Central Valley Flood Protection Plan
2022 Update

Technical Analyses Summary Report

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STATE OF CALIFORNIA
NATURAL RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

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Acronyms and Abbreviations

AEP	annual exceedance probability
Bay-Delta	San Francisco Bay/Delta Estuary
BCSD	bias correction with spatial disaggregation
BWFS	basin-wide feasibility study
CCTAG	Climate Change Technical Advisory Group
cfs	cubic feet per second
CMIP	Coupled Model Intercomparison Project
CSI	California structure inventory
CVFED	Central Valley Floodplain Evaluation and Delineation
CVFPP	Central Valley Flood Protection Plan
CVHS	Central Valley Hydrology Study
CWP	California Water Plan
Delta	Sacramento-San Joaquin Delta
DWR	California Department of Water Resources
EAD	expected annual damage
EALL	expected annual lives lost
EFREM	enhanced flood response and emergency management
F-CO	forecast-coordinated operations

FEMA	Federal Emergency Management Agency
FIO	forecast-informed operations
ft	feet
GCM	general circulation model
HEC-RAS	Hydrologic Engineering Center – River Analysis System
HEC-ResSiM	Hydrologic Engineering Center – Reservoir System Simulation
I-O	input-output
IPAST	Information Processing and Synthesis Tool
IPCC	Intergovernmental Panel on Climate Change
LOCA	locally constructed analogs
LOP	level of protection
LRC	Life Risk Calculation
LRS	Life Risk Simulation
MMC	Modeling Mapping and Consequences
NRC	National Research Council
NSI	National Structure Inventory
NULE	Non-Urban Levee Evaluations Project
PPS	persons per structure
RCP	representative concentration pathway
RMA	Resource Management Associates, Inc.

RMC	Risk Management Center
RVA	reservoir vulnerability analysis
SB	Senate Bill
SPFC	State Plan of Flood Control
SSIA	State Systemwide Investment Approach
ULE	Urban Levee Evaluations Project
USACE	U.S. Army Corps of Engineers
VIC	variable infiltration capacity
WSE	water surface elevation
1D	one-dimensional
2D	two-dimensional

CHAPTER 1

Introduction

1.1 Purpose of this Document

This report explains the technical analysis approach, tools used, and information that supported the development of the 2022 Central Valley Flood Protection Plan (CVFPP) Update.

This report also summarizes the scope, extent, process, analyses and results that were conducted to assess Central Valley flood system performance under a range of evaluation scenarios. The purpose of this report is to:

- Describe the application of updated tools for the CVFPP Update that leverage California Department of Water Resources (DWR) investments from other programs.
- Describe the methodology and results to characterize the State Plan of Flood Control's (SPFC's) performance for current (2022) and future (2072) conditions using the following:
  - Climate change trend analysis.
  - Climate change volume frequency analysis.
  - Flood risk analysis, utilizing revised levee fragility curves, updated structure inventory, and enhanced life risk analysis.
  - Reservoir vulnerability analysis.
  - Regional economic analysis.

Detailed appendices covering these topics are included with this report.

1.2 Background

As required by Senate Bill (SB) 5, also known as the Central Valley Flood Protection Act of 2008, DWR prepared the CVFPP, which was adopted by the Central Valley Flood Protection Board in 2012. The 2012 CVFPP recommended a systemwide approach to improve flood risk management and associated ecosystem and multiple benefits for lands protected and affected by existing facilities of the SPFC.

In 2012, DWR formulated and evaluated three significantly different preliminary approaches to address the CVFPP goals (See Appendix A of the 2022 CVFPP Update). The approaches focused mainly on physical changes to the existing flood management system and examined the need for policy and other management actions. The 2012 CVFPP recommended the preferred approach, referred to as the SSIA. Physical changes included improvements to urban, small community, and rural-agricultural areas to collectively benefit the entire flood system while achieving local and regional benefits in a cost-effective manner. Additionally, the physical changes included system improvements that largely focused on modifications to the SPFC. Beyond the physical changes, DWR also included flood management elements to address residual flood risk in the SSIA.

With implementation of the SSIA components, flood risk will decrease over time, but residual risk within the Central Valley will remain. Residual risk is the level of flood risk for people and assets located in a floodplain that remains after implementation of flood risk reduction actions (Shabman et al. 2014). As a result, nonstructural flood management elements that included enhanced flood emergency response, enhanced operations and maintenance, and floodplain management were evaluated and included as part of the 2017 CVFPP Update. The refined SSIA maintained the same categories as in 2012, namely systemwide physical improvements and operational elements, in addition to residual risk management actions. The residual risk management actions focused on enhanced flood response and emergency management (EFREM). Specifically, the EFREM actions included:

- Increased data collection and enhancement of forecasting tools, and expanded use of forecast-based operation to increase reservoir management flexibility and increased forecast lead times.
- Enhancements to emergency preparedness plans and ability to respond in flood emergencies and decreased notification and decision-making times.

SB 5 requires that the CVFPP be updated every five years; the 2022 CVFPP Update fulfills this requirement. The 2022 CVFPP Update used studies, tools, products, procedures, and information developed through projects and programs completed since 2012. These include the 2017 CVFPP Update, the Central Valley Hydrology Study (CVHS) (California Department of Water Resources 2015a), the Central Valley Floodplain Evaluation and Delineation (CVFED) Program (California Department of Water Resources 2013), and the Non-Urban (NULE) and Urban Levee Evaluations (ULE) (California Department of Water Resources 2016a).

In accordance with State and federal policy and technical guidance, the 2022 CVFPP Update uses the latest climate science and understanding. CVFPP inland climate change analyses were founded on the Coupled Model Intercomparison Project (CMIP) Phase 5 climate model data, which are the basis for the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (International Panel on Climate Change, 2013). The analyses specifically tailored to the Central Valley are presented in Appendix A, "Climate Change Analysis." Future sea-level-rise projections incorporated into the analyses are based on the State of California *Sea Level Rise Guidance 2018 Update* (State of California 2018).

1.3 Report Organization

The *2022 CVFPP Update – Technical Analysis Summary Report* is organized as follows:

- Chapter 1 – Introduction: Presents and describes the purpose of this report; provides background information.
- Chapter 2 – Overview of CVFPP Technical Analyses: Provides an overview of the analysis tools and methods and describes the scenarios analyzed for the 2022 CVFPP Update.
- Chapter 3 – Analyses Used from 2017 CVFPP Update: Summarizes the technical analyses from the 2017 CVFPP Update carried forward for the 2022 CVFPP Update.
- Chapter 4 – Enhanced Technical Analyses for the2022 CVFPP Update: Summarizes the enhanced technical analyses for the 2022 CVFPP Update.
- Chapter 5 – References: Lists references for the sources cited in this document.

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CHAPTER 2

Overview of Technical Analyses

The CVFPP uses a 50-year planning horizon to understand how flood risk is expected to change and to assess climate resiliency over the long-term. As part of the 2022 CVFPP Update, a series of scenarios representing different points in time through the 50-year evaluation period (2022 to 2072) were analyzed. Although system components formulated as part of SSIA and modeled for the 2017 CVFPP Update were unchanged for the 2022 CVFPP Update, updates were made to account for the effects of completed projects with the best available information at the time of the analyses. Information was collected from the DWR Flood Projects Section and the CVFPP technical team to inform added project's status' and timelines. For example, geotechnical information for levee performance was updated in the analyzed scenarios, to reflect levee improvements with completed and implemented projects since 2017 and expected by 2022.

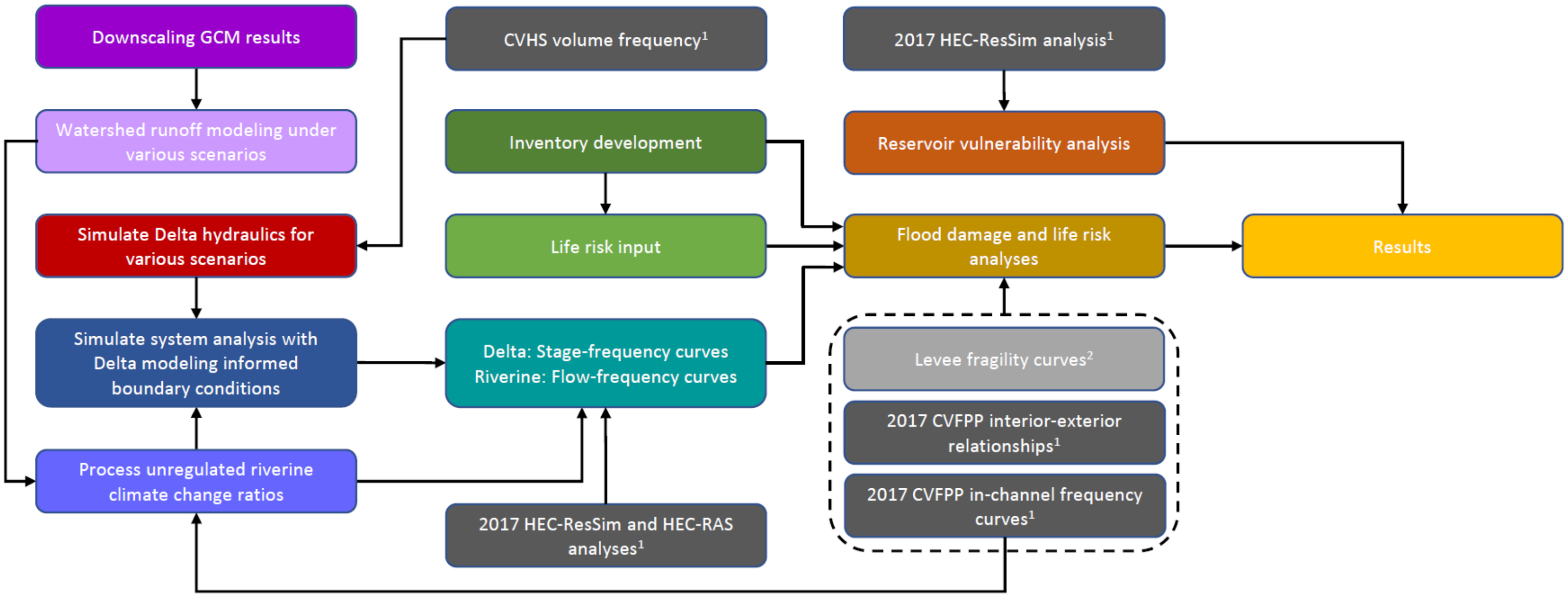
The CVFPP updates focus on use of updated techniques to refine the evaluation of the SSIA and to estimate flood risk with time. The 2017 CVFPP Update included technical analyses focused on enhancing the flood hazard aspect of flood risk, specifically the integration of CVHS hydrological tools and the hydraulic models developed by CVFED. The 2022 CVFPP Update focuses on describing the uncertainties of the climate change projections and on an enhanced analysis of the vulnerability and consequence aspects of flood risk. The vulnerability aspect was refined by updating the structure inventory and population information. The consequence aspect of the analysis was refined by using more detailed life risk assessment tools and models. Index points and impact areas remain unchanged from the 2017 CVFPP Update.

The analyses include estimates of flood risk in terms of potential economic damages and life loss, thereby provides an understanding of how the SSIA reduces flood risk in the future.

2.1 CVFPP Overview Graphic

For the 2022 CVFPP Update, tools from the 2017 CVFPP Update were used and updated including the CVHS, CVFED Program, and NULE/ULE Program. Figure 2.1 shows the overall process and various tools and models that have been used for flood risk analysis in the Central Valley for the 2022 CVFPP Update with data/tools from previous CVFPP updates shown in grey. Table 2.1 provides a summary of these modeling tools. Descriptions of these tools and methodology enhancements are described in the following sections of this report and are fully detailed in the technical appendices of this report.

Figure 2.1 **Overview of Technical Analyses and Tools Used for the 2022 CVFPP Update**



Notes: Information from these previously completed studies and analyses (noted in the dark gray boxes) are unchanged from those used in the 2017 CVFPP Update.

Levee fragility curves (noted in the light gray box) were developed during the 2017 CVFPP Update. For the 2022 CVFPP Update, the levee fragility curves were reviewed and updated at 31 index points where existing conditions have been reevaluated or recent levee improvements had been completed and implemented since 2017 and expected by 2022. The remaining index points used levee fragility curves consistent with those used in the 2017 CVFPP Update.

Table 2.1 **Modeling Tools Used in the 2022 CVFPP Update**

Tool	Version	Description	Purpose
VIC Model	4.2	Hydrologic model used to simulate the full water and energy balance by estimating land-surface interactions and flow routing.	Based on precipitation and temperature forcings, and a representation of the watershed response and losses to compute flow runoff. This model also represents snow accumulation and melting.
HEC-ResSim	3.2	The HEC-ResSim model used for the CVFPP was developed as part of CVHS. For the 2017 CVFPP Update, the model was configured for the various evaluation conditions and a range of hydrographs of different size and shape, routed through the system. The 2022 CVFPP Update relies on the reservoir simulations completed for the 2017 CVFPP Update.	The model includes a representation of the physical features and operational rules of the reservoir system. Physical features include the capacity of the reservoirs and outlets to store and release water. Given a set of inflows and initial conditions, the model simulates reservoir operation and routes releases through the defined channel network.
HEC-RAS	Sacramento River Basin: v4.2 San Joaquin River Basin: v5.0.1	Hydraulic model originally developed through the DWR's CVFED Program. The HEC-RAS model used for the CVFPP was developed as part of the 2017 CVFPP Update. The 2022 CVFPP Update technical analysis relies on the HEC-RAS runs completed for the 2017 CVFPP Update.	Central Valley systemwide hydraulic analysis of channels and floodplains.

Tool	Version	Description	Purpose
FLO-2D	2009.06	Based on CVFED. This model was used in the 2017 and 2022 CVFPP Updates.	Floodplain evaluation including flood depths, extents, and timing.
IPAST	2.2.0.16	IPAST extracts data from HEC-DSS files generated from the HEC-RAS and HEC-ResSim programs.	IPAST processes extracted HEC-ResSim and HEC-RAS data and creates unregulated flow (volume) frequency curves and unregulated-to-regulated flow transforms. Additionally, this tool supports the climate change ratio development.
LifeSim	2.0 Beta	Tool to estimate life loss from a single flood event.	Given floodplain depths and timing of the flood resulting from a levee breach, structure inventory, estimates of flood preparedness and willingness to evacuate, life loss is estimated Life loss for a single event given a channel stage and levee breach. A LifeSim model was run to develop a stage-life loss relationship.
HEC-FDA	1.4.2	Flood damage analysis tool to estimate flood damages and costs and life loss at an index point.	This model integrates the flood hazard, system performance, and vulnerability and consequences input to complete flood risk. Key inputs include Regulated flow-frequency functions, flow-stage relationships, levee performance, structure inventory, stage-life loss relationships, and depth-damage relationships. The program computes

Tool	Version	Description	Purpose
			economic and life risk, measured by expected annual damage, expected annual life loss, and annual exceedance probability.

Notes: CVFED Program = Central Valley Floodplain Evaluation and Delineation Program; CVFPP = Central Valley Flood Protection Plan; CVHS = Central Valley Hydrology Study; HEC–FDA = Hydrologic Engineering Center – Flood Damage Reduction Analysis; HEC-RAS = Hydrologic Engineering Center – River Analysis System; HEC-ResSiM Hydrologic Engineering Center – Reservoir System Simulation; IPAST = Information Processing and Synthesis Tool; VIC = variable infiltration capacity.

2.2 Overview of CVFPP Scenarios Analyzed

The CVFPP planning horizon is 30 years for investment planning purposes. However, the physical elements studied in the basin-wide feasibility studies (BWFSs) (California Department of Water Resources 2016b, 2016c) and the CVFPP are assessed over a longer horizon (50 years). The CVFPP is updated every five years, which allows for a revised understanding of how the flood risk and resiliency of elements change over time. The modeling and technical analyses presented in this report assess system performance in terms of flood risk over a 50-year period, from 2022 to 2072.

The scenarios are based on the assumptions of the state of the study area at a set point in time, namely 2022 (current) and 2072 (future), for both without-project and with-project conditions. For the future 2072 point in time, three climate change projections were used including a low, median, and high estimate. In this Technical Analysis Summary Report and in the 2022 CVFPP Update, **median** (or **medium**, or **central tendency**) scenario represent the scenario in between the low and high estimates. The eight scenarios analyzed as part of the 2022 CVFPP Update are shown in Table 2.2.

Table 2.2 2022 CVFPP Scenarios

Analysis Year	Climate Condition	Project Condition	Project Description
2022	Current	Without-project	Existing state of the system1
2022	Current	With-project	Existing state of the system + SSIA (EFREM only)
2072	Future low climate change projection	Without-project	Existing state of the system + increased population and land use changes
2072	Future medium climate change projection	Without-project	Existing state of the system + increased population and land use changes
2072	Future high climate change projection	Without-project	Existing state of the system + increased population and land use changes
2072	Future low climate change projection	With-project	Existing state of the system + increased population and land use changes + SSIA (structural + EFREM)
2072	Future medium climate change projection	With-project	Existing state of the system + increased population and land use changes + SSIA (structural + EFREM)
2072	Future high climate change projection	With-project	Existing state of the system + increased population and land use changes + SSIA (structural + EFREM)

Notes: CVFPP = Central Valley Flood Protection Plan; EFREM = enhanced flood response and emergency management; SSIA = State Systemwide Investment Approach. 1. Note that some components of the technical analysis rely on work products from the 2017 CVFPP Update, as shown in Figure 2.1 and noted elsewhere throughout this report. Therefore, the existing state of the system does not include projects that may have been authorized, funded, or started construction post-2017.

A detailed description of each scenario is provided below.

2022 Current Without-Project Scenario. This scenario includes the existing conditions of flood management systems in the Central Valley and includes projects that have been authorized and funded, or that have started construction or implementation as listed in Tables 2.3 and 2.4. However, as some components of the technical analyses rely on work products from the 2017 CVFPP Update, several projects that were authorized and funded or started construction post-2017 are not included in the 2022 Current Without-Project Scenario . Known projects underway or otherwise refined through further study post-2017 CVFPP Update, but <u>not</u> included in the without-project condition include:

- Lower Elkhorn Expansion (Lower Elkhorn Basin Levee Setback Project).
- Sacramento Bypass and Weir expansions.
- Little Egbert Multi-benefit Project (including levee degrade).
- Paradise Cut Multi-benefit Bypass Expansion.
- Lower Yolo Bypass Expansion: levee setback south of RD 2068 (Lookout Slough Tidal Habitat Restoration and Flood Improvement Project).
- Tisdale Weir Rehabilitation and Fish Passage Project.
- Smith Canal Closure structure.
- Folsom Dam raise.

These are included in the 2072 Future Low, Medium, and High Climate Change Projection With-Project Scenario as it is assumed these projects will be in operation by 2072.

2022 Current <u>With-Project</u> Scenario. This scenario is the same as the 2022 Without-Project Scenario with the addition of EFREM that includes nonstructural features. As a result, there is no change in the flood hazard between the two 2022 scenarios (Without-Project and With-Project). This scenario is intended to show the benefits of high-priority, nonstructural systemwide actions, primarily emergency response and reservoir operation actions, that could be implemented in the short term.

2072 Future Low, Medium, and High Climate Change Project <u>Without-Project</u> Scenario. These scenarios have all the same features as the 2022 Without-Project Scenario. But, the effects of inland climate change, sea level rise, and population and land use changes at the end of the planning horizon of 50 years are included. The inland climate change effects applied include a low, medium, and high estimate to provide a range of potential climate change outcomes. To account for future growth, projections of population are included. Growth factors for urban areas were only applied if urban level of protection (LOP) criterion were met under the SSIA, consistent with SB 5.

2072 Future Low, Medium, and High Climate Change Projection With-Project Scenario. These scenarios include all the features in the 2072 Without-Project Scenario, plus the systemwide and larger-scale actions as shown in Figures 2.2 and 2.3 for the Sacramento River Basin and Figures 2.4 and 2.5 for the San Joaquin River Basin. Project features are further detailed in Tables 2.3 and 2.4. This scenario also includes future growth projections.

The 2072 scenarios do not include potential for deterioration of flood management assets in the future. If these assets are allowed to deteriorate, perhaps through shortfalls in operations, maintenance, repair, rehabilitation, and replacement, then the flood risk in the 2072 Without-Project Scenario may be greater than indicated in the analyses presented in this document.

Figure 2.2 **Without-Project and With-Project Features in the Sacramento River Basin**

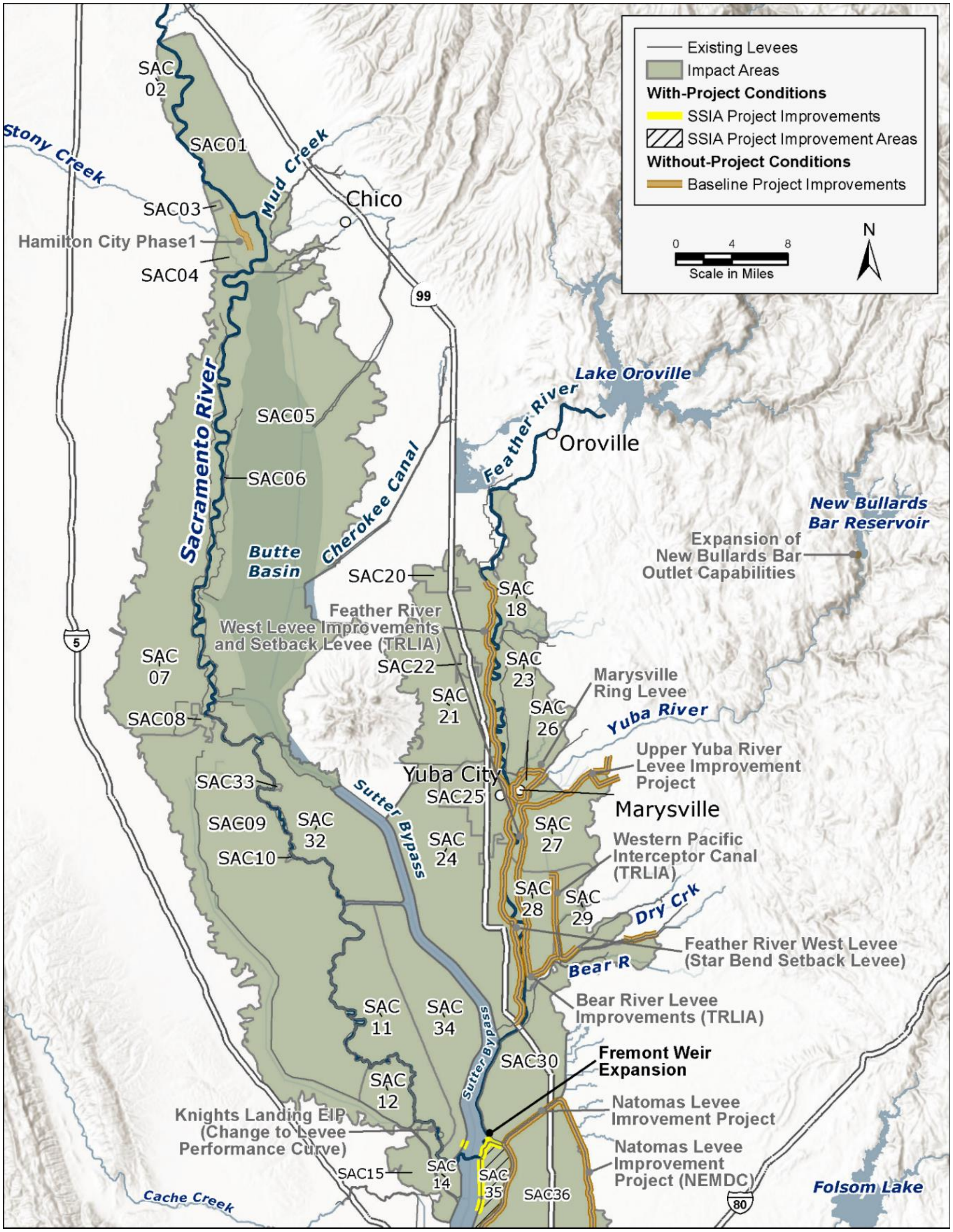


Figure 2.3 **Without-Project and With-Project Features in the Sacramento River Basin (continued)**

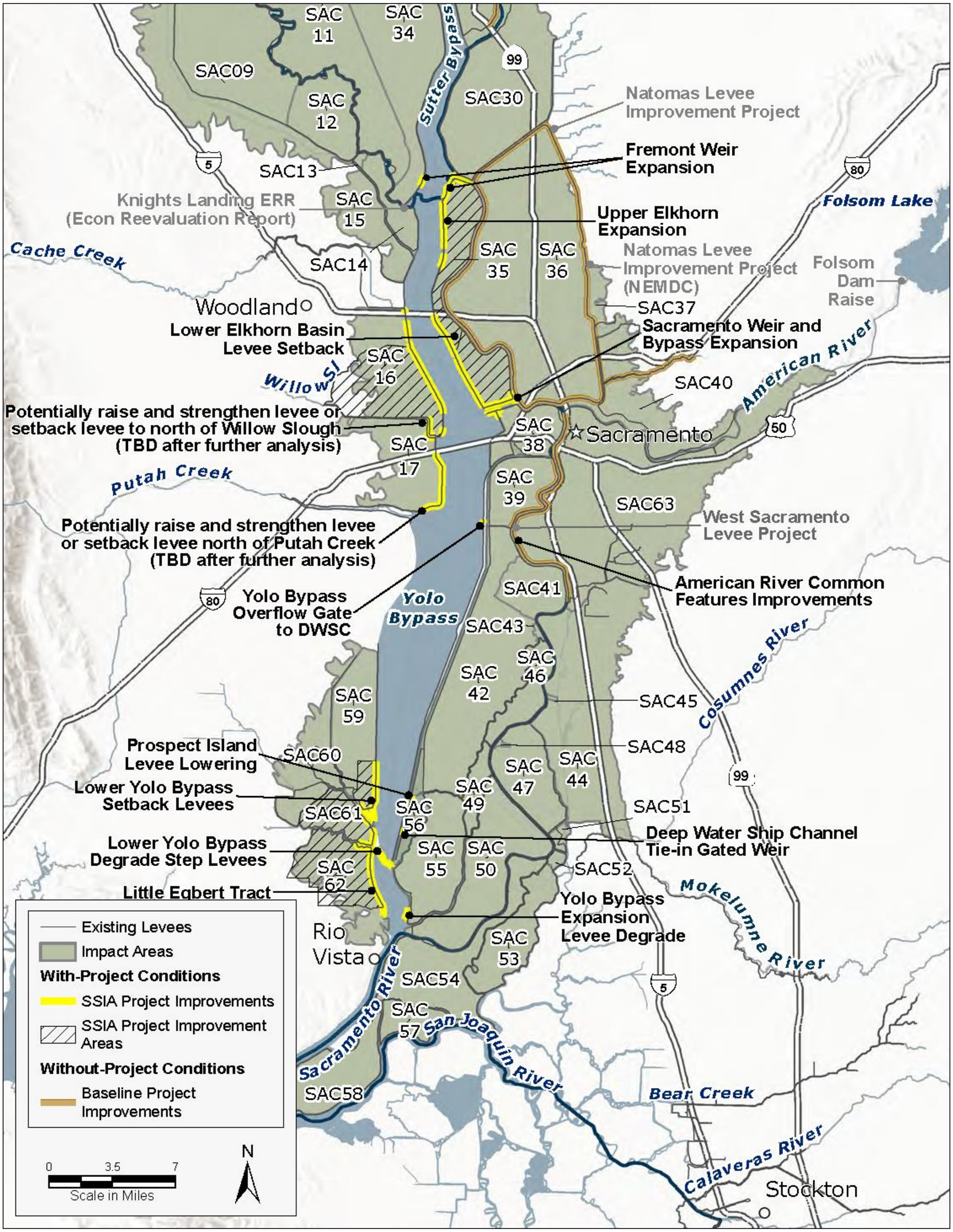


Figure 2.4 Without-Project and With-Project Features in the San Joaquin River Basin

