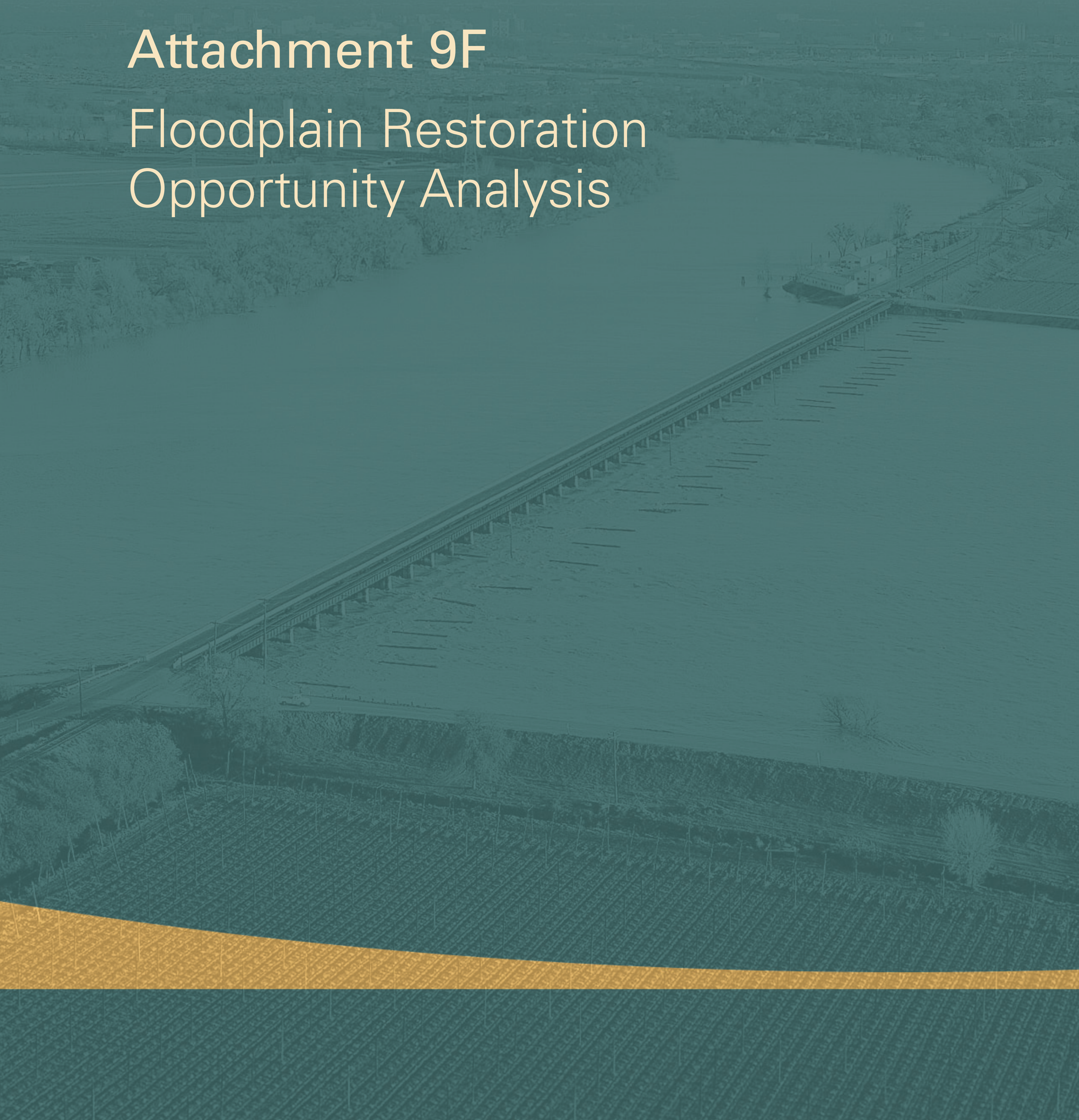
Attachment 9F

Floodplain Restoration Opportunity Analysis



CENTRAL VALLEY
FLOOD MANAGEMENT
PLANNING PROGRAM

FloodSAFE CALIFORNIA

2012 Central Valley Flood Protection Plan

Attachment 9F: Floodplain Restoration Opportunity Analysis

June 2012

STATE OF CALIFORNIA
THE NATURAL RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

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1.0 Introduction

This section provides an overview of the attachment and document organization.

1.1 Overview

Ecosystem restoration is a key component of the Central Valley Flood Protection Plan (CVFPP), and actions related to ecosystem restoration have been proposed as part of the CVFPP. This report documents an analysis of the potential for ecosystem restoration of floodplains within the Systemwide Planning Area of the State Plan of Flood Control (SPFC) (Figure 1-1).

To support the identification, development, and implementation of specific restoration actions, a Floodplain Restoration Opportunity Analysis (FROA) was conducted, which is summarized in this report. This FROA identifies areas with greater and/or more extensive potential opportunities for ecological restoration of floodplains. It does so by considering physical suitability; and opportunities and constraints related to existing land cover and land uses, locations and physical condition of levees, locations of other major infrastructure, conservation status of land, and locations that stakeholders are interested in restoring.

To evaluate physical suitability, the concept of floodplain inundation potential (FIP) was applied in a geographic information system (GIS) analysis of corridors along the Sacramento and San Joaquin rivers and their major tributaries. This analysis was selected because of the importance of floodplain inundation for ecosystem functions. To assess physical suitability for restoration actions, the FIP analysis adapted concepts from the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center (USACE-HEC) (USACE-HEC, 2009), the Frequently Activated Floodplain concept of Williams et al. (2009), and the Height Above River (HAR) GIS tool of Dilts et al. (2010). FIP analysis identifies areas of floodplain, both directly connected to the river and disconnected from the river (e.g., behind natural or built levees or other flow obstructions) that could be inundated by particular floodplain flows. The flows evaluated by the FROA included a spring flow sustained for at least 7 days and occurring in 2 out of 3 years (a 77 percent chance event), and 50 and 10 percent chance peak flows.

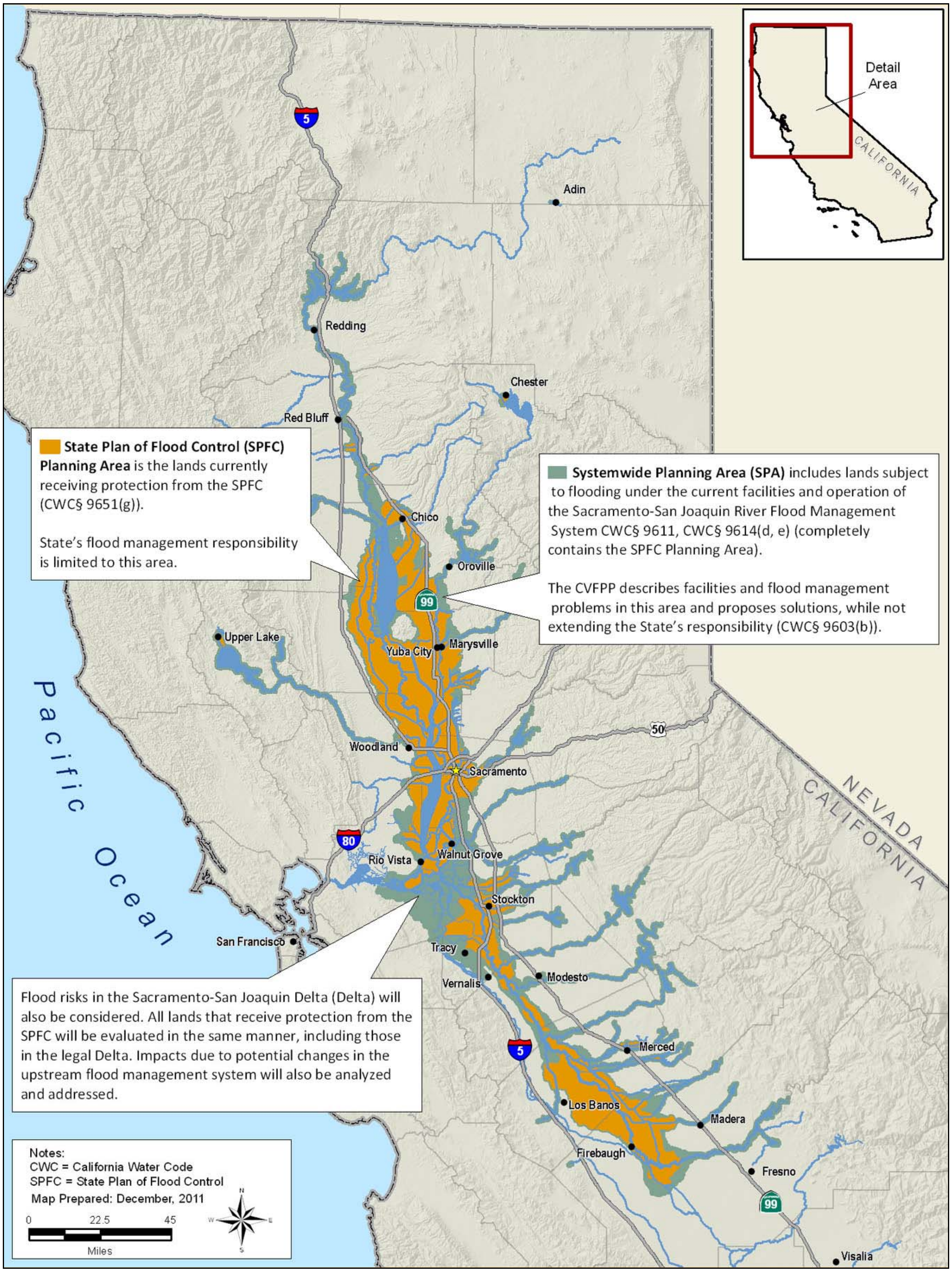

Figure 1-1. Central Valley Flood Protection Plan Planning Area

This analysis adapted existing models and hydrologic data, and thus, the FROA is limited to those reaches of the Sacramento and San Joaquin rivers and their tributaries for which such resources were available. Consequently, the FROA includes the Sacramento River from Woodson Bridge State Recreation Area to Collinsville, the San Joaquin River from Friant Dam to Stockton, the lower Feather River, and the lowermost reaches of other major tributaries of the Sacramento and San Joaquin rivers (i.e., the Bear, Yuba, American, Stanislaus, Tuolumne, and Merced rivers). It does not include smaller tributaries. The Sutter and Yolo bypasses are also included.

For the included river reaches and bypasses, oopportunities and constraints based on existing land use and land cover, major infrastructure locations, and conservation status were determined from existing and available geospatial data for existing wetland and riparian vegetation, Important Farmland (as defined by DOC, 2011), and urban areas; locations of major roads, highways, and railways; and land ownership and management. Four primary categories of existing land use and land cover were considered: developed, irrigated agricultural, open water, and natural; with natural land cover subdivided into wetland, riparian, and upland.

Stakeholder interest in restoration actions was compiled through focused outreach and review of existing reports. Stakeholders were interviewed to document potential ecosystem restoration projects previously identified by various CVFPP stakeholder groups throughout the Systemwide Planning Area. Specific information regarding potential restoration projects identified by stakeholders has been considered confidential. In addition to these interviews, existing reports that identified potential ecosystem restoration opportunities were also reviewed. Projects in reviewed reports that were located within the Systemwide Planning Area and that would provide ecosystem benefits were included with the group of stakeholder-identified projects and areas of interest.

The relationships among areas of physical suitability and opportunities and constraints were used to characterize river reaches and identify reaches with greater and/or more extensive potential opportunities for restoration. Reach boundaries were at junctions with tributaries and other frequently recognized boundaries (e.g., reach boundaries used by the San Joaquin River Restoration Program (SJRRP)).

The results of the FROA are intended to support the subsequent identification, prioritization, and further development of specific restoration opportunities. Through this subsequent planning, specific opportunities would be identified and prioritized on the basis of their potential ecological, flood management, and other benefits (e.g., reduced maintenance and regulatory compliance costs); cost; and regulatory, institutional, technological, and operational feasibility. This process for identifying and prioritizing opportunities would be both part of the continuing development of the overall CVFPP and of the development of species-focused conservation planning and corridor management strategies.

The following report summarizes the methods, results, and recommendations of the FROA.

1.2 Report Organization

The remainder of this attachment is organized into the following sections:

- Section 2.0, Methods
- Section 3.0, Results of the Floodplain Restoration Opportunities Analysis
- Section 4.0, Floodplain Restoration Opportunities: Conclusions and Recommendations
- Section 5.0, References
- Section 6.0, Abbreviations and Acronyms
- Appendix A, Floodplain Inundation and Ecosystem Functions Model Pilot Studies
- Appendix B, Investigation of USGS 10-Meter DEM Accuracy
- Appendix C, CVFED LiDAR Terrain Data Comparisons
- Appendix D, Levee Realignment Methodology
- Appendix E, Synthetic vs. Observed Hydrographs
- Appendix F, HEC-EFM Ecosystem Functional Relationships
- Appendix G, RAS/EFM Analysis FIP-based Mapping

1.3 Acknowledgments

This work was performed for the Floodway Ecosystem Sustainability Branch of the FloodSAFE Environmental Stewardship and Statewide Resources Office, California Department of Water Resources (DWR), and was accomplished by AECOM through Task Order 10-07 to Master Consulting Services Subcontract No. DWR-MSA08-EDAW-AECOM, effective July 26, 2010, with MWH Americas, Inc. (MWH). An independent review of the work was provided by cbec eco engineering, and USACE-HEC responded to technical questions regarding the application of HEC's Ecosystem Functions Model (HEC-EFM). Guidance on the application of the HAR/FIP method was also provided by the author of the software, Thomas Dilts of the University of Nevada, Reno.

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2.0 Methods

2.1 Overview

This chapter describes the general approach and methods of the FROA, which was based in part on the results and conclusions of two pilot studies conducted on the lower Feather River. The specific method used to determine FIP is described in detail in Appendix A, which provides the methods, results, and conclusions of the two pilot studies conducted on the lower Feather River to evaluate the suitability of FIP (an expanded version of the HAR method) (Dilts et al., 2010) and USACE-HEC-FEM (USACE-HEC, 2009) analyses for use in the FROA.

Traditional approaches for analyzing the inundation characteristics of river channel-floodplain land areas typically involve hydraulic models that rely on one-dimensional cross sections to describe the land surface. In addition to the limitations of cross sections to describe land surfaces, these traditional approaches also generally involve a significant amount of time to develop and use. However, because of the large geographic area covered by the CVFPP and the number of potential ecosystem restoration activities within this region, a computational tool capable of rapidly identifying and quantifying habitat restoration opportunities was desired.

Therefore, for this **planning-level study**, a simplified approach was preferred to understand the spatial extent of floodplain land areas that are connected and disconnected from the river channel for certain flow conditions. The FIP method is a GIS-based approach that does this, requires limited field data, is based on simple concepts, and is computationally efficient (Dilts et al., 2010). The FIP approach uses readily available topographic and hydrologic data sets and GIS analyses to identify floodplains potentially inundated under more frequent, ecologically valuable flow events (e.g., 50 and 10 percent chance events). Thus, GIS layers based on the results of the FIP analysis show floodplains that are connected, or could be more readily reconnected, to the river during specific flow events. **The FIP method is not intended to be a replacement for detailed hydraulic models**; instead, it is considered a viable tool for relatively quickly assessing areas that are physically suitable for restoration.

For the purpose of this work, the “FIP method” is the term used to describe the application of GIS tools provided within the ArcGIS Riparian Topography Toolbox, as described by Dilts et al. (2010). The ArcGIS

Riparian Topography Toolbox is distributed by Environmental Systems Research Institute, Inc. (ESRI) (ESRI, 2011). This GIS software uses digital terrain models and water surface elevations from hydraulic modeling to calculate the relative height of terrain above a water surface and the depth of terrain below a water surface (and thus FIP). It also determines the inundated areas that are connected or disconnected from a river channel by levees or other obstructions for a given flow event.

The Floodplain Inundation Pilot Study on the lower Feather River (Appendix A) evaluated the adaptation of the HAR tool for use in this FIP analysis. It found that the FIP method is a relatively effective way to quickly and easily find features on the land surface that are either above or below a specified water-surface profile. Color ramping of GIS layers of FIP output showing height increments both above the river (i.e., water surface) and below can provide a rapid visualization of the low-lying land areas physically connected to a river channel, or capable of being connected, and the relative depth of these topographic depressions. The results can also be used to guide qualitative assessments of potential levee setback locations. Although the FIP method is not a substitute for detailed hydraulic modeling, it does provide an ability to relatively quickly understand flood characteristics across the floodplain landscape.

The FROA is focused on identifying potential restoration areas based on the ecological functions that could be provided by inundated or potentially inundated floodplains. Initially, the Ecosystem Functions Model (HEC-EFM), developed by the USACE-HEC, was considered as a potential tool for identifying the ecological functions provided by inundated and potentially inundated floodplains. HEC-EFM allows criteria (e.g., timing and duration of inundation) to be defined for eco-hydrologic relationships. By applying these criteria to stage and flow hydrographs produced by the HEC's River Analysis System (HEC-RAS), HEC-EFM identifies specific stages and flows providing specific ecological functions to be identified and visualized.

Consequently, a second pilot study, the HEC-EFM Pilot Study, was conducted along the lower Feather River to evaluate use of the HEC-EFM in the FROA. For this pilot study, criteria were developed for the relationship of cottonwood regeneration and salmonid rearing to flow conditions. These criteria were adapted from a previous application of HEC-EFM to support the Sacramento-San Joaquin Comprehensive Study (Comprehensive Study) (USACE and The Reclamation Board, 2002) and from criteria included as part of the Sacramento River Ecological Flows Tool (SacEFT) (ESSA Technologies, 2009). These functions were selected because of their relationship to lower stage floodplains and the limited extent of these habitat functions throughout the Sacramento and San Joaquin river systems.

The methods, results, and conclusions of this pilot study are provided in Appendix A. The study identified several limitations of HEC-EFM for use in the FROA:

- Constraints on the realism of habitat evaluations: (1) use of a single set of criteria as opposed to a range that distinguishes optimal from suboptimal conditions, (2) lack of coupling of relationships (e.g., cottonwood seedling recruitment depends on suitable conditions for germination in spring followed by minimal inundation during the winter), and (3) the potential for varied relationships between ecological functions and hydrologic conditions among the Sacramento and San Joaquin rivers and their tributaries.

- Lack of functional distinctions among evaluated areas: potential habitat for the ecological functions selected was largely absent, resulting in similar habitat attributes; similar results could occur throughout the Sacramento and San Joaquin river systems,

- Cost of application: the time required to apply the HEC-EFM model would limit analysis to selected reaches of the Sacramento and San Joaquin river system.

Consequently, a more generalized approach was developed for identifying floodplain areas where inundation could provide desired ecological functions: four types of flows were used in conjunction with the FIP method to distinguish floodplain areas that could be physically suitable for providing different types or amounts of multiple ecological functions. This approach is described in the following section.

2.2 Floodplain Restoration Opportunity Analysis Approach

As diagrammed in Figure 2-1, the FROA approach consists of three steps:

- Identify Areas of Physical Suitability.
- Identify Opportunities and Constraints.
- Identify Potential Restoration Opportunities.

The methodology of each of these steps is described in the following sections.

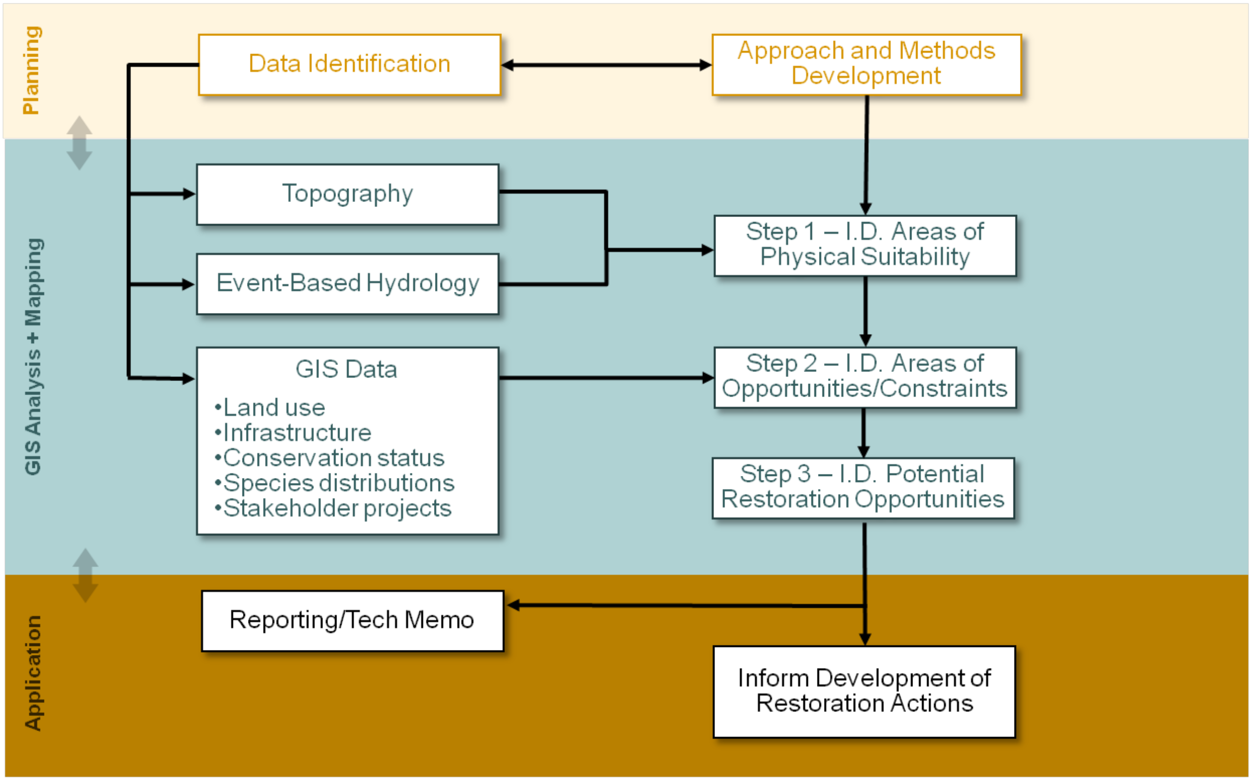

Figure 2-1. FROA Approach

2.2.1 Step 1: Identify Areas of Physical Suitability

To evaluate physical suitability for restoration actions, the FIP method was applied in a GIS analysis of corridors along the Sacramento and San Joaquin rivers and their major tributaries. This analysis was selected because of the importance of floodplain inundation for ecosystem functions, and because, at this planning level of investigation, the FIP method provided a relatively rapid approach for assessing floodplain inundation, as compared to the alternative use of more detailed hydraulic modeling. Furthermore, the pilot project application of the FIP method on the Feather River indicated its feasibility for application to the larger Sacramento and San Joaquin river systems.

The FIP analysis provides a spatial representation of floodplain inundation areas, and depths, relative to a varying water-surface profile. The FIP analysis "projects" a designated water-surface profile laterally from a stream centerline through levees or other obstructions out to a predetermined distance from a river centerline to provide an estimate of floodplain extent and depths if these obstructions were not present. It is acknowledged, however, that the actual water surface resulting from the removal of a levee or other obstruction would differ from that presented in the FIP analysis, but at this planning level the representation of potential floodplain inundation provided by the FIP analysis was deemed acceptable. The analysis was based on the results and conclusions of the pilot projects (Appendix A). It adapted concepts from the USACE HEC-EFM (USACE-HEC, 2009), the Frequently Activated Floodplain concept of Williams et al. (2009), and the HAR GIS tool of Dilts et al. (2010).

Several flows and associated water-surface profiles were evaluated using the FIP analysis, including:

- Water-surface profiles at the time of the CVFED (Central Valley Floodplain Evaluation and Delineation) Light Detection and Ranging (LiDAR) flights in March 2008 representing a low-water baseflow condition; termed the “Baseflow” FIP (most months have greater discharges and higher water surface elevations than March 2008 (e.g., during 1945 – 2010, at Red Bluff, the Sacramento River had a discharge greater than March 2008 in 93 percent of months)). Areas with Baseflow FIP would provide aquatic (riverine or lacustrine) habitats if hydrologically connected to a river.

- Seasonal flows and water-surface profiles derived using HEC-EFM representing a spring flow sustained for at least 7 days and occurring in 2 out of 3 years; termed the “67 percent chance Sustained Spring” FIP. Floodplains experiencing such sustained spring inundation would provide a variety of ecological functions, and greater aquatic foodweb productivity and fish utilization benefits than other floodplains (Williams et al. 2009).

- Peak flows and water-surface profiles associated with the 50 percent chance recurrence intervals; termed “50 percent chance” FIP. Floodplains inundated by these relatively frequent events would regularly sustain fluvial geomorphic processes (such as sediment scour and deposition) and provide inputs to the aquatic ecosystem (e.g., organic matter, including large woody material), among other functions, even where not experiencing sustained spring inundation.

- Peak flows and water-surface profiles associated with the 10 percent chance recurrence interval; termed the “10 percent chance” FIP. Floodplains inundated by these less-frequent events but not by 50 percent chance events would provide ecological functions similar to those inundated by more frequent events, but less frequently.

The analysis of FIP within the Systemwide Planning Area along the Sacramento and San Joaquin rivers and their major tributaries required topographic and hydraulic data. These data and the specific methods of the FIP analysis are described in the following sections.

Topographic Data

Accurate topographic data were required to evaluate FIP for these areas. AECOM completed an evaluation of readily available U.S. Geological Survey (USGS) 10-meter digital elevation models (DEM), and found that the data were not sufficiently detailed for this purpose.

The CVFED program recently mapped topography throughout the Central Valley, using LiDAR. AECOM received the raw LiDAR data files from the CVFED program in the fall of 2010. However, the raw data files were not usable for the Step 3 analysis, and creation of suitable files from the raw data (i.e., a digital terrain model) would duplicate work being completed by CVFED, which is not feasible from a cost or time standpoint.

As a solution to the lack of suitable topographic data, third-party software, Global Mapper, was used with the raw CVFED LiDAR data to create unprocessed digital terrain models. AECOM completed a test conversion of these digital terrain models to ArcGIS format, and found that the resultant topographic surface was usable for the FIP analysis, with minor modification and post-processing.

Hydraulic Data

For the various FIP analyses described above, hydraulic data were required to obtain water-surface profiles, with the exception of the Baseflow FIP analysis, which simply relied upon the water surfaces at the time of the CVFED LiDAR flight.

Hydraulic data for the 67 percent chance Sustained Spring FIP analysis were obtained from an analysis similar to the Feather River HEC-EFM/HEC-RAS pilot study; with a few differences that are noted and in Appendix A. Similar to the pilot study, HEC-EFM was used to query synthetic flow records for the Sacramento and San Joaquin river basins based on an ecosystem function relationship (EFR). The EFR included user-defined criteria such as a season, duration, and frequency. However, while the pilot study involved a HEC-EFM analysis of flow and stage time series produced by unsteady HEC-RAS modeling, findings from the study indicated this was not necessary and the remainder of the FROA effort simply used CalSim-derived synthetic flows that were queried directly by HEC-EFM. Comprehensive Study and Common Features HEC-RAS models were then used in a steady-flow analysis to model the flows identified by HEC-EFM, and the FIP tool was used to map the HEC-RAS water surface elevations (i.e., stages) at model cross-section locations. Major differences between the large-scale HEC-EFM/HEC-RAS analyses and the pilot-study analysis included:

1. Flow Estimation – CalSim-derived synthetic flows were queried directly by HEC-EFM after converting the Excel-based time series flow data to USACE-HEC's Data Storage System (HEC-DSS) format. The flow values were derived from CalSim simulations to capture the flow impacts of recent regulations and projects that are not reflected in the historical record. Daily values were developed from the monthly CalSim values using a pattern matching algorithm based on historical daily flow records. For the pilot study, the flows were used as boundary conditions to an unsteady-flow HEC-RAS model developed by AECOM from the Comprehensive Study and Common Features models, and the flows and stage time series produced by unsteady HEC-RAS were queried using HEC-EFM. It was initially believed that using HEC-RAS would improve the estimate of flows and would also provide useful stage data. Following the pilot study however, it was agreed that this step was unnecessary and potentially misleading, as it could be perceived that using HEC-RAS unsteady flow provided an improvement in the estimate of flow rates. Because of the nature of the CalSim-derived flows, it was agreed that HEC-RAS would not provide any improvement in the estimate of flows (primarily because the flows were originally based on a monthly time step). In addition, the hydrographs produced by unsteady HEC-RAS for areas with strong backwater influence produced significant hysteresis (see HEC-EFM), resulting in large run-times for HEC-EFM and major errors in the resulting HEC-EFM rating curves. Lastly, because the EFR used in the final analysis did not require stage data, the CalSim-derived flows alone were sufficient for completing the HEC-EFM analysis. The consensus decision by the project team was that this approach provided reasonable results consistent with the level of detail provided by the CalSim-derived flows.

2. HEC-RAS Modeling – The Sacramento and San Joaquin river basins were modeled in HEC-RAS as a single basin-wide model (as opposed to subdividing the models into individual rivers). The flow rates selected by HEC-EFM were applied at the nearest river station and a steady-flow analysis was performed. The main purpose of modeling the entire basin as a single model was to provide consistent water surfaces at tributary confluences. A secondary benefit was that the Comprehensive Study and Common Features models were originally developed as basin-wide models and this reduced the level of effort required to subdivide the models. In addition, since the HEC-EFM analysis was performed using the CalSim-derived flows directly, individual Habitat Analysis Areas (HAA) were not needed (see Section 2.3.1 for an explanation of HAAs). Additional details regarding the HEC-RAS modeling include the following:

a. Flow regimes were developed in HEC-EFM for each CalSim-derived node and for those hydrographs developed for tributaries not included in the CalSim-derived flow hydrographs. For the San Joaquin River, flow regimes were based on the restoration flows required by the San Joaquin River Restoration Settlement (as described in Reclamation, 2011). These flow regimes were developed by editing the HEC-EFM data file directly with a text-editor, as opposed to entering them individually in HEC-EFM. Also note that the stage data “required” by HEC-EFM is not necessary if stage results are not desired; thus, the flow hydrograph was used for both the flow and stage data source.

b. Where CalSim-derived flows were unavailable (e.g., Bear River, Yuba River, and Fresno Slough) flow hydrographs were developed by taking the difference between the upstream and downstream CalSim-derived hydrographs. This approach was used in the Lower Feather River Pilot Study and considered to be a reasonable estimate of the tributary flows. At confluences farther upstream on these tributaries (e.g., Union Pacific Interceptor Canal (UPIC), Dry Creek and Bear Creek (upstream from UPIC/Dry Creek)), the same approach could not be used and flows were not available; therefore, these areas were not mapped. For other areas where flows were unavailable, such as flood control bypasses and diversions and sloughs within the northern Sacramento-San Joaquin Delta (Delta), these areas were removed from the HEC-RAS models and not mapped.

c. The vertical datum of each model was not revised and was left in National Geodetic Vertical Datum of 1929 (NGVD 29). The stages output from the GIS extension to the HEC’s River Analysis System (HEC-GeoRAS) and used during the FIP were adjusted to North American Vertical Datum 1988 (NAVD 88) using the same approach as was used for the conversion of the 50 percent and 10 percent chance stages.

d. The Sacramento and San Joaquin models were converted to HEC-RAS 4.1.0 to simplify the export of results to HEC-GeoRAS and ArcGIS.

e. The Sacramento River upstream from River Mile (RM) 143.24 was taken from the Sacramento Comprehensive Study model and added to the Sacramento River basin-wide Common Features model. The Common Features model did not include the Sacramento River upstream from RM 143.24. The Comprehensive Study river stations were revised to match the Common Features model by subtracting 0.8812 mile.

f. The Mean Tidal Level (MTL) at the Port Chicago tide gage was used for a constant downstream stage boundary condition for the Sacramento and San Joaquin rivers. This approach was discussed by the project team and considered reasonable. Tidal data were obtained from the National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanographic Products and Services (NOAA, 2011). The gage's MTL datum and NAVD datum values and the NGVD-to-NAVD conversion factor were applied, as follows:

   MTL(NGVD) = (MTL – NAVD) – (NAVD NGVD Conversion Factor)

   MTL(NGVD) = (6.56 – 2.89) – (2.613205)

   MTL(NGVD) = 1.0558 feet

g. The existing HEC-RAS model cross sections were not updated because the official DWR review of the new CVFED Task Order 20 LiDAR-derived DEMs was not complete at the time of this work.

h. Additional consideration was given to whether alternative analyses of sustained spring flows should be performed using either a higher/lower frequency, extended duration, or different season. It was agreed that the 67 percent chance relationship used for this study was the best suited to identifying potential habitat areas and was consistent with past work by others.

Hydraulic data (flows and stages) for the 50 percent chance and 10 percent chance recurrence interval FIP analyses were derived directly from the Comprehensive Study UNET models. Each pair of flow and stage values represents a discrete reach within the Sacramento and San Joaquin river systems.

An important point to clarify is the difference between the 50 percent chance and 10 percent chance recurrence interval FIP analyses versus the 67 percent chance Sustained Spring FIP analysis. The 50 percent chance and 10 percent chance water-surface profile elevations (stages) used for the FIP analysis correspond to peak flow conditions derived from a statistical flood frequency analysis of a series of maximum annual flows. The stages developed for the 67 percent chance Sustained Spring FIP analysis, while corresponding to a 67 percent chance frequency, are limited to those events that occur between March 15 and May 15 and for no less than 7 days. As a result, the 67 percent chance Sustained Spring events are significantly smaller flow events than the 50 percent chance and 10 percent chance events and may correspond to non-storm conditions. For example, 67 percent chance Sustained Spring FIP on the lower American River and Sacramento River downstream from the American River correspond to flows of approximately 2,900 to 3,100 cubic feet per second (cfs) and 21,000 cfs, respectively, which are less than mean monthly winter flows. The 67 percent chance Sustained Spring FIP analysis primarily identifies potential habitat during spring (e.g., salmonid rearing habitat), while the 50 percent chance and 10 percent chance provides information about more general inundated floodplain habitat attributes.

FIP Analysis

The FIP analysis methodology established during the Feather River pilot study was applied to the remainder of the Sacramento and San Joaquin river systems. All aspects of this approach remained the same except that the CVFED pre-processed LiDAR and breakline data, which were used in the pilot study, were not available for the remainder of the Systemwide Planning Area study area. Therefore, the analysis used the unprocessed digital terrain models developed with the Global Mapper software.

Based on the results of this analysis, in combination with the data regarding opportunities and constraints described in Section 2.4.2 below, reaches were identified with greater and/or more extensive potential opportunities for restoration, as described below in Section 2.4.3.

2.2.2 Step 2: Identify Opportunities and Constraints

The identification of other opportunities and constraints besides physical suitability relied on readily available geospatial data layers, except for information on the location of existing interest in restoration, which was compiled from stakeholders for this analysis.

As part of the CVFPP planning process, existing datasets potentially of use in development of the CVFPP and related documents and appendices were reviewed (AECOM, 2010a). The intent of this review was to document those readily available and public-domain geospatial datasets that would be used for the CVFPP, subject to a defined set of selection rules. Included among these rules were the following:

- Data had to be freely available on the Internet or available from a CVFPP participant (i.e., DWR, MWH, or AECOM).
- Data had to cover the entirety of the study area, or as much of the area as possible.

- Where a choice between data currency and data detail (i.e., spatial resolution) was available, more current data were preferred over more detailed data unless it was felt that enhanced data resolution (either spatial or attribute) was essential.

Data collected to help identify areas with opportunities and/or constraints, subject to these rules, are described below.

- **Agricultural and Natural Land Use/Land Cover –** Land use/land cover data were compiled for Important Farmland (as defined by DOC, 2011) from the California Department of Conservation's Farmland Mapping and Monitoring Program (DOC, 2008) and wetlands and riparian vegetation (DWR, 2012).

- **Urban Areas –** These data were developed by DWR (2010a) using data provided by the California Department of Conservation's Farmland Mapping and Monitoring Program.

- **Major Infrastructure –** Major infrastructure consisted of data showing the locations of major roads and highways (U.S. Census Bureau, 2007), railways (Caltrans, 2009), and levees and levee condition (developed by DWR during the CVFPP planning process, and under development by DWR's Urban and Non-Urban Levee Evaluation projects).

- **Terrestrial Sensitive Species Occurrences –** Occurrences of terrestrial sensitive species, meaning species considered to be threatened, endangered, rare, fully protected, or species with similar status that are tracked by the California Department of Fish and Game (DFG) in the California Natural Diversity Database (CNDDB). The January 2011 version of the database (DFG, 2011) was used for this analysis.

- **Salmonid Spawning Reaches –** Reaches of rivers known to support spawning of fall-late-fall-run, winter-run, and spring-run Chinook salmon (*Oncorhynchus tshawytscha*), as well as Central Valley steelhead (*Oncorhynchus mykiss)*, were mapped from the CalFish abundance database (DFG, 2005).

- **Conservation Status –** Locations of preserved and protected habitat were based on the California protected areas database (GreenInfo Network, 2010).

Because of the nature of these data and known data gaps, limitations, or inaccuracies, these data were not considered to conclusively indicate areas that would be more suitable for ecological restoration relative to other areas. For example, the CNDDB only records positive sightings of species based on field surveys. It does not document the actual distribution of species, because additional populations of species tracked by CNDDB may be found in areas that have not been surveyed. This does not indicate that these data have no value in identifying potential ecosystem restoration opportunities, but it does underscore the inherent limitations of these data for use in evaluations of potential ecosystem restoration sites, particularly without considering the physical suitability of potential sites and other applicable data.

In addition to these selected geospatial datasets, information on existing interest in restoring particular areas was compiled from stakeholders. Focused outreach was conducted throughout the study area to document potential ecosystem restoration projects previously identified by various CVFPP stakeholders. Meetings were held with the stakeholder groups listed below.

- The Nature Conservancy (Northern Central Valley, California Water Program, San Joaquin Valley Project)
- American Rivers
- DWR Northern Regional Office
- DWR South Central Regional Office
- River Partners
- San Joaquin River Conservancy
- DFG (Central Region)
- U.S. Department of the Interior, Bureau of Reclamation (SJRRP)
- San Joaquin River Parkway and Conservation Trust
- Natural Resources Defense Council
- NewFields River Basin Services, LLC
- ESA PWA, Inc.

Owing to time constraints, not all potential ecosystem restoration stakeholders in the study area were interviewed.

Each interview consisted of a facilitated discussion, lead by DWR staff, to solicit stakeholder input on previously identified ecosystem restoration projects. Specific information provided by stakeholders regarding their planned projects has been treated as confidential. For each identified project, stakeholders were asked to provide the following information:

- Location of the potential project site, along with geospatial data depicting the project footprint, if available
- Project purpose, including ecosystem functions targeted for restoration
- Specific restoration activities proposed for the project, including a formal restoration plan, if available
- Current biological and physical conditions on the site, including an existing conditions report, if available
- Name and contact information for the project proponent
- Funding sources for the project
- Sources of the information described above

In addition to stakeholder interviews, existing reports that identified potential ecosystem restoration opportunities were also reviewed. These included the Sutter Basin Feasibility Study (USACE, 2010) and the Final Database of Potential Multi-Objective Flood Damage Reduction Actions (CBDA, 2004). Projects located within the study area and that would provide ecosystem benefits were included with the group of stakeholder-identified projects.

As previously described, these areas will be considered as potential restoration opportunities in the identification of reaches to be analyzed in more detail.

2.2.3 Step 3: Evaluate Potential for Restoration

The potential for restoration was determined by evaluating relationships among physically suitable areas and the locations of opportunities and constraints. This evaluation was based on the review and combination of geospatial data layers with ESRI’s ArcGIS software. Through it, reaches with greater and/or more extensive potential opportunities for restoration were identified.

The Sacramento and San Joaquin river systems were subdivided into 29 reaches. Boundaries between reaches were located at discontinuities in river or floodplain morphology, and/or to major junctions with tributaries, bypasses, or canals. In the upper Sacramento and San Joaquin river basins, reaches correspond to those established by the Sacramento River Conservation Area Forum and the SJRRP, respectively.

For each reach, four combinations of physically suitable conditions and suitable land use/land cover representing different restoration opportunities were mapped and their acreages tabulated:

- Nonurban floodplain with 67 percent chance Sustained Spring Flow or 50 percent chance FIP hydrologically connected to the river with riparian vegetation
- Nonurban floodplain with 67 percent chance Sustained Spring Flow or 50 percent chance FIP hydrologically connected to the river without riparian vegetation
- Nonurban floodplain with 67 percent chance Sustained Spring Flow FIP hydrologically disconnected from the river
- Nonurban floodplain with 50 percent chance FIP hydrologically disconnected from the river

Additional information regarding the location and extent of opportunities and constraints was also compiled for each reach.

3.0 Results of Floodplain Restoration Opportunities Analysis

For river reaches and bypasses included in the FROA, results are summarized in narrative descriptions, tables, and maps. FROA includes the Sacramento River from Woodson Bridge State Recreation Area to Collinsville, the San Joaquin River from Friant Dam to Stockton, the lower Feather River, and the lowermost reaches of other major tributaries of the Sacramento and San Joaquin rivers (i.e., the Bear, Yuba, American, Stanislaus, Tuolumne, and Merced rivers). It does not include smaller tributaries. The Sutter and Yolo bypasses are also included.

Narrative descriptions of reaches are provided in Sections 3.1 through 3.5. Maps and tables are provided in Section 3.6. Maps and tables are provided in a separate section to facilitate ease of use, particularly for comparisons of multiple maps.

In the reach descriptions, information is provided for the approximately 2-mile-wide corridors modeled along each river (with the exception of the Yolo Bypass where a 14,000-foot-wide corridor was modeled to account for levees that are set more than 2 miles apart). This information includes physical conditions (FIP and hydrologic connectivity), land use/land cover, infrastructure, conservation status, and occurrences of sensitive species.

Information in the narrative descriptions was primarily derived from the data sources displayed on the maps in this chapter, and previously described in Section 2.4. In addition, some supporting information from the following sources was also incorporated:

- Status and Trends of the Riparian and Riverine Ecosystems of the Systemwide Planning Area (DWR, 2011);
- State Plan of Flood Control Descriptive Document (DWR, 2010b);
- California Natural Diversity Database (DFG, 2011);

- Sacramento River Conservation Area Forum Handbook (Sacramento River Conservation Area Forum, 2003); and
- Draft Program Environmental Impact Statement/Environmental Impact Report San Joaquin River Restoration Program (Reclamation, 2011).

Several terms are used repeatedly in describing the reaches. “Corridor” refers to the extent of the modeled area, which generally extends approximately 1 mile from the river’s centerline. “Connected” and “disconnected” refer to hydrologic connection to the river during a 50 percent chance event (i.e., connected areas would be inundated during a 50 percent chance event). Also, throughout this text, 67 percent chance Sustained Spring FIP refers to a floodplain area 1 foot or more above the water surface of a 67 percent chance spring flow sustained for at least 7 days, but at a lower elevation than the 50 percent chance water surface. Similarly, 50 percent chance FIP refers to floodplain areas 1 foot or more above the 50 percent chance water surface and below the water surface of the 10 percent chance flow. As described in Appendix A, Section 2.9, the process used to estimate water surface elevations resulted in elevations that varied within 1 foot of true elevations. Figure 3-1 illustrates the relationship between these different water surfaces and the elevation zones corresponding to areas with a different FIP.

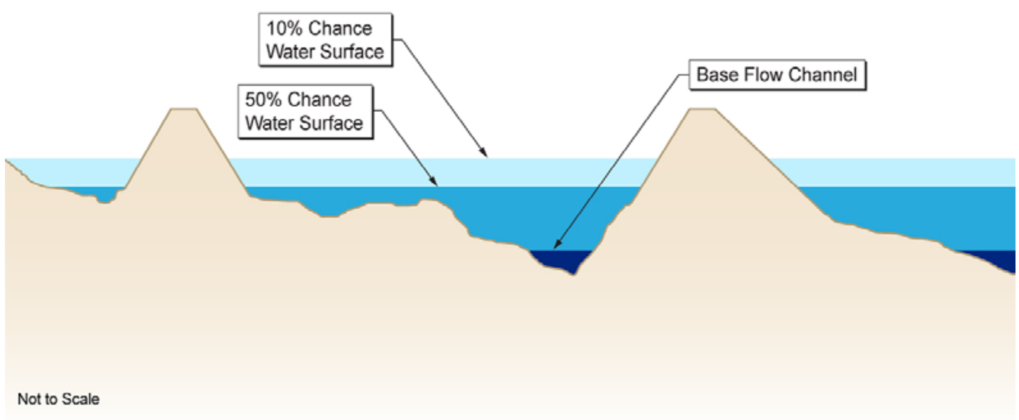

Figure 3-1. Hypothetical Cross Section with Boundary Water Surfaces of FIP Categories

3.1 Sacramento River Reach Descriptions

3.1.1 Woodson Bridge State Recreation Area to Chico Landing

From Woodson Bridge State Recreation Area (SRA) to Chico Landing, the Sacramento River actively meanders through the valley floor along much of this reach. (The majority of the banks along this reach are natural (i.e., without revetment) (DWR, 2011).) The active channel is fairly wide in some stretches and the river splits into multiple forks at many different locations, creating gravel islands, often with riparian vegetation. Historic bends in the river are visible throughout this reach and are remainders of historical channel locations with the riparian corridor and oxbow lakes still present in many locations.

In this reach, the corridor along the river is relatively evenly distributed among areas with 50 percent chance, 10 percent chance, and greater than 10 percent chance FIP. Most areas with 50 percent chance FIP are connected to the river. Only a small percentage of the floodplain has Below Baseflow FIP, and there are almost no areas with 67 percent chance Sustained Spring FIP.

Nearly 25 percent of the corridor along this reach of the Sacramento River has been conserved. Conserved areas include portions of the Sacramento River National Wildlife Refuge, Sacramento River Wildlife Area, Butte Sink Wildlife Management Area, and Bidwell-Sacramento River State Park; the Woodson Bridge SRA; Merrill's Landing Wildlife Area; Westermann, Brattan, Kaplan, and Verschagin preserves; and Bureau of Land Management-managed land.

Natural vegetation covers one-third of the corridor along this reach, and riparian/wetland vegetation approximately an eighth of the corridor. Riparian and wetland-associated sensitive species documented along this reach include Sacramento anthicid beetle (*Anthicus sacramento*), Valley elderberry longhorn beetle (VELB) (*Desmocerus californicus dimorphus*), Swainson's hawk (*Buteo swainsoni*), colonies of bank swallow (*Riparia riparia*), yellow-billed cuckoo (*Coccyzus americanus*), western red bat (*Lasiurus blossevilli*), and western mastiff bat (*Eumops perotis*). This reach also provides habitat for several sensitive fish: foraging adult green sturgeon (*Acipenser medirostris*); migrating, holding, and rearing steelhead and winter- and fall-/late-fall-run Chinook salmon; and migrating and rearing spring-run Chinook salmon.

Developed land uses occupy only a very small portion of the corridor along this reach (less than 2 percent), primarily in the vicinity of Hamilton City.

Other than levees, there is very little major infrastructure along this reach of the Sacramento River except between RM 196 and 197, where State Route (SR) 32, a natural gas pipeline, and an electrical transmission line cross the river.

Along this reach, several nonproject levees (i.e., levees that are not part of the SPFC) protect portions of both banks. This reach does not have project levees.

Stakeholders identified potential restoration opportunities along this reach of the Sacramento River.

3.1.2 Chico Landing to Colusa

From Chico Landing to Colusa, the Sacramento River actively meanders through the valley floor, actively eroding banks, producing oxbows and meander scrolls on the floodplain along much of this reach. (The majority of the banks along this reach are natural (i.e., without revetment) (DWR, 2011).) In this reach, it also historically overflowed into floodbasins. Currently, during flood flows, water from the Sacramento River enters the Butte Basin at the 3Bs natural overflow, the M&T and Goose Lake flood relief structures, and at Moulton and Colusa weirs.

In this reach, more than two-thirds of the corridor along the river has 50 percent chance FIP, and more than half of this area is connected to the river. Only a very small area has 67 percent chance Sustained Spring FIP.

Natural vegetation covers more than one-third of the corridor along this reach, and riparian/wetland vegetation approximately an eighth of the corridor. Riparian and wetland-associated sensitive species documented along this reach include woolly rose-mallow (*Hibiscus lasiocarpus* var. *occidentalis*), several beetles (Antioch Dunes anthicid beetle (*Anthicus antiochensis*), Sacramento anthicid beetle, Sacramento Valley tiger beetle (*Cicindela hirticollis abrupta*), VELB), giant garter snake (*Thamniopsis gigas*), colonies of bank swallow, Swainson's hawk, colonies of tricolored blackbirds (*Agelaius tricolor*), yellow-billed cuckoo, western mastiff bat, and western red bat. This reach also provides habitat for several sensitive fish including foraging adult green sturgeon; migrating, holding, and rearing steelhead and winter- and fall-/late-fall-run Chinook salmon; and migrating and rearing spring-run Chinook salmon.

Nearly 15 percent of the corridor along this reach of the Sacramento River has been conserved. Conserved areas along this reach include portions of the Sacramento River National Wildlife Refuge, Bidwell-Sacramento River State Park, Sacramento River Wildlife Area, and Butte Sink Wildlife

Management Area; the Colusa Bypass Wildlife Area; and the Hartley Island, Jensen, and Cannell preserves.

Developed land uses occupy only a small portion of the corridor along this reach (only about 1 percent), primarily at Colusa. Other than levees, there is little major infrastructure along this reach of the Sacramento River. Natural gas pipelines cross near RMs 184, 174, and 162. SR 162 crosses the river near RM 166, and natural gas pipelines and electrical transmission lines are along the river corridor at several hundred to several thousand feet from the river.

At Ord Ferry on the west bank and 7.5 miles downstream from Ord Ferry on the east bank, SPFC levees border the river downstream along this reach, but are often as far as 1 mile apart. The physical condition of these levees is of medium concern, except for a 10- to 12-mile-long stretch upstream from Colusa where levee physical condition is of higher concern. Upstream from these SPFC levees are several nonproject levees on portions of the reach.

Stakeholders identified potential restoration opportunities along this reach of the Sacramento River.

3.1.3 Colusa to Verona

The general character of the Sacramento River changes downstream from Colusa from a dynamic and active meandering channel to a confined, narrow channel generally restricted from migration along the majority of its length. (DWR, 2011). While levees exist along portions of the river upstream from Colusa, levees are located much closer to the river edge as the river continues south to the Delta. The channel width is fairly uniform and river bends are static as a result of confinement by levees.

From Colusa to Verona, more than half of the corridor along the river has 50 percent chance FIP, but only a small portion of this area remains connected to the river. There also are large areas with Below Base Flow FIP. Most of these areas represent historical floodbasins that are disconnected from the river. Along this reach, about 10 percent of evaluated floodplain has a 67 percent chance Sustained Spring FIP, almost all of which is disconnected from the river.

Natural vegetation covers approximately one-eighth of the corridor along this reach, and riparian/wetland vegetation covers about 3 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include woolly rose-mallow, Sacramento tiger beetle, VELB, giant garter snake, colonies of bank swallows, Swainson’s hawk, colonies of tricolored blackbirds, yellow-billed cuckoo, and western red bat. This reach also provides habitat for several sensitive fish, including Sacramento splittail (*pogonichthys macrolepidotus*), foraging adult green sturgeon; migrating, holding, and rearing steelhead and winter- and fall-/late-fall-run Chinook salmon; and migrating and rearing spring-run Chinook salmon.

Along this reach of the Sacramento River, very little of the land has been conserved (about 1 percent of the corridor). Conserved areas along this reach of the Sacramento River include the Rohleder Preserve, Collins Eddy Wildlife Area, and the Fremont Weir Wildlife Area.

Developed land uses occupy only a small portion of the corridor along this reach (only about 2 percent), primarily in the vicinity of Colusa. However, there is more major infrastructure along this reach of the Sacramento River than along upstream reaches. The Colusa Highway crosses the river between RMs 134 and 133, and SR 113 crosses near RM 90. Natural gas pipelines cross the river near RMs 140, 127, 126; and electrical transmission lines cross the river near RMs 134, 121, 92, 86, and 80. Also, major roads, natural gas pipelines, and electrical transmission lines are located within 1 mile of the river at a number of locations.

There are SPFC levees along both river banks in this reach. The physical condition of these levees is of higher concern, except for several miles of levee east of the river downstream from Colusa.

Stakeholders identified potential restoration opportunities along this reach of the Sacramento River.

3.1.4 Verona to American River

From Verona to the American River, about two-thirds of the corridor along the river has 50 percent chance FIP and about a quarter has 67 percent chance Sustained Spring FIP. Almost all of this floodplain is disconnected from the river.

Natural vegetation covers more than 20 percent of the corridor along this reach, but riparian/wetland vegetation only covers about 3 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include woolly rose-mallow, VELB, giant garter snake, western pond turtle, rookeries of wading birds, colonies of tricolored blackbird, and Swainson’s hawk. This reach also provides habitat for several sensitive fish, including Sacramento splittail, foraging adult green sturgeon; migrating, holding, and rearing steelhead and winter- and fall-/late-fall-run Chinook salmon; and migrating and rearing spring-run Chinook salmon.

Less than 10 percent of the corridor along this reach of the Sacramento River has been conserved. Conserved areas along this reach include Elkhorn Regional County Park, Sacramento Bypass Wildlife Area, several Natomas Basin Conservancy reserves, and Discovery Park at the downstream end of the American River Parkway.

Developed land uses only occupy about 15 percent of the corridor along this reach. However, at the southern end of this reach, where the river enters Sacramento and West Sacramento, developed land uses occupy most of the 2-mile-wide corridor. Along this reach of the Sacramento River, Interstate (I)-5 crosses the river near RM 71 and crosses the American River at its junction with the Sacramento, and I-80 crosses the river near RM 63. Natural gas pipelines cross near RMs 67 and 64, and an electrical transmission line crosses near RM 63. In addition to major infrastructure facilities crossing the river, the Sacramento International Airport is within 2 miles of this reach of the river, and consequently is an important constraint on the restoration of habitat.

There are SPFC levees along both banks. The physical condition of these levees varies from lower concern where sections of the Natomas levees have recently been improved and medium concern for approximately 3.5 miles of the west levee south of the I-5 crossing, to higher concern elsewhere.

Stakeholders identified potential restoration opportunities along this reach of the Sacramento River.

3.1.5 American River to Freeport

From the American River to Freeport, about 20 percent of the corridor along the river has Below Baseflow FIP, nearly 30 percent has 67 percent chance Sustained Spring FIP, and more than 40 percent has 50 percent chance FIP. This FIP distribution reflects the varied landforms along this reach that include historical floodbasins and natural levees along the river channel. Almost all of this floodplain is disconnected from the river. In this tidally influenced reach, the Sacramento River enters the legal Delta.

Natural vegetation covers nearly 20 percent of the corridor along this reach, but riparian/wetland vegetation only covers about 1 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include Sanford’s arrowhead (*Sagittaria sanfordii*), VELB, and Swainson’s hawk. This reach also provides habitat for several sensitive fish, including Sacramento splittail, foraging adult green sturgeon; migrating, holding, and rearing steelhead and winter- and fall-/late-fall-run Chinook salmon; and migrating and rearing spring-run Chinook salmon;

and this reach contains delta smelt (*Hypomesus transpacificus*)-designated critical habitat.

Along this reach of the Sacramento River, only a small amount of land has been conserved (less than 5 percent of the corridor). Conserved areas along this reach are limited to smaller city and county parks and several other public-owned parcels.

Developed land uses occupy nearly two-thirds of the floodplain along this reach. Because this reach of the Sacramento River passes through the city of Sacramento, the corridor along the river has a high density of infrastructure, particularly from RMs 60 to 57. In addition to multiple major road, pipeline, and transmission line crossings, there are a number of Cortese sites (which have hazardous materials issues) and refineries. In addition, Sacramento Executive Airport is within 2 miles of this reach of the river.

There are SPFC levees along both banks of the river. The physical condition of these levees is generally of higher concern, but the physical condition of several sections of the west levee is of lower concern.

Stakeholders identified potential restoration opportunities along this reach of the Sacramento River.

3.1.6 Freeport to Delta Cross Channel

From Freeport to the Delta Cross Channel, approximately 60 percent of the corridor along the river has a Below Baseflow FIP, and of the remainder, most has a 67 percent chance Sustained Spring FIP. This FIP distribution reflects both historical landforms, and historical and ongoing changes to landforms (e.g., subsidence of areas with drained, organic soils). Almost all of this floodplain is isolated from the river. This Delta reach of the Sacramento River is tidally influenced.

Natural vegetation covers nearly 20 percent of the corridor along this reach, and riparian/wetland vegetation covers about 3 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include woolly rose-mallow, Sanford’s arrowhead, several plants characteristic of sloughs and tidal marshes (e.g., Suisun Marsh aster (*Symphyotrichum lentum*), Delta tule pea (*Lathyrus jepsonii*), and Mason’s lilaeopsis (*Lilaeopsis masonii*)) VELB, giant garter snake, western pond turtle (*Emys marmorata*), wading bird rookeries, white-tailed kite (*Elanus leucurus*), and Swainson’s hawk, among others. This reach also provides habitat for several sensitive fish, including Sacramento splittail, delta smelt; foraging adult green sturgeon; migrating, holding, and rearing steelhead and winter- and fall-/late-fall-run Chinook salmon; and migrating and rearing spring-run Chinook salmon.

Less than 10 percent of the corridor along this reach of the Sacramento River has been conserved. Conserved lands include sanitation district and county open space land, Delta Meadows State Park, and a portion of Stone Lakes National Wildlife Refuge.

Along this reach, there are small areas of developed land uses at Cortland and near Walnut Grove, but developed land uses only occupy several percent of the corridor along this reach. Besides levees, there is little major infrastructure along this reach. SR 160 runs along the east bank of the river, and an electrical transmission line crosses the river between RMs 31 and 32.

SPFC levees are along both river banks. In the upstream half of this reach, the physical condition of the levees is generally of higher concern, but in the downstream half of this reach, their physical condition is generally of medium concern.

Stakeholders identified potential restoration opportunities along this reach of the Sacramento River.

3.1.7 Delta Cross Channel to Deep Water Ship Channel

From the Delta Cross Channel to the Deep Water Ship Channel, almost all of the corridor along the river has a Below Baseflow FIP, and is disconnected from the river. This floodplain consists of Delta islands bordered by sloughs, and that have been leveed and drained, and are in agricultural use. Consequently, the organic soils of these islands have been oxidizing and the land surface subsiding. There are only a few hundred acres along this reach with either 67 percent chance Sustained Spring FIP or 50 percent chance FIP, most of which is connected to the river. This Delta reach of the Sacramento River is tidally influenced.

Natural vegetation covers more than 10 percent of the corridor along this reach, but riparian/wetland vegetation only covers about 2 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include woolly rose-mallow, several plants characteristic of sloughs and tidal marshes, Sacramento anthicid beetle, VELB, western pond turtle, Swainson’s hawk, and western red bat. This reach also provides habitat for several sensitive fish: delta smelt; foraging adult green sturgeon; migrating, holding, and rearing steelhead and winter- and fall-/late-fall-run Chinook salmon; and migrating and rearing spring-run Chinook salmon.

Very little of the corridor along this reach of the Sacramento River has been conserved (less than 2 percent of the corridor). Conserved land along this reach is limited to a small area of state land near RM 15.

Along this reach there are small areas of developed land uses at Walnut Grove and Isleton, but developed land uses only account for several percent of the corridor along this reach. SR 160 runs along the river bank, and other major infrastructure includes an electrical transmission line that crosses the river near RM 17, and natural gas pipelines that cross the river near RMs 21, 20, and 15.

SPFC levees are along both river banks. The physical condition of the west levee is of medium concern; the physical condition of the west levee is of medium concern from the Delta Cross Channel to approximately RM 20, and of higher concern from near RM 20 to the junction with the Deep Water Ship Channel.

Stakeholders identified potential restoration opportunities along this reach of the Sacramento River.

3.1.8 Deep Water Ship Channel to Collinsville

From the Deep Water Ship Channel to Collinsville, the corridor along the river consists of Delta islands with a Below Base Flow FIP but disconnected from the river, and an area of uplands downstream from Rio Vista. There are only a few hundred acres along this reach with either 67 percent chance Sustained Spring FIP or 50 percent chance FIP, most of which is disconnected from the river. This Delta reach of the Sacramento River is strongly tidally influenced.

Natural vegetation covers more than two-thirds of the corridor along this reach, but riparian/wetland vegetation only covers about 1 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include woolly rose-mallow, several plants characteristic of sloughs and tidal marshes, Antioch Dunes and Sacramento anthicid beetles, VELB, giant garter snake, Swainson’s hawk, and western red bat. This reach also provides habitat for several sensitive fish, including delta smelt; foraging adult green sturgeon; migrating, holding, and rearing steelhead and winter- and fall-/late-fall-run Chinook salmon; and migrating and rearing spring-run Chinook salmon.

Approximately 5 percent of the corridor along this reach of the Sacramento River has been conserved. Conserved areas along this reach include Brannan Island SRA, Decker Island Wildlife Area, and Lower Sherman Island Wildlife Area.

A small portion of this reach has developed land uses at Rio Vista. In addition to levees, this reach has a high density of other major infrastructure. At Rio Vista, SR 12 crosses the river, as do two natural gas pipelines, and the Rio Vista Municipal Airport is within 1 mile of the river. Also, near the downstream end of this reach, from approximately RMs 7 to 4, nine natural gas pipelines and electrical transmission lines cross the river.

SPFC levees are on the east river bank for the entire length of the reach and on the west bank at RMs 13 to 14 (near Rio Vista). The physical condition of these levees is of higher concern.

Stakeholders did not identify potential restoration opportunities along this reach of the Sacramento River.

3.2 Sacramento River Tributary Reach Descriptions

The lowermost reaches of the Feather, Yuba, Bear, and American rivers were evaluated. These reaches begin approximately 1 mile upstream from the tributary's junction with the Sacramento River because the corridor along the Sacramento River extends 1 mile from the centerline of the Sacramento River.

3.2.1 Feather River – Thermalito Afterbay to Yuba River

Along the Feather River from Thermolito Afterbay to the Yuba River, the floodplain has almost no areas with 67 percent chance Sustained Spring FIP. Areas with 50 percent chance FIP, however, account for more than 40 percent of the corridor along the river, with the remainder evenly divided between 10 percent chance and greater than 10 percent chance FIP. More than two-thirds of areas with 50 percent chance FIP are connected to the river. A series of remnant gravel pit pools/ponds connect to the main channel in this reach. (Connected gravel pits can affect flows and water temperatures, disrupt sediment transport, and provide habitat for nonnative fish that compete with and prey on native species.)

Natural vegetation covers about one-quarter of the corridor along this reach, and riparian/wetland vegetation covers nearly 10 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include VELB, giant garter snake, colonies of bank swallows, western yellow-billed cuckoo, and Swainson's hawk. This reach also provides habitat for several sensitive fish species, including foraging adult green sturgeon; migrating, holding, spawning, and rearing fall-run

Chinook salmon; migrating, holding, and rearing steelhead; and migrating and rearing spring-run Chinook salmon.

More than 10 percent of the corridor along this reach of the Feather River has been conserved. Unlike most other reaches, the majority of conserved area is disconnected from the river. Conserved areas in this reach include the Oroville Wildlife Area and a portion of the Feather River Wildlife Area.

Less than 10 percent of the corridor along this reach has developed land uses, and most of this reach has only small amounts of developed land uses and major infrastructure: three gravel mines are near RMs 58 and 55 to 56, and a low, notched rock dam spans the river near RM 39. However, Yuba City and Marysville are at the downstream end of this reach, and along the river, developed land uses are extensive from about RM 31 to the end of the reach at RM 27. A number of pipelines, roads, and electrical transmission lines cross the river in this area. Also, there is a community airport at Yuba City within 1 mile of the river.

SPFC facilities in this reach include a levee throughout the reach on the west bank, the Sutter-Butte Canal Headgate, a levee extending downstream from Honcutt Creek on the east side of the river, and a ring levee around Marysville. The physical condition of these levees is of higher concern. There are also several nonproject levees.

Stakeholders identified potential restoration opportunities along this reach of the Feather River.

3.2.2 Feather River – Yuba River to Bear River

Between the Yuba and Bear rivers, most of the corridor along the Feather River has 50 percent chance FIP. More than two-thirds of these areas are disconnected from the river. Less than one percent of the corridor along this reach has 67 percent chance Sustained Spring FIP.

Natural vegetation covers nearly one-third of the corridor along this reach, and riparian/wetland vegetation covers approximately 10 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include VELB, giant garter snake, colonies of bank swallows, and Swainson's hawk. This reach also provides habitat for several sensitive fish species, including foraging adult green sturgeon; migrating, holding, and rearing fall-run Chinook salmon; migrating, holding, and rearing steelhead; and migrating and rearing spring-run Chinook salmon.

