Appendix I. Floodplain Restoration Opportunity Analysis

STATE OF CALIFORNIA
THE NATURAL RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

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1.0 Introduction

As part of the Conservation Strategy for the 2017 Central Valley Flood Protection Plan (CVFPP), a continuation of the Floodplain Restoration Opportunity Analysis (FROA) (DWR 2012a) was conducted to develop, identify, and prioritize potential locations for implementing management actions. Two types of management actions were considered in this analysis: modification of floodplain topography (specifically, lowering floodplain topography through targeted excavation) and levee relocation (specifically, constructing setback levees). Preliminary areas for floodplain modification and setback levees were identified within the Systemwide Planning Area (SPA) of the State Plan of Flood Control (SPFC) (Figure 1-1). The following technical memorandum documents the goal, objectives, methods, and results of this analysis.

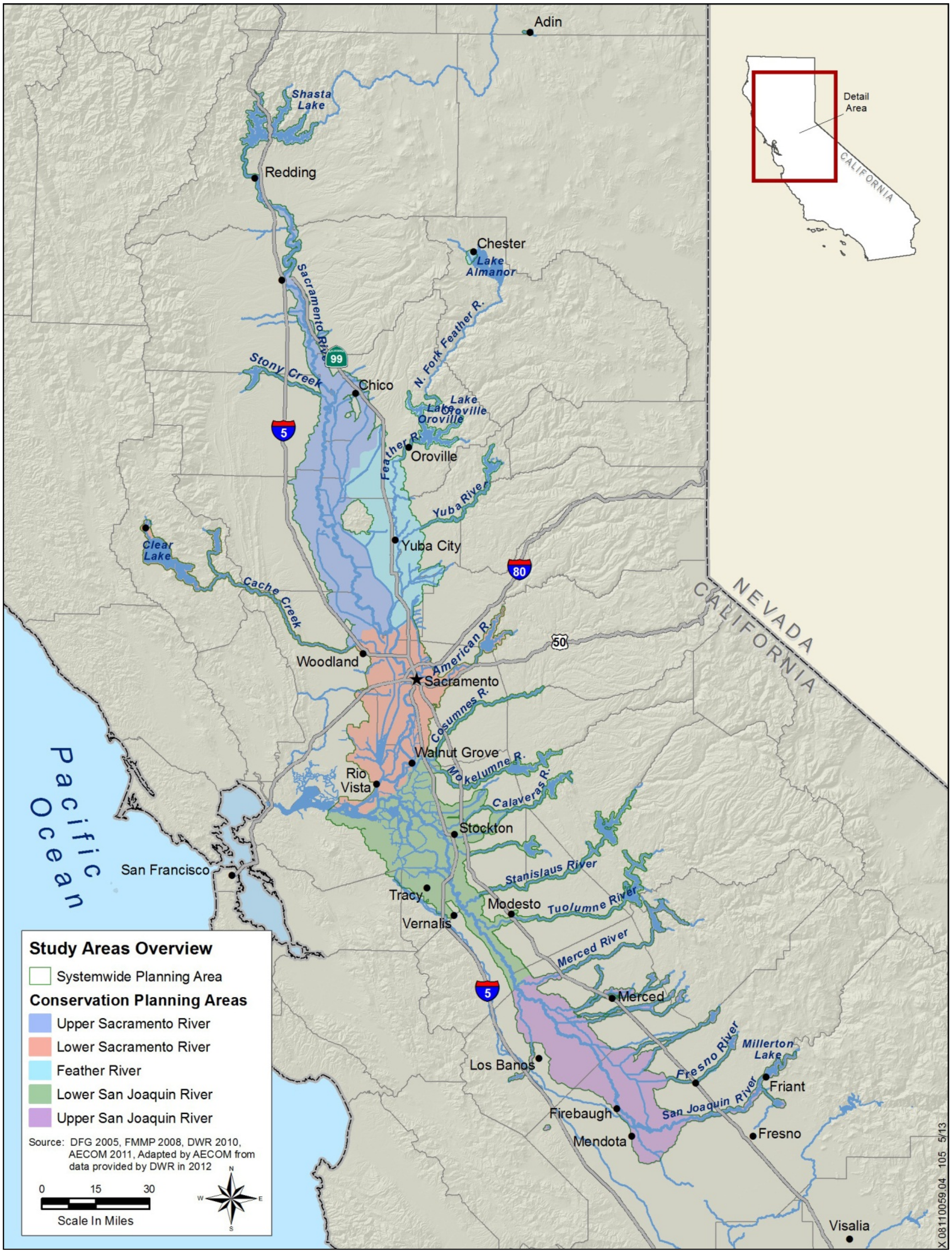

Figure 1-1. Systemwide Planning Area for the Central Valley Flood Protection Plan

2.0 Background

This work builds on concepts and data developed as part of the FROA (DWR 2012a) and contributes to the Conservation Strategy. A brief description of the FROA is provided below. In addition, the relation of this analysis to the Conservation Strategy is also described.

The FROA, a technical attachment to the 2012 CVFPP (DWR 2011a), identified the areas with the greatest and/or most extensive potential opportunities for ecological restoration of floodplains. These areas were identified by considering both their physical suitability and their opportunities and constraints. The opportunities and constraints that were considered fell into several categories: 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.