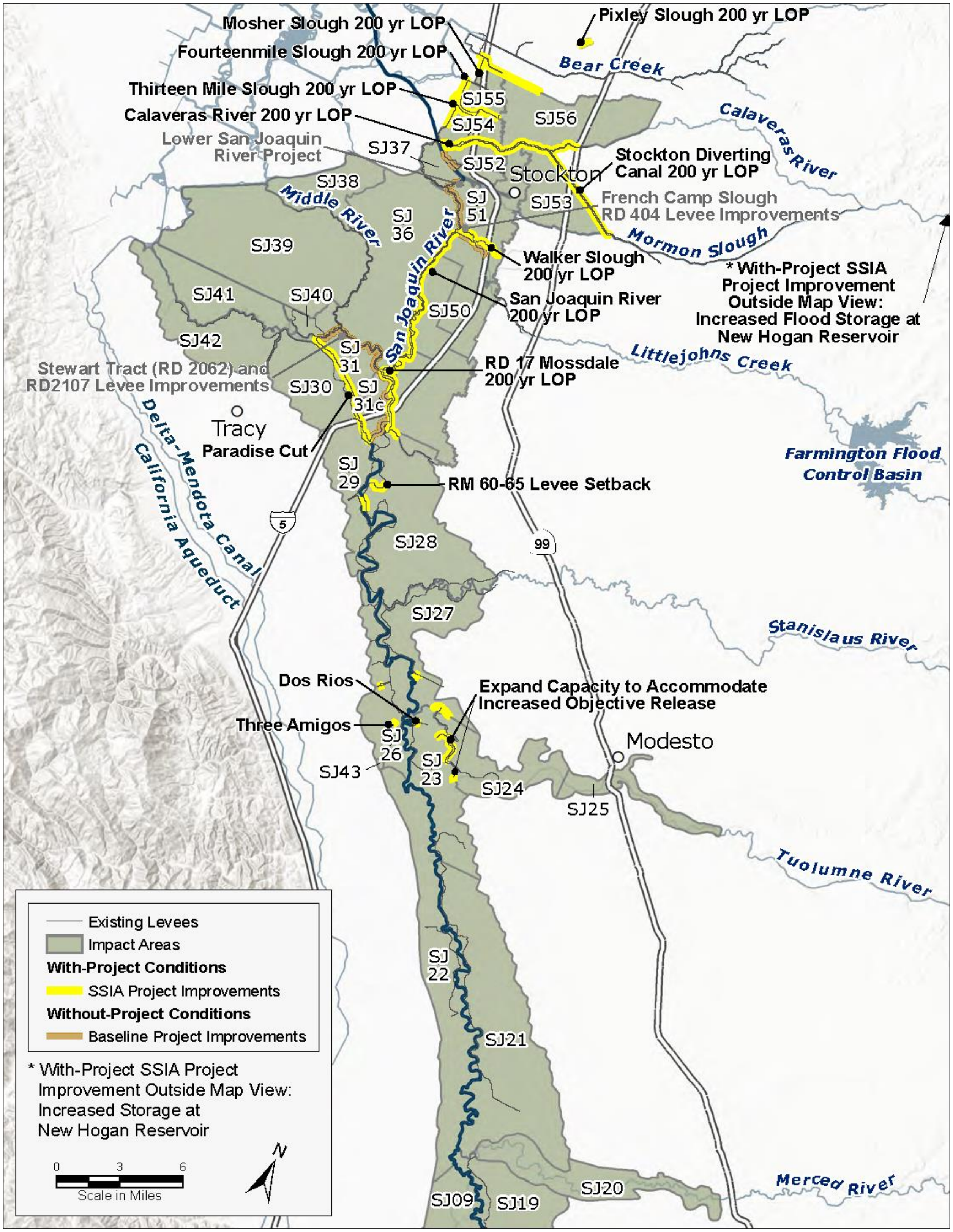


Figure 2.5 Without-Project and With-Project Features in the San Joaquin River Basin (continued)

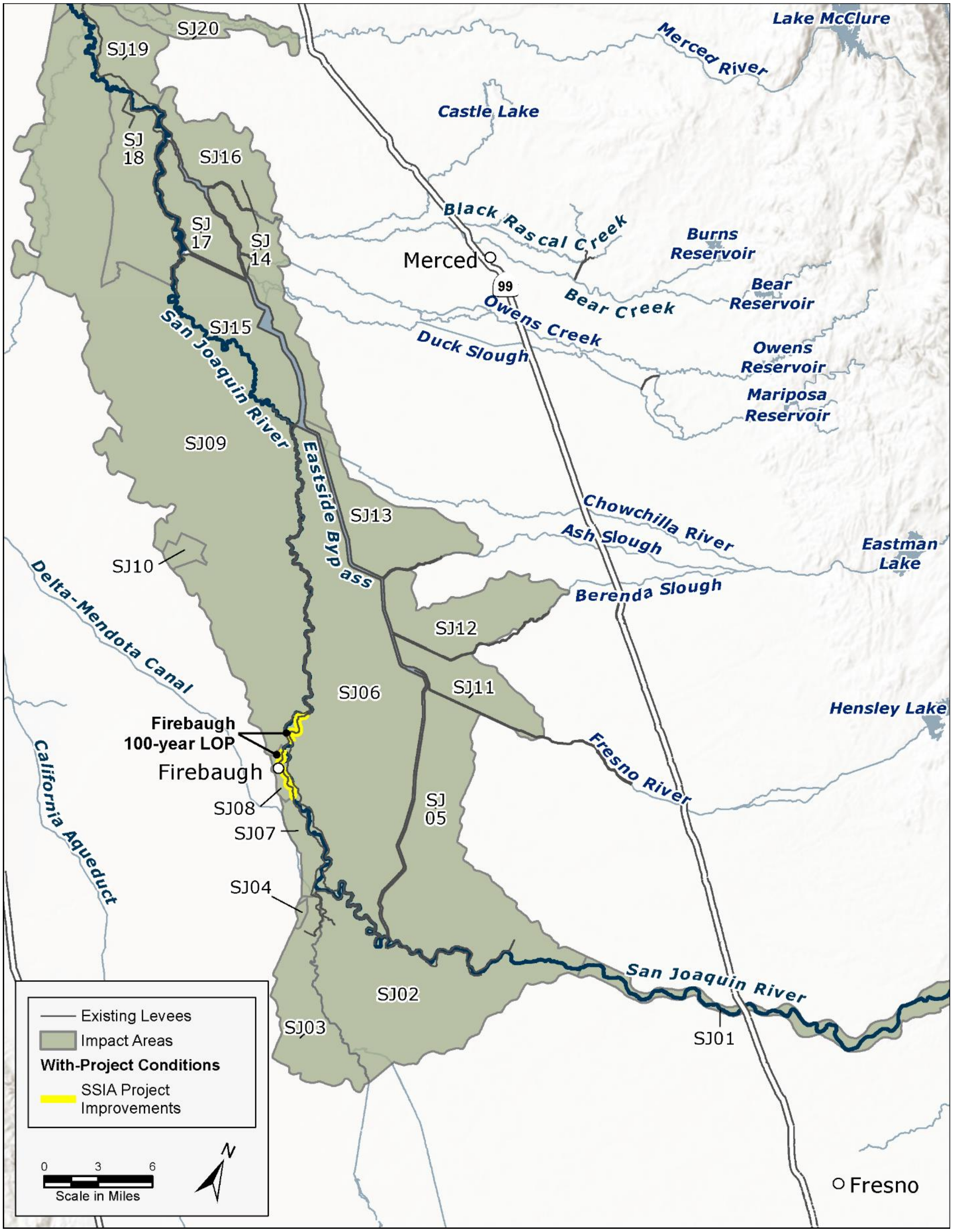


Table 2.3 **Elements for Sacramento River Basin Scenarios**

Element	2022 Without-Project	2022 With-Project	2072 Low Climate Change Projection Without-Project	2072 Medium Climate Change Projection Without-Project	2072 High Climate Change Projection Without-Project	2072 Low Climate Change Projection With-Project	2072 Medium Climate Change Projection With-Project	2072 High Climate Change Projection With-Project
Folsom Joint Federal Project spillway and reoperation	X	X	X	X	X	X	X	X
Yuba-Feather F-CO	X	X	X	X	X	X	X	X
Feather River Levee Improvements	X	X	X	X	X	X	X	X
Bear River Levee Improvements	X	X	X	X	X	X	X	X
Star Bend Levee Improvements	X	X	X	X	X	X	X	X
Marysville Ring Levee	X	X	X	X	X	X	X	X
Knights Landing ERR	X	X	X	X	X	X	X	X
Natomas Levee Improvement Project	X	X	X	X	X	X	X	X

Element	2022 Without-Project	2022 With-Project	2072 Low Climate Change Projection Without-Project	2072 Medium Climate Change Projection Without-Project	2072 High Climate Change Projection Without-Project	2072 Low Climate Change Projection With-Project	2072 Medium Climate Change Projection With-Project	2072 High Climate Change Projection With-Project
Hamilton City Phase 1 Improvements	X	X	X	X	X	X	X	X
West Sacramento Levee Project	X	X	X	X	X	X	X	X
American River Common Features GRR Project	X	X	X	X	X	X	X	X
Folsom Dam Raise						X	X	X
New Bullards Bar Lower Outlet						X	X	X
Fremont Weir Expansion: 1.5-mile expansion of Fremont Weir						X	X	X
Upper Elkhorn Expansion: 1.5-mile expansion of Yolo Bypass within the Upper Elkhorn Basin						X	X	X

Element	2022 Without-Project	2022 With-Project	2072 Low Climate Change Projection Without-Project	2072 Medium Climate Change Projection Without-Project	2072 High Climate Change Projection Without-Project	2072 Low Climate Change Projection With-Project	2072 Medium Climate Change Projection With-Project	2072 High Climate Change Projection With-Project
Lower Elkhorn Levee Setback: 3,000-foot levee setback for Yolo Bypass within the Lower Elkhorn Basin						X	X	X
Sacramento Weir Expansion: 1,500-foot expansion						X	X	X
Sacramento Bypass Expansion: 1,500-foot expansion						X	X	X
Willow Slough: Potentially raise and strengthen levee or setback levee north of Willow Slough (TBD after further analysis)						X	X	X

Element	2022 Without-Project	2022 With-Project	2072 Low Climate Change Projection Without-Project	2072 Medium Climate Change Projection Without-Project	2072 High Climate Change Projection Without-Project	2072 Low Climate Change Projection With-Project	2072 Medium Climate Change Projection With-Project	2072 High Climate Change Projection With-Project
Putah Creek: Potentially raise and strengthen levee or setback levee north of Putah Creek (TBD after further analysis)						X	X	X
Deep Water Ship Channel Tie In: a gated weir to tie the Yolo Bypass into the Sacramento River Deep Water Ship Channel						X	X	X
Degrade Step Levees: degrade remaining step levee segments in the lower Yolo Bypass						X	X	X

Element	2022 Without-Project	2022 With-Project	2072 Low Climate Change Projection Without-Project	2072 Medium Climate Change Projection Without-Project	2072 High Climate Change Projection Without-Project	2072 Low Climate Change Projection With-Project	2072 Medium Climate Change Projection With-Project	2072 High Climate Change Projection With-Project
Lower Yolo Bypass Expansion: levee setback south of RD 2068 (Lookout Slough Tidal Habitat Restoration and Flood Improvement Project)						X	X	X
Prospect Island Levees: degrade portions of the Prospect Island west levee						X	X	X
Little Egbert Tract: degrade portions of the Little Egbert Tract (RD 2084) levees						X	X	X

Element	2022 Without-Project	2022 With-Project	2072 Low Climate Change Projection Without-Project	2072 Medium Climate Change Projection Without-Project	2072 High Climate Change Projection Without-Project	2072 Low Climate Change Projection With-Project	2072 Medium Climate Change Projection With-Project	2072 High Climate Change Projection With-Project
Enhanced flood response and emergency management		X				X	X	X

Notes:
ERR = Economic Reevaluation Report
F-CO = Forecast-Coordinated Operations
FSRP = Flood System Repair Project
GRR = General Reevaluation Report
I-80 = Interstate 80
RD = Reclamation District

Table 2.4 **Elements for San Joaquin River Basin Scenarios**

Element	2022 Without-Project	2022 With-Project	2072 Low Climate Change Projection Without-Project	2072 Medium Climate Change Projection Without-Project	2072 High Climate Change Projection Without-Project	2072 Low Climate Change Projection With-Project	2072 Medium Climate Change Projection With-Project	2072 High Climate Change Projection With-Project
Stewart Tract (RD 2062) and RD 2107 levee improvements	X	X	X	X	X	X	X	X
French Camp Slough (RD 404) levee improvements	X	X	X	X	X	X	X	X
Increased Flood Storage Capacity at New Hogan Reservoir						X	X	X
Reservoir Actions for New Don Pedro Reservoir on Tuolumne River (FIO and F-CO)						X	X	X
Expand channel capacity on Tuolumne River to Increase Objective Release						X	X	X

Element	2022 Without-Project	2022 With-Project	2072 Low Climate Change Projection Without-Project	2072 Medium Climate Change Projection Without-Project	2072 High Climate Change Projection Without-Project	2072 Low Climate Change Projection With-Project	2072 Medium Climate Change Projection With-Project	2072 High Climate Change Projection With-Project
Stockton 200-year LOP levee raise on San Joaquin and Calaveras rivers						X	X	X
Smith Canal Closure						X	X	X
Fourteen Mile Slough 200-year LOP						X	X	X
Thirteen Mile Slough 200-year LOP						X	X	X
Mosher Slough 200-year LOP						X	X	X
Pixley Slough 200-year LOP						X	X	X
RD 17 Mossdale 200-year LOP with ecosystem habitat						X	X	X
French Camp Slough 200-year LOP						X	X	X

Element	2022 Without-Project	2022 With-Project	2072 Low Climate Change Projection Without-Project	2072 Medium Climate Change Projection Without-Project	2072 High Climate Change Projection Without-Project	2072 Low Climate Change Projection With-Project	2072 Medium Climate Change Projection With-Project	2072 High Climate Change Projection With-Project
Walker Slough 200-year LOP						X	X	X
Dos Rios Transitory Storage						X	X	X
Three Amigos Transitory Storage						X	X	X
Firebaugh 100-year LOP and eco-storage						X	X	X
Paradise Cut Bypass Expansion with levee raises, levee setbacks, and bench removal						X	X	X
RM 60-65 Levee Setback						X	X	X
Enhanced flood response and emergency management		X				X	X	X

Notes:

cfs = cubic feet per second
F-CO = Forecast-Coordinated Operations
FIO = Forecast-Informed Operations
LOP = level of protection
RD = Reclamation District
RM = river mile

CHAPTER 3

Analyses Used from 2017 CVFPP Update

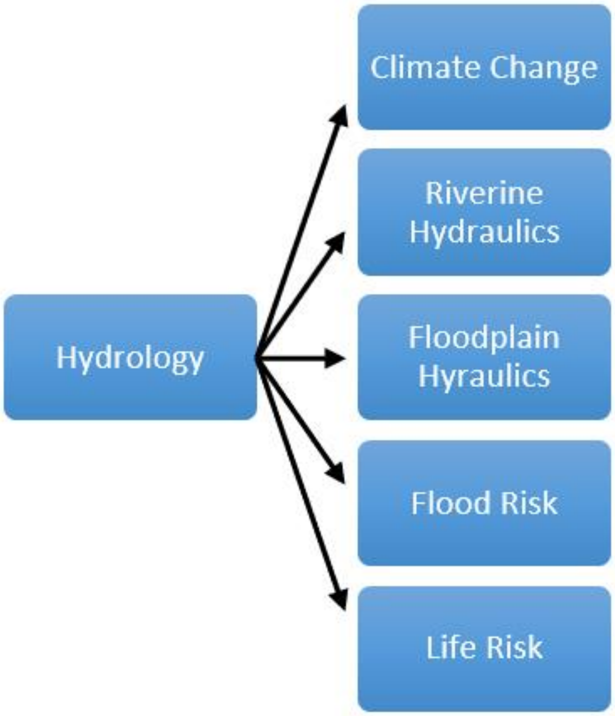
As noted, one of the intents of the CVFPP update is to integrate updated hazard, performance, and consequences information into the computation of flood risk. This current update relies on the enhanced flood hazard analysis that coupled with part of the 2017 CVFPP update. Note that the changing flood hazard as a result of climate change was updated as part of this current analysis. These areas of analysis included the flood hydrology, reservoir operations, riverine, and floodplain hydraulics as shown previously in Figure 2.1.

3.1 Flood Hydrology

For the 2017 CVFPP Update, regulated flow-frequency curves were developed at key locations in the system, referred to as CVFPP index points, for the evaluation scenarios. The methodology for development of these curves follows CVHS methods and is described in detail in the *2017 CVFPP Technical Analyses Summary Expanded Report* (California Department of Water Resources 2017a). These regulated flow-frequency curves were also used in the 2022 CVFPP Update for both the 2022 Without-Project and With-Project scenarios.

For the 2017 CVFPP Update, projected inland climate change discharge was incorporated into the frequency curves through the establishment of “climate change” volume-frequency curves using climate change ratios. The future condition volume frequency curves were revised for this analysis to reflect improved downscaling techniques of information from global climate models and a representation of the range of changes in precipitation and temperature trends. A summary of how these ratios were developed for the 2022 CVFPP Update is provided in Section 4.2 and explained in additional detail in Appendix B, “Climate Change Volume-Frequency Analysis.” Results from this flood hydrology task were used in subsequent analyses to compute hydraulic results, flood damage estimates, and life risk estimates (Figure 3.1).

Figure 3.1 Incorporation of Hydrologic Results



3.2 Reservoir Operations Analysis

In the 2017 CVFPP Update, system hydrographs based on historical or scaled historical inflows taken from CVHS were simulated through models of the reservoir systems with prescribed reservoir operating rules for each scenario. Reservoir operations analysis were completed using the HEC-ResSim model from CVHS, which combined different representations of recently implemented reservoir operation management agreements, future planned reservoir improvements, and with-project reservoir-related options within the SSIA. Results from these reservoir simulation models were used as input for the system-regulated channel routing model, at selected handoff locations.

Reservoir operations and storage components included in the evaluation scenarios are listed below:

- **Yuba-Feather Forecast-Coordinated Operations (F-CO) (Included in all evaluation scenarios)**: Oroville Reservoir along the Feather River and New Bullards Bar along the Yuba River share a common downstream operating point. Releases from both reservoirs are influenced by the total flow at the Yuba-Feather river confluence near the cities of Yuba and Marysville. F-CO is a multi-agency partnership and program to exchange information on reservoir inflow forecasts and anticipated releases from the reservoirs. The F-CO was reflected in the HEC-ResSim model by the addition of a specific rule to each reservoir that looks at the total flow at the downstream confluence. Release decisions were then made to balance the use of the flood storage between the reservoirs.

- **Expansion of New Bullards Bar Outlet capabilities (Future with-project scenarios)**: Proposed construction of a new outlet at New Bullards Bar Reservoir is currently under evaluation to increase the maximum release from the reservoir at a given water level. This expanded capacity is expected to add reservoir management flexibility and would evacuate flood waters from the flood control pool in advance of large flood events.
- **Folsom Dam Joint Federal Project (Included in all evaluation scenarios)**: This project, implemented by U.S. Army Corps of Engineers (USACE) and the U.S. Bureau of Reclamation, includes the construction of an auxiliary spillway to increase the dam’s flood protection capacity to a 200-year level. In addition, the project required modifications to the Folsom Water Control Manual (U.S. Army Corps of Engineers 2016), which dictates how flood storage, and subsequent releases are made. The USACE’s Sacramento District revised set of operating rules are based on directly forecasted volumes to make release decisions. This operating procedure is described in the engineer’s report for the Water Control Manual update (U.S. Army Corps of Engineers 2017).
- **Folsom Dam Raise (Future with-project scenarios)**: This is an authorized project. USACE’s Sacramento District would raise Folsom Dam by approximately 3.5 feet. Design of the raise and how the additional storage would be used to meet flood management objectives is currently being refined. This raise is part of the SSIA. To represent the raise, the modeling from USACE’s Sacramento District was obtained and integrated into the reservoir simulations.
- **Increased Flood Storage on the Calaveras River (Future with-project scenarios)**: In the San Joaquin BWFS, significant analysis focused on the best use of additional storage on the San Joaquin River system. Storage on the Calaveras River was determined to be beneficial for downstream flood management. The SSIA with-project condition includes 42,000 acre-feet of upper watershed flood storage at New Hogan Reservoir to reduce systemwide stages and provide climate change resiliency. Upper watershed flood storage could include a wide portfolio of actions, including upstream transitory storage, off-stream storage, reservoir re-operation to increase flood storage space in existing reservoirs, conjunctive use opportunities that increase flood

storage space, forecast-informed operations (FIO), increased reservoir objective release, or any combination of these.

- **Reservoir Actions for New Don Pedro Reservoir on Tuolumne River (Future with-project scenarios)**: This is an increase in objective release from 9,000 cubic feet per second (cfs) to 25,000 cfs to allow greater use of the channels and allow greater flexibility in flood storage.

For the 2022 CVFPP Update, HEC-ResSim simulations from the 2017 CVFPP Update were used to provide input to the riverine channel hydraulics.

3.3 Riverine Hydraulics

The 2017 CVFPP Update established flow-frequency and channel stage-discharge relationships at each index point in the Sacramento and San Joaquin river basins for input to the risk analysis. The riverine model used the reservoir releases as input and dynamically routed flow through the channel system, accounting for levee overtopping and levee breaches. Riverine analysis was completed with the most updated systemwide HEC-RAS models from the CVFED program modified to reflect the 2022 CVFPP Update evaluation scenarios.

Two HEC-RAS geometries were used for the evaluation scenarios for the Sacramento River Basin as follows:

- **Existing Conditions:** This reflects without-project conditions used for the 2022 and 2072 scenarios. As mentioned earlier, there is no hydraulic difference between without-project and with-project conditions for 2022. So, this was also used for 2022 with-project conditions.
- **With-Project:** This reflects with-project conditions and is used for the 2072 With-Project Scenarios.

Similarly, two HEC-RAS geometries were assembled for the evaluation scenarios for the San Joaquin River Basin as follows:

- **Existing Conditions:** This reflects without-project conditions used for the 2022 and 2072 scenarios, as well as 2022 with-project conditions.
- **With SSIA:** This reflects with-project conditions and is used for the 2072 With-Project Scenarios.

3.4 Floodplain Hydraulics

To estimate flood damage when a levee fails (breaches) or overtops, a relationship between channel water surface elevations (WSEs) and floodplain elevations is needed at each index point in the system.

3.4.1 Impact Areas and Index Points

Impact areas and index points form the basic framework for the flood risk assessment. Flood risk is computed at an index point, which is a location that represents the interface between an impact area and the channel, as shown in Figure 3.2. In this context, an index point is a specific location that is representative of a river reach (referred to as a damage reach) with consistent hydrologic, hydraulic, and geotechnical characteristics. The 2022 CVFPP Update used the same impact areas and index points used in the 2017 CVFPP Update. The index points and impact areas for the Sacramento and San Joaquin river basins are shown in Figures 3.3 and 3.4 (Sacramento River Basin), and Figures 3.5 and 3.6 (San Joaquin River Basin).