Nearly 15 percent of the corridor along this reach of the Feather River has been conserved. A portion of the Feather River Wildlife Area is along this reach.

Developed land uses occupy about 10 percent of the corridor along this reach. The Yuba City and Marysville areas extend along the upstream end of this reach (RMs 24 to 27), and developed land uses are extensive in these areas, an electrical transmission line and a natural gas pipeline cross the river, and a power plant is adjacent to the river. Also, both the Yuba City and Yuba County airports are within 2 miles of the river. However, downstream from the Yuba City and Marysville areas, there is little developed land or major infrastructure except for an electrical transmission line that crosses the river near RM 23 and levees that extend along both banks.

SPFC levees are on both sides of the river and are spaced from about 0.5- to 1-mile apart. The physical condition of most of the west levee is of higher concern; the physical condition of the east bank levee is of lower concern.

Stakeholders identified potential restoration opportunities along this reach of the Feather River.

3.2.3 Feather River – Bear River to Sutter Bypass

From the Bear River to the Sutter Bypass, most of the corridor along the Feather River has 50 percent chance FIP. About two-thirds of these areas are disconnected from the river. Less than one percent of the corridor along this reach has 67 percent chance Sustained Spring FIP.

Natural vegetation covers nearly half of the corridor along this reach, and riparian/wetland vegetation covers approximately 10 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include Antioch Dunes and Sacramento anthicid beetles, VELB, giant garter snake, western pond turtle, colonies of bank swallows, western yellow-billed cuckoo, and Swainson’s hawk. This reach also provides habitat for several sensitive fish, including Sacramento splittail, foraging adult green sturgeon; migrating, holding, and rearing fall-run Chinook salmon; migrating, holding, and rearing steelhead; and migrating and rearing spring-run Chinook salmon.

Nearly 15 percent of the corridor along this reach of the Feather River has been conserved. A portion of the Feather River Wildlife Area is along this reach.

This reach has only a small amount of developed land (less than 2 percent of the corridor), primarily near Nicolaus (near RM 10). SR 99 crosses the river near RM 9, and electrical transmission lines cross the river near RMs 9 and 10.

SPFC levees are on both banks along this reach. The physical condition of these levees is of higher concern except for approximately 2 miles of the north levee (from RM 10 to the junction with the Sutter Bypass).

Stakeholders identified potential restoration opportunities along this reach of the Feather River.

3.2.4 Feather River – Sutter Bypass to Sacramento River

Similar to upstream reaches, from the Sutter Bypass to the Sacramento River, most of the corridor along the Feather River has 50 percent chance FIP. However, this reach has more areas with 67 percent chance Sustained Spring FIP than upstream reaches (12 percent versus 1 percent or less). Connectivity of these areas to the river is also greater along upstream reaches. In this reach, the Feather River has a relatively straight channel located along the eastern edge of the floodway.

Natural vegetation covers more than 20 percent of the corridor along this reach, but riparian/wetland vegetation only covers several percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include Sacramento Valley tiger beetle, giant garter snake, colonies of bank swallows and tricolored blackbirds, and Swainson’s hawk. Along this reach of the Feather River, there are no conserved areas. This reach also provides habitat for several sensitive fish, including Sacramento splittail, foraging adult green sturgeon; migrating, holding, and rearing fall-run Chinook salmon; migrating, holding, and rearing steelhead; and migrating and rearing spring-run Chinook salmon.

This reach has only a small amount of developed land (less than 2 percent of the corridor), and no major infrastructure crosses the river, although an electrical transmission line is located near the east riverbank, where the Garden Highway also is located adjacent to the levee.

SPFC levees are on both river banks along this reach. The physical condition of these levees is of higher concern.

Stakeholders did not identify potential restoration opportunities along this reach of the Feather River.

3.2.5 Yuba River

The lower reach of the Yuba River is a relatively narrow floodplain constrained by nearby terraces and other uplands. Consequently, more than half of the corridor along the river has a greater than 10 percent chance FIP. More than 10 percent of the floodplain corridor had 50 percent chance FIP, about half of which is connected to the river. Very little floodplain had 67 percent chance Sustained Spring FIP. South of the river, a portion of the Yuba Goldfields is within the corridor. This extensive disturbed area contains numerous small water features and patches of riparian vegetation.

Natural vegetation covers approximately 60 percent of the corridor along this reach, but riparian/wetland vegetation only covers about 2 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include VELB, western pond turtle, California black rail (*Laterallus jamaicensis coturniculus*), colonies of tricolored black birds, and Swainson’s hawk. This reach also provides habitat for several sensitive fish, including migrating, holding, and rearing steelhead and fall-run Chinook; and migrating and rearing spring-run Chinook.

Approximately 7 percent of the corridor along this reach has been conserved. Conserved areas along this reach of the Yuba River are limited to several Bureau of Land Management-managed parcels (mostly upstream from RM 10) and City of Marysville open space approximately 1 mile upstream from the junction with the Feather River.

Developed land uses occupy less than 10 percent of the corridor along this reach. However, Marysville is at the downstream end of this reach where developed land uses are extensive. Upstream from Marysville, there is little developed land or major infrastructure. From about RM 8 to RM 10 there are two gravel mines and two electrical transmission lines that cross the river, and further upstream is Daguerre Point Dam.

SPFC levees are widely spaced on both sides of the river. There is also a nonproject levee around RMs 6 to 8. The physical condition of segments of these levees varies from lower to higher concern.

Stakeholders identified potential restoration opportunities along this reach of the Yuba River.

3.2.6 Bear River

Along the lowest reach of the Bear River, almost half of the corridor along the river had 67 percent chance Sustained Spring FIP or 50 percent chance FIP. Most of this area (85 percent or more) is disconnected from the river.

Natural vegetation covers nearly one-third of the corridor along this reach, and riparian/wetland vegetation covers several percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include VELB, giant garter snake, western pond turtle, and Swainson's hawk. This reach also provides habitat for migrating, holding, and rearing steelhead; and opportunistic/intermittent migrating, holding, spawning, and rearing for fall-run Chinook salmon.

Only a very small portion of the corridor along this reach of the Bear River has been conserved (approximately 1 percent of the corridor). Conserved areas along this reach are limited to several water district-owned parcels.

Developed land uses occupy less than 5 percent of the corridor along this reach, and are concentrated near Wheatland (near RMs 9 to 11). Major infrastructure includes river crossings by SRs 65 and 70 (near RMs 4 and 10, respectively), and crossings by electrical transmission lines and natural gas pipelines near those major road crossings.

There are SPFC levees on both banks for approximately the first 7 miles of this reach, and the south bank levee continues along Dry Creek. The physical condition of the north levee is of lower concern; the physical condition of the south levee is of higher concern.

Stakeholders did not identify potential restoration opportunities along this reach of the Bear River.

3.2.7 American River

Along the lowest reach of the American River, only about 1 percent of the corridor along the river has 67 percent chance Sustained Spring FIP, and only 14 percent has 50 percent chance FIP. Most of these areas are connected to the river.

Natural vegetation covers more than 20 percent of the corridor along this reach, and riparian/wetland vegetation covers about 8 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include Sanford's arrowhead, VELB, western pond turtle, wading bird rookeries, colonies of bank swallows, white-tailed kite, and Swainson's hawk. This reach also provides habitat for migrating, holding, and rearing steelhead; and migrating, holding, spawning, and rearing fall-run Chinook salmon.

More than 20 percent of the corridor along this reach of the American River has been conserved. This reach has the largest percentage of conserved area among reaches of the Sacramento and San Joaquin river systems. Conserved areas along this reach of the American River include the American River Parkway and associated county parks.

Because this reach passes through the Sacramento Metropolitan Area, developed land uses occupy more than three-quarters of the land along this reach. There also is a high density of major infrastructure along the river, particularly from RMs 0 to 9. Multiple major roads and railroads, natural gas pipelines, and electrical transmission lines cross the river.

SPFC levees are on both sides of the river for the first 10 miles of this reach and extend further along the north side. The physical condition of these levees is of lower concern, except for the section of the north levee between the river and the Natomas Basin, whose physical condition is of higher concern.

Stakeholders did not identify potential restoration opportunities along this reach of the American River.

3.3 Sutter and Yolo Bypass Descriptions

3.3.1 Sutter Bypass

The Sutter Bypass is a wide flood channel that carries floodwater diverted from the Sacramento River at several weirs north of the Sutter Buttes to the confluence of the Feather and Sacramento rivers, and then on to the Yolo Bypass. From the west, Butte Creek (Butte Slough) enters the bypass. It is inundated in most years by water diverted out of the Sacramento River.

The Sutter Bypass is used mainly for agriculture, and there are only small amounts of natural vegetation. Riparian and wetland-associated sensitive species documented along this reach include woolly rose-mallow, giant garter snake, western pond turtle, California black rail, yellow-headed blackbird (*Xanthocephalus xanthocephalus*), colonies of tricolored blackbirds, and Swainson’s hawk. Sutter National Wildlife Refuge extends throughout this reach of the Sutter Bypass. The Sutter Bypass also provides extremely productive inundated floodplain habitat that exports nutrients and food items to the downstream river system (Sommer et al., 2001). Inundated floodplain also provides rearing habitat for steelhead and Chinook salmon, and spawning habitat for Sacramento splittail.

There is no developed land within the Sutter Bypass, and major infrastructure is limited to just several road crossings (most notably SR 113), several interconnected electrical transmission lines, and two major water supply canals, the West Borrow Canal and East Borrow Canal, which are immediately adjacent to the waterside toes of the western and eastern Sutter Bypass levees, respectively.

The Sutter Bypass levees are project levees whose physical condition is generally of higher concern.

Stakeholders identified potential restoration opportunities in the Sutter Bypass.

3.3.2 Yolo Bypass

To the north and east, the Yolo Bypass is bordered by the natural levees of the Sacramento River and its distributary channels, on the west by the alluvial fans of Putah Creek and Cache Creek, and to the south by the tidal sloughs and islands of the Delta. During flood flows, water enters the Yolo Bypass from the Sacramento River from the north, and Cache Creek, Putah Creek, and Willow Slough from the west; and drains south to the northern Delta. During about 70 percent of years, the bypass is inundated one to several times for 0 to 135 days during May through November (DFG, 2008).

Land cover in the Yolo Bypass consists of a mosaic of agricultural and natural vegetation that includes row crops, seasonal wetlands managed as habitat (primarily for waterfowl), permanent wetlands, and uplands. Riparian and wetland-associated sensitive species documented along this reach include giant garter snake, California black rail, and Swainson's hawk. Also, as described for the Sutter Bypass, the Yolo Bypass provides extremely productive inundated floodplain habitat that benefit downstream ecosystems and provide rearing habitat for steelhead and Chinook salmon, and spawning habitat for Sacramento splittail. A substantial portion of the bypass is included in the Yolo Bypass Wildlife Area.

There is no developed land in the Yolo Bypass. Infrastructure in and adjacent to the Yolo Bypass includes levees and several major transportation features. The Sacramento Deep Water Ship Channel is east of the bypass. There are a variety of small interior levees and berms constructed for local agricultural development that prevent the inundation of particular areas from tidal fluctuations and small floods. In addition, causeways and bridge crossings of the bypass include I-80, I-5, portions of the abandoned Sacramento North Railroad, and the Southern Pacific Railroad.

The Yolo Bypass is surrounded completely on the east and partially on the west by SPFC levees. The physical condition of these levees is of higher to medium concern.

Stakeholders identified potential restoration opportunities in the Yolo Bypass.

3.4 San Joaquin River Reach Descriptions

3.4.1 Friant Dam to SR 99

Along this reach, the San Joaquin River is confined by bluffs and between the bluffs by low terraces. Consequently, the corridor along the river predominantly has greater than 10 percent chance FIP. Along the river are the pits of active and abandoned aggregate mines. A number of these pits have been captured by (i.e., become connected to) the river. (These captured pits are of conservation concern because of the potential for fish stranding and predation by warm-water fish.)

Natural vegetation covers nearly half of the corridor along this reach, and riparian/wetland vegetation covers about 8 percent of the corridor. Invasive plant species are abundant in this riparian vegetation (e.g., red sesbania (*Sesbania punicea*), blue gum (*Eucalyptus globulus*), and giant reed (*Arundo donax*)). Riparian and wetland-associated sensitive species documented along this reach include VELB and rookeries of wading birds.

More than 15 percent of the corridor along this reach has been conserved. Conserved areas include the San Joaquin River Ecological Reserve, Camp Pashayan Ecological Preserve, and several county parks and land managed by the San Joaquin River Parkway and Conservation Trust.

Developed land uses occupy nearly 30 percent of the corridor along this reach, and are most extensive south of the river. Because of its proximity to Fresno, this reach has major infrastructure throughout, particularly near SR 99, where natural gas pipelines, electrical transmission lines, and a railroad cross the river. Electrical transmission lines also cross the river near RMs 250 and 254, and SR 41 crosses the river near RM 252. In addition, there are a number of historical and several active gravel mines along this reach. Also, Sierra Sky Park Airport is within 1 mile of the river.

In addition to increasing spring–fall river flows, potential restoration actions identified for this reach by the SJRRP include isolating/eliminating selected gravel pits, modifying side channels, controlling invasive species and fish predators, modifying road crossings, and augmenting spawning gravel.

Stakeholders identified potential restoration opportunities along this reach of the San Joaquin River.

3.4.2 SR 99 to Gravelly Ford

From SR 99 to Gravelly Ford, the San Joaquin River is confined between bluffs. At the downstream end of this reach, the bluffs diminish in height and gradually merge with floodplain surfaces. Despite this change, along this entire reach of river, the evaluated corridor primarily has greater than 10 percent chance FIP.

Natural vegetation covers only about one-eighth of the corridor along this reach, and riparian/wetland vegetation covers several percent of the corridor. Riparian and wetland-associated sensitive species have not been documented along this reach in the CNDDB.

Very little of the corridor along this reach has been conserved (less than 1 percent of the corridor). A county park (Skaggs Bridge Park) is the only conserved area along this reach of the San Joaquin River.

Developed land uses occupy less than 1 percent of the corridor along this reach. Except for a natural gas pipeline that is along the length of this reach and crosses the river twice between RMs 238 and 240, there is no major infrastructure along this reach of the San Joaquin River.

In addition to increasing spring–fall river flows, potential restoration actions identified for this reach by the SJRRP include isolating/eliminating selected gravel pits, controlling invasive plant species, and modifying road crossings. Stakeholders also identified potential restoration opportunities along this reach of the San Joaquin River. Stakeholders did not identify potential restoration opportunities along this reach of the San Joaquin River.

3.4.3 Gravelly Ford to Chowchilla Bypass

From Gravelly Ford to Chowchilla Bypass, the San Joaquin River is sand bedded and meandering. Through lateral migration and avulsion the channel actively moves within the levees. The SJRRP is restoring year-round flow to this reach that, because of diversions, has had only seasonal flow. The FIP of the corridor along this reach varies considerably, with about 40 percent having 67 percent chance Sustained Spring or 50 percent chance FIP. Most of these areas are disconnected from the river.

Natural vegetation covers more than 10 percent of the corridor along this reach, and riparian/wetland vegetation covers approximately 5 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include VELB and Swainson’s hawk. There are no conserved areas along this reach of the San Joaquin River.

Developed land uses occupy much less than 1 percent of the corridor along this reach. There is very little major infrastructure along this reach of the San Joaquin River. A natural gas pipeline is within 1,000 feet of the river at RMs 219 to 220.

SPFC levees are along both river banks. The physical condition of these levees is of higher concern.

Stakeholders identified a potential restoration opportunity along this reach of the San Joaquin River.

3.4.4 Chowchilla Bypass to Mendota Dam

From Chowchilla Bypass to Mendota Dam, FIP varies considerably. However, nearly half of the corridor has 67 percent chance Sustained Spring or 50 percent chance FIP. Most of these areas are disconnected from the river.

The backwater of Mendota Pool occupies the lower few miles of this reach. This backwater is an extensive area of open water bordered by riparian and emergent wetland vegetation. The Mendota Pool is formed by Mendota Dam at the confluence of the San Joaquin River and Fresno Slough. The primary source of water to the Mendota Pool is conveyed from the Delta through the Delta-Mendota Canal. Most of the Mendota Pool is less than 10 feet deep, with the deepest areas no more than 20 feet deep and averaging about 400 feet wide. Inflows to and outflows from the pool are balanced so that the pool remains at a relatively constant depth. The pool must remain above 14.5 feet at the Mendota Dam gage for users at the southern end of the pool to be able to draw water.

Along this reach of the San Joaquin River, there are almost no conserved lands. However, the Mendota Wildlife Area is along the James Bypass, at the southern end of the Mendota Pool.

Natural vegetation covers nearly 15 percent of the corridor along this reach, and riparian/wetland vegetation covers about 5 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include Sanford’s arrowhead, giant garter snake, western pond turtle, and Swainson’s hawk.

Developed land uses occupy only about 1 percent of the corridor along this reach. Although San Mateo Road crosses the river in this reach and a natural gas pipeline repeatedly crosses the river between RMs 203 and 208, Mendota Dam and the diversions associated with Mendota Dam account for most major infrastructure along this reach. Also, there is a community airport at Mendota within 2 miles of the river.

There are nonproject levees on both banks of this reach. There are no project levees along this reach.

The SJRRP includes constructing a bypass channel around Mendota Pool, and setting back levees to create a floodplain between 500 and 3,700 feet wide. It also identifies modifying the San Mateo Road crossing as a potential restoration action. Stakeholders also identified a potential restoration opportunity along this reach of the San Joaquin River.

3.4.5 Mendota Dam to Sack Dam

Along this reach, regulated flows for water deliveries from the Delta-Mendota Canal are conveyed through the San Joaquin River channel to Sack Dam for diversion to Arroyo Canal.

From Mendota Dam to Sack Dam, about two-thirds of the corridor along the river has 50 percent chance FIP, and most of the remainder (mostly located near Firebaugh) has greater than 10 percent chance FIP. Along this reach, nearly 90 percent of areas with 50 percent chance FIP are disconnected from the river.

Natural vegetation covers about an eighth of the corridor along this reach, and riparian/wetland vegetation covers less than 4 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include giant garter snake, western pond turtle, Swainson’s hawk, and western red bat. There is almost no conserved area along this reach of the San Joaquin River.

Developed land uses occupy about 5 percent of the corridor along this reach, and are extensive in the vicinity of Firebaugh on the west bank. Major infrastructure along this reach includes a crossing by Avenue 7 ½; electrical transmission line crossings near RMs 184, 185, and 195; a natural gas pipeline crossing near RM 192; and a gravel mine near RM 188. There is also a community airport at Firebaugh that is within 1 mile of the river.

For most of its length, this reach is bounded on both sides by man-made structures, including irrigation canals and project and nonproject levees. There are no project levees along this reach. At some locations, lands within the floodway are actively used for agricultural production, and are protected by local or interior levees. During the 2006 flood, a number of these parcels were inundated.

The SJRRP has not planned or identified any restoration actions along this reach other than modification of facilities to improve fish passage, and the previously described Mendota Pool Bypass, which would reconnect to the river at the beginning of this reach. Stakeholders, however, identified a potential restoration opportunity along this reach of the San Joaquin River.

3.4.6 Sack Dam to Sand Slough Control Structure

From Sack Dam to the Sand Slough Control Structure, the geomorphology of the San Joaquin River is transitional from the meandering river channel and associated floodplain of upstream reaches to the numerous sloughs and extensive floodbasins downstream. Many sloughs originate in this and the immediately downstream reach of the San Joaquin River.

This reach normally carries only seepage water from Sack Dam and from adjacent agricultural areas. At its downstream end, any water in the channel flows through Sand Slough and into the Eastside Bypass.

Along this reach, the floodway is only about 300 feet wide. Outside of this floodway, the corridor along the river consists predominantly of areas with 50 percent chance FIP, which are disconnected from the river.

Natural vegetation covers about an eighth of the corridor along this reach, but riparian/wetland vegetation covers less than 2 percent of the corridor. Swainson’s hawk has been documented along this reach. There are no conserved lands along this reach of the San Joaquin River.

The floodplain of this reach is almost entirely in agricultural use. It virtually lacks developed land uses and has relatively little major infrastructure: SR 152 crosses the river at RM 173, an electrical transmission line crosses the river at RM 173, and a natural gas pipeline crosses the river near Sack Dam.

Nonproject levees are close to the river along all of this reach except at the northern end, where there are SPFC levees. The physical condition of these project levees is of higher concern.

The SJRRP includes projects to modify Sack Dam (to improve fish passage) and to screen the intake of the Arroyo Canal. Stakeholders did not identify potential restoration opportunities along this reach of the San Joaquin River.

3.4.7 Sand Slough Control Structure to Mariposa Bypass

In this reach, the channel of the San Joaquin River historically was connected to sloughs and floodbasins. Consequently, more than two-thirds of the corridor along the river has 67 percent chance FIP, and most of the remainder has Below Baseflow FIP. This reach has the largest percentage of 67 percent chance FIP among reaches of the San Joaquin and

Sacramento river systems. About 60 percent of these areas are disconnected from the river.

Natural vegetation covers nearly 15 percent of the corridor along this reach, and riparian/wetland vegetation covers approximately 3 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include Delta button-celery (*Eryngium racemosum*), giant garter snake, northern harrier (*Circus cyaneus*), and Swainson's hawk.

More than 5 percent of the corridor along this reach has been conserved. This conserved land is part of the San Luis National Wildlife Refuge.

This reach virtually lacks developed land uses. Other than the Sand Slough Control Structure and the Mariposa Bypass at the ends of this reach, and several levees, this reach also has almost no major infrastructure. SPFC levees are on both banks at the northern end of this reach, and nonproject levees are at two locations farther upstream. The physical condition of the SPFC levees is of higher concern.

The SJRRP includes increasing conveyance in this reach, potentially with setback levees, modifying road crossings, and modifying the San Slough Control Structure to improve fish passage and the San Joaquin River Headgate to allow improve conveyance.

Stakeholders identified potential restoration opportunities along this reach of the San Joaquin River.

3.4.8 Mariposa Bypass to Bear Creek

From the Mariposa Bypass to Bear Creek, the San Joaquin River was historically connected to sloughs and floodbasins. Approximately 90 percent of the corridor along this reach has 50 percent chance FIP. Most of this area is disconnected from the river.

Natural vegetation covers more than 90 percent of the corridor along this reach, and riparian/wetland vegetation covers nearly 15 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include Delta button-celery, northern harrier, and Swainson's hawk.

More than 70 percent of the corridor along this reach of the San Joaquin River has been conserved. Unlike most reaches, the majority of this conserved land is disconnected from the river. Conserved areas along this reach include a portion of the San Luis National Wildlife Refuge.

This reach virtually lacks developed land uses. There is very little major infrastructure along this reach other than an electrical transmission line that crosses the river at RM 142.

SPFC levees are on both banks along this reach. The physical condition of these levees is of higher concern.

Stakeholders identified potential restoration opportunities along this reach of the San Joaquin River.

3.4.9 Bear Creek to Merced River

From Bear Creek to the Merced River, the San Joaquin River has more sinuosity than in upstream reaches; and oxbow, side channel, and remnant channel landforms are present. About half of the corridor along the river has a 50 percent chance FIP, and most of these areas are connected to the river.

Natural vegetation covers more than 70 percent of the corridor along this reach, and riparian/wetland vegetation covers nearly 10 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include Delta button-celery, western pond turtle, colonies of tricolored blackbirds, northern harrier, Swainson's hawk, western red bat, and pallid bat (*Antrozous pallidus*).

More than 50 percent of this reach of the San Joaquin River has been preserved. Conserved areas along this reach include the North Grasslands Wildlife Area, Great Valley Grasslands State Park, and San Luis National Wildlife Refuge.

Developed land uses occupy only about 2 percent of the corridor along this reach. There is little major infrastructure along this reach: an electrical transmission line is located near the river at RM 116, SR 140 crosses the river near RM 123, and Lander Avenue crosses the river near RM 130.

An SPFC levee is located along the river's east side, and extends for several miles along the west side. The physical condition of the east levee is of medium concern; the physical condition of the west levee is of higher concern.

Stakeholders identified potential restoration opportunities along this reach of the San Joaquin River.

3.4.10 Merced River to Tuolumne River

Between the Merced and Tuolumne rivers, the San Joaquin River is sinuous and in some areas is actively meandering. The corridor along this reach of the San Joaquin River includes abandoned sloughs, channel portions, and oxbow cutoffs. In this reach, more than half of the corridor along the San Joaquin River has a 10 percent chance or greater than a 10 percent chance FIP. A 50 percent chance FIP accounts for almost 40 percent of the corridor, and about half of these areas are disconnected from the river.

Natural vegetation covers more than 30 percent of the corridor along this reach, and riparian/wetland vegetation covers about 6 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include Delta button-celery, VELB, wading bird rookeries, least Bell's vireo (*Vireo bellii pusillus*), colonies of tricolored blackbirds, Swainson's hawk, pallid bat, and western red bat. This reach also provides habitat for Sacramento splittail; and migrating, holding, and rearing, steelhead and fall-run Chinook salmon.

Only a small portion of the corridor along this reach of the San Joaquin River has been conserved (approximately 5 percent of the corridor). However, there are several conserved areas along this reach, including the West Hilmar Wildlife Area, a portion of the San Joaquin National Wildlife Refuge, and several county and regional parks and open space areas.

Developed land uses occupy about 5 percent of the corridor along this reach. However, major infrastructure is widely dispersed along this reach. Electrical transmission lines cross the river near RMs 85, 87, and 101, and pipelines cross the river near RMs 101 and 107. In addition to these crossings, a wastewater treatment facility is on the east bank at RMs 94 and 93, and an aggregate mine is near RM 107.

SPFC levees are along most of the east bank and portions of the west bank, but neither connects to other SPFC levees upstream or downstream from this reach. The physical condition of these levees is of higher concern, except for a west levee at the junction with the Tuolumne River, whose physical condition is of medium concern. There are several nonproject levees in intervening areas.

Stakeholders identified potential restoration opportunities along this reach of the San Joaquin River.

3.4.11 Tuolumne River to Stanislaus River

The San Joaquin River is actively meandering in portions of this reach, and the river corridor includes floodplain with complex topography, including oxbows, swales, and other products of channel migration. Between the

Tuolumne and Stanislaus rivers, nearly half of the corridor along the San Joaquin River has a 50 percent chance FIP, and most of the remainder has either 10 percent chance or greater than a 10 percent chance FIP. Approximately 60 percent of areas with a 50 percent chance FIP are disconnected from the river.

Natural vegetation covers nearly half of the corridor along this reach, and riparian/wetland vegetation covers more than 10 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include VELB, least Bell's vireo, colonies of tricolored blackbirds, Swainson's hawk, riparian woodrat (*Neotoma fuscipes riparia*), and riparian brush rabbit (*Sylvilagus bachmani riparius*). This reach also provides habitat for migrating, holding, and rearing, steelhead and fall-run Chinook salmon.

More than one-third of the corridor along this reach of the San Joaquin River has been conserved. This conserved land is part of the San Joaquin National Wildlife Refuge.

This reach virtually lacks developed land uses. Along this reach, there is little major infrastructure except for levees: between RM 78 and RM 75, Maze Boulevard, and an electrical transmission line cross the river.

There are SPFC levees on portions of both banks and nonproject levees connecting to and/or inside of the SPFC levees. The physical condition of these levees is of higher concern.

Stakeholders identified potential restoration opportunities along this reach of the San Joaquin River.

3.4.12 Stanislaus River to Stockton

The San Joaquin River is actively migrating in portions of this reach, and the corridor along the river includes floodplains with complex topography and oxbow lakes. From the Stanislaus River to Stockton, about 40 percent of the corridor along the San Joaquin River has a 50 percent chance FIP, and most of the remainder is distributed relatively evenly between areas with Below Base Flow, a 67 percent chance Sustained Spring, and a 10 percent chance FIP. About 90 percent of areas with a 67 percent chance Sustained Spring or 50 percent chance FIP are disconnected from the river. In this tidally influenced reach, the San Joaquin River enters the legal Delta.

Natural vegetation covers approximately 10 percent of the corridor along this reach, and riparian/wetland vegetation covers approximately 2 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include Sanford's arrowhead, Delta button-celery, several plants associated with marshes and sloughs (e.g., slough thistle (*Cirsium crassicaule*)), Suisun song sparrow (*Melospiza melodia maxillaris*), colonies of tricolored blackbirds, Swainson's hawk, riparian woodrat, and riparian brush rabbit. This reach also provides habitat for several sensitive fish species, including foraging adult green sturgeon; and migrating, holding, and rearing steelhead and fall-run Chinook salmon; and this reach contains delta smelt designated critical habitat.

Only a very small portion of the corridor along this reach has been conserved (approximately 1 percent of the corridor). The only conserved area along this reach is a small preserve near Vernalis.

Developed land uses are extensive, occupying more than one-quarter of the corridor along this reach. This reach of the San Joaquin River has a high density of major infrastructure that not only includes major road and railroad, natural gas pipeline, and electrical transmission line crossings, but also aggregate mines and refineries. However, there is no major infrastructure between RMs 43 and 46, RMs 47 and 56, and RMs 61 and 65.

Except for an upstream portion of the west bank, there are SPFC levees on both banks along this reach. The physical condition of these levees is predominantly of higher concern, but there are sections on both banks (that total several miles in length) whose physical condition is of medium or lower concern.

Stakeholders identified a potential restoration opportunity along this reach of the San Joaquin River.

3.5 San Joaquin River Tributary Reach Descriptions

The lowermost reach of the Merced, Tuolumne, and Stanislaus rivers were evaluated. These reaches begin approximately 1 mile upstream from the tributary's junction with the Sacramento River because the corridor along the Sacramento River extends 1 mile from the centerline of the Sacramento River.

3.5.1 Merced River

The lowermost reach of the Merced River has a relatively narrow floodplain constrained by uplands of higher elevation. Consequently, almost three-quarters of the corridor along this reach has a greater than 10 percent chance FIP. Only a very small area of floodplain has a 50 percent chance FIP or a 67 percent chance Sustained Spring FIP, most of which is connected to the river.

Natural vegetation covers nearly 10 percent of the corridor along this reach, and riparian/wetland vegetation covers about 2 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include VELB, Swainson's hawk, pallid bat, and western red bat. This reach also provides habitat for migrating, holding, and rearing, steelhead and fall-run Chinook salmon.

Only a very small portion of the corridor along this reach of the Merced River has been conserved (less than 1 percent of the corridor). Conserved areas along this reach are limited to the George J. Hatfield State Recreation Area and a county park.

Developed land uses occupy about 8 percent of the corridor along this reach. Although dispersed throughout the reach, they are more extensive near Livingston at the upstream end of the reach. Major infrastructure along this reach includes a gravel mine near RM 17, and road crossings by Landers Avenue at RM 12 and SR 99 near RM 21. Additionally, a natural gas pipeline, an oil pipeline, and an electrical transmission line cross the river within this reach.

There also are nonproject levees on the south bank of this reach at several locations, but no project levees.

Stakeholders identified potential restoration opportunities along this reach of the Merced River.

3.5.2 Tuolumne River

Similar to the Merced River, the lowermost reach of the Tuolumne River has a relatively narrow floodplain constrained by uplands of higher elevation. Consequently, nearly 90 percent of the corridor along this reach has a greater than 10 percent chance FIP. Only a very small area of floodplain has a 50 percent chance FIP or a 67 percent chance Sustained Spring FIP, about half of which is connected to the river.

Natural vegetation covers nearly an eighth of the corridor along this reach, and riparian/wetland vegetation covers about 2 percent of the corridor. Riparian and wetland-associated sensitive species documented along this reach include VELB, colonies of tricolored blackbirds, and Swainson's hawk. This reach also provides habitat for migrating, holding, and rearing, steelhead and fall-run Chinook salmon.

Only a small portion of this reach of the Tuolumne River has been conserved (nearly 5 percent of the corridor). Conserved areas along this reach include the Tuolumne River and Ceres River Bluff regional parks.

Developed land uses occupy more than one-third of the corridor along this reach. Although located throughout the reach, developed land uses and major infrastructure are most extensive at Modesto (from RMs 10 to 22).

Major infrastructure is concentrated between approximately RM 13 and RM 22. In that stretch there are major road and railroad, electrical transmission line, and natural gas pipeline crossings. The Modesto City-County Airport is also located within 1 mile of the river in this area.

There are several nonproject levees on portions of each bank along this reach, but no project levees.

Stakeholders identified potential restoration opportunities along this reach of the Tuolumne River.

3.5.3 Stanislaus River

Similar to the Merced and Tuolumne rivers, the lowermost reach of the Stanislaus River has a relatively narrow floodplain constrained by uplands of higher elevation. Consequently, more than half of the corridor along this reach has a greater than 10 percent chance FIP, and most of the remainder has a 10 percent chance FIP. Only a very small area of floodplain has a 50 percent chance FIP or a 67 percent chance Sustained Spring FIP, more than two-thirds of which is disconnected from the river.

Natural vegetation covers more than 15 percent of the corridor along this reach, but riparian/wetland vegetation accounts for about half of that land cover. Riparian and wetland-associated sensitive species documented along this reach include VELB, Swainson's hawk, riparian woodrat, and riparian brush rabbit. This reach also provides habitat for migrating, holding, and rearing, steelhead and fall-run Chinook salmon.

Nearly 15 percent of the corridor along this reach of the Stanislaus River has been conserved. Conserved areas along this reach of the Stanislaus River include Caswell State Park and San Joaquin National Wildlife Refuge.

Developed land uses occupy about 9 percent of the corridor along this reach. Although some developed land uses are located throughout the reach, they are extensive at Ripon (RMs 12 to 14). Along this reach, there is little major infrastructure besides project and nonproject levees. Natural gas pipelines cross the river near RM 4 and RM 15.

SPFC levees are on both banks for about the first 10 river miles. The physical condition of these project levees is of higher concern. Nonproject levees extend upstream discontinuously along both sides of the river.

Stakeholders identified potential restoration opportunities along this reach of the Stanislaus River.

3.6 Maps and Tables of Results

This section provides a set of maps (Figures 3-2 through 3-26) and tables (Tables 3-1 through 3-12) for 2-mile-wide corridors along (1) Sacramento River reaches, (2) Sacramento River tributary and bypass reaches, (3) upper San Joaquin River reaches, and (4) lower San Joaquin River reaches. Each set includes maps of FIP, land use/land cover, conserved areas, and major infrastructure. Each set also includes a map of nonurban floodplain areas with a 67 percent chance Sustained Spring or a 50 percent chance FIP classified by their connectivity to the river system and their land use/land cover. (Areas with a 67 percent chance Sustained Spring or a 50 percent chance FIP represent those areas with the greatest potential for providing inundated floodplain habitats.) This map represents different types of restoration opportunities. Each set of tables summarizes information displayed on the maps by reach, including FIP and connectivity, and land cover and conservation status for selected areas.

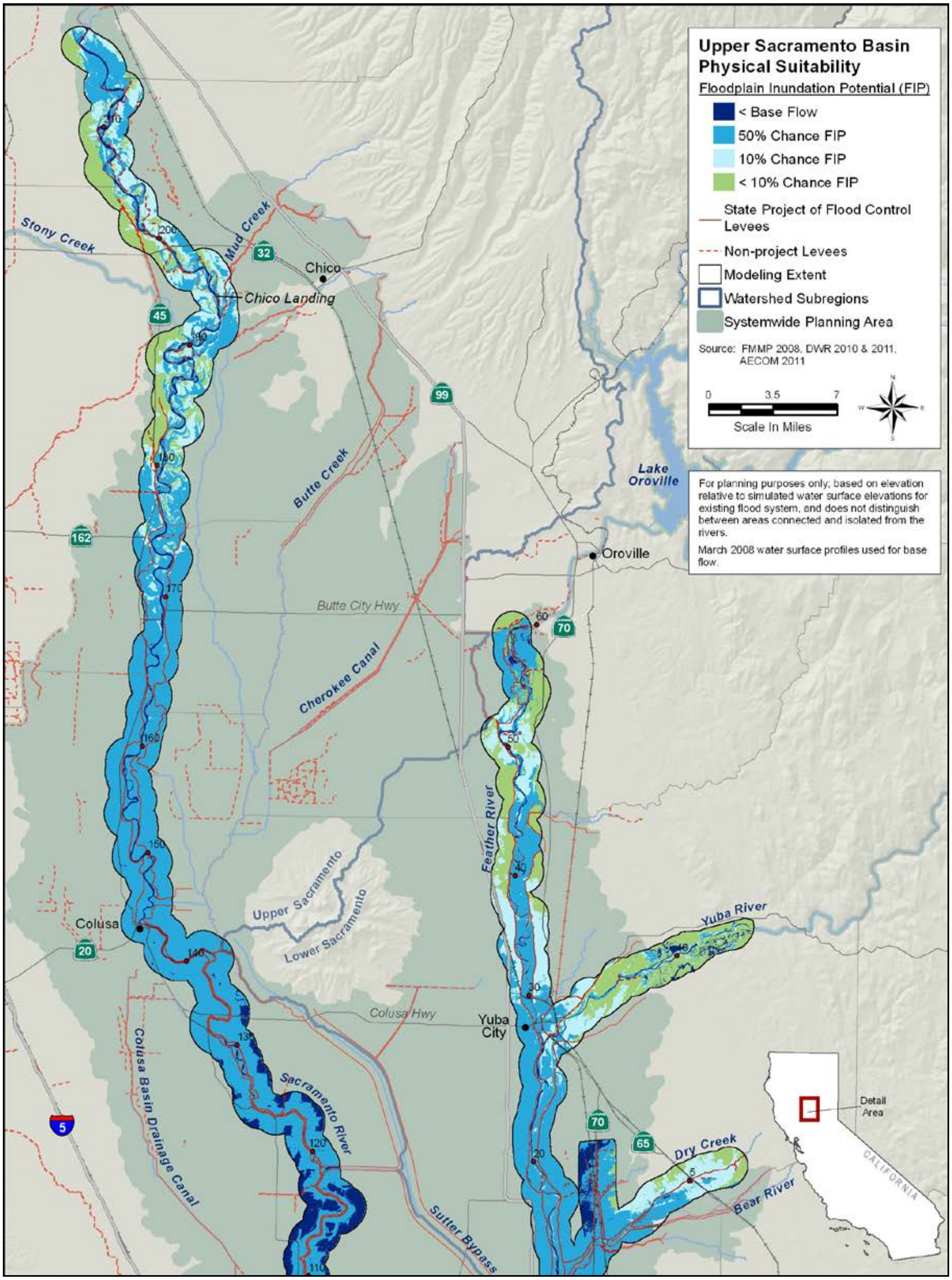

Figure 3-2. Floodplain Inundation Potential of Major River Corridors in the Upper Sacramento Basin

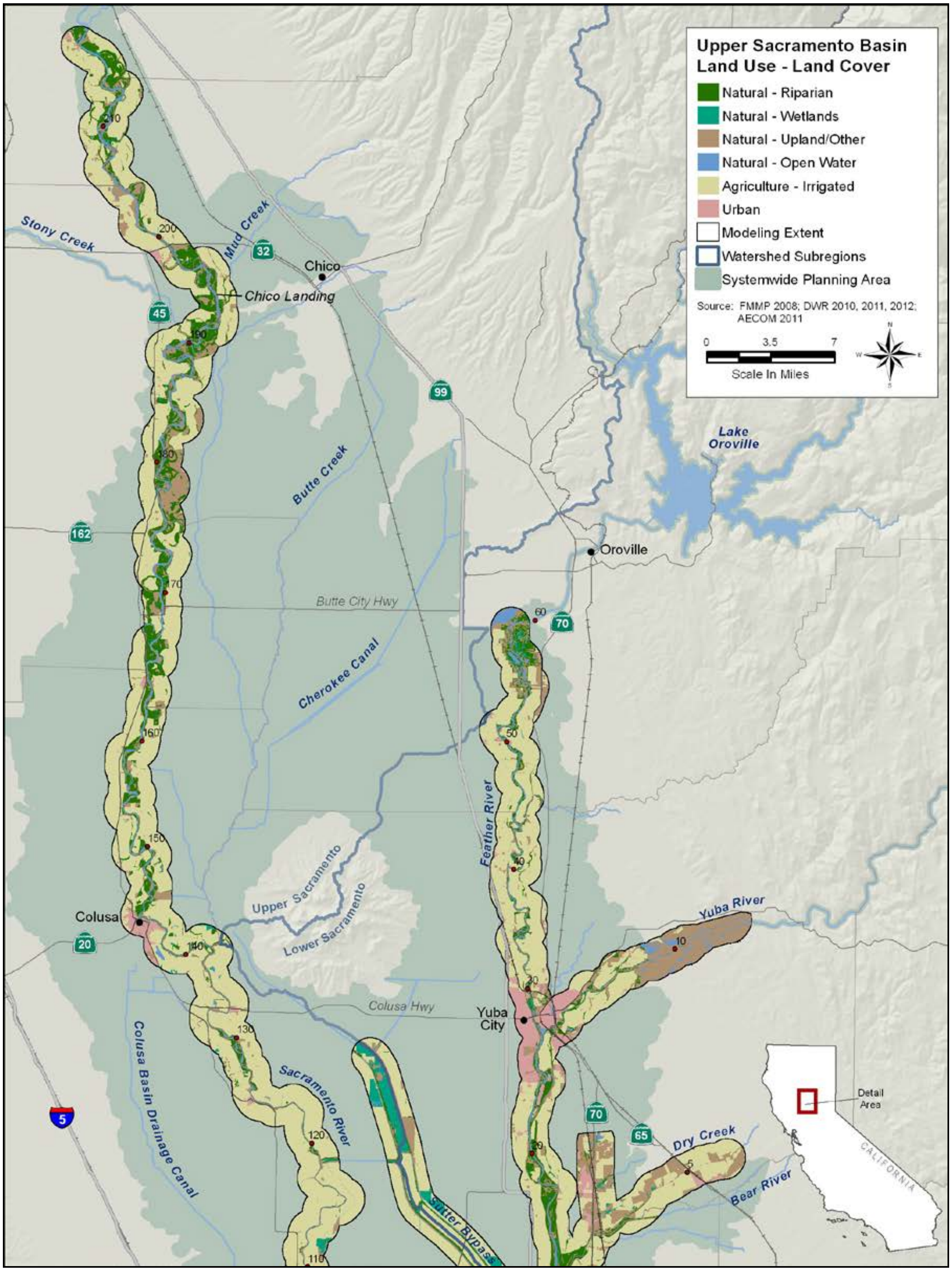

Figure 3-3. Land Use/Land Cover of River Corridors in the Upper Sacramento Basin

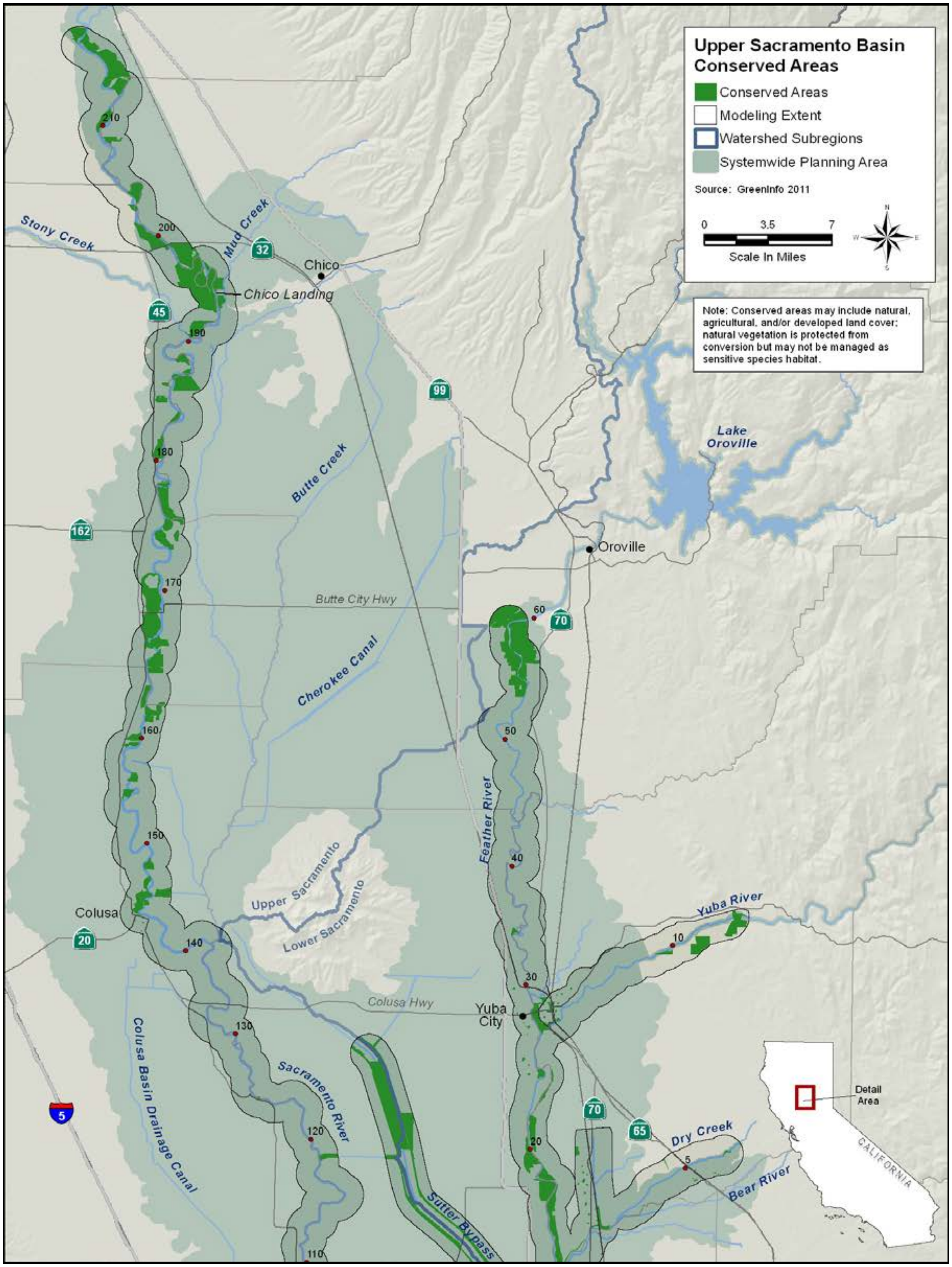

Figure 3-4. Conserved Areas of River Corridors in the Upper Sacramento Basin

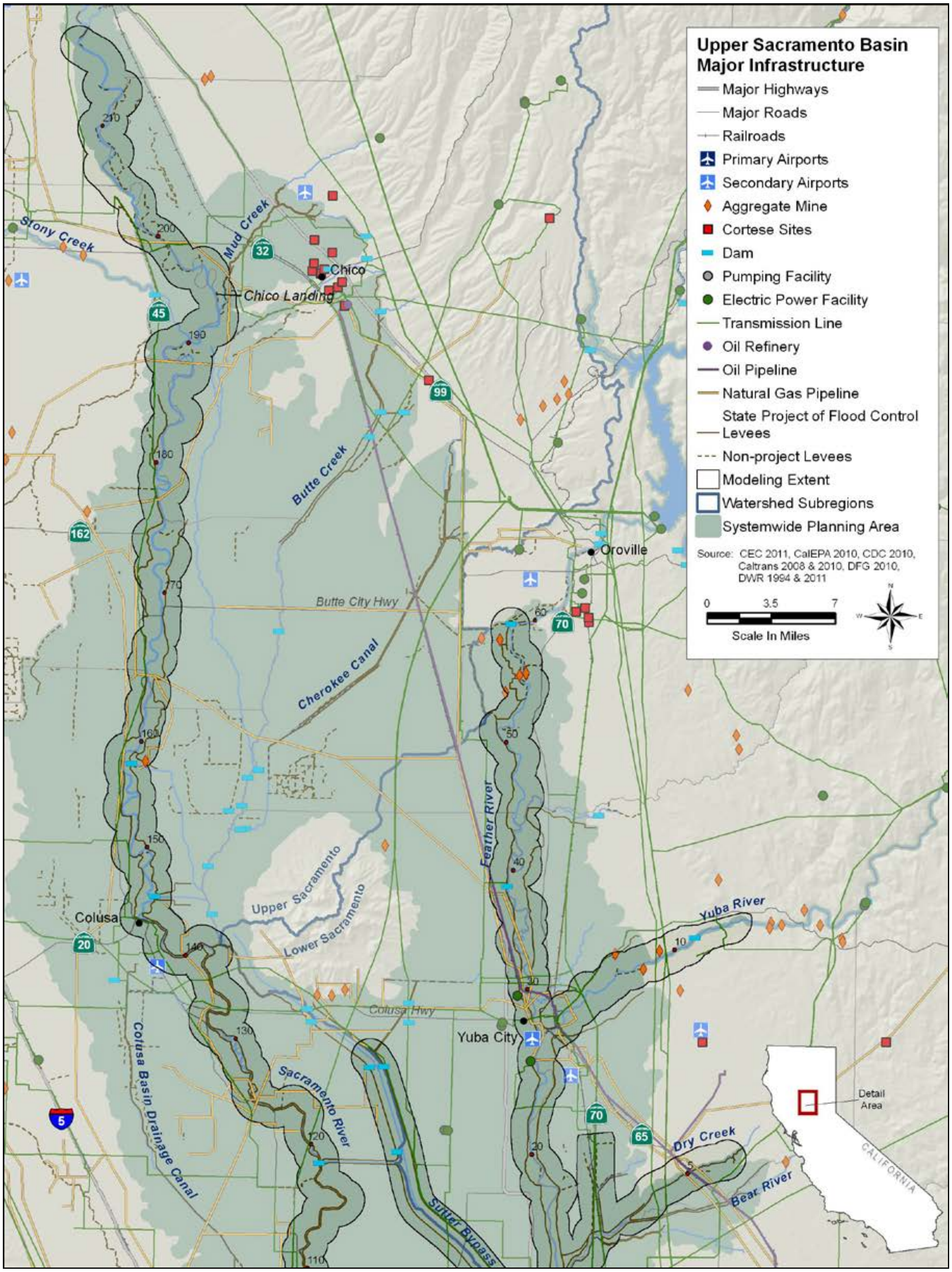

Figure 3-5. Major Infrastructure in River Corridors in the Upper Sacramento Basin

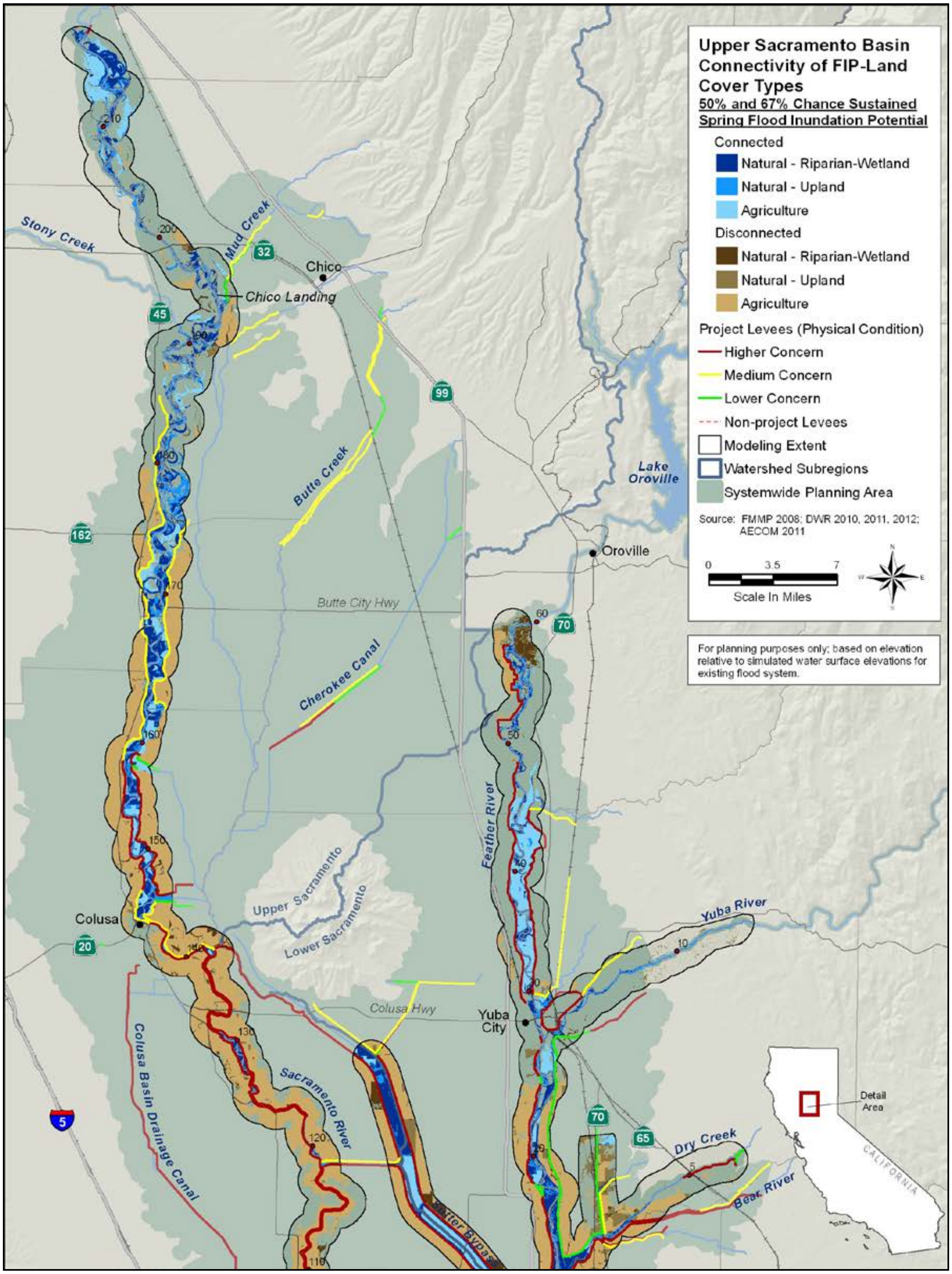

Figure 3-6. Connectivity of FIP-Land Cover Types in the Upper Sacramento Basin

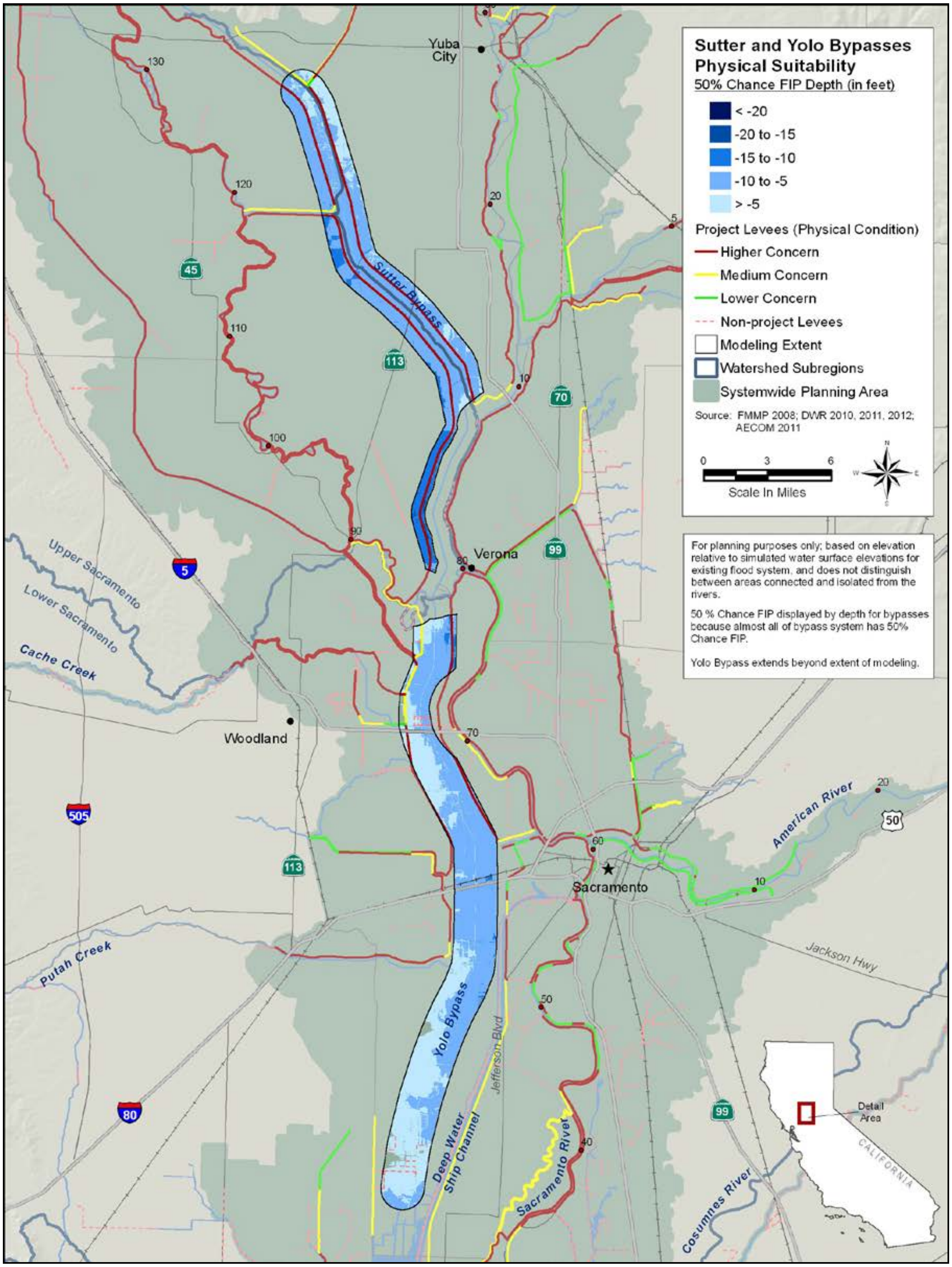

Figure 3-7. Depth of 50 Percent Chance Floodplain Inundation Potential in the Sutter and Yolo Bypasses

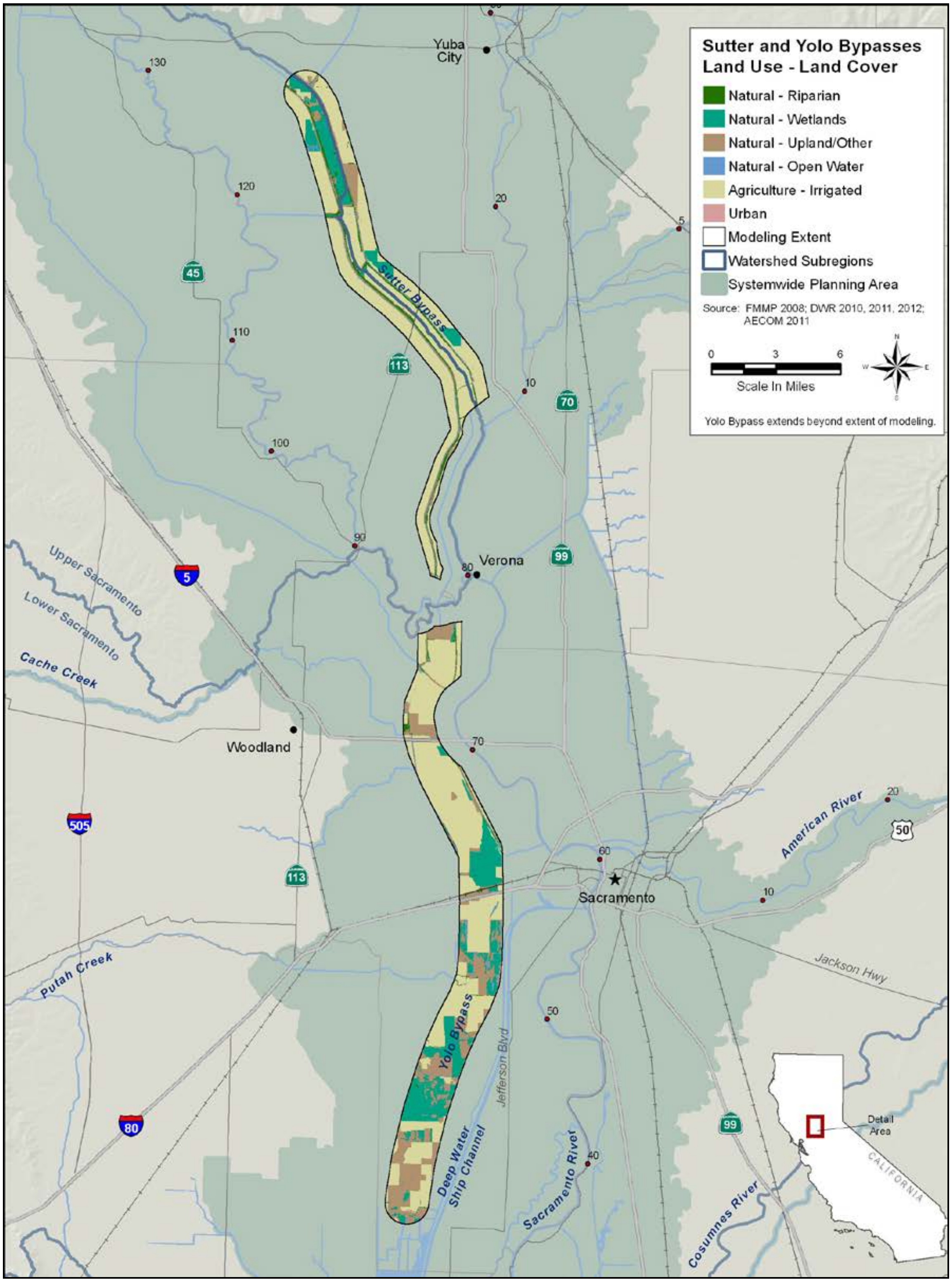

Figure 3-8. Land Use/Land Cover of River Corridors in the Sutter and Yolo Bypasses