Floodplain inundation potential (FIP) was evaluated for corridors along the Sacramento and San Joaquin rivers and the lower reaches of their major tributaries (Figure 2-1). Bypasses were not included in the evaluation primarily because the FIP modeling was focused on major rivers and their major tributaries in the flood system. Additionally, Yolo Bypass and Sutter Bypass are being evaluated in the Yolo Bypass Salmonid Habitat Restoration and Fish Passage Project (Yolo Bypass BiOp) and Sacramento Basin-wide Feasibility Studies with finer-resolution models and more current hydrologic data. These models are being used to evaluate the size and efficacy of fish passage and gated notch facilities at Fremont Weir, and potential bypass setback levees. The proposed modifications at Fremont Weir change the potential timing, volume, duration, and seasonality of flows into the Yolo Bypass and, consequently, the value of seasonal flooding to juvenile salmonids and several other sensitive species. These more detailed analyses were and are beyond the scope and capabilities of the planning-level riverine FIP and FROA tools and spatial analyses.

To assess physical suitability for restoration actions, the FIP analysis adapted concepts from the U.S. Army Corps of Engineers Hydrologic Engineering Center (USACE-HEC 2009), the Frequently Activated Floodplain concept of Williams et al. (2009), and the Height Above River (HAR) geographic information system (GIS) tool of Dilts et al. (2010). The FIP analysis identified floodplain areas that could be inundated by particular flood flows—both areas directly connected to the river and areas disconnected from the river by natural or built levees or other flow obstructions.

The FROA evaluated three types of flows:

- 67-percent-chance event
- 50-percent-chance peak flow
- 10-percent-chance peak flows

The “67-percent-chance sustained spring FIP” refers to inundation of a floodplain area 1 foot or more above the water surface of a 67-percent-chance spring flow that is sustained for at least 7 days and occurs in 2 out of 3 years, but at a lower elevation than the 50-percent-chance water

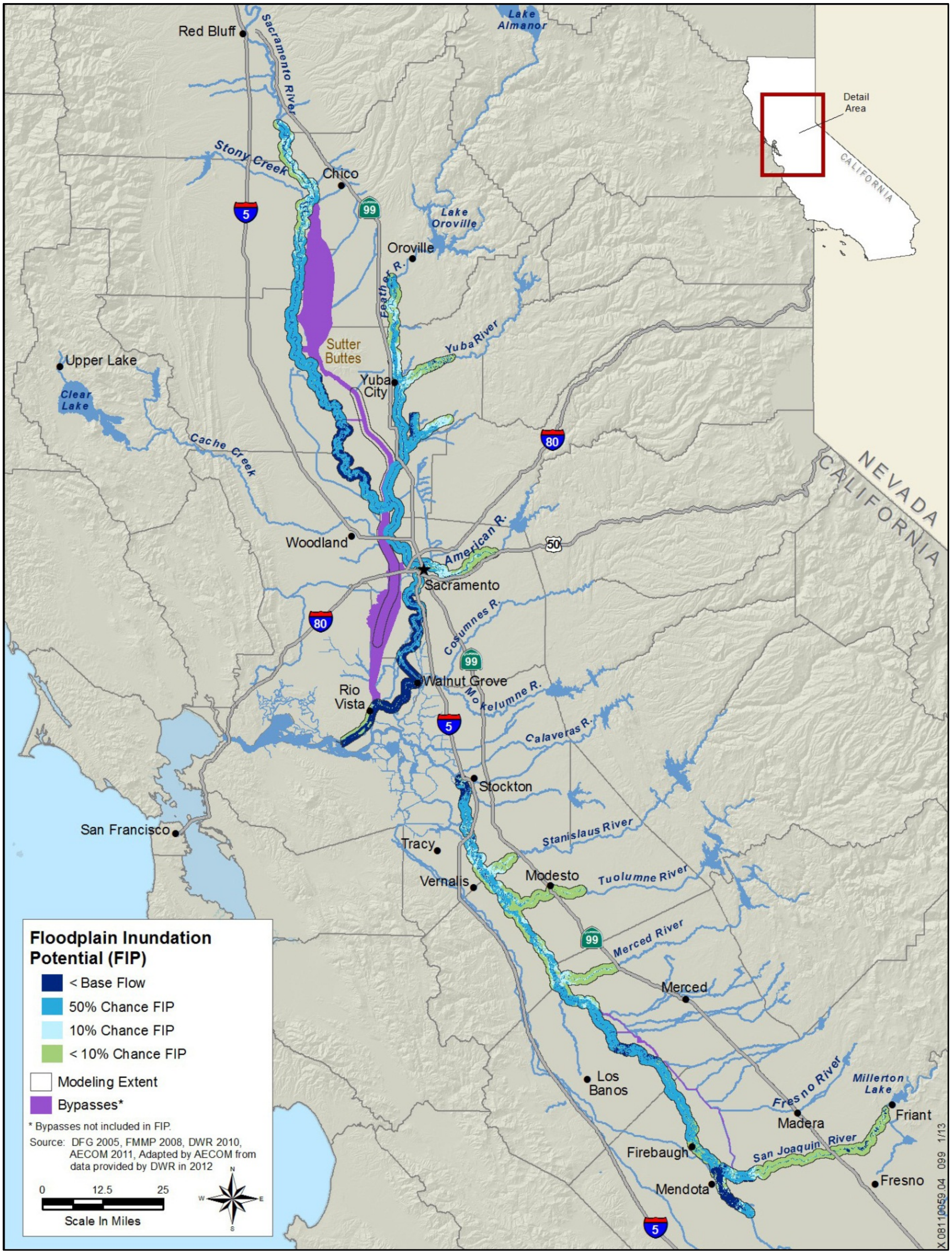

Figure 2-1. Floodplain Inundation Potential

surface. Similarly, the “50-percent-chance FIP” refers to inundation of a floodplain area 1 foot or more above the 50-percent-chance water surface, but below the water surface of the 10-percent-chance flow. The process used to estimate water surface elevations resulted in elevations that varied within 1 foot of true elevations. Figure 2-2 illustrates the relationship between these different water surfaces and the elevation zones corresponding to areas with a different FIP.