Figure 3.2 **Example Index Point/Impact Area for Flood Risk Computation**

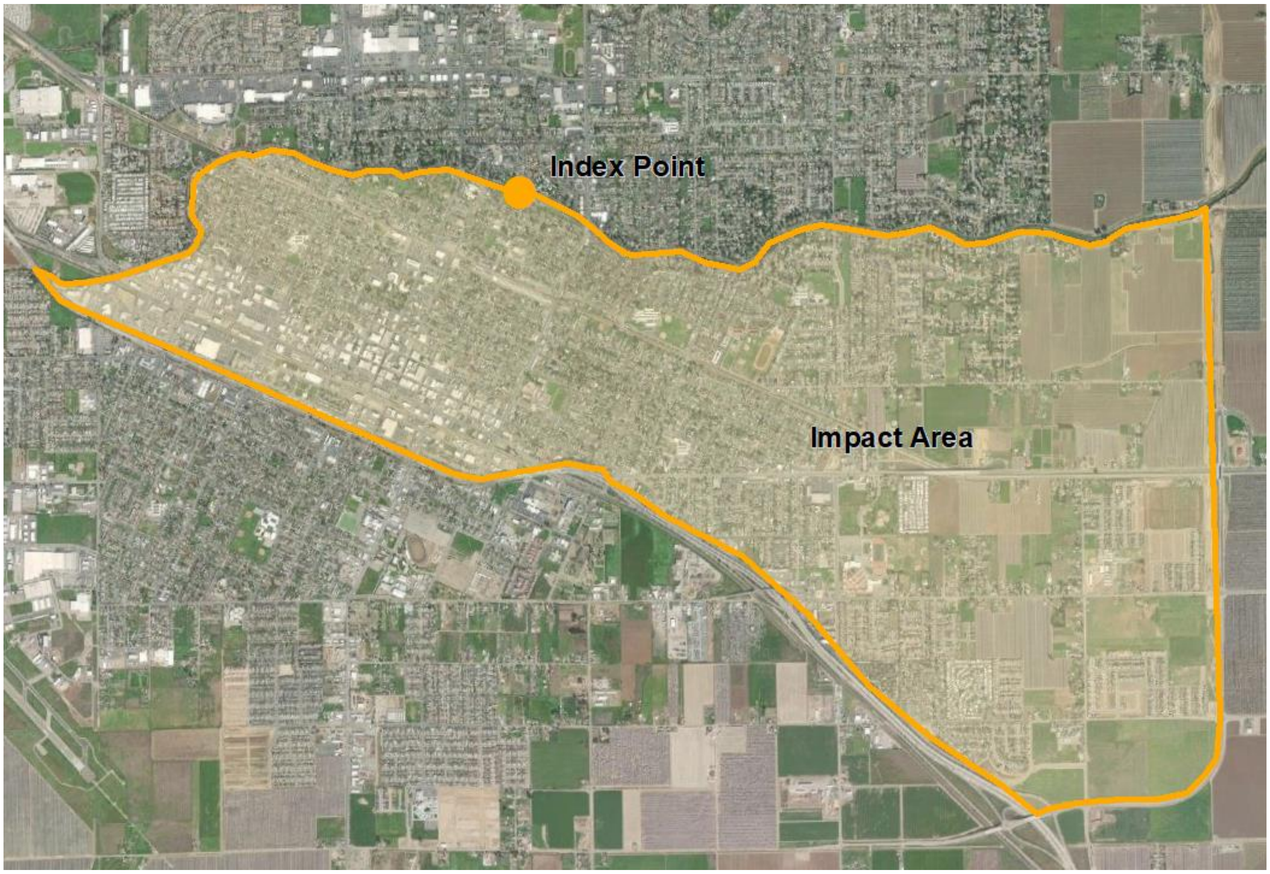


Figure 3.3 Sacramento River Basin Index Points and Impact Areas

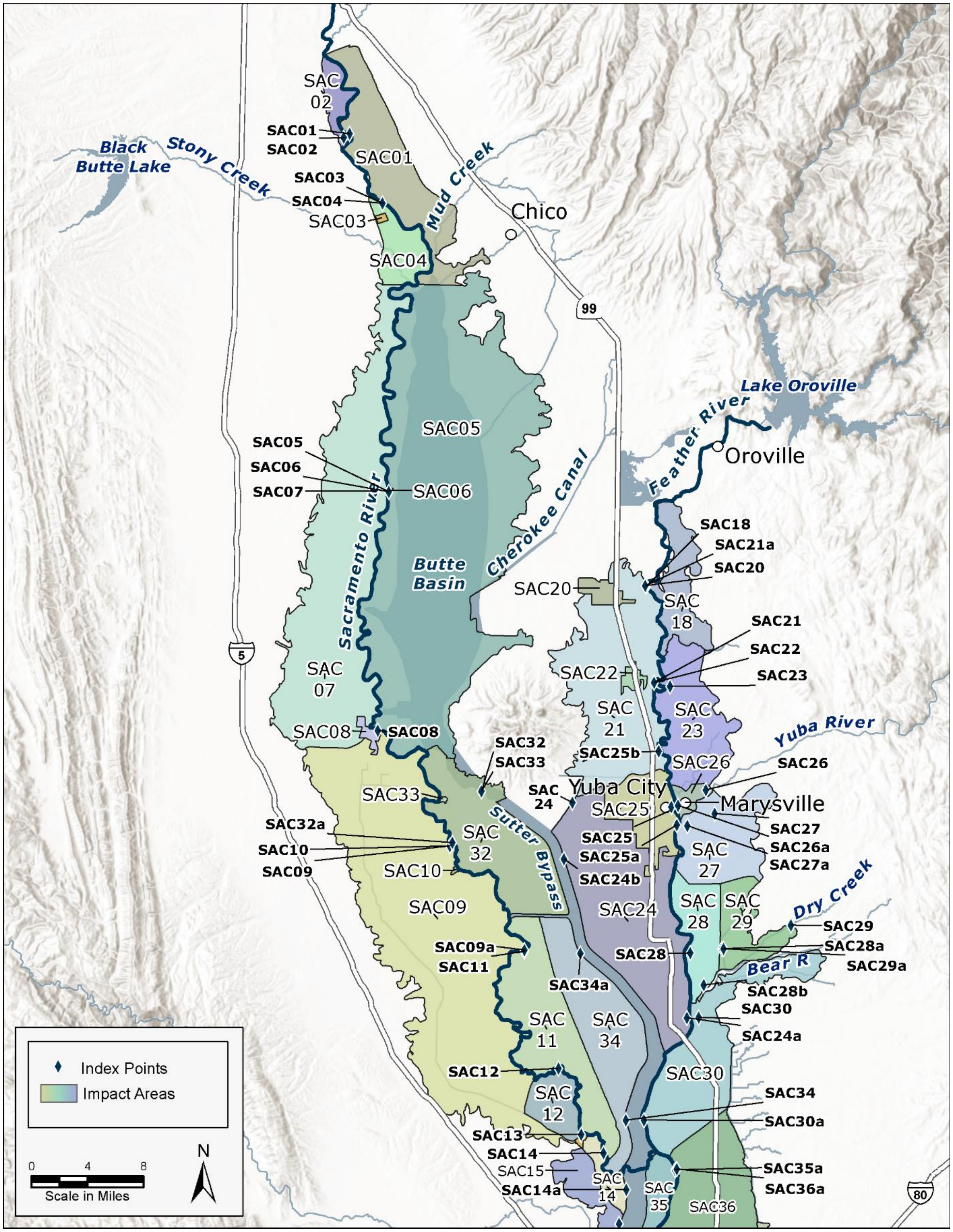


Figure 3.4 **Sacramento River Basin Index Points and Impact Areas (continued)**

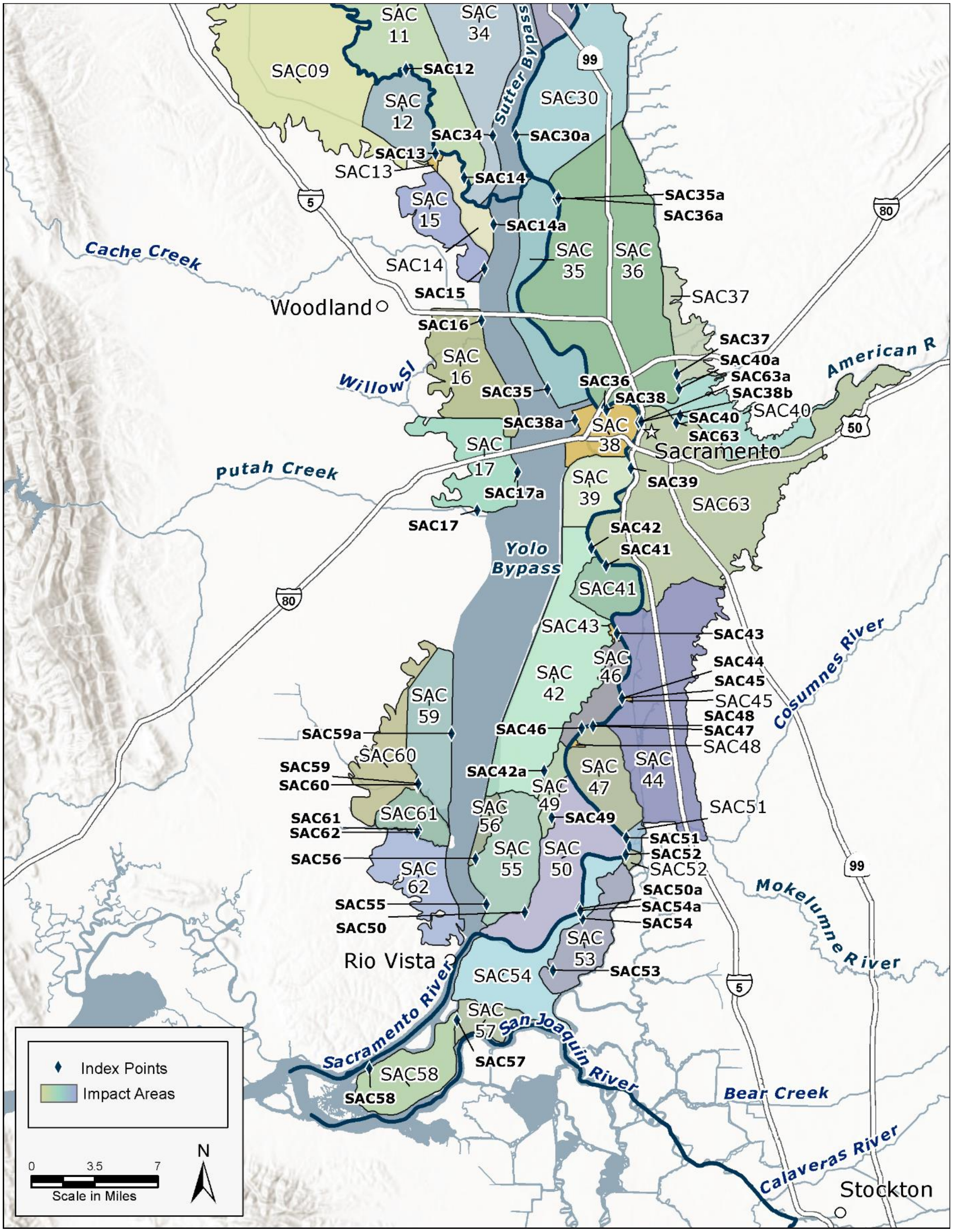


Figure 3.5 San Joaquin River Basin Index Points and Impact Areas

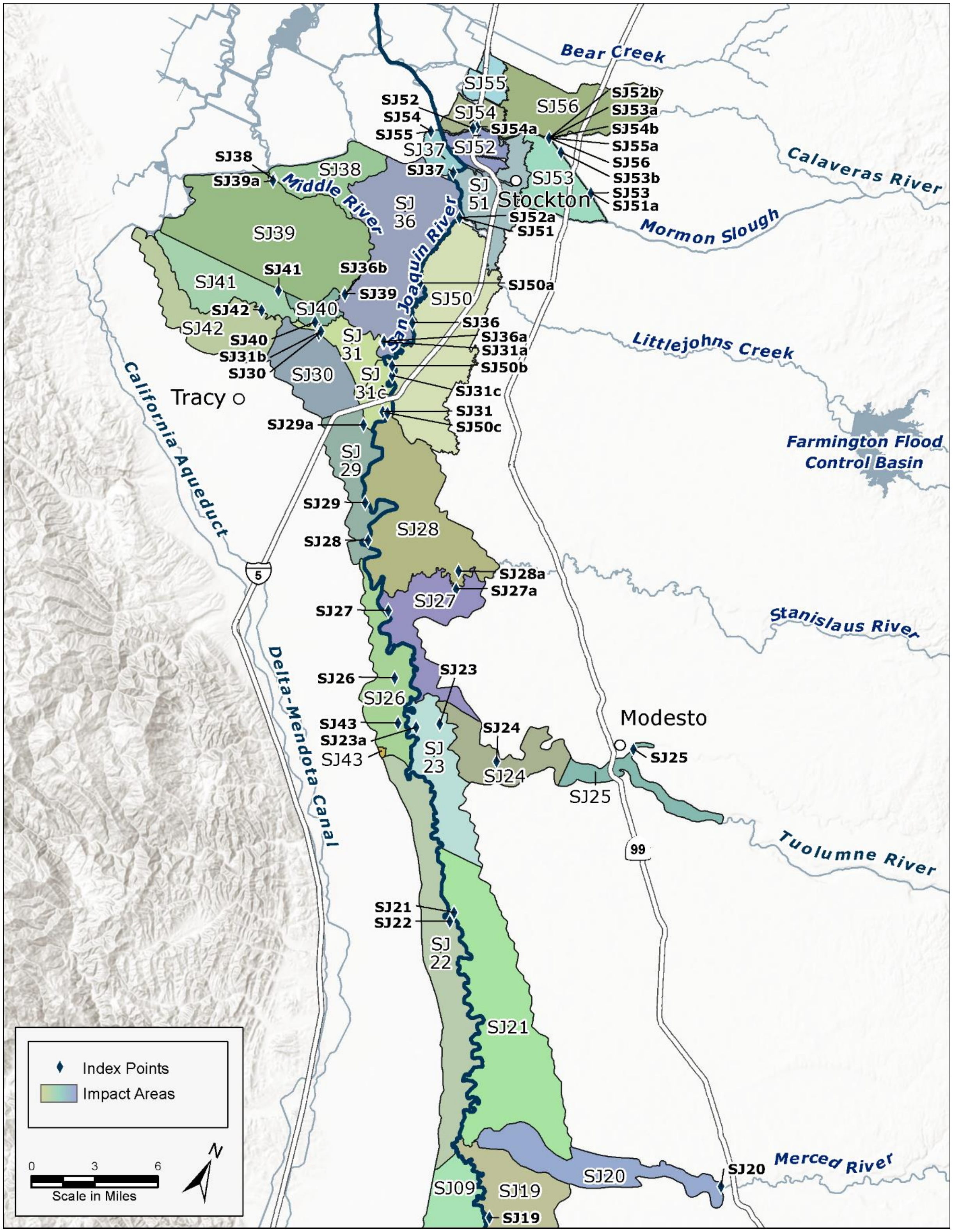
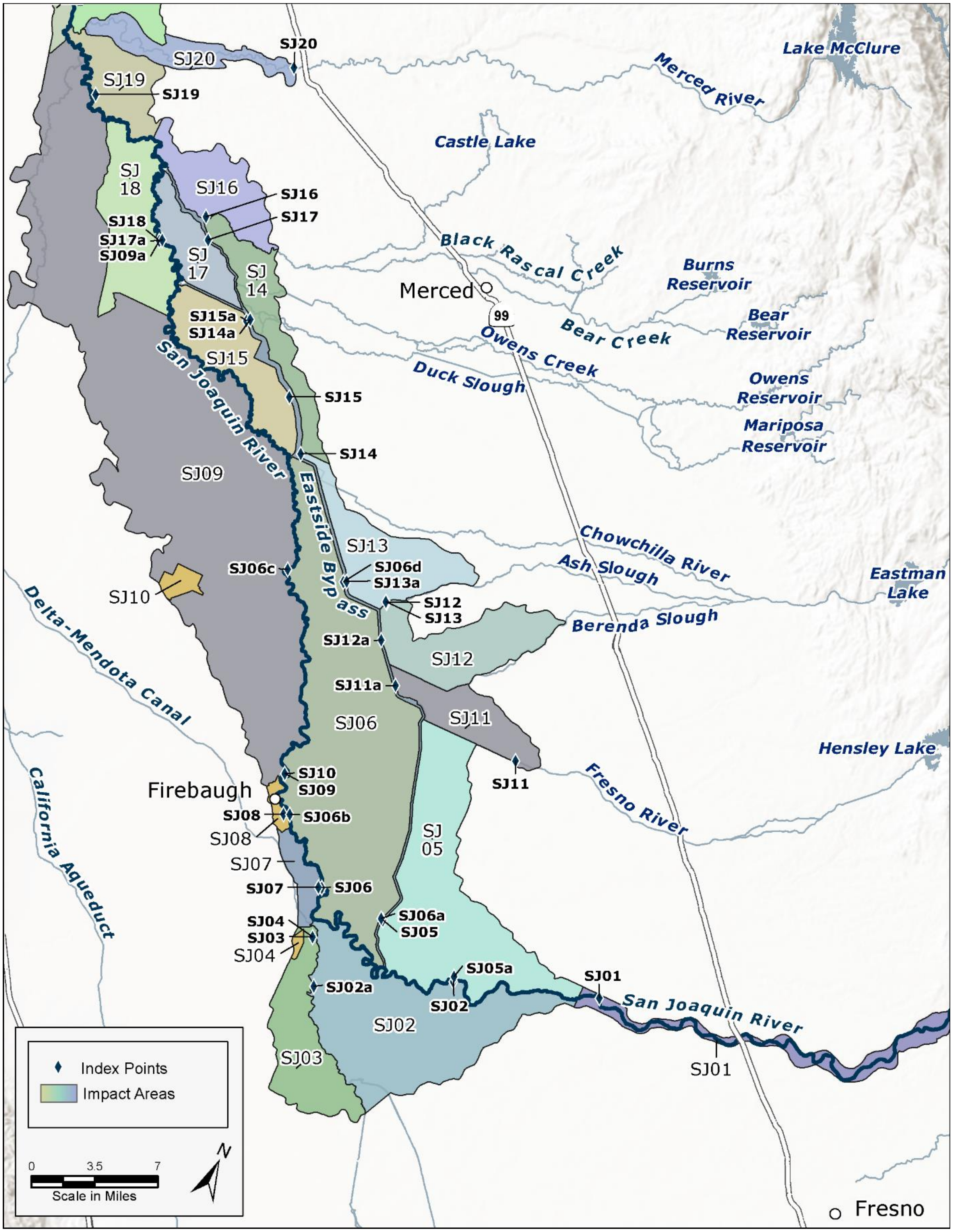


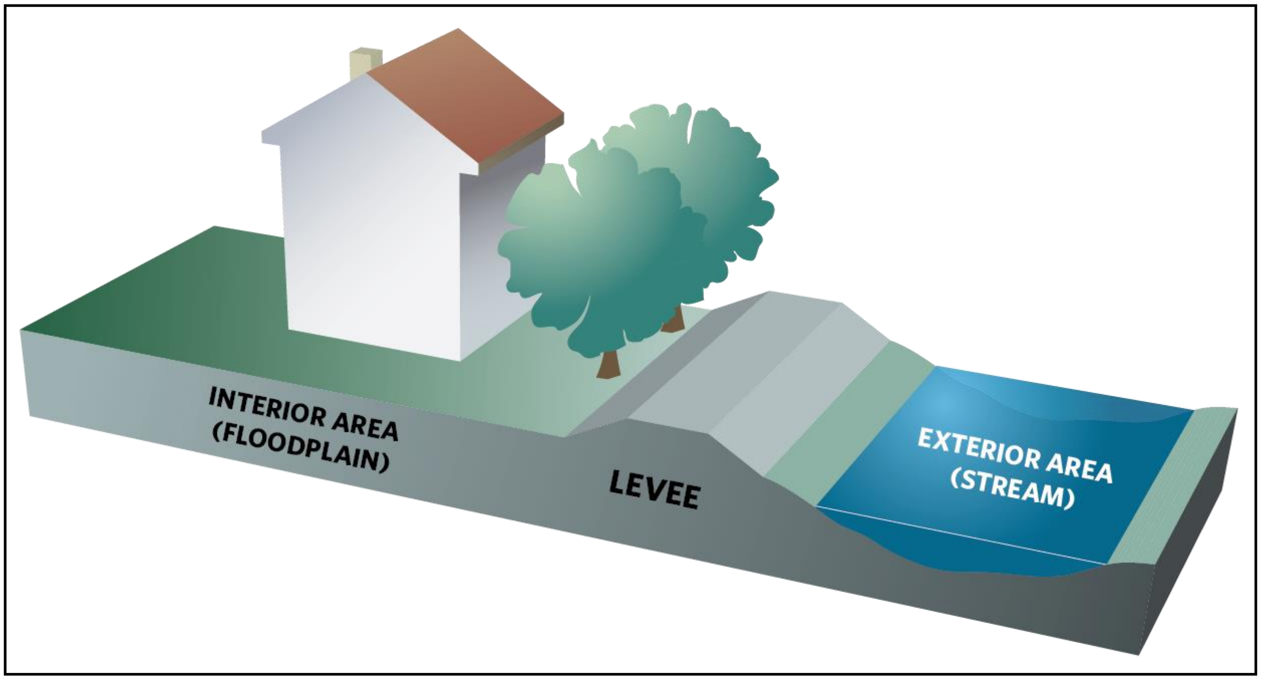
Figure 3.6 **San Joaquin River Basin Index Points and Impact Areas (continued)**



3.4.2 Interior and Exterior Areas

The floodplain is often referred to as the interior area, and the channel is referred to as the exterior area as illustrated in Figure 3.7.

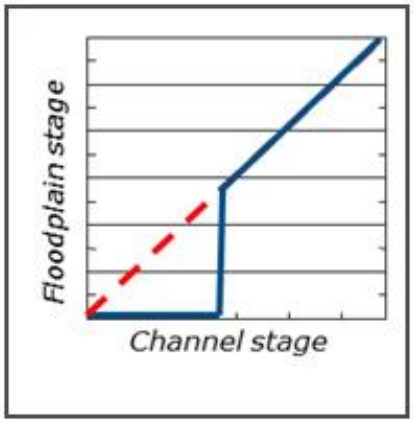
Figure 3.7 Interior and Exterior Areas



This interior-exterior relationship does not involve probabilities. Rather, it is a physical relationship based on simulation of levee failures and floodplain evaluation. The shape of the relationship is a function of the levee breach model parameters, the water in the channel that spills into the floodplain, and the floodplain topography.

Such a relationship for a simple case is illustrated on Figure 3.8. As shown on the graph, while flow is contained within the channel, the channel stage increases and floodplain stage is zero, represented by the horizontal line along the Channel Stage axis. Once the channel stage is exceeded or the levee fails, the floodplain stage increases vertically until the channel stage and floodplain stage are equal. This type of interior-exterior relationship would be representative of a basin where the floodplain fills like a "bath tub."

Figure 3.8 **Simplified Interior-Exterior Relationship**



But, in cases where the floodplain is sloped and there is a significant amount of overland flow, such as in the Central Valley, the floodplain evaluation is typically completed with an advanced two-dimensional floodplain routing model such as FLO-2D. For these cases, a channel elevation to floodplain surface is then developed.

An interior-exterior relationship was developed for each defined index point and impact area pair within the Sacramento and San Joaquin river basins using CVFED Program FLO-2D and HEC-RAS models, based on CVHS flow hydrographs during the 2017 CVFPP Update. These relationships were also used for the 2022 CVFPP Update.

3.5 Hydraulic Results

The stage- and flow-frequency curves at each index point are presented in Appendix D, “Risk Analysis Summary by Index Point.” As mentioned earlier, the 2022 With-Project Scenario is not hydraulically different from the 2022 Without-Project Scenario, but the flood damage and life risk estimates are different because of the changes in how the EFREM improves the public response to the hazard. The 2022 Without-Project and 2022 With-Project Scenarios were completed assuming present-day sea levels.

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CHAPTER 4

Enhanced Technical Analyses for the 2022 CVFPP Update

Several components of the technical analyses required to estimate flood risk within the Central Valley were enhanced for the 2022 CVFPP Update. These include:

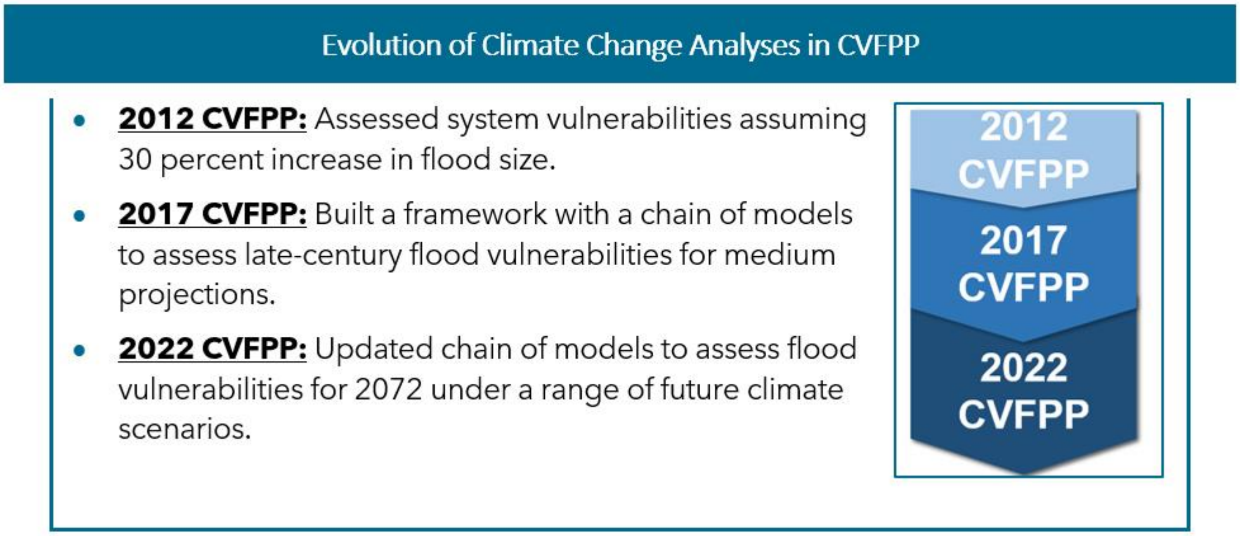
- Climate change analysis.
- Climate change volume-frequency analysis.
- Estuarine evaluations.
- Geotechnical analysis.
- Risk analysis inventory update.
- Life risk input development.
- Flood risk analyses.

4.1 Climate Change Analysis

The 2012 CVFPP assessed the system vulnerabilities for climate change by assuming a 30-percent increase in flood size. The 2017 CVFPP Update built an evaluation framework with a chain of models to assess late-century flood vulnerabilities for medium projections. Following adoption of the 2017 CVFPP Update and in response to public comments regarding uncertainties in the climate change analysis, the 2022 CVFPP Update includes a broader range of potential climate conditions in the future.

Projected climate conditions were extended to include low, medium, and high projected magnitude of change and associated impact for a planning horizon of 50 years from the 2022 CVFPP Update. The range represents a wider available sample, given available downscaled climate models and analytical tools, of plausible future changes in flood risk resulting from climate change in the Central Valley expected by 2072. Figure 4.1 shows the evolution of the climate change analyses presented in this document from 2012 to present.

Figure 4.1 **Climate Change Analyses in the CVFPP, 2012 Through 2022**



Evolution of Climate Change Analyses in CVFPP

- **2012 CVFPP:** Assessed system vulnerabilities assuming 30 percent increase in flood size.
- **2017 CVFPP:** Built a framework with a chain of models to assess late-century flood vulnerabilities for medium projections.
- **2022 CVFPP:** Updated chain of models to assess flood vulnerabilities for 2072 under a range of future climate scenarios.

Although the overall climate change analysis procedure follows the 2017 CVFPP Update, two significant enhancements were made:

1. The locally constructed analogs (LOCA) statistically downscaled dataset has replaced the bias correction with median spatial disaggregation (BCSD) method.
2. The low and high projections use 10 general circulation model (GCM) scenario members, herein referred to as "model-RCPs," to represent a drier, lesser warming condition (low), and a wetter, more warming condition (high), as well as a medium condition. Representative concentration pathways (RCPs) represent the combined climate impacts of sets of internally consistent assumptions about future changes in the global economy, technology, demographics, policy, and institutional arrangements. A model-RCP refers to the combination of a GCM and a RCP.

4.1.1 General Circulation Model Archive and Dataset

The CMIP Phase 5 multi-model dataset informed the IIPCC fifth assessment report and was released in 2013. The CMIP Phase 5 global projections of future climate conditions use four RCPs (RCP-2.6, -4.5, -6.0, and -8.5) that reflect different potential climate outcomes as a result of the total additional radiative forcing at the end of the 21st century relative to pre-industrial times. Radiative forcing refers to the difference between incoming and outgoing radiation of the planet. Overall, 38 GCMs use one or multiple RCPs to represent potential future conditions.

Of the 38 GCMs, 31 were explored in 2015 by the Climate Change Technical Advisory Group (CCTAG), from which 10 GCMs were identified to perform "better" for developing assessments and plans for California water resource issues, as well as to develop a more manageable climate change ensemble. Since then, a few additional GCMs became available but were not considered in the post-CCTAG effort.

Currently, the best available dataset of statistically downscaled GCM products for California is the LOCA archive of 32 GCMs from the CMIP Phase 5 archive at 1/16th degree spatial resolution (Pierce et al. 2014). The LOCA method is a statistical scheme that uses future climate projections combined with historical analog events to produce daily downscaled precipitation and temperature time series. The use of spatial and temporal analogs from historical events likely produces a more realistic storm pattern than the BCSD method used in the 2017 CVFPP Update. The LOCA dataset used in the 2022 CVFPP Update includes 32 GCMs under two RCPs (RCP 4.5 and 8.5), which brings the total number of model-RCPs to 64. The low, medium, and high scenarios used in climate change analysis are created from subsets of these 64 model-RCPs members. Table 4.1 shows the complete list of 38 GCMs, the 10 GCMs selected by the CCTAG, and the 32 GCMs downscaled using LOCA.

Table 4.1 GCMs Developed under CMIP Phase 5 to Inform the IPCC's Fifth Assessment Report

38 CMIP5 GCMs	GCMs screened by CCTAG	10 GCMs selected by CCTAG	32 GCMs downscaled using LOCA
ACCESS1-0	X	X	X
ACCESS1-3	X		X
BCC-CSM1-1	X		X
BCC-CSM1-1-M	X		X
BNU-ESM	X		
CANESM2	X	X	X
CCSM4	X	X	X
CESM1-BGC	X	X	X
CESM1-CAM5	X		X
CMCC-CM	X		X
CMCC-CMS	X	X	X
CNRM-CM5	X	X	X

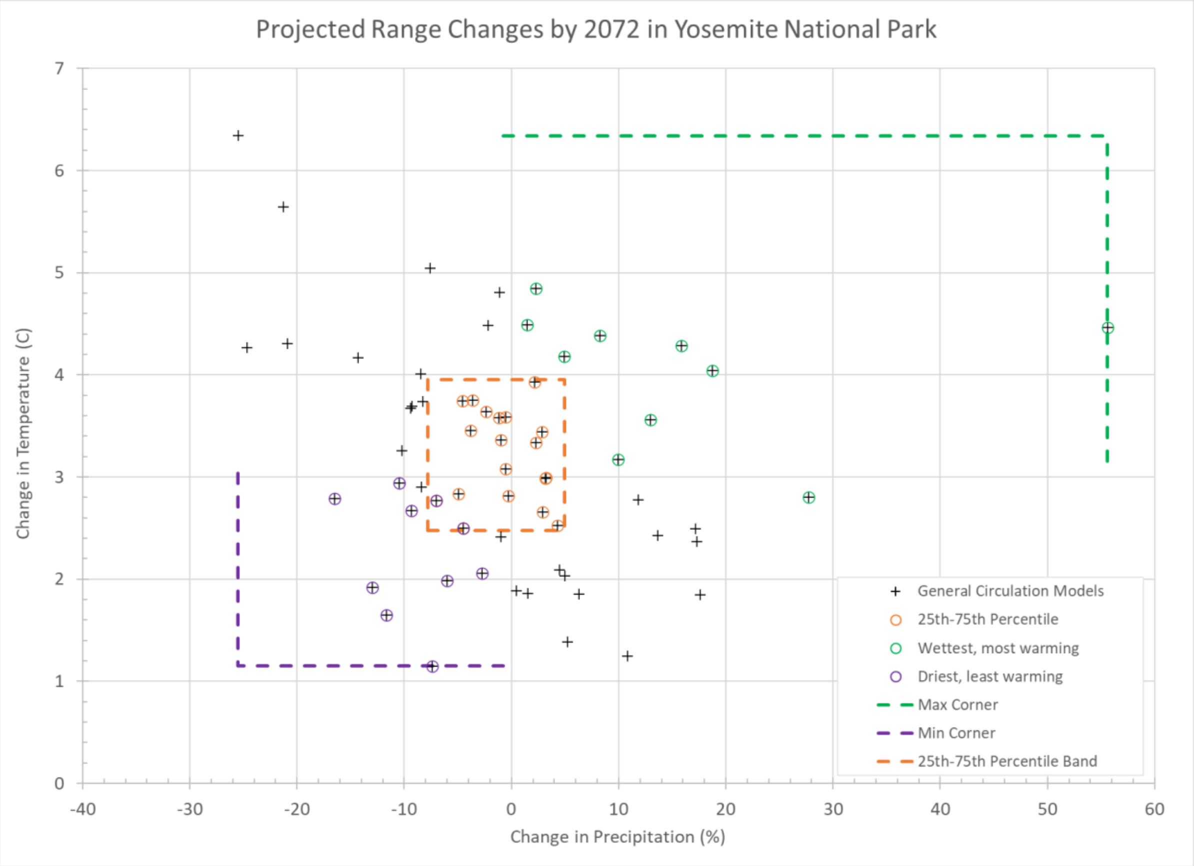
38 CMIP5 GCMs	GCMs screened by CCTAG	10 GCMs selected by CCTAG	32 GCMs downscaled using LOCA
CSIRO-MK3-6-0	X		X
EC-EARTH	X		X
FGOALS-G2	X		X
FGOALS-S2			
FIO-ESM			
GFDL-CM3	X	X	X
GFDL-ESM2G	X		X
GFDL-ESM2M	X		X
GISS-E2-H			X
GISS-E2-R			X
GISS-E2-R-CC			
HADGEM2-AO			X
HADGEM2-CC	X	X	X
HADGEM2-ES	X	X	X
INMCM4	X		X
IPSL-CM5A-LR	X		X
IPSL-CM5A-MR	X		X
IPSL-CM5B-LR	X		
MIROC-ESM	X		X
MIROC-ESM-CHEM	X		X
MIROC5	X	X	X
MPI-ESM-LR	X		X
MPI-ESM-MR	X		X
MRI-CGCM3	X		X
NORESM1-M	X		X
NORESM1-ME			

Notes: CCTAG = Climate Change Technical Advisory Group; CGM = general circulation model; CMIP = Coupled Model Intercomparison Project; IPCC = Intergovernmental Panel on Climate Change; LOCA = locally constructed analogs.