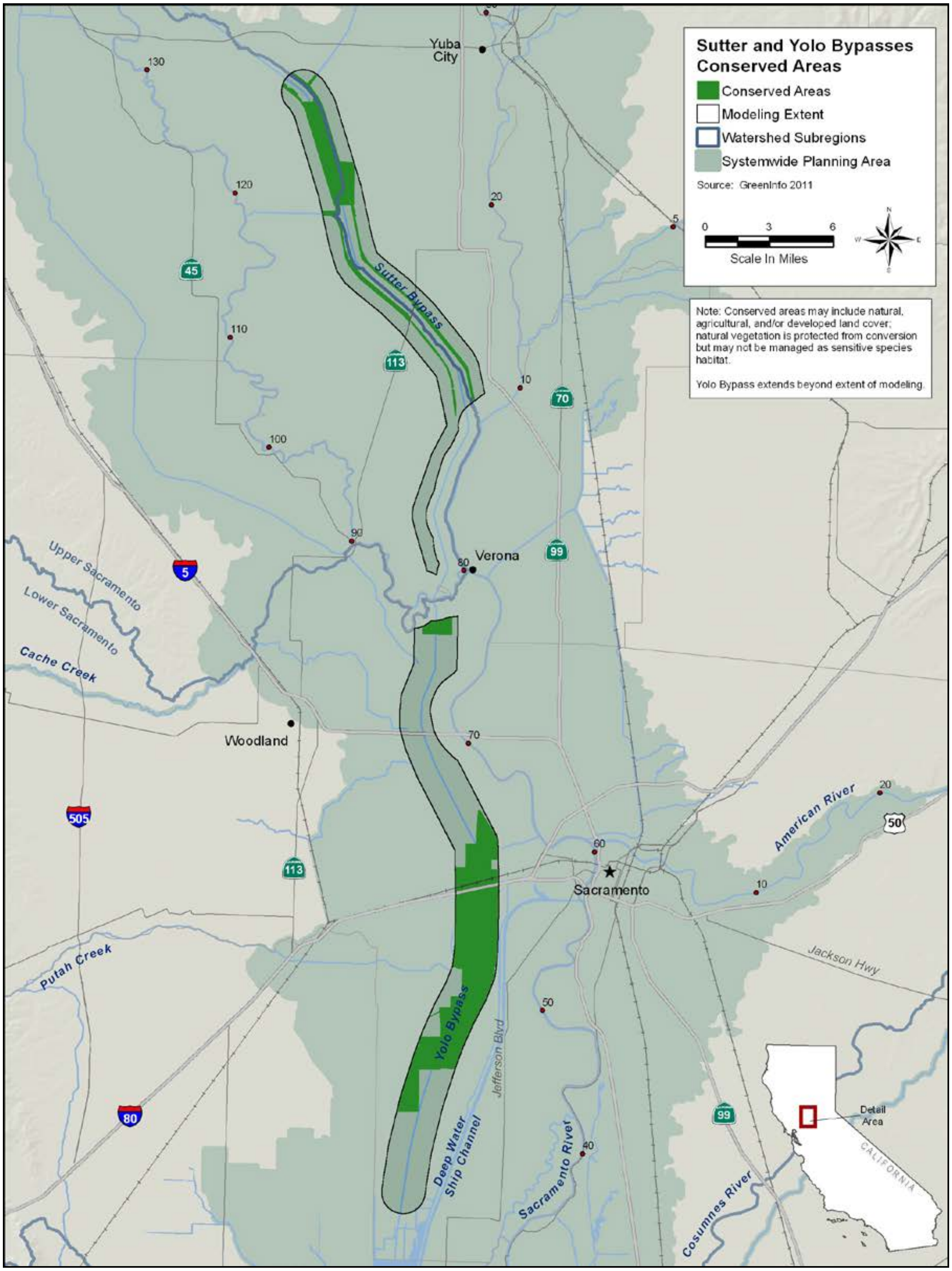

Figure 3-9. Conserved Areas of River Corridors in the Sutter and Yolo Bypasses

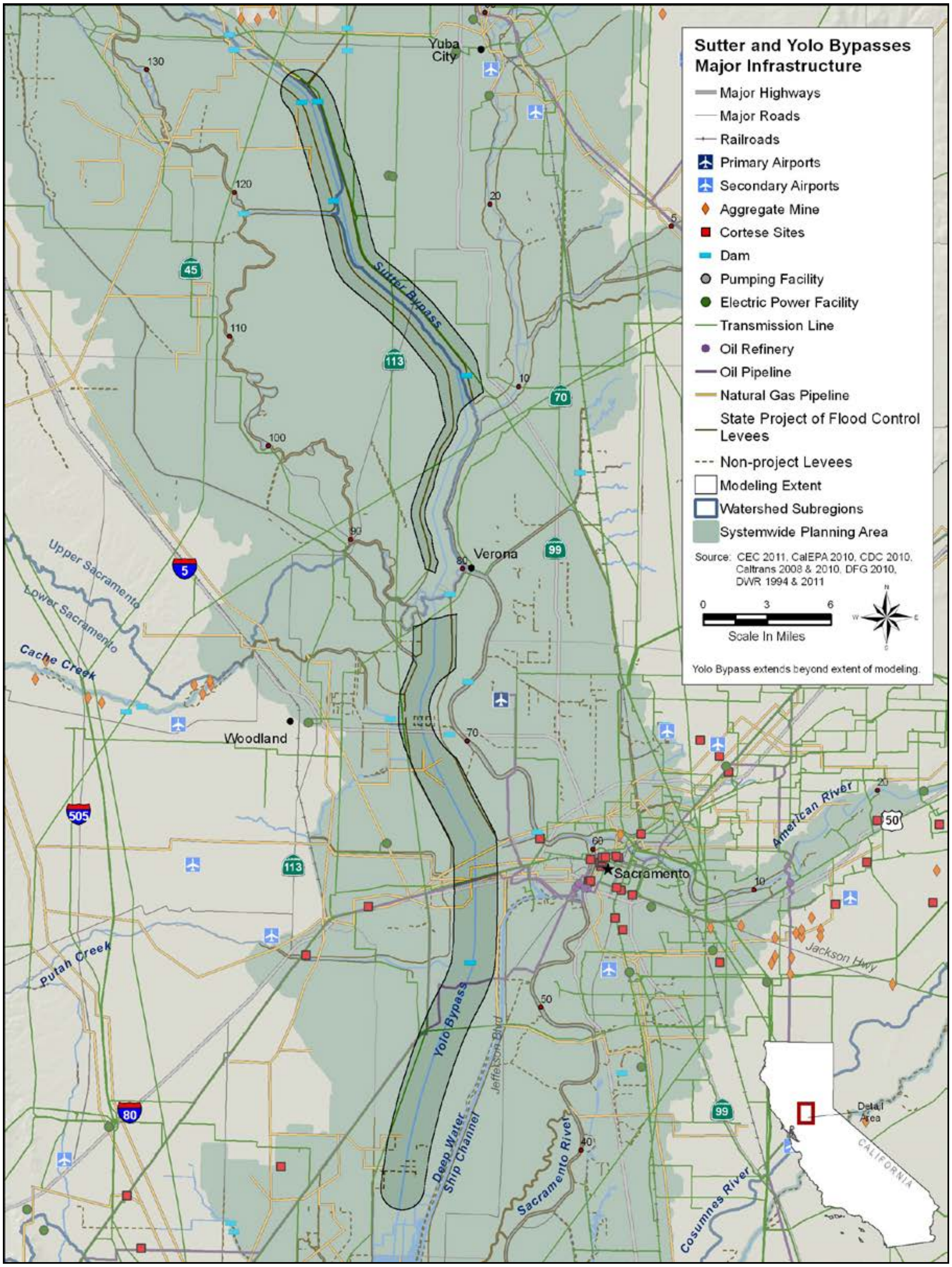

Figure 3-10. Major Infrastructure in River Corridors in the Sutter and Yolo Bypasses

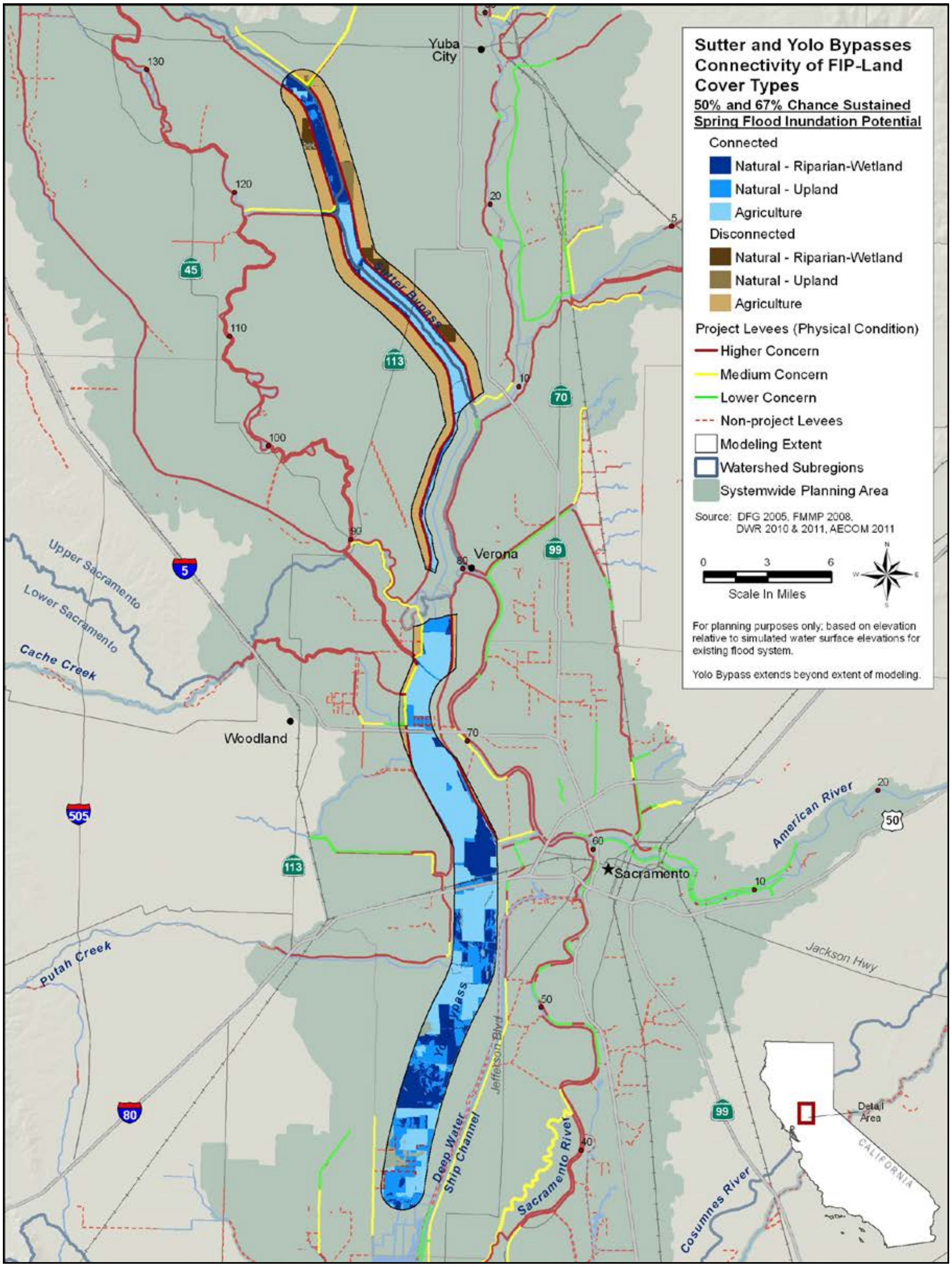

Figure 3-11. Connectivity of FIP-Land Cover Types in the Sutter and Yolo Bypasses

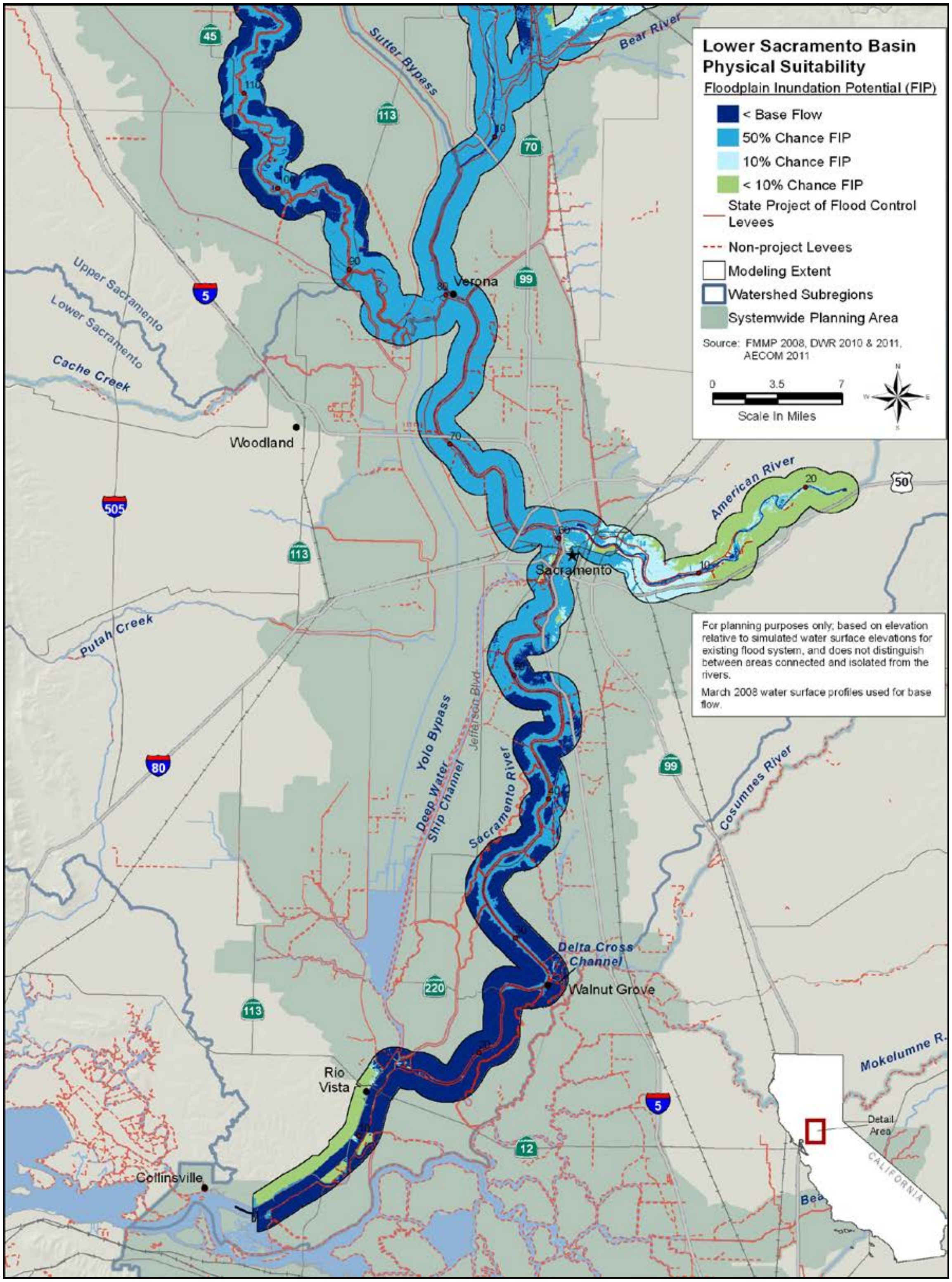

Figure 3-12. Floodplain Inundation Potential of Major River Corridors in the Lower Sacramento Basin

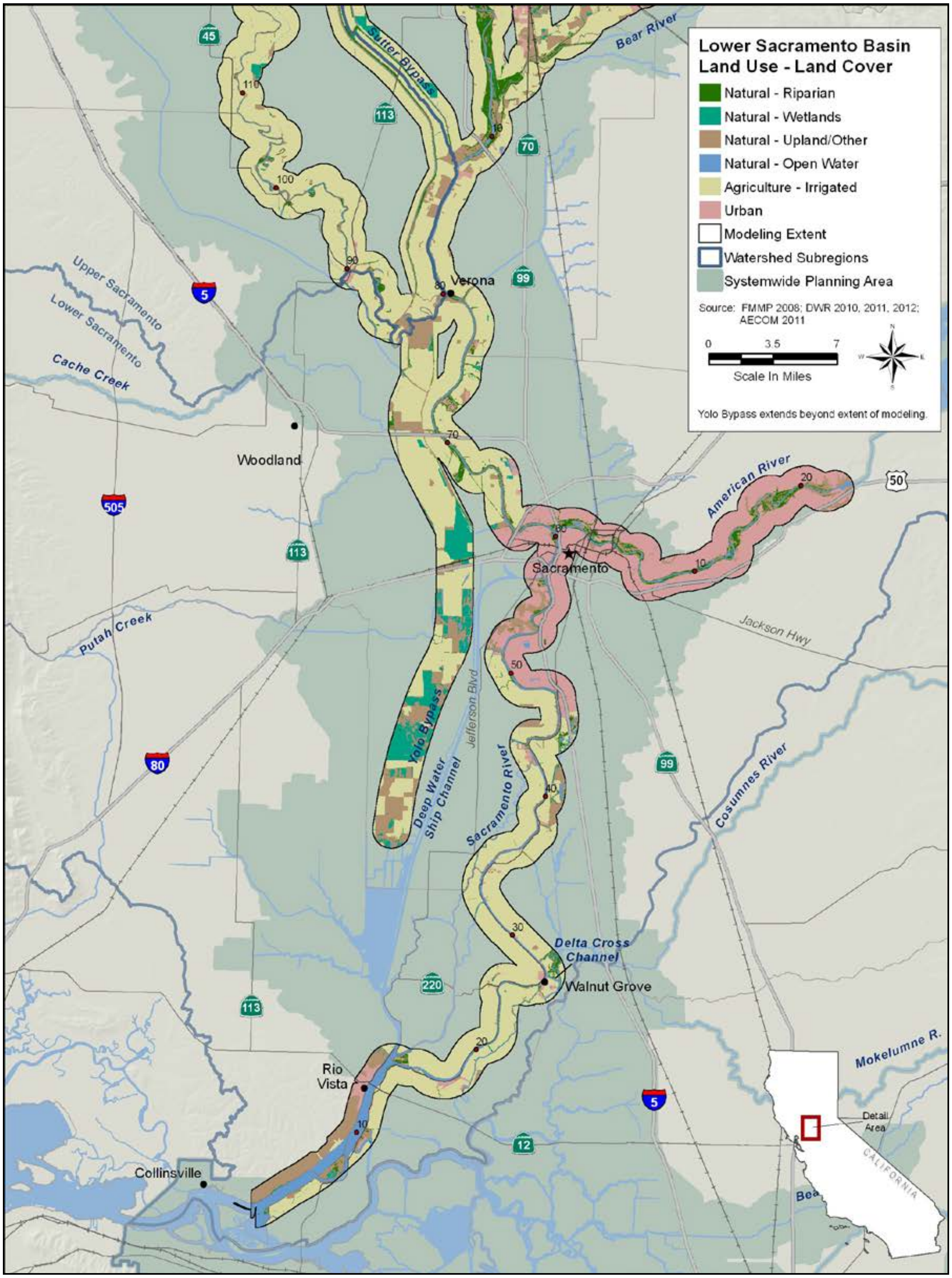

Figure 3-13. Land Use/Land Cover of River Corridors in the Lower Sacramento Basin

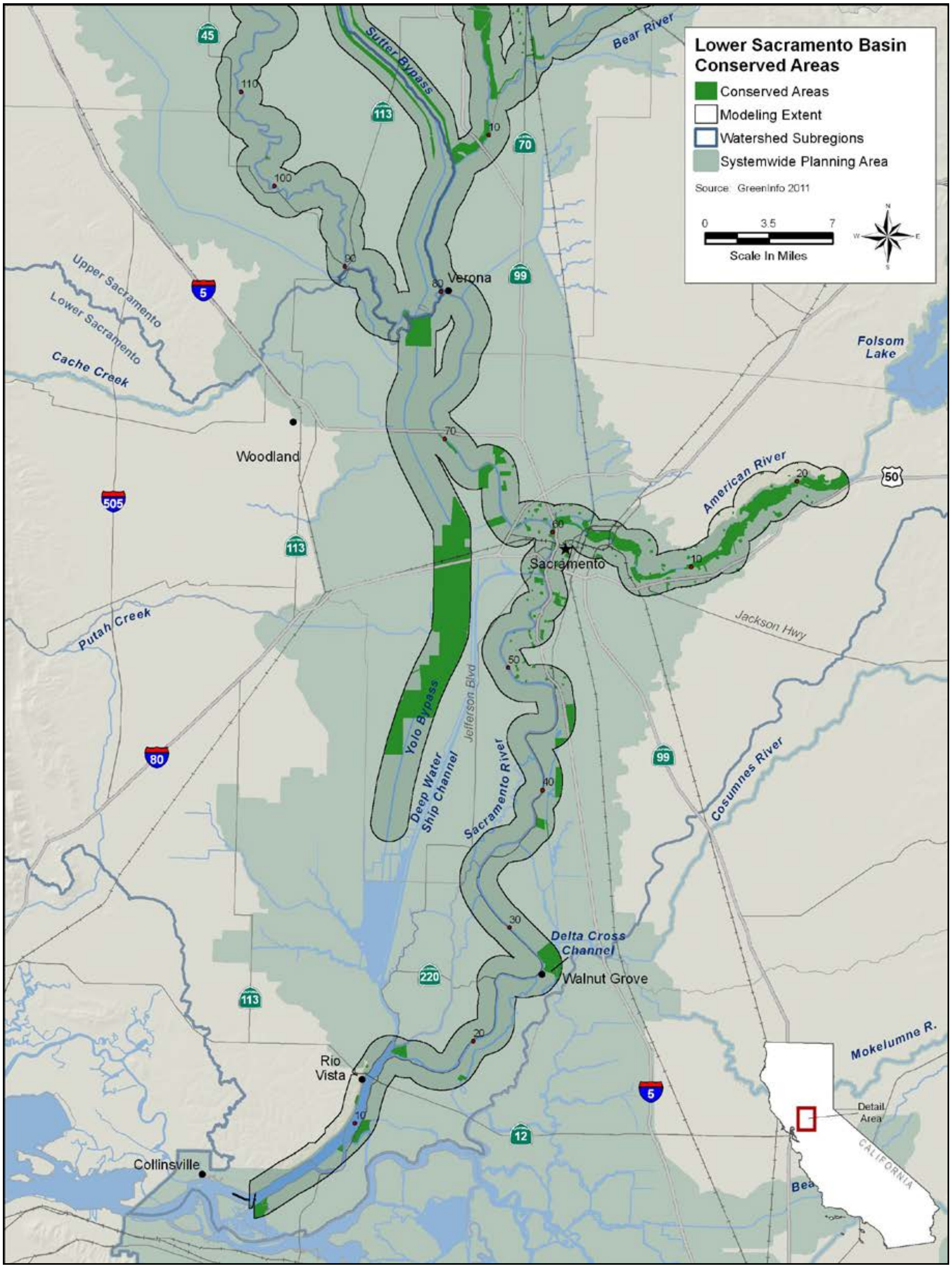

Figure 3-14. Conserved Areas of River Corridors in the Lower Sacramento Basin

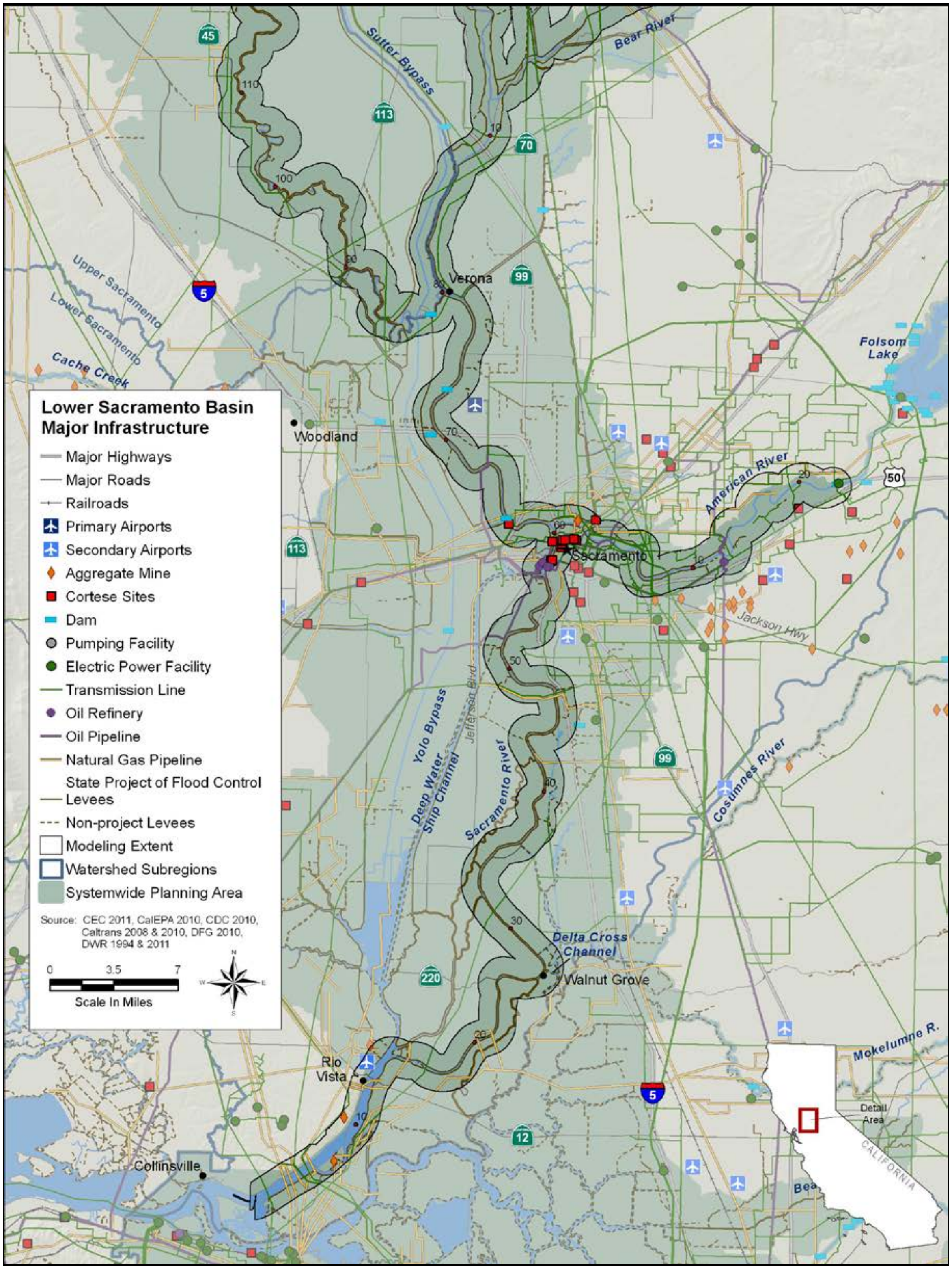

Figure 3-15. Major Infrastructure in River Corridors in the Lower Sacramento Basin

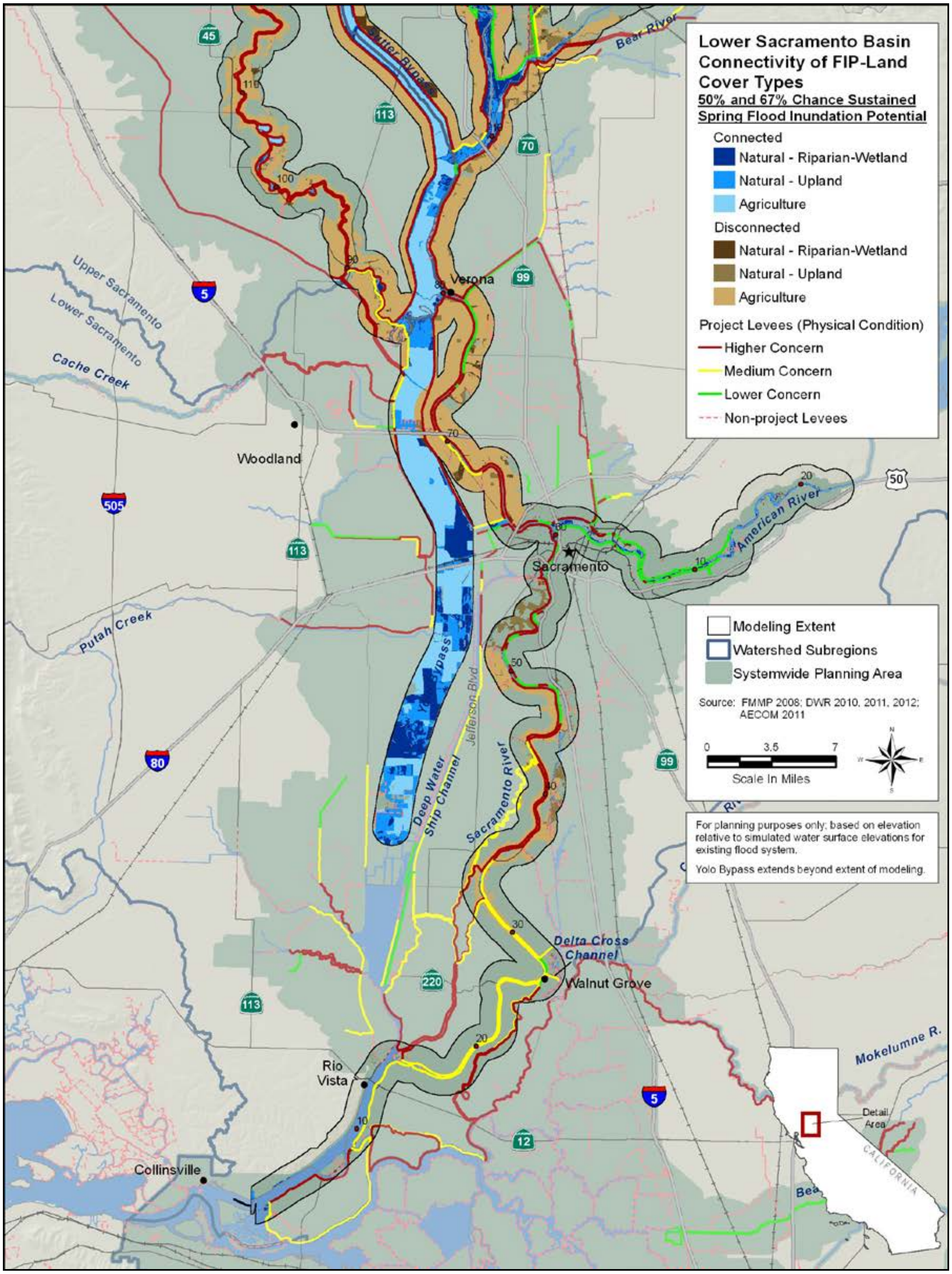

Figure 3-16. Connectivity of FIP-Land Cover Types in Lower Sacramento Basin

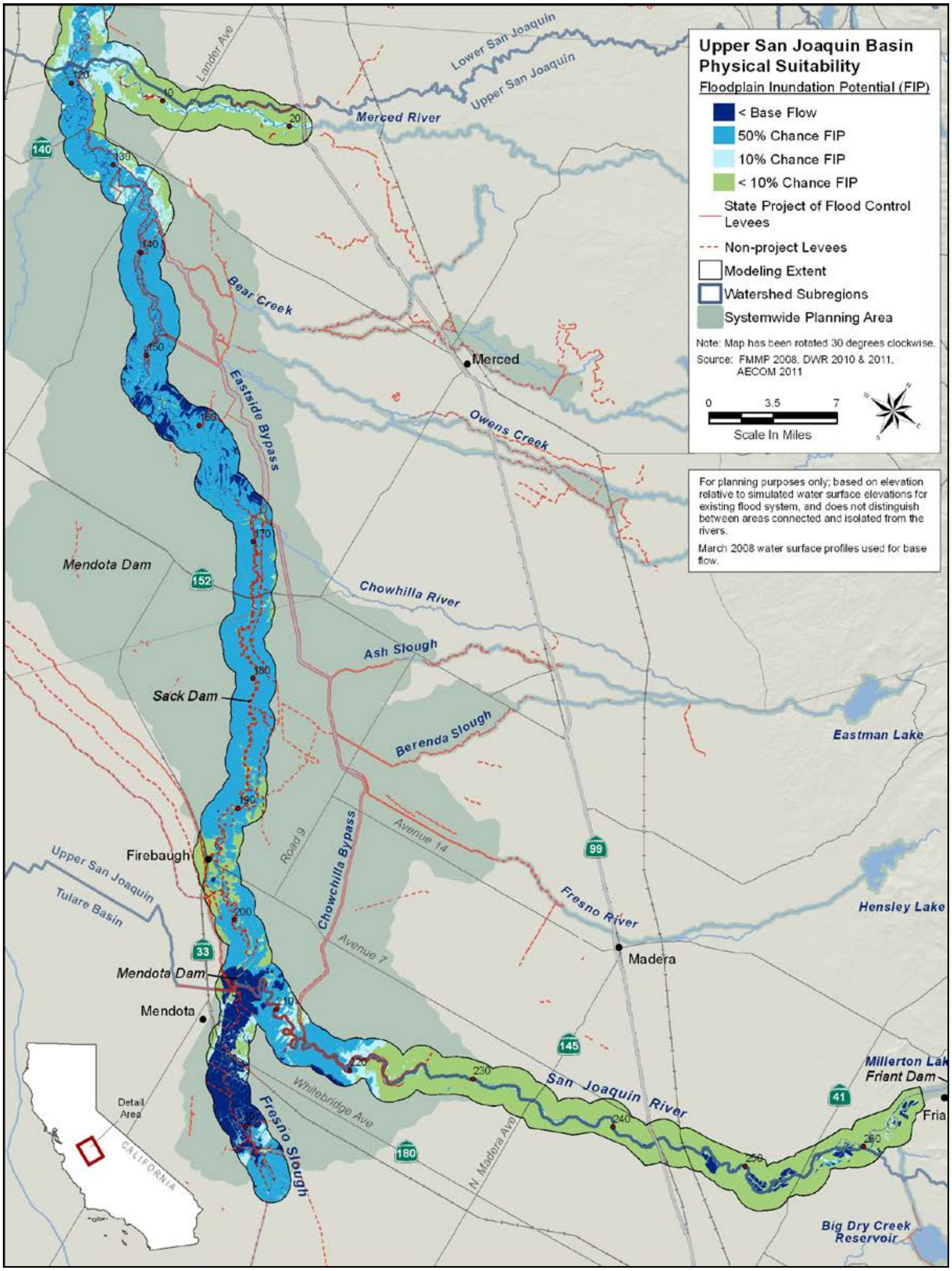

Figure 3-17. Floodplain Inundation Potential of River Corridors in the Upper San Joaquin Basin

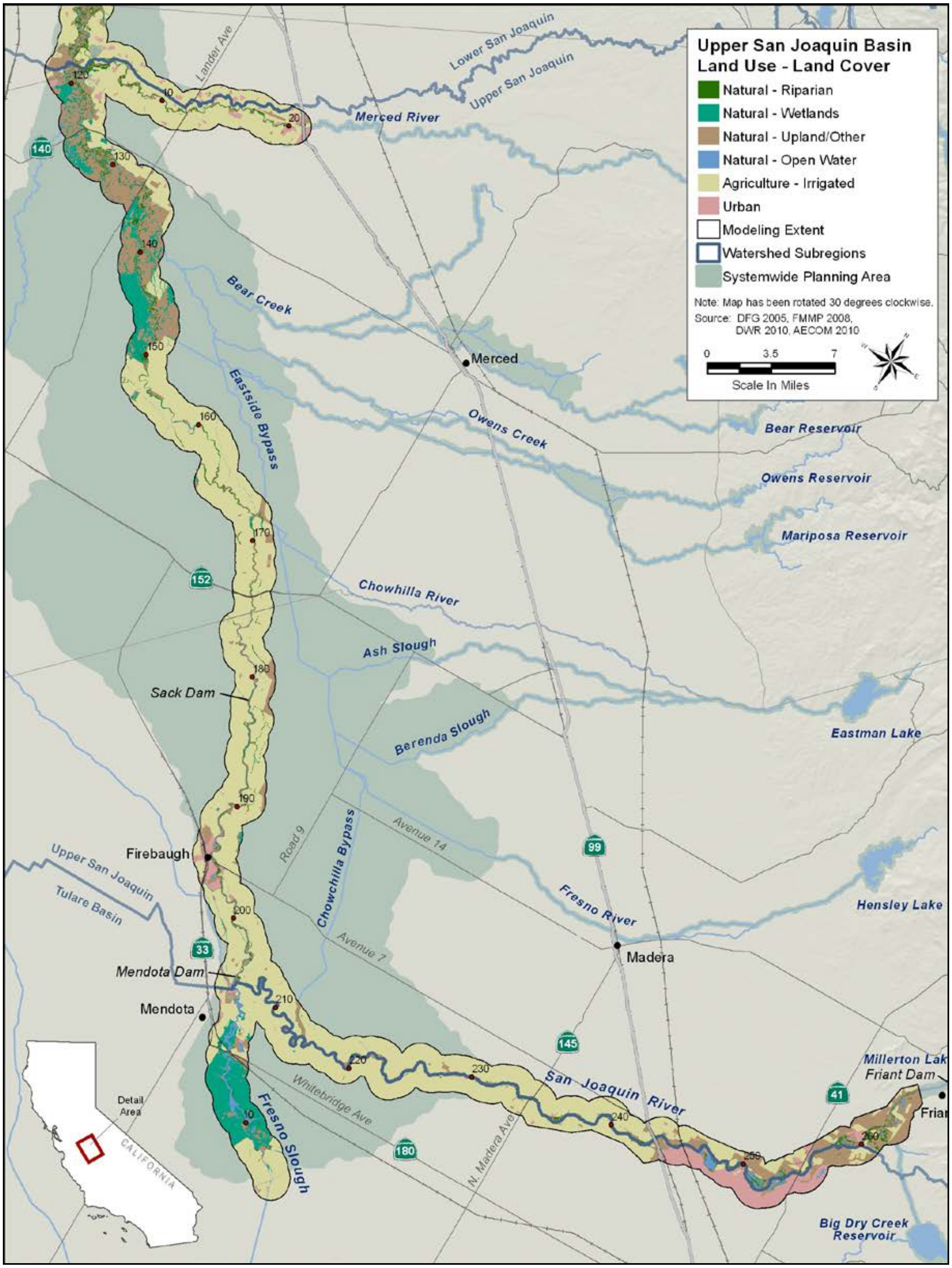

Figure 3-18. Land Use/Land Cover of River Corridors in the Upper San Joaquin Basin

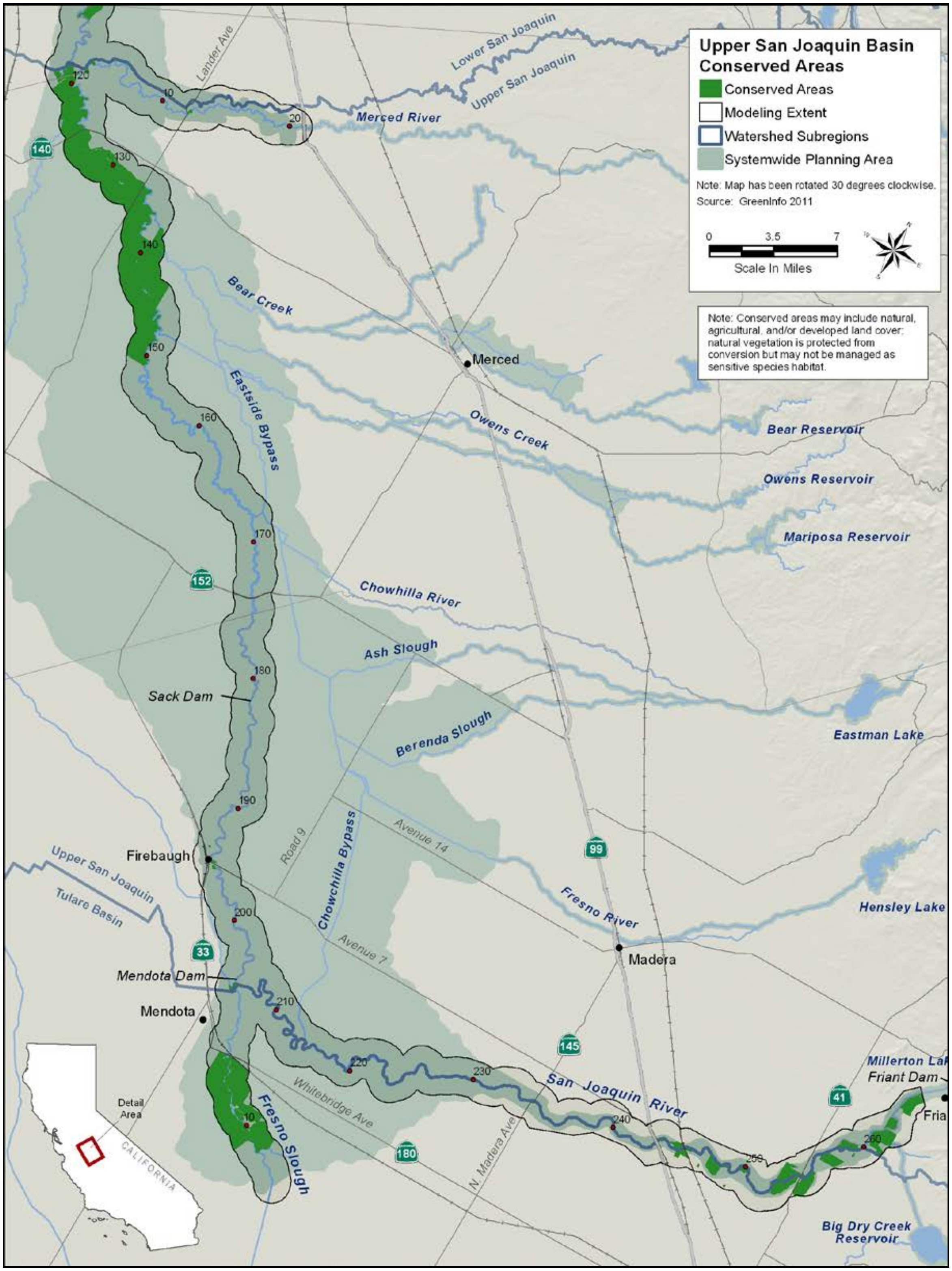

Figure 3-19. Conserved Areas of River Corridors in the Upper San Joaquin River Basin

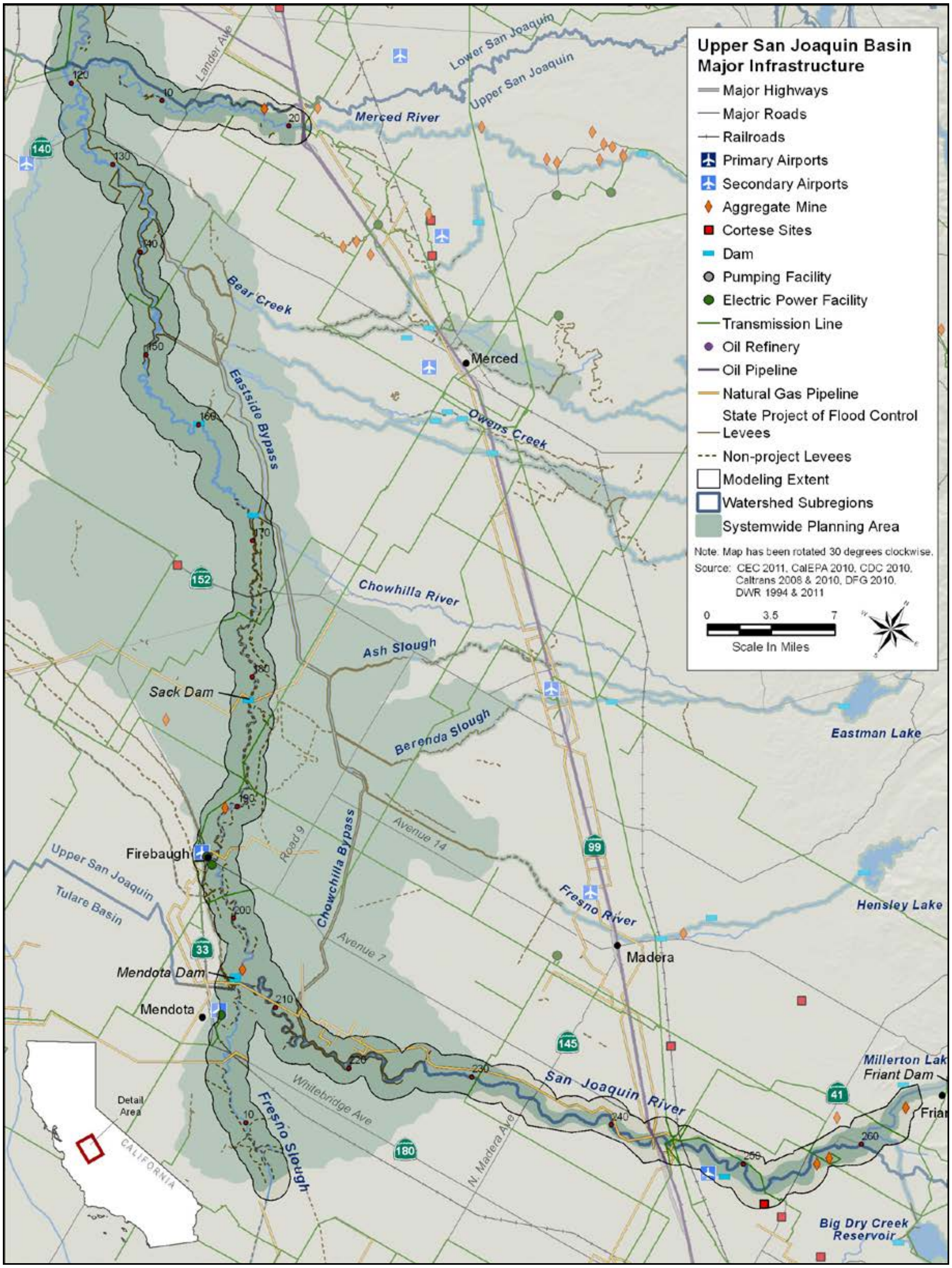

Figure 3-20. Major Infrastructure in River Corridors in the Upper San Joaquin Basin

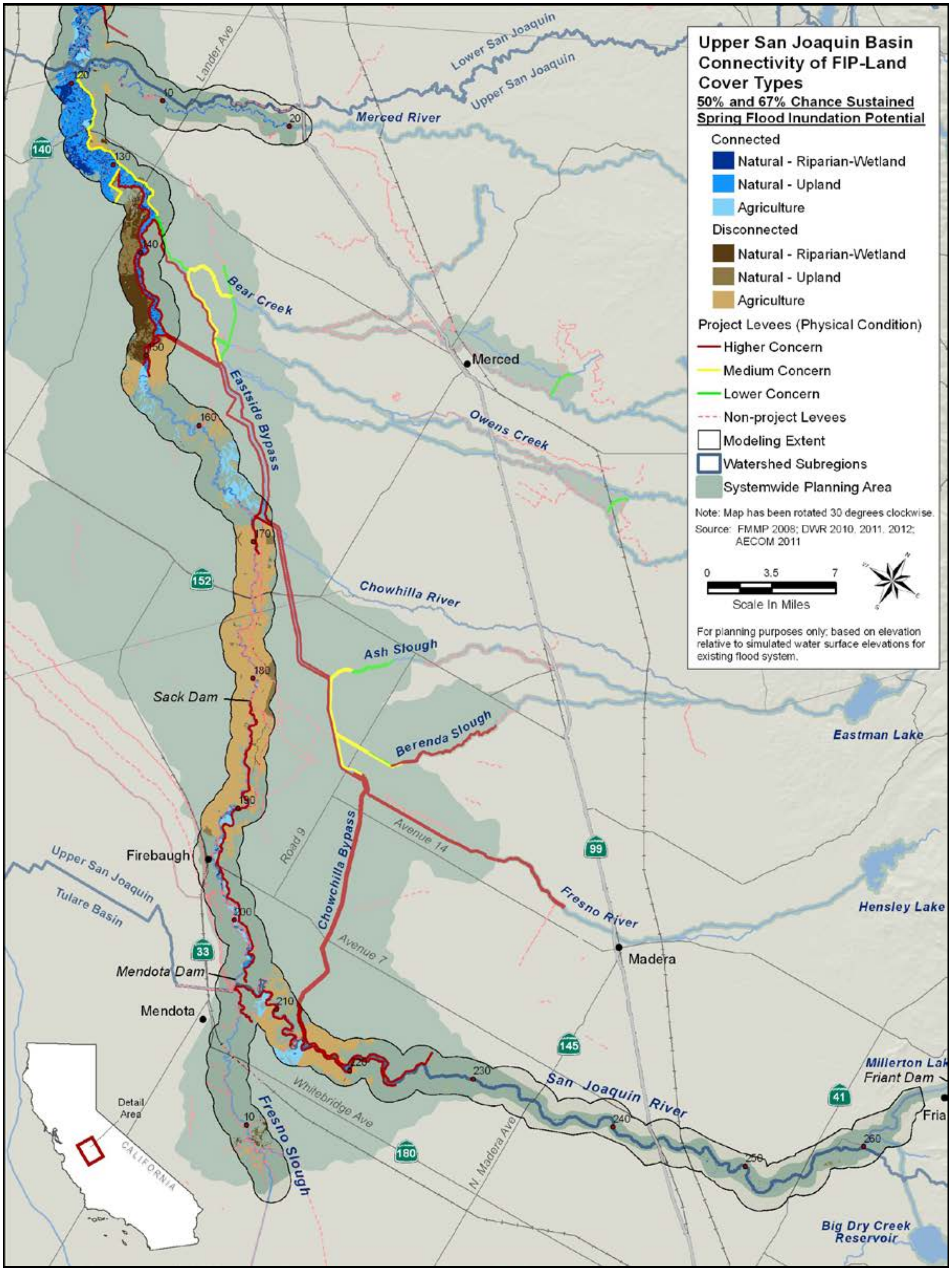

Figure 3-21. Connectivity of FIP-Land Cover Types in the Upper San Joaquin Basin

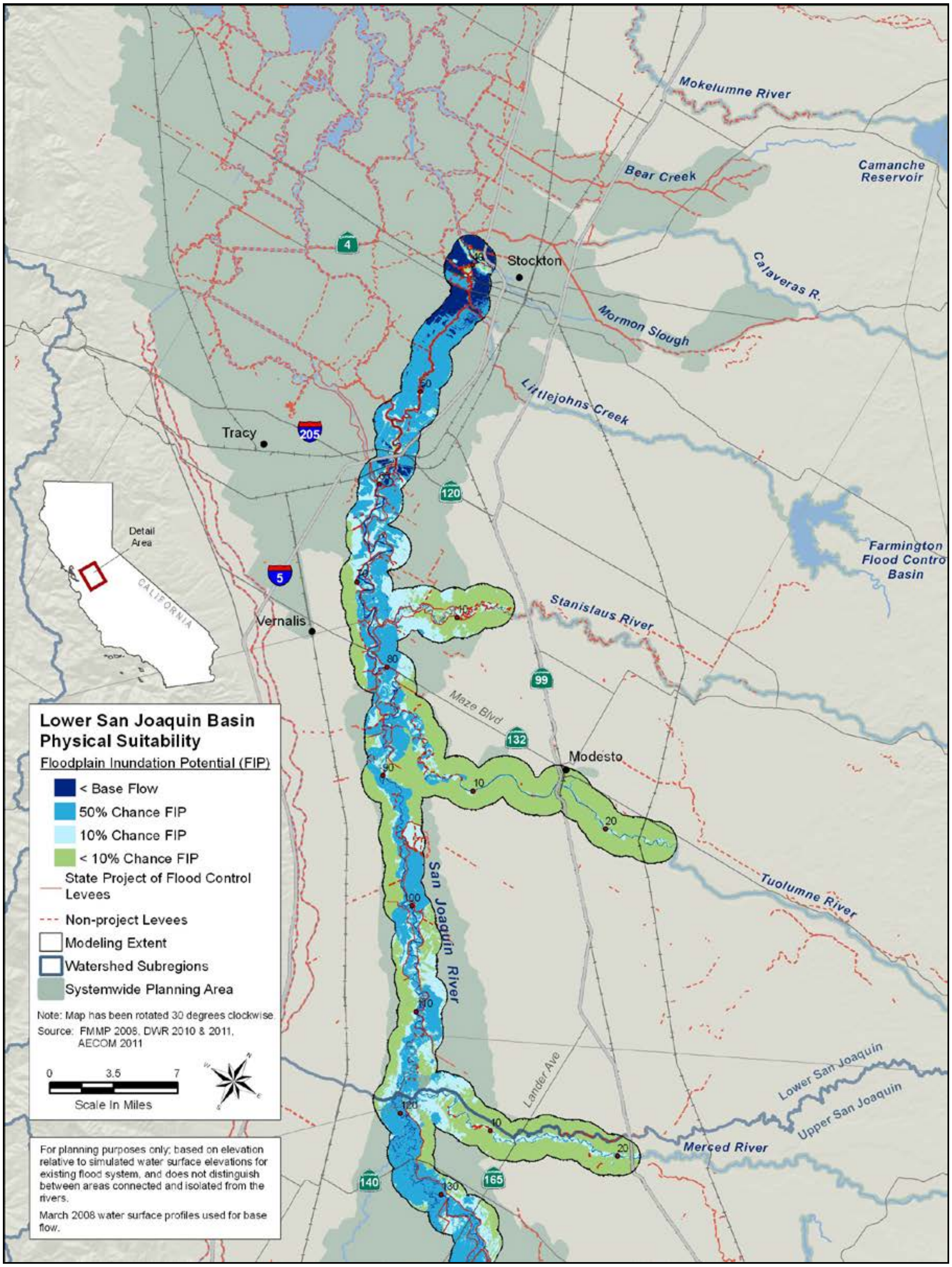

Figure 3-22. Floodplain Inundation Potential of River Corridors in the Lower San Joaquin Basin

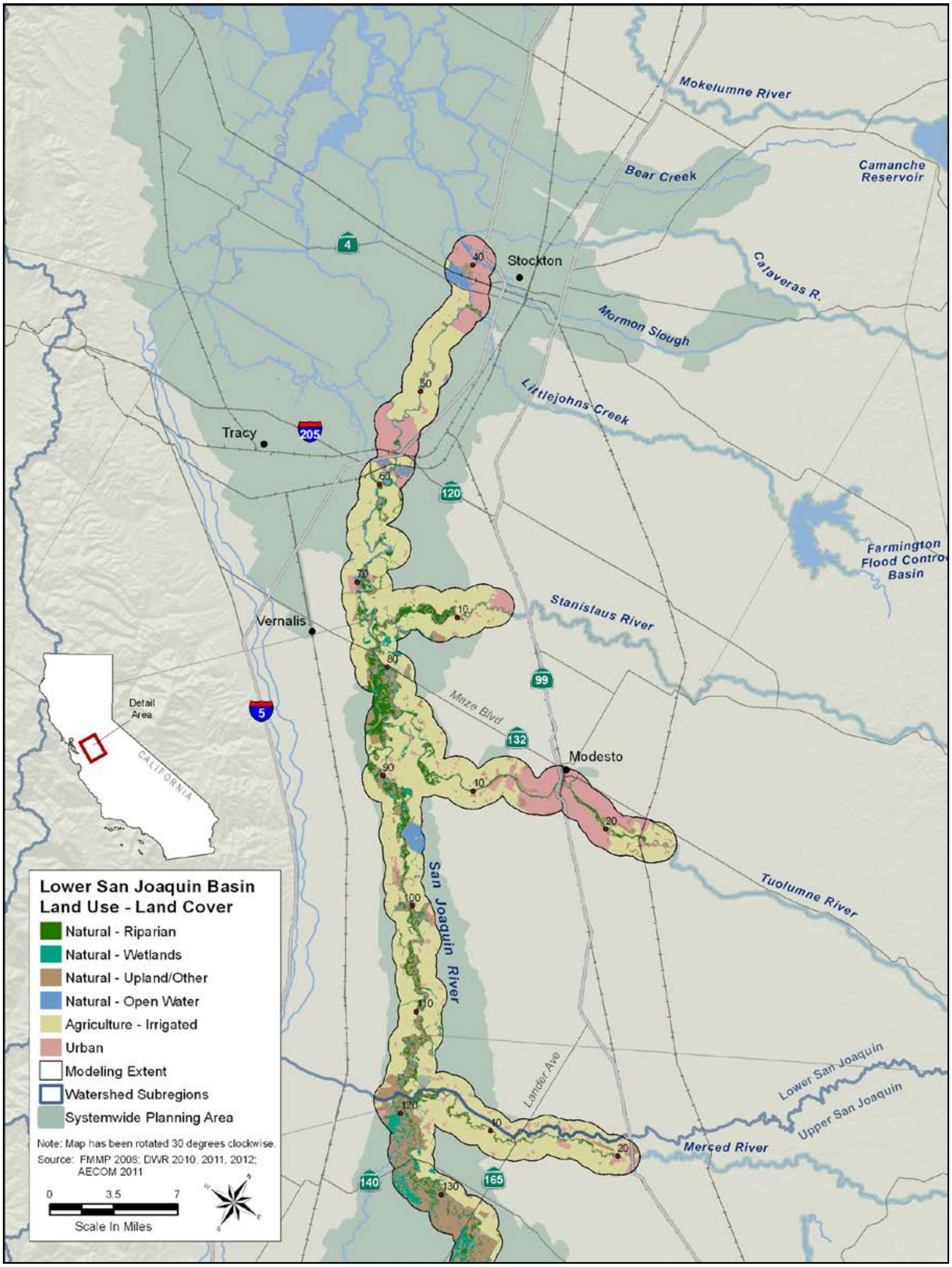

Figure 3-23. Land Use/Land Cover of River Corridors in the Lower San Joaquin Basin

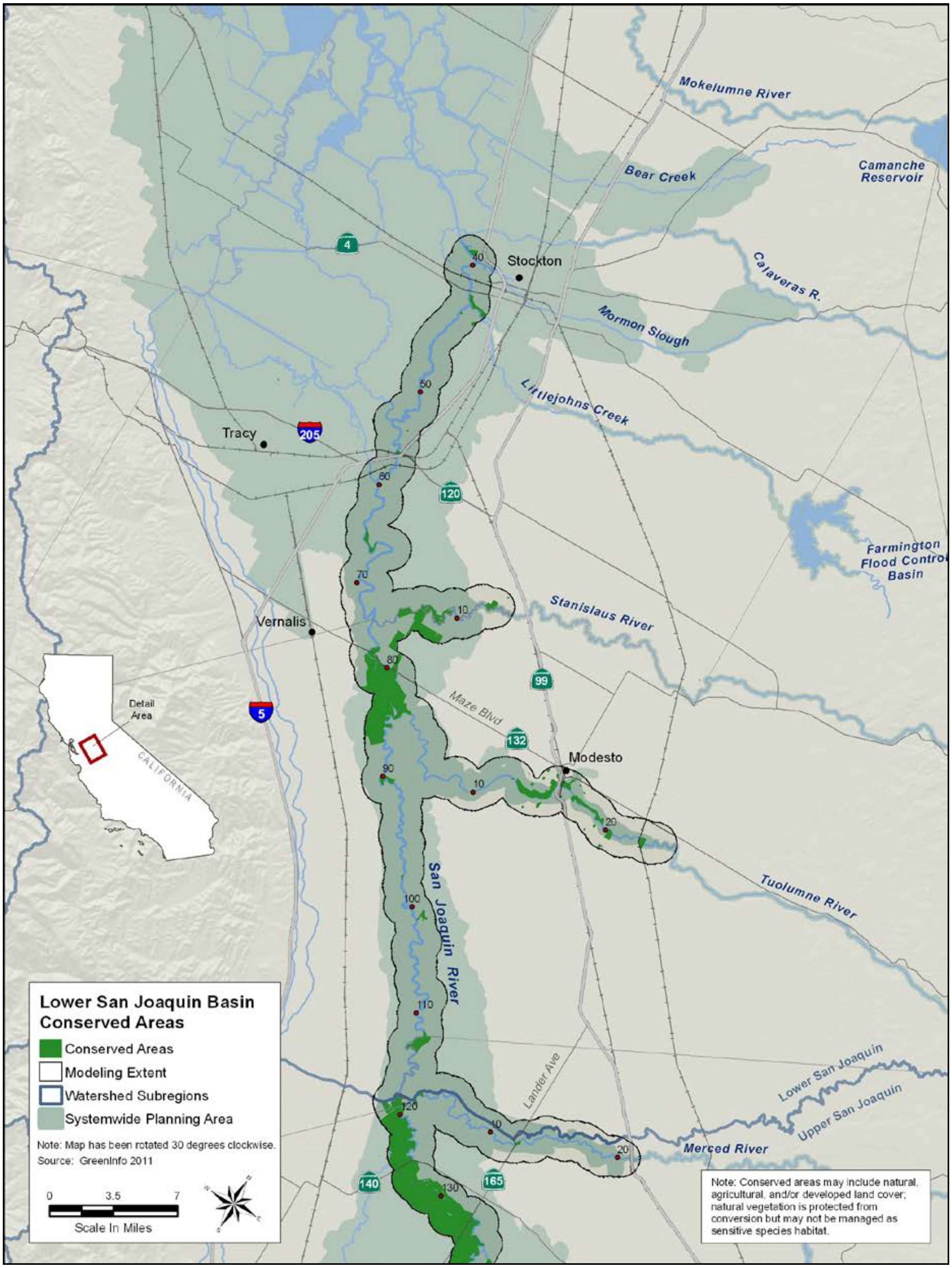

Figure 3-24. Conserved Areas of River Corridors in the Lower San Joaquin Basin

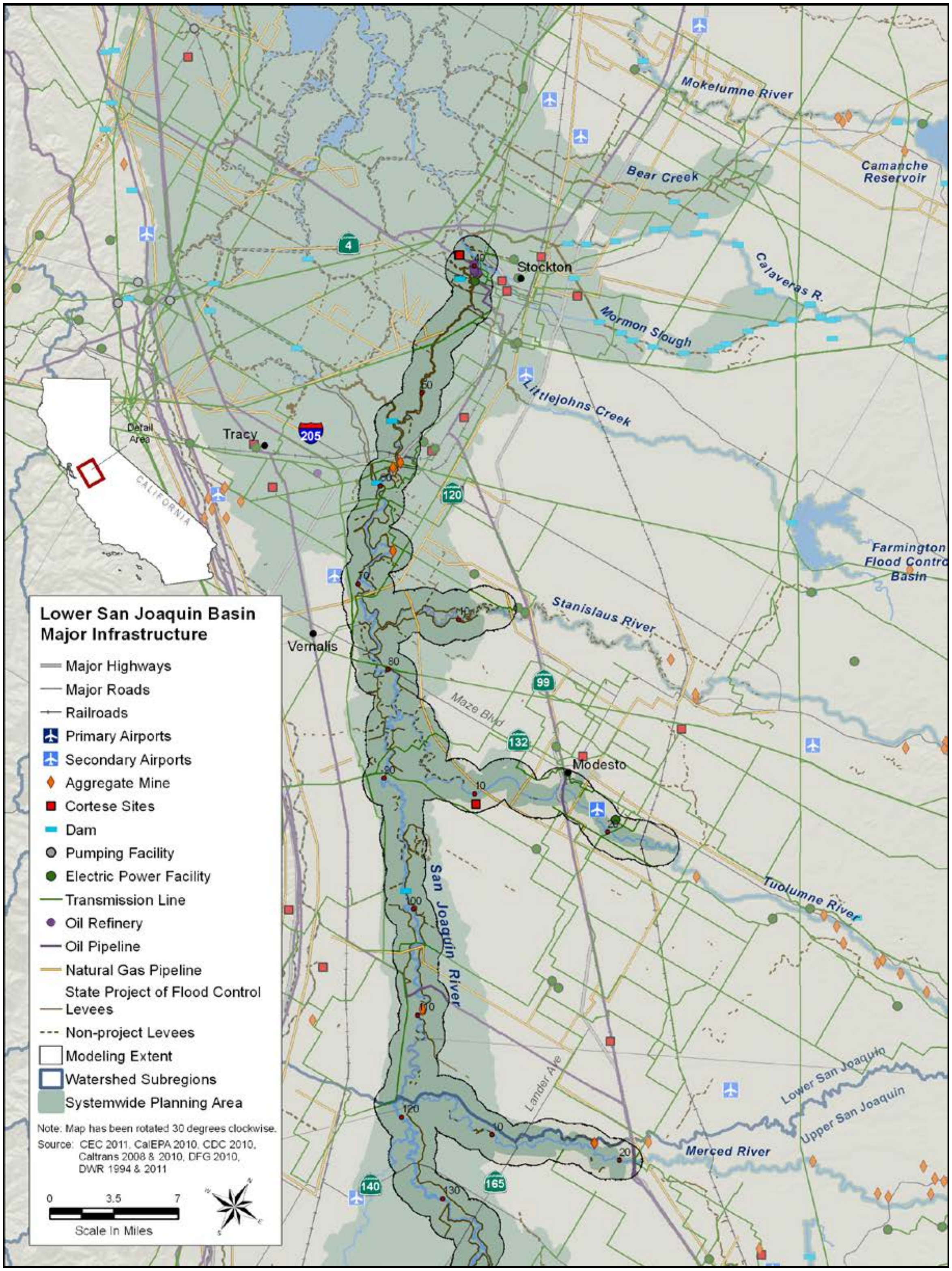

Figure 3-25. Major Infrastructure in River Corridors in the Lower San Joaquin Basin

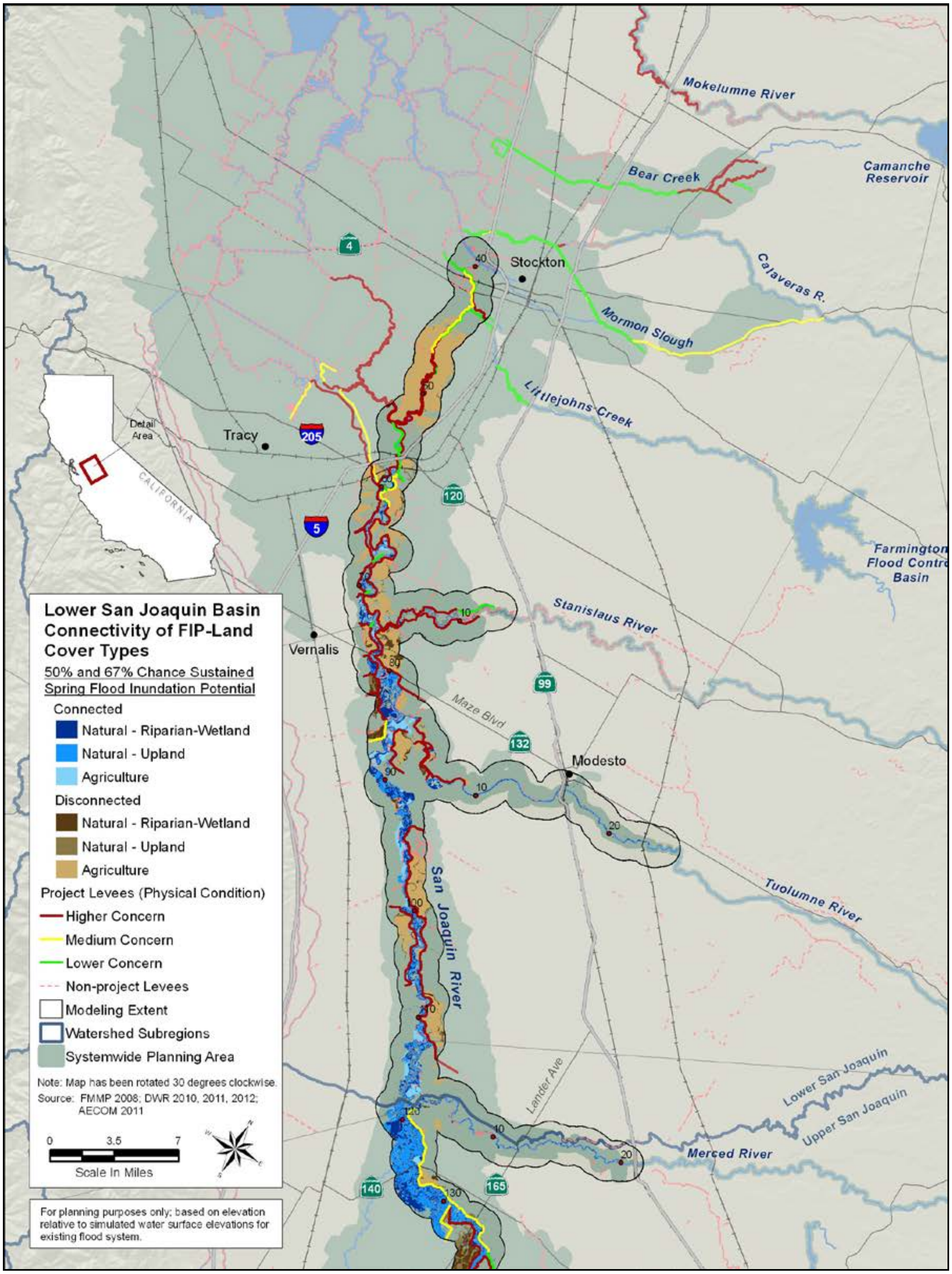

Figure 3-26. Connectivity of FIP-Land Cover Types in Lower San Joaquin Basin

Table 3-1. Floodplain Inundation Potential of Sacramento River

Reach	Modeled Area[1] (Acres)	Floodplain Inundation Potential[2] (Percent of Modeled Area)					
		< Base Flow[3]	67% Chance Spring[4]	50% Chance[5]	10% Chance[6]	< 10% Chance[7]	Total
Upper Sacramento Valley							
Woodson Bridge State Recreation Area–Chico Landing	26,800	7	<1	32	32	28	100
Chico Landing–Colusa	56,400	6	<1	71	12	11	100
Lower Sacramento Valley							
Colusa–Verona	71,400	27	10	61	0	2	100
Verona–American River	24,700	5	25	66	1	2	100
American River–Freeport	17,000	20	28	43	4	4	100
Freeport–Delta Cross Channel	24,800	61	31	5	1	2	100
Delta Cross Channel–Deep Water Ship Channel	16,200	93	3	2	1	2	100
Deep Water Ship Channel–Collinsville	14,600	60	0	3	1	35	100

Source: Data generated for this analysis by AECOM, 2011

Notes:

1 Data are for a corridor extending 1 mile from the centerline of evaluated rivers; acreages are rounded to the nearest 100 acres and percentages are rounded to the nearest percent.

