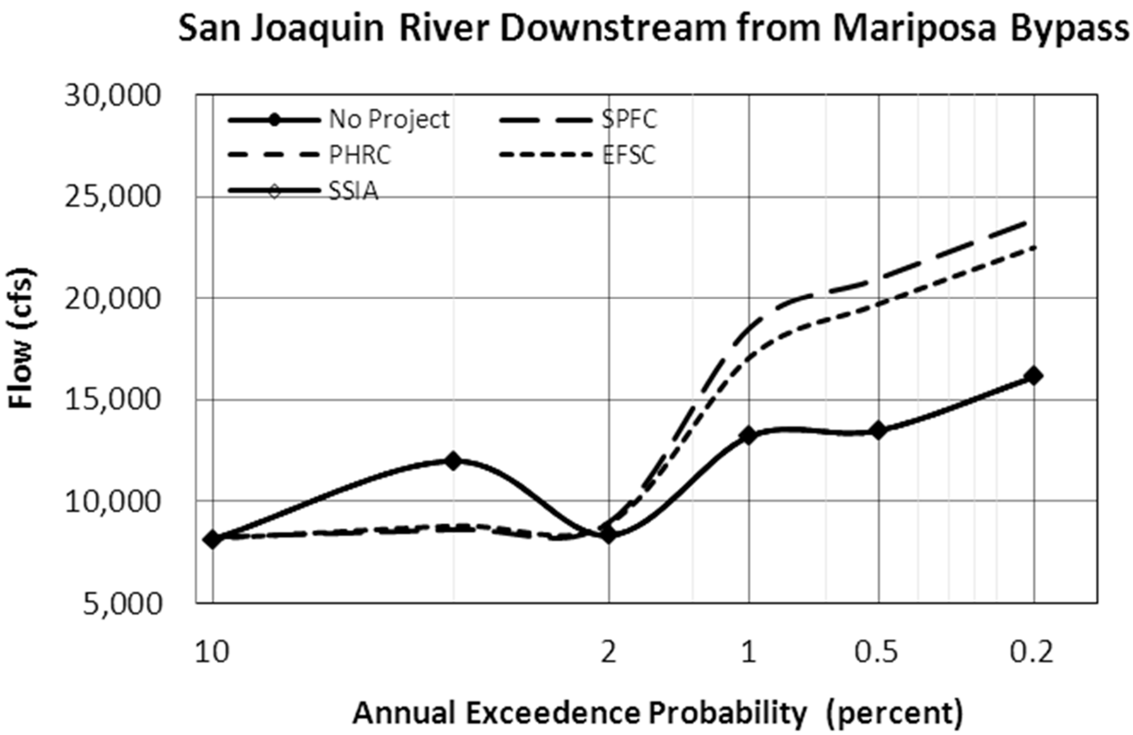
Figure 4-19. Flow- and Stage-Frequency Curves: San Joaquin River Upstream from Mud Slough [4]

- **No Project Condition, PHRC Approach, and SSIA –** Existing levees along the Chowchilla Bypass fail for all events greater than the 10 percent AEP flood, releasing a portion of the Chowchilla Bypass flow into the San Joaquin River upstream from the Mariposa Bypass. However, significant levee breaks also occur along the San Joaquin River for the 1 percent AEP event with these approaches, significantly reducing in-channel flow and stage compared to the 2 percent AEP event. In-channel flows for larger events increase only moderately because of the levee failures.

- **SPFC Approach** – Restored SPFC levees contain flow in the Chowchilla Bypass through the 4 percent AEP event, reducing San Joaquin River flows. At the 2 percent AEP event and greater those levees fail, releasing a portion of the bypass flow into the San Joaquin River upstream from the Mariposa Bypass. However, because there are fewer upstream levee breaks compared to the No Project condition, a larger volume of flow is available in the Chowchilla Bypass when levees fail, so higher flows are released into the San Joaquin River compared to the No Project condition. Improved levees along the San Joaquin River also maintain higher in-channel flows, breaking only at the 0.2 percent AEP event.

- **EFSC Approach** – Increased flood management pool at Friant Dam and restored SPFC levees allow Chowchilla and Mariposa Bypass flows to be managed through the 2 percent AEP flood event. Above the 2 percent AEP event, Chowchilla bypass levees break and release flow into the San Joaquin River. As in the SPFC approach, higher flows in the Chowchilla bypass at the time of the levee break lead to greater flows into the San Joaquin River compared to the No Project condition. Improved levees along the San Joaquin River maintain higher in-channel flows in the river compared to the No Project condition.

  River stage is consistently lower for the EFSC approach than for all other approaches despite higher flow rates at the 1 percent AEP event and greater because, when Chowchilla levees fail and release water into the floodplain the bypass and the San Joaquin River, stage in the San Joaquin River is lower than in other approaches. This lower stage (effects resulting from increased Friant flood management pool) increases the water surface slope between the floodplain and the San Joaquin River and results in more water flowing into the river channel.



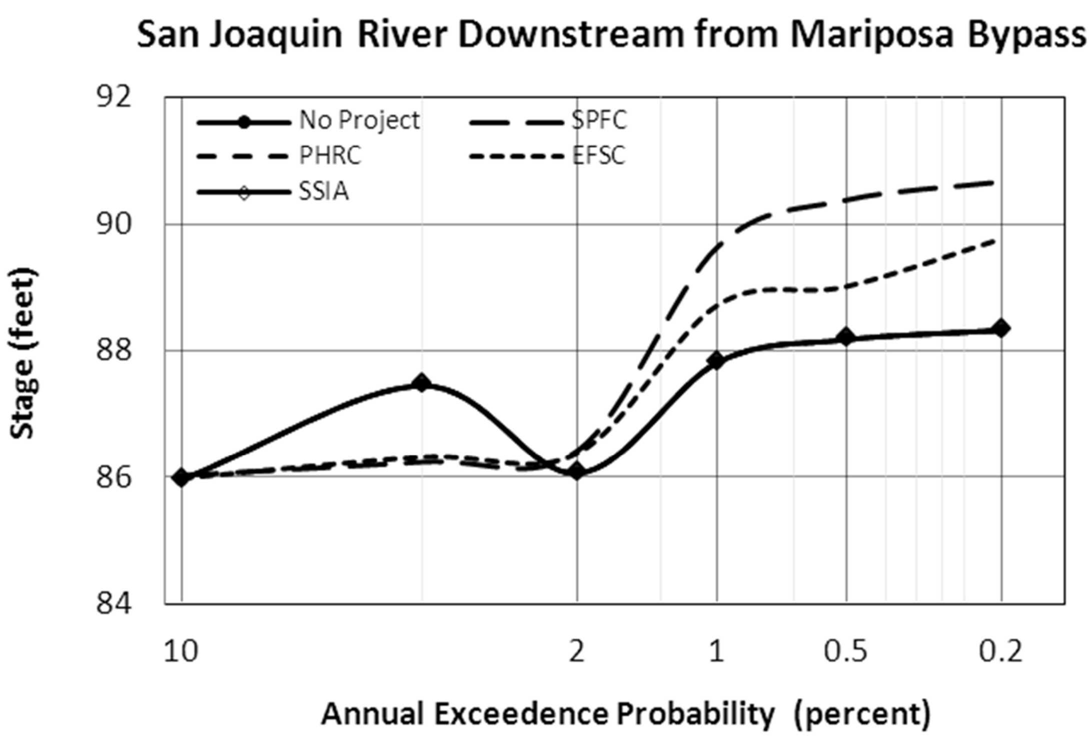


Figure 4-20. Flow- and Stage-Frequency Curves: San Joaquin River Downstream from Mariposa Bypass [5]

- **No Project Condition, PHRC Approach, and SSIA** – The stage in the San Joaquin River above the Chowchilla Bifurcation Control Structure for events greater than 4 percent AEP is high enough that significant levee breaks occur. These breaks allow large volumes of water to enter the surrounding floodplain shortly after the start of the flood event. The stage in the floodplain soon becomes great enough to breach levees along the San Joaquin River and allow water in the floodplain to enter the river. Although flow in the San Joaquin River immediately downstream from the Chowchilla Bifurcation Control Structure is the same for all scenarios, these flows re-enter the river upstream from Firebaugh and increase flow and stage. For the 1 percent AEP event through the 0.2 percent AEP event, peak flow increases slightly while the peak stage remains constant because there is a levee break immediately downstream from this location

- **SPFC Approach** – Peak flows are slightly higher for the 1 percent AEP flood event and greater compared to the No Project condition due to levee rehabilitation, and higher than in the EFSC approach due to the absence of any changes to flood storage at Friant Dam.