4.1.2 Climate Change Scenarios

As discussed above, projected climate conditions were extended to include low, medium, and high projected magnitude of change and associated impact for a planning horizon extending 50 years beyond 2022. Similar to the 2017 CVFPP Update, the medium projection is derived from the model-RCP scenarios falling within the inner quartile (25th to 75th percentile) of the 64 model-RCPs ensemble. The low and high projected conditions were derived using a nearest-neighbor approach to sample 10 model-RCPs closest to the maximum (and minimum) projected change (Figure 4.2) across the 64-member archive. The 10-nearest neighbor approach is meant to adequately represent the extreme range of climate projections without biasing the projected scenario to a single model-RCP's projected change.

Figure 4.2 Absolute Change in Average Annual Temperature and Percent Change of Average Annual Temperature at one Future 30-Year Period Centered on 2072

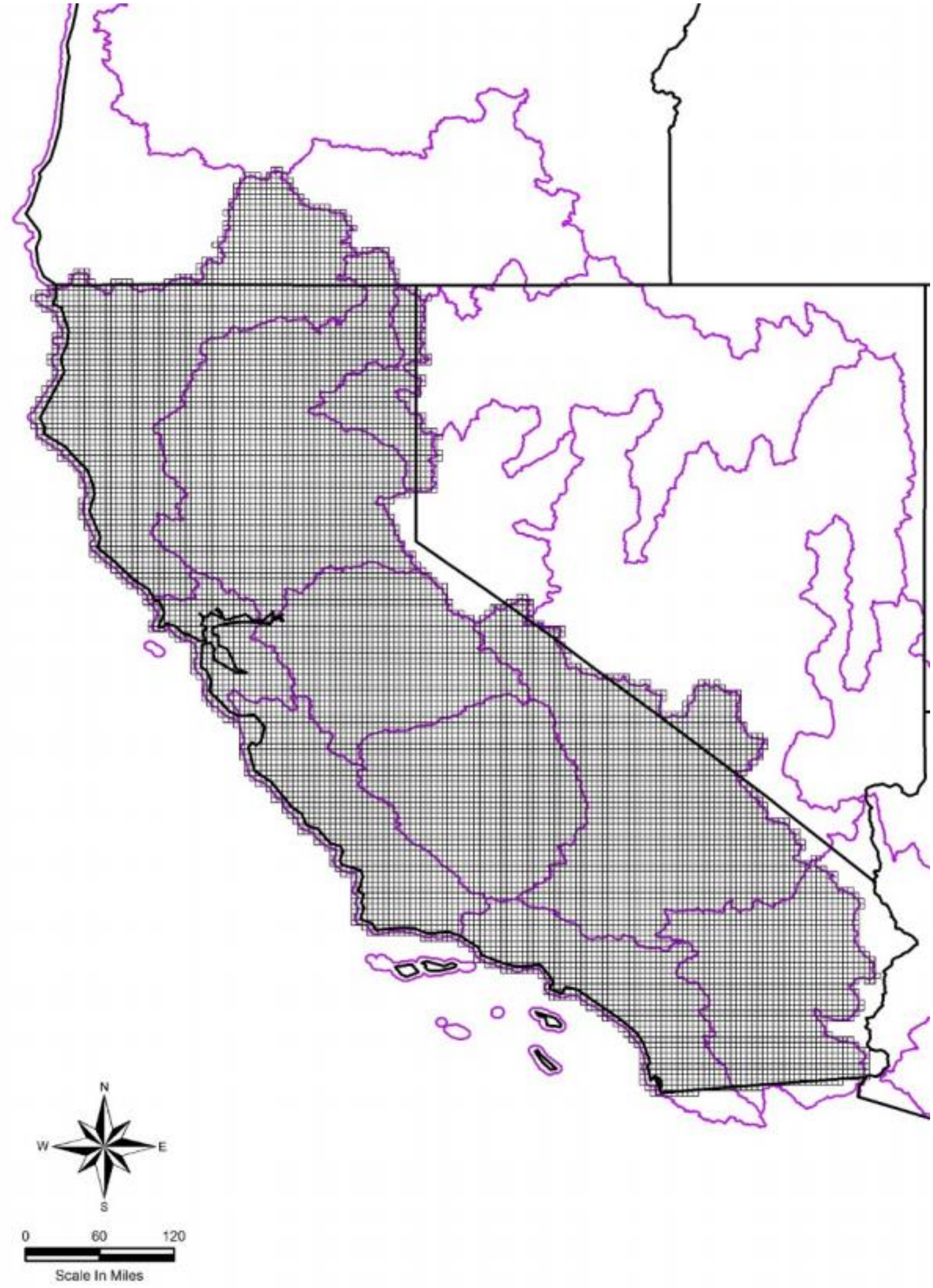


4.1.3 VIC Modeling

The variable infiltration capacity (VIC) model is a macro-scale, semi-distributed hydrologic model that solves water and energy balances and simulates land surface-atmosphere fluxes of moisture and energy. The 2017 CVFPP Update used VIC version 4.1 (whereas the 2022 CVFPP Update used version 4.2), an updated version that increases accuracy and reduces unnecessary complexities, thereby improving model output.

The VIC model domain and grid, which remain unchanged from the 2017 CVFPP Update, are shown in Figure 4.3. The VIC model domain consists of 8,419 grid cells at a 1/16th (approximately 6km or 3.75 miles) spatial resolution.

Figure 4.3 2022 CVFPP VIC Model Domain and Grid



Source: Climate Change Analysis – Phase IIB Technical Memorandum (California Department of Water Resources 2016d)

The VIC model contains several optional algorithms (modes) for performing various computations. Some of these options were developed for better understanding of hydrologic processes, and others were developed to enhance model performance in different geographic settings. For the 2022 CVFPP Update, two major simulation modes were considered:

- The water balance mode computes a daily soil water balance, but avoids computationally intensive surface energy balance calculations by assuming that soil surface temperature is equal to air temperature. In the water balance mode, VIC also solves the energy balance within the snowpack to compute snowmelt fluxes and maintain snow water equivalent.
- The energy balance mode performs iterative computations to solve the complete water balance while also minimizing the surface energy balance error. The surface energy balance computations close when a surface temperature is found, making the sum of sensible heat, ground heat, ground heat storage, outgoing longwave and indirectly latent heat equal to the sum of incoming solar and longwave radiation fluxes. In cold regions such as snow-capped mountains, a frozen soil algorithm is available for computing thermal fluxes within soil ice, which can restrict infiltration and soil moisture drainage.

The VIC model used for the 2017 CVFPP Update included full water balance computations and the frozen soil algorithm. Full energy balance algorithms were not utilized (i.e., the energy balance was turned off) for the 2017 CVFPP Update VIC model for computational efficiency. The iterative nature of energy balance computations significantly increases the computation time required to complete each model run. For the 2022 CVFPP Update, the VIC model was used to calculate annual precipitation, runoff, and baseflow for the 8,419 unique grid cells. Three VIC model simulations were developed as shown in Table 4.2.

Table 4.2 VIC Model Simulations Used in 2022 CVFPP Update Analysis

VIC Model Simulation	Software Version	Simulation Period	Energy Balance	Notes
1	4.1	January 1, 1915 – December 31, 2011	OFF	This model simulation was performed for the 2022 CVFPP Update to ensure the model was consistent with the 2017 CVFPP Update, with no need for further calibration or additional specification in the parameter files
2	4.2	January 1, 1915 – December 31, 2011	ON	Improvement from the 2017 CVFPP. Enabled the already refined model to run the energy-related portions of the model, thereby producing more reliable output variables.
3	4.2	2070	ON	Utilized the same model features as VIC Model 2, but rather than operating on the historical years of 1915 to 2011, the historical data were used to project values for the year 2072.

Notes: CVFPP = Central Valley Flood Protection Plan; VIC = variable infiltration capacity.

The VIC model simulation described above was used to calculate annual precipitation, runoff, and baseflow in the year 2072 for each of the 8,419 grid cells under each of the three climate change scenarios and the “no climate change” scenario. Figures 4.4 through 4.6 show the percent change in annual precipitation, annual runoff, and annual baseflow, respectively, as compared against the no climate change scenario for the three future climate scenarios. Precipitation is projected to increase from the warmer, drier scenario (low) to the central tendency (medium) scenario, to the hotter, wetter (high) scenario, with the highest percent increase in precipitation observed along the coastal range and eastern slopes. Increase in annual runoff in the Central Valley was observed primarily under the hotter, wetter scenario. It was also observed that there is loss of baseflow under the warmer, drier and medium scenarios and baseflow increases only under the hotter, wetter scenario.

Figure 4.4 **Percent Change in Annual Precipitation Under the Three Future Climate Scenarios**

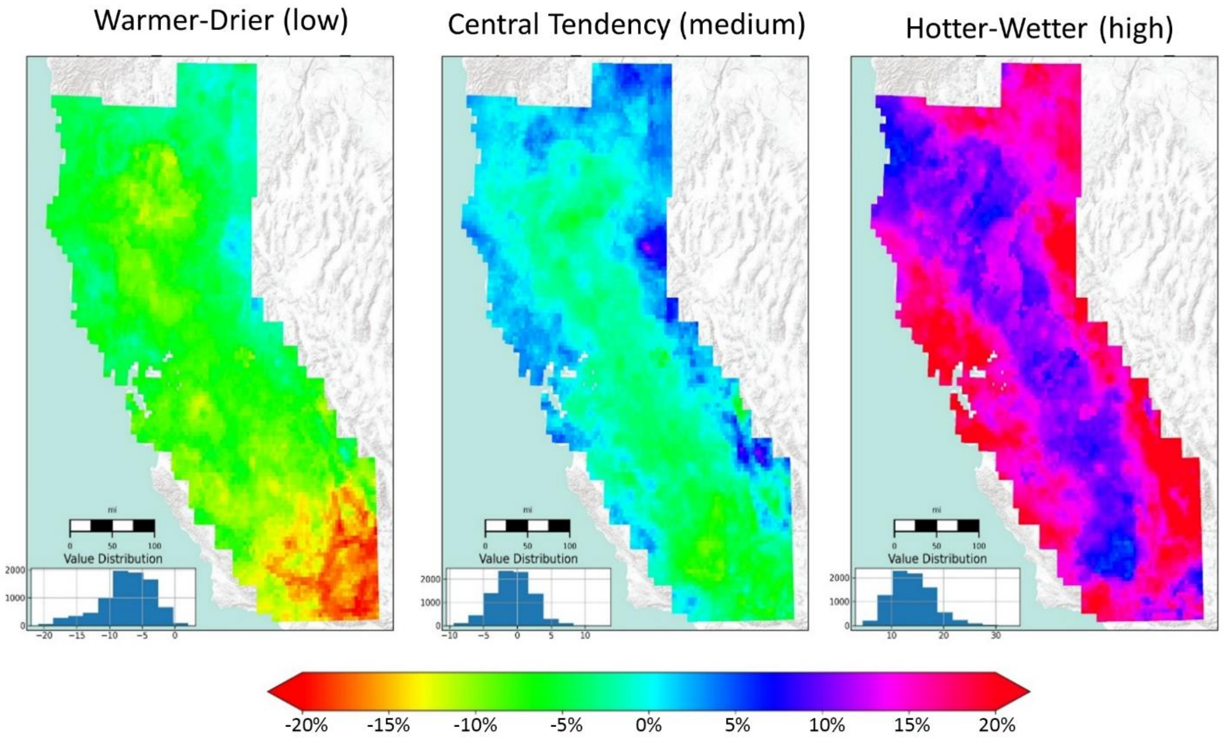


Figure 4.5 **Percent Change in Annual Runoff Under the Three Future Climate Scenarios**

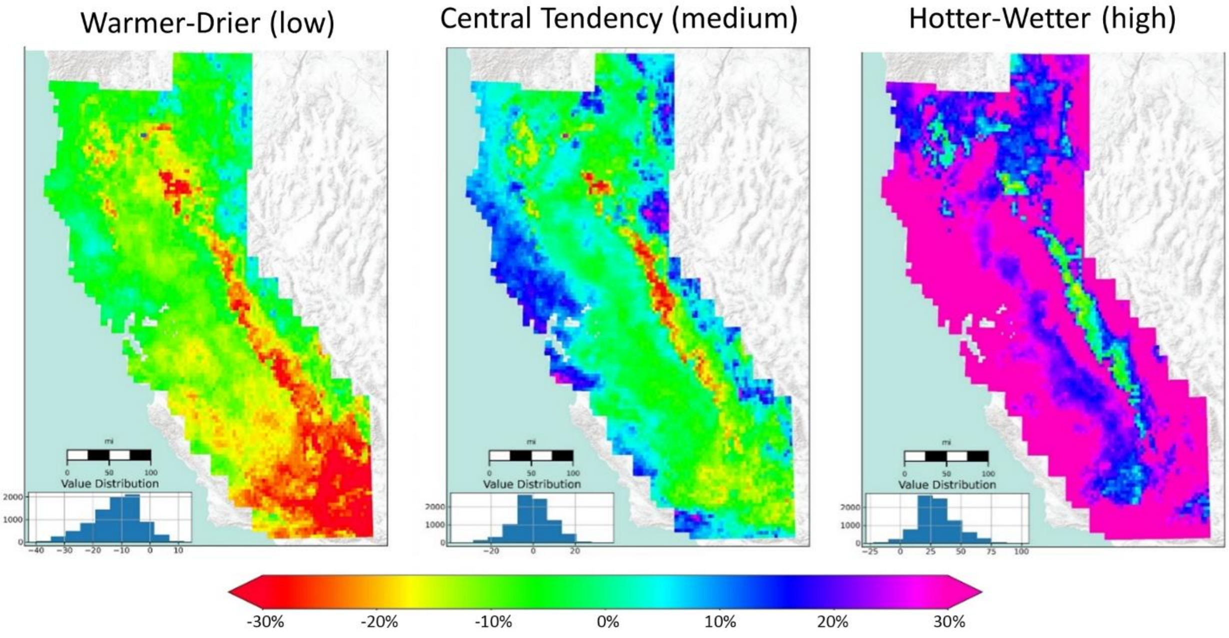
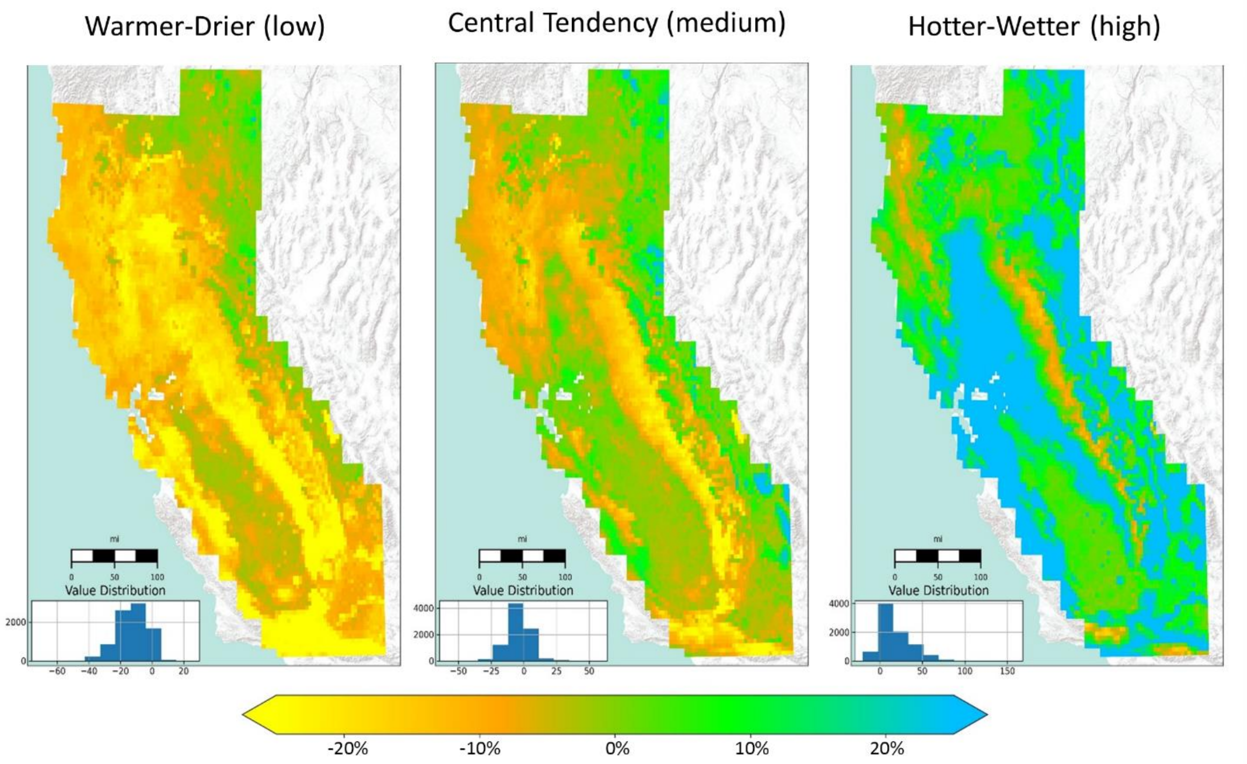


Figure 4.6 **Percent Change in Annual Baseflow Under the Three Future Climate Scenarios**



4.2 Climate Change Volume-Frequency Analysis

For the 2017 CVFPP Update climate change analysis, a detailed analysis was completed to evaluate how the CVHS volume-frequency curve could change under a climate change scenario. For this, watershed response using the VIC rainfall-runoff model was completed for historical conditions as well as a modified conditions using climate change projections. The times series at key CVHS-defined locations, called CVHS analysis points, were then used as the basis of a flow-frequency analysis. Note that for the 2017 CVFPP analysis, CVHS analysis points were associated with CVFPP index points and this same pairing was kept for the 2022 CVFPP Update.

Incorporating climate change projections into the analyses for the 2022 CVFPP Update required the development of climate change ratios. This basic procedure is the same as used in the previous update. Climate change ratios are applied to scale unregulated volume-frequency curves. These curves, along with unregulated-to-regulated flow transforms, were used to develop regulated flow-frequency information that correspond to future climate projections in the Sacramento and San Joaquin river basins. This regulated flow-frequency information was then used in the system-wide risk analysis for the 2022 CVFPP Update.

Specifically, for each condition, a simulated period of record is created with the rainfall runs made then, the annual maximum volumes were extracted for each water year between October 1 and May 31 and a statistical distribution was fit to the values. "Climate Change Ratios" were estimated as the ratio of the flow-frequency curves of with and without the projected climate change conditions. The climate change ratios were computed by dividing specific volumes developed using VIC simulation results for a given future climate condition by the volumes developed using VIC simulation results for historical conditions. The volumes used, and corresponding ratios developed were based on various durations and annual exceedance probabilities (AEPs). Subsequently, these climate change ratios were applied to the CVHS flow-frequency curves and used in the analysis as this provided a means to "normalize" the results and apply them to the volume-frequency curves derived from the Central Valley hydrology study, which used measured and synthesized historical flows.

Development of the 2022 CVFPP Update climate change ratios was consistent with the 2017 CVFPP Update climate change analysis with the following refinements:

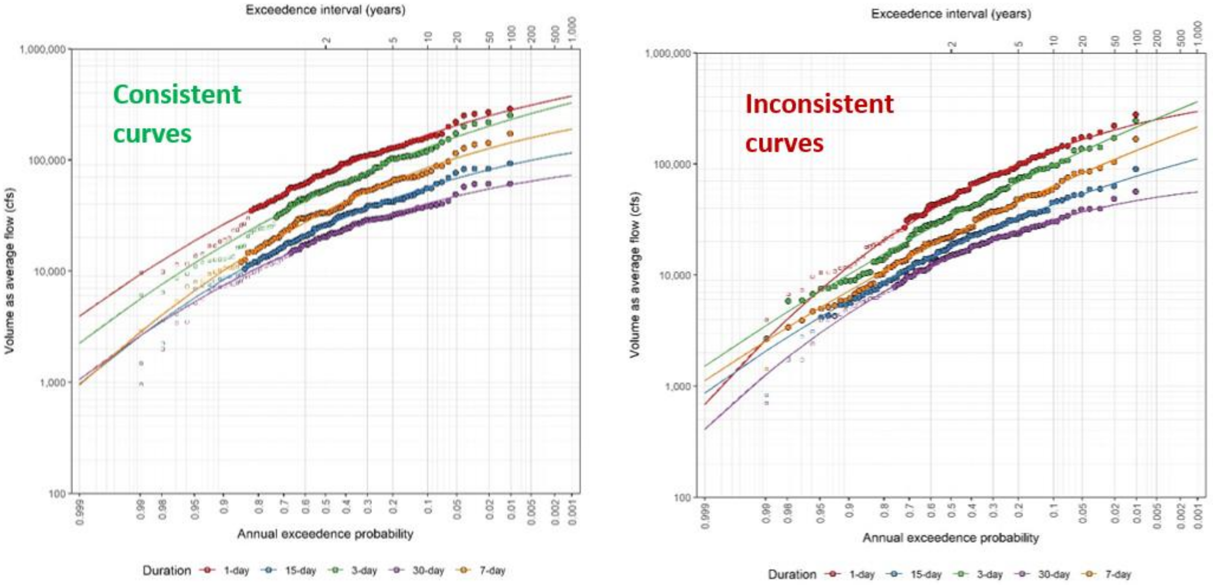
- **New analytical methods for flood frequency analysis.** Flood frequency analysis guidelines have been published in the United States since 1967 and have undergone periodic revisions. The current version of these flood frequency guidelines, Bulletin 17C, is an update to the Bulletin 17B procedures used in the 2017 CVFPP Update. The new guidelines include an adoption of a generalized representation that allows for interval and censored data; a new method, called the Expected Moments Algorithm, which extends the Method of Moments; a generalized approach to identification of low outliers in flood data, called Multiple Grubbs-Beck; and an improved method for computing confidence intervals. The current standard of practice is to use Bulletin 17C in planning activities involving water and related land resources.
- **Expanded capabilities in Information Processing and Synthesis Tool (IPAST).** IPAST is a stand-alone software application that extracts data generated by computer programs such as the USACE's Hydrologic Engineering Center – River Analysis System (HEC-RAS) and Hydrologic Engineering Center – Reservoir System Simulation (HEC-ResSim). IPAST processes the data and creates unregulated flow (volume) frequency curves and unregulated-to-regulated flow transforms among other functionalities. Consistent with the 2017 CVFPP Update, IPAST was used for the 2022 CVFPP Update climate change analysis for the application of the climate change analysis modeling results. However, IPAST capabilities were expanded to include the ability to compute climate change ratios between two sets of volume-frequency curves, publish the ratios to a comma delimited (.csv) file,

and publish plots of the ratios versus probability by duration. Additionally, IPAST was modified to include a new operation called "Develop volume frequency curve ratios" in support of the climate change ratio computations. The new operation was added to the "Operation builder," which is accessible through the graphical user interface. The new capabilities added do not change the analysis outcome, but formalize the analysis steps and help with the transparency of the analysis and intermediate results.

To develop the climate change ratios, Log-Pearson Type III statistical distributions were fit to the annual maximums extracted from the VIC modeling results to estimate annual exceedance volume quantiles using Bulletin 17C procedures. The climate change projection quantiles were then compared to those of the baseline to develop climate change ratios at each of the 46 analysis points. Fit and review of the statistical fits and computed climate change ratios included a three-phased approach as follows:

- **Phase 1:** In the first phase, volume-frequency curves were fit using Bulletin 17C procedures for each analysis point followed by review of 1-, 3-, 7-, 15-, and 30-day volume-frequency curves to check for "at-site" consistency for each analysis point. Figure 4.7 shows examples of consistent and inconsistent curve fits. Review also included adjusting and documenting statistics and low outlier threshold values for each analysis point as needed. Subsequently, climate change ratios were computed at each analysis point using IPAST.
- **Phase 2:** In the second phase, 1-, 3-, 7-, 15-, and 30-day volume-frequency curves and statistics were reviewed by scenario to check for internal consistency. This review included ensuring that each of the low, medium, and high curves do not cross for a given duration. Event-based climate change ratios were computed by dividing the ranked values for a given duration and compared to those computed using the fitted volume-frequency curves. For example, the largest 3-day high climate change scenario volume was divided by the largest 3-day baseline volume. Review also included identifying analysis points and climate change scenarios that were considered inconsistent for further possible adjustment and documented these inconsistencies.
- **Phase 3:** The last phase included review of spatial consistency of climate change ratios. Specifically, the 1-day and 3-day climate change ratios were reviewed for the p=0.1, 0.02, 0.01, and 0.005 AEPs. This phase also included further review of the volume-duration curves and computed climate change ratios to ensure that the results were consistent to changes seen in the VIC model runoff hydrographs for each climate change scenario.

Figure 4.7 **Example curve fitting, consistent curves where the durations do not cross for rare events, and inconsistent curves where the 1-day curve cross the 3-day curve near the p=0.005 (200-year) AEP**



In general, the medium climate change ratios for the San Joaquin River Basin were observed to be greater than those in the Sacramento River Basin. For example, the San Joaquin River Basin 3-day p=0.01 (100-year) ratios range from 1.07 to 1.86, whereas the Sacramento River Basin 3-day p=0.01 (100-year) ratios range from 0.99 to 1.35. Detailed results of the climate change ratios are included in Attachments A through C of Appendix B, “Climate Change Volume-Frequency Analysis.” Plots of regulated stage-frequency curves, the ultimate application of the climate change ratios, at each index point are included in Appendix D, “Risk Analysis Summary by Index Point.”

4.3 Estuary Evaluations

The Sacramento-San Joaquin Delta (Delta) poses inherent hydraulic complexity because of the contribution of flows from the Sacramento River, San Joaquin River, and eastern tributaries and tidal effects from the Pacific Ocean traveling through the San Francisco Bay/Delta Estuary (Bay-Delta). Because of this complexity, regions in the Delta require a different approach to develop flow-stage relationships than the rest of the SPFC planning area.