2 Based on potential hydrologic regime using categories described by Williams et al., 2009, as indicated by floodplain inundation potential (FIP) determined using technique of Dilts et al., 2010, and AECOM, 2011.

3 Elevation below or at water surface elevation of March 2008 base flow (i.e., LiDAR FIP ≤1 foot.). Elevations within 1 foot of base flow were considered to represent the water surface because estimated elevations varied within 1 foot of true elevations.

4 Elevation above water surface of base flow but at or below that of 67 percent chance spring flow sustained for at least 7 days (i.e., LiDAR FIP > 1 foot, and 67 percent chance Sustained Spring FIP ≤1 foot.); 67 percent chance Sustained Spring FIP corresponds to Frequently Activated Floodplain of Williams et al., 2009, and Salmonid FIP of pilot study.

5 Elevation above water surface of 67 percent chance spring flow sustained for at least 7 days but below that of 50 percent chance flow (i.e., 67 percent chance Sustained Spring FIP >1 foot. and 50 percent chance FIP ≤1 foot.).

6 Elevation above water surface of 50 percent chance flow but below that of 10 percent chance flow (i.e., 50 percent chance FIP >1 foot. and 10 percent chance FIP ≤1 foot).

7 Elevation above water surface of 10 percent chance flow (i.e., 10 percent chance FIP >1 foot).

Table 3-2. Nonurban Floodplain Connectivity Percentages for the Sacramento River

Reach	Floodplain Inundation Potential[2]					
	67% Chance Sustained Spring[4]			50% Chance[5]		
	Extent (Acres)	Connectivity[6] (Percent)		Extent (Acres)	Connectivity[6] (Percent)	
		Connected	Disconnected		Connected	Disconnected
Upper Sacramento Valley						
Woodson Bridge State Recreation Area–Chico Landing	<100	100	0	7,600	86	14
Chico Landing–Colusa	200	98	2	37,900	41	59
Lower Sacramento Valley						
Colusa–Verona	6,800	6	94	42,400	12	88
Verona–American River	5,600	4	96	13,400	5	95
American River–Freeport	2,200	5	95	1,600	10	90
Freeport–Delta Cross Channel	7,100	3	97	1,000	7	93
Delta Cross Channel–Deep Water Ship Channel	400	22	78	200	56	44
Deep Water Ship Channel–Collinsville	<100	75	25	400	71	29

Source: Data generated for this analysis by AECOM, 2011

Notes:

1 Data are for a corridor extending 1 mile from the centerline of evaluated rivers; acreages are rounded to the nearest 100 acres and percentages are rounded to the nearest percent.

2 Based on potential hydrologic regime using categories described by Williams et al., 2009, as indicated by floodplain inundation potential (FIP) determined using technique of Dilts et al., 2010, and AECOM, 2011. Connectivity not modeled for areas with 10 percent chance and > 10 percent chance FIP.

3 Elevation below or at water surface elevation of March 2008 base flow (i.e., LiDAR FIP ≤1 foot.). Elevations within 1 foot of base flow were considered to represent the water surface because estimated elevations varied within 1 foot of true elevations.

4 Elevation above water surface of base flow but at or below that of 67 percent chance spring flow sustained for at least 7 days (i.e., LiDAR FIP > 1 foot, and 67 percent chance Sustained Spring FIP ≤1 foot.); 67 percent chance Sustained Spring FIP corresponds to Frequently Activated Floodplain of Williams et al., 2009, and Salmonid FIP of EFM (used in pilot study).

5 Elevation above water surface of 67 percent chance spring flow sustained for at least 7 days but below that of 50 percent chance flow (i.e., 67 percent chance Sustained Spring FIP >1 foot. and 50 percent chance FIP ≤1 foot).

6 Connected to or disconnected from river system during a 50 percent chance flow (i.e., modeled as as below and connected to river channel by terrain below elevation of 50 percent chance flow).

Table 3-3. Sacramento River Distribution of Nonurban 67 Percent Chance Sustained Spring and 50 Percent Chance FIP by Connectivity, Land Use, and Conservation Status[1]

Landscape Category	Percentage of Evaluated Corridor by Reach[2]							
	W. Bridge SRA–Chico Landing	Chico Landing–Colusa	Colusa–Verona	Verona–American River	American River–Freeport	Freeport–Delta Cross Channel	Delta Cross Channel–Deep Water Ship Channel	Deep Water Ship Channel–Collinsville
Connected[3]								
Conserved-Riparian/Wetland	7	5	<1	1	<1	<1	<1	<1
Conserved-Natural Upland	1	2	1	1	<1	<1	0	<1
Conserved-Agricultural	1	2	<1	<1	0	<1	<1	<1
Not Conserved-Riparian/Wetland	4	8	2	2	1	<1	<1	<1
Not Conserved-Natural Upland	2	4	1	<1	<1	<1	<1	1
Not Conserved-Agricultural	9	6	3	<1	<1	<1	<1	<1
Connected Subtotal	*24*	*28*	*8*	*4*	*2*	*1*	*1*	*2*
Disconnected[3]								
Conserved-Riparian/Wetland	<1	<1	<1	<1	<1	<1	<1	0
Conserved-Natural Upland	<1	<1	<1	<1	<1	1	<1	<1
Conserved-Agricultural	1	<1	<1	4	0	1	<1	<1
Not Conserved-Riparian/Wetland	<1	1	1	3	<1	<1	<1	<1
Not Conserved-Natural Upland	<1	<1	2	4	8	3	<1	<1
Not Conserved-Agricultural	2	37	57	61	11	26	2	<1
Disconnected Subtotal	*4*	*39*	*61*	*73*	*20*	*32*	*2*	*1*
Total	**28**	**68**	**69**	**77**	**22**	**33**	**3**	**3**

Source: DFG 1997, DOC 2008, DWR 2010, and Data generated for this analysis by AECOM, 2011

Notes:

1 Based on potential hydrologic regime using categories described by Williams et al., 2009, as indicated by floodplain inundation potential (FIP) determined using technique of Dilts et al., 2010, and AECOM, 2011. 67 percent chance Sustained Spring FIP represents elevations above water surface of base flow (i.e., March 2008 flows; LiDAR FIP) but at or below that of 67 percent chance spring flow sustained for at least 7 days (i.e., LiDAR FIP > 1 foot. and 67 percent chance Sustained Spring FIP ≤1 foot.). 50 percent chance FIP represents elevations above water surface of 50 percent chance flow but below that of 10 percent chance flow (i.e., 50 percent chance FIP >1 foot, and 10 percent chance FIP ≤1 foot.).

2 Data are for a corridor extending 1 mile from the centerline of evaluated rivers; percentages are rounded to the nearest percent.

3 Connected to or disconnected from river system during a 50 percent chance flow (i.e., modeled as inundated by flood flows under 2008 infrastructure and topography).

Table 3-4. Floodplain Inundation Potential of Sacramento River Tributaries

Reach	Modeled Area[1] (Acres)	Floodplain Inundation Potential[2] (Percent of Modeled Area)					
		< Base Flow[3]	67% Chance Spring[4]	50% Chance[5]	10% Chance[6]	< 10% Chance[7]	Total
Feather River							
Thermalito Afterbay–Yuba River	35,800	4	0	41	28	27	100
Yuba River–Bear River	18,600	5	1	86	6	2	100
Bear River–Sutter Bypass	5,800	6	1	89	1	2	100
Sutter Bypass–Sacramento River	8,600	4	12	83	1	1	100
Other Tributaries							
Yuba River	15,400	8	1	11	26	54	100
Bear River	14,600	3	12	37	35	14	100
American River	26,500	4	1	14	28	53	100

Source: Data generated for this analysis by AECOM, 2011

Notes:

[1] Data are for a corridor extending 1 mile from the centerline of evaluated rivers; acreages are rounded to the nearest 100 acres and percentages are rounded to the nearest percent.

[2] Based on potential hydrologic regime using categories described by Williams et al., 2009, as indicated by floodplain inundation potential (FIP) determined using technique of Dilts et al., 2010, and AECOM, 2011.

[3] Elevation below or at water surface elevation of March 2008 base flow (i.e., LiDAR FIP ≤1 foot.). Elevations within 1 foot of base flow were considered to represent the water surface because estimated elevations varied within 1 foot of true elevations.

[4] Elevation above water surface of base flow but at or below that of 67 percent chance spring flow sustained for at least 7 days (i.e., LiDAR FIP > 1 foot, and 67 percent chance Sustained Spring FIP ≤1 foot.); 67 percent chance Sustained Spring FIP corresponds to Frequently Activated Floodplain of Williams et al., 2009, and Salmonid FIP of pilot study.

[5] Elevation above water surface of 67 percent chance spring flow sustained for at least 7 days but below that of 50 percent chance flow (i.e., 67 percent chance Sustained Spring FIP >1 foot. and 50 percent chance FIP ≤1 foot.).

[6] Elevation above water surface of 50 percent chance flow but below that of 10 percent chance flow (i.e., 50 percent chance FIP >1 foot. and 10 percent chance FIP ≤1 foot).

[7] Elevation above water surface of 10 percent chance flow (i.e., 10 percent chance FIP >1 foot).

Table 3-5. Nonurban Floodplain Connectivity Percentages for Sacramento River Tributaries

Reach	Floodplain Inundation Potential[2]					
	67% Chance Sustained Spring[4]			50% Chance[5]		
	Extent (Acres)	Connectivity[6] (Percent)		Extent (Acres)	Connectivity[6] (Percent)	
		Connected	Disconnected		Connected	Disconnected
Feather River						
Thermalito Afterbay–Yuba River	100	100	<1	11,900	69	31
Yuba River–Bear River	200	70	30	14,200	31	69
Bear River–Sutter Bypass	100	87	13	5,100	35	65
Sutter Bypass–Sacramento River	1,000	57	43	7,000	57	43
Other Tributaries						
Yuba River	100	38	62	1,200	47	53
Bear River	1,200	14	86	5,200	15	85
American River	200	98	2	1,100	84	16

Source: Data generated for this analysis by AECOM, 2011

Notes:

[1] Data are for a corridor extending 1 mile from the centerline of evaluated rivers; acreages are rounded to the nearest 100 acres and percentages are rounded to the nearest percent.

[2] Based on potential hydrologic regime using categories described by Williams et al., 2009, as indicated by floodplain inundation potential (FIP) determined using technique of Dilts et al., 2010, and AECOM, 2011. Connectivity not modeled for areas with 10 percent chance and > 10 percent chance FIP.

[3] Elevation below or at water surface elevation of March 2008 base flow (i.e., LiDAR FIP ≤1 foot.). Elevations within 1 foot of base flow were considered to represent the water surface because estimated elevations varied within 1 foot of true elevations.

[4] Elevation above water surface of base flow but at or below that of 67 percent chance spring flow sustained for at least 7 days (i.e., LiDAR FIP > 1 foot, and 67 percent chance Sustained Spring FIP ≤1 foot.); 67 percent chance Sustained Spring FIP corresponds to Frequently Activated Floodplain of Williams et al., 2009, and Salmonid FIP of EFM (used in pilot study).

[5] Elevation above water surface of 67 percent chance spring flow sustained for at least 7 days but below that of 50 percent chance flow (i.e., 67 percent chance Sustained Spring FIP >1 foot. and 50 percent chance FIP ≤1 foot).

[6] Connected to or disconnected (“Discon.”) from river system during a 50 percent chance flow (i.e., modeled as inundated by flood flows under existing conditions).

Table 3-6. Sacramento River Tributaries Distribution of Nonurban 67 Percent Chance Sustained Spring and 50 Percent Chance FIP by Connectivity, Land Use, and Conservation Status[1]

Landscape Category	Percentage of Evaluated Corridor by Reach[2]						
	Feather River				Other Tributaries		
	Thermalito Afterbay to Yuba River	Yuba River to Bear River	Bear River to Sutter Bypass	Sutter Bypass to Sacramento River	Yuba River	Bear River	American River
Connected[3]							
Conserved-Riparian/Wetland	1	8	4	0	<1	<1	2
Conserved-Natural Upland	1	3	9	0	<1	<1	1
Conserved-Agricultural	<1	1	<1	0	<1	<1	0
Not Conserved-Riparian/Wetland	4	7	9	6	1	3	<1
Not Conserved-Natural Upland	2	2	8	9	2	2	<1
Not Conserved-Agricultural	14	4	2	37	<1	1	<1
Connected Subtotal	*23*	*25*	*32*	*53*	*4*	7	4
Disconnected[3]							
Conserved-Riparian/Wetland	3	0	0	0	<1	<1	<1
Conserved-Natural Upland	1	<1	<1	0	<1	<1	<1
Conserved-Agricultural	<1	<1	<1	0	0	0	0
Not Conserved-Riparian/Wetland	<1	1	<1	<1	<1	1	<1
Not Conserved-Natural Upland	1	3	7	1	2	7	<1
Not Conserved-Agricultural	5	49	49	38	1	30	<1
Disconnected Subtotal	*10*	*53*	*57*	*40*	*5*	*38*	*1*
Total	**33**	**78**	**89**	**93**	**9**	**44**	**5**

Source: DFG 1997, DOC 2008, DWR 2010, and Data generated for this analysis by AECOM, 2011

Notes:

[1] Based on potential hydrologic regime using categories described by Williams et al., 2009, as indicated by floodplain inundation potential (FIP) determined using technique of Dilts et al., 2010, and AECOM, 2011. 67 percent chance Sustained Spring FIP represents elevations above water surface of base flow (i.e., March 2008 flows; LiDAR FIP) but at or below that of 67 percent chance spring flow sustained for at least 7 days (i.e., LiDAR FIP > 1 foot, and 67 percent chance Sustained Spring FIP ≤1 foot). 50 percent chance FIP represents elevations above water surface of 50 percent chance flow but below that of 10 percent chance flow (i.e., 50 percent chance FIP >1 foot. and 10 percent chance FIP ≤1 foot).

[2] Data are for a corridor extending 1 mile from the centerline of evaluated rivers; percentages are rounded to the nearest percent.

[3] Connected to or disconnected from river system during a 50 percent chance flow (i.e., modeled as inundated by flood flows under 2008 infrastructure and topography).

Table 3-7. Floodplain Inundation Potential of Upper San Joaquin River

Reach	Modeled Area[1] (Acres)	Floodplain Inundation Potential[2] (Percent of Modeled Area)					
		< Base Flow[3]	67% Chance[4]	50% Chance[5]	10% Chance[6]	< 10% Chance[7]	Total
Friant Dam–State Route 99	22,500	9	1	1	4	85	100
State Route 99–Gravelly Ford	19,400	2	1	2	2	92	100
Gravelly Ford–Chowchilla Bypass	10,500	6	13	29	18	34	100
Chowchilla Bypass–Mendota Dam	8,400	31	26	22	14	7	100
Mendota Dam–Sack Dam	23,800	4	3	66	1	27	100
Sack Dam–Sand Slough Control Structure	14,900	2	10	83	1	5	100
Sand Slough Control Structure–Mariposa Bypass	19,200	20	69	9	0	1	100
Mariposa Bypass–Bear Creek	9,700	2	6	90	1	1	100
Bear Creek–Merced River	16,00	4	4	52	19	20	100

Source: Data generated for this analysis by AECOM, 2011

Notes:

[1] Data are for a corridor extending 1 mile from the centerline of evaluated rivers; acreages are rounded to the nearest 100 acres and percentages are rounded to the nearest percent.

[2] Based on potential hydrologic regime using categories described by Williams et al., 2009, as indicated by floodplain inundation potential (FIP) determined using technique of Dilts et al., 2010, and AECOM, 2011.

[3] Elevation below or at water surface elevation of March 2008 base flow (i.e., LiDAR FIP ≤1 foot.). Elevations within 1 foot of base flow were considered to represent the water surface because estimated elevations varied within 1 foot of true elevations.

[4] Elevation above water surface of base flow but at or below that of 67 percent chance spring flow sustained for at least 7 days (i.e., LiDAR FIP > 1 foot, and 67 percent chance Sustained Spring FIP ≤1 foot.); 67 percent chance Sustained Spring FIP corresponds to Frequently Activated Floodplain of Williams et al., 2009, and Salmonid FIP of pilot study.

[5] Elevation above water surface of 67 percent chance Sustained Spring FIP but below that of 50 percent chance flow (i.e., 67 percent chance Sustained Spring FIP >1 foot. and 50 percent chance FIP ≤1 foot).

[6] Elevation above water surface of 50 percent chance flow but below that of 10 percent chance flow (i.e., 50 percent chance FIP >1 foot. and 10 percent chance FIP ≤1 foot).

[7] Elevation above water surface of 10 percent chance flow (i.e., 10 percent chance FIP >1 foot).

Table 3-8. Nonurban Floodplain Connectivity Percentages for Upper San Joaquin River

Reach	Floodplain Inundation Potential[2]					
	67% Chance Sustained Spring[4]			50% Chance[5]		
	Extent (Acres)	Connectivity[6] (Percent)		Extent (Acres)	Connectivity[6] (Percent)	
		Connected	Disconnected		Connected	Disconnected
Friant Dam–State Route 99	200	69	31	200	88	12
State Route 99–Gravelly Ford	300	100	0	300	96	4
Gravelly Ford–Chowchilla Bypass	1,400	19	81	2,800	11	89
Chowchilla Bypass–Mendota Dam	2,100	35	65	900	23	77
Mendota Dam–Sack Dam	600	68	32	9,300	13	87
Sack Dam–Sand Slough Control Structure	1,100	17	83	11,700	1	99
Sand Slough Control Structure–Mariposa Bypass	5,800	39	61	1,700	10	90
Mariposa Bypass–Bear Creek	500	57	43	4,800	21	79
Bear Creek–Merced River	700	99	1	7,800	84	16

Source: Data generated for this analysis by AECOM, 2011

Notes:

[1] Data are for a corridor extending 1 mile from the centerline of evaluated rivers; acreages are rounded to the nearest 100 acres and percentages are rounded to the nearest percent.

[2] Based on potential hydrologic regime using categories described by Williams et al., 2009, as indicated by floodplain inundation potential (FIP) determined using technique of Dilts et al., 2010, and AECOM, 2011. Connectivity not modeled for areas with 10 percent chance and > 10 percent chance FIP.

[3] Elevation below or at water surface elevation of March 2008 base flow (i.e., LiDAR FIP ≤1 foot.). Elevations within 1 foot of base flow were considered to represent the water surface because estimated elevations varied within 1 foot of true elevations.

[4] Elevation above water surface of base flow but at or below that of 67 percent chance spring flow sustained for at least 7 days (i.e., LiDAR FIP > 1 foot, and 67 percent chance Sustained Spring FIP ≤1 foot.); 67 percent chance Sustained Spring FIP corresponds to Frequently Activated Floodplain of Williams et al., 2009, and Salmonid FIP of EFM (used in pilot study).

[5] Elevation above water surface of 67 percent chance spring flow sustained for at least 7 days but below that of 50 percent chance flow (i.e., 67 percent chance Sustained Spring FIP >1 foot. and 50 percent chance FIP ≤1 foot).

[6] Connected to or disconnected ("Discon.") from river system during a 50 percent chance flow (i.e., modeled as inundated by flood flows under existing conditions).

Table 3-9. Upper San Joaquin Valley Distribution of Nonurban 67 Percent Chance Sustained Spring and 50 Percent Chance FIP by Connectivity, Land Use, and Conservation Status[1]

Landscape Category	Percentage of Evaluated Corridor by Reach[2]								
	Friant Dam–SR 99	SR 99–Gravelly Ford	Gravelly Ford–Chowchilla Bypass	Chowchilla Bypass–Mendota Dam	Mendota Dam–Sack Dam	Sack Dam–Sand Slough Control Structure	Sand Slough Control Structure–Mariposa Bypass	Mariposa Bypass–Bear Creek	Bear Creek–Merced River
Connected[3]									
Conserved-Riparian/Wetland	0	0	0	<1	0	0	<1	3	12
Conserved-Natural Upland	<1	<1	0	0	0	0	<1	5	24
Conserved-Agricultural	0	0	0	0	0	0	0	<1	0
Not Conserved-Riparian/Wetland	1	1	<1	<1	2	1	1	1	2
Not Conserved-Natural Upland	<1	1	4	1	2	1	1	3	5
Not Conserved-Agricultural	<1	<1	1	10	3	<1	11	0	1
Connected Subtotal	*1*	*3*	*5*	*11*	*7*	*2*	*13*	*13*	*44*
Disconnected[3]									
Conserved-Riparian/Wetland	0	0	0	0	0	0	4	25	2
Conserved-Natural Upland	<1	0	0	0	0	0	2	16	3
Conserved-Agricultural	0	0	0	0	0	0	0	<1	<1
Not Conserved-Riparian/Wetland	0	0	<1	<1	1	1	<1	<1	1
Not Conserved-Natural Upland	<1	<1	<1	1	1	6	<1	<1	1
Not Conserved-Agricultural	<1	<1	34	24	33	77	20	0	2
Disconnected Subtotal	*<1*	*<1*	*34*	*25*	*35*	*84*	*26*	*41*	*8*
Total	**1**	**3**	**42**	**48**	**42**	**92**	**39**	**54**	**52**

Source: DFG 1997, DOC 2008, DWR 2010, and Data generated for this analysis by AECOM, 2011

Notes:

[1] Based on potential hydrologic regime using categories described by Williams et al., 2009, as indicated by floodplain inundation potential (FIP) determined using technique of Dilts et al,. 2010, and AECOM, 2011. 67 percent chance Sustained Spring FIP represents elevations above water surface of base flow (i.e., March 2008 flows; LiDAR FIP) but at or below that of 67 percent chance spring flow sustained for at least 7 days (i.e., LiDAR FIP > 1 foot, and 67 percent chance Sustained Spring FIP ≤1 foot).

[2] Data are for a corridor extending 1 mile from the centerline of evaluated rivers; percentages are rounded to the nearest percent.

[3] Connected to or disconnected from river system during a 50 percent chance flow (i.e., modeled as inundated by flood flows under 2008 infrastructure and topography).

Table 3-10. Floodplain Inundation Potential of Lower San Joaquin River and Tributaries

Reach	Modeled Area[1] (Acres)	Floodplain Inundation Potential[2] (Percent of Modeled Area)					
		< Base Flow[3]	67% Chance[4]	50% Chance[5]	10% Chance[6]	< 10% Chance[7]	Total
San Joaquin River							
Merced River–Tuolumne River	32,900	3	3	38	20	36	100
Tuolumne River–Stanislaus River	9,100	4	3	47	18	28	100
Stanislaus River–Stockton	35,200	18	15	40	19	9	100
Tributaries							
Merced River	18,800	1	1	4	21	73	100
Tuolumne River	25,700	1	1	5	5	88	100
Stanislaus River	10,700	2	<1	4	37	57	100

Source: Data generated for this analysis by AECOM, 2011

Notes:

1 Data are for a corridor extending 1 mile from the centerline of evaluated rivers; acreages are rounded to the nearest 100 acres and percentages are rounded to the nearest percent.

2 Based on potential hydrologic regime using categories described by Williams et al., 2009, as indicated by floodplain inundation potential (FIP) determined using technique of Dilts et al., 2010, and AECOM, 2011.

3 Elevation below or at water surface elevation of March 2008 base flow (i.e., LiDAR FIP ≤1 foot). Elevations within 1 foot of base flow were considered to represent the water surface because estimated elevations varied within 1 foot of true elevations.

4 Elevation above water surface of base flow but at or below that of 67 percent chance spring flow sustained for at least 7 days (i.e., LiDAR FIP > 1 foot, and 67 percent chance Sustained Spring FIP ≤1 foot.); 67 percent chance Sustained Spring FIP corresponds to Frequently Activated Floodplain of Williams et al., 2009, and Salmonid FIP of pilot study.

5 Elevation above water surface of 67 percent chance spring flow sustained for at least 7 days but below that of 50 percent chance flow (i.e., 67 percent chance Sustained Spring FIP >1 foot. and 50 percent chance FIP ≤1 foot.).

6 Elevation above water surface of 50 percent chance flow but below that of 10 percent chance flow (i.e., 50 percent chance FIP >1 foot. and 10 percent chance FIP ≤1 foot).

7 Elevation above water surface of 10 percent chance flow (i.e., 10 percent chance FIP >1 foot).

Table 3-11. Nonurban Floodplain Connectivity Percentages for Lower San Joaquin River and Tributaries

Reach	Floodplain Inundation Potential[2]					
	67% Chance Sustained Spring[4]			50% Chance[5]		
	Extent (Acres)	Connectivity[6] (Percent)		Extent (Acres)	Connectivity[6] (Percent)	
		Connected	Disconnected		Connected	Disconnected
San Joaquin River						
Merced River–Tuolumne River	1,100	82	18	11,300	52	48
Tuolumne River–Stanislaus River	300	68	32	4,000	40	60
Stanislaus River–Stockton	4,200	9	91	9,300	11	89
Tributaries						
Merced River	100	96	4	500	38	62
Tuolumne River	200	85	15	1,000	49	51
Stanislaus River	<100	83	17	300	30	70

Source: Data generated for this analysis by AECOM, 2011

Notes:

[1] Data are for a corridor extending 1 mile from the centerline of evaluated rivers; acreages are rounded to the nearest 100 acres and percentages are rounded to the nearest percent.

[2] Based on potential hydrologic regime using categories described by Williams et al., 2009, as indicated by floodplain inundation potential (FIP) determined using technique of Dilts et al., 2010, and AECOM, 2011. Connectivity not modeled for areas with 10 percent chance and > 10 percent chance FIP.

[3] Elevation below or at water surface elevation of March 2008 base flow (i.e., LiDAR FIP ≤1 foot). Elevations within 1 foot of base flow were considered to represent the water surface because estimated elevations varied within 1 foot of true elevations.

[4] Elevation above water surface of base flow but at or below that of 67 percent chance spring flow sustained for at least 7 days (i.e., LiDAR FIP > 1 foot, and 67 percent chance Sustained Spring FIP ≤1 foot.); 67 percent chance Sustained Spring FIP corresponds to Frequently Activated Floodplain of Williams et al., 2009, and Salmonid FIP of EFM (used in pilot study).

[5] Elevation above water surface of 67 percent chance spring flow sustained for at least 7 days but below that of 50 percent chance flow (i.e., 67 percent chance Sustained Spring FIP >1 foot. and 50 percent chance FIP ≤1 foot.).

[6] Connected to or disconnected ("Discon.") from river system during a 50 percent chance flow; i.e., modeled as inundated by flood flows under existing conditions).

Table 3-12. Lower San Joaquin Valley Distribution of Nonurban 67 Percent Chance Sustained Spring and 50 Percent Chance FIP by Connectivity, Land Use, and Conservation Status[1]

Landscape Category	Percentage of Evaluated Corridor by Reach[2]					
	San Joaquin River			Tributaries		
	Merced River–Tuolumne River	Tuolumne River–Stanislaus River	Stanislaus River–Stockton	Merced River	Tuolumne River	Stanislaus River
Connected[3]						
Conserved-Riparian/Wetland	1	9	0	<1	<1	<1
Conserved-Natural Upland	1	5	<1	<1	<1	<1
Conserved-Agricultural	0	0	<1	0	0	0
Not Conserved-Riparian/Wetland	7	3	2	1	2	1
Not Conserved-Natural Upland	6	1	<1	<1	<1	<1
Not Conserved-Agricultural	5	1	1	<1	<1	<1
Connected Subtotal	*21*	*20*	*4*	*2*	*3*	*1*
Disconnected[3]						
Conserved-Riparian/Wetland	1	3	0	0	<1	1
Conserved-Natural Upland	<1	2	<1	0	0	<1
Conserved-Agricultural	0	5	<1	0	0	<1
Not Conserved-Riparian/Wetland	1	3	1	<1	<1	<1
Not Conserved-Natural Upland	1	2	1	<1	<1	<1
Not Conserved-Agricultural	14	12	32	1	1	1
Disconnected Subtotal	*17*	*28*	*34*	*2*	*2*	*2*
Total	**38**	**48**	**42**	**4**	**5**	**3**

Source: DFG 1997, DOC 2008, DWR 2010, and Data generated for this analysis by AECOM, 2011

Notes:

[1] Based on potential hydrologic regime using categories described by Williams et al., 2009, as indicated by floodplain inundation potential (FIP) determined using technique of Dilts et al., 2010, and AECOM, 2011. 67 percent chance Sustained Spring FIP represents elevations above water surface of base flow (i.e., March 2008 flows; LiDAR FIP) but at or below that of 67 percent chance spring flow sustained for at least 7 days (i.e., LiDAR FIP > 1 foot, and 67 percent chance Sustained Spring FIP ≤1 foot.). 50 percent chance FIP represents elevations above water surface of 50 percent chance flow but below that of 10 percent chance flow (i.e., 50 percent chance FIP >1 foot. and 10 percent chance FIP ≤1 foot).

[2] Data are for a corridor extending 1 mile from the centerline of evaluated rivers; percentages are rounded to the nearest percent.

[3] Connected to or disconnected from river system during a 50 percent chance flow (i.e., modeled as inundated by flood flows under 2008 infrastructure and topography).

4.0 Floodplain Restoration Opportunities: Conclusions and Recommendations

This chapter summarizes the relative extent of potential restoration opportunities identified along river reaches based on their physical suitability and existing land cover, and makes general recommendations for the future use of FROA results.

4.1 Conclusions

Restoration opportunities are widespread throughout the 2-mile-wide corridors evaluated along the Sacramento and San Joaquin river systems. Outside of urban areas, there are more than 320,000 acres of floodplain with a 67 percent chance Sustained Spring FIP or a 50 percent chance FIP under the existing flow regime of the Sacramento River system and the flow regime planned by the SJRRP for the San Joaquin River system.

These floodplain areas (which have the potential for frequent inundation) are most limited along several of the major tributaries (e.g., the American, Merced, Tuolumne, and Stanislaus rivers), the upper San Joaquin River from Friant Dam to Gravelly Ford, and the lower Sacramento River downstream of the Delta Cross Channel. Floodplain with 67 percent chance Sustained Spring FIP or a 50 percent chance FIP accounts for less than 5 percent of the evaluated corridors along these reaches. However, because 1 percent of a 2-mile-wide corridor is comparable to corridors about 50 feet wide on each river bank, even these reaches have restoration opportunities (e.g., creation of Shaded Riverine Aquatic habitat) that could have systemwide benefits.

Floodplain with the potential for frequent inundation is much more extensive along other river reaches, providing a greater variety of restoration opportunities. In particular, river reaches differ substantially in the extent of the following combinations of hydrologic connectivity to the river system, nonurban land use/land cover, and FIP that represent different types of restoration opportunities:

- Floodplain hydrologically connected to the river, with riparian or wetland vegetation, and with a 67 percent chance Sustained Spring Flow or a 50 percent chance FIP

- Floodplain hydrologically connected to the river, without riparian or wetland vegetation, with a 67 percent chance Sustained Spring Flow or a 50 percent chance FIP

- Floodplain hydrologically disconnected from the river with a 67 percent chance Sustained Spring Flow FIP

- Floodplain hydrologically disconnected from the river with a 50 percent chance FIP

Along all evaluated reaches of the Sacramento and San Joaquin river systems, each of these types of floodplain areas exist (Tables 4-1 and 4-2) and their restoration could provide ecologically important benefits. However, those reaches having the most extensive areas of each type probably represent greater and/or more feasible opportunities for large-scale restoration of riverine and floodplain ecosystems. The types of restoration opportunities represented by these floodplain areas and their distribution among river reaches are described further below. Their distribution among river reaches is also displayed in Tables 4-1 and 4-2.

Less than 40 percent of floodplain with a 67 percent chance Sustained Spring Flow or a 50 percent chance FIP remains hydrologically connected to the river system. Hydrologically connected floodplain is most extensive along the Sacramento River from Woodson Bridge to Colusa, the Feather River from Thermolito Afterbay to the junction with the Sacramento River, and the San Joaquin River from Bear Creek to the junction with the Stanislaus River. Hydrologically connected floodplain with a 67 percent chance Sustained Spring Flow or a 50 percent chance FIP accounts for 20 percent to 53 percent of the 2-mile-wide corridor along these reaches. The majority of this floodplain has a 50 percent chance FIP and is not frequently inundated by sustained spring flows.

Riparian and wetland vegetation covers only about a third (approximately 34 percent) of the floodplain that has remained connected to the river system, including most connected floodplain with a 67 percent chance Sustained Spring Flow FIP. In many of these areas, channel migration processes have been impeded by revetment, which has reduced habitat values. Similarly, the installation of revetment has reduced the amount of Shaded Riverine Aquatic habitat, and habitat for other species (e.g., bank swallow). Thus, there is an opportunity to restore these areas by revetment removal.

Table 4-1. Restoration Opportunities Along Sacramento River System

Reach	Modeled Area[1] (Acres)	Restoration Opportunity[2] (Percent of Modeled Area)					Notes
		Connected[3]		Disconnected[3]		Total	
		Riparian/ Wetland	Other Land Use/ Land Cover	67% Chance SS FIP[2],	50% Chance FIP[2]		
Sacramento River							
Woodson Bridge–Chico Landing	26,792	11	14	0	4	28	Extensive conserved land, bank swallow, yellow-billed cuckoo
Chico Landing–Colusa	56,442	14	14	<1	39	68	Bank swallow, yellow-billed cuckoo
Colusa–Verona	71,376	3	5	9	52	69	Bank swallow, yellow-billed cuckoo
Verona–American River	24,732	2	1	22	51	77	Extensive infrastructure constraints
American River–Freeport	16,969	1	1	12	8	22	Extensive development and infrastructure
Freeport–Delta Cross Channel	24,784	<1	1	28	4	33	Tidally influenced, in legal Delta
Delta Cross Channel–Deep Water Ship Channel	16,192	<1	1	2	1	3	Tidally influenced, in legal Delta
Deep Water Ship Channel–Collinsville	14,641	1	2	<1	1	3	Tidally influenced, in legal Delta
Feather River							
Thermalito Afterbay to Yuba River	35,830	6	18	<1	10	33	Historical and active gravel pits, fall-run Chinook spawning and rearing, bank swallow, yellow-billed cuckoo
Yuba River to Bear River	18,646	15	9	<1	53	78	Bank swallow
Bear River to Sutter Bypass	5,828	13	19	<1	57	89	Bank swallow, yellow-billed cuckoo
Sutter Bypass to Sacramento River	8,643	6	47	5	35	93	Bank swallow
Other Tributaries							
Yuba River	15,390	1	3	1	4	9	Extensive disturbed area (Yuba Gold Fields)
Bear River	14,612	3		7			Fall-run Chinook spawning and rearing (intermittent)
American River	26,489	3	2	<1	1	5	Extensive development and infrastructure, extensive conserved land, bank swallow, fall-run Chinook spawning and rearing

Source: Data generated for this analysis by AECOM in 2011

Notes:

1 Data are for a corridor extending 1 mile from each river bank of evaluated rivers; acreages are rounded to the nearest 100 acres and percentages are rounded to the nearest percent.

2 For nonurban areas and based on potential hydrologic regime using categories described by Williams et al., 2009, as indicated by floodplain inundation potential (FIP) determined using technique of Dilts et al., 2010, and AECOM, 2011. 67 percent chance Sustained Spring (SS) FIP represents elevations above water surface of base flow (i.e., March 2008 flows; LiDAR FIP) but at or below that of 67 percent chance spring flow sustained for at least 7 days (i.e., LiDAR FIP > 1 foot, and 67 percent chance Sustained Spring FIP ≤1 foot); 67 percent chance Sustained Spring FIP corresponds to Frequently Activated Floodplain of Williams et al., 2009, and Salmonid FIP of pilot study. 50 percent chance FIP represents elevations above water surface of 50 percent chance flow but below that of 10 percent chance flow (i.e., 50 percent chance FIP >1 foot. and 10 percent chance FIP ≤1 foot).

3 During 50 percent chance event, simulated under 2008 topography and infrastructure.

Table 4-2. Restoration Opportunities Along San Joaquin River System

Reach	Modeled Area[1] (Acres)	Restoration Opportunity (Percent of Modeled Area)					Notes
		Connected[3]		Disconnected[3]		Total	
		Riparian/Wetland	Other Land Use/Land Cover	67% chance SS FIP[2],	50% chance FIP[2],		
San Joaquin River							
Friant Dam to SR 99	22,545	1	<1	<1	<1	1	Extensive development and infrastructure, historical and active gravel pits, potential spawning habitat if salmon reintroduced
SR 99 to Gravelly Ford	19,373	1	2	<1	<1	3	
Gravelly Ford to Chowchilla Bypass	10,511	<1	5	10	24	40	
Chowchilla Bypass to Mendota Dam	8,368	<1	11	16	9	36	Mendota Pool – major infrastructure constraint
Mendota Dam to Sack Dam	23,842	2	5	1	34	42	Mendota Pool – major infrastructure constraint
Sack Dam to Sand Slough	14,895	1	2	6	78	86	
Sand Slough to Mariposa Bypass	19,180	1	12	18	8	39	Carries only local drainage, until modified
Mariposa Bypass to Bear Creek	9,689	5	8	2	39	54	Extensive conserved land
Bear Creek to Merced River	16,263	14	30	<1	8	52	Extensive conserved land
Merced River to Tuolumne River	32,861	8	13	1	17	38	
Tuolumne River to Stanislaus River	9,052	12	8	1	27	48	Riparian woodrat and riparian brush rabbit habitat, extensive conserved land
Stanislaus River to Stockton	35,191	2	2	11	23	38	Extensive development and infrastructure, riparian woodrat and riparian brush rabbit habitat, tidally influenced, in legal Delta
Tributaries							
Merced River	18,782	1	1	<1	2	2	
Tuolumne River	25,666	2	1	<1	2	2	Extensive development and infrastructure
Stanislaus River	10,672	1	<1	<1	2	2	Riparian woodrat and riparian brush rabbit habitat

Source: Data generated for this analysis by AECOM, 2011

Notes:

[1] Data are for a corridor extending 1 mile from each river bank of evaluated rivers; acreages are rounded to the nearest 100 acres and percentages are rounded to the nearest percent.

[2] For nonurban areas and based on potential hydrologic regime using categories described by Williams et al., 2009, as indicated by floodplain inundation potential (FIP) determined using technique of Dilts et al., 2010, and AECOM, 2011. 67 percent chance Sustained Spring FIP represents elevations above water surface of base flow (i.e., March 2008 flows; LiDAR FIP) but at or below that of 67 percent chance spring flow sustained for at least 7 days (i.e., LiDAR FIP > 1 foot, and 67 percent chance Sustained Spring FIP ≤1 foot.); 67 percent chance Sustained Spring FIP corresponds to Frequently Activated Floodplain of Williams et al., 2009, and Salmonid FIP of pilot study. 50 percent chance FIP represents elevations above water surface of 50 percent chance flow but below that of 10 percent chance flow (i.e., 50 percent chance FIP >1 foot. and 10 percent chance FIP ≤1 foot).

[3] During 50 percent chance event, simulated under 2008 topography and infrastructure.

In many areas of floodplain hydrologically connected to the river system and lacking riparian vegetation, riparian vegetation could be established through natural processes or plantings. However, the SPFC often has insufficient capacity to allow for the increased roughness (i.e., resistance to water flow) of additional riparian vegetation. Thus, there is an opportunity to facilitate future restoration of these areas by increasing the capacity of the SPFC to allow for the increased roughness of riparian vegetation.

More than 60 percent of floodplain with a 67 percent chance Sustained Spring Flow or a 50 percent chance FIP is hydrologically disconnected from the river system by levees. Riparian and wetland vegetation cover only several percent of this disconnected floodplain. Also, less than 5 percent of this disconnected floodplain is conserved along most reaches. Reconnecting these floodplains, particularly areas with a 67 percent chance Sustained Spring FIP, to the river system could provide higher quality habitat for salmonids, and other ecological functions.

Disconnected areas with a 67 percent chance Sustained Spring Flow FIP are relatively extensive along the Sacramento River from Verona to the Delta Cross Channel, and along several reaches of the San Joaquin River: Gravelly Ford to Mendota Dam, Sand Slough to the Mariposa Bypass, and from the Stanislaus River to Stockton. However, major infrastructure constraints are also extensive along several of these reaches, in particular along the Sacramento River from Verona to Freeport. Thus, large-scale opportunities to restore these areas by setting back levees or otherwise reconnecting these areas to the river system are limited.

Extensive areas of disconnected floodplain with a 50 percent chance FIP are more widespread along the Sacramento and San Joaquin river systems than areas with a 67 percent chance FIP. Floodplain with a 50 percent chance FIP are extensive along the Sacramento River from Chico Landing to the junction with the American River; the lower Feather River, particularly from the junction with the Yuba River to the junction with the Sacramento River; and much of the San Joaquin River from Gravelly Ford to Stockton.

The feasibility, costs, and benefits of restoring any of these areas are strongly influenced by their relationship to CVFPP projects and policies, and by the content of the Central Valley Flood System Conservation Strategy (CVFSCS). Also, potential benefits differ qualitatively among reaches because sensitive species differ in their distribution. For example, reaches providing salmonid spawning habitat do not provide delta smelt habitat, and reaches providing riparian brush rabbit habitat may not provide bank swallow habitat. Consequently, the identification and prioritization of restoration opportunities are both part of the continuing development of the overall CVFPP and of the development of species-focused conservation planning and corridor management strategies, as described in the Conservation Framework of the 2012 CVFPP.

Based in part on the results of this FROA, DWR is identifying, prioritizing, and further developing specific restoration opportunities for these river reaches. Opportunities are being identified and prioritized on the basis of their potential ecological, flood management, and other benefits (e.g., reduced maintenance and regulatory compliance costs); cost; and regulatory, institutional, technological, and operational feasibility.

4.2 Recommendations

The following are recommendations for future use of the results of this analysis for development of CVFPP projects and the CVFSCS:

- Consider FROA results during project planning as general indicators of potential ecosystem benefits.
- Conduct additional stakeholder interviews to develop a more comprehensive compilation of stakeholder-identified projects.
- Apply FROA results to evaluate the ecosystem effects of alternative actions.
- Apply FROA results to CVFSCS development as a component of baseline ecosystem conditions together with a more comprehensive summary of riverine and riparian-associated species.
- Use FROA results to identify and/or prioritize sites for preservation or restoration.
- Integrate FROA results with mapping of SRA, revetment, and natural banks to more specifically consider reach-scale opportunities for restoring channel migration.

5.0 References

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6.0 Acronyms and Abbreviations

cfs	cubic feet per second
CNDDB	California Natural Diversity Database
Comprehensive Study	Sacramento and San Joaquin River Basins Comprehensive Study
CVFED	Central Valley Floodplain Evaluation and Delineation
CVP	Central Valley Project
CVFPP	Central Valley Flood Protection Plan
CVFSCS	Central Valley Flood System Conservation Strategy
Delta	Sacramento-San Joaquin Delta
DEM	digital elevation model
DFG	California Department of Fish and Game
DWR	California Department of Water Resources
EFR	Ecosystem Function Relationship
ESRI	Environmental Systems Research Institute, Inc.
FIP	floodplain inundation potential
FROA	Floodplain Restoration Opportunity Analysis
GIS	geographic information system
HAA	Habitat Analysis Areas
HAR	Height Above River
HEC-DSS	Hydrologic Engineering Center's Data Storage System
HEC-EFM	Hydrologic Engineering Center's Ecosystem Functions Model
HEC-GeoRAS	Hydrologic Engineering Center's River Analysis System
HEC-RAS	Hydrologic Engineering Center's River Analysis System
LiDAR	Light Detection and Ranging
MTL	Mean Tidal Level

MWH	MWH Americas, Inc.
NAVD88	North American Vertical Datum 1988
NGVD29	National Geodetic Vertical Datum of 1929
NOAA	National Oceanic and Atmospheric Administration
RM	River Miles
SacEFT	Sacramento River Ecological Flows Tool
SJRRP	San Joaquin River Restoration Program
SPFC	State Plan of Flood Control
SR	State Route
SRA	State Recreation Area
UPID	Union Pacific Interceptor Canal
USACE	U.S. Army Corps of Engineers
USACE-HEC	U.S. Army Corps of Engineers Hydrologic Engineering Center
USGS	U.S. Geological Survey
VELB	Valley elderberry longhorn beetle

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Attachment 9F: Floodplain Restoration Opportunity Analysis Appendix A – Floodplain Inundation and Ecosystem Functions Model Pilot Studies

June 2012

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Appendix A

1.0 Overview

This appendix provides the methods, results, and conclusions of two pilot studies conducted on the lower Feather River to evaluate the suitability of floodplain inundation potential (FIP) (also known as Height Above River (HAR)) (Dilts et al., 2010) and U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center's Ecosystem Functions Model (HEC-EFM) analyses for use in the Floodplain Restoration Opportunity Analysis (FROA). Each pilot study is discussed in a separate section:

- 2.0, Floodplain Inundation Pilot Study
- 3.0, Hydrologic Engineering Center's Ecosystem Functions Model Pilot Study

The approach of the FROA was developed in part from the results and conclusions of these pilot studies.

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2.0 Floodplain Inundation Pilot Study

2.1 Overview

This pilot study is a test of the proposed approach for the FROA displayed on Figure A-1. This approach uses readily available topographic and hydrologic data sets, and straightforward geographic information system (GIS) analyses to identify floodplains inundated under more frequent, ecologically valuable flow events (e.g., 50 and 10 percent chance events). The HAR tool (Dilts et al., 2010) was identified as a method that could potentially be adapted for use in this FIP analysis. GIS layers based on the results of this analysis would show floodplains that could be more readily reconnected to the river during specific flow events. The specific method of this approach is described in the following sections.

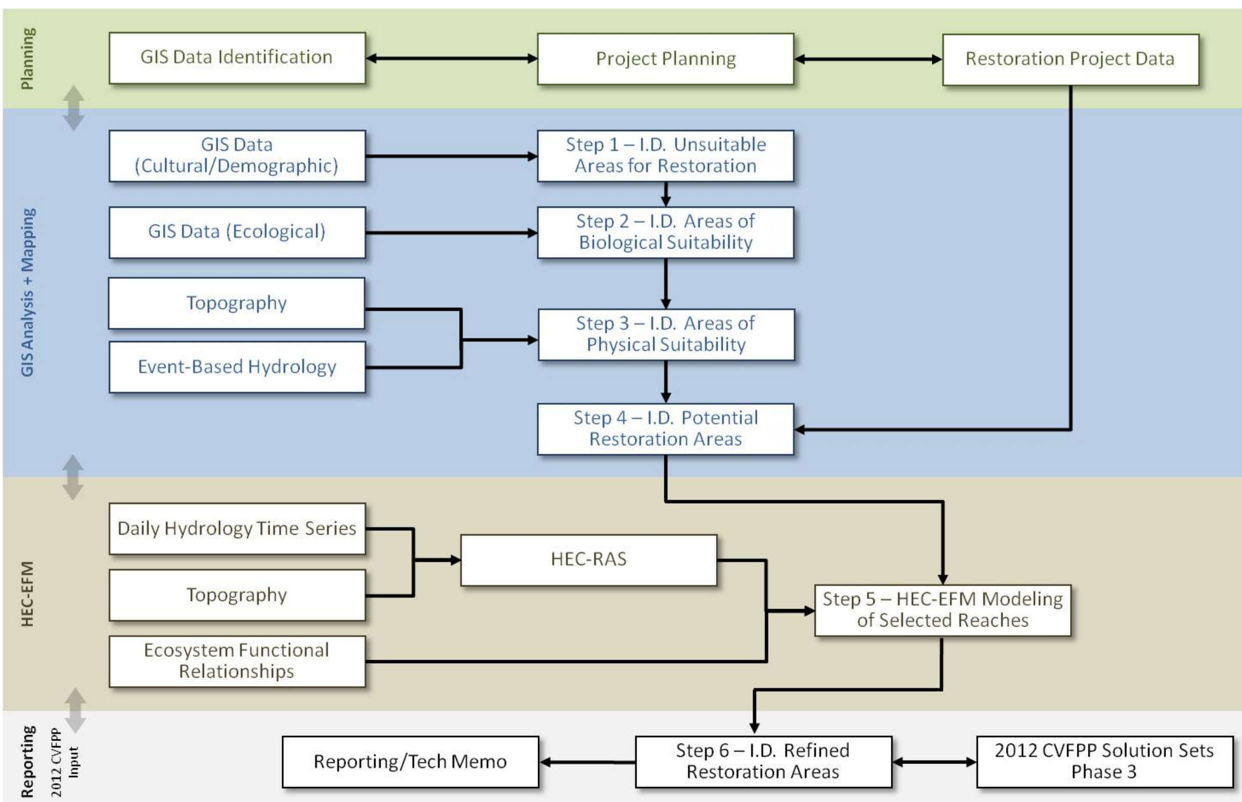

Figure A-1. Proposed Approach for CVFPP Floodplain Restoration Opportunity Analysis

For the purpose of this work, the “FIP method” is the term used to describe a series of GIS tools provided within the Riparian Topography Toolbox, as described by Dilts et al. (2010). These tools are distributed as the ArcGIS Riparian Topography Toolbox by Environmental Systems Research Institute, Inc. (ESRI) (ESRI, 2011).

Through our review and application of the publically available tools in this toolbox, and with the use of unpublished tools provided by Mr. Dilts, we have established a series of steps that constitute the FIP method. These steps are described in the following sections:

- 2.2, Identify Pilot-Study Area
- 2.3, Compile and Review Data
- 2.4, Generate Stream Raster
- 2.5, Calculate Flooplain Inundation Potential
- 2.6, Calculate Flood Height
- 2.7, Calculate Inundation Area

The Riparian Topography Toolbox tools were developed for application to actual river water surface conditions at the time of a Light Detection and Ranging (LiDAR) flight. Since an objective of this pilot study was to investigate the application of these tools to hypothetical flood conditions, other than observed water surface conditions, some deviations were made in the application of the tools; however, the Generate Stream Raster tool was common to all applications.

Section 2.8 describes notes that data were modified to account for two locations in the pilot study area, two locations where levees had been set back after the March 2008 date of the LiDAR flight. Sections 2.9 through 2.11 provide the height above river results, inundation area results, and the conclusions of this pilot study, respectively.

2.2 Identify Pilot-Study Area

An approximately 20-mile reach of the Feather River was selected for the pilot study from the confluence with the Sutter Bypass, upstream to Yuba City at River Station (RS) 27.75 (Figure A-2); the purple rectangle shown on Figure A-2 indicates the specific subreach to which the FIP method was applied.

2.3 Compile and Review Data

The following data were compiled and reviewed in preparation for the application of the HAR tool to the pilot-study area.

1. Terrain Data – Central Valley Floodplain Evaluation and Delineation (CVFED) preprocessed LiDAR and breakline data were obtained and processed into 25-foot digital elevation models (DEM).

2. Water-Surface Profiles – The following water-surface profiles were used in the pilot study:

   a. March 2008 LiDAR water-surface profiles – The river water surfaces at the time of the LiDAR flight were used for initial investigations of the relationship of water levels to floodplain inundation.

   b. Ten- and 20-foot test profiles – Arbitrary heights of 10 and 20 feet above the LiDAR water surface were used initially to evaluate floodplain inundation areas from higher water levels; these heights were replaced by the Sacramento and San Joaquin River Basins Comprehensive Study (Comprehensive Study) (USACE and The Reclamation Board 2002) 50 and 10 percent chance water-surface profiles for further investigations.

   c. Comprehensive Study 50 and 20 percent chance event water-surface profiles – Water-surface profiles for these two return period flood events were obtained by running the Comprehensive Study's model derived from the USACE Hydrologic Engineering Center's River Analysis System (HEC-RAS) for the pilot study river reach.

   d. Vertical datum conversion – Water surface elevations from the HEC-RAS models are in the older National Geodetic Vertical Datum of 1929 (NGVD29) vertical datum and were converted to the current North American Vertical Datum 1988 (NAVD88) vertical datum to match the vertical datum of the terrain data. Figure A-3 summarizes the spatial variation of the conversion factors in the Central Valley. An average of the conversion factors along the pilot-study stream reach was estimated and this value of +2.335 feet was applied to the HEC-RAS NGVD29 elevations to estimate the NAVD88 elevations.

Figure A-2. Lower Feather River Pilot-Study Area

The vertical datum conversion was cross-checked by identifying the latitude/longitude of the pilot-study reach and entering this into the National Geodetic Survey (NGS) on-line tool VERTCON (NGS, 2011) to perform the conversion, and the results were similar.

ArcGIS Riparian Topography Toolbox – The Riparian Topography Toolbox for ArcGIS was downloaded from the ESRI Web site (ESRI, 2011). The HAR tool is one of the tools contained within the Riparian Topography Toolbox and includes tools for calculating FIP, inundation area for a given FIP, and flood height.

The FIP method requires the use of a DEM terrain surface. Two sources of DEMs were evaluated for use in the pilot study: (1) U.S. Geological Survey (USGS) 10-meter DEMs (USGS, 2010), and (2) CVFED preliminary DEMs (DWR, 2010b).

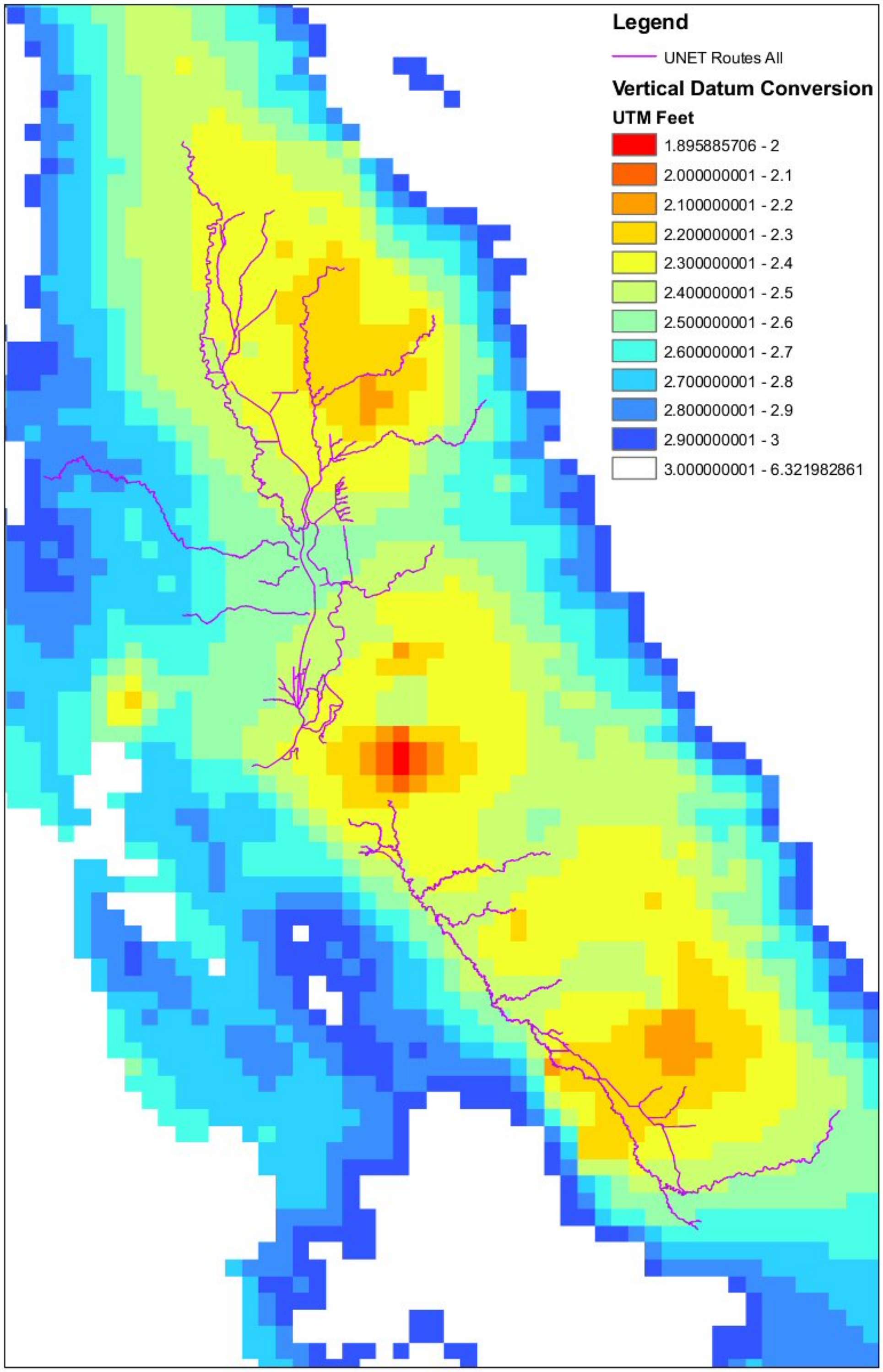

Figure A-3. Central Valley NGVD29 to NAVD88 Vertical Datum Conversion (NAVD88 elevations are higher than NGVD29 elevations)

USGS 10-meter DEMs (USGS, 2010) were obtained and evaluated for their appropriateness of use in the pilot study. Appendix B provides the methods and results of a brief assessment of the data, which led to the decision not to use the USGS data because of the significant inaccuracies found in the delineation of project levees and ground elevations.

New DEMs are being prepared as part of the CVFED program, though the final DEMs have not been completed. Available preliminary CVFED terrain data were obtained for the pilot-study area in October 2010, for use in preparing a DEM for the pilot-study area. The DEM preparation involved incorporating/building breaklines and filling in void areas found in these preliminary CVFED data. The LiDAR data had data voids where water and dense vegetation restricted the triangular irregular network (TIN) from triangulating, essentially leaving large gaps in the TIN. Points were created in those areas to help complete the TIN.

A brief comparison was done to determine the level of effort and resulting data file sizes for the preparation of a DEM with a 5-, 25-, 50-, and 100-foot grid cell resolution (Appendix C). Based on the results of this comparison, DWR decided to develop a 25-foot DEM using preprocessed CVFED data in the pilot-study area. The use of a 25-foot-resolution DEM was determined to provide a reasonable balance between the preparation time, resolution (usability), and file sizes with the intended level of detail for the final products from this planning-level exercise.

2.4 Generate Stream Raster

One of the first tasks required for the FIP analysis was the generation of the Stream Raster. This was previously accomplished through a series of steps using ArcHydro and Arc Map; however, a new unpublished tool “Derive Stream Raster” replaces the previous process and the tool was obtained from Mr. Dilts, the HAR author (Dilts, 2011). The Derive Stream Raster tool was located by navigating through the Topography Tools toolbox as follows: Topography Tools → Riparian Tools → Transverse → 2_Derive Stream Raster. The following steps were taken to complete the generation of the stream raster using Derive Stream Raster, and the input menu is shown on Figure A-4:

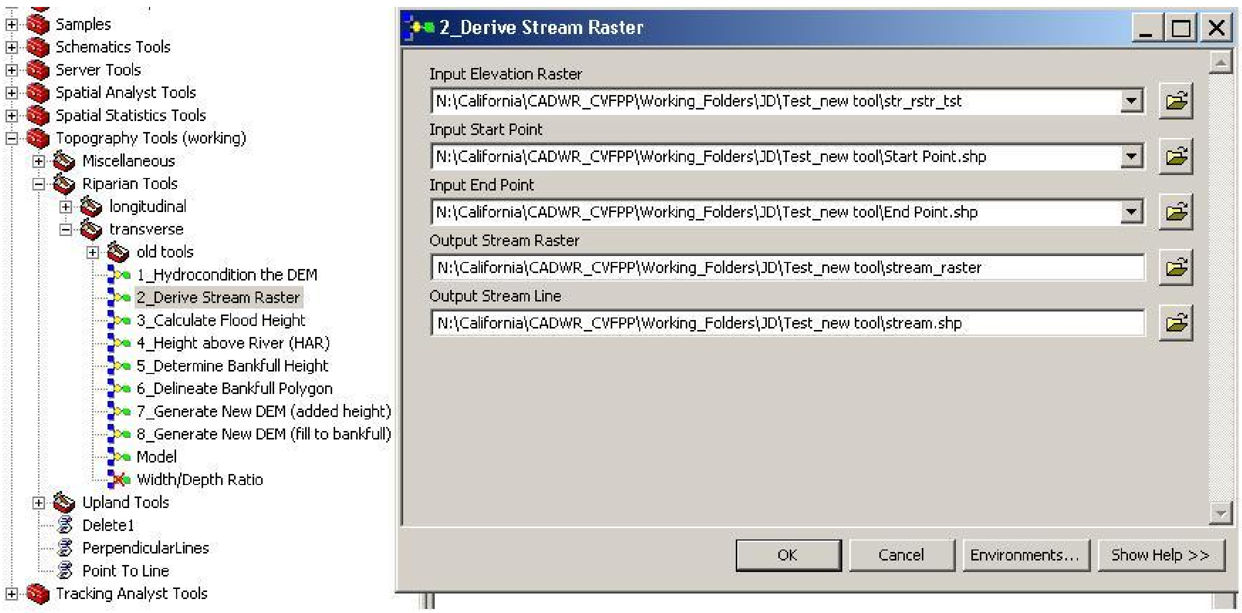

Figure A-4. Toolbox Folder Structure

1. **Input Elevation Raster** – Enter the file location for the 25-foot DEM.

2. **Input Start Point and Input End Point** – Create two new shapefiles, each consisting of one point named “Start Point” and the other “End Point.” In the Start Point shapefile, a point was placed at the start (upstream limit) of the pilot-study stream reach of interest. In End Point shapefile, a point was placed at the end (downstream limit) of the pilot-study stream reach of interest. The DEM was used as a visual aid to locate these points along the centerline of the stream channel.

3. **Output Stream Raster** – Assign name and location to place output stream raster grid cells (Figure A-5a).

4. **Output Stream Line** – Assign shapefile location and filename for stream raster grids converted to polyline (Figure A-5b).

2.5 Calculate Floodplain Inundation Potential

The HAR tool was located by navigating through the Topography Tools toolbox as follows: Topography Tools → Riparian Tools → Transverse → 2_HAR → right-click → Edit. The HAR tool methodology is shown in a flow chart on Figure A-6, where blue ovals indicate data entry steps, the yellow boxes are tool processes, and the green ovals are outputs from processes.