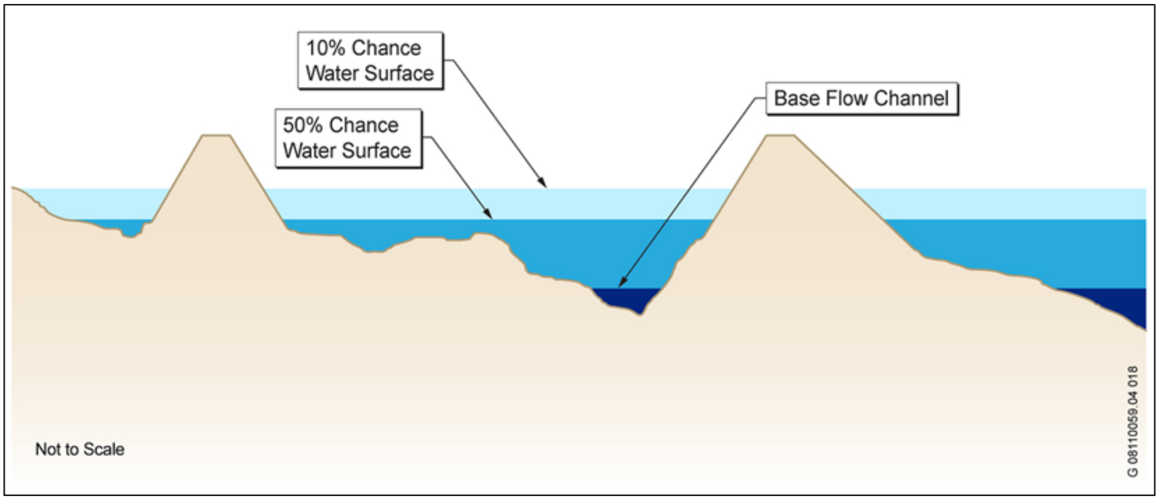

Figure 2-2. Water Surface Elevations by Floodplain Inundation Potential

The Conservation Strategy is based on integrating restoration actions into multi-benefit projects. The goals and objectives of the Conservation Strategy focus on attaining a flood management system that promotes the key physical processes and ecological functions required to yield an improved ecosystem. In support of these goals and objectives, this report preliminarily identifies potential locations to implement floodplain modification and setback levee actions.

Floodplain Modification Actions are defined as lowering or otherwise modifying the floodplain elevation to achieve longer periods of inundation, eliminate flow restrictions, or connect side channels during a greater range of flows. These actions can increase flood capacity and provide opportunities to restore marsh and riparian habitat. Floodplain Modification actions can also be designed to include side channels to create additional resting and rearing habitat for salmonids.

Setback Levee Actions are defined as relocating a levee farther from the river’s edge. Setting back levees can help restore natural dynamic hydrologic and geomorphic processes to a river reach. Potential ecosystem benefits include increased floodplain inundation; increased potential for groundwater recharge; a larger natural meander zone (NMZ); reduced need for bank armoring; opportunities to restore marsh, shaded riverine aquatic, and riparian habitats; and increased potential for greater flood storage.

3.0 Goal and Objectives

The goal of this analysis was to preliminarily identify potential areas in which two restoration actions: floodplain modification and setback levees could be implemented. The objectives of this analysis are as follows:

- *Identify potential areas for implementing restoration actions as opposed to proposing specific actions*: The intent of this analysis was to define areas where floodplain modification and/or setback levee actions would provide greater ecological value for reconnection to the rivers. For setback levees, the results show the area between the existing levee and a "relocated" levee. This area has the potential for reconnection with the river and could provide greater ecological benefits than other locations. The results are not presented as a set of potential alignments for levee relocations, because this work is not intended to dictate projects that should emerge from the flood management planning process. Rather, the results are provided to align with the results of the flood management planning process in an effort to achieve multi-benefit projects.

- *Produce simple products*: Although this work has involved using and interpreting a variety of data sets and applying relatively complex concepts, it has been done at a planning level. Therefore, the results represent general areas where the restoration actions might be considered; that is, "blobs" on a map were favored over "lines" on a map.

- *Provide technically defensible information that is useful for the regional planning process*: The results of this analysis are to be shared with regional flood management planning groups to assist them with their regional planning process.

4.0 Assumptions and Limitations

This analysis made assumptions and the results are inherently limited. These assumptions and limitations are as follows:

- This analysis was conducted at a planning level and no hydraulic modeling was performed.

- The study relied on available data provided by entities outside of AECOM (e.g., levee condition data, river mile [RM] data, NMZ data). AECOM did not verify the accuracy and reliability of these data sets.

- Considerations of spatial constraints and opportunities for the floodplain modification actions and setback levee actions were limited to the spatial data used in the GIS analyses.

- Topographic data used in this analysis included primarily heights and depths relative to a base-level water surface at the time of the Central Valley Floodplain Evaluation and Delineation Program's Light Detection and Ranging (LiDAR) flight in March 2008 (e.g., the

HAR and FIP data sets). Detailed topographic elevation data were not referenced; only generalized elevations obtained from Google Earth were referenced.