- **EFSC Approach** – Peak flows in the San Joaquin River are reduced by increased flood management storage at Friant Dam to the point that significant levee breaks are reduced or delayed through the 1 percent AEP event. As a result, the floodplain does not fill and there is little to no inflow into the San Joaquin River from the surrounding floodplain upstream from Firebaugh. However, at the 0.5 percent AEP flood and greater, although there is some reduction in peak flows below Friant Dam, even the reduced flows are too great to prevent significant levee breaks upstream from the control structure, and there are significant inflows to the San Joaquin River from the floodplain as in the No Project condition and other approaches.

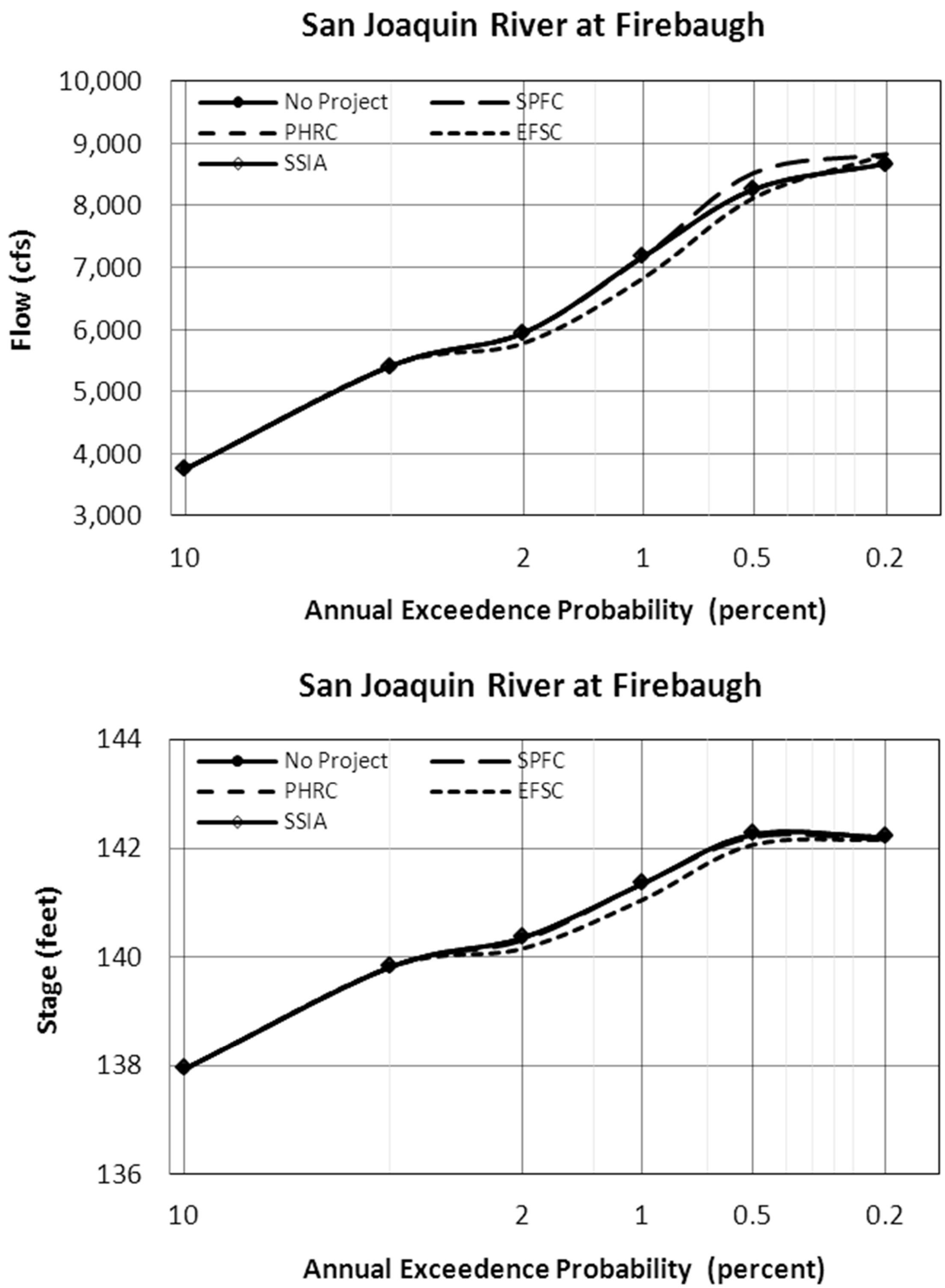
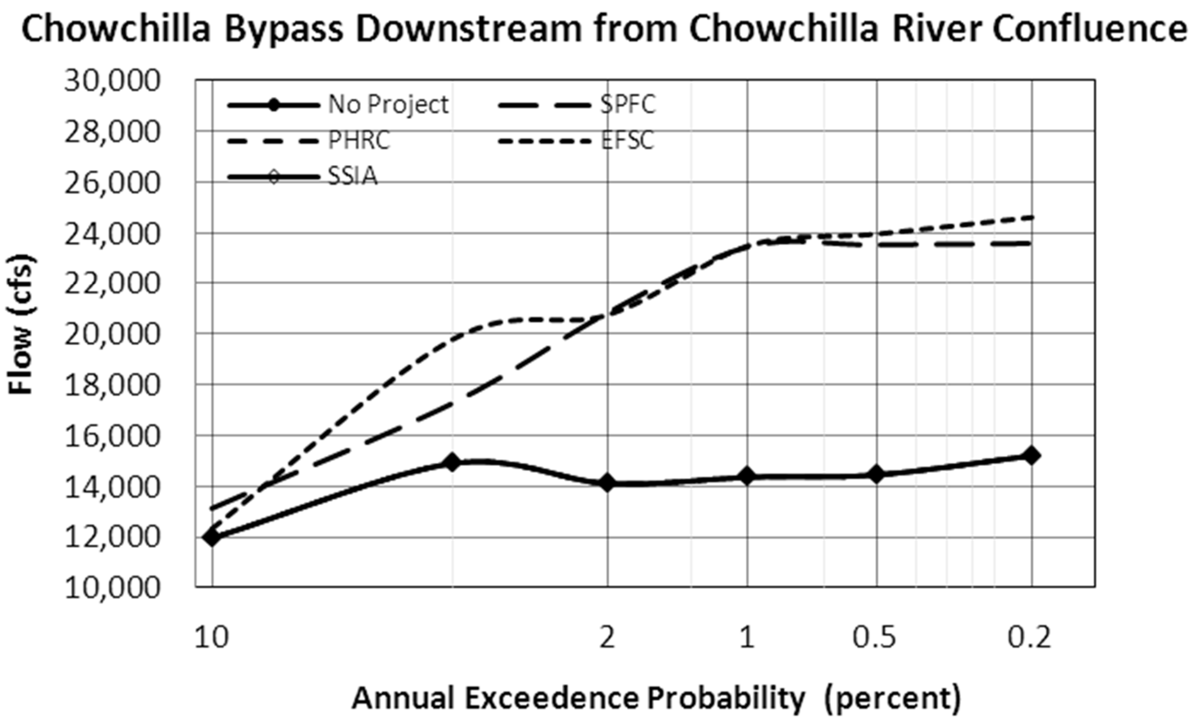


Figure 4-21. Flow- and Stage-Frequency Curves: San Joaquin River at Firebaugh [6]

- **No Project Condition** –Levee breaks occur upstream from this location, and levee breaks occur for all events larger than the 10 percent AEP flood. Levee breaks release flow into adjacent floodplains, so in-channel flows and river stages are lower than for approaches with strengthened levees for all flood events. Larger flood events (0.1 percent AEP and larger) greatly exceed the channel capacity, and cause virtually no increases in in-channel stage and flow.

- **SPFC Approach** – Restoring SPFC levees reduces the number of upstream levee breaks through the 2 percent AEP event, increasing in-channel flow and stage compared to the No Project condition. At the 1 percent AEP event and greater, significant upstream levee breaks occur, so peak flow and stage remains relatively constant; however, the improved levees maintain higher in-channel flow and stage compared to the No Project condition.

- **EFSC Approach** – Restoring SPFC levees results in higher flows and stages compared to the No Project condition. In-channel peak flows are lower for the EFSC approach compared to the SPFC approach for the 4 percent and 2 percent AEP events because of increased flood management pool at Friant Dam. Friant Dam continues to provide some management of flood peaks at the 1 percent AEP event and greater in the EFSC approach.