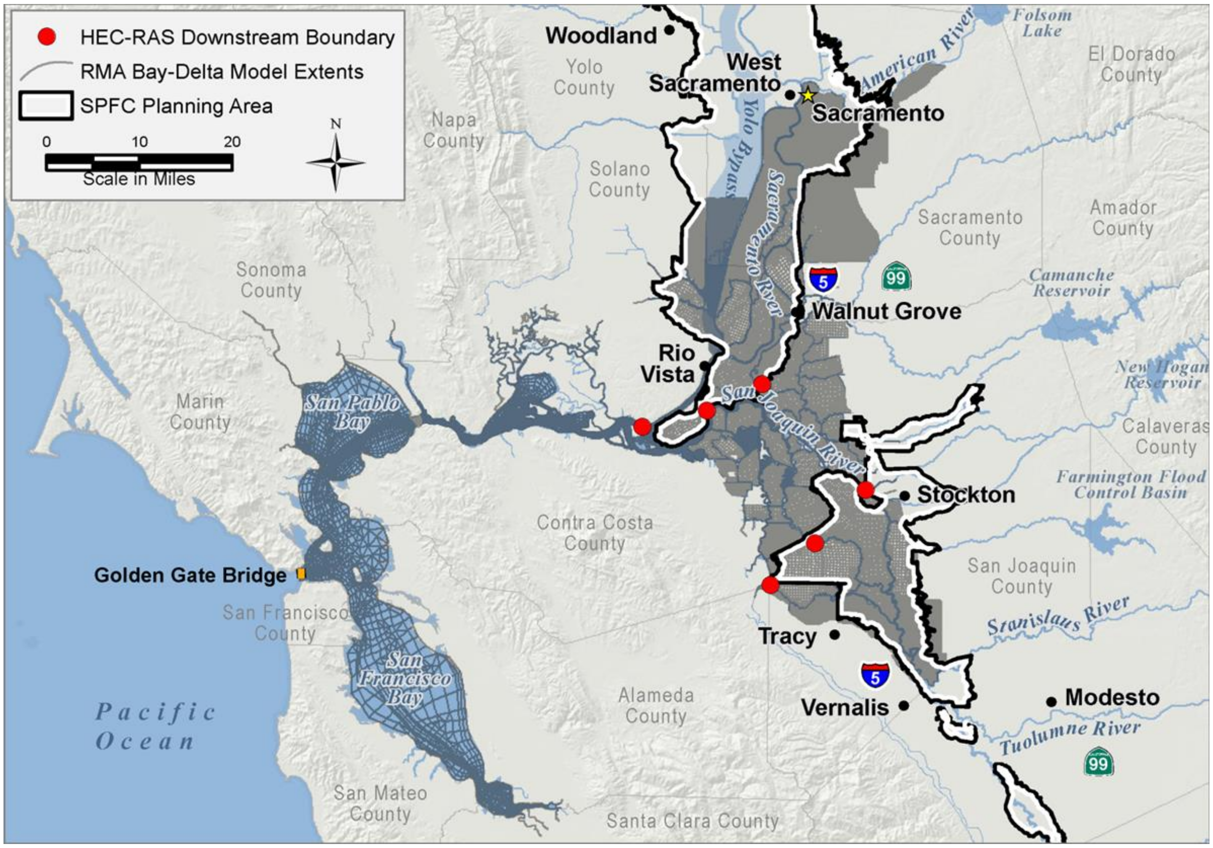
For these areas, a detailed hydraulic model of the Bay-Delta was utilized to represent the impacts of tidal conditions and riverine flows. This model was developed using

Resource Management Associates, Inc. (RMA) Bay-Delta model. Figure 4.8 shows the RMA Bay-Delta model extents and handoff points to the HEC-RAS downstream boundaries. The following steps were used to develop Delta flow-stage relationships:

1. Utilized at-latitude flow-frequency curves for the Sacramento River and San Joaquin River using CVHS procedures.
2. Selected representative flood events, scaled from historical events, to encompass the range of AEP of flood from 99 to 0.025 percent to minimize the computational expense of the RMA Bay-Delta model and CVFED hydraulic models. In the 2017 analysis, 10 flood events were used.
3. Utilized climate change factors as described in Section 4.2 to adjust unregulated volume-frequency curves to represent future climate conditions.
4. Defined the upstream boundary flow handoff locations from the CVFED hydraulic models to the RMA Bay-Delta model for Sacramento River and San Joaquin River.
5. Developed deterministic time-varying Golden Gate Bridge tidal conditions for the 10 selected flood-scaled event patterns.
6. Incorporated sea level rise, medium projection value, for year 2062 from National Research Council Report (2012) estimated at 1.26 feet.
7. Ran RMA Bay-Delta model with the 10 selected flood-scaled event patterns and deterministic tides with and without sea level rise at the Golden Gate Bridge, and created a new set of tidal-influenced boundary conditions.
8. Ran the CVFED hydraulic models with the 10 CVHS selected flood-scaled event patterns and the RMA Bay-Delta model's tidal influenced boundary conditions to determine each index point's stage-discharge rating curves.
9. Created stage-frequency curves following CVHS hydrology procedures using the CVFED hydraulic models’ stage-discharge rating curves and at-latitude flow frequency curves.

Additional details on this procedure can be found in Maendly (2018).

Figure 4.8 **Extent of the State Plan of Flood Control Planning Area, the RMA Bay-Delta Model, and HEC-RAS Downstream Boundaries**



4.3.1 RMA Bay-Delta Model Adapted for 2017 CVFPP Update

For the 2017 CVFPP Update, a numerical model of the San Francisco Bay and Delta (Figure 4.9) developed by RMA was utilized to develop tidal-influenced boundary conditions at the downstream end of the CVFED hydraulic models. The RMA Bay-Delta model stage hydrographs were then applied to the HEC-RAS models as downstream boundaries to reflect tidal influence better and simulate potential sea-level rise.

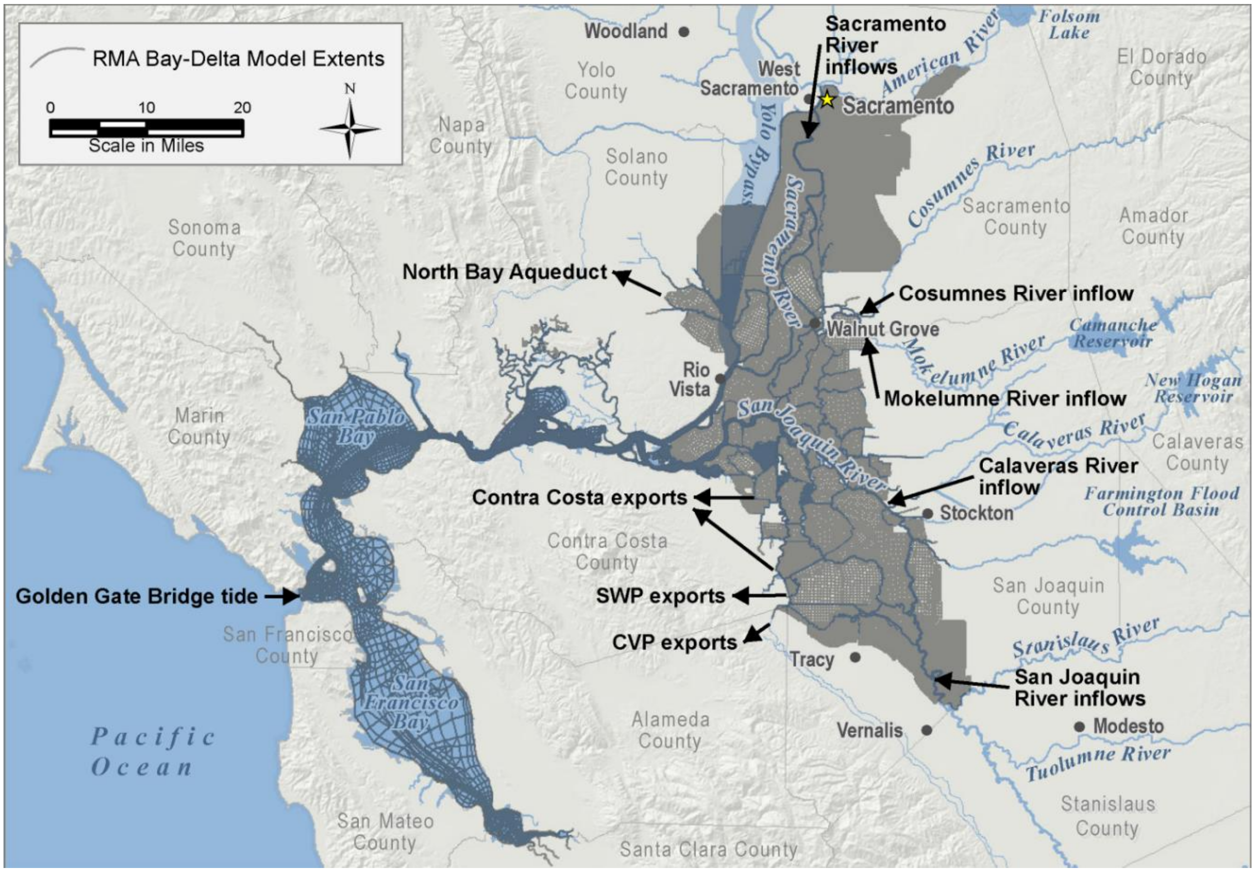
(For the San Joaquin River, the HEC-RAS downstream boundary locations are the intersection of Grant Line Canal and Old River, near the intersection of Middle River and Victoria Canal, San Joaquin River downstream of Stockton, and the San Joaquin River at Burns Cutoff. For the Sacramento River, the HEC-RAS downstream boundary locations are Georgiana Slough at Mokelumne River, Sacramento River at Collinsville and Threemile Slough at San Joaquin River.)

The RMA Bay-Delta model is a combined one-dimensional (1D) and two-dimensional (2D) hourly time step model that simulates velocities and water levels throughout the Bay-Delta using the RMA2 computational engine. The RMA2 engine combines 2D depth-averaged computational elements and 1D cross-sectionally averaged elements in a single mesh and solves the shallow-water equations to provide temporal and spatial descriptions of velocities and water depths. The RMA Bay-Delta model extends from the confluence of the American and Sacramento rivers and Vernalis on the San Joaquin River to the Golden Gate Bridge, as shown in Figure 4.9.

The RMA Bay-Delta model includes the Central Valley Project and State Water Project exports and other control structure operations in the Delta that affect water discharge and water levels (including Suisun Marsh Salinity Control gate, Delta Cross Channel, Old River near Tracy barrier, temporary barrier at the head of Old River, Middle River temporary barrier, Clifton Court Forebay Gates, Grant Line Canal barrier, and Rock Slough tide gate). The RMA Bay-Delta model provides multiple advantages over other Delta models regarding flood risk assessment, including:

- 2D representation for floodplains along the Sacramento River, San Joaquin River, and tributaries based on the latest geometry data from CVFED Program.
- Simulation of levee overtopping flow and floodplain inundation.
- Downstream boundary conditions extended to the Golden Gate Bridge, minimizing adverse boundary effects on upstream WSE.

Figure 4.9 **RMA Bay-Delta Model Used for 2017 and 2022 CVFPP Updates**



4.3.2 Enhancements for 2022 CVFPP Update

Two enhancements were made to the RMA Bay-Delta model for the 2022 CVFPP Update. First, the stage-discharge relationships in the Delta were improved by doubling the number of events simulated with the RMA model and development of the flow-stage relationship. Second, the sea-level-rise projection was changed based on the Ocean Protection Council 2018 guideline. The subsections below provide an overview of these improvements and resulting outcomes.

4.3.2.1 Additional Flood Events Representation for Stage-Discharge Relationship

Simulating the full range of scaled events through the RMA Bay-Delta model would require a high computational expense because of the complexity of this 2D model. To accelerate the modeling process without sacrificing representation of a full range of hydrology, 10 CVHS flood-scaled event patterns were selected for the 2017 CVFPP Update. For this update, 10 additional events were added.

Table 4.3 presents the 20 CVHS flood-scaled events used in the 2022 CVFPP Update. The 10 new scaled events are shown in bold font.

Table 4.3 **CVHS Flood Events used to Develop Bay-Delta Stage-Discharge Relationships**

1956 10% scaled event	**1986 40% scaled event**	**1986 100% scaled event**	**1997 135% scaled event**
1986 10% scaled event	**1956 60% scaled event**	**1997 105% scaled event**	1997 140% scaled event
1986 20% scaled event	1986 60% scaled event	**1986 115% scaled event**	1997 160% scaled event
1997 20% scaled event	**1997 60% scaled event**	1997 115% scaled event	1997 200% scaled event
1956 40% scaled event	1956 100% scaled event	1956 120% scaled event	**1997 240% scaled event**

Note: The **bold** font represents the 10 new events used for the 2022 CVFPP Update.

This expanded set of flood-scaled events encompasses the frequency range from one year to roughly 10,000 years of current hydrology in both Sacramento and San Joaquin river basins (Figures 4.10 and 4.11). In the Sacramento River Basin, these events cover approximately the same range as current hydrology under climate change. In the San Joaquin River Basin, these events cover the range of climate change projection up to roughly a 1,000-year return period.

Figure 4.10 **The Inverse of AEP or Annual Return Period for Peak Total Sacramento River Flow Rate At-latitude of the City of Sacramento for Selected CVHS Flood Events**

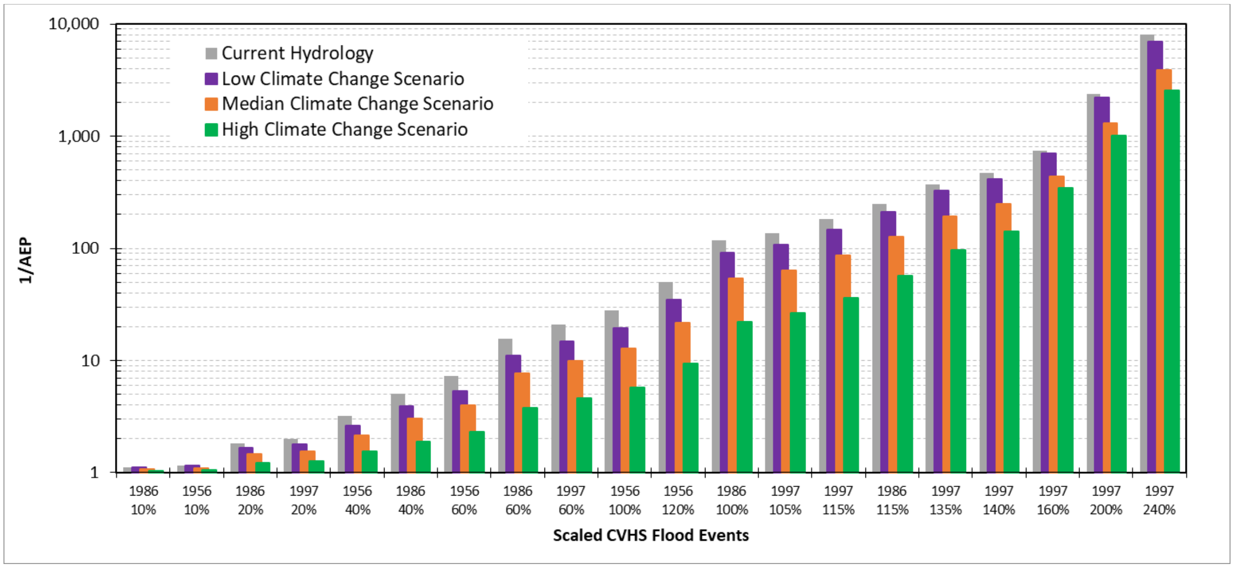
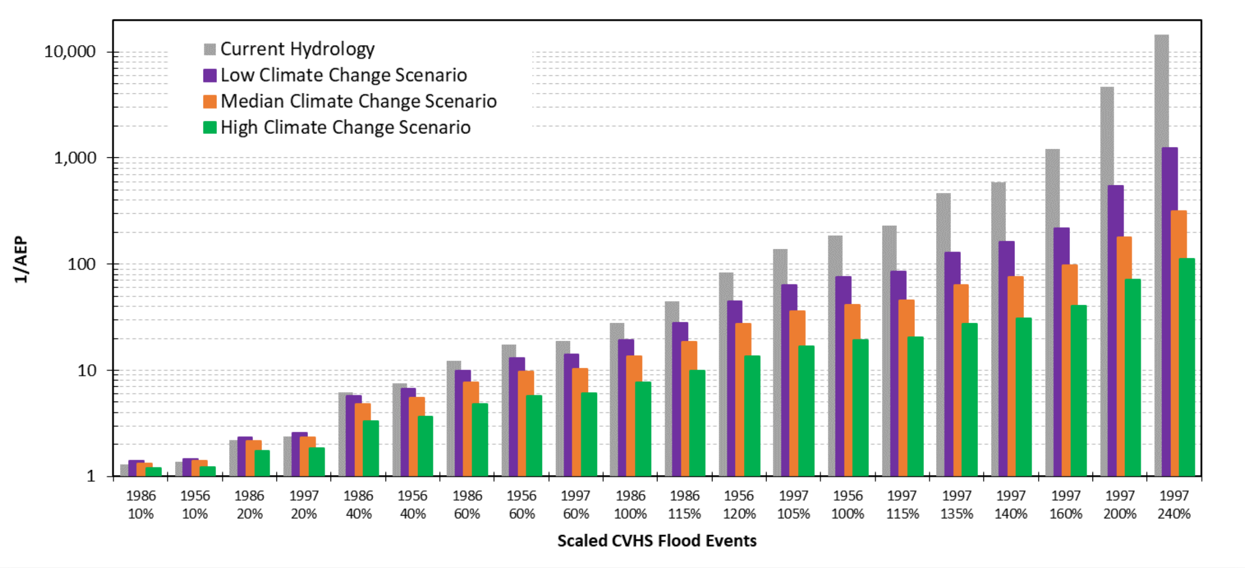


Figure 4.11 **The Inverse of AEP or Annual Return Period for Peak Total San Joaquin River Flow Rate At-latitude of Vernalis for Selected CVHS Flood Events**



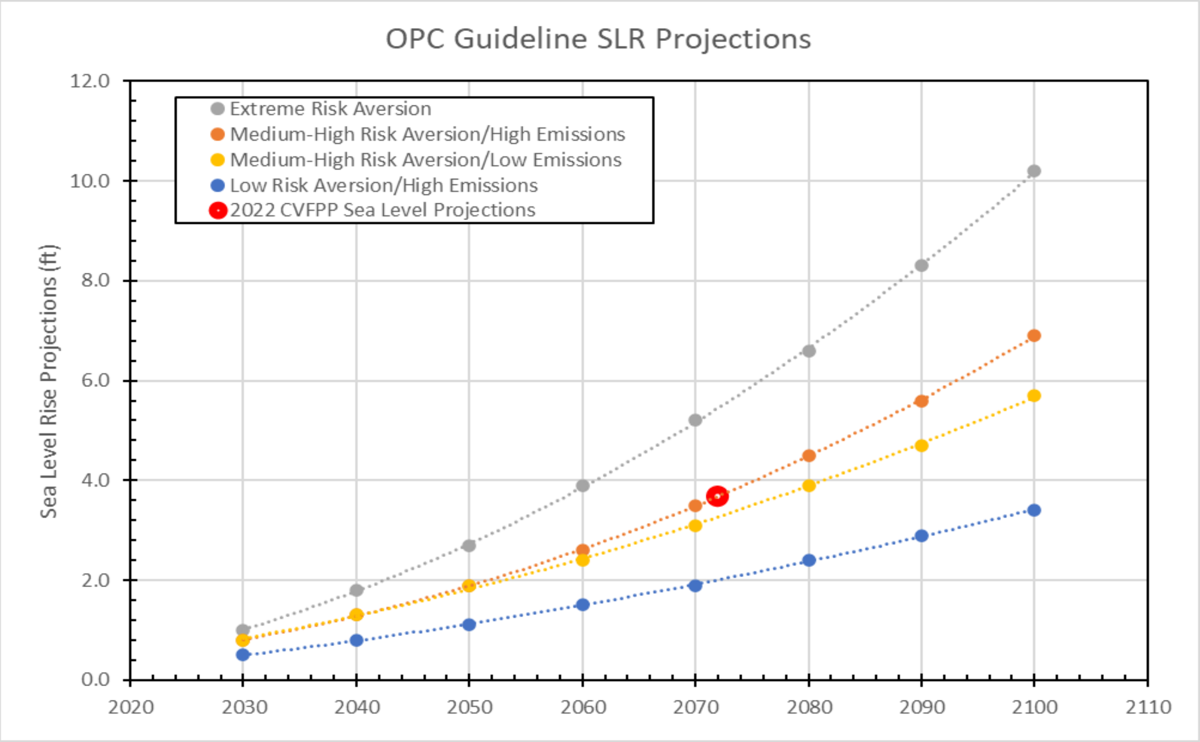
4.3.2.2 Sea Level Rise

Global and regional sea levels have been increasing over the past century and are expected to rise at an increasing rate throughout this century as the warming effects of climate change continue. Coastal sea levels impact Delta communities, infrastructure, and ecosystems as water levels and water quality conditions (i.e., salinity) propagate upstream. Severe precipitation events (particularly from atmospheric rivers) and increased regulated flows and stages will further exacerbate flood risk throughout the Delta, including tidally influenced areas of the lower Sacramento and San Joaquin river basins that are included in the CVFPP.

The 2017 CVFPP Update used the 2012 National Research Council (NRC) sea-level-rise projection. The projection was established using the late-century low-bound projection and corresponded to 1.26 feet at the Golden Gate Bridge. This projection also corresponded approximately to a mid-century mean projection at 2062.

The 2022 CVFPP Update projection for sea level rise was made with a planning horizon of 50 years from 2022 to 2072, and uses the medium-high risk aversion, high-emissions scenario from the *State of California Sea Level Rise Guidance 2018 Update*, as shown in Figure 4.12 (State of California 2018). The medium-high risk aversion has a 1-in-200 chance of being exceeded. Although the likelihood is low that sea level rise will meet or exceed this value, it is recommended to be used for less adaptive, more vulnerable projects or populations that will experience medium-to-high adverse consequences because of underestimating sea level rise. The sea level projection for the San Francisco tide gauge was interpolated using a third-order polynomial regression line. The sea-level-rise projection for 2072 (i.e., the boundary condition at the Golden Gate Bridge) was determined to be 3.68 feet. This projection is slightly above the 3.5 feet of sea level rise by 2050 goal listed in the *State Agency Sea-Level Rise Action for California* (State of California, 2022). The projected 3.68 feet of sea level rise was added to the deterministic tide hydrographs of the Golden Gate Bridge as the downstream boundary conditions for the RMA Bay-Delta model. This sea-level-rise projection was carried on to the flood risk analysis. In addition, some sensitivity analyses were conducted with a range of sea level rise from 0 to 6 feet to capture the range of uncertainties and will be further evaluated in subsequent analysis.

Figure 4.12 Projected Sea Level Rise (in feet) for San Francisco



4.3.2.3 Hydraulic Results

By routing flood-scaled event patterns listed in Table 4.3 and tidal conditions at the Golden Gate Bridge with and without sea level rise through the RMA Bay-Delta model, stage hydrographs were developed and applied to the CVFED hydraulic trimmed models' downstream boundary locations. A trimmed version of the CVFED model was used to focus on the Bay-Delta domain and shorten simulation times. The CVFED trimmed hydraulic models were then run with these updated boundary conditions to develop tidal-influenced stage hydrographs at the index point locations. Then, the stage hydrographs were used instead of the RMA Bay-Delta model results to be consistent with the 2022 CVFPP Update flood risk analysis. The upstream boundary conditions of the CVFED trimmed hydraulic models match the CVFED systemwide hydraulic models' output.

The stage-discharge rating curves at each index point location were created by matching the peak stage from the CVFED trimmed hydraulic models to the peak flow for each of the 20 selected flood-scaled event patterns and smoothed using a Locally Weighted Scatterplot Smoothing regression method. The matches were done with and without sea level rise. Eighty-four stage-discharge rating curves were created for 54 index point locations in the study area of the Delta. Twelve index points being situated at the same geo-location.

Figure 4.13 shows six stage-discharge rating curves for index points along the Sacramento and San Joaquin rivers, starting upstream in each basin and moving downstream. The locations of these curves can be found in Figures 4.13 and 4.14. At the entry of the Delta (index points SAC42 and SJ28), sea level rise has no or little effect on the curves because of higher ground. Sea level rise has a more significant effect on the curves at locations closer to the center of the Delta. Even for the largest flows, 3.86 feet of sea level rise at the Golden Gate Bridge corresponds to more than 1.5 foot of sea level rise at index points SAC58 and SJ54-55.

Stage-frequency curves for current hydrology, current hydrology with sea level rise, and climate change hydrology with sea level rise were developed for the index points located in the Delta considering a planning horizon from 2022 to 2072. Figure 4.14 shows how stage-frequency curves for current hydrology, current hydrology with sea level rise, and climate change hydrology with sea level rise changes while going downstream of the Sacramento and San Joaquin rivers. At the highest elevation of the Delta (index point locations SAC41 and SJ29), the current hydrology, and current hydrology with sea-level-rise stage-frequency curves, match one another. Sea level rise has little effect on the upstream index point locations, although climate change hydrology has the biggest effect. Moving downstream, toward the center of the Delta, sea level rise has a larger impact on the stage-frequency curves (index point locations SAC58 and SJ54-SJ55).

The stage increases to 3.1 feet at index point location SJ54-55 in Stockton and 3.3 feet at index point location SAC58 on Sherman Island, for an AEP of 0.1, or a 10-year return period flood. These stage increases reflect the 3.86 feet of sea level rise at the Golden Gate Bridge. For an AEP of 0.005, or 200-year return period flood, the same sea level rise at the Golden Gate Bridge at those locations produced a

2.2-foot stage increase at index point location SJ54-55 and a 2.7-foot increase in stage at index point location SAC58. The effect of sea level rise diminishes with more significant flood events because the flood flow drives the WSE.

Figure 4.13 Stage Discharge Rating Curves for Conditions With and Without Sea Level Rise for Six Index Points (IP) along the Sacramento and San Joaquin Rivers

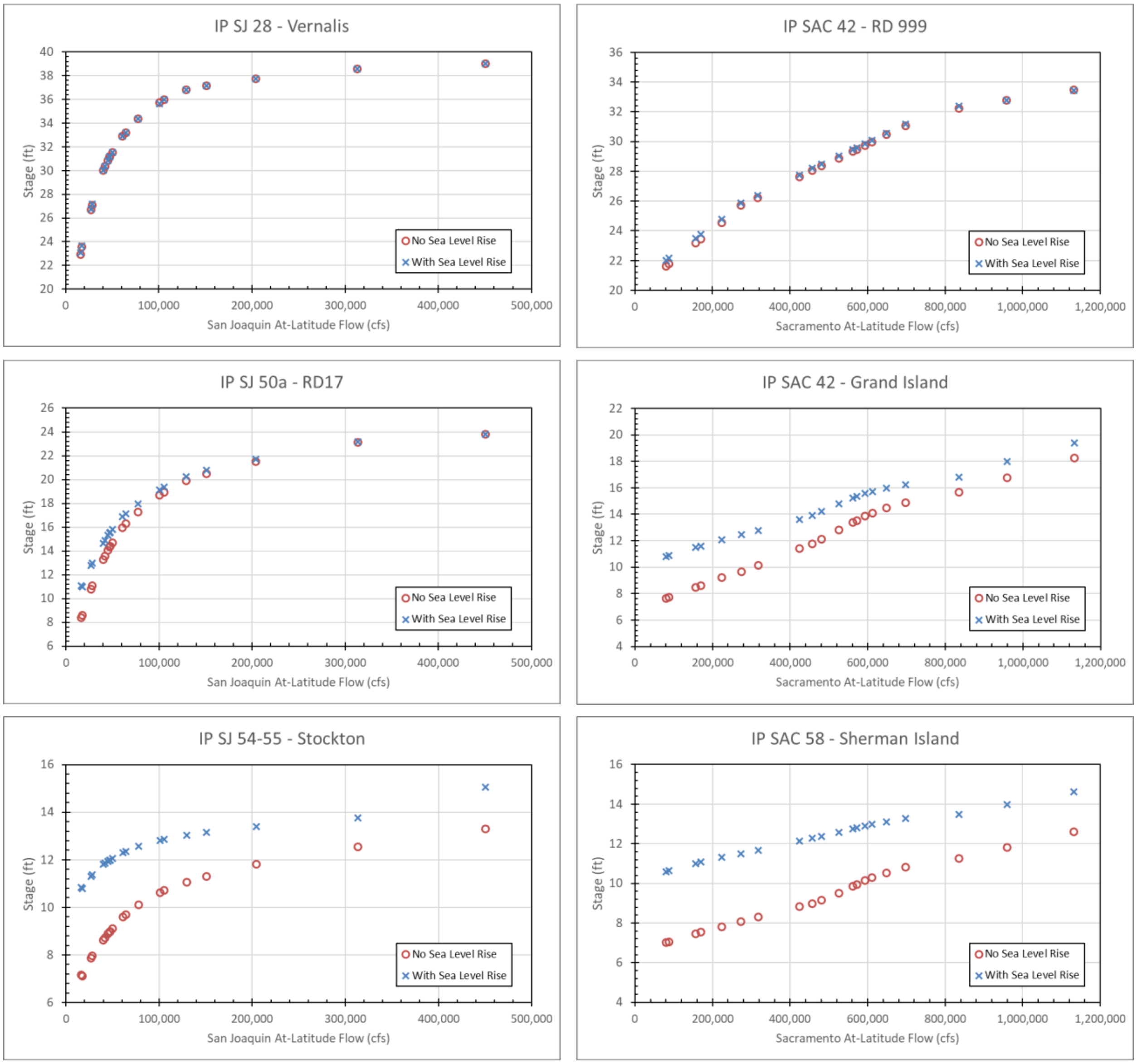
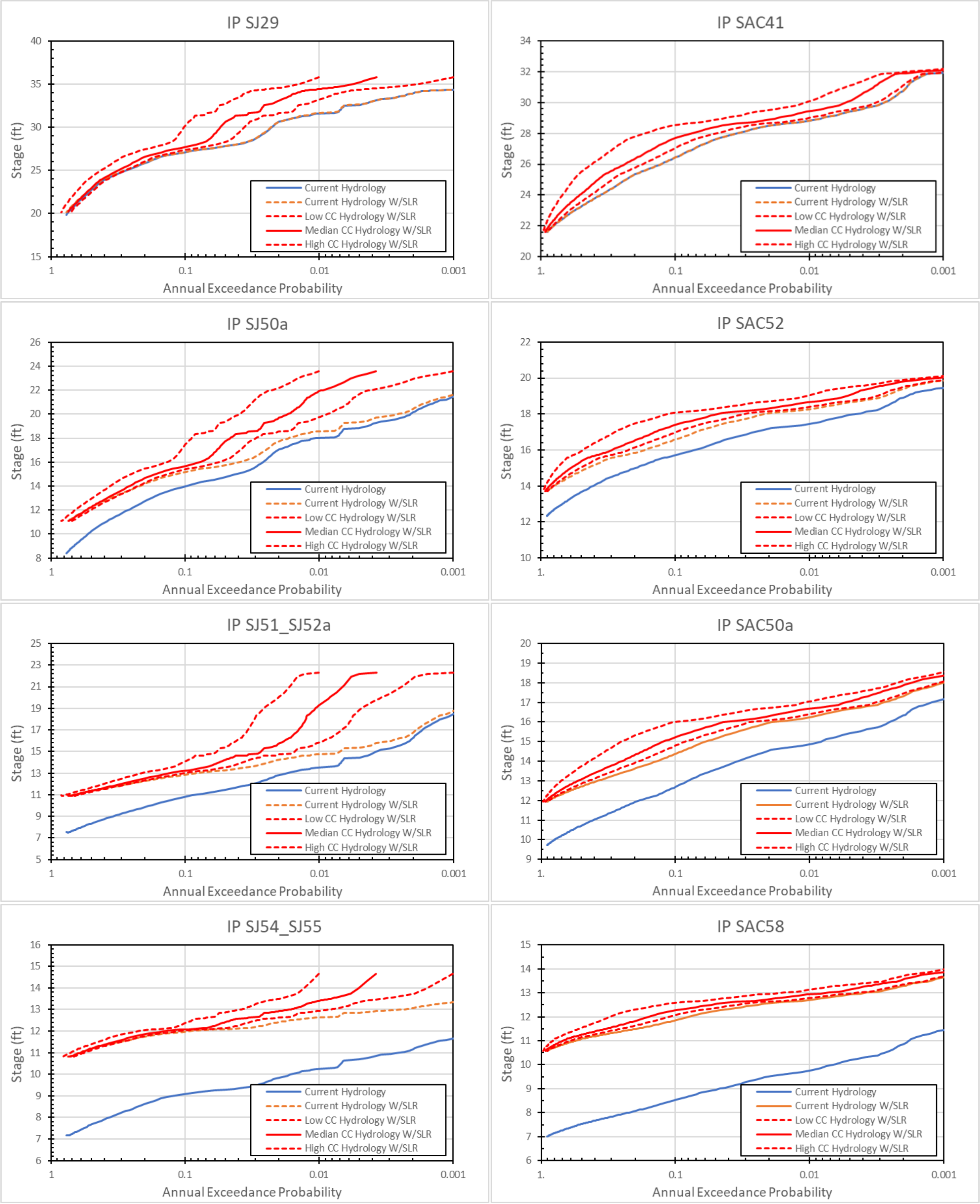


Figure 4.14 Stage-Frequency Curves for Current Hydrology, Current Hydrology with Sea Level Rise and Climate Change Hydrology with Sea Level Rise for 8 Index Points (IP) along the Sacramento River (right graphs) and the San Joaquin River (left graphs)



The stage-frequency curves at each index point in the Delta, along with hydraulic modeling results , were used to choose scaled event patterns close to the depths and flows of key return periods. Figures 4.15 and 4.16 show WSE profiles of scaled events meant to represent the 100-year flood events, without and with 3.68 feet and 6 feet of the sea-level-rise assumptions at the downstream boundaries. Similar long profiles graphics were created with the three climate change hydrology scenarios described in Section 4.1.2 and with three tidal conditions: No sea level rise and with sea level rise of 3.68 feet and 6 feet, respectively (Figures 4.15 and 4.16).