- Riparian vegetation retention sites along the Sacramento River from the 1978 atlas (MBK 1978) were digitized from a PDF of the report and delineated using GIS. This atlas depicted locations where retention of riparian vegetation was judged to be significant to the overall stability of the river and its overflow areas between Tisdale Weir (River Mile 118.8) and Hamilton City (River Mile 199).
- Potential action areas are intended only to indicate the approximate locations where these actions could occur for the greatest benefits.
- Considerations have not been made for potential impacts on agricultural land practices, irrigation (including pumps and/or diversions), or access to agricultural fields.
- The spatial extent of investigation of setback levee actions was limited to the width of the HAR and FIP data, which is typically 1 mile to either side of the major river channels.
- Major infrastructure, such as transmission lines and buried pipelines, were avoided when potential setback levee areas were delineated (see the discussion of prioritization and planning in Section 5.1).
- The boundaries of potential setback levee areas were approximately delineated by referencing roads and linear land use features observed in Google Earth imagery, and by applying general geomorphic principles to accommodate generalized channel meander zones and meander belt widths.
- Setback levee actions were assumed to not be viable within substantially perched reaches of the river systems (i.e., reaches where the elevation of the floodplain was primarily below baseflow), and setback actions were not investigated in these areas.

5.0 Approach

Five steps were taken to preliminarily identify areas within the SPA that may be suitable for either floodplain modification or setback levees:

1. Spatial areas within the SPA were prioritized based on various attributes and considerations using GIS queries.
2. The prioritized data set was partitioned out to use only the moderate, high, and highest priority areas.
3. The HAR and NMZ mapping were reviewed in correlation with prioritized areas.
4. Floodplain modification and setback levee action areas were delineated.

5. A cross-check of delineated areas was completed based on the HAR and NMZ.

Detailed descriptions of each of these steps, and visual examples of the application are provided below.

5.1 Steps 1 and 2. Prioritization and Partitioning

A series of GIS queries was used to prioritize spatial areas for applying two specific types of restoration actions: floodplain modification and setback levees. GIS data layers for the following sources were used to accomplish the prioritization:

- Major infrastructure and protected areas (Caltrans 2008, 2010; California Department of Conservation 2010; Cal/EPA 2010; California Energy Commission 2011; GIN 2010; U.S. Census Bureau 2007; USGS 2012),
- Land cover data from the medium scale vegetation mapping effort developed for the Central Valley Riparian Mapping Project (DWR 2011b),
- Critical habitat (USFWS 2013), and
- The location and attributes of levees derived from the California Levee Database (DWR 2012b).

For each type of action, areas were placed into the following categories based on various attributes and considerations that are described in more detail below.

- N/A—Not Applicable
- Low
- Moderate
- High
- Highest

The floodplain modification action applies only to areas within the existing floodway. Areas with existing riparian or wetland vegetation were eliminated because these sensitive habitats would have to be removed to lower the floodway. A decision diagram outlining this process is provided in Figure 5-1.

- LOW: These areas are outside of the critical habitat for salmonids.
- MODERATE: These areas are within critical habitat for salmonids, but in agricultural land cover. It is assumed that these areas will remain in agriculture, and thus will not provide the same benefits as an area of natural vegetation. Should agricultural lands be restored to

riparian habitat, however, areas identified as moderate could increase in priority, and this assumption would not be accurate.