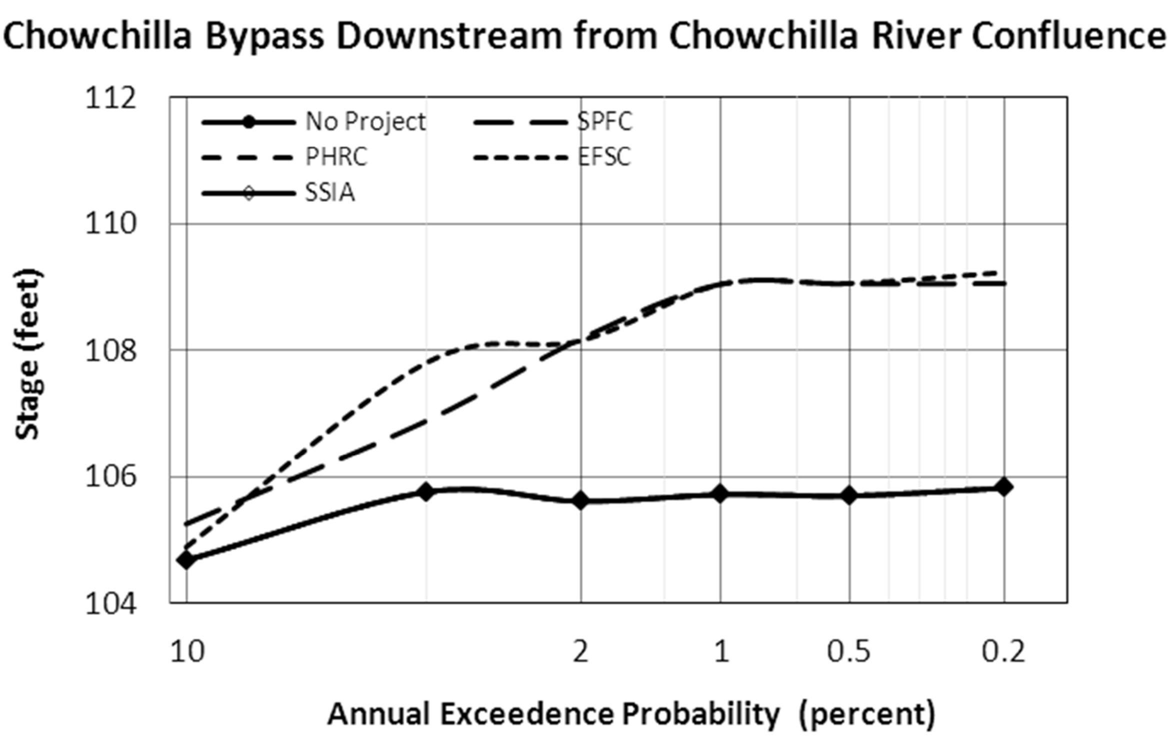
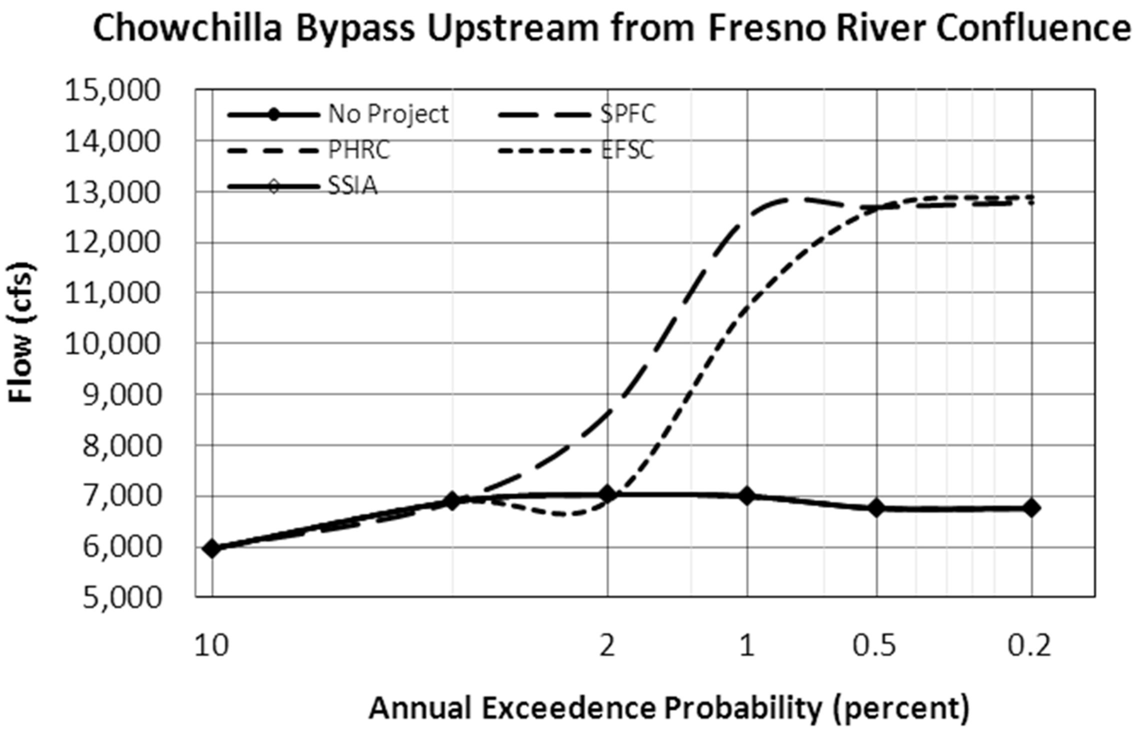


Figure 4-22. Flow- and Stage-Frequency Curves: Chowchilla Bypass Upstream from Chowchilla River Confluence [7]

- **No Project Condition, PHRC Approach, and SSIA –** No modifications to the flood management system upstream from this location, and significant levee breaks occur for all events larger than the 4 percent AEP flood. Levee breaks release flow into adjacent floodplains, so in channel flows and river stages are lower than for approaches with strengthened levees for all flood events. Maximum flows and stages decrease slightly with larger flood events because increased flows cause more upstream levee breaks.

- **SPFC Approach** – Restoring SPFC levees reduces the number of significant upstream levee breaks for all events, increasing in-channel flow and stage compared to the No Project condition. Peak flows remain nearly constant beyond the 2 percent AEP event because inflows to the bypass are reduced by upstream levee failures. Peak stage continues to increase up to the 0.5 percent AEP event because of increasing backwater effects from higher downstream flows (flows reenter the channel from the floodplain through a levee breach immediately downstream from this location).

- **EFSC Approach** – Restoring SPFC levees results in higher flows and stages compared to the No Project condition. In-channel peak flows are lower for the EFSC approach compared to the SPFC approach for the 4 percent and 2 percent AEP events because the increased flood management pool at Friant Dam reduces peak discharge rates to the San Joaquin River. Peak flow and stage is approximately equal to the SPFC approach beyond the 2 percent AEP because inflows to the Bypass are reduced by upstream levee failures.