The stage frequency curves and long profiles show that sea level rise has a more significant effect on WSE in locations closer to the center of the Delta toward the San Francisco Bay. The two principal reasons for this phenomenon are the decrease in the gradient of the channel bottoms and the tides' amplitude increase. In the Sacramento River, under the 100-year return period flood without climate change hydrology, WSE increased by 3.1 feet and 5.1 feet, respectively, for 3.68 feet and 6 feet of sea level rise at Collinsville (Figure 4.15). The same sea-level-rise projections near Clarksburg correspond to 0.3 feet and 0.5 feet. On the San Joaquin River, for the 100-year return period flood, sea level rise is projected to increase the WSE by 2.4 feet and 3.5 feet at Stockton Deepwater Ship Channel (at River Station 0 feet in Figure 4.16). The same sea level rise projection at the Junction of the San Joaquin River with Old River corresponds to 0.2 feet and 0.3 feet.

The Sacramento and San Joaquin river profiles under 100-year return period flood induced by the three climate change hydrology scenarios also show a change in WSE (Figures 4.17 and 4.18) compared to the current hydrology. In the Sacramento River near Clarksburg, the difference in WSE corresponds to 0.6 feet for the medium climate change scenario with 3.68 feet of sea level rise (0.3 to 1.3 feet for the low and high climate change scenario). Near Collinsville, this change corresponds to 3.3 feet (3.1 to 3.4 feet). In the San Joaquin River near the junction with Old River, the difference in WSE correspond to 3.3 feet (0.9 to 4.4 feet) for the medium climate change scenario and 3.68 feet of sea level rise. In Stockton Deepwater Ship Channel, the change in WSE is about 3.1 feet (2.7 to 4.6 feet).

Even without sea level rise, the medium climate change hydrology results in more than 5 feet of increase in WSE above existing conditions upstream of the confluence with French Camp Slough. Under the medium and high climate change scenario, the system is exacerbated by climate change, which impacts the flood-flow routing between the floodplain and the channel.

Figure 4.15 Sacramento River Profiles of Scaled Events Meant to Represent the 100-Year Return Period Flood for Current Hydrology and Current Hydrology with 3.68 and 6 feet of Sea Level Rise

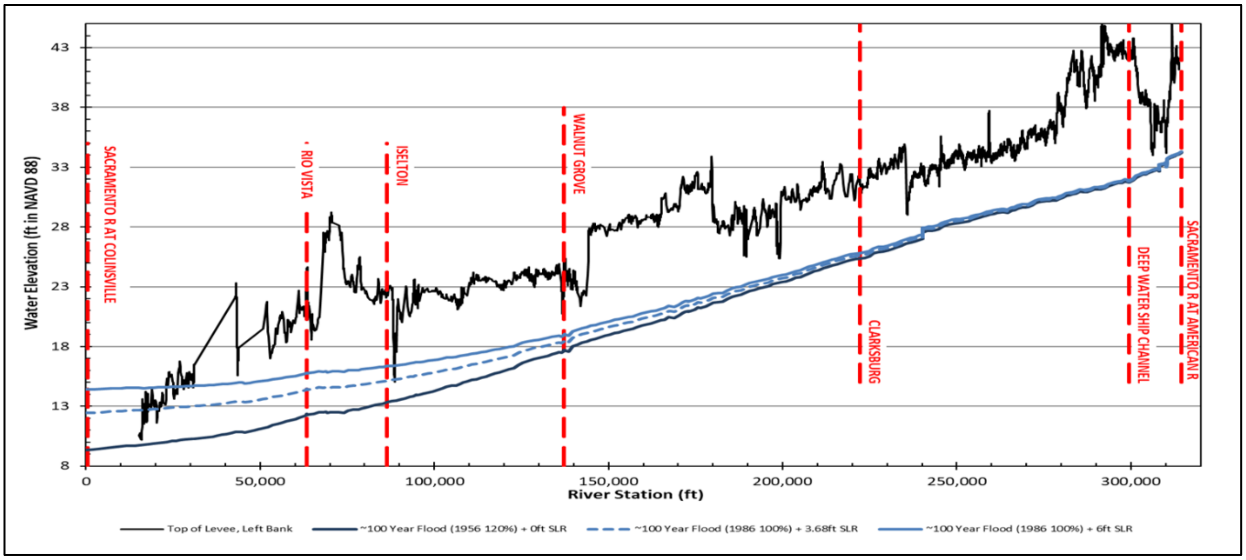


Figure 4.16 San Joaquin River Profiles of Scaled Events Meant to Represent the 100-Year Return Period Flood for Current Hydrology and Current Hydrology with 3.68 and 6 feet of Sea Level Rise

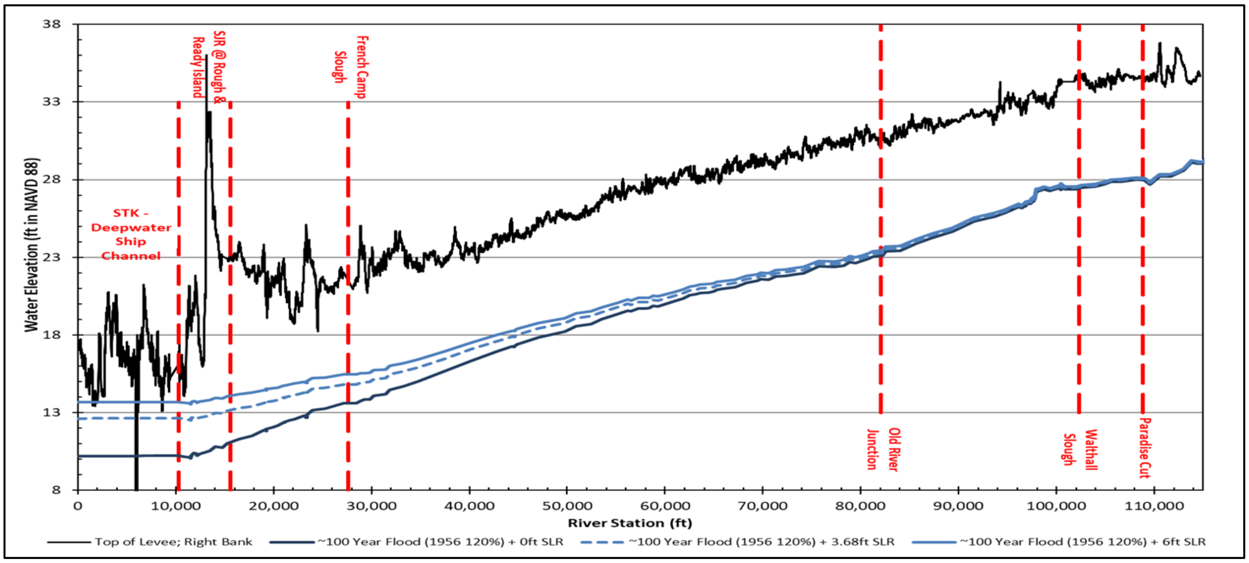


Figure 4.17 **Sacramento River Profiles of Scaled Events Meant to Represent the 100-Year Return Period Flood for Three Climate Change Hydrology and Two Sea Level Rise Conditions 3.68 and 6 feet**

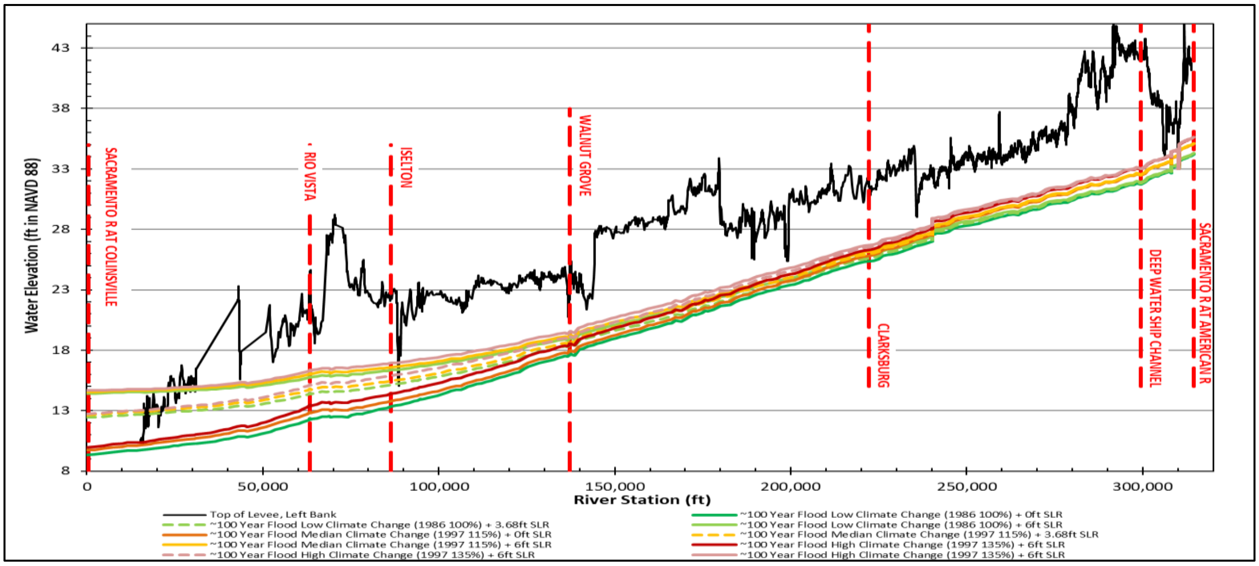
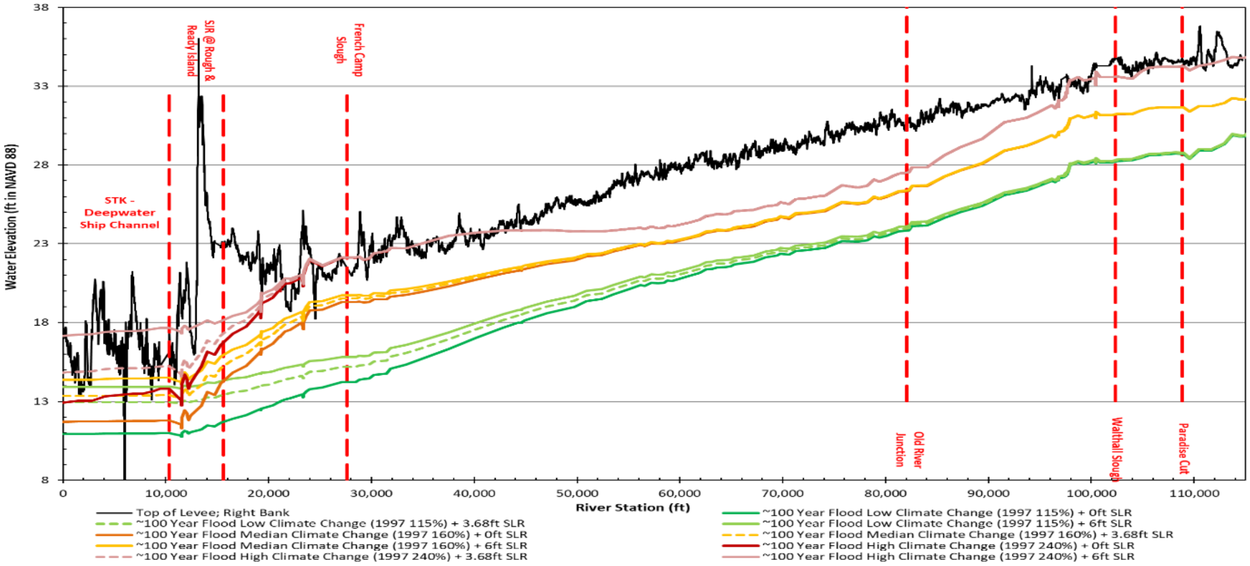


Figure 4.18 **San Joaquin River Profiles of Scaled Events Meant to Represent the 100-Year Return Period Flood for Three Climate Change Hydrology and Two Sea Level Rise Conditions 3.68 and 6 feet**



4.4 Geotechnical Analysis

Performance of a flood control system levee – particularly the uncertainty about future performance of that levee – is described in the risk analysis with a site-specific levee fragility curve. This curve estimates the probability that the levee will fail to prevent inundation of the interior floodplain area if water rises to a specified elevation in the channel. In this application, "failure" is defined as a levee breach in which water from the water side of the levee flows in an uncontrolled manner to the landside of the levee, potentially resulting in loss of life and/or economic loss.

Levee fragility curves provide relationships between river WSE (stage) and the probability that the levee segment will fail when exposed to that WSE without human intervention (flood fighting). Development of a fragility curve by a geotechnical engineer considers the physical properties of the levee and underlying foundation, manner of and history of maintenance and repairs of the levee, and history of observed performance.

For the 2017 CVFPP Update, levee fragility curves were developed at each index point for existing conditions and with-project conditions. For the 2022 CVFPP Update, the project team reviewed these fragility curves to ensure that they accurately represent the physical state of the system for each of the evaluation scenarios. Levee fragility curves were updated at index points where existing conditions were reevaluated or recent levee improvements were completed post-2017, or planned to be completed shortly after 2022, or different assumptions made for future conditions as compared to the 2017 CVFPP Update.

Updated levee fragility curves were applied to 31 index points in the Sacramento River Basin and 9 index points in the San Joaquin River Basin. These index points are listed in Table 4.4. All other index points used levee fragility curves from the 2017 CVFPP Update. Once the project team determined which levee fragility curves should be applied for each evaluation scenario, HEC-FDA models were configured with levee fragility curves (where necessary) for existing and future conditions. Plots of levee fragility curves used in the risk analyses are included in Appendix D, "Risk Analysis Summary by Index Point."

Table 4.4 Index Points with Updated Levee Fragility Curves

Sacramento River Basin Index Points	Sacramento River Basin Index Points	San Joaquin River Basin Index Points
SAC21	SAC38	SJ31
SAC22	SAC39	SJ31a
SAC24a	SAC40a	SJ31b
SAC25	SAC44	SJ31c
SAC25a	SAC45	SJ36
SAC26	SAC47	SJ37
SAC26a	SAC48	SJ50a
SAC27	SAC50	SJ50b
SAC27a	SAC50a	SJ50c
SAC28	SAC51	
SAC28a	SAC52	
SAC28b	SAC53	
SAC35	SAC54	
SAC36	SAC54a	
SAC36a	SAC63a	
SAC37		

4.5 Risk Analysis Inventory Update

As part of this update, the flood risk analyses incorporated a new inventory for damage and life risk computations. The new inventory included structures along with other elements needed to compute flood-related damages and costs, in addition to population estimates for life risk computations, herein referred to as a risk analysis inventory. To estimate structural damage as well as costs associated with flooding, several attributes about a structure within an area of flood risk are needed, such as elevation, type, and values.

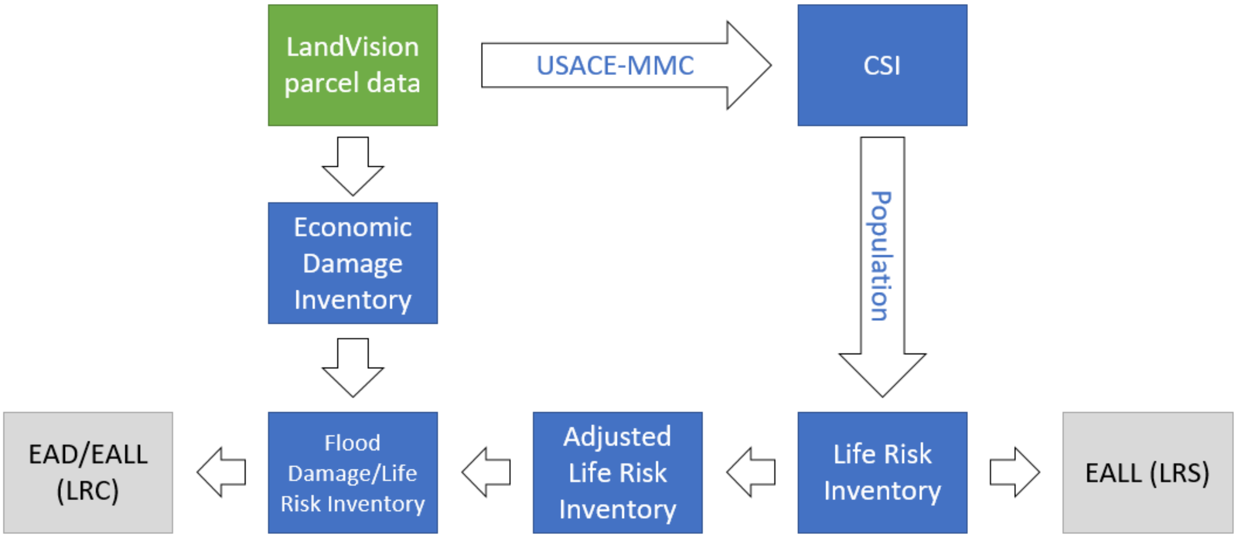
To estimate life risk, the population within a structure is needed. As discussed in Appendix F, "Life Risk Input Development," two methodologies were used to estimate life risk in the Central Valley: (1) the Life Risk Simulation (LRS) method, and (2) the Life Risk Calculation (LRC) method. The LRS method requires total population estimates, and the LRC method requires the population remaining after those that are able and willing have evacuated.

Two inventories were developed for the 2022 CVFPP Update:

1. **Life Risk Inventory.** The life risk inventory was used as an input to the USACE's computer program LifeSim to simulate flooding, warning and evacuation timeline, and estimate life loss from individual flood events.
2. **Flood Damage Inventory.** The flood damage inventory was used as an input into the USACE's HEC-FDA computer program to estimate economic losses from flooding expressed in the form of expected annual damages (EAD), in addition to estimating life risk expressed as expected annual lives lost (EALL). This inventory includes an economic damage inventory, which includes structures and costs associated with flooding of those structures. In addition, the economic damage inventory also includes the LRC method population inventory.

New LRS and LRC population inventories were developed using the California structure inventory (CSI). The CSI was developed by the USACE Modeling Mapping and Consequences (MMC) Center based on the USACE National Structure Inventory (NSI) 2.0 protocol, using the same methods and data types. However, the underlying parcel data set for the CSI is LandVision parcel data, a different parcel data set than used by the NSI 2.0. The CSI covers the state of California and includes structures, structure values, and population estimates. The process of developing the two risk assessment inventories used for the 2022 CVFPP Update are shown in Figure 4.19.

Figure 4.19 Flowchart Depicting How Three Unique Structure Inventories Were Developed for Use in the 2022 CVFPP Update



4.5.1 Life Risk Inventory

The LRS method is an enhanced life risk methodology that was not used in previous CVFPP efforts. This method relies on the USACE's software program, LifeSim, which simulates both the flood wave and warning and evacuation timeline within the software. Because the evacuation is simulated within LifeSim, the structure inventory is needed only for initial population location and distribution within structures.

Additional information on the LRS inventory development is included in Appendix E, "Risk Analysis Inventory Update."

4.5.2 Flood Damage Inventory

The development of the flood damage inventory involved developing an adjusted population, referred to as the LRC population. The LRC population inventory accounts for the evacuation of people from the study area based on flood warning. People's responses to a flood warning will vary based on where they are located and what they are doing when the warning is issued. A flood warning efficiency factor is used to reduce the population exposed because of the population's responses to flood warnings. This factor is then combined with the population inventory to develop the adjusted population inventory representing the population remaining, still at risk to flooding. The following sections describe the population inventory used, the efficiency factor development, and the method used to develop the LRC inventory for use in HEC-FDA.

The flood damage inventory used in the 2017 CVFPP Update placed people in residential structures based on a basin-wide average persons per structure (PPS) and included a separation by age, those over and under 65. The benefit of the CSI is an enhanced geographic distribution routine for population. The population is based on 2010 census data with updates for population growth and development through 2017. People are placed in residential, public, industrial, and commercial structures, with estimates divided by daytime and nighttime, considering movements between home and work or other activities, and by age, either over 65 or under 65 years. The flood damage inventory is a representation of the number of PPS divided into two categories, those under 65 (PPS_{U65}) and those over 65 (PPS_{O65}). The CSI includes PPS estimates for day (PPS_{U65D} and PPS_{O65D}) and night (PPS_{U65N} and PPS_{O65N}) to account for the shift in populations during the day.

Additional quality control was completed per USACE guidance (U.S. Army Corps Modeling and Mapping Consequences 2019, 2020) to correct for known issues with the CSI/NSI protocol including:

- Structures with high population count.
- Structures located outside of parcel boundaries or near channels.
- Structures with a high number of stories.
- Structure foundation height errors.

In addition to an adjusted population, the flood damage inventory also includes the economic damage inventory, an inventory of structures and their contents. Additionally, categories other than structural are included to capture damageable items and costs associated with flood damage. Specifically, the economic damage inventory includes:

- Structures and their Contents: Includes structure type (residential, commercial, industrial, public), structure and content value, and first-floor elevation.
- Crops: 2016 irrigated crop acreage from DWR's Land and Water Use section in addition to damage per acre estimates.
- Roads: Highway and street inventories from U.S. Geological Survey National Transportation Dataset.
- Vehicles: Developed as part of the CSI and reduced based on warning time.
- Business Loss: Flooded businesses will be forced to temporarily close, resulting in decline in business production. Estimated for all commercial, industrial, and public structures.

- Emergency Costs: Includes losses from disruption of normal economic and social activities that arise as a consequence of the physical impact of a flood.

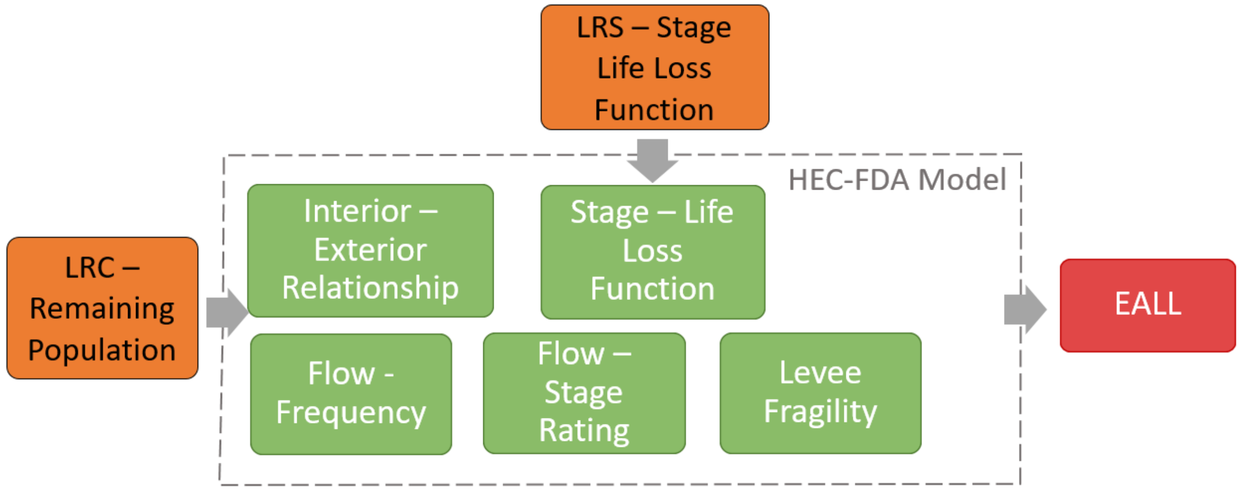
4.6 Life Risk Input Development

Life risk is the long-term average consequence of inundation within an identified area given a specified climate condition, land use condition, population, warning system, and flood management system. The consequences are fatalities that may occur in a building or vehicle during evacuation from the floodplain. To better understand the lives at risk as a result of flooding in the Sacramento and San Joaquin river basins, a risk assessment focusing on the potential life loss because of floodplain inundation is needed. Life risk is a critical augmentation to the economic risks associated with Central Valley flooding. The EALL and life risk results inform decision-makers to invest in projects benefitting public safety as well as economic development.

As mentioned above, for the 2022 CVFPP Update, life risk was assessed in two ways: (1) the procedure used in the 2017 CVFPP Update, referred to herein as the LRC method, and (2) the revised procedure using the computer program LifeSim, or LRS method. LifeSim utilizes a flood hazard and consequence simulation that accounts for various sources of uncertainty in the analysis.

The process of analyzing life risk using the two methods and how they integrate with the HEC-FDA modeling is shown in Figure 4.20. Both methods rely on the HEC-FDA model and inputs, as discussed in Appendix C, “Flood Risk Analysis,” and shown within the gray dashed box for computing EALL. For the LRC method, a population remaining after evacuation is entered directly into HEC-FDA and a stage-life loss function computed. The LRS method that includes a detailed analysis of the dynamic evacuation process and flood hazard estimates a stage-life loss function that is entered directly in HEC-FDA.

Figure 4.20 **2022 CVFPP Life Risk Analysis Processes**



4.7 Flood Risk Analyses

4.7.1 Components of Risk Analyses

Flood risk is a description of likelihood of adverse consequences from flooding for a given impact area with a specified climate condition, land use condition, and flood risk management system (existing or planned) in place. Flood risk is a function of (1) hazard, which is the frequency and magnitude of flood flows; (2) performance of flood risk reduction measures; (3) exposure of people and property in the floodplain; and (4) vulnerability of people and property in the floodplain. Consequence is the harm that results from a single occurrence of the hazard.