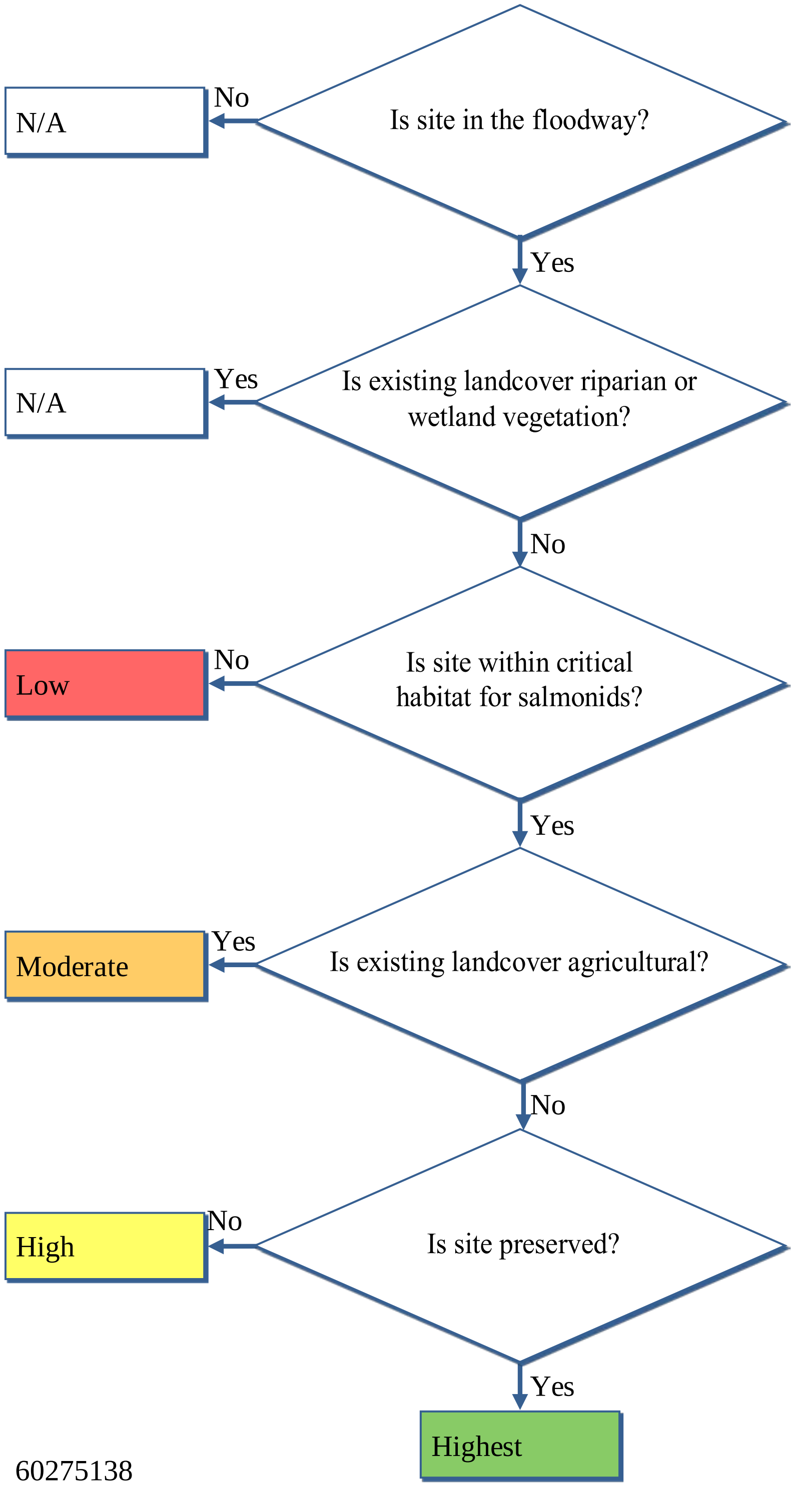

Figure 5-1. Decision Diagram for Floodplain Modification Action Areas

- HIGH: These areas are within critical habitat for salmonids and in natural land cover, but are not within preserved lands. The land cover of these areas is primarily grassland. Agricultural, riparian, and wetland land cover areas were eliminated.

- HIGHEST: These areas are in critical habitat for salmonids, in natural land cover (i.e., grassland) and preserved.

The locations identified as setback levee action areas were confined to those areas outside of river floodways with greater than a 10-percent-chance FIP. As described in Section 2.0, bypasses were not included in this analysis. Setback levees were not considered where major constraints exist in the area that could be reconnected to the river. These constraints include developed land, major infrastructure in or adjacent to the reconnection area, and sensitive vernal pool/upland habitats. Finally, to maximize the gain in flood safety, only areas adjacent to levees categorized as being of "high" concern (i.e., levees with the highest risk of failure) were considered in the analysis.

The following priority rankings were established for the setback levee actions. A decision diagram is provided in Figure 5-2.

- LOW: These areas either have a 10-percent-chance FIP (i.e., infrequent inundation potential) or have a 50-percent-chance FIP but are outside of critical habitat for salmonids[1] or riparian species.

- MODERATE: These areas have a 50-percent-chance FIP and are within critical habitat for salmonids or riparian species. However, the areas either lack natural vegetation (i.e., are in agricultural areas) or are not preserved; therefore, a greater investment of resources would be required and/or there would be greater logistical constraints associated with using these areas relative to areas ranked High.

- HIGH: These areas have a 50-percent-chance FIP, are in critical habitat for salmonids or riparian species, and either have natural vegetation or are in preserved areas.

- HIGHEST: These areas have a 67-percent sustained spring FIP and are within critical habitat for salmonids.

Once areas were prioritized, the Moderate, High, and Highest areas were partitioned out for consideration. Areas within the levees have the potential for floodplain modification actions and areas outside of the levees have the potential for setback levee actions.

This analysis did attempt to explicitly combine potential floodway lowering action areas within potential setback levee areas.

[1] Critical habitat for salmonids was attributed to the full extent of the FIP model based on the assumption that if these areas were reconnected to the river, they would become part of critical habitat.