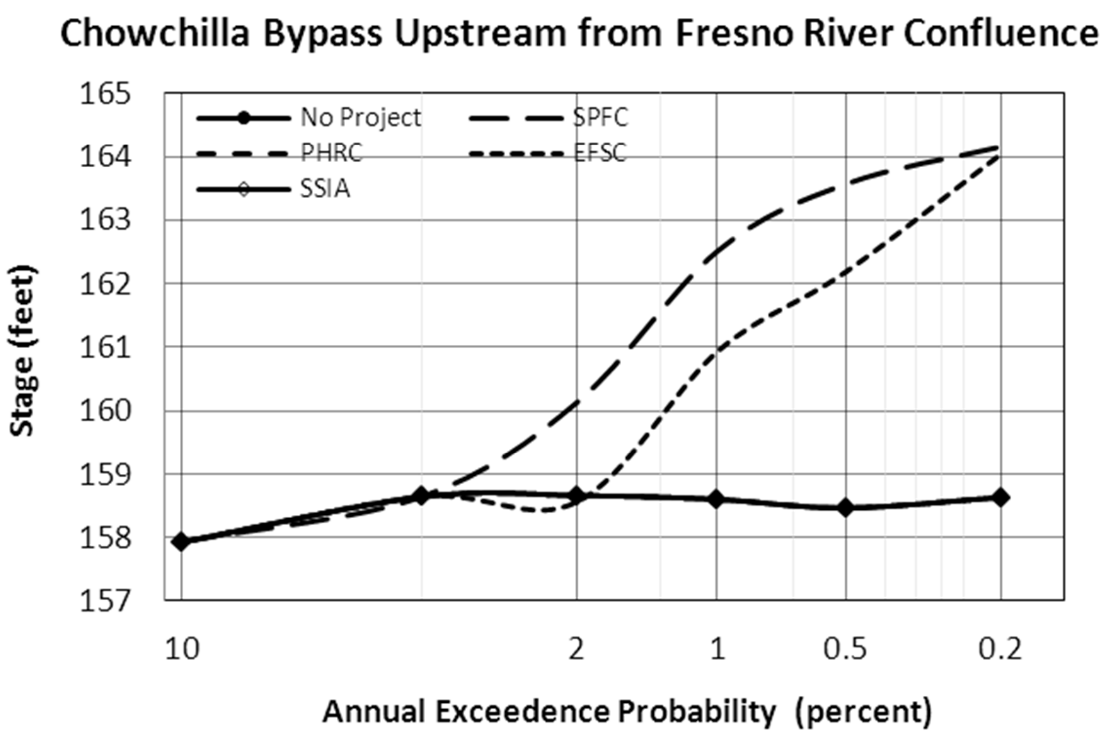
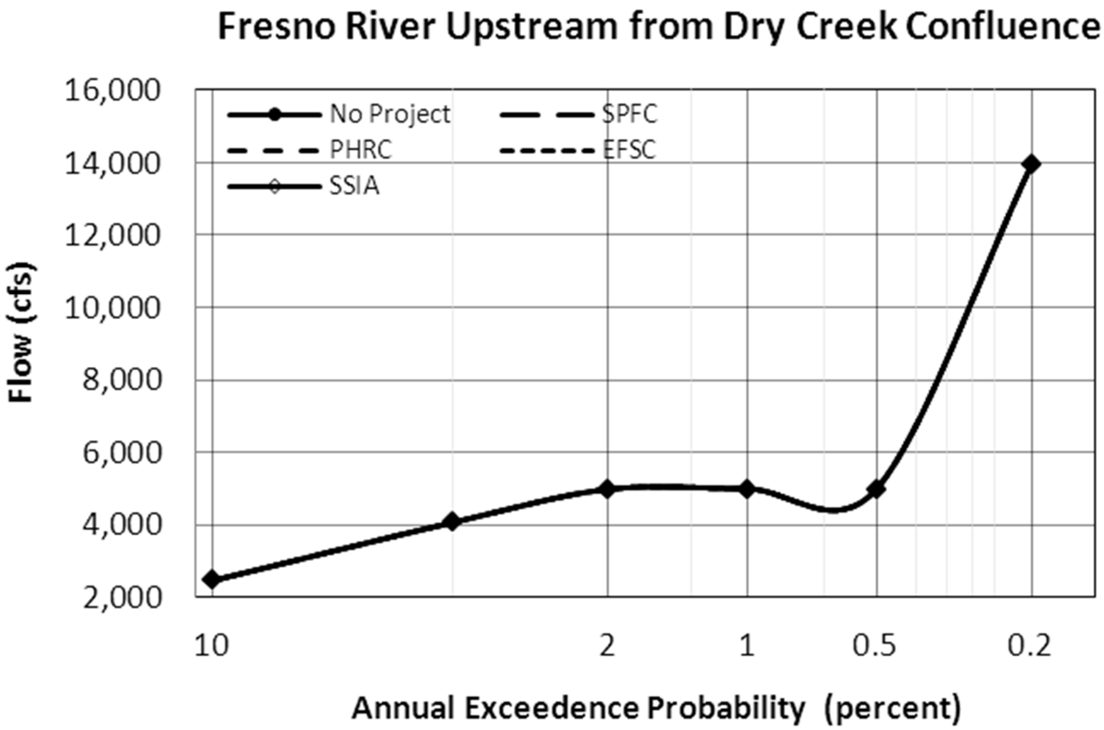


Figure 4-23. Flow- and Stage-Frequency Curves: Chowchilla bypass Upstream from Fresno River Confluence [8]

- **No Project Condition, PHRC Approach, and SSIA –** No modifications to the existing flood management system along the Fresno River, and significant levee breaks occur along the Fresno River downstream from this location for all events larger than the 2 percent AEP. Levee breaks release flow into adjacent floodplains, resulting in a decreased backwater effect and a subsequent drop in the river stage. The peak flow upstream from this location is the same for the 1 percent and 0.5 events, due to upstream reservoir operations, so there is no change in river flow or stage at these events.

- **SPFC and EFSC Approaches** – Reduce the number of downstream levee breaks on the Chowchilla Bypass for all events, resulting in an increased backwater effect and higher stages compared to the No Project condition. Because there are no modifications to the flood management system upstream from this point, peak flows are approximately equal in all events (this location is very close to a boundary point in the model, so flows are mostly controlled by boundary inflows). The peak flow upstream from this location is the same for the 1 percent and 0.5 events, due to upstream reservoir operations, so there is no change in river flow or stage at these events.



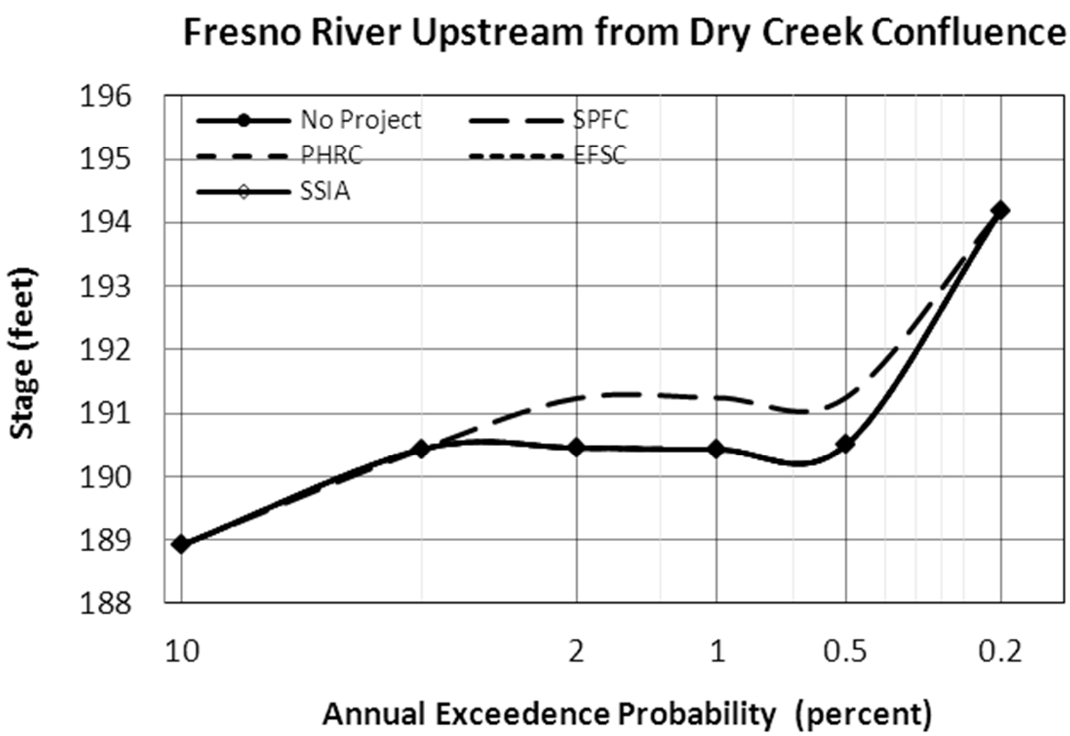


Figure 4-24. Flow- and Stage-Frequency Curves: Fresno River Upstream from Dry Creek Confluence [9]

Table 4-3. San Joaquin River Basin Simulated Out-of-System Volumes by Return Period for No Project Condition, and Change in Out-of-System Volumes for CVFPP Approaches

Approach	Return Period (years)	Flood Zones												
		1	2	3	4	5	6	7	8	9	10	11	12	13
No Project Volume (acre-feet)	10	0	0	0	0	27	0	24	0	0	0	0	0	0
	25	0	0	0	0	41	0	42	234	0	0	0	0	0
	50	0	0	0	192	82	0	58	0	0	198	0	0	0
	100	113	0	0	186	98	0	44	427	0	311	31	46	64
	200	148	0	0	301	113	69	50	485	0	370	38	86	420
	500	183	0	0	376	173	245	55	606	101	372	45	181	642
Achieve SPFC Design Flow Capacity Volume (acre-feet)	10	0	0	0	0	-27	0	-24	0	0	0	0	0	0
	25	0	0	0	0	-41	0	-42	-234	0	0	0	0	0
	50	0	0	0	-192	-82	0	-58	0	0	3	0	0	0
	100	1	0	0	-186	-98	0	-44	-76	0	2	-31	-29	-64
	200	-1	0	0	-210	-113	-69	-29	-65	0	-6	-9	0	-310
	500	-1	0	0	-241	-49	-49	-9	-73	-101	-8	-3	12	-15
Protect High Risk Communities Volume (acre-feet)	10	0	0	0	0	0	0	0	0	0	0	0	0	0
	25	0	0	0	0	0	0	0	0	0	0	0	0	0
	50	0	0	0	0	0	0	0	0	0	-194	37	0	0
	100	0	0	0	0	0	0	0	0	0	-310	-11	8	0
	200	0	0	0	0	0	0	0	0	0	-369	-1	-1	-1
	500	0	0	0	0	0	0	0	0	0	-371	0	5	-1
Enhance Flood System Capacity Volume (acre-feet)	10	0	0	0	0	-27	0	-24	0	0	0	0	0	0
	25	0	0	0	0	-41	0	-42	-234	0	0	0	0	0
	50	0	0	0	-192	-82	0	-58	0	0	-198	0	0	0
	100	-109	0	0	-186	-98	0	-44	-118	0	-189	-31	-46	-64
	200	-38	0	0	-301	-113	-69	-26	-69	0	-94	-38	-71	-411
	500	-26	0	0	-256	-49	-245	2	-61	-101	9	-20	-77	-205
State Systemwide Investment Approach Volume (acre-feet)	10	0	0	0	0	0	0	0	0	0	0	0	0	0
	25	0	0	0	0	0	0	0	0	0	0	0	0	0
	50	0	0	0	0	0	0	0	0	0	-194	37	0	0
	100	0	0	0	0	0	0	0	0	0	-310	-11	8	0
	200	0	0	0	0	0	0	0	0	0	-369	-1	-1	-1
	500	0	0	0	0	0	0	0	0	0	-371	0	5	-1