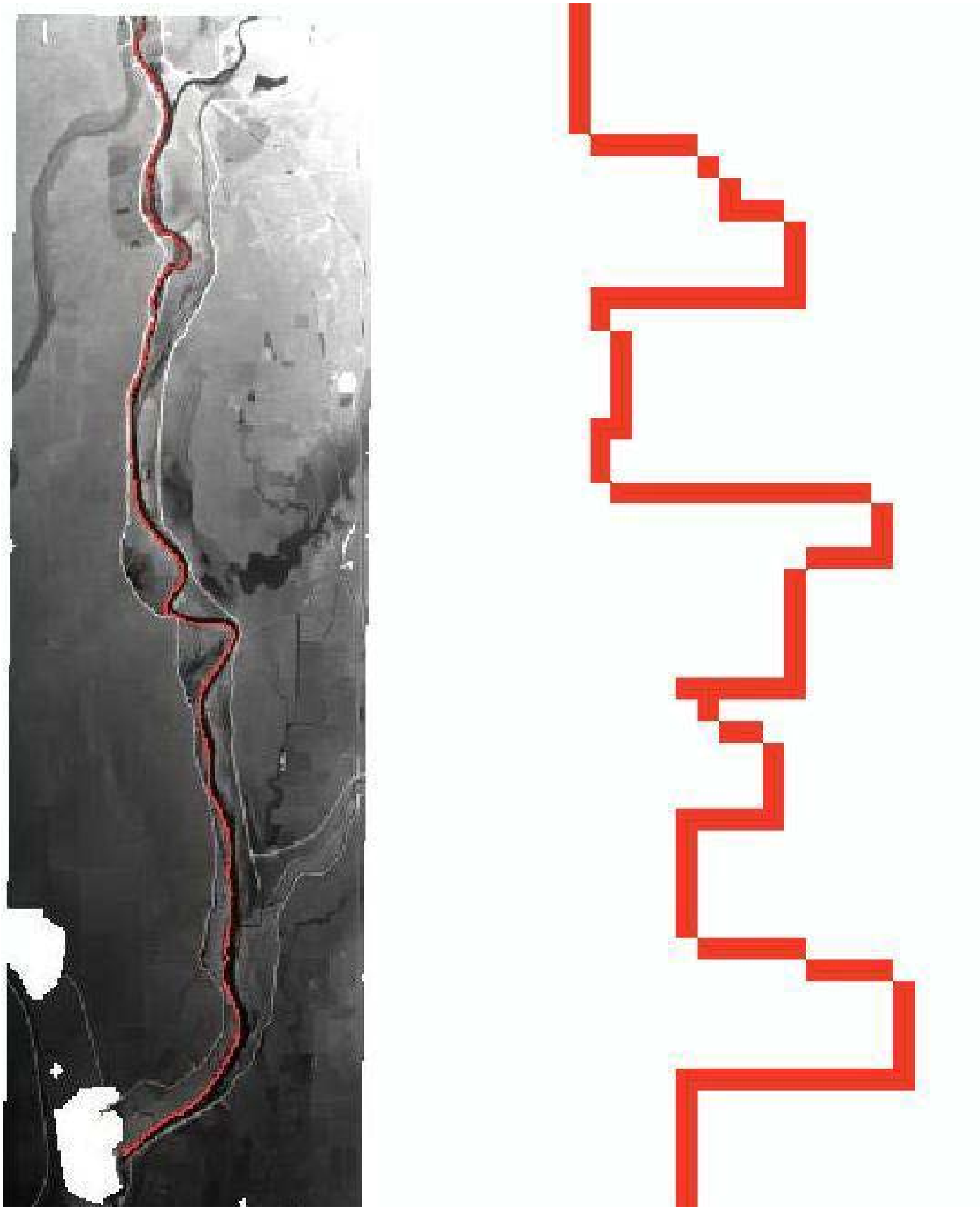

Figure A-5. Output Stream Raster (5a) and Output Stream Line (5b)

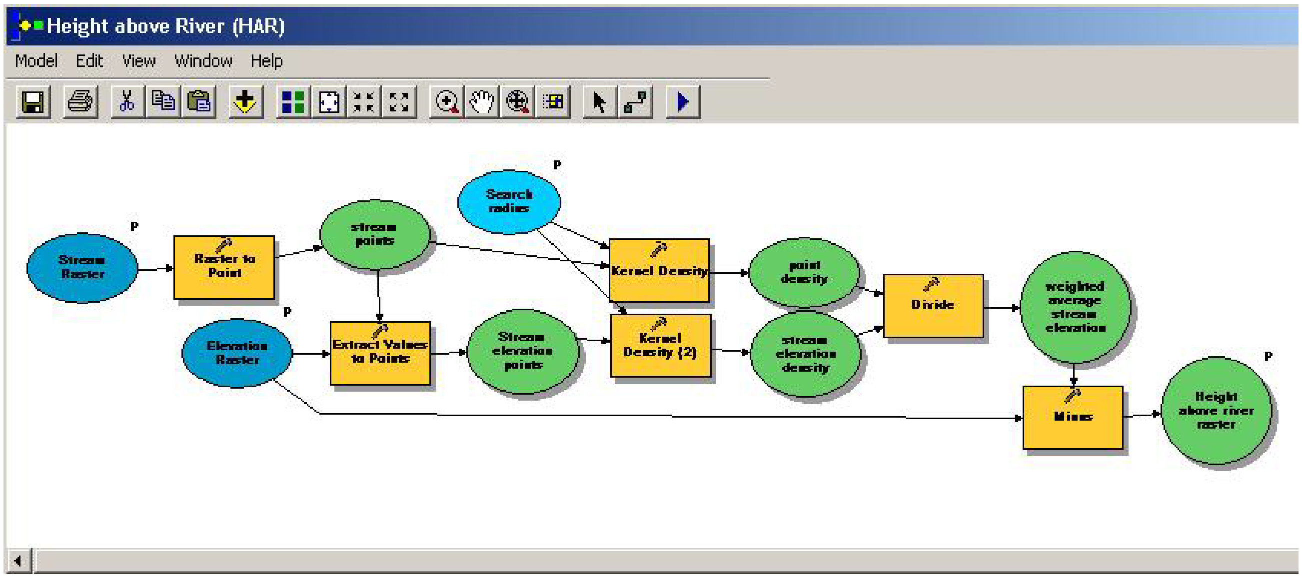

Figure A-6. HAR Tool Methodology

The significant steps in the methodology (indicated by the yellow boxes) are described as follows in the order that they were accomplished during the pilot study:

1. **Stream Raster –** Browse to the location of the output stream raster and input the file path.

2. **Elevation Raster –** Browse to the location of the DEM and input the file path. The first raster used in this process was derived from the LiDAR terrain model. To investigate the conditions associated with the 50 and 10 percent chance flood in the pilot-study reach, the initial LiDAR DEM was modified by adding the 50 and 10 percent chance water-surface profiles from the HEC-RAS model. This was done by extracting the LiDAR water surface elevations (WSEL) and inserting the HEC-RAS 50 and 10 percent chance WSELs, creating an artifically raised surface within the banks of the river channel. The remaining steps in this methodology remain the same and were applied three times to the LiDAR water-surface profile, and the 50 and 10 percent chance water-surface profiles.

3. **Search Radius –** Enter search radius (in feet only). This is the radius that was applied to each point on the stream line created in the next step and establishes the spatial extent of the FIP analysis; during the pilot study, the search radius was increased from 5,280 feet to 7,000 feet after a preliminary review of the output indicated the initial radius length did not capture all of the levees adjacent to the stream reach.

4. **Raster to Point –** The HAR tool pulls the output stream raster and converts it to points and asssigns a new filename with file location assigned by user (Figure A-7).

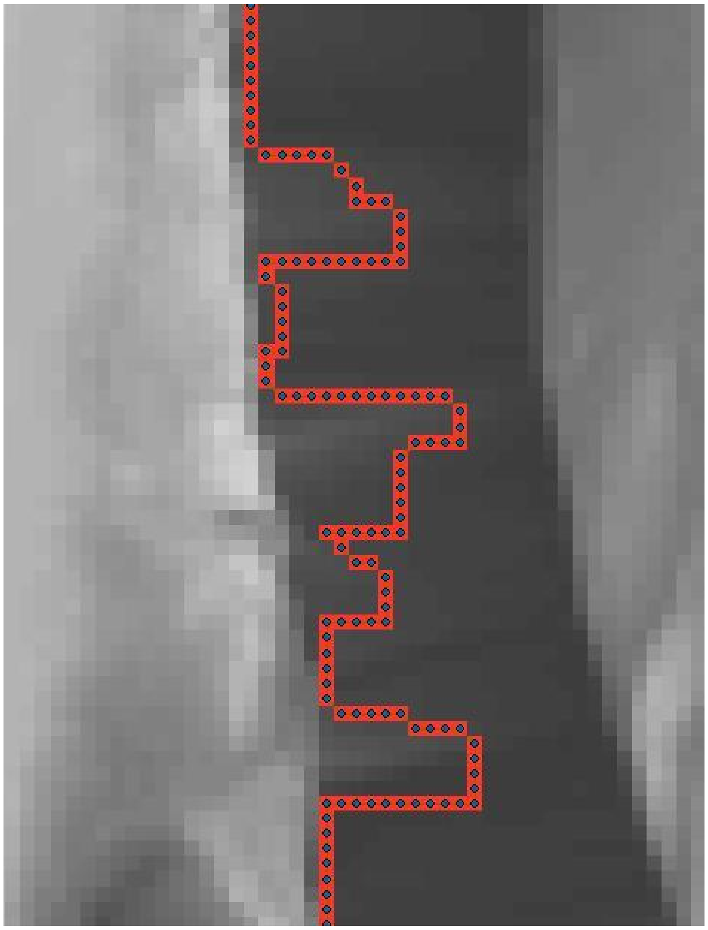

Figure A-7. Raster to Point

5. **Extract Values to Points –** The stream points (Step 4) and elevation raster (Step 2) are identifed, and the filename and file location assigned in Step 4 are assigned again by the user. Note that the HAR tool saves files to the last saved filepath and filename; thus, these default filenames and locations may need to be replaced with the correct values.

6. **Kernel Density –** The HAR tools pulls stream points (Step 4), and the population field is set at "NONE." The filename and file location assigned in Step 4 are assigned again by user. Output cell size (optional) was changed to "25" to match the DEM grid size (in feet). Search radius is pulled from Step 3 and area units was left as default "SQUARE_MAP_UNITS." The output from this process is the stream point density.

7. **Kernel Density 2 –** The HAR tools pulls stream elevation points (Step 4), and the population field is set at “RASTERVALU,” which was manually entered into the population field. The filename and file location assigned in Step 4 are assigned again. Output cell size (optional) was changed to “25” to match the DEM grid size (in feet). Search radius was pulled from Step 3 and area units was left as default “SQUARE_MAP_UNITS.” The output from this process is the stream elevation density.

8. **Divide –** The HAR tool pulls the stream elevation density file (Step 7) and point density file (Step 6) into the Input raster or constant value 1 and 2, respectively, and divides the values of the two rasters on a cell-by-cell basis. The output is the weighted average stream elevation.

9. **Minus** – The HAR tool takes the elevation raster (Step 2) and the weighted average stream elevation (Step 8) and subtracts the value of the weighted average stream elevation from the elevation raster on a cell-by-cell basis. The output is the HAR raster. A closeup of the HAR raster for the LiDAR water-surface profile is shown on Figure A-8a, with the HAR raster for the entire pilot-study reach shown on Figure A-8b.

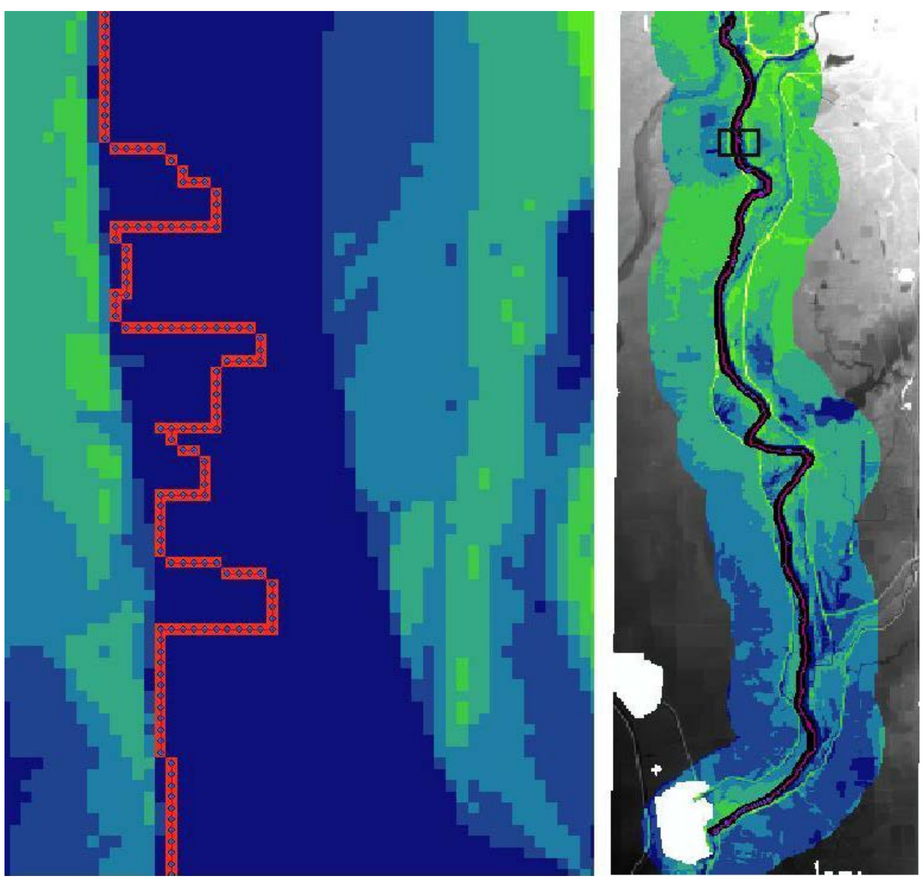

Figure A-8. HAR Closeup (8a) and Pilot Study Reach (8b)

2.6 Calculate Flood Height

A Calculate Flood Height tool is provided in the Riparian Topography Tools toolbox; however, in lieu of this approach, flood height was estimated by changing the symbology of the HAR raster. This method proved to be quicker, provided equivalent results, and involved the following steps:

1. The HAR raster was brought into ArcMap. Pyramids were built when prompted to improve image quality.

2. The HAR raster Properties were selected by right-clicking the HAR raster and clicking Properties.

3. Layer Properties – The Symbology tab was selected and the Show entered “Classified” was choosen and Compute Histogram was activated by clicking Yes when prompted.

4. Classification – The Natural Breaks (Jenks) – The Classify button was clicked to open the Classification menu box. User selects number of Breaks.

5. Break Values – These values were set so the lowest value in the HAR raster was in the same Break Value range as the height of the flooding. No other values were changed because the flood height was the only value necessary. The OK button was selected when values were set.

6. Layer Properties – Color Ramp – Symbol, Range, Label – The symbol for the range containing the lowest HAR raster value and the flood height value was changed to a color different from the rest of the ranges.

2.7 Calculate Inundation Area

The “Calculate Inundation Area” tool was located by navigating through the Riparian Topography Tools toolbox as follows: Riparian Topography Tools → Calculate Inundation Area→ right-click → edit. The “Calculate Inundation Area” tool methodology is shown in a flow chart on Figure A-9, where blue ovals indicate data entry steps, the yellow boxes are tool processes, and the green ovals are outputs from processes. The steps in the methodology are described as follows in the order that they were accomplished during the pilot study:

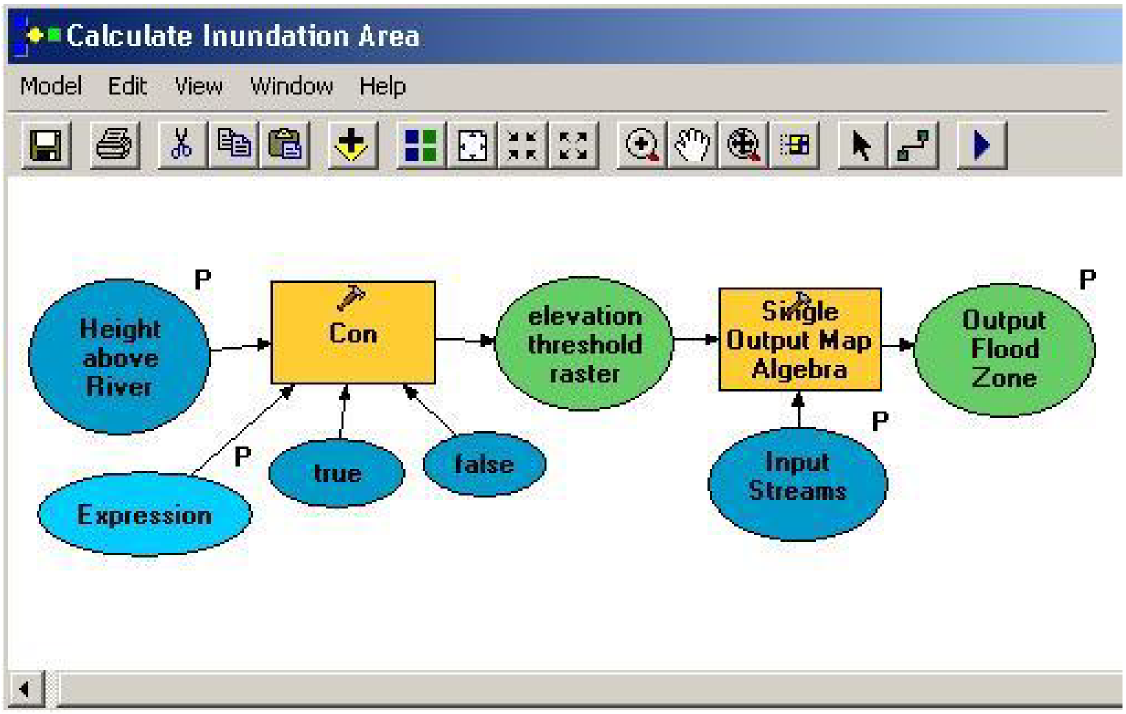

Figure A-9. Calculate Inundation Area

1. **Height above River Raster –** Browse to location of HAR raster and input file path.

2. **Input streams –** Browse to location of stream raster and input file path.

3. **Expression (optional) –** The value entered here is the height above the FIP water-surface profile, and it sets threshold elevation and code values either above or below this surface, with the cells below the FIP value directly connected to the river. Through trial and error we determined that the minimum value to enter here is 1.0 foot owing to the elevation variability imposed on the true water surface by the FIP method.

4. **Output flood zone –** Assign raster location and filename for inundation area.

2.8 Levee Realignment Methodology

Within the Feather River pilot-study reach, the project team noted that there were two locations where levees had been set back after the March 2008 date of the LiDAR flight. This resulted in a need to adjust the DEM terrain surface to show actual current topographic conditions. While the FIP output in this technical memorandum still shows the March 2008 levee positions, a separate effort was made to determine a reasonable methodology to adjust levee locations for subsequent FIP analyses. This methodology is described in Appendix D.

2.9 Height Above River Results

The LiDAR water-surface profile FIP results are shown on Figure A-10, together with an aerial photograph of the same location in the pilot study reach. Only heights above the river (water surface) are shown with increasingly lighter colors representing land areas higher above the water surface.

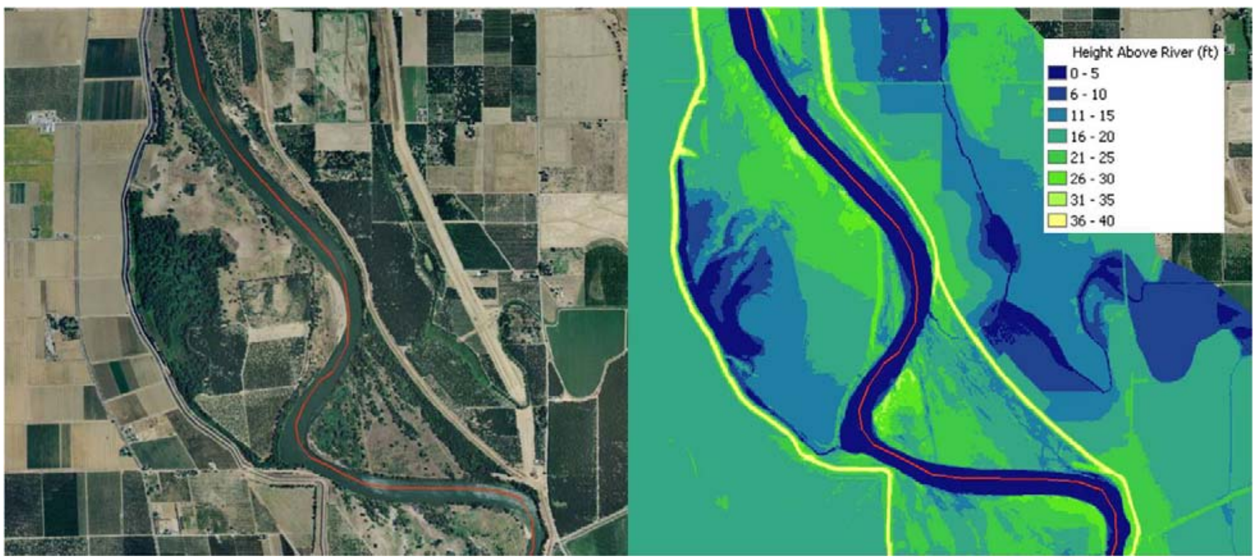

Figure A-10. LiDAR Water-Surface Profile FIP Output

This initial FIP analysis used the actual WSEL at the time of the CVFED LiDAR flights to define the FIP. The CVFED LiDAR data was flown between March 17, 2008, and March 31, 2008, when the flow was approximately 660 to 670 cubic feet per second (cfs).

The FIP output allows for a quick assessment of adjacent floodplain lands at or below the water surface of the river and above the water surface. In this particular location, the relative extent of low-lying lands west of the river is apparent (where the forested area is shown on the aerial photograph), and it is clear that this area is hydraulically connected only at the downstream end.

Other low-lying land areas are east of the river, immediately landward of the east levee. However, it is noted that in this particular reach of the Feather River, levee setbacks have occurred since the LiDAR flight date, and a portion of the levee locations shown on Figure A-10 are outdated. A technique was developed to realign levees on the DEM; this method was discussed in Section 2.2.8 and will be applied to levee sections where recent restoration projects have resulted in a change in levee alignments since the LiDAR flights in March 2008.

The 50 percent chance water-surface profile (corresponding to a discharge of approximately 80,258 cfs) was added into the DEM and run through the HAR tool. The results shown on Figure A-11 now include depths below the 50 percent chance water-surface profile, as well as above. Land elevations within +/-1 foot of the 50 percent chance water-surface profile are shown in the lightest shade of blue, with depths below this surface shown as increasingly darker shades of blue and heights above this surface shown in white. A +/- 1-foot height was used to approximate a given water surface for mapping purposes because the kernel density radius interpolation of elevation points at hydraulic model cross sections that was used to calculate the water surface resulted in an undulating surface (i.e., the interpolation routine between points of known elevation resulted in estimated elevations that varied within 1-foot of true values). The mapped area includes land area within a 7,000-foot search radius from the stream centerline, with blue shading indicating inundation areas connected to the river and gray shading indicating inundation areas disconnected from the river.

At a glance, it is clear that much of the floodplain land area in this portion of the pilot-study reach is below the 50 percent chance water-surface profile, except for the upper portion of the reach, as shown on Figure A-11.

Figure A-12 provides similar FIP output for the 10 percent chance water-surface profile (corresponding to a discharge of approximately 159,912 cfs). The color ramping of the depth increments below and of the height increments above the water surface and the scaling is consistent between the 50 and 10 percent chance FIP results, and it indicates that floodplain land area throughout the pilot-study reach is significantly below the 10 percent chance water-surface profile, with the levees being the only land features above the water surface.

2.10 Inundation Area Results

The Calculate Inundation Area tool floods all raster cells below a user-specified FIP and shows flooded land areas that are directly connected to the river. The connected and disconnected inundation areas for a portion of the pilot-study reach are shown on Figures A-11 and A-12. The connected and disconnected inundation areas for the entire pilot-study reach for the LiDAR flight (March 17 to 31, 2008), the 50 percent chance, and

10 percent chance flood profiles are provided in Appendix E. As expected, the inundation areas for the return period flood events are contained within the levees.

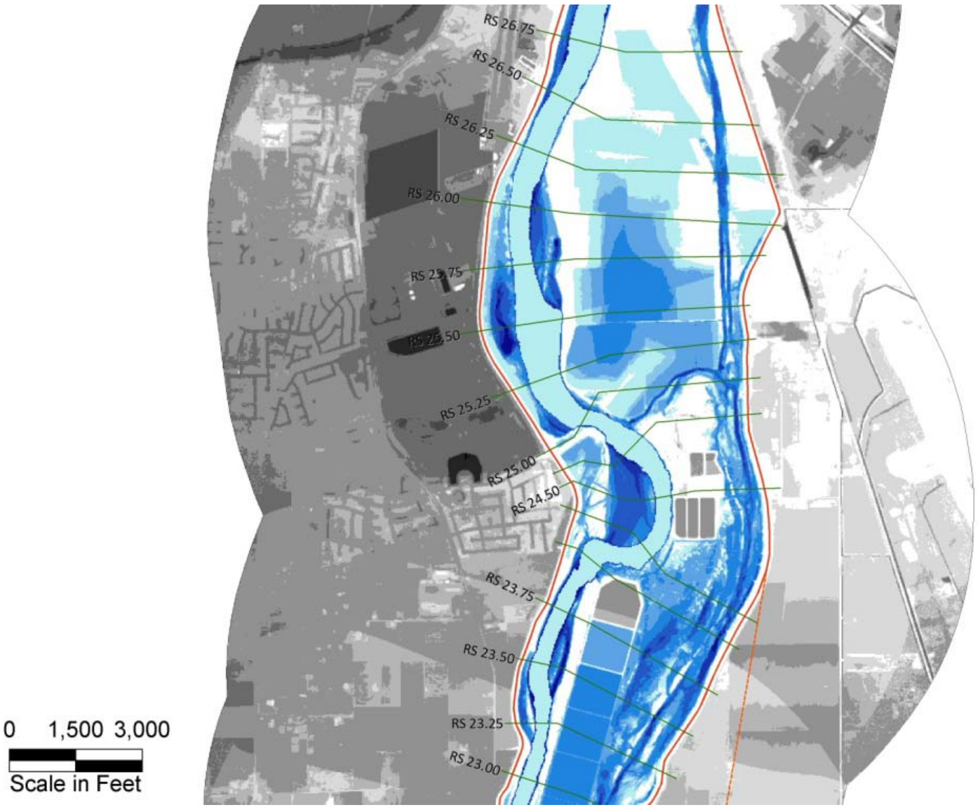

Figure A-11. 50 Percent Chance Water-Surface Profile FIP Output

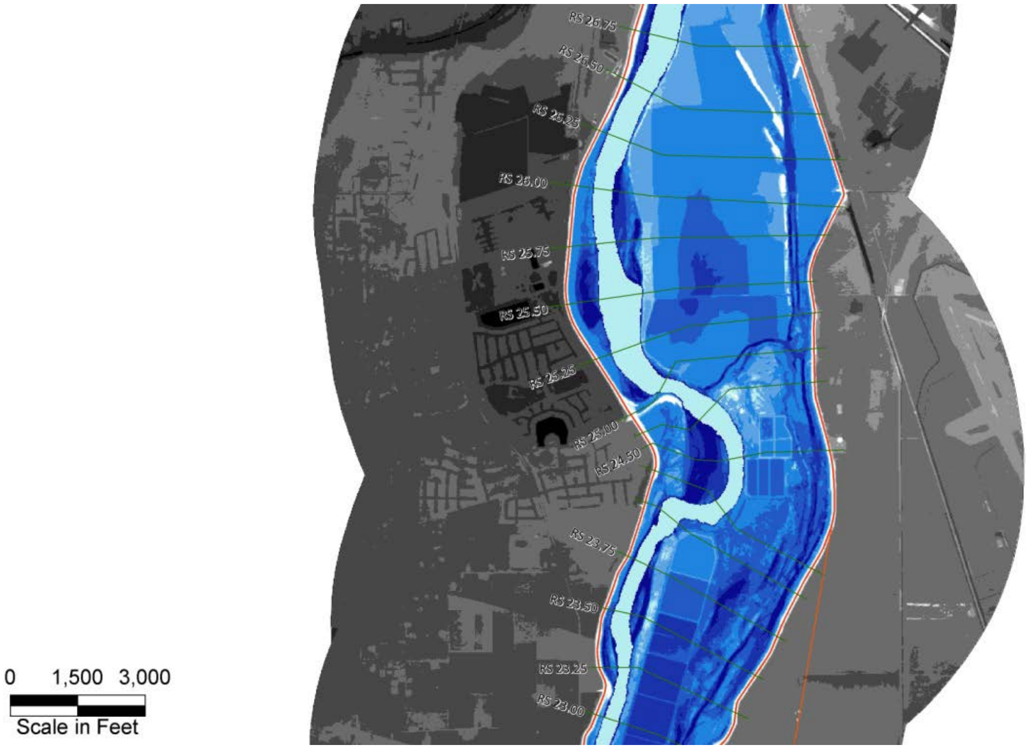

Figure A-12. 10 Percent Chance Water-Surface Profile FIP Output

After a review of these figures, a question arose as to whether the 50 percent chance flood would actually flood most of the land areas between the levees. The HEC-RAS modeling was reviewed to confirm the lateral extent of the 50 percent chance flood. Figure A-13 shows a representative cross section of the 50 percent chance flood stage at RS 19.00 on the Feather River, between the Yuba and Bear river confluences. The 50 percent chance discharge is 80,258 cfs, and the associated 50 percent chance water surface elevation is 47.99 feet. The LiDAR-based water surface elevation at the same location is between 26 feet and 27 feet, or approximately 20 feet lower than the 50 percent chance flood stage.

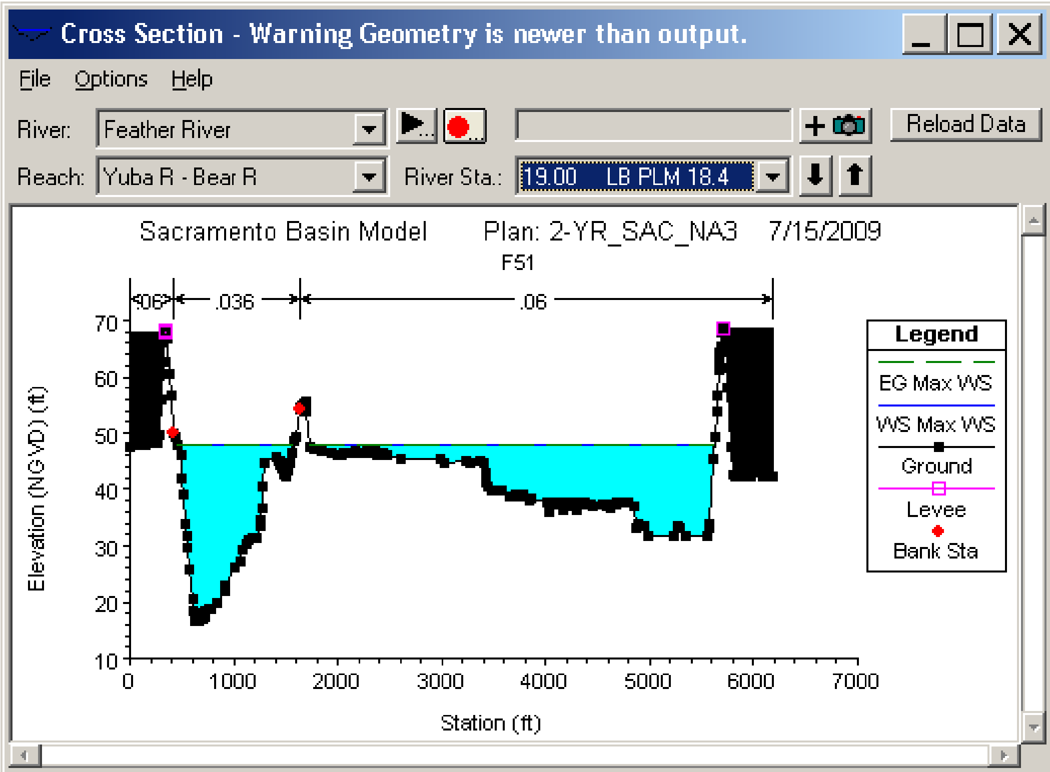

Figure A-13. Cross Section of 50 Percent Chance Flood Profile (RS 19.00)

While the right overbank area appears to be disconnected from the channel, based on the cross-section plot alone, it is possible that this overbank area is connected to the main channel upstream or downstream. Based on the results of the FIP mapping, areas were classified as either “connected” or “disconnected” to the main channel. Disconnected areas do not directly connect to the main channel.

The spatial data on inundation depths for the 50 percent chance and 10 percent chance flood events were summarized in a tabular format and are provided in Table A-1. Recognizing that the connected areas are constrained by the physical presence of levees and the disconnected areas are constrained between the levees and an imposed 7,000-foot search radius from the stream centerline, the relative change in inundation areas by depth was reviewed. For the 50 percent chance flood, the majority of the inundation area falls within the minus 2-foot to minus 9.9-foot depth classes and, as expected, the 10 percent chance inundation area falls within the deeper minus 5-foot to minus 19.9-foot depth classes. Looking at the totals, the 10 percent chance flood only inundates 3,200 additional areas than the 50 percent chance flood, about a 7 percent increase.

Table A-1. Areas of Inundation Depths at 50% and 10% Chance Flood Events

Depth Range	Areas of Inundation Depths at 50% and 10% Chance Flood Events (Acres)			
	50% Chance Connected	50% Chance Disconnected	10% Chance Connected	10% Chance Disconnected
< - 20 feet	200	300	900	1,900
- 15.0 to - 19.9 feet	400	1,100	1,400	7,800
- 10.0 to - 14.9 feet	900	4,600	2,600	15,200
- 5.0 to - 9.9 feet	2,200	13,100	2,600	6,400
- 2.0 to - 4.9 feet	1,800	7,400	700	1,100
- 1.0 to - 1.9 feet	600	1,800	100	200
1 to - 0.9 foot	2,100	3,500	1,300	1,400
Total	**8,200**	**31,800**	**9,600**	**34,000**

2.11 Conclusions

The FIP method is a relatively effective way to quickly and easily find features on the land surface that are either above or below a specified water-surface profile.

The GIS spatial output from the FIP method can provide a benefit for the visualization of floodplain restoration opportunities for planning or reconnaissance-level investigations, including the following specific considerations:

1. Color ramping of FIP output showing height increments both above the river (water surface) and below can provide a rapid visualization of the low-lying land areas physically connected to a river channel, or capable of being connected, and the relative depth of these topographic depressions.

2. The relative depth of adjacent topographic depressions can also be referenced to qualitatively assess the level of effort (e.g., earthwork) necessary for setback levees and/or floodplain terracing as a floodplain restoration technique; for example, setback levees aligned across a topographic depression will require a greater amount of fill to maintain a certain levee crest elevation than if the levee was aligned around the topographic depression on higher ground.

3. The Comprehensive Study HEC-RAS models are limited in extent, in that the model cross sections of the floodplain only extend between the levees (USACE and The Reclamation Board, 2002). The FIP output

> provides estimates of flood profile elevations and flood depths beyond the levees, and this information can be used to guide qualitative investigations into potential levee setback locations. Although the FIP method is not a substitute for detailed hydraulic modeling, it does provide an ability to relatively quickly understand flood characteristics across the floodplain landscape.

Work has been initiated to update tools and unpublished versions have been provided for use in this pilot study. Because of this, the generation of the Stream Raster, which is a very important component to the FIP, is now automated and can be applied more quickly to future FIP investigations.

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3.0 Hydrologic Engineering Center's Ecosystem Functions Model Pilot Study

This section summarizes the HEC-EFM pilot study in four sections:

- 3.1, Methods
- 3.2, Results and Sensitivity
- 3.3, Mapping
- 3.4, Conclusions

3.1 Methods

This section describes the methods and approaches used to perform the HEC-RAS/HEC-EFM (RAS/EFM) analysis on the lower Feather River near Yuba City, California. As discussed, the goal of this study was to document the standard methods and approaches required for a RAS/EFM analysis and to identify potential issues, if any, and/or alternative approaches. The following tasks were conducted as part of the RAS/EFM analysis:

- Selection of the pilot-study area
- Data collection and review
- Identification of Habitat Analysis Areas (HAA)
- HEC-RAS modeling
- HEC-EFM analysis

The remainder of this section describes these tasks in more detail.

3.1.1 Selection of the Pilot-Study Area

The pilot study was conducted on a 21-mile reach of the lower Feather River, from the confluence with the Sutter Bypass, upstream to Yuba City at RS 27.75 (see Figure A-14). The area was chosen for the availability of data and the project team's familiarity with the area. Within the study area, the lower Feather River maintains levees along both banks and receives flow from the Yuba and Bear rivers. It also maintains inflows and outflows resulting from agricultural and groundwater sources.

3.1.2 Data Collection and Review

A steady-state, geo-referenced HEC-RAS model of the Feather River, from the confluence with the Sutter Bypass to the Thermalito Afterbay, and synthetic daily flow hydrographs from October 1, 1921, to September 30, 2003, were provided to AECOM by MWH Americas, Inc. (MWH).

The HEC-RAS model was developed by MWH based on the Feather River Sacramento-San Joaquin Comprehensive Study UNET hydraulic model (USACE and The Reclamation Board 2002). MWH converted the original Comprehensive Study UNET model to HEC-RAS, geo-referenced the model, and calibrated the model to low-flow conditions. The model files were provided via FTP on November 30, 2010.

The Feather River synthetic daily flow hydrographs were developed by MWH from monthly flow hydrographs computed by the CalSim model. Hydrographs were provided by MWH via e-mail on December 8, 2010. Development methodology for the synthetic daily flow hydrographs was

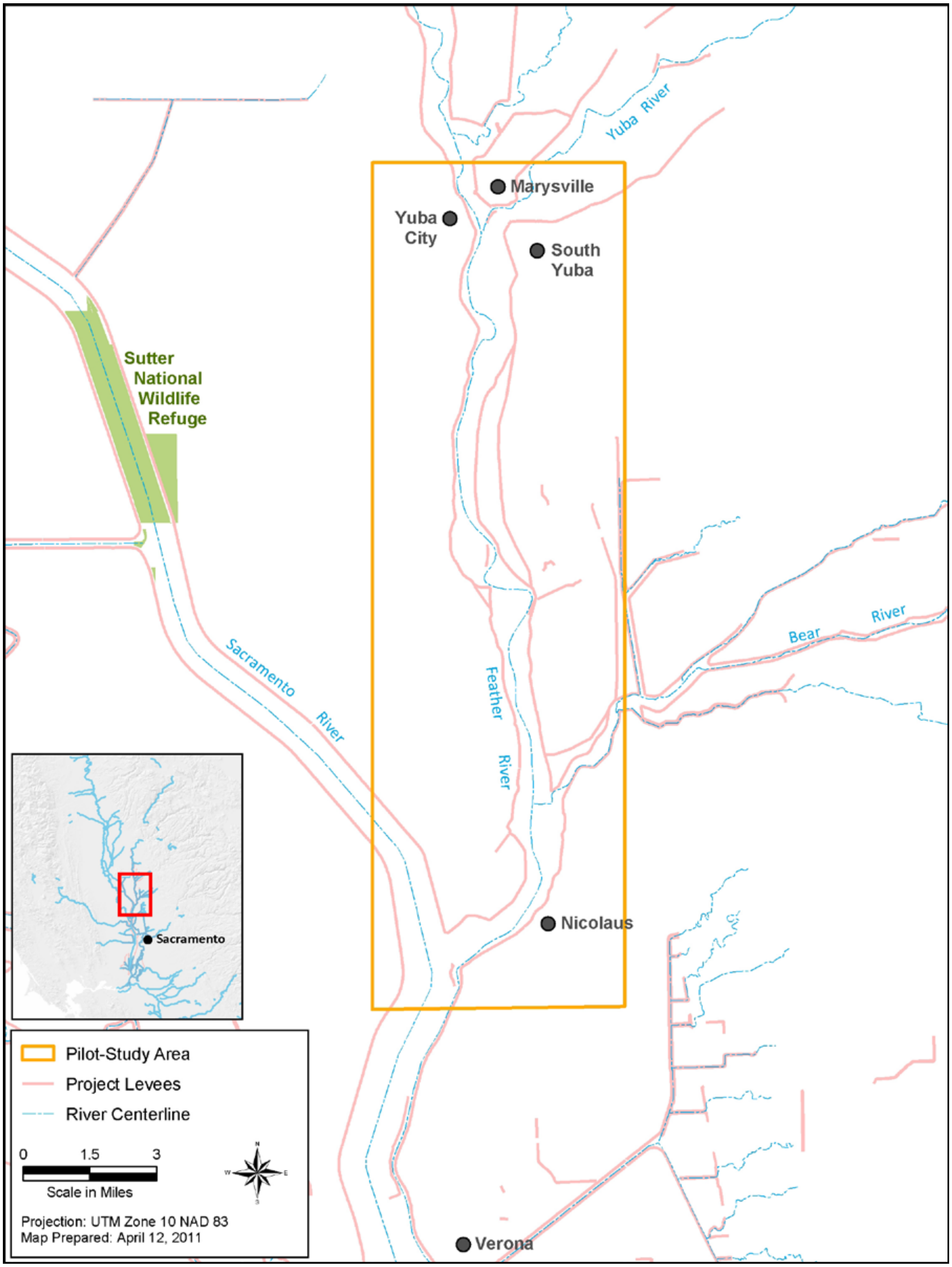

Figure A-14. Lower Feather River Pilot-Study Area

outlined in a draft document prepared by MWH, titled *Feather River Daily Flows for HEC-EFM* (2011). This document is currently being finalized by MWH and will be submitted to California Department of Water Resources (DWR) separately from this report.

The following actions were performed during the review and application of the HEC-RAS model and synthetic daily flow hydrographs.

1. The model was reviewed briefly to confirm its appropriateness for this study and to review the geo-referencing, reach lengths, and Manning's *n* values. Detailed features or assumptions, such as the value of coefficients, the stations, and elevations of levees and ineffective flows areas, and other detailed aspects of the model were not reviewed.

2. Areas of the model upstream from the Feather River and Yuba River confluence were removed and the upstream boundary was set to RS 27.75. This was done to remove unnecessary complexities upstream from the study area. Figure A-15 shows an overview of the revised HEC-RAS model.

3. An unsteady-state version of the model was developed, requiring the following actions:

    a. Modification of the model geometry

       An inline weir was added at RS 24.00 to improve model stability at the Shanghai Bend Falls, where a sudden change in the channel invert can produce super-critical and unstable conditions. The model was adjusted from the original NGVD29 datum to match the terrain datum, NAVD88, by adding 2.335 feet (see AECOM's Technical Memorandum (TM) – Height Above River Investigations (AECOM, 2011a)). The model geometry was not updated using the LiDAR-derived DEMs as described in the Scope of Sub-Consultancy Services Subtask 3.3.1.d, "recut floodplain cross-section data, combine with channel geometry." This task was not performed because official DWR review of LiDAR-derived DEMs was not complete.

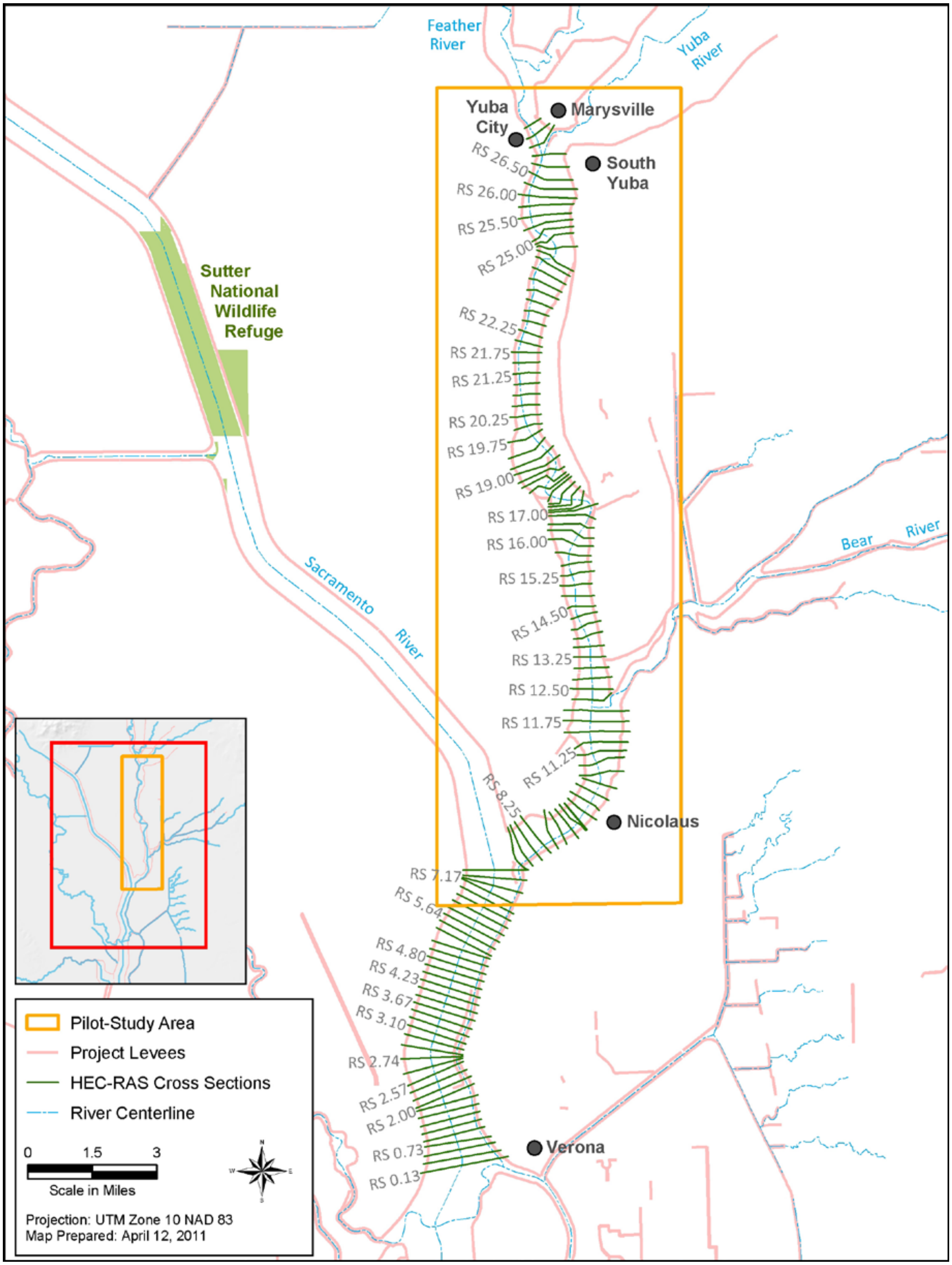

Figure A-15. Revised HEC-RAS Model

b. Development of unsteady-state boundary conditions

Unsteady-state boundary conditions were developed to simulate the synthetic period. The downstream boundary condition at RS 0.13 was set to normal depth with a friction slope of 0.0002 (0.02 percent). The upstream boundary condition at RS 27.75 was set to read the daily synthetic flow hydrograph provided by MWH at Yuba City. Inflows and outflows between Yuba City and the Sutter Bypass were applied based on the synthetic daily flow hydrographs provided by MWH.

c. Review of synthetic hydrographs

The hydrographs provided by MWH included synthetic daily-average flows from October 1, 1921, to September 30, 2003, at locations along the Feather River. The flows were developed from the CalSim State Water Project (SWP)/Central Valley Project (CVP) monthly simulation model.

The flow in the Feather River is controlled by water operations at the upstream Oroville Reservoir. Because of changes in Oroville operations to meet increasing demands both for water supply and environmental purposes, historical flows may not provide the best representation of future flows in the Feather River.

The CalSim model is specifically designed to evaluate the operations of Oroville Reservoir, and the flows in the Feather River, under potential conditions assuming that the historical precipitation from October 1921 through September 2003 reoccurs. The resulting flows may provide a better representation of expected future flows than historical flows.

The synthetic daily average flows provided by MWH to observed daily average flows at USGS flow gages (see Table A-2) were compared to determine whether the synthetic flows provided reasonable values. Figures A-16 and A-17 compare daily averaged flows and resulting flow duration curves for the period of October 1, 1969, through September 30, 1976, (Water Year (WY) 1970 through WY 1976) at Nicolaus (see Figures E-1 through E-4 in Appendix E for the Yuba City and Shanghai Bend locations). The selected period of record represents a time frame when the USGS gages were all in operation.

The comparison illustrates that while the synthetic daily averaged flows often do not reproduce individual daily averaged flows, they do reproduce the various high- and low-flow events. This is confirmed by the flow duration curves, which closely match the observed flow duration curves, although flows are consistently lower than observed.

Table A-2. USGS Gages Within the Pilot-Study Area

USGS Gage No.	Name	Period of Record
11407700	Feather River at Yuba City	10/01/1964–9/30/1976
11421700	Feather River below Shanghai Bend, near Olivehurst, California	10/01/1969–9/30/1980
11425000	Feather River near Nicolaus, California	10/01/1943–9/30/1983

Source: Data downloaded by AECOM in 2011 from USGS, 2011
Key:
USGS = U.S. Geological Survey

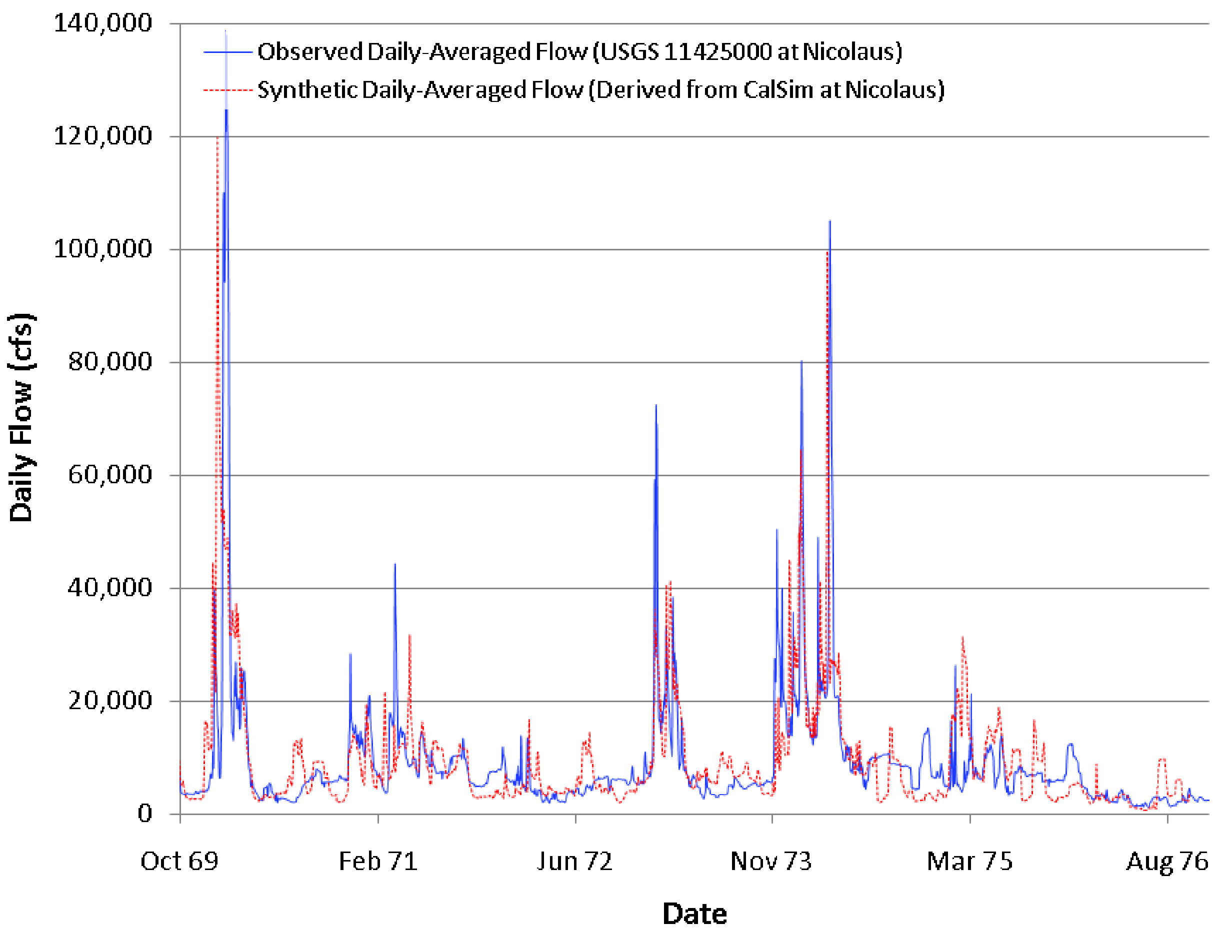

Figure A-16. Synthetic vs. Observed Daily-Averaged Flow – Nicolaus

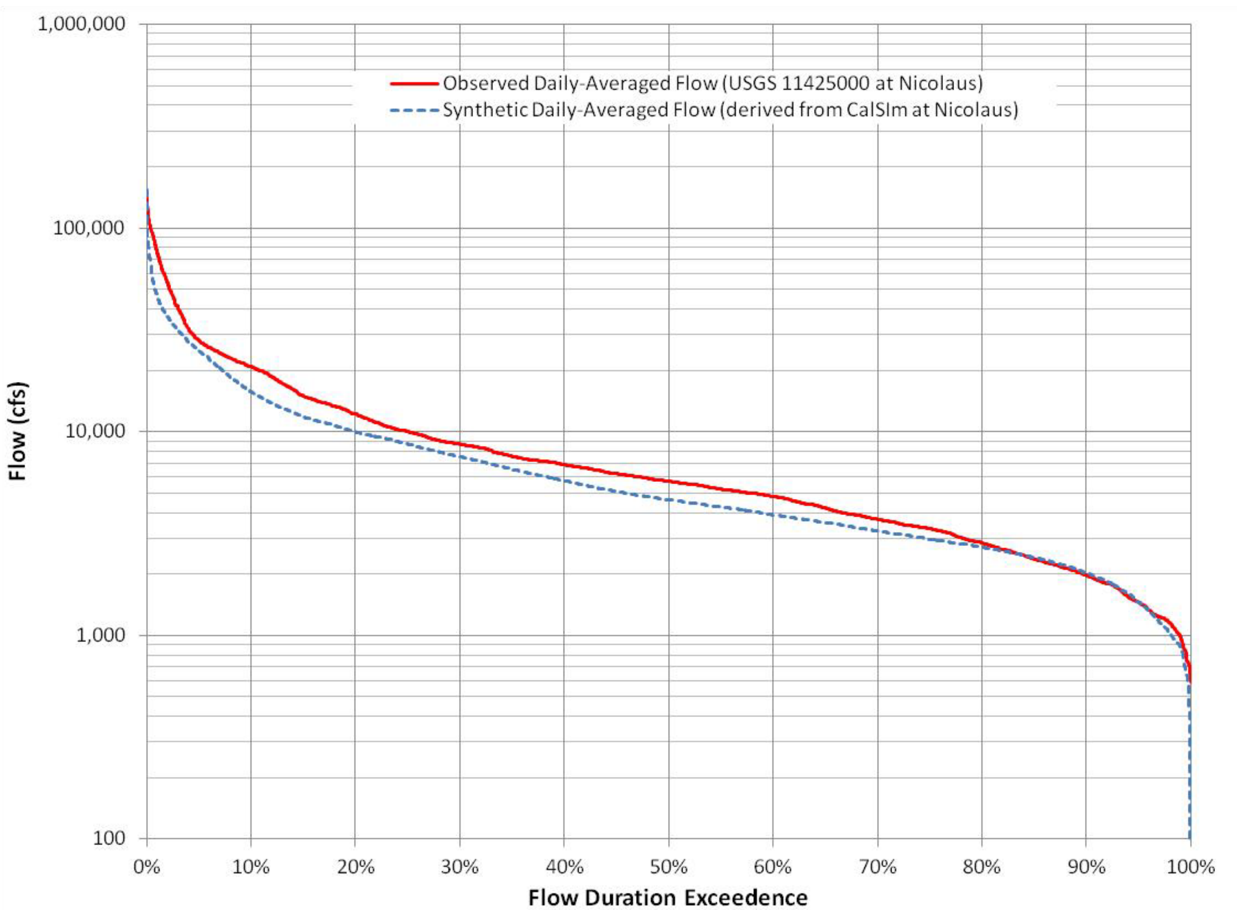

Figure A-17. Synthetic vs. Observed Flow Duration Curve – Nicolaus

d. Modification of synthetic hydrographs for HEC-RAS

The synthetic daily flow hydrographs provided by MWH were modified to be used in the HEC-RAS unsteady-state model. Since each synthetic hydrograph corresponded to the entire channel flow and not the individual inflows and outflows from tributaries, groundwater, agriculture, or other sources, the hydrographs could not be applied directly to the model.

Each Feather River flow hydrograph was subtracted from the upstream hydrograph to produce a hydrograph representing the net accretion (Feather River flow increase) or depletion (Feather River flow decrease) between Feather River flow hydrographs. For example, to estimate the accretion or depletion between the upstream boundary of the model at Yuba City (RS 27.75) and the Yuba River confluence (RS 27.25), flows at Yuba City were subtracted from the flows at the Yuba River confluence. This provided a daily time series of the total net change in flow between Yuba City and the Yuba River confluence. In general, the majority of this change can be attributed to the Yuba River, so the daily time series was applied as the Yuba River inflow hydrograph. This process was repeated at the Bear River confluence (RS 12.25) and at Nicolaus (RS 9.75).

Figure A-18 shows the synthetic daily flow at Yuba River and Nicolaus, as well as the hydrographs produced using the approach above. As shown, this process sometimes results in depletions (see time series "Net Change in Flow from Bear River to Nicolaus"). These depletions correspond to losses in flow between the Bear River and Nicolaus as a result of groundwater and agricultural withdrawals. HEC-RAS handles depletions by removing the flow from the system, which often causes instabilities for unsteady-state models. In this example, the model failed near Nicolaus when the depletions resulted in zero flow at the downstream end. Since the downstream boundary is based on normal depth, which is based in part on flow, the model failed to converge on a solution. To maintain positive flow at the downstream end, a constant flow of 50 cfs was added at RS 9.50. While this introduces a fictitious flow to the system, it is relatively small and does not significantly impact modeled stages or flows.

3.1.3 Identification of Habitat Analysis Areas

The pilot-study area was subdivided into regions, defined as HAAs. For each HAA, a RAS/EFM analysis was performed and the results were mapped in GIS. Table A-3 and Figure A-19 show each HAA, their upstream and downstream bounding cross sections, and a single "representative" cross section. Defining HAAs is critically important to the RAS/EFM analysis because HAAs are viewed by HEC-EFM as maintaining homogenous hydraulic and ecological properties. For example, HEC-EFM assumes that the flow and stage relationship at RS 11.00 is the same for all cross sections between RS 9.75 and RS 12.00. HAAs were therefore subdivided where flow changes occur, where hydraulic structures control, or where the water surface slope was significant. HAAs were subdivided at the Yuba and Bear rivers, upstream from bridges, and at Shanghai Bend.

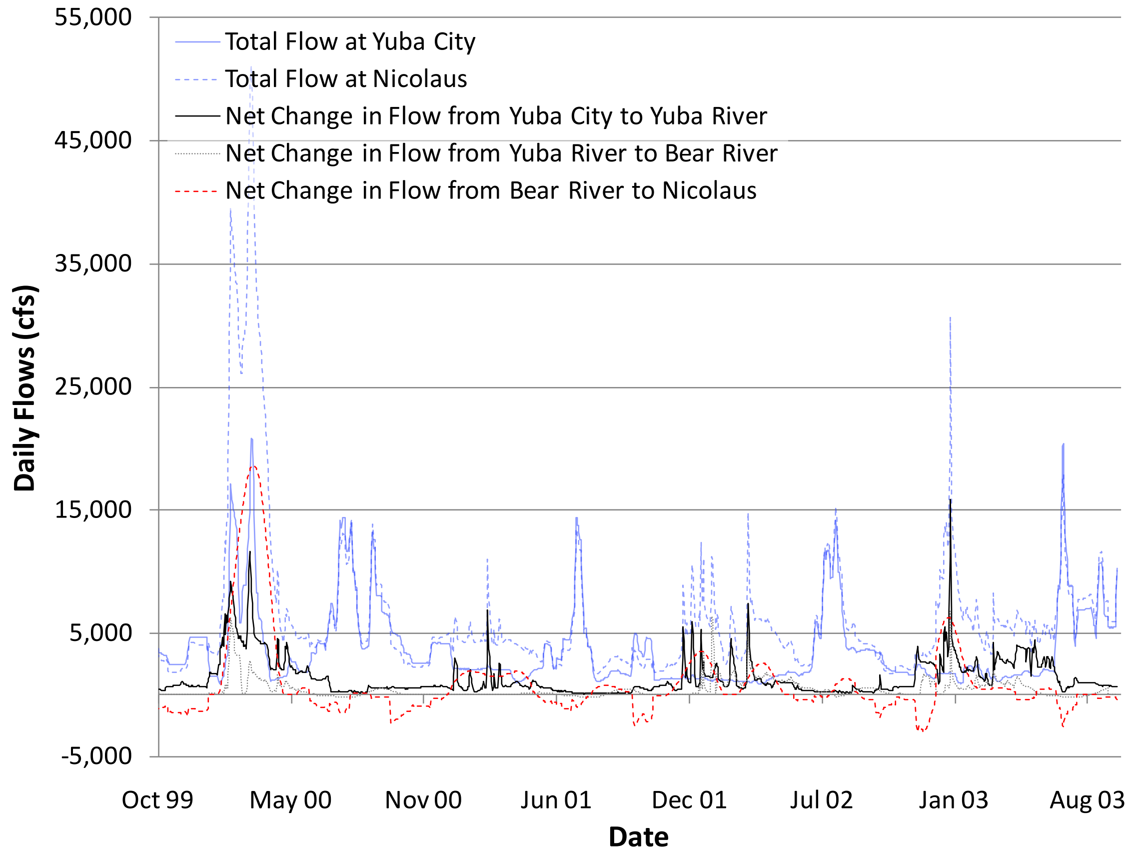

Figure A-18. Revised Daily Flow Time Series Hydrographs

Table A-3. Habitat Analysis Areas

Bounding Cross Sections	Representative Cross Sections
7.55–9.50	8.50
9.75–12.00	11.00
12.25–14.50	13.25
14.75–16.75	15.75
17.00–21.00	19.00
21.25–23.75	22.50
24.00–25.25	24.50
25.50–27.00	26.25

Source: Data generated by AECOM for this report in 2011

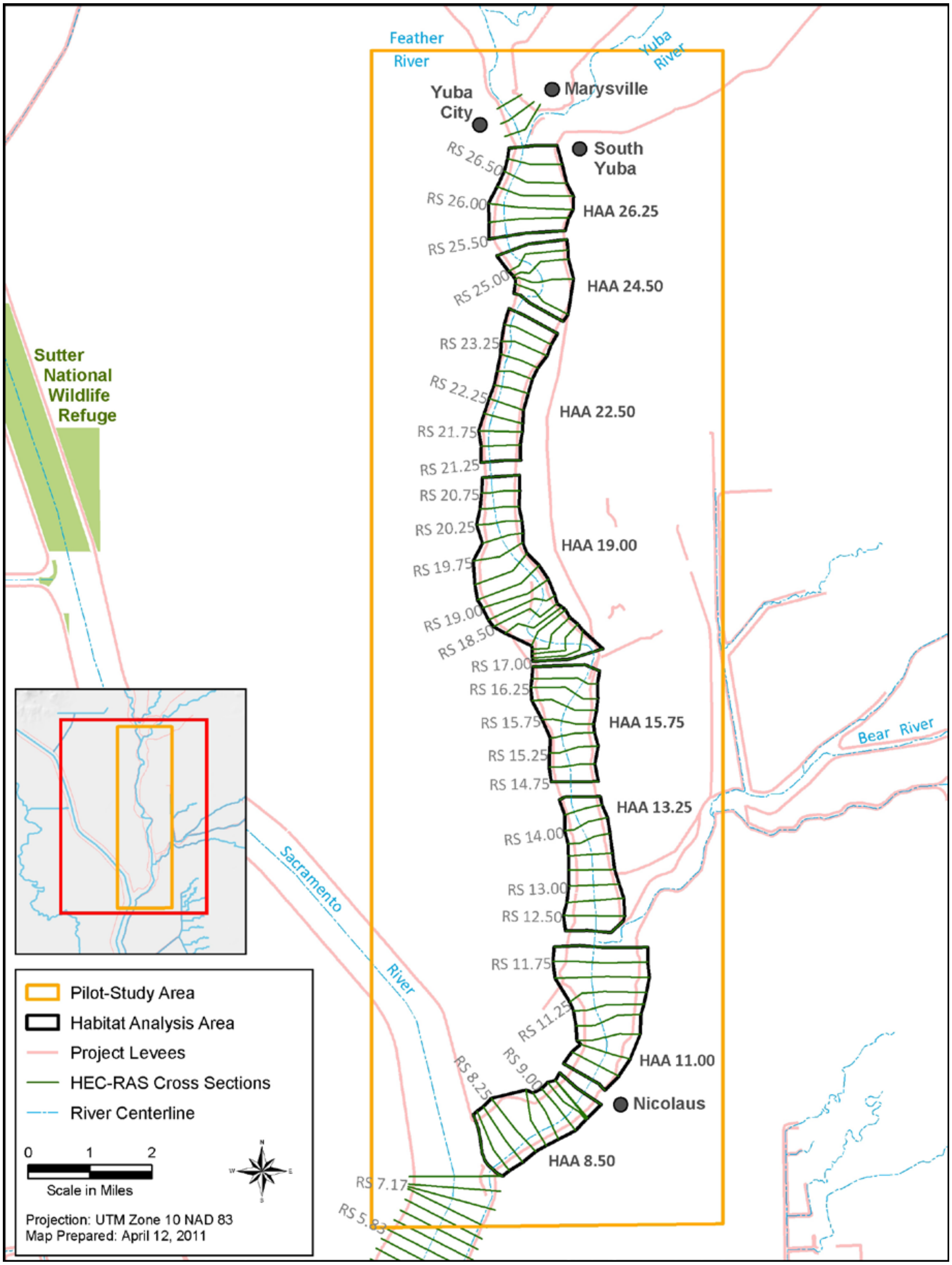

Figure A-19. Habitat Analysis Areas

3.1.4 HEC-RAS Modeling

Once HAAs were identified, the HEC-RAS unsteady-state model was used to produce synthetic stage and flow hydrographs at each representative cross section. These hydrographs were stored in a HEC Data Storage System (HEC-DSS) format database and used as input to HEC-EFM. In addition, a series of steady-state flow profiles was simulated to produce rating curves at each representative cross section. These rating curves were then used during the HEC-EFM modeling, as discussed in the following section.