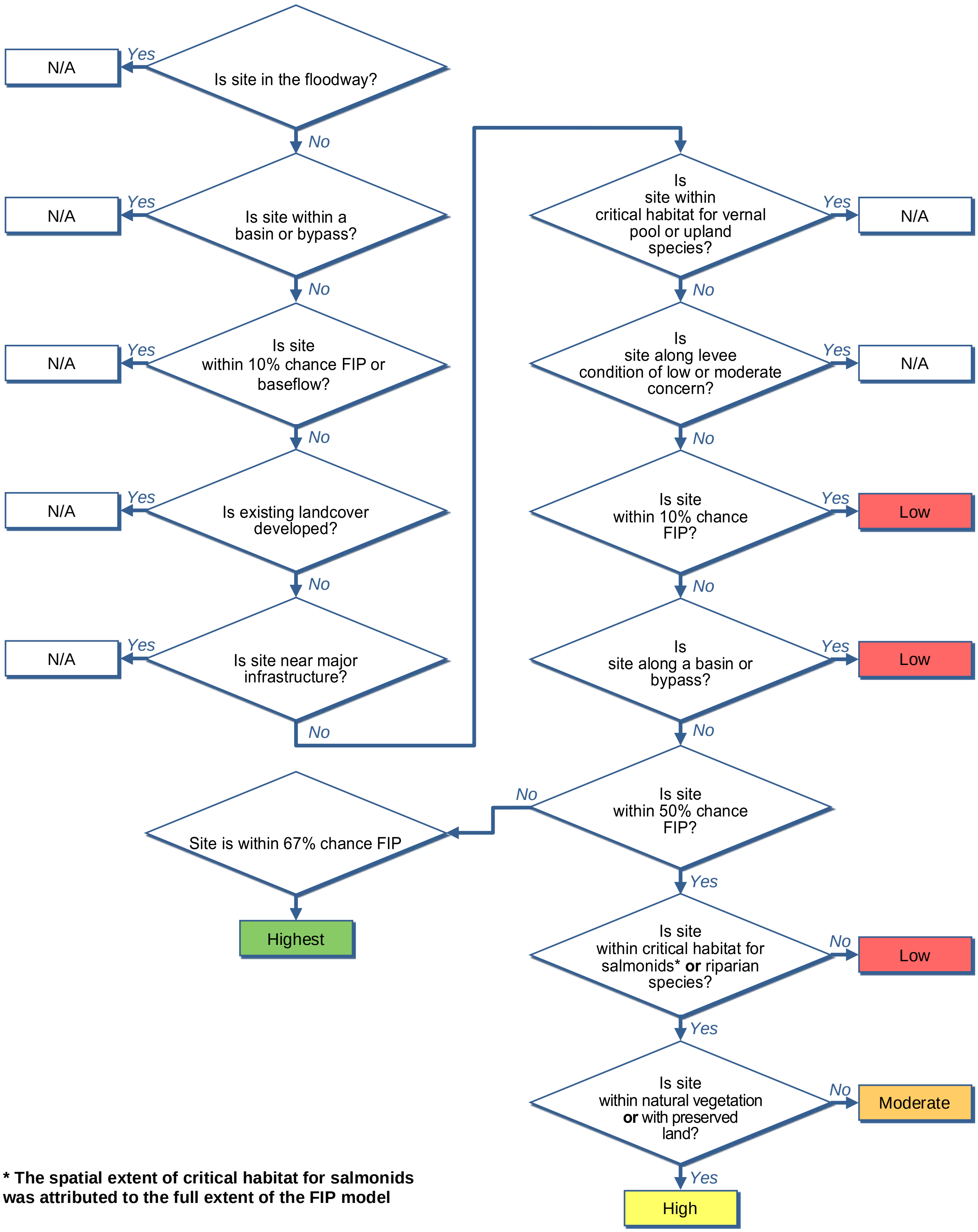

Figure 5-2. Decision Diagram for Setback Levee Action Areas

5.2 Step 3. Application of the Height Above River Analysis and the Natural Meander Zone Layers

Applying the HAR model (Dilts et al. 2010) provides a rapid visual snapshot of the topography adjacent to the river. As part of the FROA, the HAR model was applied to the SPA. Heights were displayed relative to river water levels at time of LiDAR survey in March 2008. The HAR layer was added to the prioritization to cross-check the areas.

A study completed by Larson et al. (2006) on the Sacramento River from RM 80 to RM 243 established the channel width necessary to allow natural channel dynamics (i.e., river meander migration can occur to the fullest extent, allowing the natural formation of oxbows and point bars). A minimum of three bankfull channel widths from the centerline of the river is considered to be the NMZ. The NMZ is reduced in areas with natural geologic constraints. The NMZ layer was added to the prioritization to cross-check the setback levee action areas, where available. Where not available, general geomorphic principles were applied to accommodate generalized channel meander zones and meander belt widths.

5.3 Step 4. Delineation of Floodplain Modification and Setback Levee Action Areas

Floodplain modification and setback levee action areas were then initially delineated to avoid existing major utility corridors that in some cases bisected these areas, or align with existing roadways. Utility corridors within setback levee areas were avoided to limit the inaccessibility of underground and aerial utilities during a flood event, and to limit the potential for scour of or seepage into underground utilities.

5.4 Step 5. Cross-check of Height Above River and Natural Meander Zone with the Action Areas

For the delineation of the potential floodplain modification (e.g., lowering) action areas, the HAR model was used to confirm that areas were generally located on higher ground than the water surface (i.e., river water levels at the time of the LiDAR survey in March 2008) and near the 50%-chance flood event. For the delineation of the setback levee action, higher ground levels were favored to reduce the heights of setback levees.

The NMZ was used to establish setback levee action areas that encompassed a distance of at least three active channel widths from the current channel edge to promote the eventual creation of point bars and oxbow lakes to cross-check previous steps.The potential areas were finalized as shapes with the lines removed to emphasize the point that these areas are preliminary in nature and additional studies and consideration will be required to move beyond reconnaissance level evaluations. While these areas are focused on the moderate, high, and highest prioritized areas, in some cases the shapes do encompass areas prioritized as N/A, or Low. Again, this emphasizes the point that additional project level analysis will be needed.

5.5 Additional Considerations for Levee Setback Areas

The setback levee action areas were delineated by also considering the following general guidelines:

- Prioritize setback levee action areas in upper reaches of the river system, especially immediately upstream of bypasses and perched river channel reaches (e.g., the perched channel reach on the Sacramento River from RM 0 to RM 50), to more effectively attenuate a flood wave before it reaches more restrictive and confined reaches downstream.
- Where setback levees are viable over a broad spatial area along a given river reach, align setback levee action areas to minimize the length of the ultimate setback levee (e.g., instead of placing multiple setback levees closer and parallel to the meandering river channel). Reducing total levee length will help lower levee maintenance costs.
- Prioritize setback levee action areas adjacent to existing areas of wide levee separation widths upstream and/or downstream to reduce bottlenecks in the levee alignments.
- Establish setback levee action areas to allow levee separation widths to be consistent and gradually taper transitions between setback levees and existing levee alignments.
- Minimize setback levees in perched channel reaches to avoid higher construction costs and risk associated with building setback levees at lower ground elevations and with greater levee height. Building setback levees in these areas creates the potential for greater residual risk in the event of levee failure.
- Consider the floodplain’s groundwater recharge potential in setback levee action areas. Section 3.14.7 of the 2012 CVFPP describes how a setback levee provides a benefit by contributing to increased groundwater recharge. Attachment 8L to the CVFPP (DWR 2012c) provides soil hydrologic classifications and depth-to-groundwater conditions for an initial screening to evaluate recharge potential at locations where floodplain storage may occur. Additional information that may be considered to identify potential areas of groundwater recharge in conjunction with setback levee actions has been developed by the University of California Cooperative Extension (O’Geen et al. 2015).
- Consider setback levee areas in tidally influenced reaches to lower base flow stages.
- Delineate setback levee areas to the fullest landward extent possible where the “Conservation Strategy Action—Setback Levee” spatial priority ratings are Moderate, High, or Highest. Delineating the setback levee areas in this way recognizes that making bold decisions today may optimize the balance between the long-term sustained flood reduction benefit and the economic cost of an eventual setback levee, so that repeated setbacks will not be necessary in the future.