Notes: 10 percent AEP = 10-year return period; 4 percent AEP = 25-year return period
2 percent AEP = 50-year return period; 1 percent AEP = 100-year return period
0.5 percent AEP = 200-year return period; 0.2 percent AEP = 500-year return period

Table 4-4. San Joaquin River Basin Simulated Flow Volume into Delta

Approach	*Flow Volume Entering Delta (TAF)											
	10% AEP (10-year)		4% AEP (25-year)		2% AEP (50-year)		1% AEP (100-year)		0.5% AEP (200-year)		0.2% AEP (500-year)	
	Volume	Volume Change**	Volume	Volume Change**	Volume	Volume Change**	Volume	Volume Change**	Volume	Volume Change**	Volume	Volume Change**
No Project Condition	251	-	312	-	338	-	378	-	463	-	590	-
Achieve SPFC Design Flow Capacity Approach	252	1	321	9	352	14	404	26	483	20	605	15
Protect High Risk Communities Approach	251	0	312	0	337	-1	379	1	464	1	590	0
Enhance Flood System Capacity Approach	253	2	323	11	316	-22	382	4	457	-6	566	-24
State Systemwide Investment Approach	251	0	312	0	337	-1	379	1	464	1	590	0

Notes:
*based on the volume of San Joaquin River at Vernalis during 1/18 - 1/21
** Volume Change (TAF) is the difference between each approach and the No Project Condition
Key:
AEP = annual exceedence probability
SPFC = State Plan of Flood Control
TAF = Thousand acre-feet

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5.0 Stockton Area Analysis

This section provides a description of the hydrology, hydraulic modeling, and floodplain modeling assumptions and methodology for the No Project condition and each CVFPP approach in the Stockton area. The section also contains the results from the Stockton area hydraulic and floodplain modeling.

It is important to note that the hydraulic modeling described below is a deterministic process that simulates levee breaches based on data provided regarding levee stability. Hydraulic modeling cannot and does not predict the location of actual levee breaches.

5.1 Methodology

An overview of overall CVFPP hydraulic modeling was given in Section 3.1 and Figure 3-1. As explained there, hydraulic models of the river systems are one of the tools used to evaluate the CVFPP planning approaches. As shown in Figure 5-1, input to the economic analysis models for comparison of approaches also requires floodplain modeling.

While the CVFPP used existing tools (i.e., Comprehensive Study hydrology and hydraulic models) as much as possible for evaluating the planning approaches, no models for the Calaveras River (including Mormon Slough and the Stockton Diverting Canal) and Bear Creek were developed for the Comprehensive Study. Hence, it was necessary to develop hydrology and hydraulic models for those two streams in the Stockton area as described in the following sections.

5.1.1 Hydrology Development

As described previously, riverine hydraulic models require flow hydrographs (a time-series of flows) as upstream boundary conditions. The Sacramento and San Joaquin UNET models were used to determine river stage, velocity, depth, and levee breaches, as well as breakout and return flows from overbank areas for each CVFPP approach, but these models do not cover the Stockton area. Each set of hydrographs represents either unregulated or regulated flow conditions (simulated reservoir releases from reservoir models) under different storm centerings (a centering is a set of synthetic storms covering a range of AEPs) that will result in peak flows at a given location.

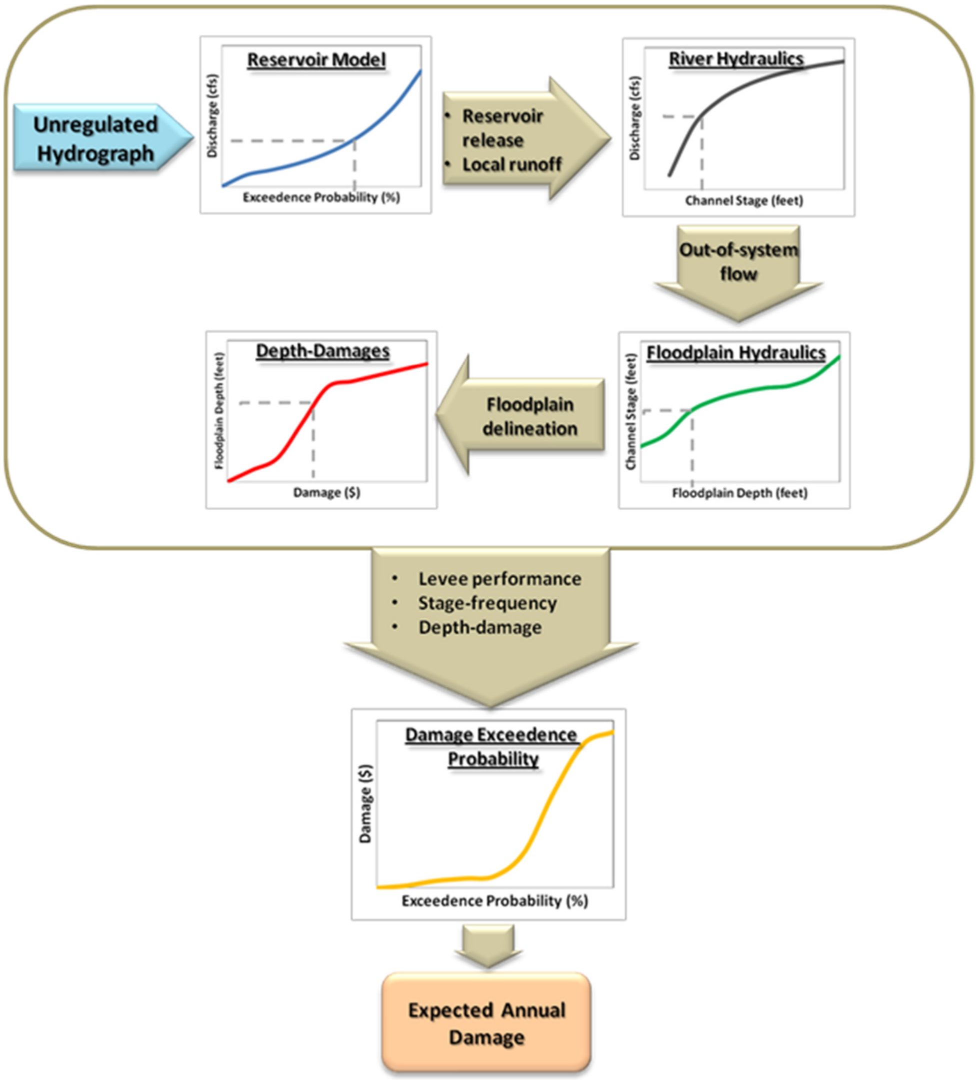

Figure 5-1. Schematic of Overall Modeling Framework

Comprehensive Study hydrology was available for the Calaveras River out of New Hogan Reservoir, leading to the upper end of Mormon Slough and then the Stockton Diverting Canal. But, Comprehensive Study hydrology was not developed for the Calaveras River downstream from the Mormon Slough Diversion, Bear Creek, Paddy Creek, Upper Mosher Creek, Pixley Slough, or Mosher Slough. To provide input data for the hydraulic analyses of reaches of the streams listed above that are protected by SPFC facilities, the following steps were taken:

1. Obtain peak flows for each stream using data from past studies.

2. Scale Duck Creek hydrology from the Comprehensive Study to produce flow hydrographs for each stream.

The peak flows used were from SJAFCA's Flood Protection Restoration Project (SJAFCA, 1998a). As part of SJAFCA's effort, hydrologic models were developed for the 50, 1 and 0.5 percent AEP (2-, 100-, and 200-year return period) storm events using the USACE HEC-1 rainfall-runoff model. Those peak flows were plotted on log-probability paper and the peak flows for the 50, 10, 4, 2, and 0.2 percent AEP storm events were interpolated or extrapolated from the curves. The peak flows are shown in Table 5-1, with the HEC-1 flows underlined.