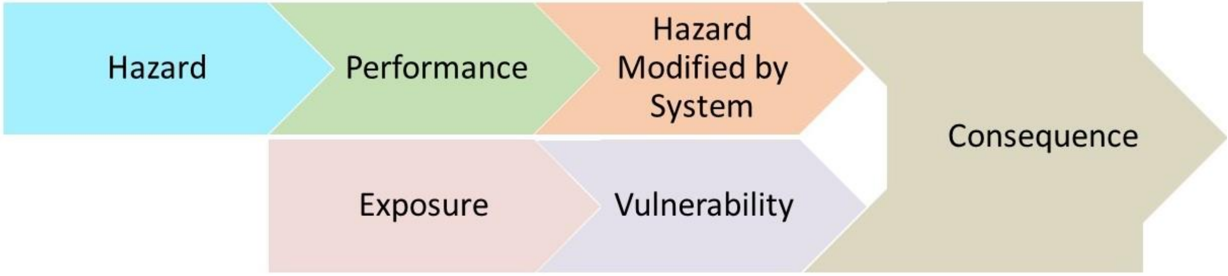
Flood risk is not the damage or loss of life incurred by a single catastrophic event. Rather, it is the probability of each of many outcomes that is expressed as a consequence-probability function. The consequence-probability function can be integrated to compute an expected or most likely value of the consequence. If the probabilities are annual values, this most likely value is called the expected annual value. The reduction in value of consequence is often used as a standard for measuring the effectiveness of proposed flood risk management measures. The consequence of flood inundation may be measured in terms of economic damage, loss of life, environmental impact, or other specified measure of flood risk.

Flood risk reduction (i.e., benefit) is achieved by altering the hazard, performance, exposure, and/or vulnerability to reduce consequences, defined as follows:

- **Hazard (also known as loading):** The hazard is what causes the harm – in this case, hazard is a flood. The flood hazard is described in terms of probability of stage, velocity, extent, depth, and other flood properties.
- **Performance:** Performance is the system's reaction to the hazard. Performance can be described for engineered systems (such as levees or reservoirs) that directly affect the hazard. Performance can also be described for nonengineered systems, such as flood warning systems and a community's flood preparedness, in terms of the efficiency of delivering critical information to the public, taking into account the time of day and people's activities when the warning is received.
- **Exposure:** Exposure is a measure of who and what may be harmed by the flood hazard. It incorporates a description of where the flooding occurs at a given frequency and what exists in that area. Tools such as flood inundation maps provide information on the extent and depth of flooding, and structure inventories, crop data, habitat acreage, and population data provide information on the people and property that may be affected by the flood hazard.
- **Vulnerability:** Vulnerability is the susceptibility to harm of people, property, and the environment exposed to the hazard. Depth-percent damage functions, depth-percent mortality functions, and other similar relationships describe vulnerability.
- **Consequence:** Consequence is the harm that results from a single occurrence of the hazard. It is measured in terms of indices such as structure damage, acreage of habitat lost, crops damaged, and lives lost.

The relationships of the flood risk components are conceptually illustrated on Figure 4.21.

Figure 4.21 Relationships of Flood Risk Analysis Components



4.7.2 Damage Categories and Occupancy Types

Economic damage computations are dependent on characteristics unique to the structure, such as structure type, first-floor elevation, and height of the structure. The general classification of structures is the damage category, such as residential or commercial. The occupancy type is a more specific definition of the structure, which includes details on:

- The flood depth to percent damage functions for the structure and contents.
- The content to structure value ratio.
- The uncertainty about the first-floor stage, the structure value, and the content-to-structure value ratio.

The 2012 CVFPP and the 2017 CVFPP Update used ParcelQuest to identify structures for each impact area. For the 2022 CVFPP Update, LandVision parcel data from fall 2019 was used to identify structures for each impact area. Using the land use description field within LandVision, structures were categorized using a broader damage category (residential, commercial, public, and industrial), as well as a more refined occupancy type attribute. Appendix E, "Risk Analysis Inventory Update," lists the LandVision land use descriptions and associated damage categories and occupancy type subcategories used during the development of the flood damage inventory.

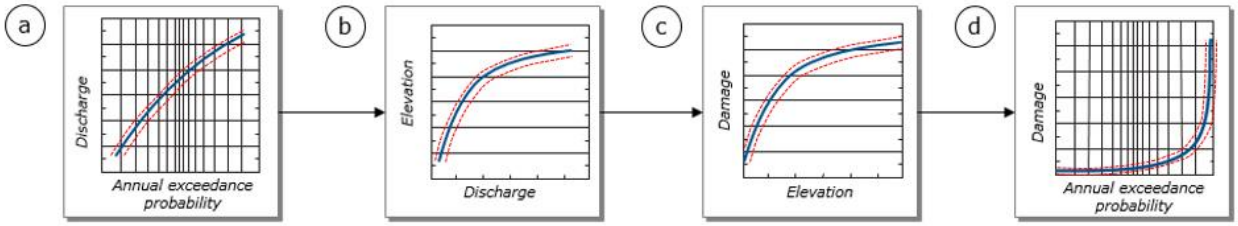
4.7.3 Growth Factors

For the 2072 with-project and without-project scenarios, growth factors were applied in the flood damage and life risk calculations to reflect projected changes in land use and population. The future growth factors were based on the California Water Plan 2018 Update (CWP) 2010–2050 projections of population by impact area (California Department of Water Resouces 2019). Growth factors for urban areas were only applied if urban level of protection (LOP), 200-year LOP, criteria were assumed met under the SSIA, consistent with SB 5. Growth factors were applied to small communities with a population of 10,000 and outside the Federal Emergency Management Agency (FEMA) 100-year floodplain.

4.7.4 Role of HEC-FDA in Risk Analyses

EAD is calculated as the integral of the damage-probability function, which weights the damage for each event by the probability of that event happening in any given year, and then sums across all possible events. The damage-probability function is commonly derived by the transformation of available hydrologic, hydraulic, and economic information, as illustrated in Figure 4.22.

Figure 4.22 EAD Computation



Part of the flood risk analysis is development of the elevation-damage relationship (Part C of Figure 4.22), which is defined as the flood damage associated with a certain set of floodplain depths. This relationship is computed within HEC-FDA through input of a detailed structure inventory (parcel by parcel), as well as properties such as structure and content value, structure elevation, and type. Relationships of depth-to-percent damage by structure type are also entered into HEC-FDA.

To compute EAD, HEC-FDA requires inputs representative of all the risk analysis components: hazard, performance, exposure, and vulnerability. A description of these inputs along with key enhancements and updates from the 2017 CVFPP Update are provided in Table 4.5.

HEC-FDA incorporates uncertainty into the discharge-exceedance probability, stage-discharge, and elevation-damage functions shown in Figure 4.22. A Monte Carlo simulation is used to compute EAD, sampling between uncertainty bands of each input function.

4.7.5 Flood Damage Analysis

The flood damage risk analysis was completed using HEC-FDA, version 1.4.2. Damage and damage reduction are reported in annualized terms as EAD. To compute EAD, HEC-FDA requires inputs representative of all the risk analysis components: hazard, performance, exposure, and vulnerability. Table 4.5 summarizes the information used and describes key enhancements and updates from the 2017 CVFPP Update (California Department of Water Resources 2017b).

Table 4.5 Inputs Required for the Risk Analysis

Required Information	Description
Hazard: Regulated flow-frequency functions*	Existing climate condition scenarios (2022), unchanged from the 2017 CVFPP Update, but updated for future year climate change scenarios (2072).
Hazard: Flow-stage transforms*	Existing climate condition scenarios (2022), unchanged from the 2017 CVFPP Update, but updated for future year climate change scenarios (2072).
Hazard: Stage-frequency relationships*	Existing climate condition scenarios (2022), unchanged from the 2017 CVFPP Update, but updated for future year climate change scenarios (2072).
Hazard: Interior (floodplain)-exterior (channel) relationships*	Unchanged from the 2017 CVFPP Update.
Performance: Levee performance functions*	Updated where new geotechnical information was available, new flood control improvement projects have been constructed since 2017 or are planned for completion by 2022, or different assumptions were made for future conditions (e.g., whether or not planned improvements would be in place by 2072).
Performance: Flood warning system effectiveness*	Updated based on interviews with emergency managers.
Exposure: Structure inventories*	**Enhanced from the 2017 CVFPP Update.** The 2022 CVFPP Update uses LandVision parcel data for all of California to create an inventory of structures, the CSI. Other adjustments from the 2017 CVFPP Update include: updates to structure geolocation, refinements to structure damage categories and occupancy types, and updates to structure values using RSMeans Quarter 1 2020.
Exposure: Vehicle inventories	**Enhanced from the 2017 CVFPP Update.** Vehicle data was sourced directly from the CSI using structure attribute data. A single vehicle was assigned a value of $9,000 in 2020 dollars. For the Sacramento and San Joaquin river basins, the total number of vehicles and total vehicle value were estimated, along with the estimated number of vehicles remaining and associated value after evacuation.

Required Information	Description
Exposure: Crop inventories	**Enhanced from the 2017 CVFPP Update.** The 2022 CVFPP Update uses the latest (as of July 2016) DWR geographic information system (GIS) statewide land use databases to develop the impact area irrigated crop acreage information.
Exposure: Highway and street inventories	**Enhanced from the 2017 CVFPP Update.** The 2022 CVFPP Update uses the U.S. Geological Survey National Transportation Dataset to estimate the total length of streets and highways in the San Joaquin and Sacramento river basins. Maximum-flood-damage-per-mile estimates were updated to January 2020 dollars and used for damage computations.
Exposure: Representation of emergency costs	**Same as the 2017 CVFPP Update.** Costs were updated to January 2020 dollars.
Vulnerability: DDF – structure/contents	**Same as the 2017 CVFPP Update.**
Vulnerability: DDF – crop damage	**Enhanced from the 2017 CVFPP Update.** Average annual crop damage per acre estimates from the 2017 CVFPP Update were reviewed and updated by DWR with best available data.
Vulnerability: Depth-business interruption days function	**Same as the 2017 CVFPP Update.**
Vulnerability: DDF – emergency costs	**Same as the 2017 CVFPP Update.**
Vulnerability: DDF – road damage	**Same as the 2017 CVFPP Update.**
Vulnerability: DDF – vehicle damage	**Same as the 2017 CVFPP Update.**

Notes: CVFPP = Central Valley Flood Protection Plan; CSI = California structure inventory; DDF = Depth-percent damage function; DWR = California Department of Water Resources. *These inputs are also used for the life risk analysis described in Section 4.7.7.

4.7.6 Life Risk Analysis

Life risk is measured by EALL. The 2012 CVFPP and 2017 CVFPP Update computed EALL using the LRC method. For the 2022 CVFPP Update, DWR used the LRC method in conjunction with a procedure that more specifically defines the sensitivity of life risk to an area's breach location, flood wave timing and depth, evacuation effectiveness, and conditions encountered by people either in a flooded structure or vehicle. This enhanced analysis method is called the LRS method. Together, life loss estimates from these two methods were used as input to compute the EALL to enhance the life risk assessment from the 2017 CVFPP Update.

The LRC method that was developed and applied for the 2017 CVFPP Update (California Department of Water Resources 2017a) was followed for the 2022 CVFPP Update with refinements to the structure and population inventories. These same structure and population inventories were also used for the LRS method. Enhancements to the structure and population inventories for the 2022 CVFPP Update are described above in Table 4.5.

For the LRS method, LifeSim, released in 2018 by USACE Risk Management Center (RMC), was used to develop life loss estimates for a suite of flood events. Models were developed using LifeSim to represent the potential life loss for select impact areas, including 14 impact areas from the Sacramento River watershed and seven impact areas from the San Joaquin River watershed. When an impact area had multiple breach locations, the life risk was based on the highest consequences to the impact area. LifeSim results were used to develop a channel stage-life loss function for each study area. This information was used as input to HEC-FDA v1.4.2 to compute EALL.

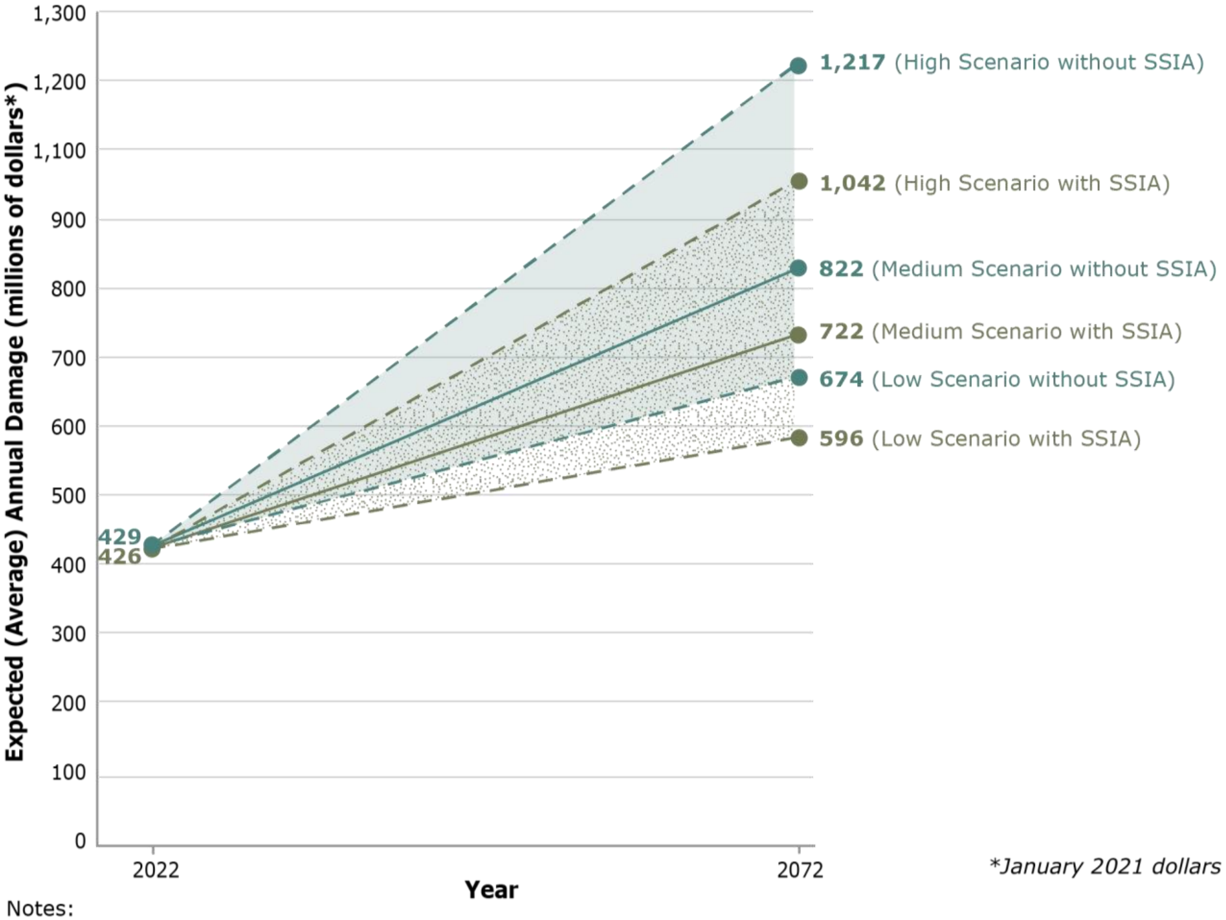
As with the flood damage analysis, uncertainty is incorporated into the key inputs for the life risk analysis.

4.7.7 Results of the Flood Risk Analyses

Flood and life risk results, measured by EAD, EALL, and project performance statistics (i.e., AEP) were computed for all index points for current and future conditions. Figures 4.23 through 4.26 show flood damage and life risk results for the Sacramento and San Joaquin river basins. AEP is reported in Appendix C, "Flood Risk Analysis."

Future conditions are shown with uncertainty because of future climate conditions. EALL results reported are a combination of the two analysis methods (LRC and LRS methods). For impact areas where LifeSim models were developed (LRS method), those results supersede results from the LRC method. Although all risk analysis inputs were developed using January 2020 dollars, all resulting damages and costs were updated to be reported in January 2021 dollars. Detailed findings for the Sacramento and San Joaquin river basins by index point are in Attachment B of Appendix C. Appendix C also provides details on the flood and life risk inputs, methodologies, and results.

Figure 4.23 **Sacramento River Basin EAD (millions of dollars)**



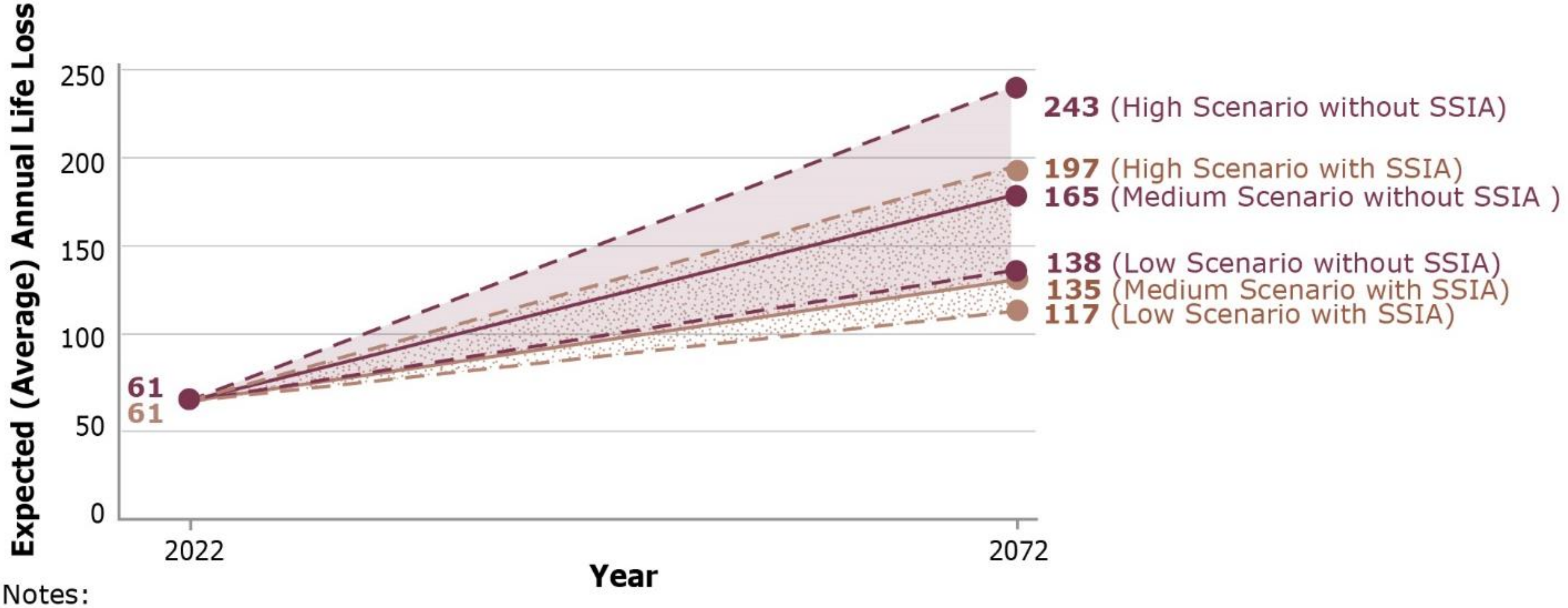
**January 2021 dollars*

Notes:

- Results indicate the change in expected annual damage over time between 2022 and 2072 for the low, medium, and high climate change scenarios (with and without SSIA).
- The expected annual damage metric indicates potential damage in any year across the full range of potential flood events and their likelihood.
- Results provide an informative metric for economic damages but do not forecast economic damages expected from a single flood event.
- Potential flood and evacuation characteristics are highly uncertain.

2022_804a

Figure 4.24 **Sacramento River Basin EALL (number of persons)**

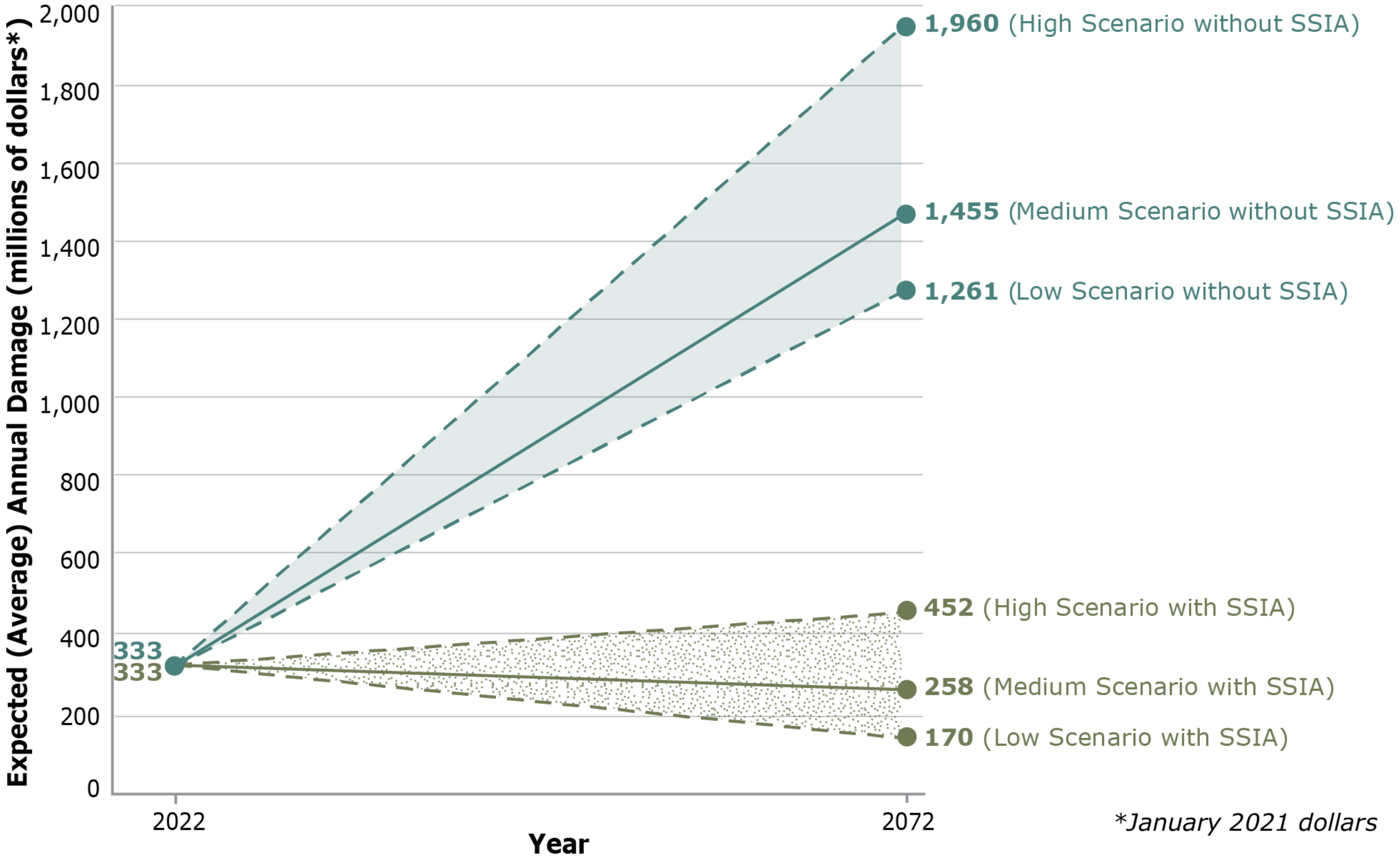


Notes:

- Results indicate the change in expected annual life loss over time between 2022 and 2072 for the low, medium, and high climate change scenarios (with and without SSIA).
- The expected annual life loss metric indicates potential life loss in any year across the full range of potential flood events and their likelihood.
- Results provide an informative metric for life risk but do not forecast deaths expected from a single flood event.
- Potential flood and evacuation characteristics are highly uncertain.

2022_804b

Figure 4.25 San Joaquin River Basin EAD (millions of dollars)

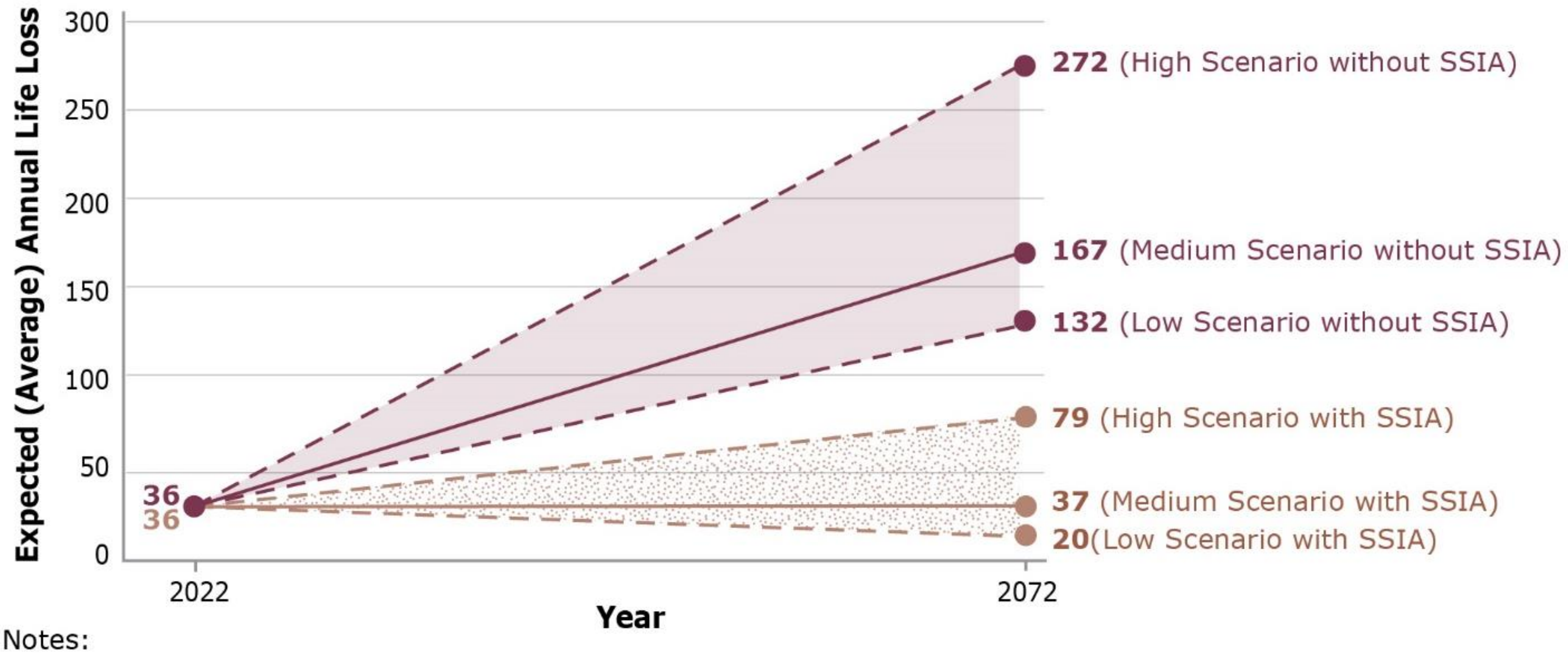


Notes:

- Results indicate the change in expected annual damage over time between 2022 and 2072 for the low, medium, and high climate change scenarios (with and without SSIA).
- The expected annual damage metric indicates potential damage in any year across the full range of potential flood events and their likelihood.
- Results provide an informative metric for economic damages but do not forecast economic damages expected from a single flood event.
- Potential flood and evacuation characteristics are highly uncertain.

2022_804c

Figure 4.26 **San Joaquin River Basin EALL (number of persons)**



Notes:

- Results indicate the change in expected annual life loss over time between 2022 and 2072 for the low, medium, and high climate change scenarios (with and without SSIA).
- The expected annual life loss metric indicates potential life loss in any year across the full range of potential flood events and their likelihood.
- Results provide an informative metric for life risk but do not forecast deaths expected from a single flood event.
- Potential flood and evacuation characteristics are highly uncertain.

2022_804d

4.8 Reservoir Vulnerability Analysis

Assessing flood risk now and into the future is a key component of the 2022 CVFPP Update. To do this, an assessment of the performance of the flood management system is needed. Reservoir operations and release decisions control and impact flow downstream throughout the flood management system and are a vital component in overall flood control planning for the future. As such, the 2022 CVFPP Update includes a reservoir vulnerability analysis (RVA) to further describe the reservoir operation aspects of the flood management system.