3.1.5 HEC-EFM Modeling

The HEC-EFM portion of the RAS/EFM analysis consisted of analyzing synthetic stage and flow hydrographs produced by HEC-RAS to determine if and when HEC-EFM Ecosystem Function Relationship (EFR) conditions were met. These conditions, defined by the user, include seasonality, duration, rate of change, and/or return frequency as a function of stage and flow.

Using the stage and flow hydrographs developed by the HEC-RAS unsteady-state model, a HEC-EFM "flow regime" was created for each HAA. These flow regimes identify the flow and stage hydrographs that correspond to each HAA. EFRs were obtained from Table 3 in the September 2010 draft of *2012 Central Valley Flood Protection Plan—Ecosystem Functions Model* (AECOM, 2010b). A summary of each EFR, directly from the above report, is provided in Table A-4. The EFRs used in this study included Salmonid-Rearing Habitat Formation, riparian Cottonwood Seedling Germination, riparian Cottonwood Seedling Inundation (death), and riparian Cottonwood Recruitment. Each EFR was added to HEC-EFM and is shown on Figures F-1 through F-4 in Appendix D-9F.

HEC-EFM was then used to analyze each EFR and HAA. HEC-EFM first performs a statistical analysis on each stage and flow hydrograph for each EFR to determine if and when conditions of the EFRs are met. During this analysis, HEC-EFM produces a stage-flow rating curve for each flow regime based on a statistical sampling of the stage and flow hydrographs. If conditions of the EFR are met, the flow or stage that meets the conditions is then used in conjunction with the rating curve to determine the corresponding flow or stage.

Table A-4. Summary of Ecosystem Functional Relationships

Ecological Process	Summary of Ecosystem Functional Relationship	Flow Parameters			
		Season	Duration	Rate of Change	Event Probability
Riparian Habitat Recruitment	Seedling germination of cottonwood and other early-seral riparian vegetation requires moist soil from April through early June for at least 2 weeks. The river stages must decline at a rate of not more than 1 inch per day to allow newly developing roots to extend with receding river stages. Germination events should occur every 10 years to permit regeneration of new habitat patches.	April 1 to June 15	2 weeks or more	1 inch or less on receding limb of hydrograph	10 percent chance recurrence interval
	Newly germinated cottonwood seedlings are susceptible to death from physiological stress if inundated for prolonged periods of 2 weeks or more following germination.	June 15 to October 30	2 weeks or more	Constant	10 percent chance recurrence interval
	Successful cottonwood recruitment has been documented to occur within specific elevation bands above summer base flow levels.	June 15 to October 30	Constant during time period	Constant	100 percent chance (annual recurrence)
Salmonid-Rearing Habitat	Shallow-water, seasonally inundated floodplains provide valuable rearing habitat for Chinook salmon and steelhead. Ecologically important floodplain inundation is defined as the river stage that is exceeded in at least 2 out of 3 years and sustained for at least 7 days from March 15 to May 15.	March 15 to May 15	1 week or more	Constant	66 percent chance

Source: Data summarized by AECOM in 2011b from USACE, 2002 and ESSA, 2009

An issue was identified during the RAS/EFM analysis that resulted in erroneous stages being produced by HEC-EFM. As discussed, HEC-EFM uses flow and stage hydrographs from HEC-RAS to identify whether the conditions of a given EFR are met. During this process, HEC-EFM develops a rating curve based on the flow and stage hydrograph. If the conditions of the EFR are met, HEC-EFM identifies the corresponding flow or stage and uses the rating curve to determine the complementary flow or stage. While HEC-EFM applies a robust statistical analysis in an attempt to produce a smooth, representative rating curve, for some HAAs the rating curve included erroneous stage values. In some cases, these values were several feet higher than expected, and for Cottonwood Seedling Germination resulted in significant error.

Figure A-20 shows three different rating curves for RS 11.00. The curve shown in red was produced by HEC-EFM, the curve in gray was produced by the HEC-RAS unsteady-state model, and the curve in blue was produced using HEC-RAS steady state as discussed. As shown, the HEC-EFM rating curve includes erroneous stages at several flow rates. As a result of these erroneous stages, HEC-EFM selects values that are not representative of actual conditions. Figure A-21 shows the same rating curves for flow rates up to 15,000 cfs and includes the results of the HEC-EFM analyses for HAA 11.00. This results from the significant amount of hysteresis that occurs at RS 11.00 during the continuous synthetic simulation. Hysteresis is a hydraulic condition in which multiple stages can correspond to a single flow. In general, this occurs when downstream conditions produce backwater that increases the stage during low flows, either because of tidal conditions, a hydraulic structure, or high-flow conditions on a main-steam reach. Within the pilot-study area, hysteresis occurs because (1) the water surface slope is relatively mild at RS 11.00, and (2) the downstream boundary condition is set to normal depth, which allows for a wide range of backwater conditions. The amount of hysteresis is reduced upstream where downstream conditions have minimal impact on stages and where the water surface slope is greater. To address this issue, a HEC-RAS steady-state profile was simulated for flow rates between 100 cfs and 140,000 cfs at 1,000 cfs intervals. This simulation produced the rating curves shown in blue on Figures A-20 and A-21. As demonstrated, this curve matches well with both the HEC-RAS unsteady state and HEC-EFM-derived rating curves. The steady-state rating curve was then used to override the HEC-EFM-derived rating curve.

3.2 Results and Sensitivity

The results of the HEC-EFM analyses are discussed in the following sections. HEC-EFM was initially run using the Sacramento River Ecological Flows Tool (SacEFT)-defined EFRs, which were previously developed for the Sacramento River. To determine whether changes in these EFRs would result in significant changes in the potential habitat area on the lower Feather River pilot-study area, the Cottonwood Seedling Germination and Salmonid Rearing Habitat EFRs were modified. Results for each EFR analyzed are included below.

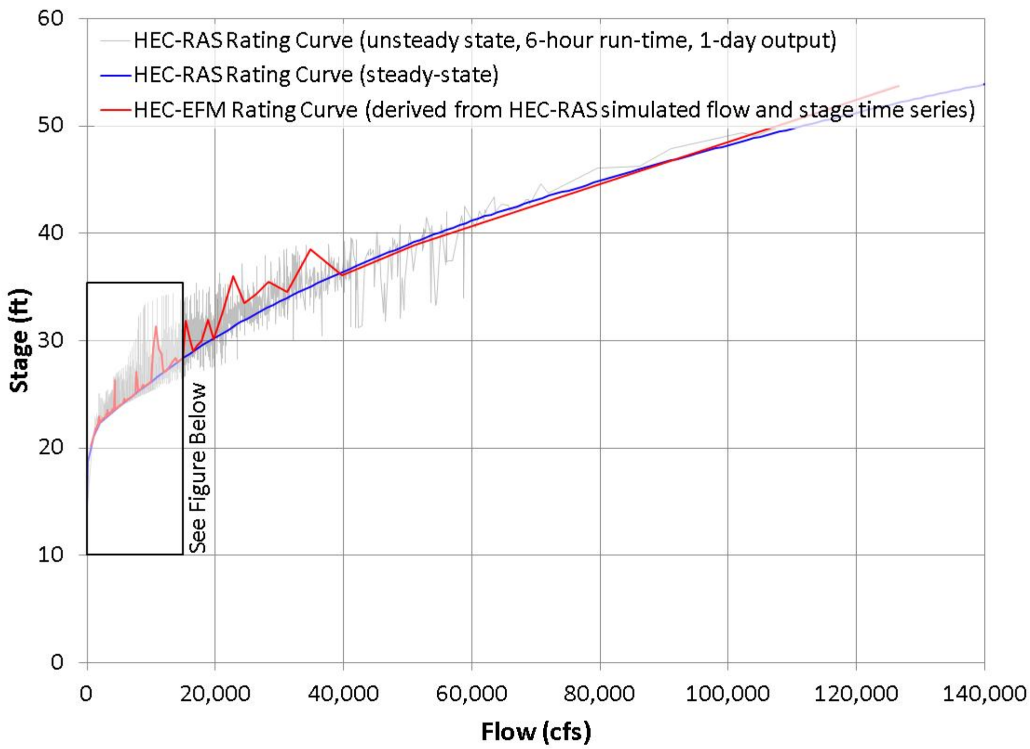

Figure A-20. Comparison of Rating Curves – RS 11.00

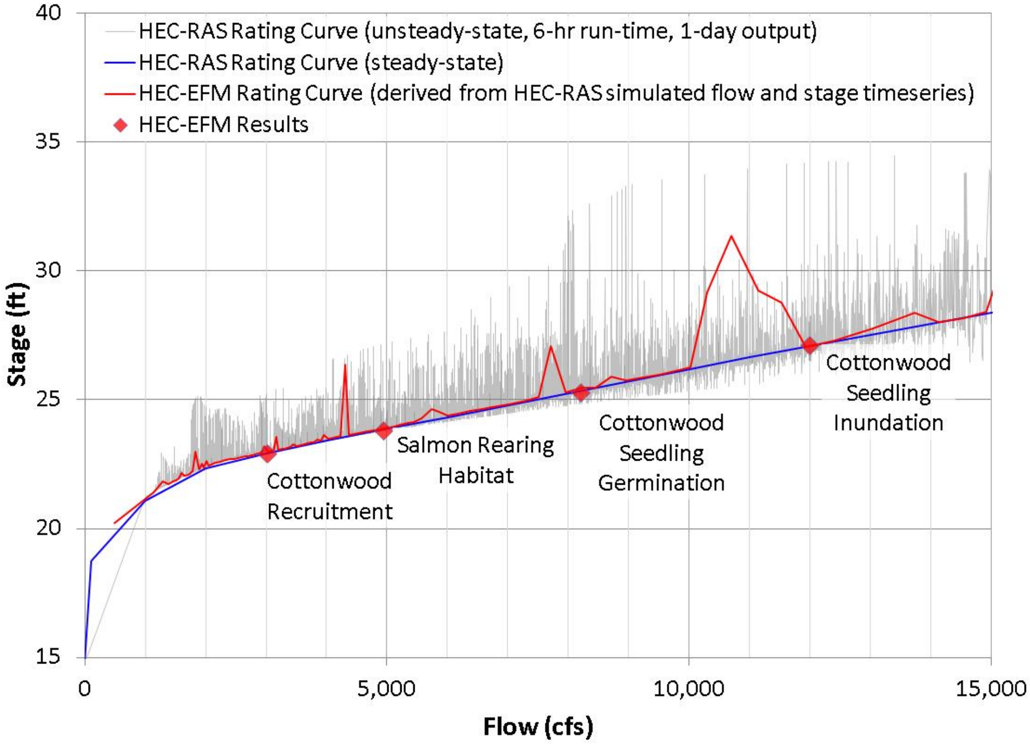

Figure A-21. Comparison of Rating Curves Showing HEC-EFM Results – RS 11.00

3.2.1 SacEFT-Defined EFRs

The results of the HEC-EFM analyses using the SacEFT-defined EFRs are shown in Tables A-5 through A-7. HEC-EFM provides a single flow and stage for each EFR and HAA, if conditions of the EFR are met. The computer processing time required to perform all 32 analyses was approximately 15 minutes.

Table A-5. HEC-EFM Results – RS 26.25–RS 22.50

Ecosystem Function Relationship	RS 26.25		RS 24.50		RS 22.50	
	Stage (feet)	Flow (cfs)	Stage (feet)	Flow (cfs)	Stage (feet)	Flow (cfs)
Cottonwood Seedling Germination	40.6	8,802	40.1	10,710	31.3	5,774
Cottonwood Seedling Inundation	41.8	11,952	40.5	11,953	34.8	11,954
Cottonwood Recruitment	37.7	3,044	37.4	3,029	29.2	3,011
Salmonid Rearing Habitat	38.4	4,142	37.9	4,150	30.2	4,159

Source: Data provided by AECOM in 2011 based on modeling using the U.S. Army Corps of Engineers Hydrologic Engineering Center's Ecosystem Functions Model and River Analysis System

Notes:
cfs = cubic feet per second
RS = River Station

Table A-6. HEC-EFM Results—RS 19.00–RS 13.25

Ecosystem Function Relationship	RS 19.00		RS 15.75		RS 13.25	
	Stage (feet)	Flow (cfs)	Stage (feet)	Flow (cfs)	Stage (feet)	Flow (cfs)
Cottonwood Seedling Germination	29.9	6,959	28.8	7,845	27.7	7,845
Cottonwood Seedling Inundation	32.4	11,962	30.6	11,965	29.0	11,965
Cottonwood Recruitment	27.2	3,015	26.1	3,044	24.9	3,044
Salmonid Rearing Habitat	28.1	4,181	26.9	4,187	25.6	4,181

Source: Data provided by AECOM in 2011 based on modeling using the U.S. Army Corps of Engineers Hydrologic Engineering Center's Ecosystem Functions Model and River Analysis System

Notes:
cfs = cubic feet per second
RS = River Station

Table A-7. HEC-EFM Results—RS 11.00–RS 8.50

Ecosystem Function Relationship	RS 11.00		RS 8.50	
	Stage (feet)	Flow (cfs)	Stage (feet)	Flow (cfs)
Cottonwood Seedling Germination	25.3	8,198	23.1	7,635
Cottonwood Seedling Inundation	27.1	11,987	25.6	12,316
Cottonwood Recruitment	22.9	3,015	19.1	2,567
Salmonid Rearing Habitat	23.8	4,942	21.8	5,684

Source: Data provided by AECOM in 2011 based on modeling using the U.S. Army Corps of Engineers Hydrologic Engineering Center's Ecosystem Functions Model and River Analysis System

Notes:
cfs = cubic feet per second
RS = River Station

3.2.2 Modified EFRs

The Cottonwood Seedling Germination and Salmonid Rearing Habitat Formation EFRs were modified to determine whether adjustments to the EFRs would result in significant changes in potential habitat area.

The Cottonwood Seedling Germination EFR Rate of Change of Stage (falling stage) statistical parameter was modified from the SacEFT-defined 1 inch per day to 2 inches per day and 3 inches per day. Also considered was a 1-inch-per-day Rate of Change of Stage from March to July, as opposed to the April to June 15 Sac-EFT-defined values. Lastly, the Rate of Change of Stage parameter was removed and instead germination was analyzed based on the 14-day minimum/maximum parameter (similar to the Cottonwood Seedling Inundation). Tables A-8 through A-10 show the results of these changes.

Table A-8. Cottonwood Seedling Germination Sensitivity – RS 26.25–RS 22.50

Ecosystem Function Relationship	RS 26.25		RS 24.50		RS 22.50	
	Stage (feet)	Flow (cfs)	Stage (feet)	Flow (cfs)	Stage (feet)	Flow (cfs)
1 inch per day	40.6	8,802	40.1	10,710	31.3	5,774
2 inches per day	42.7	14,242	41.3	15,182	35.0	12,395
3 inches per day	42.1	12,587	40.9	13,504	34.3	10,861
March - July	40.4	8,411	40.2	10,909	31.9	6,634
14-day Minimum/Maximum (no Rate of Change)	44.5	19,757	42.4	19,759	38.1	19,760

Source: Data provided by AECOM in 2011 based on modeling using the U.S. Army Corps of Engineers Hydrologic Engineering Center's Ecosystem Functions Model and River Analysis System

Notes:
cfs = cubic feet per second
RS = River Station

Table A-9. Cottonwood Seedling Germination Sensitivity – RS 19.00–RS 13.25

Ecosystem Function Relationship	RS 19.00		RS 15.75		RS 13.25	
	Stage (feet)	Flow (cfs)	Stage (feet)	Flow (cfs)	Stage (feet)	Flow (cfs)
1 inch per day	29.9	6,959	28.8	7,845	27.7	7,845
2 inches per day	33.1	13,680	31.6	14,361	29.9	14,394
3 inches per day	31.9	10,922	30.2	10,972	28.8	11,598
March - July	30.1	7,407	28.7	7,681	27.5	8,489
14-day Minimum/Maximum (no Rate of Change)	35.5	19,763	33.5	19,764	31.7	19,763

Source: Data provided by AECOM in 2011 based on modeling using the U.S. Army Corps of Engineers Hydrologic Engineering Center's Ecosystem Functions Model and River Analysis System

Notes:
cfs = cubic feet per second
RS = River Station

Table A-10. Cottonwood Seedling Germination Sensitivity – RS 11.00–RS 8.50

Ecosystem Function Relationship	RS 11.00		RS 8.50	
	Stage (feet)	Flow (cfs)	Stage (feet)	Flow (cfs)
1 inch per day	25.3	8,198	23.1	7,635
2 inches per day	28.4	15,074	27.0	15,429
3 inches per day	26.9	11,562	25.1	11,343
March - July	25.6	8,830	23.1	7,756
14-day Minimum/Maximum (no Rate of Change)	30.8	21,427	30.6	24,908

Source: Data provided by AECOM in 2011 based on modeling using the U.S. Army Corps of Engineers Hydrologic Engineering Center's Ecosystem Functions Model and River Analysis System

Notes
cfs = cubic feet per second
RS = River Station

The following can be concluded:

1. **There appears to be an "optimum" Rate of Change of Stage value that corresponds to a maximum flow and stage and thus maximum potential habitat area.**

   If this optimum Rate of Change of Stage value is considered ecologically "acceptable" (i.e., it still provides viable habitat given the greater rate of change) then it could be used to map the maximum potential habitat area.

2. **Extending the analysis period did not significantly impact flows or stages.**

   While extending the analysis period did not impact flows or changes on the lower Feather River, results may vary depending on the operational characteristics of upstream controls (e.g., dams) and therefore may vary depending on the stream reach.

3. **Using a 14-day minimum/maximum query, as opposed to the Rate of Change of Stage, significantly increased flow and stage, resulting in greater potential habitat area.**

   Consideration should be given as to the importance of the Rate of Change of Stage query since it significantly reduces the flow and stage and thus potential habitat area.

4. **When assuming a 2-inch rate of change of stage or when removing the rate of change of stage criteria and using a 14-day minimum/maximum criteria, Cottonwood Seedling Germination produces higher flows and stages than Cottonwood Seedling Inundation.**

   This suggests that successful Cottonwood recruitment may be possible under alternative EFR criteria. It should be noted, however, that Cottonwood Seedling Germination and Inundation are not dynamically linked with HEC-EFM and that any conclusions regarding recruitment success must be considered with this in mind.

The Salmonid Rearing Habitat Formation EFR was modified from the SacEFT-defined March through May, 7-day minimum/maximum and 67 percent chance frequency criteria to analyze various frequencies, including 50, 33, 20, and 10 percent chance, a 14-day duration and no duration criteria, and a 7-day duration from March through July. Tables A-11 through A-13 show the results of these changes.

The following can be concluded:

1. **Flow and stage increase linearly with frequency.**

   As expected, lower frequency criteria resulted in greater flow and stage. Figure A-22 shows the corresponding area for each 7-day duration frequency within HAA 11.00. Although the 10 percent chance frequency produces the greatest area (note: the 10 percent chance area includes all areas mapped under the 20 percent chance area, the 20 percent chance area includes all areas mapped under the 33 percent chance area, etc.), much of the area may not correspond to ideal salmonid habitat, given that successful salmonid habitat does not rely as heavily on widespread floodplain inundation but rather habitat located within side channels and along river banks.

2. **Extending the period of the analysis to include June and July significantly increases the flow by 2 to 3 times.**

   Unlike Cottonwood Seedling Germination, increasing the period of analysis results in greater potential habitat area. If June and July were considered ecologically "acceptable" periods for salmonid rearing, the period of analysis could be extended to increase the potential habitat area.

3. **Removing the duration criteria increased the flow and stage minimally, while assuming 14-day duration versus 7-day duration minimally decreased the flow and stage.**

   Adjusting the duration of the event did not significantly impact flows, stages, or potential habitat area.

Table A-11. Salmonid Rearing Habitat Sensitivity – RS 26.25–RS 22.50

Ecosystem Function Relationship	RS 26.25		RS 24.50		RS 22.50	
	Stage (feet)	Flow (cfs)	Stage (feet)	Flow (cfs)	Stage (feet)	Flow (cfs)
67% chance, 7-day duration	38.4	4,142	37.9	4,150	30.2	4,159
50% chance, 7-day duration	39.4	6,231	38.7	6,231	31.7	6,231
33% chance, 7-day duration	41.4	10,901	40.2	10,904	34.3	10,916
20% chance, 7-day duration	43.2	15,673	41.4	15,684	36.5	15,693
10% chance, 7-day duration	47.1	28,466	44.8	28,465	41.1	28,462
67% chance, 7-day duration March-July	41.6	11,265	40.3	11,232	34.4	11,200
67% chance; no duration	39.1	5,661	38.5	5,659	31.3	5,657
67% chance; 14-day duration	38.1	3,733	37.7	3,734	29.8	3,735

Source: Data provided by AECOM in 2011 based on modeling using the U.S. Army Corps of Engineers Hydrologic Engineering Center's Ecosystem Functions Model and River Analysis System

Notes:
cfs = cubic feet per second
RS = River Station

Table A-12. Salmonid Rearing Habitat Sensitivity – RS 19.00–RS 13.25

Ecosystem Function Relationship	RS 19.00		RS 15.75		RS 13.25	
	Stage (feet)	Flow (cfs)	Stage (feet)	Flow (cfs)	Stage (feet)	Flow (cfs)
67% chance, 7-day duration	28.1	4,181	26.9	4,187	25.6	4,181
50% chance, 7-day duration	29.4	6,229	28.0	6,226	26.5	6,219
33% chance, 7-day duration	31.9	10,916	30.2	10,923	28.5	10,931
20% chance, 7-day duration	34.0	15,715	32.1	15,734	30.4	15,756
10% chance, 7-day duration	38.5	28,452	36.2	28,446	24.5	28,445
67% chance, 7-day duration March-July	32.0	11,121	30.2	11,060	28.5	11,031
67% chance; no duration	29.1	5,699	27.7	5,619	26.2	5,582
67% chance; 14-day duration	27.8	3,737	26.6	3,748	25.3	3,758

Source: Data provided by AECOM in 2011 based on modeling using the U.S. Army Corps of Engineers Hydrologic Engineering Center's Ecosystem Functions Model and River Analysis System

Notes:
cfs = cubic feet per second
RS = River Station

Table A-13. Salmonid Rearing Habitat Sensitivity – RS 11.00–RS 8.50

Ecosystem Function Relationship	RS 11.00		RS 8.50	
	Stage (feet)	Flow (cfs)	Stage (feet)	Flow (cfs)
67% chance, 7-day Duration	23.8	4,942	21.8	5,684
50% chance, 7-day Duration	25.0	7,536	24.3	9,762
33% chance, 7-day Duration	27.0	11,832	27.1	15,760
20% chance, 7-day Duration	29.1	16,800	29.3	21,232
10% chance, 7-day Duration	34.4	32,453	34.7	38,506
67% chance, 7-day Duration March-July	26.7	11,175	24.7	10,592
67% chance; No Duration	24.7	6,706	23.0	7,443
67% chance; 14-day Duration	23.4	3,999	21.4	5,079

Source: Data provided by AECOM in 2011 based on modeling using the U.S. Army Corps of Engineers Hydrologic Engineering Center's Ecosystem Functions Model and River Analysis System

Notes:
cfs = cubic feet per second
RS = River Station

3.3 Mapping

This section includes the results of the HEC-EFM analysis and the use of various mapping approaches to spatially visualize the HEC-EFM results. It also includes a discussion of how the spatial results can be further refined and reviewed to identify potential alternatives and how the final results can be presented.

3.3.1 Mapping Approaches

While HEC-EFM provides a stage and flow that meets the conditions of a given EFR, additional efforts are required to visualize the spatial area along the river that meets those conditions. Three approaches to mapping the results of HEC-EFM are presented in the following sections.

HEC-GeoRAS

The HEC-EFM results discussed above were mapped using HEC-RAS and the GIS extension to HEC's River Analysis System (HEC-GeoRAS), as recommended in the USACE-HEC *HEC-EFM Quick Start Guide* (USACE-HEC, 2009 (see Figure A-23)). This approach uses the flow rates determined by HEC-EFM but disregards the stages determined by HEC-EFM.

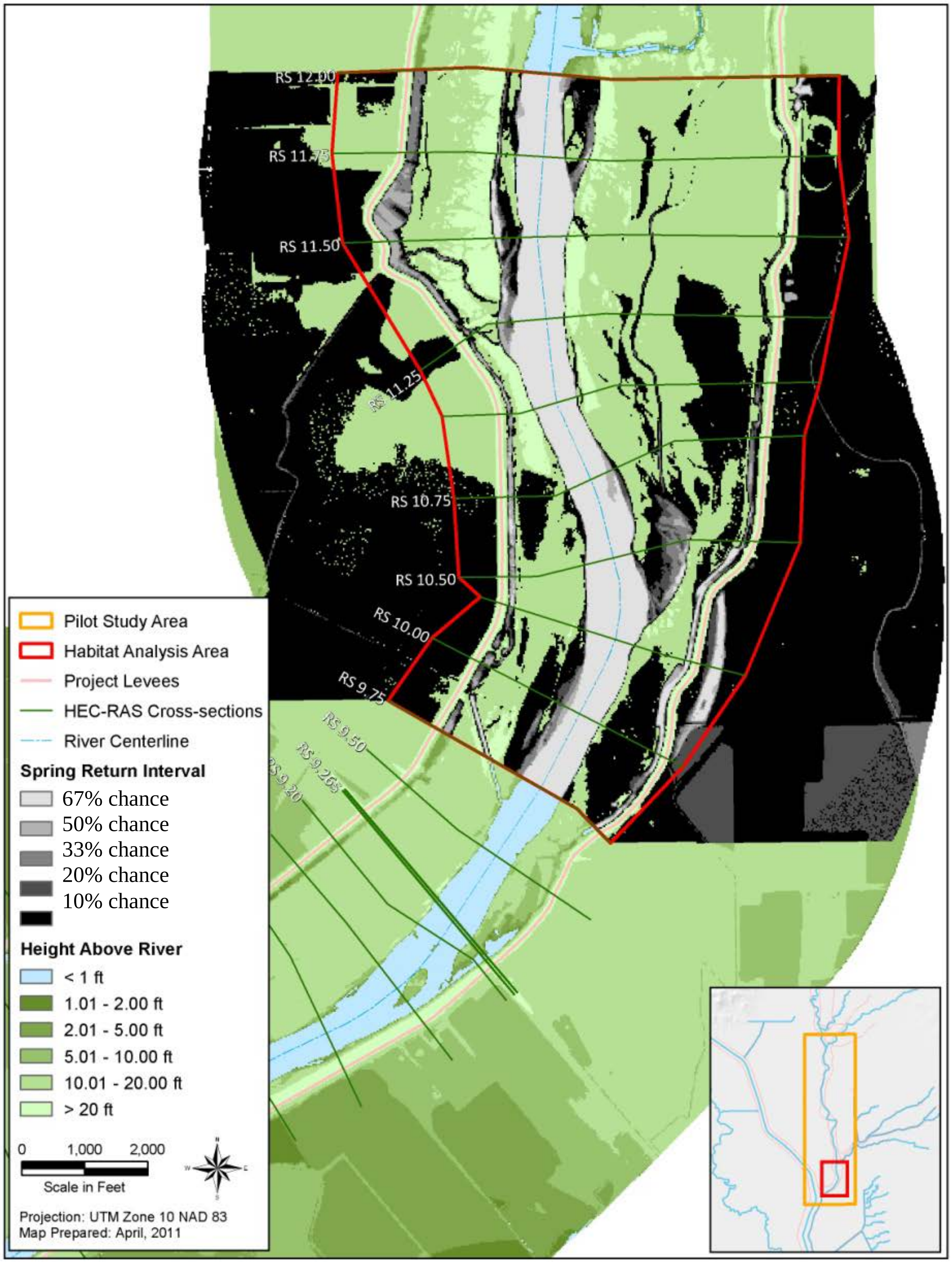

Figure A-22. Salmonid Rearing Habitat for Various Frequency Events in HAA 11.00

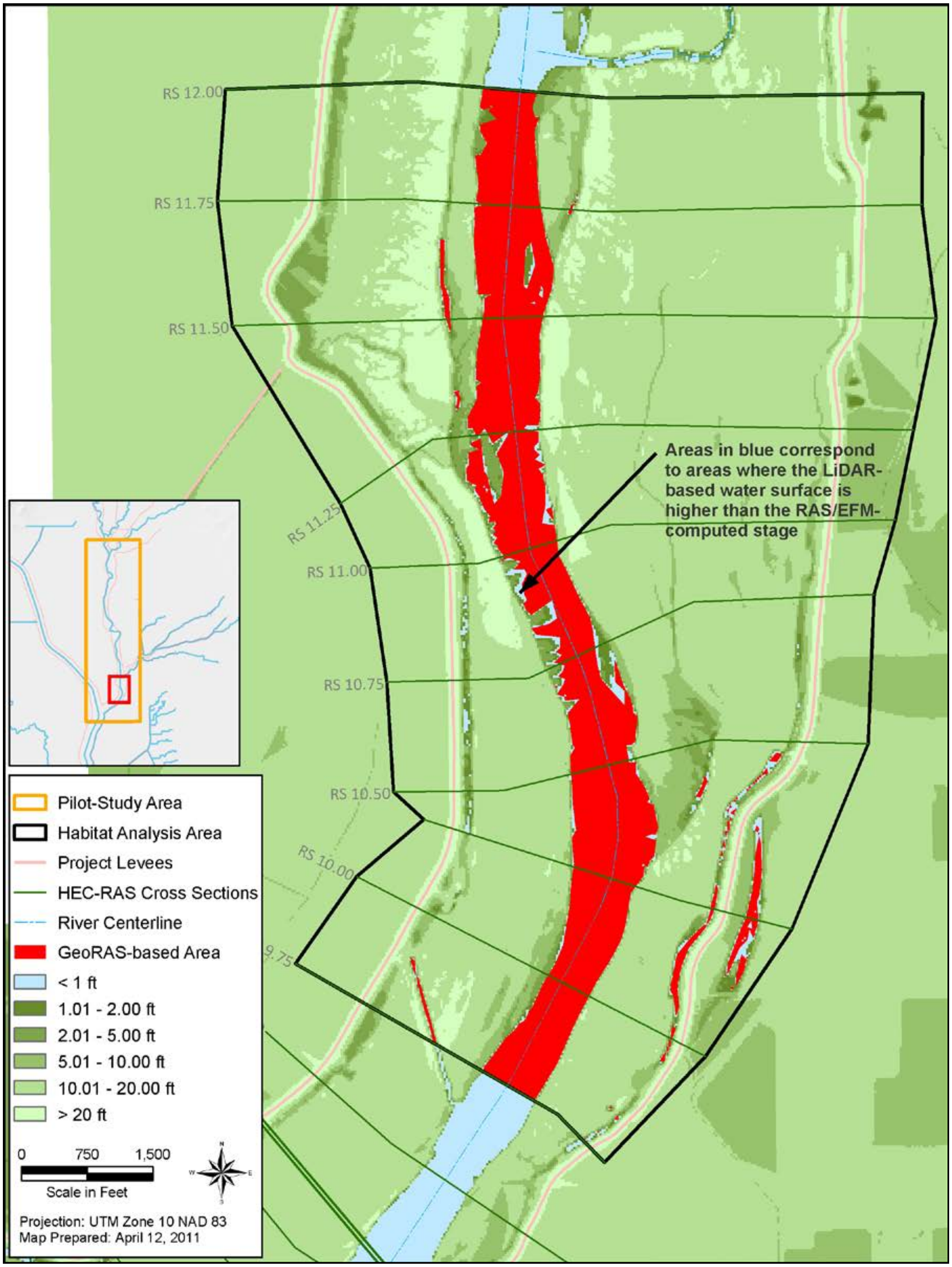

Figure A-23. Salmonid-Rearing Habitat Areas Mapped Using HEC-GeoRAS in HAA 11.00

The flow rates determined by HEC-EFM at each representative cross section were used as input for the HEC-RAS steady-state model. HEC-RAS was then used to compute the water-surface profiles for each HAA that corresponded to the flow determined by HEC-EFM. The entire pilot-study area HEC-RAS model was used to analyze each HAA (i.e., the model was not truncated to each HAA). This was done to maintain proper upstream and downstream boundary conditions and because truncating the model to each HAA would not necessarily reduce and could likely increase the level of effort.

The water-surface profile for each HAA and EFR were then mapped using the HEC-GeoRAS tool within ArcGIS. The water surface areas correspond to areas that meet the EFR conditions, as determined by HEC-EFM and HEC-RAS. It took approximately 10 minutes of processing time to run the HEC-GeoRAS tool for a single HAA and EFR. Each water surface area polygon was then clipped to its respective HAA. It should be noted that the inundation depth grid, a product of HEC-GeoRAS that is used in the HEC-EFM manual to show the extent of potential habitat, is not shown. The depth grid was not shown because the water surface area polygon is simpler for readers to identify with and is easier to work with in ArcGIS. Results are shown on Figures G-1 through G-11 in Appendix G for each HAA and EFR (Cottonwood Recruitment was not mapped because potential habitat areas outside of the channel banks were not identified). The background of each map corresponds to the LiDAR-based FIP.

The following are important findings of this approach:

1. **The water surface areas mapped are the direct, raw product of the RAS/EFM analysis.**

   Areas have not been refined based on additional ecological or biological considerations, such as soil type, vegetation type, bank slope, connectivity, or land use.

2. **HEC-RAS and HEC-GeoRAS cannot map areas beyond the HEC-RAS model cross sections.**

   As a result, areas beyond existing levees are not mapped. Cross sections would need to be extended beyond the levees to map areas outside the existing levee system.

3. **EFRs that produce stages below the LiDAR observed water surface are not mapped by HEC-GeoRAS.**

   When EFR stages are below the LiDAR-observed water surface, water surface area does exist; however, the area is simply below the LiDAR-observed water surface. To resolve this issue, bathymetry would need to be combined with the LiDAR terrain.

Height Above River

Although HEC-GeoRAS is a proven and reliable method for mapping HEC-RAS results, its limitation of mapping within cross-section extents makes it difficult to determine the potential for habitat beyond the existing levee system. Its inability to map below the LiDAR-observed water surface also reduces the value for mapping within channel banks. Thus, an alternative approach was reviewed using the FIP methodology.

After reviewing and testing the FIP approach as well as the HEC-GeoRAS and ArcGIS approaches, the FIP approach was selected as the preferred mapping approach.

Similar to the approach discussed above, HEC-RAS was used to simulate the water-surface profile for each HAA based on the flows determined by HEC-EFM. The results were exported to GIS, and HEC-GeoRAS was used to develop cross-section cut-lines with water surface elevations for each HAA and EFR. ArcGIS was then used to perform FIP analyses for each HAA and EFR. Figure A-24 shows an example of the Cottonwood Seedling Germination habitat area identified using the HEC-GeoRAS approach versus the FIP approach from RS 9.75 through RS 12.00 (HAA 11.00).

The following are important findings of this approach:

1. **The FIP analysis is capable of mapping the RAS/EFM analysis results within the entire FIP study area.**

   Mapping was not limited to the cross-section extents and provides mapping beyond the existing levee system.

2. **The FIP analysis replaces the LiDAR-observed water surface with the water-surface profiles computed by HEC-RAS, based on predefined bank breaklines.**

   As a result, the entire channel, from bank to bank, is shown as meeting the RAS/EFM analysis EFR criteria. This may overestimate the area of potential habitat within the channel. To resolve this issue, bathymetry would need to be combined with the LiDAR terrain.

3. **The water surface areas mapped are the direct, raw product of the RAS/ EFM analysis.**

   Areas have not been refined based on additional ecological or biological considerations, such as soil type, vegetation type, bank slope, connectivity, or land use.

ArcGIS

The approaches discussed above use HEC-RAS to determine the water-surface profile within each HAA that meet the conditions of each EFR. These water-surface profiles are computed by HEC-RAS using the flows determined by HEC-EFM. While these approaches provide hydraulically correct water-surface profiles through each HAA, they require a significant level of effort. An alternative was considered using ArcGIS to directly map the stage determined by HEC-EFM. This approach uses the stage determined by HEC-EFM instead of the flow rate, with the stage mapped within ArcGIS for each HAA and EFR.

This approach assumes that the stage determined by HEC-EFM for a given HAA and EFR applies uniformly across the HAA (i.e., it assumes there is no slope to the water surface throughout the HAA). This assumption may or may not be valid, depending on the hydraulic characteristics of the HAA.

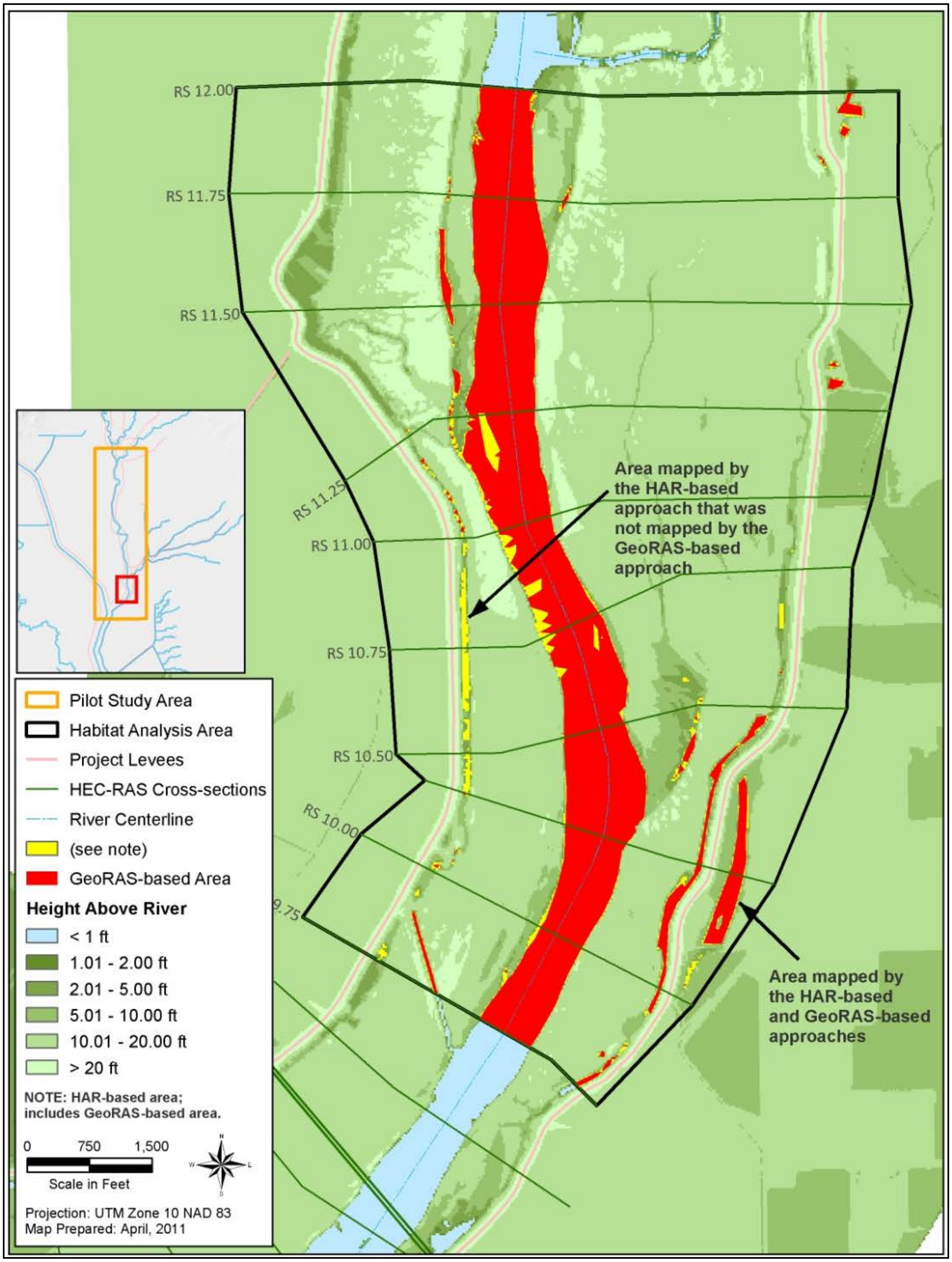

Figure A-24. Cottonwood Seedling Germination Habitat Areas Mapped Using FIP and HEC-GeoRAS in HAA 11.00

Again, this assumption *may be valid* if the HAAs were defined such that their hydraulic conditions were homogenous. Each HAA and EFR was mapped by first creating a water-surface TIN terrain model with a single elevation and then taking the difference between the TIN and the LiDAR terrain. This TIN extends beyond the cross-section extents so that mapping beyond existing levees is possible. As an example, Table A-14 shows the stages determined by HEC-RAS between RS 9.75 and RS 12.00 using the previous two mapping methods. Using this approach, the areas between these river stations would be mapped using the single stage determined by HEC-EFM for RS 11.00: 23.8 feet (see Tables A-5 through A-7).

Table A-14. HEC-RAS-Derived Stages for Salmonid-Rearing Habitat – RS 9.75–RS 11.00

River Station	Stage (feet)	River Station	Stage (feet)
9.75	22.03	11.25	24.09
10.00	22.31	11.50	24.25
10.50	23.27	11.75	24.40
10.75	23.62	12.00	24.84
11.00	23.84		

Source: Data compiled by AECOM in 2011 based on modeling using U.S. Army Corps of Engineers Hydrologic Engineering Center's River Analysis System (HEC-RAS)

Figure A-25 compares the mapping results using each method between RS 9.75 and RS 12.00 for Salmonid-Rearing Habitat. For this HAA, while there are differences between each approach, the results are similar, leading to the assumption that a single stage can represent an entire FIP is reasonable. This alternative approach took approximately a half day to map the entire study area for all EFRs, significantly less than the 1 to 2 days required to perform the HEC-GeoRAS- and FIP-based approaches.

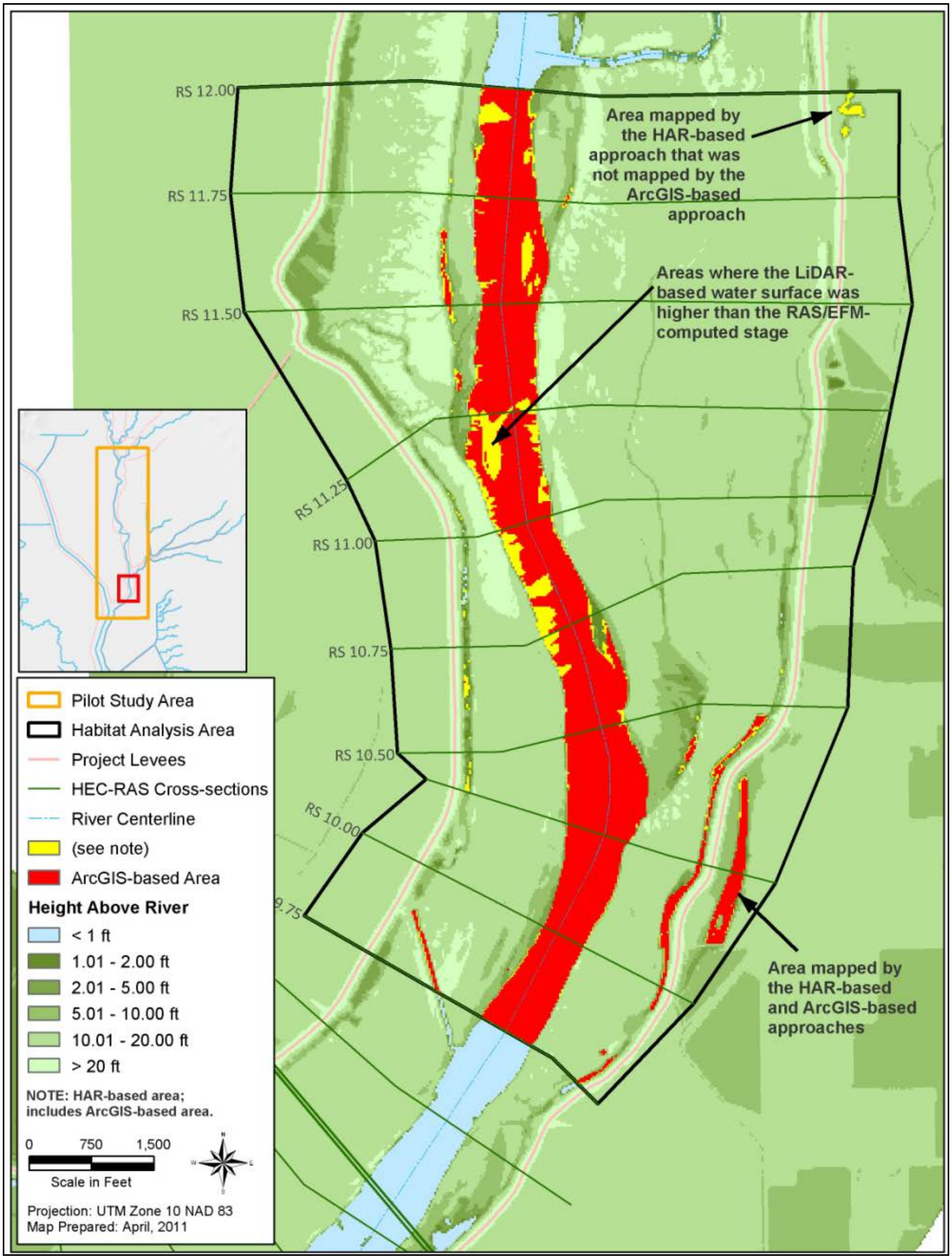

Figure A-25. Salmonid-Rearing Habitat Areas Mapped Using FIP and ArcGIS in HAA 11.00

The following are important findings of this approach:

1. **Mapping stages directly from HEC-EFM may or may not be appropriate, depending on whether the HAA is hydraulically homogenous.**

   For HAA 11.00, this approach provides a reasonable estimate of the area very similar to the FIP-based approach.

2. **The water surface areas mapped are the direct, raw product of the RAS/EFM analysis.**

   Areas have not been refined based on additional ecological or biological considerations, such as soil type, vegetation type, bank slope, connectivity, or land use.

3. **EFRs that produce stages below the LiDAR-observed water surface are not mapped by ArcGIS.**

   When EFR stages are below the LiDAR-observed water surface, water-surface area does exist; however, the area is simply below the LiDAR-observed water surface. To resolve this issue, bathymetry would need to be combined with the LiDAR terrain.

3.3.2 Refinement of Mapping Products

Results of the mapping process can be further refined, quantified, and/or visualized in ArcGIS. For example, a series of spatial analyses could be conducted to calculate the area of potential habitat based on location, connected vs. disconnected (to the main channel), and/or the specific EFR. Other GIS layers, such as soils, known habitat areas, vegetation type, bank slope, connectivity, and depth, could be used to refine the mapping products and assist in identifying areas where alternatives may be used to create additional habitat.

3.4 Conclusions

The purpose of this pilot study was to understand the methods and approaches required for the HEC-RAS and HEC-EFM analysis and to identify any issues with or alternative approaches to the analysis. The intent of this study was not to develop a final restoration opportunities analysis for the lower Feather River. This report should serve to clarify the RAS/EFM analysis and to identify topics for discussion.

The following general conclusions were reached as a result of this pilot study:

1. **While HEC-EFM is a robust tool for querying historic flow records, EFRs rely on a single set of numerical criteria (as opposed to a range) and lack dynamic (i.e., year-to-year) coupling of relationships.**

   The project team and stakeholders expressed concern that a single EFR may not adequately identify potential habitat areas because the EFR defines areas based on a single set of numerical criteria, as opposed to a range. While these criteria may reflect optimal conditions for an ecological process, the ecological process may achieve some success at sub-optimal conditions. Multiple EFRs could be developed for a single ecological process representing "optimal," "sub-optimal," and "minimal" conditions; however, this would significantly increase the level of effort required for a systemwide analysis. As an alternative, a single EFR representing a broader range of conditions could be considered.

   In addition, HEC-EFM does not dynamically couple EFRs. Since Cottonwood Seedling Recruitment relies on germination followed by minimal inundation within the same year, without dynamically coupling the two EFRs, the results are heavily skewed toward the relationship that produces the greater flow and stage.

2. **The SacEFT HEC-EFM EFRs may not be applicable systemwide.**

   The primary concern with using the SacEFT EFRs systemwide, as identified by project team members and Stakeholders, is that the existing EFRs were developed for the Sacramento River mainstem and may not be applicable to the Sacramento River tributaries and/or other rivers in the study area, such as the San Joaquin River and its tributaries.

3. **The pilot study did not identify significant amounts of potential habitat on the lower Feather River and the RAS/EFM analysis would likely produce similar results systemwide.**

   Because of the existing conditions of the lower Feather River and because of how EFRs are defined (as discussed above), limited habitat was identified on the lower Feather River. Given the conditions on other rivers within the project area (e.g., heavily leveed, restrained by dams, and/or incised), similar results may be produced systemwide.

Based on these conclusions, the project team considered developing a single EFR with a broader range of criteria, possibly with an upper- and lower-bound, to represent habitat opportunities. For example, the EFR may represent the peak 50 percent chance flow that occurs during a 7-day duration spring and/or summer storm event. An upper and lower bound EFR may correspond to a higher or lower frequency and/or greater or smaller duration and/or time period. In combination with HEC-EFM and/or other statistical tools (e.g., the USACE HEC Statistical Software Package (HEC-SSP)), the synthetic flow record derived from the CalSim model may be queried at select locations where potential habitat is likely to exist. The EFR criteria will be based solely on flow, and since the CalSim-based flow records are developed wherever significant changes in flow occur, the development of HAAs is not critical. The flows associated with the EFR at these locations would then be mapped using HEC-RAS (steady-state) and the FIP approach. Regardless of whether HEC-EFM and/or other statistical tools, such as HEC-SSP, are used to query the flow records, it is the EFR criteria that ultimately determines the amount of potential habitat area identified. Therefore, the use of HEC-EFM versus other statistical tools should be based primarily on the ease of use, time required to set up, and output results from the software.

4.0 Acronyms and Abbreviations

cfs .... cubic feet per second

Comprehensive Study .... Sacramento and San Joaquin River Basins Comprehensive Study

CVFED .... Central Valley Floodplain Evaluation and Delineation

CVP.................................... Central Valley Project

DEM .... digital elevation model

DWR .... California Department of Water Resources

EFR.................................... Ecosystem Function Relationship

ESRI.................................... Environmental Systems Research Institute, Inc.

FIP .... floodplain inundation potential

FROA .... Floodplain Restoration Opportunity Analysis

GIS...................................... geographic information system

HAA.................................... Habitat Analysis Areas

HAR .... Height Above River

HEC-DSS .... Hydrologic Engineering Center's Data Storage System

HEC-EFM............................ Hydrologic Engineering Center's Ecosystem Functions Model

HEC-GeoRAS .... Hydrologic Engineering Center's River Analysis System

HEC-RAS .... Hydrologic Engineering Center's River Analysis System

HEC-SSP .... Hydrologic Engineering Center'S Statistical Software Package

LiDAR.................................. Light Detection and Ranging

MWH .... MWH Americas, Inc.

NAVD88 .... North American Vertical Datum 1988

NGS .... National Geodetic Survey

NGVD29............................... National Geodetic Vertical Datum of 1929

RAS/EFM .... HEC-RAS/HEC-EFM

RS.. River Station
SacEFT................................ Sacramento River Ecological Flows Tool
SWP.................................... State Water Project
TIN...................................... triangular irregular network
TM....................................... Technical Memorandum
USACE................................ U.S. Army Corps of Engineers
USGS.................................. U.S. Geological Survey
WSEL.................................. water surface elevations
WY...................................... Water Year

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Attachment 9F: Floodplain Restoration Opportunity Analysis Appendix B – Investigation of USGS 10-Meter DEM Accuracy

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Appendix B

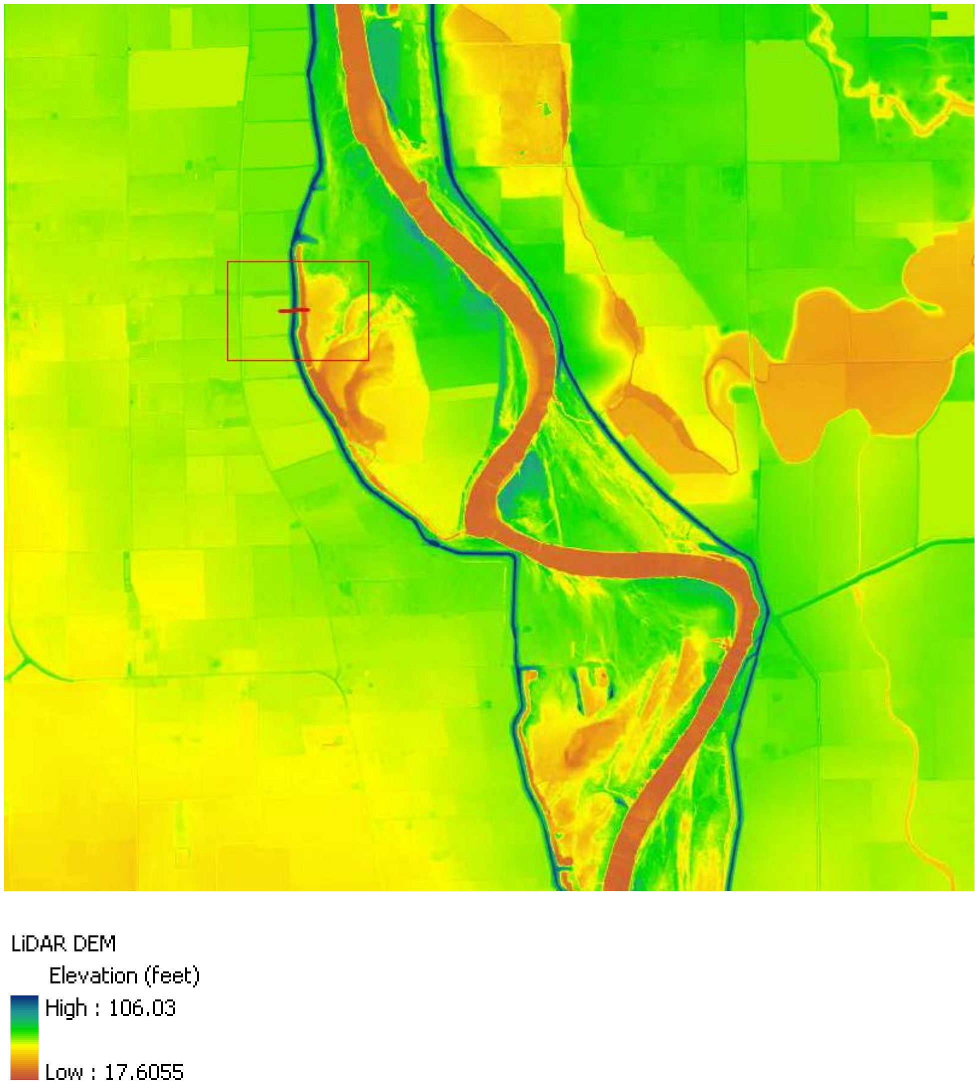
U.S. Geological Survey (USGS) 10-meter digital elevation models (DEM) were obtained (USGS, 2010) and evaluated for their appropriateness of use in the pilot study along the lower Feather River. This appendix provides the methods and results of a brief assessment of these data.

A portion of the California Department of Water Resources Central Valley Flood Evaluation and Delineation Project (CVFED) light detection and ranging (LiDAR)-derived DEM was selected (see inset box on Figure B-1) and a cross section was taken of the levee to compare the elevations from both the USGS DEM and LiDAR-derived DEM.

Elevations in the vicinity of the levee cross section are shown on Figure B-2 from the LiDAR-derived DEM, and Figure B-3 from the USGS DEM, indicating a significant difference in the two data sets with the USGS data presenting essentially “flat” topography in this location.

Figure B-4 provides a profile view of the two cross sections, demonstrating the lack of topographic relief provided in the USGS DEM data, and Figure B-5 provides tabular data indicating a USGS DEM surface is approximately 6 feet higher landward from the levee.

Given this comparison of the USGS DEM against the LiDAR DEM, it was determined that the USGS data does not pick up the crests of project levees. In many cases, the USGS data barely show any increase in elevation at the levee crest, and present a higher ground elevation landward from the levee. Based on this comparison, it was determined that the USGS DEM cannot be used as a substitute for the LiDAR-derived DEM data.



Note: Red line inside red box is a cross section used to compare the elevations of the U.S. Geological Survey digital elevation model and Light Detection and Ranging-derived digital elevation model.

Figure B-1. LiDAR-Derived DEM of the Pilot-Study Reach

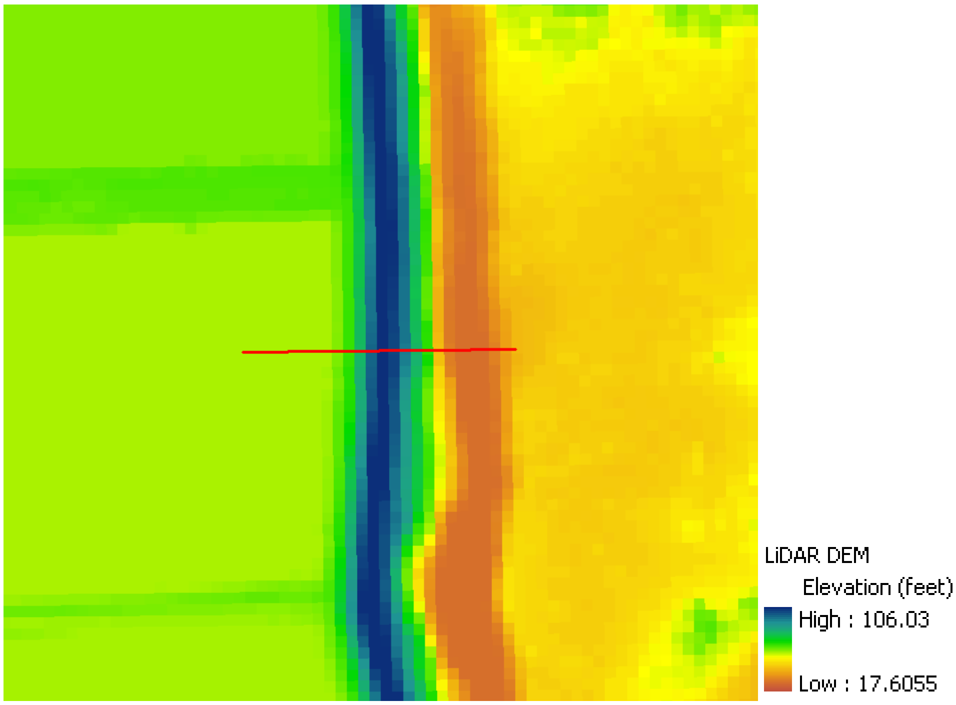


Figure B-2. Closeup of Cross Section on LiDAR DEM

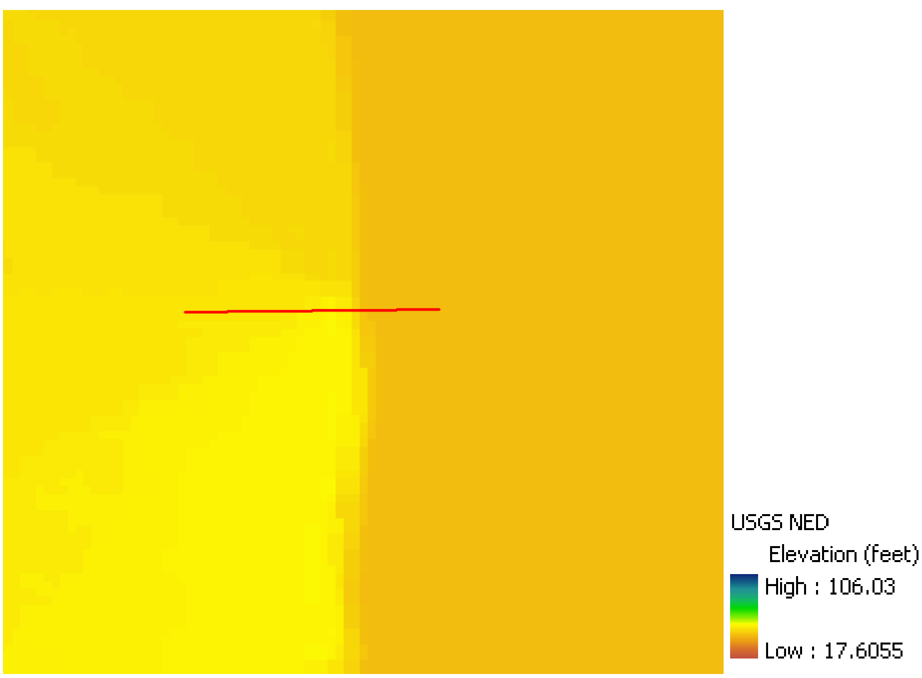


Figure B-3. Closeup of Cross Section on USGS DEM

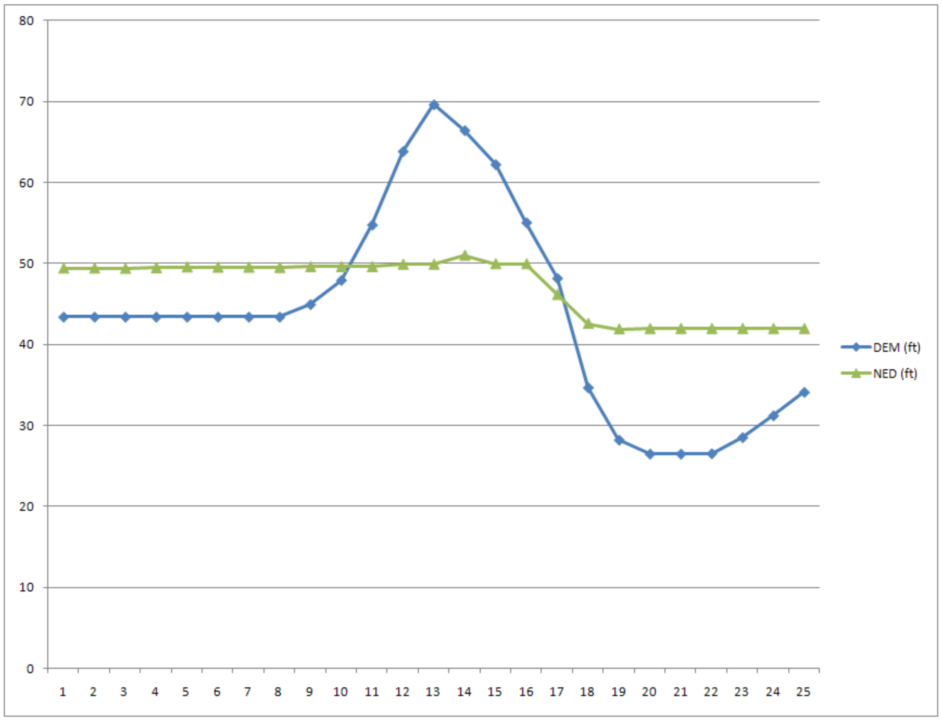


Figure B-4. Cross-Section Profiles

DEM (ft)	NED (m)	NED (ft)
43.41	15.06	49.40
43.41	15.06	49.40
43.41	15.05	49.36
43.41	15.08	49.46
43.41	15.11	49.56
43.41	15.1	49.53
43.41	15.1	49.53
43.41	15.09	49.50
44.96	15.12	49.59
47.95	15.12	49.59
54.78	15.12	49.59
63.87	15.21	49.89
69.64	15.21	49.89
66.45	15.55	51.00
62.24	15.23	49.95
55.07	15.23	49.95
48.19	14.07	46.15
34.68	12.98	42.57
28.21	12.77	41.89
26.49	12.79	41.95
26.49	12.79	41.95
26.54	12.79	41.95
28.53	12.79	41.95
31.22	12.79	41.95
34.12	12.79	41.95

Figure B-5. Tabular Comparison of Cross-Section Elevations

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Attachment 9F: Floodplain Restoration Opportunity Analysis Appendix C – CVFED LiDAR Terrain Data Comparisons

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Appendix C

Since final digital elevation models (DEM) were not available from the California Department of Water Resources (DWR) Central Valley Flood Evaluation and Delineation Project (CVFED) program at the time of this pilot study, the DEM preparation involved the use of preliminary CVFED terrain data and incorporating/building breaklines and filling in void areas found in the data to create a triangulated irregular network (TIN) from which to derive a DEM of a specified grid cell size. An approximate 30-square-mile area was defined for the DEM preparation (Figure C-1). The light detection and ranging (LiDAR) data had data voids where there is water and dense vegetation that restricted the TIN from triangulating, essentially leaving large gaps in the TIN. Points were created in those areas to help complete the TIN.