Table 5-1. Peak Flows for Various AEP Storm Events (Percent)

Stream	50% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
Bear Creek	1,137	3,100	4,300	5,300	6,367	7,279	9,300
Paddy Creek	88	210	290	360	434	510	640
Pixley Slough	121	305	430	530	667	778	980
Upper Calaveras River[1]	161	480	720	920	1,170	1,433	1,800
Mosher Slough	294	410	460	500	532	580	620
Upper Mosher Cr.	156	380	540	670	851	966	1,200
Duck Creek[2]	238	533	729	855	1,006	1,106	1,257

Source: SJAFCA, 1998s except where noted.

Notes:
Peak flows from HEC-1 are underlined.
1 Downstream from the Mormon Slough Diversion.
2 Peak flow taken from Comprehensive Study hydrology.

Key:
AEP = Annual Exceedence Probability

To be consistent with the other hydrology used for the 2012 CVFPP, the hydrology for these six streams was developed to match the Comprehensive Study pattern of flows (i.e., 34-day event, hourly flows, with the largest peak flow occurring around Day 17). To accomplish this, it was first assumed that the hydrology for these three streams would have peak flows approximately equal to the flows shown in Table 5-1 for a given AEP. Secondly, it was assumed that the shape of the flow hydrograph would match the shape the Comprehensive Study's hydrographs for Duck Creek near Farmington. This is because the characteristics of floods would be similar in the sub-watersheds.

Duck Creek near Farmington was selected as the base pattern for the Stockton area streams because its watershed is at similar elevations to the other streams and it is geographically the closest stream included in the Comprehensive Study. Hence, while Duck Creek may not be the same size as the Stockton area watersheds, it would likely experience similar precipitation patterns and is appropriate to develop hydrology for other streams for use in preliminary evaluations for the 2012 CVFPP.

In each watershed for which flood hydrographs were developed, and for each storm AEP, Duck Creek hourly flows were multiplied by a constant to develop the particular stream's hourly flows. The constant was the ratio of each stream's peak flow to Duck Creek's peak flow for a storm with a given AEP. For example, the constant for a 10 percent AEP storm on Bear Creek would be 5.8 (3,100 cubic feet per second (cfs) divided by 533 cfs). Hence, for this particular AEP flood, Duck Creek hourly flows were multiplied by 5.8 to obtain the inflow hydrograph for Bear Creek.

The Calaveras River storm centering was used for both Bear Creek and the Calaveras River because it resulted in the highest flow flood events. The hourly flows for six AEP flood events developed for the Comprehensive Study (10, 4, 2, 1, 0.5, and 0.2 percent) were used. If the flow at any hour was 0 cfs, it was changed to 1 cfs for better continuity when run in the unsteady HEC-RAS model.

5.1.2 Hydraulic Model Development

HEC-RAS Version 4.1 was used to develop the Stockton area hydraulic models for the CVFPP by translating existing HEC-2 models from SJAFCA. Two separate HEC-RAS models, Calaveras River and Bear Creek, were created in this manner (Figure 1-3). The following sections describe model settings specific to the CVFPP evaluation for the Stockton area. For more information about the capabilities of the HEC-RAS model, refer to the January 2010 HEC-RAS User's Manual (USACE, 2010).

Model Selection

The available riverine hydraulic models for the Stockton area were from the SJAFCA Flood Protection Restoration Project (SJAFCA, 1998b) and from the SJAFCA Provisionally Accredited Levee binder submittal to FEMA for the Lower Calaveras River (SJAFCA, 2010a). This project developed a HEC-RAS model set for the Calaveras River from existing models as detailed below:

- **Upper Calaveras River** – HEC-2 model (SJAFCA, 1998b)
- **Lower Calaveras River** – HEC-RAS model (SJAFCA, 2010a)
- **Mormon Slough** – HEC-2 model (SJAFCA, 1998b)
- **Stockton Diverting Canal** – HEC-2 model (SJAFCA, 1998b)

Similarly, an HEC-RAS model of Bear Creek was developed using three HEC-2 models–Bear Creek, Mosher Diversion, and Upper Mosher Creek (SJAFCA, 1998b).

The HEC-2 models from the SJAFCA Flood Protection Restoration Project (SJAFCA, 1998b) were converted to HEC-RAS using the HEC-2 import feature in HEC-RAS. Some of the model inputs were also updated to include changes to the system since 1998.

Levee Breach Modeling

In HEC-RAS, the top of a levee is defined as a station and elevation point in each cross section. At a designated cross section, a breach elevation may be entered into the model and when the computed water surface elevation equals or exceeds this breach elevation, flood flows are diverted into the floodplain. The simulated levee breach is 100 feet wide. When the levee breaches, water will flow through the breach into a storage area associated with that cross section. The storage area will continue to fill until either the stage in the river decreases below the stage in the storage area or the stage in the storage area reaches the same elevation as the stage in the river.

Boundary Conditions

The four primary types of HEC-RAS model boundary conditions used for the Stockton area are:

- **Upstream Boundary Conditions** – Upstream boundary conditions for the Stockton area HEC-RAS models are flow hydrographs (i.e., discharge in cfs over time) for each particular flood for all reaches that are not connected to another reach at their upstream end. For the Calaveras River Model, there are two upstream hydrographs: Calaveras River just east of Highway 99 and Mormon Slough at Jack Tone Road. For the Bear Creek Model, there are three upstream hydrographs: Bear Creek, South Paddy Creek at Jack Tone Road, Mosher Creek Diversion to Bear Creek, and Pixley Slough. See Figure 5-2 for the upstream boundary hydrograph locations.

  Flows with an AEP of greater than 10 percent (10-year return period) were not modeled because the Stockton area flood management systems are designed to manage flood events with AEPs less than 10 percent. Therefore, it is anticipated that storms with greater than a 10 percent AEP would not cause serious impacts.

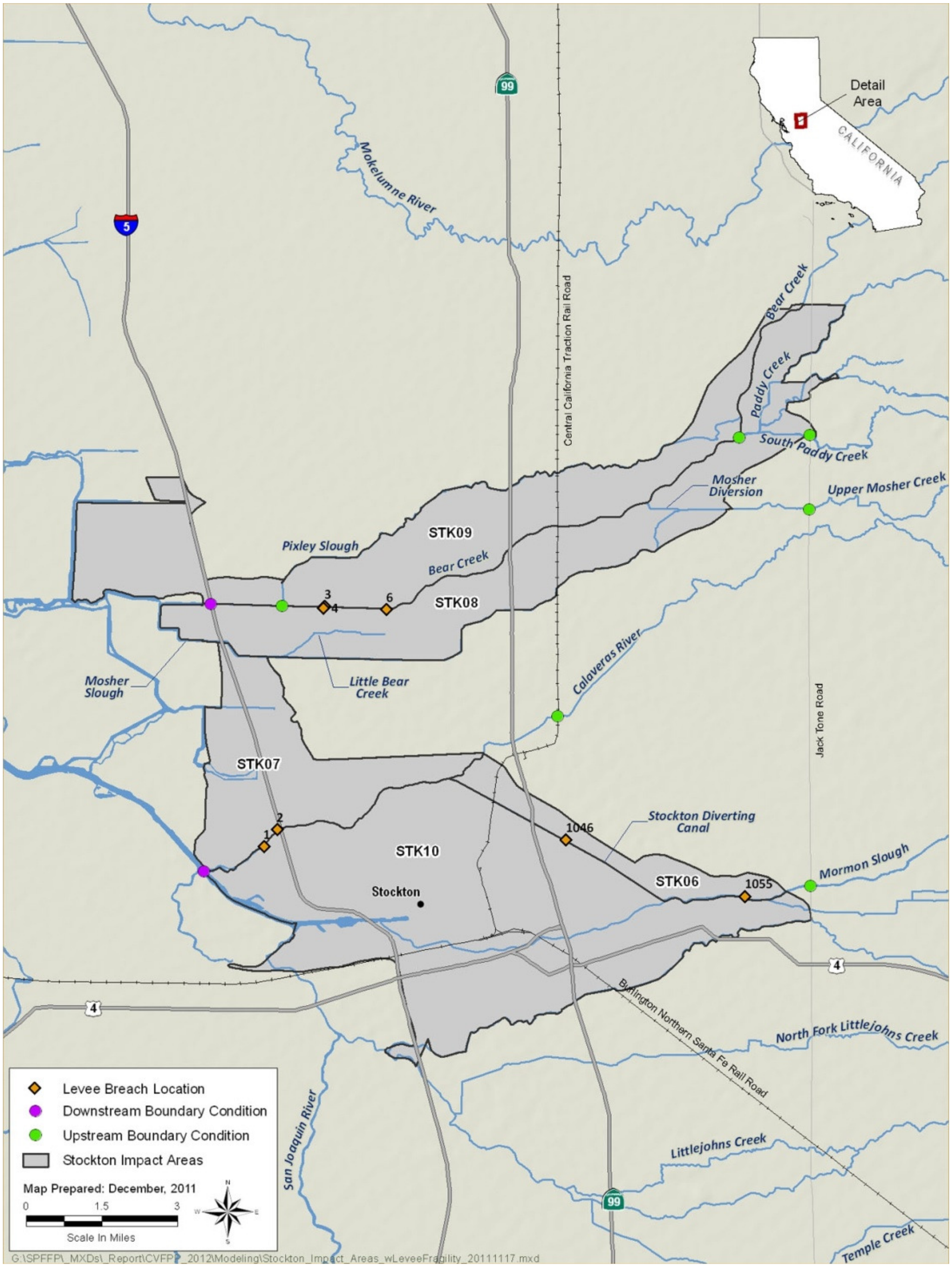

Figure 5-2. Boundary Conditions for Stockton Area Models

- **Interior Boundary Conditions –** Interior boundary conditions define the connections between stream reaches, as well as between stream reaches and other parts of the model. Interior boundary conditions ensure continuity of flow by defining river channel alignment, cross sections, and bridge geometries.