6.0 Results

The final results of this analysis are presented as a series of maps that exhibit the potential areas for floodplain modification and setback levees along the Sacramento and San Joaquin rivers within the SPA (unpublished maps and data by AECOM). The generalized locations of the potential floodplain modification and setback levee action areas are shown in Figure 6-1.

The total acreages of potential areas that were prioritized in Steps 1 and 2 for the floodplain modification and setback levee actions, and categorized as Not Applicable, Low, Moderate, High, or Highest, are shown distributed by Conservation Strategy planning regions in Table 6-1 and Table 6-2 labeled "GIS Prioritization". Additionally, the final acreages of the areas identified by this analysis as potential for Setback Levee and Floodplain Modification Actions are provided in Tables 6-3 and 6-4 labeled "Final Areas".

Table 6-1. Acreages of Potential Floodplain Modification Action Areas – GIS Prioritization[1]

Conservation Planning Areas	N/A	Low	Moderate	High	Highest	Total
Upper Sacramento River	697,768	0	7,498	2,466	1,238	708,964
Lower Sacramento River	543,563	0	14	263	232	544,072
Feather River	351,724	179	5,526	847	974	359,615
Upper San Joaquin River	515,033	1	867	1,781	4,145	521,882
Lower San Joaquin River	606,839	0	2,262	1,737	648	611,577
Systemwide Planning Area Total	2,714,927	180	16,166	7,601	7,237	2,746,110

Key: GIS = geographic information system

[1] Note: These acreages represent the potential Floodplain Modification Action areas after the application of Steps 1 and 2, "Prioritization and Partitioning."

Table 6-2. Acreages of Potential Setback Levee Action Areas – GIS Prioritization[1]

Conservation Planning Areas	N/A	Low	Moderate	High	Highest	Total
Upper Sacramento River	106,227	643	35,188	9	5,473	147,540
Lower Sacramento River	97,350	236	10,746	149	10,982	119,463
Feather River	63,392	8,367	15,264	111	1,581	88,713
Upper San Joaquin River	84,259	3,080	30,872	3,826	17,431	139,469
Lower San Joaquin River	68,510	10,055	15,056	353	2,871	96,845
Systemwide Planning Area Total	419,738	22,380	107,127	4,447	38,338	592,030

Key: GIS = geographic information system

[1] Note: These acreages represent potential Setback Levee Action areas after the application of Steps 1 and 2, "Prioritization and Partitioning."