Factors considered in the completion of the TIN and DEM included:

1. Projection – The were in a standard coordinate system; however, if they were not, then the LAS files would need to be converted to a shapefile and reprojected.

2. Data Voids – Where the data did not have interpolated points/breaklines across data void areas for the TIN to easily triangulate, “filler” points were created to provide a surface across the void areas to enable the completion of the TIN surface.

3. TIN/DEM Build – This process was iterative and required that no gaps remained in the TIN and resulting DEM. For every gap found, a search radius was applied to identify the nearest points to triangulate.

At the request of the Project Team, a comparison was made of the preparation time, resolution (usability), and file size attributes for various DEM grid size resolutions. This comparison included 5-, 25-, 50-, and 100-foot DEMs in the Feather River pilot-study area.

The time difference associated with DEM sampling from the TIN was minor. The time considerations came primarily from the initial TIN build (especially if the LiDAR has data voids) and this was estimated to take 2 to 3 days per 100 square miles. Another potentially significant impact on preparation time would be hydro-correction of the terrain surface; however, this was not done, which preserved the actual topographic condition of the floodplain surfaces.

A sample portion of the pilot-study area was prepared at the various DEM grid cell resolutions to enable a visual comparison of the resolution differences (Figures C-2 to C-5).

The file sizes resulting from the various DEM grid cell resolutions varied dramatically, with exported ASCII DEM file sizes for the same area (approximately 30 square miles) as follows: 5-foot DEM at 365.3 megabytes (MB); 25-foot DEM at 14.3MB; 50-foot DEM at 3.6MB, and 100-foot DEM at 0.9MB.

Based on the results of this comparison a decision was made by DWR to develop a 25-foot DEM using preprocessed CVFED TO20 data in the pilot-study area. The use of a 25-foot resolution DEM was determined to provide a reasonable balance among the preparation time, resolution (usability), and file sizes with the intended level of detail for the final products from this planning-level exercise.

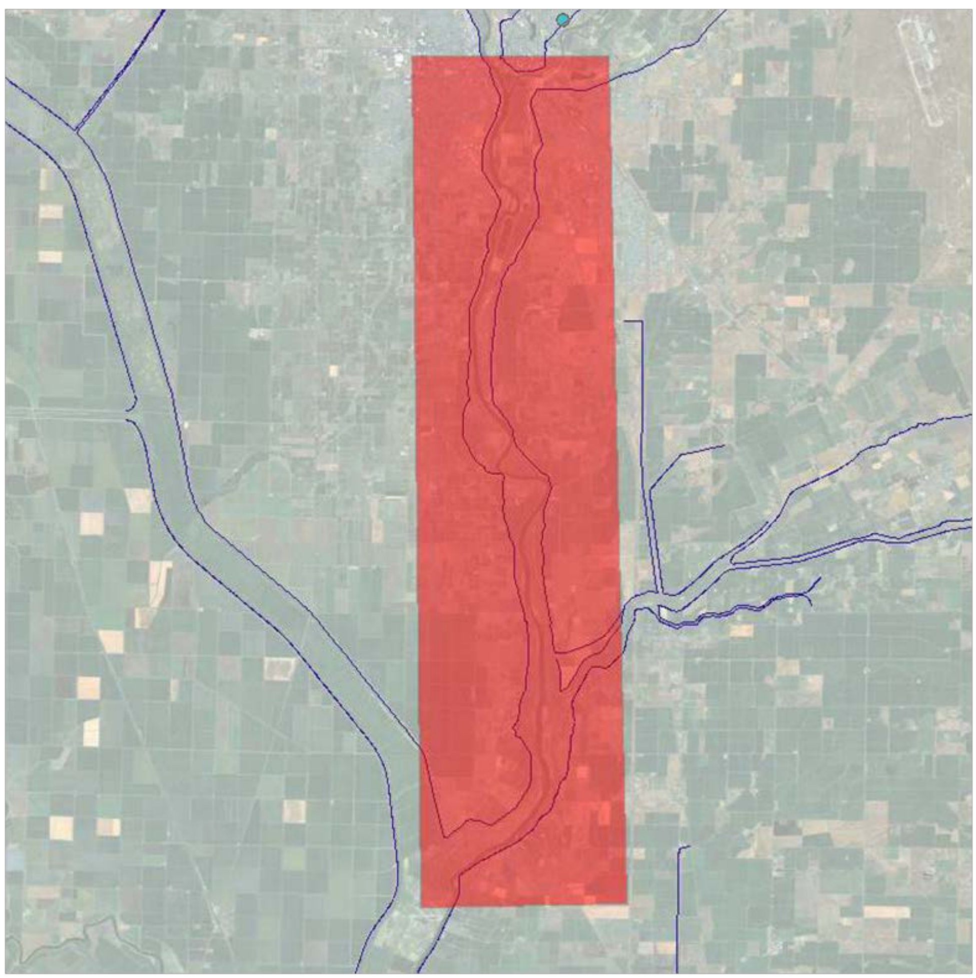

Figure C-1. Pilot-Study DEM Area

5ft DEM

25ft DEM

Figures C-2 and C-3. 5-Foot and 25-Foot DEM Grid Cell Size Resolutions, Respectively

50ft DEM

100ft DEM

Figures C-4 and C-5. 50-Foot and 100-Foot DEM Grid Cell Size Resolutions, Respectively

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Attachment 9F: Floodplain Restoration Opportunity Analysis Appendix D – Levee Realignment Methodology

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Appendix D

Within the Feather River pilot-study reach, the Project Team noted that there were two locations where levees had been set back since the March 2008 date of the light detection and ranging (LiDAR) flight. This resulted in a need to adjust the digital elevation model (DEM) terrain surface to show actual current topographic conditions. While the Height Above River (HAR) output to date still shows the old levee position, a separate effort was made to determine a reasonable approach to adjust levee locations for subsequent HAR analyses.

The following steps were taken to adjust the location of a levee in the DEM.

1. A polygon feature was created around the area of the existing and new levee locations. The polygon was used to clip the DEM, which cut down on the processing time (Figure D-1).

2. A copy of the DEM surface limited to the polygon area was extracted by using the Extract by Mask tool located in the ArcGIS Toolbox -> Spatial Analyst Tools -> Extraction -> Extract by Mask (Figures D-2 and Figure-D3, tool input Items a through c below; and Figure D-4, output resulting from Items a through c below).

    a. Input Raster – Input the DEM.

    b. Input Raster or Feature Mask Data – Input the polygon created in Step 1.

    c. User must set file location and name.

3. The raster was converted into points using the 3D Analyst Toolbar dropdown menu under Convert -> Raster to Features (Figure D-5).

    a. Output Geometry Type – Set to Point.

    b. Input Raster – This is the extracted raster from Step 2.

    c. Field – Set to <Value>.

    d. User must set output file location and name.

4. The existing and new levees were delineated with lines that were then buffered at a distance necessary to capture the entire width of the levee cells in the DEM (Figure D-6).

5. All points within the buffered areas were selected by using Main Menu -> Selection -> Select by Location (Figures D-7 and D-8, tool input Items a through d below; and Figures D-9 and D-10, output from Items a through d below).

   a. I want to – Pull down "Select Features From."

   b. The Following Layer – Click on the points file output from Step 3.

   c. That – Pull down "are within."

   d. The features in this layer – Pull down "New Levees Buffer" created from Step 4.

   e. The DEM polygon points selected within the new levee buffer area were deleted and the DEM polygon points selected within the existing levee buffer were exported using Step 6 before being deleted.

6. The points for the existing levee were selected in Step 5 and then exported by right clicking on the file name in the Layers Catalog: File Name -> Data -> Export Data. (Figures D-11 and D-12, tool input Items a through c below).

   a. Export – Pull down "Selected features."

   b. Use the same coordinate system as – Select "this layer's source data."

   c. Output shapefile or feature class – User sets file location and name.

7. The existing levee points from Step 6 were moved into the location of the deleted new levee points (Step 5e) in the Raster to Features point output from Step 3. This was done from the upstream portion of the levee to the downstream portion, where points from the existing levee were selected in groups and manually moved into the vacant new levee location. Occasionally a group of points needed to be rotated to fit the new area and maintain a consistent levee slope and height (Figure D-13).

8. The existing and new levee point layers were appended (combined) by entering the ArcGIS Toolbox, clicking on the Index Tab at the bottom,

typing “Append” into the “Type in key word to find:” box at the top, and selecting “Append (management)” (Figures D-14 and D-15, tool input Items a through c below). This combines the levee points from Step 3 (as modified in Step 5e) and the newly moved levee points from Step 7 into one file (Figure D-16).

a. Input Datasets – Enter filename for newly moved points from Step 7.

b. Target Dataset – Enter filename for points from Step 3, which were modified in Step 5e.

c. Schema Type (optional) – Pull down “NO TEST.”

9. All levee points were converted into a raster grid using the Features to Raster: Spatial Analyst toolbar -> Covert -> Features to Raster. (Figures D-17 and D-18, tool input Items a through d below).

    a. Input Features – Appended points file from Step 8.

    b. Field – This was set to GRID_CODE in the dropdown box.

    c. Output Cell Size – Should be set to the cell size of the DEM.

    d. Output Raster – User sets the raster file location and name.

10. The output raster had “NoData” value cells in the location of the existing levee because those points are no longer there. The next step involved filling these NoData cells with adjacent elevations from the DEM to create a smooth surface where the existing levee used to be (Figure D-19). This was done using the Spatial Analyst toolbar -> Raster Calculator (Figure D-20). In the expression box the following expression was typed, focalmean ([output raster from Step 9], rectangle, 3, 3, data) (Figure D-21). This expression assigns the NoData cells the Mean of the 3x3 area around them. This expression did not fill in all NoData cells on the first run, so the output of this expression was run through the raster calculator a second and third time until all NoData cells were given an elevation (Figure D-22).

11. The output raster from Step 10 was converted to Points using the same Raster to Features method as in Step 3 (Figure D-23).

12. The DEM was converted to Points using the same Raster to Features method as in Steps 3 and 11 (Figure D-24).

13. Points from the DEM points file, created in Step 12, were selected within the polygon created in Step 1, using Select by Location, which was done in Step 5 (Figure D-25). Once all points within the polygon were selected, they were deleted from the DEM points file from Step 12. The points from Step 11 were fit into the vacant area (Figure D-26).

14. The Points file from Step 13 was combined with the Points file from Step 11 using the Append (management) tool, as done in Step 8.

15. The appended Points shapefile from Step 14 was converted into a raster grid, as done in Step 9 using the Features to Raster tool, and this raster output was the final result (Figure D-27). The new levee is now in the DEM. If there are any NoData cells in the area where the new levee was added in the DEM, the expression from Step 10 can be run in the Raster Calculator.

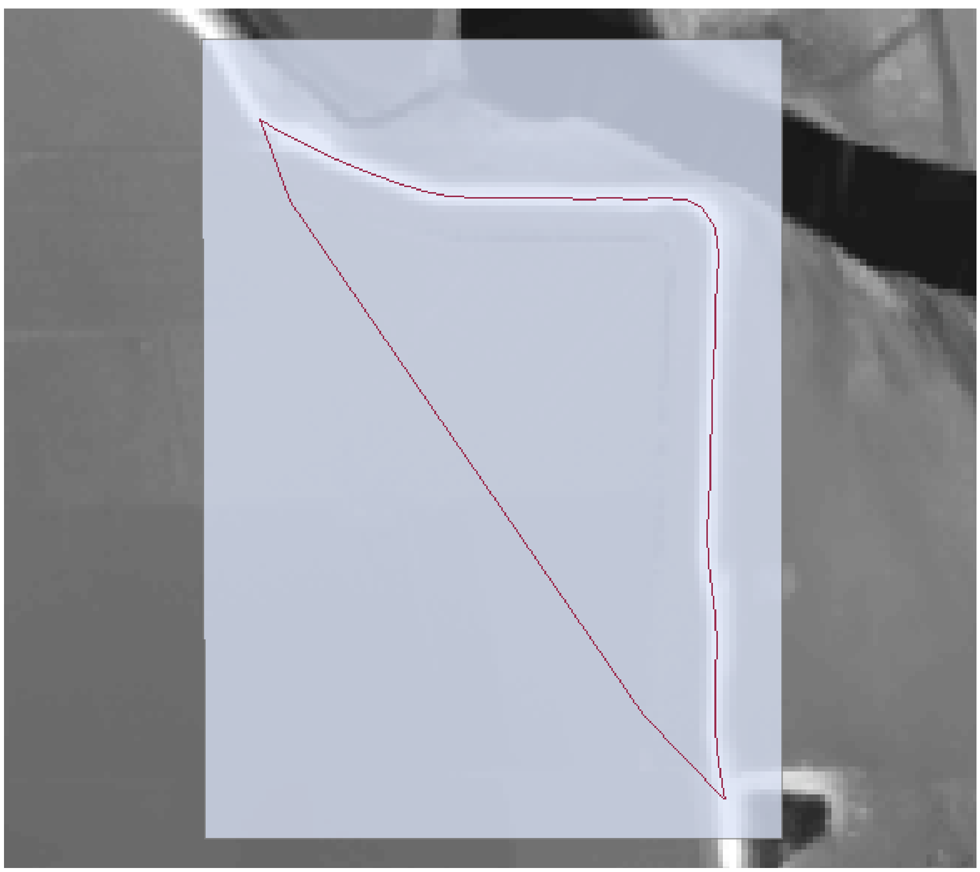

Figure D-1. Polygon Feature for DEM Extraction

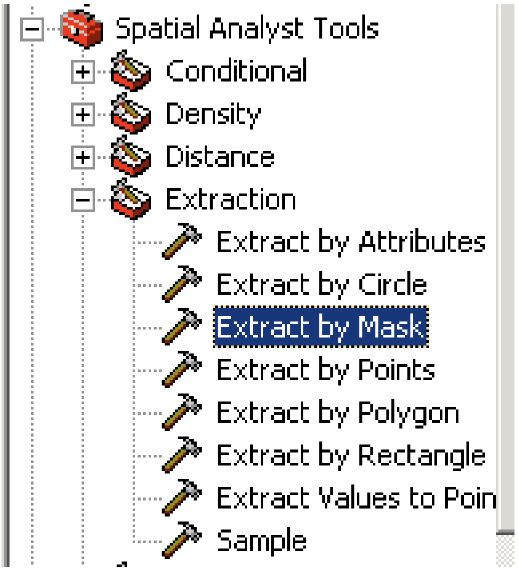

Figure D-2. Extract by Mask Tool in ArcGIS Toolbox

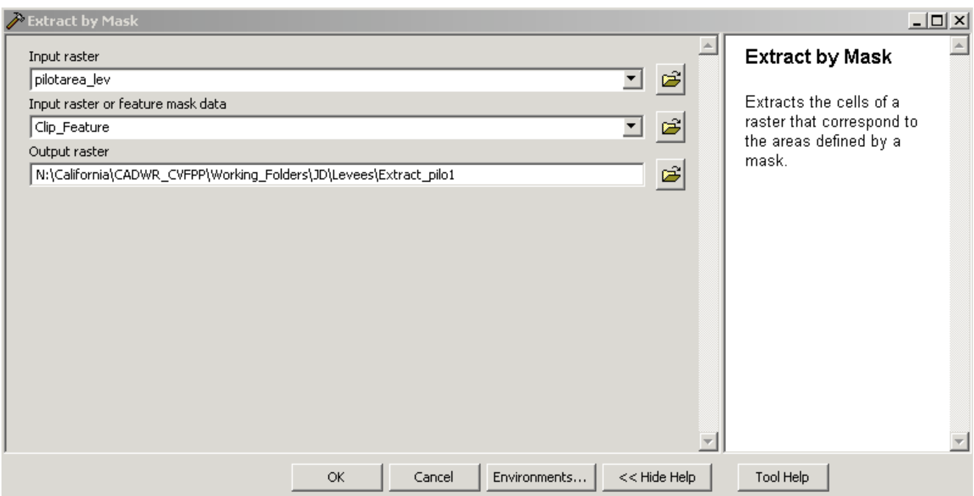

Figure D-3. Extract by Mask Menu Box

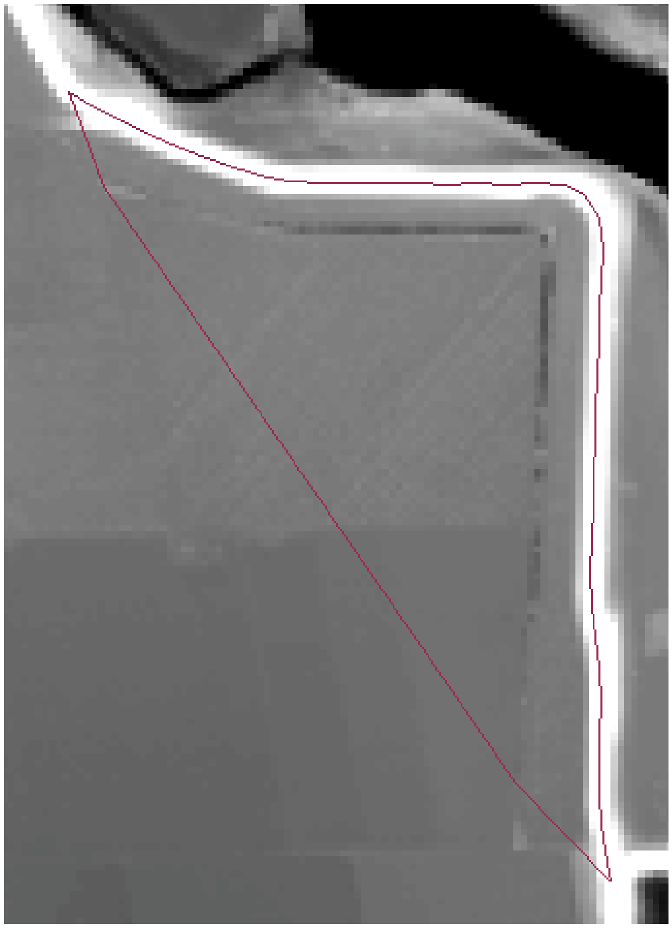

Figure D-4. Extract by Mask Output

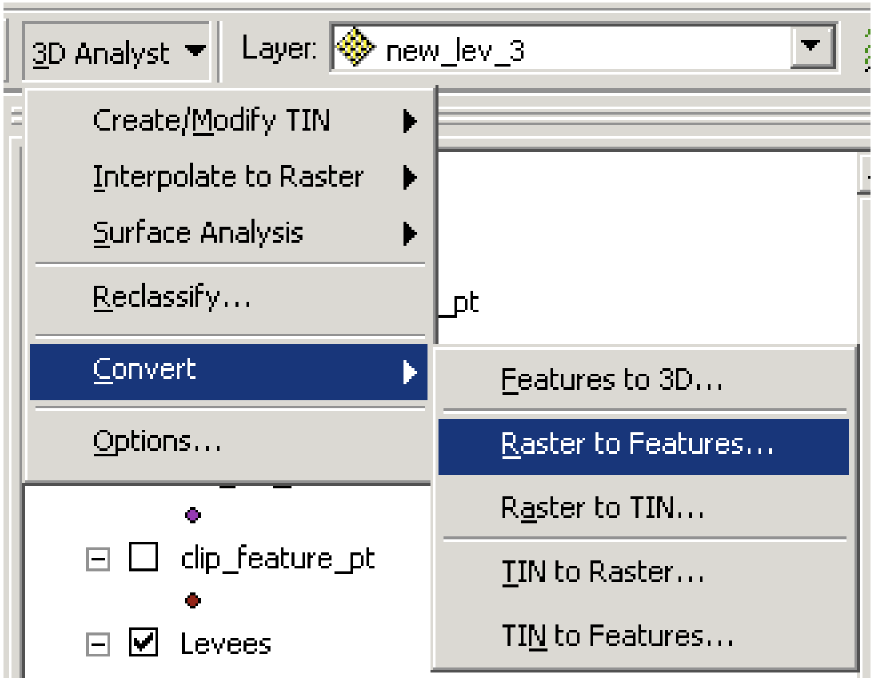

Figure D-5. Raster to Features Location in 3D Analyst Toolbar

Figure D-6. Buffer of Existing and New Levee Lines

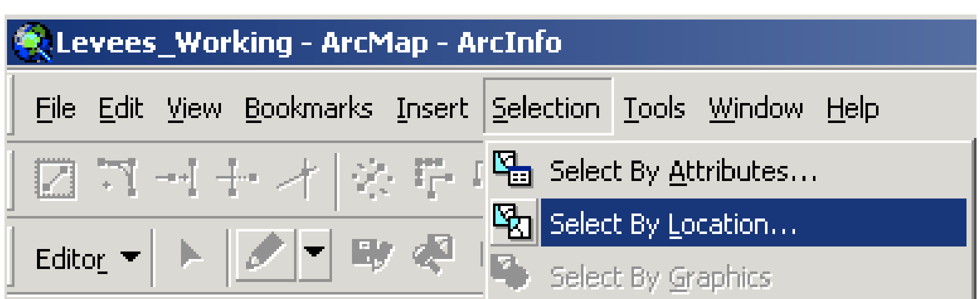

Figure D-7. Select by Location Tool

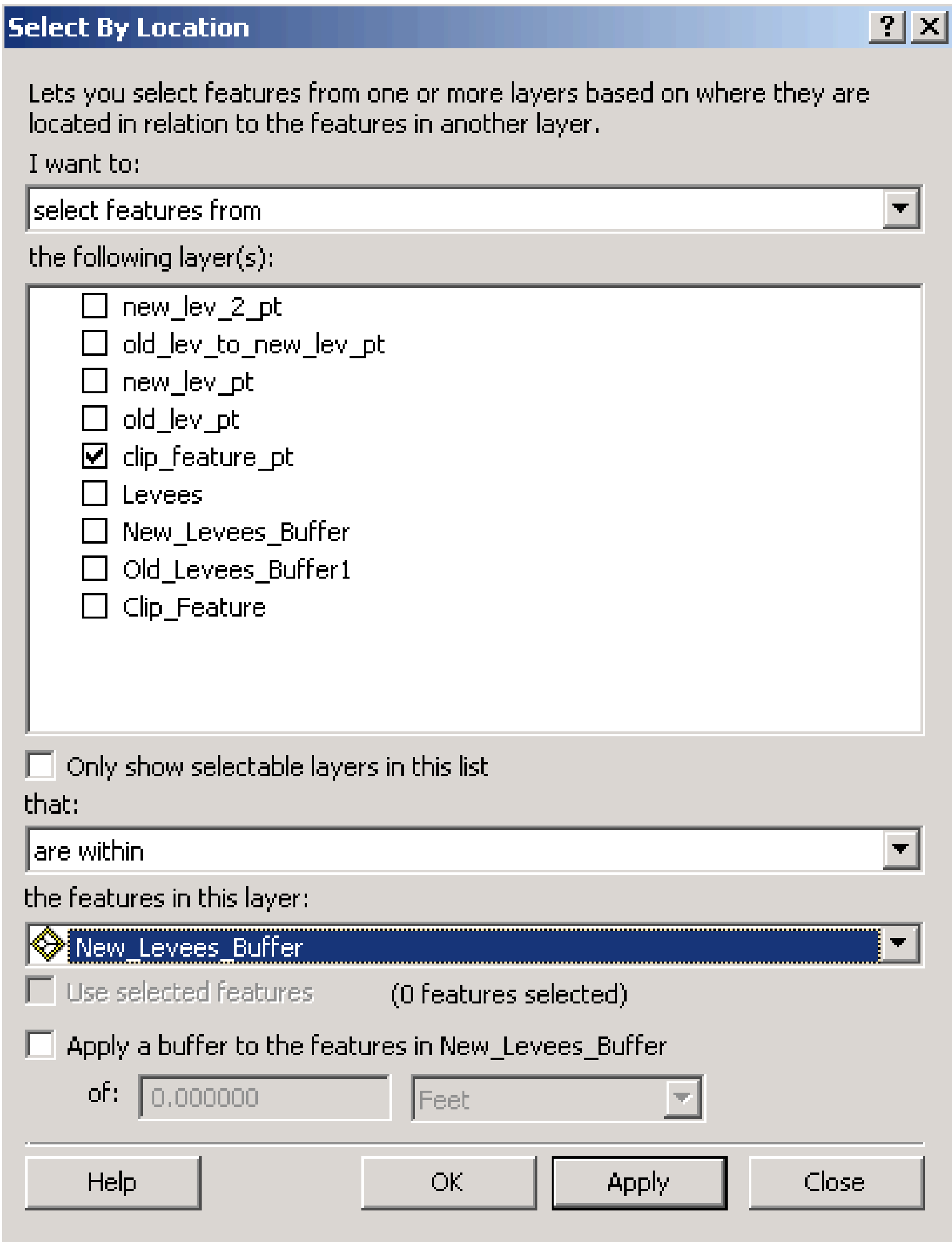

Figure D-8. Select by Location Menu Box

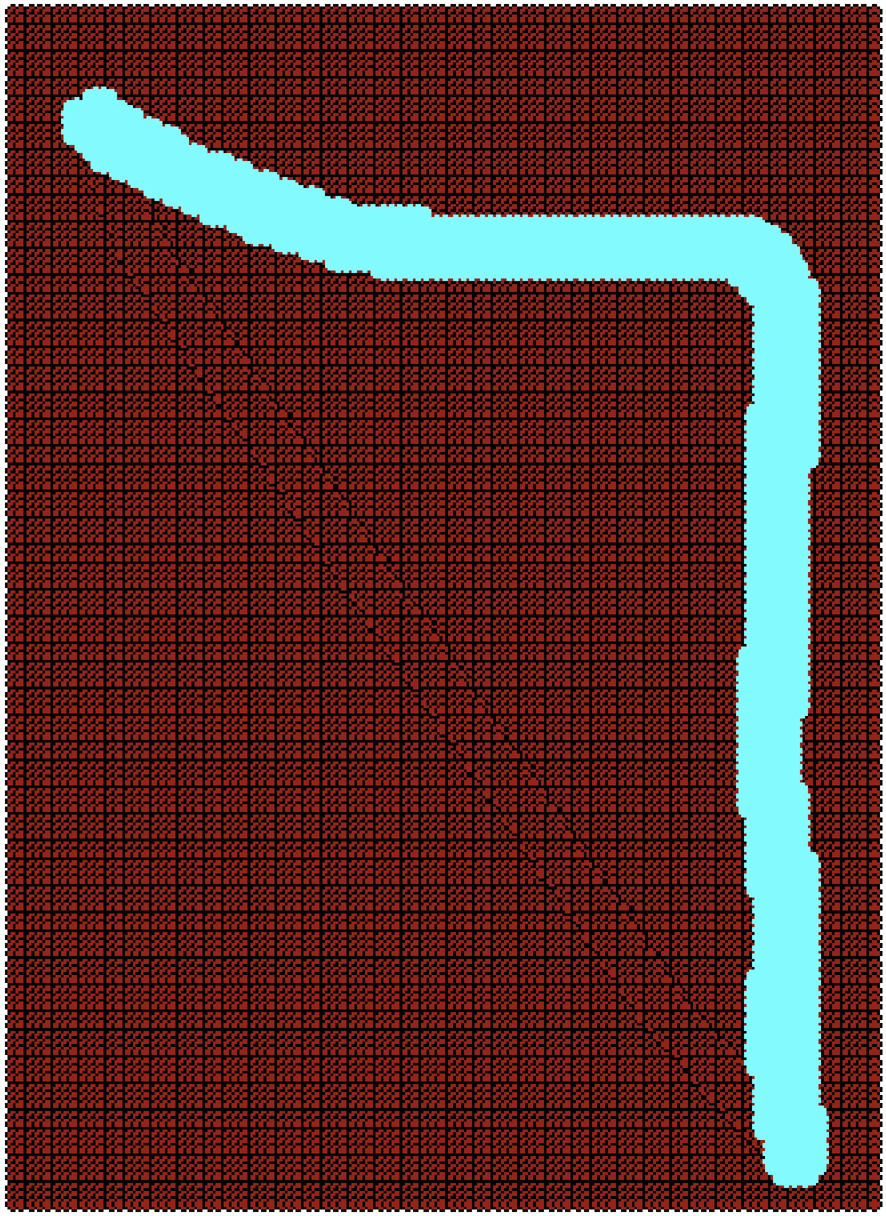

Figure D-9. Existing Levee Points

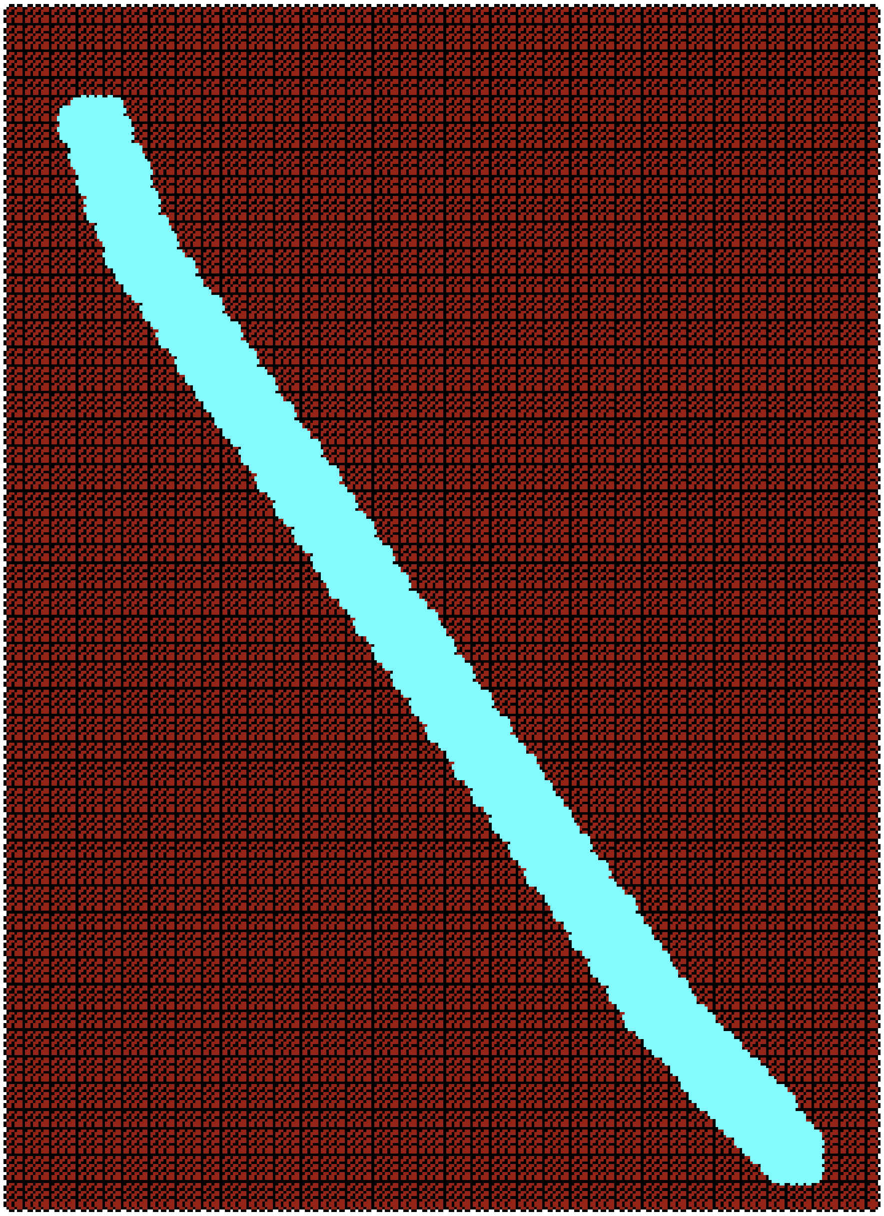

Figure D-10. New Levee Points

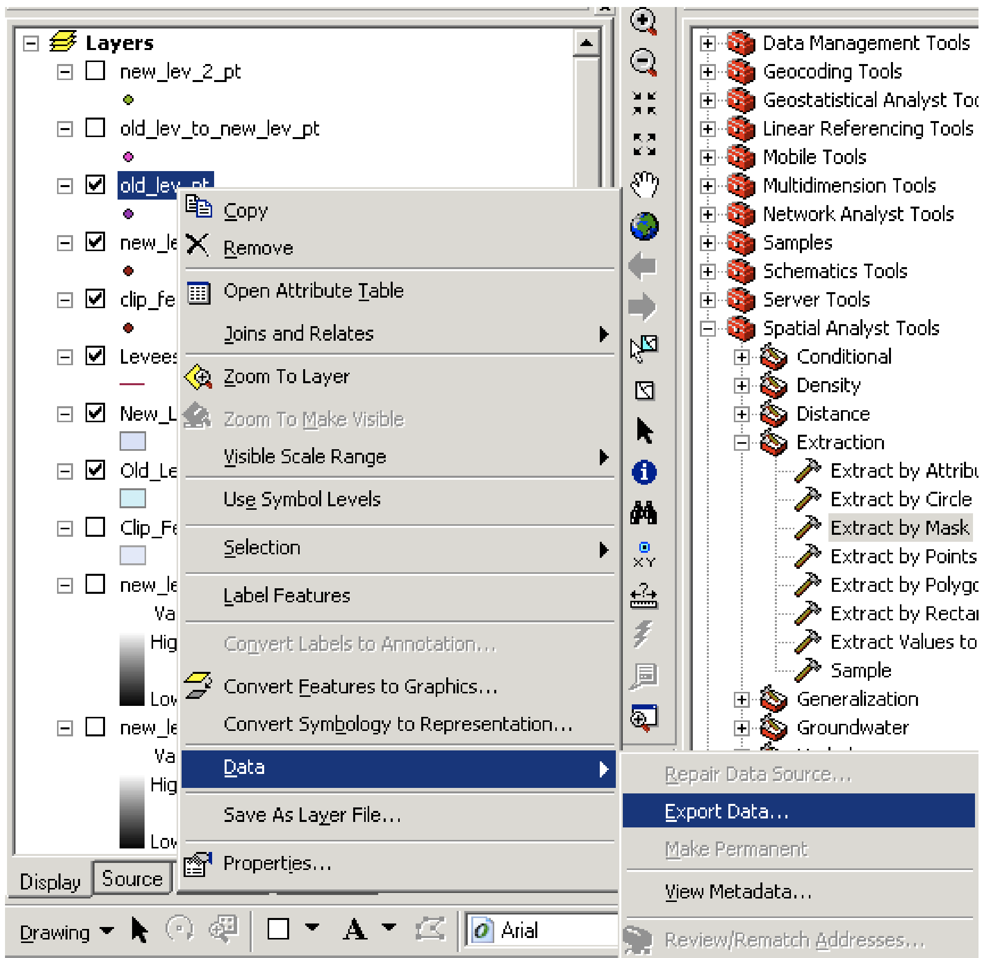

Figure D-11. Location for Export Data of the Existing Levee Points

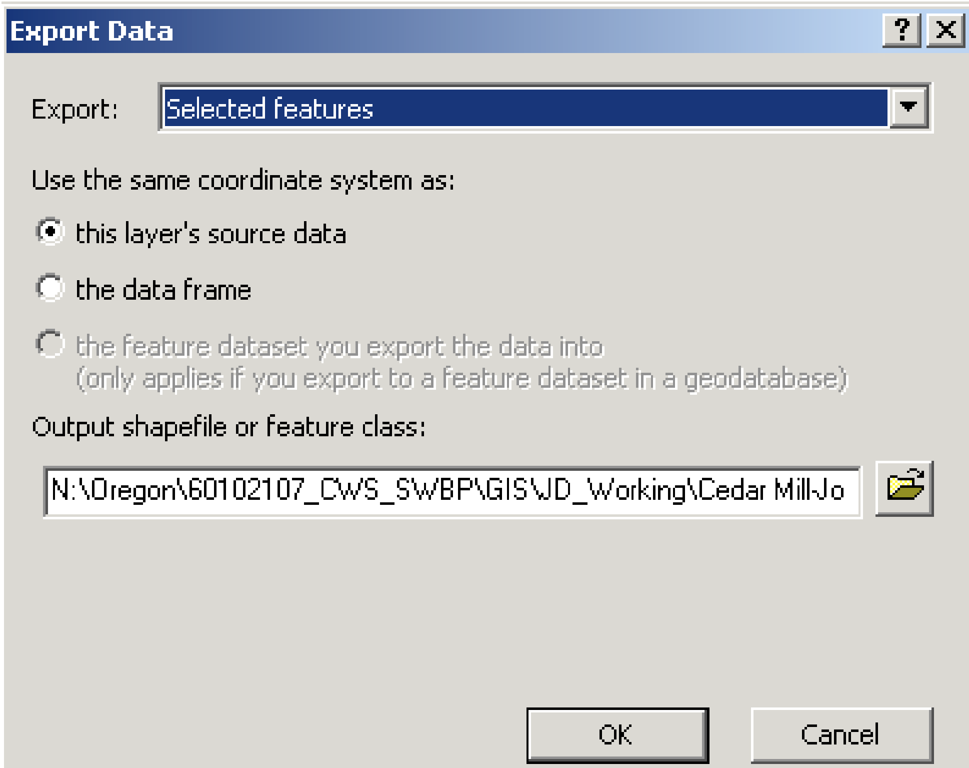

Figure D-12. Export Data Menu Box

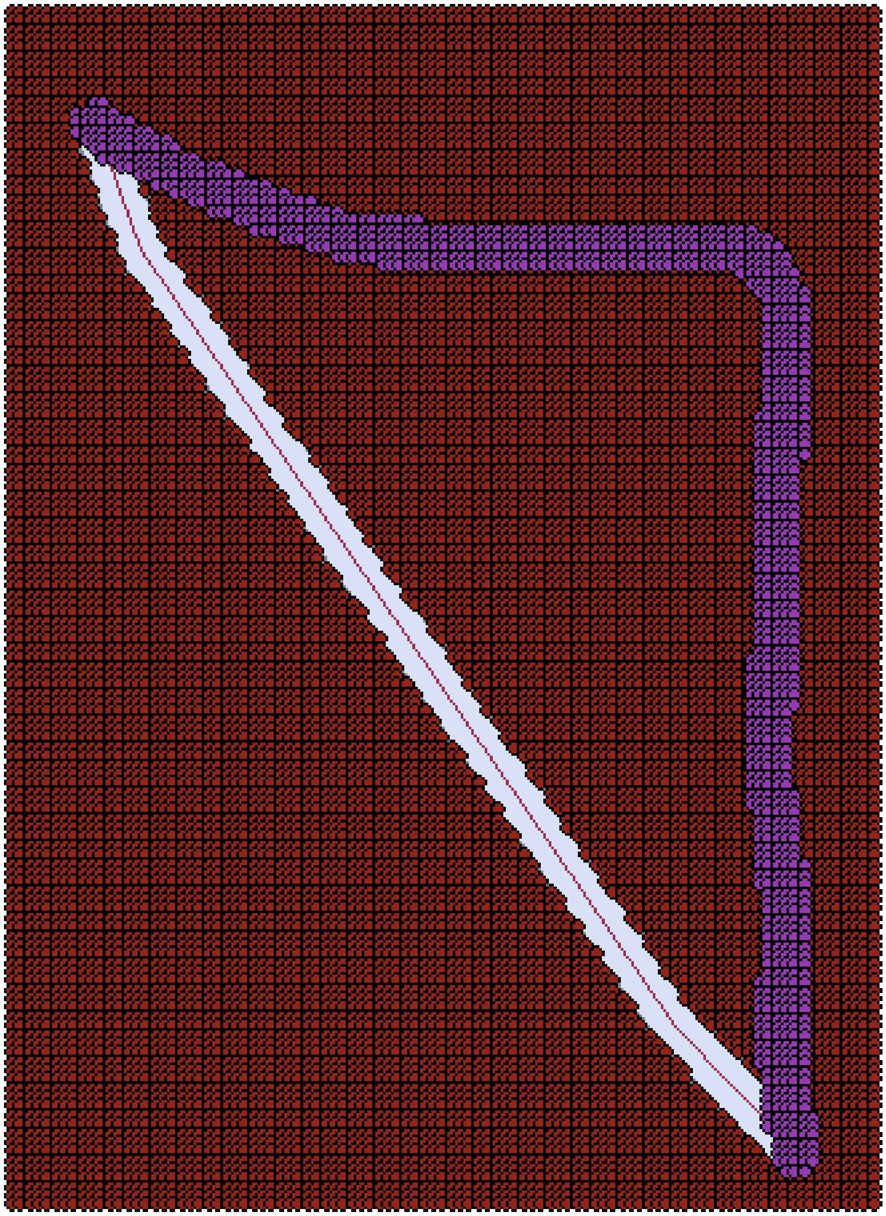

Figure D-13. Existing Levee Points (purple) Moved to New Levee Points (light grey)

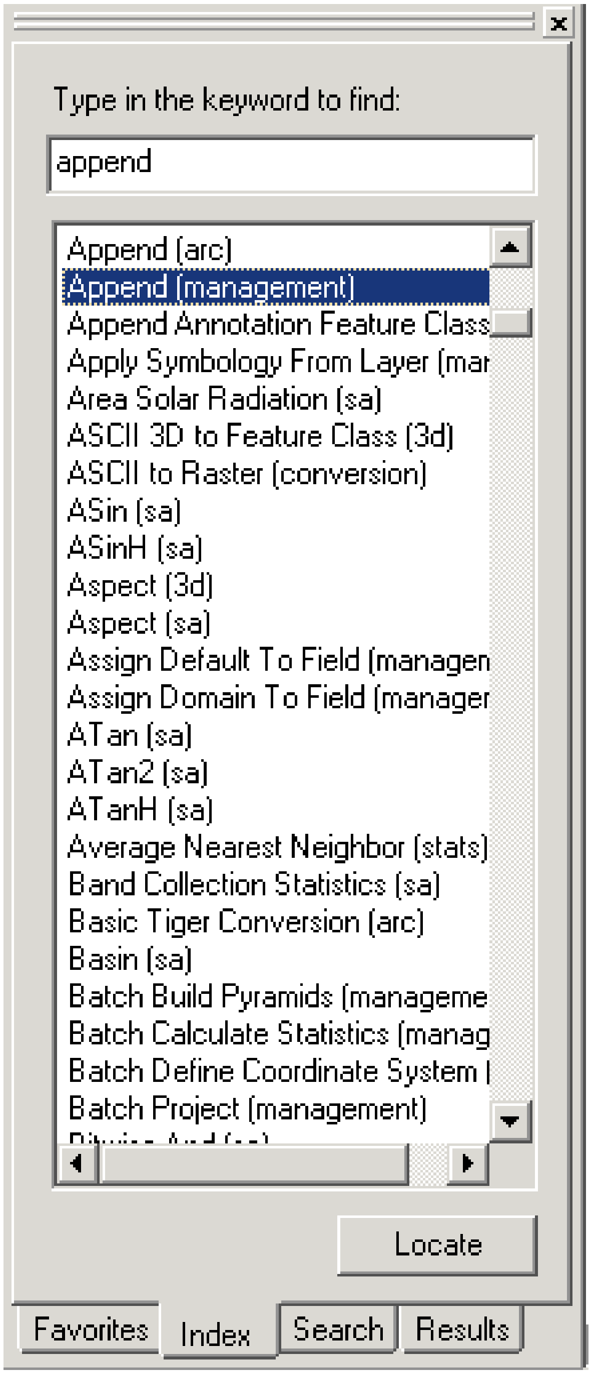

Figure D-14. Append Location in ArcGIS Toolbox

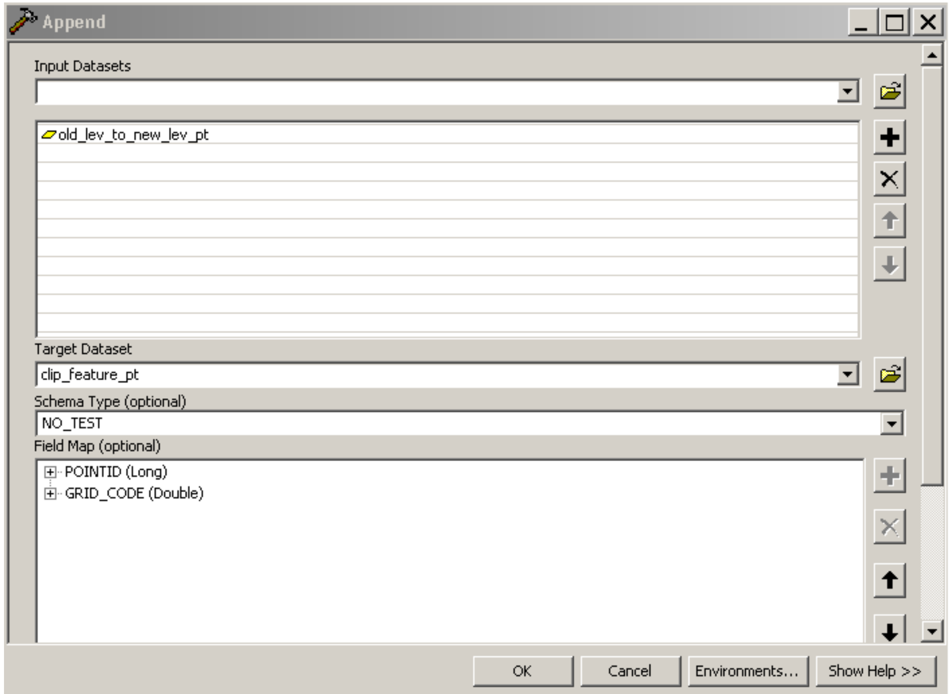

Figure D-15. Append Menu Box

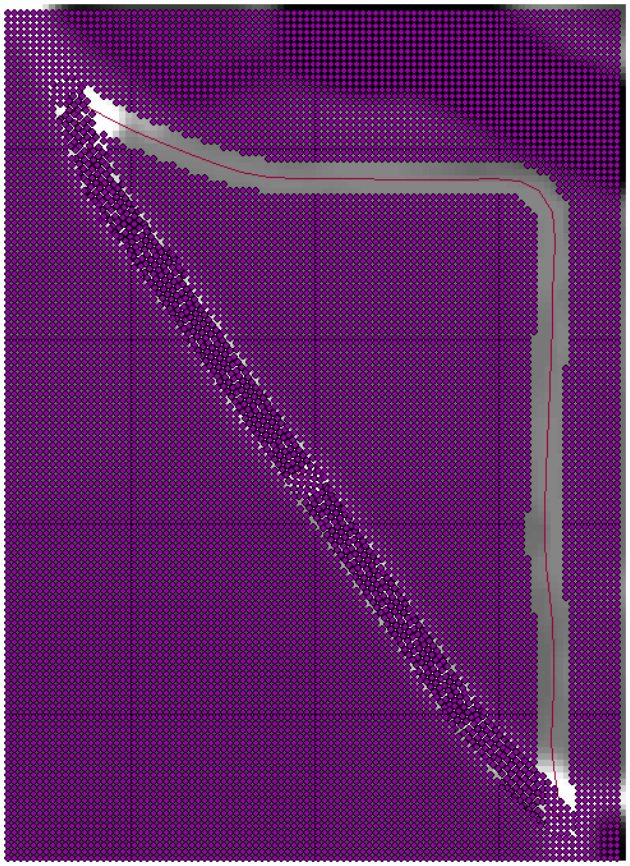

Figure D-16. Append Output

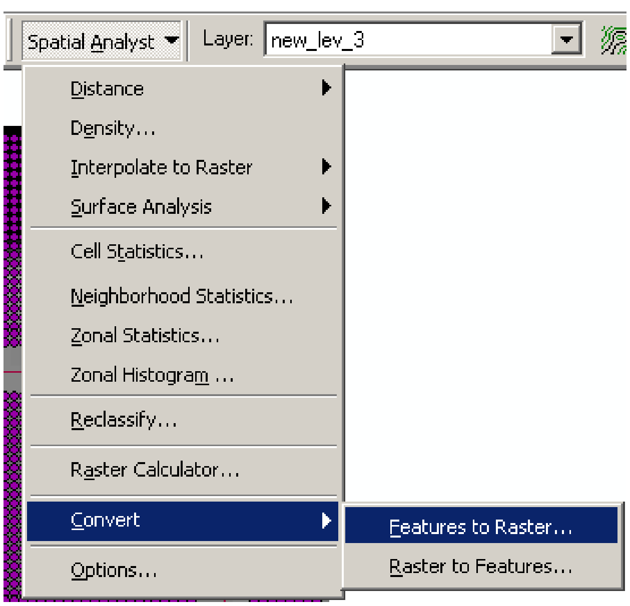

Figure D-17. Feature to Raster Location

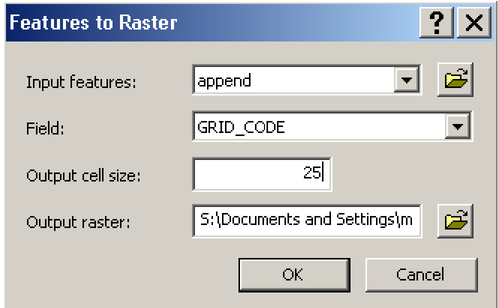

Figure D-18. Feature to Raster Menu Box

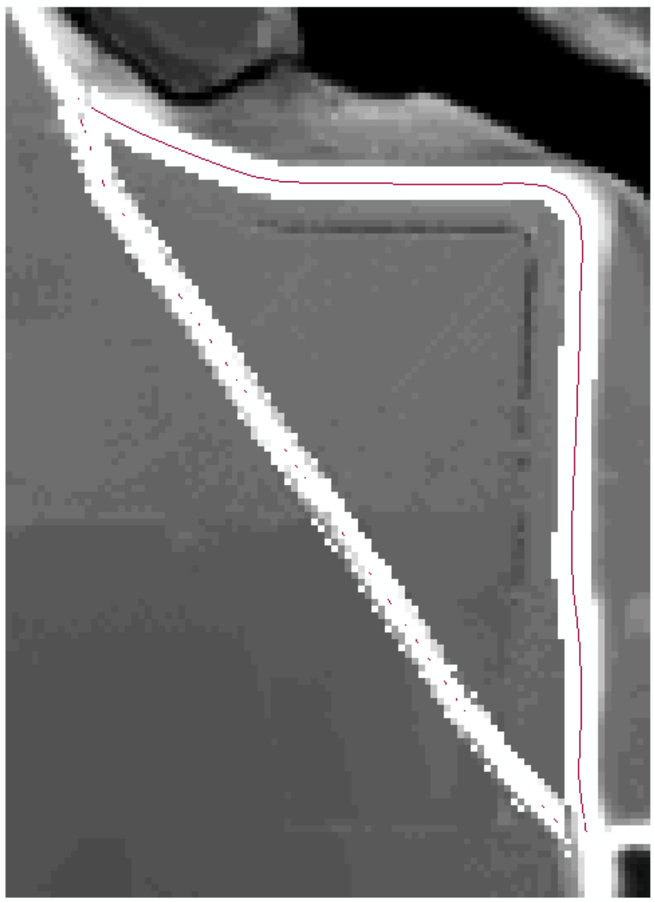

Figure D-19. Feature to Raster Output

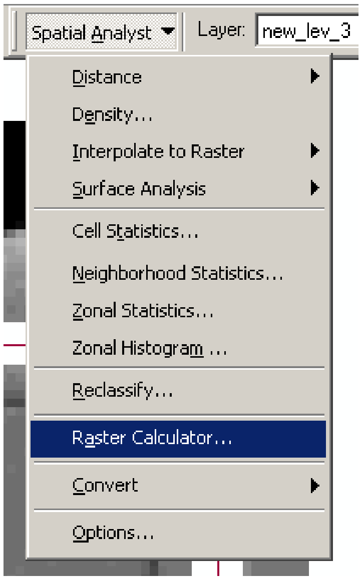

Figure D-20. Raster Calculator Location

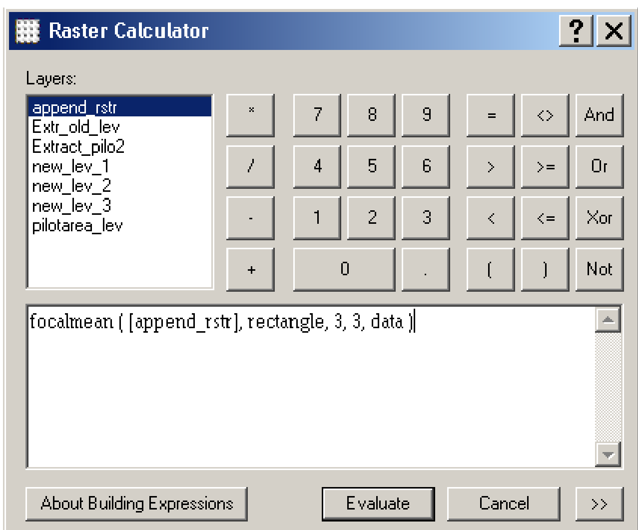

Figure D-21. Raster Calculator

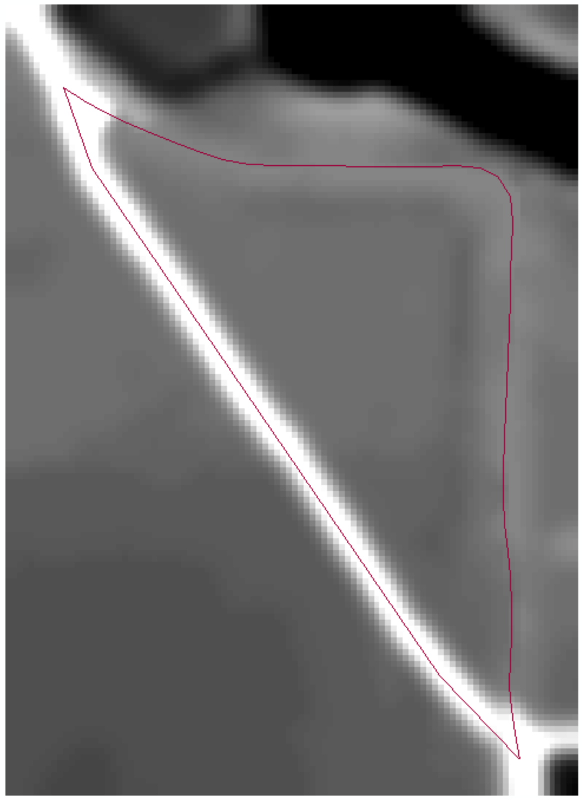

Figure D-22. Final Raster Output with New Levee

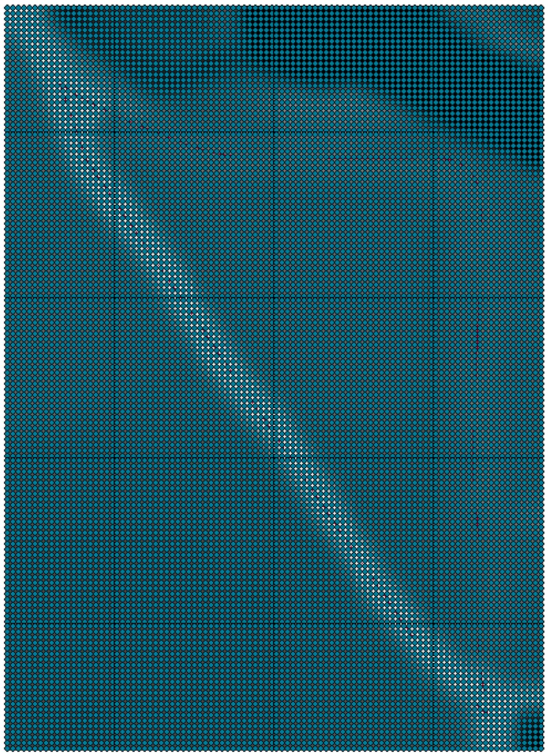

Figure D-23. Final Raster Output Converted into Points

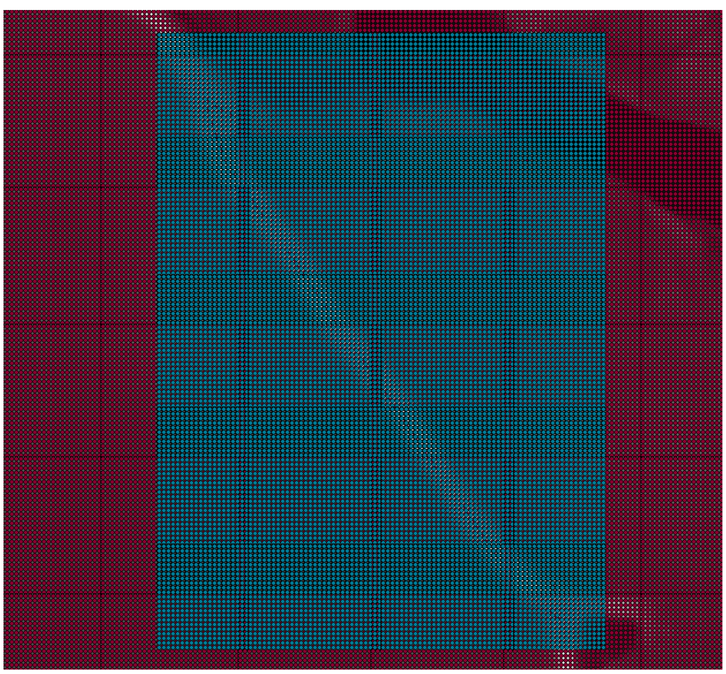

Figure D-24. DEM (outer box) and Final Raster Output (inner box)

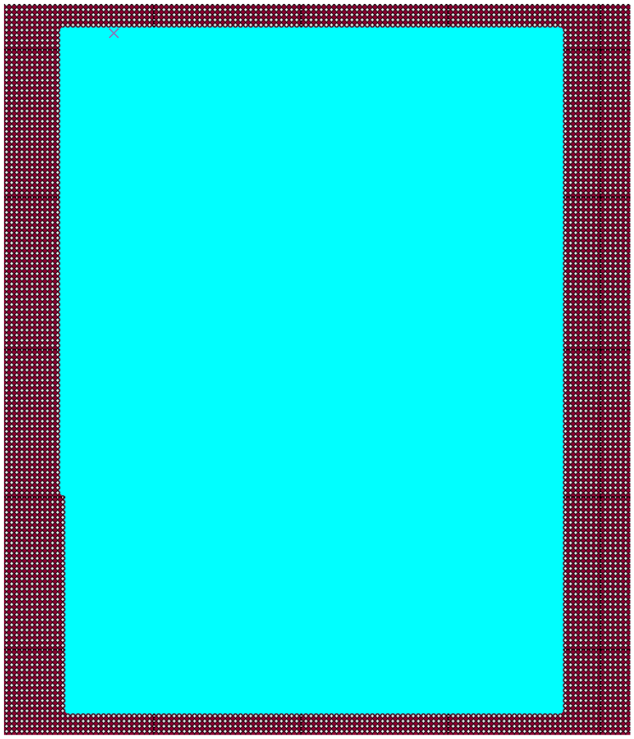

Figure D-25. DEM Points Selected with the Clip Polygon

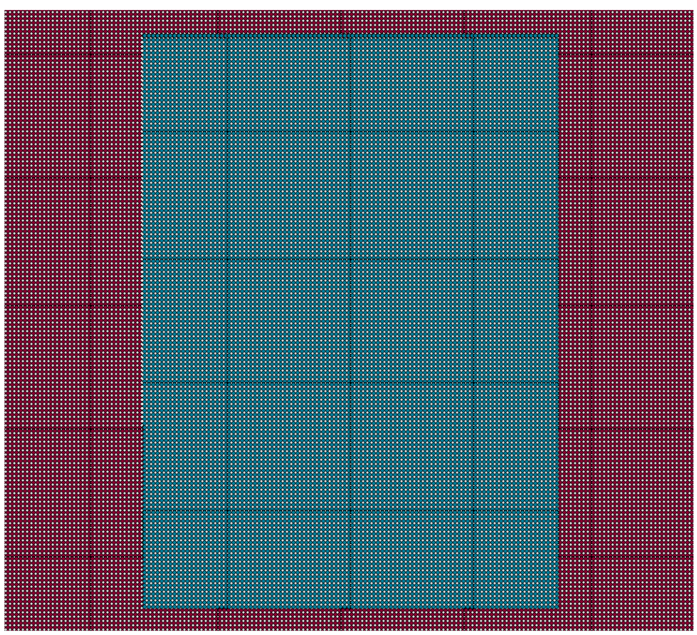

Figure D-26. Final Raster Output Points Combined in DEM

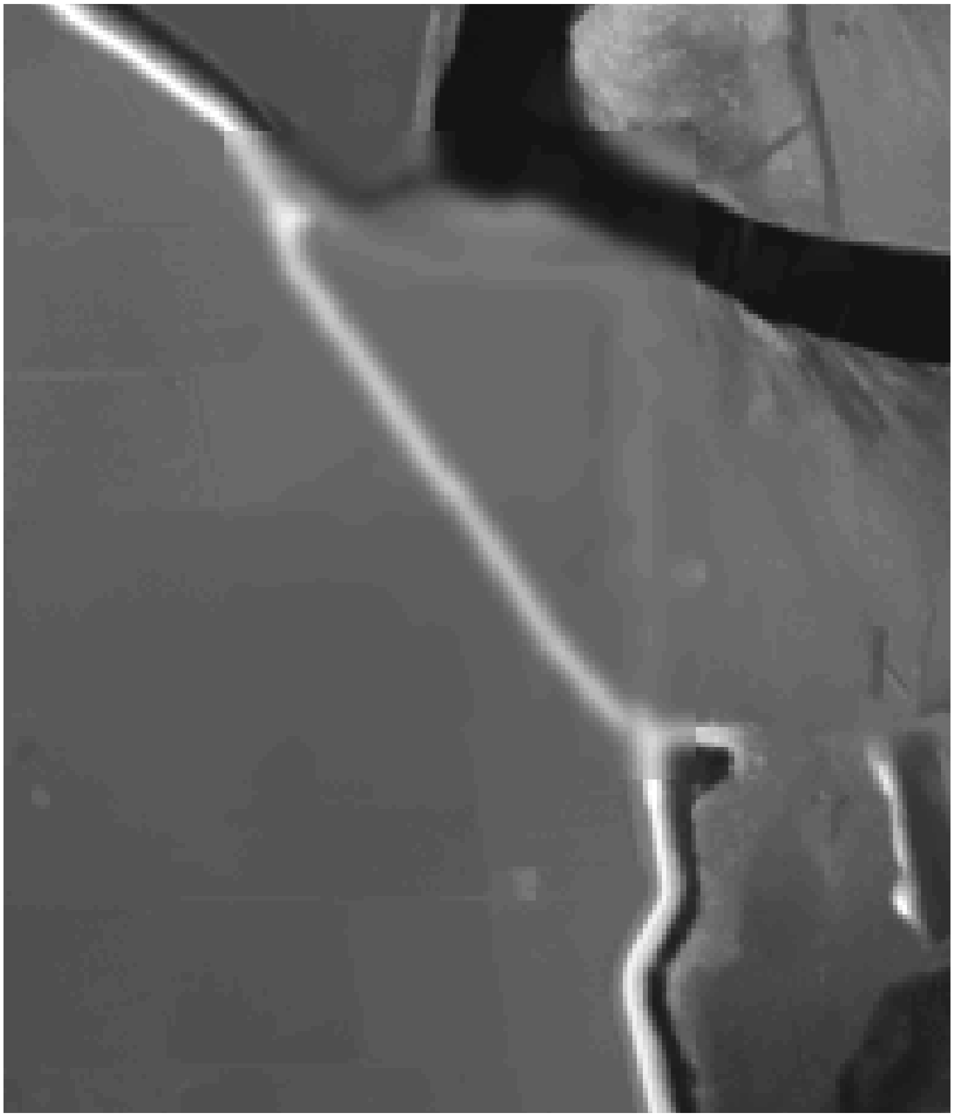

Figure D-27. DEM with New Levee Added in and Old (existing) Levee Removed

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Attachment 9F: Floodplain Restoration Opportunity Analysis Appendix E – Synthetic vs. Observed Hydrographs

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Appendix E

For Yuba City and Shanghai Bend, this appendix provides graphical comparisons of observed Feather River flows, and synthetic daily averaged flows derived from CalSim. These comparisons are displayed as time series and exceedence curves in Figures E-1 through E-4. The selected period of record (October 1, 1969, through September 30, 1976) represents a time frame when both USGS gages were in operation.