- **Downstream Boundary Conditions –** To function properly, a hydraulic model of a river system must define the water surface elevation at the downstream end of all model reaches not connected to another reach or river. Downstream boundary conditions are usually in the form of tailwater stage hydrographs that describe the variation of the downstream water surface elevation over time.

  River stage time series from the RMA Delta Model for (1) Calaveras River at San Joaquin River, and (2) Bear Creek at Disappointment Slough define the tailwater conditions for the Calaveras River Model and Bear Creek Model, respectively. See Figure 5-2 for downstream boundary hydrograph locations. Details of the RMA Delta Model are in Attachment 8D: Estuary Channel Evaluations.

- **Internal Boundary Conditions –** Internal boundary conditions are coded in the model to represent levee failure scenarios or floodplain interactions, spillways or weir overflow/diversion structures, bridge or culvert hydraulics, or pumped diversions. To simulate water leaving the river into the floodplain through breaches, storage areas representing floodplains were added to the HEC-RAS models; three for the Calaveras River Model (STK06, STK07, and STK10), and two for the Bear River Model (STK08 and STK09) (see Figure 5-2). Rating curves for the relationship between water stage and floodplain volume were developed as inputs to the models using the topographic data developed for CVFED.

Simulation Period
The simulation period for the Stockton area models was chosen to be 35 days and extends from 1:00 a.m., January 1, to midnight, February 4. This calendar period matches the time period for the UNET models.

5.1.3 Levee Performance Curves

The ULE Project and NULE Project under the DWR Levee Evaluations Program developed performance curves for levees in the Sacramento and San Joaquin river basins. Levee performance curves provide geotechnical relationships between river stage and the probability that a levee segment will breach (water from the water side of the levee flows in an uncontrolled manner to the landside of the levee) at a specific stage. Details on levee performance curve development are contained in Attachment 8E: System/Levee Performance.

Levee performance curves from ULE and NULE were used to identify two water surface elevations of interest for the hydraulic analyses. These water surface elevations and the corresponding probability of levee failure at a particular levee location are as follows:

- **Probable failure point (PFP)** – 85 percent probability of failure
- **Top of levee (TOL)** – 100 percent probability of failure

These two water surface elevations were incorporated into UNET models to simulate conditional levee failure. This means that once the simulated river stage at a specific levee location reaches either the PFP or TOL elevation, depending on the CVFPP approach being modeled, a levee breach would begin to develop in UNET. Water from the river would then enter into the adjacent floodplain through the levee breach, and the downstream river stage and flow would be reduced. On the other hand, if TOL is used in the simulation, the water surface elevation and flow would be higher both upstream and downstream before the levee breach.

The water surface elevations of interest described above are not intended to represent or predict how levees would fail under an actual flood event. For example, under the PFP scenario, all levees assigned a PFP would fail in a simulated flood event once the water surface was equal to or higher than the PFP elevation. In reality, many of these levees would not fail even when the stage exceeds the PFP elevations, while others might fail before the stage reaches the PFP elevations. Further, floodfighting and other emergency actions (conditions that are not simulated in the hydraulic models) could result in very different levee failure probabilities.

In addition to simulating the PFP and TOL scenarios, model simulations were also conducted that considered infinitely tall levees along the river channels. These “infinite channel” simulations helped estimate the maximum potential flood flows and stages at various locations in the system.

5.1.4 Floodplain Model Development

The Comprehensive Study applied FLO-2D, a two-dimensional flood routing model, to simulate the inundation of floodplains in the Sacramento and San Joaquin river basins. For 2012 CVFPP development, FLO-2D was applied to simulate the inundation of floodplains in the Stockton area that were not previously covered by the Comprehensive Study.

Preliminary LiDAR topographic data developed by CVFED were used to set the terrain elevations for the five Stockton area floodplains (damage areas) in FLO-2D.

The levee breach time-series hydrographs output from HEC-RAS were used as input to the FLO-2D models at the corresponding breach locations. FLO-2D then simulated the area of inundation and water depth of each floodplain grid over the entire simulation period. The maximum depth at each grid point in each of the impact areas was used in the HEC-FDA model of the impact area to determine flood damages (see Attachment 8F: Flood Damage Analysis).

Damage areas STK07 and STK10 did not have levee breaches up to and including the 0.2 percent AEP (500-year) flood. To provide flows to use in the FLO-2D model to develop the grid depth information, a special 0.2 percent AEP (500-year) model run was made where the breach elevations at the levee breach locations for STK07 and STK10 were lowered such that a levee breach occurred. The flow hydrographs generated from these forced levee breaches were then used as input for STK07 and STK10 when determining the depth grids for use in HEC-FDA.

5.2 Stockton Area Results

The general Stockton area hydrology and floodplain assumptions for the No Project condition are described in Section 5.1. This section contains the HEC-RAS modeling results as flow-frequency, stage-frequency tables, and out-of-system volume-frequency tables. The tables were developed for four locations based on HEC-RAS model outputs (see Figure 5-2). These locations, which are shown in Figure 5-2 include:

- Stockton Diverting Canal at Highway 99
- Bear Creek at Highway 99
- Bear Creek at Interstate 5
- Calaveras River at Interstate 5

5.2.1 Riverine Hydraulics

The results from the riverine hydraulics analysis for the Stockton area Analysis contained in Tables 5-2 and 5-3 show the flows and stages for each AEP at the locations listed above and shown on Figure 5-2.

Results are shown only for the No Project condition and the Protect High Risk Communities because in the Stockton area the Achieve SPFC Design

Flow Capacity, Protect High Risk Communities, and State Systemwide Investment approaches are essentially the same. All of the levees are treated as urban levees for Protect High Risk Communities and State Systemwide Investment approaches, and the levee heights are nearly the same as those set for the Achieve SPFC Design Flow Capacity Approach and the levee breaches function the same in the hydraulic models. The Enhance Flood System Capacity Approach in the Stockton area is the same as the No Project Condition.

5.2.2 Out-of-System Volumes to FLO-2D

Estimates of out-of-system flood flow volumes into floodplains for modeling using the two-dimensional hydraulic computer model FLO-2D are shown in Table 5-4 for the damage/storage areas shown on Figure 5-3. The depth grid results from the FLO-2D modeling, based on the volumes shown in Table 5-4, are used in the Hydrologic Engineering Center Flood Damage Analysis (HEC-FDA) model analysis described in Attachment 8F: Flood Damage Analysis.

Results are shown only for the No Project condition and the Protect High Risk Communities as described in Section 5.2.1.