The RVA summarizes current system operations, demonstrates how increased runoff volume impacts the SPFC, and discusses potential solutions to mitigating additional flood risk resulting from climate change. The role of the RVA is to provide information focused more on the current reservoir operation portion of the system evaluation and note how specific simulated events are routed through each basin. Efforts presented include a deeper investigation into reservoir vulnerability by determining the quantity of increased flood runoff volume into each reservoir under future climate conditions. The analysis focuses on the climatological and watershed conditions that contribute to the causes of increased runoff upstream of the reservoirs, how the increases will affect reservoir operations, and how the increases will impact the downstream system. In addition, the RVA provides insights into how the primary flood operation priority can change with increased runoff volume. This is an important step in understanding how downstream peaks and flows change under the climate change assumptions.

The main objective of the RVA is to assess how the selected reservoirs function as integral parts of the overall flood management system, by comparing regulated outflows under current and future climate conditions using existing reservoir operation rules. This information will be used to assess how regulated flows change within the Sacramento and San Joaquin river basins with increased runoff volume in the face of climate change. Additional objectives of the RVA include:

- Demonstrating changes to system performance as a result of predicted changes in precipitation and temperature in the Central Valley. The focus of this demonstration is the reservoir system specifically, and how changes in runoff volume can push the reservoirs beyond their ability to regulate downstream flows, thus illustrating their vulnerability.
- Documenting how flood damage mitigation measures are currently being implemented and how they improve the flood management system performance.

The strategy for meeting these objectives includes:

1. Presenting different aspects of the HEC-ResSim simulation results than previously reported in the 2017 CVFPP Update technical appendix.
2. Documenting and illustrating the operation of each reservoir individually in the system.
3. Showing how increased volumes based on climate change projections can change the operating priority of reservoir releases.
4. Showing how the full-system performance can change with climate changed increase in volumes, specifically how tributary peak flows combine and consequently increase flows and stages in the main reaches within the levee system.
5. Describing ongoing activities to reduce flood damages caused by high flows.

The intended use of the RVA is to gain a common understanding of the Central Valley flood management system, specifically each reservoir's current storage capacity, how reservoirs are operated, and how operations affect downstream flows. With increases in precipitation and ultimately unregulated runoff volume into reservoirs in the future, the system's reservoir vulnerability will increase. Next steps in the RVA that have not been conducted to date, would include evaluating how potential changes in flood risk management above, at, and below the reservoirs could reduce vulnerability and overall flood risk.

4.8.1 Current System Operations

Sixteen flood control reservoirs in the Sacramento and San Joaquin river basins were included for the RVA. The selected reservoirs represent a mix of reservoirs of different sizes and purposes within the Sacramento and San Joaquin river basins. The 16 flood control reservoirs selected for the RVA are listed and briefly described in Table 4.6 and shown on Figures 4.27 and 4.28 for the Sacramento and San Joaquin river basins, respectively.

For each of these reservoirs, detailed information regarding the contributing area, stated purpose, physical description of the facilities, operating rules, downstream flow requirements and release rules, climate change effects, and other pertinent reservoir information were gathered and summarized into a reservoir-specific information packet. The reservoir-specific information packets provide baseline information on reservoir operations for a range of inflow volumes, and how the probability of these volumes may change with the climate change scenarios.

Table 4.6 **Selected Reservoirs Within the Sacramento and San Joaquin River Basins Considered for the RVA**

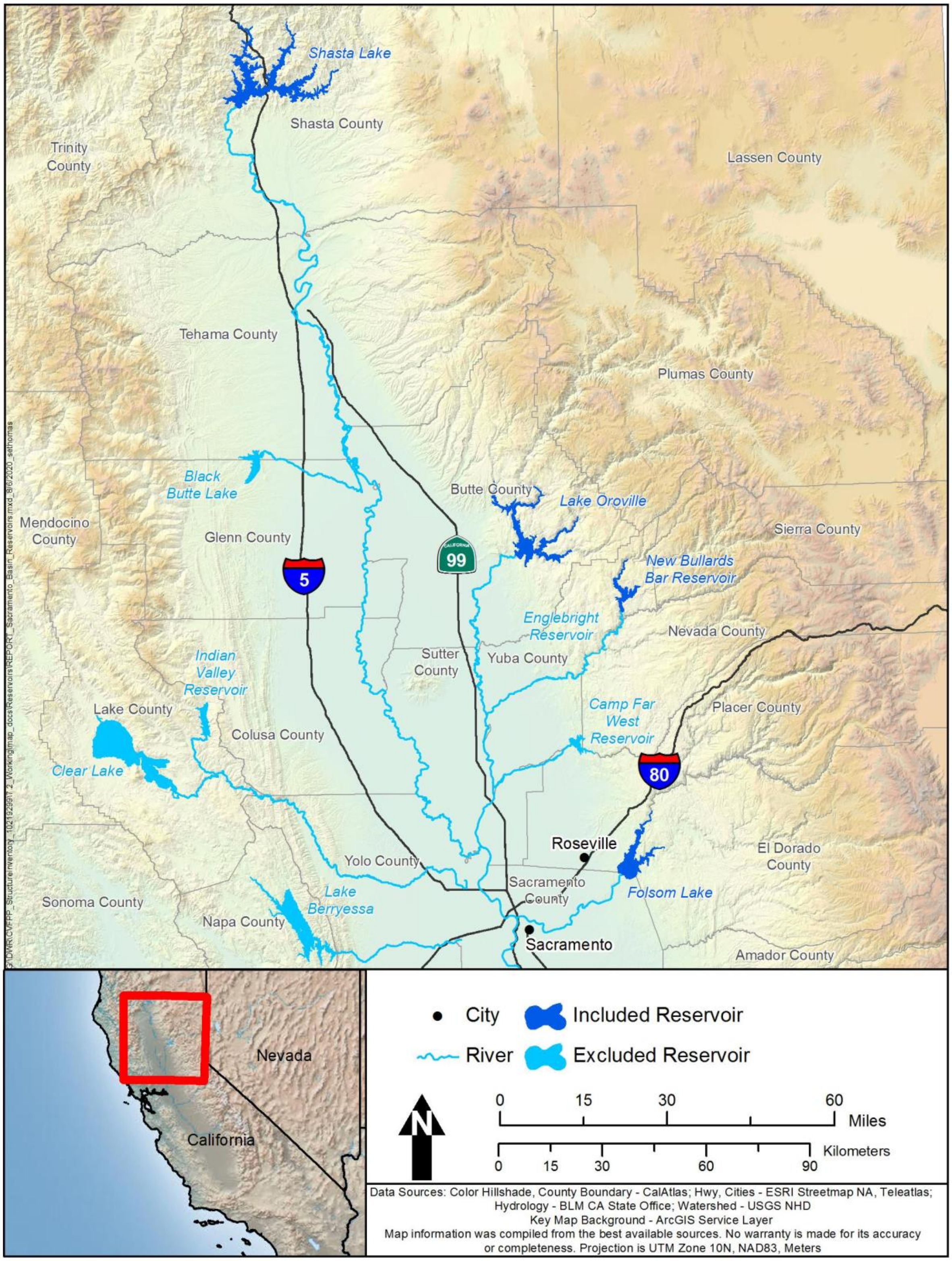
ID	Reservoir	River Basin	Owner/Operator	Reservoir Capacity at Gross Pool, Acre-Feet	Purpose
1	Shasta Lake	Sacramento	Reclamation	4,552,000	Shasta Lake is operated for flood control, power, and conservation.
2	Lake Oroville	Sacramento	DWR	3,538,000	Lake Oroville is operated for flood control, irrigation, municipal and industrial water supply, and power generation
3	New Bullards Bar Reservoir	Sacramento	Yuba Water Agency	960,000	New Bullards Bar Dam was constructed for flood control, conservation, power generation, water supply, and recreation.
4	Folsom Lake	Sacramento	Reclamation	967,000	The Folsom Dam and Lake is operated for flood control; domestic, municipal, industrial, and agricultural water supply; recreation and hydroelectric power generation; and water quality in support of downstream fisheries.
5	New Hogan Reservoir	San Joaquin	USACE	317,100	The New Hogan Reservoir is multi-purpose, with the objectives of protecting areas below New Hogan Dam with a high degree of protection from floods; providing a conservation yield for irrigation and a municipal and industrial supply including an annual firm yield; and maintaining an inactive pool of 15,000 acre-feet when water is available.

ID	Reservoir	River Basin	Owner/Operator	Reservoir Capacity at Gross Pool, Acre-Feet	Purpose
6	Farmington Flood Control Basin	San Joaquin	USACE	52,000	The purpose of the Farmington Flood Control Basin is to restrict flood flows to non-damaging levels throughout the network of channels downstream from the reservoir, without endangering the safety of the structure.
7	New Melones Reservoir	San Joaquin	Reclamation	2,420,000	New Melones Dam is operated for flood control, power generation, irrigation supply, water quality control, fishery enhancement, and recreation.
8	Don Pedro Reservoir	San Joaquin	Turlock and Modesto Irrigation Districts	2,030,000	Don Pedro Reservoir is operated for flood control, irrigation, municipal, agricultural, and industrial water supply, power generation, fishery enhancement, and recreation
9	Lake McClure (New Exchequer Dam)	San Joaquin	Merced Irrigation District	1,024,600	New Exchequer Dam was constructed for flood control, irrigation, power, and recreation. It also provides water for downstream fish and wildlife.
10	Burns Reservoir	San Joaquin	USACE	6,800	Burns Reservoir operates as one unit in a system of four foothills reservoirs, known as the Merced Streams Group, and two interstream valley floor diversion channels used for the purpose of flood control.

ID	Reservoir	River Basin	Owner/Operator	Reservoir Capacity at Gross Pool, Acre-Feet	Purpose
11	Bear Reservoir	San Joaquin	USACE	7,700	Bear Reservoir operates as one unit in a system of four foothills reservoirs, known as the Merced Streams Group, and two interstream valley floor diversion channels used for the purpose of flood control.
12	Owens Reservoir	San Joaquin	USACE	3,600	Owens Reservoir operates as one unit in a system of four foothills reservoirs, known as the Merced Streams Group, and two interstream valley floor diversion channels used for the purpose of flood control.
13	H.V. Eastman Lake (Buchanan Dam)	San Joaquin	USACE	150,000	Buchanan Dam and H.V. Eastman Lake function as part of a system of reservoirs in the San Joaquin River Basin that provide flood protection to adjacent urban and rural areas.
14	Hensley Lake (Hidden Dam)	San Joaquin	USACE	90,000	The Hidden Dam and Hensley Lake Project was authorized the purposes of flood control, irrigation, and recreation.
15	Millerton Lake (Friant Dam)	San Joaquin	Reclamation	520,500	Friant Dam is operated for flood control and conservation purposes, including irrigation.
16	Pine Flat Reservoir	San Joaquin	USACE	1,000,000	Pine Flat Dam is operated for flood control and conservation purposes, including irrigation.

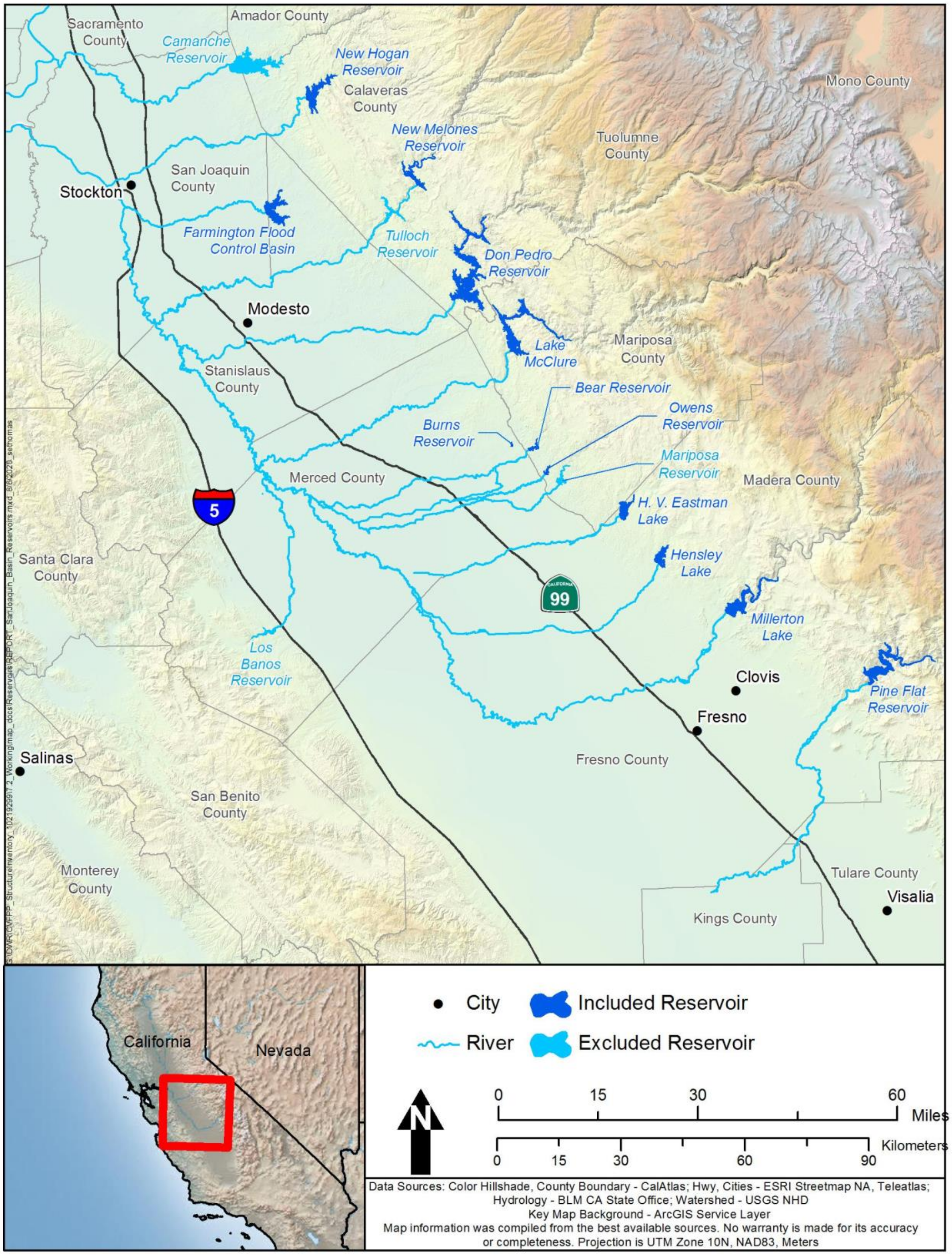
Notes: DWR = California Department of Water Resources; ID = identification; Reclamation = U.S. Bureau of Reclamation; USACE = U.S. Army Corps of Engineers.

Figure 4.27 **Selected Sacramento River Basin Reservoirs Included in this Phase of the RVA**



Data Sources: Color Hillshade, County Boundary - CalAtlas; Hwy, Cities - ESRI Streetmap NA, Teleatlas; Hydrology - BLM CA State Office; Watershed - USGS NHD
Key Map Background - ArcGIS Service Layer
Map information was compiled from the best available sources. No warranty is made for its accuracy or completeness. Projection is UTM Zone 10N, NAD83, Meters

Figure 4.28 **Selected San Joaquin River Basin Reservoirs Included in this Phase of the RVA**



Data Sources: Color Hillshade, County Boundary - CalAtlas; Hwy, Cities - ESRI Streetmap NA, Teleatlas; Hydrology - BLM CA State Office; Watershed - USGS NHD
Key Map Background - ArcGIS Service Layer
Map information was compiled from the best available sources. No warranty is made for its accuracy or completeness. Projection is UTM Zone 10N, NAD83, Meters

4.8.2 Climate Change Effect on the Overall System

Changes in unregulated inflow volumes and peak reservoir releases as a result of climate change for each of the 16 reservoirs were assessed as part of the RVA. For the Sacramento River Basin, the Sacramento River at latitude of Sacramento (analysis point SAC-42 as identified by the CVHS) unregulated volume-frequency curves were used for current and future climate scenarios. Events matching the 3-day, 100-year (p = 0.01) and 200-year (p = 0.005) unregulated volumes at that location were identified and extracted from the HEC-ResSim simulation dataset. Events were selected using the 1986 and the 1997 event patterns. For the San Joaquin River Basin, the San Joaquin River downstream of Stanislaus River (near Vernalis) (analysis point SJR-75 as identified by CVHS) unregulated volume-frequency curves were used for current and future climate conditions. Similarly, events matching the 50-year (p = 0.02) and 100-year (p = 0.01) 3-day unregulated flow at that location were identified and extracted from the simulation dataset and events were selected using the 1986 and 1997 event patterns.

The changes in unregulated inflow volumes and peak releases were analyzed for each reservoir based on a single simulated event. Each simulated event was based on a scaled historic event simulated through the reservoir (HEC-ResSim) and channel (HEC-RAS) models. These historic events were scaled using various factors to represent low, medium, and high climate change projections for the 50-year and 100-year unregulated events at SJR-75, and for the 100-year and 200-year unregulated events at SAC-42. This scaling was performed for the 1986 and 1997 patterns.

For the 1986 scaled events, unregulated inflow volumes for reservoirs in the Sacramento River Basin increased on average of approximately 20 percent when comparing the current to the medium climate change scenarios, whereas unregulated inflow volumes for reservoirs in the San Joaquin River Basin increased approximately 55 percent. For the same climate change scenario, peak releases from the reservoirs in each basin increased by varying amounts. For example, although unregulated volume increased by 37,000 cfs over three days at Folsom, the Folsom peak release did not increase. Shasta unregulated inflow volume increased 23,000 cfs average over three days, but the Shasta peak release increased by about 54,000 cfs. In the San Joaquin River Basin, peak releases at Bear, Burns, New Hogan, Buchanan, Hidden, and Owens reservoirs increased at most by a few hundred cfs, and peak releases at New Melones did not increase, whereas the Don Pedro peak release increased by approximately 64,000 cfs and the Friant peak release increased by approximately 66,000 cfs. A complete summary of the unregulated inflow volumes and peak releases associated with each of the climate change projections for each of the reservoirs in the Sacramento and San Joaquin river basins is provided in Appendix G, “Reservoir Vulnerability Analysis.”

4.8.3 Mitigation Strategies

Results from the RVA demonstrate that the projected trends of changing precipitation and temperature within the watershed can change the runoff volume-frequency relationships, and more significantly, the downstream peak regulated flow-frequency curves. The higher peak in-channel flows more often will increase flood risk. The majority of increased runoff comes from portions of the watershed upstream of the flood control reservoirs. Accordingly, opportunities to decrease flood risk and/or mitigate future increases in flood risk, exist above the reservoirs, at the reservoirs, and below the reservoirs.

Flood risk is mitigated through both structural and non-structural measures. Structural measures change the hazard(i.e., the frequency and/or hydraulic characteristics) of flood waters. Structural measures include dams, reservoirs, levees, floodwalls, large-scale channelization projects, levee setbacks, and bypasses. Non-structural measures improve flood system performance and reduce exposure, vulnerability, and consequences of flooding by adapting to the natural floodplain or inherent features of the floodplain without changing the characteristics of the flood hazard (California Department of Water Resources 2017a). Examples of non-structural measures include enhancements to flood warning systems, flood emergency preparedness plans, and evacuation plans.

Above or upstream of reservoirs, flood risk can be mitigated through non-structural measures that restore properly functioning hydrological processes in the watershed. These include increased monitoring, erosion control, wildfire fuel reduction, riparian habitat rehabilitation, and policy changes to protect upper watersheds. Structural measures that reduce inflow to reservoirs through upstream detention, storage, or other means, can also be used to mitigate flood risk.

At a reservoir, non-structural opportunities to mitigate flood risk include reservoir operations and reoperation plans to mitigate reservoir releases for climate change impacts, thereby improving the timing and accuracy of flood forecasts, and increasing the reservoirs’ flood storage by revising the flood control diagram, without any physical changes to the dam. Structural opportunities at a reservoir involve physical changes to the dam to reduce flood risk, such as changing the outlet capacity, increasing the spillway capacity, or raising the dam.

Downstream of reservoirs, non-structural flood management elements that focus on enhanced flood emergency response and emergency management, enhanced operations and maintenance, and floodplain management can be used to reduce flood risk. Structural measures implemented downstream of reservoirs that can reduce flood risk focus on improvements to the levee system, such as levee strengthening, repairs, or improvements; bypass construction and existing bypass expansion; and infrastructure improvements such as raising and waterproofing structures and building berms.

An overview of the completed, ongoing, and planned activities/projects that DWR has implemented or is actively investigating and potentially implementing that incorporate both structural and non-structural measures to reduce flood risk is provided in Appendix G, "Reservoir Vulnerability Analysis." Additionally, DWR is developing a climate change adaptation strategy. This strategy is described in the Climate Change Adaptation Measures Report (forthcoming).

4.9 Regional Economic Analysis

A regional economic analysis evaluates the effects of changes in production or expenditures in a region's economy. The 2012 CVFPP estimated two SSIA regional economic effects within the Sacramento and San Joaquin river basins: (1) SSIA project investment and (2) flood damage focusing on business production losses. A regional economic analysis was not conducted for the 2017 CVFPP Update.

The 2022 CVFPP Update includes a regional economic analysis that evaluated the primary (direct) and secondary (indirect and induced) economic effects of (1) proposed SSIA investment expenditures to improve flood protection facilities in the Sacramento and San Joaquin river basins, and (2) the reduction of business and crop production losses expected with SSIA investments. SSIA investments are expected to occur over a 30-year period. Because of this, the 2022 CVFPP Update regional economic analysis uses future 2072 medium climate change business and crop production losses as input, as reported in Appendix C, "Flood Risk Analysis." Other potential regional economic effects from flood damage were qualitatively described, such as those related to structure and contents physical damages, property value impacts, municipal fiscal impacts, and regional economic competitiveness and diversity.

The 2022 CVFPP Update's regional economic analysis focused on how implementation of the proposed 2022 SSIA portfolio will:

- Improve flood management, potentially resulting in reduced flood damages, including business and crop income losses. Avoided direct business and crop losses may result in avoided indirect losses on industry output and employment, both regionally and statewide.
- Result in SSIA construction secondary industry output and employment effects, which will stimulate regional and statewide economies. For example, construction of a setback levee project could bring new employers and employees into the local area and generate sales revenue for businesses that supply materials or goods.

IMPLAN, an economic input-output (I-O) modeling application, was used to estimate effects on the regional economy using SSIA construction costs and results from the 2022 CVFPP Update flood risk analysis. I-O analysis measures the flow of commodities and services among industries, institutions, and final consumers within an economy. An I-O model uses a matrix representation of a region's economy to predict the effect that changes in one industry will have on others, as well as consumers, government, and foreign suppliers in the economy.

I-O models capture all monetary market transactions in an economy, accounting for inter-industry linkages and availability of regionally produced goods and services. The resulting mathematical formulas allow I-O models to simulate or predict the economic impacts of a change in one or several economic activities on an entire economy. It is a static linear model of all purchases and sales, or linkages, among sectors of an economy.

IMPLAN estimates changes in the regional economy as direct, indirect, and induced economic effects for affected industries within the study area, where:

Total Output Effects = Direct Economic Effects + Indirect Economic Effects + Induced Economic Effects

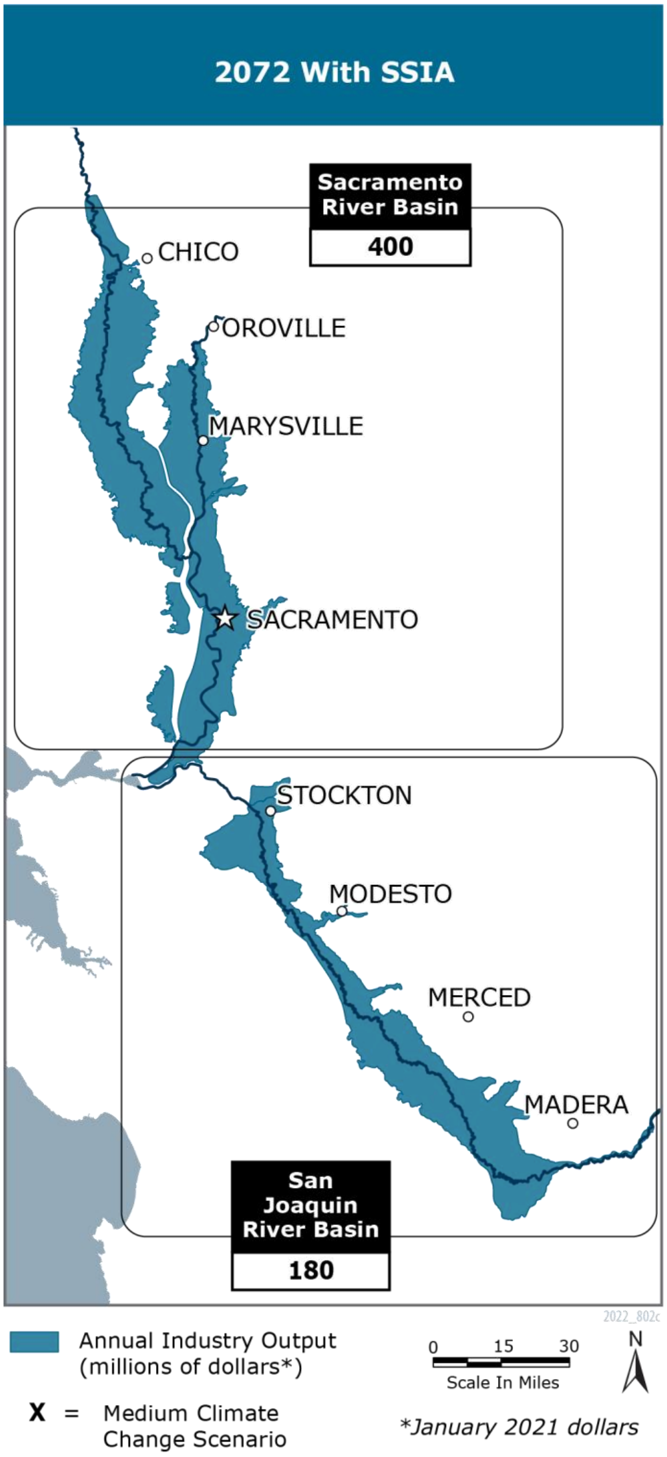
- "Direct Economic Effects" refer to the response of a given industry (i.e., changes in output, value added, and employment) based on changes in final demand for that industry's output.
- "Indirect Economic Effects" refer to changes in output, labor income, value added, and employment resulting from the iterations of industries purchasing from other industries caused by the direct economic effects.

- "Induced Economic Effects" refer to changes in output, labor income, value added, and employment caused by the expenditures associated with changes in household income generated by direct and indirect economic effects.

For the 2022 CVFPP Update regional economic analysis, the 2019 California State IMPLAN dataset was used.

Estimated stimulus from the SSIA construction regional economic analysis is summarized for total annual industry output by basin in Figure 4.29. The 2022 SSIA portfolio is estimated to annually bring approximately $400 million to the regional economy within the Sacramento River Basin and approximately $180 million to the regional economy within the San Joaquin River Basin. Additional information and results of the 2022 CVFPP Update's regional economic analysis are provided in Appendix H, "Regional Economic Analysis."

Figure 4.29 Estimated Regional Total Annual Industry Output Generated by 2022 SSIA Portfolio Investment



Note: The regional economic analysis estimates positive economic stimulus from SSIA construction expenditures, materials/services, and labor. This economic stimulus is measured as annual industry output of the 2022 SSIA portfolio that was analyzed.

4.10 Central Valley Flood Planning Atlas

DWR is involved in or leads multiple study efforts of different objectives and scales. However, information from one study can often lead to valuable information for another. In the interest of sharing information across studies, the Central Valley Flood Planning Atlas (Appendix I) has been created and is intended to be a "living document" as new information is available or existing information revised.

Appendix I documents the many distinctive overlapping study areas used for the 2022 CVFPP Update's interrelated analyses, such as the Flood Risk Analysis, Conservation Strategy, and Investment Strategy. Relevant CVFPP flood planning maps, such as for the many Central Valley local maintaining agencies, are also provided, in addition to some of the underlying critical data for assumed future projects and land use. Finally, because the various 2022 CVFPP Update study areas overlap those being used for the California Water Plan Update 2023 (i.e., planning areas/hydrologic regions), these study areas are also provided for comparison.

CHAPTER 5

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APPENDIX A – CLIMATE CHANGE ANALYSIS

APPENDIX B – CLIMATE CHANGE VOLUME FREQUENCY ANALYSIS

APPENDIX C – FLOOD RISK ANALYSIS

APPENDIX D – RISK ANALYSIS SUMMARY BY INDEX POINT

APPENDIX E – RISK ANALYSIS INVENTORY UPDATE

APPENDIX F – LIFE RISK INPUT DEVELOPMENT

APPENDIX G – RESERVOIR VULNERABILITY ANALYSIS

APPENDIX H – REGIONAL ECONOMIC ANALYSIS

APPENDIX I – CENTRAL VALLEY FLOOD PLANNING ATLAS

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