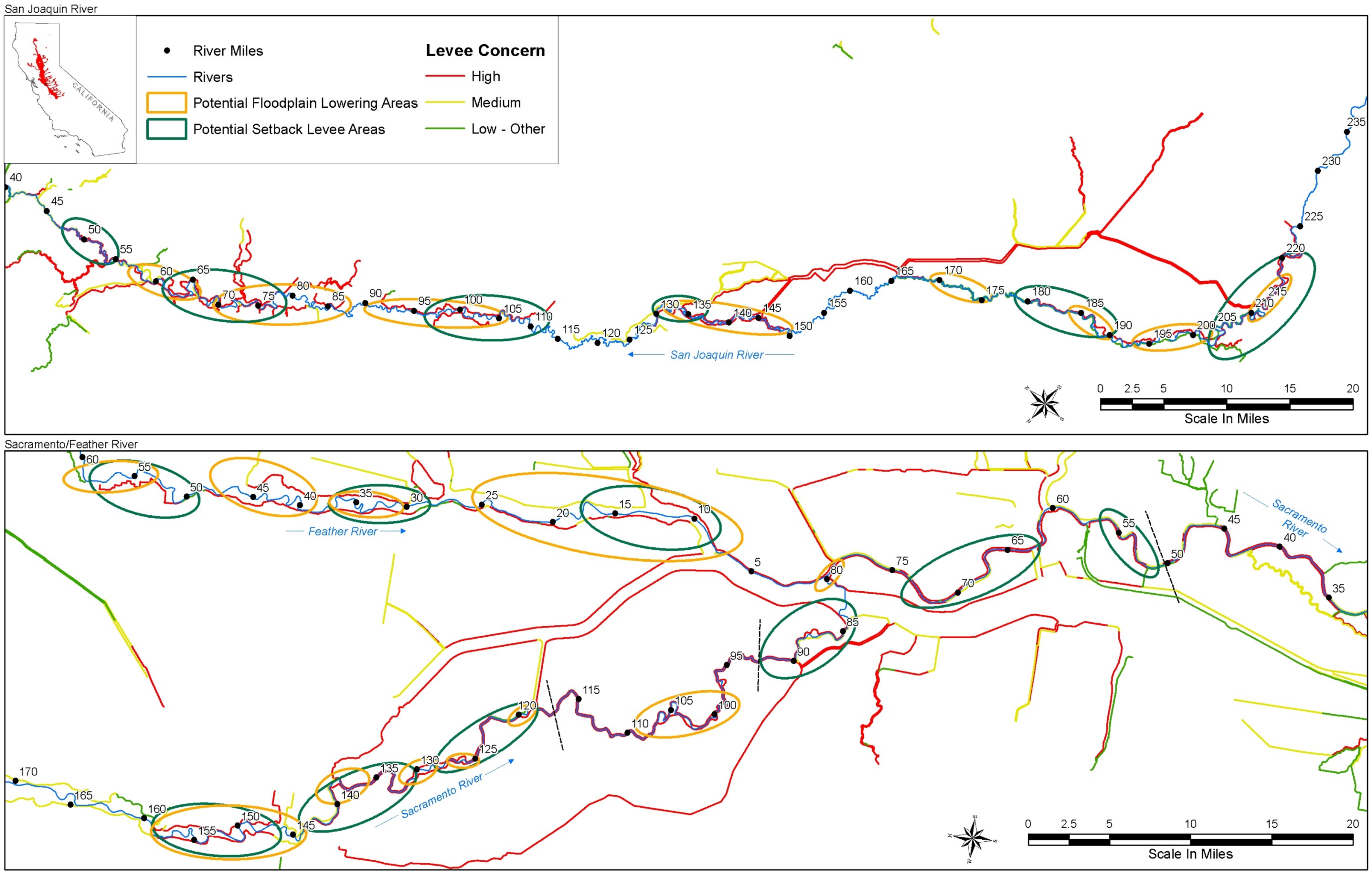

Figure 6-1. Overview of Potential Floodplain Modification and Setback Levee Action Areas

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Table 6-3. Acreages of Potential Floodplain Modification Action Areas – Final Areas[1]

Conservation Planning Areas	N/A	Low	Moderate	High	Highest	Total
Upper Sacramento River	297	0	1,612	191	26	2,127
Lower Sacramento River	1	0	0	15	0	16
Feather River	586	0	2,234	528	821	4,168
Upper San Joaquin River	250	0	644	468	412	1,774
Lower San Joaquin River	282	0	466	348	184	1,280
Systemwide Planning Area Total	1,416	0	4,956	1,550	1,443	9,364

[1] Note: These acreages represent the final results of this preliminary analysis to identify potential Floodplain Modification Areas.

Table 6-4. Acreages of Potential Setback Levee Action Areas – Final Areas[1]

Conservation Planning Areas	N/A	Low	Moderate	High	Highest	Prioritization Not Applied	Total
Upper Sacramento River	1,614	25	6,993	1	810	668	10,111
Lower Sacramento River	969	25	2,241	2	909	23	4,170
Feather River	666	485	2,437			111	3,698
Upper San Joaquin River	531	692	1,959	139	379	250	3,950
Lower San Joaquin River	568	1,236	5,680	103	432	106	8,126
Systemwide Planning Area Total	4,349	2,463	19,310	245	2,530	1,159	30,055

[1] Note: These acreages represent the final results of this preliminary analysis to identify potential Setback Levee Action Areas.

7.0 Recommendations

Several opportunities exist for continued analysis of the two specific types of restoration actions discussed in this report, floodplain modification actions and setback levee actions. Recommendations are provided below.

- *Obtain San Joaquin River Geomorphic Data.* Spatial data for the San Joaquin Channel Meander Zone and San Joaquin River Meander Belt delineations referenced in the Non-Urban Levee Evaluations Project geomorphic assessment report (Kleinfelder 2011) were not available at the time of this analysis. Incorporating these data into refined delineations of setback levees would be appropriate.

- *Continue Investigating Setback Levee Design Concepts.* The preliminary investigations of natural floodplain storage thresholds to guide setback levee distances, nonuniform floodplain levee storage, strategic flow resistance, and natural levee emulation should be completed for the entire study area.

- *Provide Input to Hydraulic Modeling.* Subsequent efforts to assess the ecological benefit of combining floodplain modification and setback levee actions should involve hydraulic modeling—preferably two-dimensional modeling—of ecological flows, such as the sustained spring FIP (the 67-percent-chance spring flow sustained for at least 7 days (DWR 2012a).

- *Consider Managed Flooding to Test Modeling and Design Decisions*. Given the highly regulated flow regime on the Sacramento and San Joaquin rivers, managed flooding should be considered as a means to reactivate and sustain the ecological functions on restored floodplain lands. Managed flooding may also be an effective means of testing modeling and design decisions by enabling replication and observation of ecological flow conditions (minor flood conditions). Managed flooding objectives can include a naturalization of the flood regime, like that proposed by Sparks et al. (1998) for the upper Mississippi River, and controlled flooding proposals by Galat et al. (1998) for the lower Missouri River.

- *Develop Aquatic and Terrestrial Species Criteria for Setback Levee Design*. Biological and engineering criteria should be considered to refine the location of setback levee alignments within setback levee action areas.

- *Consider Floodplain Groundwater Recharge and Bank Storage for Setback Levee Design*. Additional analysis of the spatial data provided in 2012 CVFPP Attachment 8L may be required to evaluate specific groundwater recharge sites that are colocated with potential floodplain storage areas and setback levee areas. The data evaluated for this attachment do not contain sufficient detail to determine site-specific soil properties. The refined setback levee concepts should include a more detailed assessment of surficial soils and geology to guide the delineation of setback levee alignments by favoring the reconnection of floodplain land areas with greater potential for seasonal bank storage of overbank floodwaters. The "underseepage susceptibility" data developed as part of the Non-Urban Levee Evaluations Project (Kleinfelder 2011) may provide this type of information.

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