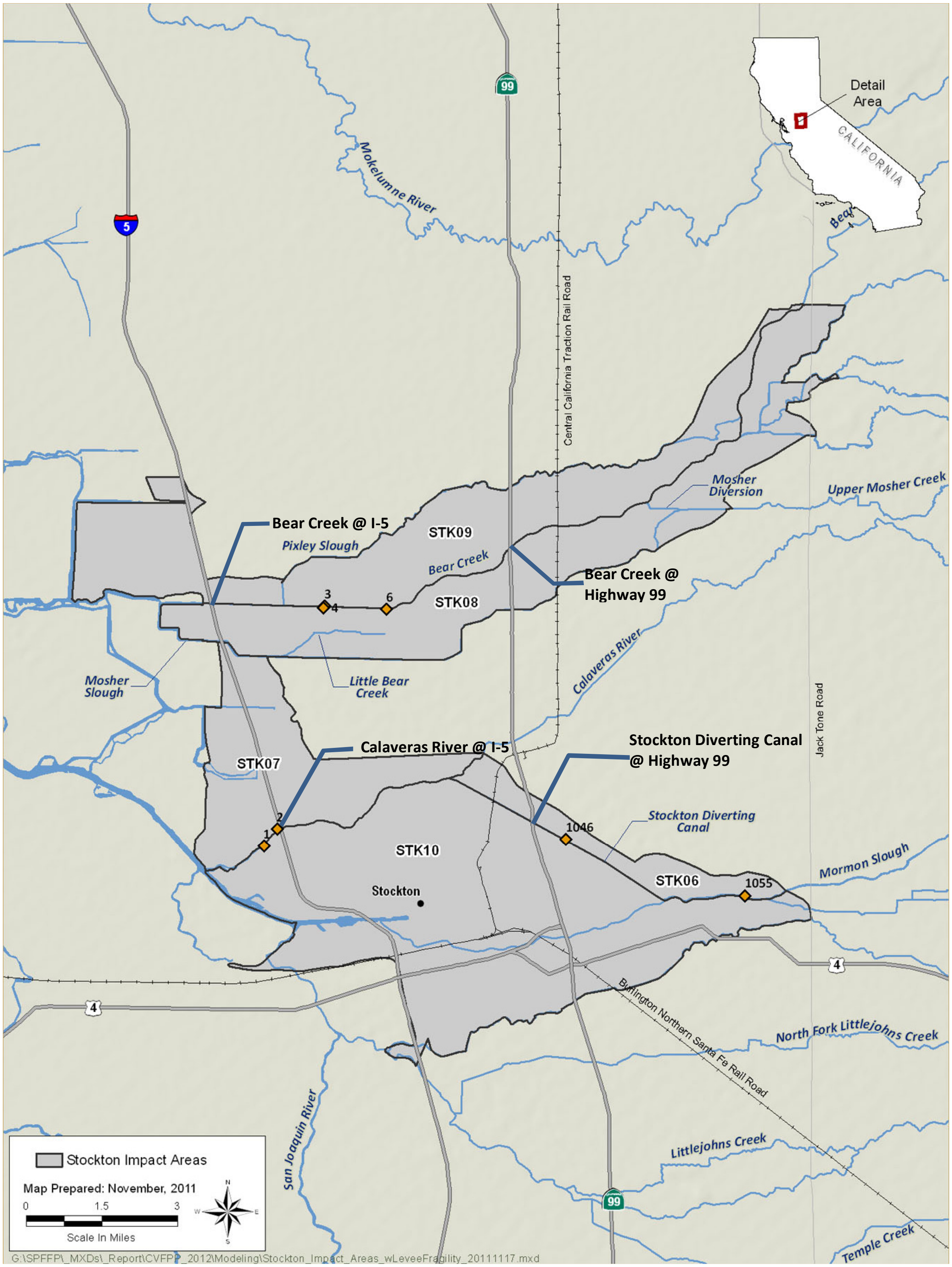

Figure 5-3. Stockton Area HEC-RAS Model Output Locations and FLO-2D Floodplains/Damage Areas

Table 5-2. Simulated Flows at Output Locations in Stockton Area

Location		Flow (cfs)					
		10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
Bear Creek @ Interstate 5	No Project	3,736	5,309	6,405	7,768	8,835	9,326
	Protect High Risk Communities	3,736	5,309	6,405	7,768	8,839	9,410
Bear Creek @ Highway 99	No Project	3,532	4,921	6,052	7,367	8,360	8,625
	Protect High Risk Communities	3,479	3,761	6,053	7,369	8,362	8,625
Calaveras River @ Interstate 5	No Project	12,441	12,011	12,485	12,489	12,339	21,408
	Protect High Risk Communities	12,441	12,011	12,485	12,489	12,339	21,415
Stockton Diverting Canal @ Highway 99	No Project	12,400	12,400	12,400	12,400	13,058	21,376
	Protect High Risk Communities	12,400	12,400	12,400	12,400	13,058	21,383

Key:
AEP = Annual Exceedence Probability
NGVD29 = National Geodetic Vertical Datum of 1929

Table 5-3. Simulated Stages at Output Locations in Stockton Area

Location		Stage (feet NGVD29)					
		10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
Bear Creek @ Interstate 5	No Project	6.1	7.0	7.7	8.5	9.2	9.5
	Protect High Risk Communities	6.1	7.0	7.7	8.5	9.2	9.5
Bear Creek @ Highway 99	No Project	39.3	39.3	39.8	41.9	42.4	42.8
	Protect High Risk Communities	39.3	39.3	39.8	41.9	42.4	42.8
Calaveras River @ Interstate 5	No Project	9.2	9.4	9.6	9.8	10.0	12.7
	Protect High Risk Communities	9.2	9.4	9.6	9.8	10.0	12.7
Stockton Diverting Canal @ Highway 99	No Project	31.2	31.2	31.2	31.2	32.0	38.9
	Protect High Risk Communities	31.2	31.2	31.2	31.2	32.0	38.9

Key:
AEP = Annual Exceedence Probability
NGVD29 = National Geodetic Vertical Datum of 1929

Table 5-4. Simulated Out-of-System Volumes in Stockton Area Floodplains (Damage Areas)

Damage Area		Out-of-System Volume (acre-feet)					
		10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
STK06	No Project	-	-	-	-	-	15,773
	Protect High Risk Communities	-	-	-	-	-	13,027
STK07	No Project	-	-	-	-	-	-
	Protect High Risk Communities	-	-	-	-	-	-
STK08	No Project	-	-	-	-	978	1,188
	Protect High Risk Communities	-	-	-	-	-	-
STK09	No Project	-	-	-	-	13,933	14,712
	Protect High Risk Communities	-	-	-	-	-	-
STK10	No Project	-	-	-	-	-	-
	Protect High Risk Communities	-	-	-	-	-	-

Key:
AEP = Annual Exceedence Probability

5.2.3 Findings

The major findings from the tabulated data described above are presented in the following sections.

No Project Condition

The No Project condition assumes that levee breaches occur when the river stage reaches the Probable Failure Point (PFP) on a levee performance curve. No simulated levee breaches occurred on either the Calaveras River system or Bear Creek at AEP more frequent than 0.5 percent.

Achieve SPFC Design Flow Capacity Approach

The Achieve SPFC Design Flow Capacity Approach assumes that levee breaches occur when the river stage reaches the top of SPFC levees that have been raised to equal the 55/57 design profile. No simulated levee breaches occurred on either the Calaveras River system or Bear Creek at AEP more frequent than 0.5 percent.

Protect High Risk Communities Approach

The Protect High Risk Communities Approach assumes levee breaches occur when the river stage reaches the top of urban levees that have been set to be the existing levee elevation or the 200-year flood plus freeboard (3 feet). No simulated levee breaches occurred on either the Calaveras River system or Bear Creek at AEP more frequent than 0.5 percent.

Enhance Flood System Capacity Approach

The Enhance Flood System Capacity Approach in the Stockton area is the same as the Achieve SPFC Design Flow Capacity Approach. No simulated levee breaches occurred on either the Calaveras River system or Bear Creek at AEP more frequent than 0.5 percent.

State Systemwide Investment Approach

The State Systemwide Investment Approach is the same as the Protect High Risk Communities Approach in the Stockton area. No simulated levee breaches occurred on either the Calaveras River system or Bear Creek at AEP more frequent than 0.5 percent.

5.2.4 Limitations

The results of the hydrologic, riverine hydraulic, and floodplain modeling for the Stockton area Analysis are suitable for use in high-level planning studies such as the CVFPP. With significant additional work and field verification and data collection, the hydraulic and floodplain models could be adapted for use in more detailed project studies.

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7.0 Acronyms and Abbreviations

1-D	one-dimensional
AEP	annual exceedence probability
Board	Central Valley Flood Protection Board
cfs	cubic feet per second
Comprehensive Study	Sacramento and San Joaquin River Basins Comprehensive Study
CVFED	Central Valley Floodplain Evaluation and Delineation Program
CVFPP	Central Valley Flood Protection Plan
Delta	Sacramento-San Joaquin Delta
DWR	California Department of Water Resources
EFSC	Enhanced Flood System Capacity Approach
HEC-RAS	Hydrologic Engineering Center River Analysis System
NAVD88	North American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
NPRJ	No Project Condition
NULE	Non-Urban Levee Evaluations
PFP	probable failure point
PHRC	Protect High Risk Communities Approach
Q-F	discharge-frequency
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
RM	River mile
SAFCA	Sacramento Area Flood Control Agency
S-F	stage-frequency
SPA	Systemwide Planning Area
SPFC	State Plan of Flood Control or Achieve SPFC Design Flow Capacity Approach
SSIA	State Systemwide Investment Approach
State	State of California

TAF .... thousand acre-feet

TOL .... top of levee

TRLIA .... Three Rivers Levee Improvement Authority

ULE .... Urban Levee Evaluations

UNET .... Unsteady flow Through a Full NETwork of open channels computer model

USACE .... U.S. Army Corps of Engineers

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