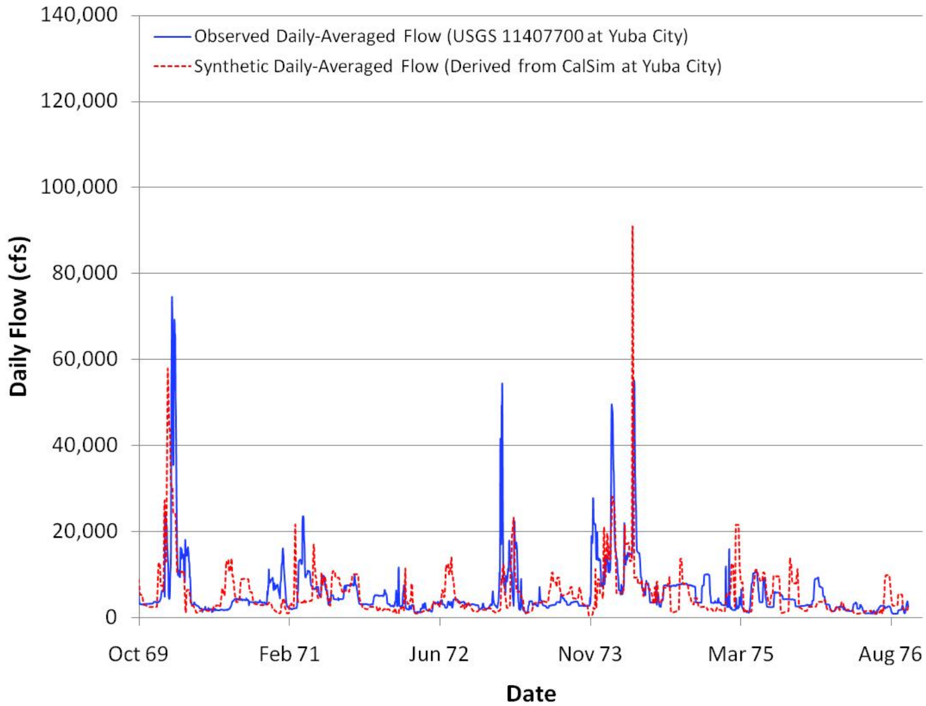

Figure E-1. Synthetic vs. Observed Flow – Yuba City

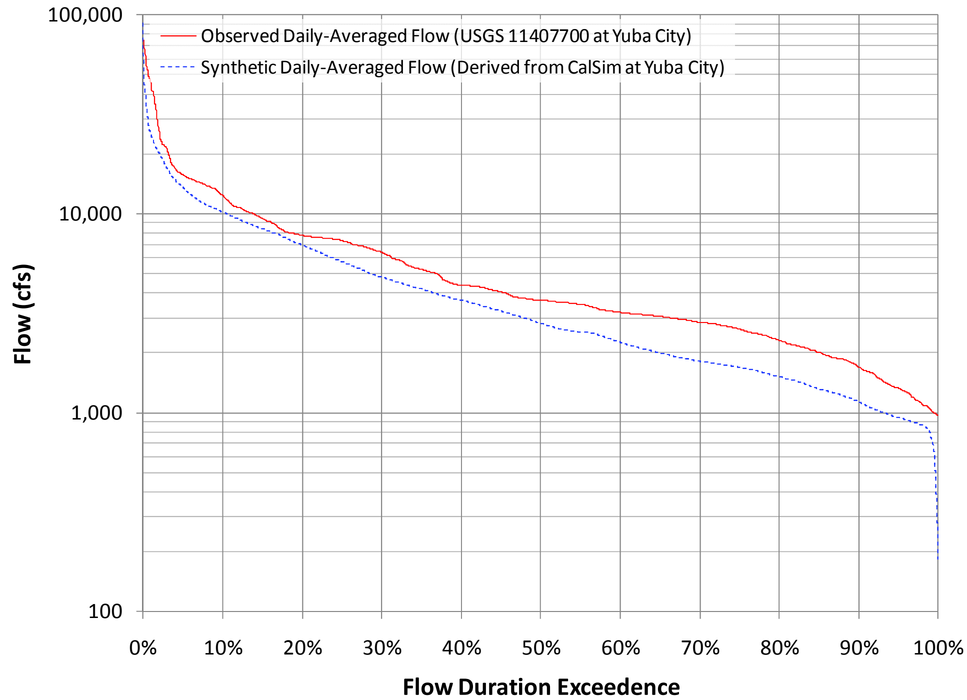

Figure E-2. Synthetic vs. Observed Flow Duration Curve – Yuba City

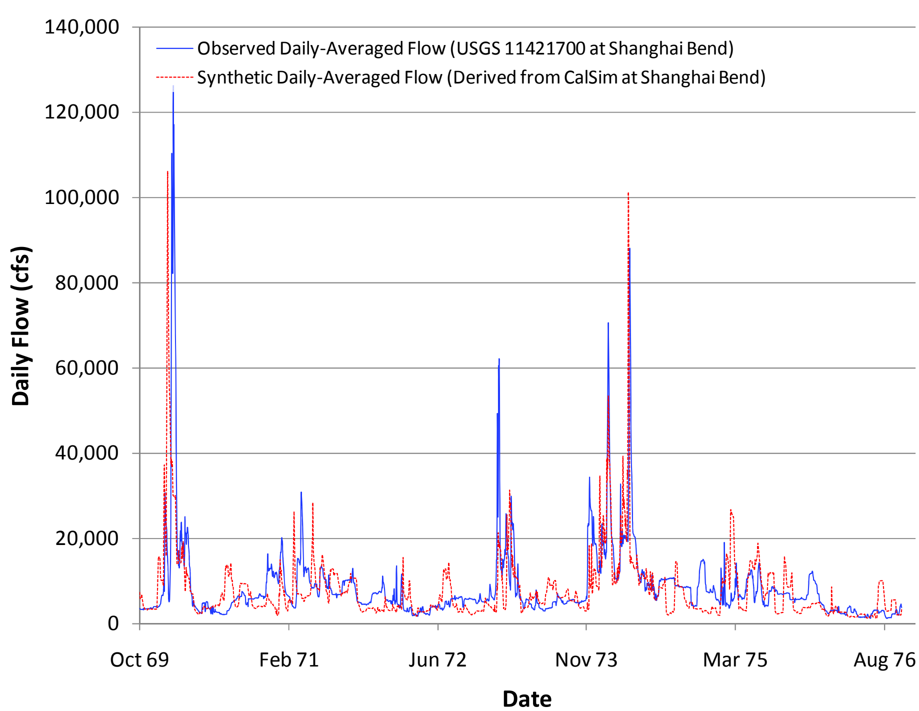

Figure E-3. Synthetic vs. Observed Flow – Shanghai Bend

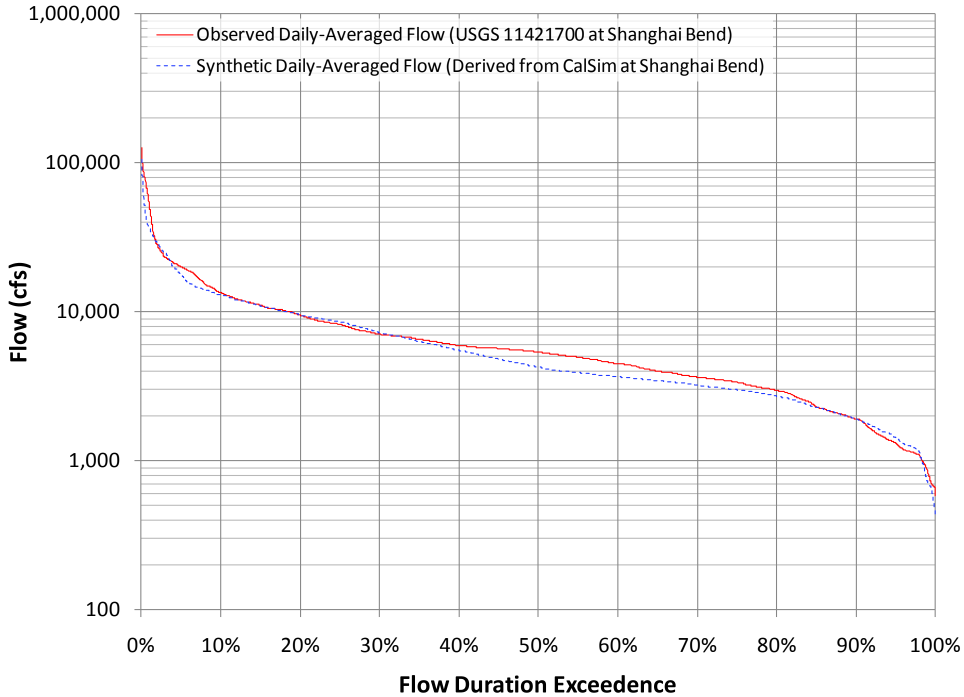

Figure E-4. Synthetic and Observed Flow Duration Curve – Shanghai Bend

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Attachment 9F: Floodplain Restoration Opportunity Analysis Appendix F – HEC-EFM Ecosystem Functional Relationships

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Appendix F

This appendix provides the criteria used for the EFRs used in this study: Salmonid-Rearing Habitat Formation, riparian Cottonwood Seedling Germination, riparian Cottonwood Seedling Inundation (death), and riparian Cottonwood Recruitment. Each of these EFR was added to HEC-EFM and a screenshot of the window with the criteria fields that displays their values is shown in Figures F-1 through F-4.

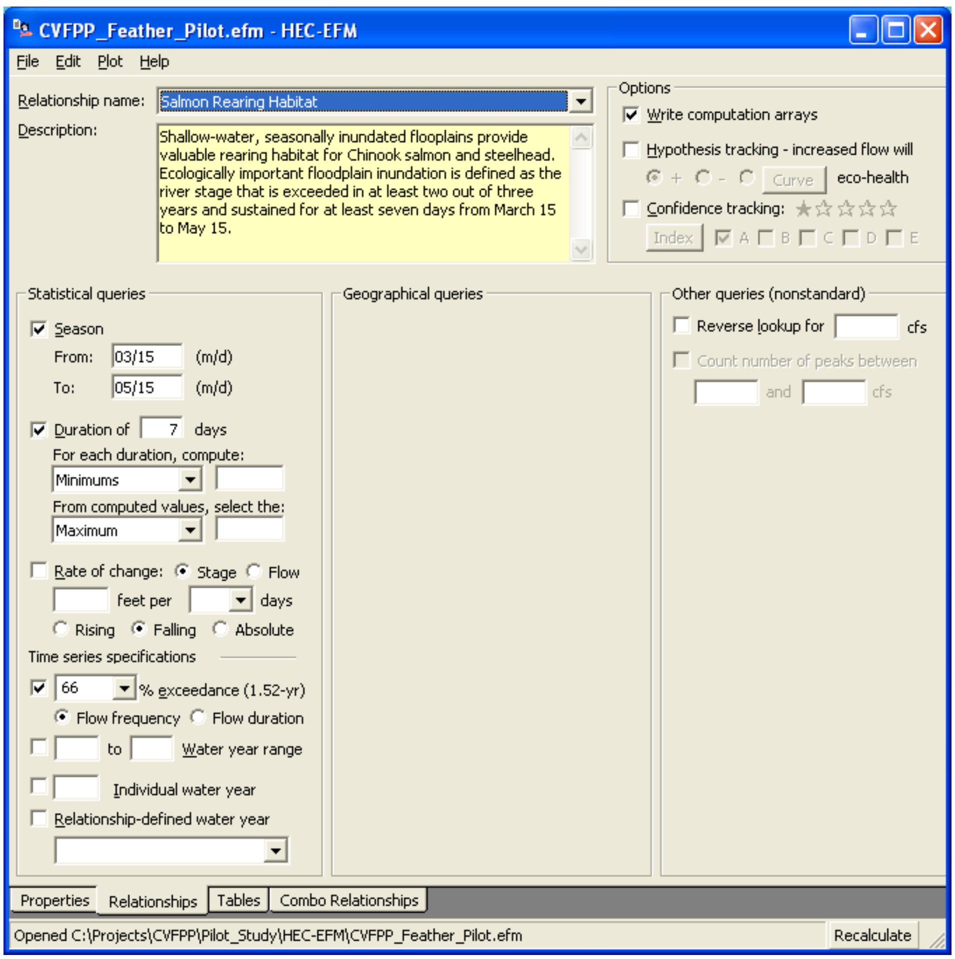

Figure F-1. Salmon Rearing Habitat Formation Ecosystem Functional Relationship (EFR)

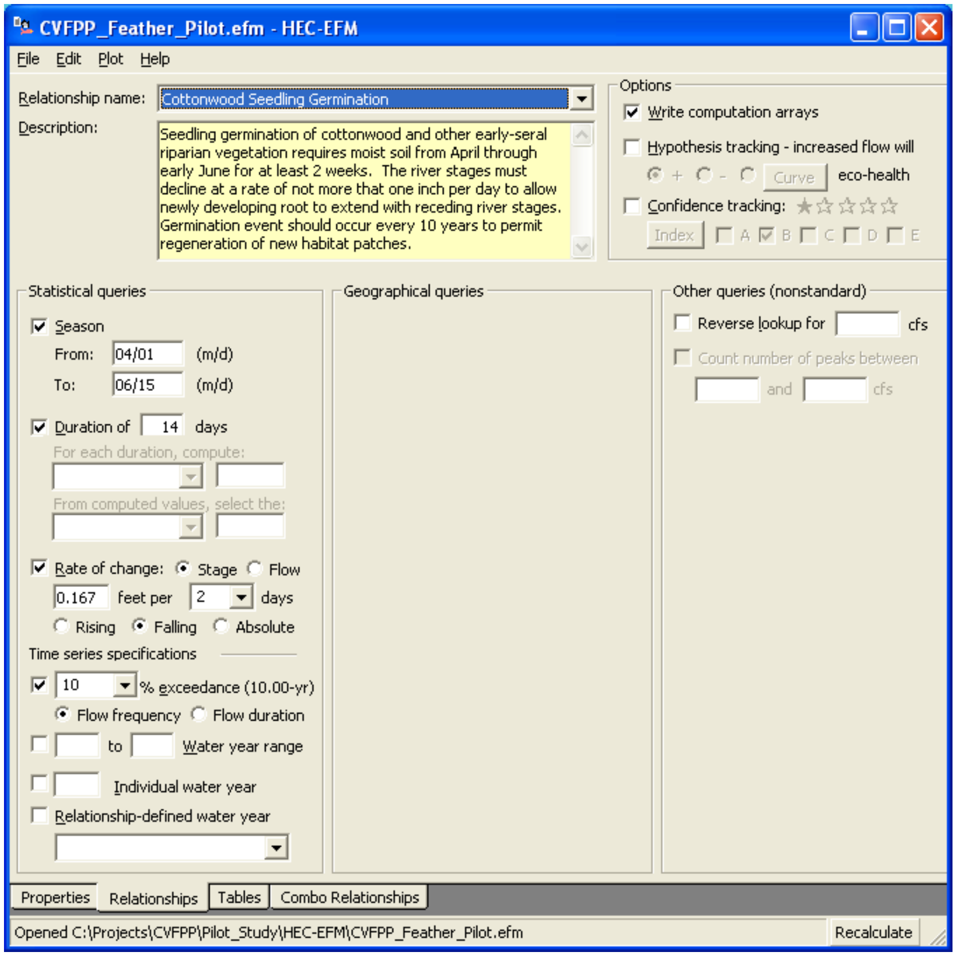

Figure F-2. Cottonwood Seedling Germination EFR

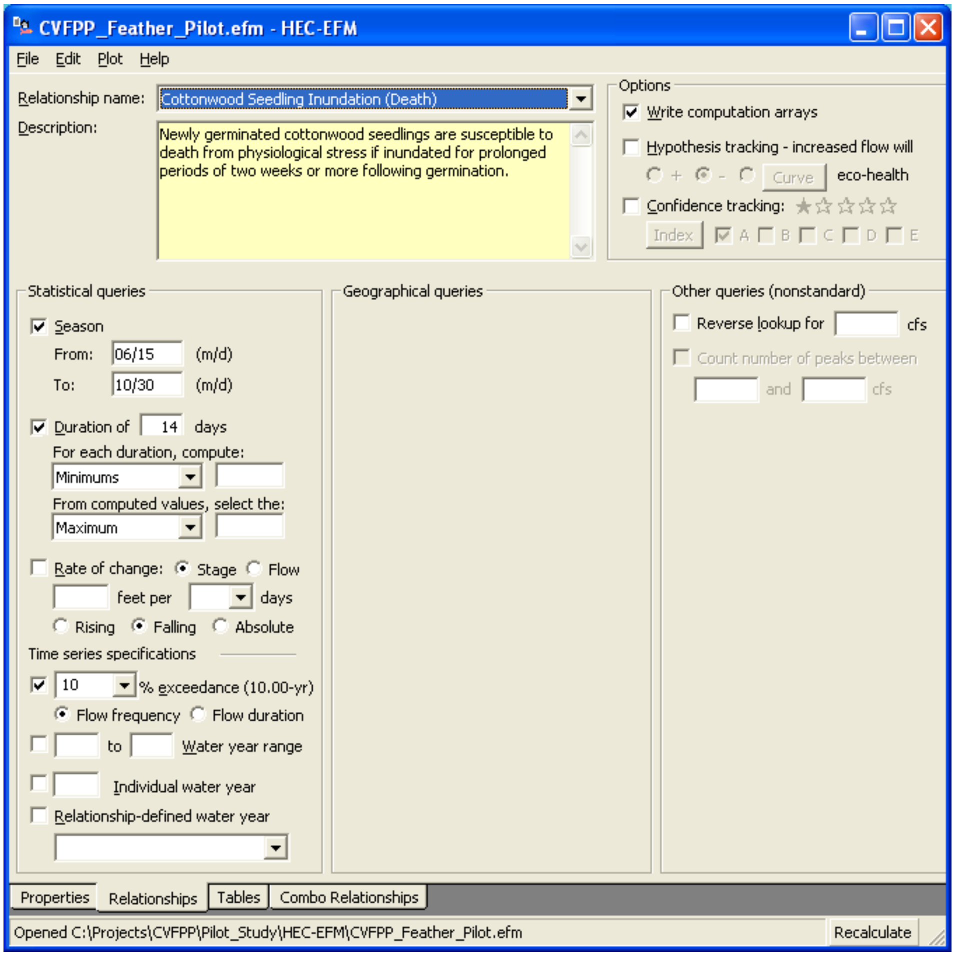

Figure F-3. Cottonwood Seedling Inundation (Death) EFR

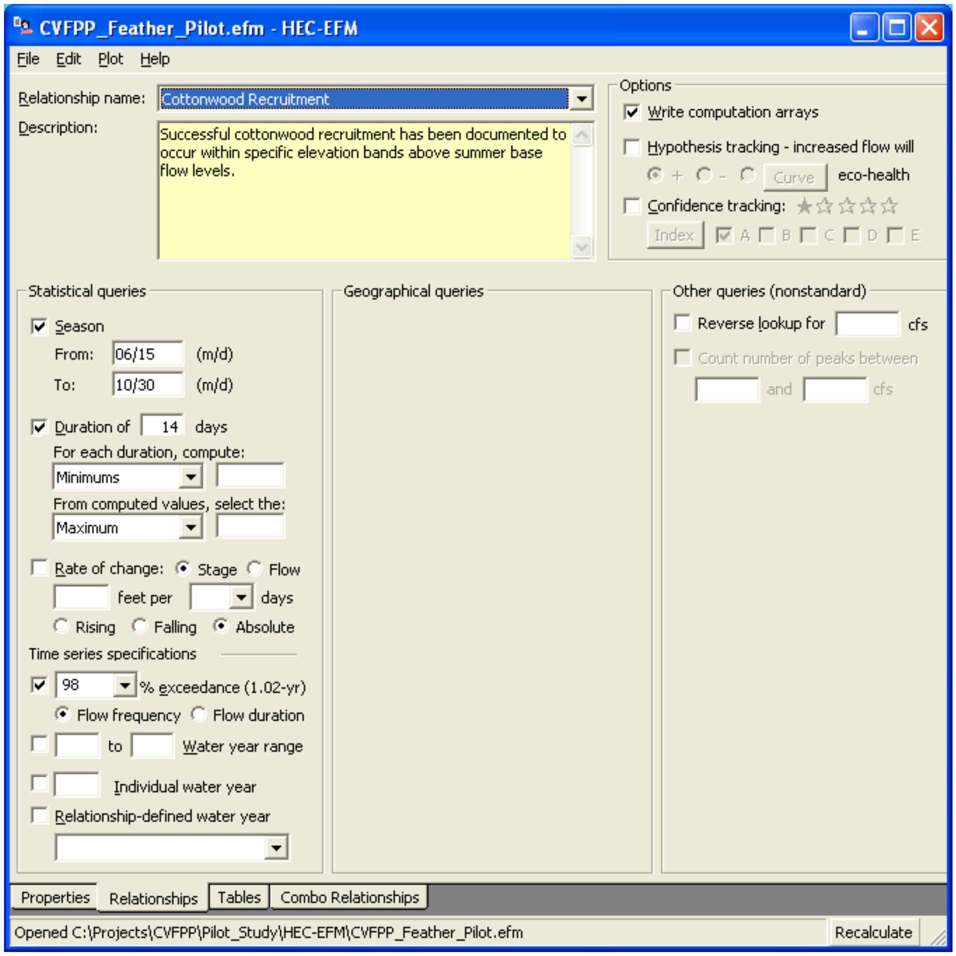

Figure F-4. Cottonwood Recruitment EFR

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Attachment 9F: Floodplain Restoration Opportunity Analysis Appendix G – RAS/EFM Analysis FIP-Based Mapping

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Appendix G

This appendix provides maps of the water-surface areas that meet the EFR conditions, as determined by HEC-EFM and HEC-RAS. These results are shown on Figures G-1 through G-10 for each HAA and EFR. (Cottonwood Recruitment was not mapped because potential habitat areas outside of the channel banks were not identified.) The background of each map corresponds to the LiDAR-based FIP.

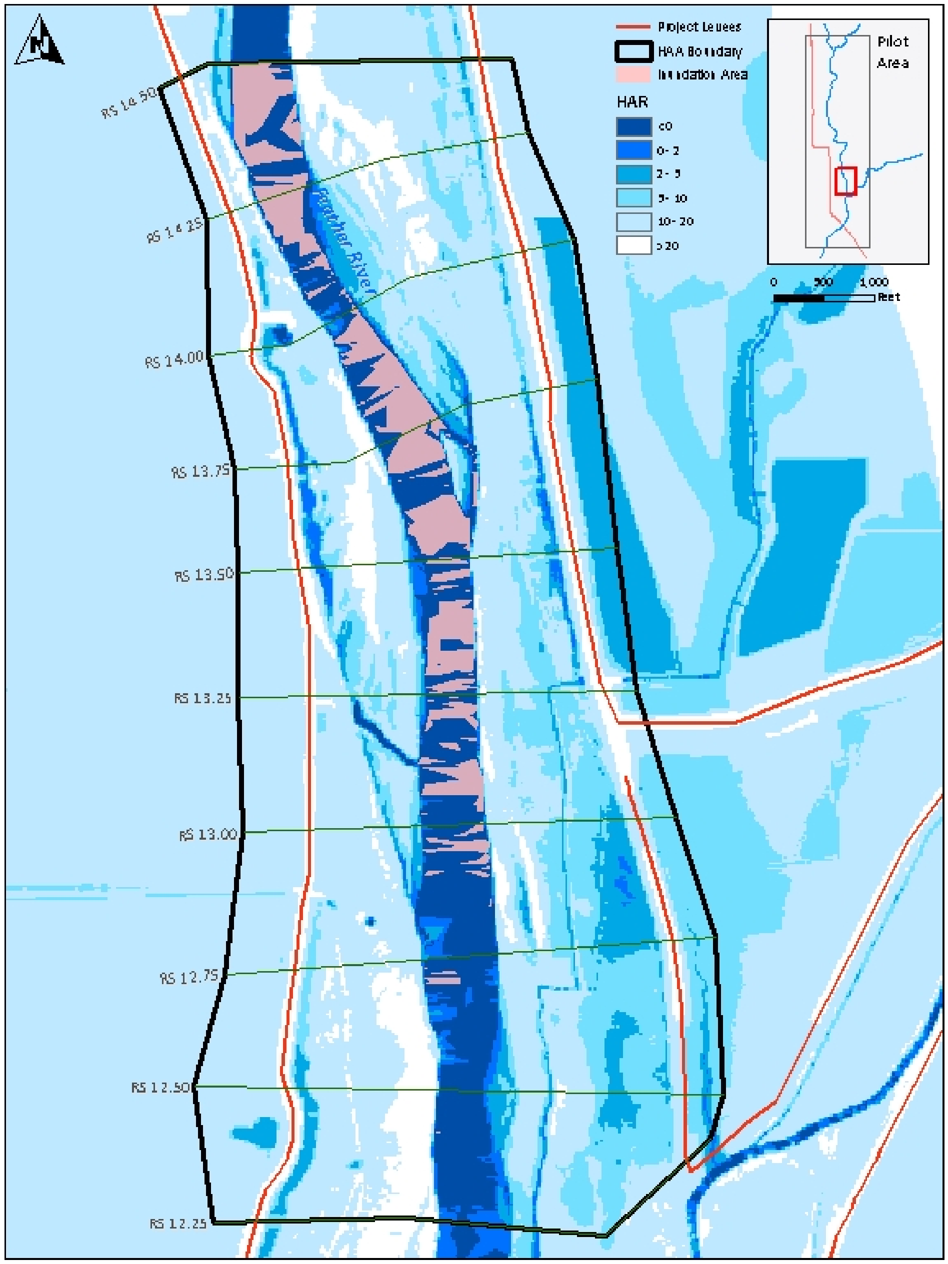

Figure G-1. Cottonwood Seedling Germination – RS 12.25 – RS 14.50

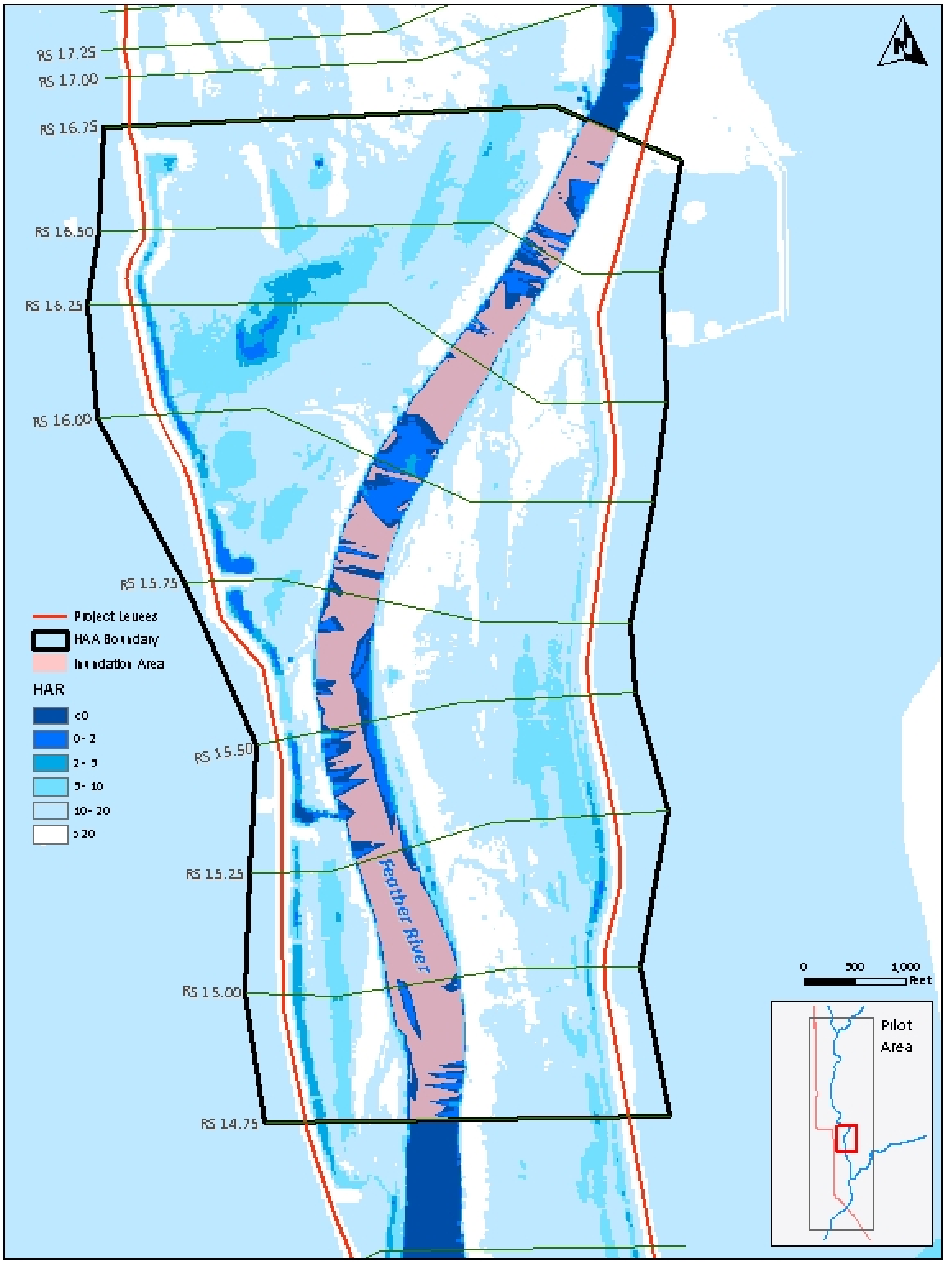

Figure G-2. Cottonwood Seedling Germination – RS 14.75 – RS 16.75

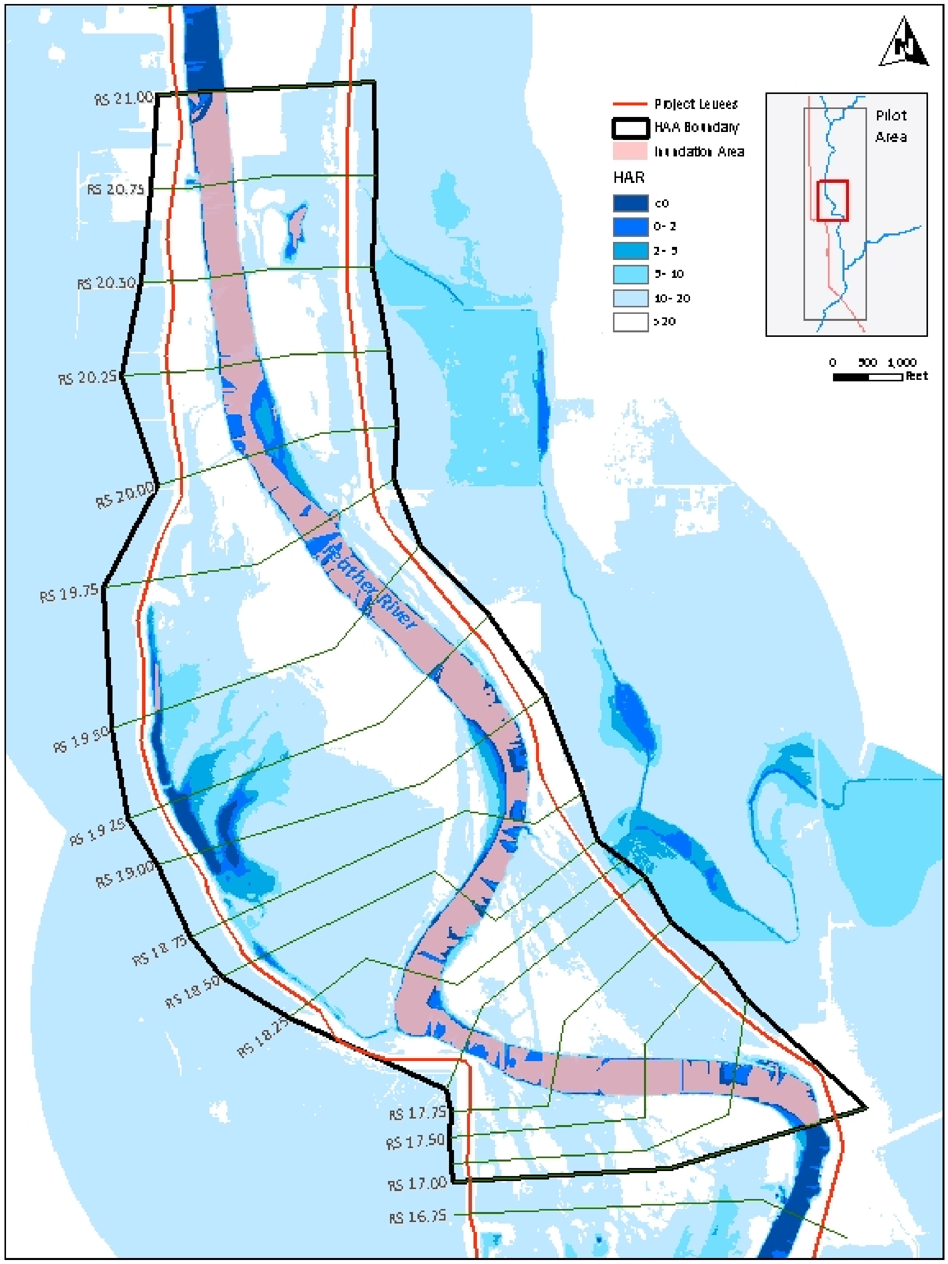

Figure G-3. Cottonwood Seedling Germination – RS 17.00 – RS 21.00

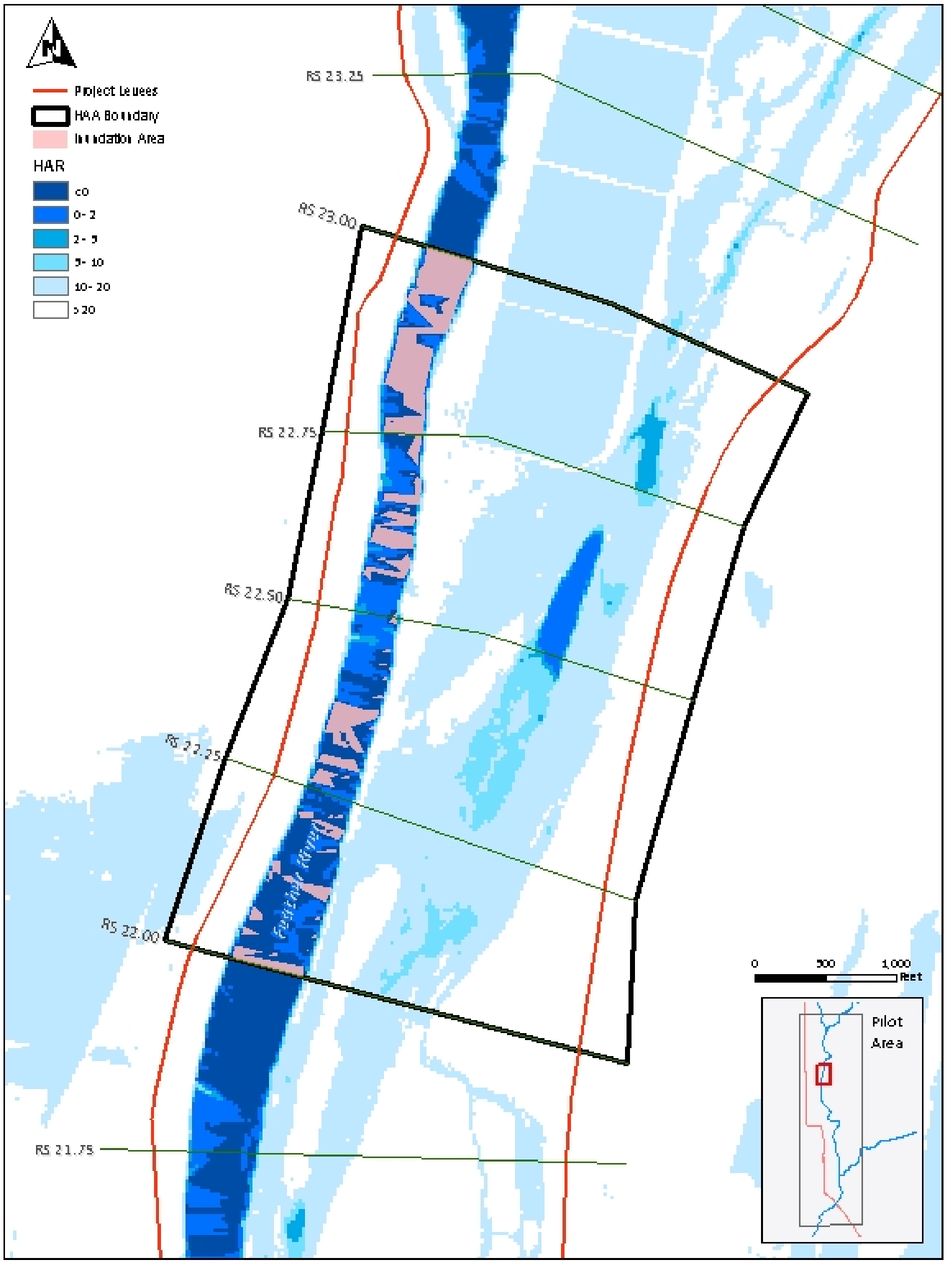

Figure G-4. Cottonwood Seedling Germination – RS 22.00 – RS 23.00

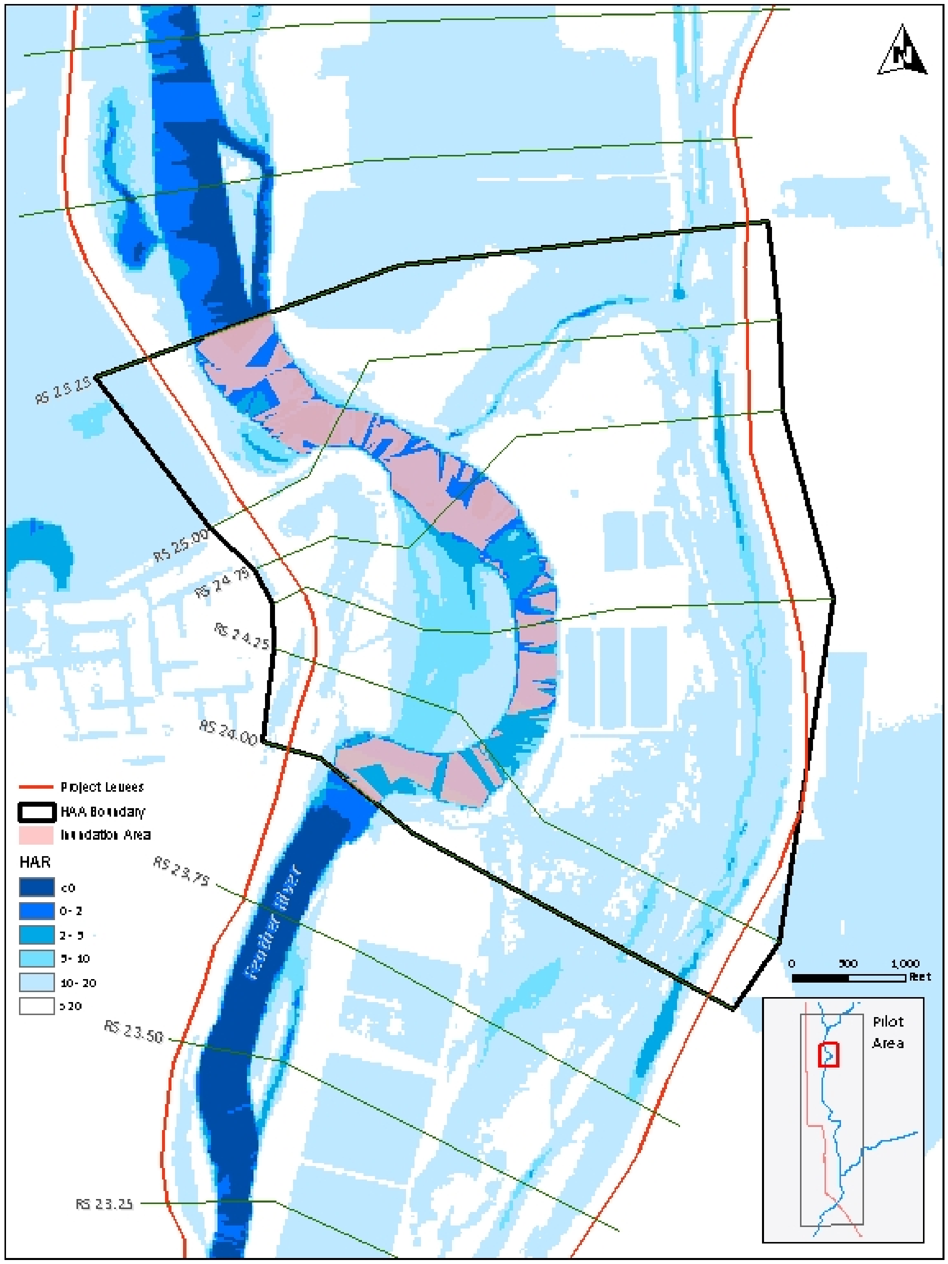

Figure G-5. Cottonwood Seedling Germination – RS 24.00 – RS 25.25

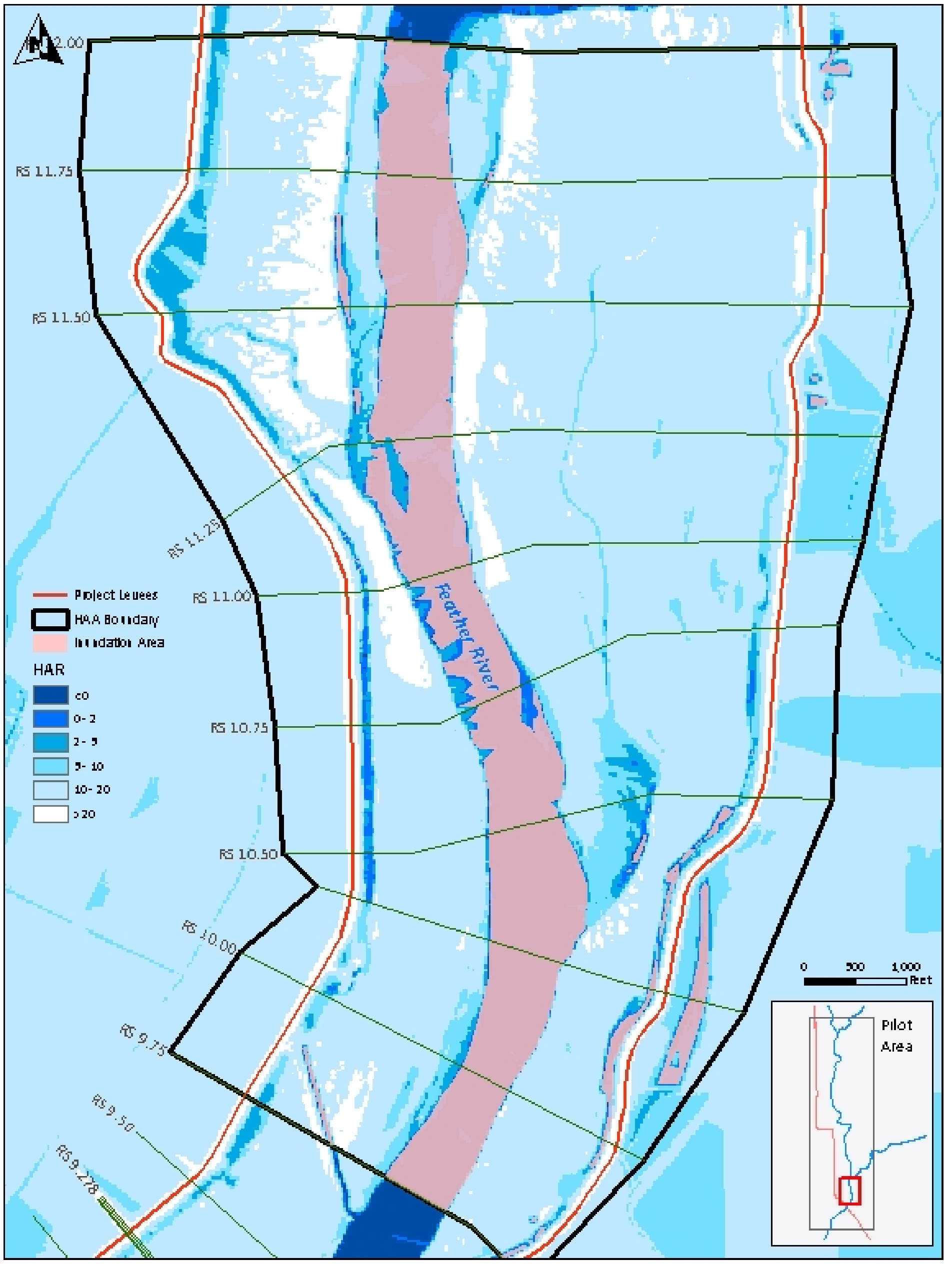

Figure G-6. Cottonwood Seedling Inundation – RS 9.75 – RS 12.00

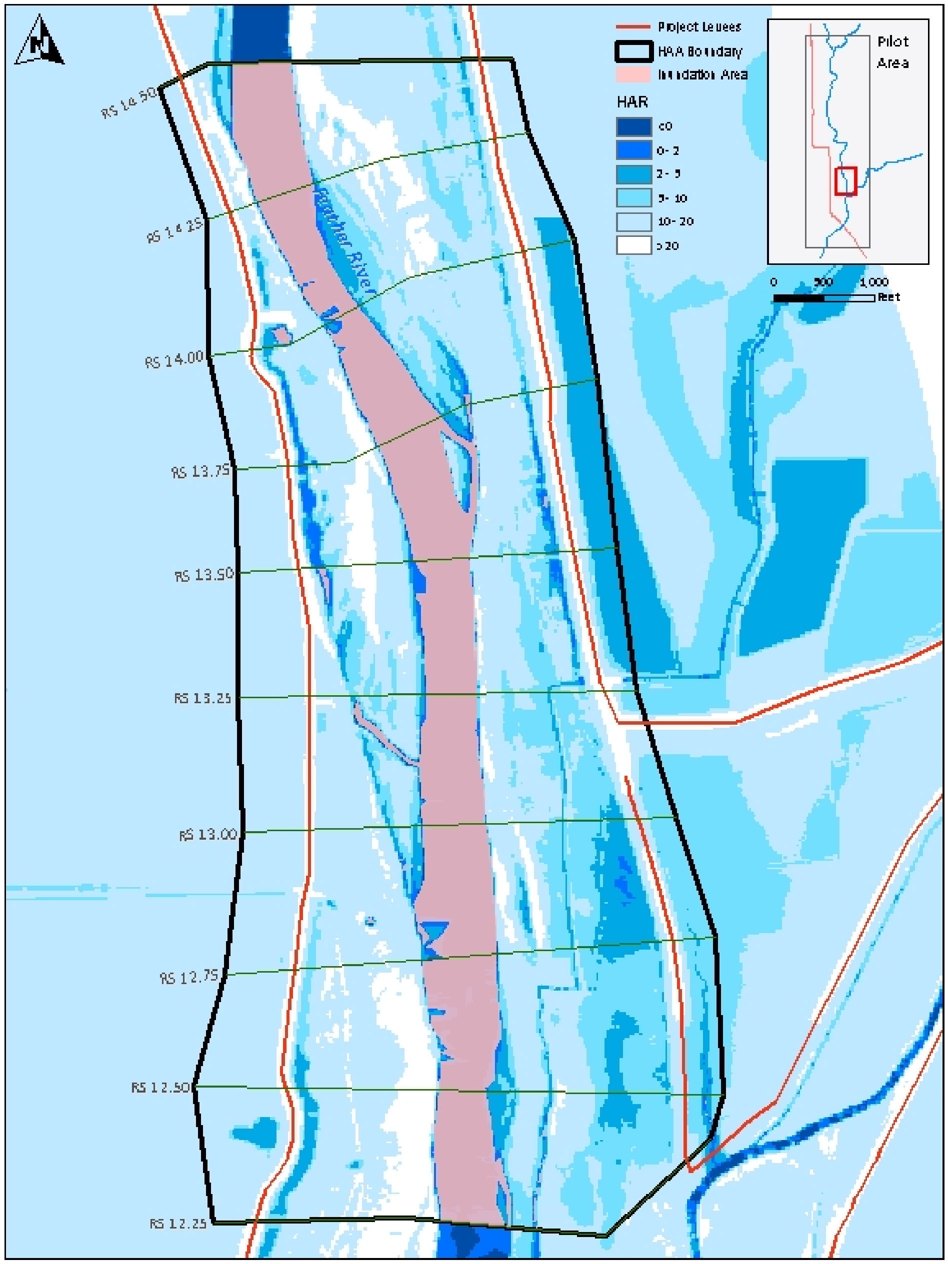

Figure G-7. Cottonwood Seedling Inundation – RS 12.25 – RS 14.50

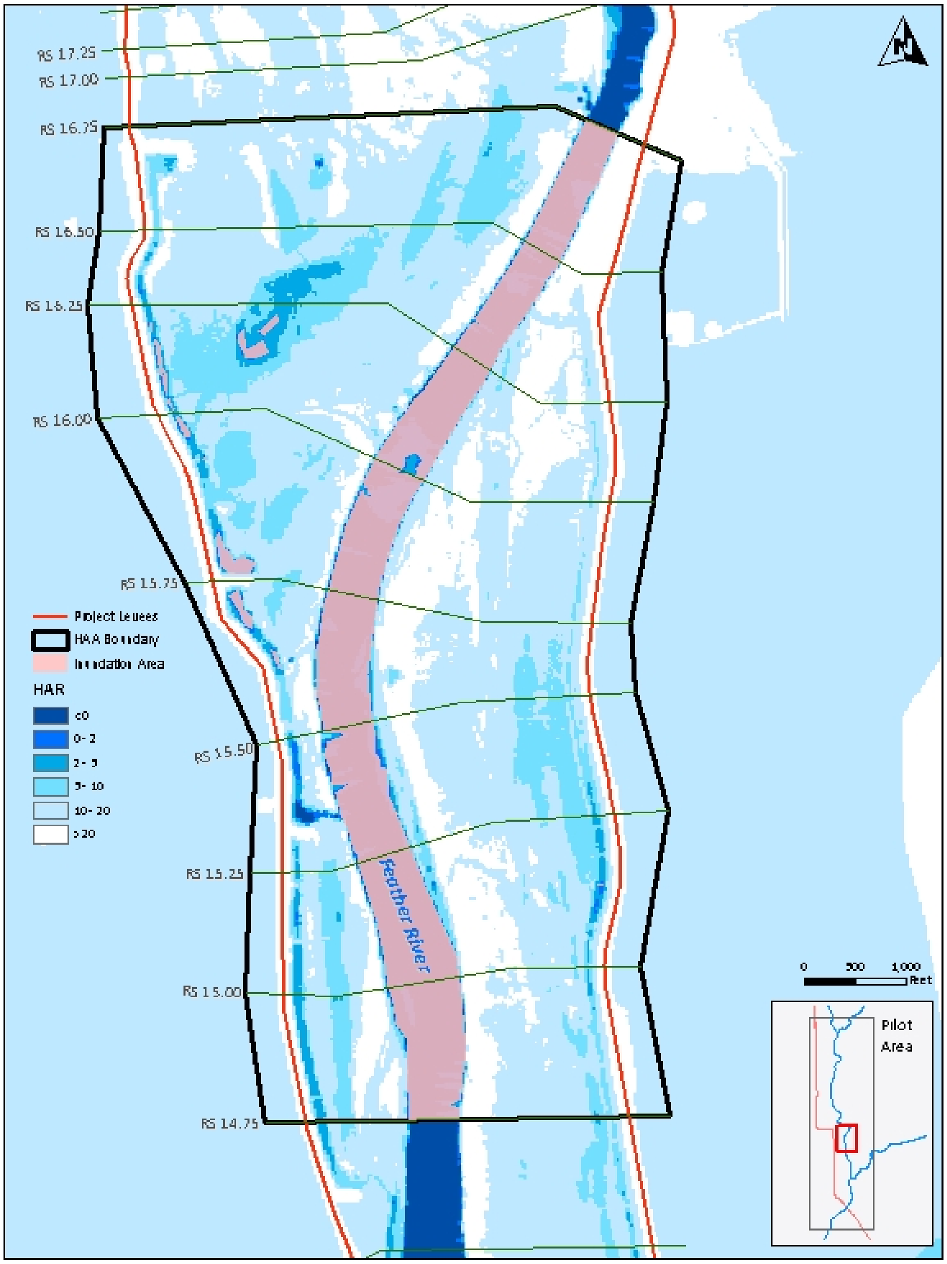

Figure G-8. Cottonwood Seedling Inundation – RS 14.75 – RS 16.75

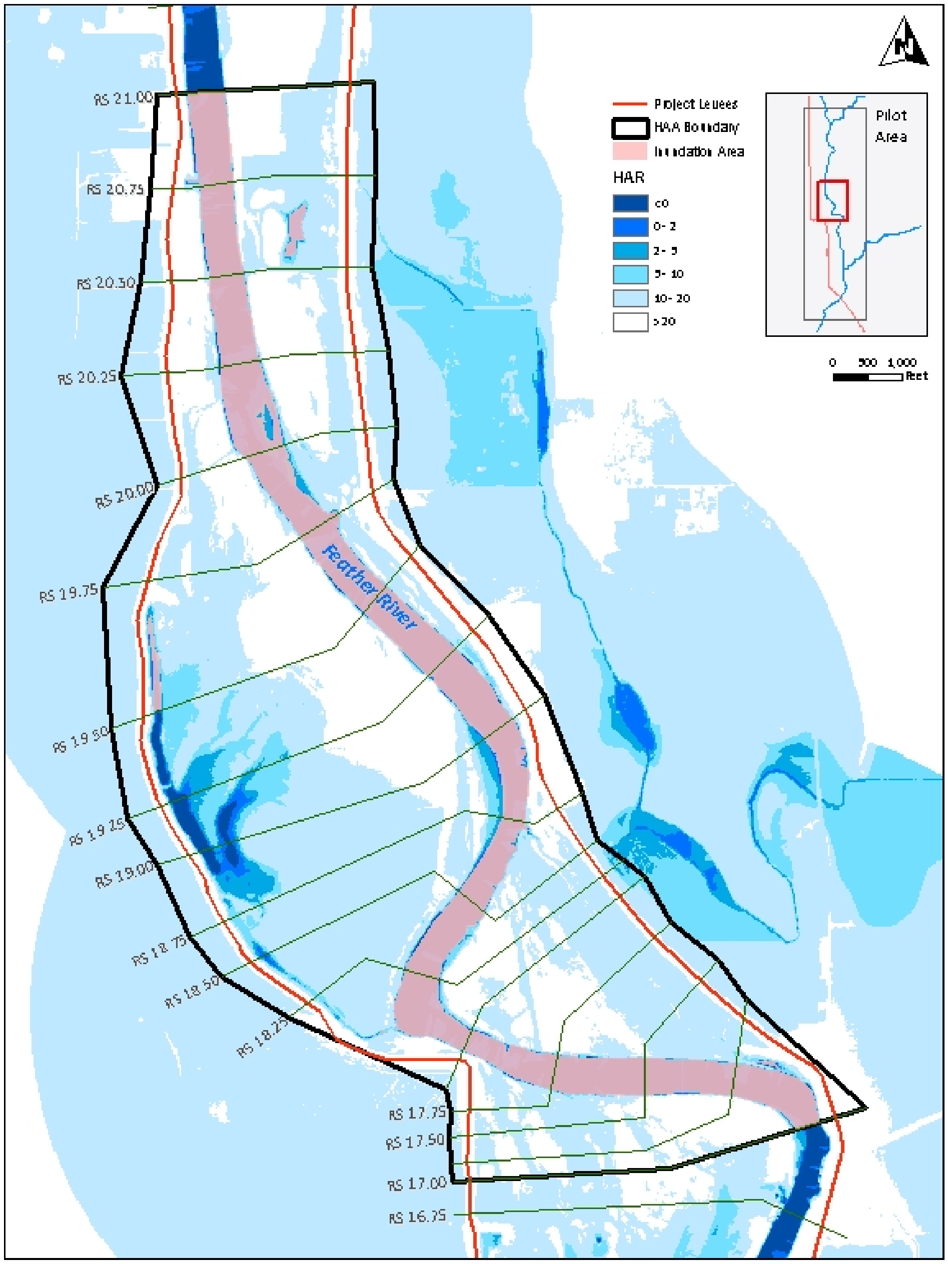

Figure G-9. Cottonwood Seedling Inundation – RS 17.00 – RS 21.00

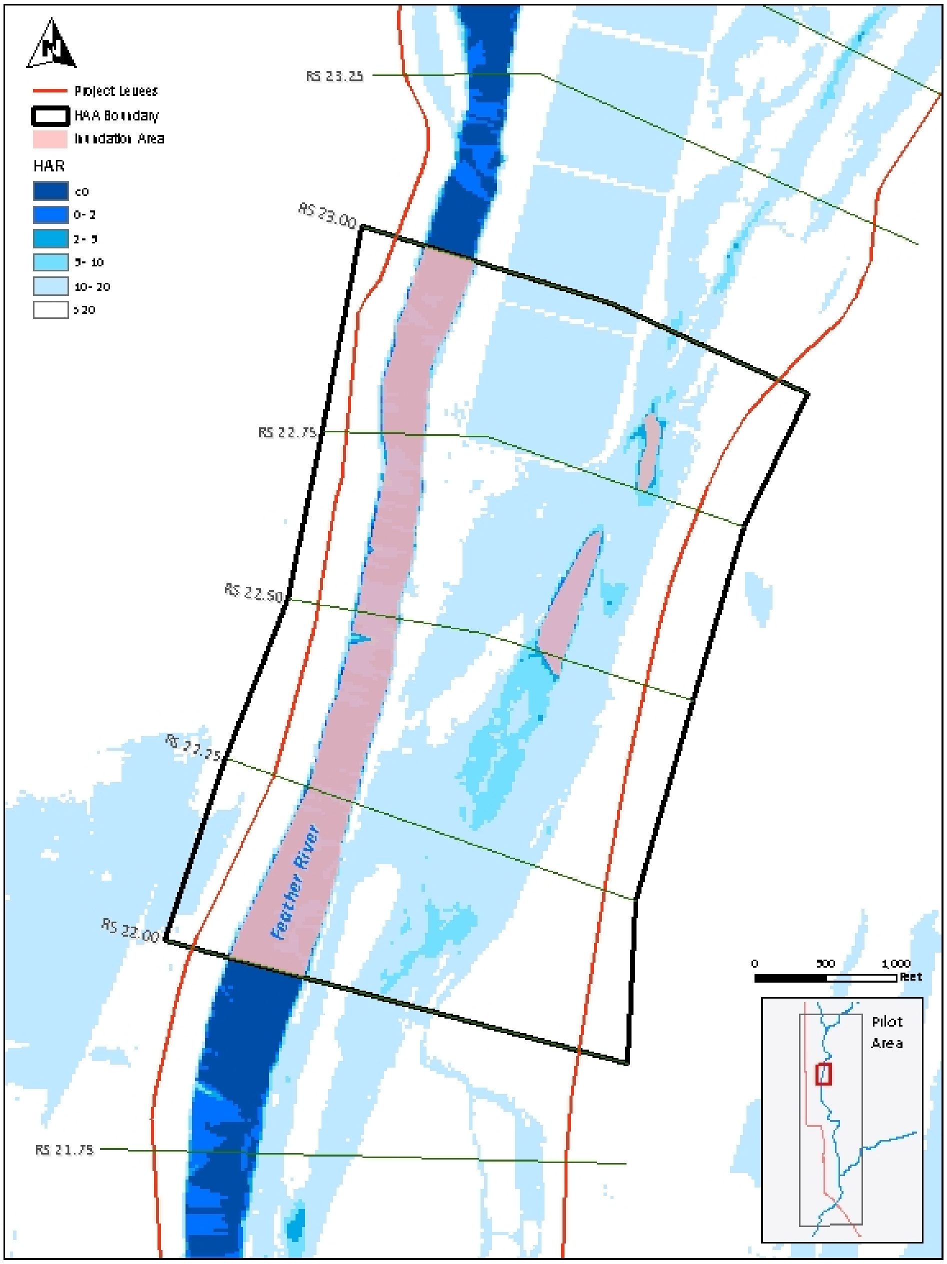

Figure G-10. Cottonwood Seedling Inundation – RS 22.00 – RS 23.00

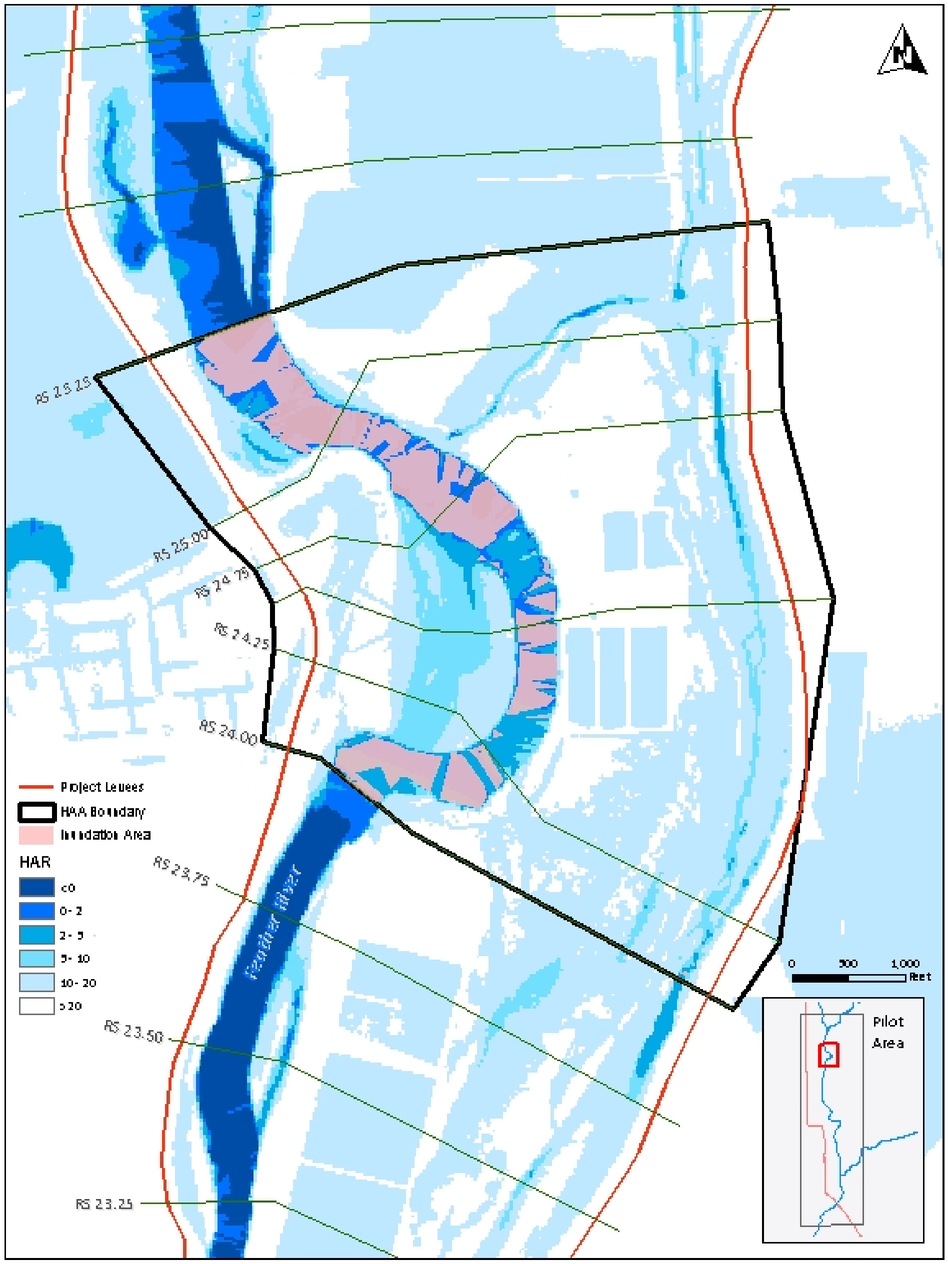

Figure G-11. Cottonwood Seedling Inundation – RS 24.00 – RS 25.25

STATE OF CALIFORNIA
THE NATURAL RESOURCES AGENCY
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